RML UT2300249 – CONDITION 35 COMPLIANCE REPORT RESPONSES TO ROUND 2 INTERROGATORIES

JUNE 17. 2014

RESPONSES TO MAY 27, 2014 – ROUND 2 INTERROGATORIES
UTAH LLRW DISPOSAL LICENSE RML UT 2300249
CONDITION 35 COMPLIANCE REPORT

June 17, 2014

For
Utah Division of Radiation Control
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1. INTRODUCTION

Energy*Solutions*, headquartered in Salt Lake City, Utah is a worldwide leader in the safe recycling, processing and disposal of nuclear material, providing innovations and technologies to the U.S. Department of Energy (DOE), commercial utilities, and medical and research facilities. At its Clive Facility, located 75 highway miles west of Salt Lake City, Energy*Solutions* operates a commercial treatment, storage and disposal facility for Class A low-level radioactive waste and Class A low-level mixed waste.

Historically, Energy*Solutions'* authorization for disposal of depleted uranium (DU) was approved by the Utah Division of Radiation Control at a concentration of 110,000 pCi/g beginning with License amendment 2 of Utah Radioactive Material License UT2300249, (approved December 3, 1990). This concentration was later increased to the specific activity of depleted uranium; i.e., pure form; with approval of the Performance Assessment submitted in support of the October 22, 1998 License renewal (limiting the depleted uranium within a container to no greater than 370,000 pCi/g, upon receipt). Under this License authorization, approximately 18,400 Ci of depleted uranium were safely disposed at Clive between 1990 and 2010.

In 2010, the Utah Radiation Control Board initiated rulemaking to require a site-specific analysis before authorizing the disposal of additional large quantities of depleted uranium. This rulemaking also applies to 3,577 metric tons (5,408 drums) of uranium trioxide (DUO_3) waste received by Energy*Solutions* from the Savannah River Site (SRS) in December 2009. In compliance with the depleted uranium Performance Assessment prerequisite, Energy*Solutions* is temporarily holding these drums in storage (awaiting Director approval of this depleted uranium Performance Assessment). In the future, Energy*Solutions* is also considering disposal of significant quantities of depleted uranium from the gaseous diffusion plants at Portsmouth, Ohio and Paducah, Kentucky.

As is illustrated in Figure 1-1, Energy*Solutions* is evaluating a new Federal Cell, using an evapotranspirative cover design, as the ultimate destination for significant quantities of depleted uranium. As initially submitted in 2009, the Federal Cell was named the "Class A South" cell, with a revised application and completeness review response package dated June 9, 2009 (Energy*Solutions*, 2009). Energy*Solutions*' records show that the Division indicated interrogatories on this design were under preparation, but not received prior to its withdrawal on May 2, 2011. The former Class A South cell included a clay isolation barrier as well as a proposed system for monitoring groundwater beneath this barrier; in order to differentiate the source of any potential groundwater contamination as being from Class A or 11e.(2) wastes. The former Class A South cell design was subjected to these additional buffer zone and monitoring requirements due to long-term stewardship being split between the State of Utah and DOE. The Federal Cell will be entirely within DOE stewardship and be physically and hydrologically separate from Energy*Solutions'* Class A West embankment; therefore, the additional requirements will not apply.

Figure 1-1, Energy*Solutions*' Proposed Federal Cell Location

On June 1, 2011, (in compliance with Condition 35.B of its Radioactive Material License UT2300249), Energy*Solutions* submitted to the Division the Report, "*Utah Low-Level Radioactive Waste Disposal License (RML UT2300249) – Condition 35 Compliance Report*," documenting the depleted uranium Performance Assessment. In response, Energy*Solutions* received on October 25, 2013 from the Utah Department of Environmental Quality "*Task 1: Preliminary Completeness Review.*" Following examination of the Preliminary Completeness Review, Energy*Solutions* submitted revision 1 of its depleted uranium Performance Assessment Report titled, "*Utah Low-Level Radioactive Waste Disposal License (RML UT2300249) – Condition 35 Compliance Report*," (Energy*Solutions*, 2013a).

On February 28, 2014, Energy*Solutions* received Round 1 Interrogatories from the Division, requesting clarification and additional information to support the Division's continued review of Energy*Solutions'* depleted uranium Performance Assessment. As a result of ongoing research Energy*Solutions* has conducted regarding cover design and in review of the Round 1 Interrogatories, Energy*Solutions* revised the initial design of the Federal Cell to include an evapotranspirative cover equivalent to that currently under review by the Division for construction on the Class A West Embankment. As a result, Energy*Solutions* created version 1.2 of its depleted uranium Performance Assessment GoldSim model. In parallel to constructing the revised GoldSim model to address the performance of the evapotranspirative cover, Energy*Solutions* submitted responses on March 31, 2014 to the Round 1 Interrogatories. Version 1.199 of the depleted uranium Performance Assessment GoldSim model was provided to DEQ reviewers on May 2, 2014 with an update to version 1.2 provided on May 15, 2014.

On May 27, 2014, Energy*Solutions* received Round 2 Interrogatories from the Division, requesting additional clarification from some of the responses provided to the Round 1 Interrogatories. Energy*Solutions* has prepared responses contained herein to the Round 2 Interrogatories.

In order to facilitate public access during the public review and comment period, Energy*Solutions* will provide the Division with a complete, self-contained Report with the final revised GoldSim model, responses to Preliminary Completeness Review, and responses to the Division's other rounds of Interrogatories.

2. RESPONSES TO MAY 27, 2014 - ROUND 2 INTERROGATORIES

Responses to the Division's Round 2 Interrogatories, requesting clarification and additional information to support the Division's continued review of Energy*Solutions'* depleted uranium Performance Assessment, are presented herein. As part of the review and response preparation for the Round 1 Interrogatories, Energy*Solutions* has revised the initial design of the Federal Cell to include an evapotranspirative cover equivalent to that currently under review by the Division for construction on the Class A West Embankment. Refer to drawing series 14004, attached. In parallel to revising the GoldSim model to address performance of the evapotranspirative cover, Energy*Solutions* responds herein to the Round 2 Interrogatories of May 27, 2014.

1. INTERROGATORY CR R313-25-19-01/1: INTERGENERATIONAL CONSEQUENCES

Round 1 Interrogatory Response is satisfactory.

2. INTERROGATORY CR R313-25-8(5)(A)-02/1: DEEP TIME

Round 1 Interrogatory Response is satisfactory.

3. INTERROGATORY CR R313-25-8(5)(A)-03/2: DEEP TIME – SEDIMENT AND LAKE CONCENTRATIONS

In response to the request to explain why FRV1 does not provide any health or environmental concentration limits for future lake water or sediments for comparison, ES stated that: "The purpose of the deep time analysis is to provide a 'qualitative analysis with simulations.' Although the intent of this requirement could be debated, calculating doses in deep time is neither required nor informative." We agree that calculating doses is not required by the current regulations. Nonetheless, we feel that once concentrations are provided (either in the water or sediment or both), those concentrations will be converted into doses (if not by ES, then perhaps by the Utah Department of Environmental Quality (DEQ) or by a third party). Additionally, in order to provide perspective, it is difficult to envision a "qualitative analysis" that does not compare the deep time concentrations provided by ES to some metric (e.g., a similar regulation, background concentrations, occupational exposures). If ES declines to provide the "metric," then in order to support the conclusions of the ES "qualitative analysis," DEQ will define it.

In response to the request to resolve discrepancies in concentration values, ES states that it will make corrections as indicated and that these revisions will be available with the next version of the GoldSim model for the DU PA. We look forward to reviewing the revised report.

In response to the request to provide a basis for presenting only the U-238 sediment concentrations, as well as the basis for concluding that these concentrations are small, ES stated that it will include information on other radionuclides in the revised PA. Any determination of the adequacy of the ES response will await a review of that submittal.

In response to the request to indicate why the soil criteria in 40 CFR Part 192 should not apply to the deep time assessment, the explanation by ES does not recognize a similar regulatory concentration (15 pCi/g Ra-226) for a radioactive materials license exemption under R313-19-13(2)(a)(i)(B). Similar to 40 CFR Part 192, this state rule is designed to protect the public from the adverse health effects of radon exposure. As stated above, if ES declines to compare the deep time concentrations to some "metric," then DEQ will perform that comparison, and the 15 pCi/g Ra-226 "metric" will be used in the "qualitative analysis.".

<u>EnergySolutions' Response</u>*:* Energy*Solutions* appreciates the Division's warning that "*once concentrations are provided (either in the water or sediment or both), those concentrations will be converted into doses . . . by the Utah Department of Environmental Quality . . .*" However, while academically interesting, such exercises diametrically oppose NRC guidance,

> "*Consistent with the above, consideration given to the issue of evaluating site conditions that may arise from <u>changes in climate</u> or the influences of human behavior should be limited so as to avoid unnecessary speculation. It is possible that, within some disposal site regions, glaciation or an interglacial <u>rise in sea level</u> could occur in response to changes in global climate. These events are envisaged as broadly disrupting the disposal site region to the extent that the human population would leave affected areas as the ice sheet or shoreline advances. Accordingly, an appropriate assumption under these conditions would be that no individual is living close enough to the facility to receive a meaningful dose [i.e. exposure]*" [*<u>emphasis added</u>*] (NUREG-1573, pg. 3-10)

As such, it is appropriate to assume zero exposures or resulting doses for any scenario including "*major changes in climate*" or "*rise in sea level.*" Therefore, dose should NOT be converted from resulting concentrations as a result of any qualitative assessment of the fate and transport of depleted uranium resulting from "*changes in climate*", "*glaciations*", or "*interglacial rise in sea level that occur in response to changes in global climate.*" By doing so, the Division invalidates the express purpose for the qualitative deep time evaluation.

4. INTERROGATORY CR R313-25-8(4)-04/1: REFERENCES

Round 1 Interrogatory Response is satisfactory.

5. INTERROGATORY CR R313-25-7(2)-05/2: RADON BARRIER

In addition to the regulatory requirements listed above, note also that NRC's NUREG-1573, Appendix D, page D-1 (section D-2, item 1), states that: "The use of Probabilistic Risk Assessment (PRA) technology should be increased in all regulatory matters to the extent supported by the state of the art in PRA methods and data and in a manner that complements NRC's deterministic approach and supports NRC's traditional defense-in-depth philosophy."

The radon barrier sensitivity analysis that ES has performed only evaluates the sensitivity of infiltration rates to changes in radon barrier integrity. This exercise involved holding the hydraulic conductivity (K) values of all soil materials overlying the radon barrier constant at proposed as-built values, and changing the hydraulic conductivity values of the upper and lower radon barriers. Due to the high evapotranspiration rates and low permeability of the soils overlying the radon barriers, the infiltration rates were shown to be insensitive to the permeability of the radon barriers. Although this analysis provides some insight into the behavior of the system under static conditions, the analysis needs to be extended to more realistic future conditions. As described in NUREG/CR-7028 (Benson et al. 2011), cover-system soils that are in service degrade over a period of several years because of a number of natural degradative processes, and the hydraulic conductivity values of these soils tend to rise to those found in a specific, identified range. Depending on the as-built hydraulic conductivity of the soils when the embankment is constructed, the in-service hydraulic conductivity values several years later typically range from one to three orders of magnitude greater than the as-built values.

The Utah Division of Radiation Control (DRC) has asked ES to adjust the hydraulic conductivity and van Genuchten alpha values of all shallow soil materials overlying the radon barrier to values within the range recommended by NUREG/CR-7028 or values correlated with this range. DRC provided ES with a possible log-alpha/log-Ks correlation, based on U.S. Nuclear Regulatory Commission (NRC) values in Table 6.1 of NUREG/CR-6346 (NRC 1996). The log-alpha/log-Ks correlation was log(alpha) = 0.42*log(Ks) – 1.8853. The R2 value for this equation was 0.91. ES has not reported on the results of this experiment, conducted several weeks ago, except to mention to John Hultquist (manager of the DRC License Section) in a conversation (based on his verbal report to DRC staff) that ES performed the exercise but did not accept the results. A simple equation relating alpha to Ks is also provided by Guarracino (2007). He shows, using a well-known soil database, that a strong correlation exists between van Genuchten alpha values and hydraulic conductivities for the soil classes in this database, and he provides the theoretical basis for this correlation.

It has been demonstrated very effectively in NUREG/CR-7028 that, based on some of the largest studies ever undertaken to date of alternative cover systems, representing many years of careful research, the hydraulic conductivities of nearly all cover-system shallow soil materials of low to moderate as-built hydraulic conductivity tested have dramatically increased over the as-built values within several years after emplacement in an actual cover system. A number of processes are believed to be responsible for this. NUREG/CR-7028 unequivocally states that, for these relatively shallow soils, “saturated hydraulic conductivity of earthen barrier and storage layers will increase over time….” Often, increases reported are of two or three orders of magnitude.

Relatively few studies have been conducted on long-term performance of cover systems for containment facilities. NUREG/CR-7028 states that “The most comprehensive of these studies is the Alternative Cover Assessment Program (ACAP), which evaluated the performance of 27 different final cover profiles at 12 locations in 8 states in the US (Albright et al. 2004).” This is the focus of much of NUREG/CR-7028, although considerable additional information is also referenced through the 112 different citations in the text and the corresponding 112 references provided at the end of that document. Twenty-seven test sections were exhumed at the ACAP sites, providing invaluable information on cover-system soil degradation, with increases in hydraulic conductivity, over time. The study found that nearly all soils at the sites studied underwent dramatic increases in hydraulic conductivity within several years after being emplaced. As noted in NUREG/CR-7028, “Larger changes were observed for soils with lower as-built saturated hydraulic conductivity and soils with a greater proportion of clay particles in the fines fraction.”

Such a characterization appears to be applicable to the proposed upper radon-barrier clay soil at the Federal Cell, which would consist of a soil “with lower as-built saturated hydraulic conductivity,” and which includes “a greater proportion of clay particles in the fines fraction.” Lesser fractional changes would be expected for other coarser textured soils in the cover system, such as the more-shallow soils mentioned previously, but it is important that changes in hydraulic conductivity and alpha values of these soils should still be considered. NUREG/CR-7028 speaks of as-built hydraulic conductivity (Ksa) of each studied soil layer and compares it with the in-service hydraulic conductivity (Ksi) years after cover construction. It reports that “for sites with lower Ksa, the in-service hydraulic conductivity can be more than 10,000 times higher than Ksa.” Figure 6.8 from NUREG/CR-7028 below shows some of these changes:

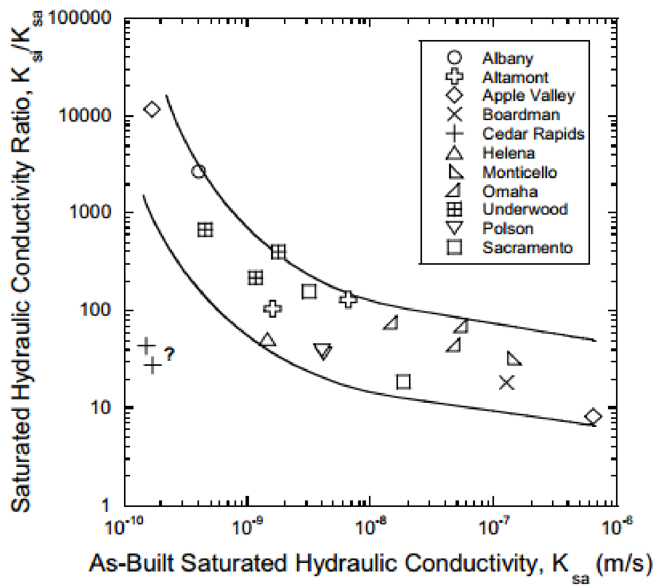


Figure 6.8 from NUREG/CR-7028 (Benson et al. 2011)

This graph shows the ratio of in-service to as-built hydraulic conductivity values for a number of important alternative cover system sites. The ratio is plotted against as-built hydraulic conductivity, expressed in meters per second (m/s) (not centimeters per second (cm/s)). The upper radon barrier, with a relatively small as-built hydraulic conductivity of 5x10-10 m/s (equivalent to 5x10-8 cm/s), can thus be expected to have an in-service hydraulic conductivity value in the range of 100 to 1,800 times as great as the as-built value. Even soils with small to moderate as-built hydraulic conductivity values increased in hydraulic conductivity value while in service, by, on average, one to two orders of magnitude. NUREG/CR-7028 found that these increases in hydraulic conductivity, as carefully measured using field tests, occurred for all soils found within about 10 feet of the ground surface.

NUREG/CR-7028 found that "the saturated hydraulic conductivity of in-service storage and barrier layers that were evaluated is sensitive to scale. Saturated hydraulic conductivities determined from testing conventional small-scale specimens (< 76-mm diameter) in the laboratory are appreciably lower (more than 1000x in some cases) than the actual field hydraulic conductivity." This is significant because the hydraulic conductivities assumed in the PA model are based on testing in a laboratory setting of conventional small-scale soil specimens (core samples), the hydraulic conductivities of which may be orders of magnitude smaller than actual field-scale hydraulic conductivities.

ES also stated that the "compromised radon barrier need not be modeled at this time because the ET Cover design will limit infiltration down to the radon barrier.

With no infiltration down to that level, the naturalization of the radon barrier will have no effect on performance." However, once the K values in the soil units overlying the radon barriers are changed, the infiltration rates may be found to be sensitive to the K of the radon barriers.

Furthermore, the demonstration of the long term integrity of the radon barrier/cover system is particularly important since the cover design does not have the multiple independent and redundant layers of defense to compensate for potential human and mechanical failures that are typical of NRC's defense-in-depth strategy.

In summary:

The ES response began by referring to two documents (Energy*Solutions* 2013b and Energy*Solutions* 2014), which obviously were not included in FRV1. ES needs to integrate the information from these two documents into the revised report. Then DRC can review and comment on how that information is being used in the DU PA.

The ES response indicates that the evapotranspirative (ET) cover would reduce infiltration by two orders of magnitude compared with the rock armor mulch cover. The revised GoldSim DU PA model (v1.199) provided by ES on May 5, 2014 (Rogers, 2014), does not support this statement. The original mean infiltration rate (VerticalFlow_BelowCap) was about 0.12 cm/yr, whereas with the ET cover the rate is about 0.04 cm/yr—reduced by only a factor of three.

The ES response indicates that the ET cover design will limit infiltration down to the radon barrier. However, the response does not address what impact (if any) burrowing animals, plant roots, gullies, and similar mechanisms would have on the radon diffusion upwards to the surface.

Finally, in its response ES described the cover performance modeling that is required. DRC looks forward to receiving and reviewing this refined modeling effort.

<u>EnergySolutions' Response</u>: (1) The proposed ET cover was designed to mimic local, native ecosystems (SWCA, 2013). Beginning at the top of the cover the layers above the waste used for the ET cover design are:

- Surface layer: This layer is composed of native vegetated Unit 4 material with 15 percent gravel mixture on the top slope and 50 percent gravel mixture for the side slope. This layer is 6 inches thick.

- Evaporative Zone layer: This layer is composed of Unit 4 material. The thickness of this layer is 12 inches.

- Frost Protection Layer: This material ranges in size from 16 inches to clay size particles. This layer is 18 inches thick. The purpose of this layer is to protect layers below from freeze/thaw cycles, wetting/drying cycles, and inhibit plant, animal, or human intrusion.

- Upper Radon Barrier: This layer consists of 12 inches of compacted clay with a low hydraulic conductivity.

- Lower Radon Barrier: This layer consists of 12 inches of compacted clay with a low hydraulic conductivity.

The upper layers of silty clay provide storage for water accumulating from precipitation events, enhance losses due to evaporation, and provide a rooting zone for plants that will further decrease the water available for downward movement. The upper layers duplicate site soil depths observed in association with the target vegetation community and have the same properties as the native soils on and near the Clive site that are associated with the vegetation community planned for the cover (SWCA, 2013). The frost-protection layer is the primary biointrusion barrier proposed for the cover. This layer consists of a 10–16 inches (25–41 cm) gravel and cobble mixture in-filled with small gravel, sand, and other fines (cobble and gravel to 16 inches diameter). SWCA (2013) describes the functioning of this layer to prevent biointrusion by using,

> "*1) large- and medium-sized cobble that is large enough that it cannot be moved by small animals; 2) pore sizes that cannot be circumvented by small animals; and 3) gravel and fines-filled interspaces that are a further deterrent to small burrowing animals.*"

The frost protection layer material provides a barrier of cobbles that are much larger than the prey species but with pore sizes between the cobbles that are too small for these species to penetrate or inhabit. Many pore spaces between the cobbles will be filled with gravel and fines that have been demonstrated to be unattractive to burrowing animals (SWCA, 2013). An additional impediment to biointrusion to the radon barriers is the overlying soil layer that is deep enough to allow for some biointrusion and soil displacement to occur without impacting the lower layers (SWCA, 2013).

Another important component of effective biointrusion barriers is an overlying soil layer that is sufficiently deep to allow for some burrowing and soil displacement without compromising underlying layers. Additional factors influencing the extent of burrowing are the proposed ET cover vegetation composition and low shrub densities that will act to limit densities of small mammals and thus limit predator foraging (SWCA, 2013).

Based on site-specific observations and documented demonstrated practice SWCA (2013) concludes that,

> "*It is not expected that the biointrusion prevention mechanisms included in the cover design will eliminate all biointrusion into lower soil layers or the frost protection zone, but that these measures will minimize any biointrusion to an insignificant level.*"

Site-specific observations of soil disturbance due to natural vegetation and demonstrated practices for minimizing disturbance were documented by SWCA (2013). Multiple soil excavations at the site demonstrated root growth behavior indicating that roots would tend to accumulate in locations to take advantage of available water rather than penetrate the radon barrier clay. These excavations showed that greasewood tap roots and other biotic activity such as fine roots and tunnels did do not extend below the compacted clay layer at 24 inches. Rather, both taproots and fine roots were found to extend laterally along the upper surface of the compacted clay layer, likely making use of any water that is perched above the clay (SWCA, 2013). The impact of natural vegetation disturbance at the site was summarized by SWCA (2013).

> "*The potential natural vegetation that will develop on the ET cover will not result in significant levels of soil disturbance in upper soil layers, or penetration of compacted clay layers due to the presence of multiple inhibitory layers (cobble, capillary barriers) that physically prevent root growth, or direct root growth laterally toward available water below the frost protection zone rather than vertically into clay barriers.*"

The effect of burrowing ants is not expected to have a large influence on transport because ant nests are not expected to penetrate to the waste layer, which is about 5m or more below ground surface for the disposal configurations considered. This is based on site-specific investigations indicating most ant burrowing will occur in the upper layers of the cover and be minimal below a depth of 42 inches (SWCA, 2013).

(2) The two order of magnitude reduction in infiltration between the rock armor cover and the ET cover described in the Rebuttal relates to a comparison using single, deterministic values for the hydraulic model parameters. Version 1.2 of the Model represents an enhanced assessment of the performance of the store and release layers in the upper part of the cover and the radon barriers. This assessment was provided in addition to the biological surveys described above that indicated insignificant disturbance of the cover due to plant and animal intrusion.

A statistical experimental design was developed to provide net infiltration and water content results using the variably saturated flow and transport model HYDRUS. The purpose of the experimental design was to capture the effect of variable hydraulic properties on water balance parameters for abstraction into version 1.2 of the Model.

The Rebuttal comments on hydraulic properties are closely linked to the Benson et al. (2011) report published by the NRC (NUREG/CR-7028). This report provides recommendations for ranges of hydraulic parameters that may be used to represent in-service conditions of store-and-release and barrier layers in covers. While this is a useful report, the topic of cover performance is complex with a wide range of research and programmatic applications (for example, ongoing work in the NRC, DOE, CERCLA/RCRA and international communities). Any modifications in data and model assumptions used for cover properties and cover performance should be based on information from multiple referenced sources.

The Surface and Evaporative Zone layers in the Clive ET cover system correspond to store-and-release layers. For the infiltration modeling, values of the van Genuchten parameter alpha for these two layers were drawn from a statistical distribution with a mean of 0.016 1/cm. The value for alpha recommended for in-service layers by Benson et al. (2011, p. 10-4) is 0.2 1/kPa which corresponds to a value of 0.02 1/cm, similar to the mean used for the infiltration simulations. The distribution used for the van Genuchten n parameter for the HYDRUS simulations had a mean of 1.32. The value for n recommended for in-service layers by Benson et al. (2011, p. 10-4) is 1.3. A single value 4.46 cm/day based on site-specific measurement was used in the experimental design for the saturated hydraulic conductivity (Ks) of the Surface and Evaporative Zone layers. Mean values of the Ks of store-and-release layers of in-service covers are listed in Table 6.6 of Benson et al. (2011). The geometric mean of these results is 8.7×10^{-7} m/s or 7.5 cm/day. This value is less than twice the value used for the infiltration modeling.

The experimental design for the infiltration modeling used a Ks distribution developed from a minimum value of 4×10^{-3} cm/day corresponding to the design specification for the upper radon barrier (Whetstone 2007, Table 8), and 50th and 99th percentile values of 0.7 cm/day (7.5 x 10^{-8} m/s rounded to 8 x 10^{-8} m/s) and 52 cm/day (6 x 10^{-6} m/s), respectively, which are from a range of in-service ("naturalized") clay barrier Ks values described by Benson et al. (2011, Section 6.4, p. 6-12). The value for Ks recommended by Benson et al (2011, p. 10-3) for modeling in-service cover layers is 5 x 10^{-7} m/s which is well within the distribution used for version 1.2 of the Modeling Report infiltration. Single values of alpha and n determined from site-specific measurements were used for the radon barrier in the infiltration modeling. A value of 0.003 1/cm was used for alpha and a value of 1.17 was used for n. Benson et al. (2011, p. 10-4) recommend using the result from a single measurement at a single site for alpha. This is a value of 0.02 1/cm. Two other values are available for sample sizes considered to be unaffected by scale for the Ks measurements (Benson et al, 2011, Table 6-9). The geometric mean of the three measurements is 0.002. A range from 1.2 to 1.4 is recommended by Benson et al. (2011) for the n parameter. The value used for the infiltration modeling is slightly below the low end of that range. More detailed descriptions of distribution development and abstraction in version 1.2 of the Model are provided in Appendix 5 - Unsaturated Zone Modeling of version 1.2 of the Modeling Report.

(3) Version 1.2 of the Model does address the impact burrowing animals, plant roots, and similar mechanisms would have on the radon diffusion upwards to the surface. Radon diffusion is given by the product of the radon concentration gradient and the effective diffusion coefficient. The effective diffusion coefficient is a function of the air-filled porosity, increasing with increasing porosity. The model for the volumetric water content of the radon barriers developed from the HYDRUS simulations and used in version 1.2 of the Model is

$$\theta = 0.3 - 0.00361\, K_s + 0.314\, \alpha - 0.013\, n$$

where

θ	is the volumetric water content [-]
K_s	is the saturated hydraulic conductivity [cm/day]
α	is a van Genuchten hydraulic model parameter [1/cm] for the Surface and Evaporative Zone layers
n	is a van Genuchten hydraulic model parameter [-] for the Surface and Evaporative Zone layers.

As an example consider using mean values from the distributions for α and n of 0.016 1/cm and 1.32 for the Surface and Evaporative Zone layers and calculating the air-filled porosity for Ks values of 4 x 10^{-3} cm/day (4.6 x 10^{-10} m/s) and 51.8 cm/day (6 x 10^{-6} m/s) which represent the minimum value and the 99th percentile of the distribution for Ks used in version 1.2 of the Modeling Report. The volumetric water contents for the low and high K_s values are 0.29 and 0.10 respectively. For a porosity of 0.43 the air contents for the low and high Ks values are 0.14 and 0.33 respectively.

For version 1.2 of the Model the effective diffusion coefficient is calculated as the product of the diffusion coefficient in free air and the tortuosity. The equation for tortuosity equation used in the model is

$$\tau_a = \frac{\theta_a}{\phi^{2/3}}$$

where

θ_a is the air-filled porosity

ϕ is the total porosity.

It can be seen that the tortuosity is directly proportional to the air-filled porosity so the radon flux for a given concentration gradient will be directly proportional to the air-filled porosity. For the example above, changing the saturated hydraulic conductivity from the as-built value to an in-service value will more than double the radon flux due to diffusion.

(4) See response to item (2).

6. INTERROGATORY CR R313-25-7(2)-06/1: GULLY MODEL ASSUMPTIONS

Round 1 Interrogatory Response is satisfactory.

7. INTERROGATORY CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS

We do not agree with the ES interpretation that UAC R313-25-7(8) limits consideration of intruder scenarios to those involving known natural resources. As stated in Interrogatory CR R313-25-20-82/1: Limitation on Inadvertent Intruder Scenarios:

Section 1.3.2.2, page 1-13, of the 2013 Compliance Report, Revision 1, states the following:

> "While an unlimited number of inadvertent intruder scenarios can be developed, known natural resources at the disposal site whose exploitation could result in inadvertent intrusion into the wastes after removal of active institutional control." UAC R313-25-7(8).

DRC does not agree with this interpretation of the regulation. The full section of R313-25-7, of which R313-25-7(8) is a sub-section, describes specific technical information that the applicant must provide: "The following information is needed to determine whether or not the applicant can meet the performance objectives and the applicable technical requirements of R313-25:…." Nothing in the regulatory language suggests that DRC plans to limit intrusion scenarios to those related to the exploration and exploitation of natural resources. Certainly, if there are known natural resources, DRC will likely wish to ensure the consideration of intruder scenarios involving their exploration and exploitation. More to the point, the definition of "inadvertent intruder" does not limit the DRC Director to only considering discovery and exploitation of natural resources. Instead, as stated in UAC R313-25-2—

Inadvertent intruder means a person who may enter the disposal site after closure and engage in activities unrelated to post closure management, such as agriculture, dwelling construction, or other pursuits which could, by disturbing the site, expose individuals to radiation.

Hence, the emphasis is not only on natural resources but also on human activities and pursuits at the disposal site after facility closure.

Interrogatory CR R313-25-8(4)(b)-07/1 requested evaluation of four scenarios, one of which included surface mining of clay, sand, and gravel. We do not find in the ES response to this interrogatory any compelling arguments as to why this scenario for inadvertent human intrusion should be excluded, particularly since it involves known natural resources. Since R313-25-8(1)(a) recognizes NUREG-0782 as a fundamental supporting document for the low-level radioactive waste rules at 10 CFR Part 61, it is reasonable to expect that the PA model report should at least consider the same intrusion scenarios the NRC staff used in 1981. These include intruder construction, intruder discovery, intruder agriculture, and intruder well. If any of these are omitted from the PA analysis, ES needs to discuss and justify why they should not be included.

<u>EnergySolutions' Response</u>: Energy*Solutions* recognizes that UAC R313-25-2 defines an Inadvertent Intruder as,

> "*Inadvertent intruder means a person who may enter the disposal site after closure and engage in activities unrelated to post closure management, such as agriculture, dwelling construction, or other pursuits which could, by disturbing the site, expose individuals to radiation.*"

While specifically defined to engage in "*activities unrelated to post closure management*," NRC has repeatedly cautioned that this definition does not create a need to analyze every possibly-conceivable intrusion activity. To the contrary, NRC specifically,

> "*does NOT expect separate intruder scenario dose analyses would be included in an LLW performance assessment because 10 CFR 61.13(b) requires that analyses of the protection of individuals from inadvertent intrusion must include a demonstration that there is reasonable assurance the waste classification and segregation requirements will be met and that adequate barriers to inadvertent intrusion will be provided.*" [EMPHASIS ADDED] (NUREG-1573, piii).

This is further emphasized by NRC in their very clear statement,

> "*The PAWG emphasizes that there should be a limit on the range of possible site conditions, processes, and events to be considered in an LLW performance assessment and that <u>unnecessary speculation</u> in the assessment should be eliminated. Additionally, consideration of <u>societal changes</u> would result in unnecessary speculation and therefore should NOT be included in a performance assessment.*" [<u>*emphasis added*</u>] (NUREG-1573, pg xii)

To the contrary, NRC suggests limiting speculation,

> "*With respect to human behavior, it may be assumed that current local land-use practices and other human behaviors continue <u>unchanged</u> throughout the duration of the analysis,"* (NUREG-1573, p3-11),

These basic concepts have recently been reinforced by the Commissioners in a Staff Requirements memorandum regarding the ongoing rulemaking for 10 CFR Part 61,

> *"…the intruder assessment should be based on intrusion scenarios that are realistic and consistent with expected activities in and around the disposal site at the time of site closure."* (SECY-13-0075)

As such, "*current local land-use practices and human behaviors*" (projected in version 1.2 of the Modeling Report include ranching, OHV, hunting, and industrial activities. "C*urrent local land-use practices and human behaviors*" do not include farming, residential construction, or direct ingestion of valley-produced groundwater. Because of this, in 20 years of numerous licensing actions, Energy*Solutions* has never been required to model groundwater ingestion inadvertent intruder scenarios unrepresentative of current practice in the Clive area.

Gravel resources are mined in the western desert to fulfill needs of Clive and other landfills, as well as the Utah Department of Transportation. Gravel sources are found in the foothills, such as those in the Grayback Hills currently being mined by Energy*Solutions.* No significant sources of gravel are located in the west desert valleys. Therefore, mining of gravel resources is not within "*current local land-use practices and human behaviors.*"

By contrast, clays and sands are being mined principally by landfills from west desert valley locations for local use only; i.e., as cover and fill material within the adjacent landfill. The cost of transportation plus availability of similar resources closer to urban areas in the Tooele and Salt Lake valleys limits the extent of clay and sand mining in the west desert.

Since NRC,

> "*does NOT expect separate intruder scenario dose analyses would be included in an LLW performance assessment because 10 CFR 61.13(b) requires that analyses of the protection of individuals from inadvertent intrusion must include a demonstration that there is reasonable assurance the waste classification and segregation requirements will be met and that adequate barriers to inadvertent intrusion will be provided,* "

the defense-in-depth offered by the engineered cover, height of the Federal Cell(discouraging cost to excavate down additional associated depths), and volume of material between the Federal Cell cover and the depleted uranium, it is extremely unlikely that any clay and sand mining would commence directly on top of the Federal Cell (40 feet above ground surface).

Since current local practices for the area surrounding Clive that share similar groundwater characteristics and yields do not include groundwater drinking wells, application of the 4 mrem/year limit promulgated in UAC R313-25-20 is inappropriate and counter to NRC guidance.

However, Energy*Solutions* recognizes occasional regional pumping of water from the deeper confined aquifer (which is still considered a Class IV aquifer) for industrial uses (such as dust suppression). See the response to Interrogatory CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS for the analysis of an inadvertent industrial intruder well scenario.

See also responses to Interrogatories CR R313-25-8(5)(A)-29/2: LIMITATION TO CURRENT CONDITIONS OF SOCIETY AND THE ENVIRONMENT, CR R313-25-8(5)(A)-38/2: FIGURES 5 AND 11 IN FRV1, CR R313-25-20-82/2: LIMITATION ON INADVERTENT INTRUDER SCENARIOS, CR R313-25-20-83/2: INTRUDER-DRILLER AND NATURAL RESOURCE EXPLORATION SCENARIOS, CR R313-25-20-92/2: INADVERTENT INTRUDER DOSE STANDARD AND SCENARIOS, CR R313-25-8(4)(a)-96/2: Current and Future Potability of Water, CR R313-25-8(4)(a)-97/2: Need for Potable and/or Industrial Water, CR R313-25-8(4)(a)-105/2: Human Use of Groundwater, CR R313-25-8(4)(a)-106/2: Desalination Potential, CR R313-25-19-135/2: EXPOSURE TO GROUNDWATER, CR R313-25-8(5)(a)-163/2: Groundwater Compliance for 10,000 Years, CR R313-25-20-172/2: INADVERTENT INTRUDER PROTECTION, CR UGW450005 PART I.D.1-180/2: COMPLIANCE PERIOD, and CR R313-25-19-182/2: Groundwater Exposure Pathways.

8. INTERROGATORY CR R313-25-8(4)(A)-08/1: GROUNDWATER CONCENTRATION ENDPOINTS

Round 1 Interrogatory Response is satisfactory.

9. INTERROGATORY CR R313-25-19-09/1: DEFINITION OF ALARA

Round 1 Interrogatory Response is satisfactory.

10. INTERROGATORY CR R313-22-32(2)-10/2: EFFECT OF BIOLOGICALS ON RADIONUCLIDE TRANSPORT

The interrogatory had asked ES to support its statement that the effect of plants, ants, and burrowing mammals on radionuclide transport might be small. The response instead discussed how the effects related to such transport would decline as distance from the ground surface increases. However, this response does not satisfy the interrogatory with regard to how the effect of plants, ants, and burrowing mammals on radionuclide transport itself was determined to be small.

EnergySolutions' Response*:* Section 4.1.2.8 will be revised to delete the phrase "*the severity of their effect on radionuclides transport might be small.*" The revised text will read:

> "*Based upon the rooting profiles of the site flora and burrowing characteristics of site fauna, impacts from biota will be limited to the top several meters. As discussed in the Biological Modeling white paper (Appendix 9), burrowing profiles of mammals and ants are expected to occur within the top 2.2 meters. Rooting of grasses, forbs and shrubs (other than greasewood) currently found on site occur primarily in the top 1.5 meters. SWCA (2013) found that both taproots and fine roots of plants at the site tended to spread laterally across the top of the compacted clay layer present approximately 60 cm below ground surface at the site. Greasewood may extend taproots as deep as 5.7 meters, though the bulk of the root biomass remains in the upper layers. Details for all three categories can be found in the Biological Modeling white paper (Appendix 9).*"

11. INTERROGATORY CR R313-25-20-11/1: INADVERTENT HUMAN INTRUDER

Interrogatory Response will be evaluated after resolution of Interrogatory CR R313-25-8(4)(B)-07/2: Applicability of NRC Human Intrusion Scenarios.

EnergySolutions' Response*:* See the response to Interrogatory CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS.

12. INTERROGATORY CR R313-25-20-12/2: SELECTION OF INTRUSION SCENARIOS

Although correct, the statement above does not address the main point of the interrogatory, namely that several inadvertent intruder scenarios should be considered, similar to the need to consider surface mining of clay, sand, and gravel, as mentioned in the comments on Interrogatory CR R313-25-8(4)(b)-07/1: Applicability of NRC Human Intrusion Scenarios. ES should also address the remaining scenarios or explain and justify why they are not relevant.

EnergySolutions' Response*:* See the response to Interrogatory CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS.

13. INTERROGATORY CR R313-25-7-13/1: REFERENCE FOR LONG-TERM CLIMATIC CYCLES

Round 1 Interrogatory Response is satisfactory.

14. INTERROGATORY CR R313-25-8(4)(D)-14/2: SEDIMENT MIXING

ES did not address the situation in which sediments from the first lake are not yet covered and mixed with sediments from the second lake. During the teleconference on April 9, 2014, ES committed to evaluate a deep time scenario in which in situ DU waste is not scoured by pluvial lake wave action and is left at or near the ground surface after the lake recedes, which should address this concern. We await the results of that evaluation. For subsequent lakes, complete mixing ensures that the DU would be near the ground surface, rather than buried beneath a layer of newly deposited sediment.

***EnergySolutions' Response**:* Energy*Solutions* recognizes that the Division is of the opinion that the Burmester and Knolls cores are not sufficiently representative of the Clive area. In an interview conducted to evaluate this concern, Jack Oviatt (2014b) made the following observations:

1. For the types of information considered so far (sedimentation rate per 100ky), Oviatt thinks that the Knolls and Burmester cores are sufficiently representative (so long as the cores are in the same basins), of what is expected for Lake Bonneville or any other deep lake that would cover Clive. Under these conditions, Oviatt (2014b) considers that the deposition patterns would be similar (confirming Energy*Solutions'* claims). However, Oviatt (2014b) does acknowledge that some differences may be observable, if further detailed information about specific biology or chemistry were sought. However, since the Deep Time sub-model is a high level qualitative model, a less-detailed level of information is sufficient.

2. In preparation of responses to Round 2 interrogatories and Oviatt (2014b), Energy*Solutions* has recognized that the concentration of approximately 1,500 pCi/g U-238 reported in Deep Time sediment is a typographical error and should be reported as 770 pCi/g. This typographical error will be corrected in the ultimate comprehensive deliverable. As a reminder, even though Energy*Solutions* commits to only disposing of depleted uranium below grade, version 1.2 of the Model disperses all of the waste at the time the overburden material is obliterated (as an overly conservative assumption). When more representative assumptions are modeled, sediment concentrations closer to background are projected.

3. In further assessment of the Burmester and Knolls cores, Oviatt (2014b) also compared the pit wall to the Knolls core. Both the pit wall and the Knolls core date back to approximately 150ky. However, the Knolls core is actually deeper than the pit wall. Like the Burmester and Wendover cores, the Knolls core currently resides at the University of Utah. Although these cores are old (1960s) they still exist and provide information to further inform this Model.

Oviatt (2014b) cautions, though, that information is quite “old” and was not originally developed to support this model.

4. One other issue Oviatt (2014b) addresses is the impact on grade elevation of the aerial deposition rates. While not specifically included in version 1.2 of the Model, such an effect would provide additional stabilization at the Clive site.

See also the response to Interrogatory CR R313-25-8(5)(A)-86/2: CONSEQUENCES OF SEDIMENTATION ON DISPOSAL CELL.

15. INTERROGATORY CR R317-6-6.3(Q)-15/2: URANIUM CHEMICAL TOXICITY

As discussed in several interrogatories (e.g., Interrogatory CR R313-25-8(4)(a)-96/2: Current and Future Potability of Water), ES has not provided convincing evidence that ingestion of groundwater is not a potential exposure pathway. Consequently, ES needs to provide a revised response to this interrogatory.

EnergySolutions’ Response*:* See the response to Interrogatory CR R313-25-19-182/2: Groundwater Exposure Pathways.

16. INTERROGATORY CR R313-25-8(4)(A)-16/2: RADON PRODUCTION AND BURROWING ANIMALS

Round 1 Interrogatory Response is satisfactory.

17. INTERROGATORY CR R317-6-6.3(Q)-17/1: URANIUM PARENTS

Round 1 Interrogatory Response is satisfactory.

18. INTERROGATORY CR R313-25-8(5)(A)-18/2: SEDIMENT ACCUMULATION

ES stated: “However, recent research suggests that it is unlikely that a lake will inundate Clive in the current 100ky glacial cycle.” As stated with regard to Interrogatory CR R313-25-8(4)(d)-122/2: Size of Pluvial Lakes, ES must consider climatic change intervals that are localized to the Great Basin and not rely on global cycles. Inundation of the Clive site (at an elevation of about 4,270 feet or about 70 feet above the level of the modern Great Salt Lake) could occur as a result of a “small” or “intermediate” lake forming during one of these shorter term climate cycles. This has been discussed in other interrogatories. For example, in response to Interrogatory CR R313-25-8(5)(a)-44/1: Occurrence of Intermediate Lakes, ES indicated that it will add the statement that: “Intermediate lakes are assumed to be smaller lakes that reach and exceed the altitude of Clive….”

ES also stated that: "Aeolian sedimentation rates at Clive are expected to be between 0.1 and 3 mm/yr during the current inter-pluvial period based on analogue measurements at dry pluvial lake sites throughout the world and in the arid SW United States." However, ES did not provide a reference for this statement, which appears to be flawed. If these accumulation rates were correct, the entire Great Basin would now be covered by an average of 1 to 3 meters of Aeolian sediment that has been accumulating since the onset of the Holocene, masking significant areas of bedrock, shorelines, and other subtle geomorphic features. Aeolian material almost certainly forms the substrate for desert soils in this part of the world, but this mantling material has thicknesses of tens of centimeters, not meters. Many places of the Great Basin have no mantling Aeolian material whatsoever.

Cursory efforts located the following summary table indicating Aeolian accumulation rates about one order of magnitude lower than that indicated in ES' response. The data do not appear to support the idea that the ES site will be covered by a thick layer of dust before the onset of the next shallow lake cycle.

Table 9.1 Annual dust deposition rates on land (after Middleton, 1997 and Goudie, 1995)

References	Location	Deposition rate ($t\ km^{-2}\ a^{-1}$)	Deposition rate ($mm\ 1000\ a^{-1}$)[a]
Sahara			
Mediterranean region			
Löye-Pilot *et al.* (1986)	Corsica	14	16
Yaalon and Ganor (1975)	Israel	22–83	25–93
Goossens (1995)	Negev	15–30	10–20
Bücher and Lucas (1975)	Pyrenees	18–23	20–26
Pye (1992)	Crete	10–100	11–112
Harmattan plume			
Maley (1980)	S Chad	109	122
McTainsh and Walker (1982)	N Nigeria	137–181	154–203
Drees *et al.* (1993)	SW Niger	200	100–150
USA			
Smith *et al.* (1970)	High Plains	65–85	73–96
Péwé *et al.* (1981)	Arizona	54	61
Gile and Grossman (1979)	New Mexico	9.3–125.8	10–141
Muhs (1983)	California	24–31	27–35
Reheis and Kihl (1995)	California/Nevada	4.3–15.7	5–18
Middle East			
Safar (1985)	Kuwait	100	112
Behairy *et al.* (1985)	W Saudi Arabia	13–109	15–122
Miscellaneous			
Inoue and Naruse (1991)	Japan	3.5–6	4–7
Tiller *et al.* (1987)	SE Australia	5–10	6–11
Kukal (1971)	Caspian Sea	39.5	44

[a] Calculated on bulk density of dust of 0.89 g cm^3 where not derived in original reference.

Source: Goudie et al. 1997.

***EnergySolutions*' *Response*:** The text in Appendix 13 – Deep Time Assessment from the version 1.2 Modeling Report has been extensively revised, with many clarifications added. The "*deep*", *intermediate*", and "*small*" lake classifications are simply defined for convenience in the heuristic deep time model. Energy*Solutions* has revised the following statement in Section 3.3 of Appendix 13:

> "*For modeling purposes, a distinction is made between shallow, intermediate and large lakes. Large lakes are assumed to be similar to Lake Bonneville, and occur no more than once per 100 ky glacial cycle (assumption of the heuristic model approach). Intermediate lakes are assumed to be smaller lakes that reach and exceed the altitude of Clive, but are not large (or deep) enough that carbonate sedimentation is the dominant mode of lake deposition. The Bonneville and Provo shorelines of Lake Bonneville are examples of large lakes; the transgressive and*

regressive phases of the Bonneville and Provo shoreline lakes represent intermediate lakes during the transient phases of the lakes where they exceeded the elevation of the Clive site and sedimentation was dominated by clastic deposition associated with wave activity and reworking of lake sediments (see Table 2 for the chronology of the lake cycles). Shallow lakes are assumed to exist at all other times. The current Great Salt Lake is an example as is the reinterpreted Gilbert shoreline lake (Oviatt, 2014a) that has now been shown to have not reached the elevation of the Clive site (contrast with Currey et al. 1984). For the purpose of modeling, the specific depths of small, intermediate and large lakes are not important in the Deep Time Model. Under current climate conditions, it is assumed that intermediate lakes will not occur (only small lakes). Under future climate conditions, some glacial cycles will produce a large lake in the Bonneville Basin, and intermediate lakes will occur during the transgressive and regressive phases of a large lake, or during glacial cycles that do not exhibit a large lake. The approximate timing of the return of the first intermediate lake is relatively important in the Deep Time Model, because it is assumed that the Clive waste disposal site is destroyed upon the occurrence of the first intermediate lake,"

Thus, by definition, "*large*" lakes (e.g., Bonneville, Provo) will cover the Clive site; "intermediate" lakes are lakes that reach and exceed the altitude of Clive, but are not large or deep) enough that carbonate sedimentation is the dominant mode of lake deposition; and smaller lakes will not reach the elevation of the Clive site at all. A small lake, by definition, is not of concern with regard to stability or sedimentation germane to the Clive site.

The Rebuttal text quoting an Energy*Solutions* response with aeolian sedimentation rates of 0.1 to 3 mm/year are not included in Appendix 13. Sedimentation rates for aeolian deposition were not used in the model prior to the formation of the first intermediate or deep lake; instead an assumption was made that the next lake would destroy the disposal mound. The concept of aeolian sedimentation, to the extent it occurs, was introduced as an additional defense in depth consideration.

19. INTERROGATORY CR R313-25-8(5)(A)-19/1: REFERENCE FOR SEDIMENT CORE RECORDS

Round 1 Interrogatory Response is satisfactory.

20. INTERROGATORY CR R317-6-2.1-20/2: GROUNDWATER CONCENTRATIONS

It is unclear why the formation of gullies that would erode through the barriers and focus surface water would result in only minor local changes in infiltration.

Furthermore, it is unclear where the PA models increased recharge (due to gully formation) to demonstrate that the groundwater concentrations do not change. The ES response also referenced doses due to the thinning cover. It may be true that the radon dose is so much higher than the potential groundwater dose (increases in groundwater concentrations are insignificant), but that does not explain why the groundwater concentrations are conceptualized so that they do not increase when the cover is compromised.

ES should provide more information to explain and reconcile these concerns.

EnergySolutions' Response: Justification for the size and number distributions for gully formation is documented in Section 5 of Appendix 10 – Erosion Modeling from version 1.2 of the Modeling Report. As stated therein,

> "*A random number of gullies sampled from a discrete distribution is chosen to occur, simply to evaluate the effect a variable number of gullies would have on dose. Each of these gullies is identical for a given realization, in order to keep the gully model simple. The fraction of the cover surface area that is consumed by gullies is calculated in order to determine if the quantity of erosion is physically reasonable for an intact embankment.*" (Appendix 10, pg 23)

While the formation of some of the gullies may actually erode through significant depths of the evapotranspirative cover, the ratio of gully footprint to total evapotranspirative cover surface area remains minimal. As such, the overall evapotranspirative cover surface continues to perform and limit infiltration, as designed. The gullies' influences are further tempered when including the effects of the extreme depth between the bases of the deepest probable gullies to the below-grade depleted uranium waste, resulting in insignificant increases in resulting groundwater concentrations.

Under the conditions of inadvertent intruder created gullies, NRC warns that,

> "*Finally, the disruptive actions of an inadvertent intruder do not need to be considered when assessing releases of radioactivity offsite* [that may result in subsequent exposure to members of the general public]." (NUREG-1573, pg. 3-11).

Therefore, NRC considers it inappropriate to model doses to the general public that result from the actions of an inadvertent intruder.

21. INTERROGATORY CR R313-25-8(4)(D)-21/2: INFILTRATION RATES

Previous ES infiltration modeling for the facility used the unsaturated flow model UNSAT-H to overcome such HELP model overestimation. ES should explain and justify why HYDRUS, with its variable saturation equations, could not eliminate the flux overestimation problem. Note that SC&A is currently investigating the reasonableness of the recharge rates predicted by HYDRUS.

EnergySolutions*' *Response: Numerous peer-reviewed studies have been conducted comparing the accuracy of the HYDRUS and HELP models under a variety of conditions. One such representative study was conducted for the U.S. Air Force to evaluate evapotranspirative landfill cover performance using a variety of hydrologic models in arid conditions (Air Force, 2004). The evaluation examined,

- Accuracy of model estimates of evapotranspiration, surface runoff, and deep percolation
- Plant parameter inputs, their use within the model, and appropriateness for the design problem
- Soil parameter inputs, their use within the model and appropriateness of estimates that affect plant growth, and water use and storage
- Climate parameter inputs or generation
- Completeness of the hydrologic system evaluation
- Model output and satisfaction of design needs
- Level of support required from other models or other sources
- Model characteristics that may affect accuracy and completeness of ET cover design and/or evaluation

Over a variety of conditions, the Air Force analysis found,

> "*The HELP model was designed to evaluate the hydrology of complete, barrier-type landfill covers, including the cover, waste, bottom liner, and leachate collection. As explained in Section 4.3, the focus of the HELP model is on the manmade features of landfills and waste properties and not on natural systems that control the water balance of the cover. The HELP model achieves the goal set for it for manmade structures and waste but it is less accurate than desired for natural systems. . . The HELP*

model [as compared to other models] has limited usefulness in design or evaluation of ET landfill covers." (Air Force, 2004, pg 51)

In a similar assessment of model accuracy conducted for the U.S. Environmental Protection Agency by Desert Research Institute (2002) found,

> "*Three concerns with HELP were (i) a non-realistic response of increased drainage as available water capacity increased, (ii) insensitivity of drainage to thickness of the cover surface layer, (iii) consistent overprediction of drainage. The over-prediction of drainage was found to be as much as an order of magnitude for the arid site. For water-balance codes such as HELP . . . in which evapotranspiration is removed only from an arbitrary evaporative zone, it is critical that the evaporative depth be accurately characterized. Since evaporative depth is a fairly nebulous property that is extremely difficult to characterize, implies that model calibration is needed with these codes.*" [*emphasis added*] (EPA, 2002, pg ii).

By comparison, EPA (2002) found that,

> "*HYDRUS-2D exhibited the most physically realistic response patterns in the sensitivity tests. . . For the Coshocton lysimeter, all codes were better able to predict the measured drainage than observed for the arid conditions, however, . . . HYDRUS-2D exhibited superior ability."* (EPA, 2002, pg iii)

Finally, EPA (2002) concludes,

> "*This study suggests that the Richards' Equation-based codes (HYDRUS-2D, UNSAT-H) were better able to capture the behavior of alternative earthen covers under both arid and humid conditions than the simple water-balance codes (HELP, EPIC).*" (EPA 2002, pg. iii)

22. INTERROGATORY CR R313-25-7-22/1: DEFINITION OF FEPS

Round 1 Interrogatory Response is satisfactory.

23. INTERROGATORY CR R313-25-7(2)-23/1: CANISTER DEGRADATION AND CORROSION

Round 1 Interrogatory Response is satisfactory.

24. INTERROGATORY CR R313-15-101(1)-24/1: UTAH REGULATIONS

Round 1 Interrogatory Response is satisfactory.

25. INTERROGATORY CR R313-25-7(9)-25/1: DISPOSITION OF CONTAMINANTS IN UF6

Round 1 Interrogatory Response is satisfactory.

26. INTERROGATORY CR R313-25-8(4)(A)-26/2: RADON DIFFUSION IN THE UNSATURATED ZONE

The PA should also indicate which processes are being modeled by GoldSim for the transport of radon, particularly in the unsaturated zone (e.g., diffusion, advection).

EnergySolutions' Response*:* The text in Section 6.6 of Appendix 2 - Conceptual Site Model for Disposal of Depleted Uranium at the Clive Facility to version 1.2 of the Modeling Report has been modified to clarify that the transport of radon in the saturated and in the unsaturated zone from the waste to the ground surface is included in the PA model, resolving the apparent inconsistency.

27. INTERROGATORY CR R313-25-8(4)(A)-27/2: DIFFUSION PATHWAY MODELING

It is not clear what is meant by PA maintenance and whether quantification will in fact be included in a forthcoming revised PA report. DEQ is not aware of any formal plans by ES for PA maintenance. Any such plans should be described.

In addition, "difficult to quantify" is not a sufficient reason for not performing the modeling if it is necessary. In response to this interrogatory, ES should provide modeling that quantitatively accounts for these processes and effects, taking into account NRC guidance such as that in NUREG/CR-7028. Alternatively, it should explain why DRC should not require ES to perform the quantification effort now, rather than in the future.

EnergySolutions' Response*:* Unless they become necessary as a result of preparation of responses to the upcoming Round 3 Interrogatories, no further revision or PA maintenance is planned to version 1.2 of the Modeling Report.

See responses to items (2) and (3) of INTERROGATORY CR R313-25-7(2)-05/2: RADON BARRIER.

28. INTERROGATORY CR R313-25-8(4)(A)-28/2: BIOTURBATION EFFECTS AND CONSEQUENCES

1. The ES response began by referring to two documents (Energy*Solutions* 2013d and Energy*Solutions* 2014), which obviously were not included in FRV1. ES needs to integrate the information from these two documents into the revised report. Then DEQ can review and comment on how that information is being used in the DU PA.

2. The ES response indicates that the ET cover would reduce infiltration by two orders of magnitude compared with the rock armor mulch cover. The revised GoldSim DU PA model (v1.199) provided by ES on May 5, 2014 (Rogers 2014), does not support this statement. The original mean infiltration rate (VerticalFlow_BelowCap) was about 0.12 cm/yr, whereas with the ET cover the rate is about 0.04 cm/yr—reduced by only a factor of three.

3. The ES response indicates that an increase in the radon barrier hydraulic conductivity resulted in no increase in infiltration. However, the response does not address what impact (if any) burrowing animals, plant roots, gullies, and similar mechanisms would have on the radon diffusion upwards to the surface.

4. Finally, in its response ES indicated that the "mammal burrowing model" would be updated at an unspecified time in the future, as part of PA maintenance. DEQ looks forward to receiving and reviewing this refined modeling effort. ES should provide a schedule for the completion of PA maintenance.

***EnergySolutions*' Response**:*

1. See the response to interrogatory CR R313-25-7(2)-05/2: RADON BARRIER.
2. See the response to interrogatory CR R313-25-8(4)(D)-153/2: IMPACT OF PEDOGENIC PROCESS ON THE RADON BARRIER.
3. See the response to interrogatory CR R313-25-8(4)(D)-153/2: IMPACT OF PEDOGENIC PROCESS ON THE RADON BARRIER.
4. See the response to interrogatory CR R313-25-8(4)(D)-27/2: DIFFUSION PATHWAY MODELING.

29. INTERROGATORY CR R313-25-8(5)(A)-29/2: LIMITATION TO CURRENT CONDITIONS OF SOCIETY AND THE ENVIRONMENT

We concur with this position. However, as indicated elsewhere in this document, we are not convinced that it is appropriate to exclude as human intrusion scenarios mining of sand, clay, and gravel, or exploration drilling for resources, or extraction of deeper lying groundwater for a variety of beneficial uses. ES needs to address these scenarios. Further, NUREG-1573 also provides guidance for the PA model developer when a proposed disposal site currently lacks residents, as follows:

Finally, with respect to the portion of this question concerning how the critical group approach would be implemented if there were no residents near a candidate disposal site, the PAWG expects that the LLW disposal facility developer would identify some analog site, of comparable geology and climate, and define the critical group in terms of the analogue site. Again, the LLW disposal facility developer needs to document the technical basis for his or her decision-making - regarding how both the analogue site was selected and the critical group subsequently defined. [page B-60]

ES should also consider this information as it selects the various human intrusion scenarios for the 10,000-year compliance period PA analysis. We look forward to reviewing the revised report.

***EnergySolutions' Response**:* See the responses to Interrogatories CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS and CR R313-25-19-182/2: Groundwater Exposure Pathways.

30. INTERROGATORY CR R313-25-8(5)(A)-30/1: INCLUSION OF SRS-2002 DATA IN THE SENSITIVITY ANALYSIS

Round 1 Interrogatory Response is satisfactory.

31. INTERROGATORY CR R313-25-8(5)(A)-31/2: TC-99 CONTENT IN THE WASTE AND INCLUSION IN THE SENSITIVITY ANALYSIS

We look forward the updated results regarding Tc-99 inventory and its effects on dose results. We presume the new analyses will include, among other considerations, an indication of the sensitivity of Tc-99 content to compliance with the GWPL and doses from groundwater over 10,000 years.

***EnergySolutions' Response**:* The Tc-99 groundwater concentrations at 500 years have been updated in Section 6.1.1 of version 1.2 of the Modeling Report. The updated sensitivity analysis in Section 6.1.2 indicated that the K_d for technetium in sand was the most sensitive parameter. A new appendix containing all the sensitivity analysis results is included with Appendix 15 (II) – Sensitivity Analysis Results. EnergySolutions reminds the Division that, under conditions of their Ground Water Quality Discharge Permit, Energy*Solutions* is required to protect the Clive groundwater resource for a period of 500 years following initial startup of waste placement. Since this is a concentration-limited standard and that the groundwater pathway is specifically not a dose pathway, the projecting of the GWQDP limit beyond 500 years is expressly contrary to NRC guidance.

See the responses to Interrogatories CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS and CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS.

32. INTERROGATORY CR R313-25-8(4)(A)-32/1: EFFECT OF OTHER POTENTIAL CONTAMINANTS ON PA

Round 1 Interrogatory Response is satisfactory.

33. INTERROGATORY CR R315-101-5.3(6)-33/1: CLARIFICATION OF THE PHRASE "PROOF-OF-PRINCIPLE EXERCISE" AND SENSITIVITY TO URANIUM ORAL REFERENCE DOSE FACTORS

Round 1 Interrogatory Response is satisfactory.

34. INTERROGATORY CR R313-25-8(5)(A)-34/1: INTENT OF THE PA

With the following edits (in **bold**), the Round 1 Interrogatory Response is satisfactory:

"The role of PA in a regulatory context is often restricted to the narrow use of evaluating compliance. In the present case, the Clive DU PA **GoldSim** Model ~~v1.0~~ can be used to evaluate compliance—and inform a PA document that presents the argument that demonstrates compliance—with 10 CFR 61 Subpart C and the corresponding provisions of the Utah Administrative Code**, including (1) quantitative PA modeling for at least 10,000 years and (2) complete additional PA simulations for a 1,000,000 year timeframe**. In addition to that role, however, and because of the long-term nature of the analysis, the intent of the Model is not necessarily to estimate actual long-term human health impacts or risks from a closed facility. Rather, the purpose is to provide a robust analysis that can examine and identify the key elements and components of the site, the engineered system, and the environmental setting that could contribute to potential long-term impacts. Because of the time-scales of the analysis and the associated uncertainty in knowledge of characteristics of the site, the waste inventory, the engineered system and its potential to degrade over time, and changing environmental conditions, a critical part of the PA process is also the consideration of uncertainty and evaluation of model and parameter sensitivity in interpretation of PA modeling results."

EnergySolutions' Response: Edits noted without comment.

35. INTERROGATORY CR R313-25-19-35/1: REFERENCE FOR COST PER PERSON-REM

Round 1 Interrogatory Response is satisfactory.

36. INTERROGATORY CR R313-25-8(4)(A)-36/1: ANT NEST EXTRAPOLATIONS

Round 1 Interrogatory Response is satisfactory.

37. INTERROGATORY CR R313-25-8(5)(A)-37/2: DISTRIBUTION AVERAGING

This is a complex topic, and DRC believes that more information is needed to understand how distribution averaging is actually implemented in GoldSim:

1. ES described a scaling process that is specific to a given model cell. Provide additional details and numerical examples of specific parameters in support of these statements contained in the response: "Data that represent points in time and/or space cannot be used directly in this type of model. The data range and variance is too broad for the large spatial or temporal effects that are being modeled."
2. Provide a more detailed description, with examples of how the input parameter distributions are applied when calculating an average response for cells with linear response, and the types of modifications required for cells with non-linear response.
3. Describe how the final model outputs are calculated using the cell-specific averages.

EnergySolutions' Response:

1) The scaling of distributed parameters is best illustrated by example. The first example considers spatial variation. Consider the porosity of a given porous medium. This is estimated from the analysis of several samples taken at different locations, or even at the same location. Each sample represents the porosity of the sample, and each sample is part of a larger population of samples for the entire expanse of, for the sake of argument, Unit 4 sediments. A model that requires a representative porosity for Unit 4, such as an infiltration model built in HYDRUS, or version 1.2 of the Model, considers the Unit 4 sediments to be homogeneous in space. That is, local variations in porosity (and other bulk material properties) are not considered, as this would impose a tremendous computational burden with no real benefit for the larger

scope of decision making. So, every part of the model that contains the Unit 4 sediments uses the same value of porosity. The porosity is not perfectly known, of course, so the uncertainty in this representative porosity value is captured in a statistical distribution from which a porosity value is selected. This value must reasonably represent the average porosity of the entirety of Unit 4 as represented in the model domain. This volume is much larger than any sample, and although it includes all the samples, its estimated average value has much less variation than is found in the individual samples. If the input distribution, from which an average porosity is chosen, were to be based on the porosity data, then there would be the possibility of selecting some extreme porosity value to represent the entire Unit 4, and this would not be a reasonable representation of the average value. This is why it is inappropriate to build a distribution simply from the data points. Doing so does build a distribution of the data, and could be used to estimate porosities of a sample here or there, but does not produce a distribution of the average value that would apply across large volumes of Unit 4. What is needed is a distribution of the average porosity of Unit 4. This is done through the application of statistical techniques such as bootstrapping to generate a distribution of the average. The distribution of the average value is invariably narrower than the distribution of the data.

Another example illustrates averaging in both time and space. Consider the pattern of rainfall over a given area and length of time. At one extreme there may be intense storms, local and brief, and at the other extreme may be long extensive dry spells. The monthly, daily, or hourly behavior depends quite strongly on the intervals of time and space chosen for recording the measurement. In a model that runs simulations for thousands of years, the daily and even yearly events all get “averaged out” into a spatiotemporal average value. If the fine-scale data were used to build a distribution of rainfall that is to be applied over a large area and time, there would be the possibility of having a hundred-year return period storm every day for thousands of years, or no rain at all—neither of which is a reasonable representation of the climatic behavior at the site. Again, what is needed is an average value that will produce average results, with an appropriate amount of uncertainty. But even the extremes of the input distribution for rainfall must be reasonable for a long-term and large-area average. As in the former example, the distribution of the average will be narrower than the distribution of the data.

Note that these spatiotemporal scaling relationships are not limited to definitions of Cell pathway elements in GoldSim. These concepts extend to system level modeling in general.

2) Version 1.2 of the Model does not contain "cells of linear response" or "cells of non-linear response". Depending on their location, Cell pathway elements may be subject simultaneously to one or more non-linear processes, and to many linear ones, as well as events that may change rates or conditions, potentially altering those processes. The state of the contents of the Cell (including what we are most concerned with, the array of radionuclides defined in the Species element) depends on so many variables and processes that it is difficult to predict exactly in advance, unlike a purely linear model.

   Again, some examples may help to illustrate some linear and non-linear aspects of the model. One example of a linear process, or at least one that is modeled as linear, is the dose response to the concentration of a radionuclide in some exposure medium. The dose conversion factor, or DCF, for ^{210}Pb in the dust inhalation exposure pathway is a linear function of both the concentration of ^{210}Pb in airborne dust and of the rate of inhalation. If either one doubles, the resulting dose doubles. If they both double, the dose is increased by a factor of four. This is, of course, a simplification of reality, but it is what is called a first-order approximation, and depending on the results of the sensitivity analysis, it may be sufficient for informing decision making.

   An example of nonlinear behavior in the model is the aqueous concentration of uranium in a given cell pathway element. This concentration is also a function of several processes which independently have linear relationships to concentration, but together become non-linear: One set of processes are those involved in partitioning between phases, whereby the mass of uranium in the cell is partitioned between Water and Loess or whatever porous medium constitutes the cell volume. At low concentrations, the uranium is allocated between water and solid using a simple linear ratio of concentrations (the soil/water partition coefficient, or K_d). As the water concentration or uranium increases, however, a limit is encountered and no more uranium can be dissolved in the water. The rest of it is allocated to the solid phase, and the simple linear K_d ratio is lost, and with it the linearity of the system. Once the solubility limit is reached, the system becomes non-linear. This is why, for example, adding more uranium to a source or inventory does not result in higher concentrations emanating from the waste—rather it reaches a constant concentration but maintains it for a longer period of time.

   Given that the concentration of uranium in a given cell may be non-linear at times, and given that the isotopes of uranium are tightly linked to the fate and transport of their progeny, the non-linearities in the model spread.

   The linear or non-linear response of a model does not depend on parameter distributions, or on specific cells. Distributions of input parameters such as K_d, solubility, or DCF are developed with no regard for the model's degree of linear or non-linear behavior. There are no modifications to a parameter depending on whether a particular cell is behaving linearly or non-linearly.

3) See responses 1 and 2, above.

38. INTERROGATORY CR R313-25-8(5)(A)-38/2: FIGURES 5 AND 11 IN FRV1

We find this position to be reasonable with regard to the unconfined aquifer. However, groundwater is being extracted for beneficial uses in the Clive area, presumably from the confined aquifer that lies below the shallow unconfined aquifer. For example, ES uses groundwater from a local well to suppress dust.

Several deep wells have been drilled near Clive, Utah. A log for one well just west of the Clive turnoff from Interstate 80 was drilled in 1969 to a depth of 350 feet for the Cox Construction Company. The intended use was for highway construction sprinkling and compaction (see http://waterrights.utah.gov/cblapps/wrprint.exe?wrnum=16-545). The location is said to have been S 2100 ft E 1100 ft from NW cor, Sec 18, T 1S, R 11W, SLBM. The well is reported to have produced groundwater during a pumping test in 1969 at a rate of 600 gpm over 10 hours of testing (click on Well Log link at http://waterrights.utah.gov/cgi-bin/docview.exe?Folder=welllog427264). The well is now associated with Utah water right 16-722, with a well whose location is said to be at S 1900 ft W 1400 ft from NE cor, Sec 18, T 1S, R 11W, SLBM. The well log shown on the Utah Water Rights website is the same as that for the well previously described for water right 16-545. Groundwater pumped from the well is reported to be used for dust suppression and control and truck washdown (http://www.waterrights.utah.gov/cblapps/wrprint.exe?wrnum=16-772). The well reportedly had produced about 15,313,800 gallons of groundwater by 2008.

Another well, located about 3 miles east of the Clive low-level waste disposal facility, is related to Utah groundwater right 16-190 by Skull Valley Company for water for livestock (see http://www.waterrights.utah.gov/cblapps/wrprint.exe?wrnum=16-190). The depth is 293 feet, with water down at 263 feet. The flow is given as only 0.0377 cfs. Another reference shows a map for the Grassy Mountain Facility, northwest of Clive, with wells called the North USPCI Water Supply Well and the South USPCI Water Supply Well (Hansen, Allen and Luce, Inc., 2010). USPCI also drilled a well west of the Clive facility (http://www.waterrights.utah.gov/cblapps/wrprint.exe?wrnum=16-796). That well was drilled in 1992, and a well test was conducted then with an air lift yield of 0.134 cfs. Repairs were attempted in 1997, along with pumping at 350 gpm, before the well was abandoned.

The ES response has not addressed the possibility that drawdown associated from these or similar wells located just off-site at Clive could pull contamination from the Federal Cell through the underlying unsaturated and saturated zones via discontinuities in the confining layer into the confined aquifer from where it could be pumped to the surface. Water from the deeper aquifer would probably be too saline for domestic uses without treatment but could be used for dust suppression and similar purposes.

It is also possible that this water could be treated by techniques such as reverse osmosis and be used as drinking water as is currently happening at the nearby Delle Auto Truck Stop. We understand that water quality at this location is governed by state regulations since, as defined in R209-100(4), (1) “A public drinking water system is a system, either publicly or privately owned, providing water for human consumption and other domestic uses, which: (b) Serves an average of at least 25 individuals daily at least 60 days out of the year….”

It is also our understanding that regulation of small sources that do not meet the test of a public water system as described in R309-100-4 are regulated by local health organizations. In the case of Tooele County, the county health department requires that for any culinary water use, the water user needs to pay for what the County Health Department refers to the “full chemical test” based on EPA standards. These EPA standards do not include “radiologicals,” unlike the situation with public drinking water systems. Thus, the water user would not know about potential exposure to radioactive contaminants. In the case of reverse osmosis treatment, the contaminants would partition between the treated water and the wastewater creating multiple exposure pathways.

Another pathway that should be examined is the flow of contaminants from the unconfined aquifer to the confined aquifer through the annulus between borehole and the well casing. We recognize that drilling regulations require boreholes to be sealed. In Tooele County, borehole sealing inspections are performed by the county health department. However, failure to properly seal the annular space is not unusual in well drilling.

Both of these groundwater exposure pathways need to be examined and the results compared to the R313-25-19 groundwater dose limit.

After the additional information discussed here is provided, disposition of this and related interrogatories can be addressed. These include the following:

Interrogatory CR R313-25-8(4)(a)-96/1: Current and Future Potability of Water

Interrogatory CR R313-25-8(4)(a)-97/1: Need for Potable and/or Industrial Water

Interrogatory CR R313-25-8(4)(a)-105/1: Human Use of Groundwater

Interrogatory CR R313-25-8(4)(a)-106/1: Desalination Potential

Interrogatory CR R313-25-8(5)(a)-163/1: Groundwater Compliance for 10,000 Years

Interrogatory CR R313-25-19-182/1: Groundwater Exposure Pathways

EnergySolutions' Response*:* See the responses to Interrogatories CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS and CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS.

39. INTERROGATORY CR R313-25-8(5)(A)-39/1: FIGURE 6 CAPTION

Round 1 Interrogatory Response is satisfactory.

40. INTERROGATORY CR R313-25-8(5)(A)-40/1: FIGURES 7, 8, 9, 10, AND 11

Round 1 Interrogatory Response is satisfactory.

41. INTERROGATORY CR R315-101-5.3(6)-41/1: TABLE 7

Round 1 Interrogatory Response is satisfactory.

42. INTERROGATORY CR R315-101-5.3(6)-42/1: HAZARD QUOTIENT IN TABLES 7 AND 8

Round 1 Interrogatory Response is satisfactory.

43. INTERROGATORY CR R313-25-19-43/1: PEAK DOSE IN TABLE 11

Round 1 Interrogatory Response is satisfactory.

44. INTERROGATORY CR R313-25-8(5)(A)-44/2: OCCURRENCE OF INTERMEDIATE LAKES

We are troubled by ES' ongoing statements concerning carbonate sedimentation in lakes: "Intermediate lakes are assumed to be smaller lakes that reach and exceed the altitude of Clive, but are not large enough that carbonate sedimentation can occur [at Clive]." Similar statements also appear in ES responses to other interrogatories, such as Interrogatory CR R313-25-8(4)(d)-126/1: Shallow Lake Cycles.

There seems to be a sense in the PA that lacustrine carbonate sedimentation is restricted to the deep, distal (profundal) portions of large lakes. Evidence, however, indicates that this is not correct. Other than the very near shore, fine-grained carbonate sedimentation is a function of water chemistry and can occur in lakes, large or small, at virtually all depths. Provo age (~15.5–13.5 kya) marl in Lake Bonneville is common at paleodepths as shallow as 5 to 10 meters. Modern sediments of the Great Salt Lake have carbonate concentrations as great as 70% (Eardley, 1938; 1966). Preliminary research on a small lake (< 1 km2 area, 50 meters maximum depth) in upstate New York found that fine-grained carbonate constitutes approximately 75% of the bottom sediment (Takahashi et al., 1968). Further, calcium carbonate tufa deposits have been mapped in Gilbert-age lake sediments on the Grayback Hills, a short distance northwest of Clive (Doelling et al. 1994, page 13).

Given the importance of sediment characteristics to the mobility and sequestration of radionuclides, more serious consideration needs to be given to this issue. For example, radium is often precipitated with the carbonates, which could significantly impact the concentrations in the lake water.

EnergySolutions' Response*:* The deep time model is simply a high-level heuristic model designed to assist decision-making with regard to periods of time beyond the compliance period. The defined broad classes of different types of lakes are intended to explore the potential processes and impacts of different elevations of lake. Statements on carbonate sedimentation have been revised in Appendix 13 - the Deep Time. For example, new text includes the following in Section 3.3:

> "*Carbonate deposition is likely to occur under a wide range of lake conditions but the ratio of carbonate deposition to clastic sedimentation will increase as the lake deepens because of the reduction in sedimentary influx with increased distance from shoreline processes and decreased wave activity.*"

And text has been adding to state that the model is not dependent on the dynamics of carbonate deposition and that it conservatively assumes all waste is precipitated with and incorporated into local sediments during lake recession:

> "*The model parameters used in the deep time assessment are sensitive to lake duration and sedimentation rates but are not dependent on the dynamics of carbonate deposition. Radionuclides in sediment will partition between the lake water and solid phase dependent on element-specific solubility and assigned sorption properties. Radionuclides remaining in the pore water can diffuse into the lake water. Some radionuclide species may bind with carbonate ions in the lake water and*

precipitate as carbonate. However, the deep time assessment conservatively assumes all waste is precipitated with and incorporated into local sediments during lake recession."

The last sentence in the preceding text represents a highly conservative (i.e., protective) assumption.

45. INTERROGATORY CR R313-25-7(2)-45/1: INACCURATE CROSS-REFERENCE

Round 1 Interrogatory Response is satisfactory.

46. INTERROGATORY CR R313-25-7(1)-46/1: TORNADOS

Round 1 Interrogatory Response is satisfactory.

47. INTERROGATORY CR R313-25-7(1)-47/1: SELECTION OF BIOME

Round 1 Interrogatory Response is satisfactory.

48. INTERROGATORY CR R313-25-7(9)-48/2: SOURCE AND COMPOSITION OF DU WASTE

We look forward to reviewing the new data demonstrating the sensitivity of the waste composition to PA results. In addition, although it would be ideal to use the actual quantitative method of employing the scaling factors, this seems like an appropriate way to quantify I-129. Given the high dose conversion factor, it is very important to use a conservative approach for I-129. With regard to the statement about a lack of model sensitivity, DEQ will evaluate this after ES completes PA modeling for the groundwater pathway for a time period of at least 10,000 years.

EnergySolutions' Response*:* See the responses to interrogatories CR R313-25-7(1)-149/2: AMERICIUM SORPTION, CR R313-25-7(1)-147/2: DETERMINATION OF KD VALUE FOR URANIUM, and CR R313-25-7(1)-148/2: INFLUENCE OF CARBONATE ON URANIUM SPECIATION.

49. INTERROGATORY CR R313-25-7(9)-49/1: COMPOSITION OF MATERIAL MASS

Round 1 Interrogatory Response is satisfactory.

50. INTERROGATORY CR R313-25-7(9)-50/1: SAMPLES COLLECTED

Round 1 Interrogatory Response is satisfactory.

51. INTERROGATORY CR R313-25-7(9)-51/1: NATURE OF CONTAMINATION

Round 1 Interrogatory Response is satisfactory.

52. INTERROGATORY CR R313-25-7(9)-52/1: MEASUREMENT TYPES FOR SAMPLING EVENTS

Round 1 Interrogatory Response is satisfactory.

53. INTERROGATORY CR R313-25-7(9)-53/1: SUBSCRIPTS IN EQUATION 1

Round 1 Interrogatory Response is satisfactory.

54. INTERROGATORY CR R313-25-7(9)-54/1: PARTITIONING IN THE SENSITIVITY ANALYSIS

Round 1 Interrogatory Response is satisfactory.

55. INTERROGATORY CR R313-25-8(5)(A)-55/2: URANIUM ISOTOPE DISTRIBUTIONS

ES does not appear to have answered the interrogatory. ES stated that the statistical analysis examined how the results varied due to the uranium distributions given in the Waste Inventory report, but it did not state how that distribution (or impacts) would vary if the uranium isotope distribution varies. The uranium isotopic distributions should be revised if any of the literature being reviewed under Interrogatory CR R313-25-7(9)-51/1: Nature of Contamination uncovers relevant new data.

EnergySolutions' Response*:* As is reported in Appendix 15(II) – Sensitivity Analysis Results from version 1.2 of the Modeling Report, no scenario doses show sensitivity to the uranium isotopic distribution. Therefore, the uranium isotopic distributions were not further revised.

56. INTERROGATORY CR R313-25-7(9)-56/1: INTERPRETATION OF BOX PLOTS

Round 1 Interrogatory Response is satisfactory.

57. INTERROGATORY CR R313-25-7(9)-57/1: DASHED LINES IN FIGURE 4

Round 1 Interrogatory Response is satisfactory.

58. INTERROGATORY CR R313-25-7(9)-58/1: REFERENCE FOR PERSONAL COMMUNICATION

Round 1 Interrogatory Response is satisfactory.

59. INTERROGATORY CR R313-25-7(2)-59/2: BATHTUB EFFECT

The ES response was developed for the rip-rap design and therefore may not be appropriate for the newly proposed ET cover design. In addition, other interrogatories requested examination of the effects of pedogenesis, biointrusion, and other phenomena on the permeability of the radon barrier. We appreciate ES' forthcoming efforts to reexamine the potential for ponding within the waste as part of the ET cover design. We look forward to reviewing the revised report.

***EnergySolutions' Response**:* For version 1.2 of the model, it was assumed that the "*top clay liner*" referred to in the Interrogatory is the clay liner below the waste zone and not one of the radon barriers in the ET cover system. Net infiltration in version 1.2 of the Model is calculated using stochastic inputs. The implementation in Version 1.2 of the Model is described in detail in Appendix 5 - Unsaturated Zone Modeling from version 1.2 of the Modeling Report. To evaluate the likelihood of the bathtub effect occurring a distribution of net infiltration rates for the ET cover was developed from 10,000 realizations of the net infiltration model. The 99th percentile value of this distribution was 0.43 mm/yr. The design value for the saturated hydraulic conductivity of the clay liner below the waste is $1.0E^{-6}$ cm/s (31.5 mm/yr) (Appendix 5 - Unsaturated Zone Modeling, Section 10.0). At steady state under unit gradient conditions this hydraulic conductivity corresponds to the flux of water through the saturated clay liner. Given the much greater capacity of the clay liner to allow water to flow through it in comparison to the 99th percentile of net infiltration rates, the bathtub effect is not possible. Any increase in saturated hydraulic conductivity of the clay liner below the waste due to naturalization will make the bathtub effect even less likely.

For an examination of the effects of pedogenesis, biointrusion, and other phenomena on the permeability of the radon barrier see the responses to items (1), (2), and (3) for INTERROGATORY CR R313-25-7(2)-05/2: RADON BARRIER.

60. INTERROGATORY CR R313-25-7(3)-60/2: MODELED RADON BARRIERS

Refer to the Rebuttals for Interrogatories R313-25-7(2)-05/1; R313-25-8(5)(a)-176/1; and R313-25-8(4)(a)-108/1.

Additional explanation is needed in the sensitivity analysis of infiltration rates to the hydraulic conductivity of the radon barriers underlying the ET cover (Energy*Solutions* 2014). In particular, it is unclear why a decrease in the hydraulic conductivity of the upper radon barrier leads to an increase in infiltration at the top of the waste. This is counterintuitive and appears to be inconsistent with the results of the earlier Whetstone analyses (presented in the 2014 sensitivity analysis). In that study of infiltration through a rock armor cover, an increase in the hydraulic conductivity by two orders of magnitude increased the infiltration rate from 0.143 to 0.676 inches per year. Furthermore, a more detailed review of the HYDRUS modeling will be performed as part of the revised PA review.

DRC staff members also raised multiple concerns during their review of the Class A West cell ET cover proposal. These concerns must be resolved before such a cover can be considered on the DU embankment.

In addition, the reference to Benson, et al., 2011 in the response does not refer to Benson, et al., 2011 provided in the references in Section 3 of the response document. Rather, it refers to NUREG/CR-7028, which was not included in Section 3.

EnergySolutions' Response*:* An enhanced assessment of the performance of the Evapotranspiration cover system is described in the response to INTERROGATORY CR R313-25-7(2)-05/2: RADON BARRIER. A statistical experimental design was developed to provide net infiltration and water content models for version 1.2 of the Model using the variably saturated flow and transport model HYDRUS. One outcome of the statistical analysis was that the net infiltration rate was found to be insensitive to the saturated hydraulic conductivity of the radon barriers.

61. INTERROGATORY CR R313-25-8(4)(A)-61/2: MASS-BALANCE INFORMATION

The fact that mass balance is not externally tracked and reported in GoldSim does not provide a level of confidence that mass is being adequately tracked. Although modeling precision can be made progressively tighter to see if the solution converges to the same values, this does not necessarily indicate good mass balance since this approach will only check over the temporal and spatial discretization internally defined by GoldSim. It is also unknown whether mass is conserved within the mass-flux links of the process-level models (unsaturated to saturated zone) and the external pathway function. The inability to independently verify that mass is conserved is a major limitation of the GoldSim code. Notwithstanding this, ES should provide references to the code developer's test problems that demonstrate that mass is conserved.

DRC notes that it is “strongly recommended” in the GoldSim Containment Transport User’s Guide that the GoldSim user “specifically enforce media flow balances by specifying pathway flow rates and media volumes and masses in a manner that is physically consistent with the mechanics of the system being modeled” (page 229). ES should describe how this has been accomplished in the DU PA model and indicate where it is documented.

DRC also notices that GoldSim “provides a warning message [to the Run Log] if the absolute difference between the inflow and the outflow [of a pathway] exceeds 1E-10 m^3/sec AND the ratio of the absolute difference to the inflow exceeds 1E-6.” ES should indicate whether it has used this feature to determine whether mass balance is being maintained in the DU PA model. If it has, ES should indicate the results of that determination and where they are reported.

EnergySolutions' Response*:*

An extensive explanation of the mass balance of media flows (e.g. water) is provided in the response to part 3 of Interrogatory CR R313-25-8(4)(A)-69/2: LONGITUDINAL DISPERSIVITY. As explained in that response, material mass balance is already verified with independent calculations within version 1.2 of the Model.

GoldSim External Pathway elements are not used in version 1.2 of the Modeling Report.

> *“Notwithstanding this, ES should provide references to the code developer’s test problems that demonstrate that mass is conserved.”*

GoldSim has a 437 page Verification Plan that is generated by its developers for every release. It checks all the fundamental calculations carried out by GoldSim (including mass transport). Note also that GoldSim has been used worldwide for these calculations for over 20 years, and has thereby undergone extensive field testing.

62. INTERROGATORY CR R313-25-7(2)-62/2: NUMERICAL TESTING OF RUNGE-KUTTA METHOD

On May 9, 2014, ES (Energy*Solutions* 2014) provided a draft revision to the Unsaturated Zone Modeling report (Neptune 2014). We expected that the revised report would provide more extensive documentation of the testing of the Runge-Kutta solution method. Instead, a search of the report found no mention of the term “Runge-Kutta.” DRC anticipates that ES will restore and expand upon the description of the Runge-Kutta solution method in the final version of the revised

Unsaturated Zone Modeling report (Appendix 5 to FRV1), as ES had indicated in its Round 1 response. We look forward to reviewing the revised report.

***EnergySolutions*' Response**: An Appendix has been attached to Appendix 5 - Unsaturated Zone Modeling describing the development and testing of the Runge-Kutta method for estimating volumetric water content of the waste, clay liner, and unsaturated zone below the waste.

63. INTERROGATORY CR R313-25-8(4)(A)-63/2: AIR-PHASE ADVECTION

Since the degree of movement of radon will have a significant impact on dose estimates, ES should investigate transport from all potentially significant processes. We look forward to reviewing the revised report.

***EnergySolutions*' Response**: In version 1.2 of the Modeling Report volatile radionuclides are transported by aqueous advection and aqueous and gaseous diffusion. Fluctuations in barometric pressure at a site with an open ground surface have been shown by Massman and Farrier (1992) to result in the movement of fresh air into the subsurface during a barometric pressure cycle. Velocities simulated at the high point of the pressure cycle and the low point were equal in magnitude and opposite in direction indicating that the fresh air that migrates into the vadose zone moves back out of the vadose zone as the barometric pressure decreases. From a contaminant transport perspective, gas that migrates upward from depth in homogeneous permeable media during a low barometric pressure event will be pushed back down as the barometric pressure increases (Nilson et al., 1991). The presence of fractures, however, has been shown by Nilson et al. (1991) to produce conditions for net outflow of gas from the vadose zone due to barometric pressure fluctuations. The effects on gas transport due to barometric pressure fluctuations shown in numerical simulations by Massman and Farrier (1992), Nilson et al. (1991) and others are considered to be negligible in the field by Weisbrod et al. (2009) who argue that the advective events required to drive these pressure fluctuations are infrequent and depend on local weather variability. The low frequency of atmospheric events required to drive advective transport and the need for fractures to make it effective are reasons that air advection is not considered in performance assessment models.

However, other processes may contribute to significant net transport of gas. Gas migration to the atmosphere due to thermally driven convection has been demonstrated in the field by Weisbrod et al. (2009). The experiment was conducted in the Negev Desert, Israel on a fracture with an aperture that varied from 1 to 5 cm. Temperature gradients due to daily thermal cycles were shown to be sufficient to induce convective venting. The aperture of the fracture tested was larger than any expected in the ET cover and thermal gradients in the Negev Desert are steep. Given the extreme conditions of the field experiment the influence of this process on radon advection at the Clive site is expected to be much smaller than that observed by Weisbrod et al. (2009).

Remediation of uranium mining legacy sites in Germany conducted by WISMUT GmbH involved developing a strategy to reduce radon releases from waste rock piles. Radon emissions from the waste rock piles resulted in high outdoor concentrations in the vicinity of the waste rock piles of up to 1,500 Bq/m^3 (Regner and Schmidt, 2013). Investigations at the sites determined that radon releases from the rock piles due to convective movement varied spatially and temporally due to changes in buoyancy. The remediation plan implemented was to reduce radon releases by covering the waste rock piles with a mineral soil layer. For the three sites described the covers ranged in thickness from 1.0 meter (m) to 1.9 m (Paul, 2007). The 1.0 m thick design consisted of 0.2 m of topsoil underlain by 0.8 m of mineral sub-soil. The 1.6 m thick design consisted of a 0.4m revegetation layer above a 1.2 m thick loam soil layer to provide storage of soil moisture. The third design was 1.9 m thick and consisted of a 0.4 m low permeability layer on top of the waste rock overlain by a 1.5 m thick soil layer for moisture storage (Paul, 2007). These designs were determined to be protective of human health and the environment and to allow re-utilization of the remediated areas. These designs are similar in thickness and composition to the ET cover design for the Federal DU cell.

64. INTERROGATORY CR R313-25-8(4)(A)-64/2: YUCCA MOUNTAIN STUDIES

These solubility values are based on the assumption that these ions are dissolving from pure solutions. However, it is more likely that the ions are present as solid-solutions within the uranium solid phases. The PA should explain whether the differences between solubility of a pure phase versus that of a solid-solution have been considered in the models.

The phase diagrams in Figures 1–3 below were generated to illustrate the solubility of uranium versus redox potential in the presence and absence of carbonate using Geochemist Workbench with the Lawrence Livermore National Laboratory (LLNL) v8r6+ database. The diagrams were generated using the dissolved ion concentrations from Tables 5 and 6 in the Geochemical Modeling report (Appendix 6 to FRV1), with and without carbonate included and with the pH fixed at 7. The EH and total uranium were varied, and the diagrams are shown in a pourbaix format with the dominant species shown in each region. Under reducing conditions, formation of U(IV) minerals limits the solubility of uranium through formation of uraninite.

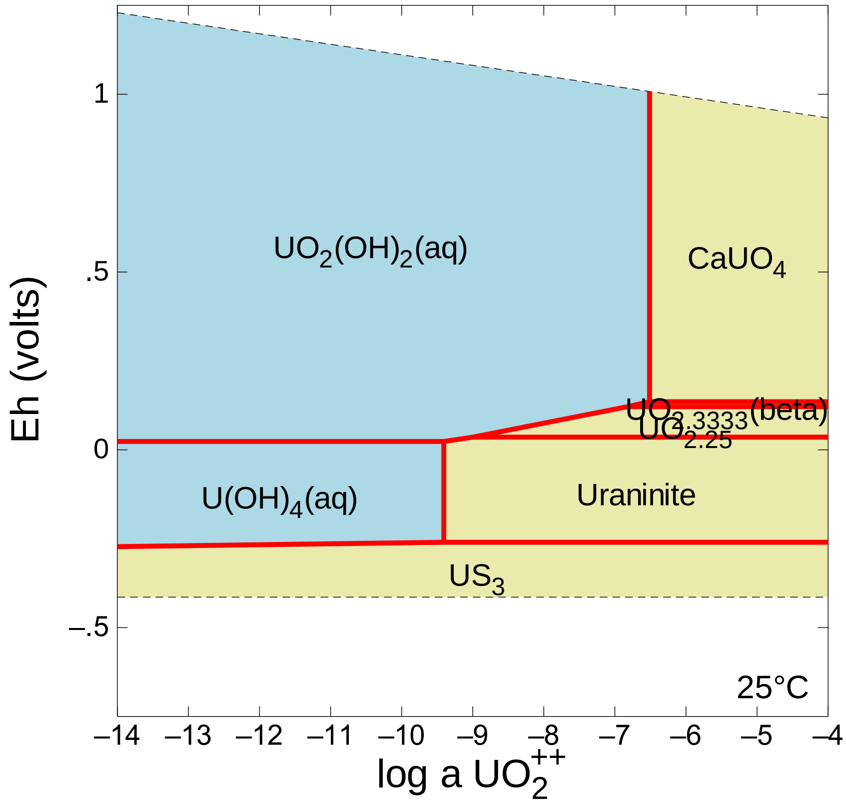


Figure 1. EH-activity diagram demonstrating uranium speciation and solubility in the absence of carbonate. Note yellow regions indicate formation of a solid phase. Model generated using Geochemist Workbench and LLNL v8r6+ database.

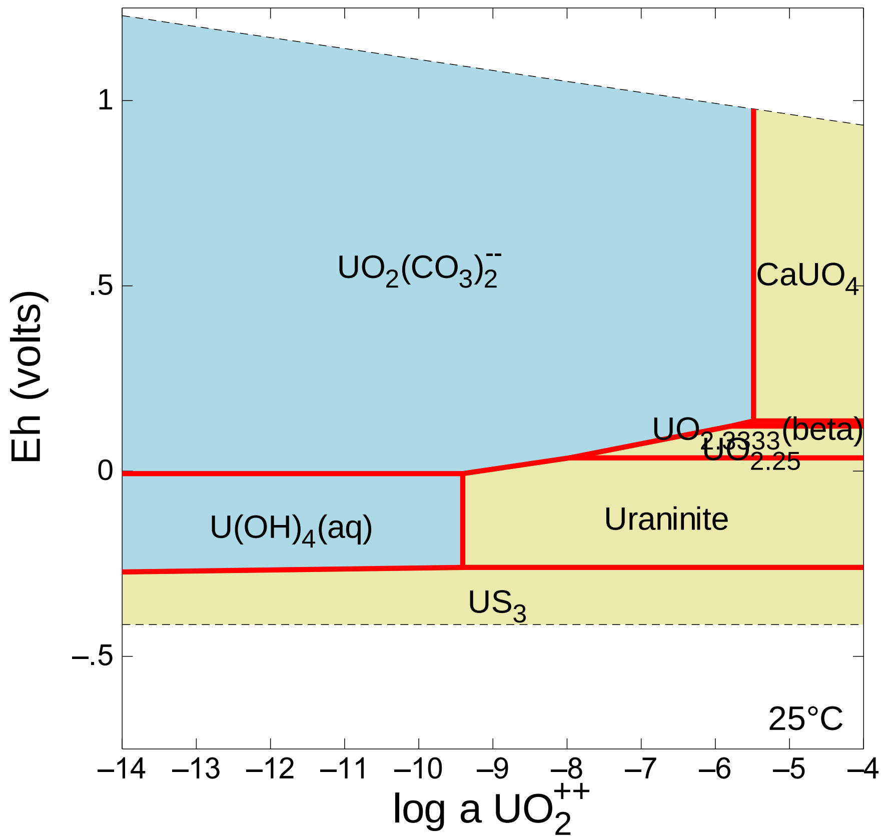


Figure 2. EH-activity diagram demonstrating uranium speciation and solubility in the presence of approximately 100 mg/L carbonate. Note yellow regions indicate formation of a solid phase. Model generated using Geochemist Workbench and LLNL v8r6+ database.

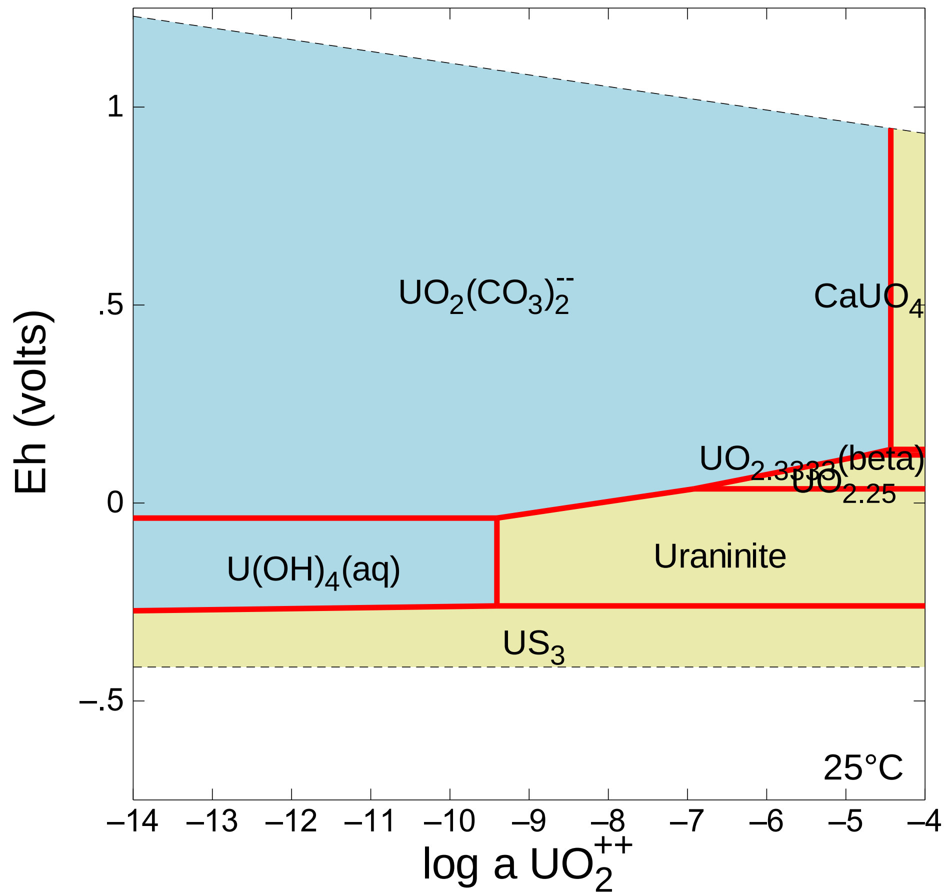
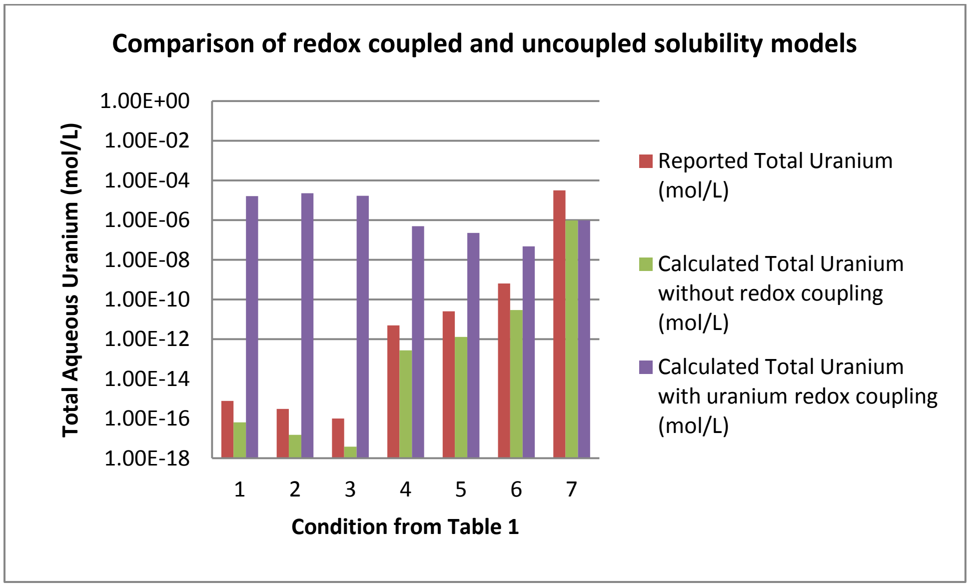


Figure 3. EH-activity diagram demonstrating uranium speciation and solubility in the presence of approximately 350 mg/L carbonate. Note yellow regions indicate formation of a solid phase. Model generated using Geochemist Workbench and LLNL v8r6+ database.

The last line of Table 2-64/1 provided in the response presents uranium solubility data from SNL (2007). The uranium concentrations reported in Table 2-64/1 seem to only include the solubility of U(VI) phases and do not consider the potential formation of U(IV) phases, which will have significantly decreased solubility. The PA should indicate whether the geochemical model considers the potential formation of uraninite or other U(IV) phases and the expected redox conditions of the waste. Not considering the U(IV) phases if they are indeed forming will result in a very overly conservative estimate of aqueous uranium concentrations.

Also relevant to the overall prediction of the solubility of uranium is that the solubilities listed in Table 10 of the Geochemical Modeling report (Appendix 6 to FRV1) represent the output of a Visual MINTEQ model of U3O8 solubility. Given the low solubilities of uranium reported in Table 10, it is clear that oxidation of U(IV) to U(VI) was not considered. This must be done by “coupling” the U(IV)/U(VI) reaction within Visual MINTEQ before running the model. It appears that the intent of the modeling exercises examining schoepite and U3O8 solubility in Tables 8–10 was to give boundaries of uranium solubility. However, it is unrealistic to run a model with a relatively high EH/pH condition (such as pH 8, EH 200 mV in Table 10) and not allow for the oxidation of reduced species. Therefore, the reported low solubility values in Table 10 are not reliable for use as the source term in reactive transport models. The table and figure below show the reported values from Table 10 as well as two columns of output from additional Visual MINTEQ runs. In the first column, data from Tables 5, 6, and 10 of the Geochemical Modeling report (Appendix 6 to FRV1) were used as noted in an attempt to reproduce the reported total dissolved uranium concentrations shown in Table 10. This was done by running the model with the U(IV)/U(VI) system "uncoupled," as was apparently done for the model output shown in Table 10. However, the final column in the table below shows the total uranium concentration in a Visual MINTEQ model with the U(IV)/U(VI) reaction coupled. Oxidation of U(IV) to U(VI) is therefore allowed and the expected total dissolved uranium concentrations are significantly higher. Since the redox chemistry of the waste disposal site in this work is variable, it is recommended that redox coupled solubility calculations be used when defining the source concentrations in reactive transport models. The specific EH and pH ranges expected under the various geologic conditions considered in the reactive transport models must be used in this source term analysis.



EnergySolutions' Response*:* It is not clear that the solid phases that are modeled in version 1.2 of the Modeling Report are "*likely solid-solutions*" since solid solutions imply a crystalline matrix that is changing internally. The waste form will likely evolve over time so that the expected solid phase in the waste layer is actually a heterogeneous mix of several different solid phases. But these would not likely be solid solutions. According to Sparks 1998 (p. 215), solid solutions "*are thermodynamically unstable at room temperature*." It is clear in Appendix 6 - Geochemical Modeling from version 1.2 of the Modeling Report that the solid phase assumptions for uranium (at least) are for equilibrium with pure solids, e.g., when it references modeling shoepite for uranium. It is assumed that the heterogeneity of the system is captured by the uncertainty in the input distribution, or else in the choice for different solid phase solubilities.

The reviewers are correct that the redox equation for U(IV)/U(VI) should be included in solubility calculations for uranium. However, note that changing the U3O8 solubility does not make a difference in the 10,000-year quantitative model. For the 10,000-year model, only UO3 is considered as a solid phase. U3O8 solubility is used in the Deep Time portion of version 1.2 of the Model. Therefore, the U3O8 solubility input distribution includes appropriate assumptions for the Deep Time portion of version 1.2 of the Model. With the return of a lake, it might be expected that the redox conditions be lower than what would be expected in the range of current groundwater conditions. According to Table 3 of the Rebuttal, uranium solubility, then, would be slightly greater than what is currently being used in version 1.2 of the Modeling Report. Because the Deep Time section already has significant conservatism built-in, a revision of the U3O8 solubility distribution will not make a noticeable difference, if that model conservatism is removed.

See the response to interrogatory CR R313-25-7-170/2: DU WASTE FORM RELEASE MECHANISMS AND RATES.

65. INTERROGATORY CR R317-6-6.3(Q)-65/2: COLLOID TRANSPORT

ES described what seems to be an appropriate way of addressing colloids. However, changes in ionic strength can generate mobile colloids. ES should review Cheng and Saiers (2009) and Ryan and Elimelech (1996) and revise the report to discuss potential impacts on the PA model.

EnergySolutions' Response*:* The discussion of colloidal transport has been expanded in Appendix 6 – Geochemistry Modeling in version 1.2 of the Modeling Report.

66. INTERROGATORY CR R313-25-8(4)(A)-66/2: COLLOID RETENTION

An evaluation of the simulation of colloidal transport will be conducted after the DRC staff reviews the additional references provided by ES in response to this interrogatory. ES should forward the references that are cited in the response as soon as possible.

***EnergySolutions' Response**:* Energy*Solutions* cannot send the references to the State of Utah directly because of copyright issues. Below are the references and website links to find the references cited in response to this interrogatory.

CRWMS M&O (Civilian Radioactive Waste Management System). 2000. Colloid-Associated Radionuclide Concentration Limits . ANL-EBS-MD-000020 REV 00 ICN 01. This reference can be found at: http://pbadupws.nrc.gov/docs/ML0906/ML090690319.pdf

Degueldre, C., I. Triay, J. Kim, P, Vilks, M. Laaksoharju, N. Mieleley. 2000. "Groundwater colloid properties: a global approach." Applied Geochemistry, vol.15, p. 1043 – 1052. This reference can be found at: http://www.sciencedirect.com/science/article/pii/S088329279900102X

Ryan, J. N., and M. Elimelech, Colloid mobilization and transport in groundwater, Colloids and Surfaces A: Physicochemical and Engineering Aspects, Vol. 107, No. 1, 1996. This reference can be found at: http://www.sciencedirect.com/science/article/pii/092777579503384X

67. INTERROGATORY CR R313-25-8(4)(A)-67/2: SOLUBILITY AND SPECIATION OF RADIONUCLIDES

We look forward to reviewing the revised report.

***EnergySolutions' Response**:* The discussion of solubility and speciation has been expanded in Appendix 6 – Geochemistry Modeling from version 1.2 of the Modeling Report.

68. INTERROGATORY CR R313-25-8(4)(A)-68/2: DISTRIBUTION OF HYDRAULIC GRADIENTS

The original interrogatory asked ES to consider four possible events or phenomena that could increase local hydraulic gradient. In its response, ES made reference to conditions at Clive between 1999 and 2010. Unfortunately, three of the requested events did not occur during this time period, namely climate change, gully erosion, and biodegradation of the radon barrier. Further, ES' claim that the hydraulic gradient was not a sensitive parameter needs to be revisited after ES increases the modeling time interval from 500 to more than 10,000 years. ES should provide the missing information; we look forward to reviewing the revised report.

EnergySolutions' Response: The influence of climate change on groundwater levels was addressed by the Intergovernmental Panel on Climate Change (IPCC) in the 5th Assessment Report (IPCC, 2014). In evaluating evidence of climate change influence they observed that changes in groundwater level are often difficult to attribute to climate change as they are also influenced by land use changes and groundwater abstractions (IPCC, 2014, Section 3.2.4). The report notes that a significant number of studies on the relationship between groundwater and climate change have been conducted since 2007. Based on these studies the IPCC report concludes "*The sensitivity of groundwater recharge and levels to climate change is diminished by perennial vegetation, fine-grained soils and aquitards*" (IPCC, 2014, Section 3.4.5). Given the fine grained texture of the Unit 4 soil forming the upper layers of the cover and the surrounding area, the fine-grained texture of Unit 2 forming the shallow aquifer, and the confined nature of the deep aquifer, climate change is not expected to influence hydraulic gradients on the scale of the Clive site.

As is reported in Appendix 15(II) – Sensitivity Analysis Results from version 1.2 of the Modeling Report, hydraulic gradient is not sensitive for all scenarios except groundwater concentration within 500 years. Even then, the sensitivity index of results to changes in K_d of uranium in sand and clay dwarfs that of hydraulic gradient.
Version 1.2 of the Modeling Report includes an enhanced assessment of the influence of radon barriers, surface layer, and evaporative zone layer performance degradation on net infiltration. See item (2) of the response to INTERROGATORY CR R313-25-7(2)-05/2: RADON BARRIER.

69. INTERROGATORY CR R313-25-8(4)(A)-69/2: LONGITUDINAL DISPERSIVITY

The ES response generated the following questions:

1. Omission of Horizontal Dispersivity Calculations: Since longitudinal dispersion would decrease the time it takes for the contaminant to reach the compliance point, ES should explain how this omission produces a result that is either conservative (protective of the environment) or is representative of Clive site conditions. We note the offer by ES to perform sensitivity testing of the model to evaluate dispersivities. ES should provide this information in its next report revision and ensure that the model used simulates a time period of 10,000 years or more.

2. Unconfined Aquifer Dimensions: A review of the schematic in Figure 1 of the Saturated Zone Modeling report (Appendix 7 to FRV1) indicates that the saturated horizontal pathway had a constant aquifer thickness (model cell height). ES should explain how this geometry will provide conservative or representative model results given that a large groundwater recharge mound is found along the south and southwest margins of the proposed Federal Cell, thereby increasing the unconfined aquifer thickness there. Conversely, a thinner aquifer on the north side of the disposal cell should increase shallow aquifer velocity. ES should also explain whether instantaneous full vertical mixing, which will dilute the plume, makes sense over a travel distance of 232 feet.

3. Mass Balance: ES should provide evidence to support the statement that the model author (operator) ensured that all flows are properly accounted for. ES should provide the criteria used to determine what magnitude or ratio of mass balance was deemed satisfactory. We appreciate the insight on how DEQ may examine this issue for itself. We are particularly concerned that the model properly accounts for the mass entering the saturated zone from the unsaturated zone.

4. Grid Spacing: Although the grid spacing appears reasonable, ES should calculate and present the Peclet number since that is the more traditional approach to guide space discretization. Ideally, the number should be less than 2.

We look forward to reviewing the revised report.

***EnergySolutions*' Response**: 1) Horizontal dispersion is not calculated because of the geometry of the transport pathway. In the realm of contaminant transport, this is known as a rectangular plane source, as illustrated in Figure 1. As shown in the figure, if a point of interest (in this case the compliance well) is relatively close to the rectangular source (in this case the Federal DU Cell), horizontal dispersion (transverse to the flow direction) becomes negligible.

The width of the disposed waste is the dimension perpendicular to the groundwater flow direction. This distance is 1,429.6 ft (“length overall” in Figure 3 of the Embankment Modeling white paper). The distance from the edge of the embankment (the “toe of the waste”, which would be in the side slope section) to the compliance point is 90 ft as required by the groundwater discharge permit. For version 1.2 of the Modeling Report the point of compliance is a virtual well at a fixed location 232 ft from the edge of the DU waste, since the length travelled under the side slope of the embankment, which contains no DU waste (142 ft), is added to the 90 ft. The edge of a plume would be at a distance of 1429.6/2 = 715ft perpendicular to the direction for flow from the well. This distance is three times the distance from the waste to the well. Given the much greater horizontal distance, any horizontal dispersion at the edge of the plume would have an insignificant effect on concentrations at the well.

2) Version 1.2 of the Modeling Report does not attempt to represent the shallow aquifer below the Federal Cell to the level of detail described in the interrogatory. Due to the uncertainty in the aquifer thickness, this parameter is represented in the model as a normal distribution with a mean of 16.2 ft and a standard deviation of 0.25 ft. This distribution for aquifer thickness is considered to be representative. Given the aquifer's small thickness relative to the Federal Cell dimensions the aquifer is assumed to be fully-mixed in the vertical direction. This, along with the approximation of the rectangular source shown in Figure 1, allows the aquifer to be represented by a 1 dimensional column oriented parallel to the flow direction.

A characteristic of all groundwater transport models is the movement of material from the source zone into cells or elements representing the aquifer. For version 1.2 of the Modeling Report the shallow aquifer under the waste is represented by 25 cells that are 16.2 ft thick in the vertical direction. The shortest time-step in the model is the initial time-step of 0.1 yr or 36 days. Time-steps after the first year extend to 1 year length and longer. A time period of 36 days is considered to be adequate for full vertical mixing in the shallow aquifer below the waste.

3) The flow of water from one modeling cell to another in version 1.2 of the Modeling Report is defined by the model developer, and is not subject to numerical approximations. The mass balance of such flows, therefore, is entirely within the control of the modeler. Before examining the details of water flow in version 1.2 of the Modeling Report, however, a bit of background on how GoldSim handles materials flows is in order.

The columns and pathways for water flow in version 1.2 of the Modeling Report are constructed from GoldSim Cell Pathway elements, which are part of the Contaminant Transport module. Each of these elements is mathematically represented as a "continuously-stirred tank reactor" (CSTR), meaning that all materials and contaminants in the Cell are assumed to be instantaneously and thoroughly mixed throughout the Cell. In version 1.2 of the Modeling Report, these Cell elements are arranged in series, making a 1 D column of what is, in effect, a finite difference model. Each Cell contains a mass of a single solid material (a function of its bulk density), as well as some volume of water (a function of the water content) and a volume of air (a function of the air content, which is zero in the saturated zone). The total volume of each Cell is defined by the cross-sectional area of the column times its thickness. Water may be "moved" between Cells by defining advective flux links. An important subtlety in GoldSim is that it does not actually keep track of water that would be moved—that is up to the modeler to define. Rather than actually moving water, GoldSim moves, from one cell to another, the contamination that would be in the material that is moved. This material could actually be water, soil, or air.

For a given Cell, then, water may flow in and out, depending on the advective flux links for water that the modeler has defined. In general, a modeler would make sure that the volume of water flowing into a Cell is equal to the amount of water flowing out, thereby ensuring mass balance by definition. GoldSim, however, does not require that these values be equal, and manages the difference in flows according to the concept of virtual uncontaminated water. This is best illustrated by an example from version 1.2 of the Modeling Report: The TopSlope container hosts a 1 D column of cells, subdivided into CapLayers, WasteLayers, Liner, and UnsatLayer. These are all connected into a single column, as the subdivision is for other purposes. Water is conceptualized to flow downward through this column as a set flow rate, which can be seen by examining any of the cell definitions (for example, in CapLayers). The rate of water flow from one cell into another cell is defined as an Outflow, on the Outflow tab of the Cell Pathway Properties dialog. Each of the cells in the column has an outflow defined for the Medium Water, with the same volumetric flow rate: WaterFlux. This is defined as the InfiltrationRate times the cross-sectional area of the column, which is the area of the top slope part of the Federal Cell. (Also note that as of version 1.2 of the Modeling Report, this disposal cell is known by its former name, the Class A South Cell). This WaterFlux is the same value for all cells in the column, so by definition the mass balance of water is zero. Each cell in the column is defined to have the same volume of water coming in as going out. A similar setup is used for the side slope cells, though for the purposes of version 1.2 of the Modeling Report, there is no inventory to contaminate the side slope.

At the water table, where the model joins the 1 D vertical unsaturated column to a 1 D horizontal saturated zone column, the allocation of recharge water is a bit more complicated, but again is in the control of the modeler. The saturated zone column has 25 cells that underlie the embankment, and several cells that lie between the embankment and the monitoring well. A conceptual illustration of this arrangement is shown in Figure 2. The allocation of recharge water from the top slope and side slope columns is illustrated in the Waste_to_Footprint and UZ_SZ_Illustration containers. The figures shown in those containers are reproduced in Figures 3 and 4 below. All accounting of flow from the top slope and side slope into the saturated zone is accomplished in the Waste_to_Footprint container, where the relative areas of the top slope and side slope are calculated and the volumetric flux of recharge is allocated to each of the 25 cells comprising the saturated zone beneath the embankment footprint.

Given the complexity of this bookkeeping of water flow, a modeler would like to have assurances that it was performed correctly, and these calculations are provided at the bottom of the Waste_to_Footprint container. To wit: There are two checksum Summation elements, named Recharge_SS_Checksum and Recharge_TS_Checksum. These add up the fractions applied to the recharge volumes into each of the 25 saturated zone cells. The fractions must sum to 1 for the top slope and for the side slope, and a simple check of the values of these summation elements verifies that indeed they do. The fractions are applied to the WaterFlux coming from the top slope, so that it is subdivided into the 25 saturated zone cells appropriately. The side slope has a similar calculation. Since WaterFlux is allocated by several fractions that all sum to 1, mass balance of recharge water is verified.

Within the horizontal column that represents the saturated zone (in the SZ_ClassASouthFootprint container), a somewhat different approach is used. Here, all saturated zone cells are connected by flow volume, similar to the 1 D unsaturated zone columns, though the volumetric flux from one cell to the next is defined by SZ_WaterFlux. This is the product of the SZ_DarcyVelocity (calculated by application of the Darcy equation in the SatZone_Parameters container) and SZ_CrossSectionalArea, the cross-sectional area of the saturated zone column, perpendicular to the groundwater flow direction. A natural question to ask is how a constant flow through the saturated zone column is indicated given that at each cell within the footprint of the embankment, water is being added to the flow? For each footprint cell in the saturated zone, flow is entering from the upstream cell (SZ_WaterFlux), as well as from recharge from the top slope and side slope, yet flow is leaving to the next cell downstream only at the rate of SZ_WaterFlux. This would seem to cause a mass balance problem, and will generate warnings in the model run log, but in fact these flows are taken into account.

This is where a subtle GoldSim modeling construct comes into play. If a GoldSim Cell Pathway is defined to have more water leaving it than coming in, GoldSim simply makes up the difference, as it were, with clean water. What GoldSim is actually doing is honoring the fundamental definition of how much water is in the cell, as discussed earlier. If there is 1 m^3 of water in a cell, then there is always 1 m^3 of water in the cell, irrespective of the flows in and out. GoldSim does not actually move water—GoldSim moves contaminants, and moves them in accordance with how much contamination would be transported if a given volume of water were moved. If we have a cell with 1 m^3 of water in it, and set up an advective flux link to another cell at a rate of 0.1 m^3/y, and have defined no inflow to the upstream cell, GoldSim will move 1/10 of the contamination in water to the downstream cell. The volume of water in the upstream cell remains the same, so in effect 1/10 of the water moved out and was replaced with clean water from some implied source. GoldSim modelers must be keenly aware of this behavior and account for it.

In the case of version 1.2 of the Modeling Report saturated zone, cells are rather overfilled with water. That is, each cell is expelling a water flux of SZ_WaterFlux, but is receiving water through SZ_WaterFlux (from the upstream SZ cell) as well as water from its fraction of recharge from the top slope and the side slope. Since the volume of water in the SZ cell never changes (it is set simply to the porosity of the solid medium that is in the cell), the water from the top slope and side slope effectively disappears, but, importantly, the contamination associated with that water remains in the SZ cell. This is a conservative assumption with respect to concentration within the saturated zone. It's as if there were a filter along the bottom of the aquifer that allowed clean water to pass through, but not contamination. As the water flows through the SZ column under the footprint, then, it receives more and more contamination, and the concentration increases since the clean water is implicitly removed from the system.

An alternative way to model the contamination of the saturated zone would be to allow each cell to leak water out the bottom (or the sides) at the same rate that water is entering from recharge. This would explicitly account for water in the system, and would have the effect of removing contamination from the SZ horizontal column and introducing it into the lower groundwater and hence removing it from the Model. This would also reduce concentrations at the monitoring well. Since the deeper groundwater hydraulics are not well understood, the conceptual model for the site is defined to keep all groundwater contamination "in bounds", even if it means erring on the side of increased concentrations at the virtual monitoring well. The 1 D column model, which does not permit flow out the bottom or sides, is conservative in this regard.

4) The Peclet number (Pe) is given by Bear (1972, p. 606) as

$$Pe = \frac{V\,d}{D_d}$$

where

V	is the velocity (L/T),
d	is the mean grain size or other characteristic length of the medium (L), and
D_d	is the diffusion coefficient (L2/T).

The velocity is calculated as

$$V = \frac{q}{n} = \frac{Ki}{n}$$

where

q is the volumetric flux (L/T),
n is the porosity of the medium (—),
K is the saturated hydraulic conductivity (L/T), and
i is the hydraulic gradient (—).

The diffusion coefficient of the medium is

$$D_d = D_b n^{4/3}$$

where

Db is the bulk diffusion coefficient of 〖"UO" 〗_2^(2+) in water (L2/T).

Values used for the Peclet number calculation taken from version 1.2 of the Modeling Report and are listed below. The shallow aquifer occurs in Unit 2 below the Federal DU Cell. Unit 2 is composed primarily of clay so a mean grain size of 2 µm was used.

Parameter	**Value**	**Units**
K	9.6×10^{-04}	cm/s
i	6.9×10^{-04}	—
n	0.29	—
d	2.0×10^{-4}	cm
D_b	4.3×10^{-6}	cm^2/s

Using these values a Peclet number of 6×10^{-4} is obtained. Comparison with Figure 10.4.1 from Bear (1972, p. 607) indicates that a Peclet number of this magnitude is characteristic of a diffusion-dominated transport system.

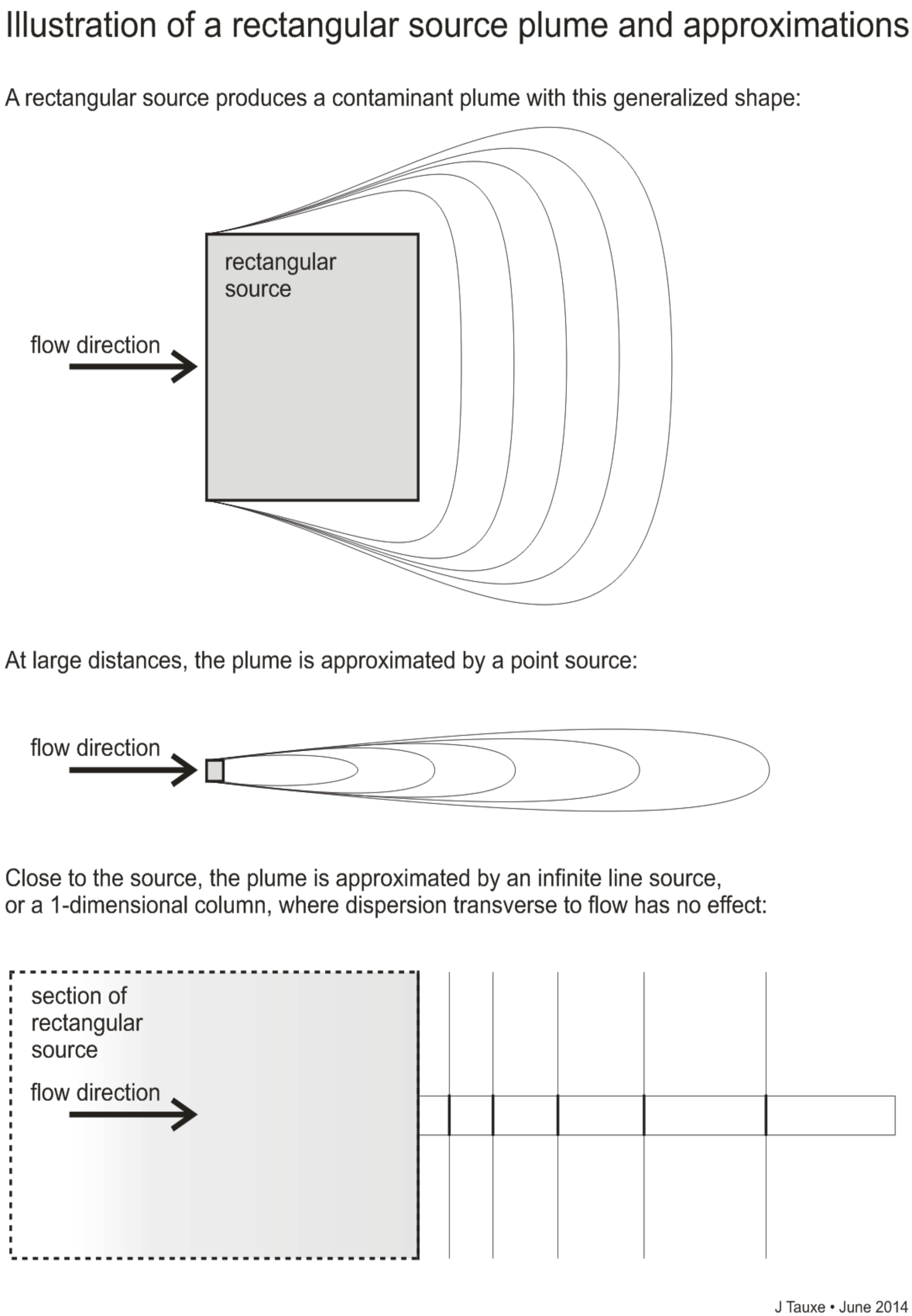


Figure 1. Approximations of a rectangular source plume.

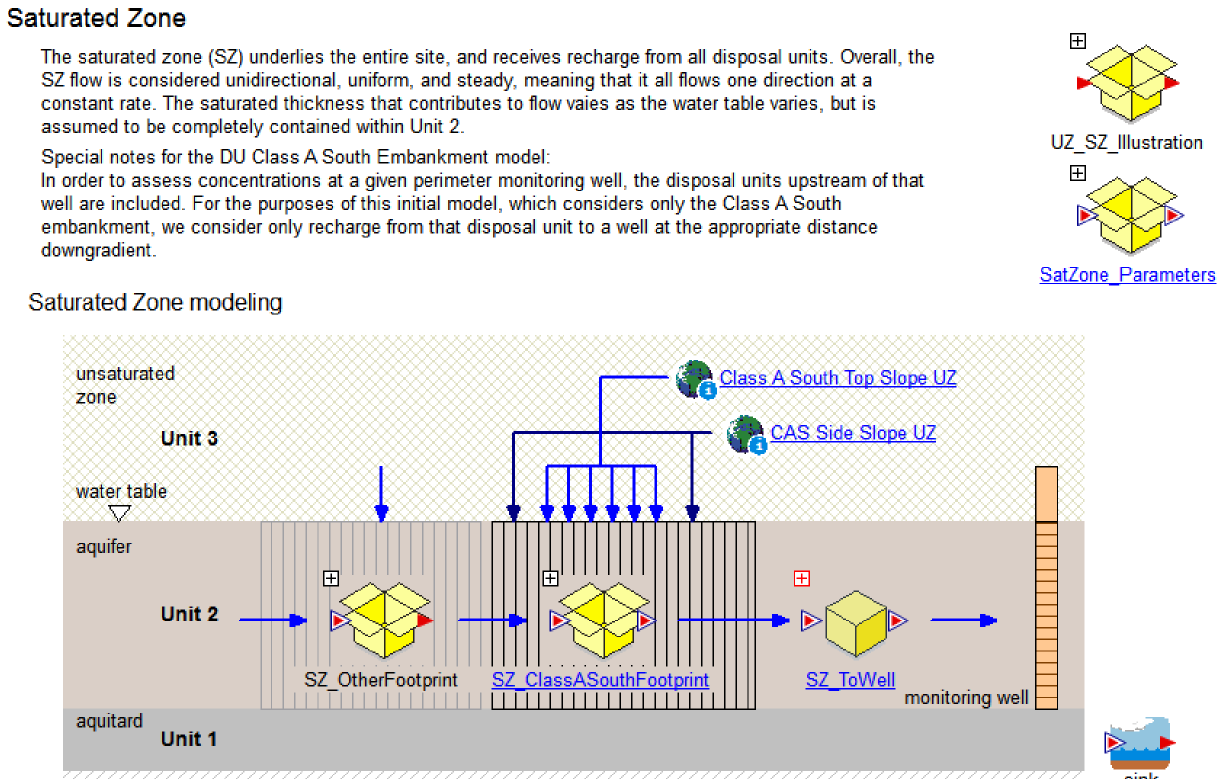


Figure 2. Clive DU PA Model SatZone container.

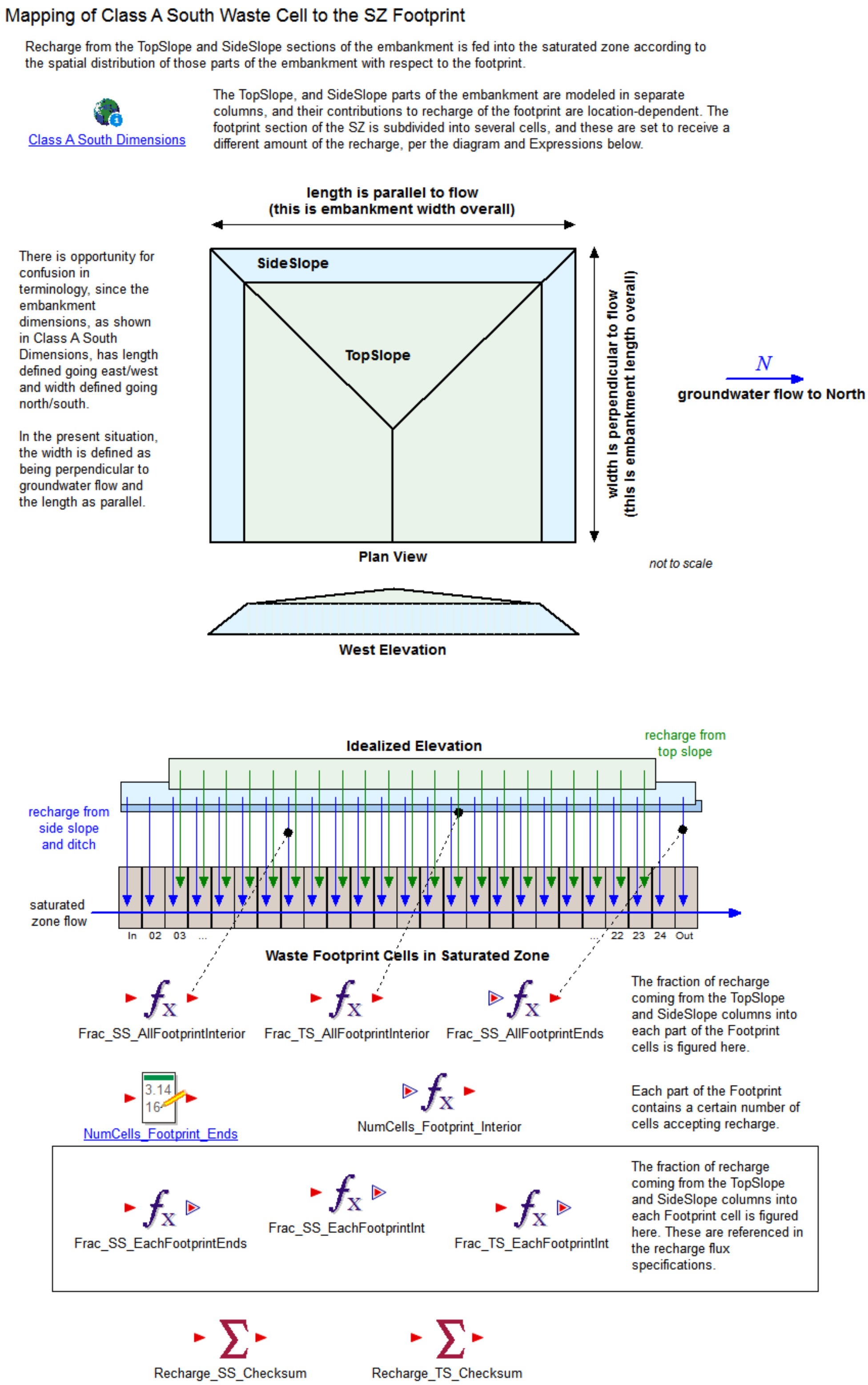


Figure 3. Clive DU PA Model Waste_to_Footprint container.

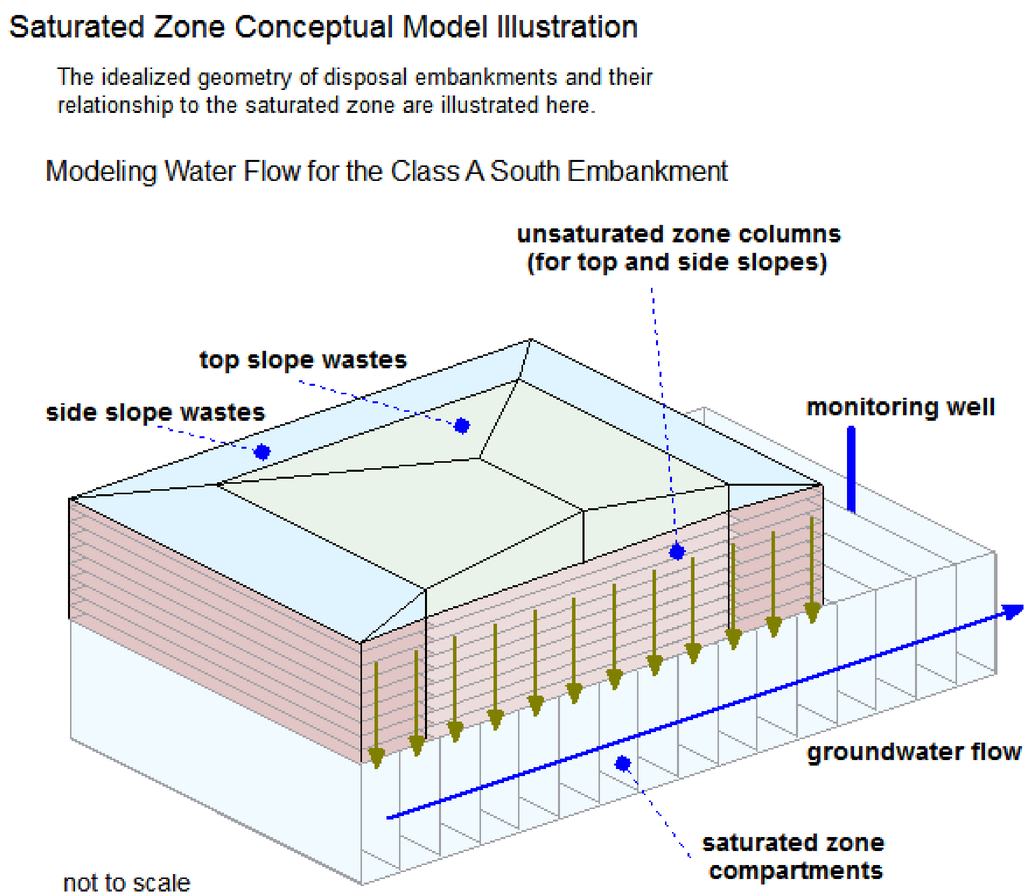


Figure 4. Clive DU PA Model UZ_SZ_Illustration container.

70. INTERROGATORY CR R313-25-7(2)-70/2: GULLY SCREENING MODEL

The PA must consider gully erosion and its effects on infiltration, radon emanation, and groundwater contamination. ES should ensure that the model includes an analysis of the effects of gully formation on cover system infiltration, radon emanation, and groundwater contamination. We look forward to reviewing this response when the revised ET cover report is available.

EnergySolutions' Response*:* See the response to Interrogatory CR R317-6-2.1-20/2: GROUNDWATER CONCENTRATIONS.

71. INTERROGATORY CR R313-25-8(4)(A)-71/1: BIOTIC PROCESSES IN GULLY FORMATION

Round 1 Interrogatory Response is satisfactory.

72. INTERROGATORY CR R313-25-8(4)(A)-72/1: DE MINIMIS DOSE VALUE

Round 1 Interrogatory Response is satisfactory.

73. INTERROGATORY CR R313-25-19-73/1: ALARA CONCEPT

Round 1 Interrogatory Response is satisfactory.

74. INTERROGATORY CR R313-25-8(5)(A)-74/1: TAILORED DISCUSSION OF SENSITIVITY ANALYSIS

Round 1 Interrogatory Response is satisfactory.

75. INTERROGATORY CR R313-25-7(9)-75/1: BRANCHING FRACTIONS

Round 1 Interrogatory Response is satisfactory.

76. INTERROGATORY CR R313-25-7(10)-76/1: QUALITY ASSURANCE PROJECT PLAN SIGNATURE PAGE

Round 1 Interrogatory Response is satisfactory.

77. INTERROGATORY CR R313-25-7(10)-77/1: QUALITY ASSURANCE PROJECT PLAN PAGE NUMBERING

Round 1 Interrogatory Response is satisfactory.

78. INTERROGATORY CR R313-25-7(10)-78/2: GOLDSIM MODEL CALIBRATION

Since we could identify very little of this type of information within the published literature, it would provide some measure of confidence in the GoldSim DU PA model if ES provided DRC with documentation of any of the results of any "global sensitivity analysis" that has been performed on the GoldSim DU PA model. We look forward to reviewing the revised report.

***EnergySolutions' Response**:* Appendix 15(II) - Sensitivity Analysis Results from version 1.2 of the Modeling Report has been expanded to include more information on methods than previously, and a sensitivity analysis results appendix (Appendix 15(II)) has been added that shows all of the sensitivity analysis results.

79. INTERROGATORY CR R313-25-7(10)-79/1: CRITICAL TASKS AND SCHEDULE

Round 1 Interrogatory Response is satisfactory.

80. INTERROGATORY CR R313-25-7(10)-80/2: TESTING OF GOLDSIM ABSTRACTIONS

Since we could identify very little of this type of information within the published literature, it would provide some measure of confidence in the GoldSim DU PA model if ES provided DRC with documentation of any of the model validation/verification and benchmarking that Neptune has conducted. We look forward to reviewing the revised report.

***EnergySolutions' Response**:* Section 5 of this interrogatory response document provides "Verification Plan – GoldSim Version 10.50 SP1" published by the GoldSim Technology Group LLC (2011). GoldSim (2011) documents verification completed to demonstrate that the GoldSim software performs its numerical and logical operations correctly.

It is presumed that what is meant by "GoldSim abstractions" is the relationship between a process as modeled in version 1.2 of the Modeling Report and how it is modeled in some external process modeling software, such as HELP or HYDRUS. In the case of HELP, which was referenced in version 1.0 of the Modeling Report, no abstraction was involved. Infiltration values calculated using HELP were used directly to build distributions representative of the model's behavior. Appendix 5 - Unsaturated Zone from version 1.0 of the Modeling Report of May 2011 states:

> "*It is important to note that these deterministic (fixed, constant) values from the HELP modeling were calculated external to GoldSim, not directly in the probabilistic Clive DU PA Model itself. They are used in the development of the uncertain stochastic distributions that are used in the GoldSim model, as developed in subsequent sections, and summarized in Section 1.0, Table 1.*"

Other than the development of statistical distributions for infiltration rates, no abstraction in version 1.0 of the Modeling Report occurred.

A similar approach was taken in version 1.2 of the Modeling Report, with its revised evapotranspirative (ET) cover that is modeled using HYDRUS. The results from several HYDRUS simulations, which covered variations in saturated hydraulic conductivity, van Genuchten's α and van Genuchten's n, are used to develop a statistical regression fit of the infiltration rate. This regression surface is derived directly from the HYDRUS results and is used directly in version 1.2 of the Model, so again no GoldSim abstraction was involved beyond the regression fit. Since the implementation of infiltration rates in version 1.2 of the Model is based directly on the statistical fit to the results of the HYDRUS modeling, and no separate modeling is performed, no verification is indicated other than a quality assurance check to assure that the values were properly transferred.

These approaches are described in the Clive DU PA Model container \Disposal\ClassASouthCell\TopSlope\Column_Transport\WaterTransport as well as in Appendix 5 - Unsaturated Zone Modeling from version 1.2 of the Modeling Report.

81. INTERROGATORY CR R313-25-7(2) AND 7(6)-81/2: COMPARISON OF DISPOSAL CELL DESIGNS

None of the ES responses provided the requested comparison between the Class A West Cell and the Federal Cell cover designs. It is our belief that such a comparison of the structural design and expected performance of the cells with rock-armor and/or ET cover systems is needed to enable DRC to compare proposed and existing designs and ensure that the proposed designs comply with R313-25-7(2) and (6).

At present, only a rock-armor cover system has been approved for the Class A West cell, and the proposed ET cover system for that cell is undergoing DRC review and has not yet been approved. ES should compare the proposed Federal Cell with all alternative cover systems that have been proposed for the Class A West cell, or with an approved cover system only.

The proposed Federal Cell that contains the DU waste must have an approved design such that its cover system is fully integrated with, or completely isolated from, the existing 11e.(2) cover system, as appropriate, based on applicable federal and state laws and regulations. ES should show how the proposed ET cover system, based on soil, will be integrated with, or isolated from, the existing 11e.(2) rock-armor cover system. ES should describe how the design of that part of the Federal Cell containing DU waste will meet all potentially applicable DOE and NRC regulations, including types of wastes disposed of and connection, or lack of connection, with nearby waste cells, and also types of influence, or lack of influence, on or by other nearby waste cells, including the existing 11e.(2) cell.

At this time, DRC does not expect ES to provide a "stand-alone engineering design report," as was requested in the original interrogatory. However, a more complete description of structural design and performance is requested, particularly in the design of features of the proposed cell contrasting with features of existing cells. We look forward to reviewing the revised information.

***EnergySolutions*' *Response*:** See the response to interrogatory CR R313-25-7(2)-160/2: COMPARISON OF CLASS A WEST AND FEDERAL CELL DESIGNS.

82. INTERROGATORY CR R313-25-20-82/2: LIMITATION ON INADVERTENT INTRUDER SCENARIOS

As described in the discussion of Interrogatory CR R313-25-8(4)(b)-07/2: Applicability of NRC Human Intrusion Scenarios and Interrogatory CR R313-25-20-12/2: Selection of Intrusion Scenarios, we do not accept that position. ES must provide arguments as to why the proposed inadvertent intruder scenarios should not be included, or else include them in the DU PA. We look forward to reviewing the revised report.

***EnergySolutions*' *Response*:** See the response to Interrogatory CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS.

83. INTERROGATORY CR R313-25-20-83/2: INTRUDER-DRILLER AND NATURAL RESOURCE EXPLORATION SCENARIOS

*ES did not explain why drilling to explore for water had been included in a previous PA (Energy*Solutions*, 2012) based on* "a very remote but finite chance that someone in the future might drill a well to determine whether potable groundwater exists at the Clive, UT site*," but was excluded here. ES also did not address the possibility of mineral exploration. Additional findings relevant to this topic are found in the discussion of Interrogatory CR R313-25-8(5)(a)-29/2: Limitation to Current Conditions of Society and the Environment. ES needs to address these issues as well as those found in Interrogatory CR313-25-8(4)(b)-*

07/2 before this interrogatory can be closed. We look forward to reviewing the revised report.

***EnergySolutions' Response**:* See the responses to Interrogatories CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS and CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS.

84. INTERROGATORY CR R313-25-7(6)-84/2: BELOW-GRADE DISPOSAL OF DU

We look forward to reviewing the new material on the cover system discussing its potential impacts on infiltration and groundwater, and the potential effects of erosion on below-grade disposal and on the effects of Aeolian deposition on near-term and deep time modeling. ES should ensure that these revisions are consistent with and resolve other related DEQ concerns in Interrogatories CR R313-25-8(5)(a)-18/2: Sediment Accumulation and CR R313-25-8(4)(d)-159/2: Embankment Damage by Lake Formation.

In response to the request under this interrogatory to "describe the types, forms, and locations of intruder barriers," ES responded that "there is no requirement for an intruder barrier,…" and did not provide additional information. However, in response to a similar question in Interrogatory CR R313-25-8(4)(b)-07/1: Applicability of NRC Human Intrusion Scenarios, ES responded that the "intruder barriers of Energy*Solutions'* Federal Cell are the same as its licensed Low Level Radioactive Waste Disposal facility, which are those defined in UAC R313-25-2…." ES should clarify these apparent conflicting statements. We look forward to reviewing the revised report.

***EnergySolutions' Response**:* The Condition 35 Compliance Report has been revised to reflect the response to interrogatory CR R313-25-8(4)(b)-07/2: Applicability of NRC Human Intrusion Scenarios.

85. INTERROGATORY CR R313-25-8(4)(A)-85/1: UNCERTAINTY DISTRIBUTIONS ASSIGNED TO DOSE CONVERSION FACTORS

Round 1 Interrogatory Response is satisfactory.

86. INTERROGATORY CR R313-25-8(5)(A)-86/2: CONSEQUENCES OF SEDIMENTATION ON DISPOSAL CELL

ES did not address expanding the current limited deep time model to address "other" exposure pathways. Such pathways include wave-cutting increasing access to waste, which could occur if waves were to remove the top portion of the embankment, followed by retreat of the lake, leaving non-dispersed DU exposed.

ES should construct a PA analysis scenario to simulate possible dose effects for this situation.

EnergySolutions' Response*:* Additional features, events, and processes have been added to Appendix 13 – Deep Time Assessment from version 1.2 of the Modeling Report. However, these additions expressly do not constitute "exposure pathways". As noted by NRC,

> "*Consistent with the above, consideration given to the issue of evaluating site conditions that may arise from changes in climate or the influences of human behavior should be limited so as to avoid unnecessary speculation. It is possible that, within some disposal site regions, glaciation or an interglacial rise in sea level could occur in response to changes in global climate. These events are envisaged as broadly disrupting the disposal site region to the extent that the human population would leave affected areas as the ice sheet or shoreline advances. Accordingly, an appropriate assumption under these conditions would be that no individual is living close enough to the facility to receive a meaningful dose [i.e. exposure]*" [*emphasis added*] (NUREG-1573, pg. 3-10)

The Rebuttal requests that the effects of other pathways such as wave-cutting of the embankment be addressed. With the current disposal configuration placing all depleted uranium waste below grade, the dispersal mechanisms previously considered in the Deep Time component of version 1.0 of the Model are no longer applicable.

87. INTERROGATORY CR R315-101-5.3(6)-87/2: ORAL TOXICITY PARAMETERS

The discussion of RfD for uranium toxicity provided by ES is adequate. However, we do not agree that ingestion of groundwater is not a pathway. See, inter alia, Interrogatory CR R313-25-8(4)(a)-96/2: Current and Future Potability of Water.

EnergySolutions' Response*:* See the responses to Interrogatories CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS and CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS.

88. INTERROGATORY CR R313-25-19-88/2: COLLECTIVE DOSE AND ALARA

The ES response commits to resolve this issue in the next report revision. We look forward to reviewing the revised text.

EnergySolutions' Response*:* Collective doses and ALARA have been corrected in Version 1.2 of the Modeling Report.

89. INTERROGATORY CR R313-25-7(9)-89/2: CONTAMINATION LEVELS IN DUF6

We note that the correct regulatory citation should actually be UAC R313-25-8(5)(c). However, we do not understand why that regulation addresses the main point of the interrogatory. R313-25-8(5)(a) specifies concentrated DU and other wastes as separate materials. The question remains as to why the PA did not include "other wastes" as required by R313-25-8(5)(a). This issue needs to be resolved if ES is to demonstrate compliance with R313-25-8(5)(a). We look forward to reviewing the revised text.

EnergySolutions' Response*:* See the response to interrogatory CR R313-25-8(5)(A)-157/2: INCLUSION OF DU AND OTHER WASTES IN PA.

90. INTERROGATORY CR R313-25-7(1–2)-90/2: CALIBRATION OF INFILTRATION RATES

We look forward to reviewing the new ET cover design for the Federal Cell and the related PA model results. Some of the information we expect to see regarding the new ET cover for the Federal Cell includes the following:

- Cover layer characteristics: Characteristics include thickness, types of soil texture, particle gradation specifications, moisture retention characteristics, slope angle, slope length, upgradient drainage areas, slope runoff coefficients, leaf area index, and soil porosity and saturated permeability.

- Effects of aging on hydraulic conductivities of cover materials.

- Duration of model simulations: ES should ensure that all infiltration and contaminant transport models simulate cover performance for at least 10,000 years or more, as called for in Interrogatory CR R313-25-8(4)(d)-155/1: Cover Performance for 10,000 Years.

- Coordination of interrogatory resolution: When describing the ET cover design, ES should coordinate responses to other related interrogatories, including the following:
  - CR R313-25-7(2)-05/1: Radon Barrier
  - CR R313-25-7(3)-60/1: Modeled Radon Barriers
  - CR R313-25-7(1)-100/1: Groundwater Recharge from Precipitation
  - CR R313-25-8(4)(a)-112/1: Hydraulic Conductivity
  - CR R313-25-8(4)(d)-153/1: Impact of Pedogenic Process on the Radon Barrier
  - CR R313-25-8(5)(a)-176/1: Representative Hydraulic Conductivity Rates

We look forward to reviewing the revised report. Additional information related to this topic and the ET cover system will be presented in an upcoming interrogatory on the promised ES ET cover system report.

***EnergySolutions' Response**:* See the responses to interrogatories CR R313-25-7(2)-91/2: DESIGN CRITERIA FOR INFILTRATION, CR R313-25-7(2)-05/2: RADON BARRIER, CR R313-25-8(4)(d)-155/2: COVER PERFORMANCE FOR 10,000 YEARS, CR R313-25-7(3)-60/2: MODELED RADON BARRIERS, CR R313-25-7(1)-100/2: GROUNDWATER RECHARGE FROM PRECIPITATION, CR R313-25-8(4)(A)-112/2: HYDRAULIC CONDUCTIVITY, CR R313-25-8(4)(D)-153/2: IMPACT OF PEDOGENIC PROCESS ON THE RADON BARRIER, and CR R313-25-8(5)(A)-176/2: REPRESENTATIVE HYDRAULIC CONDUCTIVITY RATES.

91. INTERROGATORY CR R313-25-7(2)-91/1: DESIGN CRITERIA FOR INFILTRATION

Information related to this topic and the ET cover system will be presented in an upcoming interrogatory related to the ES ET cover system report.

***EnergySolutions' Response**:* Appendices 2 – Conceptual Site Model for Disposal of Depleted Uranium at the Clive Site and 3 – Embankment Modeling from version 1.2 of the Modeling Report have been revised to address the design of the proposed Federal Cell evapotranspirative Cover.

92. INTERROGATORY CR R313-25-20-92/2: INADVERTENT INTRUDER DOSE STANDARD AND SCENARIOS

It is our understanding that the Utah DEQ Director has determined that the acceptable level is a policy decision of DEQ/DRC.

***EnergySolutions*' Response**: In its "Basis of Interrogatory," the Division acknowledges that NRC precedent establishes a dose limit of 500 mrem/yr for the inadvertent intruder. Similarly, Utah law prohibits the Radiation Control Board from adopting rules,

> "*for the purpose of assuming responsibilities from the United States Nuclear Regulatory Commission with respect to regulation of sources of ionizing radiation, that are more stringent than the corresponding federal regulations which address the same circumstances*" unless the board "*makes a written finding after public comment and hearing and based on evidence in the record that corresponding federal regulations are not adequate to protect public health and the environment of the state,*" and such findings are "*accompanied by an opinion referring to and evaluating the public health and environmental information and studies contained in the record which form the basis for the board's conclusion*" Utah Code Ann. § 19-3-104(8) and (9) –

Use of a "policy decision" by the Division for application of an intruder dose limit other than 500 mrem/year is expressly prohibited.

93. INTERROGATORY CR R313-25-22-93/2: STABILITY OF DISPOSAL SITE AFTER CLOSURE

See DEQ comments on the ES responses to the following interrogatories:

CR R313-25-8(5)(a)-03/1: Deep Time – Sediment and Lake Concentrations

CR R313-25-8(5)(a)-86/1: Consequences of Sedimentation on Disposal Cell

CR R313-25-8(4)(d)-129/1: Lake Erosion

CR R313-25-8(4)(d)-131/1: Potential Wave Energy

We look forward to reviewing the revised report.

***EnergySolutions*' Response**: The discussion of lake cycles in Appendix 13 – Deep time Assessment has been revised. Additionally, see the responses to interrogatories CR R313-25-8(5)(a)-03/2: DEEP TIME – SEDIMENT AND LAKE CONCENTRATIONS, CR R313-25-8(5)(A)-86/2: CONSEQUENCES OF SEDIMENTATION ON DISPOSAL CELL, CR R313-25-8(4)(D)-129/2: LAKE EROSION, and CR R313-25-8(4)(D)-131/1: POTENTIAL WAVE ENERGY.

94. INTERROGATORY CR R313-25-3(8)-94/1: ULTIMATE SITE OWNER

Round 1 Interrogatory Response is satisfactory.

95. INTERROGATORY CR R313-25-8(4)(A)-95/2: ESTIMATION OF I-129 CONCENTRATIONS

We look forward to reviewing the revised report.

***EnergySolutions' Response**:* The discussion of I-129 concentrations has been expanded in Appendix 4 – Waste Inventory from version 1.2 of the Modeling Report.

96. INTERROGATORY CR R313-25-8(4)(A)-96/2: CURRENT AND FUTURE POTABILITY OF WATER

We find the position on limited yield to be reasonable with regard to the shallow unconfined aquifer. However, groundwater is being extracted for beneficial uses in the Clive area presumably from the deeper confined aquifer. For example, ES uses or has used groundwater from a local well to suppress dust and decontaminate equipment and waste containers.

Several deep wells have been drilled near Clive, Utah. A log for one well just west of the Clive turnoff from Interstate 80 was drilled in 1969 to a depth of 350 feet for the Cox Construction Company. The intended use was for highway construction sprinkling and compaction (see http://waterrights.utah.gov/cblapps/wrprint.exe?wrnum=16-545). The location is said to have been S 2100 ft E 1100 ft from NW cor, Sec 18, T 1S, R 11W, SLBM. The well is reported to have produced groundwater during a pumping test in 1969 at a rate of 600 gpm over 10 hours of testing (click on Well Log link at http://waterrights.utah.gov/cgi-bin/docview.exe?Folder=welllog427264). The well is now associated with Utah water right 16-722, with a well whose location is said to be at S 1900 ft W 1400 ft from NE cor, Sec 18, T 1S, R 11W, SLBM. The well log shown on the Utah Water Rights website is the same as that for the well previously described for water right 16-545. Groundwater pumped from the well is reported to be used for dust suppression and control and truck washdown (http://www.waterrights.utah.gov/cblapps/wrprint.exe?wrnum=16-772). The well reportedly had produced about 15,313,800 gallons of groundwater by 2008. Another well, located about 3 miles east of the Clive low-level waste disposal facility, is related to Utah groundwater right 16-190 by Skull Valley Company for water for livestock (see http://www.waterrights.utah.gov/cblapps/wrprint.exe?wrnum=16-190). The depth is 293 feet, with water down at 263 feet. The flow is given as only 0.0377 cfs. Another reference shows a map for the Grassy Mountain Facility, northwest of Clive, with wells called the North USPCI Water Supply Well and the South USPCI Water Supply Well (Hansen, Allen and Luce, Inc., 2010). USPCI also drilled a well west of the Clive facility (http://www.waterrights.utah.gov/cblapps/wrprint.exe?wrnum=16-796). That well was drilled in 1992, and a well test was conducted then with an air lift yield of

0.134 cfs. Repairs were attempted in 1997, along with pumping at 350 gpm, before the well was abandoned.

The ES response has not addressed the possibility that drawdown associated from these or similar wells located just off site at Clive could pull contamination from the Federal Cell through the underlying unsaturated zone and water table via discontinuities in the confining layer into the confined aquifer, from where it could be pumped to the surface and put to beneficial use. Although water from the deeper aquifer would probably be too saline for direct domestic use without treatment, it could be used for dust suppression and similar industrial purposes.

It is also possible that this deep groundwater could be treated by techniques such as reverse osmosis and be used as drinking water, as is currently happening at the nearby Delle Auto Truck Stop. This is also the case at Aragonite, a commercial hazardous waste incinerator owned by Clean Harbors, located about 4 miles east of Clive, where two deep wells exist (between 700 and 800 feet bgs) (Earthfax 1999). Both of these deep wells, located directly to the northeast of the Aragonite facility, are currently being pumped to supply drinking water to approximately 100 employees through a reverse osmosis system. Therefore, a drinking water scenario in an industrial setting from a deep well in the confined aquifer outside the facility’s boundaries should be considered.

It is our understanding that local health organizations regulate small sources that do not meet the test of a public water system as described in R309-100-4. In the case of Tooele County, the county health department requires that for any culinary water use, the water user needs to pay for what the department refers to as the “full chemical test” based on EPA standards. These EPA standards do not include “radiologicals”. Thus, the water user would not necessarily know about potential exposure to radioactive contaminants. In the case of reverse osmosis treatment, the contaminants would partition between the treated water and the wastewater byproduct, creating multiple exposure pathways.

Another pathway that should be examined is the flow of contaminants from the unconfined aquifer to the confined aquifer through the annulus between borehole and the well casing. We recognize that drilling regulations require boreholes to be sealed. In Tooele County, borehole sealing inspections are performed by the county health department. However, failure to properly seal the annular space is not unusual in well drilling.

Both of these groundwater exposure pathways need to be examined and the results compared to the R313-25-19 groundwater dose limit.

Energy*Solutions'* Response: Energy*Solutions* has assessed the possible inadvertent exposure to an intruder constructing and industrially using water from the deeper confined strata that has become cross-contaminated by gradient-driven communication with depleted uranium-related wastes that have migrated into the upper unconfined aquifer, (see the response to Interrogatory CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS for the projected industrial intruder results). Because of the high saline and total dissolved solid content of the confined aquifer (similar to that found in the unconfined aquifer), groundwater pumped from the deep aquifer is classified as Category IV and therefore unpotable.

However, important hydrogeologic differences exist between a possible inadvertent industrial intruder well and the other examples cited by in the Division's Interrogatory. For example, the bore logs of both the Skull Valley Company and Aragonite wells located several miles east of the Federal Cell proposed location reveals they are primarily an extended gravel zone within the recharge zone of the foothills of the Cedar Mountains (extremely dissimilar to that immediately adjacent to the proposed Federal Cell).

Energy*Solutions* further recognizes that while not producing water within similar geohydrological conditions, NRC suggests the awareness demonstrated by Aragonite well owners for the need to treat the Class IV groundwater prior to ingestion,

> "*that current local well-drilling techniques and/or water use practices will be followed at all times in the future."* (NUREG-1573).

Therefore, since current local practices for the area surrounding Clive that share similar groundwater characteristics and yields do not include groundwater drinking wells without known treatment, consideration of a groundwater ingestion exposure pathway is inappropriate and counter to NRC guidance.

See also the response to Interrogatory CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS.

97. INTERROGATORY CR R313-25-8(4)(A)-97/2: NEED FOR POTABLE AND/OR INDUSTRIAL WATER

As discussed under Interrogatory CR R313-25-8(4)(a)-96/2: Current and Future Potability of Water, ES fails to mention a nearby well that has been used for dust suppression and equipment decontamination. Assuming that this water is obtained from the deeper confined aquifer, it could become contaminated from pollution in the overlying water table aquifer and cause exposure to surface workers. Likewise, future treatment of the deep confined aquifer could render this water beneficial for other industrial applications and drinking water. These possibilities need to be examined.

***EnergySolutions*' *Response*:** See the responses to Interrogatories CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS and CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS.

98. INTERROGATORY CR R313-25-7(1)-98/1: MONTHLY TEMPERATURES

Round 1 Interrogatory Response is satisfactory.

99. INTERROGATORY CR R313-25-7(1)-99/1: EVAPORATION

Round 1 Interrogatory Response is satisfactory.

100. INTERROGATORY CR R313-25-7(1)-100/2: GROUNDWATER RECHARGE FROM PRECIPITATION

In the process of modifying the text for the revised report, ES should provide a reference for the quoted text in its response to this interrogatory (Energy*Solutions* 2014, pages 102–103). ES should also document the presence or absence of rip rap on part of the side slopes; if rip rap is present anywhere, the model should be amended to account for reduced evaporation in these areas of rip rap. We look forward to reviewing the revised report.

***EnergySolutions*' *Response*:** The statement from Section 3.2.3 of Appendix 2 – Conceptual Site Model for Disposal of Depleted Uranium at the Clive Site has been referenced. Note that the last few sentences in the quoted text in the Round 1 Interrogatory Response document were not included in Appendix 2, because they were considered unnecessary to fulfill the request of the Interrogatory.

Riprap is not used in the cover design. SWCA (2013, p.5) describe the design as "the cover designs … include riprap-lined diversion ditches to direct water away from the ET cover, but the top and sides of the ET cover do not include riprap as part of the cover materials."See the response to interrogatory CR R313-25-7(2)-179/1: RIP RAP as to continued Division-authorized use of riprap for Clive's surface water management ditch network.

101. INTERROGATORY CR R313-25-7(1)-101/2: NATURE OF UNITS 1 AND 2

The ES response is largely satisfactory, providing that DRC finds the promised description in the revised report to be adequate. However, ES should include in the revised report all of the additional text and description provided in its response to this interrogatory. Furthermore, ES should document and explain eh cause of the shallow groundwater mounding in the vicinity of Wells MW-60 and MW-63 in the southern part of Section 32 (see Energy*Solutions*, 2014) and discuss quantitatively its impact throughout time on vertical components of hydraulic gradient. We look forward to reviewing the revised report.

***EnergySolutions' Response**:* The descriptions of units 1 and 2 materials in Section 3.3.1 of Appendix 2 – Conceptual Site Model for Disposal of Depleted Uranium at the Clive Site from version 1.2 of the Modeling Report has been revised. The shallow groundwater mounding in the vicinity of wells MW-60 and MW-63 has been also added to Appendix 2.

102. INTERROGATORY CR R313-25-7-102/1: SEISMIC ACTIVITY

Round 1 Interrogatory Response is satisfactory.

103. INTERROGATORY CR R313-25-7-103/2: HISTORICAL FLOODING

ES does not discuss historical non-chronic flooding at the site, as was requested in the interrogatory. After times of heavy precipitation, water at the site may collect in depressions along the surface in various places. ES should provide details about locations and depths and how the water management system operates to remove the water. Reference to Clive's exterior berm system, as found in the ES LLRW license renewal application dated March 6, 2013, is not appropriate, in that (1) that berm is designed for the active operational life of the facility, and (2) that berm will not persist after facility closure. If it were to, the need for active, ongoing maintenance would be evident; however, such maintenance does not comply the requirements of several state regulations for LLRW, including, but not limited to, R313-25-8(4)(d), R313-25-22, and R313-25-24(1). Consequently, ES should revise its response to address and resolve this interrogatory. We look forward to reviewing the revised report.

***EnergySolutions' Response**:* As noted in the Rebuttal quoted above, reference to operational procedures and conditions is not appropriate, since post-closure conditions should assume no active management. Similarly, historical non-chronic flooding due to site topography during operations is not relevant to the PA. Should localized depressions near the closed embankment accumulate water for short periods of time, their impact is expected to be minimal since evaporation far exceeds precipitation at Clive. See also the response to Interrogatory CR R313-25-8(4)(A)-68/2: DISTRIBUTION OF HYDRAULIC GRADIENTS.

104. INTERROGATORY CR R313-25-7(2)-104/2: INFILTRATION IN THE PRESENCE OF RIP RAP OR NATURAL ROCK

Upcoming report revisions will add new text and better describe the model use. Therefore, the ES response will be evaluated as part of the more detailed review of the HYDRUS modeling during the review of the forthcoming revised PA. With reference to the proposed text for Section 7.2.1.6 of the Conceptual Site Model report, ES should clarify which disposal cell design is being referred to (the rip rap or an ET design). Any rip rap on side slops of an ET cover system should be described. ES should also explain and justify how this design will mitigate future pluvial lake flooding at Clive. We look forward to reviewing the revised report.

***EnergySolutions*' Response**: Section 7.2.1.6 of Appendix 2 - Conceptual Site Model for Disposal of Depleted Uranium at the Clive Site has been revised to address the Federal Cell's disposal design and evapotranspirative cover system. The design's performance regarding pluvial lake flooding has also been addressed. The currently-approved use of riprap to line Clive's drainage ditch network will not require revision as a result of the construction of the Federal Cell.

105. INTERROGATORY CR R313-25-8(4)(A)-105/2: HUMAN USE OF GROUNDWATER

Based on the discussion provided under Interrogatory CR R313-25-8(4)(A)-96/2: Current and Future Potability of Water, a member of the general population could drill a well into the confined aquifer and treat the water for domestic and industrial uses. Under current Tooele County regulations, if the domestic uses do not qualify as a public water system, there are no requirements for testing for radioactive contamination. It is also possible that future demand for municipal and industrial water in Utah, combined with currently available treatment technology, could render the deep aquifer useable for drinking water and many other industrial uses. These types of exposure scenarios need to be evaluated.

***EnergySolutions*' Response**: See the responses to Interrogatories CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS and CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS.

106. INTERROGATORY CR R313-25-8(4)(A)-106/2: DESALINATION POTENTIAL

ES stated that the Conceptual Site Model report (Appendix 2 to FRV1) was being revised to acknowledge the technical feasibility and practical improbability of groundwater desalination at Clive. However, contrary to what ES indicated the proposed revision would acknowledge, the actual ES language does not comment on the technical feasibility of desalination, nor does it recognize that desalination is accomplished in the vicinity of Clive to produce potable water. This needs to be corrected. Further, the probability that Clive groundwater will someday be extracted, treated, and put to beneficial use as drinking and/or industrial water will be a function of economics. Like most Western States, Utah, with a finite quantity of water resources and a growing population, will someday be forced to draw on West Desert groundwater to service future generations. To help DEQ assess groundwater conditions in the deep aquifer in the well near I-80 at the south end of the Grayback Hills, ES should provide comprehensive well completion details, groundwater elevation, and water quality sampling and analysis results for this deep well.

EnergySolutions*' *Response: See the responses to Interrogatories CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS and CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS.

Note also that the interrogatory statement "Like most Western States, Utah, with a finite quantity of water resources and a growing population, will someday be forced to draw on West Desert groundwater to service future generations" is exceedingly speculative, contrary to NRC guidance for performance assessment. While one could speculate on the perceived inevitability of groundwater treatment in the West Desert, one could as easily speculate on the "inevitability" of overpopulation resulting in war over resources or pandemic illnesses resulting in a population crash. NRC correctly cautions against such speculation. See the response to Interrogatory CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS.

107. INTERROGATORY CR R313-25-7(1)-107/2: PREDOMINANT VEGETATION AT THE CLIVE SITE

It is clear that this area has experienced substantial historic disturbance from grazing. This, in combination with stressful climatic and substrate conditions, has left a vascular plant cover that is weedy and ephemeral. This cryptobiotic crust cover, while not comprised of vascular plants, is still a biotic component that likely has substantial importance in the stability of the soil surface.

The PA still needs to address a number of questions pertaining to the plant cover, including the kind of plant community that can be expected beyond 500 years on the ET cover, whether it will be robust and self-sustaining, whether any of the plants will set deep roots, and if so, how deep, and how effective the plant community will be in reducing infiltration.

EnergySolutions*' *Response: As is reported in Appendix 15(II) – Sensitivity Analysis Results from version 1.2 of the Modeling Report, biomass % cover and productivity is not sensitive for all scenarios. Furthermore, to help discourage unbounded speculation regarding the impact of long-term environmental changes on a site's plant community, NRC has stated,

> "*Given the uncertainty in projecting the site's biological environment beyond relatively short periods of a few hundred years, it is sufficient to assume that current biological trends remain unchanged throughout the period of analyzed performance.*" (NUREG-1573, pg 3-11).

Accordingly, Appendix 2 – Conceptual Site Model for Disposal of Depleted Uranium at the Clive Site and Appendix 9 – Biological Modeling from version 1.2 of the Modeling Report have been expanded to explain that the projected vegetation community expected to become established on the evapotranspirative cover well prior to the completion of any institutional control period will be equivalent to the vascular plant cover and the associated crust observable at Clive today.

108. INTERROGATORY CR R313-25-8(4)(A)-108/2: BIOINTRUSION

We await the results of that evaluation.

EnergySolutions*' *Response: Section 3.5.2 of Appendix 2 – Conceptual Site Model for Disposal of Depleted Uranium at the Clive Site and Appendix 9 – Biological modeling from version 1.2 of the Modeling Report have been revised to incorporate and reference analysis conducted by SWCA (2011).

109. INTERROGATORY CR R313-25-7(2)-109/1: GEOCHEMICAL DEGRADATION OF RIP RAP

ES notes that this interrogatory is no longer relevant for the top slope of the Federal Cell since the Federal Cell will largely use an ET cover. However, this interrogatory should be addressed in regard to rip rap that will be used on portions of the side slope and on ditches.

EnergySolutions*' *Response: In the basis for Interrogatory CR R313-25-7(2)-109/1: GEOCHEMICAL DEGRADATION OF RIP RAP, the Division states,

> "*DRC and EnergySolutions have paid attention to a small but significant portion of the rock at the nearby Vitro site that has degraded geochemically at a substantial rate within the past several decades.*"

In a Notice of Confirmatory Action received from the Division on May 30, 2012, direction was included regarding the inclusion of surety funds to account for the analysis of the impact on the Class A and Class A North embankments' final cover performance integrity of the rapid weathering apparently observed by U.S. Department of Energy (DOE) and Division representatives on the Vitro and LARW Embankments. As a means of qualitatively assessing the rate of aggregate degradation, Energy*Solutions* commissioned Wiss, Janney, Elstner Associates, Inc. (WJE) to conduct a Rock Fragment Petrographic Study (WJE, 2013).

In their Study, WJE studied subjectively selected aggregate rock samples from the LARW embankment cover and current Clive stockpiles that displayed cracking and degradation similar to those Vitro areas under continued observation by DOE staff, as well as samples that appeared to be the same rock type but did not have visible cracking or degradation. For the eleven rock fragments specifically chosen as representative of the Vitro degradation, WJE concluded that "*severe distress suggests that these particles were in a weak and highly weathered condition at the time the fill was installed.*" WJE further observed that the most weathered rocks were "*most likely in a weakened condition at the time it was placed as fill.*" As a result of these observations, WJE noted that "This type of normal degradation takes place relatively slowly (over geologic time) *[not at a substantial rate within the past several decades]*," and as such is not indicative of Division's inaccurate concerns of "*rapid weathering*."

Additionally, the current LLRW and 11e.(2) CQA/QC Manual - Rock Erosion Barrier Work Element includes Quality of Rock controls that mirror WJE's recommendation for selection of material that "*would be less prone to relatively rapid deterioration that has reportedly occurred relatively soon after the material was installed.*" Finally, the results of the DOE and WJE studies further demonstrate that the weathered rock observed on the Vitro and LARW covers is limited to a small percentage of the overall rock covering (less than 1%) and are not expected to increase in the geologic short term. The currently-approved use of riprap to line Clive's precipitation management network will not require revision as a result of the construction of the Federal Cell.

110. INTERROGATORY CR R313-25-8(4)(A)-110/1: RADON TRANSFER FROM WATER

Round 1 Interrogatory Response is satisfactory.

111. INTERROGATORY CR R313-25-7-111/2: LIKELIHOOD OF LAVA DAM FORMATION

The cited documents were not included in the reference list in Section 3 of the response document. ES should provide full reference information so that we can review these sources.

***EnergySolutions' Response**:* The complete list of references for the Round 1 response for this interrogatory are listed below. Note that the citation for (Nash, 1989) in the text of the response should have been (Nash, 1990).

- Link, P.K., D. S. Kaufman, and G. D. Thackray, 1998, Field Guide to Pleistocene Lakes Thatcher and Bonneville and the Bonneville Flood, Southeastern Idaho, in Hughes, S.S. and Thackray, G.D. eds., Guidebook to the Geology of Eastern Idaho, Idaho Museum of Natural History, p. 251-266.

- Nash, W.P., 1990, Black Rock Desert, Utah, in C.A Woods and J. Kienle, eds. Volcanoes of North America, Cambridge University Press, Cambridge p. 271-273.

- Oviatt, C.G. and W. P. Nash, 1989, Late Pleistocene Basaltic Ash and Volcanic Eruptions in the Bonneville Basin, Utah, Bulletin Geological Society of America, V. 101, p. 292-303.

- Oviatt, C.G., and B. P. Nash, 2014a, The Pony Express Basaltic Ash: A Stratigraphic Marker in Lake Bonneville Sediments, Utah, Miscellaneous Publication 14-1, Utah Geological Survey 10 p.

112. INTERROGATORY CR R313-25-8(4)(A)-112/1: HYDRAULIC CONDUCTIVITY

The ES response is not adequate, in that the analysis mentioned does not account for changes in hydraulic conductivity of the surface layer and the evaporative zone. Currently, with presently modeled hydraulic conductivities, the PA model indicates that water does not infiltrate down to the radon barriers at significant rates. As a result, the model currently shows the radon barriers to be insensitive to changes in hydraulic conductivity. However, that may very well change once the PA modeling accounts for changes in hydraulic conductivity of the surface layer and the evaporative zone. Increases in hydraulic conductivity may permit greater rates of infiltration and lesser fractional removal of water via evaporation. Furthermore, a strong correlation exists between van Genuchten alpha values and hydraulic conductivity, as shown by Guarracino (2007). Therefore, the correlated values of alpha should be made also when changes in hydraulic conductivity are made for the surface layer and the evaporative zone in the model.

Also, the interrogatories referenced are in need of additional information and resolution. Therefore, resolution of this interrogatory will also require resolution of several others, including those listed in Interrogatory CR R313-25-7(1–2)-90/1: Calibration of Infiltration Rates.

EnergySolutions' Response*:* See the responses to interrogatories CR R313-25-7(2)-05/2: RADON BARRIER and CR R313-25-7(3)-60/2: MODELED RADON BARRIERS.

113. INTERROGATORY CR R313-25-8(5)(A)-113/2: PLACEMENT OF BULK LOW-LEVEL WASTE AMONG DU CANISTERS

It is not clear how the ES response satisfies the UAC R313-25-8(5)(a) requirement that the PA include "total quantities of concentrated depleted uranium and other wastes." Doses from DU and other wastes (including bulk waste) will sum and must be accounted for in the model quantitatively for 10,000 years and qualitatively (after concentrations are modeled quantitatively) until peak dose is attained. Neither of these requirements is satisfied currently in the PA model. Among other open questions is (1) how the source term for DU and other wastes will be developed and (2) how relevant engineering requirements related to R313-25-7(2) and (10) will be satisfied, including structural stability of backfill and quality assurance for waste emplacement, respectively. Alternatively, ES could commit not to use bulk low-level radioactive waste as in-fill for DU container disposal. We look forward to reviewing the revised text.

EnergySolutions' Response*:* See the response to interrogatories CR R313-25-8(5)(A)-157/2: INCLUSION OF DU AND OTHER WASTES IN PA and CR R313-25-7(2)-173/2: STABILITY OF EMBANKMENT.

114. INTERROGATORY CR R313-25-19-114/2: ELEVATED CONCENTRATIONS OF TC-99

We look forward to reviewing the results of the new ET cover design and how it may affect Tc-99 concentrations in the groundwater over 10,000 years or more. These results would need to be integrated in the groundwater exposure scenarios discussed in Interrogatory CR R313-25-8(4)(a)-96/2: Current and Future Potability of Water, and Interrogatory CR R313-25-8(4)(a)-97/2: Need for Potable and/or Industrial Water.

With regard to general strategies for addressing Tc-99, the possibility of locating Tc-99 contaminated waste higher in the embankment is inconsistent with the current approach of burying the DU waste below native grade levels. However, the second strategy has merit, especially since there appears to be inadequate volume below grade to bury all of the DU waste.

EnergySolutions' Response: Appendix 3 – Waste Inventory, Appendix 11 – Dose Assessment and version 1.2 of the Modeling Report have been revised to project the fate and transport of Tc-99 in groundwater from water percolating through an evapotranspirative cover over the Federal Cell. Since Energy*Solutions* has already committed to only dispose of depleted uranium wastes below ground surface, the Division's proposed second strategy is inapplicable. Additionally, see responses prepared for Interrogatories CR UGW450005 PART I.D.1-180/2: COMPLIANCE PERIOD and CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS.

115. INTERROGATORY CR R315-101-5.3(6)-115/1: URANIUM TOXICITY REFERENCE DOSES

Round 1 Interrogatory Response is satisfactory.

116. INTERROGATORY CR R313-25-8(4)(A)-116/1: CS-137 DECAY

Round 1 Interrogatory Response is satisfactory.

117. INTERROGATORY CR R313-25-8(5)(A)-117/2: GROUNDWATER PROTECTION LIMIT FOR TC-99

Limitations on exposures to the general public are established in R313-25-19. Pursuant to R313-25¬8(5)(a), these standards must be met for 10,000 years or more for any viable groundwater or other pathway. See our comments on Interrogatory CR R313-25-8(4)(a)-96/2: Current and Future Potability of Water. We note that ES did not provide a response to our query regarding Tc-99 concentrations in the embankment side slopes. The requested explanation should be provided.

EnergySolutions' Response: Since Energy*Solutions'* commitment to limit disposal of depleted uranium to below grade regions beneath the Federal Cell tops slope, the Division's inquiries as to Tc-99 concentrations in the embankment side slopes is inapplicable. Furthermore, see responses prepared for Interrogatories CR UGW450005 PART I.D.1-180/2: COMPLIANCE PERIOD and CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS regarding the unreasonableness of further groundwater ingestion analysis.

118. INTERROGATORY CR R313-25-7(10)-118/1: GOLDSIM RESULTS

Round 1 Interrogatory Response is satisfactory.

119. INTERROGATORY CR R313-25-8(4)(A)-119/1: RESUSPENSION AND AIRBORNE PATHWAYS

Round 1 Interrogatory Response is satisfactory.

120. INTERROGATORY CR R313-25-8(4)(A)-120/2: GULLIES AND RADON

We assume that this "further…modeling" will include the impact of erosion on the radon flux, and we look forward to receiving and reviewing these further erosion modeling efforts.

EnergySolutions' Response*:* See the response prepare for Interrogatory CR R317-6-2.1-20/2: GROUNDWATER CONCENTRATIONS

121. INTERROGATORY CR R313-25-19-121/2: GULLIES AND RECEPTOR LOCATION

First, this interrogatory has more to do with the OHV enthusiast dose model than with the gully/erosion model. Thus, this interrogatory applies equally well to the existing and revised gully/erosion models.

The gist of this interrogatory is that OHV riders would spend proportionally more of their time in gullies than on the top surface of the embankment. ES argued that the steep walls of the gullies would preclude OHV enthusiasts from riding in the gullies. However, the steep gully walls would offer a challenge to the OHV enthusiasts and encourage them to ride there to demonstrate the capabilities of their machine and/or to demonstrate their driving skills. A cursory review of results to a Google search on "dunes gullies ATVs" demonstrates that gullies are some of the favorite places for ATV enthusiasts to ride.

Furthermore, a gully in the side of the embankment would provide a preferential path to the top for the OHV enthusiasts, so that they would not have to go up the steeper sides of the un-eroded embankment.

In brief, DRC does not agree with the ES response and believes that further investigation into this issue is warranted. We look forward to reviewing the revised report.

EnergySolutions' Response*:* The lack of result sensitivity to the Division's proposed variations in the time and ultimate impact of OHV in and around dune gullies is contemplated as part of the comprehensive parameter sensitivity documented in Appendices 15 (I and II) – Sensitivity Analysis Methods and Results from version 1.2 of the Modeling Report.

Additionally, while the formation of some of the gullies may actually erode through significant depths of the evapotranspirative cover, the ratio of gully footprint to total evapotranspirative cover surface area remains minimal. As such, the overall evapotranspirative cover surface continues to perform and limit infiltration, as designed. The gullies' influences are further tempered when including the effects of the extreme depth between the bases of the deepest probable gullies to the below-grade depleted uranium waste, resulting in insignificant increases in resulting groundwater concentrations.

Under the conditions of inadvertent intruder-created gullies, NRC warns that,

> "Finally, the disruptive actions of an inadvertent intruder do not need to be considered when assessing releases of radioactivity offsite [that may result in subsequent exposure to members of the general public]." (NUREG-1573, pg. 3-11).

Therefore, NRC considers it inappropriate to model doses or further impacts to the general public that result from the actions of an inadvertent intruder. See also the response to Interrogatory CR R317-6-2.1-20/2: GROUNDWATER CONCENTRATIONS.

122. INTERROGATORY CR R313-25-8(4)(D)-122/2: SIZE OF PLUVIAL LAKES

The ES response is satisfactory; ES should correct the text accordingly in the revised report. We look forward to reviewing the revised report.

<u>EnergySolutions' Response</u>: Section 3.1 of Appendix 13 – Deep Time Assessment from version 1.2 of the Modeling Report has been revised to address the size of pluvial lake formation.

123. INTERROGATORY CR R313-25-8(4)(D)-123/2: TIMING OF LAKE CYCLES

We continue to believe the descriptions of the Clive exposure are not relatable to the Burmester core, and that the Knoll section documentation of the Deep Time Assessment report (Appendix 13 to FRV1) is inadequate. ES should revise its report to resolve this finding.

<u>EnergySolutions' Response</u>: Appendix 13 - Deep Time from version 1.2 of the Modeling Report has been substantially revised. Please refer to new text revisions for additional context on the discussions of the Clive exposure and Burmester core. See also the response prepared for Interrogatory CR R313-25-8(4)(D)-14/2: SEDIMENT MIXING.

124. INTERROGATORY CR R313-25-8(4)(D)-124/2: MECHANISMS FOR PLUVIAL LAKE FORMATION

ES should correct the text accordingly in the revised report. We look forward to reviewing the revised text.

EnergySolutions' Response*:* Section 3.2 of Appendix 13 – Deep Time Assessment from version 1.2 of the Modeling Report has been revised to address the mechanisms for pluvial lake formation.

125. INTERROGATORY CR R313-25-8(4)(D)-125/2: DEEP LAKE CYCLES

ES should correct the text accordingly in the revised report. We look forward to reviewing the revised text.

EnergySolutions' Response*:* Section 3.2 of Appendix 13 – Deep Time Assessment from version 1.2 of the Modeling Report has been revised to address deep lake cycles.

126. INTERROGATORY CR R313-25-8(4)(D)-126/2: SHALLOW LAKE CYCLES

ES stated that: "Intermediate lakes are assumed to be smaller lakes that reach and exceed the altitude of Clive, but are not large enough that carbonate sedimentation can occur." We believe that this assumption is incorrect, as explained in the comments on the ES response to Interrogatory CR R313-25-8(5)(a)-44/1: Occurrence of Intermediate Lakes. ES should revise the report accordingly.

EnergySolutions' Response*:* Please refer to the response to Interrogatory CR R313-25-8(5)(a)-44/2: Occurrence of Intermediate Lakes.

127. INTERROGATORY CR R313-25-8(4)(D)-127/2: CARBONATE SEDIMENTATION

The ES response is satisfactory; ES should correct the text accordingly in the revised report. We look forward to reviewing the revised report.

EnergySolutions' Response*:* Section 3.3 of Appendix 13 – Deep Time Assessment from version 1.2 of the Modeling Report has been revised to address carbonate sedimentation.

128. INTERROGATORY CR R313-25-8(4)(D)-128/2: LAKE SEDIMENTATION

We agree with the ES response but recommend that the final report discuss a deep time sensitivity analysis, similar to that provided for doses, which expands on the information provided in the ES response. ES should revise the report accordingly.

***EnergySolutions*' Response**: Additional features, events, and processes regarding deep time sensitivity have been added to Appendices 13 – Deep Time Assessment, 15(I) Sensitivity Analysis Methods, and 15(II) Sensitivity Analysis Results from version 1.2 of the Modeling Report. However, these additions expressly do not constitute "doses". As noted by NRC,

> "*Consistent with the above, consideration given to the issue of evaluating site conditions that may arise from changes in climate or the influences of human behavior should be limited so as to avoid unnecessary speculation. It is possible that, within some disposal site regions, glaciation or an interglacial rise in sea level could occur in response to changes in global climate. These events are envisaged as broadly disrupting the disposal site region to the extent that the human population would leave affected areas as the ice sheet or shoreline advances. Accordingly, an appropriate assumption under these conditions would be that no individual is living close enough to the facility to receive a meaningful dose [i.e. exposure]*" [*emphasis added*] (NUREG-1573, pg. 3-10)

129. INTERROGATORY CR R313-25-8(4)(D)-129/2: LAKE EROSION

We agree with the ES response but recommend that the final report discuss a deep time sensitivity analysis, similar to that provided for doses, which expands on the information provided in the ES response. ES should revise the report accordingly.

***EnergySolutions*' Response**: Additional features, events, and processes regarding deep time lake erosion have been added to Appendices 13 – Deep Time Assessment, 15(I) Sensitivity Analysis Methods, and 15(II) Sensitivity Analysis Results from version 1.2 of the Modeling Report. However, these additions expressly do not constitute "doses". As noted by NRC,

> "*Consistent with the above, consideration given to the issue of evaluating site conditions that may arise from changes in climate or the influences of human behavior should be limited so as to avoid unnecessary speculation. It is possible that, within some disposal site regions, glaciation or an interglacial rise in sea level could occur in response to changes in global climate. These events are envisaged as broadly disrupting the disposal site region to the extent that the human population would leave affected areas as the ice sheet or shoreline advances. Accordingly, an appropriate assumption under these conditions would be that no individual is living close enough to the facility to receive a meaningful dose [i.e. exposure]*" [*emphasis added*] (NUREG-1573, pg. 3-10)

130. INTERROGATORY CR R313-25-8(4)(D)-130/1: LAKE GEOCHEMISTRY

Round 1 Interrogatory Response is satisfactory.

131. INTERROGATORY CR R313-25-8(4)(D)-131/2: POTENTIAL WAVE ENERGY

This position appears to be the opposite of that taken in the Deep Time Assessment report (Appendix 13 to FRV1), as indicated by the text from Section 4.0 quoted above. ES should clarify its position on the effects of wave action from small lakes, provide appropriate references for this conclusion, and ensure that its position is consistent throughout the report.

EnergySolutions' Response: The text has been changed in Appendix 13 – Deep Time from version 1.2 of the Modeling Report. The text in v1.2 (Section 4.1) currently states:

> "*It should be noted that a Gilbert-sized lake would not reach the Clive elevation (Oviatt, 2014a). The size of a lake in the PA model that is needed to obliterate the waste embankment can be as shallow as 1 m, which may or may not have sufficient wave power to [actually] obliterate the site." [Brackets added to point out PA model assumption versus reality.]*

Energy*Solutions* assumes, for purposes of deep time modeling, that any lake that reaches the Federal Cell, with a depth as shallow as 1 m at the embankment, will obliterate the embankment. All text is now consistent on this issue.

The assumption of complete erosion of the embankment during the first lake return to the Clive site is a simplifying and conservative assumption.

132. INTERROGATORY CR R313-25-8(4)(D)-132/2: SEDIMENTATION MODEL

We look forward to reviewing the revised report, including a description of how wind-blown sediments, sediments moved by lake action, and sediments resulting from oolitic precipitation affect the overall lake sedimentation.

EnergySolutions' Response: Section 3.4 of Appendix 13 – Deep Time Assessment from version 1.2 of the Modeling Report has been revised.

133. INTERROGATORY CR R313-25-8(4)(D)-133/2: CALCULATIONS OF RADIOACTIVITY IN WATER AND SEDIMENT

The ES response is adequate, assuming that ES will add to the revised PA report the information provided in the response. We look forward to reviewing the revised report.

***EnergySolutions*' Response**: Section 6.5.2 of Appendix 13 – Deep Time Assessment from version 1.2 of the Modeling Report has been revised.

134. INTERROGATORY CR R313-25-8(4)(D)-134/1: FUTURE LAKE LEVEL ELEVATIONS

Round 1 Interrogatory Response is satisfactory, with the exception of the statement that "Intermediate lakes are assumed to be smaller lakes that reach and exceed the altitude of Clive, but are not large enough that carbonate sedimentation can occur." ES should revise this statement to be consistent with corrections needed in response to Interrogatories CR R313-25-8(5)(a)-44/2: Occurrence of Intermediate Lakes and CR R313-25-8(4)(d)-126/2: Shallow Lake Cycles. We look forward to reviewing the revised report.

***EnergySolutions*' Response**: Please refer to the response to Interrogatory CR R313-25-8(5)(a)-44/2: Occurrence of Intermediate Lakes.

135. INTERROGATORY CR R313-25-19-135/2: EXPOSURE TO GROUNDWATER

As discussed elsewhere (see, for example, Interrogatory CR 313-25-8(4)(a)-96/2: Current and Future Potability of Water, and Interrogatory CR R313-25-8(4)(a)-97/2: Need for Potable and/or Industrial Water), SC&A believes that additional information must be provided to demonstrate the groundwater at Clive is not a potential dose pathway. Under Interrogatory CR 313-25-8(4)(a)-96/2, SC&A indicates that ES needs to examine the possibility that the lower confined aquifer at Clive could become contaminated and thus become a source of exposure. If the water from this deep aquifer were used for domestic and/or industrial uses but did not meet the test of a public water system, regulation would be left to the Tooele County. It is our understanding that the County does not require testing for uranium or other radioactive contaminants. It does, however, require that the TDS for an individual water system be less than 2,000 mg/L. As noted in the table above, for Tc-99 Pathway Maximum Dose, when treating Clive groundwater, exposures exceeding the limits of R313-25-19 are possible, depending on the initial concentration of Tc-99 in the groundwater.

ES needs to explain why there are no viable groundwater pathways such as those discussed in Interrogatory CR 313-25-8(4)(a)-96/2 or include them in the DU PA.

***EnergySolutions*' Response**: See the responses to Interrogatories CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS, and CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS.

136. INTERROGATORY CR R313-25-7(1)-136/2: IRON (HYDRO)OXIDE FORMATION

ES provided an approach that seems appropriate, although overly conservative. In addition to revising the Geochemical Modeling report to state that no credit was taken for adsorption onto the steel drums, ES should also state that no credit was taken for iron (oxyhydr)oxide phases formed during canister degradation. Based on the concerns raised in the discussion for Interrogatory CR R313-25-8(4)(a)-64/1: Yucca Mountain Studies, the modeling of the source term will be reevaluated with regard to the estimation of uranium solubilities. We look forward to reviewing the revised report.

***EnergySolutions' Response**:* No credit in version 1.2 of the Modeling Report was taken for iron (oxyhydr)oxide phases formed during canister degradation.

137. INTERROGATORY CR R313-25-7(1)-137/2: TOTAL DISSOLVED CARBONATE CONCENTRATIONS AND OTHER GEOCHEMICAL DATA

We look forward to reviewing the revised report.

***EnergySolutions' Response**:* 1. The carbonate concentrations are higher than that with atmospheric pressure of CO_2. Reviewing Appendix 6 - Geochemical Modeling from version 1.2 of the Modeling Report, though, it is of minimal significance in the development of input distributions. The distributions are sufficiently wide to incorporate higher carbonate content.

2. and 4. Recent groundwater data (Energy*Solutions*, 2012) shows that data from the 76 monitoring wells agree with the values in (previously numbered) Tables 5 and 6. The ranges of the newer data are within the ranges in those tables, with only a few exceptions. For Table 5, for example, there were 3 pH values greater than the max pH presented in (previously numbered) Table 5; there was one Eh value less than the minimum Eh; there was 1 bicarbonate value slightly less than the lowest bicarbonate. Only the TDS values were quite a bit different with a range of the 76 groundwater well data from 3300 to 23,500 mg/L (as compared to 26,000 to 75,000 mg/L in Table 5). With similar data values to Table 5 for key chemical parameters like pH, Eh and bicarbonate, changes in solubilities and K_ds do not need to be made due to the newer data.

For Table 6, most of the newer groundwater wells have ranges that are lower than those from the initial groundwater wells. The only exception is sulfate, for which the range widened with 12 values greater than the maximum sulfate concentration in Table 6.

Note as well, that variability in these geochemical parameters is expected between the groundwater and the unsaturated zone, waste layers and cap.

3. Addressed in Appendix 6 - Geochemical Modeling from version 1.2 of the Modeling Report.

138. INTERROGATORY CR R313-25-26(1)-138/2: MONITORING WELL COMPLETION ZONES

The ES response is adequate. ES should complete the clarification to the report as described. We look forward to reviewing the revised report.

***EnergySolutions' Response**:* Section 2.2 of Appendix 6 – Geochemical Modeling from version 1.2 of the Modeling Report has been revised.

139. INTERROGATORY CR R313-25-7(1)-139/2: ION CHARGE BALANCE

The ES response appears adequate, but it may need to be modified depending on the reassessment of total dissolved carbonate concentration and the justification for the representativeness and range of TDS data described in Interrogatory CR R313-25-7(1)-137/2: Total Dissolved Carbonate Concentrations and Other Geochemical Data. We look forward to reviewing the revised report.

***EnergySolutions' Response**:* The discussion of ion charge balance has been expanded in Appendix 6 – Geochemistry Modeling from version 1.2 of the Modeling Report.

140. INTERROGATORY CR R313-25-7(1)-140/2: DETERMINATION OF KD VALUES

We look forward to reviewing the associated text changes described in the response.

***EnergySolutions' Response**:* The discussion of K_D determination has been expanded in Appendix 6 – Geochemistry Modeling from version 1.2 of the Modeling Report.

141. INTERROGATORY CR R313-25-7(1)-141/2: PH AND KD VALUES AND SERNE (2007)

The clarification of the chemical speciation of the element will be vitally important text since it provides justifications for the selected Kd ranges. We look forward to reviewing the revised Geochemical Modeling report (Appendix 6 to FRV1).

It is indeed likely that pH and carbonate are more important than the specific sorbing phases. However, since the model is based on empirical Kd values, it is unclear how variable clay and iron content will be used. ES should discuss the manner by which all factors (pH, dissolved ions (competing ion effect), and solid phase composition) are used to determine the appropriate Kd range.

EnergySolutions*' *Response: The second paragraph of the rebuttal actually applies to Interrogatory CR R313-25-7(1)-142/2: REFERENCES FOR KD DISCUSSION, not this interrogatory. See the response to Interrogatory CR R313-25-7(1)-142/2: REFERENCES FOR KD DISCUSSION.

142. INTERROGATORY CR R313-25-7(1)-142/2: REFERENCES FOR KD DISCUSSION

The text modification described will be vitally important text since it provides justifications for the selected Kd ranges. We look forward to reviewing the revised report.

Regarding the second statement, it is indeed likely that pH and carbonate are more important than the specific sorbing phases. However, since the model is based on empirical Kd values, it is unclear how variable clay and iron content will be used. ES should discuss the manner by which all factors (pH, dissolved ions (competing ion effect), and solid phase composition) are used to determine the appropriate Kd range. The use of empirical Kd values for Clive soils and groundwater is imperative in the PA analysis process.

EnergySolutions*' *Response: As stated in Section 3.0 of Appendix 6 - Geochemistry Modeling from version 1.2 of the Modeling Report, literature studies were screened for those that applied to the different hydrostratigraphic units of the waste disposal site. Once the appropriate literature sources were identified, these studies were all considered to be equally viable for geochemical input parameter values, such that the minimum and maximum literature values were identified and a log-normal distribution was developed. As described in subsections of Section 4, adsorption onto clays is considered for the K_d input distribution for clay in the model (used in the unsaturated zone). Iron oxide adsorption was considered for neptunium and uranium.

The intention of the distribution development is to include a wide range for parameter input distributions, considering site conditions. If any of these input parameters is shown to be a sensitive parameter, the input distribution can be refined to reduce the uncertainty in the results, if that uncertainty of results is unacceptable. Except for the K_d distributions for technetium and iodine, which are described in Section 3, only ranges of values for both K_d and solubility were considered, since a log-normal distribution was used. Note that central values for solubility are presented in the Table 4, but these central values are not used in the distribution development.

143. INTERROGATORY CR R313-25-7(1)-143/2: NEPTUNIUM SPECIATION

With regard to the first statement, we note that EPA 2004 was not included in the references in Section 3 of the ES response document and so could not be reviewed. ES is correct that both EH-pH and activity-pH diagrams need to be considered. However, the EH-pH diagrams provided do show the dominance of the carbonate complexes discussed here. At carbonate concentrations higher than 57 mg/L, mono-, di-, and tri-carbonate species can dominate Np(V) speciation. Therefore, while the point made by ES using the activity-pH diagram is well taken, it should be noted that the speciation is highly sensitive to the total carbonate concentration and should be considered in establishing solubility ranges. The sensitivity of neptunium solubility to high salinities should also be considered, in particular whether the Visual MINTEQ thermodynamic database is as robust as the Pitzer database used for PHREEQC.

With regard to the second statement, we encourage ES to review Bidoglio et al. (1985), Kohler et al. (1999), Turner et al. (1998), and Yu et al. (2007) and incorporate some consideration of the influence of Np-carbonate complexes. ES should revise the report to address these issues and concerns.

EnergySolutions' Response: The discussion of neptunium speciation has been expanded in Appendix 6 – Geochemistry Modeling from version 1.2 of the Modeling Report.

144. INTERROGATORY CR R313-25-7(1)-144/2: PLUTONIUM SPECIATION

ES should delete the following sentence of its response, since it would also not be correct for Pu(VI): "It is assumed that discussion of neptunium in the Interrogatory text is a typo and should have been plutonium." The DEQ error with reference to Np(VI) has been corrected and there is no need for further explanation.

Regarding the statement about EPA (1999), there is considerable debate regarding the appropriate Pu(IV) hydroxycarbonate species and the associated stability constants. Therefore, if this speciation information is used for Kd determination, it has a potential for introducing a high degree of uncertainty. ES should review Clark et al. (1995) for a discussion of the Pu(IV) hydroxycarbonate species. Additional discussion and justification are needed to incorporate findings from this literature reference. We look forward to reviewing the revised report.

***<u>EnergySolutions' Response</u>**:* The discussion of plutonium speciation has been expanded in Appendix 6 – Geochemistry Modeling from version 1.2 of the Modeling Report.

145. INTERROGATORY CR R313-25-7(1)-145/2: SORPTION REVERSIBILITY AND GLOVER ET AL. (1976) DATASET

ES should explain why the higher Kd values for plutonium used in the Geochemical Modeling report (Appendix 6 to FRV1), rather than those in Glover et al. (1976), are more current or applicable to Clive soil and groundwater conditions. We look forward to reviewing the revised report.

***<u>EnergySolutions' Response</u>**:* The discussion of sorption reversibility has been expanded in Appendix 6 – Geochemistry Modeling from version 1.2 of the Modeling Report.

146. INTERROGATORY CR R313-25-7(1)-146/2: DETERMINATION OF KD VALUES

We look forward to reviewing the revised report.

***<u>EnergySolutions' Response</u>**:* Table 3 of Appendix 6 - Geochemical Modeling from version 1.2 of the Modeling Report has been revised to include a table of the ranges of K_d values for the three soil textures (sand, silt, clay) for each element in the model, and relate them to the literature references as described in the subsections of the Modeling Report. Providing these ranges clarifies the values chosen from the literature and how they were used to develop probability distributions as described in Section 3.0 of Appendix 6.

147. INTERROGATORY CR R313-25-7(1)-147/2: DETERMINATION OF KD VALUE FOR URANIUM

We look forward to reviewing the revised report.

***<u>EnergySolutions' Response</u>**:* The reference to EPA (1999) in Appendix 6 – Geochemical Modeling from version 1.2 of the Modeling Report has been revised to reflect conclusions from EPA (1999) that some of these high K_d values correspond to experiments where precipitation of U occurred in addition to adsorption. As such, Appendix 6 has been modified to clarify assumptions and derivations of geochemical parameters.

148. INTERROGATORY CR R313-25-7(1)-148/2: INFLUENCE OF CARBONATE ON URANIUM SPECIATION

We look forward to reviewing the revised report.

***EnergySolutions*' Response**: Section 4.1.13 of Appendix 6 from version 1.2 of the Modeling Report has been revised to focus on the effects of carbonate and p_H on U sorption. Additionally, the carbonate assumptions included in version 1.2 of the Modeling Report have been clarified as to the applicability of the references used for K_d distribution development to the Clive site, with respect to the high carbonates expected at Clive. More detail of how these distributions were developed has also been provided in Appendix 6 - Geochemical Modeling from version 1.2 of the Modeling Report.

149. INTERROGATORY CR R313-25-7(1)-149/2: AMERICIUM SORPTION

As ES extends its groundwater infiltration and transport modeling from 500 to more than 10,000 years, additional model inputs could be found to be "sensitive." We look forward to reviewing the revised report. Furthermore, several of the exponents are missing negative signs in the paragraph of the response that begins "Given these assumptions…."

***EnergySolutions*' Response**: Analysis of the sensitivity of groundwater migration to various model input parameters is reported in Appendix 15(II) – Sensitivity Analysis Results from version 1.2 of the Model Report. Additionally, typographical errors have been corrected in Appendices 15(I and II) – Sensitivity Analysis Methods and Results from version 1.2 of the Modeling Report.

See also the responses to Interrogatories CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS and CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS.

150. INTERROGATORY CR R313-25-7(2)-150/2: PLANT GROWTH AND COVER PERFORMANCE

The PA indicates that greasewood size and rooting depth on the site is likely limited by the presence of a shallow, compressed, thin clay layer currently located 2 feet below the ground surface that apparently traps water and maintains roots at shallow depth. However, there is no evidence that, subsequent to this shallow, compressed, thin clay layer being locally homogenized with other soil and lost as a distinct layer as a result of mining and processing of portions of the on-site near-surface silty clay layer prior to emplacement in the Federal Cell, and with the shallow perching layer that this thin layer once created therefore being locally destroyed, conditions will exist at the site that will inhibit or prevent deeper rooting by shrubs such as greasewood. Changes will occur. Moreover, the size of greasewood plants at the surface is not a sure indicator of the length of their taproots. One expert, whose views are presented by the U.S. Forest Service in an article on SPECIES: Sarcobatus vermiculatus, indicates that greasewood typically sends taproots down to the water table and states that there is an inverse relationship between above-ground greasewood height, canopy coverage and total leaf surface area and the associated depth to groundwater (Anderson, 2004): "Black greasewood height, canopy coverage, and total leaf surface area are inversely related to depth to water." In other words, when groundwater is deep, and taproots must extend down to a great depth to acquire pore water from the capillary fringe, greasewood plant size at the surface tends to be small, just as is seen at the Clive site. Excavations of root systems of only two greasewood plants on the site by one of the licensee's consultants do not make for a comprehensive study that can be fully relied on, when numerous other studies claim that greasewood taproots in arid or semi-arid environments can grow down to depths of 12.7 meters (42 feet) below ground surface or more (Chimner and Cooper, 2004; Harr and Price, 1972; Nichols, 1993; Meinzer, 1927; Waugh and Smith, 1998; White, 1932; WSDNR, 2011). We understand that the ET cover system is currently being modeled and that a report will soon be presented that deals with deep plant rooting. We look forward to reviewing this response when the ET cover report is available.

***EnergySolutions*' *Response*:** Although the limited field excavations of shrubs at the Clive site noted relatively shallowly rooted individuals, the model extends black greasewood roots to 5.7 m. As noted in the previous response, the use of 5.7 m in the PA model as the maximum greasewood rooting depth is considered conservative for two reasons. The first reason is that the roots are not expected to penetrate (nor would they need to penetrate) the radon barriers (thick clay layers) in the ET cover, which start at a depth of 3 ft. This assumption is supported by the limited root profile excavations performed at the Clive site, which found that tap roots and fine roots tend to spread laterally on top of the compact clay layer that occurs naturally at the site approximately 60 cm below ground surface (SWCA 2013). Though the naturally occurring compact clay layer will be removed/disrupted during construction activities, with regard to plant rooting it can be considered analogous to the compact clay radon barriers in the constructed cover. As noted a number of times throughout the round 2 interrogatories, the constructed cover is likely to evolve from an as-built condition toward one more closely resembling native soils. Thus, the compacted radon barrier, built to a specification of no less than 95% compaction, can reasonably be expected to exceed or approximate the native compacted clay layer approximately 2 feet below the surface.

Though root penetration of the radon barriers is not expected to occur, the PA model conservatively assumes a maximum rooting depth well beyond the depth of the barriers. The second reason that 5.7 m was selected as the maximum rooting depth is that 5.7 m represents an estimate of what Groeneveld (1989) terms "maximum effective root depth" for greasewood. Isolated roots may grow well below this depth under special circumstances of water availability and aeration. The maximum root depth of 19 m cited by Robertson (1983) and others is an example of such special circumstances, as Groeneveld suggests that this maximum depth for greasewood is an artifact of preferential pathways created by mining activities. These preferential pathways are not expected to occur in the constructed cover, especially with the compacted clay radon barrier occurring 3 ft below ground surface. Also, as previously noted, when the constructed cover is in place, depth to groundwater at the site will be in excess of 23 m, beyond even the most conservative report of maximum root depth, meaning that black greasewood and other shrubs would not be able to exploit the current aquifer.

Version 1.2 of the Model currently assesses shrubs in two different categories – deeply rooted shrubs, as represented by black greasewood, and more shallowly rooted shrubs, as represented by shadscale and gray molly. We concur with the reviewer's comment that four-winged saltbush roots more deeply than shadscale. However, four-winged saltbush is much less common at the site than either shadscale or black greasewood, and we believe the growth attributes of four-winged saltbush are adequately captured in the model by the input parameters for the black greasewood category.

The reviewer notes that there is an inverse relationship between above-ground greasewood height, canopy coverage and total leaf surface area and the associated depth to groundwater (Anderson, 2004): "Black greasewood height, canopy coverage, and total leaf surface area are inversely related to depth to water." The reviewer implies that this is because the plant must sink more of its resources into tap root development to reach the groundwater, and also implies that the small plants sizes noted at the Clive site would suggest a large taproot development. We disagree with this interpretation. A review of the primary study (Harr and Price, 1972) cited by Anderson (2004) shows that the smaller plants associated with deeper groundwater used only half as much groundwater as the plants associated with shallow groundwater. This may be attributed to reduced capability of roots to reach groundwater. Indeed, Anderson (2004) states in the sentence immediately following the one quoted by the reviewer that there is a reduction in root growth associated with increasing soil depth, not the other way around. Therefore, for all of the reasons stated above, we feel that a maximum shrub rooting depth of 5.7 m adequately represents maximum rooting depths of black greasewood and four-winged saltbush at the Clive site.

To help discourage unbounded speculation regarding a site's plant community, it is important to recognize that NRC has stated,

> "*Given the uncertainty in projecting the site's biological environment beyond relatively short periods of a few hundred years, it is sufficient to assume that current biological trends remain unchanged throughout the period of analyzed performance.*" (NUREG-1573, pg 3-11).

Accordingly, NRC considers that the current biological trends and Clive conditions reported in SWCA (2011) are preferential to the non-site specific general studies cited by the Division. See also the response prepared to Interrogatory CR R313-25-7(2)-05/2: RADON BARRIER.

151. INTERROGATORY CR R313-25-8(4)(A)-151/2: RADON BARRIER ATTENUATION

We look forward to reviewing the results of the ET cover radon modeling effort, and we anticipate that these results will be consistent with previous results for the Clive site.

EnergySolutions' Response: Radon modeling is documented in Appendix 18 – Radon Diffusion Modeling from version 1.2 of the Modeling Report. Section 4 of Appendix 18 documents the methodology for diffusion calculations performed by GoldSim. Calibration is documented in Section 6 of Appendix 18. Doses resulting from the inhalation of radon that manages to escape into the atmosphere are reported in Section 6 of version 1.2 of the Modeling Report. Additionally, Table 10 of Appendix 15 – Sensitivity Analysis Results from version 1.2 of the Modeling Report illustrates parameters to which ground surface radon flux is sensitive.

152. INTERROGATORY CR R313-25-8(5)(A)-152/2: GOLDSIM INPUT PARAMETERS

ES described how to run the GoldSim model to gain the answer to the question. However, we do not agree with this approach. A reader of the report should not be forced to run the GoldSim model to "gain an appreciation of where [the radon correction factors] come from." It is the report's function to provide this information to its readers, particularly those without access to GoldSim.

In addition, while the radon correction factors are calculated by GoldSim, for the purposes of the PA they are treated like input parameters. As such, they should be described in the documentation, just as any other input parameter. We look forward to reviewing the revised report.

EnergySolutions' Response: Appendix 18 - Radon Modeling from version 1.2 of the Modeling Report explains the behavior of radon in the model, as well as the need for calibration of the diffusivity of radon (in order to counteract numerical dispersion) and the methodology employed to do so. The calibration factors are not input variables, as they change as other inputs in the model change, such as material properties, cell dimensions, or burial depths. That said, a recent calibration done with the top of the DU waste at a depth of 3 m below the clay radon barrier resulted in the following values:

Waste	0.349
Radon barrier clay	0.894
ET cover materials	0.974

Version 1.2 of the Model contains documentation within it that helps one to understand processes and interrelationships. While these are also discussed in the appendices from version 1.2 of the Modeling Report, the Model itself is the best manifestation of the Performance Assessment, and serves the role of a supplemental comprehensive document.

153. INTERROGATORY CR R313-25-8(4)(D)-153/2: IMPACT OF PEDOGENIC PROCESS ON THE RADON BARRIER

ES' response focused on infiltration; it should also address radon diffusion:

1. The ES response began by referring to Energy*Solutions* 2014, which obviously was not included in FRV1. ES needs to integrate the information from this document into the revised report. Then DRC can review and comment on how that information is being used in the DU PA.

2. The ES response indicates that the ET cover would reduce infiltration by two orders of magnitude compared with the rock armor mulch cover. The revised GoldSim DU PA model (v1.199) provided by ES on May 5, 2014 (Rogers 2014) does not support this statement. The original mean infiltration rate (VerticalFlow_BelowCap) was about 0.12 cm/yr, whereas with the ET cover the rate is about 0.04 cm/yr—reduced by only a factor of three.

3. The ES response indicates that the ET cover design will limit infiltration down to the radon barrier. However, the response does not address what impact pedogenesis, burrowing animals (if any), plant roots, gullies, and similar mechanisms would have on the radon diffusion upwards to the surface.

4. Finally, in its response ES described the cover performance modeling that is required. DRC looks forward to receiving and reviewing this refined modeling effort.

1. ***EnergySolutions' Response****:* The Energy*Solutions*, (2014a) reference was provided DRC in hardcopy of March 31, 2014 and electronically on April 10, 2014. See also the response to Interrogatory CR R313-25-7(2)-05/2: RADON BARRIER.

2. While Energy*Solutions* does not understand why the Division considers an infiltration "reduced by only a factor of three" for the evapotranspirative cover compared to the traditional rock armor as a criticism of the revised Federal

Cell cover design, the presentation of infiltration rates has been revised in Appendices 2 – Conceptual Site Model for Disposal of Depleted Uranium at the Clive Site, 3 – Embankment Modeling, 5 – Unsaturated Zone Modeling, 11 – Dose Assessment, and the main report from version 1.2 of the Modeling Report.

3. See the responses for INTERROGATORY CR R313-25-7(2)-05/2: RADON BARRIER.

4. The evapotranspirative cover performance has been added to Appendices 2 – Conceptual Site Model for Disposal of Depleted Uranium at the Clive Site, 3 – Embankment Modeling, 5 – Unsaturated Zone Modeling, 11 – Dose Assessment, and the main report from version 1.2 of the Modeling Report.

154. INTERROGATORY CR R313-25-8(4)(D)-154/2: USE OF FIELD DATA TO VALIDATE DISPOSAL CELL COVER PERFORMANCE

ES did not address the fact that the Monticello Disposal Facility in Utah uses an ET cover, but the measured percolation rate is substantially higher than that proposed for the Federal Cell. ES should address the possible causes of this discrepancy.

With regard to ES' responses related to Cover Test Cell (CTC) data collected to date, DEQ has determined that only cover soil temperature data are reliable from that facility. Hence, ES reference to other water balance-related data collected at the CTC facility may be suspect. Further, the CTC facility was constructed to simulate the riprap cover design of the Low-Activity Radioactive Waste Cell, and not any ET cover now proposed for the DU disposal cell.

Also see Interrogatory CR R313-25-7(3)-60/2: Modeled Radon Barriers.

We look forward to completing our review of this response when the revised ET cover report is available.

EnergySolutions' Response: The cover system employed at the Monticello, Utah Mill Tailings Site Disposal Facility is described as:

> "*The cover system consists of multiple layers (from top to bottom): blended top soil with vegetation that limits erosion, a layer of fine-grained soil that provides frost protection, 12 inches of sand that limit the buildup of water, a high-density polyethylene geomembrane that protects the underlying radon barrier, and a 2-foot compacted clay layer that serves as the radon barrier.*" (DOE, 1995, pg. 1).

There are a number of differences that may contribute to Monticello's higher projected infiltration. For example, Monticello reports an average precipitation of 353.8 mm/year, 1.6 times higher than Clive's 19-year average of 215.9 mm/year. Monticello's blended surface layer includes no gravel admixture and consists of materials with higher hydraulic conductivities than that proposed for the Federal Cell. Additionally, Monticello's overall thickness is less than that proposed for the Federal Cell.

Energy*Solutions* recognizes that the Cover Test Cell facility was constructed to simulate the riprap cover design of the Low-Activity Radioactive Waste Cell, and not the evapotranspirative Federal Cell cover. Even so, the Cover Test Cell confirms that models developed in support of the rock armor cover have over-predicted infiltration; this result is not unexpected for an above-grade embankment in an arid climate.

Also see the response to Interrogatory CR R313-25-7(3)-5/2: RADON BARRIER.

155. INTERROGATORY CR R313-25-8(4)(D)-155/2: COVER PERFORMANCE FOR 10,000 YEARS

It is not clear that a naturalized radon barrier has no effect on radon releases. Affirmative evidence is needed to support this claim. ES should also indicate when the compromised radon-barrier report mentioned in its response will be available. It is not clear why this modeling should not be part of the DU PA. The claim that "the ET Cover design will limit infiltration down to the radon barrier" is not substantiated when considering that the PA model to date has not accounted for or implemented NRC guidance indicating that, based on a vast amount of experimental and field data, shallow soil layers (<10 feet deep) in a cover system undergo dramatic degradation over time; that is, with increases of hydraulic conductivity values generally ranging from one to three orders of magnitude (see Benson et al., 2011, in NUREG/CR-7028). Moreover, the same study shows that the use of small-diameter soil samples in laboratory testing of soil hydraulic conductivity values generally underestimates these values compared to actual field-scale hydraulic conductivities by one or more orders of magnitude. The PA uses small-diameter soil sample values instead of field-scale values. Both of these factors suggest that the current, unmodified PA modeling does not properly account for increased rates of infiltration down to the radon barrier. ES should modify the PA model to account for these factors.

The ES response also mentioned possibility of a new study of "volcanic landforms in the Black Rock Desert." If that study has been completed, ES should provide the results/data for DEQ review. If not, ES should provide a schedule for completion of the new study, or the reason it is not being undertaken.

In addition, the interrogatory requested a discussion of historical analogs of similar structures and how they have functioned over long periods of time. ES did not provide such a discussion.

The ES response also stated that: “It is not considered necessary at this time because the ET Cover design will limit infiltration down to the radon barrier. With no infiltration down to that level….” The revised GoldSim DU PA model (v1.199) provided by ES on May 5, 2014 (Rogers 2014), does not support this statement. The original mean infiltration rate at the waste level (VerticalFlow_BelowCap) was about 0.12 cm/yr, whereas the rate with the ET cover is about 0.04 cm/yr—reduced by only a factor of three, instead of being eliminated as claimed in the ES response. ES should clarify. Moreover, that calculated infiltration rate reflects modeling without ES having made adjustments in hydraulic conductivity values as requested above, which would likely increase modeled rates of infiltration down to the waste.

We look forward to evaluating other issues (such as erosion) when the ET cover report is available.

Also see Interrogatory CR R313-25-7(3)-60/2: Modeled Radon Barriers.

***EnergySolutions*' Response**: It is important to note that while an informative analysis, the covers examined by Benson, 2011 are not equivalent to that proposed for the Federal Cell. Even so, the effects of equivalent cover parameter ranges on cover performance are addressed in the response to Interrogatory CR R313-25-7(2)-05/2: RADON BARRIER.

156. INTERROGATORY CR R313-25-26(2–3)-156/2: SEPARATION OF WASTES IN FEDERAL CELL

The ES response is satisfactory assuming that the appropriate written agreements as to long-term stewardship are obtained from DOE on a timely basis.

***EnergySolutions*' Response**: Noted without comment.

157. INTERROGATORY CR R313-25-8(5)(A)-157/2: INCLUSION OF DU AND OTHER WASTES IN PA

It is not clear how the ES response satisfies the UAC R313-25-8(5)(a) requirement that the PA include “total quantities of concentrated depleted uranium and other wastes.” Among other open questions is how the source term for total quantities of DU and other wastes will be developed. ES should coordinate resolution of this interrogatory with Interrogatory CR R313-25-7(9)-89/2: Contamination Levels in DUF6. We look forward to reviewing the revised report.

***EnergySolutions' Response**:* As is reported in the Condition 35 Compliance Report and version 1.2 of the Modeling Report, Energy*Solutions* has committed not to dispose of any “other wastes” in the Federal Cell until a Performance Assessment can be compiled that includes both DU and other Class A wastes. Until that time, Energy*Solutions* will only dispose of depleted uranium waste below grade in the Federal Cell. As such, the waste inventory included in version 1.2 of the Modeling Report is representative of all wastes currently projected to be disposed of in the Federal Cell.

158. INTERROGATORY CR R313-15-1009(2)(B)(I)-158/2: WASTE PACKAGING

It is our understanding that that ES has experienced some problems in the past with shipments from Terranear (DOE subcontractor) in soft sided packaging. ES should provide a discussion of these problems and indicate the relevance of the Terranear experience to handling of DU3O8 in soft-sided packaging.

***EnergySolutions' Response**:* The Division is fully aware of the issues with shipments from Terranear in soft-sided packaging, having cited them under the GSAP program for a shipment in October 2011 that had unexpected tritium contamination on the exterior of the package when it arrived at Clive.

In the context of version 1.2 of the Model, shipment packaging issues are irrelevant, since no credit is taken for the package in enhancing containment of the waste once disposed. Furthermore, the issues alluded to in the interrogatory relate to tritium containment. Tritium is not a contaminant in the depleted uranium wastes being considered; thus, the concern is irrelevant.

159. INTERROGATORY CR R313-25-8(4)(D)-159/2: EMBANKMENT DAMAGE BY LAKE FORMATION

We believe that this assumption regarding aeolian deposition is incorrect, as explained in the comments on the ES response to Interrogatory CR R313-25-8(5)(a)-18/1: Sediment Accumulation. In addition, with regard to the period beyond 10,000 years, see comments on Interrogatory CR R313-25-8(5)(a)-86/2: Consequences of Sedimentation on Disposal Cell.

***EnergySolutions' Response**:* The Rebuttal text quoting an Energy*Solutions* response with aeolian sedimentation rates of > 0.1 mm/year are not included in Appendix 13 - Deep Time from version 1.2 of the Modeling Report. Sedimentation rates for aeolian deposition were not used in the model prior to the formation of the first intermediate or deep lake; instead an assumption was made that the next lake would destroy the disposal mound. No credit is taken for potential mitigating effects of aeolian deposition.

160. INTERROGATORY CR R313-25-7(2)-160/2: COMPARISON OF CLASS A WEST AND FEDERAL CELL DESIGNS

It is our understanding that an ET cover is now being considered for the Class A West cell as well as for the Federal Cell. Comparisons of the structural design and expected performance of the two cells are needed. The following issues still need to be addressed in the PA:

The geometry, slopes, and boundary shapes and sizes would differ between the two different cells.

The distance to a monitoring well from the central portion of the cell would differ between the two cells.

The current PA proposes that the DU waste disposal cell be conjoined with the 11e.(2) cell, with no isolation barrier between them, whereas the Class A West cell would not be conjoined with an 11e.(2) cell.

DU waste components in the Federal Cell would ingrow, thereby becoming more hazardous instead of less hazardous with time, contrary to what would be the case for most of the waste in the Class A West cell.

Over a sufficiently long time, Ra-226, which would be present at relatively high concentrations in the Federal Cell, would increase in activity until it exceeds Class C limits, unlike the bulk of the waste disposed of in the Class A West cell.

Some of the containers from the Paducah and Portsmouth GDPs that would be disposed of in the Federal Cell would contain heels having relatively high concentrations of highly mobile Tc-99, unlike the bulk of the waste disposed of in the Class A West cell.

The heels in these cylinders would also contain transuranics, unlike the bulk of the waste deposited in the Class A West cell.

The Federal Cell design must meet performance standards for a minimum of 10,000 years.

As previously discussed, any proposed Federal Cell that contains DU waste must have an approved design such that its cover system is fully integrated with, or completely isolated from, the existing 11e.(2) cover system, as required by applicable federal and state laws, regulations, and rules. Pertinent DOE and NRC guidance should be followed as well. A more complete description of structural design and performance of the proposed Federal Cell, one that incorporates and accounts for all of the factors mentioned above, is requested.

EnergySolutions' Response*:* Version 1.2 of the Modeling Report has been revised to reflect the construction of an evapotranspirative cover over the proposed Federal Cell. While Energy*Solutions* recognizes that it is seeking separate approval for construction of a similar cover system over its Class A West (CAW) embankment from the Division, demonstration of the CAW cover's ability to satisfy low-level radioactive waste disposal performance objectives unique to Class A-type waste are unrelated to the requirements imposed on the Federal Cell evapotranspirative cover's ability to satisfy the unique depleted uranium performance criteria addressed in version 1.2 of the Modeling Report.

161. INTERROGATORY CR R313-25-7(2–3)-161/2: INCONSISTENT INFORMATION ON WASTE EMPLACEMENT

We look forward to confirming the disposition plan by reviewing the revised Figure 1.2 and note that, regardless of the depth of disposal, the revised report should not contain discrepancies, including but not limited to inconsistencies regarding available below-grade DU disposal volume and DU container dimensions. ES should include in its response information on the number of containers (cylinders and drums) of DU waste that can be placed in the designed disposal space, including the volume of backfill materials and any protective earthen blanket layers required. ES should also indicate how this number of DU containers and waste volume compares with the total DOE inventory needing disposal.

EnergySolutions' Response*:* As was reported in the Round 1 responses of March 2014, Figure 1.2 has been clarified to reflect Energy*Solutions'* commitment that only a volume of depleted uranium that can be disposed of below grade in the

Federal Cell will be managed. Because Energy*Solutions* has committed to only dispose of significant quantities of depleted uranium below grade in the Federal Cell, neither the total volume of DOE inventory, third-party inventory, or DOD inventory available for management need be revised.

162. INTERROGATORY CR R313-25-22-162/2: DISPOSAL CELL STABILITY

We look forward to judging the adequacy of parts of the response once we have the results of the SIBERIA modeling.

EnergySolutions' Response*:* Appendix 10 – Erosion Modeling from version 1.2 of the Modeling Report has been revised to include results of incorporation of the SIBERIA model into version 1.2 of the Model.

163. INTERROGATORY CR R313-25-8(5)(A)-163/2: GROUNDWATER COMPLIANCE FOR 10,000 YEARS

As discussed elsewhere (see, for example, Interrogatory CR R313-25-8(4)(a)-96/2: Current and Future Potability of Water, and Interrogatory CR R313-25-8(4)(a)-97/2: Need for Potable and/or Industrial Water), SC&A believes that additional information must be provided to demonstrate the groundwater at Clive is not a potential dose pathway. Under Interrogatory CR R313-25-8(4)(a)-96/2, SC&A indicates that ES needs to examine the possibility of that the lower confined aquifer at Clive could become contaminated and thus become a source of exposure. If the water from this aquifer were used for domestic uses but did not meet the test of a public water system, regulation would be left to Tooele County. It is our understanding that the County does not require testing for uranium or other radioactive contaminants.

EnergySolutions' Response*:* See the responses to Interrogatories CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS and CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS.

164. INTERROGATORY CR R313-15-1009-164/1: INCORRECT RULE CITATION

Round 1 Interrogatory Response is satisfactory.

165. INTERROGATORY CR R313-15-1009(1)(C)(I)-165/1: INCORRECT CITATION OF RA 226 LIMIT

Round 1 Interrogatory Response is satisfactory.

166. INTERROGATORY CR R313-25-22-166/2: STABILITY OF WASTE

ES should indicate what revisions to the quality assurance/quality control procedures will be needed to handle the DU oxide shipments in canisters from the GDPs or explain how canisters are covered under current quality assurance/quality control procedures. Examples of some of the topics that need to be addressed include, but are not limited to, the following:

Details on how headspace will be eliminated from the DUF6 containers after arrival at Clive, including methods and equipment necessary for detecting headspace, access of the container to insert CLSM fill material, and re-sealing or closure of the DUF6 container

Discussion of potential interactions between CLSM material and DU waste materials, including any possible effects on the ability of the CLSM material to harden sufficiently to sustain needed stresses without deformation of the cover system

DUF6 container spacing and geometry on a waste lift and details about any co-location of DUF6 cylinders with DU waste drums

Placement of fill material between individual containers on a waste lift.

EnergySolutions*' Response: No revisions will be needed to the LLRW and 11e.(2) Construction Quality Assurance/Quality Control Manual. DUF6 container headspace mitigation will not require revision to these procedures; field methods such as opening ports or valves will be used to gain access for CLSM. If ports or valves are not available in suitable size or location, the drums and cylinders will be penetrated. A large variety of tools are available for this task and have been used successfully at Clive for containers and waste forms ranging from steel liners to steam generators formerly used at nuclear power plants. There is no need to re-seal or close the DUF6 canister; and this is not typically done for other waste forms placed in CLSM. These procedures have successfully been used in the disposal of approximately 40,000 tons of depleted uranium, with no adverse interactions between the Controlled Low Strength Material (CLSM) and depleted uranium. CLSM will be the fill material used in DU disposal. See also revised drawing 14004-L1.

167. INTERROGATORY CR R313-15-1009(2)(A)(VII)-167/1: PYROPHORICITY OF DUO2

Round 1 Interrogatory Response is generally satisfactory, but a license condition may be needed to set an upper limit on particle sizes and quantities of DUO2 in any given container. Such conditions will be coordinated with the resolution of

Interrogatories CR R313-15-1009(2)(b)(i)-158/2: Waste Packaging, CR R313-25-22-162/2: Disposal Cell Stability, and CR R313-25-22-166/2: Stability of Waste.

***EnergySolutions' Response**:* Condition 16.B of Energy*Solutions'* Radioactive Material License UT2300249 already prohibits receipt of waste "*readily capable of detonation or of explosive decomposition or reaction at normal pressures and temperatures, or of explosive reaction with water*." Similarly, Condition 16.D prohibits receipt of waste that is "*pyrophoric*." These conditions would continue to be sufficient without the addition of a duplicative License Condition.

168. INTERROGATORY CR R313-25-7(2)-168/1: RIP RAP SIZING

ES notes that this interrogatory is no longer relevant since the Federal Cell will use an ET cover and rip rap is not used in the ET cover. However, ES should describe any use of rip rap on the lower parts of side slopes and on adjacent ditches and discuss the issues associated with this interrogatory that are pertinent to this use.

***EnergySolutions' Response**:* As is reflected in Section 3.1.2 of Appendix 3 – Embankment Modeling to version 1.2 of the Modeling Report (attached as Appendix A to the Compliance Report), there is no riprap material included in the construction of the proposed evapotranspirative cover. No changes in the Division–approved riprap specifications for Energy*Solutions'* current drainage ditch network is required as a result of approval of the Federal Cell. Approved riprap specifications are summarized in Figure 6 of Appendix 3.

169. INTERROGATORY CR R313-25-7(9)-169/1: CLARIFICATION OF STATISTICAL TREATMENT OF CHEMICAL AND ISOTOPIC ASSAYS

Round 1 Interrogatory Response is satisfactory.

170. INTERROGATORY CR R313-25-7-170/2: DU WASTE FORM RELEASE MECHANISMS AND RATES

However, UO3 is a mineral and will not be "mobile," although the ions dissolving from UO3 may be mobile. The major distinction between U3O8 and UO3 is the uranium oxidation state. U3O8 is less soluble because the U(IV) present in the mineral is less soluble. Therefore, the discussion of the potential release rates and the likely solid phases present in the facility need to be tied to the redox conditions of the site. In addition, the clarifications noted in the ES response regarding release of waste should be added to the PA documentation. We look forward to reviewing the revised report.

***EnergySolutions*' Response**: It is recognized that ions dissolving from any mineral phase are generally "mobile," whereas the mineral form itself is not assumed to move.

Redox conditions were considered in the development of solubility and K_d input distributions, which control the release rate of the radionuclides in the waste. The discussion of the relationship between the redox conditions and the potential release rates of UO3 and U3O8 and the solid phases likely to be present has been expanded in Section 4, 5, and 6 of Appendix 6 of version 1.2 of the Modeling Report and in the response prepared to Interrogatory CR R313-25-8(4)(A)-64/2: YUCCA MOUNTAIN STUDIES.

171. INTERROGATORY CR R313-25-7-171/2: ADEQUACY OF DU CELL BUFFER ZONE

The ES position is contingent upon DOE accepting stewardship of the combined cell and DEQ receipt of a written/executed agreement between ES and DOE. On page 1-3 of the Compliance Report, Revision 1, ES indicated that this policy issue must be resolved before disposing of concentrated DU in the Federal Cell. We note that ES did not include a reference for the approval of the License Amendment Request on November 26, 2012. This should be provided to ensure completeness of the review record.

***EnergySolutions*' Response**: Reference to the requested approval letter of November 26, 2012 will be added to the Compliance Report.

172. INTERROGATORY CR R313-25-20-172/2: INADVERTENT INTRUDER PROTECTION

ES did not address one of the concerns stated in the interrogatory, namely that the failure to demolish and reclaim existing ES buildings in Section 29 (currently not accounted for in the ES LLRW or 11e.(2) sureties) could attract people in the future to occupy this adjoining land. The presence of these buildings could encourage human activities of many kinds on the margin of the buffer zone, thus increasing the chance of intrusion into the buffer zone or embankment at a later date. This concern needs to be addressed.

***EnergySolutions*' Response**: Results of bounding scenarios considering inadvertent intrusion demonstrate the protection of the inadvertent intruder to applicable regulatory limits. The Division lacks jurisdiction to apply requirements outside the boundaries of the licensed facility, particularly since inadvertent intrusion, by definition, occurs within the facility buffer zone. Considering that the potential for inadvertent intrusion to occur is considered to be 1; i.e., credit is not taken for any probability associated with this intrusion; the presence or absence of structures on adjacent land is irrelevant to the analysis.

The numerous unlicensed and unregulated buildings, structures, and equipment Energy*Solutions* owns and uses to support its day-to-day business operations (such as the Administration Building located on Clive's Section 29, Energy*Solutions'* Corporate Offices in Salt Lake City – Utah, or Energy*Solutions* offices in Tooele – Utah) do not fall within the area subject to the License at the Clive "*disposal site*" and are not subject to the Division's regulation.

These buildings and facilities are instead governed by various municipal zoning and business regulations. Their purpose is solely administrative, as they do not house or handle any low-level radioactive waste. There is no legal or regulatory justification for the Division's application of regulatory required performance objectives to buildings, equipment and facilities that are entirely outside the area defined in the License. Even if demolition were included as a license condition or in the Performance Assessment, the Division lacks legal authority to enforce a demolition requirement.

In fact, in the highly unexpected event that Energy*Solutions* were to file for bankruptcy or otherwise become defunct, a bankruptcy receiver or other entity would assume ownership of these facilities and would have the legal authority to dispose of them. Any attempt by the Division to require demolition of such facilities under a bankruptcy scenario would represent a significant infringement on private property rights.

173. INTERROGATORY CR R313-25-7(2)-173/2: STABILITY OF EMBANKMENT

ES should provide additional information in response to the following comments on this calculation:

- The calculation appears to have included the weight of only one cylindrical shell rather than two. The currently proposed design involves stacking an additional cylindrical shell over each cylindrical shell at the base of the embankment for at least a portion of the embankment.

- The shell weight was assumed to be 2,500 lb, whereas the B&W Conversion Services website (http://www.bwconversionservices.com/our-process/) indicates that some shells weigh 4,500 lb.

- The density of the U3O8 is assumed to be 8.3 g/cc. Presumably, this is the particle density. The bulk density, as noted in the ES response to Interrogatory CR R313-25-22-162/1: Disposal Cell Stability, is 2.4 to 2.7 g/cc. Using the value of 2.7 g/cc and assuming that the shell is completely filled with U3O8, the mass of the contents would be about 25,000 lb. This mass is similar to the range of DUF6 masses of 20,000 lb to 28,000 lb, depending on container wall thickness, quoted by B&W Conversion Services.

- ES engineering drawing 14004-L1 provided in the response to Round 1 Interrogatories, dated March 31, 2014, shows the DU disposal zone to be between 7.0 to 7.8 feet thick. Since UF6 cylinders have a nominal diameter of 4 feet, it is apparent that ES may place drummed waste immediately above or below a cylinder. If this is the case, the calculations also need to account for this added weight.

In addition, the loading calculation does not include the contribution of materials in the embankment above the DU layers. We look forward to reviewing the revised report.

EnergySolutions' Response*:* The bearing calculations have been revised, as follow, to include the comments provided by the DRC.

- The previously submitted calculations did include the weight of two (2) cylinders for the double stack scenario. The proposed double stacking configuration requires the overlying (2nd layer) cylinders to be offset as shown on the “Conceptual Double Stack Configuration” detail on Drawing 14004-L1 (Revision 1), attached. A cylinder on the 1st layer supports 2 overlying cylinders but it shares the load with the cylinders on either side of it. Therefore, it would bear only ½ the weight of each cylinder on top of it. The calculations were not revised per this comment.

- The calculations have been revised to assume the analyzed cylinder shells weigh 4500 lbs each.

- Energy*Solutions* opted for the most conservative weight in the original calculation by using the particle density of 8.3 g/cc. However, we agree that it is more accurate (while still conservative) to use a bulk density of 2.7 g/cc. The calculations have been revised accordingly. Please note that the revision (along with using a shell weight of 4500 lbs) results in a maximum weight of 29,901 lbs, which is slightly higher than the reported cylinder weight range of 20,000 to 28,000 lbs.

The calculations were revised to incorporate the first 3 comments and the results are as follow. Please also note that in addition the revised calculations now include the weight of sand fill between the cylinders. The calculations are attached.

Single Layer Bearing on the Clay Liner Surface = 653 psf

Double Layer Bearing on the Clay Liner Surface = 1,208 psf

- Energy*Solutions* agrees that there is the potential to place a single layer of drums over a single layer of the cylinders. Two placement configurations, as show in the "Conceptual Cylinder-Drum Stack Configuration" detail on the attached Drawing 14004-L1 (Revision 1), were analyzed. As seen in the figure, there is the potential for a cylinder to support the weight of up to fourteen (14) 55 gallon drums. Please note that the placement configuration shows the drums positioned horizontally rather than vertically. This is because although a 55 gallon drum is slightly less than 3 ft tall, on a pallet it is closer to 3.5 ft tall, which combined with a 4 ft diameter cylinder would exceed 7 ft in combined height. A horizontal placement of the drums would assure that the combined height does not exceed 7 ft. The bearing calculations (attached) at the surface of the clay liner were performed and resulted in a bearing of 1,010 psf.

As requested, Energy*Solutions* has performed and attached loading calculations at the foundation surface (bottom of the clay liner) that accounts for all overlying materials (liner, DU, fill, waste, radon barrier, and erosion barrier layers). The layer unit weights for liner, waste, radon barrier, filter rock and rock cover were obtained from the "Mixed Waste Design Engineering Report (DER)", dated May 7, 2003.

The total loading on the in-situ soils (foundation) is calculated to be just over 7,528 psf.

174. INTERROGATORY CR R313-25-7(6)-174/1: WASTE EMPLACEMENT IN CLASS A SOUTH DISPOSAL CELL

Round 1 Interrogatory Response is satisfactory.

175. INTERROGATORY CR R313-25-7(2)-175/1: INFILTRATION RATES FOR THE FEDERAL CELL VERSUS THE CLASS A WEST CELL

ES notes that this interrogatory is no longer relevant since the Federal Cell will use an ET cover. We agree with this position. However, a thorough discussion of the modeling of infiltration rates, with soil hydraulic conductivity values as provided in NUREG/CR-7028 (Benson et al., 2011), is expected in the report on the ET cover system.

***EnergySolutions' Response**:* A methodology for assessment of the full range of initial Federal Cell cover geophysical properties and sensitivity of the projected infiltration on their degradation over time is included in Appendix 15(I) of version 1.2 of the Modeling Report. As is reported in the sensitivity results included in Appendix 15(II), the Federal Cell cover characteristic for which infiltration is most sensitive are Biomass % cover, Clay K_d for Pu, Clay K_d for Cs, Silt K_d for Ra, tortuosity of water content exponent, and cover layer gravel admixture density (all of which exhibit a sensitivity index of < 0.01, meaning the results are not sensitive to their variations). Variations in geophysical characteristics suggested by Benson et al., 2011 were not demonstrated sensitive. See also the response for INTERROGATORY CR R313-25-7(2)-05/2: RADON BARRIER.

176. INTERROGATORY CR R313-25-8(5)(A)-176/1: REPRESENTATIVE HYDRAULIC CONDUCTIVITY RATES

Claims made regarding PA modeling for the Class A West Cell ET cover design require review and verification by DEQ. Until such time, this interrogatory will remain open. We recognize that this interrogatory spans two topics: (1) alternative assignments of initial cover properties and (2) alternative approaches to degradation models for changes in cover properties over time.

***EnergySolutions' Response**:* See the responses to interrogatory CR R313-25-7(2)-05/2: RADON BARRIER for additional detail on the sensitivity of cover geophysical characteristics.

While Energy*Solutions* recognizes that it is seeking separate approval for construction of a similar cover system over its Class A West (CAW) embankment from the Division, demonstration of the CAW cover's ability to satisfy low-level radioactive waste disposal performance objectives unique to Class A-type waste are unrelated to the requirements imposed on the Federal Cell evapotranspirative cover's ability to satisfy the unique depleted uranium performance criteria addressed in version 1.2 of the Modeling Report. Similarly, neither the already closed LARW embankment, nor the ongoing cover construction projects for Energy*Solutions'* Mixed Waste embankment have impact on version 1.2 of the Modeling Reports demonstration that the Federal Cell meets the necessary performance objectives. The Mixed Waste and Class A Westembankments are independent physically and hydraulically separate from the proposed Federal Cell. Therefore, there are no outstanding claims regarding the unrelated Class A West cell cover design that require review and verification before closure of this Interrogatory.

177. INTERROGATORY CR R313-25-8(5)(A)-177/2: DOSE FROM PLANT UPTAKE

This statement is correct in that the currently approved cover at Clive has a capillary break in it above the radon barrier, which would discourage deep rooting. However, ES has proposed an ET cover for the DU waste. This ET cover has no effective capillary break layer in it. The grain size distribution has not been engineered thus far to provide for one. Therefore, ES needs to address potential doses from plant uptake assuming that the ET cover system is used. Furthermore, ES needs to consider the potential for plant uptake and potential doses beyond 500 years.

EnergySolutions' Response*:* It is recognized that the evapotranspirative cover proposed for the Federal Cell does not include a capillary break layer. The evapotranspirative cover does include two radon barriers, which are comparable to the natural 60-cm deep compacted clay layer observed at the Clive area surrounding the Federal Cell, upon which plant roots appear to extend laterally and to not penetrate (SWCA 2013, Figure 6). However, in version 1.2 of the Model, plant roots have maximum rooting depths of 5.7 m, 4.5 m, 1.5 m, 1.1 m, and 0.5 m below ground surface for greasewood, trees, grasses, shrubs, and forbs, respectively. Therefore, plant roots are assumed to penetrate through the entire cover in version 1.2 of the Model (but not all the way to the depleted uranium waste – due to its depth of disposal), and can transport radionuclides to the ground surface where plant litter gets mixed instantaneously with the top layer of soil (1-cm thick) and is subject to transport by downward water advection, diffusion in air and water, burrow collapse, and resuspension in air. Therefore, plant roots are a pathway in version 1.2 of the Model. However, doses from the plant uptake of depleted uranium pathway are very small (e.g. < 0.01 mrem/year mean dose to rancher within 10,000 years).

178. INTERROGATORY CR R313-25-8(5)(A)-178/2: SURFACE WATER PATHWAY

Although limited potential exposure pathways could be the case for the next 500 years, the site has to be modeled at least 10,000 years quantitatively and 1,000,000 years qualitatively. Furthermore, ES needs to address potential surface water pathways associated with the ET cover as opposed to the rip rap.

EnergySolutions' Response: There are differences between the expected performance of the ET cover system and the rock armor system with respect to runoff. First, the rock armor system has filter layers designed to route water out of the cover system to a retention pond. The ET cover system has no designed lateral flow layers. While the upper layer of the rock armor cover consisted of rip-rap with a low water holding capacity, the upper two layers of the ET cover system are designed to function as store-and-release layers. These layers reduce runoff by providing storage for water accumulating from precipitation events and enhancing losses by evaporation. As described previously, the Clive facility is sited in an area of extremely low topographic relief, and surface water features such as stream channels are non-existent on site and in the immediate vicinity. The ancestral lake bed is quite flat, so there is little in the way of land surface gradients which might drive surface water flow. Any runoff and associated sediment transport will be local, and is likely to remain in the vicinity of the site.

Furthermore, the purpose of the qualitative exploration beyond 10,000 years is informative and specifically NOT to assess or determine "exposure pathways." While arbitrarily assigning exposure pathways to the qualitative assessment may be academically interesting, such exercises are directly opposing NRC guidance,

> "*Consistent with the above, consideration given to the issue of evaluating site conditions that may arise from changes in climate or the influences of human behavior should be limited so as to avoid unnecessary speculation. It is possible that, within some disposal site regions, glaciation or an interglacial rise in sea level could occur in response to changes in global climate. These events are envisaged as broadly disrupting the disposal site region to the extent that the human population would leave affected areas as the ice sheet or shoreline advances. Accordingly, an appropriate assumption under these conditions would be that no individual is living close enough to the facility to receive a meaningful dose [i.e. exposure]*" [*emphasis added*] (NUREG-1573, pg. 3-10)

As such, exposure and dose should NOT be converted from resulting concentrations as a result of any qualitative assessment of the fate and transport of depleted uranium resulting from "changes in climate", "glaciations", or "interglacial rise in sea level that occur in response to changes in global climate." By doing so, the Division invalidates the express purpose for the qualitative deep time evaluation.

179. INTERROGATORY CR R313-25-7(2)-179/1: RIP RAP

ES notes that this interrogatory is no longer relevant for the top slope of the Federal Cell since the Federal Cell will largely use an ET cover. However, this interrogatory should be addressed in regard to any rip rap that will be used on portions of the side slope and on ditches.

EnergySolutions' Response: As is reflected in Section 3.1.2 of Appendix 3 – Embankment Modeling to version 1.2 of the Modeling Report (attached as Appendix A to the Compliance Report), there is no riprap material included in the construction of the proposed evapotranspirative cover. No changes in the Division–approved riprap specifications for Energy*Solutions'* current drainage ditch network is required as a result of approval of the Federal Cell. Approved riprap specifications are summarized in Figure 6 of Appendix 3.

While there are several sources for this material, Energy*Solutions* has typically secured riprap for other similar construction needs via long-term contract with the U.S. Bureau of Land Management for their rock pits in the nearby Central Grayback 62744 Community Pit. As part of the Division's review of Energy*Solutions'* annual LLRW surety revision, the availability of sufficient rock to complete cover construction for the 11e.(2), LLRW, and Mixed Waste embankments and associated ditch network has already been successfully demonstrated.

180. INTERROGATORY CR UGW450005 PART I.D.1-180/2: COMPLIANCE PERIOD

However, it is still necessary for ES to demonstrate that exposures to groundwater will remain below the R313-25-19 dose limit (4 mrem/yr) during the entire R313-25-8(5)(a) defined compliance period (10,000 years or more). No additional response to this interrogatory is required from ES.

181. *ENERGYSOLUTIONS' RESPONSE*: THE 4 MREM/YEAR LIMIT PROMULGATED IN UAC R313-25-20 STRICTLY APPLIES TO DOSES INCURRED TO ANY MEMBER OF THE GENERAL PUBLIC FROM THE INGESTION OF GROUNDWATER. SEE THE RESPONSE TO INTERROGATORY CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS FOR FURTHER DEMONSTRATION THAT GROUNDWATER INGESTION IS NOT A REASONABLE PATHWAY FOR ANALYSIS. INTERROGATORY CR R313-25-19-181/2: GROUNDWATER MORTALITY

The issue with the untraceability of the data ES used remains, and the response also did not address the use of incorrect statistical analysis performed by ES. Both of these facts severely weaken the arguments presented in the response and limit our ability to agree with ES' conclusions.

***EnergySolutions' Response**:* Responses to the Division's insistence of reaching beyond NRC guidance regarding bounding analyses to current water uses by forcing a groundwater ingestion dose pathway are found in responses to Interrogatories CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS and CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS.

182. INTERROGATORY CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS

As discussed elsewhere (see, for example, Interrogatory CR R313-25-8(4)(a)-96/2 and Interrogatory CR R313-25-8(4)(a)-97/2: Need for Potable and/or Industrial Water), SC&A believes that additional information must be provided to demonstrate the groundwater at Clive is not a potential dose pathway. Under Interrogatory CR R313-25-8(4)(a)-96/2, SC&A indicates that ES needs to examine the possibility that the lower confined aquifer at Clive could become contaminated and thus become a source of exposure, either to an inadvertent intruder or to a member of the public. If the water from this aquifer were used for domestic uses but did not meet the test of a public water system, regulation would be left to Tooele County. It is our understanding that the County does not require testing for uranium or other radioactive contaminants.

***EnergySolutions' Response**:* As is reflected in Energy*Solutions* (2013), both the upper unconfined and lower confined aquifers have been classified as Class IV, "*non-potable, saline ground water*" due to total dissolved solids and other naturally-present constituents. As such, consideration of a groundwater ingestion scenario as an exposure or dose pathway is not representative of "*current local well-drilling techniques and/or water use practices*," (NRC, 2000). Even so, Energy*Solutions* recognizes current local groundwater practices involve pumping of water as a limited source of non-ingestible industrial water (such as for dust suppression). While of comparably poor water quality, similar local wells installed for the production of industrial water have been screened into the deeper confined aquifer as production sources for industrial water (due to the relatively low yield of the upper, unconfined aquifer). In fact, Energy*Solutions* requested permission from the Division to install such a well in Section 29 (immediately north of the area licensed for radioactive waste management), (Envirocare, 2005; included as Section 6 to this Response Report). Analyses and representative well characteristics from Envirocare (2005) have been used to model potential doses for an inadvertent industrial intruder well scenario in support of the response to this Interrogatory.

While highly improbable, it is assumed that an inadvertent industrial intruder driller uses a mud rotary system (which is common in the Clive area) to drill a well (similar in physical characteristics to that proposed in 2005) 90 feet from the design toe of the DU waste within the Federal Cell. For the purposed of this analysis, it is assumed that this occurs sometime after site closure/ institutional control. As is justified in the response to Interrogatory CR R313-25-20-92/2: Inadvertent Intruder Dose Standard and Scenarios, all exposure scenarios (whether acute or chronic) are subject to a dose limit of 500 mrem/year.

ACUTE INADVERTENT WELL DRILLER INTRUDER SCENARIO DEFINITION: A distinct acute exposure scenario to an inadvertent intruder considered in this analysis is referred to as the "*acute well drilling scenario*". The acute well drilling scenario is based on the assumption that after active institutional control ceases, an intruder drills a well within the licensed buffer zone (90 feet from the toe of the disposed depleted uranium). The acute well drilling scenario considers exposures during the short period of time required for drilling and construction of the well. During well drilling, the following relevant exposure pathways are assumed:

- External exposure photon-emitting radionuclides in the unshielded cuttings pile containing waste, and
- Inhalation of radionuclides suspended in air from the uncovered cuttings pile containing waste.

The importance of the acute well drilling scenario arises primarily from the assumption that an inadvertent intruder could be located near an unshielded cutting pile for a substantial period of time. Probabilistic isotopic concentrations in the unconfined aquifer (as projected in version 1.2 of the Modeling Report) are used to calculate the associated acute well drilling scenario isotopic dose [$D_{wd}(i,t)$] for each isotope, *i*, at the unique time, *t*, corresponding to that isotopic concentration in the unconfined aquifer.

$$D_{wd}(i,t) = DC_{wd}(i) \times C_{pit}(i,t)$$

where

$D_{wd}(i,t)$	=	The acute dose to the well driller for isotope, *i*, at the time of its peak shallow aquifer concentration (as projected in version 1.2 of the Modeling Report), (mrem/year).
$DC_{wd}(i)$	=	Acute well drilling scenario dose coefficient for radionuclide, *i*, (mrem/year per uCi/m^3).

$C_{shallow}(i,t)$ = Isotopic, i, concentration of the waste in the shallow aquifer, (uCi/m^3).

The acute well drilling scenario dose coefficient for isotope, *i*, [$DC_{wd}(i)$] is estimated by summing the exposure pathway dose coefficients:

$$DC_{wd}(i) = DC_{ext}(i) + DC_{inh}(i)$$

where

$DC_{ext}(i)$ = Acute well drilling scenario external exposure dose coefficient for radionuclide, *i*, (mrem/year per uCi/m^3).

$DC_{inh}(i)$ = Acute well drilling scenario inhalation exposure dose coefficient for radionuclide, *i*, (mrem/year per uCi/m^3).

The acute well drilling external exposure dose coefficient for isotope, *i*, [$DC_{ext}(i)$] is estimated by:

$$DC_{ext}(i) = f_c \text{ x } U_y(wd) \text{ x } DCF_{ie15}$$

where

f_c = Dilution factor for mixture of upper aquifer waste water, deep aquifer clean water, geologic cuttings, and well drilling mud, (unitless).

$U_y(wd)$ = Fraction of a year well driller is exposed to cuttings and mud management pit while drilling the well, (unitless).

DCF_{ie15} = Dose conversion factor for external exposure to 15 cm of soil and mud uniformly contaminated with radionuclide, *i*, (mrem/year per uCi/m^3).

The acute well drilling inhalation exposure dose coefficient for isotope, *i*, [$DC_{inh}(i)$] is estimated by:

$$DC_{inh}(i) = \left(\frac{\mathrm{f_c \text{ x } U_y(wd) \text{ x } I_{aw} \text{ x } L_a(wd) \text{ x } DCF_{inh}}}{\rho_{mud}}\right)$$

where

I_{aw}	=	Annual air intake for driller (m^3/year)
$L_a(wd)$	=	Air mass loading during drilling (kg/m^3)
DCF_{inh}	=	Dose conversion factor for inhalation of radionuclide, *i*, (mrem per uCi).
ρ_{mud}	=	Average bulk density of geologic cuttings (kg/m^3)

The dilution factor, f_c, that accounts for the mixture of upper aquifer waste water, deep aquifer clean water, geologic cuttings, and well drilling mud is computed as:

$$f_c = \left(\frac{V_{shallow}}{V_{shallow} + V_{deep} + V_{mud} + V_{cuttings}}\right)$$

where

$V_{shallow}$	=	Volume of contaminated water from the shallow aquifer brought up as part of the well excavation process, (m^3).
V_{deep}	=	Volume of clean water from the deep aquifer brought up as part of the well excavation process, (m^3).
V_{mud}	=	Volume of drill mud used up as part of the well excavation process, (m^3).
$V_{cuttings}$	=	Volume of drill cuttings excavated from the well drilling process, (m^3).

The volume of drill cuttings, $V_{cuttings}$, brought up as part of the excavation process is computed as:

$$V_{cuttings} = \pi z_{excavation}\left(\frac{DIA_{excavation}}{2}\right)^2$$

where

$z_{excavation}$	=	Total depth of excavation, (m).
$DIA_{excavation}$	=	Total diameter of excavation, (m).

The volume of water from the confined aquifer, V_{deep}, brought up as part of the excavation process (assumed to be from the region of 2 times the excavation diameter) is computed as:

$$V_{deep} = \pi n_{deep} z_{deep} (DIA_{excavation})^2$$

where

z_{deep}	=	Depth of excavation in unit 1 (deep aquifer hosting zone), (m).
n_{deep}	=	Effective porosity of unit 1 (deep aquifer hosting zone), (unitless).

The volume of water from the unconfined aquifer, $V_{shallow}$, brought up as part of the excavation process (assumed to be from the region of 2 times the excavation diameter) is computed as:

$$V_{shallow} = \pi (n_{uncon} z_4 + n_{uncon} z_3)(DIA_{excavation})^2$$

where

z_4	=	Thickness of excavation in unit 4 between water table and lower layer boundary (unconfined aquifer hosting zone), (m).
z_3	=	Thickness of unit 3, (m).
n_{uncon}	=	Effective porosity of unconfined aquifer, (unitless).

CHRONIC INADVERTENT INDUSTRIAL INTRUDER SCENARIO DEFINITION: A distinct chronic exposure scenario to an inadvertent intruder considered in this analysis is referred to as the chronic post- drilling scenario. The chronic post- drilling scenario is based on the assumption that after active institutional control ceases, an inadvertent intruder who works near the Federal Cell, uses water produced from the intruder well for industrial purposes (such as dust suppression). While it is recognized that this industrial individual did not conduct activities that actually intruded into the waste, it is assumed that any associated industrial activities are conducted within the buffer area. Additionally, it is assumed that the industrial intruder is unaware of any possible depleted uranium-related contaminants that may have leached into the unconfined aquifer. Under this condition, NRC still characterizes the inadvertent industrial user as an inadvertent intruder, since:

> "*Finally, the disruptive actions of an inadvertent intruder do not need to be considered when assessing releases of radioactivity offsite* [that may result in subsequent exposure to members of the general public]." (NUREG-1573, pg. 3-11).

The following relevant exposure pathways involving the contaminated material sprayed onto the surface are then assumed to occur:

- External exposure photon-emitting radionuclides in the unshielded surface-sprayed wastewater, and

- Inhalation of radionuclides suspended in air from the unshielded surface-sprayed wastewater.

The importance of the chronic post-drilling scenario arises primarily from the assumption that an intruder could inadvertently use contaminated water for dust suppression for a substantial period of time. It is assumed that water extracted from the production well consists of contaminated wastewater from the unconfined aquifer (not within the well screen depth) that has leaked down into the uncontaminated deep aquifer (where the well casing is screened). The chronic post-drilling scenario isotopic dose [$D_{pd}(i,t)$] is estimated for each isotope, *i*, at its unique time of peak concentration, *t*, in the unconfined aquifer.

$$D_{pd}(i,t) = DC_{pd}(i) \times C_{shallow}(i,t)$$

where

$D_{pd}(i,t)$ = The chronic dose to the post driller for isotope, *i*, at the time of its peak shallow aquifer concentration (as projected in version 1.2 of the Modeling Report), (mrem/year).

$DC_{pd}(i)$ = Chronic post-drilling scenario dose coefficient for radionuclide, *i*, (mrem/year per uCi/m^3).

The chronic post-drilling scenario dose coefficient for isotope, *i*, [$DC_{pd}(i)$] is estimated by summing the exposure pathway dose coefficients:

$$DC_{pd}(i) = DC_{pd\text{-}ext}(i) + DC_{pd\text{-}inh}(i)$$

where

$DC_{pd\text{-}ext}(i)$ = Chronic post-drilling scenario external exposure dose coefficient for radionuclide, *i*, (mrem/year per uCi/m^3).

$DC_{pd\text{-}inh}(i)$ = Chronic post-drilling scenario inhalation exposure dose coefficient for radionuclide, *i*, (mrem/year per uCi/m^3).

The chronic post-drilling scenario external exposure dose coefficient for isotope, *i*, [$DC_{pd\text{-}ext}(i)$] is estimated by:

$$DC_{pd\text{-}ext}(i) = f_{pdc} \text{ x } U_y(pd) \text{ x } DCF_{ie15}$$

where

f_{pdc} = Dilution factor for mixture of upper aquifer waste water and deep aquifer clean water, (unitless).

$U_y(pd)$ = Fraction of a year inadvertent industrial worker is exposed to ground surface contaminated by dust suppression spray, (unitless).

The chronic post-drilling inhalation exposure dose coefficient for isotope, *i*, [$DC_{pd\text{-}inh}(i)$] is estimated by:

$$DC_{pd-inh}(i) = \left(\frac{f_{pdc} \text{ x } U_y(pd) \text{ x } I_{aw} \text{ x } L_a(wd) \text{ x } DCF_{inh}}{\rho_s}\right)$$

where

ρ_s = Average bulk density of surface soils (kg/m^3)

The well water dilution factor, f_{pdc}, that accounts for the mixture of upper aquifer waste water that has been allowed to leak downward into the confined aquifer and the deep aquifer clean water is computed as:

$$f_{pdc} = \left(\frac{Q_{shallow}}{Q_{produced}}\right)$$

where

$Q_{shallow}$ = Shallow aquifer water downward leakage rate, (m^3/year).

$Q_{produced}$ = Total rate of water produced from the well (including from the deep, confined aquifer and any water leaked from the upper confined aquifer) for industrial uses, (m^3/year).

The volume of contaminated wastewater transported from the upper unconfined aquifer, through the leaking well casing, and downward to the deep, confined aquifer, $Q_{shallow}$, is computed using the Thiem-Dupuit's method (Freeze, R.A. and J.A. Cherry, 1979) as the volume of water producible from the unconfined aquifer, under steady-state pumping, that would result in the localized waste table drop (i.e., cone of depression), projected in Envirocare (2005), as:

$$Q_{shallow} = 2\pi K_{shallow} D \left(\frac{s'_{m1} - s'_{m2}}{ln\left({}^{r_2}/{}_{r_1}\right)}\right)$$

where the parameters are illustrated in the following:

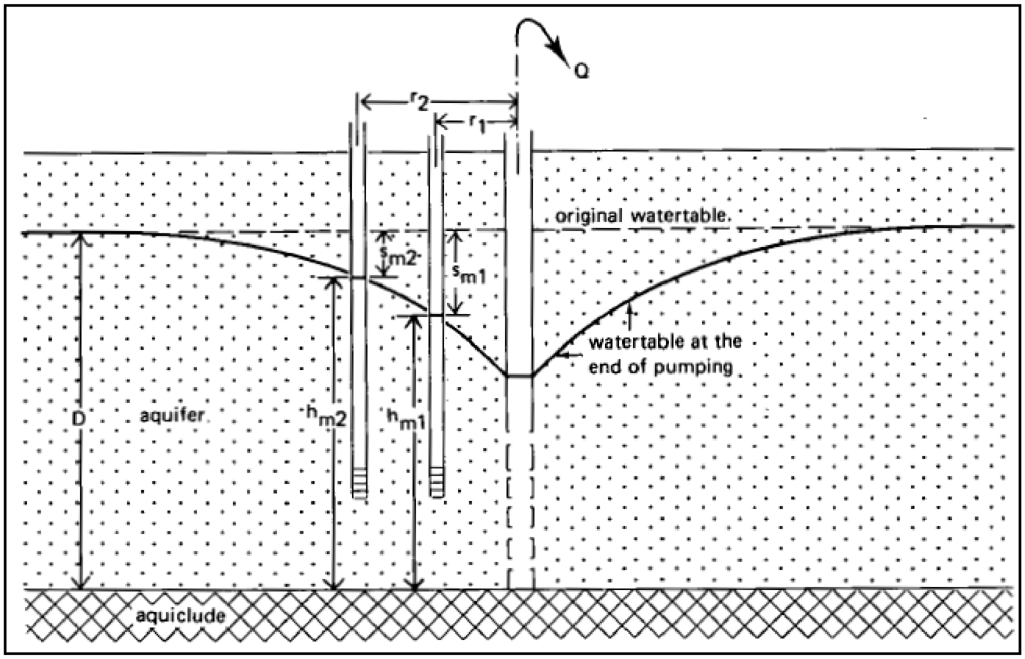


Figure - Thiem-Dupuit's method scenario parameter layout

INADVERTENT INTRUDER WELL DOSE CALCULATIONS:
Doses in the inadvertent intruder groundwater analysis were estimated by using the isotopic concentrations projected in the upper unconfined aquifer in version 1.2 of the Modeling Report and well characteristics similar to that proposed in Envirocare (2005). For each exposure pathway in a scenario of interest, an effective dose equivalent (EDE) in mrem/year for each isotope of interest is calculated.

TABLE – Inadvertent Intruder Well Model Input Parameters

INPUT PARAMETER	DESCRIPTION	VALUE	UNIT	REFERENCE
$Q_{produced}$	Total rate of water produced from the well (including from the deep, confined aquifer and any water leaked from the upper confined aquifer) for industrial uses	1.33E+05	m^3/year	Envirocare, 2005
z_{deep}	Depth of excavation in unit 1 (deep aquifer hosting zone)	1.71E+02	m	Envirocare, 2005
n_{deep}	Effective porosity of unit 1 (deep aquifer hosting zone)	1.30E-01	unitless	Envirocare, 2005
$U_y(wd)$	Fraction of a year well driller is exposed to cuttings and mud management pit while drilling the well	4.57E-03	unitless	EPA, 2011
I_{aw}	Annual air intake for driller	2.19E+04	m^3/year	EPA, 2011
$L_a(wd)$	Air mass loading during drilling	1.00E-06	kg/m^3	EPA, 2011
ρ_{mud}	Average bulk density of geologic cuttings	1.00E+03	kg/m^3	Envirocare, 2005
$z_{excavation}$	Total depth of excavation	1.83E+02	m	Envirocare, 2005
$DIA_{excavation}$	Total diameter of excavation	2.41E-01	m	Envirocare, 2005
z_4	Average thickness of unit 4	3.05E+00	m	Envirocare, 2005
z_3	Average thickness of unit 3	4.57E+00	m	Envirocare, 2005
n_{uncon}	Effective porosity of saturated regions of units 4 and 3	2.90E-01	unitless	Envirocare, 2005
$U_y(pd)$	Fraction of a year inadvertent industrial worker is exposed to ground surface contaminated by dust suppression spray	2.28E-01	unitless	EPA, 2011
ρ_s	Average bulk density of surface soils	1.60E+03	kg/m^3	Envirocare, 2005
D_{wt}	Average depth from ground surface to unconfined aquifer (water table)	5.18E+00	m	Envirocare, 2005
D	Average thickness of unconfined aquifer	6.10E+00	m	Envirocare, 2005

INPUT PARAMETER	DESCRIPTION	VALUE	UNIT	REFERENCE
$K_{shallow}$	Effective hydraulic Conductivity of saturated regions of units 4 and 3	1.06E+02	m/yr	Envirocare, 2005
r_1	Radial distance to 1st unconfined aquifer drawdown reading	9.14E+02	m	Envirocare, 2005
r_2	Radial distance to 2nd unconfined aquifer drawdown reading	2.13E+03	m	Envirocare, 2005
s'_1	Steady-state draw down in unconfined aquifer at 1st location	2.13E-01	m	Envirocare, 2005
s'_2	Steady-state draw down in unconfined aquifer at 2nd location	1.22E-01	m	Envirocare, 2005
V_{mud}	Volume of drilling mud	1.69E+02	m^3	Fleming, et. al 2012
Sr-90	Peak unconfined shallow aquifer concentration - mean	0.00E+00	uCi/m^3	Table 2 Modeling Report (v1.2)
Tc-99	Peak unconfined shallow aquifer concentration - mean	7.40E-01	uCi/m^3	Table 2 Modeling Report (v1.2)
I-129	Peak unconfined shallow aquifer concentration - mean	4.82E-04	uCi/m^3	Table 2 Modeling Report (v1.2)
Th-230	Peak unconfined shallow aquifer concentration - mean	1.85E-29	uCi/m^3	Table 2 Modeling Report (v1.2)
Th-232	Peak unconfined shallow aquifer concentration - mean	1.44E-35	uCi/m^3	Table 2 Modeling Report (v1.2)
Np-237	Peak unconfined shallow aquifer concentration - mean	9.75E-21	uCi/m^3	Table 2 Modeling Report (v1.2)
U-233	Peak unconfined shallow aquifer concentration - mean	3.86E-25	uCi/m^3	Table 2 Modeling Report (v1.2)
U-234	Peak unconfined shallow aquifer concentration - mean	1.51E-24	uCi/m^3	Table 2 Modeling Report (v1.2)
U-235	Peak unconfined shallow aquifer concentration - mean	1.10E-25	uCi/m^3	Table 2 Modeling Report (v1.2)
U-236	Peak unconfined shallow aquifer concentration - mean	2.24E-25	uCi/m^3	Table 2 Modeling Report (v1.2)
U-238	Peak unconfined shallow aquifer concentration - mean	1.12E-23	uCi/m^3	Table 2 Modeling Report (v1.2)
Sr-90	Peak unconfined shallow aquifer concentration - median	0.00E+00	uCi/m^3	Table 2 Modeling Report (v1.2)
Tc-99	Peak unconfined shallow aquifer concentration - median	1.95E-02	uCi/m^3	Table 2 Modeling

INPUT PARAMETER	DESCRIPTION	VALUE	UNIT	REFERENCE
				Report (v1.2)
I-129	Peak unconfined shallow aquifer concentration - median	6.76E-10	uCi/m^3	Table 2 Modeling Report (v1.2)
Th-230	Peak unconfined shallow aquifer concentration - median	0.00E+00	uCi/m^3	Table 2 Modeling Report (v1.2)
Th-232	Peak unconfined shallow aquifer concentration - median	0.00E+00	uCi/m^3	Table 2 Modeling Report (v1.2)
Np-237	Peak unconfined shallow aquifer concentration - median	0.00E+00	uCi/m^3	Table 2 Modeling Report (v1.2)
U-233	Peak unconfined shallow aquifer concentration - median	0.00E+00	uCi/m^3	Table 2 Modeling Report (v1.2)
U-234	Peak unconfined shallow aquifer concentration - median	0.00E+00	uCi/m^3	Table 2 Modeling Report (v1.2)
U-235	Peak unconfined shallow aquifer concentration - median	0.00E+00	uCi/m^3	Table 2 Modeling Report (v1.2)
U-236	Peak unconfined shallow aquifer concentration - median	0.00E+00	uCi/m^3	Table 2 Modeling Report (v1.2)
U-238	Peak unconfined shallow aquifer concentration - median	2.21E-39	uCi/m^3	Table 2 Modeling Report (v1.2)
Sr-90	Peak unconfined shallow aquifer concentration - 95th %ile	0.00E+00	uCi/m^3	Table 2 Modeling Report (v1.2)
Tc-99	Peak unconfined shallow aquifer concentration - 95th %ile	4.46E+00	uCi/m^3	Table 2 Modeling Report (v1.2)
I-129	Peak unconfined shallow aquifer concentration - 95th %ile	3.39E-03	uCi/m^3	Table 2 Modeling Report (v1.2)
Th-230	Peak unconfined shallow aquifer concentration - 95th %ile	3.35E-34	uCi/m^3	Table 2 Modeling Report (v1.2)
Th-232	Peak unconfined shallow aquifer concentration - 95th %ile	2.09E-40	uCi/m^3	Table 2 Modeling Report (v1.2)
Np-237	Peak unconfined shallow aquifer concentration - 95th %ile	1.32E-27	uCi/m^3	Table 2 Modeling Report (v1.2)
U-233	Peak unconfined shallow aquifer concentration - 95th %ile	1.00E-28	uCi/m^3	Table 2 Modeling Report (v1.2)

INPUT PARAMETER	DESCRIPTION	VALUE	UNIT	REFERENCE
U-234	Peak unconfined shallow aquifer concentration - 95th %ile	8.10E-29	uCi/m^3	Table 2 Modeling Report (v1.2)
U-235	Peak unconfined shallow aquifer concentration - 95th %ile	6.77E-30	uCi/m^3	Table 2 Modeling Report (v1.2)
U-236	Peak unconfined shallow aquifer concentration - 95th %ile	1.08E-29	uCi/m^3	Table 2 Modeling Report (v1.2)
U-238	Peak unconfined shallow aquifer concentration - 95th %ile	6.35E-28	uCi/m^3	Table 2 Modeling Report (v1.2)
Sr-90	Mean Dose Conversion Factor (inhalation)	5.92E+02	mrem per uCi	Appendix 11, Modeling Report (v1.2)
Tc-99	Mean Dose Conversion Factor (inhalation)	4.81E+01	mrem per uCi	Appendix 11, Modeling Report (v1.2)
I-129	Mean Dose Conversion Factor (inhalation)	3.55E+02	mrem per uCi	Appendix 11, Modeling Report (v1.2)
Th-230	Mean Dose Conversion Factor (inhalation)	3.70E+05	mrem per uCi	Appendix 11, Modeling Report (v1.2)
Th-232	Mean Dose Conversion Factor (inhalation)	4.07E+05	mrem per uCi	Appendix 11, Modeling Report (v1.2)
Np-237	Mean Dose Conversion Factor (inhalation)	1.85E+05	mrem per uCi	Appendix 11, Modeling Report (v1.2)
U-233	Mean Dose Conversion Factor (inhalation)	3.55E+04	mrem per uCi	Appendix 11, Modeling Report (v1.2)
U-234	Mean Dose Conversion Factor (inhalation)	3.48E+04	mrem per uCi	Appendix 11, Modeling Report (v1.2)
U-235	Mean Dose Conversion Factor (inhalation)	3.15E+04	mrem per uCi	Appendix 11, Modeling Report (v1.2)
U-236	Mean Dose Conversion Factor (inhalation)	3.22E+04	mrem per uCi	Appendix 11, Modeling Report (v1.2)
U-238	Mean Dose Conversion Factor (inhalation)	2.96E+04	mrem per uCi	Appendix 11, Modeling Report (v1.2)
Sr-90	Mean Dose Conversion Factor ext - 15cm)	4.40E-04	mrem/year per uCi/m^3	Appendix 11, Modeling Report (v1.2)
Tc-99	Mean Dose Conversion Factor ext - 15cm)	7.84E-05	mrem/year per	Appendix 11, Modeling

INPUT PARAMETER	DESCRIPTION	VALUE	UNIT	REFERENCE
			uCi/m^3	Report (v1.2)
I-129	Mean Dose Conversion Factor ext - 15cm)	8.09E-03	mrem/year per uCi/m^3	Appendix 11, Modeling Report (v1.2)
Th-230	Mean Dose Conversion Factor ext - 15cm)	7.56E-04	mrem/year per uCi/m^3	Appendix 11, Modeling Report (v1.2)
Th-232	Mean Dose Conversion Factor ext - 15cm)	3.26E-04	mrem/year per uCi/m^3	Appendix 11, Modeling Report (v1.2)
Np-237	Mean Dose Conversion Factor ext - 15cm)	4.87E-02	mrem/year per uCi/m^3	Appendix 11, Modeling Report (v1.2)
U-233	Mean Dose Conversion Factor ext - 15cm)	8.73E-04	mrem/year per uCi/m^3	Appendix 11, Modeling Report (v1.2)
U-234	Mean Dose Conversion Factor ext - 15cm)	2.51E-04	mrem/year per uCi/m^3	Appendix 11, Modeling Report (v1.2)
U-235	Mean Dose Conversion Factor ext - 15cm)	4.51E-01	mrem/year per uCi/m^3	Appendix 11, Modeling Report (v1.2)
U-236	Mean Dose Conversion Factor ext - 15cm)	1.34E-04	mrem/year per uCi/m^3	Appendix 11, Modeling Report (v1.2)
U-238	Mean Dose Conversion Factor ext - 15cm)	6.44E-05	mrem/year per uCi/m^3	Appendix 11, Modeling Report (v1.2)

Using these input parameters, there are several factors (independent of isotope) that are calculated according to the approach summarized above.

TABLE – Inadvertent Intruder Well Model Calculated Parameters

CALCULATED PARAMETER	DESCRIPTION	VALUE	UNIT
$Q_{shallow}$	Shallow aquifer water downward leakage rate	4.37E+02	m^3/year
f_{pdc}	Dilution factor for mixture of upper aquifer waste water and deep aquifer clean water	3.28E-03	unitless
$V_{shallow}$	Volume of contaminated water from the shallow aquifer brought up as part of the well excavation process	4.04E-01	m^3
V_{deep}	Volume of clean water from the deep aquifer brought up as part of the well excavation process	4.06E+00	m^3
$V_{cuttings}$	Volume of drill cuttings excavated from the well drilling process	8.36E+00	m^3
f_c	Mud driller dilution factor	2.22E-03	unitless
$DC_{inh}(i)$ / DCF_{inh}	Intermittent ratio (isotope independent)	2.22E-10	m^3/year
$DC_{ext}(i)$ / DCF_{ie15}	Intermittent ratio (isotope independent)	1.02E-05	m^3/year
$DC_{pd\text{-}inh}(i)$ / DCF_{inh}	Intermittent ratio (isotope independent)	1.03E-08	m^3/year
$DC_{pd\text{-}ext}(i)$ / DCF_{ie15}	Intermittent ratio (isotope independent)	7.50E-04	m^3/year

These calculated factors can then be used to estimate inadvertent intruder well doses from isotopic unconfined aquifer concentrations projected in version 1.2 of the Modeling Report. As such, isotopic doses are to the acute Intruder Driller from unconfined shallow aquifer concentrations output from version 1.2 of the Modeling Report as calculated below.

TABLE – Acute Well Driller Isotopic Doses

ISOTOPE	ACUTE DOSE FROM MEAN SHALLOW AQUIFER CONCENTRATION (mrem/year)	ACUTE DOSE FROM MEDIAN SHALLOW AQUIFER CONCENTRATION (mrem/year)	ACUTE DOSE FROM 95% ILE SHALLOW AQUIFER CONCENTRATION (mrem/year)
Sr-90	0.00E+00	0.00E+00	0.00E+00
Tc-99	8.51E-09	2.24E-10	5.13E-08
I-129	7.77E-11	1.09E-16	5.47E-10
Th-230	1.52E-33	0.00E+00	2.76E-38
Th-232	1.30E-39	0.00E+00	1.89E-44
Np-237	4.06E-25	0.00E+00	5.50E-32
U-233	3.05E-30	0.00E+00	7.91E-34
U-234	1.17E-29	0.00E+00	6.27E-34
U-235	1.27E-30	0.00E+00	7.84E-35
U-236	1.60E-30	0.00E+00	7.74E-35
U-238	7.38E-29	1.46E-44	4.18E-33

Since the version 1.2 Model Report-projected isotopic mean, median, and 95-percentile concentrations do not occur at the same point in time, it is inappropriate to estimate a total effective dose equivalent by summing over all isotopes. However, doing so does create a bounding estimate, above which the total dose estimated to the acute well driller will not exceed (upper dose limit from mean shallow aquifer concentrations = 8.6E-09 mrem/year, upper dose limit from median shallow aquifer concentrations = 2.2e-10 mrem/year, and upper dose limit from 95-percentile shallow aquifer concentrations = 5.2E-08 mrem/year), all of which are significantly lower than the 500 mrem/year intruder limit.

Application of the calculated factors can also be used to estimate isotopic doses to the chronic Industrial Intruder from isotopic unconfined aquifer concentrations projected in version 1.2 of the Modeling Report.

TABLE – Chronic Well User Isotopic Doses

ISOTOPE	CHRONIC DOSE FROM MEAN SHALLOW AQUIFER CONCENTRATION (mrem/year)	CHRONIC DOSE FROM MEDIAN SHALLOW AQUIFER CONCENTRATION (mrem/year)	CHRONIC DOSE FROM 95% ILE SHALLOW AQUIFER CONCENTRATION (mrem/year)
Sr-90	0.00E+00	0.00E+00	0.00E+00
Tc-99	4.09E-07	1.08E-08	2.46E-06
I-129	4.68E-09	6.56E-15	3.29E-08
Th-230	7.02E-32	0.00E+00	1.27E-36
Th-232	6.01E-38	0.00E+00	8.73E-43
Np-237	1.89E-23	0.00E+00	2.55E-30
U-233	1.41E-28	0.00E+00	3.65E-32
U-234	5.39E-28	0.00E+00	2.89E-32
U-235	7.26E-29	0.00E+00	4.47E-33
U-236	7.40E-29	0.00E+00	3.57E-33
U-238	3.40E-27	6.71E-43	1.93E-31

Since the version 1.2 Model Report-projected isotopic mean, median, and 95-percentile concentrations do not occur at the same point in time, it is inappropriate to estimate a total effective dose equivalent by summing over all isotopes. However, doing so does create a bounding estimate, above which the total dose estimated to the chronic inadvertent industrial well user will not exceed (upper dose limit from mean shallow aquifer concentrations = 4.2E-07 mrem/year, upper dose limit from median shallow aquifer concentrations = 1.1E-08 mrem/year, and upper dose limit from 95-percentile shallow aquifer concentrations = 2.6E-06 mrem/year), all of which are significantly lower than the 500 mrem/year intruder limit.

By using this same methodology and setting the dose to the inadvertent chronic industrial well user at 500 mrem/year, upper bounding equivalent depleted uranium isotopic concentrations can be reverse-calculated for SRS waste, assuming only the SRS depleted uranium wastes were disposed of in the Federal Cell (as are reported in Table 5 and 6 of Appendix 4 from version 1.2 of the Modeling Report).

TABLE – SRS Depleted Uranium Concentrations Equivalent to 500 mrem/year Chronic Well Isotopic Doses

ISOTOPE	ACTUAL MEAN SRS ACTIVITY FROM TABLES 5 AND 6 OF APPENDIX 4 (pCi/g)	NECESSARY SRS ACTIVITY TO CREATE AN ISOTOPIC-SPECIFIC 500 MREM/YEAR CHRONIC DOSE TO THE INADVERTENT INDUSTRIAL WELL USER (pCi/g)
Sr-90	47	5.69E+10
Tc-99	23800	2.88E+13
I-129	18.6	2.25E+10
Np-237	5.68	6.87E+09
U-233	478	5.78E+11
U-234	2170	2.62E+12
U-235	750	9.07E+11
U-236	1170	1.42E+12
U-238	6640	8.03E+12

When compared to the doses projected in Appendix 11 – Dose Assessment from version 1.2 of the Modeling Report, it is clear that doses from neither the proposed acute well driller inadvertent intruder nor the chronic industrial well user inadvertent intruder limit the analysis.

See also the response to Interrogatories CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS.

183. INTERROGATORY CR R313-25-19-183/2: MEAT INGESTION

Round 1 Interrogatory Response is satisfactory.

184. INTERROGATORY CR R313-25-19-184/2: GOLDSIM SKIPS STABILITY CALCULATION

Depending on whether GoldSim Player 10.5 SP1 or SP4 is used, the same GoldSim DU PA model file can produce significantly different results. ES needs to determine, demonstrate, and document which GoldSim version produced the “correct” results.

Additionally, steps need to be taken to ensure that only the “right” GoldSim version is used in conjunction with the DU PA model file. For example, if ES demonstrates that SP1 is giving "correct" results, then the DU PA model file should be "crippled" so as not to run under SP4, or anything other than SP1.

EnergySolutions*' Response: Version 1.2 of the Model is designed and correctly runs without error within the GoldSim 10.5 (SP4) platform. The GoldSim 10.5 (SP4) installation file (free for public distribution) will be provided with the final comprehensive deliverable for public review.

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4. REVISED DEPLETED URANIUM BEARING CAPACITY CALCULATION

DU Cylinder's Bearing Capacity Calculation 13-Jun-14

Find the bearing pressure of a DU cylinder's weight in a Double Stack DU cylinder configuration to verify its bearing pressure at the top of the clay liner.
Details of DU Cylinder(s):

Assume DU cylinder is 12' long x 4' diameter, made of 3/8" thick steel: assume cylinder weight of 4500 lbs.
Assuming the the bulk density of U_3O_8 is 2.7 g/cm3 (Wikipedia 2014) from the Interrogatory:
Waste weight: 2.7 gm/cm3 = 168.534 lb/cf

Assume all cylinders are 100% full and that a cylinder placed on the lower tier supports 50% of the weight of each of two upper tier cylinders. Spaces in between cylinders are filled with flowable sand at a density of 112 pcf, which is included in the calculation.

Size of Cylinder:	Length (ft)	Diameter (ft)	Volume (cf)	Area (sf)	Weight (lbs)
Maximum DU Cylinder total waste weight (weight of two upper and one lower cylinder) -using 50% of each of the two upper cylinders.	12.0	4.0	150.7	48.00	**59,803**
Weight of flowable sand between the double stacked DU Cylinders	NA	NA	82.6	NA	**9,247**

Soil Cover:	Thickness		Unit Weight	
Liner Protective Cover	1	feet	97.6	pcf

Calculations:

Use Westergaard Theory (Fig. 8.26) to determine loading at level of Clay Liner. Center controls.

	m value	2.00
	n value	6.00
I-sigma value from Fig 8.26		0.193

Bearing Pressure of Component:	**1,208**	**psf**

< CQA 3,000 psf allowable for large components

ENERGYSOLUTIONS

DU Cylinder & DU Drums Bearing Capacity Calculation 13-Jun-14

Find the bearing pressure of a DU cylinder weight in single Stack DU Cylinder Configuration with overlying 55 gallon DU drums to verify its bearing pressure at the top of the clay liner.
Details of DU Cylinder and 55 gallon DU Drums:

Assume DU Cylinder is 12' long x 4' diameter, made of 3/8" thick steel: assume cylinder weight of 4500 lbs.
Assume fourteen (14) 55 gallon DU drums above a 12x4 DU Cylinder, each empty 55 gallon DU drum weighs 50 lbs and contains 7.353 cf of DU waste as shown below. Drum sizes approximated at: 3' L x 2' Dia.
Assuming the the bulk density of U3O8 is 2.7 g/cm3 (Wikipedia 2014) from the Interrogatory:
Waste weight: 2.7 gm/cm3 = 168.534 lb/cf

Assume a cylinder placed in the lower tier supports the weight of fourteen upper tier 55 gallon drums and calculate the bearing capacity using the weight of these 100% filled cylinder and drums. Spaces around the cylinder and around the drums are filled with flowable sand at a density of 112 pcf, which is included in the calculation.

Size of Cylinder:	Length (ft)	Diameter (ft)	Volume (cf)	Area (sf)	Weight (lbs)
Maximum DU Cylinder total weight for one lower 12' x 4' DU cylinder.	12.0	4.0	150.7	48.00	**29,901**
Weight of 14 upper 55 gallon DU Drums bearing on one lower 12' x 4' DU cylinder.	3.0	2.0	7.353	NA	**18,049**
Volume of flowable sand around the single stacked DU Cylinder	NA	NA	41.3	NA	**4,623**
Volume of flowable sand between the DU Drums	NA	NA	37.2	NA	**4,164**

Soil Cover:	Thickness		Unit Weight	
Liner Protective Cover	1	feet	97.6	pcf

Calculations:
Use Westergaard Theory (Fig. 8.26) to determine loading at level of Clay Liner. Center controls.

	m value	2.00
	n value	6.00
I-sigma value from Fig 8.26		0.193

Bearing Pressure of Component: 1,010 psf

< CQA 3,000 psf allowable for large components

ENERGYSOLUTIONS

DU Cylinder's Bearing Capacity Calculation 13-Jun-14

Find the bearing pressure of a DU cylinders weight in Single Stack DU cylinder configuration to verify its bearing pressure at the top of the clay liner.
Details of DU Cylinder:

Assume a DU cylinder is 12' long x 4' diameter, made of 3/8" thick steel: assume cylinder weight of 4500 lbs.
Assuming the the bulk density of U3O8 is 2.7 g/cm3 (Wikipedia 2014) from the Interrogatory:
Waste weight: 2.7 gm/cm3 = 168.534 lb/cf

Assume a cylinder placed in the lower tier and calculate the bearing capacity using the weight of this 100% filled cylinder. Spaces around the cylinder are filled with flowable sand at a density of 112 pcf, which is included in the calculation.

Size of Cylinder:	Length (ft)	Diameter (ft)	Volume (cf)	Area (sf)	Weight (lbs)
Maximum DU Cylinder total waste weight.	12.0	4.0	150.7	48.00	**29,901**
Weight of flowable sand between the single stacked DU Cylinder	NA	NA	41.3	NA	**4,623**

Soil Cover:	Thickness		Unit Weight	
Liner Protective Cover	1	feet	97.6	pcf

Calculations:
Use Westergaard Theory (Fig. 8.26) to determine loading at level of Clay Liner. Center controls.

m value	2.00
n value	6.00
I-sigma value from Fig 8.26	0.193

Bearing Pressure of Component: 653 psf

< CQA 3,000 psf allowable for large components

Federal Cell Bearing Capacity Calculation 13-Jun-14

Find the bearing pressure of the Federal Waste cell in the location of a double stacked DU cylinder configuration to verify its maximum bearing pressure on the bottom in-situ clay (i.e. foundation).

Assume uniform waste weight of 125 pcf and various layers' thicknesses and weights as follows:
DU Waste weight: (Double Stack Bearing Load) 1,208 psf

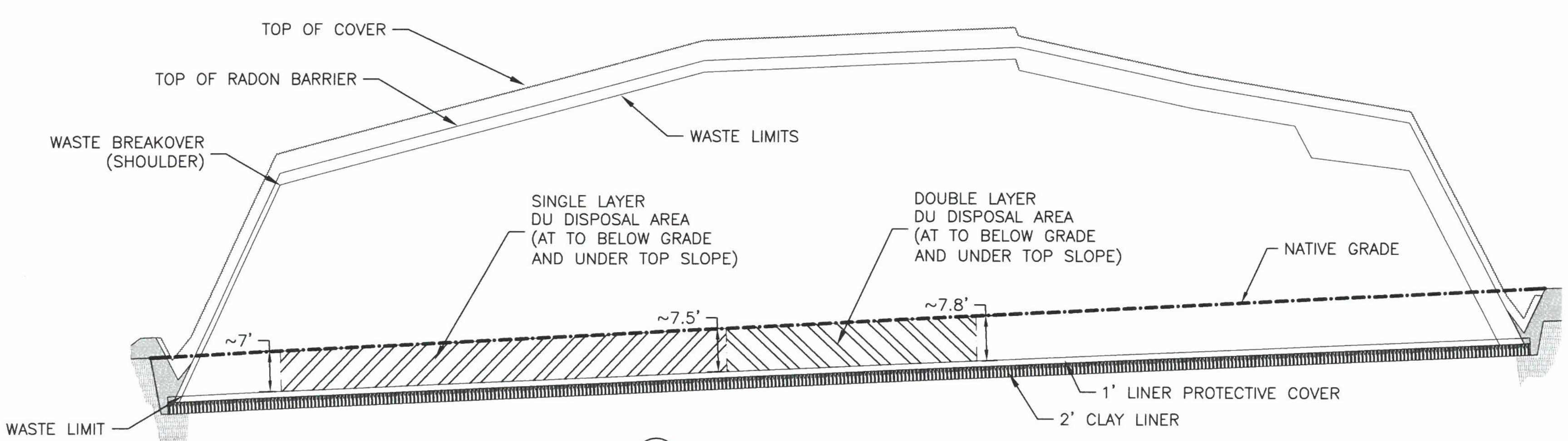
Embankment Layer:		Thickness	x	Unit Weight (pcf)	psf	
Clay Liner		2.0	feet	97.6	195.2	
Liner Protective Cover		1.0		97.6	97.6	
DU Waste (Cylinders)		7.3		165.5	1208.1	
Waste above DU		42.8		125	5350.0	
Radon Barrier		4.0		97.6	390.4	
Filter Rock		1.0		142	142.0	
Rock Cover		1.0		145	145.0	
	Total	59.1	feet		**7,528.3**	**psf**

Assumptions:

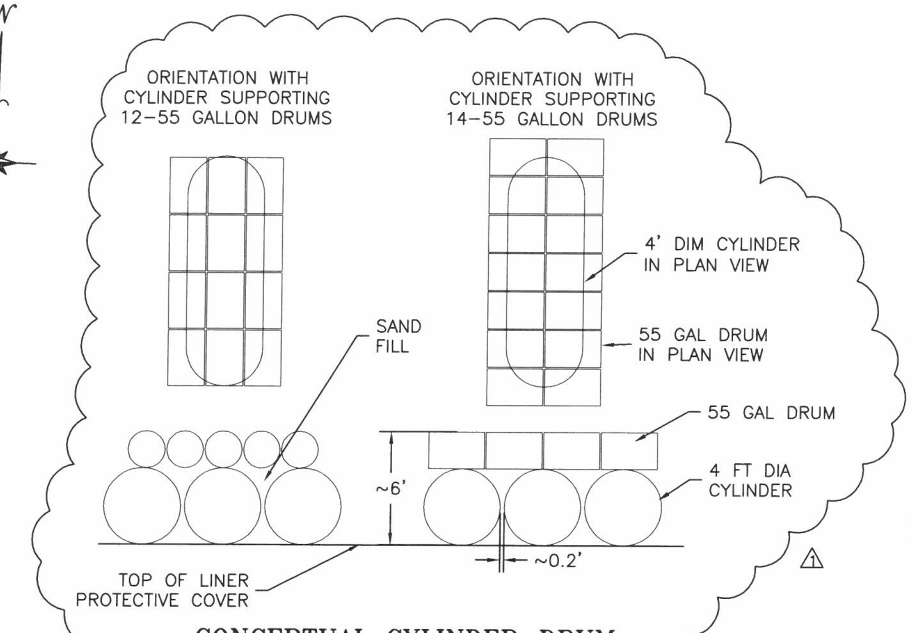
Assume worst case scenario: Drums in double stack orientation at base of Federal Cell over one foot of protective cover over clay liner.

Values used for clay, rock, filter and waste units were taken from the Mixed Waste Design Engineering Report (DER), Dated May 7, 2003. The total value calculated in the DER for the Mixed Waste cell was 7,077.7 psf by comparison with the proposed Federal Cell.

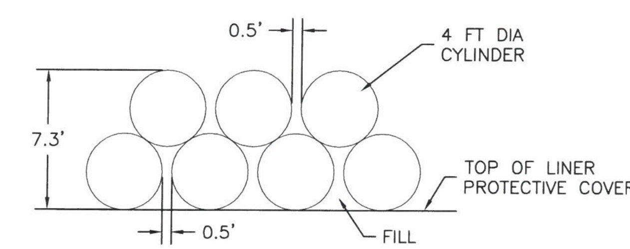
PLAN VIEW



B WEST–EAST CROSS SECTION
HORIZONATAL SCALE:VERTICAL SCALE = 1:10



CONCEPTUAL CYLINDER–DRUM STACK CONFIGURATION
NOT TO SCALE



CONCEPTUAL DOUBLE STACK CONFIGURATION
NOT TO SCALE

NOTES

1. LIMITS FOR SINGLE AND DOUBLE LAYER DISPOSAL ARE CONCEPTUAL ONLY, BASED ON CONSERVATIVE ASSUMPTIONS FOR NATIVE GRADE, CYLINDER SIZES, SPACING, AND STACKING CONFIGURATION.
2. ESTIMATED NUMBER OF CYLINDERS ASSUMES THAT ALL CYLINDERS ARE 12–Mg CYLINDERS (12' LONG X 4' DIA), AND ASSUMES THE FOLLOWING PLACED SPACING.
   SINGLE LAYER: CYLINDERS ARE SPACED 0.2 FT END–TO–END AND SIDE–TO–SIDE, AND DRUMS ARE PLACED ON 4'X4' PALLETS SPACED AT 0.1 FT.
   DOUBLE LAYER: CYLINDERS ARE SPACED 0.2 FT END–TO–END AND 0.5 FT SIDE TO SIDE, BOTH LAYERS.

LICENSED PROFESSIONAL ENGINEER
No. 189500
DAVID F BOOTH
6/13/14
STATE OF UTAH

DATE	BY	DESCRIPTION OF CHANGE
6/13/14	DFB	ADDED CYLINER–DRUM STACK DISPOSAL CONFIGURATION
3/31/14	DFB	PRELIMINARY

ENERGYSOLUTIONS

CLIVE FACILITY
FEDERAL WASTE CELL
CONCEPTUAL DU DISPOSAL PLAN
CLIVE, UTAH

DRAFTED BY: D.BOOTH
REVIEWED BY: G.DUTSON
APPROVED BY: D.BOOTH
SCALE: AS NOTED
DATE: 03/28/14
DRAWING NO. 14004
L1

ENERGYSOLUTIONS

5. GOLDSIM V10.5 VERIFICATION PLAN

VERIFICATION PLAN

GOLDSIM VERSION 10.50 SP1

GoldSim Technology Group LLC

Issaquah, Washington

January 2011

TABLE OF CONTENTS

1. INTRODUCTION

1.1 DOCUMENT PURPOSE

This document, referred to here as a *software verification plan*, is intended to provide all necessary information for verification of the computer program GoldSim. The definition of verification used here is as provided in SANDIA (1995): "The process of demonstrating that a computer software program performs its numerical and logical operations correctly." Software verification should not be confused with validation, which is the demonstration that a computer program is appropriate for use in modeling a physical process.

1.2 BACKGROUND

GoldSim is a computer program developed by GoldSim Technology Group LLC for probabilistically evaluating the performance of complex environmental systems. It is essentially a complex contaminant transport model, consisting of a series of inter-connected, coupled component models with input/output relationships for contaminant transfer. Output from the model includes contaminant release rates, concentrations of contaminants in various environmental media, and time histories of dose or risk to specified human receptors. GoldSim runs only on personal computers having Microsoft Windows 98, NT, 2000 or XP as the operating system.

GoldSim's capabilities are specified in two key documents: the GoldSim User Guide (Kossik and Miller (2008a)) the GoldSim Contaminant Transport User Guide (Kossik and Miller (2008b)), the GoldSim Reliability Module User Guide (2008c), the GoldSim Distributed Processing User Guide (2008d), and the GoldSim Dashboard Authoring Module (2008e). This verification plan is intended primarily to test all GoldSim capabilities which could affect the accuracy of results calculated by GoldSim. Secondarily, it tests to ensure that all important user interface functions operate as intended.

1.3 DOCUMENT ORGANIZATION

This plan describes a series of tests intended to confirm that the GoldSim model performs all quality-affecting operations correctly. Chapter 2 describes the procedures that the Verifier should follow.

The verification tests are divided into major functional groups evaluating the core software, result presentation, Monte Carlo tests, Contaminant Transport and Reliability tests.

This plan incorporates by reference a suite of GoldSim input files, which are required in order to perform the specified tests. These files, which are listed in Appendix I, are controlled by the same quality procedures as the plan itself. The Verifier should be provided with both the plan and the test files.

In addition, there are a number of additional verification tests incorporated by reference into this document. These include tests evaluating the licensing and the Financial Module. These tests should be part of all full verification tests.

2. VERIFICATION PROCEDURE

Verifying GoldSim requires the user to generate results for each test problem, and compare those results with others that are known to be correct. Instructions on generating and viewing results are given in Section 3, and a discussion of the result required for each test problem is included in Sections 3 to 10. This section contains an explanation of how such comparisons are to be done.

The Verifier is expected to perform the verification according to a prescribed quality assurance procedure, which will specify any necessary qualifications or training required, and the form of the verification report to be produced. Typically the verification report is a brief summary confirming that all tests were performed, and identifying any cases where the expected results were not produced plus any other anomalous items.

2.1 INSTALLING GOLDSIM

GoldSim will be provided as a self-extracting install file which automatically installs GoldSim onto the tester's system. It is recommended that the user accept the default installation folder: c:\Program Files\GTG\GoldSim 9.

The GoldSim test files consist of a set of .gsm files which should also be copied to the test folder.

2.2 RUNNING GOLDSIM

GoldSim may be started from the Start/Programs menu.

2.3 OBTAINING VERIFICATION FILES

Verification files should be obtained from SourceSafe, and for major (full number) releases should be updated using the candidate version to verify the proper functioning of the conversion code. This should be done using a batch file that opens, runs and saves the verification files (the batch file is described in the User's Guide). When the files are opened for the verification tests, this process also serves to verify model serialization in the candidate version.

For major releases, the base files should be set aside to be checked into SourceSafe once verification is complete.

2.4 COMPARING RESULTS

The user will need to generate and view numerical and/or graphical results for many of the test problems. These results are then directly compared to the expected results given in Sections 3 and 4. GoldSim results generated for comparison can be viewed using several different methods. Typically, the user will right-click on the icon for the desired output, and GoldSim will then display the results.

In general, the computational verification tests are considered acceptable if the verification result agrees to **three** significant figures with the closed-form or benchmark-code solution. Any exceptions to this standard are described along with the particular test information.

3. BASIC GOLDSIM FUNCTIONAL TESTS

This Chapter tests all core computational functions of the GoldSim program.

3.1 BASIC GOLDSIM ELEMENT FUNCTIONALITY TESTS

The basic functionality tests address parsing, unit conversion, expression evaluation, probability distribution, and all of the basic GoldSim element classes: data, stock, selector, and table. They also test database links for data and stochastic elements. Finally, they test clones and external functions.

Parsing, Unit Conversions and Function Operations

A test file called ParseTest.dat has been developed to automatically test all of the basic parsing and unit conversion capabilities and most of the function operators in GoldSim. First copy file ParseTest.dat (available from the Units_Parse directory in Source Safe) to the root directory from which GoldSim is executed. GoldSim automatically executes this file when the Verifier presses Ctrl-F8. The results are written to an ASCII output file, ParseRes.txt. The Verifier then compares ParseRes.txt to the correct master result file, ParseRes01.txt which is provided along with the verification test problems. (Note that Word can be used to identify any differences between the two files). Any differences between the master and output file should be recorded.

The test file, ParseTest.dat, and the master file, ParseRes01.txt, are presented in Appendix II.

A second automatic test is initiated by pressing Ctrl-Alt-F9. This produces an output file “UnitsEcho.txt” which contains the conversion factors for all of GoldSim’s built-in units. The Verifier should compare this file to the reference file, UnitsEcho0.txt (available from Source Safe in the Units_Parse directory, and also included in Appendix II), and note any differences.

General Simulation

GS0_Run_Controller

This test verifies the correct functioning of the run controller, including the run controller buttons, displays, and error checking.

1. Error States

Enter the container Error_Checks. This container tests error-checking and the Run Controller's Error state. The test proceeds as follows:

a. Identifying invalid model expressions before the simulation:
   i. In the element named Vector, type in the following formula in the equation field: Non_zero (i.e., type the name of the element Non_zero). Accept the warning message by clicking the Yes button.
   ii. Run the model (i.e., click the Run button on the main toolbar).
   iii. Before the Run Controller can appear, a dialog box should appear indicating that Vector has an invalid local expression. Click the OK button.
   iv. Run the model again. This time when the invalid local expression dialog appears, click the Edit button. The properties dialog for Vector should appear. Replace the existing formula by typing Vector_Input in the equation field. You should be able to close the dialog without errors.

b. <u>Error State</u>:
   i. In the element named Divide_By_Zero, type the following formula in the equation field: Non_zero / Zero.
   ii. Run the model (i.e., click the Run button on the main toolbar. When the Run Controller appears, click the Run button on the Run Controller). A runtime dialog should appear, indicating a divide-by-zero error in the first realization.
   iii. Click OK to close the error dialog. The Run Controller now shows a status of Error. Ensure that clicking the run realization and run one timestep asks the user if they would like to restart the simulation.
   iv. While in the Error state, you should be able to browse the model. Try this.
   v. Click the Edit button and the model should return to the Edit Mode.
   vi. Replace the formula in Divide_by_Zero with the value of 0.0.

Return to the main model window.

Ready, Running, and Paused States and Run Controller Options

Enter the container named Model. Tests in this container ensure that: 1) the Run Controller's Ready, Running, and Paused states, and 2) the Run Controller options work correctly.

a. <u>Ready State</u>
   i. Either click the Run button on the toolbar or hit the F5 key to launch the Run Controller. When the Run Controller appears, the GoldSim status bar should indicate "Run Mode" in a red box at the right side. The Run Controller should display a status of Ready.
   ii. Press the Edit button on the Run Controller, or press the F4 button to switch to the Edit Mode. The Run Controller should close and the GoldSim status bar should indicate "Edit Mode".
   iii. Alternately press F5 and F4 several times to activate and deactivate the Run Controller.

iv. With the Run Controller active and in a Ready status (the model is in Run Mode), save and close the GoldSim model file. Re-open the file. The file should be in Edit Mode.
v. From the main GoldSim menu, open the Options Dialog (i.e., Model | Options, General tab).
vi. De-select the “Show Run Controller in Result Mode” box. Close the Model Options dialog.
vii. Run the model (i.e., click the Run button on the main toolbar, then click the Run button on the Run Controller, or simply press F5 twice instead of clicking on the Run buttons). Click OK on the Simulation Complete! dialog. The model should enter Result Mode (as indicated on the right side of the GoldSim status bar) and the Run Controller should close automatically.
viii. Re-enter the Run Controller Options and re-select the “Show Run Controller in Result Mode” box. Close the Model Options dialog.
ix. Run the model again. Click OK on the Simulation Complete! dialog. This time, the Run Controller should stay active when the model enters the Result Mode.
x. Close the Run Controller either by clicking on the Edit button or by pressing F4.
xi. Re-enter the Run Controller Options and select the “Begin Simulation immediately on entering Run Mode” box. Close the Model Options dialog.
xii. Run the model by clicking on the Run button on the GoldSim toolbar. The simulation should commence without clicking the Run button on the Run Controller. Click the Edit button on the Run Controller to return to Edit Mode (i.e., close the Run Controller).
xiii. Re-enter the Run Controller Options and de-select the “Begin Simulation immediately on entering Run Mode” box. Close the Model Options dialog.
xiv. Run the model by first clicking the Run button on the GoldSim toolbar (or pressing F5). This time, it should be necessary to also click the Run button on the Run Controller to start the simulation.

b. Running State

i. If the Run Controller is not already active, click Run on the GoldSim toolbar. When the Run Controller opens (if it is not already open), slide the speed-control slider to the left end (slow). This will allow use of a small model to test the Running state.
ii. Click the Run Controller’s Run button. Make sure that the Run Controller status changes from either Results or Ready (depending on the current state) to Running. The GoldSim status bar should also indicate that the model is in Run Mode.
iii. Make sure that the progress of the simulation is tracked by the timestep and realization progress bars, and by the elapsed and simulation time clocks.
iv. Click the Pause button. The simulation should pause and the Run Controller state should change to Paused. Click the Resume button to restart the simulation.
v. Slide the speed control to the right and ensure that the simulation speed increases accordingly.
vi. Rerun the simulation and click the Abort button during the first realization (it may be necessary to adjust the speed control to do this). Click Discard. The model should immediately switch to Edit mode and no results should be available.
vii. Rerun the simulation and click the Abort button during the first realization (it may be necessary to adjust the speed control to do this). Click Keep. The model should now be in results mode and results should be available until the time the simulation was aborted. The value of the Last_Update_Time Expression element in the final saved realization should equal to the time at which the simulation was aborted.
viii. Rerun the simulation and click the Abort button after the first realization is complete. Choose the Keep option but do not check the “Include results of current

partially completed realization" box. The model should be placed in Result Mode and the run controller should show the model is in Abort mode. Check to ensure results are available only for the realizations prior to the realization during which the simulation was aborted.

ix. Rerun the simulation and click the Abort button after the first realization is complete. Choose the Keep option and check the "Include results of current partially completed realization" box. The model should be placed in Result Mode and the run controller should show the model is in Abort mode. Check to ensure results are available for all realizations up to and including the realization during which simulation was aborted. Also ensure that the value of the Last_Update_Time Expression element in the final saved realization is equal to the time at which the simulation was aborted.

x. Re-run the model, Abort after several realizations are complete, and then choose to discard the results. The model should enter Edit Mode and no results should be available.

c. Paused State

i. Run the model again. Click the Pause button on the Run Controller to pause the model.

ii. Ensure that the Run Controller changes to the Paused state. The GoldSim cursor should now appear in red. The GoldSim status bar should still show Run Mode.

iii. Browse the model as if it were in Result Mode (although it should still be in Run Mode). Look for the following:

a. Tool tips should show the last value calculated (i.e., the value at the end of the last timestep, or a subsequent value if updated since the last timestep). Note that for vectors and matrices, the output port must be opened to view the last calculated value.
b. View time histories for several outputs. The time histories should show values up to the current simulation time.
c. You should be able to navigate the model, but containers should act as if they are sealed (i.e., you should not be allowed to make any changes to the model that would affect how it runs, nor add any Result elements). You also cannot save the model or close the model.
d. Click the Resume button to restart the simulation.
e. Click the Abort button to abort the simulation. You should experience model behavior as described in the previous test section.

Stepping Through a Simulation

b. Simulate one realization - Ensure that this feature works by clicking the R button. After the simulation pauses, repeat some browsing tasks (see "Browse the model…" above). Open the Time_History plot in the Model container. Resume running the model (you may have to move the speed-control slider to the left). Ensure that the time history updates to reflect the current timestep (there may be some lag). Either pause and restart the model, or simply let it run to completion.

c. Simulate one timestep - Ensure that this feature works by clicking the T button. After the simulation pauses, repeat some browsing tasks (see "Browse the model…" above). Open the Time_History plot in the Model container. Resume running the model (you may have to move the speed-control slider to the left). Ensure that the time history updates to reflect the current timestep (there may be some lag). Repeat for several timesteps.

d. Complete the simulation by clicking the Resume button to ensure that the simulation completes normally.

<GS0a_Licensing – Removed and in a separate document "GoldSim_Licensing_Tests". See section 9 for details>

GS00_User_Interface_Tests

This test exercises the GoldSim user interface (e.g., pull-down menu commands and context-sensitive menu commands). In essence, this test allows the verifier to "test drive" the user-interface in both a structured and verifier-prescribed manner in order to verify the major user-interface features and functionality. The test consists of six parts: the first four parts (1. through 4.) exercise the user interface via a pre-existing file (GS00_User_Interface.gsm), while the final part (5.) requires the user to build and run a simple model from scratch.

***** Before performing the test, save the open file (GS00_User_Interface base file.gsm) as a new file (GS00_User_Interface_tested.gsm) to ensure that no changes are made to the base file. Also, make sure the registered version of GoldSim includes CT or RT. *****

1. Structured (basic user interface tests): To execute the test, perform the following operations inside Container1, unless noted otherwise:

   a. Open the Extension Modules dialog by pressing CTRL+M, then check the box under "Active" for Contaminant Transport (or Radionuclide Transport) module and click "OK". The Materials container should appear in the upper-left corner of the main model window, and the Species and Water reference-fluid elements should be inside that container. Next, right-click in the main model window and select "Insert Element". Ensure that a "Contaminant Transport" submenu has been added to the "Insert Element" menu. Next, reopen the Extension Modules dialog again, de-select the Contaminant Transport module, and click "OK". A message should appear indicating that all environmental elements will be deleted from the model (there should be 2 such elements). Click "Yes" to unload the module.

   b. From the File pull-down menu, select Send To. If the computer has an e-mail software program installed, a new e-mail message window should appear with this GoldSim file inserted as an attachment. Either enter an e-mail address and send the message or close the message window to cancel without sending the model.

   c. From the File pull-down menu select Print Preview. Close the Print Preview screen, then go to File|Print and print the model. Ensure that the printed output properly displays the source model.

   d. From the View pull-down menu, activate the model browser. Ensure that the containment and class views function for the browser operate appropriately. Ensure that elements are properly highlighted upon selection and that the graphical pane is correctly synchronized with the browser. Deactivate the browser, and then reactivate the browser. Repeat these tests using the appropriate buttons on the toolbar.

   e. Ensure that the property dialog box for an element is opened when the element is double-clicked in the browser. Turn on the "Show Element Subitems" option (right click in the browser and select the option).

f. Ensure that elements are properly highlighted upon a search and that the graphical pane is correctly synchronized with the browser. Ensure that the search control appears at the top of all browser windows (main browser and function of/affects view)

g. Starting from the main model window, enter Container1, then ContainerA, then ContainerB. Use the "Go to previous container" menu button (i.e., the 'back' arrow) to navigate back out to the main model window. Use the "Go to next container" menu button (i.e., the 'forward' arrow) to navigate back down into ContainerB. Return to the main level of the model by clicking the "Go to the top" button (appears as a folder with a 1 inside).

h. Superceded by GS00a_FilterGraphicsOptions.

i. Using the Graphics pull-down menu, exercise the graphics functions (zoom, align, rotate) by selecting one or more of the items in the graphical pane.

j. From the Run pull-down menu, select "Simulation Settings…" to open the Simulation Settings dialog box. Ensure that changes can be made in each of the input fields. Click the Cancel button to exit without making changes.

k. Return to Container 1 and edit the output attributes for Data1 to have units (e.g., m). Close the dialog, and ensure that when you exit the Data1 element, it has a value and dimensions. Press F9 and ensure that the links that exist between Data1 and Stochastic1 and between Data1 and Event1 disappear. You should get a message indicating that the units don't match (Data1 has units; Stochastic1 is dimensionless). Next, open the properties dialog for Stochastic1 and edit the distribution. (You may receive another message regarding input "mean" having incompatible data types. Press "No".) Cancel out of Stochastic1 (don't change anything). Go back to Data1 and make its output dimensionless again. Exit Data1. Press F9 to update the links. The link between Data1 and Stochastic1 and Data1 and Event1 should re-appear.

l. Select a number of the elements (including some with links to other elements) and then from the context menu, use the "Move To" command to move them into ContainerA. Press F9 to update the links. Ensure that the links update. Move the elements back out to the main model window and ensure that all of the links update.

m. Copy and paste several elements (both single elements and groups of elements) into ContainerA. Delete the pasted elements.

n. Move the cursor over several of the links (influence arrows) in the model. A tooltip window should appear with the number of links represented by the arrow. Double-click on the arrow and ensure that the "Influence Content" dialog appears, indicating the influences and link type for each link. Click the output and input element hyperlinks and ensure that the target element is properly selected, and that the link dialog closes.

o. With the model in Edit Mode (the default for the file), move the cursor over each element in turn (the input and output ports and the element's icon). Ensure that the tooltip window for each element appears and is yellow in color. The current value of each element should be reported, if appropriate. Activate the browser. Move the cursor over elements. Ensure that a yellow tooltip box appears with the name of the element and its value.

p. With the screen scale setting at 100%, move the cursor over the input and output ports for each element. Ensure that the cursor changes from an arrow to a hand when the cursor passes over each port. Left mouse-click on each port and ensure that the input or output dialog boxes appear, respectively. Right-click on each port and ensure that the "Show Links" option appears. Click on any available influences options and ensure that the appropriate influences are displayed. Move the cursor over the expansion point for each container (i.e., the "+" portion of the icon). Ensure that the cursor changes from an arrow to an open book. Click and make sure that the container is opened.

q. Repeat n. for two different model-window scale settings: 67% and 137%.

r. Using the context menu, edit the appearance (font, fill, line, etc.) of several elements.

s. Insert text using the Drawing Tools toolbar.

t. Insert one object from each selection (e.g., line) in the Drawing Tools toolbar.

u. Insert a picture into the document (e.g., bitmap) using the appropriate button on the Drawing Tools toolbar.

v. Insert a hyperlink to a document (using the hyperlink button on the Drawing Tools toolbar) and ensure that the hyperlink works.

w. Insert another hyperlink into the document, but this time link to an element in this model file. For example, for the link, select "Open container" from the drop down list and enter "\Container1\ContainerA" as the address. After creating this link, test the hyperlink to ensure that it works (i.e., double-click the hyperlink and the model window should switch to an internal view of ContainerA. Similar tests can be conducted for elements by selecting "Go to element" from the drop down list and entering the path to an element in the link field.

x. Inside Container1, ensure that the label for Stochastic4 is underlined (and possibly in blue text, depending on GoldSim preference settings) in the main model window, indicating that a note is attached to this element. Point to the label, ensure that the cursor changes to a hand, and then click on the label to activate the note pane. The note should read "Test note for Stochastic4". Next, run the cursor over the icon for Stochastic4 in the main model window. Repeat this test in the main browser. Next, select an element, activate the note pane using the note icon on the standard toolbar, and enter a note for that element. Close the note window and ensure that the label for the element changes to underlined (and in blue) in the main model window.

y. Run the model. An error message should appear indicating that the model cannot be run, and that the problem lies with element External1. Click on the "Edit…" button and ensure that the dialog box for External1 opens. Click "Cancel" to escape without making any changes.

z. Delete the spreadsheet element and external element. Then, in the Model Simulation Settings, set the duration to 0 days, and enter 1000 for the number of realizations. Add Stochastic1 as an input to Result4. Run the model. Open Result4 and view the result distribution for Stochastic1 in chart and table form. Ensure that both look appropriate (e.g., the PDF looks normal with the correct mean value, etc.). Modify the style settings for the chart form and ensure that the changes "stick".

aa. With the model in Results Mode (the default for the file now that the model has been run), move the cursor over each element in turn (the input and output ports and the element's icon). Ensure that the tooltip window for each element appears and is green in color. The current value of each element should be reported, if appropriate. Activate the browser. The names of all elements for which results are available should be shown in bold text. Move the cursor over elements. Ensure that a green tooltip box appears with the name of the element and the value, if appropriate.

bb. Select a group of element icons in the main model window. Then, from the File pull-down menu, select Export Graphic Selection. Assign a file name and location in the file dialog box and click "OK". Open that file and ensure that the file displays an image of the selected items.

cc. Switch to edit mode. Copy Container 1_1 and paste the new container (Container1_1_1) next to Container 1_1. Accept the "copy as localized container" message. Enter Container1_1_1 so that the contents are visible in the Graphical pane. Next, open the browser (e.g., using the browser button on the GoldSim toolbar). From the browser, highlight Container1_1_1 and then delete it. The container should be deleted from the model, the browser should update automatically to reflect the deletion, and the Graphical pane should return to a view of the main model window. Re-enter Container1 and ensure that Container1_1_1 has been deleted.

dd. Insert a new Data element. Try to re-name the element with any of the "protected" function names (e.g., SIN, COS, etc.) and ensure that the names are rejected by GoldSim.

2. Structured (property-dialog-box tests): Inside Container1_1 (which is inside Container1), test the property dialog box for each element type. In general, click on every radio button, check box, and enter something in every field (although not necessarily all at the same time). Ensure that the changes "stick". Additional specific items for each element type include the following:
   a. Data elements (Data3) – click on the "Type" button and make the following changes one at a time, followed by clicking "OK" and closing the "Type" dialog after each change. The tests include the following: Change the type of the Data element to a condition from a value (click "OK" on the "Type" dialog), and then back again. Next, change the order to a vector, then to a matrix, then back to a scalar.

   b. Stochastic elements (Stochastic3) – click on the "Edit Distribution" button. Change the type of the distribution from the drop-down scroll menu. Edit the values for the distribution parameters. Click "OK" to exit this dialog. Re-enter the "Edit Distribution" dialog and ensure that the changes "stick". Repeat several times. Click on the "Importance Sampling" button. Change the option to "high end" or "low end". Change the factor to a number greater than 1 but less than 10. Exit this dialog and then re-enter to make sure that the changes "stick".

   c. Time histories (InfoTimeSeries1 and MaterialTimeSeries1) – Click the "Edit Table" button to access the local table-definition dialog. Add data points, then exit this dialog and re-enter to ensure that the changes "stick" (i.e., correct values, correct number of rows and columns, etc.). Convert the element to vector type and repeat the same tests.

   d. Integrator and Reservoir elements – follow the instructions for the Data element.

e. Expression element - Follow the same instructions as for the Data element.

f. Previous Value element – change the type of the previous value element and ensure that its outputs are updated and that the input field requires the selected type.

g. Extrema element – Add an input and ensure the link is made.

h. Selector elements (Selector3) – Test the type as for the Data elements. Then, click on the "Edit Switches" button to access the switches dialog. Add a switch and edit its fields. Exit the dialog and re-enter to confirm the changes. Click on a switch and then delete it. Ensure that the switch is deleted.

i. Splitter and Allocator – Add new outputs, and change the type from value to discrete change. Ensure that fields are editable when appropriate.

j. Sum element – Add and delete inputs from the main dialog. Ensure that the links are made properly.

k. Table elements (Table11) – Click the "Edit Data" button to access the local table-definition dialog. Test the table in 1D, 2D, and 3D modes by adding rows (1D, 2D, 3D), columns (2D, 3D), and layers (3D). Add entries into those new rows and columns, then exit this dialog and re-enter to ensure that the changes "stick" (i.e., correct values, correct number of rows and columns, etc.).

l. Convolution element – Check that settings stick and ensure that the lag local property is available in input fields.

m. History Generator – Ensure all settings stick and that the correlation features matrix is enabled when the Type is changed to Vector.

n. And, Or and Not Elements – follow the instructions for the Sum element.

o. File element – no special instructions.

p. Event and Delay type elements – no special instructions except for the "type" of consequence. For this, follow the instructions for the Data element. Ignore triggering.

q. Result elements – add inputs or outputs (as appropriate) and delete them. Ensure that all options for selecting realizations function.

3. Structured (units, dimensions, and links): Enter Container2 and look at the elements contained within. Then enter Container3. Following the instructions below, duplicate in Container3 the elements and links contained in Container2. The intent is to test the elements for proper functioning of units, dimensions, and links through the process of inserting new elements and creating new links. The steps are as follows:

a) Insert two of each of the following elements. Leave the first element of each type dimensionless, but assign display units of meters (m) to the second of each type. The values that should be assigned to each element of each type are discussed below:

i) Data - assign a value of 1 and 1 m, respectively, to the two elements.

ii) Stochastic - accept the default input distribution, which is uniform between 0 and 1 and 0 m and 1m, respectively.

iii) Lookup Tables

(a) Create two 1-D tables – one dimensionless and one with a Result Dimension of m. Enter a Row unit of m for the independent variable in the table with a Result Dimension of m . Enter a value of 1 and 1, respectively, for the independent and dependent variable in both tables. The two tables will therefore have only one row and one output value.

(b) Create two 2-D tables – one dimensionless and one with a Result Dimension of m. Enter a Row and Column unit of m for the independent variable in the table with a Result Dimension of m . Define the table locally, and input the values shown in Table GS00-1

Table GS00-1

	0	**1**
0	0	2
1	1	3

(c) Create two 3-D tables – one dimensionless and one with a Result Dimension of m. Enter a Row, Column and Layer unit of m for the independent variable in the table with a Result Dimension of m . Define two layers – 0 and 1. Enter values of 0 and 1, for the row and column variables. Input 0s in all of the dependent variable fields in layer 0. On layer 1, input the dependent variable values in Table GS00-1. The table will therefore have two rows, two columns, two layers, and eight dependent variable values.

iv) Expression – Expression4 should be dimensionless and given a value of 1. Expression5 should have display units of m and a value of 1m.

v) Selector – Define a switch that has a value of 1 (1m for the dimensional Selector) if the dimensionless (dimensional) Data element has a value of 1 (1m). Otherwise, a value of 0 will be implemented by the ‘Else’ case of the Selector.

vi) Integrator – Assign an initial value of 1 (1m for the dimensional Integrator).

vii) Reservoir – Assign an initial value of 1 (1m for the dimensional Reservoir).

viii) Extrema – Assign a value of 1 (1m for the dimensional Extrema)

b) Now, save the model if you have not already done so.

c) Add an expression element and leave its display units as dimensionless. In the equation box, create the sum of all the main outputs for the dimensionless elements created in a) above (e.g., Data + Stochastic + … + Extrema). For the lookup table elements, use the dimensionless Data element for the independent variable(s). Save the model.

d) Repeat c) for the dimensional elements (i.e., units of m). Save the model.

e) In the model simulation settings dialog box, set the model duration to 1 day, use 1 timestep, and one realization. Run the model. Ensure that the output values, units, and dimensions for all of the elements created in a), c), and d) above are correct. In particular, ensure that the expressions that add the other elements have the correct value (i.e., the sum of all the component elements should be between 13 and 14 (13m and 14m), depending on the value realized for the stochastic elements and on the values entered in the table elements).

f) Save the model, close the file, re-open the file, re-run the model and check results again. Ensure that all the answers are still correct.

g) Return to edit mode and create three data elements inside Container 3 (call them A, B, and C). Set C’s definition to equal ‘A+B’. Close the dialog for C. Open the dialog box for C and edit C's definition so that it no longer references A or B. Ensure that while the definition is being edited that the links to A and B do not disappear until a valid definition is entered. Move the cursor out of the input field and ensure that the links to A and B disappear.

4. Structured (sealing and locking containers): Activate the property dialog for the container Container4 . Click on the "Protection" checkbox. The tester's computer or login username should appear in the Author box.

   a) Click on the "Seal" option and press OK. The dialog should close. Look for Container4 in the browser. Its name should be grayed out, as should the names of all elements within Container4. Pass the cursor over Container4 in the main browser and in the main model window. The tooltip window for the container should state that the container is localized and sealed.

   b) Next, re-open the properties dialog for Container4. When you click on the Protection option, the dialog box will display text indicating that the container was "Sealed by: …" the login user, and the date and time that the seal was created. Next, click on the "Protection" checkbox. When prompted as to whether you wish to remove the seal, press the "Yes" button. You should be returned to the property dialog box. The seal information should no longer be visible.

   c) Re-seal Container4 as described in a) above.

      i) Next, enter Container4 and attempt to edit the name and an input value for several of the elements. Each time, a message box should appear stating that the container is sealed and asking if you want to continue and break the seal. Click "No" to cancel the action.

      ii) Try to insert a new element into Container4. The same message should appear. Click "No" to cancel the action and retain the seal.

      iii) Exit Container4. Try to move the element Data4 into Container4. The same message should appear. Again, click "No" to cancel the action.

      iv) Select the output port for Data4, then double-click on the output "Data4" to activate the link cursor. Next, enter Container4 and attempt to link with the input of one of the Expression elements. The same message should appear, and again click "No" to cancel the action.

      v) Exit Container4 . Insert a new Data element. Enter Container4 , select the output port for one of the elements, then double-click to select an output for that element and activate the link cursor. Exit Container4 and try to link with the input of the new element. This operation should be allowed.

      vi) Inside Container4 , try to move elements within the model window, changing the appearance of text and labels, etc. These cosmetic changes should be allowed without a message warning appearing.

   d) Repeat c) i) above for one element, except this time click "Yes" to break the seal. Then make the change to the element, close the element properties dialog box, and then reactivate the properties dialog for Container4. The sealing information should now document when the seal was broken, and by whom.

e) Re-seal the container as described in a) above. Then reactivate the properties dialog for Container4 and ensure that the sealing information includes when the container was sealed and by whom.

f) Remove the seal. Click the “Protection “ checkbox again, and select the “Lock Container” option. Enter a password in the appropriate fields (if desired, but this is not required), then click “OK”. The dialog should disappear. Pass the cursor over Container4 in the main browser and in the main model window. The tooltip window for Container4 should state that the container is localized and locked. The name for Container4 and all of its elements should be grayed out in the main browser.

g) Enter the locked Container4. The edit and drawing menus should be grayed out, and no changes of any kind should be allowed within the container or to any elements within the container. However, the properties dialog boxes should still be accessible (but unalterable), as should be the properties of the links among elements.

h) Activate the link cursor by selecting the output for Data1 inside the locked Container4. Exit Container4. Enter a link to Data1 as the input to Data4. Ensure that a link arrow appears between the output of Container4 and Data4.

5. New Model Wizard: Close GS00_User_Interface.gsm by opening a new file. The New Model Wizard should appear (if it does not, go into the Model/Options dialog and make sure the “Display New Model Wizard when opening a new file” checkbox is selected).

   a) Fill in the Author Name and Analysis Description. Select “Elapsed time” in the duration pick list. On the next screen, select 100 for the duration, Year for the display unit, and 200 for the number of timesteps and click Next. On the next screen, select “Use Monte Carlo” and enter 200 for the number of realizations. Click Finish. Open the Simulation Settings dialog and make sure the settings you selected have been placed in the appropriate fields. In particular, make sure the “Duration” radio button is selected and the duration and time units are correct.

   b) Create another new model and fill in the author and description. Select Calendar Date/Time in the duration pick list. Change the Start Date, Start Time, End Date, End Time, and Number of Timesteps. Click Next. Leave the defaults on the next screen, and click Finish. Open the Simulation Settings dialog and make sure the settings you selected have been placed in the appropriate fields. In particular, make sure the “Date-Time” radio button is selected and proper start and end date and times are entered.

   c) Create another new model and fill in the author and description. Select “Zero Duration” in the duration pick list. Select Use Monte Carlo and change the number of realizations. Open the Simulation Settings dialog and make sure the settings you selected have been placed in the appropriate fields. In particular, make sure the duration is set to 0 days.

GS00a_FilterGraphicsOptions

This test verifies the proper functioning of custom influences and graphics options in GoldSim.

To run the test, the verifier should open the file called GS00a_FilterGraphicsOptions.gsm and run through the following tests (it is not necessary to run the model):

1. Ensure that all link types have the color and weight specified in the Graphics tab of the model root container's property dialog.

2. Resize and change the color of the graphics pane and ensure these changes are reflected in the model root. Continue by changing the influence shape, color, weight, and filtering options for the different link types.

3. Enter the TopLevel1 and TopLevel2 containers and ensure none of these changes have been propagated to the lower level containers.

4. Customize a number of influences and then see that they are reset when the Reset customized influences option is checked in the Graphics tab.

5. Apply the changes to the TopLevel1 container. See that the appropriate changes are made in the TopLevel1 container, and that no changes are made to the TopLevel2 subcontainer.

6. Apply the changes to the model and select the "Nested" option. Ensure that all links in the model have been changed to reflect the graphical changes.

GS00b_Password

This test verifies the proper functioning of password protection for models. The test file is a simple GoldSim file protected by a password (the password is *GoldSim!*).

The verifier should follow these steps to ensure that the protection functions correctly.

1. Open the model file by double clicking on it in Windows Explorer – you should be prompted to enter a password. Enter an incorrect password. GoldSim should prevent you from opening the model and create a new model instead. Close GoldSim.

2. Reopen the model file by double clicking on it in Windows Explorer – you should be prompted to enter a password. Enter the correct password. The model should open successfully.

3. Create a new model file using CTRL+N, then try to open the test model file. Enter an incorrect password. GoldSim should not open the model.

4. Try to open the model file again, but enter the correct password. The model should open successfully.

5. Set up a single DP slave on the local machine and run the model file. It should run successfully and it should not be necessary to enter a password.

6. Save a Player version of the file. Attempt to open it in the GoldSim Player. You should be prompted for a password. Enter an incorrect password. The Player file should not open and you should be returned to the Player splash screen. Reopen the Player file and specify the correct password. The Player file should open correctly.

7. Create a new model file, then attempt to import the test file as a SubModel. You should be required to enter the password. Enter an incorrect password. The import should fail and a new blank SubModel should be created.

8. Create a second Submodel and attempt to import the test file. Enter the correct password and ensure that the model is correctly imported as a SubModel.

9. Place a copy of the test file in the installation directory of the candidate build. Run the model file from the command line using goldsim –r . Ensure you are prompted for a password. Enter an incorrect password – the file should not be opened or run. Close GoldSim and start a new run from the command line. Enter the correct password and ensure that the file is run correctly.

10. Open the test file and remove protection by entering the current password and then specifying a blank password. Save the model file as GS00b_Unlocked.gsm. Create a new model file using CTRL+N, then reopen GS00b_Unlocked.gsm. It should not be necessary to provide a password.

GS01_Spreadsheet: Spreadsheet Elements

This file verifies that the Spreadsheet Element correctly uploads and retrieves values from specified cells in an Excel spreadsheet, and that the visual selection of cells in Excel works properly. It also verifies that offsets and shifts work correctly, and that the spreadsheet correctly handles error conditions.

The verifier should note that these instructions describe the procedures for running these tests using ,xls files saved in Excel 2003. These tests should be repeated a second time with Excel 2007 using the _2007 version of the test file and copies of the test spreadsheets saved in Excel 2007’s .xlsx format.

1. The first test of the spreadsheet can be found in the container called “Link_Tests.” The GoldSim file defines two scalar inputs (Data Elements A and B), one 3 x 1 vector input (Data Element C), and one 3 x 2 matrix input (Data Element D). These elements are linked as inputs to cells in the EXCEL spreadsheet GS01.xls via a Spreadsheet Element (SS_01). Each spreadsheet takes the input values in its cells in Sheet1, applies simple formulas to the values, and records the results in Sheet2. GoldSim then retrieves the results of the EXCEL calculations by defining two scalar outputs (Data Elements D10 and AB), one 3 x 1 vector output (Data Element AC), and one 3 x 2 matrix input (Data Element CD) to be equal to the values in the cells in Sheet2 of GS01.xls.

To run the test, the verifier must first construct the links in the spreadsheet element. The first input and output link should be created using the Wizard. The steps are as follows:

a) Open the SS_01 element and ensure that GS01.xls is specified as the linked spreadsheet.
b) Open GS01.xls and ensure that the input fields on Sheet1 are blank.
c) Construct links to and from the spreadsheet according to Table GS01_1 and GS01_2. Try creating these links with and without the Spreadsheet Wizard.

Data Exported to Excel:

Table GS01_1

Input Name	Output Element	Destination Cell
A	A	Sheet1!C6
B	B	Sheet1!C7

C	C	Sheet1!C9:C11
D	D	Sheet1!C15:D17

Data Imported from Excel:

Table GS01_2

Output Name	**Output Type**	**Linked Cell**
Output1	Scalar	Sheet2!C6
Output2	Scalar	Sheet2!C7
Output3	Vector (3X1) [Rows3]	Sheet2!C9:C11
Output4	Matrix (3X2) [Rows3,Col89]	Sheet2!C15:D17

d) Press <F9> to parse the model. Links should appear between SS01 and Constant10, AB, AC, and Dplus10. If they do not, ensure that Constant10, Output2, Output3 and Output4 are defined as indicated in Table GS01_3**.**

Table GS01_3

Data Element	**Definition**
Constant10	SS01.Output1
AB	SS01.Output2
AC	SS01.Output3 (Each item in the vector must be linked individually)
Dplus10	SS01.Output4 (Each item in the vector must be linked individually)

The results should be confirmed in two ways (expected results are shown in the ToolTip window for the output Data Elements and in Table GS01_4).

First check the outputs after clicking the Update Spreadsheet option in the Options button menu.

Table GS01_4

Element Being Tested (Check output in both containers)	Expected Output
SS 01.Output1	Constant10 = 10
SS 01.Output2	AB = 14
SS 01.Output3	AC = { 21 28 35 }
SS 01.Output4	Dplus10 = $\begin{bmatrix} 16 & 19 \\ 17 & 20 \\ 18 & 21 \end{bmatrix}$

Then confirm the results by running the model and viewing the outputs in Result mode.

2. This part of the test is used to check the correct functioning of cloning in the Spreadsheet element.

a) The verifier should clone the Original_Spreadsheet element and enter the cloned element. Ensure the properties for both elements are identical.

b) Open the cloned element and create a new Input to export Vector3 to the spreadsheet. Place vector three in the indicated location in the linked spreadsheet. Close the element and check that the input is added to the original element.

c) Add a new Output to the original element that brings in the 2 column matrix called "Vector3 added to both columns of the 2 column matrix" in the spreadsheet. This output should be a matrix of Days and Set1_2. Close the element and ensure this output is added to the clone.

d) Run the model and ensure that the outputs are as follows:

Original_Spreadsheet - Matrix_Vector1_and_2

45	78
21	22
78	2
412	78
88	67
12	91
5	82

Original Spreadsheet - Vector3 added to both columns

46	79
31	32
143	67
450	116
106	85
27	106
61	138

e. Change the linked spreadsheet to GS01_Clone_2.xls. Ensure that the outputs of both the original and cloned elements are as follows:

Changed Spreadsheet - Matrix_Vector1_and_2

78	45
22	21
2	78
78	412
67	88
91	12
82	5

Changed Spreadsheet - Vector3 added to both columns

79	46
32	31
67	143
116	450
85	106
106	27
138	61

In the clone, remove the Matrix_Vector1_and_2 output. Ensure this change is reflected in the original element.

3. Enter the container entitled Data_Types. The spreadsheet element GS01_2 in this container tests GoldSim's ability to correctly read certain Excel cell formats. The verifier should create the outputs listed in Table GS01_5. If there are already links for GS01_2, delete all existing links first.

Data Imported from Excel:

Table GS01_5

Output Name	**Output Type**	**Linked Cell**
Number	Scalar	Sheet1!C4
Text	Scalar	Sheet1!C5
Blank	Scalar	Sheet1!C6
Currency	Scalar	Sheet1!C7
Percentage	Scalar	Sheet1!C8
Date	Scalar	Sheet1!C9
Date_days	Scalar (units of days)	Sheet1!C9
Date_datetime	Scalar (units of datetime)	Sheet1!C9
Boolean_True	Scalar (dimensionless)	Sheet1!C10
Boolean_False	Scalar (dimensionless)	Sheet1!C11

After creating the outputs, the verifier should run through the following steps:

a) Run the model - GoldSim should generate a fatal error due to the text in the second input.
b) Delete the text input and re-run the model. Another fatal error should occur when the blank cell is read in.
c) The blank output should be deleted and the model re-run.
d) Re-run the model - another fatal error should occur when the date input is read in to a dimensionless output. Delete the Date output and rerun the model. The tester should ensure that the valid links generate the expected values noted in the spreadsheet element's tool-tip and in Table GS01_6.

Table GS01_ 6

Output Name	Expected Output
Numbers	2
Currency	5.5
Percentage	0.72
Date (in days)	38018 days
Date (in datetime)	2/1/2004

Boolean_True	1
Boolean_False	0

4. The verifier should enter the Offsets container and proceed through the following steps to test the Offset functionality of the Spreadsheet element:
   a) Ensure that the value of Output of the Offset_SS element equals the output of the Offset_Stochastic element.
   b) Specify a spreadsheet input called "Test" that exports the Offset_Stochastic value with a target cell of Sheet1!A1, and a row, column and sheet offset of -2,-2, and -2. Run the model and ensure that GoldSim generates a fatal error, as the offset targets a cell outside of the worksheet.
   c) For testing Excel 2003 and the corresponding file, modify the "Test" input offset, specifying a row offset of 70000 a column offset of 300, and a sheet offset of 0. Run the model and ensure that GoldSim generates a fatal error, as the offset targets a cell outside of the worksheet. For testing Excel 2007 and the corresponding file, modify the "Test input offset, specifying a row offset of 1,200,000 a column offset of 20,000.
   d) Modify the input with a row, column and sheet offset of 0, 0, and 4. Run the model and verify that GoldSim has added two new sheets to the spreadsheet, and that the Offset_Stochastic value has been properly placed in cell A1 of Sheet5.

5. This portion of the test verifies the proper functioning of the Shift functionality in the Spreadsheet element. The verifier should enter the Range_Shift container and then proceed through the following steps:
   a) Open the spreadsheet element called Shift_Tests.
   b) Select the "TopLeftCorner" input and attempt to use the Shift function to shift the target cell up and to the left. In both cases, an error message should be displayed, stating that the edge of the spreadsheet has been reached.
   c) Select the BottomRightCorner output and attempt to shift it down and to the right. In both cases, an error message should be displayed, stating that the edge of the spreadsheet has been reached.
   d) Select ShiftCells1 and ShiftCells2, and shift them in the following order – right, up, left, down. It should be confirmed that each shift changes the "Location in Spreadsheet" value, and that the "Location in Spreadsheet" value at the end of the test is Sheet1!C5 for ShiftCells1, and Sheet1!E7 for Shift Cells2.
   e) Leave ShiftCells1 and ShiftCells2 selected. Click the Change Sheet button and select Sheet2. Ensure the sheet reference for ShiftCells1 and ShiftCells2 both change to Sheet2 and that TopLeftCorner and BottomRightCorner still refer to Sheet1. Run the model - an error should be generated. Change the sheet reference for ShiftCells1 and ShiftCells2 back to Sheet1 and run the model. No errors should be generated.

6. The final test involves verifying the proper functioning of the Create and Select option in the spreadsheet element. For this test, create a new dynamic GoldSim model, and call it GS01_Spreadsheet_Calc.
   a) Create a new spreadsheet element in the root level of the model. Select the Create and Select option, and save a new spreadsheet file (GS01_Created.xls). Open the file (using the Open option) and set it up to accept an argument into cell A1, and then set B1 equal to 2*A1. Save the spreadsheet file, export ETime to cell A1 and import the value of cell B1 to GoldSim. Run the model and ensure that the output is equal to 2*ETime throughout the simulation.

GS01b_Spreadsheet_Update: Spreadsheet Update Tests

Spreadsheets can operate in one of three modes: import only, export only or recalculated during the simulation. This test verifies that GoldSim accesses the spreadsheet exactly at the times specified in the manual.

The verifier should note that these instructions describe the procedures for running these tests using ,xls files saved in Excel 2003. These tests should be repeated a second time with Excel 2007 using the _2007 version of the test file and copies of the test spreadsheets saved in Excel 2007's .xlsx format.

1. Import Only – When a GoldSim spreadsheet element only imports data, the values of the spreadsheet element's outputs are only updated when the output's offset changes. To run this portion of the test, open GS1b_Import.gsm and run it. The model imports two values – Output1 has a row offset equal to ETime|s|, so it is imported each timestep. while Output2 has no offset, and is only imported at the start of the simulation. The graph of the Result Time History element should look like Fig. GS01b-1:

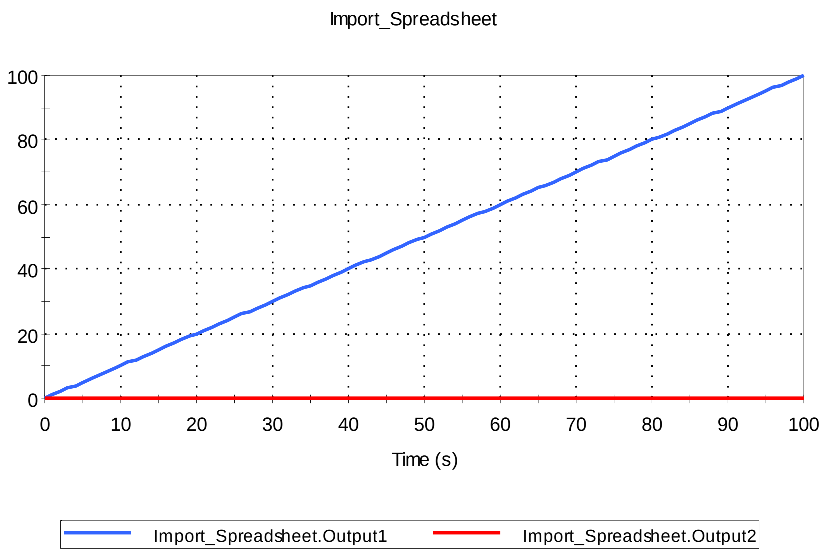


Fig. GS01b-1

2. Export Only – When a GoldSim spreadsheet element only exports data, the value of the spreadsheet element's outputs are only updated at the end of the simulation or when an offset changes. The model exports two values – Output1 has a row offset equal to ETime|s|, so it is exported each timestep. while Output2 has no offset, and is only exported at the end of the simulation. To run this portion of the test, open GS1b_Export.xls and delete any data inside. Save and close the spreadsheet and then run the model file. Reopen the spreadsheet – column A should contain integer numbers from 0 to 100, while cell B1 should contain a value of 100.

3. Export and Import – When a Spreadsheet element exports and imports data, the result depends on whether a) the spreadsheet is recalculated or b) whether offsets are used. This portion of the test checks all four possible combinations of those settings. To conduct the

test, open GS1b_Export_Import.gsm and run it. Ensure the following results (also repeated in Fig GS01b-2):

- No_Recalc_No_Offsets: constant 0 (unless an offset changes Excel ignores the Recalculate setting).
- Recalc_No_Offsets: Value returned from the spreadsheet should be 10*ETime. (Imported cell is equal to 10*Exported Cell)
- No_Recalc_Offsets: Should be a constant 25 except at time 50, where it is 0..
- Recalc_Offsets: Value returned from the spreadsheet should be 5*ETime. (Imported cell is equal to 5*Exported Cell)

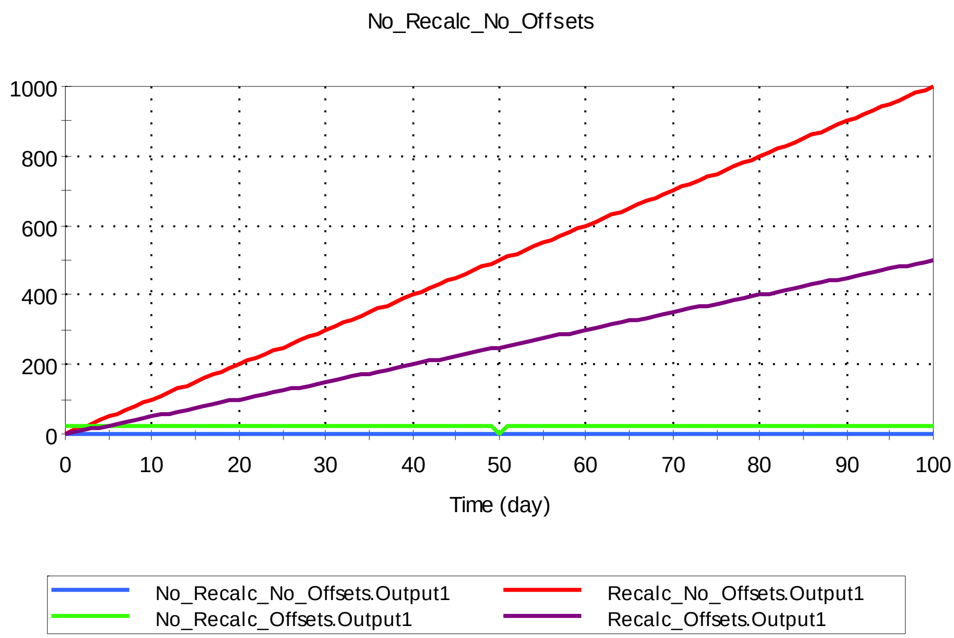


Fig. GS01b-2

GS01c_Large_Spreadsheet: Large Spreadsheet Tests

This test checks that GoldSim can successfully deal with large spreadsheets being accessed by multiple elements on multiple sheets.

The verifier should note that these instructions describe the procedures for running these tests using ,xls files saved in Excel 2003. These tests should be repeated a second time with Excel 2007 using the _2007 version of the test file and copies of the test spreadsheets saved in Excel 2007's .xlsx format.

To run the test, close any open instances of Excel and run the model. The model should run without errors, and after the simulation is complete the verifier should ensure that there are no instances of Excel showing in the processes tab of the Task Manager. The verifier should then check that the spreadsheet outputs are as follows:

- Spreadsheet1: Output should be 5*ETime for the duration of the simulation.
- Spreadsheet2: Output should be 25*ETime for the duration of the simulation.
- Spreadsheet3: Output should be 50*ETime for the duration of the simulation.
- Spreadsheet4: Output should be 100*ETime for the duration of the simulation.

GS02_Expressions: Expressions and Data

Expressions with data links are verified by creating a model with an element for each expression to be tested and comparing model results with known results. The expected results for each static output are presented in the tool tip window for each element for easy comparison with the current value output. Where applicable, tests are conducted to ensure that appropriate functions also support term-by-term operations on array input arguments. The functions checked in this section include:

<u>Trigonometry functions</u>

- sine function **sin**(x)
- cosine function **cos**(x)
- tangent function **tan**(x)
- cotangent function **cot**(x)
- arcsine function **asin**(x)
- arccosine function **acos**(x)
- arctangent function **atan**(x)
- hyperbolic sine function **sinh**(x)
- hyperbolic cosine function **cosh**(x)
- hyperbolic tangent function **tanh**(x)

<u>Math functions</u>

- addition
- subtraction
- multiplication
- division
- square root function **sqrt**(x),
- power function x**y
- absolute value function **abs**(x)
- logrithmic function (base 10) **log**(x)

- natural logrithmic function (base “e”) **ln**(x)
- minimum value function **min**(x,y)
- maximum value function **max**(x,y)
- modulus function **mod**(x)
- exponent function **exp**(x)
- truncate number function **trunc**(x)
- round number function **round**(x)
- vector of minima from a matrix
- vector of maxima from a matrix
- row in which minimum value occurs in a vector, rowmin(vector)
- row in which maximum value occurs in a vector, rowmax(vector)
- search for a value within a vector output, return its fractional index.
- interpolate for a value within a vector output given its fractional index.

Special Functions

- error function **erf**(x),
- Bessel function **bess**(x,v),
- Beta function **beta**(x,y),
- if function **if**(x,y,z)
- if function **if**(x then y else z)

Probability Functions

- Standard Normal Probability function **normprob**(U), where U = (x-mean)/stddev
- Inverse Standard Normal Distribution function **normsds**(prob)
- Student’s t-distribution function **tdist**(prob, dof), where dof is the degrees of freedom
- Cumulative t-distribution probability function **tprob**(tdist, dof)
- Gamma function **gamma**(k), where k = positive scalar

Financial Functions

- present value function **ftop**(x,y)
- future value function **ptof**(x,y)
- present value of annuity **atop**(x,y)
- future value of annuity **atof**(x,y)
- annuity amount of p **ptoa**(p,x)
- periodically compounded to continuously compounded interest rate **pc2cc**(x,y)

- continuously compounded to periodically compounded interest rate **cc2pc**(x,y)
- geometric mean to continuous mean **gm2cm**(x)
- continuous mean to geometric mean **cm2gm**(x)
- arithmetic mean to continuous mean **ari2cm**(x)
- arithmetic mean/SD to volatility **ari2vol**(x,y)
- geometic mean/SD to volatility **geo2vol**(x,y)

Special Operators

- equality operator “==“
- inequality operator “<>“
- greater than operator “>”
- less than operator “<”
- greater than or equal to operator “>=”
- less than or equal to operator “<=”
- and operator “&&”
- or operator “||”
- not operator “!”
- complex dimension change operation **sin**(x|s|{deg}), where x is in seconds

Get Functions

- GetItem(vector,row)
- GetRowCount(Vector)
- GetItem(Matrix, Row, Column)
- GetRowCount(Matrix)
- GetColCount(Matrix)
- GetRow(Matrix, Row)
- GetColumn(Matrix, Column)

Array Indexing Functions

- Retreiving items from vectors and matrices with named and indexed array label sets
- Retreiving vectors from matrices using the * wilcard
- Dynamically retrieving items from vectors and matrices

The verification results are presented in Tables GS2_1 to Table GS2_3. It is not necessary for the user to enter any data but the model must be run to see certain results. The user compares model current values against results presented in the tables to verify the expressions and functions.

TABLE GS2_1

Containers	Test Element	Expected Result
Trig_Functions		
	SIN_function	0.84147
	COS_function	0.54030
	TAN_function	1.5574
	ASIN_function	48.590 deg
	ACOS_function	41.410 deg
	ATAN_function	36.870 deg
	SINH_function	0.52110
	COSH_function	1.1276
	TANH_function	0.46212
	COT_function	0.64209
Math_Functions		
	ADD_function	5
	SUBTRACT_function	3
	MULTIPLY_function	10
	DIVIDE_function	2.5
	SQRT_function	2
	POWER_function	25
	ABS_function	2
	LOG_function	2.3464
	LN_function	-0.69315
	MIN_function	1
	MAX_function	5
	MOD_function	2
	EXP_function	2.7183
	TRUNC_function	1
	ROUND_function	1
Vector	Vector_of_mins	{ 0 1 –2 1 }
Vector	Vector_of_maxes	{ 4 3 2 3 }
Vector	Rowmin1	1
Vector	Rowmax1	4
Special_Functions		
	BESS_function	2.5154e-007
	BETA_function	0.50000
	ERF_function	0.842701
	IF_function	1
	IF_function2	1
	IF_Invalid_Not_Used	0 at t = 0 50 at t = 0.02 No errors should be generated due to this expression.
Financial_Functions		
	FTOP_function	$61.39
	PTOF_function	$162.89
	ATOP_function	$772.17
	ATOF_function	$1257.79

TABLE GS2_1

Containers	Test Element	Expected Result
	PTOA_function	$12.950
	PC2CC	0.0988
	CC2PC	0.1013
	GM2CM	0.0953
	CM2GM	0.1052
	ARI2CM	0.04472
	ARI2VOL	1.2686
	GEO2VOL	0.9699
Special_Operators		
	Equality_operator	0
	Inequality_operator	1
	Greater_operator	0
	Less_operator	1
	Greater_Equal_operator	0
	Less_Equal_operator	1
	And_operator	0
	Or_operator	1
	Not_operator	0
	Complex_dimension_change	0.86602
Probability_ Functions		
	StdNormCDF_1	0.02275
	StdNormCDF_2	0.97725
	InvStdNormCDF_1	2
	InvStdNormCDF_2	-2
	t_Distr_1	0.765
	t_Distr_2	1.708
	CumProb_t_Distr_1	0.75
	CumProb_t_Distr_2	0.95
	GammaFunction_1	2
	GammaFunction_2	362880

TABLE GS2_2 – Array Argument Tests

Containers	Test Element	Expected Result
Trigonometry_Tests		
	SIN_function	0, 0.7071 0.7071, 1
	COS_function	1, 0.7071 0.7071, 0
	TAN_function	0, 1 1, approaching infinity
	ASIN_function	0 deg, 45 deg 45 deg, 90 deg
	ACOS_function	0 deg, 45 deg 45 deg, 90 deg
	ATAN_function	0 deg, 45 deg

TABLE GS2_1

Containers	Test Element	Expected Result
		45 deg, 90 deg
	SINH_function	0, 0.8687 0.8687, 2.3013
	COSH_function	1, 1.3246 1.3246, 2.5092
	TANH_function	0, 0.6558 0.6558, 0.917152
	COT_function	0.642093, 1.83049 -0.642093, -1.33865
Math_Tests		
	SQRTX	2 m, 4 m 3 m, 5 m
	ABS_U	1, 0.5 1, 2.5
	ABS_X	4 m2, 16 m2 9 m2, 25 m2
	LOG_U1	0, -0.3010 0, 0.3979
	LN_U1	0, -0.6931 0, 0.9163
	MIN_U_U1	1, 0.5 -1, 2.5
	MAX_U_U1	1, 0.5 1, 2.5
	MOD_X_X	0 m2, 0 m2 0 m2, 0 m2
	EXP_U	2.7183, 1.6487 0.3679, 12.1825
	TRUNC_U	1, 0 -1, 2
	ROUND_U	1, 1 -1, 3
Special_Functions_1		
	BESS_function	0.440051, 0.352834 0.309063, 0.281129
	BETA_function	1, 0.16666 0.03333, 0.00714286
	ERF_function	0.842701, 1 1, 1
	IF_function	1,2,3,4
	IF_function2	1,2,3,4
	ScalarOr	True, False
	ScalarAnd	True, False
Financial_Tests		
	FTOP_function	\$231.38, \$694.13 \$462.75, \$925.51
	PTOF_function	\$4321.94, \$12965.83

TABLE GS2_1

Containers	Test Element	Expected Result
		$8643.89, $17287.77
	ATOP_function	$15372.45, $46117.35 $30744.90, $61489.80
	ATOF_function	$66438.85, $199316.54 $132877.70, $265755.39
	PTOA_function	$65.05, $195.15 $130.10, $260.21
	PC2CC	0.0998 0.0749 0.0200 0.0500
	CC2PC	0.1002 0.0751 0.0200 0.0500
	GM2CM	0.0953 0.0723 0.0198 0.0488
	CM2GM	0.1052 0.0779 0.0202 0.0513
	ARI2CM	0.0894 0.0624 0.0074 0.0354
	ARI2VOL	0.4724 0.6064 1.4075 0.8326
	GEO2VOL	0.4339 0.5364 1.0559 0.6937
Probability Expressions		
	StdNormCDF_1	0.5, 0.8413 0.1587, 0.02275
	StdNormCDF_2	0.5, 0.158655 0.841345, 0.97725
	InvStdNormCDF_1	0, -1, 1, 2
	InvStdNormCDF_2	0, 1, -1, -2
	t_Distr_1	0, 0, 0.740667, 1.47586
	CumProb_t_Distr_1	0.5, 0.5, 0.75, 0.90
	GammaFunction_1	1, 1, 2, 6
	GammaFunction_2	24, 720, 40320, 362880
Comparison_Tests		
	GreaterThan	True, True False, True
	GreaterThanEqual	True, True False, True
	IsEqualTo	All False
	LessThan	True, True False, True
	LessThanEqual	True, True False, True
	NotEqualTo	All True
	ScalarGreaterThan	False, True
	ScalarGreaterThanEqual	True, True
	ScalarIsEqualTo	True, False

TABLE GS2_1

Containers	Test Element	Expected Result
	ScalarLessThan	False, True True, True
	ScalarLessThan	True, False False, False
	ScalarNotEqualTo	False, True True, True

TABLE GS2_3

Get_Functions		
	Item_From_Vector	4
	Row_Count	7
	Item_From_Matrix	32
	Mat_Row_Count	3
	Mat_Col_Count	4
	Row_from_Matrix	[21,22,23,24]
	Column_from_Matrix	[13,23,33]
	Row_From_Vector	33
Get_Functions_ Condition		
	Item_From_Vector	False
	Row_Count	5
	Item_From_Matrix	True
	Mat_Row_Count	4
	Mat_Col_Count	5
	Row_from_Matrix	[False, False, True, True, True]
	Column_from_Matrix	[False, True, False, True]
	Row_From_Vector	False
Array_Indexing_ Value		
	Item_From_Named_Vector	4
	Dynamic_Value_Result	See GS02_Array_1 plot below
	Item_From_Indexed_Vector	4
	Dynamic_Value_Result_Indexed	See GS02_Array_2 plot below
	Item_from_Matrix	32
	Row_from_Matrix	[21, 22, 23,24]
	Column_from_Matrix	[13,23,33]
	Dynamic_Matrix_Plot	See GS02_Array_3 plot below
Array_Indexing_ Condition		
	Item_From_Named_Vector	True
	Dynamic_Value_Result	See GS02_Array_4 plot below
	Item_From_Indexed_Vector	True
	Dynamic_Value_Result_Indexed	See GS02_Array_5 plot below
	Item_from_Matrix	True

	Row_from_Matrix	[False, True, False, False]
	Column_from_Matrix	[False, True, False]
	Dynamic_Matrix_Plot	See GS02_Array_6 plot below

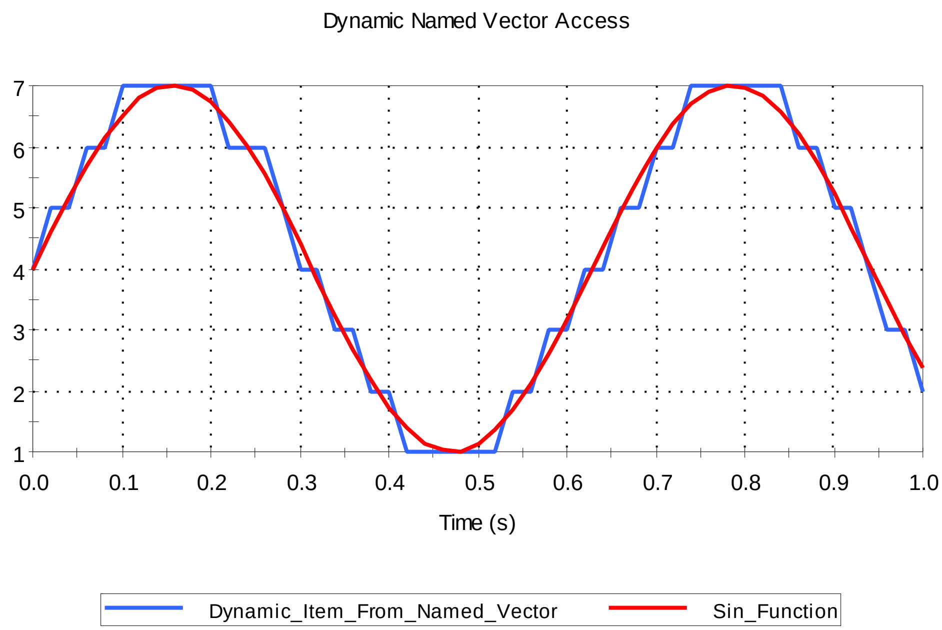


Fig. GS02_Array_1

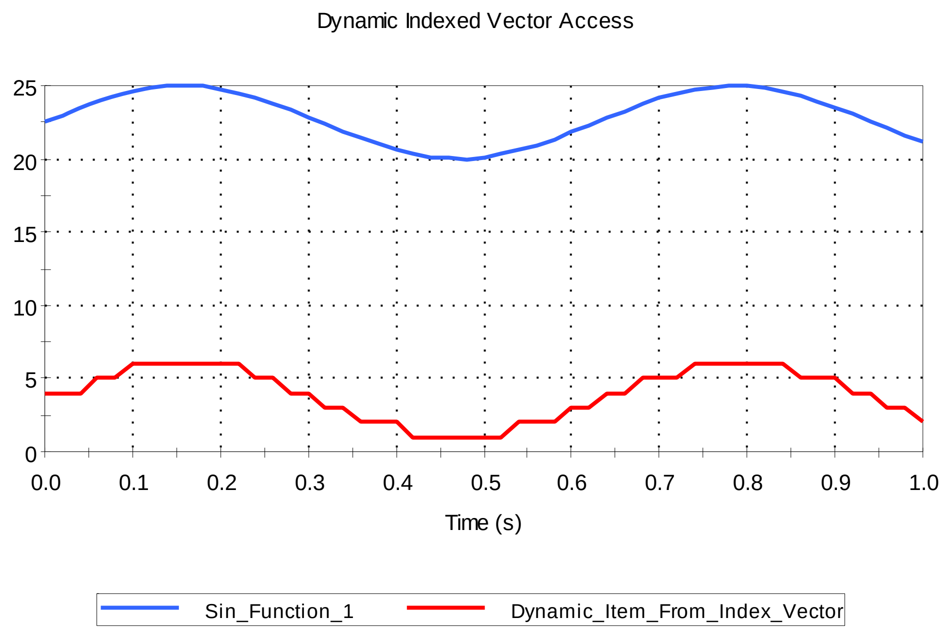


Fig. GS02_Array_2

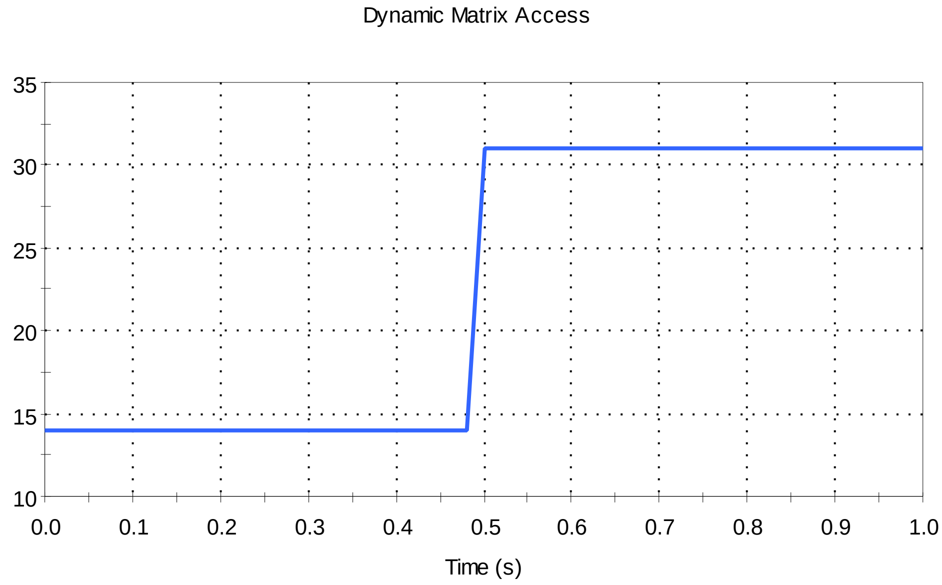


Fig. GS02_Array_3

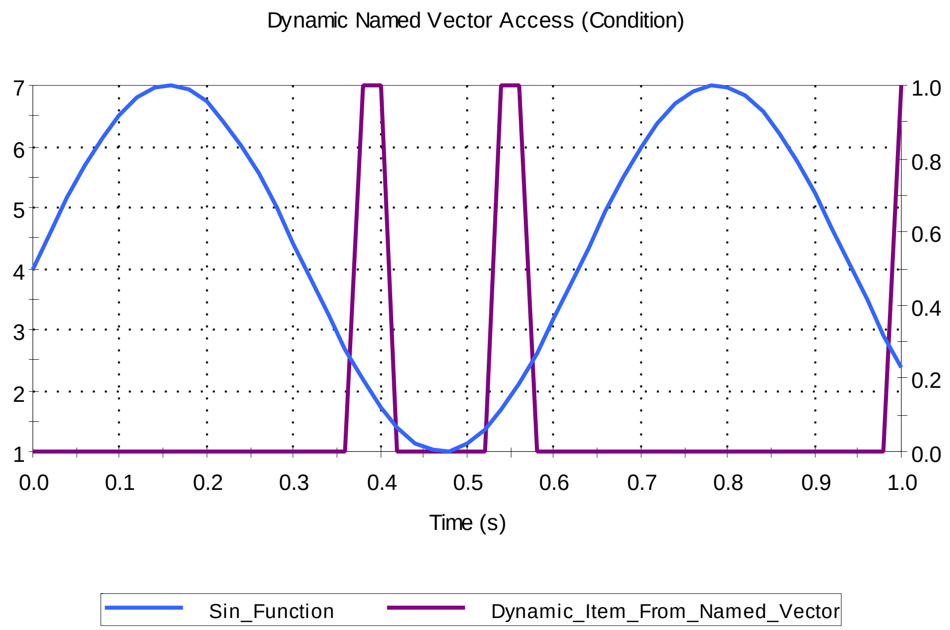


Fig. GS02_Array_4

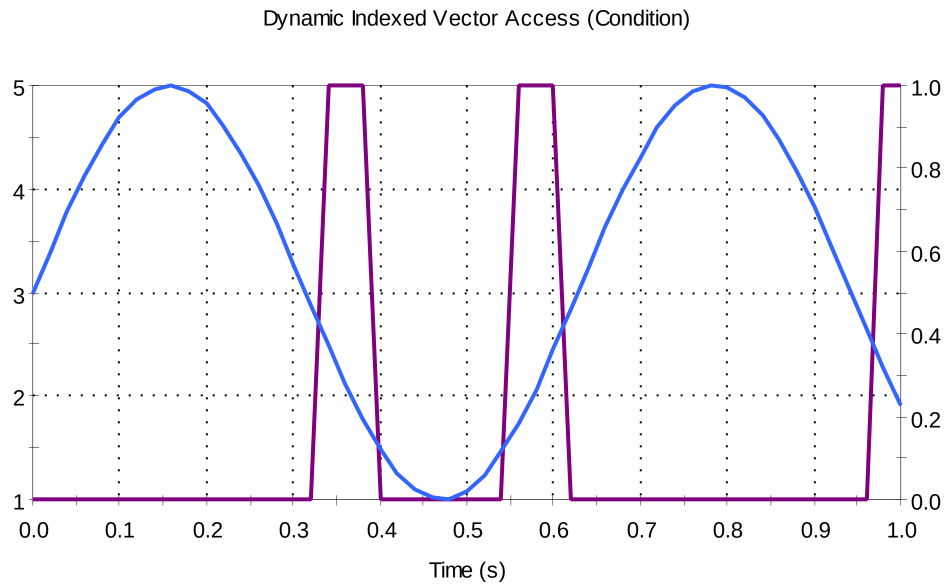


Fig. GS02_Array_5

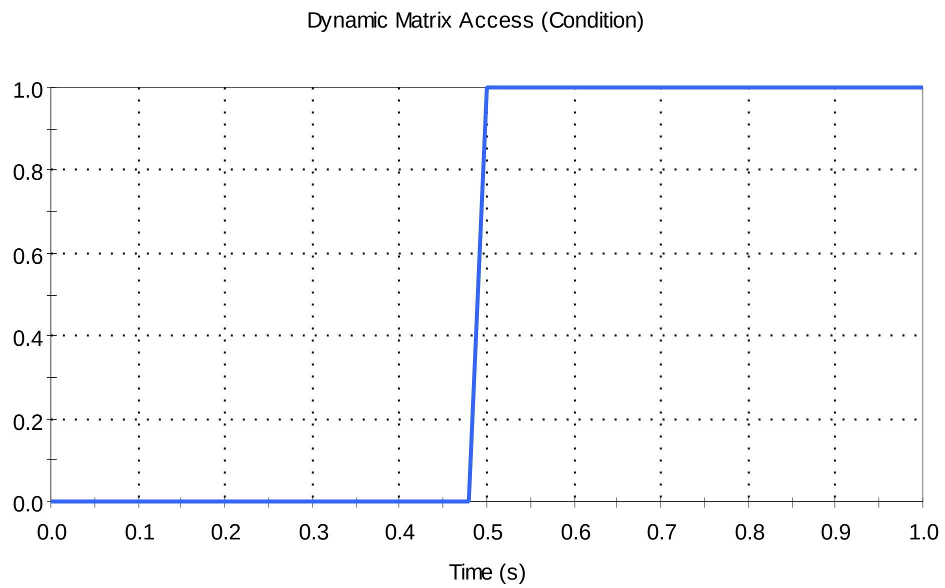


Fig. GS02_Array_6

GS02b_ExpressionsConstructor

This test verifies that vector and matrix constructors function correctly. The verifier should run the test and confirm that the results match the expected values listed in Table 2-4.
Arrays (vectors and matrices) are tested in two parts. The first set of tests involves Array Operators. The second set of tests involves miscellaneous array functionality, such as pasting data into arrays.

TABLE GS2_4

Container	Element	Expected Value
Vector_Matrix_Static _Single		
	Vector_Positive	[5,5,5] [m]
	Vector_Negative	[-4,-4,-4] [ft/s^2]
	Matrix_Positive	$\begin{bmatrix} 5 & 5 & 5 \\ 5 & 5 & 5 \\ 5 & 5 & 5 \end{bmatrix}$ [kg]
	Matrix_Negative	$\begin{bmatrix} -4 & -4 & -4 \\ -4 & -4 & -4 \\ -4 & -4 & -4 \end{bmatrix}$ [ft/s]
Vector_Matrix_Static		
	Vector_Static	[2, -5, 3.048][m]
	Matrix_Static	$\begin{bmatrix} 5 & 0 & 22.7 \\ 0.05 & 3 & -10 \\ 1 & 2 & 3 \end{bmatrix}$ [kg]
Vector_Matrix_Dynamic _Single		
	Max_Deviation_Vector	<1E-6
	Max_Deviation_Matrix	<1E-6
Vector_Matrix_Dynamic		
	Max_Deviation_Vector	<1E-6
	Max_Deviation_Matrix	<1E-6
Row_Column		
	Vector_Row	[1 1 5]
	Matrix_Row_Column	$\begin{bmatrix} 1 & -10 & 1 \\ 1 & -10 & 1 \\ -10 & -10 & -10 \end{bmatrix}$
Matrix_From_Vectors		
	Square_Matrix	$\begin{bmatrix} 1 & 10 & 100 \\ 5 & 50 & 500 \\ 1 & 10 & 100 \end{bmatrix} [kg]$
	Two_Rows_Three_Cols	$\begin{bmatrix} 5 & 5 & 5 \\ 100 & 100 & 100 \end{bmatrix} [d]$
	Two_Rows_Three_Cols	$\begin{bmatrix} 1 & 100 \\ 2 & 100 \\ 3 & 100 \end{bmatrix} [d]$

GS03_Array: Array Operators and Data

Arrays (vectors and matrices) are tested in two parts. The first set of tests involves Array Operators. The second set of tests involves miscellaneous array functionality, such as pasting data into arrays.

1. Array Operators. Array operators with data links are verified by creating a model with each operator and comparing model results with known results. The expected results for each output are presented in the notes window, or tool tip window, for each element for easy comparison with the calculated array final values. The operators and functions checked in this section include:

Vector Operators (Term-by-Term for Values)

- vector sum **sumv**(Xi)
- vector minimum **minv**(Xi)
- vector maximum **maxv**(Xi)
- vector mean **meanv**(Xi)
- vector standard deviation **sdv**(Xi)
- vector/vector addition Xi+Yi
- vector/vector subtraction Xi-Yi
- vector/vector dot product Xi*Yi (scalar result)
- vector/scalar multiplication Xi*a
- vector/scalar division Xi/a
- change signs of vector –Xi
- term-by-term use of lookup tables by vectors
- search for a value within a vector output, return its fractional index.
- interpolate for a value within a vector output given its fractional index.

Matrix Operators (Term-by-Term for Values)

- matrix row sum **sumr**(Xij)
- matrix row mean **meanr**(Xij)
- matrix row standard deviation **sdr**(Xij)
- matrix row maximum **mixr**(Xij)
- matrix row minimum **minr**(Xij)
- matrix column sum **sumc**(Xij)
- matrix column mean **meanc**(Xij)
- matrix column standard deviation **sdc**(Xij)
- matrix column maximum **maxc**(Xij)

- matrix column minimum **minc**(Xij)
- nested matrix operation, Xij***trans**(Yik)
- term by term multiplication of two matrices **prod**(Xij, Xij)
- term by term division of two matrices **div**(Xij, Xij)
- matrix multiplication by scalar a*Xij
- matrix division by scalar Xij/a
- term-by-term use of lookup tables by vectors

Linear Algebra (Matrix and Vector Operations for Values)

- matrix - vector multiplication **mult(Xii, Vi)**
- vector - matrix multiplication **mult(Yi, Xii)**
- matrix – matrix multiplication **mult(Xij, Yjk)**
- vector – vector multiplication (matrix product) **vvmatrix(V1, V2)**
- matrix transpose of values
- matrix inversion
- vector/vector dot product **dot(Xi,Yi)** (scalar result)

Vector and Matrix Operators (Term-by-Term for Conditions)

- OR of elements in row of matrix **sumr(M1)**
- OR of elements in column of matrix **sumc(M2)**
- AND of elements in row of matrix **prodr(M1)**
- AND of elements in column of matrix **prodc(M1)**
- OR of elements in vector **sumv(V1)**
- AND of elements in vector **prodv(V1)**
- matrix transpose of conditions

Complex Operators

- nested matrix and vector operation **sin**((pi/180)* (6+Yi*(Yi*Xii)))
- nested matrix and vector operation **asin**((Yi*(6+Yi*(Xii***inv**(Xii))))/3)
- nested matrix operation Xii***inv**(Xii)

The verification results are presented in Table GS03_1. It is not necessary for the user to enter any data but it is necessary to run the model. The user compares model current or final values against results presented in Table GS03_1 to verify the array operators.

TABLE GS03_1

Container	Test Element	Expected Result
Vector_ TermbyTerm		
	SUMV_Function	28
	MINV_Function	1
	MAXV_Function	7
	MEANV_Function	4
	SDV_Function	2
	Sort_123_Function	1 ,2, 3, 4, 5, 6, 7
	Sort_321_Function	7, 6, 5, 4, 3, 2, 1
	Vector_Vector_multiplication	1, 4, 9
	Vector_Scalar_multiplication	2, 4, 6, 8, 10, 12, 14
	Vector_Vector_Division	1, 1, 1
	Vector_Scalar_division	0.5, 1, 1.5, 2, 2.5, 3, 3.5
	Vector_Vector_addition	8, 8, 8, 8, 8, 8, 8
	Vector_Vector_subtraction	-6, -4, -2, 0, 2, 4, 6
	PRODV_function	6
	Scalar_Vector_division	2, 1, 0.6667, 0.5, 0.4, 0.333, 0.2857
	Lookup_Term_by_Term_Vector	[10, 20, 30]
	vIndexFunc	3.674
	vInterpTest	0.5 in
Matrix_ TermbyTerm		
	SUMR_Matrix_function	3 7
	PRODR_Matrix_function	6 48
	MEANR_Matrix_function	1.5 3.5
	MAXR_Matrix_function	2 4
	MINR_Matrix_function	1 3
	SDR_Matrix_function	0.5 0.5
	SUMR_Matrix	6 12
	SUMC_Matrix_function	4 6
	PRODC_Matrix_function	3 8

TABLE GS03_1

Container	Test Element	Expected Result
	MEANC_Matrix_function	2 3
	MAXC_Matrix_function	3 4
	MINC_Matrix_function	1 2
	SDC_Matrix_function	1 1
	SUMC_Matrix	3 6 9
	PRODC_Matrix	2 8 18
	TRANS_Matrix_function	1 3 2 4
	INV_Matrix_function	-2 1 1.5 -0.5
	Matrix_matrix_multiplication	1 4 9 16
	Matrix_matrix_division	1 1 1 1
	Nested_matrix_mult_trans	1 6 6 16
	Matrix_Scalar_multiplication	2 4 6 8
	Matrix_Scalar_division	0.5 1 1.5 2
	Scalar_ Matrix_division	2 1 0.667 0.5
	Lookup_Term_by_Term_Matrix	10 20 30 40 50 60
Linear_Algebra		
	Matrix_Multiplication (mult(M1, M2))	14, 28 28, 56
	Matrix_times_Vector (mult(M, V))	14 28
	Vector_times_Matrix (mult(V, M))	14, 28
	Vector_times_Vector (vvmatrix(V1,V2))	1, 2, 3 2, 4, 6 3, 6, 9

TABLE GS03_1

Container	Test Element	Expected Result
	Vector_Dot_Product (dot(V1, V2)	14
Complex_ Operations		
	Nested_sin_vector_matrix	1
	Nested_asin_vector_matrix	90 deg
	Matrix_inverse_product	1, 0, 0 0, 1, 0 0, 0, 1
Condition_Tests		
	Prodr_Conditions_1	True,True,True
	Prodr_Conditions_2	True,False,True
	Sumr_Conditions	True,True,True
	Prodc_Conditions_1	True,True,True
	Prodc_Conditions_2	True,False,True
	Sumc_Conditions	True,True,True
	TRANS_Condition_Matrix_function	false, true, true false, true, false false, true, false
	Prodv_Conditions_1	True
	Prodv_Conditions_2	False

TABLE GS03_1

Container	Test Element	Expected Result
	Sumv_Conditions	True

2. Miscellaneous Array Functionality

Before beginning this portion of the test, GoldSim should be placed in Edit mode.

Pasting data into Arrays. This test verifies that data (e.g., from an Excel spreadsheet) can be pasted into Arrays (vectors or matrices). Test elements are located in the Pasting container, and the test proceeds as follows:

a. Throughout the test, ensure that the "Edit Data" dialog boxes can be resized.

b. Before beginning the rest of the test, change the vector and matrix elements to scalars which will remove any existing data. The Vector_Data element should then be changed back to a vector of Months, and the Matrix_Data element should be changed back to a Matrix of Months by Days.

c. Double-click on the hyperlink to the spreadsheet containing the data to be pasted (labeled "Pasting Data"). In the workbook named "Pasted cells to keep GS tests.xls", Enter the worksheet named "GS03". Copy (CTRL C) the range of cells intended to be pasted into the element Vector_Data (as directed in the spreadsheet).

d. Enter the container named Pasting and open the "Edit Vector" dialog for the element Vector_Data.

e. Paste (CTRL V) the copied cells into Vector_Data by clicking on the upper left cell (above the row heading "January"). Ensure that the pasted values match the copied values.

f. Close the element dialog and then re-open it to ensure that it shows the correct values.

g. In the spreadsheet, copy (CTRL C) the range of cells intended to be pasted into the element Matrix_Data (as directed in the spreadsheet).

h. Open the "Edit Matrix" dialog for the element Matrix_Data.

i. Paste (CTRL V) the copied cells into Matrix_Data by clicking on the upper left cell (above the row heading "January"). Ensure that the pasted values match the copied values.

j. Close the element dialog and then re-open it to ensure that it shows the correct values.

k. Save the file, exit, re-open it, and ensure that all values are still shown correctly.

Tool-tip display for Array Cells. Enter the container Tool_Tip_Test. Open the properties dialog box for the Data element Check_Display. Run the cursor over all of the cells and ensure that the tool-tip window correctly reports the value in each cell, including 1.#INF for infinity.

Invalid Arguments for Vector or Matrix Functions. Copy several of the existing test Expression elements (e.g., from containers Vector_TermByTerm or Matrix_TermByTerm) that utilize a vector or matrix operator (e.g., sumv(), maxr(), etc.). Try to replace the valid argument with a scalar (e.g., 5). In all cases, GoldSim should provide you with a message indicating that vector or matrix inputs are required. When done, delete the elements that were pasted for this portion of the test.

GS04_Stoc: Stochastic Distributions

Stochastic elements are verified by creating a model with each distribution and comparing model results with analytical results, numerical integration, or results generated from At Risk®. The expected results for each output are viewed in the edit distribution window of the element dialog. The distributions checked in this section include:

Distributions

- Uniform
- Log-Uniform
- Triangular
- Log-Triangular
- Normal
- Log-Normal
- Truncated Normal
- Truncated Log-Normal
- Beta
- Binomial
- Boolean
- Cumulative
- Discrete
- Gamma
- Truncated Gamma
- Poisson
- Weibull
- Truncated Weibull
- Student-t
- Exponential
- Pareto
- Negative Binomial

These test problems verify correct evaluation of stochastic elements and represent each of the 22 probability distributions supported by Goldsim. The tests verify the probability and cumulative distributions based on the parameter inputs. These tests include verifying distribution moments (i.e. mean and standard deviation when applicable) and several selected percentiles. The function of the Goldsim calculator is also verified with these tests. The distribution form is verified by comparing the displayed values at various percentiles against the “true” form of the distribution. The “true” form was calculated mathematically for those distributions for which a closed-form solution was readily available. Otherwise, the “true” form was approximated using results from @Risk by running 100,000 realizations employing Latin-Hypercube sampling. @Risk was used to compute the “true” form for the following distributions: normal, lognormal, truncated normal, truncated lognormal, and gamma. In some instances, numerical integration was applied to compute the cdf. This method was checked against @Risk results with both methods in close agreement (to 4 significant figures). The numerical integration method was used to compute the “true” form for the following distributions: truncated gamma and truncated weibull. Note that because random sampling is involved, small differences between the “true” values and the values reported by Goldsim are to be expected. This is also relevant for “true” results generated by @Risk. Also, some error is introduced using the numerical integration method. For the purposes of this verification, comparisons involving random sampling error (i.e., @Risk simulations) and numerical integration error must agree to 3 significant figures to pass the verification.

The verification results are presented in Table GS04_1. It is not necessary to run the model to verify results. The user compares verification results to displayed values in the “Edit Distribution” window of each element. Percentile results are viewed by clicking on the “%” icon in the lower left-hand corner of the “Edit Distribution” window. It is necessary for the user to enter data in the calculator box of the edit distribution window to verify calculator results. The required value or cumulative probability inputs to the calculator are also presented in Table GS04_1.

TABLE GS04_1

Tests Element	Result Type	Expected Results
Uniform	Element dialog, edit distribution	Mean = 500 St. Dev. = 289 5%: x = 50.0 25%: x = 250 50%: x = 500 75%: x = 750 90%: x = 900
	Element dialog, edit distribution, calculator value input 900	Cum. Prob. = 0.900 Prob. Density = 0.001
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 900 Prob. Density = 0.001

TABLE GS04_1

Tests Element	Result Type	Expected Results
Uniform__Log	Element dialog, edit distribution	Mean = 215 St. Dev. = 250 5%: x = 12.6 25%: x = 31.6 50%: x = 100 75%: x = 316 90%: x = 631
	Element dialog, edit distribution, calculator value input 100	Cum. Prob. = 0.500 Prob. Density = 0.00217
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 631 Prob. Density = .000344
Triangular	Element dialog, edit distribution	Mean = 46.7 St. Dev. = 19.3 5%: x = 19.5 25%: x = 31.3 50%: x = 43.9 75%: x = 60.3 90%: x = 74.9
	Element dialog, edit distribution, calculator value input 50	Cum. Prob. = 0.603 Prob. Density = 0.0159
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 74.9 Prob. Density = .00797
Triangular_Log	Element dialog, edit distribution	Mean = 34.7 St. Dev. = 16.7 5%: x = 14.3 25%: x = 22.1 50%: x = 30.8 75%: x = 43.5 90%: x = 59.1
	Element dialog, edit distribution, calculator value input 50	Cum. Prob. = 0.827 Prob. Density = 0.0100
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 59.1 Prob. Density = 0.00643
Normal	Element dialog, edit distribution	5%: x = 67.1 25%: x = 86.5 50%: x = 100 75%: x = 113 90%: x = 126
	Element dialog, edit distribution, calculator value input 80	Cum. Prob. = 0.159 Prob. Density = 0.0121
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 126 Prob. Density = .00877

TABLE GS04_1

Tests Element	Result Type	Expected Results
Normal_Log	Element dialog, edit distribution	geo. Mean = 89.4 geo. St. Dev. = 1.60 5%: x = 41.1 25%: x = 65.0 50%: x = 89.4 75%: x = 123 90%: x = 164
	Element dialog, edit distribution, calculator value input 80	Cum. Prob. = 0.407 Prob. Density = 0.0103
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 164 Prob. Density = 0.00227
Normal_Truncated	Element dialog, edit distribution	5%: x = 70.6 25%: x = 87.2 50%: x = 100. 75%: x = 113 90%: x = 124
	Element dialog, edit distribution, calculator value input 80	Cum. Prob. = 0.142 Prob. Density = 0.0127
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 124 Prob. Density = 0.0104
Normal_Log_Truncated	Element dialog, edit distribution	geo. Mean = 89.4 geo. St. Dev. = 1.60 5%: x = 54.5 25%: x = 69.6 50%: x = 88.0 75%: x = 111 90%: x = 130
	Element dialog, edit distribution, calculator value input 80	Cum. Prob. = 0.395 Prob. Density = 0.0136
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 130 Prob. Density = 0.00624
Gamma	Element dialog, edit distribution	5%: x = 5.47 25%: x = 10.1 50%: x = 14.7 75%: x = 20.4 90%: x = 26.7
	Element dialog, edit distribution, calculator value input 20	Cum. Prob. = 0.735 Prob. Density = 0.0351

TABLE GS04_1

Tests Element	Result Type	Expected Results
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 26.7 Prob. Density = 0.0156
Gamma_Truncated	Element dialog, edit distribution	5%: x = 6.43 25%: x = 10.1 50%: x = 13.8 75%: x = 18.1 90%: x = 21.6
	Element dialog, edit distribution, calculator value input 20	Cum. Prob. = 0.838 Prob. Density = 0.0422
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 21.6 Prob. Density = 0.0357
Weibull	Element dialog, edit distribution	Mean = 18.9 St. Dev. = 4.63 5%: x = 12.3 25%: x = 15.4 50%: x = 18.3 75%: x = 21.8 90%: x = 25.2
	Element dialog, edit distribution, calculator value input 25	Cum. Prob. = 0.895 Prob. Density = 0.0316
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 25.2 Prob. Density = 0.0303
Weibull_Truncated	Element dialog, edit distribution	Mean = 17.7 5%: x = 12.1 25%: x = 15.0 50%: x = 17.7 75%: x = 20.5 90%: x = 22.8

TABLE GS04_1

Tests Element	Result Type	Expected Results
	Element dialog, edit distribution, calculator value input 20	Cum. Prob. = 0.707 Prob. Density = 0.0822
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 22.8 Prob. Density = 0.0557
Beta (generalized)	Element dialog, edit distribution	5%: x = 9.76 25%: x = 24.3 50%: x = 38.6 75%: x = 54.4 90%: x = 68.0
	Element dialog, edit distribution, calculator value input 30	Cum. Prob. = 0.348 Prob. Density = 0.0176
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 68.0 Prob. Density = 0.00837
Binomial	Element dialog, edit distribution	Mean = 25.0 St. Dev. = 4.33 5%: x = 18 25%: x = 22 50%: x = 25 75%: x = 28 90%: x = 31
	Element dialog, edit distribution, calculator value input 20	Cum. Prob. = 0.149 Prob. Density = 0.0493
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 31 Prob. Density = 0.0344
Boolean	Element dialog, edit distribution	Mean = 0.75 5%: x = 0 25%: x = 1 50%: x = 1 75%: x = 1 90%: x = 1
	Element dialog, edit distribution, calculator value input 0	Cum. Prob. = 0.25
	Element dialog, edit distribution, calculator cumulative probability input 0.75	Value = 1

TABLE GS04_1

Tests Element	Result Type	Expected Results
Cumulative	Element dialog, edit distribution	Mean = 50 5%: x = 5 25%: x = 25 50%: x = 50 75%: x = 75 90%: x = 90
	Element dialog, edit distribution, calculator value input 60	Cum. Prob. = 0.60 Prob. Density = 0.01
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 90 Prob. Density = 0.01
Discrete	Element dialog, edit distribution	Mean = 50 St. Dev. = 28.4 5%: x = 5 25%: x = 25 50%: x = 50 75%: x = 75 90%: x = 95
	Element dialog, edit distribution, calculator value input 26	Cum. Prob. = 0.252 Prob. Density = 0
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 95 Prob. Density = 0.200
Exponential	Element dialog, edit distribution	Mean = 20 SD = 20 5%: x = 1.026 25%: x = 5.754 50%: x = 13.863 75%: x = 27.726 90%: x = 46.052
	Element dialog, edit distribution, calculator value input 46.052	Cum. Prob. = 0.90 Prob. Density = 0.005
	Element dialog, edit distribution, calculator cumulative probability input 0.90	Value = 46.052 Prob. Density = 0.005
Pareto	Element dialog, edit distribution	Mean = 5.2632 SD = 0.2774 5%: x = 5.013 25%: x = 5.072 50%: x = 5.176 75%: x = 5.359 90%: x = 5.610
	Element dialog, edit distribution, calculator value input 5.610	Cum. Prob. = 0.90 Prob. Density = 0.357
	Element dialog, edit distribution, calculator cumulative probability input 0.90	Value = 5.610 Prob. Density = 0.357

TABLE GS04_1

Tests Element	Result Type	Expected Results
Poisson	Element dialog, edit distribution	Mean = 25cm St. Dev. = 5.00cm 5%: x = 17cm 25%: x = 22cm 50%: x = 25cm 75%: x = 28cm 90%: x = 32cm
	Element dialog, edit distribution, calculator value input 20	Cum. Prob. = 0.185 Prob. Density = 0.0519 1/cm
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 32 Prob. Density = 0.0286 1/cm
Truncated Pareto	Element dialog, edit distribution	Mean = 5.2052 5%: x = 5.012 25%: x = 5.067 50%: x = 5.161 75%: x = 5.314 95%: x = 5.588
	Element dialog, edit distribution, calculator value input 5.488	Cum. Prob. = 0.90 Prob. Density = 0.602
	Element dialog, edit distribution, calculator cumulative probability input 0.90	Value = 5.488 Prob. Density = 0.602
Negative Binomial	Element dialog, edit distribution	Mean = 3.3333 SD = 2.1082 5%: x = 0 25%: x = 2 50%: x = 3 75%: x = 5 95%: x = 7
	Element dialog, edit distribution, calculator value input 7	Cum. Prob. = 0.960 Prob. Density = 0.039
	Element dialog, edit distribution, calculator cumulative probability input 0.90	Value = 6 Prob. Density = 0.0688
Student-t	Element dialog, edit distribution	Mean = 0 SD = 1.0426 5%: x = -1.708 25%: x = -0.684 50%: x = 0 75%: x = 0.684 95%: x = 1.708
	Element dialog, edit distribution, calculator value input 1.708	Cum. Prob. = 0.95 Prob. Density = 0.940
	Element dialog, edit distribution, calculator cumulative probability input 0.95	Value = 1.708 Prob. Density = 0.940

TABLE GS04_1

Tests Element	Result Type	Expected Results
Beta_Success_ Failure	Element dialog, edit distribution	Mean = 0.4444 SD = 0.07326 Skewness = 0.0645 5%: x = 0.325 25%: x = 0.394 50%: x = 0.444 75%: x = 0.494 95%: x = 0.567
	Element dialog, edit distribution, calculator value input 0.5	Cum. Prob. = 0.774 Prob. Density = 4.004 CTE=0.542
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 0.540 Prob. Density = 2.347 CTE = 0.574
Extreme Probability (Maximum)	Element dialog, edit distribution	Mean = 0.8333 SD = 0.1409 Skewness = -1.183 5%: x = 0.549 25%: x = 0.758 50%: x = 0.871 75%: x = 0.944 95%: x = 0.990
	Element dialog, edit distribution, calculator value input 0.8	Cum. Prob. = 0.328 Prob. Density = 2.048 CTE = 0.915
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 0.979 Prob. Density = 4.599 CTE = 0.990
Extreme Probability (Minimum)	Element dialog, edit distribution	Mean = 0.0909 SD = 0.0830 Skewness = 1.517 5%: x = 0.0050 25%: x = 0.0280 50%: x = 0.0667 75%: x = 0.129 95%: x = 0.259
	Element dialog, edit distribution, calculator value input 0.3	Cum. Prob. = 0.972 Prob. Density = 0.404 CTE = 0.362
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 0.205 Prob. Density = 1.262 CTE = 0.276
Extreme Value (Maximum)	Element dialog, edit distribution	Mean = 6.1544 SD = 2.5651 Skewness = 1.14 Kurtosis = 2.4 5%: x = 2.806 25%: x = 4.347

TABLE GS04_1

Tests Element	Result Type	Expected Results
		50%: x = 5.733 75%: x = 7.492 95%: x = 10.94
	Element dialog, edit distribution, calculator value input 7	Cum. Prob. = 0.692 Prob. Density = 0.127
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 9.501 Prob. Density = 0.047
Extreme Value (Minimum)	Element dialog, edit distribution	Mean = 8.268 SD = 3.848 Skewness = -1.14 Kurtosis = 2.4 5%: x = 1.089 25%: x = 6.262 50%: x = 8.900 75%: x = 10.98 95%: x = 13.29
	Element dialog, edit distribution, calculator value input 7	Cum. Prob. = 0.308 Prob. Density = 0.0849
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 12.50 Prob. Density = 0.0768
Pearson	Element dialog, edit distribution	Mean = 16 SD = 4.2426 Skewness = 1.4142 5%: x = 11.07 25%: x = 12..88 50%: x = 15.04 75%: x = 18.08 95%: x = 24.23
	Element dialog, edit distribution, calculator value input 20	Cum. Prob. = 0.8454 Prob. Density = 0.039
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 21.67 Prob. Density = 0.027

GS04a_Stoc_Array

Version 8.00 of GoldSim added the capability to specify a Stochastic element that is an array. This test uses the array Days and specifies uniform distributions that range from 1-10 for Sunday to 7-10 for Saturday. The test confirms that the specified distributions are correctly sampled, that no inadvertent correlations are created, and that triggering a new sample at each time step works correctly.

After running the test the correlation matrix should be displayed. All of the off-diagonal terms should be small, typically less than 0.02.

The CDF's for the seven terms in the vector should also be displayed, to confirm that they represent uniform distributions with the specified lower and upper bounds.

GS04b_Conditional_Tail_Expectation

This test verifies the correct functioning of the Conditional Tail Expectation (CTE) calculations in the Stochastic element and the Result Distibution element.

These elements use different methodologies for calculating the value of the CTE. To verify the performance of the elements the tester should check that the CTE values for the Stochastic element and the corresponding Result Distribution match the expected values listed below:

Normal/Result_Normal:

Probability level of 0.75 should result in a CTE of 16.355.
Value of 0 should result in a CTE of 10.276.

Lognormal/Result_Lognormal:

Probability level of 0.32 should result in a CTE of 10.988.
Value of 4 should result in a CTE of 10.

Uniform/Result_Uniform:

Probability level of 0.05 should result in a CTE of 0.525.
Probability level of 0.25 should result in a CTE of 0.625.
Probability level of 0.5 should result in a CTE of 0.75
Probabiliy level of 0.90 should result in a CTE of 0.95.
Value of 0.3 should result in a CTE of 0.65.
Value of 0.8 should result in a CTE of 0.9.
Value of 1.5 should result in a CTE of 1.

Triangular/Result_Triangular:

Probability level of 0.4 should result in a CTE of 54.0.
Value of 65 should result in a CTE of 68.33

GS04c_Sampled_Results

This test verifies the correct functioning of the Sampled Results and Sampled Results (Extrapolated) distributions.

The Sampled Results distribution is tested by sampling values from a Uniform distribution and then pasting those into the Sampled Results distribution. Since both should produce roughly identical results the verifier should should confirm that the Mean, Standard Deviation, Skewness, Kurtosis and PDF plots for the two distributions in the Comparison result element are statistically identical.

The Sampled Results (Extrapolated) option extrapolates the distribution at both ends of the sampled data to predict the value at cumulative probability levels of 0 and 1. This is done by drawing a line between the fifth from extreme observation and the extreme observation until it reaches the 0 or 1 cumulative probability level.

To confirm the proper functioning of this option the verifier should enter the Sampled_Extrapolated Stochastic element. The verifier should confirm the following using the Stochastic element's probability calculator:

- Cumulative probability of 0 should result in a value of 9.975 (calculated slope is 10.53-10.16 = 0.37 , 10.16-0.37/2 = 9.975)
- Cumulative probability of 1 should result in a value of 20 (calculated slope is 19.74 - 19.22 = 0.52, 19.74 + 0.52/2 = 20)

GS04d_Correlation_Matrix

All of the multivariate result elements should show the following correlations (these are shown in the _Correlations Multivariate Result elements):

	1	2	3	4	5
1	1	0	0.75	0	0
2	0	1	0	0.1	0.35
3	0.75	0	1	0	0
4	0	0.1	0	1	0.93
5	0	0.35	0	0.93	1

The verifier should note that the correlations predicted by the Multivariate Result elements may not exactly agree with the matrix specified in the History Generator elements, especially for the t-distribution copula with one degree of freedom.

The verifier should also check that the correlation between variables agrees with the correlation type specified. To do this, the verifier should check the _Plots Multivariate Result elements. The Gaussian and Iman and Conover correlations should show a stronger correlation in the middle than at the tails. The 1 degree of freedom t-distribution copula should show a stronger correlation at the tails than in the middle. The 25 degree of freedom t-distribution copula should resemble the Gaussian copula (as the number of degrees of freedom increases, the t-distribution copula begins to approximate the Gaussian copula).

GS04e_Percentile

This test verifies the proper functioning of Percentile correlation, where a distribution reports the specified percentile of its distribution.

A source distribution (Uniform on 0,1) is resampled each model update. This is used as the input to the correlation input field for both a Normal [0,1] and a Uniform [0,1] distribution with Percentile correlation enabled. It is possible to directly calculate the value that should be sampled for both the normal and uniform distribution. The expected and calculated values are compared and an Extrema element is used to identify the largest deviation.

The verifier should run the model and then ensure that the Extrema element reports a negligable value (less than 1E-6).

GS05_Integrator1: Integrator Elements (formerly Quantity and Accumulator Elements)

Integrators with data links are verified by creating a model with Integrator elements and comparing model results with known results. The expected results for each static output are presented in the tool tip window for each element for easy comparison with the current value output when appropriate. Expected values are presented in the element notes for vector results. The functions checked in this section include:

<u>Scalar Integrators</u>

Integrator with scalar initial value and scalar rate of change

Integrator with scalar initial value and time dependent rate of change

<u>Vector (or Matrix) Integrators</u>

Vector (or matrix) of Integrators with vector (or matrix) of initial values and vector (or matrix) of rates of change

The verification results are presented in Table GS05_1. It is not necessary for the user to enter any data but it is necessary to run the model. The user compares model current values against results presented in Table GS05_1 to verify the Integrator elements.

TABLE GS05_1

Tests Element	Result Type	Expected Values
Integrator_Simple	Element tool tip , time histories	At 20s = 300
Integrator _Time_Dep	Element tool tip , time histories	At 10s = 50 At 20s = 150
Vector_Integrator	Element time histories	At 20s = [30,50,70,90,110,130,150]
Matrix_Integrator	Element time histories	At 20s = (2x2 matrix) 120 20 20 1020

GS06_ Integrator 2: More Integrator-Element Tests

This file contains tests to verify that Integrator Elements correctly manipulate initial values, rates of change, and discrete changes. The file evaluates calculated (dimensionless) quantities over a 200-day simulation and uses a one-day timestep. Calculated results are compared to theoretical results evaluated using EXCEL. Note that the first few tests in this file duplicate several of the scalar tests in GS05_INTEGRATOR1, but are included in GS06_INTEGRATOR2 for completeness.

<u>Basic Tests</u>

1. Rate-integration tests (initial value = 0; no discrete changes)
   a) Rate of change of 0 / day
   b) Rate of change of 1 / day
   c) Rate of change of –10 / day
   d) Rate of change of (Time in days / 1 day) {1 / day}
   e) Rate of change of (Time in days / 1 day) {1 / day}, backwards-difference option
   f) Rate of change equal to the value of a time-dependent variable (normal forward-difference option).
2. Initial-value tests (rate of change = 0; no discrete changes)
   a) Value input directly into the Integrator Element’s initial-value field directly
   b) Initial value is a link to a Data Element
   c) Initial value is a link to an Expression Element
   d) Initial value is a link to a Selector Element
3. Discrete-change tests (initial value = 0; rate as specified below)
   a) Input from a Discrete Change: Add a constant
   b) Input from a Discrete Change: Replace by a constant
   c) Multiple, discrete changes (from three Discrete Changes)
   d) Discrete change at a specified time (replace by constant) AND a rate of change equal to (Time in days / 1 day) {1 / day}

The model must be run to see calculated results. The expected outputs are shown either in the tooltip window for each Integrator Element (i.e., move the cursor over the Integrator Element being evaluated, and a tooltip window will automatically appear) or graphically as specified in the file. Specific tests and expected results are shown in Table GS06_1.

Table GS06_1

Element being evaluated	Test	Expected Result / Output
Integrator1	1 a)	Value of 1 for all times
Integrator 2	1 b)	A linear increase in value from 0 at time 0 to 100 at time 100 days
Integrator 3	1 c)	A linear decrease from 0 at time 0 to –1,000 at time 100 days
Integrator 4	1 d)	Parabolic with a value of 0 at time 0 and a value of 4999 at time 100 days
Integrator 4b	1 e)	Parabolic with a value of 0 at time 0 and a value of 5001 at time 100 days (rate of change is 0.02/day greater than test 1 d).
Integrator 5	1 f)	See Figure GS06.1
Integrator 6	2 a)	Expected output is a value of 10 at time 0 and a value of 110 at time 100 days.
Integrator 7	2 b)	Expected output is a value of

		10 at time 0 and a value of 110 at time 100 days.
Integrator 8	2 c)	Expected output is a value of 10 at time 0 and a value of 110 at time 100 days.
Integrator 8b	2 d)	Expected output is a value of 10 at time 0 and a value of 110 at time 100 days.
Integrator 9	3 a)	Expected output is an increase in value from 0 to 1 at time 50 days.
Integrator 10	3 b)	Expected output is a decrease in value from 10 to 5 at 50 days.
Integrator 12	3 c)	Expected output is a change in value from 0 to 25 at time 50 days.
Integrator 13	3 d)	See Figure GS06.2

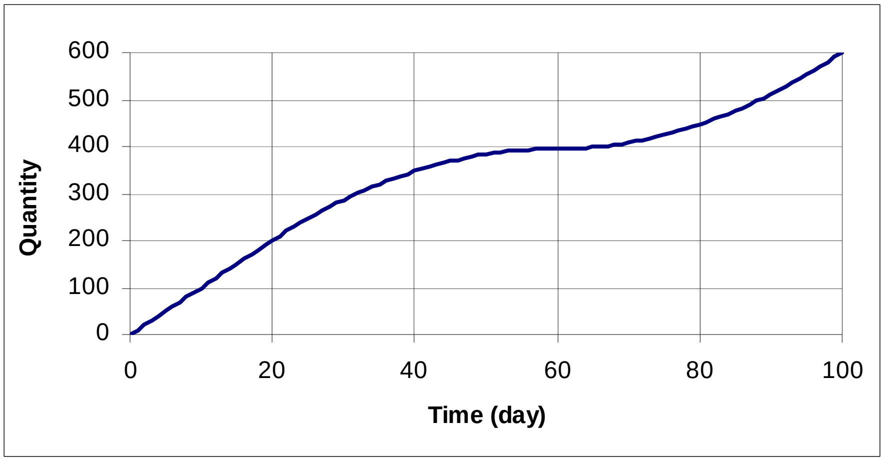


Figure GS06.1. Expected results for Test 1 f).

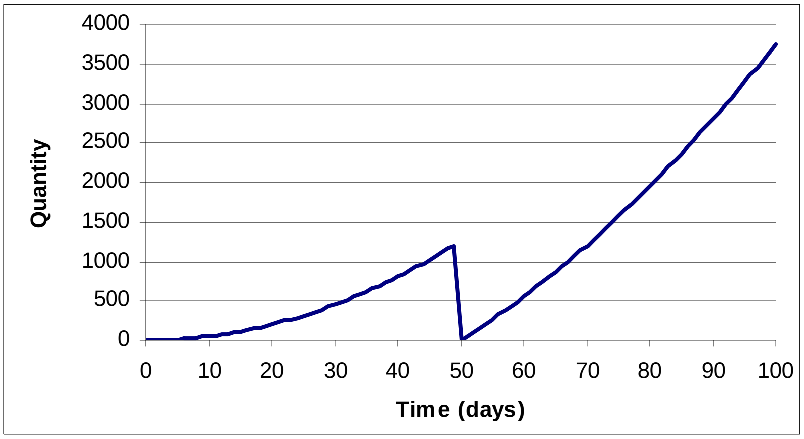


Figure GS06.2. Expected results for Test 3 d)

GS07_Selc: Selectors

Selector functions with data links are verified by creating a model with selector elements and comparing model results with known results. The expected results for each non-time dependent output are presented in the tool tip window for each element for easy comparison with the current value output. Expected values for time dependent selector tests are presented in the element notes for vector results. The functions checked in this section include:

Basic Tests

- first two conditions are false, third is true (== operator is tested)
- first two conditions are false, third is true (!= operator is tested)
- first two conditions are false, third is true (< operator is tested)
- first two conditions are false, third is true (> operator is tested)
- first two conditions are false, third is true (<= operator is tested)
- first two conditions are false, third is true (>= operator is tested)
- first four conditions are false, last is true
- all conditions are false, uses default value

Time Dependent Tests

- time dependent conditions
- time dependent conditions and time condition in output IF statement
- time dependent conditions and time as the output

Nested Test

- time dependent condition with a linked time dependent selector as the output

The verification results are presented in Table GS07_1. It is not necessary for the user to enter any data but it is necessary to run the model. The user compares model final values or time histories against results presented in Table GS07_1 to verify the selector elements.

TABLE GS07_1

Tests Element	Result Type	Expected Values
Selector_Basic_1	Element tool tip, time histories	Selector_Basic_1 = 3

TABLE GS07_1

Tests Element	Result Type	Expected Values
Selector_Basic_2	Element tool tip, time histories	Selector_Basic_2 = 3
Selector_Basic_3	Element tool tip, time histories	Selector_Basic_3 = 3
Selector_Basic_4	Element tool tip, time histories	Selector_Basic_4 = 3
Selector_Basic_5	Element tool tip, time histories	Selector_Basic_5 = 3
Selector_Basic_6	Element tool tip, time histories	Selector_Basic_6 = 3
Selector_Basic_7	Element tool tip, time histories	Selector_Basic_7 = 5
Selector_Basic_8	Element tool tip, time histories	Selector_Basic_8 = 5
Selector_Time_1	Element time histories	time=0 to <1s value = 0 time=1 to <2s value = 1 time=2 to <3s value = 2 time=3 to <4s value = 3 time=4 to <5s value = 4 time>=5 value = 5
Selector_Time_2	Element time histories	time<5s value = 0 time=5s to <10s value = 1 time >= 10s value = 2

TABLE GS07_1

Tests Element	Result Type	Expected Values
Selector_Time_3	Element time histories	time <= 5s, value = time time >5s value = 1s
Selector_Nested	Element time histories	time=0 to <1s value = 0 time=1 to <2s value = 1 time=2 to <3s value = 2 time=3 to <4s value = 3 time=4 to <5s value = 4 time=5 to <10s value = 5 time>=10s value = 10

GS08_Look: Look-up Tables

<REVISED LOOKUP TABLES WERE INTRODUCED IN VERSION 9 –SUPPORT FOR OLD STYLE TABLES WAS DISCONTINUED IN VERSION 9.60>

<THIS TEST SUPERCEDED BY GS50 FOR VERSION 9.60 AND LATER>

GS09a_Dbas: Database Links/Downloading

Linking and downloading from the Yucca Mountain, Simple, and Generic databases is verified by setting up a model with elements prepared for download execution.

Yucca Mountain Database

The Yucca Mountain database link/download tests include:

Constants

- scalar constant with length conversion
- scalar constant with mass conversion
- scalar constant with time conversion
- vector data definition
- matrix data definition

Tables

- 1-D table
- 2-D table

Stochastics

- Uniform
- Log-Uniform
- Triangular

- Log-Triangular
- Normal
- Log-Normal (importing arithmetic mean and geometric mean)
- Truncated Normal
- Truncated Log-Normal (importing arithmetic mean and geometric mean)
- Beta
- Binomial
- Boolean
- Cumulative
- Discrete
- Gamma
- Truncated Gamma
- Poisson
- Weibull
- Truncated Weibull
- Exponential
- Pareto
- Negative Binomial
- Truncated Pareto

The database links/download tests set up for failure include:

- Attempting to import scalar constant with incompatible units
- Attempting to import scalar constant with no units declared in the database
- Attempting to import 1-D table with incompatible units
- Attempting to import 2-D table with incompatible units
- Attempting to import stochastic distribution with incompatible units
- Attempting to import stochastic distribution with no units declared in the database
- Attempting to import a matrix with more than 60 columns
- Attempting to import a matrix with too many records in the Value Component Table
- Attempting to import a vector with an incorrect parameter code in the Parameter Table
- Attempting to import a vector without enough records in the Value Component Table

In order to access and download from the Yucca Mountain database that is set up for verification testing, the user must perform the following steps:

1. Copy file **GS09_Yucca_DB.MDB** to the root directory from which GoldSim is executed.
2. Open the WINDOWS control panel and double click the Administrative Tools" icon. Double click the "ODBC Data Sources (32 Bit)" icon.
3. In the "System DSN" tab click the "Add" button, highlight Microsoft Access Driver in the new dialog window and click the "Finish" button. This will open a dialog window called "OBDC Microsoft Access 97 Setup". In the "Data Source Name" box type "Yucca Database Verification" then click the "Select" button in the "Database" box. Another dialog window called "Select Database" will open, select the directory in which the file **GS09_Yucca_DB.MDB** is located and select the file **GS09_Yucca_DB.MDB** . Click the "OK" button to close all ODBC dialog windows.
4. In the GoldSim model GS09a_DBAS.gsm do the following for each element:
   a. Open each element in the container labeled "Yucca_Mountain_Database" and click on its "Database" tab.
   b. Select "Yucca Mountain Database" from the dropdown menu for the Database Type, and select "Yucca Database Verification" from the dropdown menu for Database.
   c. Click the "Download Now" button. If the download was successful the "Status" box in the "Database" dialog of the element will display a message indicating the time of the successful download.
   d. Compare each downloaded element against results presented in Table GS09_DBAS_1 to verify linking to the Yucca Mountain database. **For the old style table elements (prior to version 9) the user may have to choose the option "do not link to database" in the database tab of the element dialog to view table data.** Re-connect to the Yucca Mountain Database after verifying the contents of tables.
   e. Leave each element connected to the Yucca Mountain database after it has been successfully downloaded.

It is not necessary to run the program.

Simple Database

The Simple database link/download tests include:

<u>Constants</u>

- scalar constant with length conversion
- vector data definition
- matrix data definition

<u>Stochastics</u>

- Uniform
- Log-Uniform
- Triangular
- Log-Triangular
- Normal
- Log-Normal (importing arithmetic mean and geometric mean)
- Truncated Normal
- Truncated Log-Normal (importing arithmetic mean and geometric mean)
- Beta
- Binomial
- Boolean
- Cumulative
- Discrete
- Gamma
- Truncated Gamma
- Poisson
- Weibull
- Truncated Weibull
- Exponential
- Pareto
- Negative Binomial
- Truncated Pareto

The database links/download tests set up for failure include:

- Attempting to import scalar constant with incompatible units
- Attempting to import scalar constant with no units declared in the database
- Attempting to import stochastic distribution with incompatible units
- Attempting to import stochastic distribution with no units declared in the database
- Attempting to import a vector with a row index in the Array Value Table out of bounds
- Attempting to import a vector with a column index in the Array Value Table out of bounds

- Attempting to import a vector with too many records in the Array Value Table
- Attempting to import a vector without enough records in the Array Value Table
- Attempting to import a vector with an argument mismatch in the Parameter Table (the dimensions in the Parameter Table do not match those of the vector)
- Attempting to import a vector with a column entry of zero in the Array Value Table
- Attempting to import a matrix with no records in the Array Value Table

In order to access and download from the Simple database that is set up for verification testing, the user must perform the following steps:

1. Copy file **GS09_SIMPLE_DB.MDB** to the root directory from which GoldSim is executed.
2. Open the WINDOWS control panel and open the “ODBC Data Sources (32 Bit)” folder.
3. In the “System DSN” tab click the “Add” button, highlight Microsoft Access Driver in the new dialog window and click the “Finish” button. This will open a dialog window called “OBDC Microsoft Access 97 Setup”. In the “Data Source Name” box type “Simple Database Verification” then click the “Select” button in the “Database” box. Another dialog window called “Select Database” will open, select the directory in which the file **GS09_SIMPLE_DB.MDB** is located and select the file **GS09_SIMPLE_DB.MDB**. Click the “OK” button to close all ODBC dialog windows.
4. In the GoldSim model GS09_DBASa.gsm do the following for each element:
   a. Open each element in the container labeled “Simple_Database” and click on its “Database” tab.
   b. Select "Simple GoldSim Database" from the dropdown menu for the Database Type, and select “Simple Database Verification” from the dropdown menu for Database.
   c. Click the “Download Now” button. If the download was successful the “Status” box in the “Database” dialog of the element will display a message indicating the time of the successful download.
   d. The user compares each downloaded element against the verification results presented in Table GS09_DBAS_2 to verify linking to a Simple database. The user may have to choose the option “do not link to database” in the database tab of the element dialog to view tables. Re-connect to the Simple Database after verifying table data.
   e. Leave each element connected to the Simple database after it has been successfully downloaded.

Generic Database

The Generic database link/download tests include:

- Scalar constant with length conversion
- Scalar constant with mass conversion
- Scalar constant with time conversion

In order to access and download from the generic database that is set up for verification testing the user must perform the following steps:

1. Copy file **GS09_GEN_DB.MDB** to the root directory from which GoldSim is executed.
2. Open the WINDOWS control panel and open the “ODBC Data Sources (32 Bit)” folder.
3. In the “System DSN” tab click the “Add” button, highlight Microsoft Access Driver in the new dialog window and click the “Finish” button. This will open a dialog window called “OBDC Microsoft Access 97 Setup”. In the “Data Source Name” box type “Generic Database Verification” then click the “Select” button in the “Database” box. Another dialog window called “Select Database” will open, select the directory in which the file **GS09_GEN_DB.MDB** is located and select the file **GS09_GEN_DB.MDB**. Click the “OK” button to close all ODBC dialog windows.
4. In the GoldSim model GS09a_DBAS.gsm open each element in the container labeled “Container_Generic_Database” and click on the “Database” tab.
5. Select “Generic Database” from the dropdown menu for the Database Type, and select “Generic Database Verification” from the dropdown menu for the Database.
6. Enter the following into the "Database" tab for each of the test elements listed below (note that you may need to first clear the database link, by setting the “Select Database Type” pick list back to “No Database”, and then re-establish it in order to view the correct results):

	Define Fields	Where	Incoming Units
Constant_Generic_Volume:	Value	ID = 'one'	m3
Constant_Generic_Mass:	Value	ID = 'two'	kg
Constant_Generic_Time:	Value	ID = 'three'	sec

7. Click the “Download Now” button. If the download was successful the “Status” box in the “Database” dialog of the element will display a message indicating the time of the successful download.
8. The user compares each downloaded element against results presented in Table GS09_DBAS_3 to verify linking to a Generic database.
9. Leave each element connected to the Generic database after it has been successfully downloaded.

TABLE GS09a_ DBAS_1 - Yucca Mountain Database

Tests Element	Result Type	Expected Values
Constant_Length	Element tool tip	Constant_Length = 3.281 ft Linked To: Yucca Mountain Database Status: Download Succeeded at (date/time of last download) Effective Date : 1999-06-25 00:00:00

TABLE GS09a_ DBAS_1 - Yucca Mountain Database

Tests Element	Result Type	Expected Values
		Reference Document: Constant Document ID: B00000000-01717-4301-00003 DTN: LL9807079704242.042 MOL: MOL.19980724.092
Constant_Mass	Element tool tip	Constant_Mass = 2.2046 lbm
Constant_Time	Element tool tip	Constant_Time = 1 hr
Vector_Days	Element dialog, edit Vector	Sun 1 Mon 2 Tues 3 Wed 4 Thur 5 Fri 6 Sat 7
Matrix_Days_X_Weeks	Element dialog, edit Matrix	*S M T W T F S* w1 27 28 29 30 31 1 2 w2 3 4 5 6 7 8 9 w3 10 11 12 13 14 15 16 w4 17 18 19 20 21 22 23 w5 24 25 26 27 28 1 2
Table_1D	Element properties	0 gal -40 F 1 gal 0 F 2 gal 32 F 3 gal 100 F
Table_2D	Element properties	**col** **row 1 g 2 g 3 g** **1 ft** -10 C 10 C 100 C **2 ft** -20 C 20 C 200 C **3 ft** -30 C 30 C 300 C
Uniform	Element dialog, edit distribution	min = 0 min max =1000 min
Uniform_Log	Element dialog, edit distribution	min = 1 hr max = 1000 hr
Normal	Element dialog, edit distribution	mean = 100 mol/l st. dev. = 20 mol/l
Normal_Truncated	Element dialog, edit distribution	mean = 100 mol/gal st. dev. = 20 mol/gal min = 60 mol/gal max = 140 mol/gal
Normal_Log_geo	Element dialog, edit distribution	geometric mean = 89.4521 ft/day geometric st. dev. = 1.60381
Normal_Log_trunc_geo	Element dialog, edit distribution	geometric mean = 89.4521 ft/day geometric st. dev. = 1.60381 min = 50 ft/day max =150 ft/day
Normal_Log_true	Element dialog, edit distribution	true mean = 100 m/s true st. dev. = 50 m/s
Normal_Log_trunc_true	Element dialog, edit distribution	true mean = 100 m/s true st. dev. = 50 m/s

TABLE GS09a_ DBAS_1 - Yucca Mountain Database

Tests Element	Result Type	Expected Values
		min = 50 m/s max = 150 m/s
Triangular	Element dialog, edit distribution	min = 10 acre most likely = 30 acre max = 100 acre
Triangular_Log	Element dialog, edit distribution	min = 10 ha most likely = 30 ha max = 100 ha
Cumulative	Element dialog, edit distribution	probability value 0 0 deg 0.1 10 deg 0.2 20 deg 0.3 30 deg 0.4 40 deg 0.5 50 deg 0.6 60 deg 0.7 70 deg 0.8 80 deg 1.0 100 deg
Discrete	Element dialog, edit distribution	probability value 0.1 $\pi/2$ = 1.570796 rad 0.2 π = 3.141593 rad 0.3 $3\pi/2$= 4.712389 rad 0.4 2π = 6.283185 rad
Poisson	Element dialog, edit distribution	expected value = 25
Beta	Element dialog, edit distribution	mean = 40 gpm st. dev. = 20 gpm min = 0 gpm max = 100 gpm
Gamma	Element dialog, edit distribution	mean = 16 mg st. dev. = 8 mg
Gamma_Truncated	Element dialog, edit distribution	mean = 16 g st. dev. = 8 g min = 5 g max = 25 g
Weibull	Element dialog, edit distribution	min = 10 day Weibull slope = 2 mean-min = 8.8625 day
Weibull_Truncated	Element dialog, edit distribution	min = 10 a Weibull slope = 2 mean-min = 8.8625 a max = 25 a
Binomial	Element dialog, edit distribution	batch size = 100 probability = 0.25
Boolean	Element dialog, edit distribution	probability of true = 0.75
Student's t	Element dialog, edit distribution	degrees of freedom = 20
Exponential	Element dialog, edit distribution	Mean = 20 d

TABLE GS09a_ DBAS_1 - Yucca Mountain Database

Tests Element	Result Type	Expected Values
Pareto	Element dialog, edit distribution	a = 20, b = 5
Negative Binomial	Element dialog, edit distribution	number of successes = 10 probability of success = 0.5
Truncated Pareto	Element dialog, edit distribution	a = 10, b = 5 Maximum = 5.75$
Beta (Success, Failures)	Element dialog, edit distribution	Number of successes = 5 Number of failures = 15
Extreme Value (Min)	Element dialog, edit distribution	Location = 20 gal Scale = 2 gal
Extreme Value (Max)	Element dialog, edit distribution	Location = 150 kg Scale = 10 kg
Extreme Probability (Min)	Element dialog, edit distribution	Number of samples = 5
Extreme Probability (Max)	Element dialog, edit distribution	Number of samples = 20
Pearson Type III	Element dialog, edit distribution	Location = $50000 Scale = $500 Shape = 2
Sampled Result	Element dialog, edit distribution	50 52 52 53 54
Sampled Result (Extrapolated)	Element dialog, edit distribution	95 100 105 120 130
Constant_Length_Fail	Element dialog, download status	download failed
Constant_Mass_Fail	Element dialog, download status	download failed
Matrix_Fail_Too_Many_Rows	Element dialog, download status	download failed
Matrix_Fail_Too_Many_Columns	Element dialog, download status	download failed
Vector_Fail_Too_Few_Rows	Element dialog, download status	download failed
Vector_Fail_Bad_Param_Code	Element dialog, download status	download failed
Normal_Fail_Units	Element dialog, download status	download failed
Normal_Fail_No_Units	Element dialog, download status	download failed
Table-1D_Units	Element dialog, download status	download failed
Table-2D_Units	Element dialog, download status	download failed

TABLE GS09a_ 2 - Simple Database

<table>
<tr><th>Test Element</th><th>Result Type</th><th>Expected Value</th></tr>
<tr><td>Data1</td><td>Element tool tip</td><td>Data1 = 105
Linked to: Simple GoldSim Database
Status: Download Succeeded at (date/time of download)</td></tr>
<tr><td>Vector</td><td>Element dialog, edit vector</td><td><table><tr><td>Sun</td><td>7</td></tr><tr><td>Mon</td><td>6</td></tr><tr><td>Tues</td><td>5</td></tr><tr><td>Wed</td><td>4</td></tr><tr><td>Thur</td><td>3</td></tr><tr><td>Fri</td><td>2</td></tr><tr><td>Sat</td><td>1</td></tr></table></td></tr>
<tr><td>Matrix</td><td>Element dialog, edit matrix</td><td><table><tr><td></td><td>W</td><td>P</td><td>P</td><td>H</td></tr><tr><td>A</td><td>6</td><td>5</td><td>4</td><td>3</td></tr><tr><td>O</td><td>5</td><td>4</td><td>3</td><td>2</td></tr><tr><td>P</td><td>4</td><td>3</td><td>2</td><td>1</td></tr></table></td></tr>
<tr><td>Uniform_1</td><td>Element dialog, edit distribution</td><td>min = 25
max =50</td></tr>
<tr><td>Uniform_Log_1</td><td>Element dialog, edit distribution</td><td>min = 0.01 m
max = 1 m</td></tr>
<tr><td>Normal_1</td><td>Element dialog, edit distribution</td><td>mean = 25
st. dev. = 5</td></tr>
<tr><td>Normal_Truncated_1</td><td>Element dialog, edit distribution</td><td>mean = 100 $
st. dev. = 20 $
min = 60 $
max = 140 $</td></tr>
<tr><td>Normal_Log_geo_1</td><td>Element dialog, edit distribution</td><td>geometric mean = 89ft
geometric st. dev. = 1.6</td></tr>
<tr><td>Normal_Log_trunc_geo_1</td><td>Element dialog, edit distribution</td><td>geometric mean = 89
geometric st. dev. = 2
min = 80
max =150</td></tr>
<tr><td>Normal_Log_true_1</td><td>Element dialog, edit distribution</td><td>true mean = 100
true st. dev. = 50</td></tr>
<tr><td>Normal_Log_trunc_true_1</td><td>Element dialog, edit distribution</td><td>true mean = 100
true st. dev. = 50
min = 50
max = 150</td></tr>
<tr><td>Triangular_1</td><td>Element dialog, edit distribution</td><td>min = 10
most likely = 30
max = 100</td></tr>
<tr><td>Triangular_Log_1</td><td>Element dialog, edit distribution</td><td>min = 10
most likely = 30
max = 100</td></tr>
<tr><td>Cumulative_1</td><td>Element dialog, edit distribution</td><td>probability value
0 0
0.2 1
0.3 7
1.0 8</td></tr>
<tr><td>Discrete_1</td><td>Element dialog, edit distribution</td><td>probability value
0.1 1</td></tr>
</table>

		0.4 2 0.5 3
Poisson_1	Element dialog, edit distribution	expected value = 40
Beta_1	Element dialog, edit distribution	mean = 40 st. dev. = 20 min = 0 max = 100
Gamma_1	Element dialog, edit distribution	mean = 16 st. dev. = 8
Gamma_Truncated_1	Element dialog, edit distribution	mean = 16 st. dev. = 8 min = 5 max = 25
Weibull_1	Element dialog, edit distribution	min = 10 Weibull slope = 2 mean-min = 8
Weibull_Truncated_1	Element dialog, edit distribution	min = 10 Weibull slope = 2 mean-min = 8 max = 25
Binomial_1	Element dialog, edit distribution	batch size = 60 probability = 0.25
Boolean_1	Element dialog, edit distribution	probability of true = 0.75
Student's t	Element dialog, edit distribution	degrees of freedom = 15
Exponential	Element dialog, edit distribution	Mean = 30 d
Pareto	Element dialog, edit distribution	a = 30, b = 10
Negative Binomial	Element dialog, edit distribution	number of successes = 15 probability of success = 0.6
Truncated Pareto	Element dialog, edit distribution	a = 30, b = 10 Maximum = 12
Beta (Success, Failures)	Element dialog, edit distribution	Number of successes = 12 Number of failures = 35
Extreme Value (Min)	Element dialog, edit distribution	Location = 10 kg Scale = 1kg
Extreme Value (Max)	Element dialog, edit distribution	Location = 30 gal Scale = 3 gal
Extreme Probability (Min)	Element dialog, edit distribution	Number of samples = 25
Extreme Probability (Max)	Element dialog, edit distribution	Number of samples = 100
Pearson Type III	Element dialog, edit distribution	Location = $1000 Scale = $250 Shape = 2
Sampled Result	Element dialog, edit distribution	10 12 12 10 11
Sampled Result (Extrapolated)	Element dialog, edit distribution	201 203 210

		215
Vector_Row_Num_too_Big	Element dialog, download status	download failed
Vector_Col_Num_too_Big	Element dialog, download status	download failed
Vector_Too_Many_Records	Element dialog, download status	download failed
Vector_Not_Enough_Records	Element dialog, download status	download failed
Vector_Parm_Arg_Mismatch	Element dialog, download status	download failed
Vector_Zero_Entry	Element dialog, download status	download failed
Matrix_No_Records_In_AVT	Element dialog, download status	download failed
Constant_Length_Fail_1	Element dialog, download status	download failed
Constant_Mass_Fail_1	Element dialog, download status	download failed
Normal_Fail_Units_1	Element dialog, download status	download failed
Normal_Fail_No_Units_1	Element dialog, download status	download failed

Table GS09a_ 3 - Generic Database

Test Element	Result Type	Expected Value
Constant_Generic _ Volume	Element tool tip	Constant_Generic_Volume = 264 gal
Constant_Generic_Mass	Element tool tip	Constant_Generic_Mass = 1000 g
Constant_Generic_Time	Element tool tip	Constant_Generic_Time = 60 min

GS09b_Dbas: Database Links/Downloading - Global Download

Linking and downloading from the Yucca Mountain, Simple, and Generic databases are verified by setting up a model with elements prepared for download execution.

1. Save GS09a_DBAS.gsm and then save it again as GS09b_DBAS.gsm.
2. This test also uses the ODBC connections as those used in GS09a.
3. Press the global download button labeled "DB" in the toolbar and click "OK" to use the default date shown in the control.
4. A Run Log should appear that displays 21 warnings. These warnings should only appear for the elements that were set up for failure.
5. Compare the downloaded elements against the results presented in Tables GS09a_DBAS_1, GS09a_DBAS_2, and GS09a_DBAS_3 to verify linking to a Yucca Mountain, Simple, and Generic database.
6. Press the global download button again and check the box to set a specific date. Change the date to "2/25/99" and click "OK".

7. A Run Log should appear that displays 21 warnings. These warnings should only appear for the elements that were set up for failure.
8. Compare the downloaded elements linked to the Yucca Mountain database against the results presented in Table GS09b_ 1.

Table GS09b_ 1 - Yucca Mountain Database, 2/25/99 Effective Date

Test Element	Result Type	Expected Value
Constant_Length	Element tool tip	Constant_Length = 6.56ft
Constant_Mass	Element tool tip	Constant_Mass = 4.4092 lbm
Constant_Time	Element tool tip	Constant_Time = 2 hr
Vector_Days	Element dialog, edit Vector	Sun 7 Mon 6 Tues 5 Wed 4 Thur 3 Fri 2 Sat 1
Matrix_Days_X_Weeks	Element dialog, edit Matrix	*S M T W T F S* w1 1 2 3 4 5 6 7 w2 8 9 10 11 12 13 14 w3 15 16 17 18 19 20 21 w4 22 23 24 25 26 27 28 w5 29 30 31 32 33 34 35
Table_1D	Element properties	0gal -40F 1gal -0F 2gal 32F 3gal 100F
Table_2D	Element properties	**Col** **row 1g 2g 3g** **1ft** -10C 10C 100C **2ft** -20C 20C 200C **3ft** -30C 30C 300C
Uniform	Element dialog, edit distribution	min = 0min max =1000min
Uniform_Log	Element dialog, edit distribution	min = 2hr max = 2000hr
Normal	Element dialog, edit distribution	mean = 200mol/l st. dev. = 40mol/l
Normal_Truncated	Element dialog, edit distribution	mean = 200mol/gal st. dev. = 40mol/gal min = 120mol/gal max = 280mol/gal
Normal_Log_geo	Element dialog, edit distribution	geometric mean = 178.90419ft/day geometric st. dev. = 3.20762
Normal_Log_trunc_geo	Element dialog, edit distribution	geometric mean = 178.90419ft/day geometric st. dev. = 3.20762

		min = 100ft/day max =300ft/day
Normal_Log_true	Element dialog, edit distribution	true mean = 200m/s true st. dev. = 100m/s
Normal_Log_trunc_true	Element dialog, edit distribution	true mean = 200m/s true st. dev. = 100m/s min = 50m/s max = 150m/s
Triangular	Element dialog, edit distribution	min = 20acre most likely = 60acre max = 200acre
Triangular_Log	Element dialog, edit distribution	min = 20ha most likely = 60ha max = 200ha
Cumulative	Element dialog, edit distribution	probability value 0 0deg 0.1 10deg 0.2 20deg 0.3 30deg 0.4 40deg 0.5 50deg 0.6 60deg 0.7 70deg 0.8 80deg 1.0 100deg
Discrete	Element dialog, edit distribution	probability value 0.1 π = 3.141593rad 0.2 $3\pi/2$ = 4.712389rad 0.3 2π = 6.283185rad 0.4 4π = 12.566rad
Poisson	Element dialog, edit distribution	Expected value = 50
Beta	Element dialog, edit distribution	mean = 80gpm st. dev. = 40gpm min = 0gpm max = 200gpm
Gamma	Element dialog, edit distribution	mean = 32mg st. dev. = 16mg
Gamma_Truncated	Element dialog, edit distribution	mean = 32g st. dev. = 16g min = 10g max = 50g
Weibull	Element dialog, edit distribution	min = 20day Weibull slope = 2 mean-min = 17.7250029day
Weibull_Truncated	Element dialog, edit distribution	min = 20a Weibull slope = 2 mean-min = 17.72499a max = 50a
Binomial	Element dialog, edit distribution	batch size = 200 probability = 0.5

Boolean	Element dialog, edit distribution	probability of true = 0.80
Student's t	Element dialog, edit distribution	degrees of freedom = 10
Exponential	Element dialog, edit distribution	Mean = 35 d
Pareto	Element dialog, edit distribution	a = 15, b = 7
Negative Binomial	Element dialog, edit distribution	number of successes = 20 probability of success = 0.8
Truncated Pareto	Element dialog, edit distribution	a = 5, b = 15$ Maximum = 17$
Beta (Success, Failures)	Element dialog, edit distribution	Number of successes = 28 Number of failures = 46
Extreme Value (Min)	Element dialog, edit distribution	Location = 50 gal Scale = 3 gal
Extreme Value (Max)	Element dialog, edit distribution	Location = 190 kg Scale = 13 kg
Extreme Probability (Min)	Element dialog, edit distribution	Number of samples = 20
Extreme Probability (Max)	Element dialog, edit distribution	Number of samples = 5
Pearson Type III	Element dialog, edit distribution	Location = $200000 Scale = $10000 Shape = 5
Sampled Result	Element dialog, edit distribution	100 105 108 108 110
Sampled Result (Extrapolated)	Element dialog, edit distribution	200 220 250 260 270

GS09c_File Element: Finding Local Files for File Elements

This file tests the ability of the File Element to locate a local text file and to download a file defined in a Yucca database. Open File. Ensure that the local file "FileHere.txt" is in the test folder. Next, click on the "Database" button, then click again to deactivate it. This will cause the element to search for the specified local file name. Ensure that "FileHere.txt" is still found (i.e., the message "Local File" shows up Status box).

Then delete FileHere.txt, connect to the Yucca test database, and download. Confirm that a file is downloaded to the current directory, with the local file name that you specified.

Next, turn off the download and delete FileNotHere.txt from your folder if it exists. Open File_Failed and ensure that "Local file missing" is the message reported (the file that File_Failed is trying to find in fact does not exist locally).

Finally, try to download File_Failed from the database. The download should fail because the database does not contain a CRC code for the file. However, a copy of the file should be placed into your folder.

GS10_Clone1: Basic Clone Tests

This file contains a number of tests to verify the proper performance of cloned elements in GoldSim. The test consists of two major parts.

1. Cloning of elements: Cloned elements in GoldSim are verified by setting up a model with 5 containers holding every possible element that can be cloned. The container "Container_Basic_Element_Clones" holds clones of basic elements side by side. To verify the clone characteristics of basic elements, the user changes the value and parameters in one clone and checks that the other clone element is updated to the changed parameters. The element description, notes, and Save Results options are not cloned. The Script element is not allowed to be cloned. To test the Script element, try cloning the Test_Script_Element container. Then go into the Test_Script_Element container, and try cloning the Script element. In both casesyou should receive an error message. The user does not need to run the model.

Stochastic clones are stored in a separate container "Container_Stochastic_Clones". Each type of stochastic distribution is present in this container, along with elements intended to exercise the advanced stochastic features such as correlation and importance sampling.

A third container "Container_Numerous_Clones" holds 57 clones of a data element. To verify the clone characteristics of multiple clones of the same element the user changes the value of any one of the elements and checks that the current value of all the clones has updated to the new value. The user does not need to run the model.

The environment clone elements are held in the containers "Container_Enviro_Element_Clon1" and "Container_Enviro_Element_Clon2". To verify the clone characteristics of environmental element clones the user changes the parameters of any one element in "Container_Enviro_Element_Clon2" and checks that the parameters are updated in the clone element in "Container_Enviro_Element_Clon1". The user does not need to run the model.

2. Sealing of cloned containers: This test verifies that sealing of cloned containers works properly. In this container, Container5_1 is the clone of Container5. To perform the test, proceed as follows (first, ensure that all containers inside Container1 are neither locked nor sealed):

> 1. Seal Container5 (path: \C1\C2\C5). Ensure that the clone, Container5_1, has also been sealed as a result of sealing C5. Containers \C5\C6 and \C5_1\C6 should also now be sealed (e.g., look at the containers' tooltip windows or in the main browser to confirm the sealed status).
>
> 2. Remove (don't break) the seal on Container5, and ensure the seal on Container5_1 is also removed as a result. Containers \C5\C6 and \C5_1\C6 should still be sealed.
>
> 3. Re-seal Container5. Next, break the seal on Container5 by changing the input value for the element Data1 inside Container5. Ensure that the seal for Container5_1 is also broken. However, the seals for containers \C5\C6 and \C5_1\C6 should still be intact.

4. Lock Container5. Container5_1 and all of the contents of Containers5 and 5_1 should now be locked (as evidenced by their names being grayed out in the main browser window and the unavailability of menu and toolbar options inside the locked elements.

5. Unlock Container5, then seal Container1. Try to clone an element that resides inside Container5. Cloning should not be allowed without breaking the seal. Repeat for a locked Container1. Unlock Container1, Container2, and Container5.

6. Seal Container5. Try to change the input value, type, display units, results flags and database links for Data1_Clone. None of these changes should be allowed without breaking the seal. Repeat for a locked Container5.

3. Database Linked Clones: This test verifies cloning of elements linked to a database works properly. The side by side elements are clones. To perform the test, proceed as follows: Open the original element (left-hand or top element of the pairs) and download from the Yucca Mountain Database (Use the same database connection that was required to perform GS09_DBAS). Open the clone element and check that the parameters match the values of the original element. This applies to elements ”Constant Length”, ”Normal”, “Table_1D”, and “Table_2D” in ”Container_DBAS_Linked_Clones”.

GS11_Clone2: Cloned Containers and Models

This file contains two simple tests of container-cloning functionality:

1. Dam_System_A describes the occurrence and consequences of a dam break for one dam in a site system. The container and all of its elements are all original (not cloned). Dam_System_A_1 is a clone of Dam_System_A and should show the same average results, since both share identical inputs. Dam_System_A_1_1 is a clone of Dam_System_A_1. Run the model to see results. Expected results are shown in the tool-tip window for the integrator element within each container, and are also shown in Table GS11_1. Note that the results for these cloned containers will not be identical because cloned stochastics are sampled independently.

2. Dam_System_A_2 is a clone of Dam_System_A, but A_2 uses a different rate of occurrence for dam breaks. Expected results are shown in the tool-tip window for the integrator element within each container, and are also shown in Table GS11_1.

Table GS11_1

Elements Tested	Test	Expected Output / Result
Dam_System_A, A_1, A_1_1	1	Expected result is a Cum_Flood_ DamBreak between 10,000 and 20,000 m3 over 10 dam breaks (range in possible results is due to stochastic element used in the model)
Dam_System_A_2	2	Expected result is a Cum_Flood_DamBreak

		between 5,000 and 10,000 m3 over 5 dam breaks

3. *Copying and Moving Tests:*
   a) Copy container A11 and ensure that the copy is not a clone by changing the properties of a number of elements inside the copied container, and rerunning the model – results in the Dam_System_A_1_1 container should not change.
   b) Delete the copied container and place container A1 and A11 inside a new container (call it Original).
   c) Make changes to Dam_System_A, and ensure these changes are reflected in the clones inside the Original container. Now copy the Original container and paste it (call it Copied).
   d) In the Copied container, Dam_System_A_1 and Dam_System_A_1_1 should still be clones. Confirm this by making a number of changes to one of the cloned Dam_System containers. Ensure these changes are reflected in the other cloned container within the Copied container, but not in Dam_System_A or the Dam_System containers inside the Original container.

GS11b_SubSystem_Cloning

This test verifies that cloning works properly for Conditional, Internal Clock and Looping Containers.

To run the test, clone each of the Submodels and run the model. The verifier should then ensure that the results within both containers correspond with the expected results below (also pasted to the left of each container in the model).

Conditional Container: The container is activated at 20s and deactivated at 80s. It contains an Integrator element whose value increases by 1s/s. Therefore, the Integrator element inside the original and cloned Submodel should have a value of 60s.

Internal Clock Submodel: The container has a Timed Event that occurs four times per second, and a Triggered Event that is triggered each time the clock changes. Events cannot occur between timesteps inside the Submodel, and the minimum timestep length is 0.5s. Therefore, the TriggeredEvent element inside the original and cloned Submodel should have a value of 201.

Looping Container: A function element inside the looping container is equal to the current value of local.LoopCount. The container loops until the value of local.LoopCount is 50. Therefore, in Time History view, the Function element inside the original and cloned Submodel should have a constant value of 50.

GS12_External: External Functions

This test verifies the correct functioning of the External element for Value and Condition type outputs (time series and table definition types are tested in GS29_External2).

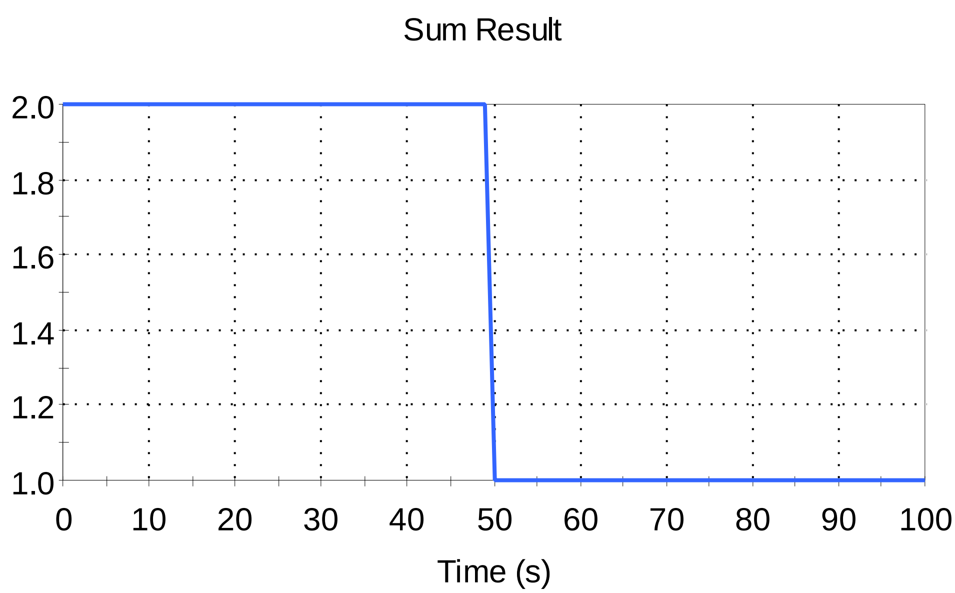
The verifier should first enter the Value container. External function elements in GoldSim are verified by calling the external function “XF004”. The function returns the sum and product of two input values. To call the external function the user must map the path to the file “cfstubs.dll” in the element dialog. To verify the external function capability of GoldSim the user must change the element inputs to 5 and 10 in the element dialog, run the model and check that outputs “sum” = 15 and “ product” = 50. The outputs can be checked by opening the element in the left-hand browser and pointing to the outputs sum and product. The outputs can also be checked by clicking on the green diamond on the right-hand side of the "External" element.

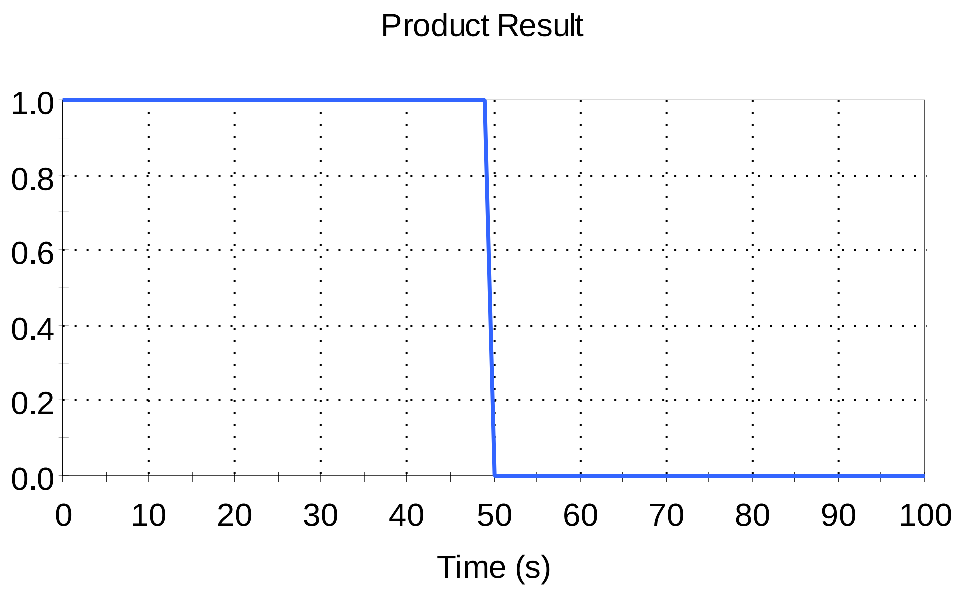
In order to test the ability for a DLL to return an error message, change the value of the first input to the external to 99, and rerun. You should see an error message indicating that a value of 99 was used.

Repeat both tests with the 'Run in Separate Process' check-box checked.

The verifier should then enter the Condition container. Again the External function element uses the cfstubs.dll and the XF004 external function, but this time a conditional value (True_Then_False) is passed as the first argument, and a value of 1 is passed as the second argument. The External element is also modified so that the Product result is returned as a condition (a value of 1 equals true, and 0 equals false). The conditional argument is treated as a 1 when true and a 0 when false.

Expected results for the two Time History elements are as follows:





Repeat both tests in the \Conditional container with the 'Run in Separate Process' check-box checked.

The test should be repeated in its entirety a second time with a 64-bit version of the test file and DLL (GS12_External64.gsm and cfstubs64.dll).

GS12b_External_Options

This test verifies the proper functioning of the Unload and Cleanup options in the External element. The test DLL that is used provides a pop-up dialog that informs the user when it is opened, called, and cleaned up.
The verifier should start the test with the Unload and Cleanup options turned off. The model should then be run. The DLL should be called and cleaned up when the tester brings up the run controller. It should be called and cleaned up again when the model is run. The DLL should then be opened and called 4 times.
The Unload option should then be enabled and the model run. Again the DLL should be called (but not calculated) when the run controller is opened and the model is run. It should then then be loaded/unloaded/calculated 4 times.
The Unload option should then be cleared and the Cleanup option checked. The DLL should be called and cleaned up when the run controller is opened and the model run. The DLL should be called twice per realization and then unloaded at the end of each realization.

This test should be repeated with a 64-bit version of the test DLL (GS12b_External_Options64.gsm and GSCoreTestDLL64.dll).

GS13_Sum: Sum Elements

This file contains all of the tests for the Sum Element. Tests include the following:

1. scalar + scalar
2. vector + vector (scalar vector elements; vector dimension is 1 x 4)

3. matrix + matrix (scalar matrix elements; 4 x 3 matrices)
4. vector + vector (time-variable vector elements; vector dimension is 1 x 4)
5. sum of five vectors (vector dimension is 1 x 4)
6. matrix + matrix (time-variable matrix elements; 4 x 3 matrices)

The model must be run to calculate results. Expected results are shown in the tooltip window for each Sum Element or in tables in the file. Expected results are also shown in Table GS13_1.

Table GS13_1

Element being tested	Test	Expected Output / Result
Scalar_Scalar	1	7
Vector_Vector	2	{2 0 6 0}
Matrix_Matrix	3	{2 0 6}, {4 0 8}, {6 0 10} and {8 0 12} for rows 1, 2, 3, and 4 respectively
Vector_Vector_from_ expressions	4	{7 10 15 16}
Multiple_vectors	5	{14 15 26 21}
Matrix_Matrix_from_ expressions	6	{4 0 6}, {10 0 8}, {20 0 10} and {22 0 12} for rows 1, 2, 3, and 4 respectively

GS14_Extrema: Extrema Elements

This file contains all of the tests for the Extrema Element. The file makes use of four time-dependent expressions (each is a different time-varying function). The following tests are conducted:

<u>Basic Tests</u> (up to a specified time of 100 days)

1. Maximum value of a function
2. Minimum value of a function
3. Vector of maximum values from a vector of time-varying functions (vector dimension is 1 x 4)
4. Vector of minimum values from a vector of time-varying functions vector dimension is 1 x 4)
5. Matrix of maximum values from a matrix of time-varying functions (matrix dimension is 2 x 2)
6. Matrix of minimum values from a matrix of time-varying functions (matrix dimension is 2 x 2)
7. ETime at which maximum/minimum value occurs

The model must be run to calculate results. Expected results are shown in a table located in the file, and are shown in Table GS14_1.

Table GS14_1

Element being tested:	Test	Expected Result / Output
X_max	1	0.992

X_min	2	-0.969
Vector_of_maxes	3	{0.992, 0.866, 0.992, 1}
Vector_of_mins	4	{-0.969, -0.901, -0.969, 0}
Matrix_of_maxes	5	0.992 0.992 0.866 1
Matrix_of_mins	6	-0.969 -0.969 -0.901 0
Time_of_Max (for X)	7	53.9 days
Time_of_Min (for X)	7	42.1 days

GS15_Logical: Logic Elements

This file contains all of the tests for the Logic Elements (AND, OR, NOT). The test makes use of condition-type Data Elements X, Y, and Z, and condition-type Selector Element A. Tests include the following:

1. X AND Y
2. X AND Y AND Z
3. X OR Y
4. X OR Y OR Z
5. X AND A
6. X OR A
7. NOT X
8. NOT A
9. NOT(X OR Y OR Z)
10. NOT(X AND A)

The model must be run to see time-dependent results. Expected results are found in a table located in the file, and are presented in Table GS15_1.

Table GS15_1

Element being tested	Test	Expected Output / Result
And_X_Y	1	TRUE (value of 1)
And_X_Y_Z	2	FALSE (value of 0)
Or_X_Y	3	TRUE
Or_X_Y_Z	4	TRUE
And_X_A	5	FALSE for time <= 50 days; TRUE for time > 50 days
Or_X_A	6	TRUE for all times
Not_X	7	False
Not_A	8	TRUE for time <= 50 days; FALSE for time > 50 days
Not_Or	9	False
Not_And	10	TRUE for time <= 50 days; FALSE for time > 50 days

GS16_Delay: Delay Elements

This test requires the use of two test files, GS16a_Delays - Event and Discrete Change.gsm and GS16b_Information and Material Delays.gsm. The tests verify that Delays function properly by testing inputs, outputs, dispersion, and delay times.

GS16a_Delays - Event and Discrete Change:

This file contains tests for the Event Delay and the Discrete Change Delay. The verifier should run the model and then proceed through the tests below.

1. Enter the Erlang_Dispersion container. In this container, there are a number of event and discrete change delays with different Erlang dispersions (n = 1, 10 and 100). Verify that the Event_Delay_Erlang and Discrete_Change_Delay_Erlang result element graphs correspond with the graphs pasted inside the container, and in figure GS16_01 and GS16_02 below.

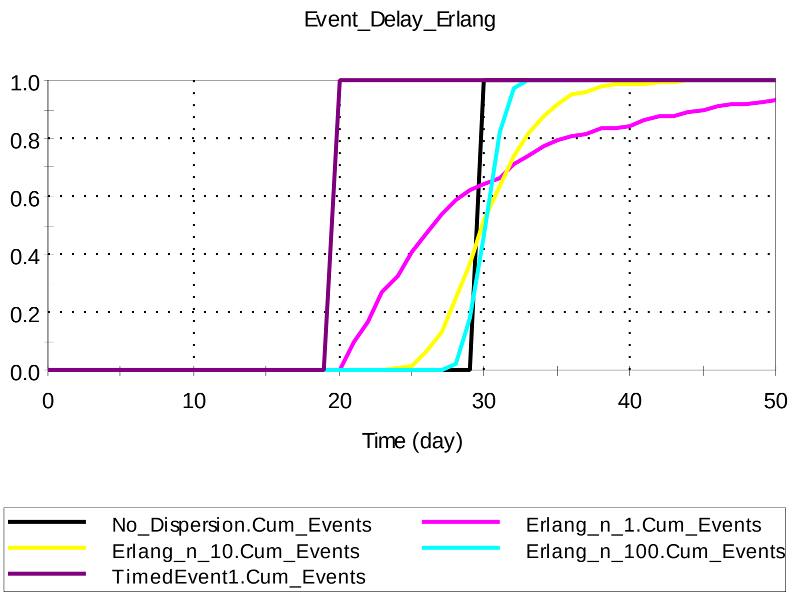


Figure GS16_01

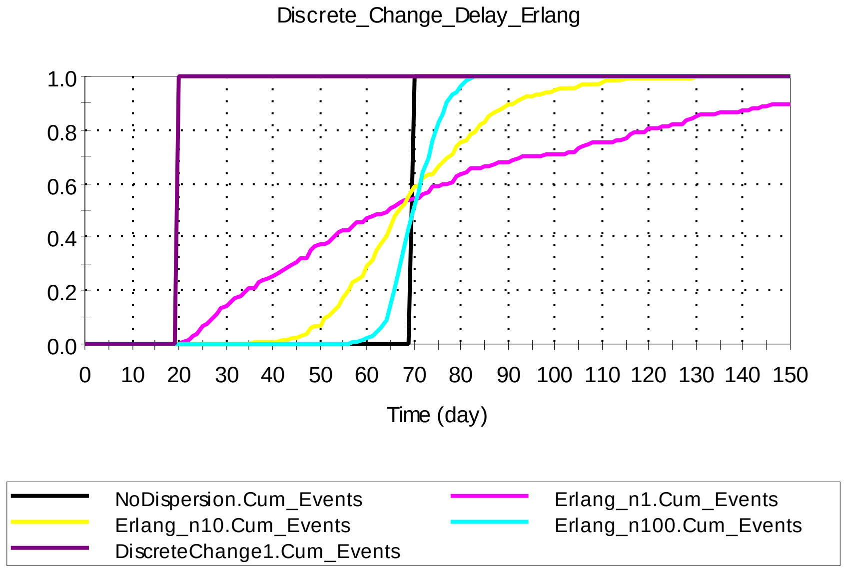


Figure GS16_02

2. Enter the Erlang_Dispersion_1 container. This container tests that conveyor and non-conveyor behavior both work correctly. In this test, the mean delay time is reduced to zero after the timed event enters the delay at 20d. This means that the conveyor delay should emit the event at 20d, while the non-conveyor element is not affected (and is emitted after a 10d delay with an Erlang dispersion with an n value of 1). Compare the output for Event_Delay_Erlang and DC_Delay_Erlang to their expected outputs in Figure GS16_03 and GS16_03b below (also reproduced in the model).

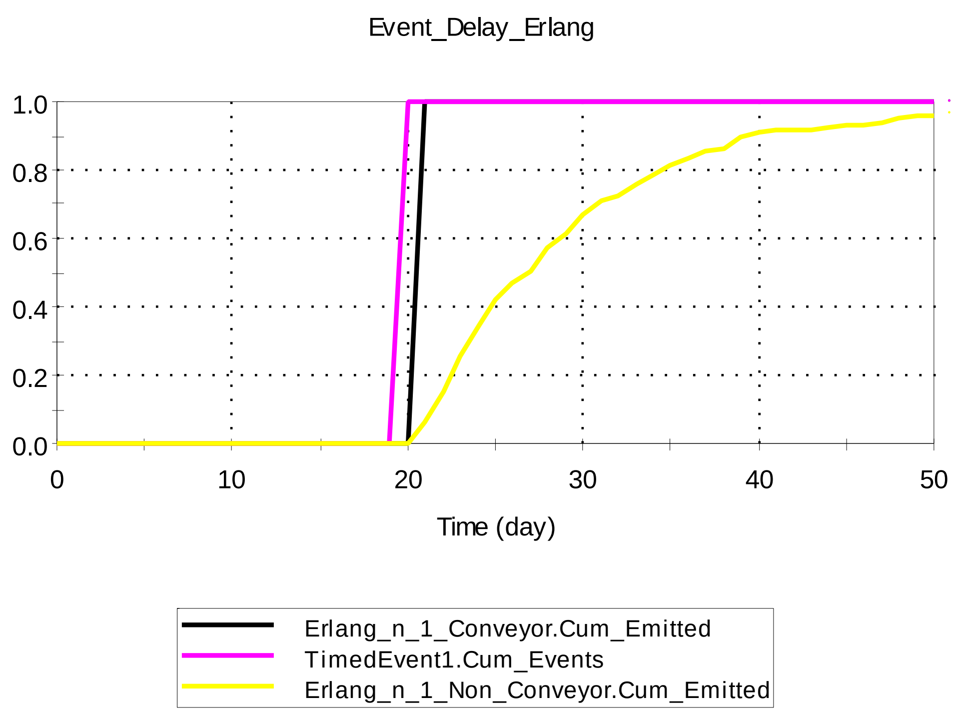


Figure GS16_03

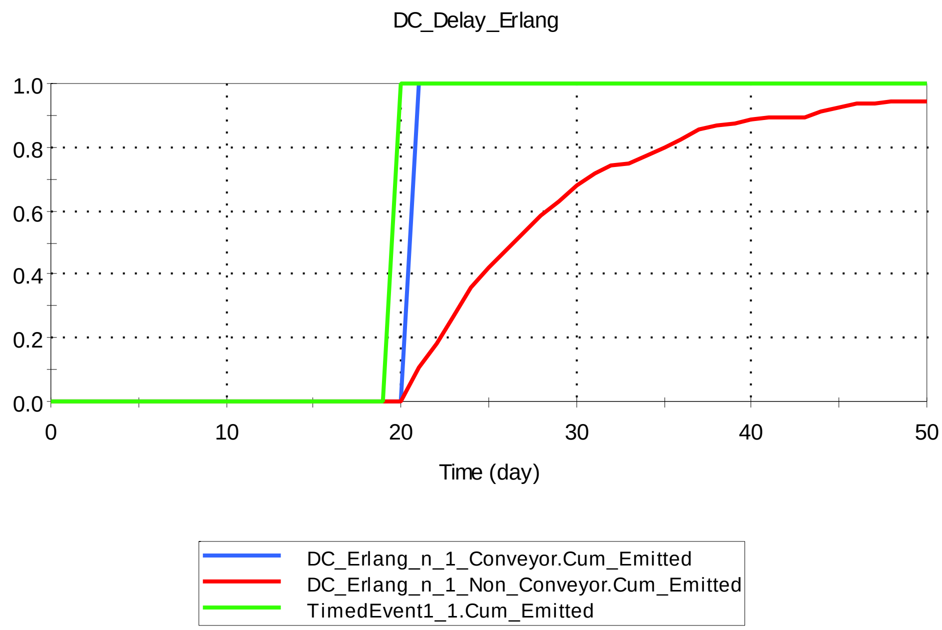


Figure GS16_03b

3. Enter the Std_Dev_Dispersion container. In this container, there are a number of event and discrete change delays with different standard deviation dispersions (S.D. = 0, the delay, one half of the delay). Verify that the Event_Delay_Erlang and Discrete_Change_Delay_Erlang result element graphs correspond with the graphs pasted inside the container, and in figure GS16_04 and GS16_05 below.

4.

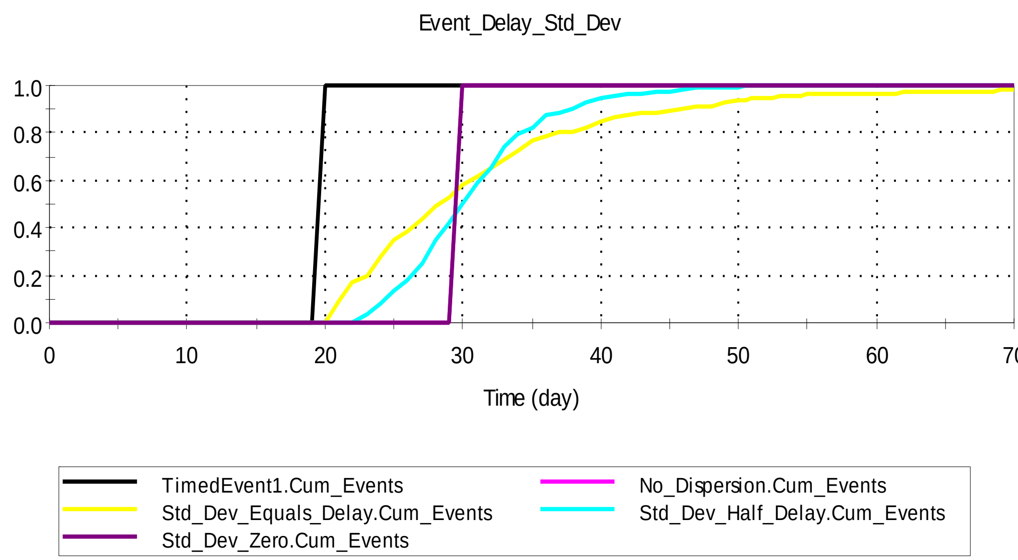


Figure GS16_04

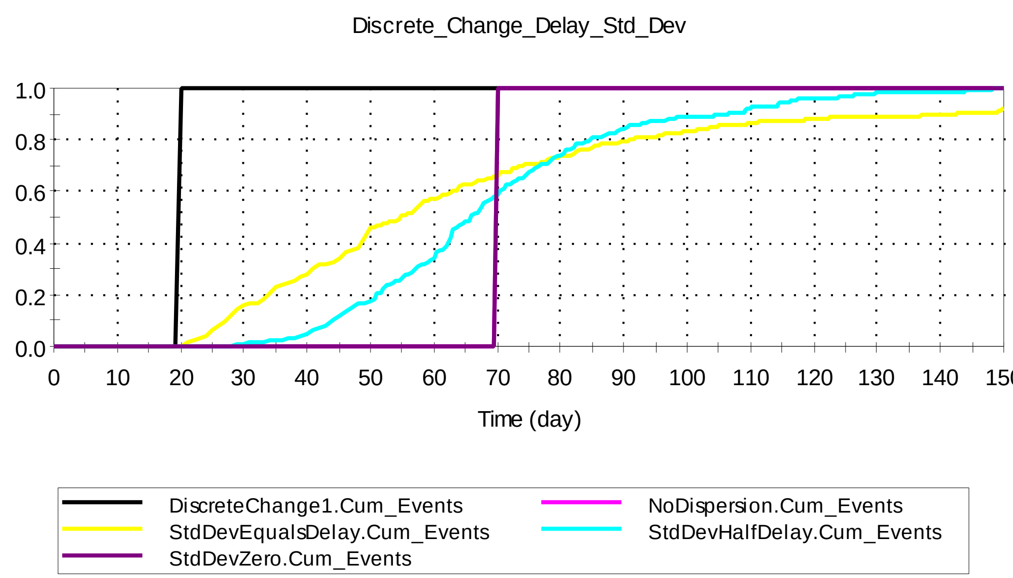


Figure GS16_05

5. Enter the Std_Dev_Dispersion_1 container. This container tests that conveyor and non-conveyor behavior both work correctly. In this test, the mean delay time is reduced to zero after the timed event enters the delay at 20d. This means that the conveyor delay should emit the event at 20d, while the non-conveyor element is not affected (and is emitted after a 10d delay with an Standard Deviation dispersion equal to half the delay (5d)). Compare the output for Event_Delay_Std_Dev and DC_Delay_Std_Dev to their expected output in Figure GS16_06 and GS16_06b below (also reproduced in the model).

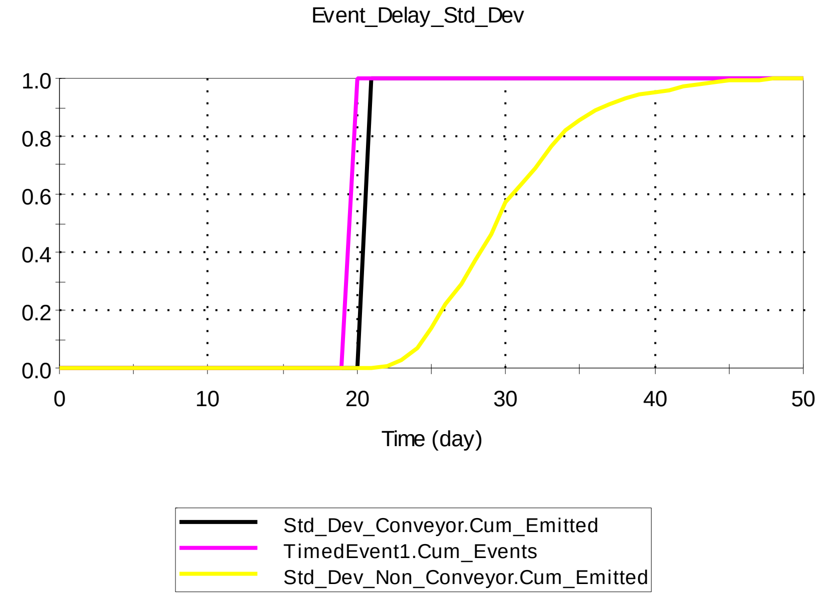


Figure GS16_06

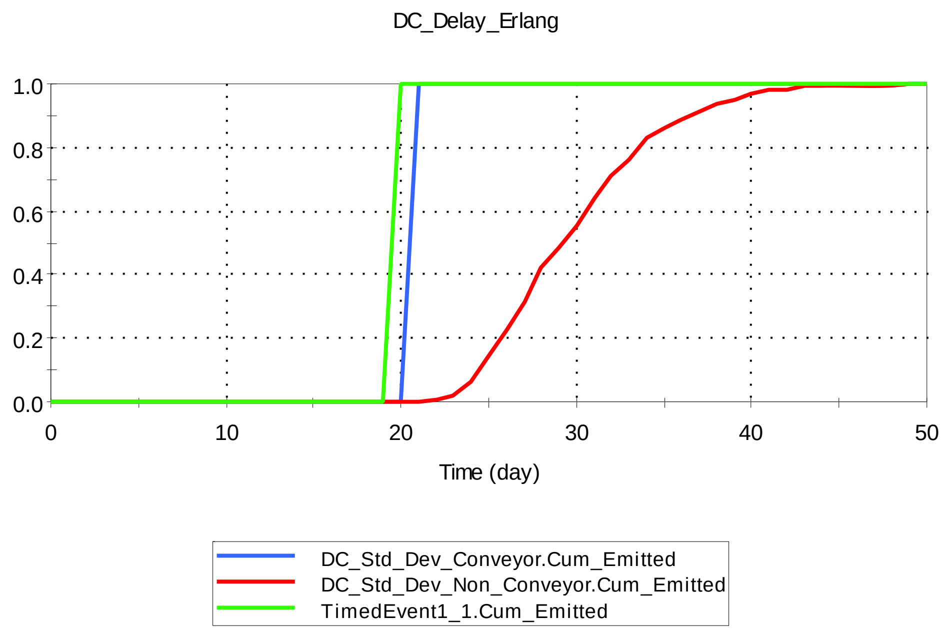


Figure GS16_06b

6. Enter the Variable_Delay_Time container. Confirm that the Conveyor element emits its first event at 25d (admitted at 10d, delay increased from 10 to 20d at 15d), and its second event at 35d (admitted at 15d, 20 d delay) and that the Non-Conveyor element releases its first event at 20d, and its second at 35d. Confirm that the initial discrete change is delayed by 15 days, and the second by 20 days (the first discrete change enters when the delay time is 10 days, and is halfway through the delay when the delay jumps to 20 days).

7. Enter the Zero_Delay_Time container. Confirm that both the Event and Discrete Change delays emit a single event at 10 days and three events at 15 days.

8. Enter the Stochastic container. This test generates an event within the Event_Delay1 element at the start of the simulation and delays it by a period determined by sampling the Normal(125,25) distribution. A second event is issued by TimedEvent1 at time = 100 days to ensure that the Event_Delay does not exhibit conveyor behaviour.

   A successful test is indicated by the 5%/95% confidence bounds in the Result Array in the Milestone_Time CDF including the following values for the given percentiles:

   5th percentile: 83.9 days
   25th percentile: 108.1 days
   50th percentile:125 days
   75th percentile: 141.9 days
   95th percentile: 166.1 days

9. Enter the Statistics container. Confirm that the mean for the Milestone_Time approximately equals 30 days (i.e., the input delay time + time for TimedEvent1 to fire) and that the standard deviation of Milestone_Time approximately equals 5 days (i.e., the dispersion (standard deviation) for the delay).

10. Enter the Queueing_Behavior container. Perform the following checks:
    a. Compare the tabular history for the following outputs of Simple_Queue:
        i. Cum_Emitted = 0 for t<6; 1 for t=6; 2 for 7<=t<=10
        ii. Num_in_Transit = 0 for t=0; 1 for t=1; 2 for t>1
        iii. Num_in_Queue = 0 for t<3; 1 for t=3; 2 for t=4; 3 for 5<=t<=7
    b. Compare the tabular history for the following outputs of Simple_Queue_DC:
        i. Cum_Emitted = 0 for t<6; 1 for t=6; 2 for 7<=t<=10
        ii. Num_in_Transit = 0 for t=0; 1 for t=1; 2 for t>1
        iii. Num_in_Queue = 0 for t<3; 1 for t=3; 2 for t=4; 3 for 5<=t<=7
    c. Compare the tabular history for the following outputs of Variable_Num_in_Transit and Variable_Num_in_Transit_DC:
        i. Capacity increases to 125 at 125 days, then decreases back to 0.
        ii. Num_in_Transit should grow to 125, then decline by 1 per day starting at 200 days
        iii. Num_in_Queue decreases to 25 and remains there until the end of the simulation.
    d. Compare the ServiceTimeResults plot to Figure GS16_7 below.

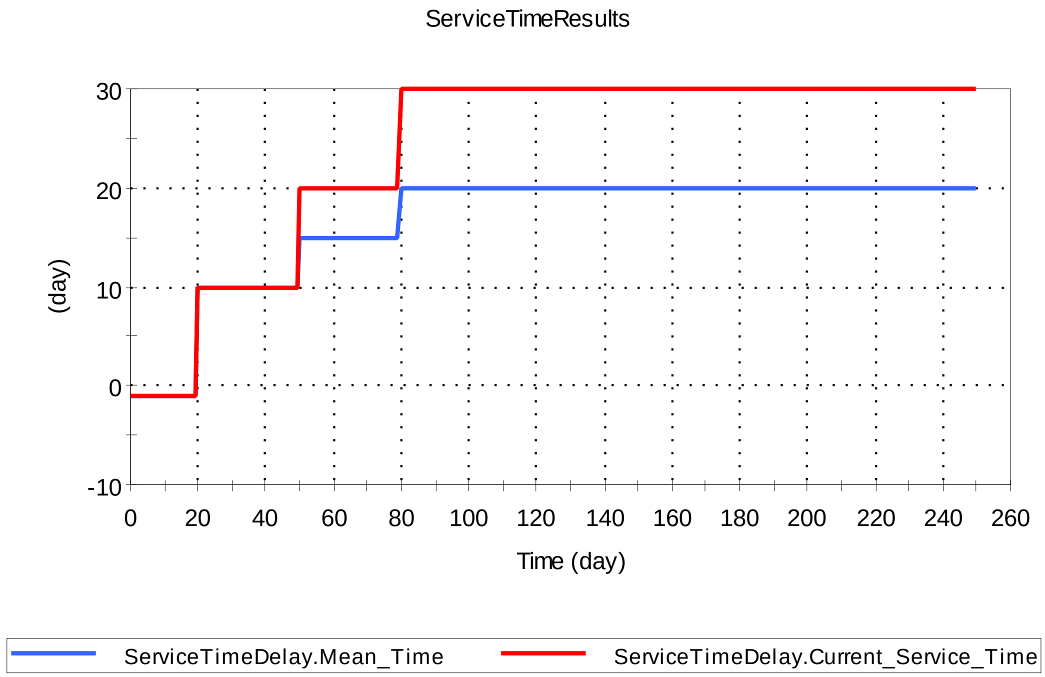


Figure GS16_7

11. Enter the Multiple_Inputs_Event_Delay container. Using Cum_Events, Confirm that Event_Count and Delay_Count end up with the same values (Delay_Count should lag Event_Count by 10 days; the 'value' is the total number of event outputs).

12. Enter the Multiple_Inputs_DiscreteChange container. Using the Cum_Events Result element, confirm that Event_Count and Delay_Count end up with the same values (Delay_Count should lag Event_Count by 10 days; the 'value' is the total number of event outputs). Using High_Dispersion, confirm that the sequence of discrete changes comes out dispersed and in random order (view the probability history to see this).

13. Enter the DC_Amount_Prop container. This container tests that the ~DC_Amount available property functions correctly. A discrete change is triggered at time zero and samples a distribution for its amount. The delay time in the Discrete Change Delay is equal to 1d/kg of material in the discrete change.

    The discrete change triggers a Milestone when it exits the delay. The time to emerge can be compared to the sampled value and checked to ensure the available property is functioning correctly. This is done in the Check element.

    The property is operating correctly if the value of the Check element in Result Mode is less than 1E-6 for all realizations.

GS16b_Information and Material Delays:

This file contains tests for the Information Delay and Material Delay. Expected results are described in the test Containers. This test requires running the model twice:

1. In Simulation Settings, set the model to have all timesteps the same length. Run the model. and compare output to the expected results.

2. In Simulations Settings, set the model to have phases with different timestep lengths. Run the model and view results in the containers named Info_Delays_and_Dispersion and Material_Delays_and_Dispersion.

GS17_Timed Events and Discrete Changes

This file contains all of the tests for verifying Timed Events and Discrete Changes. Tests include the following:

1) Single-event tests
   a) Constant rate, recurring event
   b) Constant rate, non-recurring event
   c) Time-dependent rate (i.e., variable rate)
   d) Multiple occurrences of an event within a single timestep
2) Multiple-event tests
   a) Occurrence of Event 1 increases the rate of occurrence of Event 2
   b) Occurrence of Event 1 "turns off" Event 2
   c) Rate for Event 2 is a function of a parameter that is modified by the occurrence of Event 1
   d) Rate is dynamic over the course of the simulation
3) Tests for Discrete Changes
   a) Add constant discrete change
   b) Replace with current time (i.e., a variable discrete change)
   c) Realize a stochastic, then set discrete change to realized value
   d) Multiple explicit triggers
   e) Update of amount for discrete changes triggered more than once in a timestep
4) Checks to ensure that the Remaining Time to Event Timed Events function correctly.
5) Stochastic timed events tests.
6) Cumulative maximum number of events test.
7) Tests that remaining time to event functionality works properly.
8) Confirms the behavior of the occurs function.

The model must be in elapsed time mode and run to calculate results. The verifier should ensure that timed events can interrupt the simulation, and then proceed through the following steps:

1. Confirm that Integrator element outputs in the Single_Event_Tests, Mutliple_Events, and Discrete_Change elements correspond with the expected results shown in the tooltip window, and shown in Table GS17_1.

Table GS17_1

Element being tested	Test	Expected Output / Result (access either via Event or Consequence Elements directly, or via the Integrator Elements that follow the E/C elements)
Event_regular_1	1 a)	One occurrence every 100 days, for a total of 10 occurrences over 1,000 days.
Event_reg_cannot_recur	1 b)	Only one occurrence, and at a time of 100

		days.
Event_regular_2	1 c)	One occurrence at time 750 days (Sep. 18/2001).
Event_10_unchanged	2a)	One occurrence at time 667 days (Jun 26/01).
Event_10	2 a)	One occurrence at time 502 days (Jan 14/01)
Event_10_1	2 b)	No occurrences (value of 0 for all times)
Event_12	2 c)	One occurrence at time 503 days. (Jan 1514/01)
Result6	2d)	All curves should have the same shape and the final number of events should be within 1% of the integrated value.
Quantity_5a	3 a)	10 at a time of 1000 days; increases from 0 by 1 each 100 days.
Quantity_5b	3 b)	1,000 at a time of 1,000 days; increases from 0 by 100 each 100 days (same as Add_1)
Quantity_6	3 c)	time history of values equals the time history for Stoch_1 for all events which begin at 100 days.
Quantity_4	3 d)	6; start at 0 and add 1 at times 200, 400, 500, 600, 800, and 1,000 days.
Integrator1	3 e)	3; initial value of integrator is 5, discrete changes of 5, 10, and 20 added at time 0 for a total of 40.

4. Enter the container labeled “Stochastic_Timed_Events.” This test generates an event after a time interval sampled from a normal distribution with mean 20 days and a standard deviation of 5 days . A successful test is indicated by the 5%/95% confidence bounds on the Milestone_Time CDF including the following values for the given percentiles:

   5th percentile: 11.8 days/36414 date-time
   25th percentile: 16.6 days/36419 date-time
   50th percentile: 20 days/36423 date-time
   75th percentile: 23.4 days/36426 date-time
   95th percentile: 28.2 days/36431 date-time

2. Enter the container labeled “Cumulative_Max_Events.” Conduct the following tests:
   a. TimedEvent2 is of the Defined cumulative event count type, with the event count equal to 1000 for the first 500 days, and equal to 2000 for the remainder of the simulation. Verify that the value of TimedEvent2.Cum_emitted is 1000 for ETime < 500 d and 2000 for ETime > 500 d.
   b. TimedEvent3 is of the regular time interval type and emits an event once per day. However, it has a Maximum Number of Events of 500. Verify that the value of TimedEvent3.Cum_emitted increases by one per day, reaching a maximum of 500.
3. Enter the container labeled “Time_to_Event.” Ensure that the absolute value of Distance_to_Event is less than 1E-5 for all realizations (this can be viewed in the Result Distribution element). Also verify that only one event per realization is emitted by Time_to_Event2 at 500d.
4. Return to the Single_Events_Test container, and verify that the time-history element “Occurs” does not show the event occurring when events are allowed to occur between timesteps. Then turn off the option to allow timed events to interrupt the simulation. Run

the model for a single realization and ensure that the output of Occurrs1 is true whenever Event_regular_1 emits an event (once every hundred days).

All tests should be rerun with the model in date-time mode.

GS18_ RandomTimed Event

This file contains a test to verify the functionality of GoldSim's Timed Event Element. Run the model to see results. Compare the simulated mean value and standard deviation to the theoretical values in Table GS18_1. Next, compare the cumulative probabilities for various values of N to the theoretical values in Table GS18_1. To do this, enter the value of the cumulative probability from Table GS18_1into the GoldSim result-statistic Calculator, and then read the resulting value of N from the Calculator. Compare this value of N to the value for N in Table GS18_1. Because the simulation only performs 10,000 realizations, results are approximate. Therefore, for purposes of verification, if the simulated results match the theoretical results to within about 1% (mean and standard deviation) and to within a probability of 0.01 (for the CDF), then the test is considered to have passed.

Table GS18_1

Mean =	10
Std Dev =	3.16

N	Cumulative Probability of N
1	4.540E-04
2	0.003
3	0.010
4	0.029
5	0.067
6	0.130
7	0.220
8	0.333
9	0.458
10	0.583
11	0.697
12	0.792
13	0.864
14	0.916
15	0.951
16	0.973
17	0.986
18	0.993
19	0.997
20	0.998
21	0.999

GS19_Reservoir: Reservoir Elements

This file contains all of the tests for the Reservoir Element. Tests include the following:

1. Current_Value tests: Scalar values and no specified reservoir bounds
   a) Constant rates of addition and withdrawal where addition rate exceeds withdrawal rate;
   b) Constant rates of addition and withdrawal where withdrawal rate exceeds addition rate;
   c) Time-variable rate of addition, constant rate of withdrawal, where addition rate exceeds withdrawal rate;
   d) Constant rate of addition and withdrawal where addition rate exceeds withdrawal rate; one discrete addition and one discrete withdrawal;
   e) Same as d), except two discrete additions and no discrete withdrawals.
   f) Same as e), with a replace discrete change

2. Overflow_Rate and Withdrawal_Rate tests: Scalar values and specified reservoir bounds
   a) Constant rates of addition and withdrawal where addition rate exceeds withdrawal rate;
   b) Constant rates of addition and withdrawal where withdrawal rate exceeds addition rate;
   c) Time-variable rate of addition, constant rate of withdrawal, where addition rate exceeds withdrawal rate;
   d) Constant rate of addition and withdrawal where addition rate exceeds withdrawal rate; one discrete addition and one discrete withdrawal;
   e) Same as d), except two discrete additions and no discrete withdrawals.
   f) Same as e), with a replace discrete change

3. Vector inputs with reservoir bounds (tests Reservoir Element vector capabilities) – 3 x 1 reservoir vector; constant rates of addition and withdrawal, no discrete changes.

4. Matrix inputs with reservoir bounds (tests Reservoir Element matrix capabilities) – 2 x 2 reservoirs matrix; constant rates of addition and withdrawal, no discrete changes.

The model must be run to calculate results. Expected results are shown in the tooltip window for the Reservoir Element or in plots in the file. The results are also shown in Table GS19_1 and Figures GS19.1 and GS19.2.

5. To test the requirement that discrete additions and withdrawals must be positive, enter the container Positive_Tests and do the following:
   a. Run the model using the value of 100 for Discrete_Addition and 50 for Discrete_Withdrawal. Model should run to completion.
   b. Change Discrete_Addition to -100. Run the model. An error message should appear that states that negative discrete additions are not allowed.
   c. Abort, Change Discrete_Addition back to 100, and then change Discrete_Withdrawal to -50. Run the model. An error message should appear that states that negative discrete withdrawals are not allowed.
   f. Abort, Change Discrete_Withdrawal back to 50 and save the model.
6. To test the Discrete_Overflow output, view the results in container Discrete_OF.
7. To test the ability to do matrix discrete changes, view the results in Container MatrixChanges. All results should increment at time 10, then return to zero at time 20.

Table GS19_1

Element Being Tested	Test	Expected Output (value of Reservoir Element):
Reservoir1	1 a)	Volume (Current_Value) increases linearly from 1,000 gal at 0 days to 6,000 gal at 100 days. Withdrawal_Rate is 50 gal/day for all times.

Reservoir2	1 b)	Volume decreases linearly from 1,000 gal at 0 days to -4,000 gal at 100 days. Withdrawal_Rate is 100 gal/day for all times.
Reservoir3	1 c)	see Figure GS19.1
Reservoir4	1 d)	see Figure GS19.1
Reservoir5	1 e)	see Figure GS19.1
Reservoir10	1f)	see Figure GS19.1 (replace reduces value to 6000 at 80 days, should then follow slope of Reservoir4 and 5)
Reservoir1a	2 a)	Current_Value increases linearly in volume from 1,000 gal at 0 days to 5,500 gal at 90 days; Overflow_rate of 50 gal/day from days 90 to 100; Withdrawal_Rate is a constant 50 gal/day. See Fig. GS19_3 for Is_Full.
Reservoir 2a	2 b)	Volume (Current_value) decreases from 1000 gal to 500 by day 10; withdrawal rate is 100 gal/day from day 1 thru day 9, and 50 gal/day thereafter.
Reservoir 3a	2 c)	See Fig. GS19.2 for Current_Value; Overflow_Rate is a constant 0 gal/day; Withdrawal_Rate is a constant 50 gal/day.
Reservoir 4a	2 d)	See Fig GS19.2 for Current_Value; Overflow_Rate is 50 gal/day between days 70 and 75 and from day 95 on; Withdrawal_Rate is a constant 50 gal/day. See Fig. GS19_3 for Is_Full.
Reservoir 5a	2 e)	See Fig GS19.2 for Current_Value; Overflow_Rate is zero until day 70, when it becomes 50 gal/day. Withdrawal_Rate is a constant 50 gal/day. See Fig. GS19_3 for Is_Full.
Reservoir10a	2f)	See Fig GS19.2 for Current_Value; Overflow_Rate is zero until day 70, when it becomes 50 gal/day. Withdrawal_Rate is a constant 50 gal/day. See Fig. GS19_3 for Is_Full.
Reservoir6	3	Current_Values at day 100 for the three reservoirs are 2350 gal for the first reservoir; 2900 gal for the second; and 1000 gal for the third (the third reservoir should be 1000 gal starting at day 90). IsFullCheck should be zero.
Reservoir7	4	Current_Value starts at 2,000 gal for all four; final values at time 100 days are: 2500 gal for [1,1] and [2,2]; 3000 gal for [1,2]; and 1000 gal for [2,1]. IsFullCheck should be zero.
Reservoir8	6	Element Discrete_Overflow should be 0 until day 49, then jump to 50 at time 50 and remain there.

Reservoir9	7	Values increment at 10 days, decrement at 20 days.

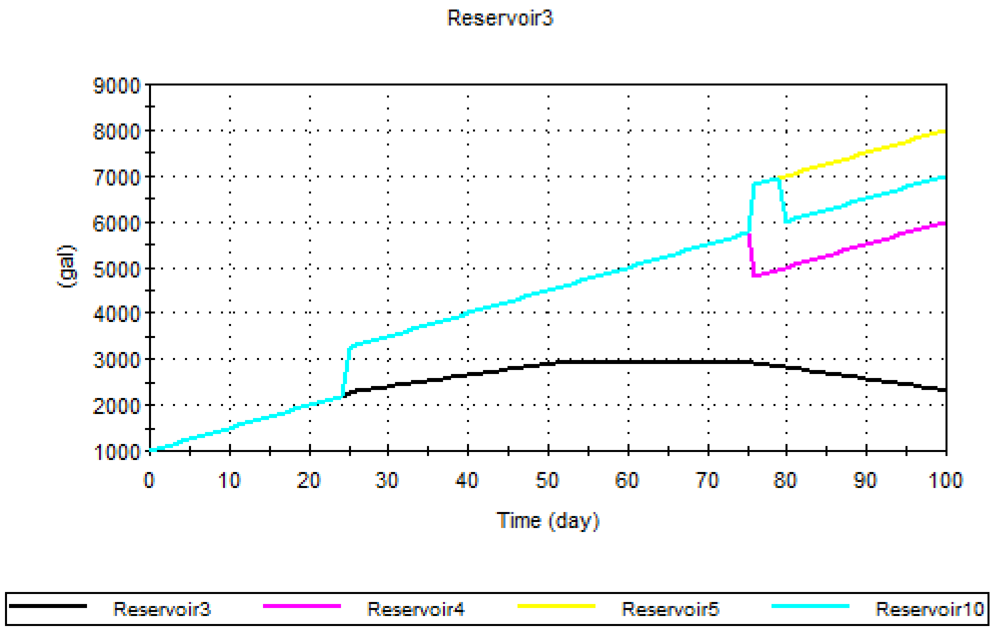


Figure GS19.1. Results for Reservoir-Element Tests.

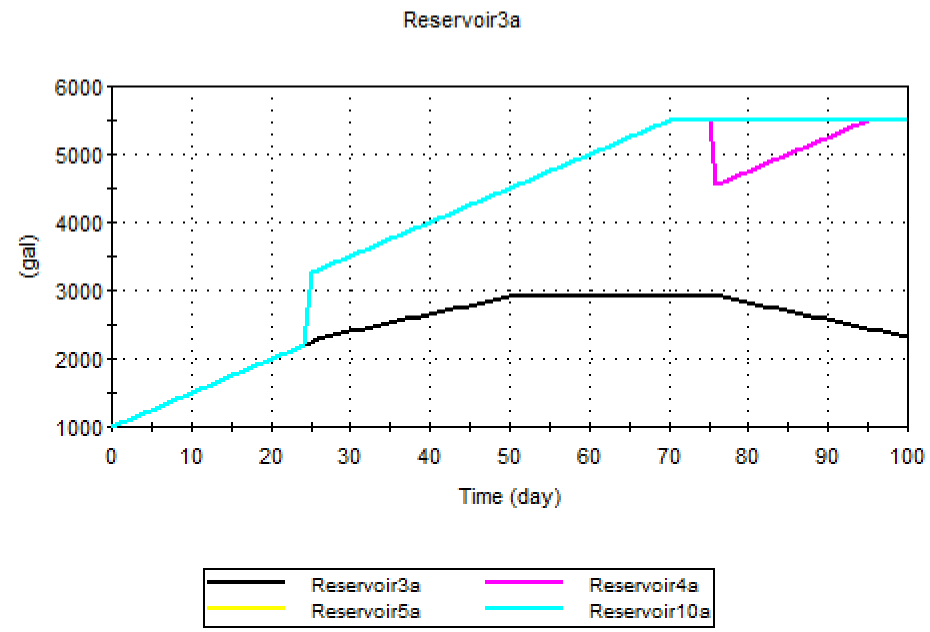


Figure GS19.2. Results for Reservoir-Element Tests

Note to verification plan writers: If the graphs above need to be updated, they are stored in a spreadsheet called vplancalculations.xls, stored in the same folder as the verification plan in Visual Source Safe.

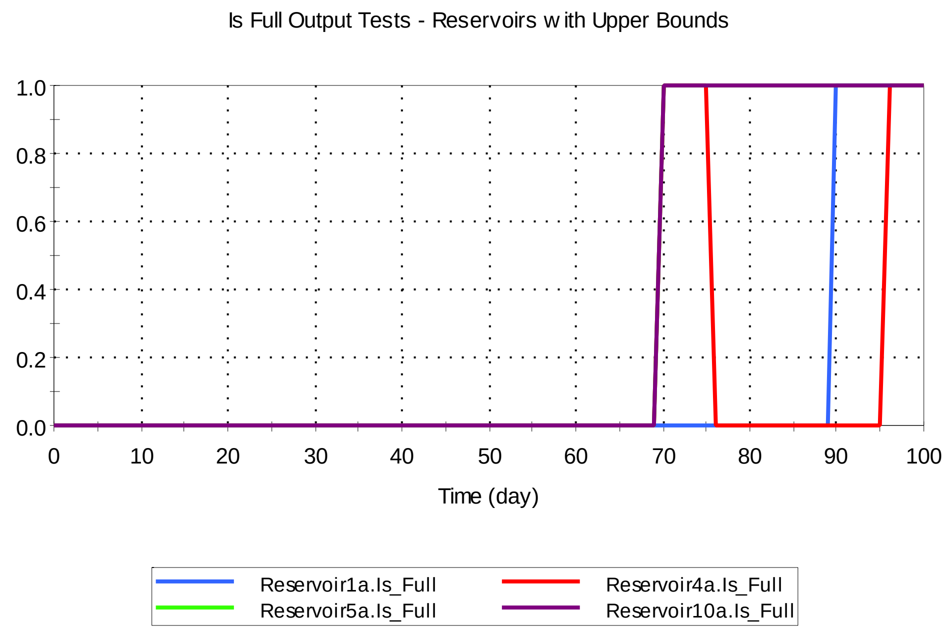


Figure GS19.3. Scalar IsFull Tests

GS19a_Reservoir_2: Reservoir Elements with Changing Bounds

This file tests the ability of Reservoir Elements to handle time-variable upper and/or lower bounds. The test consists of two parts: 1) running the model using multiple timesteps and checking results (to ensure that the time history of volume is calculated correctly); and 2) inducing run-time errors related to illegal bound/volume relationships. In all cases, the expected output for the test reservoir element is located in the tooltip window for the reservoir element.

1. **Multiple timesteps**: Enter the container named Multiple_Timesteps. Open the Model Simulation Settings dialog box and change the number of timesteps to 100 (i.e., a 0.1-day timestep) and click 'ok'. Run the model. Enter each "Case" container in turn and ensure that the simulation result for each reservoir element matches the expected result (especially the time history). Expected results are shown in Table GS19a_ below.

Table GS19a_

Test Case	Scenario	Expected Output from Reservoir Element
Case 1	Constant lower bound, increasing upper bound, volume increases faster than upper bound.	Final Reservoir Volume = 20 m3; Total overflow = 15 m3; volume should follow upper bound after time = 2.5 days. Since the upper bound is constantly increasing, the Is_Full output should almost always be false. (Due to rounding of floating points, the output may not be false at several timesteps.)
Case 2	Constant lower bound, increasing upper bound, volume increases slower than upper bound.	Final Reservoir Volume = 14.95 m3; Total overflow = 0.05 m3; volume is below upper bound. Is_Full should be true at time = 0.

Case 3	Constant lower bound, increasing upper bound, volume decreases.	Final Reservoir Volume = 5 m3; Total overflow = 0 m3; volume is below upper bound.
Case 4	Constant lower bound, decreasing upper bound, volume increases.	Final Reservoir Volume = 15 m3; Total overflow = 15 m3; volume should follow upper bound and Is_Full should be true after time = 4 days.
Case 5	Constant lower bound, decreasing upper bound, volume decreases faster than upper bound decreases.	Final Reservoir Volume = 0 m3; Total overflow = 0 m3; volume is below upper bound.
Case 6	Constant lower bound, decreasing upper bound, volume decreases more slowly than upper bound decreases.	Final Reservoir Volume = 7 m3; Total overflow = 2 m3; volume should follow upper bound and Is_Full should be true after time t = 5 days.
Case 7	Constant upper bound, increasing lower bound, volume increases faster than lower bound increases.	Final Reservoir Volume = 35 m3; Total withdrawal = 5 m3; volume is above the lower bound.
Case 8	Constant upper bound, decreasing lower bound, volume increases.	Final Reservoir Volume = 35 m3; Total withdrawal = 5 m3; volume is above the lower bound.
Case 9	Constant upper bound, decreasing lower bound, volume decreases faster than the lower bound decreases.	Final Reservoir Volume = 3.003 m3; Total withdrawal = 11.99 m3; volume should follow lower bound after time t = 4 days.
Case 10	Constant upper bound, decreasing lower bound, volume decreases faster than the lower bound decreases.	Final Reservoir Volume = 5 m3; Total withdrawal = 5 m3; Total overflow = 15 m3; volume follows both bounds throughout the simulation. Is_Full true for the duration of the simulation.

2. **Failure Case**: Enter the container named Fail_Case. To activate this model, enter the following values: Net_Rate_Change= 0 {m3/day} and Initial_Volume=15 m3. Then, run the model. The expected result is a fatal error at day 5.1 (“The lower bound is increasing at a faster rate than the volume”). Change Net_Rate_Change back to 1 {m3/day}, Initial_Volume to 20 m3, and save model. The test is complete.

GS20_Element Activation

This file verifies that common elements activate correctly. Tests include:

1. A container that does not activate contains a number of elements that do not activate.
2. A container that activates, deactivates, then reactivates contains a number of elements that become active.

Run the model to calculate results. Expected results for each element are shown in the tooltip window for the element, and are shown in Table GS20_1. 2 run log warning should be generated.

Table GS20_1

Element being tested	Expected Output / Result
All elements in container 'Never_Active'	None of the elements in this container ever activate. All elements report a value of zero for all times, with the following exceptions: Data1, InfoTimeSeries1, MaterialTimeSeries1, Data2, InfoDelay1 and MaterialDelay1. These each report a value of 5 for all times (even though they are never activated). Stochastic 1 – reports a constant sampled value Reservoir1 – run log reports that material was received while the element was inactive
Elements in container 'Activate_Reactivate':	Container is active between days 100 and 1100, then inactive between days 1101 and 1200, then reactivates at day 1200.
Data1	Should report a value of 5 at all times, even while inactive.
InfoTimeSeries1	Should report a value of 5 at all times.
MaterialTimeSeries1	Should report a value of 5 kg at all times.
Data2	Should report a value of 5kg at all times.
Data4	Time history follows: 0 for time < 100 days; step to 100 at time = 100d; linear increase to 1100 between time 100 and 1100d; plateau at 1100 between 1100 and 1200d; step to 1200 at 1200d; linear increase to 2000 between 1200 and 2000d.
Integrator1	Time history follows: 0 for time < 100; linear increase from 100 to 1,100 between time 100 and 1100; linear increase from 1,200 to 2,000 from time 1200 to time 2000.
Reservoir1	Same time history as for Integrator1, except with units of kg.
Stochastic1	Expected output is 0 prior to time 100, then a new sampled value at time 100, then another new value at time 1200.
Expression1	Same time history as for Integrator1
Min1	Value is always 0
Max1	Same time history as for Integrator1
Sum1	Same time history as for 2 * Integrator1
Selector1	Time history follows: value is 0 prior to time 100, and value is 5 thereafter.
Event1	Time history for Cum_Emitted is 0 prior to time 100, and 1 thereafter.
DiscreteChange1	Time history for Cum_Emitted is 0 prior to time 100; 1 at time 100; and 2 at time 1200.
Decision1	Time history for Last_Decision is the same as for Event1.Cum_Emitted.
Milestone1	Time history for Completion_Status is the same as for Event1.Cum_Emitted.
EventDelay1	Time history for Cum_Emitted is 0 prior to time 200, and 1 thereafter.
ChangeDelay1	Time history for Cum_Emitted is 0 prior to time 200; 1 at time 200; and 2 at time 1300.
InfoDelay1	Should report a value of 5 at all times, even while inactive.
MaterialDelay1	Should report a value of 5kg except between time 1101 and 1200 when it should report a value of zero.
Random_Choice	Time history for Last_Choice is the same as for

Element being tested	Expected Output / Result
	Event1.Cum_Emitted.

GS21_ Conditional Containers

This file verifies that conditional containers perform properly. The test file evaluates container activation, deactivation with completion, and deactivation with termination. The tests are repeated for both unconditional and conditional parent containers.

Run the model to calculate results.

The first test checks that Conditional Containers activate and deactivate properly. The expected results for each test container are described in the tooltip window for the container, and are summarized in Table GS21 below. You will have to navigate the model to locate many of the test containers. The results in Table 21 apply to both the parent containers 'UnConditional' and 'Conditional'.

Table GS21

Test Container	Expected Results
Activation_Deactivation	Activity status: Changes to 1 at time 20; 0 at time 30; 1 at time 50; and 0 at time 60. Completion status: changes to 1 at time 30; 0 at time 50; and 1 at time 60. Num_Activations = 2. Duration (final stage) = 40.
Nested_Inside1	Should never activate (since parent is not active when the activation trigger fires)
Nested_Inside2	Activates at time 50

The verifier should then check to make sure that the Events and Duration plots in the 'UnConditional' and 'Conditional' container match the plots in Figure GS21_1 through GS21_4,

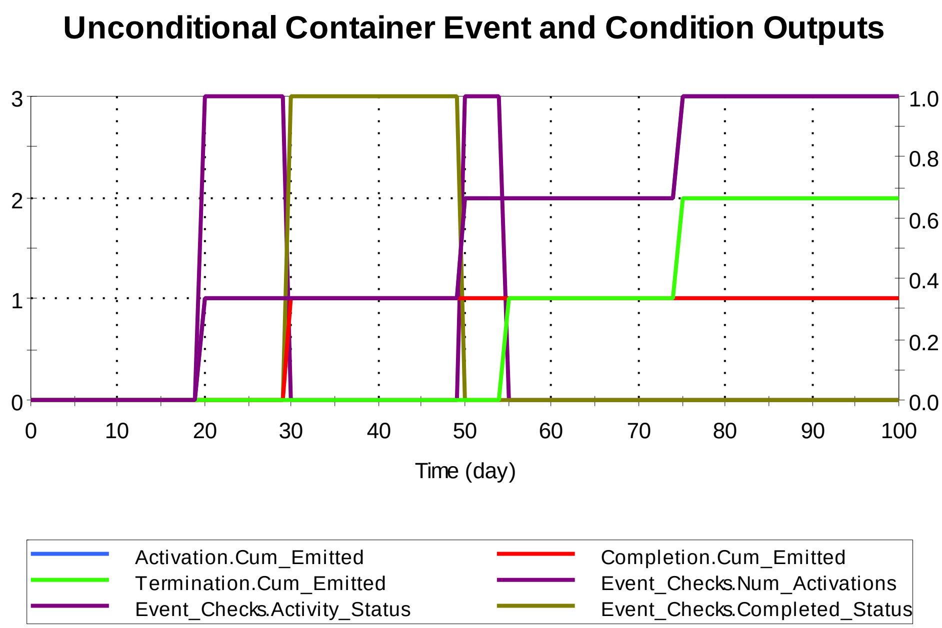


Figure GS21_1: Expected plot for Events Time History in the UnCondtional Container

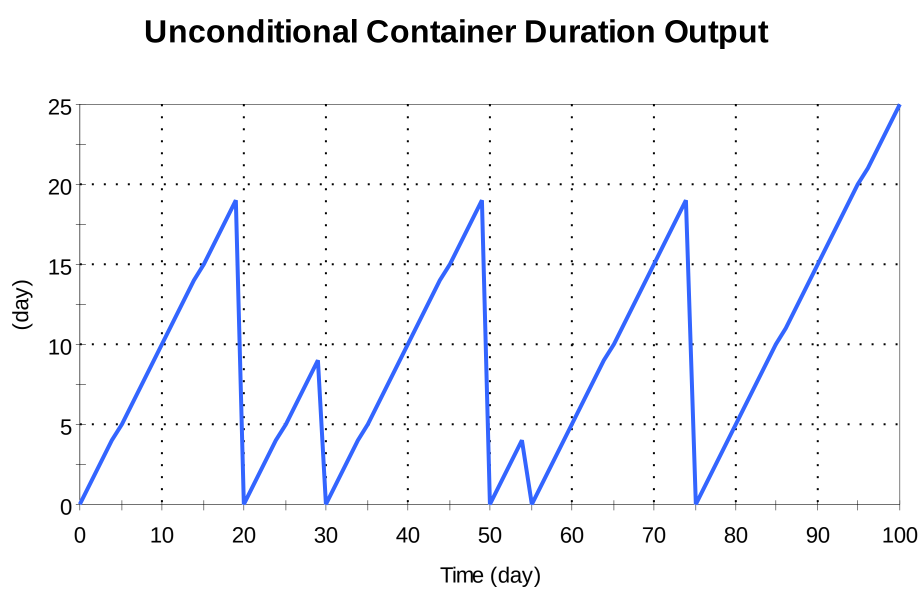


Figure GS21_2: Expected plot for Duration Time History in the UnCondtional Container

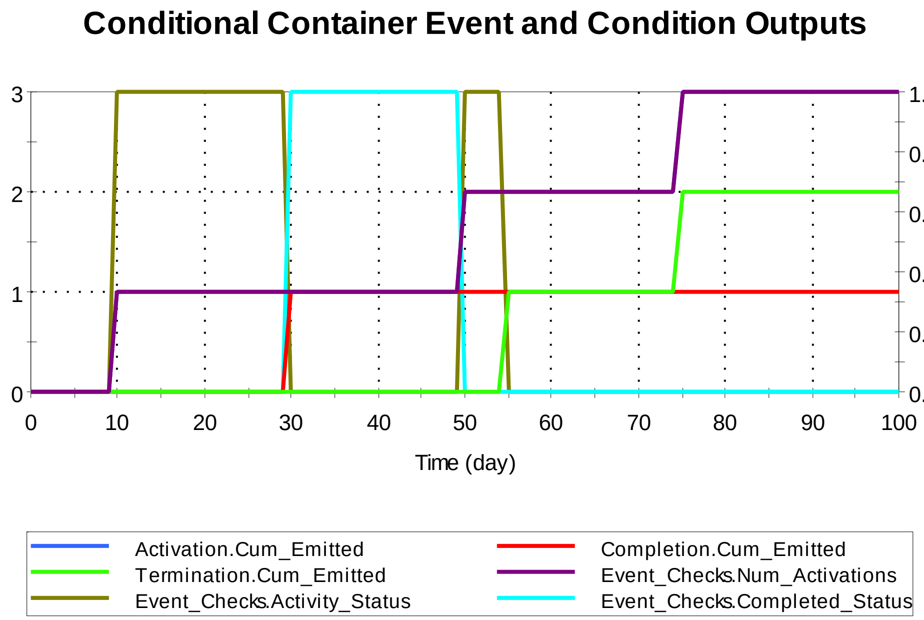


Figure GS21_3: Expected plot for Events Time History in the Condtional Container

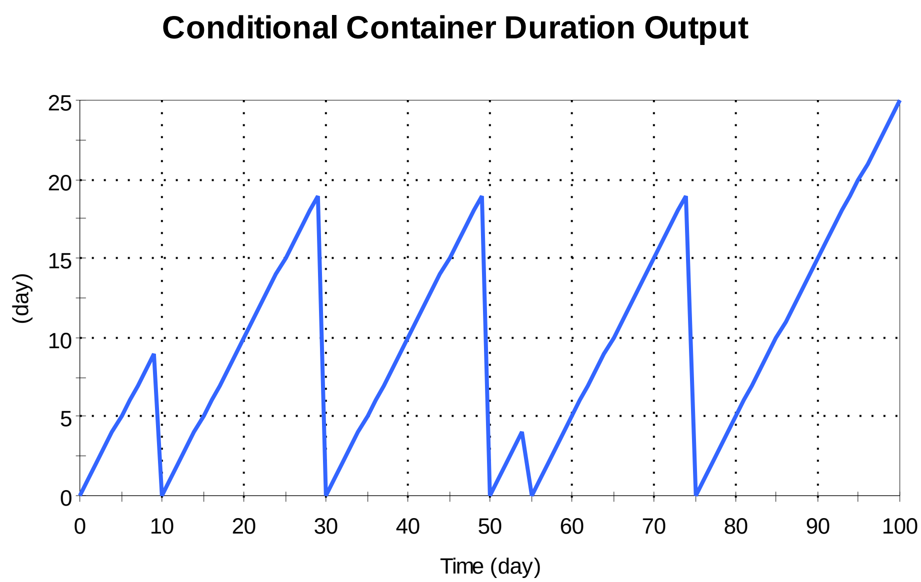


Figure GS21_4: Expected plot for Duration Time History in the Conditional Container

The verifier should also ensure that the value of the Time_at_Last_Update Expression element in Event_Checks is 75 days in both the UnConditional and Conditional containers. This check verifies that elements inside a Conditional Container that is activated and deactivated at the same timestep are properly updated.

GS22_Datetime: Track Serial Date and Time

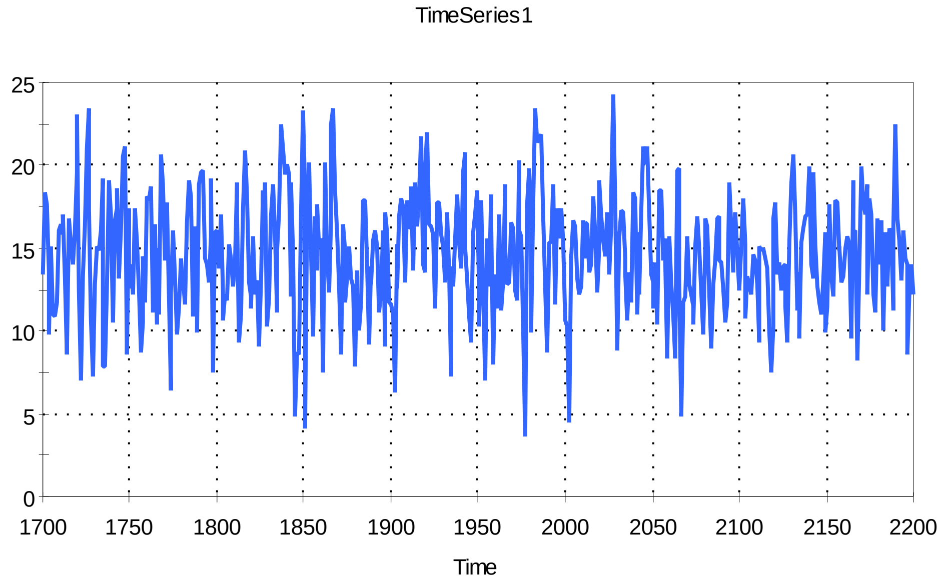
This first part of this test verifies that GoldSim correctly tracks simulation time when the simulation duration is specified in the Master Clock using the Date-Time option. The simulated timeframe is specified as 1/1/99, 12:00:20 AM to 12/31/99, 11:59:50 PM. Run the model to calculate results. Expected results are shown in a table in the file and are shown in Table GS22_DATETIME. The results are in terms of the Serial date system, as calculated by EXCEL, which starts a numeric count of days on December 30st, 1899 (e.g., Serial Day 3.00 = the end of Jan. 1, 1900).

Also, confirm that the date-axis for the history plot, are displayed in date-time format.

Table GS22_1

Serial Date Number for Year	
Date:	Serial
1-Jan	36161
31-Jan	36191
1-Feb	36192
28-Feb	36219
1-Mar	36220
31-Mar	36250
1-Apr	36251
30-Apr	36280
1-May	36281
31-May	36311
1-Jun	36312
30-Jun	36341
1-Jul	36342
31-Jul	36372
1-Aug	36373
31-Aug	36403
1-Sep	36404
30-Sep	36433
1-Oct	36434
31-Oct	36464
1-Nov	36465
30-Nov	36494
1-Dec	36495
31-Dec	36525

The second test checks GoldSim's ability to simulate models beginning in 1700 and ending after 2100. The tester should change the simulation settings to a model running from 1/1/1700 to 1/1/2200 in 500 steps. Then run the model and compare the graph in Result1 to the image pasted beside it and below this paragraph. Finally, reset the X axis limits in Result1 to show only 1/1/1700 to 1/1/1900. Confirm the plot shows the limited date range.



The third test checks GoldSim's ability to format times as datetimes and dates. Run the model to completion and confirm that Datetime_Check shows 1/1/2200 0:00:00 and Date_Check shows 1/1/2200 if the model is run from 1/1/1700 to 1/1/2200 in 500 steps.

GS23_Elapsetime: Track Elapsed Simulation Time

This file verifies that GoldSim correctly evaluates elapsed simulation time and correctly converts among various units of time. The file verifies GoldSim's calculation of Serial seconds, hours, days, months, and years for a simulation with a duration of 1 year. Run the model to calculate results. Expected results are shown in a table in the file and are shown in Table GS23_1. The results are in terms of the Serial date system, as calculated by EXCEL, which starts a numeric count of days on December 30st, 1899 (e.g., Serial Day 3.00 = the end of Jan. 1, 1900).

Table GS23_1

For Year 1999:	
Total Seconds:	3.1536E+07
Total Hours:	8760
Total Days:	365
Total Months:	12
Total Years:	1

GS24_Timestep: Variable Timesteps

This file verifies that GoldSim functions properly when variable timesteps are used. Run the model to calculate results. The tests are as follows:

1. In the first test, values of a time-dependent function are generated using a variable timestep for a period of 10,000 days:
   0 - 1,000 days: timestep = 50 days
   1,001-2,000 days: 12.5 days
   2,001-10,000 days: 100 days
   Run the model to generate results. Ensure that the correct timestep was used in each phase. Expected results are as shown in the table below. Expected results are shown in a table in the file and in Table GS24_1. Expected results are the theoretical values of the time-dependent expression.

Table GS24_1

Time (days)	Function
0	0.000E+00
900	0.000E+00
1000	1.000E+00
2000	8.208E-02
3000	6.738E-03
4000	5.531E-04
5000	4.540E-05
6000	3.727E-06
7000	3.059E-07
8000	2.511E-08
9000	2.061E-09
10000	1.692E-10

2. In this test, an Integrator element is tested to ensure that they correctly integrate their rate over time when variable timesteps are used. Expected result is a value of 10,000 at time equal to 10,000 days. In addition, the value of the Integrator element should be equal to time throughout the duration of the simulation.

3. This test ensures that a timed event fires at the correct time when variable timesteps are used. Expected result is that the event fires every 50 days, for a total of 200 occurrences. View the time history of results to confirm.

4. The final test verifies the correct functioning of the Timestep_Length local property. It should match the scheduled timestep for the first 2000 d (value of 50d from 0 -1000 days and a value of 12.5 days from 1001-2000 days) and then return to a value of 50 days for the remainder of the simulation (even though a 100 day timestep is being used, events issued by Event1 will cause the simulation to be updated once every 50 days.

GS25_Multiprocessor Networked Solution Tests

In order to verify the networked capability of GoldSim, the user has to run a GoldSim Master application and at least one Slave application. The slave application does not need to be on a different computer from the master application. The user can run more than one slave at the same time in one computer, which will be effective if it has multiple processors. Up to 20 slave applications can be run on each computer. The Master process assigns individual realizations of the GoldSim model to available slaves. Each slave makes a local copy of the model and any required auxiliary files (eg. DLL files used by External and External Pathway elements, XLS files used by spreadsheet elements, and arbitrary files defined by File elements). At the completion of the simulation, the results of all of the realizations are re-assembled into the .GSM file.

The multiprocessor test consists of two GoldSim models: GS25a_Multiprocessor Dynamic.gsm tests the multiprocessor capability for dynamic models, while GS25b_Multiprocessor Static.gsm does the same for static models. These files and all supporting files are contained within a folder called GS25_Multiprocessor. Follow the steps outlined below for each test file.

GS25a_Multiprocessor Dynamic

File preparation: The user should load file GS25a_Multiprocessor Dynamic.gsm prior to doing the networked verification.

Setting up the test: The user needs to launch GoldSim on each Slave machine. The tester should launch a copy of both GoldSim and the Player in slave mode. To launch the player in slave mode, the tester types the following in the Run dialog for Windows (accessed from the Start button) on the appropriate Slave machine:

"*path to GSPlayer.exe*" –s

where *path to GSPlayer.exe* is the path to the GoldSim Player executable on the slave machine. The quotes must be included and the –s must go outside the quotes. Upon entering this run command, the GoldSim Network Client dialog will appear on the Slave machine, with a Client Status of "Client is ready to connect to Master". The Slave machine is now ready to receive commands from the Master. GoldSim is started in slave mode the same way, with the path to GoldSim.exe being placed inside the quotes. The –s switch is still required.

Next, the user must specify the slaves' addresses in the NetworkSettings dialog on the Master machine. This can be done by selecting "Run on Network…" from the Model menu. Slave address can be entered either as a computer name or as an IP address (e.g., obtained from browsing the Network Neighborhood). If one computer is to have more than one slave application running, the user should define the slave system multiple times, once per slave.

Next, the user should make connections from the master to all desired slaves. Pressing the "Update Slave Status" button will not only do this for the user, it also verifies that the specified computer has a GoldSim slave running. After the Master knows which slaves are active and which ones are not, it is ready to do the simulation. Pressing the "Run Simulation" button will start the networked simulation.

Performing the test: The Networked version of GoldSim has many features to speed up the simulation. The user will verify all of them according to the step-by-step instructions that are given in this section. Some of the features require the simulation to be run, and some do not.

1. Adding a new slave address.
   To do this, user does not need to run the simulation. The user can add a new slave address by inputting it in the 'New slave address' edit box and pressing the 'Add Slave' button. The new slave address will be shown on the grid, which is located above the buttons.

2. Modifying a slave address
   To do this, user does not need to run the simulation. The user can modify a slave's

address by editing it directly from the grid. The user should click the slave address cell and input a modified slave address.

3. Removing a slave from the list
   To do this, the user does not need to run the simulation. The user can remove a slave from the master list by first selecting the slave, and then pressing the "Remove Slave" button. The selected slave address will be removed from the grid.

4. Abort the simulation
   If the 'Abort' button is clicked during a simulation, the simulation should terminate.

5. Rerun after Abort
   The user should rerun the simulation using the runs completed prior to the abort.

6. Abort and Discard
   The user should rerun the simulation, abort the run, rerun the simulation, and then discard the results.

The user should carry out all of the above tests, and confirm that the requested actions are performed, and for the simulations the final results for each element are identical to a normal simulation where no slaves are used.

GS25b_Multiprocessor Static

Open the file GS25b_Multiprocessor Static.gsm. Follow the steps listed above for GS25a under "setting up the test" and "performing the test".

GS25c_Multiprocessor – Loading/Saving Slave Lists

Confirm that a list of slaves can be loaded and saved to a file by selecting the "Run on Network..." option in the Model menu and using the "Export" button to save the current list of slaves to a file (with extension .SLV) and using the "Import" button to load the list back in. During loading of a slave list, verify that the user is asked whether to remove the existing slaves in the list and whether to immediately update their status.

GS25d_Multiprocessor – Auto-Launching Slaves using Slave Manager

Preparation: The Slave Manager (NT service) – as well as GoldSim itself – must be installed on all client machines running GoldSim Slaves. Preferably this would be done on both the master station and one other networked PC. The Slave Manager can be installed during the main GoldSim install or by running the stand-alone install: GSSlaveMgr130.exe. You may verify that the Slave Manager is running by using Windows Control Panel to go into Administrative Tools and selecting "Services." In the list of services, you should see "GoldSim Slave Manager" listed with a status of "started." If a formal install is not provided for the verification, it is necessary to modify the registry key for the version in HKEY_LOCAL_MACHINE\SOFTWARE\GTG\GoldSim. A String value called "InstallPath" must be added to the key, and its value should be set equal to the path to the test version. After adding the value, the GoldSim Slave Manager service must be restarted.

Performing the Test: Open GS25a_Multiprocessor Dynamic.gsm . From the GoldSim master, with a model loaded, select "Run on Network..." from the Model menu. In the list of slaves, add 3 slaves for a networked PC running Windows XP. Verify on the networked PC that the slaves are not already running. Press the "Update Status" button in the dialog. Observe the results. The slaves should be automatically launched on the networked PC and run to completion successfully.

Open GS25d_Multiprocessor_WinVista.gsm . From the GoldSim master, with a model loaded, select "Run on Network..." from the Model menu. In the list of slaves, add 3 slaves for the local PC (client address should be "localhost") and 3 slaves for a networked PC. At least one of the two PC's should be running Windows Vista. Verify on both PCs that the slaves are not already running. Press the "Update Status" button in the dialog. Observe the results. The slaves should be automatically launched on both PCs. Run the model to completion. None of the slaves should crash, and all realizations should run successfully.

GS25e_Multiprocessor – 32/64-bit Slave Detection

Preparation: GoldSim should be installed and slaves manually started on a 32-bit PC and a 64-bit PC.

Performing the Test: Open GS25e_Multiprocessor64.gsm . From the GoldSim master, with a model loaded, select "Run on Network..." from the Model menu. In the list of slaves, list the machine name for the 32-bit and 64-bit slave machines.

Run the model. Only the 64-bit machine should process realizations. The 32-bit machine should report a fatal error, but the simulation should run successfully and the verifier should ensure that result values match the expected values listed in the GS25a test.

GS26_Event_Substep: Firing an Event Within a Timestep

This test verifies the proper functioning of the "Allow timed events to occur between timesteps" option and the Minimum timestep length field.
The Timed Event occurs once, at a minimum of 30.31 years.
For the first test, run the model without allowing timed events to occur between timesteps. Event_Time should be equal to 200 years and the Quantity integrator should have a value of 0m^3 at the end of the simulation.
The model should then be run with the "Allow events to occur between timesteps" option selected. Run the model with the default minimum timestep of 0yr. The event should occur at 30.31 years, and the Quantity integrator should have a value of 1696.97 m^3 at the end of the simulation.
Run the model again with the following settings and confirm the following results:

Minimum Timestep Length	Event Time	Quantity Value at Simulation End
100 yr	100 yr	1000 m^3
50 yr	50 yr	1500 m^3
25 yr	30.31 yr	1696.97 m^3
10 yr	30.31 yr	1696.97 m^3

GS26b_MaximumTimestep_EditModeUpdates

This test verifies the proper functioning of the Maximum Timestep Length setting, and also verifies the proper function of the Edit Mode Update setting.

1. Run the model and ensure that 101 events are generated by the Triggered Event (the event is triggered each time that the simulation clock changes, meaning that an event is generated at each model update).

2. Return to edit mode. Set the Edit Mode Update time to 0s. Check that the predicted values correspond with the expected values listed in the tooltip.

3. Set the Edit Mode Update time to 50s. Check that the predicted values correspond with the expected values listed in the tooltip.

GS27_Triggering: Basic Trigger Functionality

This test verifies basic triggering functionality by exercising the triggering dialog common to all elements that can be triggered. The test evaluates the three triggering modes (automatic versus user-defined triggers, optional precedence completion, and optional go/no-go conditions) individually and in combinations.

To complete the test, run the model. Compare the model results to the expected result for each Triggered Event element shown in Table GS27.

Table GS27

Element Being Tested	Functionality Tested	Expected Output
Trigger1	Automatic trigger	Triggered once at time 0
Trigger2	Automatic trigger + precedence completion	Triggered once at time 25
Trigger3	Automatic trigger + go/no-go condition	Triggered once at time 0
Trigger3_ Condition	Same as Trigger3, but with go/no-go condition as a precedence condition	Triggered once at time 0
Trigger4	Automatic + precedence + go/no-go condition	Triggered once at time 25
Trigger4_ Condition	Same as Trigger4, but with go/no-go condition as a precedence condition	Triggered once at time 25
Trigger5	Automatic + precedence + go/no-go condition	Never triggered
Trigger5_ Condition	Same as Trigger5, but with go/no-go condition as a precedence condition	Triggered once at time 50
Trigger6	Automatic inside conditional container	Triggered once at time 10
Trigger17	Automatic + precedence completion inside conditional container	Triggered once at time 25
Trigger18	Automatic + go/no-go condition inside conditional container	Triggered once at time 25
Trigger18_	Same as Trigger18, but with go/no-go	Triggered once at time 25

Condition	condition as a precedence condition	
Trigger19	Automatic + go/no-go condition inside conditional container	Never triggered
Trigger19_ Condition	Same as Trigger19, but with go/no-go condition as a precedence condition	Triggered once at time 30
Trigger7	User-defined (on Event) inside conditional container	Triggered once at time 10
Trigger8	User-defined (on True) inside conditional container	Triggered once at time 20
Trigger9	User-defined (on Changed) inside conditional container	Triggered once at time 25
Trigger10	User-defined (on Event + on True + on Changed) inside conditional container	Triggered once each at times 10, 20, and 25
Trigger11	Same as for Trigger10 + on False	Triggered once each at times 10, 20, 25, and 50
Trigger12a	Act just once for simultaneous triggers	Triggered once at time 15.
Trigger12b	Act once for each simultaneous trigger option off.	Triggered three times at time 15.
Trigger13	Same as for Trigger11 + precedence completion	Triggered three times at time 25 and once at time 50.
Trigger13_ActOnce	Same as for Trigger11 + precedence completion + Act once option selected	Triggered once at time 25 and once at time 50.
Trigger14	Same as for Trigger11 + go/no-go condition	Triggered once each at times 20, 25, and 50.
Trigger14_ Condition	Same as Trigger14, but with go/no-go condition as a precedence condition	Triggered once at time 15, 20, 25, and 50.
Trigger15	Same as for Trigger11 + precedence completion + go/no-go condition	Triggered three times at time 25 and once at time 50.
Trigger15_ Condition	Same as Trigger15, but with go/no-go condition as a precedence condition	Triggered three times at time 25 and once at time 50.
Trigger15_ActOnce	Same as for Trigger11 + precedence completion + go/no-go condition + act once option selected	Triggered once at time 25 and once at time 50.
Trigger15_ Condition	Same as Trigger15, but with go/no-go condition as a precedence condition + act once option selected	Triggered once at time 25 and once at time 50.
Trigger16	Same as for Trigger11 + precedence completion + go/no-go condition	Triggered once at time 50.
Trigger16_ Condition	Same as Trigger16, but with go/no-go condition as a precedence condition	Triggered three times at time 26 and once at time 50.
Trigger16_ActOnce	Same as for Trigger11 + precedence completion + go/no-go condition + act once option selected	Triggered once at time 50.
Trigger16_ Condition_ActOnce	Same as Trigger16, but with go/no-go condition as a precedence condition + act once option selected	Triggered once at time 26 and once at time 50.
Trigger20	User-defined inside inactive container	Triggered once at time 50.

Trigger21	*******Removed******	If True trigger no longer supported.
Trigger22	OnFalse when time exceeds 50	Triggered once at time 51.
Trigger23	OnEvent with multiple required events	Triggered once at time 77.
Trigger24	OnEvent triggering using a discrete change	Triggered once at time 50.

GS28_Deterministic Options: Deterministic Simulation settings

This file tests the different Deterministic Simulation Settings. The test consists of two parts:

Part 1: Deterministic modes – enter the container named Deterministic_Modes.

1. Under the Monte Carlo Tab of the Simulation Settings Dialog(SS), select the "Run Deterministic" simulation mode, and then select the "Use Element's Deterministic Value" option.

2. Open one of the stochastic elements, click 'Define', then 'Use mean (expected) value', and then click 'Apply to all stochastic elements'. Run the model. Compare the result for each stochastic element with the expected value in the tooltip window for the element.

3. On the Monte Carlo tab of the SS dialog, select "Use Specified Quantile" option, enter a value of 0.5, and then click 'OK'. Run the model. Compare the result for each stochastic with the median value in the tooltip window for the element.

4. On the Monte Carlo tab of the SS dialog, select "Use Mean" and then click 'OK'. Run the model. Compare the result for each stochastic with the expected value in the tooltip window for the element. Under MSS, select "Use Element's Deterministic Value" option.

5. Open one of the stochastic elements, click 'Define', then 'Use median value', and then click 'Apply to all stochastic elements'. Run the model. Compare the result for each stochastic element with the median value in the tooltip window for the element.

6. Open one of the stochastic elements, click 'Define', 'Use quantile', enter a value of 0.5, and then click 'Apply to all stochastic elements'. Run the model. Compare the result for each stochastic element with the median (0.5 quantile) value in the tooltip window for the element.

8. Open one of the stochastic elements, click 'Define', 'Use specified value', and enter a value for the variate (may be outside the range for the defined distribution). Close the dialog, run the model, and ensure that the specified value was produced by that stochastic.

9. Repeat step 8, but this time specify the value by inserting a link to element Data1 in the 'specified value' field for the stochastic.

10. Open one of the stochastic elements for which a value was not specified in steps 8 and 9. Click 'Define', 'Use quantile', enter a value of 0.5, and then click 'Apply to all stochastic elements'. Run the model. Compare the result for each stochastic element with the median (0.5 quantile) value in the tooltip window for the element.

11. Open one of the elements for which a value was specified in Steps 8 or 9. This element should show a deterministic input of Quantile = 0.5. Next, check the "Use Specified Value" radio button. The value that was previously specified for this element in Step 8 or 9 should re-appear (i.e. GoldSim remembers this value).

Table GS28_ 1

Element being tested	Median value and 0.5 Quantile [-]	Expected value [-]
Uniform	50.5	50.5
Log_Uniform	10.0	21.5
Normal	10.0	10.0
Log_Normal	0.894	1.0
Triangular	5.257	5.333
Log_Triangular	1.853	1.863
Cumulative	34.0	35.0
Discrete	3.0	3.0
Poisson	5	5
Binomial	1	1.25
Beta	4.61	5.0
Gamma	4.74	5.0
Weibull	3.76	4.0

Part2: Random Timed Events in deterministic mode: Enter container Event_Checks.

1. In the Model Simulations Settings dialog, select 'Run All Realizations' from the Simulation Run Mode list box.

2. Run the model. The value of the Integrator element should change from 0 to 1 at sometime between 0 and 100 days (an average rate of occurrence for the random timed event Event1 of 0.1/day was specified).

3. In the Model Simulations Settings dialog, select the 'Run Deterministic ' option and then 'Use Element's Deterministic Value'.

4. Run the model. The value of the Integrator element should change from 0 to 1 at a time of 10 days (i.e., GoldSim now treats the random timed event as a regular timed event).

GS29_External2: External-Element Table and Time Series Definition Output

This test verifies that the Table and Time Series Definition outputs of the External Element work correctly. The Table-Definition output allows the user to create a lookup table externally and import it into GoldSim. The file cfstubs.dll contains the test data tables and is called by the External Elements in this test file, while the TS_Proc.dll is used by the Time Series elements. The test proceeds as follows:

1. Enter the container labeled "Table_Def_1D", which houses the tests for the 1D Table-Definition output. These tests verify the functionality of the 1D Table Definition

output, including unit conversions made in the transfer from the External Element to the Table Element. It also verifies that the Table definition output type can be transmitted to a SubModel.
a. Run the model. Verify that the output of Expression1 and SubModel_Result1 is 102160 (for Element A = 0.6 m/s).
b. Change the value of Element A to 1.2 m/s. Run the model. Verify that the value of both Expression elements has changed to 104320 {m}.
c. Change the value of Element A to 12 m/s. Run the model. Verify that both Expression elements now have a value of 143200 m.

2. Enter the container labeled “Table_Def_2D”, which houses the tests for the 2D Table-Definition output. These tests verify the functionality of the 2D Table Definition output, including unit conversions made in the transfer from the External Element to the Table Element. It also verifies that the Table definition output type can be transmitted to a SubModel.

   a. Run the model. Verify that Expression2 and SubModel_Result2 both have a value of 115000 m (for Speed = 0.5555 m/s = 2 km/hr and Fuel = 101 gal).
   b. Change the value of Speed to 1.11111 m/s. Run the model. Verify that the output of both Expression elements is now 116500 m.
   c. Change the value of Fuel to 107 gal. Run the model. Verify that the output of both Expression elements have changed to 122000 m.

3. Enter the container labeled “Table_Def_3D”, which houses the tests for the 3D Table-Definition output. These tests verify the functionality of the 3D Table Definition output, including unit conversions made in the transfer from the External Element to the Table Element. It also verifies that the Table definition output type can be transmitted to a SubModel.

   a. Run the model. Verify that the value of Expression 3 and SubModel_Result3 is 1150000 m (for Speed1 = 0.5555 m/s = 2 km/hr, Fuel1 = 101 gal, and Engine_displacement = 1000 cc).
   b. Change the value of Speed1 to 1.11111 m/s. Run the model. Verify that the value of both Expression elements has changed to 1165000 {m}.
   c. Change the value of Speed1 back to 0.55555 m/s, and then change the value of Engine_displacement to 2000. Run the model. Verify that the value of both Expression elements has changed to 2115000 m.

4. Enter the container labeled “Time_Series.” Enter the Instantaneous, Constant_Over_Next, Constant_Over_Previous, Change_Over_Previous, and Change_Over_Next_Interval containers and ensure that the values for TimeSeries 1 and TimeSeries2[1] are identical. The verifier should then enter the Discrete_Change container and confirm that Integrator1 and Integrator2[1] produce identical histories. Finally the tester should enter the Instantaneous, Constant_Over_Next, Constant_Over_Previous, Change_Over_Previous, and Change_Over_Next containers and change TimeSeries1 from elapsed time to calendar basis. The tester should then run the model and re-verify all of the time series result graphs in these containers.

Repeat the test using the 64-bit version of the test file and DLLs (GS29_External264.gsm, cfstubs_x64.dll, and TS_Proc_x64.dll)

GS30_Table Function: Using a Table Element Like a Function

<REVISED LOOKUP TABLES WERE INTRODUCED IN VERSION 9 –SUPPORT FOR OLD STYLE TABLES WAS DISCONTINUED IN VERSION 9.60>

<THIS TEST SUPERCEDED BY GS50 FOR VERSION 9.60 AND LATER>

GS31_Param Import Samp: Parameter Importance Sampling

This file verifies that GoldSim's stochastic-parameter importance-sampling algorithm functions properly. The tests in this file evaluate GoldSim's output for a single uniformly-distributed random variable, U(0,1). Each test case must be run in succession. To run a test case, adjust the location for sampling enhancement (low, high, none) in the properties dialog box for the element 'Uniform'. Then run the model and view the Results Distribution and Results Array **(this is a button below the plot in the Result Distribution dialog)** to evaluate the model output against the expected results shown in Table GS31_ 1 below. Note that all tests should report the same mean value and standard deviation because GoldSim corrects for the sampling weights before reporting results.

Table GS31_ 1

For n=10000 realizations, Random Number Seed = 1 and Latin Hypercube Sampling Disabled

Test Case	Enhance-ment Location	Mean Value	Standard Deviation	Weight of sorted sample (n = 1 or n = 10000)[1]	Visual measure of confidence bounds on sampled values	# of Realiza-tions in Enhanced Zone[2]
1	none	0.50 +/-	0.29 +/-	0.0001 (for all)	equal for all samples	NA
2	lower	0.50 +/-	0.29 +/-	Approx. 1E-8	tighter near lower end	on the order of 1000
3	upper	0.50 +/-	0.29 +/-	Approx. 1E-8	tighter near upper end	on the order of 1000

Notes:

1. For lower enhancement, use n = 1 in the sorted list shown in the Results Array; for upper enhancement, use n = 10,000.
2. For this test, the enhanced zone is taken as between 0 and 0.01 for the "low end" and 0.99 and 1.0 for the "high end". Thus, count the number of values realized between these values when sampling from the corresponding "end". The values specified in the table are approximate.
3. Because GoldSim results are stored in single precision, the high-end of the results when run with the upper end enhanced contains a number of results that round to 1.0 in single precision. As a result, the results array display will show a count of several results and their combined weight, rather than the 1E-8 weight of the highest result.

GS31b_ImportanceSampling:

This test verifies that Importance Sampling features in the Timed Event, Random Choice and Reliability elements function properly.

As part of the test the verifier will run the model three times. The first time the model should be run with importance sampling enabled only for the Timed Event. The verifier should confirm that the probability of an event in a given realization is approximately 0.00995, and then they should check the Result Array to ensure that there are on the order of 500 realizations in the enhanced zone.

The model should be run a second time with importance sampling enabled only for the Random Choice element. The verifier should confirm that Result3 shows a probability for the

LowProbEvent of approximately 0.00100, and that GoldSim reports approximately 150 observations in the enhanced zone.

The model should be run a final time with importance sampling enabled only for the Function element. The verifier should confirm that Result1 shows that the probability of the failure mode occurring during a given realization is approximately 0.00140 and that there are on the order of 50 realizations in the enhanced zone.

GS32_Save_Results

This file is used to verify that result-saving for multiple user-defined time phases works correctly. For each realization, the result X equals the realization number multiplied by the time. Run this problem a total of eight times (i.e., in the following 2 x 2 x 2 = 8 scenarios):

1. (If the player version is available to perform network runs) Do each run once as a normal run, and once using two Slave processes running on your system (launch these by entering "goldsim.exe -s" from the Start/Run Windows input, as described in GS25_MULTIPROCESSOR earlier).

2. Save 1 and 100 histories.

3. Run with and without 'Save results at the end of each Phase" set in the simulation settings/customize timesteps dialog.

Ensure that all appropriate results are correctly saved for each scenario (e.g., for 100 realizations, saving results at end of each phase, and for element "Stats", the mean value at time 10 days should be approximately 500; at 50 days, 2,500; and at 100 days, 5,000).

GS33_Previous_Value

This file tests the Previous Value element, which delays a value, condition, event or discrete change input by one timestep. Tests are stored in three containers, and the test is run with the “Allow events to occur between timesteps” option turned off. To conduct the test, the verifier should run the model and verify the specified results in each container.

Scalar Container

Open Result1 and ensure that:

1. Previous_Timestep_Value has a value that lags one day behind that of SIN_Function;
2. Difference and Difference2 are evaluated correctly (see their formulas); and
3. On day 75, Integrator1 should assume a value equal to Previous_Timestep_Value.

These results may best be seen by viewing Result1 in Table mode.

Vector_Matrix Container

1. The value of elements in the PreviousValue1 vector should lag the values in the Stochastic1 vector by one timestep.

2. The output of members of the Condition_Matrix and the Value_Matrix should be True and 1 respectively at day 50. Members of the previous value matrices should lag their respective inputs by one day.
3. Expression 1 tests the Previous Value element's Rate of Change output. It should be 1 1/d on day 50 and -1 1/d on day 51. (The increase to 1 on day 50 is an average rate of change of 1 1/d and the decrease back to 0 -1 1/d).

Events_Discrete_Changes Container

1. The time output of Milestone1 should take on a value of 1 at time = 1 day, and a value of 101 at time = 101 days, as TriggeredEvent1 is activated at time = 0 d and at time = 100d.

2. Integrator2 should take on a value of 442 at time = 1 day, and a value of 884 at time = 101 days, as DiscreteChange1 (with a value of 442) is activated at time = 0 d and at time = 100d.

Initial_Values Container

1. Verify that the value of X in the Initial_Values container is 502. This is because the Previous Value element has an Initial Value of 100, and 2 is added to the previous value at each update (200 timesteps = 201 updates = 402 added).

2. Enter the Cond_Initial_Values container and verify that the value of X is 482. This is because the Previous Value element has an Initial Value of 100, and 2 is added to the previous value at each update (the container is activated at 10 days, so it receives 191 updates = 382 added).

Static_Submodel

Enter the looping container inside the static submodel and confirm that the script element inside has recorded the values 0,1,2,3,4,5,6,7,8,9 as a vector of 10 items.

GS34_Modify_Units_and_Sets

This file verifies that 1) members of an array-label can be added or deleted without causing elements based on that set to "crash"; and 2) user-defined units (that are currently used by the model) cannot be deleted.

1) The test for adding/removing members of an ordinal set proceeds as follows:

a. Open the elements IQ and Cooperation_Factor to view their current values. Next, open the Array Labels dialog box (under the pull-down menu Model, select Array Labels). Then select the "People" array labels, and then "Edit Set".

b. Add one or more entries to the set and click "OK" and "Close" to exit the Array Labels dialog.

c. Open the element IQ and ensure that a new member (row) has been added to the vector for each new set member. Likewise, open Cooperation_Factor and ensure that a new row and column has been added for each new set member. The values in all new cells should be 0.0.

d. Finally, open the Array Label dialog and delete one or more entries from the People set. Ensure that the corresponding rows and/or columns are removed from IQ and Cooperation_Factor.

Also ensure that no other "problems" result from these operations.

2) The test for removing a user-defined unit that is currently in use is as follows. Enter the container User_Defined_Unit_Test. From the Model menu, select Units. Then, scroll to the “Math Constants” folder, highlight the unit with name “Trho”, and then select the “Remove” button on the right side of the dialog box. You should get a message that the unit cannot be deleted because it is in use. Click the “Show References” button to make sure that Data1 is listed. Click the “Close” button to complete the test.

GS34b_Units_Wizard

This file tests the units wizard. Open the model and go to the units wizard. Create a unit abbreviated dmgL and define it as 1 day * 1 mg/L. Put it in the category of WeightedConcentration. After closing the units wizard, go to the element Integrated_Concentration and give it units of dmgL.

Create another unit for langleys and abbreviate it as lang. Define it as 41840 kg/s2. Put it in the Solar_Radiation category of units. Close the units dialog and make sure the element Solar_Radiation is defined as 1 lang/day and it has display units of kW/m2. Run the model and confirm the element True_if_everything_works is true.

GS35_Dynamic_Export

This test verifies that the Export feature correctly exports results to an ASCII file, binary file and a database. This particular test file represents a dynamic model. The model must be run to calculate the results.

Structured ASCII Text File Format

1. After running the model, select File from the menu bar, then Export, and then Results.

2. First, select the “ASCII Text” export option. Next, select one or two reservoir elements to be exported. Then select one or more time points, but not all of the time points. Next, select one or more realizations, but not all of the realizations. Next, enter a file name and path where you would like the text file to be saved. Click Finish. Open the text file and compare the results with the results for the output Data Element “Reservoir1”, "Reservoir1_1", and "Reservoir1_2".

Repeat the steps above, however, this time select all elements, all time points and all realizations. Open both text files and compare the results with the results for "Resveroir1", "Reservoir1_1", and "Reservoir1_2" in the model.

Binary File – MayDay Format:

1. After running the model, select File from the menu bar, then Export, and then Results.

2. First, select one or two reservoir elements to be exported. Then select one or select one or more time points, but not all of the time points. Next, select one or more realizations, but not all of the realizations. Next, enter a file name and path where you would like the binary file to be saved. Click Finish. Use Mayday Reader to view the binary file and compare the results with the results for the output Data Element "Reservoir1", "Reservoir1_1", and "Reservoir1_2".7.

Repeat the steps above, however, this time select all time points and all realizations. Use Mayday Reader to view the binary file and compare the results with the results for "Resveroir1", "Reservoir1_1", and "Reservoir1_2" in the model.

Results Database (MS-Access-MDB file)

1. After running the model, select File from the menu bar, then Export, and then Results.

2. First, select one or two reservoir elements to be exported. Then select one or more time points, but not all of the time points. Next, select one or more realizations, but not all of the realizations. Next, enter a file name and path where you would like the database to be saved. Click Finish. Open the database and compare the results in tblResults with the results in the output Data Elements "Reservoir1", "Reservoir1_1", and "Reservoir1_2".. Also, compare the results in tblUserDistribution with tables GS35_ 5 and GS35_ Cumulative and - Discrete.

Repeat the steps above, however, this time select all elements, all time points and all realizations. Open the database and compare the results in tblResults with the results for "Resveroir1", "Reservoir1_1", and "Reservoir1_2" in the model.

GS36_Static_export

This test verifies that the Export Feature correctly exports results to an ASCII file, binary file and a database. This particular test file represents a static model.

Structured ASCII Text File Format

1. After running the model, select File from the menu bar, then Export, and then Results.

2. Select one or two reservoirs and one or more realizations for export. Next, enter a file name and path where you would like the text file to be saved. Click Finish. Open the text file and compare the results with those for "Resveroir1", "Reservoir1_1", and "Reservoir1_2" in the model.

3. Repeat the steps above, however, this time select all elements and realizations. Open the text file and compare the results with those for "Resveroir1", "Reservoir1_1", and "Reservoir1_2" in the model.

Binary File – MayDay Format:

1. After running the model, select File from the menu bar, then Export, and then Results.

2. Select one or two reservoir elements and one or more realizations, but not all of the realizations for export. Next, enter a file name and path where you would like the binary

file to be saved. Click Finish. Use Mayday Reader to view the binary file and compare the results with those for "Resveroir1", "Reservoir1_1", and "Reservoir1_2" in the model.

3. Repeat the steps above, however, this time select all elements and all realizations. Use the Mayday Reader to view the binary and compare the results with those for "Resveroir1", "Reservoir1_1", and "Reservoir1_2" in the model.

4. Results Database (MS-Access-MDB file)

1. After running the model, select File from the menu bar, then Export, and then Results.

2. Select one or two reservoirs and one or more realizations, but not all of the realizations for export. Next, enter a file name and path where you would like the database to be saved. Click Finish. Open the database and compare the results with those for "Resveroir1", "Reservoir1_1", and "Reservoir1_2" in the model.

3. Repeat the steps above, however, this time select all elements and all realizations. Open the database and compare the results with those for "Resveroir1", "Reservoir1_1", and "Reservoir1_2" in the model. Also, compare the results in tblUserDistribution with table GS36_Static_Export – Cumulative and –Discrete..

Table GS36_Static_Export - Cumulative - User Distribution

Probability	Value
0	0
0.2	1
0.3	7
1	8

Table GS36_Static_Export - Discrete - User Distribution

Probability	Value
0.1	1
0.4	2
0.5	3

GS37_Initial Values and Previous-Value Elements

This file verifies the functionality of initial values and previous-value links for GoldSim elements. Follow the tests below. Expected results are listed in the appropriate sub-sections.

Initial Values and Activation

Enter the container Initial_Values. This container activates at time = 10 days. Run the model and compare model results to the following:

a. The results for all elements should be 0.5 except for Stochastic1 and Selector 1. Stochastic1 should be a sampled stochastic value between 0 and 1. Selector1 should be 0 before time = 10 days and 0.5 thereafter.

Return to the main model window.

Previous-Value Links

The Previous_Value_Links container contains tests to verify that only certain elements can originate a previous-value link. No action is necessary in this container; if the model has been run successfully for the previously-described tests in this file, then all tests in this container have been completed.

'Function of' and 'Affects' with Previous-Value Links

Enter the container Function_of. This container verifies that the 'Function of' and 'Affects' dialogs work properly when previous value links are present. The test proceeds as follows:

1. Check the 'Function of' dialog for Expression8. It should show that Expression8 is a function of Expression7, Integrator3_1, PV_Expression8 and Expression8 (forming a loop).

2. Check the 'Affects' dialog for Integrator3_1. It should show that Integrator3_1 affects Expression7, Expression8, PV_Expression8 and Integrator3_1 (forming a loop).

Illegal Initial Values

Enter the container named Failed_Initial_Values. Tests in this container verify that initial values for certain elements cannot contain previous-value links. The test proceeds as follows:

a. Place GoldSim in edit mode and enter the element Previous as the initial value for Integrator2. Run the model. You should get a message stating that initial values cannot contain previous value links. Return to edit mode and change the initial value back to 0.0.
b. Enter the element Previous as the initial value for Reservoir2. Run the model. You should get a message stating that initial values cannot contain previous value links. Change the initial value back to 0.0.

GS38_Changed and Occurs

This file verifies that the functions *changed()* and *occurs()* operate correctly. Run the model. For each element listed in Table GS38, compare the model output with the expected results shown in the table.

TABLE GS38

Test Element	Expected Result	Purpose of Test
Changed1	Value spikes to 1 at time 10, and is zero for all other times	Event occurrences are recorded by changed()
Changed2	Number of events changes from 0 to 1 at time 10 days	Changed() can be used as a condition in the trigger dialog
Changed3	Value spikes to 1 at time 10, and is zero for all other times	Container status changes are recorded by changed()
Changed4	Value changes from 0 to 1 at time	Ensures that changed()

Test Element	Expected Result	Purpose of Test
	10 days, and then remains at a value of 1	behaves properly for continuously-varying input parameter
Changed5	Value spikes to 1 at time 10, and is zero for all other times	Repeats Changed1 test with a Data element.
Occurs1	Value spikes to 1 at time 10, and is zero for all other times	Triggered Event transaction recorded by occurs()
Occurs2	Value spikes to 1 at time 10, and is zero for all other times	Timed Event transaction recorded by occurs()
Occurs3	Value spikes to 1 at time 11, and is zero for all other times	Event Delay transaction recorded by occurs()

GS39_Decision_Milestone_Status

This file verifies that the Decision, Milestone, and Status elements operate correctly. Run the model. For each element listed in Table GS39_1, compare the model output with the expected results shown in the table.

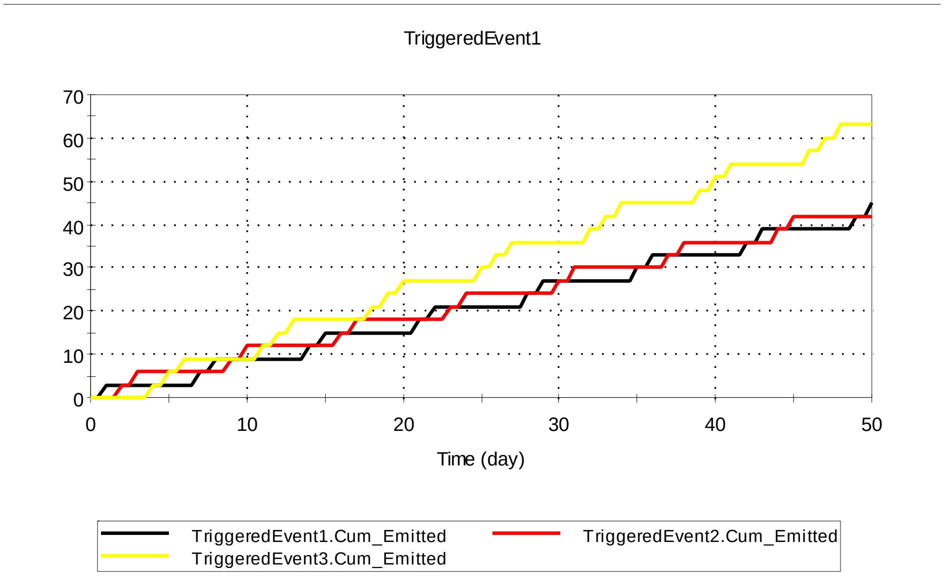
Table GS39_1

Test Element	Expected Result	Purpose of Test
Milestone1	Time = 10 days. The following warning message is also generated: "Ignoring attempt to achieve Milestone Milestone1, which was already achieved at time 10 day."	Ensures that GoldSim produces a warning message when the "Event may only occur once" option is selected
Milestone2	Time = 15 day.	Tests Automatic Triggering
Milestone3	Time = 15 day.	Tests User-defined Triggering with onTrue trigger type.
Milestone4	Time = 1.5 day.	Tests User-defined triggering with onEvent trigger type.
Milestone5	Time = 15 day.	Tests User-defined triggering with onChanged trigger type.
Milestone6	Time = 10 days	Tests the "Event may occur multiple times/Store time of first occurrence" option (milestone triggered at 10 and 20 days).
Milestone7	Time = 40 days	Tests the "Event may occur multiple times/Store time of latest occurrence" option (milestone triggered at 10, 25 and 40 days).
Milestone8	Never activated	Tests the "Record a warning message if this milestone is never achieved" option. Should generate a run log warning when the model is run.

Test Element	Expected Result	Purpose of Test
Decision1	Value will change from 0 to 3 at time 10 days.	Tests Automatic triggering with two outputs.
Decision2	Value will change from 0 to 2 at time 10 days.	Tests Automatic triggering with three outputs.
Decision3	Value will change from 0 to 1 at time 12 days.	Tests User-defined triggering with two outputs.
Decision4	Value will change from 0 to 2 at time 12 days.	Tests User-defined triggering with three outputs.
Decision6	Value of LastDecision output should jump to 1 at time 1 day and then oscillate between 1 and 3 for the remainder of the simulation	Tests the ability of the decision element to reference its LastDecision output.
Status1	Value changes from 0 to 1 at 5 days, from 1 to 0 at 10 days, from 0 to 1 at 20 days, and from 1 to 0 at 25 days	Test that User-defined triggering sets the Status output to true or false when the triggers fire.
Status2	Value changes from 0 to 1 at time 25 days	Test User-defined triggering.
Status3	Value changes from 1 to 0 at time 20 days	Test User-defined triggering.
References_Itself	Value starts at true, and then oscillates between true and false for the rest of the simulation (changes value once per timestep).	Tests dynamic features of status elements (initialization and ability to reference itself).

Then enter the container called “Decisions\Multiple_Simultaneous_Events” and ensure that both the shape and values in the Result1 graph correspond with Figure GS39_1 below (also pasted in the model).

Figure GS39_1



GS40_Information Time Series

<REVISED TIME SERIES ELEMENTS WERE INTRODUCED IN VERSION 9.60 WITH EXISTING ELEMENTS AUTOMATICALLY CONVERTED>

<THIS TEST SUPERCEDED BY GS60 FOR VERSION 9.60 AND LATER>

GS40b_InformationTimeSeriesExcelSupport

<REVISED TIME SERIES ELEMENTS WERE INTRODUCED IN VERSION 9.60 WITH EXISTING ELEMENTS AUTOMATICALLY CONVERTED>

<THIS TEST SUPERCEDED BY GS60 FOR VERSION 9.60 AND LATER>

GS41_Material Time Series

<REVISED TIME SERIES ELEMENTS WERE INTRODUCED IN VERSION 9.60 WITH EXISTING ELEMENTS AUTOMATICALLY CONVERTED>

<THIS TEST SUPERCEDED BY GS60 FOR VERSION 9.60 AND LATER>

GS41b_InformationTimeSeriesExcelSupport

<REVISED TIME SERIES ELEMENTS WERE INTRODUCED IN VERSION 9.60 WITH EXISTING ELEMENTS AUTOMATICALLY CONVERTED>

<THIS TEST SUPERCEDED BY GS60 FOR VERSION 9.60 AND LATER>

GS42_Date Time Series

This file verifies that Information and Material Time Series elements function correctly in date/time mode. The tester should perform the following steps:

1. With the model in date/time mode:
    a. Switch each history table between elapsed and date-time modes, and confirm that the contents do not change. The start date of Jan 15, 2001 10:00 AM should convert to 15 days of elapsed time relative to a start date of January 1, 2001 10:00 AM.
    b. Run the model with the tables in each mode, and confirm that the results do not change.
2. With the model in elapsed-time mode:
    a. Switch each history table between elapsed and date-time modes, and confirm that the contents do not change. The start date of Jan 15, 2001 10:00 AM should convert to 15 days of elapsed time relative to a start date of January 1, 2001 8:00 AM.
    b. Run the model with the tables in each mode, and confirm that the results do not change.

GS43_Versioning

There is no predefined test file for this case. Start with a new GoldSim file, and carry out the following steps:

1. Enable all modules that have elements (i.e. the RT, FN, RL modules).

2. Add a new Container, “C”.

3. Use the Model/Versioning menu, enable versioning, add a first version titled “one”, and from the Version Manager dialog select the first version as the ‘Show’ version. Exit the Version Manager.

4. Add a Data element into the root Container. Then add one of every other type of element (except SubModel) into Container C.

5. Enable the browser and confirm that all elements are flagged in red except for those existing prior to enabling versioning. Display the element context-menu option “Show Changes…” for several elements and Containers, and confirm that the appropriate logging messages are present: element added (for normal elements), and a summary of the elements added for the Containers.

6. Delete one or more of the elements. Move one or more elements to a different container.

7. Add a Version Change Note using its context menu to one of the elements. Confirm that the note is accessible from that element’s change log.

8. Add a new version; “two”, and make it the reference version by clicking the “Show” checkbox next to it in the versioning dialog.

9. Randomly change different properties of a number of elements, and confirm that their change logs are updated correctly:
    a. Element ID
    b. Element description
    c. A normal input field
    d. A setting such as a check-box

10. Select one element and change all its available properties. Switch to version “one” as the reference version, and confirm that appropriate log messages are displayed for this element. Test the ‘Show History’ and ‘Show Global Changes’ options and confirm that the changes are reported. Test using either “one” or “two” as the reference version.

11. Move several elements between the root and “C” folders. Confirm that their change logs and the Container change logs report the moves.

12. Delete several elements. Confirm that their (previous) Containers indicate they were deleted.

13. Return to the Version Manager dialog and generate a report. Print the report. Confirm for several elements that the report correctly reflects their change logs.

14. In the Version Manager, delete version “one”. Test several elements and confirm that their change logs reflect their changes since version “two”. Confirm that the elements that were added and then deleted prior to version “two” are not present in the change logs. Confirm that the elements that were moved prior to version “two” are no longer shown as moved.

15. To test serializing of the change logs, save the test file. Open a new file. Reopen the test file, and confirm that the change logs for several elements are identical to their contents prior to saving and reopening the file.

GS44_External File Locking

This test checks the external file locking capability of the Spreadsheet, File, External, and External Pathway elements. There are four test files, each containing one of the above elements linked to an external file. Each file is first run to ensure that the simulation can be conducted without error using the original locked files. Next, each of the locked files is replaced with a different file of the same name, and the model files are re-run. Each should issue an error message stating that the locked external file has been modified, and the simulation should be terminated.

1) Open GS44_CRC_Spreadsheet and run the model. The simulation should execute successfully. (If an error message is presented, un-check and then re-check the “Lock External File” checkbox and re-run the simulation).
2) Rename the external file GS44.xls to GS44_old.xls, then copy GS44_Modified.xls and rename the copy to match the original filename (GS44.xls). Re-run the model. You should receive an error message stating that the locked external file has been modified, and the simulation should terminate.
3) Open GS44_CRC_File and run the model. The simulation should execute successfully. (If an error message is presented, un-check and then re-check the “Lock External File” checkbox and re-run the simulation).
4) Rename the external file GS44.txt to GS44_old.txt, then copy GS44_Modified.txt and rename the copy to match the original filename (GS44.txt). Re-run the model. You should receive an error message stating that the locked external file has been modified, and the simulation should terminate.
5) Open GS44_CRC_External and run the model. The simulation should execute successfully. (If an error message is presented, un-check and then re-check the “Lock External File” checkbox and re-run the simulation).
6) Rename the external file GS44.dll to GS44_old.dll, then copy GS44_Modified.dll and rename the copy to match the original filename (GS44.dll). Re-run the model. You should receive an error message stating that the locked external file has been modified, and the simulation should terminate.
7) Open GS44_CRC_ExternalPath and run the model. The simulation should execute successfully. (If an error message is presented, un-check and then re-check the “Lock External File” checkbox and re-run the simulation).
8) Rename the external file GS44_Pathway.dll to GS44_Pathway_old.dll, then copy GS44_Pathway_Modified.dll and rename the copy to match the original filename (GS44_Pathway.dll). Re-run the model. You should receive an error message stating that the locked external file has been modified, and the simulation should terminate.
9) Open GS44_CRC_Lookup and run the model. The simulation should execute successfully. (If an error message is presented, un-check and then re-check the “Lock External File” checkbox and re-run the simulation).Rename the external files

GS44_LookupTable.txt and GS44_lookupTable.xlsx to GS44_LookupTable_old.txt and GS44_lookupTable_old.xlsx respectively, then copy GS44_LookupTable_Modified.txt and GS44_lookupTable_Modified.xlsx and rename the copies to match the original filenames (GS44_LookupTable.txt and GS44_lookupTable.xlsx). Re-run the model. You should receive an error message stating that the locked external file has been modified, and the simulation should terminate.

GS45_Command-Line Arguments

These tests verify that the various command-line arguments are functioning properly. Open a command line window and navigate to the directory containing the GoldSim executable file. For those tests that require a model file, you will need to either copy the model file into the GoldSim root directory, or specify the full path (in quotes) to the model file. Type the following commands into the command line window. You should exit GoldSim after conducting each test:

1. *goldsim –show Container1 "{path}GS45_Command.gsm"* - GoldSim should open and show the contents of Container1.

2. *goldsim -d "InitialValue = 10d" -r -sv "{path} GS45_Command2.gsm"-x "{path]GS45_Command.gsm"* – GoldSim should open and immediately run the simulation, then save it as GS_Command2.gsm and close. Confirm that the Integrator in Container1 has a value of 101 at the end of the simulation.

3. *goldsim -data "Integrator1.Initial Value = 20d" -r -sv "{path} GS45_Command3.gsm"-x "{path]GS45_Command.gsm"* – GoldSim should open and immediately run the simulation, then save it as GS_Command3.gsm and close. Confirm that the Integrator in Container1 has a value of 120 at the end of the simulation and that the Initial Value field in the Integrator shows 20d instead of being linked to InitialValue.

4. *goldsim –s* - GoldSim should launch in slave mode.

5. *goldsim –slave* - GoldSim should launch in slave mode.

GS46_Dashboard and Player

The dashboard and player test consists of four separate sub-tests. The first is designed to verify the proper functionality of each of the dashboard elements, including inputs, outputs, and buttons. The second sub-test exercises the linkages between dashboard elements and the underlying model elements. The third test verifies the creation of a player file, and the fourth test verifies the proper functionality of the GoldSim Player.

1. Open file GS46_Dashboard1.gsm and go into Dashboard1. Place the Model in Edit Mode and Activate the Dashboard.
    a. Change the values of each of the four input controls. Try entering values less than 0 and greater than 2 into the text box (these values should not be allowed and an error message will result). Flip to Design Mode, and then change the smallest allowed increment for the controls for Data1 through 4. Activate the dashboard and ensure that GoldSim warns if a prohibited value is entered or automatically adjusts the value to the nearest permitted value. During these tests

confirm that the value reported by each of the output controls equals Data1 + Data2 + (Data3 * Data4) + Data5 + Data6 + ETime. Make sure the reported values are correct. Check and uncheck the checkbox and make sure the results are correctly updated. (Etime should have a value of 0 before the simulation is run). Verify that the value of Data 7 changes when different dates are selected.

b. Click the Run Model button to run the simulation. Make sure the results are still correct. Etime should now have a value of 10, so the displayed results should have been incremented by this amount.
c. Check (or uncheck) the checkbox (Data3) and re-run the model. Again, verify the results.
d. Click the Reset Values button. Ensure all controls return to their defaults.
e. Click the button labeled "Go To Data1". The model container should be shown in the graphics pane, and element Data1 should be selected.
f. Return to the dashboard and click the button labeled "Open Data1". The property page for element Data1 should be displayed. Also, the value displayed in the definition field should match that shown in the dashboard control labeled Data1.
g. Click the button "Show Container1". The graphical pane should display the contents of Container1. Use the Back arrow on the graphics pane to return to the dashboard.
h. Repeat the previous test, this time using the hyperlink in Container1 to return to the dashboard.
i. Return to the dashboard and click the "Execute Application" button. A new copy of GoldSim should be launched. (If this doesn't work, first edit the properties of that button and make sure the path represents the correct path to the GoldSim executable on your machine).
j. Click the button labeled "Open File.txt". A text file should appear in notepad. (If this doesn't work, first make sure the test file of that name is present in the same directory as the verification test file).
k. Click the button labeled "Open URL". The GoldSim website should open in a web browser.
l. Click the button labeled "Open Dashboard2". Dashboard2 should open be opened. Click the button labeled "Open Dashboard1" to return.
m. Click the button labeled "Show Result". A chart of Data5 should be displayed. (Note that you will need to be in results mode to view actual results).
n. Click the button labeled "Database Download". The database download dialogs should appear. Check element Data1 in the Simple_Database container to make sure the download took place by inspecting the date/time label in the Database tab. (In order to complete this step, you will need to have set up the connection to the Simple Database test file as outlined in test GS09_DBAS).
o. Click the button labeled Open TimeSettings – the time page of the Simulation Settings dialog should open.
p. Click the button labeled OpenMonteCarlo – the time page of the Simulation Settings dialog should open.
q. Click the Edit Time Series button. Ensure that a value of 0 is specified at 0d and a value of 100 is specified for 100d.
r. Click the Edit Lookup Table button. Ensure that a value of 0 is specified for an independent variable value of 0d and a value of 50 is specified for an independent variable value of 10d.
s. Click the Change Spreadsheet button. Ensure that GS46DashboardA.xlsx is selected.

t. Run the model and click the Show TS/Table/SS Values button. The TimeSeries should change from 0 to 100 linearly over the course of the simulation, while Expression1 (linked to a Lookup Table) should linearly increase from 0 to 50 over the course of the simulation. The Spreadsheet output should show a constant value equal to Data1.
u. Return to Edit/Ready Mode. Click the Edit Time Series button and make changes to the Time Series data (add an extra time point, change the starting and ending values).
v. Click the Edit Lookup Table button. Add additional data points and edit the existing dependent values.
w. Click the Change Spreadsheet button. Select GS46DashboardB.xlsx.
x. Re-run the model and click the Show TS/Table/SS Values button. The outputs from the TimeSeries and the Expression that uses the LookupTable should reflect the changes made in step u) and v). The output of the Spreadsheet element should now be equal to 5 * Data1.

2. Open file GS46_Dashboard2.
    a. Move each of the four data elements from the root container into Container2. Go into the dashboard and place the model in run mode. Change each of the input values and make sure the output values display the correct result (Data1 + Data2 + Data3*Data4 + Data5 + Data6). Run the model and re-check the results.
    b. Rename each of the four data elements and then repeat checks in Step a.
    c. Delete one of the input data elements. Go back into the dashboard and try to place the file into Run Mode. You should receive an error message referring to the deleted element not being found. You should not be able to run the model or interact with the dashboard in run mode.

3. Re-open file GS46_Dashboard1. Make sure the model is in Result mode. From the File menu, select "Save Player File". (Note that you must be running GoldSim Pro, and have the "Dashboard Publishing" option checked in the Extension Modules dialog.)
    a. In the second step of the wizard, fill in the author name, model title, and model description. Click Next.
    b. Accept the defaults in Step 3 and click Finish to save the player file as GS46_Player1.gsp.
    c. Next, re-enter the wizard and save a new player file. This time, select the "Show Top Level Container when model opens" and "Allow User to Run Model" options. Under the "Allow User to Run Model" entry, check the boxes to allow the user to change both the Time and Monte Carlo simulation settings. Save the file as GS46_Player2.gsp.
    d. Look in the directory you specified and make sure that the two player files were created.

4. Launch the GoldSim Player.
    a. Open file GS46_Player1.gsp. Repeat steps a) through m) in Part 1 of this test. You should observe the following differences in behavior (because running the model was disabled for this player file):
        i. The dashboard inputs will not be editable because the file is in results mode (steps a, c)
        ii. The "Run Model" will do nothing (step b);
        iii. The "Database Download" button will issue a message that database downloads cannot be conducted in Results mode (step m).

b. Click the “Show Container1” button again to browse the model. Click through the menu items and toolbar buttons. Refer to the user interface steps listed in GS_00_User_Interface. For each of the individual checks listed in the User Interface test, the appropriate behavior in the Player is described below.
    i. Extension Modules – should not be available in the Model|Options dialog
    ii. Send to – should not be available in the File Menu
    iii. Property Dialogs – the property dialog for an element should be available on double-click, but all input fields should be grayed out.
    iv. Search and Synchronization – The Search tool should function in the same manner as GoldSim, and the graphical and browser panes should synchronize correctly.
    v. Navigation Buttons - The navigation buttons should function in the same manner as in GoldSim.
    vi. Filter – the Filter should not be available.
    vii. Graphics – the Graphics menu should not be available, nor should the right-click graphics options.
    viii. Simulation Settings – the simulation settings dialog should be available by going to Model|Simulation Settings.
    ix. Editing – editing of element properties should be disabled.
    x. Moving, Copying, Deleting – moving, copying, and deleting of elements should not be available.
    xi. ToolTips – tooltips should function in the same manner as in GoldSim.
    xii. Input/Output Windows – the input and output popup windows should function in the same manner as in GoldSim.
    xiii. Zooming – the zoom, zoom to fit, and pan options should be available on the toolbar, but not from the right-click context menu.
    xiv. Appearance – the appearance options in the context menu should all be unavailable.
    xv. Drawing Tools – the drawing tools (text, shapes, links, etc.) should all be disabled.
    xvi. Run Mode – the Model menu option should not be available, the Run button on the toolbar should be disabled, and F5 should do nothing.
    xvii. Result Mode – the model should be in Result mode by default. All behaviors should be the same as in GoldSim.
    xviii. Export Graphics – this feature should not be available.
    xix. Inserting Elements – Inserting elements should not be possible.
    xx. Link Cursor – the link cursor should be disabled.

c. Open file GS46_Player2.gsp. Repeat steps a), and b) in Part 1 of this test. You should observe the same behavior as described in that test (i.e., the model should run successfully). Save the model in the Player, and then close the Player and reopen GS46_Player2.gsp. Ensure that changes to Dashboard elements are retained and no errors occur when the model is loaded.

d. Click the “Show Container1” button again to browse the model. Check the following behaviors specific to running the model:
    i. Simulation Settings – the simulation settings dialog should be available from the Model menu. Duration, timesteps and Monte Carlo options (with the exception of those in the Advanced dialog) should be editable.

ii. Run Mode – run mode should be available from the Model menu, the toolbar button, and by hitting F5. All of the standard run mode functionality (run, pause, abort, resume, reset) should be available.
iii. View Run Log – the run log should be accessible from the Model menu.
iv. Options Dialog – the options dialog should be accessible from the Model menu, but only the Results tab should be visible.

e. Return to Dashboard1. Change the values for Data1 through Data7 and record the changes. Click the Go to Data1 button. Ensure that Data1, through Data7 show the appropriate values in their tool tips. Return to Dashboard 1 and ensure that the controls for Data1 through Data7 continue to display the changed values.

f. Change the values for Data1, Data2, Data3, and Data4 a second time and record the changes. Run the model, then click the Go to Data1 button. Verify that the data elements show the correct values when you view their tooltips. Return to Dashboard1 and ensure that the dashboard continues to display the changed values.

GS46a_Dynamic_Dashboard

This test verifies that dashboard editing is prohibited during the simulation unless authorized by the model creator. It also ensures that if the dashboard controls can be edited during a run that the linked elements update their values correctly.

To run the test, open GS46a_Dynamic_Dashboard.gsm and follow these steps:

1. Enter the dashboard and ensure all controls are set to their default value and that editing of the controls is not permitted during the simulation run (the "Allow value to be changed during simulation" option should not be checked).

2. Run the model and pause it midway through the simulation (it may be necessary to reduce the speed of the simulation using the slider in the run controller).

3. Attempt to edit all of the controls in the dashboard. They should not be editable. Allow the simulation to run to completion and view the Result time history. The values of all outputs should be 1 over the course of the simulation except for the Condition type Data element's value, which should be 0 and the DateTime control, which should show its default value.

4. Return to Edit Mode and make the Dashboard controls editable during the simulation by checking the "Allow value to be changed during simulation" box on each control's property dialog.

5. Run the model and pause it midway through the simulation (it may be necessary to reduce the speed of the simulation using the slider in the run controller).

6. Change the value of the Input Field and Sliders to 2, check both Checkboxes, select option B in the Combo and List Boxes, and specify a value of two for both items in the Grid Control. Select a different date in the DateTime Control. Run the model to completion and view the Result time histories by clicking the Dashboard buttons. Values should be 1 until the point at which the simulation was paused and 2 for the

remainder of the simulation. The Condition output should be false until the point the simulation was paused and true for the remainder of the simulation. The DateTime graph should show the default value up until the time the simulation was paused and the user-selected value after that.

GS46b_DB_Grid_Controls

This test verifies the correct functioning of the Grid Controls added in GoldSim Version 10. It consists of a dashboard and a series of data elements.

To complete the test the user should enter each of the containers (Scalar, Vector and Matrix). They should ensure that the values in the controlled data elements update when changes are made in the grid control, and they should also ensure that the grid controls return to their defaults when the Reset to Defaults button is selected. The verifier should also ensure the controlled elements also change to the default values.

GS46c_Status_Control

This test verifies the correct functioning of the Status dashboard output control added in GoldSim Version 10.

To run the verification test simply enter each dashboard in the test file and confirm the Status controls change their appearance in the manner described as the value of the input control is varied.

GS47_Run Properties

This test checks that the Run Properties produce the correct values. This test consists of two parts: the first (file GS47_RunProperties a) tests a calendar date/time simulation which runs from January 1, 2002 to December 31, 2002 The second (GS47_RunPropertiesb) tests an elapsed time simulation, which runs for 365 days. The verification files GS47_RunPropertiesa and GS47_RunPropertiesb must first be run. For expected results, see tables GS47_RunPropertiesa and GS47_RunProperties

Table GS47_RunPropertiesa

Output	Expected Result
Year_1	2002
Day_1	31
Month_1	12
Hour_1	23
Minute_1	59
Second_1	59
DayOfWeek_1	3
WeekOfYear_1	53
DayOfYear_1	365
Quarter_1	4
Realization_1	1
Timestep_Length_1	1 day
Start_Time_1	1/1/2002 12:00:00AM
Time_1	37622 day
Etime_1	365 day

Table GS47_RunPropertiesb

Output	Expected Result
Year_1	1
Day_1	31
Month_1	12
Hour_1	0
Minute_1	0
Second_1	0
DayOfWeek_1	2
WeekOfYear_1	53
DayOfYear_1	366
Quarter_1	4
Realization_1	1
Timestep_Length_1	1 day
Start_Time_1	Dec. 30, 1999
Time_1	365 day
Etime_1	365 day

GS48_Convolution

This test verifies the performance of the Convolution element. The test evaluates both scalar and vector inputs, and both Transfer function and Integrated Transfer function inputs.

The input function is a step that starts at 1.0 at time 0, and becomes equal to -1.0 at time 50.

The transfer function is a normal distribution with mean 20 seconds and standard deviation 5 seconds, which produces a delayed, ‘smeared’ response to the input function.

The integral of the transfer function is a cumulative normal distribution. This is input to those elements defined to have a integrated function.

The transformed result is calculated analytically using Expression elements.

The user should run the model, and then compare the curves in each of the three time-history result elements to ensure that the analytical and computed results are closely similar. Because the Convolution element uses a numerical integration, small discrepancies are acceptable.

GS48b_Truncated_Convolution

This test verifies the proper functioning of the truncation features in the Convolution element. It takes a constant signal (1) and feeds it through a Convolution element with a step transfer function (0.05 between 10 and 30s, 0 otherwise).
Run the model and compare Result1 to the Figure GS48b-01 below.

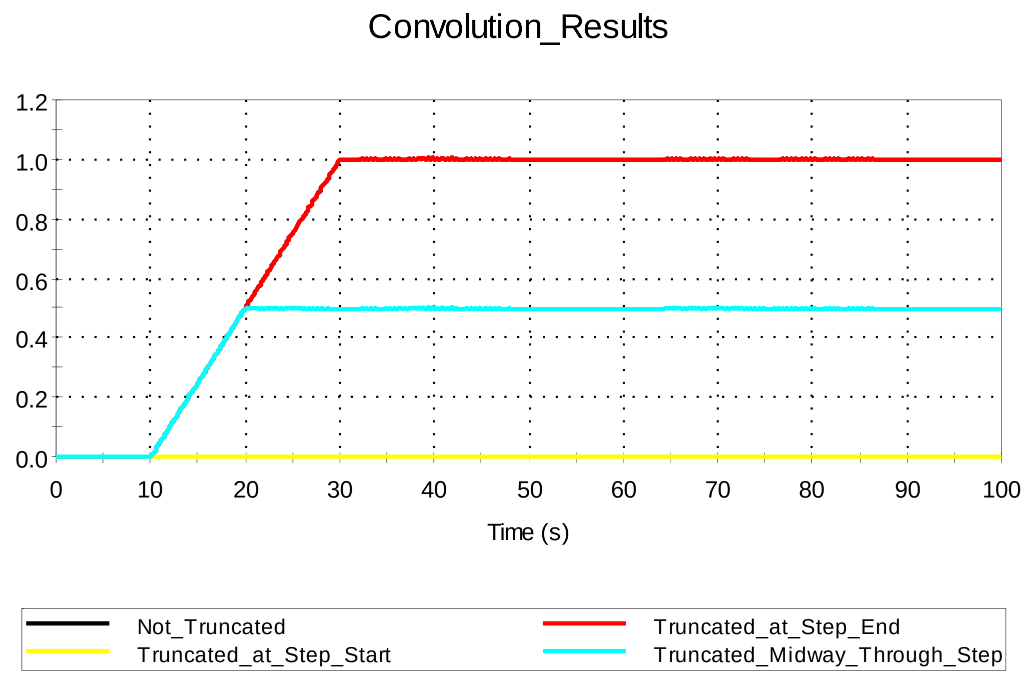


Figure GS48b-01

Verify that the final values of the convolution elements are as follows:

Not_Truncated = 1
Truncated_at_Step_End = 0.9975
Truncated_Midway_Through_Step = 0.4975
Truncated_at_Step_Start = 0

GS49_RandomChoice

This test verifies the proper functioning of the Random Choice element. A timed event element generates 1000 events at the start of the first and second timestep, and these events should be divided according to the proportions defined in the random choice element. These proportions are:

Event1 - 0.15 first timestep, 0.25 second timestep

Event2 - 0.35 first timestep, 0.5 second timestep
Event3 - 0.25 first timestep, 0.05 second timestep
LastEvent - 0.25 first timestep, 0.2 second timestep

Instructions/Expected Results: Run the model and check that the cumulative emitted values for each of the "Random" timed events corresponds with the expected value below.

Random_1 - 400
Random_2 - 850
Random_3 – 300
Random_4 - 450

GS50_LookupTables

This file contains tests for Look-up tables that are defined locally (i.e., either defined within the element or read in from a text file using the "Import Table" feature) as opposed to defined externally. The test consists of six parts:

1. Pasting data into Tables
2. General testing of lookup, extrapolation and interpolation features.
3. Importing Tables
4. Call tests
5. Miscellaneous features
6. Verifying that the user is warned properly when a table receives a query that is outside its bounds

1. Pasting data into Tables. In order to test the ability to paste copied data into Table elements, the user should execute the following procedure. First, in the file GS50_look.gsm, enter the container Pasting_Tests.

a. Open the Excel spreadsheet that is linked to GS50_look.gsm (double-click on the hyperlink titled "Data to Paste", which is found next to the container Pasting_Tests) and enter the worksheet named "GS50".

b. 1D Table: Open the 1D Table, and click "Edit Data". Click in the upper left cell in the table grid (there should only be two cells available). Go to the spreadsheet, highlight the 2 column x 51 row data set indicated by the text, and copy it (CTRL C). Return to GoldSim and paste the data (CTRL V). The 1D Table grid should expand to encompass the data, and all data should appear as in the spreadsheet. Verify that the paste was completed successfully by scrolling through the table. Click "OK" twice to exit the 1D Table's dialog boxes.

c. 2D Table: Open the 2D Table, and click "Edit Data". Click in the upper left cell in the table grid (this cell is above the row heading and to the left of the column heading for the single existing data cell). Go to the spreadsheet, highlight the 51 column x 51 row data set indicated by the text, and copy it (CTRL C). Return to GoldSim and paste the data (CTRL V). The 2D Table grid should expand to encompass the data (all 2500 entries), and all data should appear as in the spreadsheet. Verify that the paste was completed successfully by scrolling through the table. Click "OK" twice to exit the 2D Table's dialog boxes.

d. 3D Table. First, click "Edit Data" and then add a new layer (Layer 1). Then switch current the layer back to 0. Next, follow the same instructions as for the 2D Table for

Layer0. Then, switch to Layer 1 and ensure that Layer 1 is now a 50 x 50 cell grid. Add a new layer (Layer 2) and ensure that it is added as a 50 x 50 grid. Close and re-open the 3-D table element and ensure that the pasted data remains correct.

e. Run the model and open the Result element called "Time_History". All three time histories should be identical with the exception of the 3d table at the first two timepoints. Because the 3d table does not permit extrapolation it will show its minimum value of 2 at 0s and 0.5s.

2. General testing of lookup, extrapolation and interpolation features. Look-up table functionality is verified by comparing model results with known results. The expected results for each non-time dependent output are presented either in a note or in the tool tip window for each element for easy comparison with the current value output. The look-up table tests checked in this section include:

1D Table

- look-up data point at, between, and outside table data points, linear interpolation and extrapolation
- look-up data point at, between, and outside table data points, linear interpolation and no extrapolation
- look-up data point at, between, and outside table data points, linear interpolation and extrapolation on the dependent variable axis, log interpolation and extrapolation on the independent axis
- look-up data point at, between, and outside table data points, log interpolation and extrapolation on the dependent variable axis, linear interpolation and extrapolation on the independent axis

2D Table

- look-up data point at table data point
- look-up data point between table data points with linear interpolation on the dependent and independent variables
- look-up data point with logarithmic dependent variable interpolation and linear independent variable interpolation
- look-up data point with linear dependent variable interpolation and linear independent variable interpolation

3D Table

- look-up data point at table data point
- look-up data point between table data points with linear interpolation on the dependent and independent variables
- look-up data point with logarithmic dependent variable interpolation and linear independent variable interpolation

- look-up data point with linear dependent variable interpolation and linear independent variable interpolation

The verification results are presented in Table GS50_01. It is not necessary for the user to enter any data but it is necessary to run the model to verify the above tests.

TABLE GS50_1

Tests Element	Result Type	Expected Values
Table_1D_1	Element time histories	time = 0s, value = 0 time = 10s, value = 1 time = 20s, value = 2 time = 30s, value = 3 time = 40s, value = 4 time = 50s, value = 5
Table_1D_2	Element time histories	time <= 10s, value = 1 time = 20s, value = 2 time = 30s, value = 3 time >= 40s, value = 4
Table_1D_3	Element time histories	time = 0s, value = 1 time = 10s, value = 10 time = 20s, value = 100 time = 30s, value = 1000 time = 40s, value = 10000 time = 50s, value = 100000
Table_1D_4	Element time histories	time = 0.5s, value = 10 time = 1s, value = 10 time = 10s, value = 20 time = 40s, value = 26.021
Table_1D_5	Element time histories	time = 0 – 19.5, value = 1 time = 20-29.5, value = 2 time = 30-39.5, value = 3 time = 40-50, value = 4
Table_1D_6	Element time histories	time in seconds = value
Table_2D_1	Element tool tip	Table_2D_1 = 3

TABLE GS50_1

Tests Element	Result Type	Expected Values
Table_2D_2	Element tool tip	Table_2D_2 = 3
Table_2D_3	Element tool tip	Table_2D_3 = 1000
Table_2D_4	Element tool tip	Table_2D_4 = 3
Table_2D_5	Element tool tip	Table_2D_5 = 3
Table_3D_1	Element tool tip	Table_3D_1 = 7
Table_3D_2	Element tool tip	Table_3D_2 = 4
Table_3D_3	Element tool tip	Table_3D_3 = 10000
Table_3D_4	Element tool tip	Table_3D_4 = 4

TABLE GS50_1

Tests Element	Result Type	Expected Values
Table_3D_5	Element tool tip	Table_3D_4 = 3.48
Table_1D_Import	Element edit data, Import file Lookup1d.txt	col row 1.5 10 2.5 20 3.5 30 4.5 40
Table_2D_import	Element edit data, Import file Lookup2d.txt	**col** **1 2 3** **row** **10** 1 2 3 **20** 4 5 6 **30** 7 8 9 **40** 10 11 12
Table_3D_import	Element edit data, To import a table: Import file Lookup3d.txt	**col** **row 1 2** **10** 1 2 **20** 3 4 **30** 5 6 **10** 10 20 **20** 30 40 **30** 50 60 **10** 100 200 **20** 300 400 **30** 500 600
Table_3D_import_layer	Element edit data, To import a layer: Import file Lookup2d.txt	**col** **1 2 3** **row** **10** 1 2 3 **20** 4 5 6 **30** 7 8 9 **40** 10 11 12

3. Importing Tables. Verifying the table import capabilities requires some user interaction. It is necessary to test importing data using both text files and spreadsheets.

File import tests:

- import 1D table
- import 2D table
- import 3D table
- import a table layer (2D table) into a 3D table

File import is tested using elements inside the "Import_Tables" container. The verifier should open each test element, click the "Edit Data" button, then click the "Import Table" or "Import Layer" button, and choose the desired import file (this should be done from the import table button that is accessible after pushing the Edit Data button). The import file names and verification results are presented in Table GS50_1. Then the tester should change the data source for the tables, so that each is reading an ASCII text file at run time. The filenames should be entered, and then the tester should run the model and confirm the values are imported at run time.

Spreadsheet import tests:

- import 1D table
- import 2D table
- import 3D table

Spreadsheet import is tested using elements inside the "Spreadsheet_Import" container. The verifier should open each test element, switch to the Excel tab, and click the "Import Data" button. The verifier should also create two additional table elements:

1. Create a new 3D table (call it Created_3D), selecting Excel as the data source, and referencing 3dtable.xls as the source file. The user should use the Location button to select the row and layer variables, and should type in the appropriate cell reference for the starting column variable.

2. Create a new 1D table (call it Created_1D), selecting Excel as the data source. Use the "Create and select new spreadsheet" option, call the new spreadsheet GS50_created.xls (if this file already exists from a prior verification, it should be deleted), and use the open option to view the new spreadsheet. Create a simple data set (e.g., {1,2,3,4,5} as the independent variable and {10,20,30,40,50} as the dependent variable). Save the Excel file and specify the appropriate starting cell using the location button. Click the "Import Data" button and ensure that data is successfully imported.

After the user has completed the tests, the model should be run to ensure the spreadsheets can be successfully imported at runtime.

4. Call tests. This portion of the test verifies that a Table Element can be accessed by referencing the table's name (i.e., a function-like call to a specified value in the desired table from within an Expression Element). The file tests valid and invalid calls to 1D, 2D, and 3D tables. Run the model to verify the results of the valid calls.

Table GS50_ 2: Valid Calls

Element Being Tested	**Expected Result**	**Comment** (base case: Depth = 5m, Position =

		50ft, Layer = 4)
Sat1D_const_2	0.2	constant argument = 2m
Sat1D_const_5	0.4	constant argument = 5m
Sat1D_variable	0.4	variable argument = 'Depth'
Sat1D_expression	0.2	expression argument = max(0 m , Depth – 2 m) = 3m
Sat1D_sum	0.8	Saturation_1D(Depth) + Saturation_1D(Depth)
Sat2D_const_5_50	0.4	constant arguments = (5m, 50ft)
Sat2D_const_3_40	0	constant argument = (3m, 40ft)
Sat2D_variable	0.4	variable argument = (Depth, Position)
Sat2D_expression	0.2	expression arguments = (max(0 m , Depth – 2 m), 2*Position/2)
Sat2D_sum12	0.8	= Saturation_1D(Depth) + Saturation_2D(Depth, Position)
Sat2D_sum22	-0.4	Saturation_2D(Depth, Position) – 2*Saturation_2D(Depth, Position)
Sat3D_const_5_50_4	0.4	
Sat3D_5_50_3	0.3	
Sat3D_variable	0.4	arguments = (Depth, Position, Layer)
Sat3D_expression	0.2	expression arguments = (max(0 m , Depth – 2 m), 2*Position/2, Layer)
Sat3D_sum33	0.8	Saturation_3D(Depth, Position, Layer) + Saturation_3D(Depth, Position, Layer)
Sat3D_sum123	1.2	Saturation_1D(Depth) + Saturation_2D(Depth, Position) + Saturation_3D(Depth, Position, Layer)

Once the expected results of the valid calls have been verified, return to edit mode and ensure that the following invalid calls are not permitted by GoldSim.

Table GS50_ 3: Invalid Calls

Element	**Changes that should result in errors while editing the element's properties;** cancel without making changes before moving on to next case.
Sat1D_1	Base case: argument = Depth (valid state)
	Case 1: change arg to 5 gal
	Case 2: change arg to 5 (no units)
	Case 3: change arg to argument = Layer
Sat2D_1	Base case: arguments = (Depth, Position)
	Case 1: change arg1 to 5 gal
	Case 2: change arg2 to 50 gal
	Case 3: change arg1 to 5 (no units)
Sat3D_1	Base case: args = (Depth, Position, Layer)
	Case 1: change arg1 to 5 gal
	Case 2: change arg2 to 50 gal
	Case 3: change arg1 to 5 (no units)
	Case 4: switch argument positions: (Layer, Depth, Position)

<u>5. Miscellaneous tests.</u> These tests verify the functionality of some of the user-interface features of Table elements. To execute these tests, use the Table elements created in Part 3. above:

a. Ensure that in all of the following tests that the row and column headings in the Table are always visible (i.e., while scrolling through a large table grid).

b. Resizing: Open the Edit Data dialogs for several tables and re-size the dialogs by dragging on a corner of the dialog box (as for any standard Windows window). Ensure that the dialog re-sizes as intended and that all pertinent information (text, buttons) remains fully visible.

c. Removing: After clicking into a cell in the table, click on the "remove" class of buttons (rows, columns) and ensure that the appropriate row or column is removed. A row or column can be removed either by placing the cursor in a single cell and then selecting "remove", or by highlighting the headings (except for the first column or row, which cannot be deleted). Click on "Cancel" to exit the dialog without making any changes. Remove buttons should not be available in tables linked to Excel spreadsheets.

d. Adding: After clicking into a cell in the table, click on the "add" class of buttons (rows, columns) and ensure that a new row or column is added below (for rows) or to the right (for columns) of the current location. Next, click CTRL + Add (row or column). A dialog should pop up requesting the number of rows or columns to add. Ensure that the appropriate numbers are added below (for rows) or to the right (for columns) of the current location. Click on "Cancel" to exit the dialog without making any changes. Add buttons should not be available in tables linked to Excel spreadsheets.

e. Sorting: Add a new 1D Table element and call it "Sorting". Enter the following values into the table in the order shown:

Independent	Dependent
1	5
3	3
2	4
5	1
4	2

Click "OK". Ensure that the Table does not sort the values into ascending order (with respect to the independent variable) before clicking "OK". Re-open the Edit Data dialog box and ensure that the table is sorted into ascending order by the independent variable (1,2,3,4,5). Ensure that the dependent variable is sorted properly as well (5,4,3,2,1)

6. <u>Verifying that a fatal error is generated when a table receives a query that is outside its bounds.</u> Open the file called "GS50_lookb.gsm". Enter the container called "Bounds Check" and run the model.

a. The first error will be caused by the 1-D table at t=40.5s. Go into the table element and select extrapolate in the Handling of Data Section.

b. Rerun the model - it should now have an error at 41.5s (caused by the 2D table). Change the 2D table so that the data extends to the end of the simulation (change the column independent label from 41s to 50s).

c. Rerun the model - it should now have an error at 42.5s (caused by the 3D table). Change the 3D table so that the data extends to the end of the simulation (change the second layer's independent variable from 42s to 50s).

d. Rerun the model. It should run until 45s, at which point the Lookup Table in the Exact_Only container will generate a fatal error when it is queried with a value that does not exist in its lookup table.

GS51_Looping

This model verifies the proper functioning of looping containers by using them to do an iterative solution of a nonlinear equation.

At each time step, the model iterates to solve the equation: X + X^2 = Time (in days).

It uses Newton's method to make successive adjustments to the value X, until the solution converges or ten iterations have been completed.

To run the test, open and run GS51_Looping.gsm
The verifier should run the model and ensure that the constraints are respected (error less than 1E-6 and loops <10, or error >1E-6 and loops = 10). Error can be viewed in the History plots, and Loops in the Number of Loops plots. It should also be verified that on the TestPlot graphs that Y increases in direct proportion to time throughout the simulation.

A second test is included in the Stock_Test container. This test ensures that GoldSim only applies Rate of Change inputs when the timestep changes and not each time a loop occurs. At the end of the simulation the Integrator and Reservoir elements inside the container should both report a value of 100d.

GS52_InternalClocks

This test verifies the proper functioning of Internal Clock Submodels. It consists of two parts. The first test verifies the functioning of the maximum timestep length setting, while the second test verifies the functioning of the minimum timestep length option/setting.

In the first test, there is an integrator with a rate that increases by 1/s each timestep inside an internal clock container (Container 1). The internal clock maximum timestep length changes from 20s (greater than the model timestep) to 1s after a triggered event occurs at 20s. This means that the Rate element should be equal to 1/s at 0s, 2/s at 10s, 3/s at 20s, 4/s at 21s, 5/s at 22/s and so on. The Integrator1 element should increase by 20 between 0 and 20s (1/s * 10s + 2/s * 10s), and then by the rate multiplied by 1s for every timestep after that (this is equivalent to the Sum(all n between 3 and 82)) . This means that the Integrator1 element has an expected final value of 3430.

To run the test, the verifier should run the model and confirm that the Rate Integrator inside Container1 is equal to 83 1/s at 100s, and that Integrator1 is equal to 3430 at 100s.

In the second test, both Container2 and Container2_1 have a Timed Event that issues an event regularly once per second. In addition, each container has a second TriggeredEvent element, which has an On Changed Etime trigger (in effect, the TriggeredEvent counts the number of timesteps in the container). Container2 does not permit events to occur between timesteps, while Container2_1 allows events to occur with a 5s minimum timestep.

To run the test, the verifier should run the model and confirm that the cumulative emitted output of the TriggeredEvent inside each container. The TriggeredEvent element inside Container2 should show a cumulative emitted value of 11, while the TriggeredEvent element inside Container2_1 should show a cumulative emitted value of 21.

GS53_Sensitivity

This test verifies the proper functioning of the Sensitivity Analysis features in GoldSim.

The tester should open the Sensitivity Analysis dialog by selecting Run|Sensitivity Analysis. The user should turn off the use quantiles option and set up the sensitivity analysis with the following values:

Variaible	Lower Bound	Center Value	Upper Bound
A	-2	-2	-2
B	-3	5	87
C	-10	0	20
D	25	45	100

E is the result to be analyzed.

Ensure that the result data matches the expected values on the Numbers worksheet in the GS53_Sensitivity.xls spreadsheet.

Ensure that the individual, global and tornado plots correspond with the result data values.

Select the "use quantiles" option and rerun the sensitivity analysis. Ensure that the result data matches the expected values on the Quantiles worksheet in the GS53_Sensitivity.xls spreadsheet.

Again, ensure that the individual, global and tornado plots correspond with the result data values.

GS54_Splitter

This test verifies that the Splitter element functions correctly for values and discrete changes. It includes tests of the element when the sum of fractions must equal one and where the sum of fractions can take on any value. Inputs to all test elements vary dynamically, and a test is included to ensure the correct functioning of the ~Amount local property.

Instructions/Expected Results: The verifier should run the model and ensure the Max_Deviation element has a value of 0 at the end of the simulation. If the Max_Deviation element is nonzero, the subcontainers in the Values and Discrete_Changes containers each have a Container_Check Extrema element that can be used to narrow down the source of the problem.

GS55_Allocator

This test verifies that the Allocator element functions correctly. It has a number of containers that test the functions of the Allocator element for Value and Discrete change inputs.

Dynamic_Demand_Values:

This test checks the value of the ~Total and ~Remainder local properties and also verifies that the element reacts correctly to dynamic changes in demand for value inputs. The Output1 demand (which has the highest priority) has a demand of ~Total **-** ~Remainder and so should be zero for the duration of the simulation. Output three is dynamic – it only demands 30 after 50 days and is zero for the remainder of the simulation. The verifier should ensure that the following values are shown in the Results_Dynamic_Demand Time History element:

Time	Output1	Output2	Output3	Output4	Unused
0-50	0	65	0	15	20
60-100	0	65	30	5	0

Values_Dyn_Neg_0:

This test checks that GoldSim correctly handles Allocator elements with value inputs where the priorities are editable. When priorities are editable, negative, zero and dynamic priorities can be specified. To confirm the correct functioning of the element, the verifier should ensure that the values in the Result_Dyn_Neg_0 Time History are as follows:

Time	Output1	Output2	Output3	Output4	Unused
0-20	0	70	0	30	0
30-40	0	70	30	0	0
50	15	70	15	0	0

Values_Equal_Priorities:

This test ensures that GoldSim correctly handlest Allocator elements with equal priorities but different demands. To ensure the correct functioning of the element under these conditions, the verifier should ensure that the values in the Values_Equal_Priorities container are as follows:

Equal Share:

Time	Output1	Output2	Output3	Output4	Unused
0-50	40	25	25	10	0
60-100	40	20	20	10	0

Proportional:

Time	Output1	Output2	Output3	Output4	Unused
0-50	40	25.7	25.7	8.57	0
60-100	40	20.8	20.8	8.33	0

Value_Dynamic_Amount:

In this container, the response of an allocator element to a dynamic value input is tested. The output of the allocator is recreated using basic Goldsim elements and compared with the output from the Allocator element. The verifier should check that the Max_Deviation Extrema element has a value of 0.

Single_Output:

In this container, the response of an Allocator element with a single output is tested. The expected output of the Allocator is recreated using basic Goldsim elements and compared with the output from the Allocator element. The verifier should check that the Max_Deviation Extrema element has a value of 0.

Dynamic_Demand_DC:

This test checks the value of the ~Total and ~Remainder local properties and also verifies that the element correctly handles dynamic changes in demand for discrete change inputs. The Output1 demand (which has the highest priority) has a demand of ~Total - ~Remainder and so should be zero for the duration of the simulation. Output three is dynamic – it only demands 30 after 50 days and is zero for the remainder of the simulation. The verifier should ensure that the following values are shown in the Results_Dynamic_Demand Time History element:

Time	Output1	Output2	Output3	Output4	Unused
30	0	65	0	15	20
70	0	130	30	20	20

DC_Dyn_Neg_0:

This test checks that GoldSim correctly handles Discrete Change Allocator elements where the priorities are editable. When priorities are editable, negative, zero and dynamic priorities can be specified. To confirm the correct functioning of the element, the verifier should ensure that the values in the Result_Dyn_Neg_0 Time History are as follows:

Time	Output1	Output2	Output3	Output4	Unused
30	0	70	30	0	0
50	15	140	45	0	0
70	45	210	45	0	0

DC_Equal_Priorities:

This test ensures that GoldSim correctly handles Allocator elements with equal priorities but different demands when processing discrete changes. To ensure the correct functioning of the element under these conditions, the verifier should ensure that the values in the DC_Equal_Priorities container are as follows:

Equal Share:

Time	Output1	Output2	Output3	Output4	Unused
0	40	25	25	10	0
60	80	45	45	20	0

Proportional:

Time	Output1	Output2	Output3	Output4	Unused
0	40	25.7	25.7	8.57	0

60	80	46.5	46.5	16.9	0

DC_Amount_Add:

In this container, the response of an Allocator element to a dynamic Discrete Change input is tested. The output of the Allocator is recreated using basic Goldsim elements and compared with the output from the Allocator element. The verifier should check that the Max_Deviation Extrema element has a value of 0.

DC_Amount_Replace:

In this container, the response of an Allocator element to a dynamic Discrete Change input is tested. The output of the Allocator is recreated using basic Goldsim elements and compared with the output from the Allocator element. The verifier should check that the Max_Deviation Extrema element has a value of 0.

GS56_History_Generator

This test verifies the correct functioning of the HistoryGenerator element. Individual settings are primarily tested using scalar History Generators, with correlations tested using Vector-type history generators.

To run the test, the verifier should run the model. They should then confirm that the results generated by the model are as follows:

Scalar_HistGen Container:

Element	**Test**	**Expected Result**
Geometric_Scalar	Tests the Geometric Growth setting	Result1 should show the final result has a mean of 0.5 and a standard deviation of 0.447
Geometric_Scalar_Reversion	Tests geometric growth with reversion	Result2 should show the final result has a mean of 0.5 and a standard deviation of 0.215.
Random_Scalar	Tests the Random Walk setting	Result3 should show a mean of 50$ and a standard deviation of 33.54$
Random_Scalar_Reversion	Tests reversion in the random walk case	Result4 should show a mean of 50$ and a standard deviation of 16.13$.
Random_Scalar_ No_Neg	Tests the allow negative values setting	Result5 and Result6 should show identical means and standard deviations.
Difference_Lag	Tests that median reverts to previous timestep value with high reversion rates.	Difference_Lag should be negligible (<0.01$)
Difference_No_Lag	Tests the do not lag target option	Difference_No_Lag should be negligible (<0.01$)

Vector_HistGen Container:

All of the multivariate result elements should show the following correlations (these are shown in the _Correlations Multivariate Result elements):

	1	2	3	4	5
1	1	0	0.75	0	0
2	0	1	0	0.1	0.35
3	0.75	0	1	0	0
4	0	0.1	0	1	0.93
5	0	0.35	0	0.93	1

The verifier should note that the correlations predicted by the Multivariate Result elements may not exactly agree with the matrix specified in the History Generator elements, especially for the t-distribution copula with one degree of freedom.

The verifier should also check that the correlation between variables agrees with the correlation type specified. To do this, the verifier should check the _2_Variables Multivariate Result elements. The Gaussian correlations should show a stronger correlation in the middle than at the tails. The 1 degree of freedom t-distribution copula should show a stronger correlation at the tails than in the middle. The 25 degree of freedom t-distribution copula should resemble the Gaussian copula (as the number of degrees of freedom increases, the t-distribution copula begins to approximate the Gaussian copula).

GS56a_History_Generator_Iman_Conover

This test confirms the proper functioning of the Iman and Conover correlation algorithm. This algorithm is actually designed for static models, so the test model only runs a single timestep (after the first timestep the algorithm behaves like a Gaussian copula). To conduct the test, run the model and ensure that the correlation matrix generated by the Multivariate result elements in each container agrees with the correlation matrix pasted in the GS56 test. The verifier should also ensure that the 2D plots approximate the 2D plots for the Gaussian distribution in the GS56 test.

GS57_Interrupt

This test verifies that the Interrupt element functions correctly. It starts with a base file where the interrupt is triggered when an Expression element reaches a value of 50.

To run the test, do the following:

1. Run the model – an interrupt should occur after 50 days in Realization 1. Check the “Ignore interrupt for this simulation” option. The simulation should run to completion. Open the run log and ensure no messages have been added by the Interrupt.

2. Run the model again. This time click **Pause** on the dialog that appears. This stops the run partway through the causality sequence, so Expression2 should show its previous timestep’s value (49 + 2 = 51) and the Triggered Event element (triggered when Expression1 becomes

50) should show a Cum_Emitted value of 0. The verifier should then abort the model and discard results. The model should automatically return to edit mode.

3. Run the model again but this time log the message as a run log message. Continue the model when prompted until realization 5. Then choose the ignore option and run the simulation model to completion. Open the run log and ensure that messages are added for the 5 interrupts that were not ignored.

4. Run the model again but log the message as a warning. Continue the model when prompted until realization 5. Then choose the ignore option and run the simulation model to completion. A message saying that 5 warnings occurred should be displayer. Open the run log and ensure that the five warnings were added.

5. Disable the interrupt element and rerun the model. It should run to completion and no warnings should be added to the run log.

6. Open the Interrupt's dialog , and enable the element. Disable the message, turn off the addition of warnings to the run log and select continue in the drop-down list for the element's action when the message is disabled or off. Run the model – it should run to completion with no interrupts.

7. Open the Interrupt's dialog and select "Skip remainder of current realization and continue" in the drop-down list for the element's action when the message is disabled or off. Run the model – it should run to completion with no interrupts. Check the time history for Expression2 and TriggeredEvent1.Cum_Emitted in Result 1. Check that these values are 52 and 1 from 50 days on (even though the interrupt occurs midway through the causality sequence, skipping the remainder of the realization completes the current update).

8. Open the Interrupt's dialog and select "Skip remainder of current realization and abort" in the drop-down list for the element's action when the message is disabled or off. Run the model – the simulation should be aborted after realization 1 and the model should be in Result Mode. Check the time history for Expression2 and TriggeredEvent1.Cum_Emitted in Result 1. Check that these values are 52 and 1 from 50 days on (even though the interrupt occurs midway through the causality sequence, skipping the remainder of the realization completes the current update).

9. Open the Interrupt's dialog and select "Discard this realization and abort" in the drop-down list for the element's action when the message is disabled or off. Run the model – the simulation should return to Edit Mode after 50 days.

10. Open the Interrupt's dialog and select "Abort and return to Edit Mode" in the drop-down list for the element's action when the message is disabled or off. Run the model – the simulation should return to Edit Mode after 50 days

11. Open the Interrupt element's property dialog, click More and then activate the "Check if this condition is true" option. Specify a condition of Realization = 5.

12. Open the Interrupt's dialog and select "Skip remainder of current realization and continue" in the drop-down list for the element's action when the message is disabled or off. Run the model – it should run to completion with no interrupts. Check the time history for Expression2 and TriggeredEvent1.Cum_Emitted in Result 1. In realization 5, check that

these values are 52 and 1 from 50 days on (even though the interrupt occurs midway through the causality sequence, skipping the remainder of the realization completes the current update). The other realizations should show a final Expression2 value of 102 and a TriggeredEvent1.Cum_Emitted value of 1.

13. Open the Interrupt's dialog and select "Skip remainder of current realization and abort" in the drop-down list for the element's action when the message is disabled or off. Run the model – it should stop after the fifth realization and the model should be in Result Mode. Check the time history for Expression2 and TriggeredEvent1.Cum_Emitted in Result 1. In realization 5, check that these values are 52 and 1 from 50 days on (even though the interrupt occurs midway through the causality sequence, skipping the remainder of the realization completes the current update). The first four realizations should show a final Expression2 value of 102 and a TriggeredEvent1.Cum_Emitted value of 1.

14. Open the Interrupt's dialog and select "Discard current Realization and abort" in the drop-down list for the element's action when the message is disabled or off. Run the model – it should stop after the fifth realization and the model should be in Result Mode. Only four realizations should be available and each should show a final Expression2 value of 102 and a TriggeredEvent1.Cum_Emitted value of 1.

GS58_Currencies

This test verifies that currency unit conversion features work properly. It contains 20 data elements (one for each built in currency in GoldSim). These elements are equal to 1 unit of their particular currency (with fictional rates), but are set to display results in US dollars.

Run the model – the expected values of the data element tool-tips are as follows:

Element	**Expected Value**
Dollar	1$
Euro	2$
Pound	3$
Yen	4$
AUD	5$
BRL	6$
CAD	7$
CNY	8$
CZK	9$
DKK	10$
HKD	11$
HUF	12$
MXN	13$
NZD	14$
NOK	15$
RUB	16$
SGD	17$
SEK	18$
CHF	19$
ZAR	20$

The verifier should then flip to Edit Mode, open the currencies dialog and then change the base currency. After closing the Currencies dialog, the verifier should run the model and ensure that all of the element values are the same for the new default currency as for the old default currency.

The verifier should reopen the Currencies dialog and set the newly selected base currency as the default. They should then insert a number of Financial Module elements and ensure that they have the new default unit selected.

After that, the verifier should reopen the Currencies dialog and switch the base currency back to US dollars. Again, the verifier should run the model and check that the values of the data elements are as listed in the table above. The verifier should then switch the default currency to US dollars and insert a number of Financial Module elements – these elements should have US dollars selected in the currency drop-down.

GS59_Submodels

The GS59 test for Submodels is actually a suite of several different tests, each of which is described in detail below.

GS59a_Submodel_Run_Properties

This test ensures that Submodels with externally controlled run properties behave appropriately. The model file contains six SubModels, each of which has a different run property controlled by the outer simulation. The difference elements check that the value passed to the Submodel is the same value used by the inner simulation.

To run the test, the verifier should run the model. They should then confirm that the Diff elements had a negligible value for all outer loops by checking the Final Value Distribution elements in the model.

GS59b_Submodel_Statistics

This test ensures the proper functioning of the final value statistics generated by the Submodel. It includes two Submodels, one with a continuous stochastic input and another with a discrete stochastic input. These are fed into an expression element, and the final value of the expression element is exported to the outer loop using all appropriate methodologies.

To conduct the test, the verifier simply needs to run the model. They should then confirm the following Submodel outputs:

SubModel	Output	Value
Continuous	Cond_Tail	114 kg
	Mean	100 kg
	Prob_Less_115	0.933
	Result_08	108.416 kg
	SD	10
Discrete	Cond_Tail	2 m
	Mean	50
	Prob_Equal	0.2
	Prob_Less_60	0.983

	Result_08	54
	SD	5 (values between 4.99 and 5.01 are acceptable)
	Prob_True	0.8

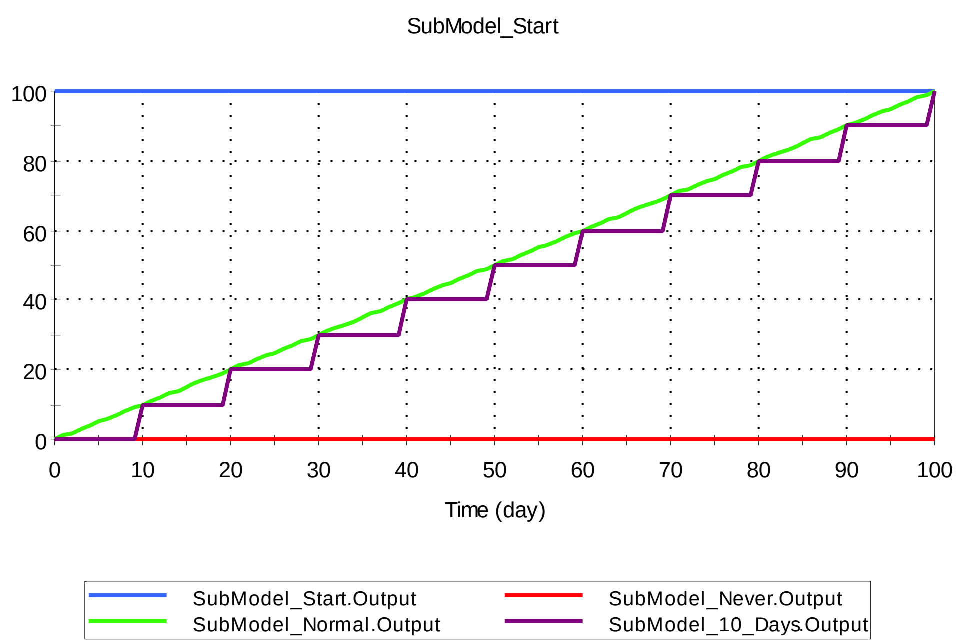
GS59c_Submodel_Triggering

This test ensures that SubModel triggering functions properly.

To conduct the test, the verifier should run the model. Expected results are as follows:

Element	**Expected Result**
SubModel_Start	100 for the duration of the simulation
SubModel_Never	0 for the duration of the simulation
SubModel_Normal	Increases linearly from 0 to 100 over the course of the simulation
SubModel_10_Days	Increases by 10 every 10 days

The Result time history should look like this:



GS59d_Submodel_Protection

This test ensures that Protection features work correctly in a Submodel.

The verifier should first test sealing the SubModel. Once the SubModel is sealed, the verifier should attempt to change settings and inputs on the property pages of the elements contained within the SubModel. Any changes should result in a warning that this will break the seal. If the seal is not broken, any changes should be reversed.

The verifier should unseal the SubModel and ensure changes can now be made to the SubModel's property dialog and to the elements inside. The SubModel should then be locked. GoldSim should prevent any changes to the elements inside the SubModel.

Then the verifier should unlock the model and ensure changes can be made to elements inside the SubModel.

GS59e_Submodel_Static_Outer_Model

This test ensures the proper functioning of SubModels contained within an outer static model. Three Submodels are included: one static, one dynamic and one optimization.

Results should be as follows:

SubModel_Static.Output: Mean value = 100
SubModel_Dynamic.Output : Mean value = 200
SubModel_Optimization.Output: Mean value = 0

The verifier should also pause the model midway through the simulation and ensure that the abort options work correctly. Discarding results should return the model to edit mode, while keeping results should place the model in Result mode and make results available for all realizations prior to the abort (and including the abort if that option is selected).

GS59f_Submodel_Dynamic_Outer_Model

This test ensures the proper functioning of SubModels contained within an outer static model. This test involves two separate test files: GS59f_Submodel_Dynamic_Outer_Model_1.gsm, which tests a dynamic outer model with a static and dynamic SubModel, and GS59f_Submodel_Dynamic_Outer_Model_2.gsm which tests a dynamic outer model with an Optimization SubModel.

Results for GS59f_Submodel_Dynamic_Outer_Model_1.gsm should be as follows:

SubModel_Static.Output: Mean value = 200
SubModel_Dynamic.Output : Mean value = 300

The verifier should also pause the model midway through the simulation and ensure that abort functionality works correctly. Discarding results should return the model to edit mode, while keeping results should place the model in Result mode and make results available for all realizations prior to the abort (and including the abort if that option is selected).

Results for GS59f_Submodel_Dynamic_Outer_Model_2.gsm should be as follows:

SubModel_Optimization.Output: Mean value = 0 (a mean value less than 0.05 is acceptable)

The verifier should also pause the model midway through the simulation and ensure that the three abort options work correctly. Discarding results should return the model to edit mode, while keeping results should place the model in Result mode and make results available for all realizations prior to the abort (and including the abort if that option is selected).

GS59g_Submodel_Import

This test ensures that SubModels correctly import Currency settings, custom Units, and Array Labels.

To run the test, open the outer model file, GS59g_Submodel_Import_Outer. Perform the following checks to ensure the test file is ready.

1. View the Currency dialog. Ensure that their default exchange rates are 1. The Bermudian Dollar (BMD) should not be shown in the Currency dialog.
2. View the units dialog - there should not be a Flux (Volume) unit defined called meters cubed per minute (MCPM) and there should not be a user defined unit category called Created.
3. View the array labels dialog. Only the default array labels of Days and Months should be shown.

The verifier should then insert a new Submodel element and import GS59g_Submodel_Import_Inner. The following checks should be performed:

1. Check that the Edit Mode values of Expression 1 and Expression 2 are still [1 GS, 2 GS, 3 GS] and 0.5 $-MCPM for all elements of Expression 2.

2. Verify that the following Units and Unit Category have been added to the model:

    - New Unit Category called Created, with dimension M3L2T.
    - New Unit in the Created category called GoldSims, abbreviated GS and equal to 334.45094 kg3-m2-s
    - New Unit in the Flux (Volume) category called meters cubed per minute (abbreviated MCPM) that is equal to 1 m3/min.

3. Verify that the following Array Label sets have been added to the outer model:

    - New Array Label Set called Named, with labels Rick, Stefan and Ian
    - New Array Label Set called Indexed, with labels 1 through 5

GS59h_Submodel_Import_Error_Conditions

This test ensures that GoldSim does not crash if the user tries to import models that have Units, Currencies and Array Label sets that conflict with those in the outer simulation model. First, open and save three Mismatch models (GS59h_Array_Index_Mismatch.gsm, GS59h_Array_Named_Mismatch.gsm and GS59h_CurrencyMismatch.gsm) in the test build.

1. Open the outer model file, GS59h_Submodel_Import_Error_Conditions. Attempt to import GS59h_Currency_Mismatch as a SubModel. A message should be displayed stating that the conversion rates in the two models do not match for US dollars, Euros, Pounds and Yen and that the rate from the outer model should be used. The verifier should also check that the default currency remains as US Dollars, and that the exchange rates in the outer model are all ones. The verifier should then enter the imported model and insert a data element equal to 1 Euro, but display the value in US dollars. They should then hit F9 and ensure that the element's tooltip shows a value of 1$.

2. Attempt to import GS59h_Unit_Conversion_Mismatch as a SubModel. A message should be displayed stating that there is a discrepancy in the conversion rate for GoldSims. The unit in the outer model should not change (it should retain its initial value of 334.45094 kg3-m2-s). GoldSims can be found in the Created unit category. The verifier should then enter the imported model and insert a data element equal to 1 GS, but display the value in kg3-m2-s. They should then hit F9 and ensure that the element's tooltip shows a value of 334.45094 kg3-m2-s.

3. Next try to import GS59h_Unit_Dimension_Mismatch as a SubModel. The import should fail due to a discrepancy in the dimension of the GoldSims unit. The dimension in the outer model should not change from M3L2T.

4. Attempt to import GS59h_Array_Index_Mistmatch as a SubModel. The import should fail because the two array label sets called Indexed have a different dimension. The Indexed array label set in the outer model should not be changed during the attempted import (labels should be 1 to 5).

5. Finally, try to import GS59h_Array_Named_Mismatch as a SubModel. The import should fail because of a difference in one of the elements of the Named array label set in both models. The Named array label set in the outer model should not be changed during the attempted import (it should remain as Rick, Stefan, and Ian).

GS59i_Submodel_Export_Versioning

This test ensures that GoldSim correctly exports Globals, Output Interfaces, Array Labels, Units and Currency Information.

1. To run the test, simply export the Submodel inside the test model file (GS59i_SubModel_Export_Versioning) to a standalone GoldSim file (call it ExportedSubmodel.gsm). Confirm the following information in the exported file:

   - The following custom currencies should be available and have the following conversions:

     - Bermudan Dollar (BMD) equal to 0.5 $
     - Canadian Tire Money (CTM) equal to 2 $

   - The following array label sets should be available:

     - Indexed [1 to 5]
     - Named [Rick, Stefan, Ian]

   - The following custom units should be listed in the Units dialog:

     - In the Flux(Volume) category, a meters cubed per minute (MCPM) unit equal to 1 m3/min should be listed.
     - In the Created category, a unit called GoldSims should be listed. It should be equal to 334.45094 kg3-m2-s.

- The verifier should also confirm that three versions of the model are listed in the Versioning dialog (A through C).

2. The Input Interface expressions in the Globals tab should be changed to static values. Run the model – it should run without errors.

3. A new version (Version D) should be added to the exported model and the model saved as ExportedSubmodel2.gsm.

4. The verifier should then open the original model file (GS59i_SubModel_Export_Versioning) and import the ExportedSubmodel.gsm into a second SubModel container. The Interface should be identical to the original SubModel. Versioning information for elements contained in the SubModel elements should also be identical on an element and global level.

5. Next the verifier should import ExportedSubModel2.gsm into a new SubModel container. There should be no record of changes made prior to importation for elements brought in from the ExportedSubModel2.gsm file, but this should not affect the versioning information for the remainder of the model.

GS59j_Submodel_Monte_Carlo_Repeated_Sampling

This test verifies that the "Use a different random seed for each realization of the parent model" option works correctly. The model consists of a SubModel with a uniform stochastic inside (0,10). The SubModel is run for 10 Monte Carlo realizations and returns the 95^{th} percentile of the values sampled from the stochastic over the ten realizations.

The verifier should ensure that the parent model selects random points in each LHS stratum and then run the model with the SubModel's option to "Use a different random seed for each realization of the parent model" disabled. The model should return the same value for all ten realizations. This can be confirmed by viewing the result array in the Result Distribution. The model should then be re-run with the option enabled. All 10 realizations should return different values. In all cases result from the SubModel should be between 9 and 10 (as LHS is enabled).

GS60_Time_Series

<Supercedes GS40_Information Time Series and GS41_Material Time Series>

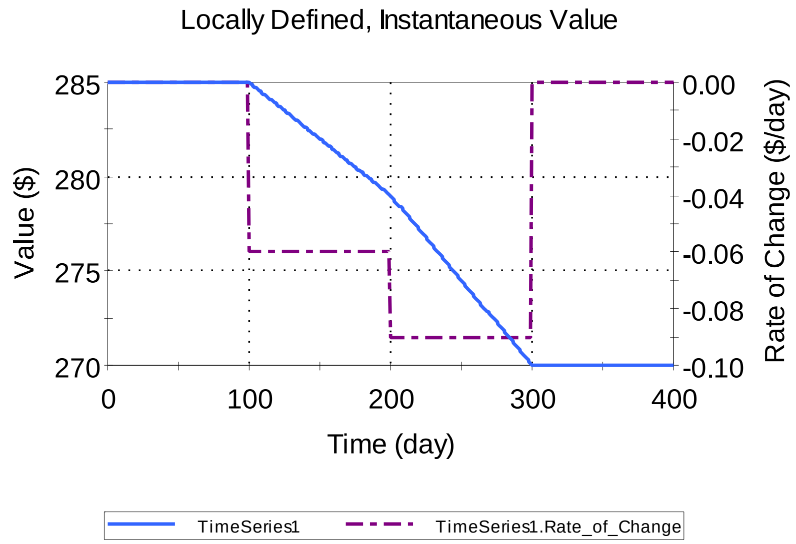
This test ensures the proper functioning of the second generation Time Series elements (introduced in GoldSim 9.60). Excel functionality is tested separately in the GS60b_Time_Series.gsm test.

The test should be run and then the verifier should enter each of the top level containers and perform the tests prescribed inside.

Basic_Functionality Container

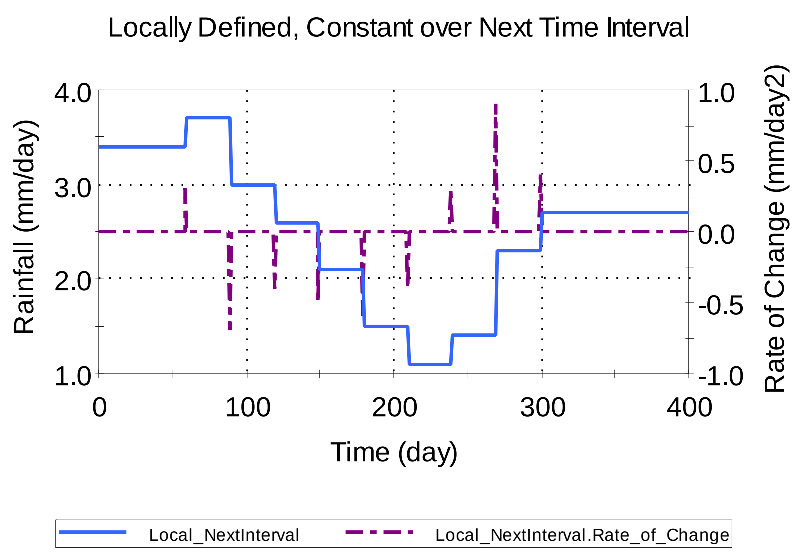
These tests ensure the proper behavior of the Time Series elements for locally defined data. Tests cover all source data types, the rate of change output, and the two main output settings for Value-type data.

1. Locally Defined Instantaneous – The verifier should check that the graph of Locally_Defined_Results matches the following graph:

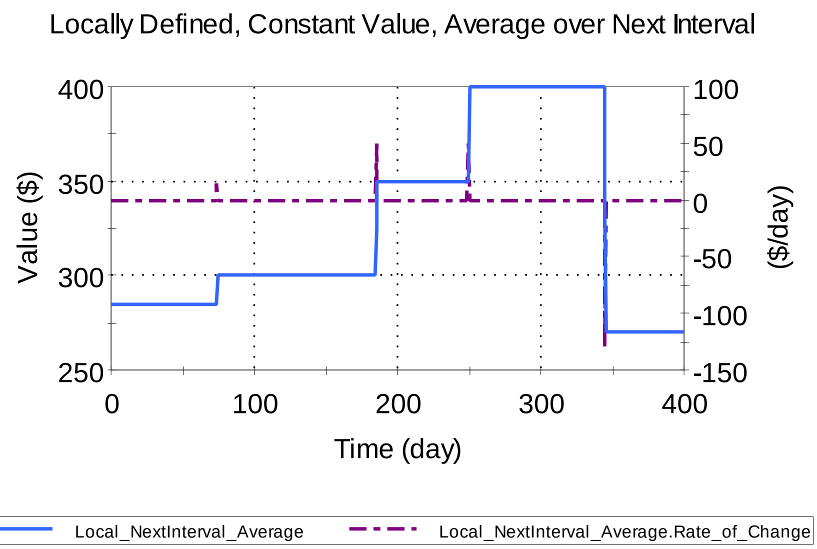


The verifier should also ensure that the value of Max_Deviation is negligible.

2. Locally Defined Next Interval – The verifier should check that the graph of Local_Next_Interval_Results matches the following graph:



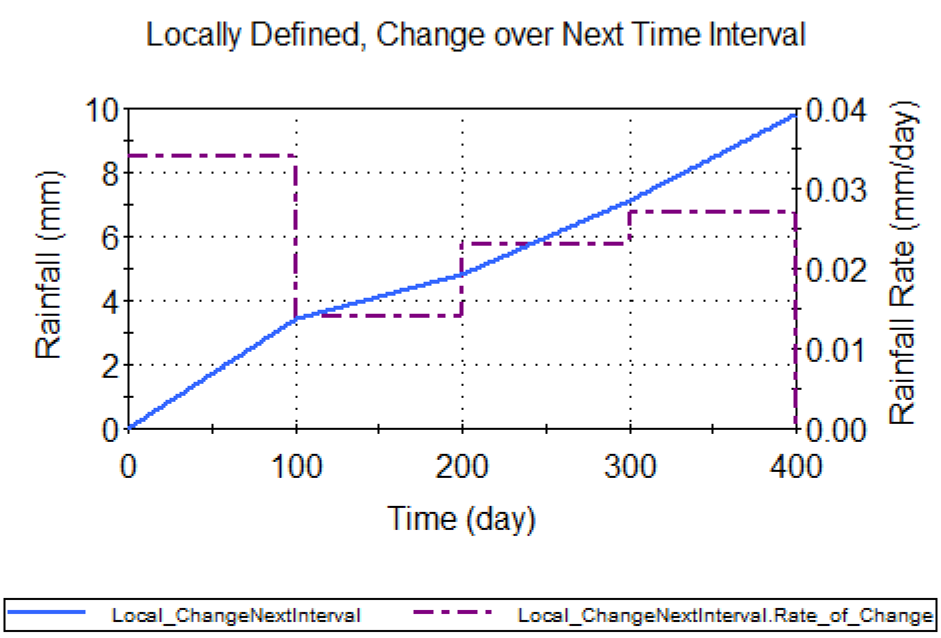
It should also be confirmed that Local_Constan_Avg matches this graph:



The verifier should also ensure that that the value of Local_NextInterval_Average and Local_NextInterval_Average.Rate_of_Change have the following values at the specified times (this tests the average value over next timestep calculation):

Time (days)	Value ($)	Rate of Change ($/day)
185	325	50
345	335	-130

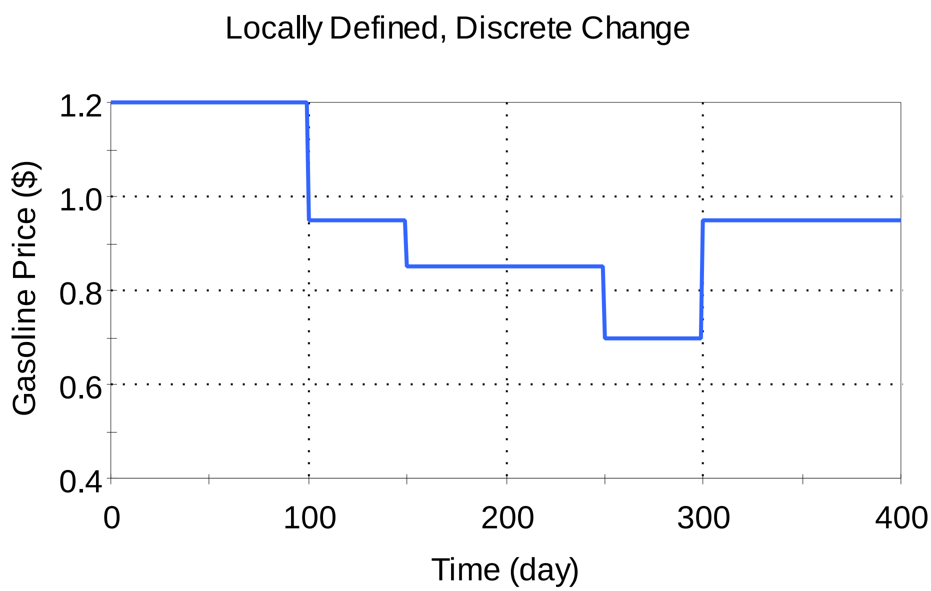
3. Locally Defined Change – The verifier should check that the graph of Local_Change_Interval_Results matches the following graph:



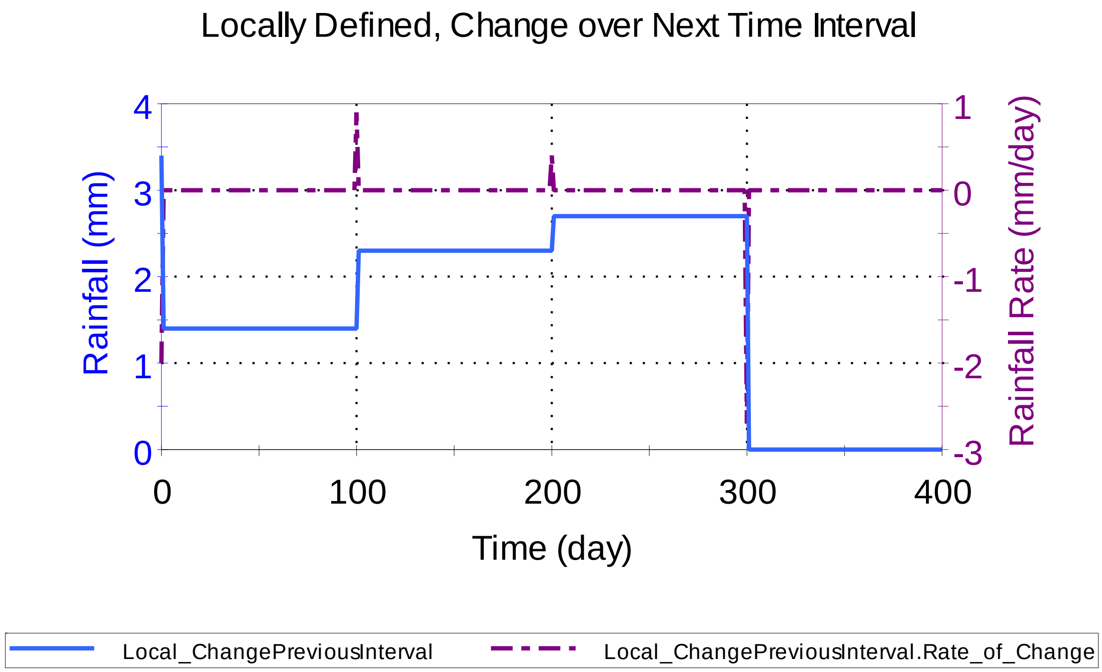
The verifier should also ensure that that the value of Local_ChangeNextInterval_Avg and Local_ChangeNextInterval_Avg.Rate_of_Change have the following values at the specified times (this tests the average value over next timestep calculation):

Time (days)	Value (mm)	Rate of Change (mm/day)
100	3.3975	0.023915
200	4.8011	0.0185
300	7.1005	0.025

4. Locally Defined DC – The verifier should check that the graph of Local_DC_Results matches the following graph:



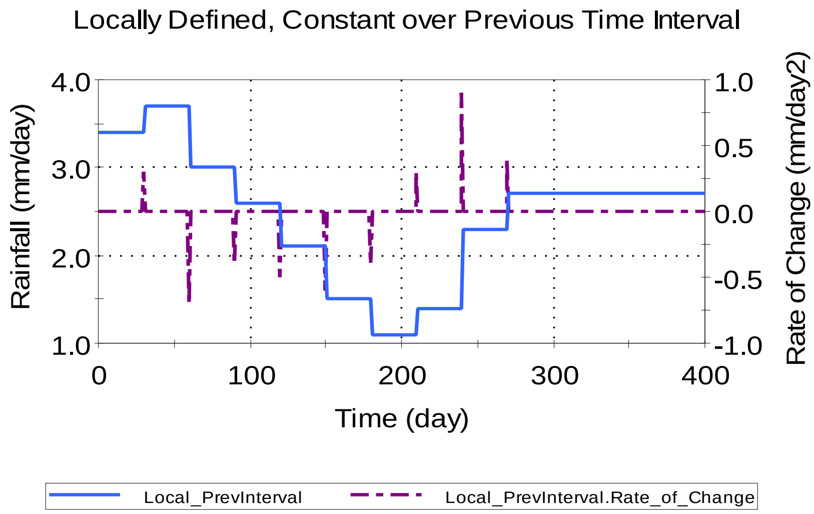
5. Locally defined Previous Change. The verifier should enter this container and confirm that the result element, Local_Change_Interval_Results, shows the following graph:



In addition the tester should enter the Local_Constant_Avg element and open its table to confirm the following three data points:

T = 100 days Expected Value = 1.85 mm Expected Rate of Change: 0.9 mm/day
T = 200 days Expected Value = 2.5 mm Expected Rate of Change: 0.4 mm/day
T = 300 days Expected Value = 1.35 mm Expected Rate of Change: -2.7 mm/day

6. Locally Defined Previous Interval- The tester should enter this container and confirm the result element Local_Prev_Interval_Results has a graph like the one pictured below:

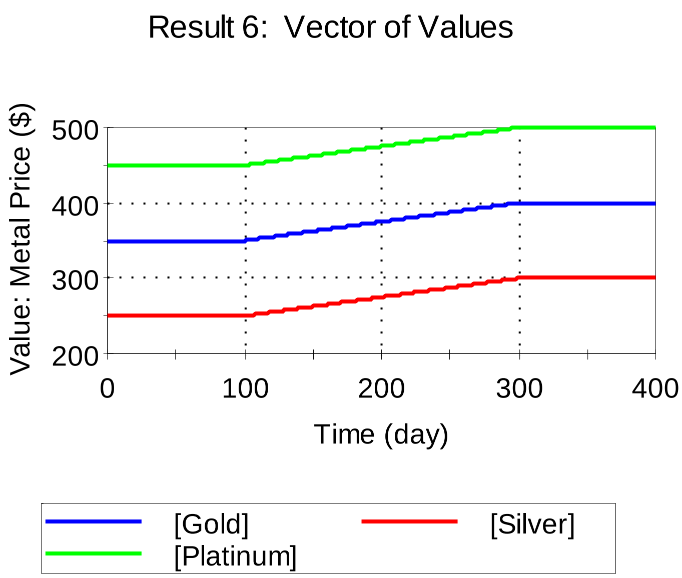


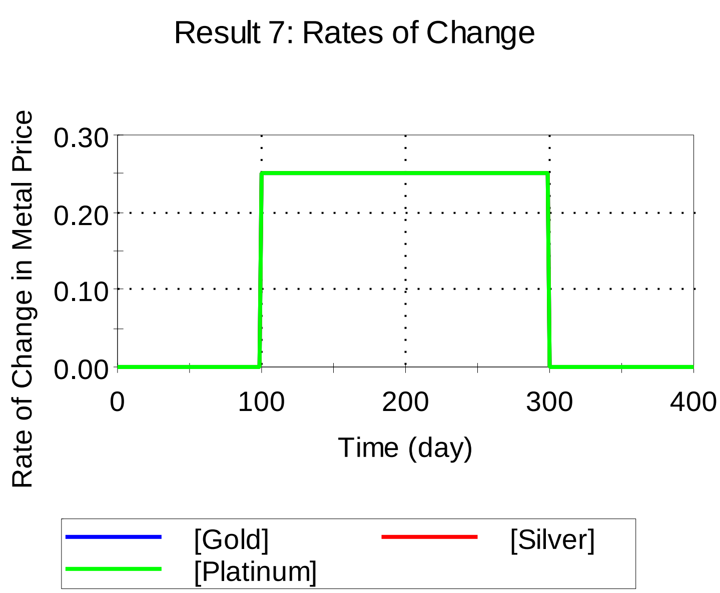
In addition, the tester should open the table for the result element Local_Prev_Constant_Avg and confirm the following two data points:

T = 185 days Expected Value = $375 Expected Rate of Change $50/day

T = 345 days   Expected Value = $275 Expected Rate of Change -$10/day

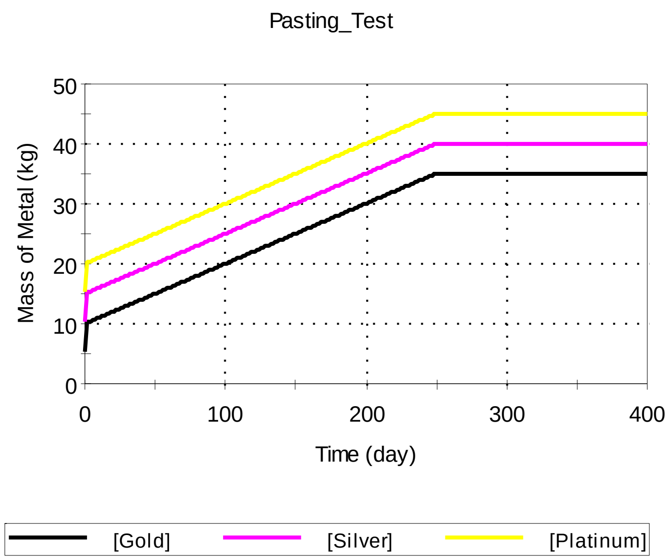
7. Vector Input – The verifier should check that Result6 and Result7 match the graphs pasted below:





8. Pasting Tests – The verifier should follow these steps:
   a) Open Pasting_Test, Edit Data. If data exists, remove it.
   b) Open the Excel file "Pasted Cells keep GS Tests.xls" (located in the directory containing this test file), and go to the tab labeled "GS40".
   c) Copy the indicated array of values (inside the bold border) from GS40.
   d) In GoldSim, click into the upper left cell in the 'Edit Data' field of Pasting_Test.
   e) Click CTRL + V to paste the copied array of values into Pasting_Test.

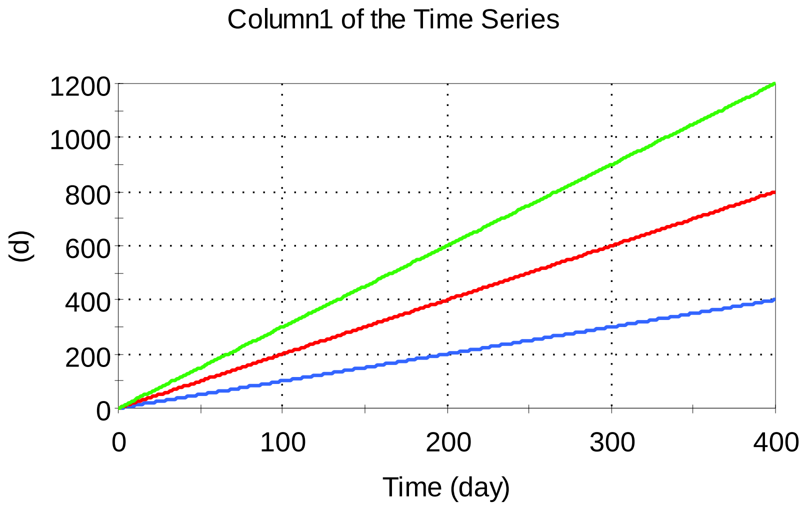
f) The copied data should be inserted into the 'Edit Data' field, and the field should automatically re-size to accommodate the pasted data.
g) Click 'OK' twice to accept the pasting operation.
h) Run the model file and ensure that Result8 (i.e., mass of metal) matches the following graph:



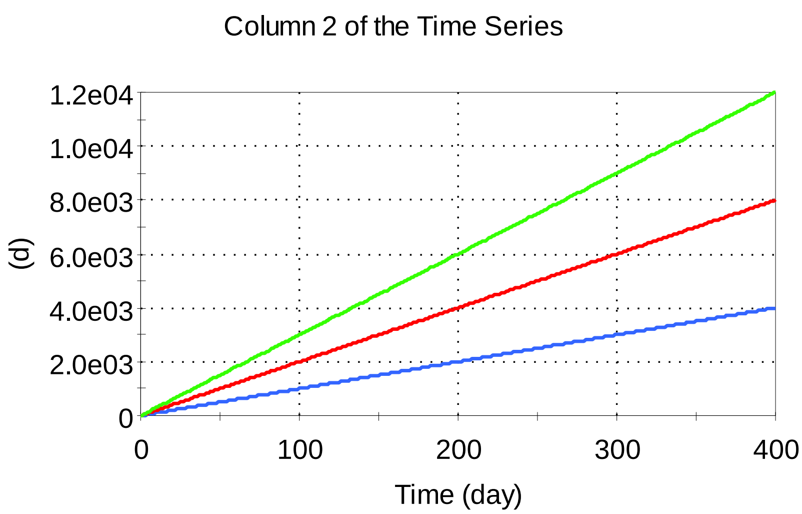
i) Repeat the test using calendar time data from the GS40datetime worksheet in "Pasted Cells keep GS Tests.xls" - ensure that the model start date is 9/13/1999 at 9:32 am

9. Matrix Tests – The verifier should enter the Matrix_Tests container and follow these steps:
   a) Delete the data in the TimeSeries1 element and turn it into a recording element. Link it to Expression1.
   b) Run the Model. Verify that the Column1 and 2 Time Histories correspond with the graphs pasted below.
   c) Change TimeSeries1 to Locally defined and run the model.
   d) Verify that the Column1 and 2 Time Histories correspond with the graphs pasted below:

Column1:



Column2:



Timestep_Interruption Container

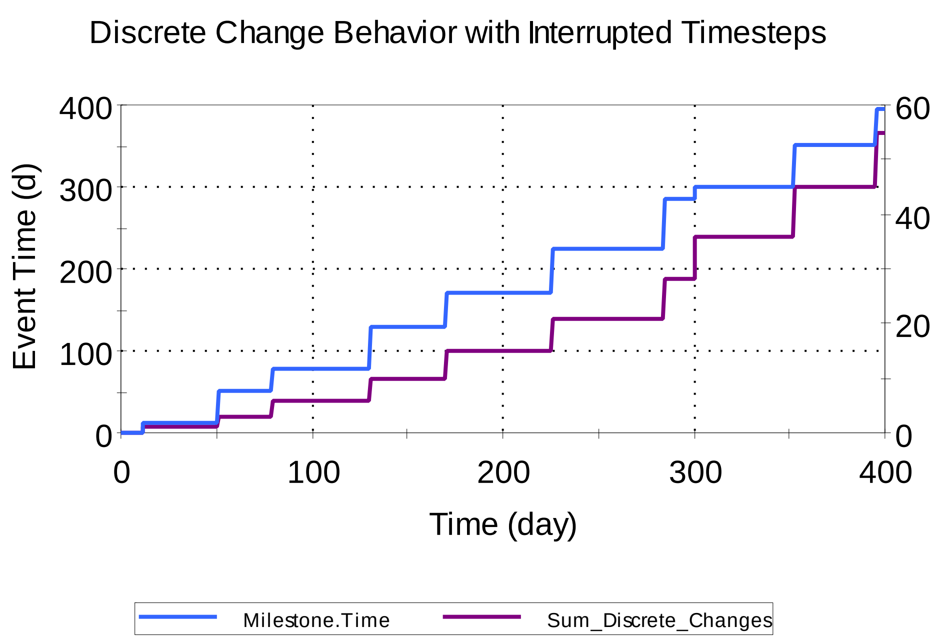
These tests ensure the proper behavior of the Value and Rate of Change Outputs for Value Type Data when events can occur between timesteps. This test also ensures that Discrete Change time series correctly interrupt the clock when a discrete change occurs betwen timesteps.

The verifier should ensure that Extrema elements inside the Locally_Defined_Instantaneous_1, Locally_Defined_Next_Int_1, and Locally_Defined_Change_1 containers have a negligible value at the end of the simulation.

Note that due to a timestep inserted at 24.5 d, Local_ChangeNextAverage in the Locally_Defined_Change_1 container outputs a slightly different value from the theoretical value at 25d. Therefore, the output for Max_Deviation_Avg_2 may not be negligible. If this is the case, look at the time history of Check_Ang_1 and confirm that it is in fact negligible everwhere except at 25d.

Timestep interruption is also tested with time series elements that are constant over previous interval and change over previous interval. Interrupt elements will be triggered if these tests fail and the message will point the tester to the type of calculation that is failing.

They should also confirm that the graph of Discrete_Change_Interrupted in the Discrete_Change_Interrupt is as follows:



Links Container

These tests ensure that Time Series links to and from SubModels function correctly. The verifier should enter the container and confirm that the final value for all four Extrema elements is negligible.

Recording Container

These tests ensure that the Time Series element correctly records source data, and that all recording options function correctly. To complete the test the verifier should enter the four subcontainers and ensure that the recorded values match the expected values described for each element.

Instantaneous

Element	**Records**	**Expected # of Values**
Record_Fixed_Change_Only	ETime at all fixed timesteps	401
Record_All_Timesteps	ETime at all timesteps	801
Record_Fixed_All	$100 at each fixed timestep	401
Record_All	$100 at all timesteps	801

Constant Over Next Interval
The following data points should be recorded:

Edit Time Series Data

Time Unit: Day (day)

	Elapsed Time [day]	Value
1	0	2
2	100	2.995
3	200	4.49
4	300	5.995
5	400	6

Constant Over Previous Interval

Edit Time Series Data

Time Unit: Day (day)

	Elapsed Time [day]	Value
1	0	0
2	100	2
3	200	2.995
4	300	4.49
5	400	5.995

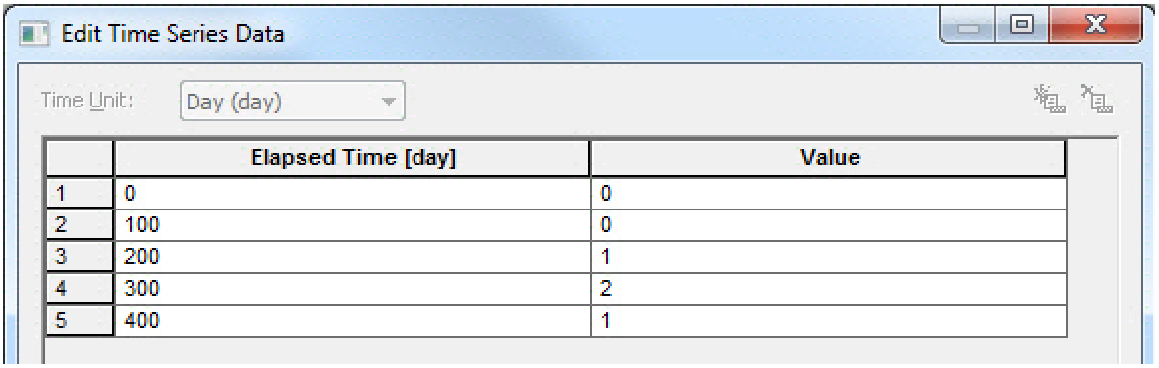
Change over Previous Interval
The following data points should be recorded:

Edit Time Series Data

Time Unit: Day (day)

	Elapsed Time [day]	Value
1	0	0
2	100	0
3	200	1
4	300	2
5	400	1

Change Over Next Interval



Discrete Change

Element	Records	Expected # of Values
Record	Discrete change equal to record number in table for all fixed timesteps	800
Zeroes_Not_Recorded	Records a discrete change at every fixed timestep before 200d. The discrete change's value should be equal to the elapsed time for each entry	399
Record_Multiple_and_Zeroes	records two discrete changes at every timestep. The value of each discrete change value should be equal to the elapsed time for each entry until 200 days, at which point all further entries should have a value of zero.	1600
Record_and_Combine	Records a discrete change at every timestep. The discrete change's value should be equal to the twice the elapsed time for each entry until 200 days, at which point all further entries should have a value of zero.	800

Data Wrapping Elapsed Container

These tests ensure the proper behavior of the Time Series elements when start year synchronization is enabled and when periodicity is specified in an Elapsed time model.

Tests in the Instantaneous and Average Value containers check to ensure that wrapping functionality and shifts are handled correctly for Instantaneous value and Constant over next time interval Time Series elements. This is done by comparing the output of an automatically wrapped time series with a manually wrapped time series. Shifting for Change over next time interval and Discrete change time series is confirmed by checking a graph of the outputs of the two time series. This test is only done in the instantaneous value container.

Element	**Tests**	**Expected Result**
Calendar_Shift\ Instantaneous_Value\ Diff_Instant	Tests calendar shifting and wrapping for instantaneous time series elements.	Negligable (<1E-4)
Calendar_Shift\ Instantaneous_Value\ Diff_Wrap	Tests calendar shifting and wrapping for constant over next time interval time series elements.	Negligable (<1E-4)
Calendar_Shift\ Average_Value_Over_Timestep\ Diff_Instant	Tests calendar shifting and wrapping for instantaneous time series elements.	Negligable (<1E-4)
Calendar_Shift\ Average_Value_Over_Timestep\ Diff_Wrap	Tests calendar shifting and wrapping for constant over next time interval time series elements.	Negligable (<1E-4)
Random_Starting_Point\ No_Periodicity\ Random_Result	Tests random selection of start point within data set.	Result array should show real values. Plot should appear uniform as shown in Fig. GS60_Wrap_Elapsed_2
Random_Starting_Point\ Annual_Periodicity\ Annual_Result	Tests random selection of start point with annual periodicity.	Result array should show observations at 0,365 and 730.
Random_Starting_Point\ Daily_Periodicity\ Daily_Result	Tests random selection of start point with daily periodicity.	Result array should show integer values. Plot should appear uniform as shown in Fig. GS60_Wrap_Elapsed_4

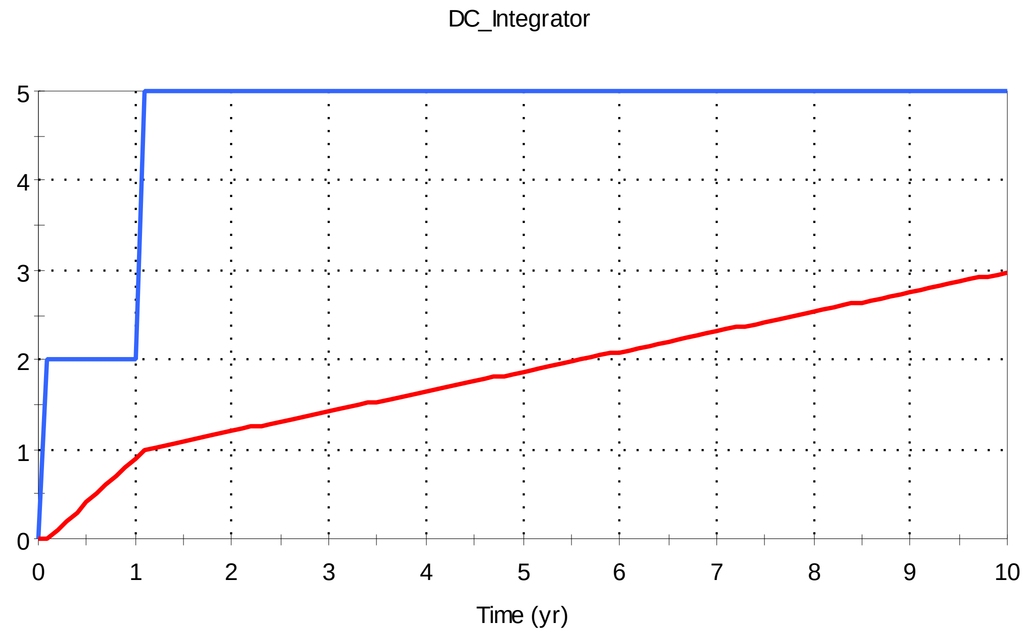


Fig. GS60_Wrap_Elapsed_1

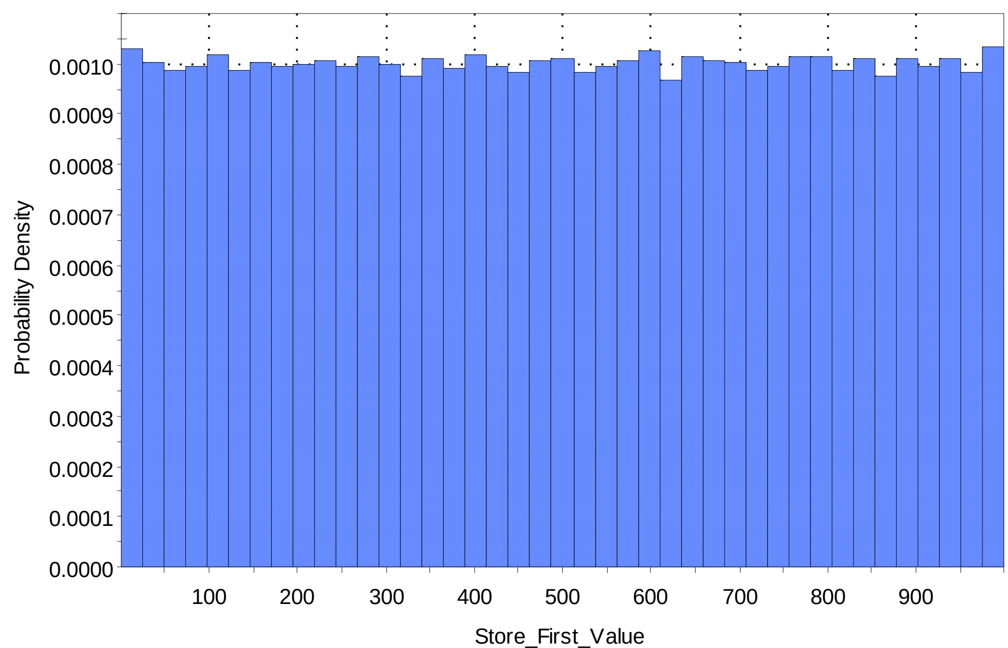


Fig. GS60_Wrap_Elapsed_2

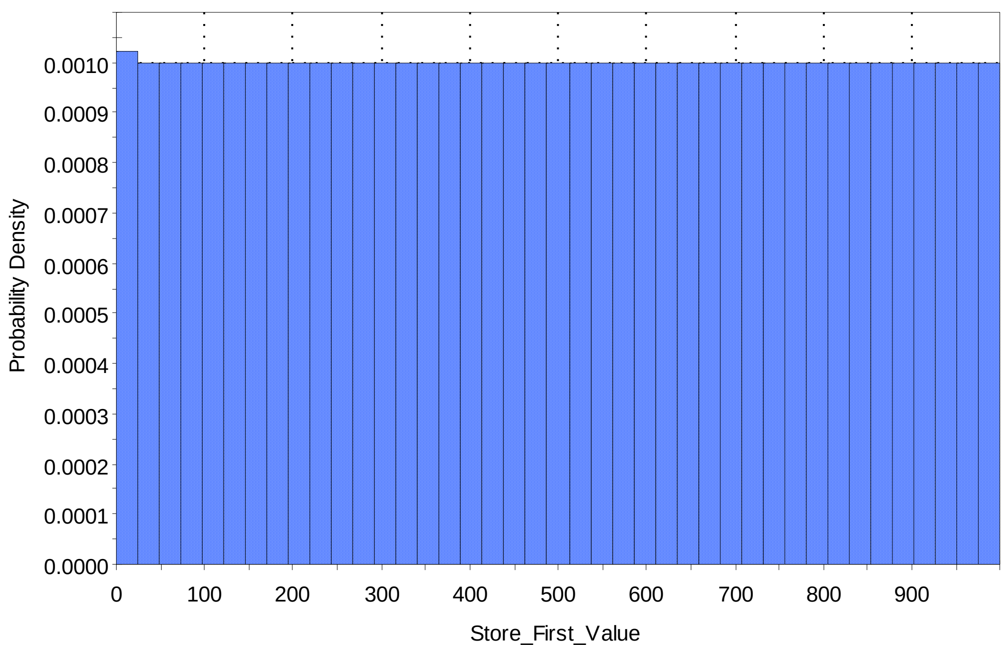


Fig. GS60_Wrap_Elapsed_4

Data Wrapping Cal Container

These tests ensure the proper behavior of the Time Series elements when start year synchronization is enabled and when periodicity is specified in an Calendat time model.

Tests in the Instantaneous and Average Value containers check to ensure that wrapping functionality and shifts are handled correctly for Instantaneous value and Constant over next time interval Time Series elements. This is done by comparing the output of an automatically wrapped time series with a manually wrapped time series. Shifting for Change over next time interval and Discrete change time series is confirmed by checking a graph of the outputs of the two time series. This test is only done in the instantaneous value container.

Element	**Tests**	**Expected Result**
Calendar_Shift\ Instantaneous_Value\ Diff_Instant	Tests calendar shifting and wrapping for instantaneous time series elements.	Negligable (<1E-4)
Calendar_Shift\ Instantaneous_Value\ Diff_Constant	Tests calendar shifting and wrapping for constant over next time interval time series elements.	Negligable (<1E-4)
Calendar_Shift\ Average_Value_Over_Timestep\ Diff_Instant	Tests calendar shifting and wrapping for instantaneous time series elements.	Negligable (<1E-4)
Calendar_Shift\ Average_Value_Over_Timestep\ Diff_Constant	Tests calendar shifting and wrapping for constant over next time interval time series	Negligable (<1E-4)

	elements.	
Random_Starting_Point\ No_Periodicity\ Random_Result	Tests random selection of start point within data set.	Result array should show real values. Plot should appear uniform as shown in Fig. GS60_Wrap_Elapsed_2
Random_Starting_Point\ Annual_Periodicity\ Annual_Result	Tests random selection of start point with annual periodicity.	Result array should show observations at 0, 365 and 730. Plot should appear as shown in Fig. GS60_Wrap_Elapsed_3
Random_Starting_Point\ Daily_Periodicity\ Daily_Result	Tests random selection of start point with daily periodicity.	Result array should show integer values. Plot should appear uniform as shown in Fig. GS60_Wrap_Elapsed_4

Multiple Series Container

These tests ensure the proper behavior of the Time Series elements with mulitple data sets and Time History input from other GoldSim models. It also checks that multi-set data can be sent and returned from SubModel elements.

Open the Retrived_from_Other_File element. Delete any existing data, then download Time History result data from GS60_TimeSeries_Source (the Result element). Run the model and ensure the two Extrema elements show a negligible value (<1E-4).

Element	**Tests**	**Expected Result**
Multiple_Series\ Diff_SubModel	Tests multi-set export to SubModels, multi-set recording and linking, and export from SubModels	Negligable (<1E-4)
Multiple_Series\ Diff_OtherModel	Tests multi-set import from other GoldSim models.	Negligable (<1E-4)

GS60b_Time_Series

<Supercedes GS40b_Information Time SeriesExcelSupport and GS41b_Material Time SeriesExcelSupport>

This test ensures the proper functioning of Excel functionality in the second generation Time Series elements (introduced in GoldSim 9.60).

The first part of the test checks error handling – enter the container called Errors. Enter each property page and click the View Data button on the definition tab and Import data now option on the Excel tab. In both cases, you should receive identical error messages. The problems, and the expected error message with each Time Series element are listed below.

Element	**Problem**	**Error Message**
Columns_Extra_Row	Number of rows to read > number in Excel file	Empty spreadsheet cell found at A11

Rows_Extra_Column	Number of columns to read > number in Excel file	Empty spreadsheet cell found at K1
Missing_Dependent_Variable_Row	Missing dependent variable entry – 5th data point	Empty spreadsheet cell found at B5.
Missing_Dependent_Variable_Cmn	Missing dependent variable entry – 5th data point	Empty spreadsheet cell found at E2.
No_Cell_Specified	No starting cell specified	Column position is not specified for cell.
No_Excel_File_Specified	No Excel file specified	No spreadsheet specified.

Now enter the Too_Many_Cells container. In this container, there are two time series elements that check that the user is warned if they attempt to import a number of data points larger than the number available in an Excel sheet. The tester should enter the Extra_Rows element, and attempt to specify a number of rows to be read in greater than the Excel maximum (this is 65536 for Excel versions after Excel97). A warning should be generated. Clicking OK in the dialog should redisplay the warning (and the dialog should remain open).

Repeat the procedure for the Extra_Columns element – in this case, the tester should attempt to change the number of columns to be read in to a number greater than the maximum number of columns supported by Excel (256 for Excel versions after Excel97). A warning should be generated, and data should not be imported. Clicking OK in the dialog should redisplay the warning (and the dialog should remain open).

The second part of the test checks that the Excel import works correctly under normal conditions. Enter the container called Normal.

Open the property dialog for each of the four elements, click the Import data from MS-Excel file now option, and then return to the Definition page and click the View Data button. The expected results are as follows:

For Columns_Till_Empty and Rows_Till_Empty:

Time (d)	Value
1	10
2	20
3	30
4	40
5	50
6	60
7	70
8	80
9	90
10	100

For Columns_Num_Rows and Rows_Num_Columns, the data should be identical, but there should be no entries after 5 days.

The last part of the test verifies that the ‘create new spreadsheet’, ‘select spreadsheet’, ‘open spreadsheet’ and ‘update spreadsheet’ options work correctly.

Enter the Creating_Selecting_Updating container, and change the data source for the Time Series elements to None, then back to MS-Excel. Open the property dialog for the Select_Existing element, and go to the Excel tab. Choose Select existing MS-Excel file and choose 10Row10Column.xls. Click the Excel button in the data section and specify cell A1 on the sheet "Data in Columns" as the starting cell. Choose Import data now from MS-Excel, and verify using the View Data button on the Definition tab the following result:

Time (d)	Value
1	10
2	20
3	30
4	40
5	50
6	60
7	70
8	80
9	90
10	100

Now open the Create_New time series element - create a new spreadsheet called TSTest.xls. Open it using the Open command accessed through the options button. Enter 1,2,3,4,5 in column A and 10,20,30,40, 50 in column B. Save and close the Excel file. Click the Excel button in the data section and specify cell A1 on Sheet1 as the starting cell. Choose Import data now from MS-Excel, and verify using the View Data button on the Definition tab that the data you input into the new spreadsheet has been properly imported.

GS60c_Recording_Time_Series_Cond

OBSOLETE AS OF GOLDSIM 10.10

GS61_SubSystem_Stock

This test ensures that stocks within SubSystems (excluding Internal Clock SubSystems) participate in the update to time process.

Run the model - it should run to completion. Compare the plots in the SubSystem, Conditonal, Looping and Resources containers to Figures GS61_1 through GS61_4 below. Enter the Internal_Clock container and check the Internal Clock option on the SubSystem container - an error should be generated and the model should not run.

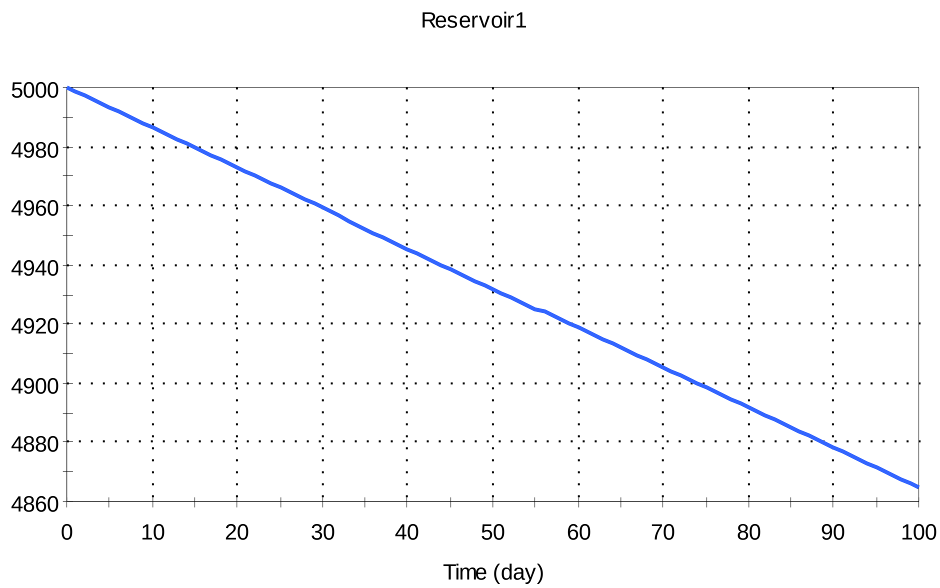


Fig. GS61_1 – SubSystem

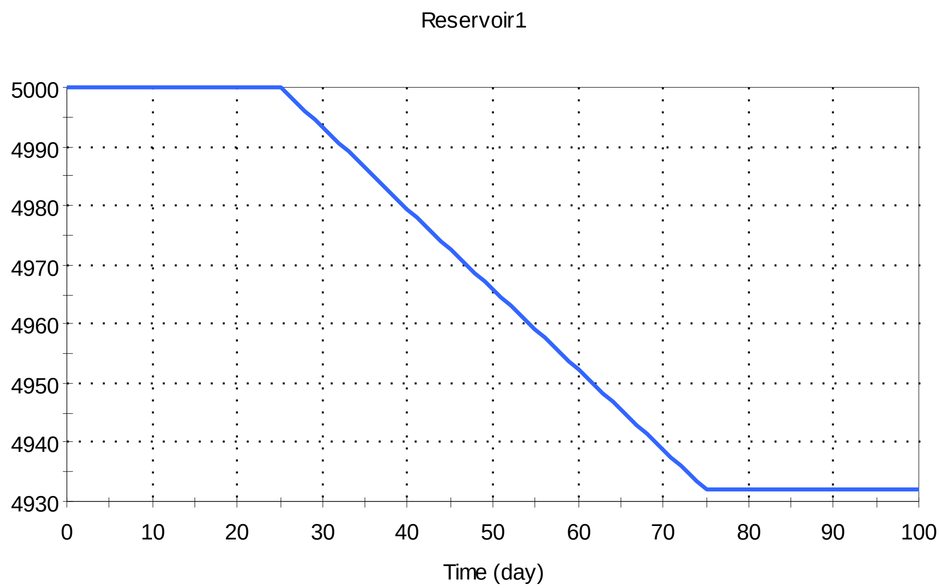


Fig. GS61_2 – Conditional Container

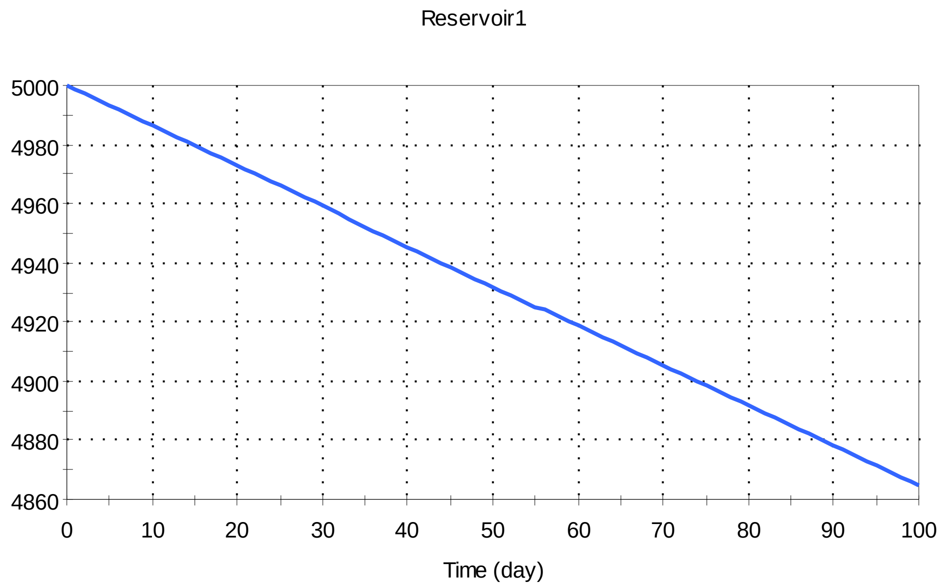


Fig. GS61_3 – Looping Container

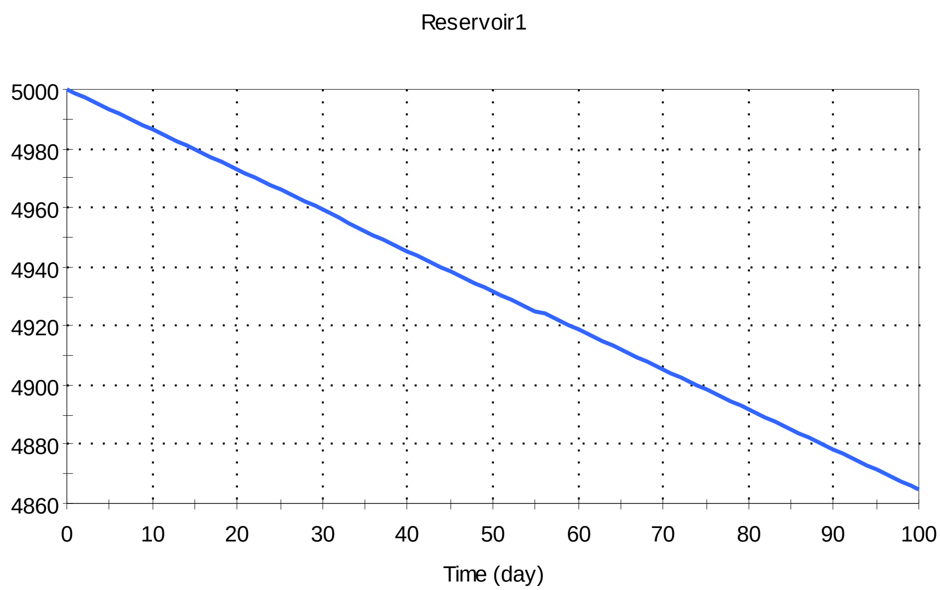


Fig. GS61_4 – Local Resources Store

GS62_Resources

This test verifies general Resource functionality as well as resource functionality specific to conditional containers by requiring resources from continuous scalar and vector resources for activation and operation.

The verifier should run the model and ensure the plots correspond with the expected results in Fig. GS62_1 through GS62_8 below.

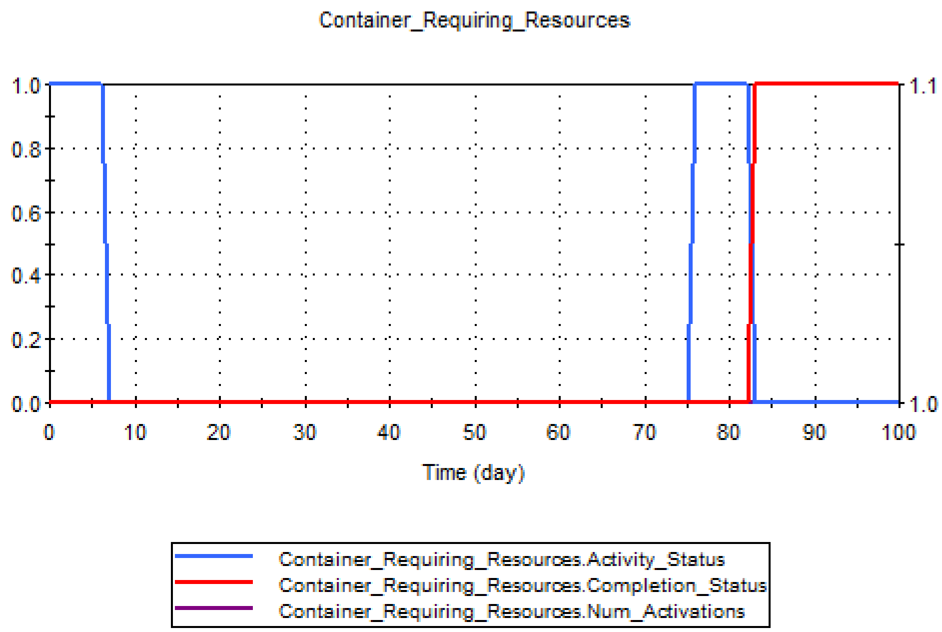


Fig. GS62_1 – Status_Activations

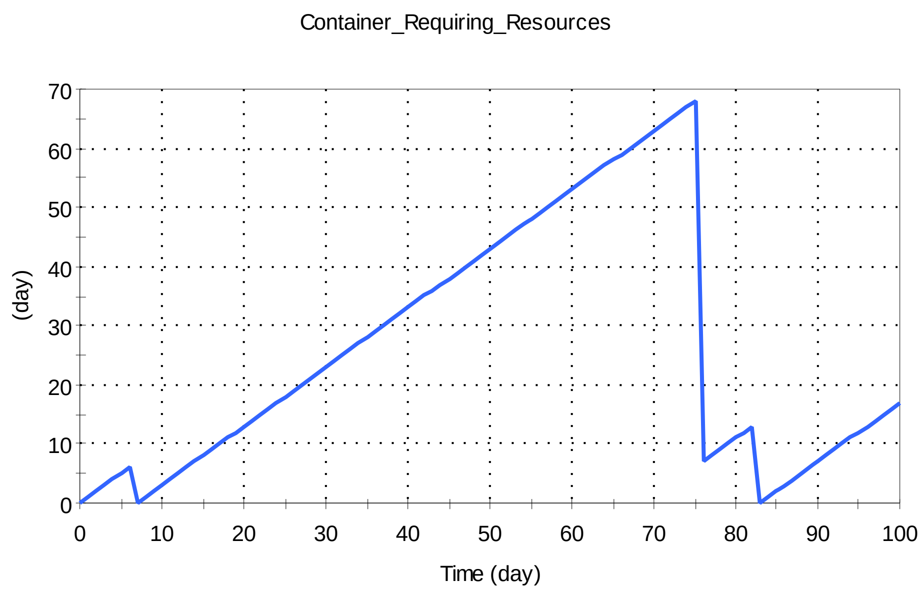


Fig. GS62_2 – Duration

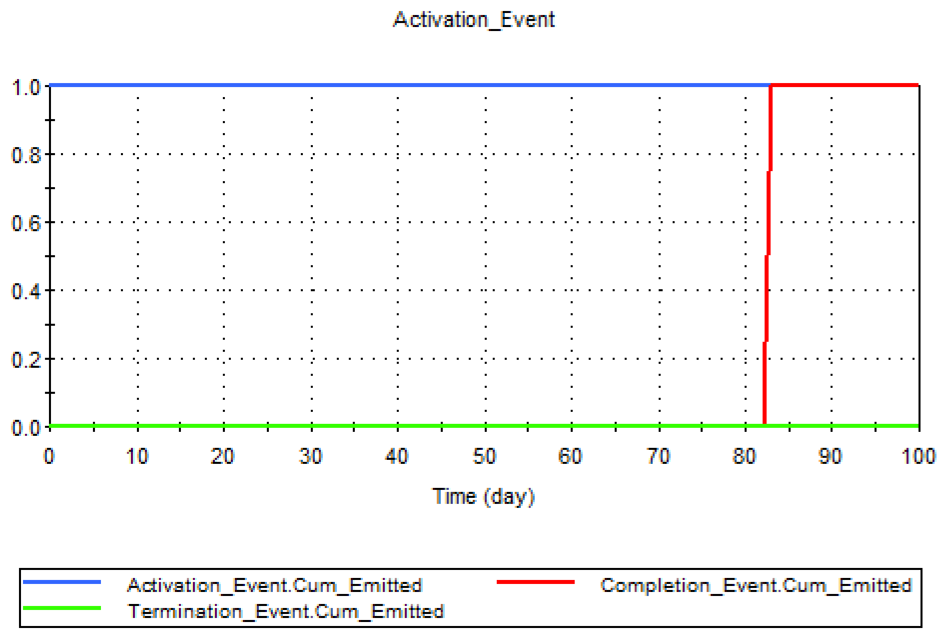


Fig. GS62_3 – Event_Plots

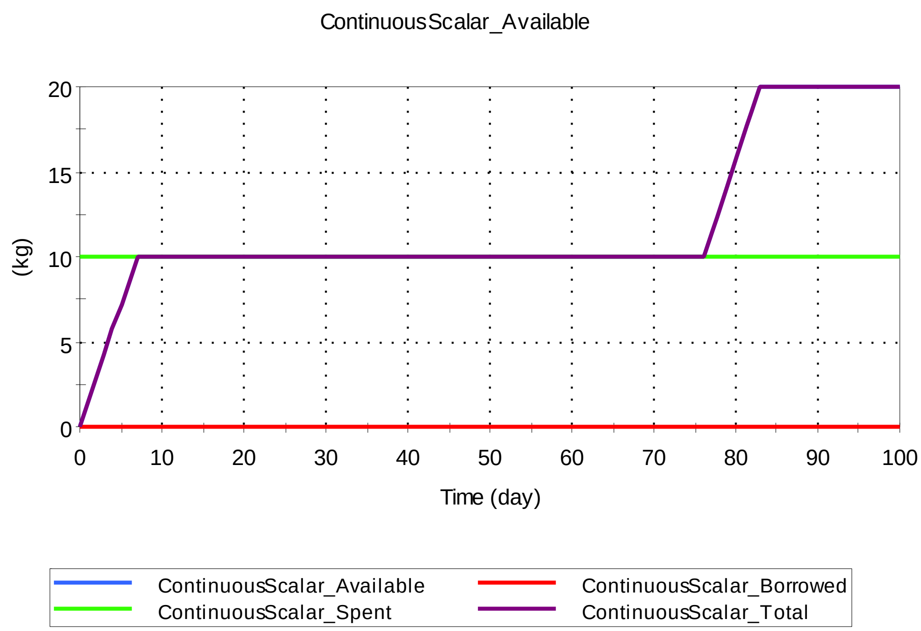


Fig. GS62_4 – ContinuousScalar

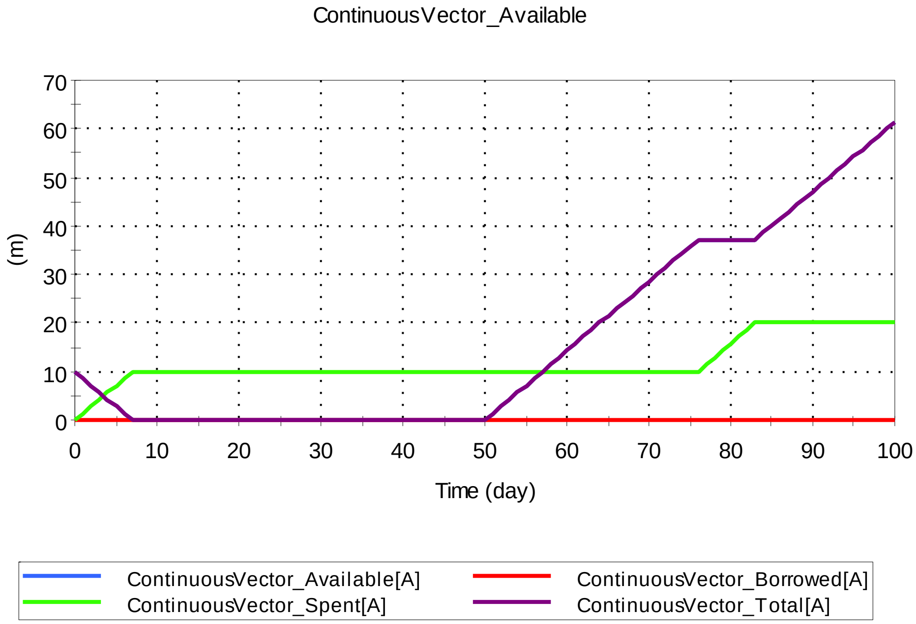


Fig. GS62_5 – VectorA

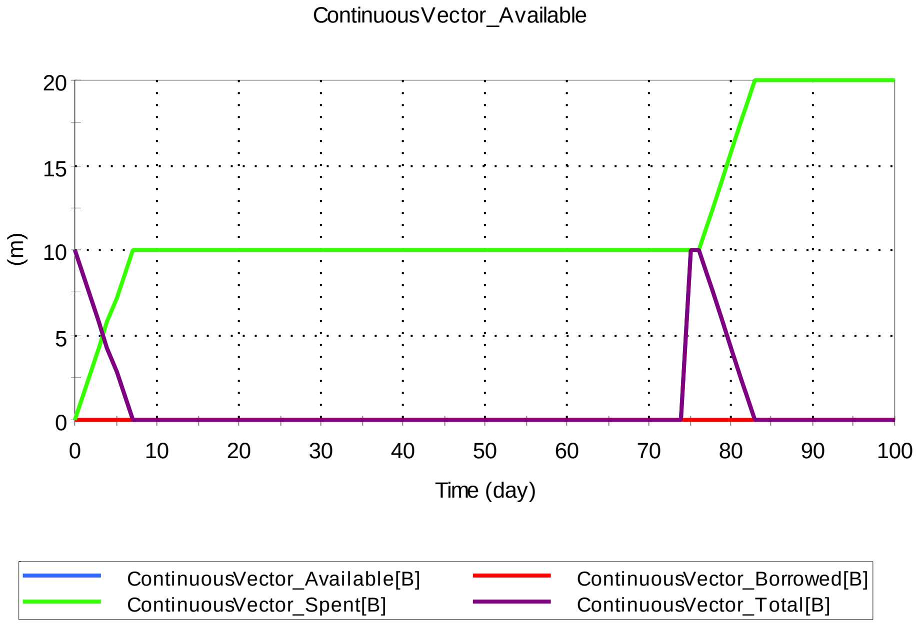


Fig. GS62_6 – VectorB

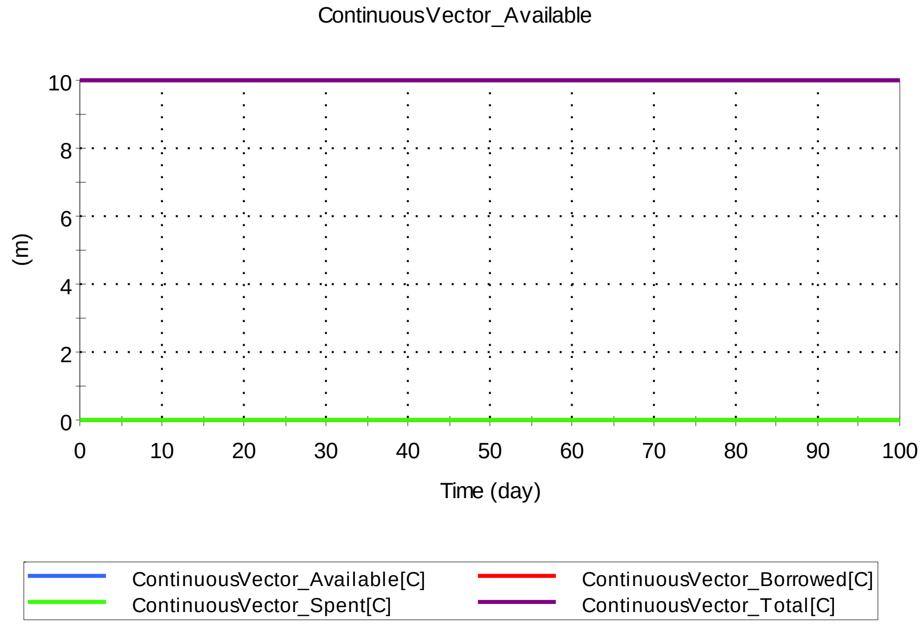


Fig. GS62_7 – VectorC

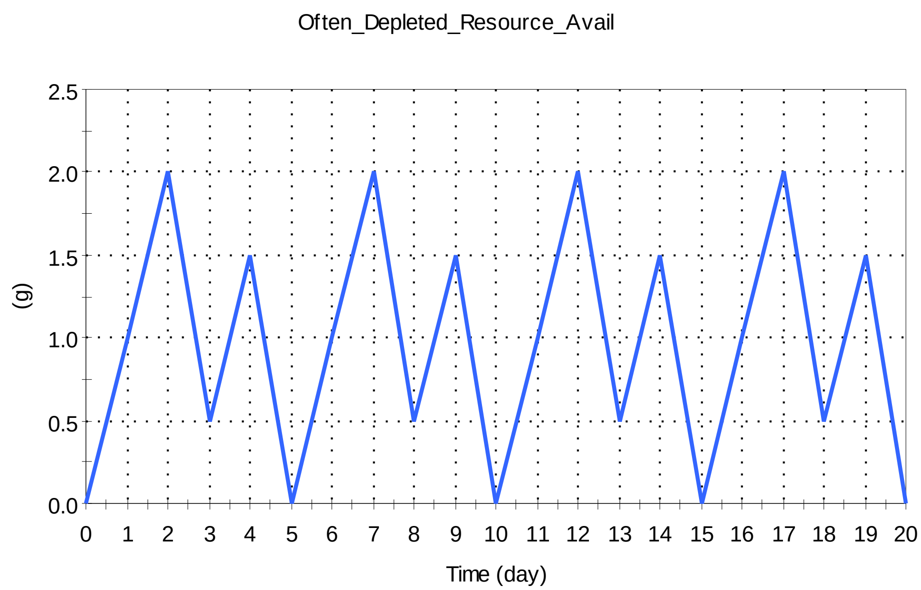


Fig. GS62_8 – Often_Depleted

GS62b_Resources

This test verifies general Resource functionality as well as resource functionality specific to Triggered Events by requiring resources from discrete scalar and vector resources for activation and operation.

The verifier should run the model and ensure the plots correspond with the expected results in Fig. GS62b_1 through GS62b_5 below.

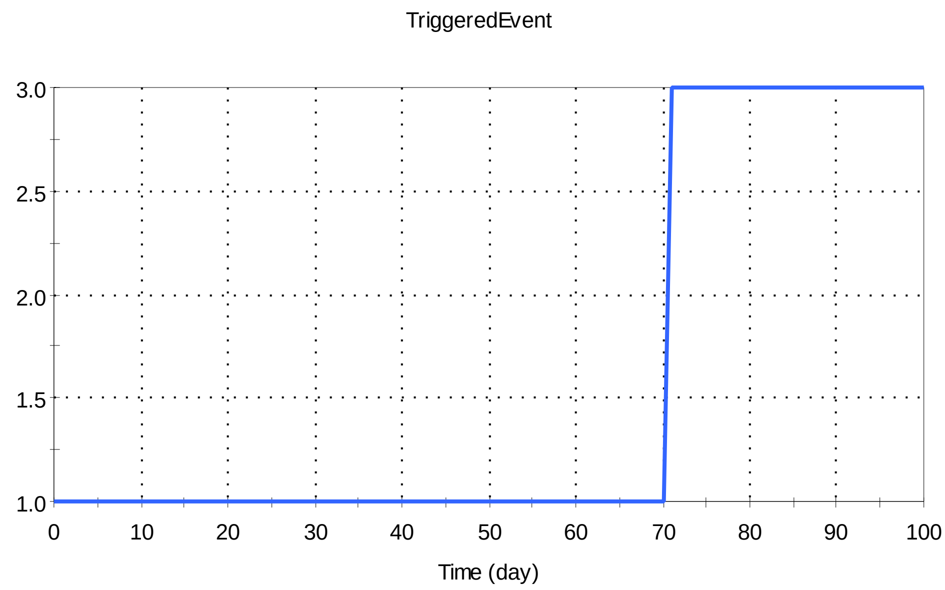


Fig. GS62b_1 – Cum_Emitted

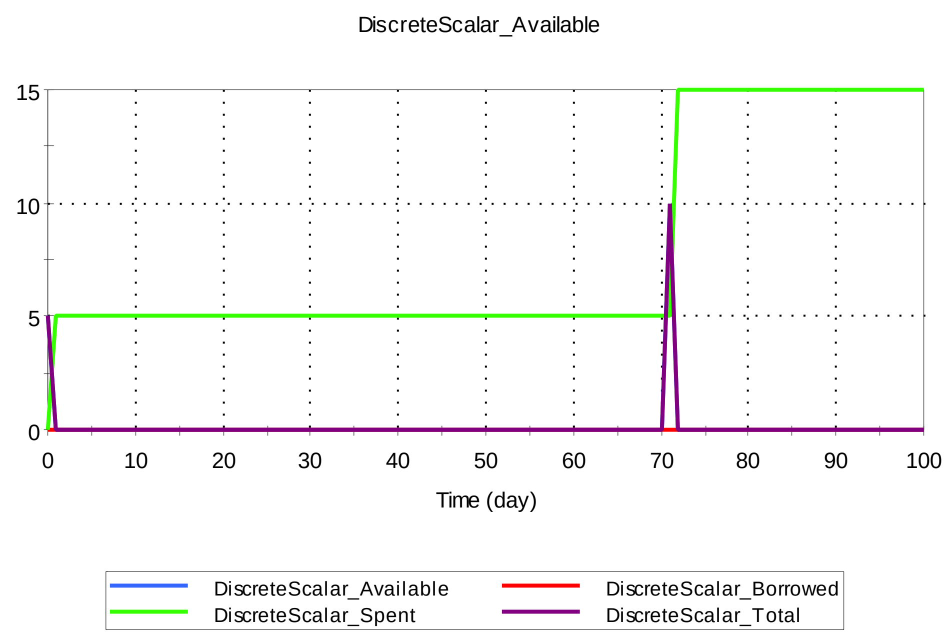


Fig. GS62b_2 –DiscreteScalar

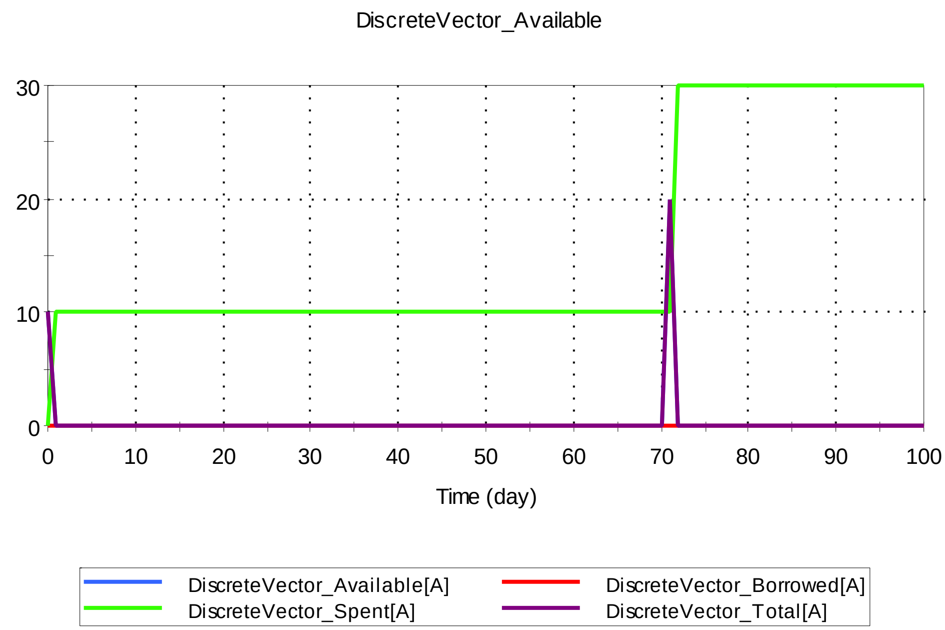


Fig. GS62b_3 – VectorA

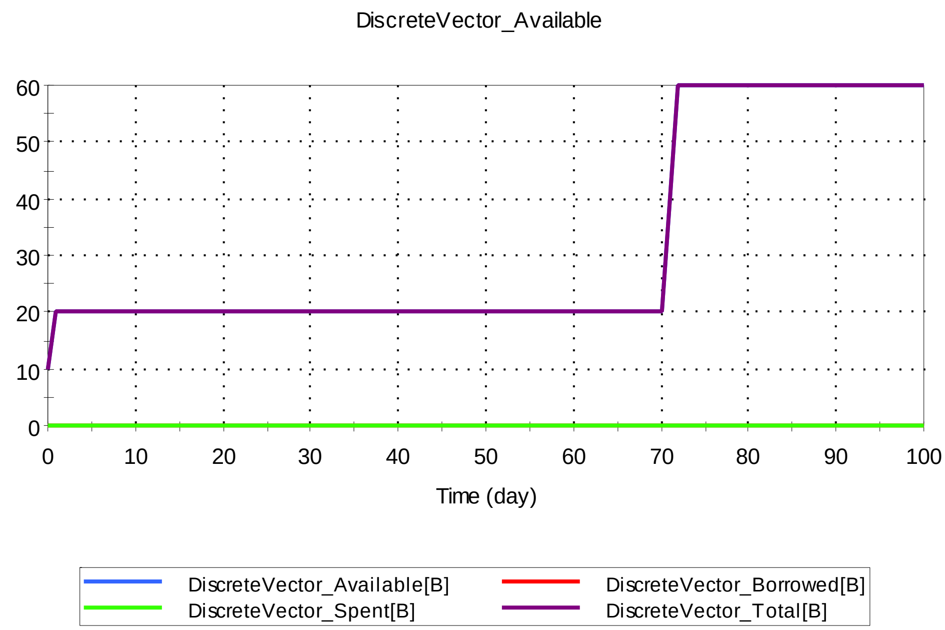


Fig. GS62b_4 – VectorB

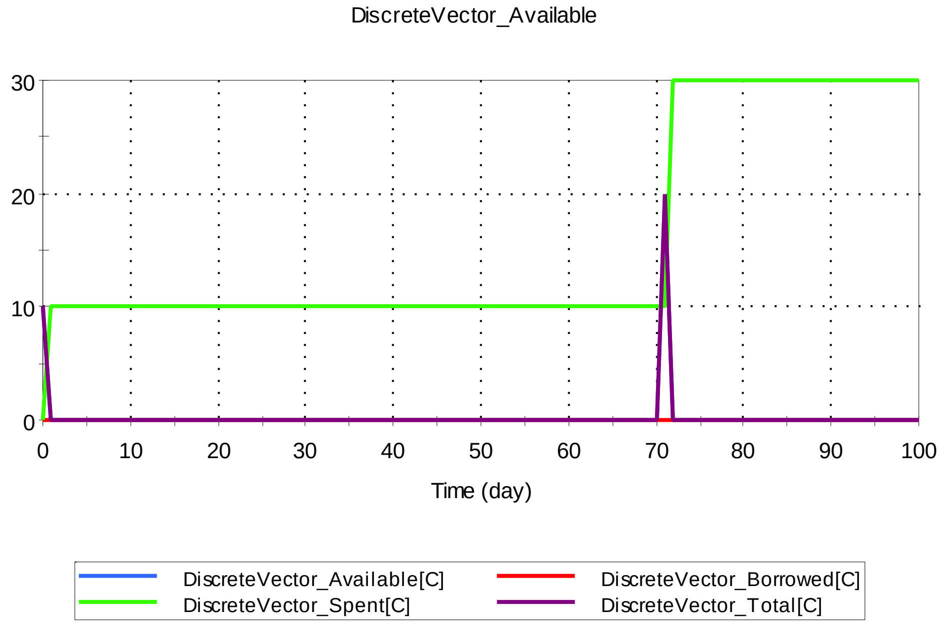


Fig. GS62b_5 – VectorC

GS62c_Resources

This test verifies general Resource functionality as well as resource functionality specific to Event Delays by requiring resources from discrete scalar and vector resources for activation and operation.

The verifier should run the model and ensure the plots correspond with the expected results in Fig. GS62c_1 through GS62c_6 below.

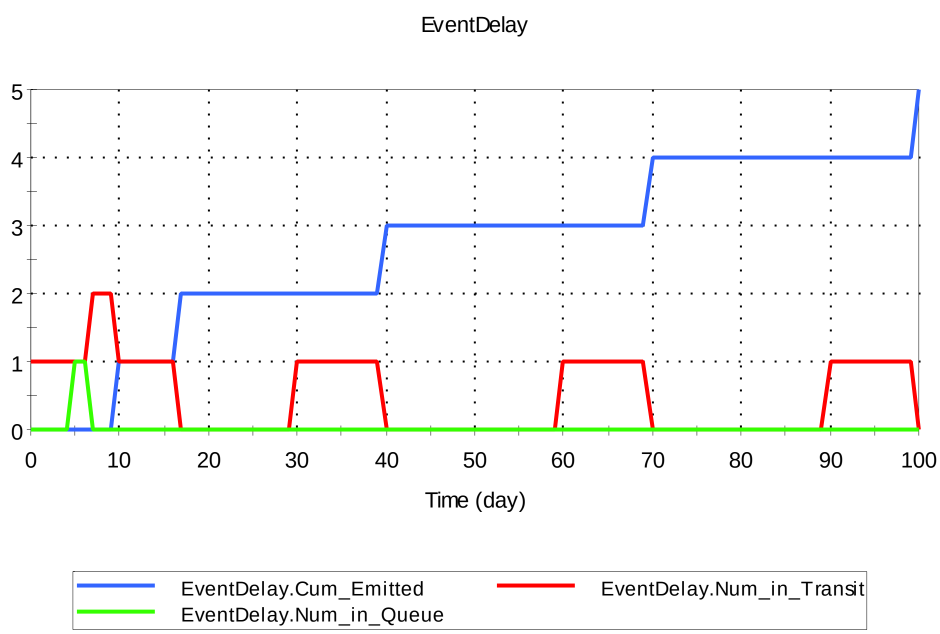


Fig. GS62c_1 – EventDelayOutputs

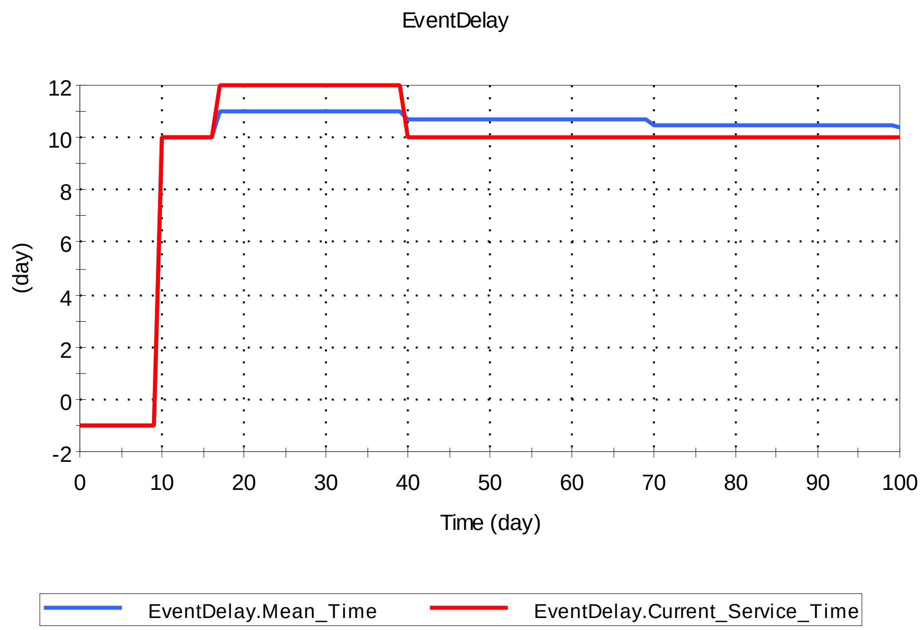


Fig. GS62c_2 – ServiceTimes

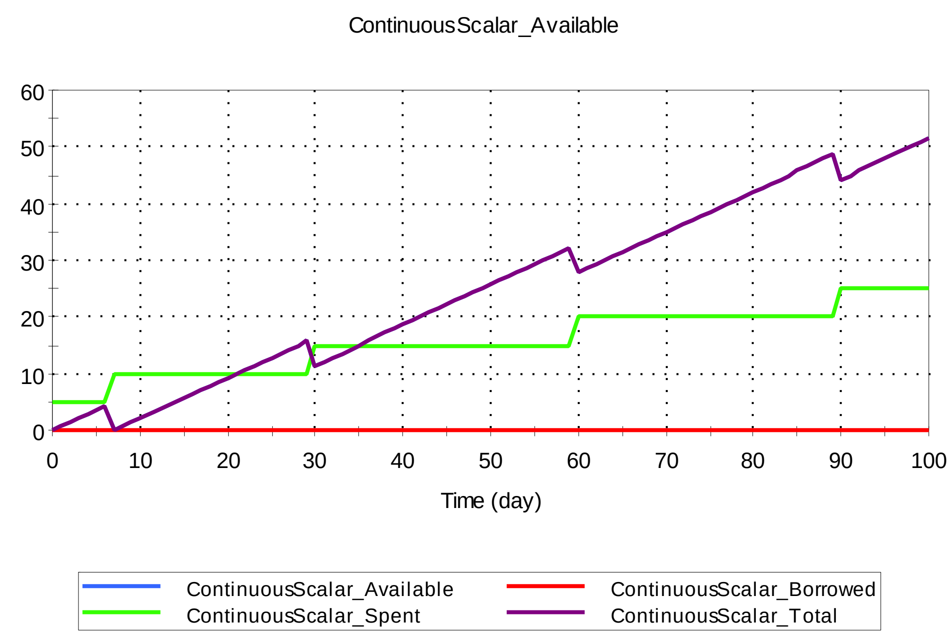


Fig. GS62c_3 – ContinuousScalar

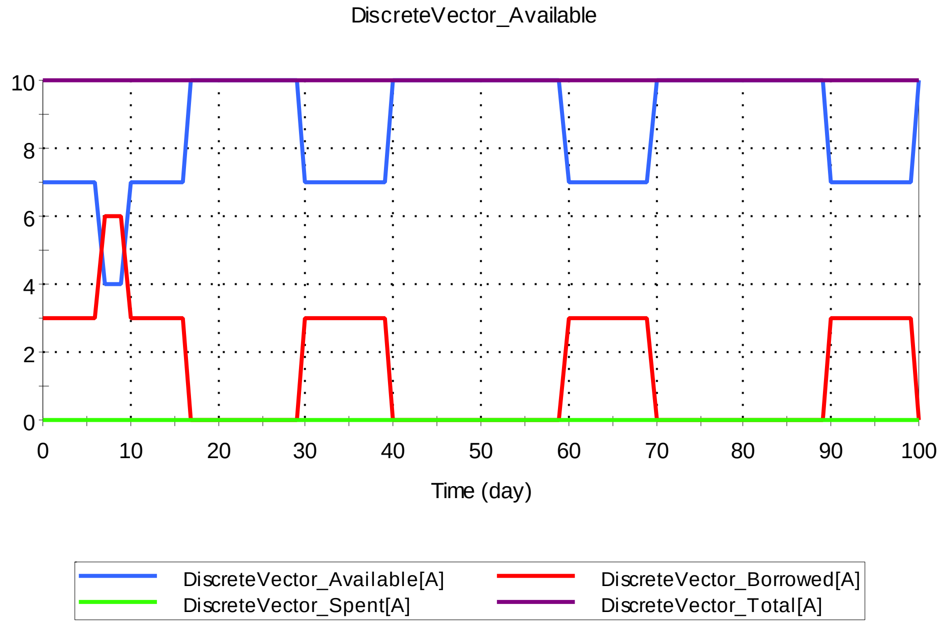


Fig. GS62c_4 – VectorA

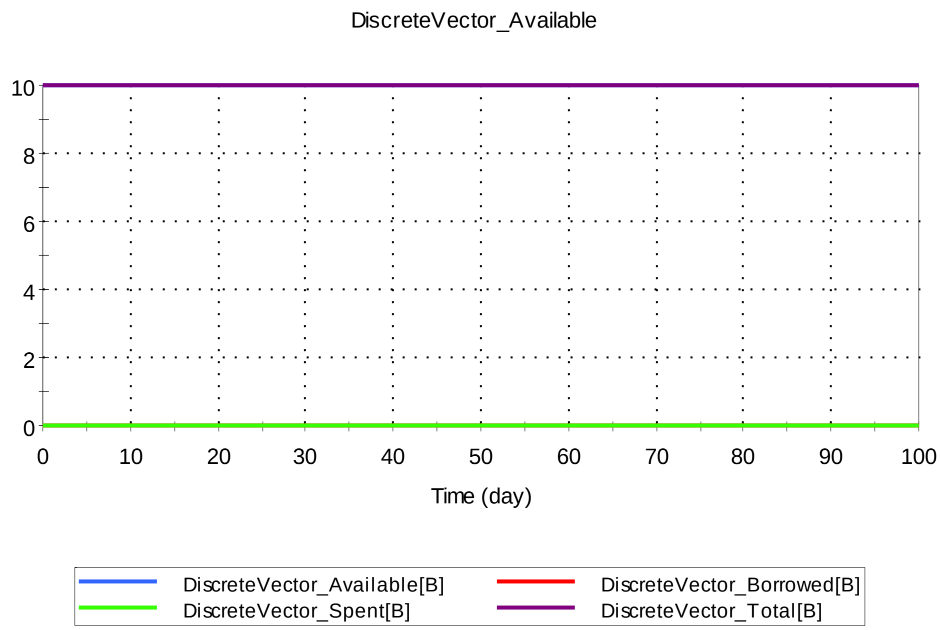


Fig. GS62c_5 – VectorB

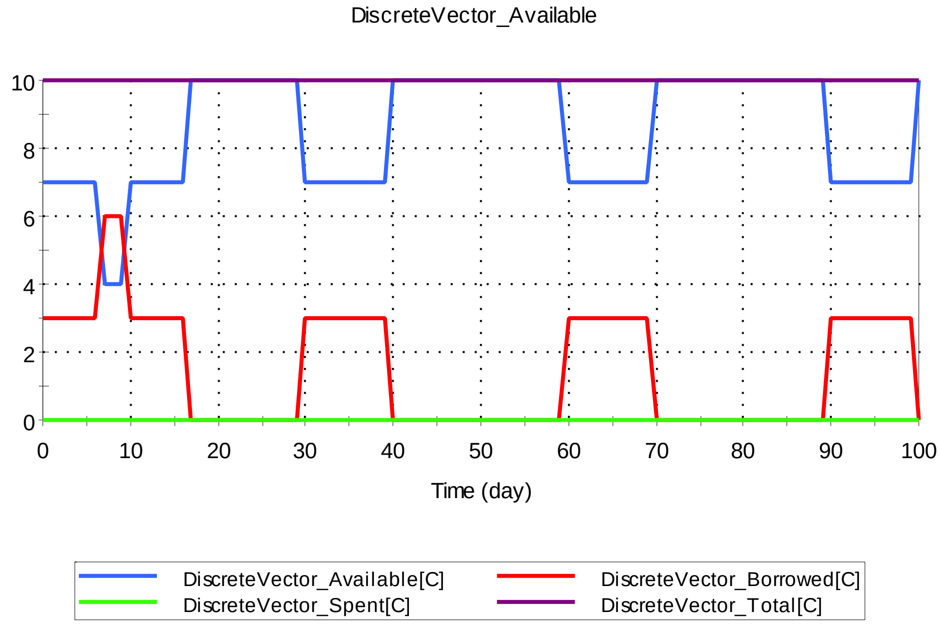


Fig. GS62c_6 – VectorC

GS62d_Resources

This test verifies general Resource functionality as well as resource functionality specific to Discrete Change Delays by requiring resources from discrete scalar and vector resources for activation and operation.

The verifier should run the model and ensure the plots correspond with the expected results in Fig. GS62d_1 through GS62d_5 below.

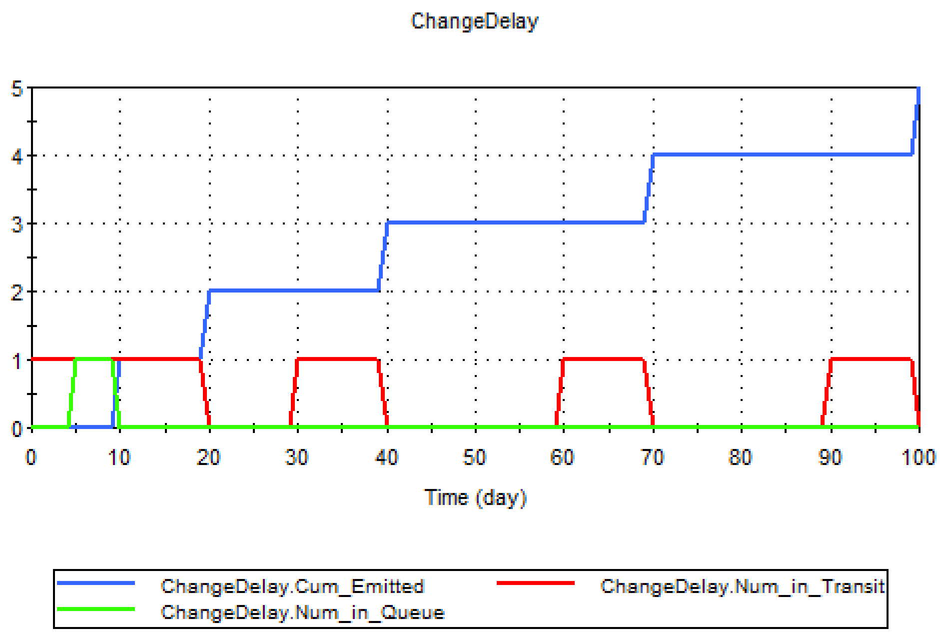


Fig. GS62d_1 – ChangeDelayOutputs

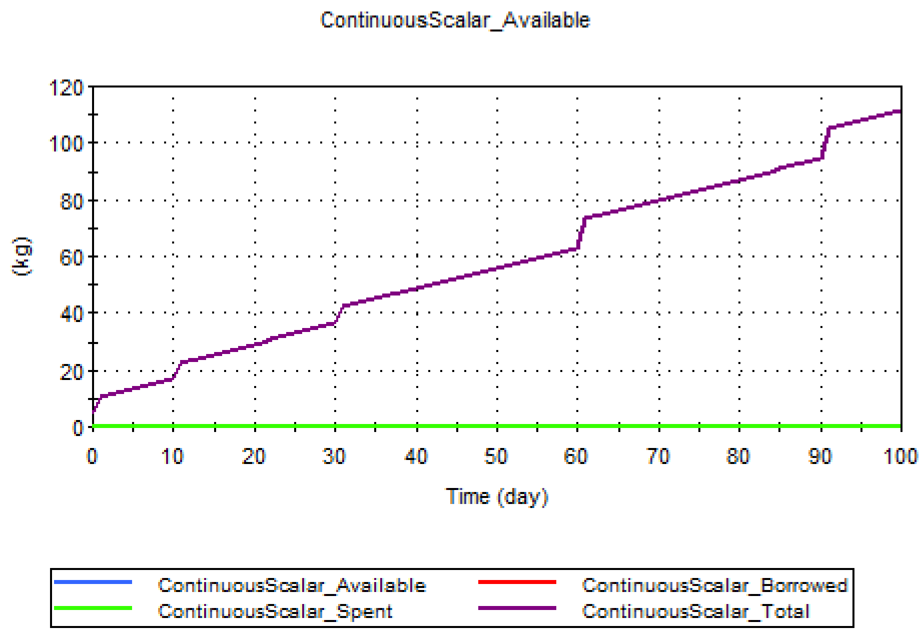


Fig. GS62d_2 –ContinuousScalar

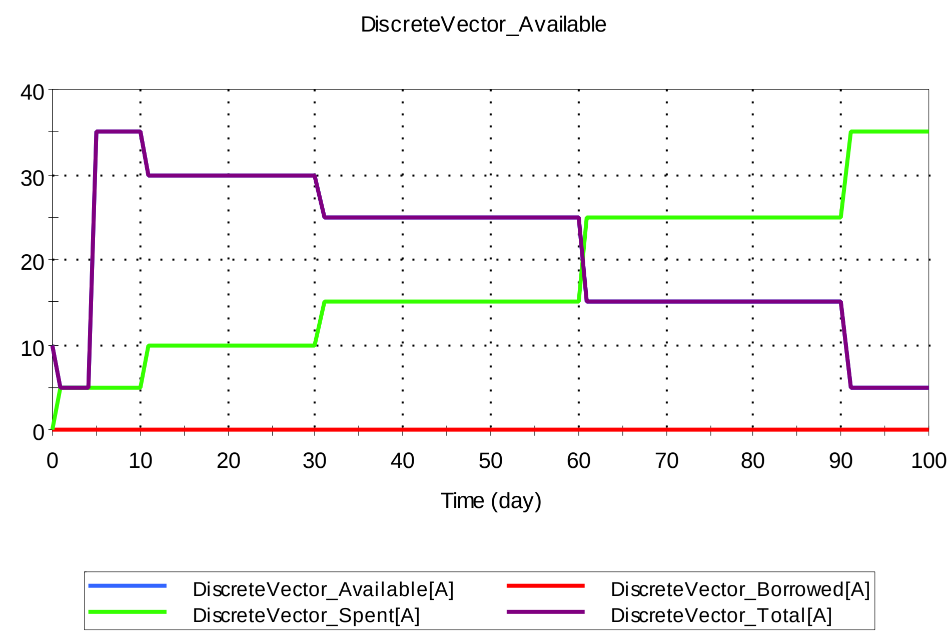


Fig. GS62d_3 – VectorA

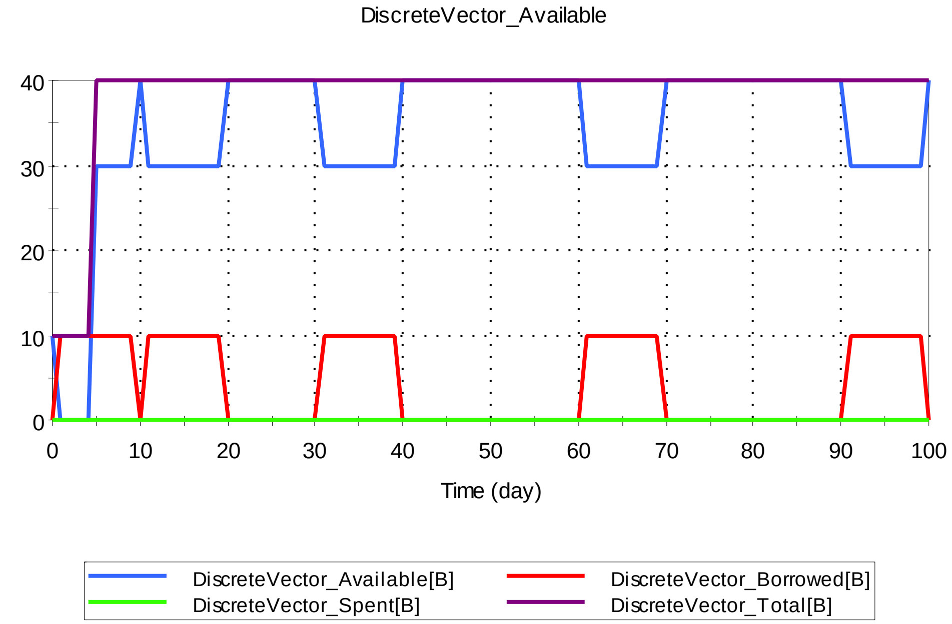


Fig. GS62d_4 – VectorB

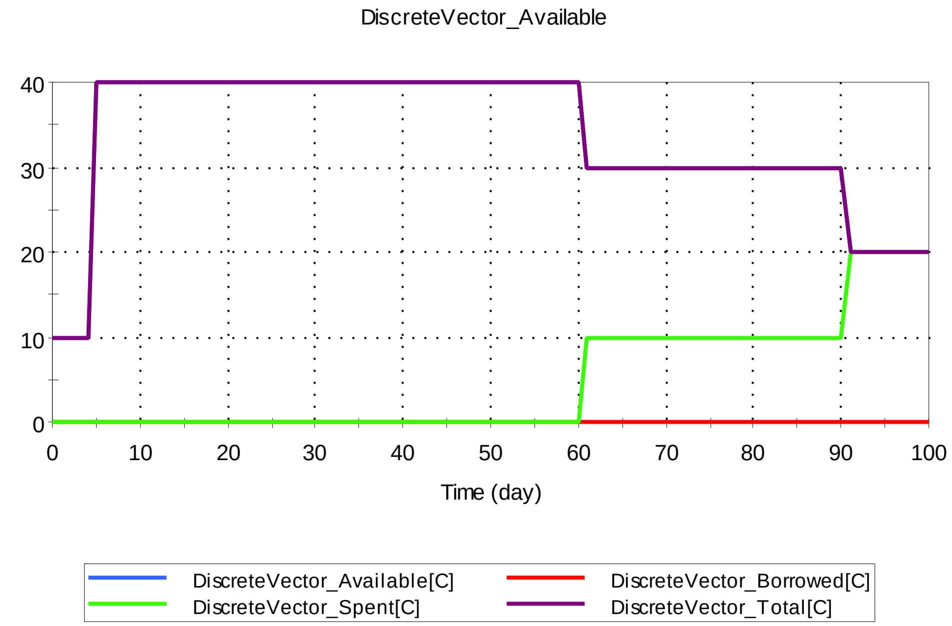


Fig. GS62d_5 – VectorC

GS62e_Resource_Results

This test verifies that Resource results function correctly. The verifier should run the test and open the Resources dialog using F8. Confirm that the Locations dialog shows the result below in Figure GS62e_1. Then open the ContainerWithStore container and verify that the Locations dialog shows the result pasted to the left of the container.

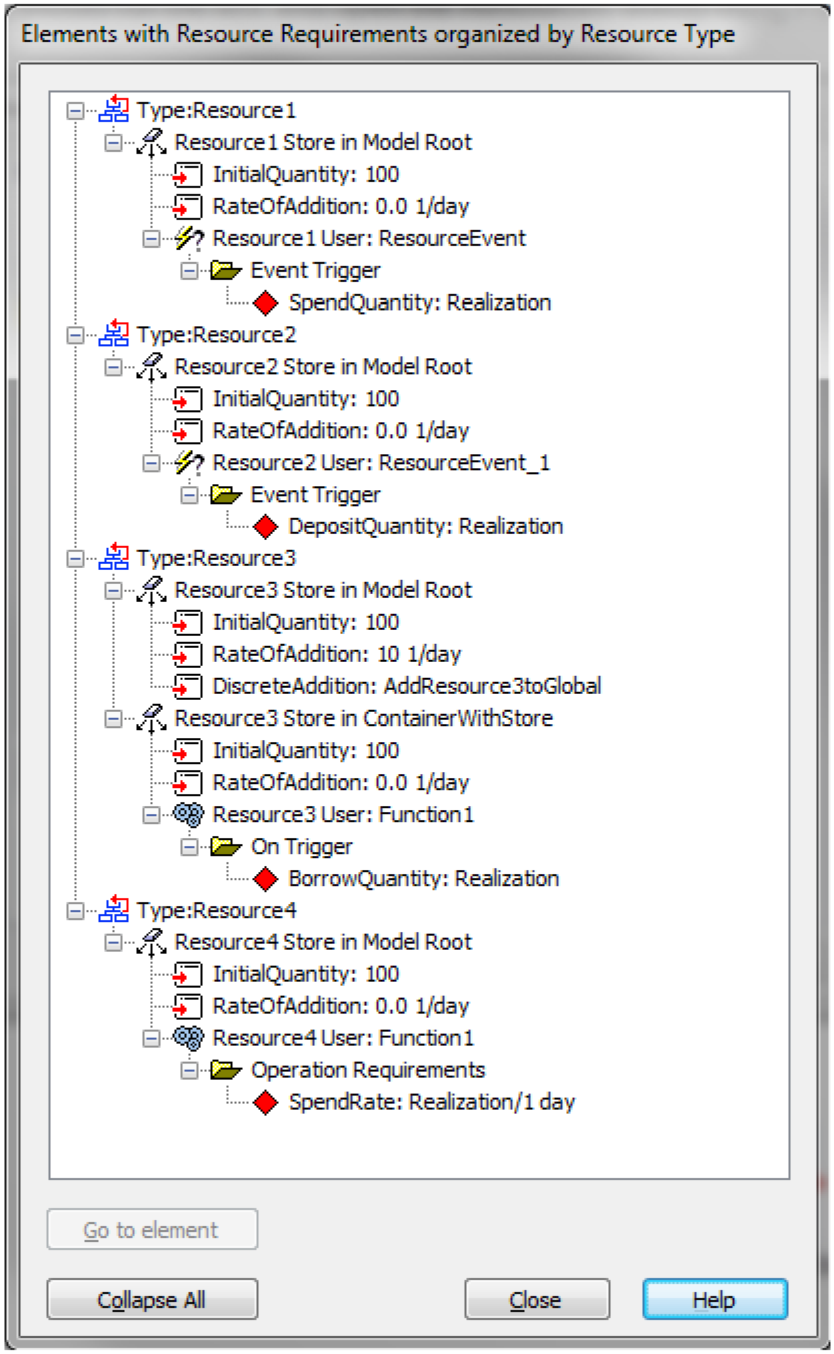


Figure GS62e_1 (Global Locations Dialog)

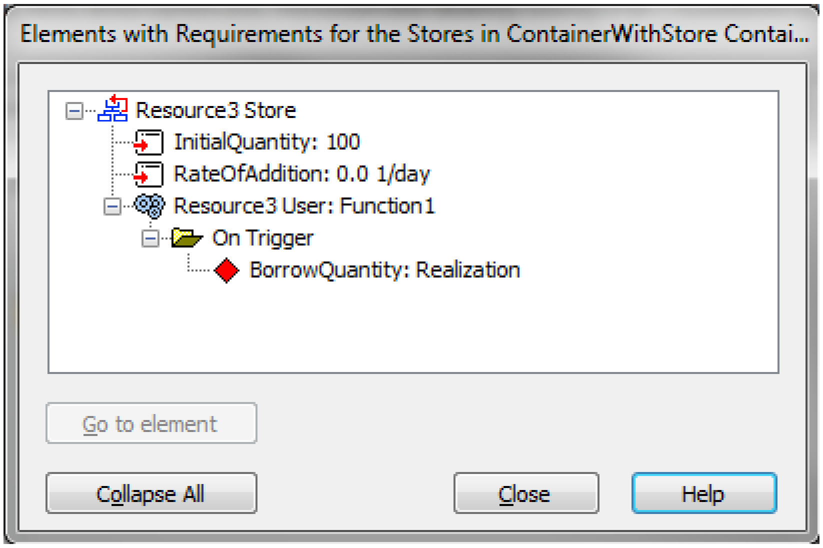
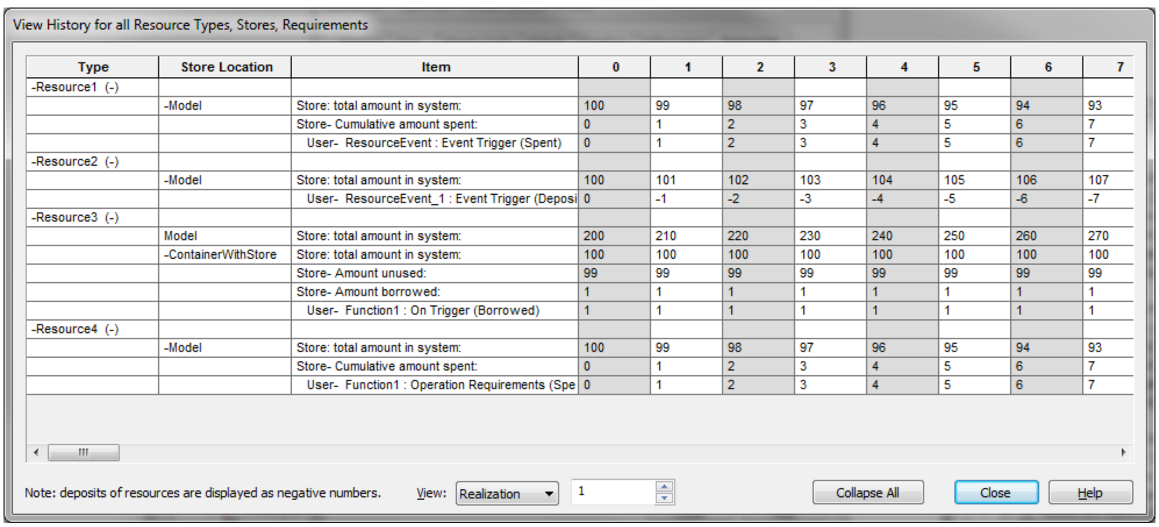


Figure GS62e_2 (Container With Store Locations Dialog)

View the Histories dialog for the model. Each realization elements which spend or deposit resources at the currrent Realization number. Resources will be borrowed at the current realization number for the duration of the simulation. Confirm this using the example results in Figure GS62e_3 (for Realization 1) and GS62e_4 (for Realization 10).



Type	Store Location	Item	0	1	2	3	4	5	6	7
-Resource1 (-)										
	-Model	Store: total amount in system:	100	99	98	97	96	95	94	93
		Store- Cumulative amount spent:	0	1	2	3	4	5	6	7
		User- ResourceEvent : Event Trigger (Spent)	0	1	2	3	4	5	6	7
-Resource2 (-)										
	-Model	Store: total amount in system:	100	101	102	103	104	105	106	107
		User- ResourceEvent_1 : Event Trigger (Deposi	0	-1	-2	-3	-4	-5	-6	-7
-Resource3 (-)										
	Model	Store: total amount in system:	200	210	220	230	240	250	260	270
	-ContainerWithStore	Store: total amount in system:	100	100	100	100	100	100	100	100
		Store- Amount unused:	99	99	99	99	99	99	99	99
		Store- Amount borrowed:	1	1	1	1	1	1	1	1
		User- Function1 : On Trigger (Borrowed)	1	1	1	1	1	1	1	1
-Resource4 (-)										
	-Model	Store: total amount in system:	100	99	98	97	96	95	94	93
		Store- Cumulative amount spent:	0	1	2	3	4	5	6	7
		User- Function1 : Operation Requirements (Spe	0	1	2	3	4	5	6	7

Figure GS62e_3 (Realization 1 Results)

View History for all Resource Types, Stores, Requirements

Type	Store Location	Item	0	1	2	3	4	5	6	7
-Resource1 (-)										
	-Model	Store: total amount in system:	100	90	80	70	60	50	40	30
		Store- Cumulative amount spent:	0	10	20	30	40	50	60	70
		User- ResourceEvent : Event Trigger (Spent)	0	10	20	30	40	50	60	70
-Resource2 (-)										
	-Model	Store: total amount in system:	100	110	120	130	140	150	160	170
		User- ResourceEvent_1 : Event Trigger (Deposi	0	-10	-20	-30	-40	-50	-60	-70
-Resource3 (-)										
	Model	Store: total amount in system:	200	210	220	230	240	250	260	270
	-ContainerWithStore	Store: total amount in system:	100	100	100	100	100	100	100	100
		Store- Amount unused:	90	90	90	90	90	90	90	90
		Store- Amount borrowed:	10	10	10	10	10	10	10	10
		User- Function1 : On Trigger (Borrowed)	10	10	10	10	10	10	10	10
-Resource4 (-)										
	-Model	Store: total amount in system:	100	90	80	70	60	50	40	30
		Store- Cumulative amount spent:	0	10	20	30	40	50	60	70
		User- Function1 : Operation Requirements (Spe	0	10	20	30	40	50	60	70

Note: deposits of resources are displayed as negative numbers. View: Realization 10 Collapse All Close Help

Figure GS62e_4 (Realization 10 Results)

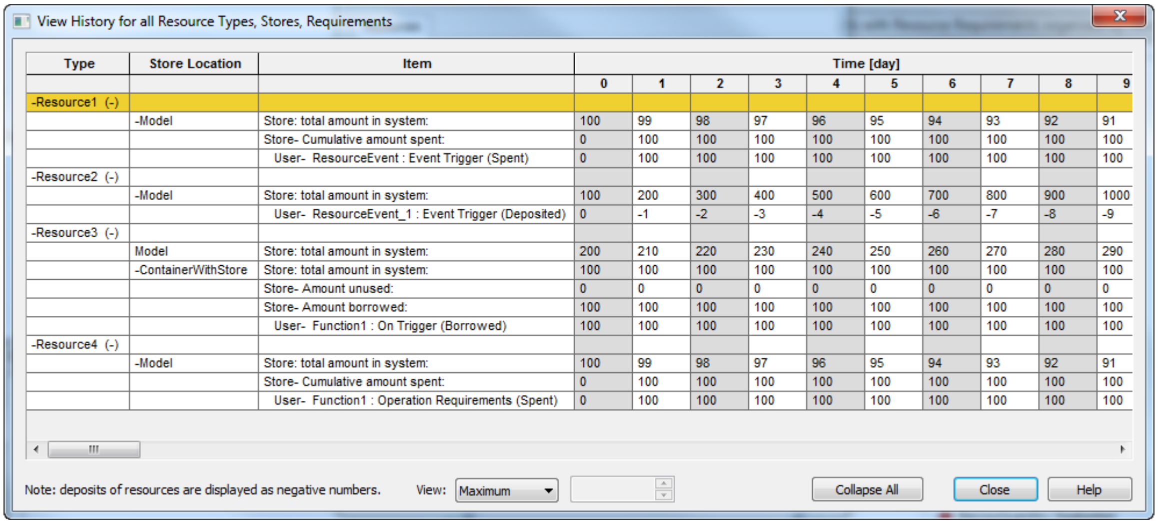
Minimum, Maximum and Mean results can be confirmed by comparing the results from the first few steps to the screenshots in Figure GS62e_5 through Figure GS62e_7 below.

View History for all Resource Types, Stores, Requirements

Type	Store Location	Item	0	1	2	3	4	5	6	7
-Resource1 (-)										
	-Model	Store: total amount in system:	100	0	0	0	0	0	0	0
		Store- Cumulative amount spent:	0	1	2	3	4	5	6	7
		User- ResourceEvent : Event Trigger (Spent)	0	1	2	3	4	5	6	7
-Resource2 (-)										
	-Model	Store: total amount in system:	100	101	102	103	104	105	106	107
		User- ResourceEvent_1 : Event Trigger (Deposi	0	-100	-200	-300	-400	-500	-600	-700
-Resource3 (-)										
	Model	Store: total amount in system:	200	210	220	230	240	250	260	270
	-ContainerWithStore	Store: total amount in system:	100	100	100	100	100	100	100	100
		Store- Amount unused:	99	99	99	99	99	99	99	99
		Store- Amount borrowed:	1	1	1	1	1	1	1	1
		User- Function1 : On Trigger (Borrowed)	1	1	1	1	1	1	1	1
-Resource4 (-)										
	-Model	Store: total amount in system:	100	0	0	0	0	0	0	0
		Store- Cumulative amount spent:	0	1	2	3	4	5	6	7
		User- Function1 : Operation Requirements (Spe	0	1	2	3	4	5	6	7

Note: deposits of resources are displayed as negative numbers. View: Minimum Collapse All Close Help

Figure GS62e_5 (Minimum)

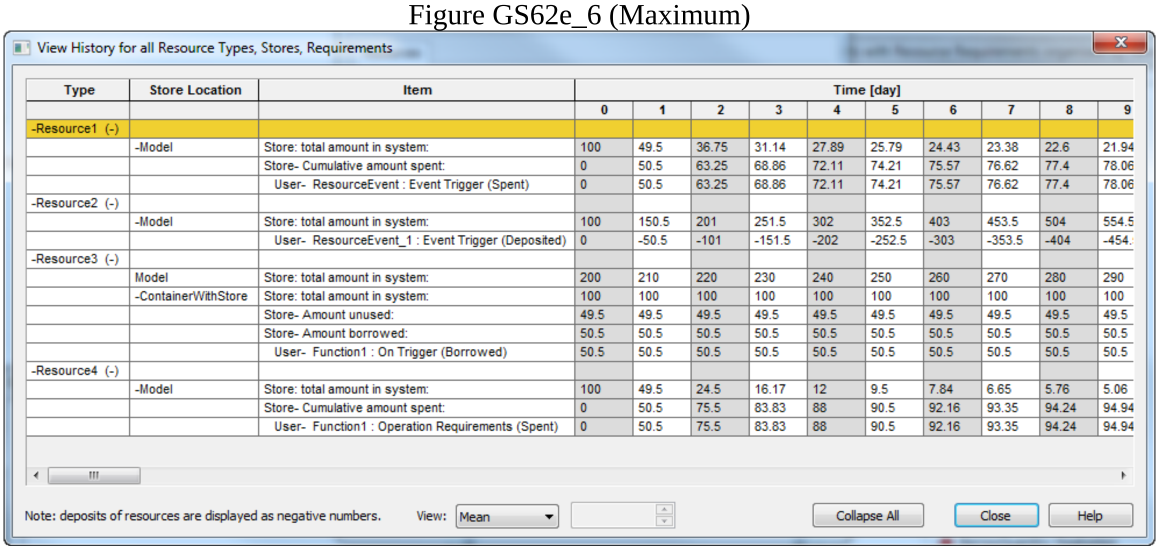


View History for all Resource Types, Stores, Requirements

Type	Store Location	Item	Time [day]									
			0	1	2	3	4	5	6	7	8	9
-Resource1 (-)												
	-Model	Store: total amount in system:	100	99	98	97	96	95	94	93	92	91
		Store- Cumulative amount spent:	0	100	100	100	100	100	100	100	100	100
		User- ResourceEvent : Event Trigger (Spent)	0	100	100	100	100	100	100	100	100	100
-Resource2 (-)												
	-Model	Store: total amount in system:	100	200	300	400	500	600	700	800	900	1000
		User- ResourceEvent_1 : Event Trigger (Deposited)	0	-1	-2	-3	-4	-5	-6	-7	-8	-9
-Resource3 (-)												
	Model	Store: total amount in system:	200	210	220	230	240	250	260	270	280	290
	-ContainerWithStore	Store: total amount in system:	100	100	100	100	100	100	100	100	100	100
		Store- Amount unused:	0	0	0	0	0	0	0	0	0	0
		Store- Amount borrowed:	100	100	100	100	100	100	100	100	100	100
		User- Function1 : On Trigger (Borrowed)	100	100	100	100	100	100	100	100	100	100
-Resource4 (-)												
	-Model	Store: total amount in system:	100	99	98	97	96	95	94	93	92	91
		Store- Cumulative amount spent:	0	100	100	100	100	100	100	100	100	100
		User- Function1 : Operation Requirements (Spent)	0	100	100	100	100	100	100	100	100	100

Note: deposits of resources are displayed as negative numbers. View: Maximum — Collapse All — Close — Help

Figure GS62e_6 (Maximum)



View History for all Resource Types, Stores, Requirements

Type	Store Location	Item	Time [day]									
			0	1	2	3	4	5	6	7	8	9
-Resource1 (-)												
	-Model	Store: total amount in system:	100	49.5	36.75	31.14	27.89	25.79	24.43	23.38	22.6	21.94
		Store- Cumulative amount spent:	0	50.5	63.25	68.86	72.11	74.21	75.57	76.62	77.4	78.06
		User- ResourceEvent : Event Trigger (Spent)	0	50.5	63.25	68.86	72.11	74.21	75.57	76.62	77.4	78.06
-Resource2 (-)												
	-Model	Store: total amount in system:	100	150.5	201	251.5	302	352.5	403	453.5	504	554.5
		User- ResourceEvent_1 : Event Trigger (Deposited)	0	-50.5	-101	-151.5	-202	-252.5	-303	-353.5	-404	-454.
-Resource3 (-)												
	Model	Store: total amount in system:	200	210	220	230	240	250	260	270	280	290
	-ContainerWithStore	Store: total amount in system:	100	100	100	100	100	100	100	100	100	100
		Store- Amount unused:	49.5	49.5	49.5	49.5	49.5	49.5	49.5	49.5	49.5	49.5
		Store- Amount borrowed:	50.5	50.5	50.5	50.5	50.5	50.5	50.5	50.5	50.5	50.5
		User- Function1 : On Trigger (Borrowed)	50.5	50.5	50.5	50.5	50.5	50.5	50.5	50.5	50.5	50.5
-Resource4 (-)												
	-Model	Store: total amount in system:	100	49.5	24.5	16.17	12	9.5	7.84	6.65	5.76	5.06
		Store- Cumulative amount spent:	0	50.5	75.5	83.83	88	90.5	92.16	93.35	94.24	94.94
		User- Function1 : Operation Requirements (Spent)	0	50.5	75.5	83.83	88	90.5	92.16	93.35	94.24	94.94

Note: deposits of resources are displayed as negative numbers. View: Mean — Collapse All — Close — Help

Figure GS62e_7 (Mean)

GS62f_Resources

This test verifies Resource functionality in SubModels. It is a copy of the GS62_Resources test with a second copy of the GS62_Resources test imported as a SubModel.

The verifier should run the model and ensure the plots in the main model and SubModle correspond with the expected results in Fig. GS62_1 through GS62_7 below.

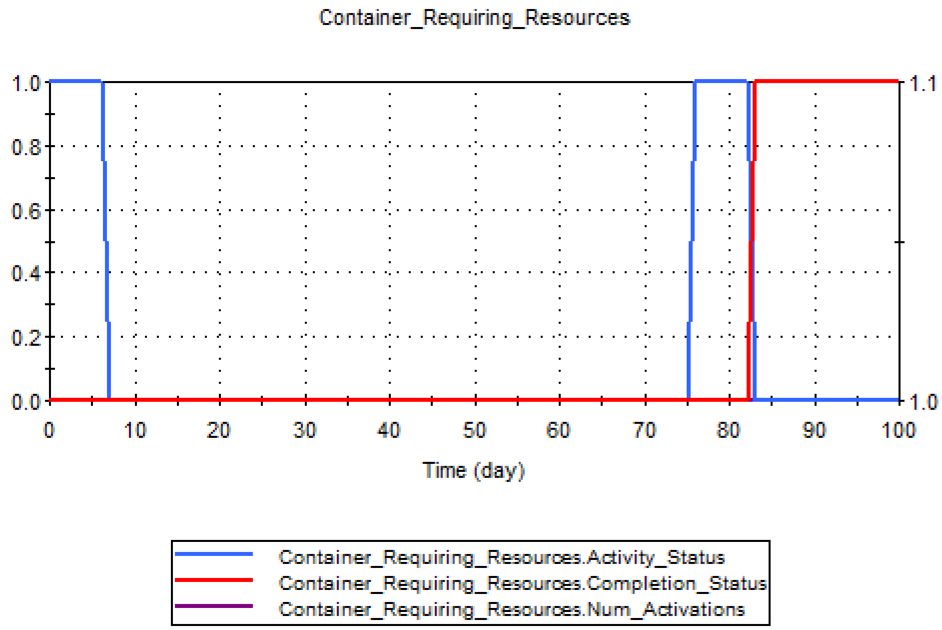


Fig. GS62f_1 – Status_Activations

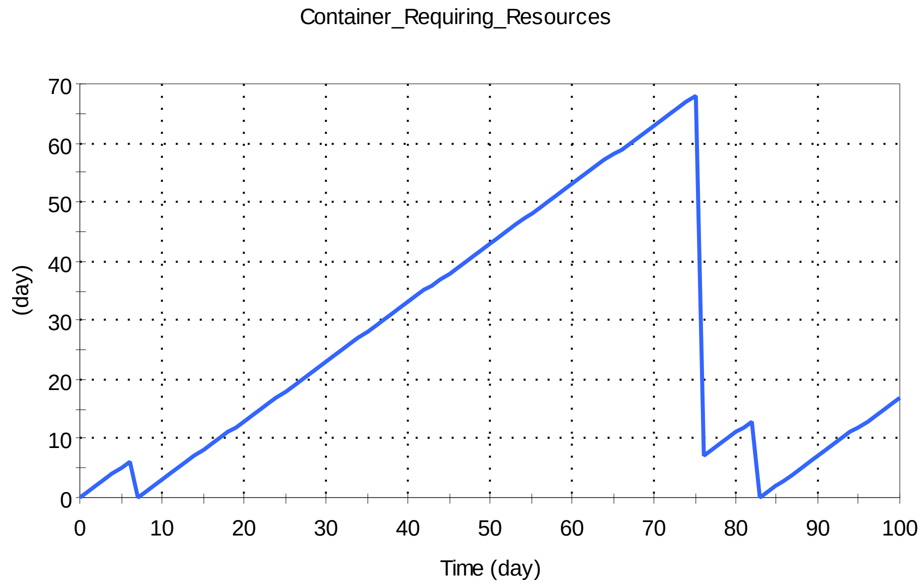


Fig. GS62f_2 – Duration

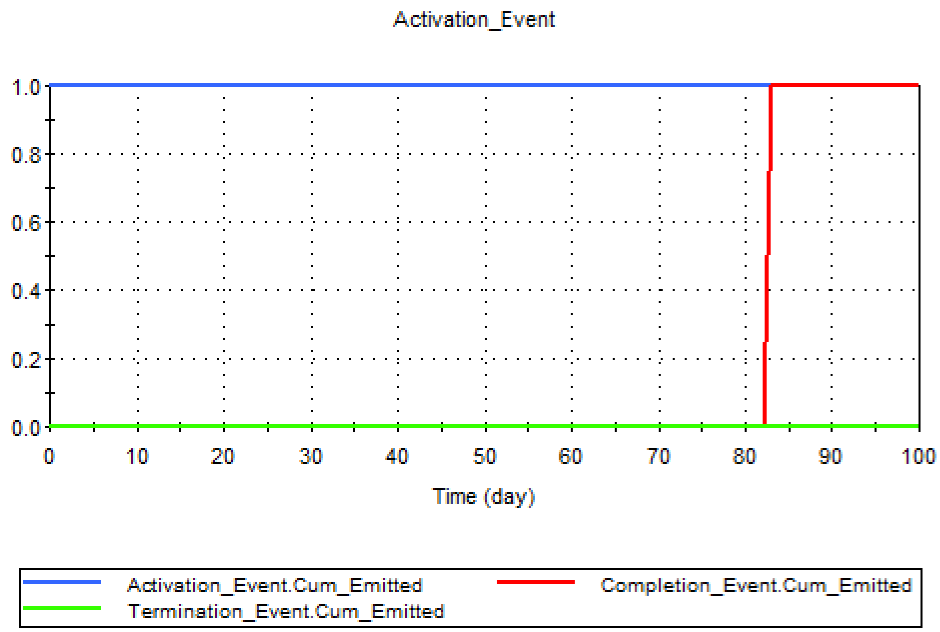


Fig. GS62f_3 – Event_Plots

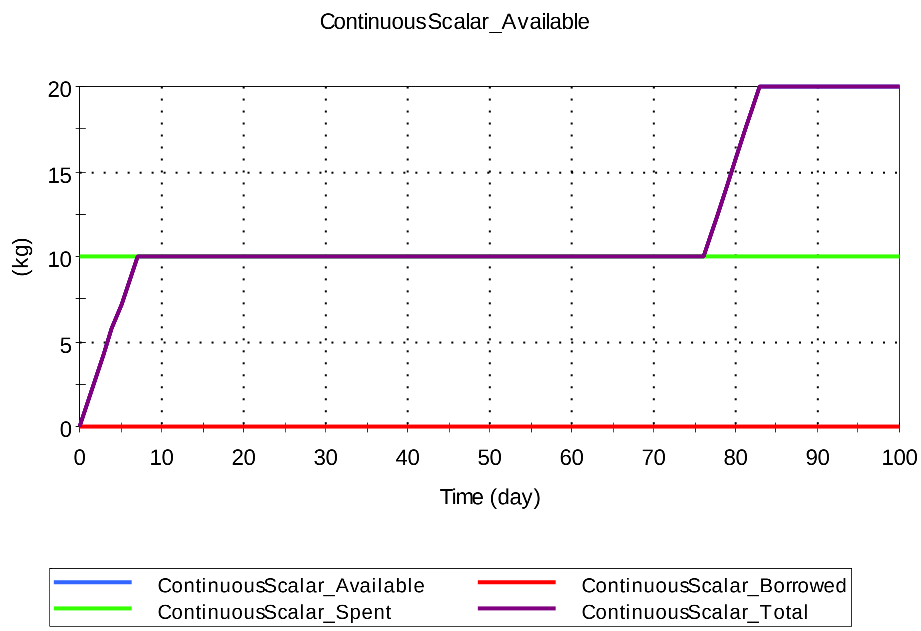


Fig. GS62f_4 – ContinuousScalar

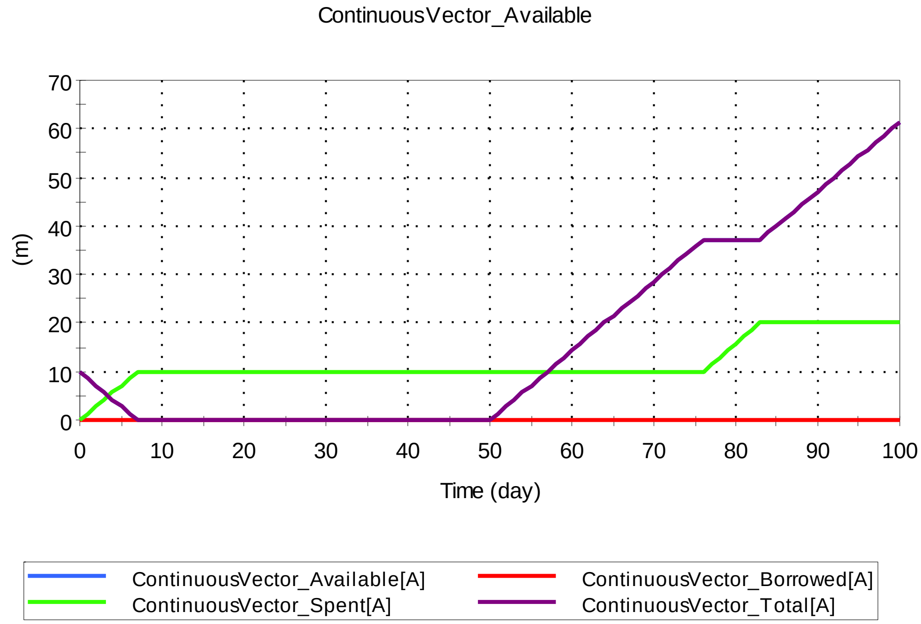


Fig. GS62f_5 – VectorA

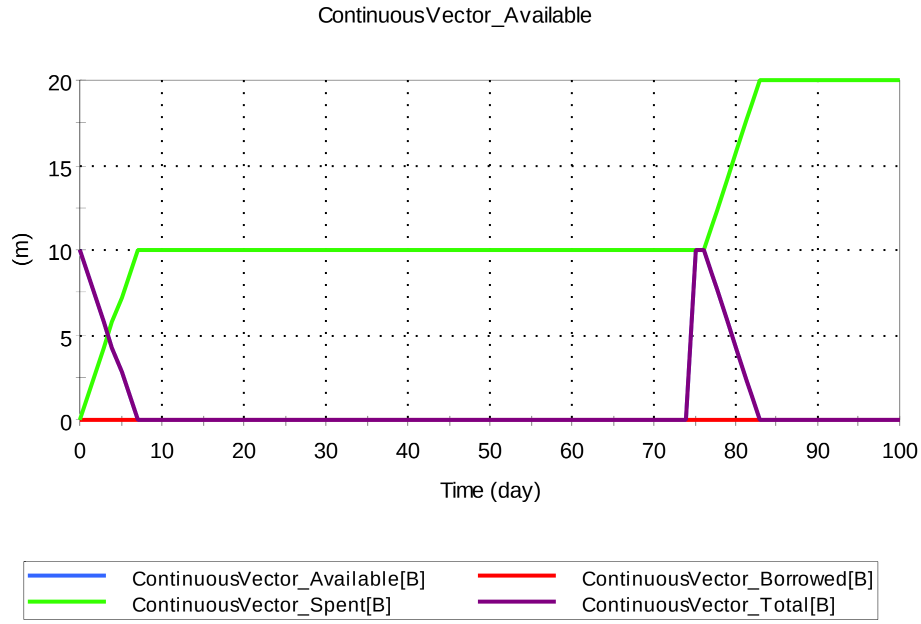


Fig. GS62f_6 – VectorB

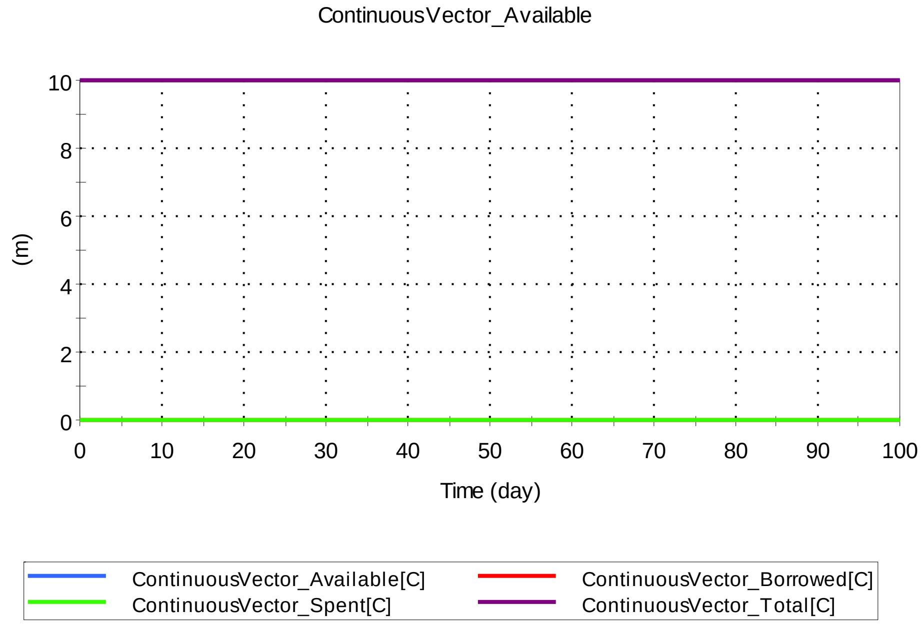


Fig. GS62f_7 – VectorC

GS63_Script_General

There are 6 files testing the script element's calculations. One is a file of general tests that examine all statement types to varying degrees (GS63_Script_General). These tests are similar to real world applications, with several scripts sorting vectors, one calculating a correlation matrix, and one calculating a square root by Newton's method. The other five files (GS63b to GS63f) are aimed at testing specific loop statements and logging of messages, errors, and warnings from the script element. Throughout all tests, variable definition and assignment statements, if statements, and break and continue statements are also tested.

GS63_Script_General consists of 6 script elements. The tester should run the model and confirm that the element True_if_all_Scripts_worked is true. If that element is not true, it is necessary to look more closely at each script element's verification, as described below.

The first script in this file is called Index_and_Sort. This element does a bubble sorting algorithm that should give the same results as the vector function sort123. It tests nested for loops and if statements and assignment to arrays. If this script is working, the element True_if_Sort_Worked will be true.

The next two script elements, Correlation_Matrix_For_Loop and Correlation_Matrix_While_Loop, calculate by different techniques the correlation matrix for a uniform random matrix of numbers. As the names indicate, one script element uses nested for loops and one element uses nested while loops; both test assignment of a matrix item by item. They should give the same result as the element Correlation_Matrix_From_Excel. If these scripts are functioning normally, the elements True_if_Correlation_works1 and True_if_Correlation_works2 will both be true.

The next two script elements in the file, Tied_Rank_by_Do_Loop and Tied_Rank_by_For_Loop, calculate the tied ranks for a vector of random integers with several ties. These elements test nested while loops, do loops, for loops, and assignment to vectors. If these script elements are working, the element True_if_Tied_Rank_Worked should be true.

The final test in this file calculates the square root of a number through Newton's method. It tests for loops, if statements, and break statements. If this script is functioning properly, the element True_if_Square_Root_Works should be true.

GS63b_Script_If_and_Log

This file tests if statements, log statements, and showing messages. The tester should set the element Turn_on_Container1 to false and then run the model. The following three messages should be produced:

Var1 is equal to 9

Check that Input1 is equal to 5. If so, this test works, but check also that this message is added as a message to the run log.

If input1 does not have a value of 6, then you should be seeing this message. This will be added to the run log as a warning, so check there.

Then the tester should change the element Turn_on_Container1 to true and run the model. When Etime is equal to 50 days, this should generate a correctly parsed error message like this:

You should see this message as a fatal error at Etime of 50 days if Turn_on_Container1 is true. Check that this appears in the run log at 50 days. This message occurred at Etime=50 days

GS63c_Script_For

This file tests for loops, including nested for loops, for loops with break and continue statements, for loops with non-constant increments, and for loops with reassignment of the loop variable. The tester should run the model and confirm the element True_if_all_work is true. If this element is not true, at least one of the script elements is not working. To find out which, if any, of the script elements is not working, the tester should look at the elements with names beginning with "True" to see which one is false.

GS63d_Script_Do

This file tests do loops, including nested do loops, repeat loops within do loops, reassignment of the do loop variable, and do loops that count down without the loop variable exactly matching the stopping value. The tester should run the model and confirm the element True_if_all_work is true. If this element is not true, the tester should examine the conditional expression elements with names beginning with "True" to see which script element is not functioning properly.

GS63e_Script_Repeat

This file tests repeat loops, including nested repeat loops, repeat loops with break and continue statements and assignments to matrices. The tester should run the model and confirm the element

True_if_everything_works is true. If this element is not true, at least one of the three script elements is not functioning proprerly and it is necessary to look at the conditional expression elements with names beginning with “True” to see which script element is not working.

GS63f_Script_While

This file tests while loops, including a simple while loop and a nested while loop. The tester should run the model and confirm the element True_if_everything_works is true. If this element is false, one of the two script elements is not working properly. In this case, the tester should examine the other two elements with names beginning with “True” to see which of the two script elements with while loops is not functioning properly.

GS64_CausalitySequence_View

This test verifies the UI and proper viewing of Causality Sequence in the Causality Sequence dialog.

1. Open GS64a_CausalitySequence_View.gsm. Click F9 in order to update the sequences. Click F10 to open the Causality Sequence dialog. Make sure that Container1, three discrete changes (DC1, DC2 and DC3), and three reservoir elements (Pond1, Pond2 and Pond3) are displayed in the Function sequence view. Change to the Static sequence view and make sure that three inflows are displayed. Close the dialog.

2. Go into Container2. Open the Causality Sequence dialog and check that both the Function and Static sequence views display identically to the ones in the main model container. Change the selection to “Elements in current container/child containers. Two discrete changes (DC2 and DC3) and two pond elements (Pond2 and Pond3) should be displayed. Change the Selection to Elements in the current container only. You should see only DC2 and Pond2.

3. Go back to the main model container. Now enter Container1. Open the Causality Sequence dialog. Six elements should appear in the function sequence and none in the static sequence. Close the dialog, select a few elements and re-open the causality sequence dialog. Selected elements names should be shown bold.

GS64_CausalitySequence_AddPrecedent

This test verifies the proper functioning of Causality Sequence through defining precedents for elements.

1. Open GS64b_CausalitySequence_AddPrecedents.gsm. Go into the Container Add_Precident. Run the model, open the result plot and make sure that all three discrete change signals are emitted on the 11^{th} second. Go back the edit mode.

2. Add DC2 as a precedent of DC1, DC3 as a precedent of DC2. Make sure that input ports of DC1 and DC2 have changed their colors to blue. Open the Causality Sequence dialog

and make sure that the order is DC3, DC2 and DC1. DC2 and DC1 should be highlighted with blue. Make sure that the precedent condition is stated in element tool tips in the dialog.

3. Tick the check box for showing causality sequence position in element tooltips. Close the dialog and check that precedent conditions are stated in tooltips.

4. Try adding DC1 as a precedent of DC3. It should fail because it causes a loop in the logic.

5. Run the model and check that DC3 is emitted on the 12th second.

6. Go into Add-Precedent_Fail. Try adding DC5 as a precedent for DC4. This should fail because it causes a loop in the logic.

TIME AND MONTE-CARLO TESTS

3.2 BASIC TIME AND MONTE CARLO TESTS

TMC-01 Time-Control Tests

Test TMC_01 confirms that the desired run-duration, time-step length and plot-steps are functioning correctly. It uses a simple Integrator element to generate a time-history indicating the time-points used. The test uses 100 time steps of 1 second each, for a total duration of 100 sec. It plots every second time step for the first 10 seconds, then every tenth time step for the balance of the simulation. The rate of change is 1/sec until time 50, then 2/sec thereafter.

Confirm that time-history results are generated at 0, 2, 4, …, 10, 20, … 100 seconds, that the time-history plot has two straight-line sections with a slope-change at 50 seconds, and that the final result is 149.

TMC-02 Monte Carlo Tests

Test TMC_02 tests the random-number generation process. It uses a stochastic distribution (Uniform 0-1), and carries out three tests:

1. With Latin hypercube sampling (LHS) enabled, do 100 realizations of the system. Review the ‘results array’ table to confirm that there is exactly one result between 0.00 - 0.01, one between 0.01 - 0.02, and so on up to 0.99 - 1.00.

2. Then, disable LHS and run the model for 1,000 realizations. Open in turn elements Result1 through Result1_9 and display the results array table. Copy the contents of the last two columns (the confidence bounds) to the clipboard, and paste them in turn into each of the ten highlighted sections of the associated spreadsheet file (TMC02.xls), in the first sheet.

After the tenth paste the CheckRatio term at the top of the spreadsheet should show up green, indicating that it lies between 0.5 and 2.0. This is the fraction of results that are outside of the confidence bounds, divided by the expected number outside (1000). (Expected mean is 1.0).

3. Similarly, open the R2 through R2_9 elements and display their results array tables. For the second entry (0.5), copy the contents of the last two columns (the confidence bounds) to the clipboard, and paste them into one of the ten highlighted sections of the associated spreadsheet file's second sheet.

After the tenth paste the CheckRatio term at the top of the spreadsheet should show up green, indicating that it lies between 0 and 0.3 (the mean fraction outside the confidence limits). Expected mean is 0.1.

TMC-03 Correlation Tests

Test TMC_03 generates a set of **rank-**correlated stochastic element values for four correlated elements. The desired **rank-**correlation matrix for these is:

	A	**B**	**C**	**D**
A	1.00	0.50	0.00	-0.50
B	0.50	1.00	N/A	N/A
C	0.00	N/A	1.00	N/A
D	-0.50	N/A	N/A	1.00

The Verifier should confirm that the calculated results for 1,000 realizations are close to the above table (the "N/A" values need not be checked). Because GoldSim uses an approximate algorithm to generate correlated variables, the results for the +/_ 0.5 correlations are only expected to be accurate to within one significant figure.

TMC-04 Confidence Bounds on Mean Values

<u>**t-Distribution Approach**</u>

GoldSim version 7.21.100 added a capability to estimate confidence bounds on the mean value for a Result Distribution element. This approach uses the t distribution, which is strictly valid only if the underlying distribution is normal. The 5% and 95% confidence bounds are calculated as defined below:

$$\mathrm{P}\{\overline{\mathrm{X}} + \mathrm{t}_{0.05}\frac{\mathrm{s}_x}{\sqrt{\mathrm{n}}}\} < \mu \ = \ 0.05 \ \text{(i.e., 5\% bound = } \overline{\mathrm{X}} - \mathrm{t}_{0.05}\frac{\mathrm{s}_x}{\sqrt{\mathrm{n}}}\text{)}$$

and $P\{\overline{\mathrm{X}} + t_{0.95}\frac{s_x}{\sqrt{n}}\} \geq \mu \ = \ 0.05 \ \text{(i.e., 95\% bound = } \overline{\mathrm{X}} + \mathrm{t}_{0.05}\frac{\mathrm{s}_x}{\sqrt{\mathrm{n}}}\text{)}$

Where:

$\overline{X}$ is the sample mean

$t_{0.05}$ is the 5% value of the t distribution for n-1 degrees of freedom

$t_{0.95}$ is the 95% value, = $-t_{0.05}$.
s_x is the sample mean
μ is the true mean of the population, and
n is the number of samples (realizations).

As the number of realizations, n, becomes large the Central Limit theorem becomes effective, the t distribution approaches the normal distribution, and the assumption of normality is no longer required. Normality may generally be assumed for n in the order of 30 to 100 or greater.

Verification Test

Test problem TimeMonteCarlo-04.gsm contains a single Stochastic element. Run the sample for the numbers of realizations in the following table, and confirm manually that the confidence bounds on the mean correspond to the correct t-distribution values using the above formulae. The fourth column in the table, N0.05, shows the corresponding deviation of the normal distribution.

# Realizations	Deg. Of freedom	$T_{0.05}$	$N_{0.05}$
10	9	1.833	1.645
100	99	1.666	1.645
1000	999	1.645	1.645

For example, for a random sampling seed of 1 (repeated sampling sequence) and with no Latin Hypercube Sampling, the following are the 5% and 95% confidence bounds calculated from the simulated sample mean and standard deviation for S:

# Realizations	Simulated Sample Mean	Simulated Sample Std Dev	5% Confidence Bound	95% Confidence Bound
10	0.2834	0.6830	-0.1125	0.6793
100	0.1098	0.8817	-0.0371	0.2566
1000	-0.0131	0.9923	-0.0648	0.0384

TMC-04b CorrelationValueCheck

This test verifies that GoldSim correctly calculates correlation coefficients and sensitivity analysis results based on rank and based on value. It uses three uniform distributions, with distributions B and C correlated to A.

The verifier should run the model and verify that the results from both calculation methods for the Sensitivity Analysis and Variable Correlation results agree to two significant figures. (Because uniform distributions are used, there will be little difference in terms of the two calculation methodologies as it is unlikely that there will be two identical sampled values).

The values for the calculated correlation coefficients should also be compared with the actual values:

B is correlated to A with a 0.6 correlation coefficient
C is correlated to A with a 0.3 correlation coefficient

TMC-05 Autocorrelation

This test verifies that autocorrelation of stochastics works properly. The Autocorrelation stochastic is correlated to itself with a coefficient of 0.5. The Stochastic2 element in the \Correlation_to_Element container should be correlated to Stochastic1 with a coefficient of 0.75.

The verifier should run the model and view the correlation coefficients. As no confidence bounds are provided, the model should be run a number of times to ensure that the coefficient values are centered around the expected value.

TMC-06 Sensitivity Analysis

This test verifies the proper functioning of the sensitivity analysis features and correlation coefficient calculation in the Multivariate result element.

This model should reproduce the results of Mishra (2004).

The verifier should run the model for 1,000 realizations, and then display the sensitivity analysis window. It should be confirmed that the partial rank correlation coefficients should approximately match those from Mishra:

v ~0.93
k ~0.71
B ~0.89

In addition, the verifier should display the correlation matrix, and confirm that the rank correlations are similar to the Mishra results (the small results in the table should be zero, and are non-zero due to randomness):

	Result	**V**	**k**	**B**
Result	1	0.83	0.61	0.46
X2	0.83	1	0.49	0.02
X3	0.61	0.49	1	-0.01
X1	0.46	0.02	-0.01	1

Note that a variance of up to 10% in the values calculated by GoldSim is acceptable.

TMC-07_Sensitivity Analysis

This test confirms the correct calculation of the different statistics provided in the sensitivity analysis, with the exception of the importance measure.

This test is run on the function Y = X1 + X2^2 + 10X3^3.

Where:

X1 is a random variable with a uniform distribution between 1 and 2.
X2 is a random variable with a uniform distribution between -10 and 10.
X3 is a random variable with a uniform distribution between -2 and 2.

The verifier should run the model with and without low-end importance sampling enabled for X3. They should then confirm the results in the Sensitivity Analysis display of the Analysis element by comparing them to those in the Verification Plan. The verifier should note that exact results are expected only for cases where importance sampling is disabled. If importance sampling is enabled small variations (less than 0.05) from the results in the plan are acceptable.

Analysis based on values:

Variable Correlations:

	Y	**X2**	**X3**	**X1**
Y	1	0.006	0.618	-0.002
X2	0.006	1	0.008	0.000
X3	0.618	0.008	1	-0.003
X1	-0.002	0.000	-0.003	1

Sensitivity Analysis:

R^2 value: 0.381366

Variable	**Corr. Coeff.**	**SRC**	**Partial Coeff.**
X2	-0.006	0.002	0.002
X3	0.618	0.618	0.618
X1	-0.002	0.000	0.001

Analysis based on rank:

Value Correlations:

	Y	**X2**	**X3**	**X1**
Y	1	-0.008	0.618	0.013
X2	-0.008	1	0.008	0.000
X3	0.618	0.008	1	-0.003
X1	-0.013	0.000	-0.003	1

Sensitivity Analysis:

R^2 value: 0.35194

Variable	**Corr. Coeff.**	**SRC**	**Partial Coeff.**
X2	-0.008	-0.012	-0.015
X3	0.593	0.593	0.593
X1	-0.013	-0.011	-0.013

Note: If necessary to confirm or modify these results, a spreadsheet which implements the same methodology as GoldSim is available in SourceSafe with the Time and Monte Carlo Tests. It is called SensitivityAnalysisCorrelationCheckTMC-07.xls.

TMC-08_Importance

This test verifies the calculation of the importance statistic in the Sensitivity Analysis option in the Multivariate result element.

The verifier should run the model for 1000 realizations and open the Sensitivity Analysis dialog in Result1.

Stochastic1 is a uniform distribution between 0 and 1, with variance equal to 0.083336.
Stochastic2 is a uniform distribution between 0 and 0.1, with variance equal to 8.3336 E-4.

This means that the importance of Stochastic1 has a theoretical value of 0.99, while the theoretical value for Stochastic2's importance is 0.01.

In this case, the actual values (even though we are running 1000 realizations) will be slightly different (as GoldSim is partitioning the range of final values in the mutivariate element to determine the local variance for the importance calculation).

Importance values for Stochastic1 between 0.975 and 0.995, and for Stochastic2 between 0.000 and 0.03 are acceptable.

TMC-09_Strata_Sampling

This test verifies the correct function of the mid-point/random point LHS strata sampling option. The test contains a uniform stochastic (0, 10000), and the model is run for 11,000 realizations.

The verifier should run the model with the mid-point option selected. The values from the result array should be copied to the TMC-09_Strata_Sampling.xls worksheet under “Mid-point” results. Note that the tester should display 8 significant figures in the Result Array table (the number of significant figures can be checked and adjusted by hitting CTRL+SHIFT+S in the table). The process should then be repeated with the random point option selected and copied to the Random section of the TMC-09_Strata_Sampling.xls worksheet. The verifier should check that the results generated by GoldSim are acceptable in the Results section of the worksheet.

3.3 RESULT PRESENTATION TESTS

Result-01 Time-History Results Presentation

Test Result-01_TimeHistoryResult.gsm produces 10 realizations of a 20-step time history for a matrix expression. Each realization consists of a random number (0-1) multiplied by sin(time) multiplied by the constant matrix:

Row\Col	**11**	**12**	**13**
Sunday	1	11	1*time|sec|
Monday	2	12	2*time|sec|
Tuesday	3	13	3*time|sec|
Wednesday	4	14	4*time|sec|
Thursday	5	15	5*time|sec|
Friday	6	16	6*time|sec|
Saturday	7	17	7*time|sec|

The Verifier should use the time-history display functions to display raw and graphical histories for the results, testing the ability to plot single and multiple components of the data, and single and multiple realizations.

Next, return to Edit mode and open the properties dialog for the element Result1. Delete all of the inputs (if any are present). Next, click the “Add input” button, then double-click on the element “Result”. All of the outputs from “Result” should be automatically added as outputs to Result1 (7 x 3 = 21 matrix elements). Run the model again to produce results for Result1. Next, select the different outputs using the Select Array Items dialog and ensure that the proper results are displayed.

Result-02 Array-Result and Distribution Result Presentation

Part 1. Array Results. The Expression Element 'Result' produces 10 realizations of a matrix expression, evaluated at time=5{sec}. The expression is the same as for test Result-01.

First, the user should use the array-result display (for element Result1) to confirm:

Correct table-view display for each realization

Correct chart-view display for each realization

Correct calculation of total row/columns (using Ctrl-T).

Second, the user should open the Array of Final Values for the element Result (i.e., the table of output values). The user should then test sorting the table of values by column. Click on the column header "11". The header should change to red and the table should sort by increasing value in that column (if it is not already sorted that way). Click again to sort the table by decreasing order in that column. Ensure that the entire table sorts (i.e., the row headers and the remaining columns' values should remain "tied to" the corresponding value in the sorted column. Sort the table by the other columns and ensure sorting works correctly. Finally, right-click the mouse in the table and select "reset sorting" to return the table to its original form. Ensure that this feature works correctly.

Third, the user should switch to edit mode and change the name of the expression element "Result" and ensure that the edited name is automatically updated in outputs section of the result element "Result1" (Result1 is linked to Result). To check this, right-click on Result1, select Properties, and then view the name in the "link" input field to ensure that it matches the edited name for Result. Rename the expression element to 'Result' and re-run the model.

Part 2. Preview Chart for Distribution Results. Element 'Random' produces results for 10 realizations. Open the Distribution Result Result2. Exercise all of the options for the preview chart (e.g., confidence bounds on/off, switching from PDF to CDF to CCDF and back, probability calculator, etc.) to ensure that they work. Ensure that changes made to Result2 (e.g., changing the scale of the X axis in the chart view) do not affect Result3, which also displays the results from Random.

Result-03 Probability Results Presentation

Test Result-03_ProbabilityResult.gsm file contains several stochastic elements and functions. After running 10,000 realizations, the Verifier should confirm the following items:

Confirm that the mean, standard deviation, skewness and kurtosis for the results of the two normal distributions match their input definitions (10, 5, 0, 0) and (20, 10, 0, 0) respectively.

Confirm that the mean and standard deviation for the sum of the two normal distributions are 30 and 11.2.

Confirm that the statistics summary table for the sum of the normals approximately matches the results below. Results may only be correct to 1 significant figure near the tails of the distribution:

Probability	Value
0.001	-3.60
0.010	3.96
0.050	11.58
0.100	15.66
0.250	22.44
0.500	30.00
0.750	37.56
0.900	44.34
0.950	48.42
0.990	56.10
0.999	63.6

Result-04 Screening of Results

This file tests the entire screening process for stochastic results. Test Result-04_ResultScreening.gsm contains two stochastic elements. One is a normal distribution with mean=10 and standard deviation=5. The other is an identical distribution truncated at 5 and 20. This test runs 10,000 realizations, and then screens the results based on the output from the first element, screening for results between 5 and 20.

To screen the results for the element “Normal”, go to Run|Screen Realizations. The screening dialog should show up with the appropriate settings in place. Click “Update List” and then “OK” to complete screening. “Normal” is now truncated.

The Verifier should confirm that the result-statistics for the screened element are essentially the same as those for the truncated-distribution element (i.e., mean of 11.2 and standard deviation of 3.6). To view the result statistics, click on the output port for the element “Normal”, then right click on the output named “Normal”, then select “Final Value” and “Result Distribution”.

Result-05 Controlling and Tracking Saved Results

This test (Result-05_ControllingTrackingResults.gsm) evaluates the various options for saving time histories and arrays of final values. The tests are as follows:

1. Put the model in Edit Mode, then go to the View Menu and select “Highlight Saved Results”. Check the options for “Time Histories” and “Final Values”. Then look at the main browser window. The elements Data1, Stochastic1, Expression1, and Container1 should be shown in bold font in the model browser to indicate that time histories and final values will be saved for these elements (the default settings for the file upon opening the file is to save results for these elements).

2. Run the model. Enter Container1 and view the time history for Expression1 (or Result1). The chart should show three time histories (one for each species that make up the vector called Expression1) for each realization. Similar results for a total of 10 realizations should be available. (If the Probability History button is selected, de-select it to view the results for each realization.)

3. Exit Container1, enter Edit Mode, then open Container1's dialog box. Clear the Final Values and Time Histories checkboxes and then go to the information tab. Run the model. The number of saved time histories should be 1, while the number of saved final values should be 0. Enter Container1 and open the element dialog boxes one by one. The "Final Value" checkboxes for all elements should be turned off (i.e., not checked). The "Time Histories" boxes should be turned off for the Data and Stochastic elements, but should be on for the Expression element. Verify that the time history for the expression element was saved by viewing the time history from the Expression element and the Result element.

4. Look at the main browser window. Data1 and Stochastic1 should be shown in normal text (indicating no results were saved), while Expression1 and Container1 should be shown in bold text (indicating results were saved).

5. Exit Container1. Enter Edit Mode, open Container1's dialog box and check the boxes next to Time Histories and Final Values for the subelements and close the dialog. Run the model. Go to the information page – the number of saved time histories and final values should now be 5. Enter Container1 and open the element dialog boxes one by one. The "Final Value" and "Time History" checkboxes for all elements should be turned on (i.e., checked). Verify that the final values and time histories were saved by viewing them for each element. The results should be the same as for the initial model run in step 1 above.

Result-06 Probability Histories

This test (Result-06_ProbHistories.gsm) runs 1000 realizations of the model but saves only ten (10) of the realizations, as defined in the Model Simulation Settings dialog box. This test verifies that the information essential for computing the probability histories is saved (e.g., the mean and sum of the squares of the simulated values at a given time) even though the full time histories are not saved.

Note: when you open each result element, first ensure that the element displays the *chart form* of the *probability histories*. Make any adjustments necessary to the display to get in this form before carrying out the corresponding tests, because the instructions are based on this format.

To perform the test, first run the model. Then perform the following tasks:

1. Inside the Container "Scalar_Tests", Open the Time-History Result element called "Time Histories". Ensure that the Chart View median time history values match those shown in Figure Result-06.1 below (this figure was generated in Excel using median values obtained from the Table View for the same GoldSim element. Next, Click on the probability-history button at the top of the chart to switch to time-history mode. Time histories should be available for only ten (10) realizations (provided that only ten are saved in the Model Simulation Settings dialog box). Switch back to probability-history mode. Click on the Chart Style button. Edit the chart style to ensure that the probability history chart can be edited and that changes "stick". Click on the table-view button. The table should show the mean value, standard deviation, median, lower and upper bounds, and the selected confidence bounds (5th and 95th percentiles, in this case) as a function of time for the duration of the simulation.

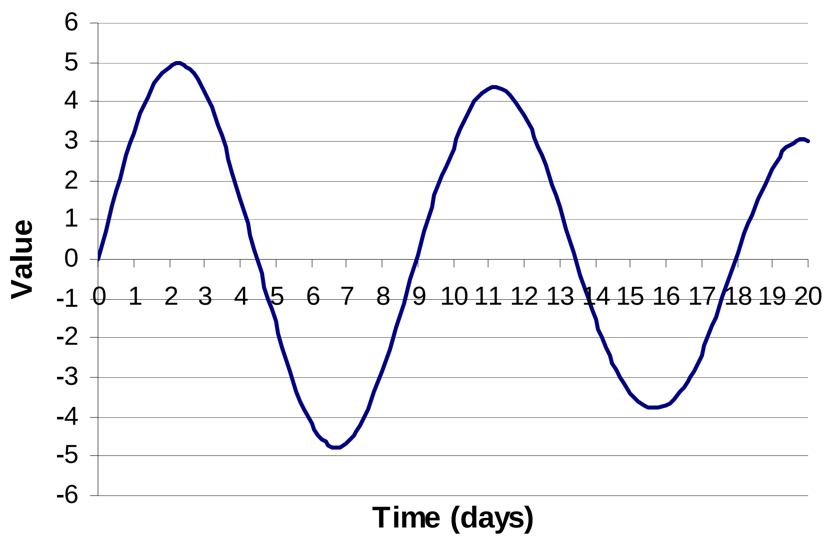


Figure Result-06.1. Median-value probability history

2. Inside the Container "Vector_Tests":

   Part 1. Open the Time-History Result element called "Time Histories_Vector". By default, the MEAN time history for all four matrix elements will be shown (see Figure Result-06.2). Ensure that the simulated results match Figure Result-06.2. Click on the Mean Time History button to switch to the View Realizations mode. Ensure that the ten (10) individual saved realizations are available for all four vector elements. Next, click on the table-view button. The MEAN time history (i.e., the mean value for 1,000 realizations at each point in time) for each of the four vector elements should appear side-by-side in table form. Click on the Probability History button to switch to viewing a single realization. Ensure that the simulated values for all four vector elements can be viewed side-by-side (one realization at a time) for the ten saved realizations.

   Part 2. Next, click on the properties dialog button, then Select Array Items, and de-select all but one of the items (i.e., vector elements). Click OK and then "Display Table". When the Mean Time History button is selected, the table should show the mean value, standard deviation, median, lower and upper bounds, and the selected confidence bounds (5th and 95th percentiles in this case) as a function of time for the simulation. When the Mean Time History button is de-selected, the time histories for all of the saved realizations should be shown side-by-side for the selected vector element. Repeat for the Chart View. In the Chart View, each realization is plotted separately, and the mean time history will also show the median, the bounds, and the selected percentiles. Finally, re-select all four Array Items and then save the model.

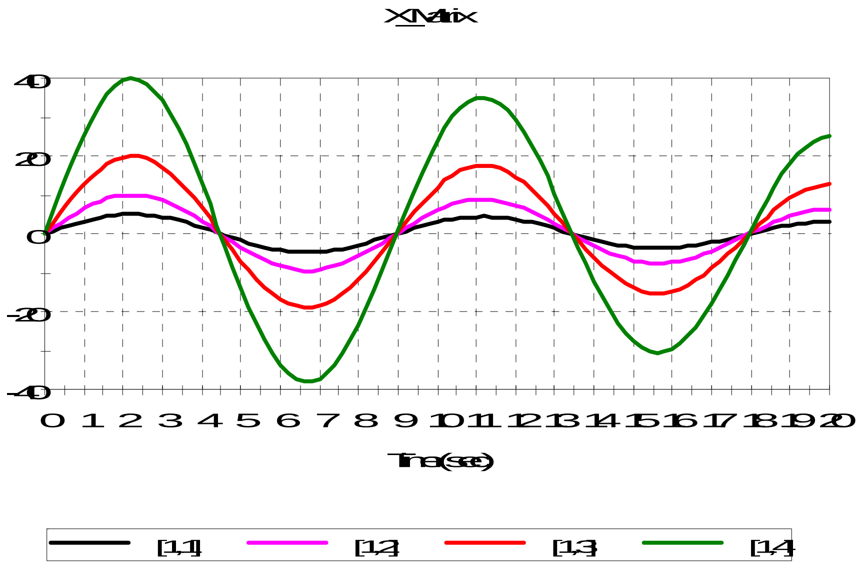


Figure Result-06.2. Mean-value probability history for four array elements.

3. Enter the container called “Matrix_Tests”.

Open the Time-History Result element called "Time Histories_Matrix". This element can simultaneously display either 1) the time histories for each realization OR 2) the mean time histories for every matrix element in a single row or column of the matrix (i.e., the results for all four elements in a single row or single column in the same chart or table). Follow the instructions outlined above for Parts 1 and 2 for “Time_Histories_Matrix”. The steps and results are similar, except that now four matrix outputs are plotted instead of four vector outputs.

4. Enter the container called “Condition_Tests”.

Open the Time-History Result element called "Cond_Time_Histories". This element should display the mean fraction true history chart. Click on the table-view icon and confirm that the table values are equivalent to the chart. Then click to turn off probability-view, and confirm that the first ten histories can be displayed as true/false or 1/0 values.

Then open the Result Distribution element “Cond_PDF”. Confirm that the display indicated two possible values, False or True, and that each has a 50% probability.

5. Enter the container called “Saving_Time_Histories.” To confirm that statistical results reflect the full set of 1000 realizations, copy the table results from the Time_Histories graph into the Result-06.xls spreadsheet. Rerun the model, saving all time histories, and copy the table from the Time_Histories element to the Results-06_ProbHistories.xls spreadsheet. Ensure that the difference between the two sets of results is within the acceptable range (<0.05 deviation on average over all timesteps).

Result-06a Probability Histories from Distributed Processing

This test is the same test as Result-06, but Result-06a verifies the probability-history calculations using the distributed processing (i.e., networked) feature of GoldSim. To complete this test, run the test file using two local slaves, and then verify results as in Result-06.

Open the file Result-06_ProbHistories.gsm.

To start the local slaves and run the test file, do the following: ***Launch a GoldSim slave on the local machine by typing the following in the Windows Run dialog (accessed from the Start button):***

“path to GoldSim.exe” –s

Include the quotes and leave a space between the last quotation mark and the hyphen. Upon entering this command, the GoldSim Network Client dialog will appear on the slave machine (which is also the local machine), with a Client Status of “Client is Ready to Connect to Master”.

Repeat Step 2 to open a second slave on the local machine.

Next, specify the slaves’ network addresses in the Network Settings dialog on the master machine. This can be done by selecting “Run on Network…” from the Model menu and then entering the local machine’s network name for both of the slaves.

Press the “Update Slave Status” button to make connections between the master and slave machines. Ensure that the master recognizes both slaves as active.

Run the networked simulation by pressing the “Run Simulation” button.

When the simulation is complete, check results as described for Result-06.gsm.

Result-07 Dynamic Result Viewing

This file (Result-07_DynamicViewing.gsm) verifies that results can be viewed during model simulations, and that they updated dynamically. The test proceeds as follows:

Part 1. Dynamic Time Histories. Enter the container named Time_Histories. Repeat the following steps for each element Scalar, Vector, and Matrix in succession:

Activate the Run Controller. Slide the speed-control slider to the left.

Open the appropriate result element (i.e., Scalar_TH, Vector_TH, or Matrix_TH).

Run the model. Ensure that the time histories are updated with time and that they match the expected result shown in the corresponding figure in the test file.

Part 2. Dynamic Array Chart. Open Array1, select 2D plot and run the model. The plot should update dynamically as the model is run. You should see the final value at the end of each realization reported on the chart.

Part 3. Dynamic Multi-Variate Chart. Open Multi_Variate1, run the model, and ensure that it updates dynamically as the model is run. You should see a linear 1:1 plot (perfectly-correlated variates) building with time (see the chart in the test file).

Part 4. Dynamic PDF Chart. Open PDF1, run the model, and ensure that it updates dynamically as the model is run. You should see the PDF plot building with time.

Result-08 Time History Export

This test (Result-08_TimeHistoryExport) verifies the proper functioning of the time history export to text and spreadsheet files.

The verifier should delete all Result8_*.xls and Result8_*.txt files from the test directory. Run the model. New files for each of the result elements should be created. Enter each file and verify that the data has been correctly exported (the data exported is ETime*Realization Number in days). Expected final values for statistics (exported only from even numbered result elements, i.e., Result8_2.xls and Result8_14.txt would have statistics) are:

Mean/Median = 55
Lower bound = 10
Upper bound = 100

Also, the verifier should check that data in each of the text files has the correct number of significant digits (4 for Result8_13.txt, and 6 for Result8_14.txt), and that time values are exported with Result8_13.txt and not with Result8_14.txt.

Result8_15.xls should contain data and statistical information from Expression1 (ETime * Realization) and Expression2 (Realization).

Deactivate automatic export for Result1 and Result13. Change the simulation to a calendar time simulation with duration 10 days. Run the model and ensure that Result8_1.xls and Result8_13.txt are unchanged. Verify that the other exported files now display the simulation time in calendar time.

Now change the save location and filename of the excel file in Result2. Change the location so it is saved outside the local directory, by specifying an absolute path. Make the filename be %rundate%_%runtime%.xls. Run the model again and confirm Results8_2.xls in the local directory is the same as the newly created file with the current rundate and runtime in the filename.

Result-09 Time History Export Overflow Check

This test (Result-09_ExportOverflow.gsm) verifies that Excel correctly generates an error when the amount of data exported exceeds the number of available cells on the worksheet.

To run the test, the verifier should first run the model if it's not already in Result mode. This generates one realization of data with 100000 data points (too much data to be accommodated in the number of rows and columns in an Excel worksheet).

Go to the Excel tab in the result element and select the Save in rows option. Click the **Export Now** button. You should receive an error stating that the column number for cell FF1 is too large.

Repeat the same process but instead select the Save in columns option. Click the **Export Now** button. You should receive an error stating that the row number for cell A100002 is too large.

Result-10 Global Export Setting

This test (Result-10_GlobalExport.gsm) verifies the proper functioning global results export settings on the Results tab of the Model|Options dialog.

To run the test, ensure the simulation is in elapsed time mode and set for a duration of 10 days. In the Results tab of the Model|Options dialog, set the Automatic Export for Result Elements to "Do not export results." Delete Result10.xls if it exists in the test directory and run the model. Result10.xls should not be created. Re-enter the Results tab of the Model|Options dialog and change the Automatic Export for Result Elements drop down to "Prompt before exporting results". Re-run the model and click No when prompted to export results. Again Result10.xls should not be created. Re-run the model again, and this time, export results.

View Result10.xls and verify that the data have been correctly exported (the data exported is ETime*Realization Number in days). Expected final values for statistics are:

Mean/Median = 55
Lower bound = 10
Upper bound = 100

Change the simulation to a calendar time simulation with duration 10 days. Go back to the Results tab of the Model|Options dialog and change the Automatic Export for Result Elements drop down to "Export results after simulation." Run the model - you will be asked if you wish to overwrite the data in Result10.xls. Click Yes and verify that Result10.xls now displays the simulation time in calendar time.

Result-11 Quantile for Multiple Histories

This test verifies the correct functioning of the "Display this result if multiple histories are selected" option in the Probability Histories dialog. This setting allows users to define the quantile that should be displayed when viewing time history data.

To test this feature, the verifier should open the test file, Result-11_Time_History_Quantile.gsm. This file contains two time history elements – one that is linked to two scalar expressions, and the other linked to two elements of a vector expression. Both time histories should always produce values that start at zero, and move linearly towards the value that corresponds with the specified quantile.

The verifier should note that time histories where not all realizations are saved will differ slightly from the results calculated by the Result Distribution element (which uses the exact final values from all realizations). The verifier should note that discrepancies for predicted and plotted values are expected to be larger for quantiles more distant from the median.

The test should first be run with the Quantile set to Mean. The verifier should run the model with 1001 realizations, saving all time histories. The verifier should ensure that the mean values predicted by the Result Distribution elements correspond with the final values plotted in the corresponding Time History element. This process should be repeated with 1001 realizations saving 10 time histories, and a finally with one saved time history. The verifier should note that mean plots centered around zero with not all time histories saved may be erratic, but are acceptable as long as the largest absolute values are less than 1E-4.

The quantile should then be set to one of the pre-defined values (e.g. 50%). The model should be run with 1001 realizations, saving all time histories. The final value plotted for the time history should correspond with the value predicted for the specified quantile by the calculator in the Result Distribution element. The test should be repeated, but only 10 of the 1001 time histories should be saved. Again the predicted and plotted values should be compared. The test should then be run with a single realization, and the verifier should ensure that the graph title shows “Time History” instead of the specified quantile.

Finally the quantile should then be set to a user-defined value (e.g. 42.5%). The model should be run with 1001 realizations, saving all time histories. The final value plotted for the time history should correspond with the value predicted for the specified quantile by the calculator in the Result Distribution element. The test should be repeated, but only 10 of the 1001 time histories should be saved. Again the predicted and plotted values should be compared. The test should then be run with a single realization, and the verifier should ensure that the graph title shows “Time History” instead of the specified quantile.

Result-12 Table Format Text File Export

This test verifies the proper functioning of table format text file export in the Time History element. It consists of two test files, Result-12a_Single_Rel_Table_Export.gsm and Result-12b_Multi_Rel_Table_Export.gsm, which test table export functionality in single and multiple realization simulations. The verifier should note that the text file output is in tab-delimited format as opposed to a grid format, so column headers may not line up exactly with the corresponding data.

Single Realization Case: Result-12a_Single_Rel_Table_Export.gsm

The verifier should load the test file and ensure that Result-12_Single_Rel_Scalar.txt and Result-12_Single_Rel_Vector.txt have been deleted prior to running the test. After running the model, Result-12_Single_Rel_Scalar.txt and Result-12_Single_Rel_Vector.txt should be created, and should contain a header block (marked by exclamation points stating the source model and element information) along with the same information as the corresponding Time History elements in table view.

Multiple Realization Case: Result-12b_Multi_Rel_Table_Export.gsm

The verifier should ensure that Result-12_Multi_Scalar.txt and Result-12_Multil_Vector.txt have been deleted prior to running the test. The "Display this result if multiple histories are selected" option in the Probability Histories dialog should be set to "Mean."

The verifier should then run the model with 100 realizations, saving all time histories. The two text files should be created with the appropriate header information and the data inside should correspond directly with the data displayed in Table view in the corresponding Result element.

The model should then be rerun with only 10 of the 100 time histories saved. Again the verifier should ensure that the data in the two text files is identical to the data shown in Table view in the two Time History elements.

These tests should be repeated should then be run with the "Display this result if multiple histories are selected" option in the Probability Histories dialog set to a user-selected value other than Mean.

Result-13 Enabling/Disabling Time History Results

This test is designed to test the functioning of the Disable Time History result feature.

To perform the test, the verifier should open the Result-13_TH_Disable.gsm test file and follow these steps:

1. Open the Property dialog for Expression1. Ensure the Time History result flag is checked. Open Result1 and disable it. Return to Expression1's property dialog and ensure that the Time History result flag is unchecked.

2. Add a new Expression element. Ensure that the Time History result flag is checked. Add it as an input to Result1. Return to the new Expression's property dialog and ensure that the Time History result flag has been cleared.

3. Open the property dialog for Container1 and clear the "Enable Time Histories" checkbox. Run the model - ensure that none of the result files (Result-13_Excel.xls, Result-13_Table.txt and Result-13_Text.txt) are created in the test directory. Also ensure that none of the three Time History elements in Container1 can be opened.

4. Return to Edit mode and enter \Container1\Container2. Enable the Result4 Time History element. Go back to Container1's property dialog. The "Enable Time Histories" checkbox should now have a square inside it. Check the Enable Time Histories checkbox and run the model. The three export files should be created, and Result2,
Result3 and Result4 should be accessible in Result Mode.

Result-14 Results Inside SubModels

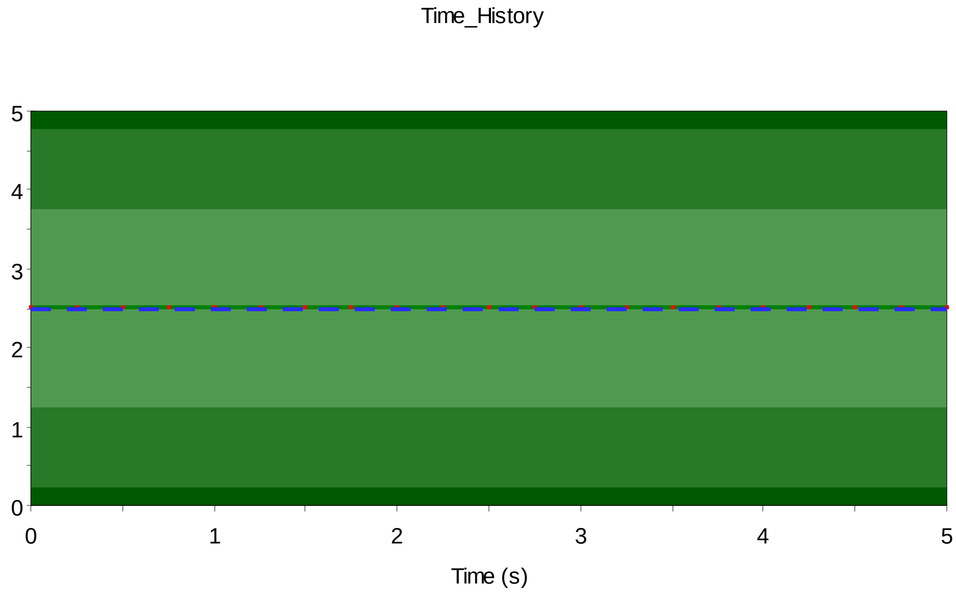
This test is designed to ensure that Result elements inside a SubModel record the appropriate values when the “Save Results from most recent Simulation” option is selected.

The test contains two SubModels – Static and Dynamic. The model should first be run with the Save Results option turned off in both SubModels. The model should run to completion without errors. Confirm that no results are saved inside the Submodels, and that result elements there behave appropriately when double-clicked.

The verifier should then run the model with the Save Results option turned on. The model should run to completion and the verifier should then check the following:

Dynamic SubModel:

Time_History: The graph of the Time History element should be as follows:



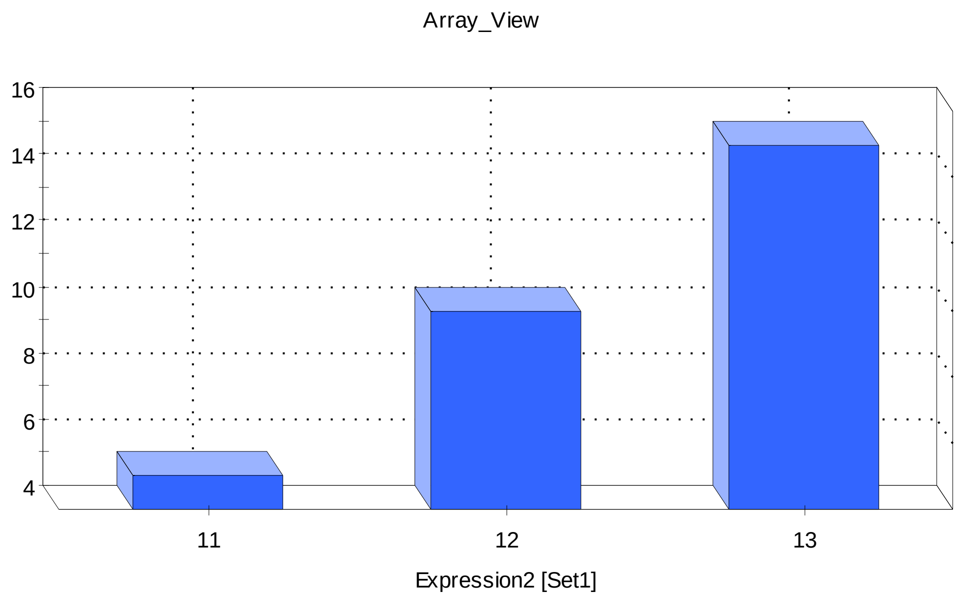
Result Distribution: Results should be uniformly distributed over the range from 0 to 5. The Result_Distribution element should also report the following statistics:

Mean: 2.5
S.D.: 1.4577
5%/95%: 2.2592/2.7408

Multivariate Element: The multivariate element should report the following values for correlations:

	Stochastic1	Stochastic2	Stochastic3
Stochastic1	1	0.5	0.8
Stochastic2	0.5	1	N/A
Stochastic3	0.8	N/A	1

Array Chart: The element should provide the following graph for Realization 101:



Static SubModel:

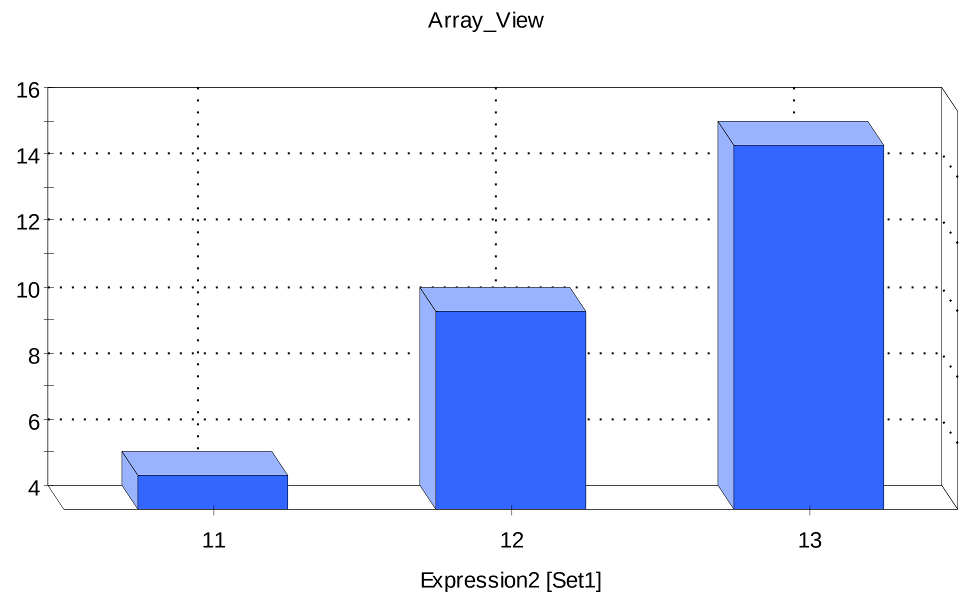
Result Distribution: Results should be uniformly distributed over the range from 0 to 5. The Result_Distribution element should also report the following statistics:

Mean: 2.5
S.D.: 1.4577
5%/95%: 2.2592/2.7408

Multivariate Element: The multivariate element should report the following values for correlations:

	Stochastic1	Stochastic2	Stochastic3
Stochastic1	1	0.5	0.8
Stochastic2	0.5	1	N/A
Stochastic3	0.8	N/A	1

Array Chart: The element should provide the following graph for Realization 101:



Result-15 Mixed Discrete and Continuous Results

This test verifies that GoldSim correctly plots mixed discrete and continuous data. The test consists of two stochastics - one is a Boolean with an equal chance of being true or false. If the Boolean stochastic is true, the result is sampled from a uniform distribution on (0,10). Otherwise the result is 5.

The verifier should run the model and ensure that GoldSim plots a spike in the data in the histogram bin that includes 5. The mean probability density elsewhere should be 0.05. CDF and CCDF plots should also be checked to ensure that the discrete behavior at 5 is captured.

Result-16 Scattered Plot Result Classification

This verification is designed to test the result classification for multi-variate scatter plots. The test contains three elements including stochastic elements that are connected to a muti-variate plot. The model runs for 100 realizations and the results are classified into 3 different classes.

The first class, Reali_LT20, contains results from the first 19 realizations (Realization_Number <20). The next class, F_LT_0, contains points from realizations where the value F is less than zero, and all the rest is labeled Other. Because F is defined S2*Sin(Realization), where S2 is randomly sampled from an interval between 0 and 1, F should be scattered randomly between -1 and 1. Therefore those 81 points which didn't pass the condition for Reali_LT20 should be approximately equally divided into F_LT_0 and Other.

To perform this test, the verifier should open the Result-16_ScatteredPlot_Result_Classification.gsm test file and follow these steps:

1. Open the Classification tab of the Malti-Variate Properties dialog and confirm the following classification categories are defined:

Legend Label	Classification Condition	Count
Real_LT20	Realization_Number < 20	n/a
F_LT_0	F < 0	n/a
Other	*all others*	n/a

2. Close the properties dialog and run the model. Open the 3D plot, and confirm the following remarks on the plot:

   a. Real_LT20 (blue) points are scattered all over the plot seen from any direction, consisting of 20 percent of all points. (Figure Result 16-1)

   b. Rotate the plot so that the label F is shown horizontally in front. Confirm that all F_LT_0 (red) points are on the left side and all Other (pink) points are on the right side of the plane F = 0. (Figure Result 16-2)

3. Right click on the plot and from the context menu choose to "Switch to 2D view." Confirm that all F_LT_0 (red) points are on the left and Other (pink) points are on the right side of the line F = 0. (Figure Result 16-3)

4. Open the result property dialog and go to the Classification tab. Make sure that there are 19 points in the first label Class1 and that the rest of 81 points are approximately equally divided into two other labels.

Now we are going to test adding a new label to the classification. The new label is going to be called S1_LT_05 and has a condition of "S1 < 0.5." Because S1 randomly samples values between 0 and 1, approximately half of examined points fall into this category.

5. Add a new label. Name the label S1_LT_05, and define the condition "S1 < 0.5" and hit enter. Make sure that the counts are automatically updated. It should show something close to 50.

6. Move the label S1_LT_05 down using the "Move Down" button until it is underneath F_LT_0. Confirm that the counts are updated. Values should be approximately as follows:

Real_LT20	Realization_Number < 20	19
F_LT_0	F < 0	41
S1_LT_05	S1 < 0.5	21
Other	*all others*	19

7. Go back to the 3D plot and confirm that points with a new color (S1_LT_05) are added.

4. CONTAMINANT TRANSPORT TESTS

Note that because the CT/RT component of GoldSim is a separate module, the user may have to use the File/Extension Modules… menu to enable it. The contaminant transport/radionuclide transport module also has its own options dialog, which is accessed through the Model/Options menu.

The verifier should note that the degree of precision to be expected when comparing the contaminant transport tests to the reference values is variable. In some cases, the reference results do not represent exact analytical values, but are the results of independent software programs that have some degree of numerical approximation.

For test cases involving Cell elements, GoldSim's algorithm should in general provide results accurate to at least 2 or 3 significant figures, depending on the timestep length and the precision setting for the model. This degree of precision should be expected of the calculated changes in values from the initial to the final states, but this precision will not necessarily occur when calculating near-zero final values. For example, if the initial condition for a problem had a concentration of 10.0, and the final value was expected to be 5.0, the result should be within three significant figures of 5.0. However, if the initial concentration was 10.0 and the final concentration was 1.0e-10, the result should only be expected to be less than 0.001.

4.1 PIPE TESTS

The GoldSim pipe element provides a powerful ability to calculate mass transport in porous/fractured media, including advection, dispersion, radionuclide chain decay, and matrix diffusion.

The test problems described in the following section fall into two distinct categories: comparison with analytical solutions, and cross-verification with published results from an independent solute transport code (PICNIC) (Barten, 1996). The cross-verification allows a greater range of features to be tested, as analytical solutions to problems incorporating diffusion and retardation in both the flowing fracture and immobile zones are rare.

The test problems were designed to test a hierarchy of transport processes represented in the Pipe element, and range in complexity from strictly one-dimensional advective-dispersive transport of a single, non-reactive solute, to cross verification of the migration of a three-member decay chain with the PICNIC code. The PICNIC tests were performed by Dr. Werner Barten of Paul Scherrer Institute (PSI).

CT_Pipes-01 : Single-porosity Test Problem

In this test the following components of the Pipe element are tested:

- basic advective dispersion algorithm
- effect of infill porosity
- effect of infill retardation
- effect of coating retardation

- effect of pipe fluid saturation
- effect of suspended particulates

This problem consists of the transport of a single stable solute (decay constant λ = 0.0) by advection and dispersion in a single-porosity domain. The pipe is 100m long, with a flow rate of 1.0 m^3/day, the pipe's flowing area, A, equals 1.0 m^2 and the longitudinal dispersivity, α, is 1.0 m. Diffusion along the flow direction is neglected. The Ogata and Banks (Ogata and Banks, 1961) analytic solution is for a Dirichlet boundary condition setting the inlet concentration to 1.0 Ci/m^3. This is a close approximation to GoldSim's constant-flux boundary condition of 1g/day, and the difference is minor and is only apparent at very early times.

A subset of the Ogata and Banks analytic results is presented in the following table:

Distance along Fracture (m)	**Time 25 days**	**Time 50 days**	**Time 75 days**
40	0.0215	0.8679	0.9986

Test problem CT_Pipes-01 contains five pipes which should each match the above table:

1. An unretarded pipe with no infill.

2. A pipe with an infill with porosity = 0.2, density = 2600kg/m^3, and partition coefficient = 0.0003076923{m3/kg}. The partition coefficient produces a retardation factor of 5, which exactly cancels the effect of the porosity.

3. A pipe one tenth as long (4m), with a coating having an effective retardation of 10 (1mm of material with density = 2500kg/m^3 and partition coefficient = 1.8{m3/kg}). This also produces a retardation factor of 5, which exactly cancels the effect of the porosity.

4. A pipe with a saturation of 0.1, and a coating thickness of 0.0001. This gives an effective retardation factor of R=10, which counteracts the effect of the saturation.

5. A pipe one half as long (20m), with a coating and suspended solids having a combined retardation factor of R=2. (Make the amount of solute dissolved/suspended equal to the amount sorbed on the coating:

$$A(1m)(1 + C_p K_d) = P(1m) t_c \rho K_d$$

where:

A	=	Flowing area, L^2
C_p	=	Concentration of suspended particulates, ML^{-3}
ρ	=	Density of the solid, ML^{-3}
K_d	=	Partition actor, L^3M^{-1}
P	=	Perimeter, L
t_c	=	Coating thickness, L

Have GoldSim solve this problem three times, using the three different precision options (low, medium and high) from the model option menu. Confirm that all solutions are within acceptable accuracy (at least two significant figures correct, with the exception of results at 100 days at low precision, which are expected to be slightly higher than analytical values at 1.008).

CT_Pipes-02: Transport of Tritium in a System of Parallel Fractures

This problem models the transport of a decaying, non-sorbing (i.e., R = 1.0) solute in a double-porosity system comprised of parallel fractures embedded in a low-permeability, low-porosity rock matrix. The solute is tritium which has a half-life of 12.35 years ($\lambda = 1.54\text{x}10^{-4}$ day^{-1}). The flow system is 50 m in length and the aperture of the parallel fractures, spaced at 0.1 m, is 100 μm. With this setting, for a gross area of 1m^2 the pipe flowing area, A, is equal to 10^{-3} m^2. The flow rate is 10^{-4} m^3/day, giving a velocity of 0.1 m/day in the fractures. The longitudinal dispersivity of the fractures, α_L, is 0.1 m. The free-solution diffusion coefficient for tritium, D^o, equals $1.38\text{x}10^{-4}$ m^2/day. The matrix porosity, θ_{im}, and tortuosity, τ, are 0.01 and 0.1, respectively. A maximum diffusion distance, d, equal to the half-spacing of the fractures (0.05m) was used.

The analytical solution (Sudicky and Frind, 1982) has a concentration fixed at 1.0g/m^3 at the inlet boundary. Again, after the early-time period this is a close approximation to GoldSim's constant mass flux of 10^{-4}g/day. Note that the extremely low dispersivity for this case results in a high Peclet number, and as a result it is necessary to increase the number of de Hoog terms to 25 (Model/Option/Mass Transport).

The following table presents the analytical solution at times of 1,000, 10,000 and 100,000 days (equal to steady state).

Distance along Fracture (m)	**Time 1,000 days**	**Time 10,000 days**	**Time 100,000 days**
50	0.0000	0.4332	0.4305[1]

CT_Pipes-03: Single Fracture with Two Diffusive Zones in Parallel

This case tests the transport of a non-decaying solute in a single 5m long fracture with two matrix immobile zones attached in parallel. The results are compared against those obtained independently by PSI using PICNIC.

The mobile fracture has a flow area of 9.3006 x 10^{-5} m^2, a velocity of 16830.7 m/yr, and a dispersion length of 0.25m. The free-water diffusivity of the solute is 2.5e^{-11}m^2/sec. The first associated slab immobile zone (MB_1) has a thickness of 6.2mm, porosity of 0.062, density of 2500kg/m^3, perimeter of 2.0m, and tortuosity of 1.0. The solute is non-sorbing in MB_1, and therefore has a partition coefficient of 0.0 m^3/kg.

The second slab immobile zone (MB_2) has a thickness of 0.5mm, a porosity of 0.062 and a tortuosity of 1.0. The partition coefficient for MB_2 is 2.232e^{-4} m^3/kg. Immobile zone 1 (MB_1)

[1] This value is approximate, due to the solution technique used in the reference. Two significant figures of accuracy is acceptable.

covers 40% of the fracture surface area, with MB_2 covering the remainder. A mass of 1g is released into the pathway as a delta function at the start of the simulation.

Time, yrs	Mass flux, g/yr
0.001	~310
0.002	~140
0.004	~51
0.01	~3.5

Note: PICNIC results may be somewhat higher than GoldSim at early times, due to their different boundary conditions. GoldSim results should match the PICNIC results to 1 – 2 significant figures.

CT_Pipes-04: Single Fracture with Two Diffusive Zones in Series

This case tests the ability of GoldSim to model two immobile zones in series. The results are again compared against those obtained independently by PSI using PICNIC.

The properties of the flowing fracture are identical to test case CT_Pipes-03. The first "skin" immobile zone adjacent to the fracture is 1mm in thickness and has the properties of MB_1. The second immobile zone is 0.5mm in thickness and has the properties of MB_2. The input to the pathway is a mass of 1g, released as a delta function at the start of the simulation.

Time, yrs	Mass flux, g/yr
0.0004	~1600
0.001	~120
0.004	~18
0.01	~9.5

Note: PICNIC results may be somewhat higher than GoldSim at early times, due to their different boundary conditions.

CT_Pipes-05: Single Fracture with Skin and Two Diffusive Zones in Parallel

This test case combines a skin diffusive zone in series with two immobile zones in parallel. The results are again compared against those obtained independently by PSI using PICNIC.

The source definition, and the parameters for the flowing fracture and the two immobile zones in parallel are identical to those in CT_Pipes-03. The skin immobile zone immediately adjacent to the fracture (MB_3) has a thickness of 1.0mm, a porosity of 0.1 and a tortuosity of 1.0. The partition coefficient for the skin is 2 x 10^{-4} m^3/kg.

Time, yrs	Mass flux, g/yr
0.001	~290
0.002	~130
0.004	~54

0.01	~19

Note: PICNIC results may be somewhat higher than GoldSim at early times, due to their different boundary conditions.

CT_Pipes-06: Single Fracture with Stagnant Zone

As there are no published solutions for pathways with stagnant zones, this example compares the GoldSim stagnant zone model to an approximate solution using a series of Cells that represent the stagnant zone explicitly.

The single pathway is 10m in length, with a total fracture area of $0.1m^2$, and a flow rate (Q) of $0.1m^3/yr$. The fraction of the area in the stagnant zone (F) is 0.6, and the transfer rate into the stagnant zone (β) is $0.5\ m^{-1}$. A mass of 1g is released into the pathway as a delta function at the start of the simulation. The dispersivity is 0.102m, equal to half the cell-length.

The replicate cell model comprises 49 cells in series to represent the flowing portion of the fracture, and a parallel row of 49 cells representing the stagnant portion of the fracture. Each "flowing" cell is attached to a stagnant zone cell via two advective connections flowing β x Q x cell length between the cells.

Expected results are shown in the table below. GoldSim results should match these to 1 – 2 significant figures.:

Approximate Solution	
Time, yrs	**Mass Flux, g/yr**
5	0.064
10	0.096
15	0.037
20	0.0081

CT_Pipes-07: Fracture with Changing Properties

This test is based on CT_Pipes-02, and tests the pipe's response to changing material properties. At a time of 10,000 days the rock matrix porosity is tripled, from 0.01 to 0.03. As a result, all mass entering the pathway after 10,000 days will have a breakthrough curve that is approximately three times more delayed, and will emerge at a significantly lower concentration due to the increased radioactive decay.

The results should show a 'mirror image' of the initial breakthrough curve starting at 10,000 days, as the original batch of input flushes out. The second batch should start to breakthrough subsequently, with a breakthrough-time approximately three times greater than the original curve, and at a reduced level due to decay.

CT_Pipes-08: Decay-chain Transport with Matrix Diffusion

This problem models the transport of a radioactive species and its daughters in a double-porosity system comprised of parallel fractures embedded in a low-permeability, low-porosity rock matrix. The aperture of the parallel fractures, spaced at 0.1 m, is 100 μm. With this setting, the pipe area for a single 1m wide fracture, *A*, is 10^{-4} m^2. The pore velocity is 100 m/yr in the fractures and the longitudinal dispersivity of the fractures, α_L, is 10 m. The matrix porosity and tortuosity are 0.01 and 0.1, respectively. A maximum diffusion distance, *d*, equal to the half-spacing of the fractures (0.05 m) was used.

This analytic comparison involves the transport of the decay chain Uranium 234 → Thorium 230 → Radium 226 in a system of parallel fractures. The matrix (i.e., immobile zone) retardation factors for U^{234}, Th^{230} and Ra^{226} were assigned values equal to 1.43×10^4, 5.00×10^4 and 5.00×10^2, respectively, and the decay constants equal 2.83×10^{-6}, 9.00×10^{-6} and 4.33×10^{-6} $year^{-1}$, respectively. For simplicity, retardation on the surfaces of the fractures (i.e., pipes) was neglected. The diffusion coefficients for each of the species, D^o, were assigned identical values equal to 3.154×10^{-2} m^2/year. A prescribed concentration of 1.0 mol/m^3 was assigned for U^{234} at the fracture inlet, and 0.0 mol/m^3 was used as the inlet concentration for Th^{230} and Ra^{226}.

The tabulated analytical results from Hodgkinson and Maul (1985) at 100,000 years, at selected distances along the pipe are shown below:

Analytical Solution for Verification Test CT_Pipes-08

Distance	**Concentration (mol/m3)**		
	U-234	Th-230	Ra-226
10	9.54E-01	1.84E-02	1.12E-02
50	6.80E-01	2.51E-02	5.79E-02
100	2.50E-01	6.39E-03	7.80E-02
200	4.27E-03	5.66E-05	7.37E-02
400	4.80E-09	0.00E+00	5.80E-02

Note: To obtain the final values for the different distances, change the value of the Length data element to each of the distances shown in the table.

CT_Pipes-09: Source Length

This files tests the "Source Length" feature of the Pipe Pathway Element. The file consists of two Pipe Pathways. Run the model to see results. The first pipe has an advective transit time of 3 seconds, and a source-zone over the first 2/3 of its length.

The breakthrough curve (accessed by clicking on the result element) should start at time 1.0, and increase linearly to a peak of 1.0 after 3.0 seconds. The concentration should drop linearly to 0 over the time range from 7 to 9 seconds. The second pipe has a source-zone twice as long as the pipe itself. Its breakthrough curve should start at time 0, increase to 0.5 after 3 seconds, and drop back to 0 starting at 6 and ending at 9 seconds.

CT_Pipes-10: Suspended Solids in Pipes

This test compares the calculated breakthrough times for three species to the expected retarded times. The model contains suspended solids and a skin, which compete for sorption of the suspended solids. The more suspended solids, the less the retardation due to the skin.

Run the model, and display the breakthrough curves in the time-history element. Compare the times when the concentration equals 0.5 to the retarded times calculated by element RetTimes, and confirm that they are within a few percent.

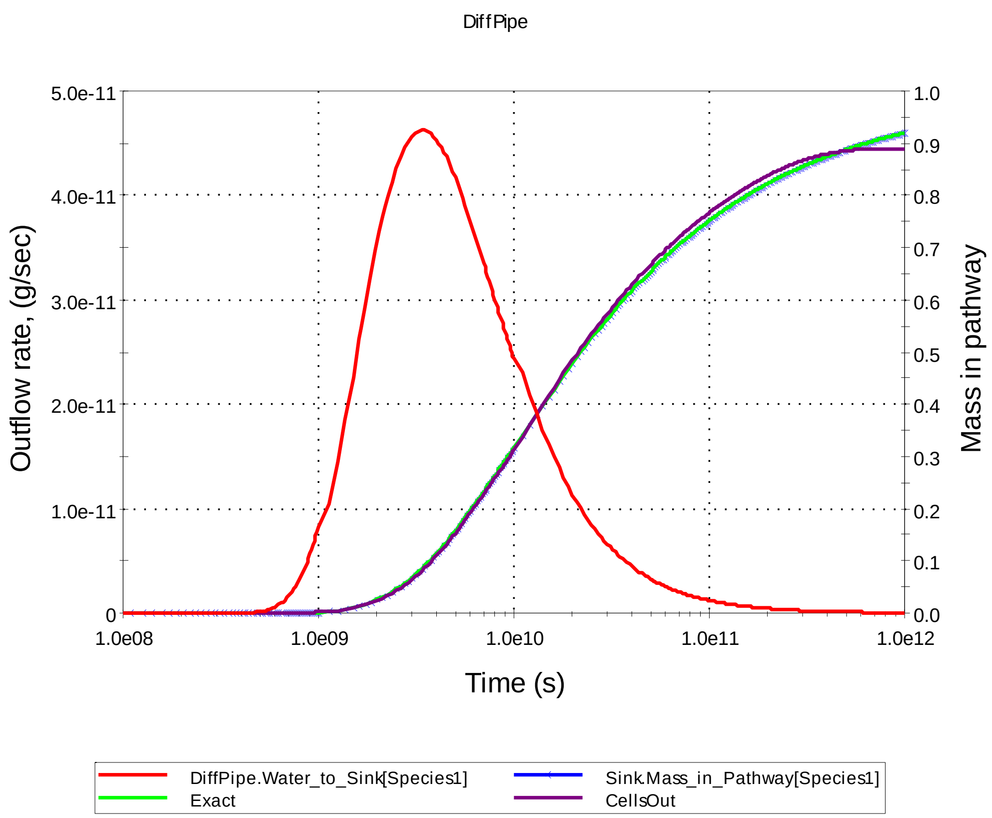
Analytical Solution for Verification Test CT_Pipes-10

Species	Median Breakthrough Time, sec
Species1	10.00
Species2	14.55
Species3	35.00

CT_Pipes-11 Longitudinal Diffusion in Pipes

This test has a negligible advective flow rate through a Pipe element. The user should confirm that the cumulative discharge to the Sink Cell matches the analytical solution. Note that the system of Cells is only present for comparison purposes, and is not expected to match the exact result closely. Also note that the calculated concentration leaving the Pipe element is not expected to be realistic, as it is simply set equal to the mass outflux rate divided by the water flow rate.

The plot element should show results similar to the following figure:



4.2 CELL TESTS

These test problems are specifically targeted at verifying the mixing cell algorithm. With one exception, rather than using Source Terms, mass is entered into the system by specifying an initial condition in one or more cells. All problems in this group are run without radioactive decay. With one exception, a 100 year timestep is used for these problems.

Solutions which cannot be readily computed analytically (e.g., coupled sets of differential equations) were solved using the commercially available program MATLAB® (Math Works Inc.). MATLAB® is a mathematical analysis program that can be used to solve complex matrix equations.

The default for all of the Cell tests is to run with high accuracy and the family-by-family solution option. Test CT_Cells5-03 specifically tests the medium and low accuracy options.

CT_Cells1 - Partitioning and Media Concentrations

These problems verify the correct partitioning of mass within a cell and the calculation of concentrations. One cell is defined, with no connections, and an initial mass inventory with 100 Ci each of Am-241, Am-242, and Am-243.

Expected concentrations for these tests (and other tests in this section) are computed as follows:

$$c_{ims} = P_{ime}\, M_{is} W_s$$

where:

$$P_{ime} = \frac{K_{mre}}{\sum_{g=1}^{NM_i} K_{gre} \cdot AM_{ig}}$$

and:

M_{is}	=	moles of species s in cell i;
W_s	=	atomic weight of species s;
K_{mre}	=	partition coefficient between medium m and reference fluid r for element e (where species s is an isotope of element e) [(L3 reference fluid r)/(L3 fluid m)] or [(L3 reference fluid r/M solid m];
K_{gre}	=	partition coefficient between medium g and reference fluid r for element e (where species s is an isotope of element e) [(L3 medium r)/(L3 fluid g)] or [(L3 medium 1/M solid g];
AM_{ig}	=	amount of medium m in cell i [L3 fluid m] or [M solid g]; and
NM_i	=	the number of media in cell i.

The total amount of moles of an element that cell i can hold when the reference fluid is saturated can be computed as follows:

$$Msat_{ie} = cmax_{re} \sum_{m=1}^{NM_i} K_{mre} \cdot AM_{im} = \frac{cmax_{re}}{P_{ire}}$$

where $cmax_{re}$ is the molar solubility of element e in reference fluid r.

If the sum of the moles of all of the isotopes of element e (Mt_{ie}) does not exceed $Msat_{ie}$, the equation shown above can be used to compute concentrations.

If, however, Mt_{ie} exceeds $Msat_{ie}$, it implies that mass has precipitated out of the system, and the concentrations must be computed as follows:

$$c_{ims} = c_{ims,\,ds} + c_{ims,\,p}$$

where

$$c_{ims,\,ds} = \left(\frac{M_{is}}{Mt_{ie}}\right)\left[P_{ime} \cdot Msat_{ie}\right]$$

$$c_{ims,\,p} = \left(\frac{M_{is}}{Mt_{ie}}\right)\left[P'_{ime} \cdot (Mt_{ie} - Msat_{ie})\right]$$

and

$c_{ims,ds}$	=	the dissolved (for fluids) or sorbed (for solids) concentration of species s in medium m within cell i [M/L3 or M/M];
$c_{ims,p}$	=	the precipitated concentration of species s in medium m within cell i [M/L3];
W_S	=	atomic weight of species s;

$$P'_{ime} = \frac{1}{\sum_{g=1;\, g \neq fluid}^{NM_i} AM_{ig}} \qquad \text{(if m is a non-suspended solid);}$$

$$P'_{ime} = 0 \qquad \text{(if m is a fluid)}$$

Hence, $c_{ims,p}$ is zero if m is a fluid.

The P'_{ime} operator partitions precipitated mass among the solids present in the cell based on their masses (i.e., the concentration of precipitated mass in each solid is the same).

Note that when suspended particulates are present, the *effective* concentration in a fluid is computed as follows:

$$ce_{ims} = c_{ims} + \sum_{t=1}^{NPT_{im}} c_{it,\,ds} \cdot cp_{imt}$$

where:

c_{ims}	=	the dissolved concentration of species s in fluid m within cell i [M/L3];
NPT_{im}	=	the number of solid media suspended in fluid m within cell i;
$c_{it,ds}$	=	the sorbed concentration of species s in solid medium t within cell i [M/M]; and
cp_{imt}	=	the concentration of solid particulate t within fluid m in cell i [M/L3].

Hence, particulates are only assumed to carry sorbed contaminant. Precipitated contaminant does not move with particulates.

CT_Cells1-01 - Partitioning Between Two Fluids and Two Solids in a Cell

A single cell is assigned two fluid media (WATER, the reference, and OIL) and two solid media (SAND and CLAY). The initial inventory of the cell contains 100 Ci each of Am-241, Am-242 and Am-243, input as 29.09g, 10.27g, and 500.8g respectively. The solubility of Am in WATER is unlimited.

The volume, masses and partition coefficients for the media are listed below:

Medium	Volume (m^3) or Mass (kg)	Partition Coefficient relative to WATER (m^3/m^3) for fluids; (m^3/kg) for solids
WATER	10	1
OIL	5	0.1
SAND	10	0.2
CLAY	20	5

Using the equations presented above, the constant concentrations in each of the media are as follows:

Medium	Am-241 (g/m^3) or (g/kg)	Am-242 (g/m^3) or (g/kg)	Am-243 (g/m3) or (g/kg)
WATER	2.586E-1	9.131E-2	4.451E+0
OIL	2.586E-2	9.131E-3	4.451E-1
SAND	5.172E-2	1.826E-2	8.902E-1
CLAY	1.293E+0	4.565E-1	2.226E+1

CT_Cells1-02 - Partitioning Between Fluids and Solids in a Cell, 0 Partition Coefficient for One Solid

This problem is identical to CT_Cells1-01, except the partition coefficient for CLAY is specified as zero. The volume, masses and partition coefficients for the media are listed below:

Medium	Volume (m^3) or Mass (kg)	Partition Coefficient relative to WATER (m^3/m^3) for fluids; (m^3/kg) for solids
WATER	10	1
OIL	5	0.1
SAND	10	0.2
CLAY	20	0

Using the equations presented above, the constant concentrations in each of the media are as follows:

Medium	Am-241 (g/m^3) or (g/kg)	Am-242 (g/m^3) or (g/kg)	Am-243 (g/m3) or (g/kg)
WATER	2.327E+0	8.217E-1	4.006E+1
OIL	2.327E-1	8.217E-2	4.006E+0
SAND	4.655E-1	1.643E-1	8.022E+0
CLAY	0	0	0

CT_Cells1-03 - Partitioning Between Fluids and Solids in a Cell, Solubility Limit Exceeded

This problem is identical to CT_Cells1-01, except the solubility limit is exceeded for Am (the solubility limited being specified as 0.25 g/m^3).

Using the equations presented above, the constant concentrations in each of the media are as follows:

Medium	Am-241 (g/m^3) or (g/kg)	Am-242 (g/m^3) or (g/kg)	Am-243 (g/m3) or (g/kg)
WATER	1.357E-2	4.791E-3	2.336E-1
OIL	1.357E-3	4.791E-4	2.336E-2
SAND	9.216E-1	3.254E-1	1.586E+1
CLAY	9.867E-1	3.484E-1	1.698E+1

CT_Cells1-04 - Partitioning Between Fluids and Solids in a Cell with Suspended Particulates

This problem is identical to CT_Cells1-01, except that a portion of each of the two solids is suspended in each of the two fluids. The suspended solid concentrations are listed below:

Solid	Concentration in WATER (kg/m^3)
SAND	0.2
CLAY	0.02

Using the equations presented above, the constant *effective* concentrations in each of the media are as follows:

Medium	Am-241 (g/m^3) or (g/kg)	Am-242 (g/m^3) or (g/kg)	Am-243 (g/m3) or (g/kg)
WATER	2.948E-1	1.041E-1	5.074E+0
OIL	2.586E-2	9.131E-3	4.451E-1
SAND	5.172E-2	1.826E-2	8.902E-1
CLAY	1.293E+0	4.565E-1	2.226E+1

CT_Cells1-05 - Partitioning between Fluids and Solids in a Cell with Solubility Limit and Suspended Particulates

This problem is identical to CT_Cells1-04, except that the solubility limit defined in CT_Cells1-03 is imposed. Note that when a solubility limit is exceeded, precipitated species are assumed to 'plate out' only onto solids, and not onto suspended (particulate) solids.

Using the equations presented above, the constant effective concentrations in each of the media are as follows:

Medium	Am-241 (g/m^3) or (g/kg)	Am-242 (g/m^3) or (g/kg)	Am-243 (g/m3) or (g/kg)
WATER	1.547E-2	5.462E-3	2.663E-1
OIL	1.357E-3	4.791E-4	2.336E-2
SAND	9.943E-1	3.511E-1	1.711E+1
CLAY	1.059E+0	3.741E-1	1.824E+1

CT_Cells1-06 - Concentration in a Cell, Solubility Limit Exceeded, One Medium

This problem is identical to CT_Cells1-03 except the only medium present in the cell is WATER.

Using the equations presented above, the constant concentrations in WATER are as follows:

Medium	Am-241 (g/m^3)	Am-242 (g/m^3)	Am-243 (g/m3)
WATER	1.357E-2	4.791E-3	2.336E-1

CT_Cells1-07 - Partitioning Between Fluids and Solids in a Cell with Solubility Limits, Suspended Particulates, and Inaccessible Porosity

This problem is similar to CT_Cells-05, except that part of the porosity in both of the solids is inaccessible, and a number of the input values have been modified. Since the dissolved species cannot access the inaccessible pore spaces, this effectively reduces the amount of fluids in the cell.

If the user specifies an available porosity for an element in a solid to be less than 1, the effective volume of fluid for that element in a cell containing that solid is reduced (and AM becomes element specific). In particular, for fluids, AM^{*}_{ige} is computed as follows:

$$AM^{*}_{ige} = VR_{ie} \cdot AM_{ig} = \left\{ \frac{\sum_{h=1;\,h=fluid}^{NM_i} AM_{ih} - \left[\sum_{h=1;\,h=solid}^{NM_i} AM_{ih} \frac{n_h}{DD_h} (1 - f_{he}) \right]}{\sum_{h=1;\,h=fluid}^{NM_i} AM_{ih}} \right\} AM_{ig}$$

where:

VR_{ie}	=	the volume reduction factor for element e for fluids in cell i;
AM_{ig}	=	the actual amount of medium g in cell i [m^3fluid] or [kg solid];
n_h	=	the porosity of solid h;
DD_h	=	the dry density of solid h [kg/ m^3]; and
f_{he}	=	is the fraction of accessible porosity for element e in solid h.

In this problem, the actual media quantities are 10 m^3 WATER, 5 m^3 OIL, 50,000 kg SAND, and 20,000 kg CLAY. The K_d for sand is 2E-5 m^3/kg, and the K_d for CLAY is 5E-5 m^3/kg. The solubility of Am has been reduced to 2.5E-4. The concentration of suspended SAND is 2000 kg/m^3 in WATER. The concentration of suspended CLAY is 200 kg/m^3 in WATER. SAND is assigned a porosity of .25, and a dry density of 2000 kg/m^3. CLAY is assigned a porosity of .4, and a dry density of 2500 kg/m^3. The element of interest in this problem (Am) has an accessible porosity of 90% in SAND and 50% in CLAY. Using the equation presented above, this results in a effective volume factor for Am for the fluids in the cell of 0.85167.

Using the equations presented previously, the constant effective concentrations in each of the media are as follows:

Medium	**Am-241 (g/m^3) or (g/kg)**	**Am-242 (g/m^3) or (g/kg)**	**Am-243 (g/m^3) or (g/kg)**
WATER	1.425E-5	5.031E-6	2.453E-4
OIL	1.357E-6	4.791E-7	2.336E-5
SAND	6.061E-4	2.140E-4	1.043E-2
CLAY	6.061E-4	2.140E-4	1.043E-2

CT_Cells1-08 – Fixed Concentration Boundary Conditions

This tests cells that have fixed concentration boundary conditions. The test has two parts. The first tests advective connections from a cell with a fixed concentration, and the second tests diffusive connections from a cell with a fixed concentration boundary condition.

The advective test compares the results of two cells in series to a reservoir element that integrates an advective flux. The diffusive flux test has two cells with a diffusive connection and, to simulate a fixed concentration in one cell, a discrete change element is used to replace any mass that leaves the cell on each time step. As the time step approaches zero the difference between the two sets of diffusive cells should approach zero.

The tester should run the model. Then the tester should enter the Fixed_Concentration_Diffusive container and confirm the result graph looks like the image pasted beside it. The tester should also enter the fixed_Concentration_Advective container and confirm the Max_difference elment is near zero (< 1e-6 g).

CT_Cells2 - Advective Connections from Cells

These problems test simple advective connections from cells. For these problems, one or more advective connections *from* the cell to a sink are defined with non-zero flows. For problems in which decay is turned off, the total mass in the cell is governed by the following equation:

$$M_{is} = \sum_{c=1}^{NC_i} f_{cs}$$

where:

M_{is}	=	rate of increase of species s in cell i [M/t];
NC_i	=	number of mass transfer connections for cell i; and
f_{cs}	=	influx rate of species s (into cell i) through connection c [M/t].

Note that for an advective connection from cell i, f_{cs} is defined as follows:

$$f_{cs} = -(c_{ims} + \sum_{t=1}^{NPT_{im}} c_{its,\,ds} \cdot cp_{imt})q_c$$

where:

q_c	=	the rate of advection for connection c [L3/t for fluid connections and M/t for solid connections];
c_{ims}	=	the concentration of species s in medium m within cell i [M/L3 if m is a fluid; M/M if m is a solid];
NPT_{im}	=	the number of solid media suspended in medium m within cell i;
cits,ds	=	the sorbed concentration of species s in solid medium t within cell i [M/M];
cp_{imt}	=	the concentration of solid particulate t within fluid m in cell i [M/L3];

Note that by definition, q_c cannot be a negative number.

The second term accounts for the advection of suspended solids in a fluid. Note that for solid advective connections, the second term is not applicable (i.e., $NPT_{im} = 0$).

The manner is which the concentrations (e.g., c_{ims}, c_{its}) are computed for each species in every medium in a cell was discussed above in Section 5.7.1.

CT_Cells1 -08 – Cells with Fixed Concentrations

This model tests cells with fixed concentration boundary conditions. There are two tests in this model. The tester should run the model and confirm the Max_Difference element in the Fixed_Concentration_Advective container is near zero (<1e-6 g) and that the plot in the Fixed_Concentration_Diffusive container matches the image pasted beside it.

In the Fixed_Concentration_Advective test, water advects from a cell with a fixed concentration to a sink. A reservoir is used to integrate the mass loading rate over time as verification. The two methods should be identical (Max_Difference < 1e-6 g)..

In the Fixed_Concentration_Diffusive test, a cell with a fixed concentration has a diffusive connection to a sink cell (Sink2). A second pair of cells is set up to emulate these calculations. In the second set, there is a diffusive connection, but a fixed concentration boundary condition is emulated by simplying replacing the amount of mass that diffused to the sink cell (Sink3) on the previous time step. The differences between Sink2 and Sink3 should approach zero as the timestep length approaches zero.

CT_Cells2 -01 - Simple Fluid Advection

This problem is identical to CT_Cells1-01, except a second cell is added, with an advective connection between the two cells. The second cell contains only WATER, and the flow rate (QW) from the first cell to the second cell is 0.1 m^3/yr.

For a cell with only one advective connection and no decay, the governing equation is:

$$M_{is} = -c_{ims} * QW$$

Substituting for c_{ims}, and recalling that in this case m is WATER, the above equation becomes:

$$M_{is} = -(QW*P_{i,WATER,e})\, m_{is}$$

The solution to this equation is

$$m_{is} = m^o_{is} \exp-\{(QW*P_{i,WATER,e})\, t\}$$

Given the total mass in the cell as a function of time, the mass flux from the cell and the concentration in each medium can be readily computed as discussed in the previous section. The analytical solution is presented in the following table. Note that Results are not expected to match the very small exact results at time 10,000 with high precision.

Medium	**Am-241 (g/m^3) or (g/kg)**	**Am-242 (g/m^3) or (g/kg)**	**Am-243 (g/m^3) or (g/kg)**
WATER			
time = 100	2.37E-1	8.37E-2	4.07
time = 1000	1.06E-1	3.75E-2	1.83
time = 10,000	3.57E-5	1.26E-5	6.14E-4
OIL			
time = 100	2.37E-2	8.37E-3	4.07E-1
time = 1000	1.06E-2	3.75E-3	1.83E-1
time = 10,000	3.57E-6	1.26E-6	6.14E-5
SAND			
time = 100	4.73E-2	1.67E-2	8.15E-1
time = 1000	2.13E-2	7.51E-3	3.66E-1
time = 10,000	7.13E-6	2.52E-6	1.23E-4
CLAY			
time = 100	1.18	4.18E-1	2.04E+1

time = 1000	5.32E-1	1.88E-1	9.15
time = 10,000	1.78E-4	6.30E-5	3.07E-3

CT_Cells2 -02 - Fluid Advection with Multiple Connections

This problem is identical to CT_Cells2-01, except that three connections involving WATER, OIL and SAND are defined for the cell, with flow rates of QW (0.02 m^3/yr), QO (0.3 m^3/yr), and QS (0.25 kg/yr), respectively. Allowing for the partition factors, these media carry the same amount of Am as the water in CT_Cells2-01.

The governing equation becomes:

$$M_{is} = - \Sigma\, C_{ims} * Q_m$$

Since $\Sigma\, C_{ims} * Q_m$ = QW (as defined in the previous problem), the results should be identical to CT_Cells2-01. . Note that Results are not expected to match the very small exact results at time 10,000 with high precision

CT_Cells2 -03 - Fluid Advection with Solubility Constraint

This problem is identical to CT_Cells2-01, except that the solubility limit is exceeded for Am (the solubility limited being specified as 0.25 g/m^3). The solubility and flow rates are low enough such that the cell is always saturated. The rate of advection for water is reduced to 0.02 m^3/yr.

The governing equation is:

$$M_{is} = -c_{i,WATER,s}\ QW$$

Substituting for the concentration terms, and recalling that solubility limit is exceeded, the above equation becomes:

$$M_{is} = -(QW * P_{i,WATER,e} * msat_{ie}\ )\ m_{is} / mt_{ie}$$

Writing this in terms of the three species, the system of equations is:

$$M_{i1} = -QW\ [P_{i,WATER,e} * msat_{ie}]\ (m_{i1} / mt_{ie})$$

$$M_{i2} = -QW\ [P_{i,WATER,e} * msat_{ie}]\ (m_{i2} / mt_{ie})$$

$$M_{i3} = -QW\ [P_{i,WATER,e} * msat_{ie}]\ (m_{i3} / mt_{ie})$$

$$mt_{ie} = m_{i1} + m_{i2} + m_{i3}$$

The solution (using MATLAB) is as follows:

Medium	Am-241 (g/m^3) or (g/kg)	Am-242 (g/m^3) or (g/kg)	Am-243 (g/m^3) or (g/kg)
WATER			
time = 100	1.35E-2	4.75E-3	2.32E-1
time = 1000	1.35E-2	4.75E-3	2.32E-1
time = 10,000	1.35E-2	4.75E-3	2.32E-1
OIL			
time = 100	1.35E-3	4.75E-4	2.32E-2
time = 1000	1.35E-3	4.75E-4	2.32E-2
time = 10,000	1.35E-3	4.75E-4	2.32E-2
SAND			
time = 100	9.21E-1	3.25E-1	1.59E+1
time = 1000	9.13E-1	3.22E-1	1.57E+1
time = 10,000	8.32E-1	2.94E-1	1.43E+1
CLAY			
time = 100	9.86E-1	3.48E-1	1.70E+1
time = 1000	9.78E-1	3.45E-1	1.68E+1
time = 10,000	8.97E-1	3.17E-1	1.54E+1

Note: the MATLAB solution assumes that the mass (not molar) solubility is identical for all three isotopes. This creates a small error in the calculated results, of less than 1%. The verifier should therefore accept a small difference between GoldSim's results and the MATLAB results reported above.

CT_Cells2 -04 - Fluid Advection with Particulates

This problem is identical to CT_Cells2-01, except a portion of each of the two solids is suspended in WATER.

Solid	Concentration in WATER (kg/m^3)
SAND	0.1
CLAY	0.01

The governing equation is:

$$M_{is} = -[c_{i,WATER,s} + (c_{i,SAND,s} * cp_{i,WATER,SAND}) + (c_{i,CLAY,s} * cp_{i,WATER,CLAY})]\ QW$$

Substituting for the concentration terms, the above equation becomes:

$$M_{is} = -QW\ [P_{i,WATER,e} + (P_{i,SAND,e} * cp_{i,WATER,SAND}) + (P_{i,CLAY,e} * cp_{i,WATER,CLAY})]\ m_{is}$$

The solution to this equation is:

$$m_{is} = m^{o}_{is} \exp\text{-}\{\ QW\ [P_{i,WATER,e} + (P_{i,SAND,e} * cp_{i,WATER,SAND}) + (P_{i,CLAY,e} * cp_{i,WATER,CLAY})]\ t\}$$

Given the total mass in the cell as a function of time, the mass flux from the cell and the concentration in each media can be readily computed as discussed in the previous section. The analytical solution is as follows:

Medium	Am-241 (g/m^3) or (g/kg)	Am-242 (g/m^3) or (g/kg)	Am-243 (g/m^3) or (g/kg)
WATER			
time = 100	2.52E-1	8.88E-2	4.33
time = 1000	1.07E-1	3.77E-2	1.84
time = 10,000	2.05E-5	7.23E-6	3.53E-4
OIL			
time = 100	2.35e-2	8.30E-3	4.05E-1
time = 1000	9.99E-3	3.53E-3	1.72E-1
time = 10,000	1.91E-6	6.76E-7	3.30E-5
SAND			
time = 100	4.70E-2	1.66E-2	8.10E-1
time = 1000	2.00E-2	7.05E-3	3.44E-1
time = 10,000	3.83E-6	1.35E-6	6.59E-5
CLAY			
time = 100	1.18	4.51e-1	2.02E+1
time = 1000	5.00E-1	1.76E-1	8.60
time = 10,000	9.57E-5	3.38E-5	1.65E-3

CT_Cells2 -05 - Fluid Advection with Particulates and Solubility Constraint

This problem is identical to CT_Cells2-01, except that the solubility limit is exceeded for Am (the solubility limited being specified as 0.25 g/m^3) and a portion of the SAND and CLAY is suspended in WATER (0.1 kg/m^3 SAND and 0.01 kg/m^3 CLAY). The advective flow rate for water is reduced to 0.05 m^3/yr.

The governing equation is:

$$M_{is} = -[c_{i,WATER,s} + (c_{i,SAND,s} * cp_{i,WATER,SAND}) + (c_{i,CLAY,s} * cp_{i,WATER,CLAY})] QW$$

Substituting for the concentration terms, and recalling that solubility limit is exceeded, the above equation becomes:

$$M_{is} = - QW\{[P_{i,WATER,e} * msat_{ie}] + cp_{i,WATER,SAND} * [P_{i,SAND,e} * msat_{ie}] + cp_{i,WATER,CLAY} * [P_{i,CLAY,e} * msat_{ie}]\}(m_{is} / mt_{ie})$$

Writing this in terms of the three species, the system of equations is:

$$M_{i1} = - QW\{[P_{i,WATER,e} * msat_{ie}] + cp_{i,WATER,SAND} * [P_{i,SAND,e} * msat_{ie}] + cp_{i,WATER,CLAY} * [P_{i,CLAY,e} * msat_{ie}]\}(m_{i1} / mt_{ie})$$

$$M_{i2} = - QW\{[P_{i,WATER,e} * msat_{ie}] + cp_{i,WATER,SAND} * [P_{i,SAND,e} * msat_{ie}] + cp_{i,WATER,CLAY} * [P_{i,CLAY,e} * msat_{ie}]\}(m_{i2} / mt_{ie})$$

$M_{i3} =$ $- QW\{[P_{i,WATER,e} * msat_{ie}]$

$+ cp_{i,WATER,SAND*}[P_{i,SAND,e} * msat_{ie}] + cp_{i,WATER,CLAY*}[P_{i,CLAY,e} * msat_{ie}]\}(m_{i3} / mt_{ie})$

$mt_{ie} = m_{i1} + m_{i2} + m_{i3}$

The solution (solved using MATLAB) is as follows:

Medium	Am-241 (g/m^3) or (g/kg)	Am-242 (g/m^3) or (g/kg)	Am-243 (g/m^3) or (g/kg)
WATER			
time = 100	1.44E-2	5.09E-3	2.48E-1
time = 1000	1.44E-2	5.09E-3	2.48E-1
time = 10,000	1.44E-2	5.09E-3	2.48E-1
OIL			
time = 100	1.35E-3	4.75E-4	2.32E-2
time = 1000	1.35E-3	4.75E-4	2.32E-2
time = 10,000	1.35E-3	4.75E-4	2.32E-2
SAND			
time = 100	9.54E-1	3.37E-1	1.64E+1
time = 1000	9.32E-1	3.29E-1	1.60E+1
time = 10,000	7.08E-1	2.50E-1	1.22E+1
CLAY			
time = 100	1.019	3.60E-1	1.75E+1
time = 1000	9.97E-1	3.52E-1	1.72E+1
time = 10,000	7.72E-1	2.73E-1	1.33E+1

Note: the MATLAB solution assumes that the mass (not molar) solubility is identical for all three isotopes. This creates a small error in the calculated results, of less than 1%. The verifier should therefore accept a small difference between GoldSim's results and the MATLAB results reported above.

CT_Cells2 -06 - Simple Solid Advection

This problem is identical to CT_Cells2-01, except the solid SAND is being advected, rather than WATER.

The flow rate of sand (QS) from the first cell to the second cell is 0.05 kg/yr.

For a cell with only one advective connection and no decay, the governing equation is:

$$M_{is} = -c_{ims} * QS$$

Substituting for c_{ims}, and recalling that in this case m is SAND, the above equation becomes:

$$M_{is} = -(QS*P_{i,SAND,e})\, m_{is}$$

The solution to this equation is

$$m_{is} = m^{o}_{is} \exp-\{(QS*P_{i,SAND,e})\, t\}$$

Given the total mass in the cell as a function of time, the mass flux from the cell and the concentration in each media can be readily computed as discussed in the previous section. The analytical solution is as follows:

Medium	Am-241 (g/m^3) or (g/kg)	Am-242 (g/m^3) or (g/kg)	Am-243 (g/m^3) or (g/kg)
WATER			
time = 100	2.56E-1	9.05E-2	4.41
time = 1000	2.37E-1	8.35E-2	4.07
time = 10,000	1.06E-1	3.75E-2	1.83
OIL			
time = 100	2.56E-2	9.05E-3	4.41E-1
time = 1000	2.37E-2	8.35E-3	4.07E-1
time = 10,000	1.06E-2	3.75E-3	1.83E-1
SAND			
time = 100	5.13E-2	1.81E-2	8.82E-1
time = 1000	4.73E-2	1.67E-2	8.15E-1
time = 10,000	2.13E-2	7.51E-3	3.66E-1
CLAY			
time = 100	1.28	4.25E-1	2.21E+1
time = 1000	1.18	4.18E-1	2.04E+1
time = 10,000	5.32E-1	1.88E-1	9.15

CT_Cells2 -07 - Advection with Multiple Connections from Different Media

This problem is identical to CT_Cells1-01, except an advective connection from the cell exists for all four media (WATER, OIL, SAND, and CLAY). The WATER flow rate is QW (0.1 m^3/yr), OIL flow rate is QO (0.05 m^3/yr), the SAND flow rate is QS (0.05 kg/yr) and the CLAY flow rate is QC (0.20 kg/yr). .

The governing equation is:

$$M_{is} = -c_{i,WATER,s} * QW - c_{i,OIL,s} * QO - c_{i,SAND,s} * QS - c_{i,CLAY,s} * QC$$

Substituting for the concentrations, the above equation becomes:

$$M_{is} = -(QW * P_{i,WATER,e} + QO * P_{i,OIL,e} + QS * P_{i,SAND,e} + QC * P_{i,CLAY,e})\, m_{is}$$

The solution to this equation is:

$$m_{is} = m^o_{is} \exp\text{-}\{(QW * P_{i,WATER,e} + QO * P_{i,OIL,e} + QS * P_{i,SAND,e} + QC * P_{i,CLAY,e})\, t\}$$

Given the total mass in the cell as a function of time, the mass flux from the cell and the concentration in each media can be readily computed as discussed in the previous section. The analytical solution is shown in the following table. Note that Results are not expected to match the very small exact results at time 10,000 with high precision.

Medium	Am-241 (g/m^3) or (g/kg)	Am-242 (g/m^3) or (g/kg)	Am-243 (g/m^3) or (g/kg)
WATER			
time = 100	9.60E-2	3.39E-2	1.65
time = 1000	1.28E-5	4.53E-6	2.21E-4
time = 10,000	<1E-40	<1E-40	<1E-40
OIL			
time = 100	9.60E-3	3.39E-3	1.65E-1
time = 1000	1.28E-6	4.53E-7	2.21E-5
time = 10,000	<1E-40	<1E-40	<1E-40
SAND			
time = 100	1.92E-2	6.78E-3	3.30E-1
time = 1000	2.57E-6	9.06E-7	4.42E-5
time = 10,000	<1E-40	<1E-40	<1E-40
CLAY			
time = 100	4.80E-1	1.69E-1	8.26
time = 1000	6.42E-5	2.27E-5	1.10E-3
time = 10,000	<1E-40	<1E-40	<1E-40

CT_Cells2 -08 - Fluid Advection with Particulates into a Pipe Pathway

This problem is identical to CT_Cells2-04, except that the cell is connected to a pathway.

The governing equation is:

$$M_{is} = -[c_{i,WATER,s} + (c_{i,SAND,s} * cp_{i,WATER,SAND}) + (c_{i,CLAY,s} * cp_{i,WATER,CLAY})]\ QW$$

The solution for the cell concentrations and fluxes is identical to CT_Cells2-04.

Additional test: The test problem has an expression called TotalMass that computes the sum of the mass in the original cell plus the mass in the Sink downstream of the pipe pathway. Confirm that all of the mass that originates in the original cell ends up in the sink, by checking that the mass in TotalMass at the end of the simulation equals the amount at the beginning of the simulation.

CT_Cells2 -09 - Fluid Advection with Solubility Constraint; Concentration Drops Below Solubility

This problem is similar to CT_Cells2-04, except that the solubility and flow rate are specified such that after a certain time period, the solubility constraint is no longer exceeded in the cell. The second cell is dimensioned such that the solubility limit is exceeded in the receiving cell at some time after the first cell has dropped below the limit.

The initial mass of each species in the first cell is 10 Ci and the advective flow rate of WATER is 0.2 m^3/year. The quantities of media in the second cell are 1.2 times larger than in the first cell.

For cell 1, the governing equation is:

$M_{1s} = -c_{1,WATER,s}\ QW1$

For cell 2, the governing equation is:

$M_{2s} = c_{1,WATER,s}\ QW1$

This results in a non-linear set of equations (solved by MATLAB). The solution is as follows:

Cell 1

Medium	Am-241 (g/m^3) or (g/kg)	Am-242 (g/m^3) or (g/kg)	Am-243 (g/m^3) or (g/kg)
WATER			
time = 10	1.35E-2	4.75E-3	2.32E-1
time = 100	1.35E-2	4.75E-3	2.32E-1
time = 500	1.35E-2	4.75E-3	2.32E-1
time = 1000	5.71E-3	2.02E-3	9.83E-2

Sink

Medium	Am-241 (g/m^3) or (g/kg)	Am-242 (g/m^3) or (g/kg)	Am-243 (g/m^3) or (g/kg)
WATER			
time = 10	1.99E-4	7.04E-5	3.43E-3
time = 100	2.00E-3	7.04E-4	3.43E-2
time = 500	9.98E-3	3.52E-3	1.72E-1
time = 1000	1.35E-2	4.75E-3	2.32E-1

Note: the MATLAB solution assumes that the mass (not molar) solubility is identical for all three isotopes. This creates a small error in the calculated results, of less than 1%. The verifier should therefore accept a small difference between GoldSim's results and the MATLAB results reported above.

CT_Cells2-10 - Solid Advection with Solubility Constraint

This problem is identical to CT_Cells2-07, except that the solubility limit is exceeded for Am (the solubility limited being specified as 0.25 g/m^3). The solubility and flow rates are low enough such that the cell is always saturated. The rate of advection for SAND is reduced to 0.01 kg/yr.

The governing equation is:

$M_{is} = -c_{i,SAND,s}\ QS$

Substituting for the concentration terms, and recalling that solubility limit is exceeded, the above equation becomes:

$$M_{is} = -QS\,[\,P_{i,SAND,e} * msat_{ie} + P'_{i,SAND,e}\,(mt_{ie} - msat_{ie})]\,m_{is} / mt_{ie}$$

Writing this in terms of the three species, the system of equations is:

$$M_{i1} = -QS\,[\,P_{i,SAND,e} * msat_{ie} + P'_{i,SAND,e}\,(mt_{ie} - msat_{ie})]\,m_{i1} / mt_{ie}$$

$$M_{i2} = -QS\,[\,P_{i,SAND,e} * msat_{ie} + P'_{i,SAND,e}\,(mt_{ie} - msat_{ie})]\,m_{i2} / mt_{ie}$$

$$M_{i3} = -QS\,[\,P_{i,SAND,e} * msat_{ie} + P'_{i,SAND,e}\,(mt_{ie} - msat_{ie})]\,m_{i3} / mt_{ie}$$

$$mt_{ie} = m_{i1} + m_{i2} + m_{i3}$$

The solution (using MATLAB) is as follows:

Medium	**Am-241 (g/m^3) or (g/kg)**	**Am-242 (g/m^3) or (g/kg)**	**Am-243 (g/m^3) or (g/kg)**
WATER			
time = 100	1.35E-2	4.75E-3	2.32E-1
time = 1000	1.35E-2	4.75E-3	2.32E-1
time = 10,000	1.35E-2	4.75E-3	2.32E-1
OIL			
time = 100	1.35E-3	4.75E-4	2.32E-2
time = 1000	1.35E-3	4.75E-4	2.32E-2
time = 10,000	1.35E-3	4.75E-4	2.32E-2
SAND			
time = 100	8.92E-1	3.15E-1	1.54E+1
time = 1000	6.61E-1	2.33E-1	1.14E+1
time = 10,000	3.29E-2	1.16E-2	5.66E-1
CLAY			
time = 100	9.56E-1	3.38E-1	1.65E+1
time = 1000	7.25E-1	2.56E-1	1.25E+1
time = 10,000	9.75E-2	3.44E-2	1.68

Note: the MATLAB solution assumes that the mass (not molar) solubility is identical for all three isotopes. This creates a small error in the calculated results, of less than 1%. The verifier should therefore accept a small difference between GoldSim's results and the MATLAB results reported above.

CT_Cells2-11 – Advective Links with Negative Flow Rates

This test verifies that cell elements support negative advective flow rates.
In this test Cell A has an initial inventory consisting of Species A, while Cell B has an inventory consisting of species B. The initial flow rate is from B to A, and the half-life for the amount of mass in each cell is 14 days (note that half-life does not refer to decay in this case, but rather to the amount of material in each cell).
Later, the flow switches to be from A to B, and the half-life changes as well (to 3.46 days).
The verifier should run the model and confirm that the masses in each Cell diminish appropriately, with the approximate half life specified by the HalfLife element (this can be confimed graphically by comparing the MassesChart Time History plot in the model to Figure CT_Cells2-11a below).

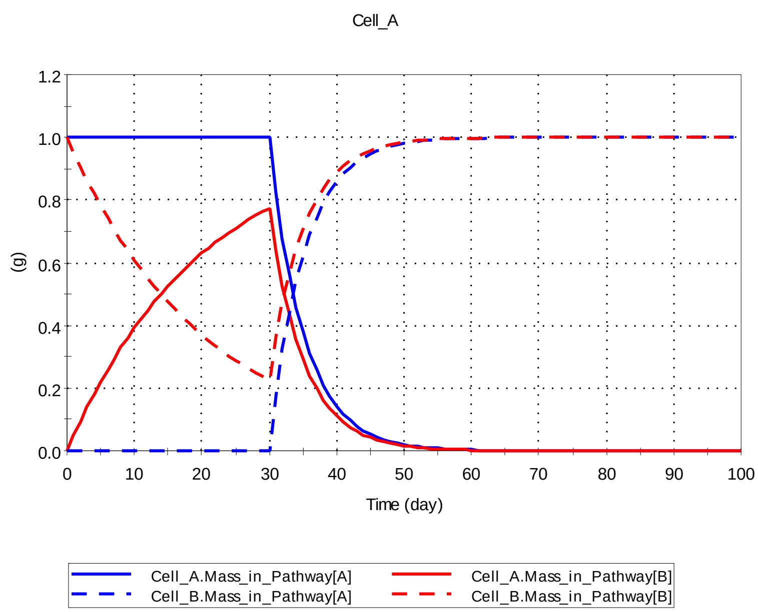


Figure CT_Cells2-11a

The verifier should then enter the Pipe_Test container and create an advective link between CellA and the Pipe. The verifier should specify a negative flow rate for the link, and then run the model. A fatal error should be generated.

CT_Cells2-12 – Colloid Velocity Multiplier

This test verifies that the Colloid Velocity Multiplier functions properly. The test verifies the effect of the Velocity Factor on the speed of species flow from the Cell and Pipe elements when a high Kd is specified, then checks to ensure the flux is not affected by the Velocity Factor for low Kd values.
The verifier should start by setting the Kd value to 1m3/g and the VelFactor element to 5 (representing a five-fold increase in velocity). The verifier should run the model , then open the Fluxes plot and confirm that the flux is 0.005 g/s. Next the verifier should open the Breakthrough plot and verify that the peak of the breakthrough curve occurs at 11s.

The test should then be repeated with a Kd of 1ml/g. In this scenario, the small Kd dominates. The Fluxes plot should show a flux of 1E-6 g/s. The verifier should then open the Breakthrough plot and verify that the peak of the breakthrough curve occurs at 50s.

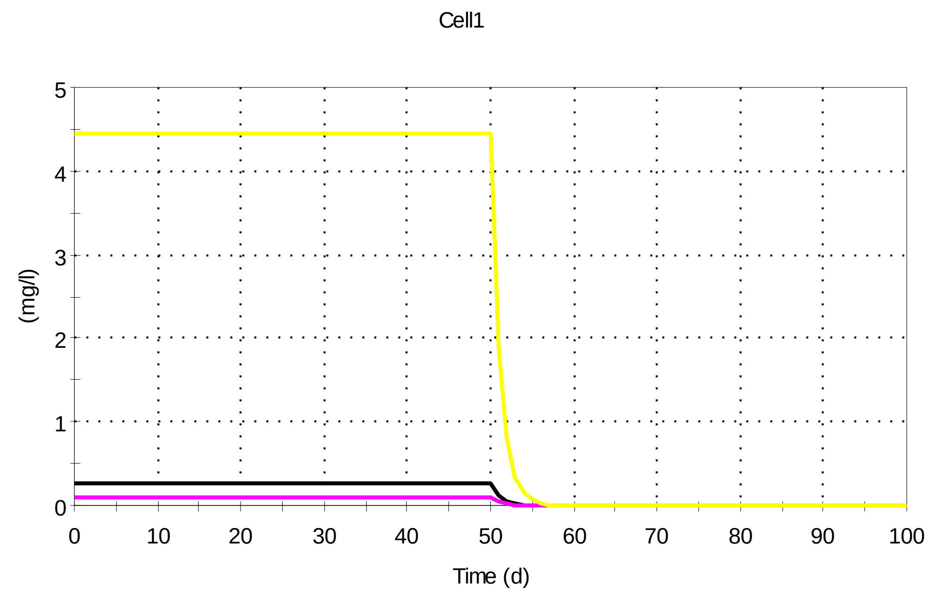


Figure CT_Cells2-12

CT_Cells3 - Diffusive Connections from Cells

These problems test simple diffusive connections from cells. For these problems, one or more diffusive connections *from* the cell to a sink are defined. For problems in which decay is turned off, the total mass in the cell is governed by the following equation:

$$M_{is} = \sum_{c=1}^{NC_i} f_{cs}$$

where:

M_{is}	=	rate of increase of species s in cell i [M/t];
NC_i	=	number of mass transfer connections for cell i; and
f_{cs}	=	influx rate of species s (into cell i) through connection c [M/t].

Note that for an advective connection from cell i, f_{cs} is defined as follows:

Diffusive mass transfer connections can only be specified to occur through fluids. The flux f_{cs} *to* path i is computed as follows for diffusive mass transfer connections:

$$f_{cs} = D_{cs}(-c_{ims} + \frac{c_{jns}}{K_{nms}}) + \sum_{t=1}^{NPT_{im}} PFD_{ct} \cdot D_{ct}(-c_{its,\,ds} \cdot cp_{imt} + c_{jts,\,ds} \cdot cp_{jnt})$$

where:

D_{cs}	=	diffusive conductance for species s in connection c [L3/t];
c_{ims}	=	the dissolved concentration of species s in medium m within cell i [M/L3];
c_{jns}	=	the dissolved concentration of species s in medium n within cell j [M/L3];

K_{nms} = partition coefficient between fluid medium n (in cell j) and fluid medium m (in cell i) for species s [L3 medium m / L3 medium n];

NPT_{im} = the number of particulate solid media in fluid m within cell i;

PFD_{ct} = Boolean flag (0 or 1) which indicates whether diffusion of solid t suspended in the fluid for connection c is allowed;

D_{ct} = diffusive conductance for particulate t in connection c [L3/t];

$c_{its,ds}$ = the sorbed concentration of species s associated with solid t within cell i [M/M];

cp_{imt} = the concentration of solid particulate t within fluid m in cell i [M/L3];

$c_{jts,ds}$ = the sorbed concentration of species s associated with solid t within cell [M/M]; and

cp_{jnt} = the concentration of solid particulate t within fluid n in cell j [M/L3].

The first term in Equation (1-4) accounts for diffusion of dissolved species, while the second term accounts for diffusion of particulates suspended in the fluid. Note that unlike advective connections, the fluid media involved in cells i (medium m) and j (medium n) need not be identical. Note also that if j is a pathway, c_{jns} and cp_{jnt} are assumed to be zero. (Hence, mass can diffuse from a cell to a pathway, but cannot diffuse from a pathway to a cell).

The diffusive conductance terms are computed as follows:

$$D_{cs} = \frac{A_c}{\dfrac{L_{ci}}{d_{ms} \cdot t_{Pci} \cdot n_{Pci}} + \dfrac{L_{cj}}{d_{ns} \cdot t_{Pcj} \cdot n_{Pcj} \cdot K_{nms}}}$$

where:

A_c = the area of diffusive connection c [L2];

L_{ci} = diffusive length for connection c in cell i [L];

L_{cj} = diffusive length for connection c in cell j [L];

d_{ms} = diffusivity for species s for fluid m (in cell i) [L2/t];

d_{ns} = diffusivity for species s for the fluid n (in cell j) [L2/t];

tp_{ci} = tortuosity for the porous medium Pci defined for connection c in cell i (≤ 1);

tp_{cj} = tortuosity for the porous medium Pcj defined for connection c in cell j (≤ 1);

np_{ci} = porosity for the porous medium Pci defined for connection c in cell i;

np_{cj} = porosity for the porous medium Pcj defined for connection c in cell j; and

K_{nms} = partition coefficient between fluid media n (in cell j) and fluid media m (in cell i) for species s [L3 medium m / L3 medium n].

and

$$D_{ct} = \frac{A_c}{\dfrac{L_{ci}}{d_{mt} \cdot t_{Pci} \cdot n_{Pci}} + \dfrac{L_{cj}}{d_{nt} \cdot t_{Pcj} \cdot n_{Pcj}}}$$

where A_c, L_{ci}, L_{cj}, t_{Pci}, t_{Pcj}, n_{Pci}, and n_{Pcj} are as defined previously, and

d_{mt} = diffusivity for particulate t within the fluid m (in cell i) [L2/t]; and

d_{nt} = diffusivity for particulate t within the fluid n (in cell j) [L2/t].

If j is a pipe, L_{cj} is automatically assumed to be 0 (no diffusive resistance is present on the pipe side of the connection). The equation above does not contain a partitioning term because, as will be shown below, intermedia diffusive transport is not allowed for suspended particulates.

The partition coefficient (K_{mns}) present in the above equations is defined as follows:

$$K_{nms} = \frac{K_{nre}}{K_{mre}}$$

where:

K_{mre} = partition coefficient between fluid medium m and reference fluid r for element e (where species s is an isotope of element e) [L3 fluid r/L3 fluid m]; and

K_{n1e} = partition coefficient between fluid medium n and reference fluid r for element e (where species s is an isotope of element e) [L3 fluid r/L3 fluid n].

Note that K_{mre} and K_{nre} are direct user inputs.

PFD_{ct} is defined as follows:

IF [fluid m = fluid n]

THEN (PFD_{ct} = 1),

ELSE (PFD_{ct} = 0)

That is, diffusive transport of particulates through a fluid from cell i to receiving cell (or pipe) j is only allowed if fluid m (in cell i) is the same as fluid n (in cell or pipe j).

Particulate solid concentrations in fluids (cp_{imt}, cp_{jnt}) are specified directly by the user. Contaminant concentrations in various media (c_{ims}, c_{jns}, c_{its}, c_{jts}) are computed as described in Section 5.7.1.

CT_Cells3 -01 - Simple Diffusion

This problem is identical to CT_Cells1-01, except a second cell is added, with a diffusive connection between the two cells (WATER to WATER). Both cells contain all four media, and the diffusive connection properies are as listed below:

	diffusive length (m)	**tortuosity**	**porosity**
Cell 1	0.02	0.1 (SAND)	0.3 (SAND)
Cell 2	0.02	0.15 (CLAY)	0.4 (CLAY)

The diffusive area is 20 m^2 and the diffusivity for all species in water is 1e-3 m^2/yr.

For a cell with only one diffusive connection to another cell through the same fluid, the governing equations for each species are (assuming no decay):

$M_{1s} = D_{cs} (-c_{1,WATER,s} + c_{2,WATER,s})$

$M_{2s} = D_{cs} (c_{1,WATER,s} - c_{2,WATER,s})$

Substituting for c_{ims}, the above equations become:

$M_{1s} = D_{cs} (-P_{1,WATER,e}\ m_{1s} + P_{2,WATER,e}\ m_{2s})$

$M_{2s} = D_{cs} (P_{1,WATER,e}\ m_{1s} - P_{2,WATER,e}\ m_{2s})$

This is a linear systems of equations. The resulting concentrations are as follows:

Cell 1

Medium	Am-241 (g/m^3)	Am-242 (g/m^3)	Am-243 (g/m^3)
WATER			
time = 100	2.54E-1	8.97E-2	4.37
time = 1000	2.20E-1	7.76E-2	3.79
time = 10,000	1.33E-1	4.70E-2	2.29

Sink

Medium	Am-241 (g/m^3)	Am-242 (g/m^3)	Am-243 (g/m^3)
WATER			
time = 100	4.52E-3	1.59E-3	7.77E-2
time = 1000	3.87E-2	1.37E-2	6.66E-1
time = 10,000	1.26E-1	4.43E-2	2.16

CT_Cells3 -02 - Simple Intermedia Diffusion

This problem is identical to CT_Cells3-01, except that the diffusive connection is from WATER to OIL. The diffusivity for all 3 species in OIL is 5e-4 m^2/yr.

For a cell with only one diffusive connection to another cell with a different fluid, the governing equations for each species are (assuming no decay):

$M_{1s} = D_{cs} (-c_{1,WATER,s} + c_{2,OIL,s}/K_{OIL,WATER,s})$

$M_{2s} = D_{cs} (c_{1,WATER,s} - c_{2,OIL,s}/K_{OIL,WATER,s})$

Substituting for c_{ims}, the above equations become:

$M_{1s} = D_{cs} (-P_{1,WATER,e}\ m_{1s} + P_{2,OIL,e}\ m_{2s}/K_{OIL,WATER,s})$

$M_{2s} = D_{cs} (P_{1,WATER,e}\ m_{1s} - P_{2,OIL,e}\ m_{2s}/K_{OIL,WATER,s})$

This is a linear system of equations. The resulting concentrations are as follows:

Cell 1

Medium	Am-241 (g/m^3)	Am-242 (g/m^3)	Am-243 (g/m^3)
WATER			
time = 100	2.58E-1	9.11E-2	4.44
time = 1000	2.53E-1	8.91E-2	4.35
time = 10,000	2.09E-1	7.38E-2	3.60

Sink

Medium	Am-241 (g/m^3)	Am-242 (g/m^3)	Am-243 (g/m^3)
WATER			
time = 100	6.25E-4	2.208E-4	1.08E-2
time = 1000	6.12E-3	2.16E-3	1.05E-1
time = 10,000	4.97E-2	1.75E-2	8.55E-1

CT_Cells3 -03 - Simple Diffusion With Multiple Connections

This problem is identical to CT_Cells3-01, except that two diffusive connections to a second cell are defined:

	diffusive length (m)	tortuosity	porosity
Connection 1			
Cell 1	0.02	0.1 (SAND)	0.3 (SAND)
Cell 2	0.02	0.15 (CLAY)	0.4 (CLAY)
Connection 2			
Cell 1	0.04	0.1 (SAND)	0.3 (SAND)
Cell 2	0.04	0.15 (CLAY)	0.4 (CLAY)

The diffusive area is for the first connection is 10 m^2; the diffusive area for the second connection is 20 m^2.

For a cell with two diffusive connections to another cell through the same fluid, the governing equations for each species are (assuming no decay):

$$M_{1s} = D_{1s} (-c_{1,WATER,s} + c_{2,WATER,s}) + D_{2s} (-c_{1,WATER,s} + c_{2,WATER,s})$$

$$M_{2s} = D_{1s} (c_{1,WATER,s} - c_{2,WATER,s}) + D_{2s} (c_{1,WATER,s} - c_{2,WATER,s})$$

Substituting for c_{ims}, the above equations become:

$$M_{1s} = D_{1s} (-P_{1,WATER,e}\ m_{1s} + P_{2,WATER,e}\ m_{2s}) + D_{2s} (-P_{1,WATER,e}\ m_{1s} + P_{2,WATER,e}\ m_{2s})$$

$$M_{2s} = D_{1s} (P_{1,WATER,e}\ m_{1s} - P_{2,WATER,e}\ m_{2s}) + D_{2s} (P_{1,WATER,e}\ m_{1s} - P_{2,WATER,e}\ m_{2s})$$

This is a linear systems of equations. The resulting concentrations are as follows:

Cell 1

Medium	Am-241 (g/m^3)	Am-242 (g/m^3)	Am-243 (g/m^3)
WATER			
time = 100	2.54E-1	8.97E-2	4.37
time = 1000	2.20E-1	7.76E-2	3.79
time = 10,000	1.33E-1	4.70E-2	2.29

Sink

Medium	Am-241 (g/m^3)	Am-242 (g/m^3)	Am-243 (g/m^3)
WATER			
time = 100	4.52E-3	1.59E-3	7.77E-2
time = 1000	3.87E-2	1.37E-2	6.66E-1
time = 10,000	1.26E-1	4.43E-2	2.16

CT_Cells3 -04 - Simple Diffusion With Multiple Connections to Two Cells

This problem is identical to CT_Cells3-03, except that two diffusive connections to two different cells are defined. The connection settings are identical to those in CT_Cells3-03, but the mass and volume of the four media in the two receiving cells (Cells 2 and 3) are half of those in Cell 1.

For a cell with two diffusive connections to two other cells through the same fluid, the governing equations for each species are (assuming no decay):

$$M_{1s} = D_{1s} (-c_{1,WATER,s} + c_{2,WATER,s}) + D_{2s} (-c_{1,WATER,s} + c_{3,WATER,s})$$

$$M_{2s} = D_{1s} (c_{1,WATER,s} - c_{2,WATER,s})$$

$$M_{3s} = D_{2s} (c_{1,WATER,s} - c_{3,WATER,s})$$

Substituting for c_{ims}, the above equations become:

$$M_{1s} = D_{1s} (-P_{1,WATER,e}\, m_{1s} + P_{2,WATER,e}\, m_{2s}) + D_{2s} (-P_{1,WATER,e}\, m_{1s} + P_{3,WATER,e}\, m_{3s})$$

$$M_{2s} = D_{1s} (P_{1,WATER,e}\, m_{1s} - P_{2,WATER,e}\, m_{2s})$$

$$M_{3s} = D_{2s} (P_{1,WATER,e}\, m_{1s} - P_{3,WATER,e}\, m_{3s})$$

This is a linear systems of equations. The resulting concentrations are as follows:

Cell 1

Medium	Am-241 (g/m^3)	Am-242 (g/m^3)	Am-243 (g/m^3)
WATER			
time = 100	2.54E-1	8.97E-2	4.37
time = 1000	2.20E-1	7.76E-2	3.79
time = 10,000	1.33E-1	4.70E-2	2.29

Sink

Medium	Am-241 (g/m^3)	Am-242 (g/m^3)	Am-243 (g/m^3)
WATER			
time = 100	4.52E-3	1.59E-3	7.77E-2
time = 1000	3.87E-2	1.37E-2	6.66E-1
time = 10,000	1.26E-1	4.43E-2	2.16

Sink2

Medium	Am-241 (g/m^3)	Am-242 (g/m^3)	Am-243 (g/m^3)
WATER			
time = 100	4.52E-3	1.59E-3	7.77E-2
time = 1000	3.87E-2	1.37E-2	6.66E-1
time = 10,000	1.26E-1	4.43E-2	2.16

CT_Cells3 -05 - Diffusion with Particulates

This problem is identical to CT_Cells3-01, except that a portion of each of the two solids is suspended in each of the two fluids. The suspended solid concentrations are listed below:

Solid	Concentration in WATER (kg/m^3)	Concentration in OIL (kg/m^3)
SAND	0.1	0.2
CLAY	0.01	0.02

The diffusivity of the solids in the two fluids are listed below:

Solid	diffusivity in WATER (m^2/year)	diffusivity in OIL (m2/year)
SAND	2e-3	1e-3
CLAY	5e-3	2e-3

The governing equations for each species are (assuming no decay):

$$M_{1s} = D_{cs} (-c_{1,WATER,s} + c_{2,WATER,s})$$

$$+ D_{c,SAND} (-c_{1,SAND,s*}cp_{1,WATER,SAND} + c_{2,SAND,s*}cp_{2,WATER,SAND})$$

$$+ D_{c,CLAY} (-c_{1,CLAY,s*}cp_{1,WATER,CLAY} + c_{2,CLAY,s*}cp_{2,WATER,CLAY})$$

$$M_{2s} = D_{cs} (c_{1,WATER,s} - c_{2,WATER,s})$$

$$+ D_{c,SAND} (c_{1,SAND,s*}cp_{1,WATER,SAND} - c_{2,SAND,s*}cp_{2,WATER,SAND})$$

$$+ D_{c,CLAY} (c_{1,CLAY,s*}cp_{1,WATER,CLAY} - c_{2,CLAY,s*}cp_{2,WATER,CLAY})$$

This is a linear system of equations. The resulting concentrations are as follows:

Cell 1

Medium	Am-241 (g/m^3)	Am-242 (g/m^3)	Am-243 (g/m^3)
WATER			
time = 100	2.71E-1	9.55E-2	4.66
time = 1000	2.26E-1	7.97E-2	3.89
time = 10,000	1.40E-1	4.93E-2	2.41

Sink

Medium	Am-241 (g/m^3)	Am-242 (g/m^3)	Am-243 (g/m^3)
WATER			
time = 100	6.20E-3	2.19E-3	1.07E-1
time = 1000	5.09E-2	1.80E-2	8.76E-1
time = 10,000	1.37E-1	4.84E-2	2.36

CT_Cells3 -06 - Diffusion with Particulates into a Pipe

This problem is identical to CT_Cells3-05, except that the first cell is connected to a pipe, rather than a cell. As a result, the diffusive resistance in the second half of the connection is zero. Note that the governing equations shown below assume an infinitely large pathway such that the pathway concentration approaches zero.

The governing equations for each species are (assuming no decay):

$$M_{1s} = D_{cs}(-c_{1,WATER,s}) + D_{c,SAND}(-c_{1,SAND,s*}cp_{1,WATER,SAND})$$

$$+ D_{c,CLAY}(-c_{1,CLAY,s*}cp_{1,WATER,CLAY})$$

This is a linear system of equations. The resulting concentrations are as follows:

Cell 1

Medium	Am-241 (g/m^3)	Am-242 (g/m^3)	Am-243 (g/m^3)
WATER			
time = 100	2.67E-1	9.44E-2	4.60
time = 1000	1.96E-1	6.93E-2	3.38
time = 10,000	8.87E-3	3.13E-3	1.53E-1

Additional test: The test problem has an expression called TotalMass that computes the sum of the mass in the original cell plus the mass in the Sink downstream of the pipe pathway. Confirm that all of the mass that originates in the original cell ends up in the sink, by checking that the mass in TotalMass at the end of the simulation equals the amount at the beginning of the simulation.

CT_Cells3 -07 - Diffusion with Particulates into a Cell with Zero Particulate Concentration

This problem is identical to CT_Cells3-05, except that the second cell has zero particulate concentrations.

The governing equations for each species are (assuming no decay):

$$M_{1s} = D_{cs}\,(-c_{1,WATER,s} + c_{2,WATER,s})$$
$$+ D_{c,SAND}\,(-c_{1,SAND,s} * cp_{1,WATER,SAND})$$
$$+ D_{c,CLAY}\,(-c_{1,CLAY,s} * cp_{1,WATER,CLAY})$$

$$M_{2s} = D_{cs}\,(c_{1,WATER,s} - c_{2,WATER,s})$$
$$+ D_{c,SAND}\,(c_{1,SAND,s} * cp_{1,WATER,SAND})$$
$$+ D_{c,CLAY}\,(c_{1,CLAY,s} * cp_{1,WATER,CLAY})$$

This is a linear systems of equations. The resulting concentrations are as follows:

Cell 1

Medium	Am-241 (g/m^3)	Am-242 (g/m^3)	Am-243 (g/m^3)
WATER			
time = 100	2.71E-1	9.55E-2	4.66
time = 1000	2.25E-1	7.93E-2	3.87
time = 10,000	1.24E-1	4.36E-2	2.13

Sink

Medium	Am-241 (g/m^3)	Am-242 (g/m^3)	Am-243 (g/m^3)
WATER			
time = 100	5.81E-3	2.05E-3	1.00E-1
time = 1000	4.87E-2	1.72E-2	8.39E-1
time = 10,000	1.43E-1	5.06E-2	2.46

CT_Cells3 -08 - Intermedia Diffusion with Particulates

This problem is identical to CT_Cells3-02, except that a portion of each of the two solids is suspended in each of the two fluids, as in CT_Cells3-05. Because intermedia particulate diffusion is not allowed, the solution is similar to the solution for CT_Cells3-02, because the same amount of mass should diffuse to the sink. Note that results are not expected to match the very small exact results at time 10,000 with high precision

CT_Cells3 -09 - Diffusion With Multiple Connections from Multiple Media

This problem is identical to CT_Cells3-01, except that two diffusive connections to a second cell are defined:

	transport medium	diffusive length (m)	tortuosity	porosity
Connection 1	WATER			
Cell 1		0.02	0.1 (SAND)	0.3 (SAND)
Cell 2		0.02	0.15 (CLAY)	0.4 (CLAY)
Connection 2	OIL			
Cell 1		0.04	0.1 (SAND)	0.3 (SAND)
Cell 2		0.04	0.15 (CLAY)	0.4 (CLAY)

The diffusive area is for the first connection is 10 m^2; the diffusive area for the second connection is 400 m^2.

For a cell with two diffusive connections to another cell, the governing equations for each species are (assuming no decay):

$$M_{1s} = D_{1s}\,(-c_{1,WATER,s} + c_{2,WATER,s}) + D_{2s}\,(-c_{1,OIL,s} + c_{2,OIL,s})$$

$$M_{2s} = D_{1s}\,(c_{1,WATER,s} - c_{2,WATER,s}) + D_{2s}\,(c_{1,OIL,s} - c_{2,OIL,s})$$

Substituting for c_{ims}, the above equations become:

$$M_{1s} = D_{1s}\,(-P_{1,WATER,e}\,m_{1s} + P_{2,WATER,e}\,m_{2s}) + D_{2s}\,(-P_{1,OIL,e}\,m_{1s} + P_{2,OIL,e}\,m_{2s})$$

$$M_{2s} = D_{1s}\,(P_{1,WATER,e}\,m_{1s} - P_{2,WATER,e}\,m_{2s}) + D_{2s}\,(P_{1,OIL,e}\,m_{1s} - P_{2,OIL,e}\,m_{2s})$$

This is a linear systems of equations. The resulting concentrations are as follows:

Cell 1

Medium	Am-241 (g/m^3)	Am-242 (g/m^3)	Am-243 (g/m^3)
WATER			
time = 100	2.54E-1	8.97E-2	4.37
time = 1000	2.20E-1	7.76E-2	3.79
time = 10,000	1.33E-1	4.70E-2	2.29

Sink

Medium	Am-241 (g/m^3)	Am-242 (g/m^3)	Am-243 (g/m^3)
WATER			
time = 100	4.52E-3	1.59E-3	7.77E-2
time = 1000	3.87E-2	1.37E-2	6.66E-1
time = 10,000	1.26E-1	4.43E-2	2.16

CT_Cells3-10 - Intermedia Diffusion with Zero Partition Coefficient for Fluid in Second Cell

This problem is identical to CT_Cells3-02, except that the partition coefficient from WATER to OIL is zero. As a result, no diffusive transport occurs, and the mass and concentration in the first cell stay constant. The concentrations in WATER for Am-241, Am-242 and Am-243, are, respectively, 2.60E-1, 9.17E-2, and 4.47.

CT_Cells3-11 - Diffusion with Zero Length in Receiving Cell

This problem is identical to CT_Cells3-01, except that the diffusive length in the second cell is zero. This modifies the value of D_{cs}.

The governing equations for each species are (assuming no decay):

$M_{1s} = D_{cs} (-c_{1,WATER,s} + c_{2,WATER,s})$

$M_{2s} = D_{cs} (c_{1,WATER,s} - c_{2,WATER,s})$

Substituting for c_{ims}, the above equations become:

$M_{1s} = D_{cs} (-P_{1,WATER,e}\ m_{1s} + P_{2,WATER,e}\ m_{2s})$

$M_{2s} = D_{cs} (P_{1,WATER,e}\ m_{1s} - P_{2,WATER,e}\ m_{2s})$

This is a linear systems of equations. The resulting concentrations are as follows:

Cell 1

Medium	**Am-241 (g/m^3)**	**Am-242 (g/m^3)**	**Am-243 (g/m^3)**
WATER			
time = 100	2.52E-1	8.89E-2	4.34
time = 1000	2.05E-1	7.24E-2	3.53
time = 10,000	1.30E-1	4.59E-2	2.24

Sink

Medium	**Am-241 (g/m^3)**	**Am-242 (g/m^3)**	**Am-243 (g/m^3)**
WATER			
time = 100	6.72E-3	2.37E-3	1.16E-1
time = 1000	5.34E-2	1.89E-2	9.20E-1
time = 10,000	1.29E-1	4.54E-2	2.21

CT_Cells3-12 - Diffusion with No Porous Media

This problem is identical to CT_Cells3-01, except that no porous media is specified in either cell for the diffusive connections. This modifies the value of D_{cs}.

The governing equations for each species are (assuming no decay):

$M_{1s} = D_{cs} (-c_{1,WATER,s} + c_{2,WATER,s})$

$M_{2s} = D_{cs} (c_{1,WATER,s} - c_{2,WATER,s})$

Substituting for c_{ims}, the above equations become:

$$M_{1s} = D_{cs} (-P_{1,WATER,e}\ m_{1s} + P_{2,WATER,e}\ m_{2s})$$

$$M_{2s} = D_{cs} (P_{1,WATER,e}\ m_{1s} - P_{2,WATER,e}\ m_{2s})$$

This is a linear systems of equations. The resulting concentrations are as follows:

Cell 1

Medium	Am-241 (g/m^3)	Am-242 (g/m^3)	Am-243 (g/m^3)
WATER			
time = 100	1.83E-1	6.44E-2	3.14
time = 1000	1.29E-1	4.57E-2	2.23
time = 10,000	1.29E-1	4.57E-2	2.23

Sink

Medium	Am-241 (g/m^3)	Am-242 (g/m^3)	Am-243 (g/m^3)
WATER			
time = 100	7.61E-2	2.69E-2	1.31
time = 1000	1.29E-1	4.56E-2	2.23
time = 10,000	1.29E-1	4.57E-2	2.23

CT_Cells3-13 - Diffusion with Solubility Constraint

This problem is identical to CT_Cells3-01, except that the solubility limit is exceeded for Am (the solubility limited being specified as 0.25 g/m^3) in the first cell (and is never exceeded in the second cell).

The governing equations for each species are (assuming no decay):

$$M_{1s} = D_{cs} (-c_{1,WATER,s} + c_{2,WATER,s})$$

$$M_{2s} = D_{cs} (c_{1,WATER,s} - c_{2,WATER,s})$$

Substituting for the concentration terms, expanding for all three species in both cells, and recalling that solubility limit is exceeded, the above equations become:

$$M_{11} = D_{c1} (-P_{1,WATER,e} * msat_{1e*}\ m_{11} / mt_{1e} + P_{2,WATER,e*} m_{21})$$

$M_{21} = D_{c1} (P_{1,WATER,e} * msat_{1e*} m_{11} / mt_{1e} - P_{2,WATER,e*}m_{21})$

$M_{12} = D_{c2} (-P_{1,WATER,e} * msat_{1e*} m_{12} / mt_{1e} + P_{2,WATER,e*}m_{22})$

$M_{22} = D_{c2} (P_{1,WATER,e} * msat_{1e*} m_{12} / mt_{1e} - P_{2,WATER,e*}m_{22})$

$M_{13} = D_{c3} (-P_{1,WATER,e} * msat_{1e*} m_{13} / mt_{1e} + P_{2,WATER,e*}m_{23})$

$M_{21} = D_{c3} (P_{1,WATER,e} * msat_{1e*} m_{13} / mt_{1e} - P_{2,WATER,e*}m_{23})$

$mt_{ie} = m_{i1} + m_{i2} + m_{i3}$

This is a non-linear systems of equations (solved using MATLAB). The resulting concentrations are as follows:

Cell 1

Medium	**Am-241 (g/m^3)**	**Am-242 (g/m^3)**	**Am-243 (g/m^3)**
WATER			
time = 100	1.35E-2	4.75E-3	2.32E-1
time = 1000	1.35E-2	4.75E-3	2.32E-1
time = 10,000	1.35E-2	4.75E-3	2.32E-1

Sink

Medium	**Am-241 (g/m^3)**	**Am-242 (g/m^3)**	**Am-243 (g/m^3)**
WATER			
time = 100	2.37E-4	8.38E-5	4.08E-3
time = 1000	2.19E-3	7.74E-4	3.78E-2
time = 10,000	1.12E-2	3.95E-3	1.93E-1

Note: the MATLAB solution assumes that the mass (not molar) solubility is identical for all three isotopes. This creates a small error in the calculated results, of less than 1%. The verifier should therefore accept a small difference between GoldSim's results and the MATLAB results reported above.

CT_Cells3-14 - Two Cells Diffuse to Equilibrium

This problem is similar to CT_Cells3-01, except that each of the two cells has an initial inventory with a different isotope of a single element. Cell1 initially has 100 g of Am-241 and Cell2 initially has 100 Ci of Am-243. The cells should diffuse until equilibrium is reached.

For a cell with only one diffusive connection to another cell through the same fluid, the governing equations for each species are (assuming no decay):

$$M_{1s} = D_{cs} (-c_{1,WATER,s} + c_{2,WATER,s})$$

$$M_{2s} = D_{cs} (c_{1,WATER,s} - c_{2,WATER,s})$$

Substituting for c_{ims}, the above equations become:

$$M_{1s} = D_{cs} (-P_{1,WATER,e}\ m_{1s} + P_{2,WATER,e}\ m_{2s})$$

$$M_{2s} = D_{cs} (P_{1,WATER,e}\ m_{1s} - P_{2,WATER,e}\ m_{2s})$$

This is a linear systems of equations. The resulting concentrations are as follows:

Cell 1

Medium	**Am-241 (g/m^3)**	**Am-243 (g/m^3)**
WATER		
time = 100	2.54E-1	7.77E-2
time = 1000	2.20E-1	6.66E-1
time = 10,000	1.33E-1	2.16

Sink

Medium	**Am-241 (g/m^3)**	**Am-243 (g/m^3)**
WATER		
time = 100	4.52E-3	4.37
time = 1000	3.87E-2	3.79
time = 10,000	1.26E-1	2.29

CT_Cells3-15 - Diffusion with Particulates into a Pathway, with a Solubility Constraint

This problem is identical to CT_Cells3-06, except that a solubility constraint (of 0.25g/m^3) is imposed in the cell.

The governing equations for each species are (assuming no decay):

$$M_{1s} = D_{cs}(-c_{1,WATER,s}) + D_{c,SAND}(-c_{1,SAND,s} * cp_{1,WATER,SAND}) + D_{c,CLAY}(-c_{1,CLAY,s} * cp_{1,WATER,CLAY})$$

Substituting for the concentration terms, expanding for all three species, and recalling that the solubility limit is exceeded, the above equation becomes:

$$M_{11} = (m_{11} / mt_{1e})\{D_{cs}(-P_{1,WATER,e} * msat_{1e}) + D_{c,SAND}(-cp_{1,WATER,SAND})[P_{1,SAND,e} * msat_{1e}] + D_{c,CLAY}(-cp_{1,WATER,CLAY})[P_{1,CLAY,e} * msat_{1e}]\}$$

$$M_{12} = (m_{12} / mt_{1e})\{D_{cs}(-P_{1,WATER,e} * msat_{1e}) + D_{c,SAND}(-cp_{1,WATER,SAND})[P_{1,SAND,e} * msat_{1e}] + D_{c,CLAY}(-cp_{1,WATER,CLAY})[P_{1,CLAY,e} * msat_{1e}]\}$$

$$M_{13} = (m_{13} / mt_{1e})\{D_{cs}(-P_{1,WATER,e} * msat_{1e}) + D_{c,SAND}(-cp_{1,WATER,SAND})[P_{1,SAND,e} * msat_{1e}] + D_{c,CLAY}(-cp_{1,WATER,CLAY})[P_{1,CLAY,e} * msat_{1e}]\}$$

$$mt_{ie} = m_{i1} + m_{i2} + m_{i3}$$

This set of equations must be solved by MATLAB. The resulting effective concentrations are as follows:

Medium	Am-241 (g/m^3) or (g/kg)	Am-242 (g/m^3) or (g/kg)	Am-243 (g/m^3) or (g/kg)
WATER			
time = 100	1.44E-2	5.09E-3	2.48E-1
time = 1000	1.44E-2	5.09E-3	2.48E-1
time = 10,000	1.44E-2	5.09E-3	2.48E-1
OIL			
time = 100	1.35E-3	4.75E-4	2.32E-2
time = 1000	1.35E-3	4.75E-4	2.32E-2
time = 10,000	1.35E-3	4.75E-4	2.32E-2
SAND			
time = 100	9.55E-1	3.37E-1	1.64E1
time = 1000	9.39E-1	3.32E-1	1.62E1
time = 10,000	7.77E-1	2.74E-1	1.34E1
CLAY			
time = 100	1.02	3.60E-1	1.76E1
time = 1000	1.00	3.54E-1	1.73E1
time = 10,000	8.41E-1	2.97E-1	1.45E1

Note: the MATLAB solution assumes that the mass (not molar) solubility is identical for all three isotopes. This creates a small error in the calculated results, of less than 1%. The verifier should therefore accept a small difference between GoldSim's results and the MATLAB results reported above.

CT_Cells3-16 – Diffusion with Inaccessible Porosity

This problem is identical to CT_Cells1-07, except a second cell is added, with a diffusive connection between the two cells (WATER to WATER). In addition, the particulates are removed from both cells, and no solubility constraint is imposed. The second cell contains 10 m^3 of water, 5 m^3 of oil, 75,000kg of sand, and 30000kg of clay,

Both cells contain all four media, and the diffusive connection properties are as listed below:

	diffusive length (m)	porous medium	Tortuosity
Cell 1	0.02	SAND	0.10
Cell 2	0.02	CLAY	0.15

The diffusive area is 20 m^2 and the diffusivity for all species in water is 1e-3 m^2/yr. Note that when inaccessible porosity is specified, it has two impacts: 1) it modifies the effective volume of fluids (as discussed in CT_Cells1-07); and 2) it modifies the diffusive conductance for the connection as follows:

$$D_{cs} = \frac{A_c}{\dfrac{L_{ci}}{d_{ms} \cdot t_{Pci} \cdot n_{Pci} \cdot f_{Pcis}} + \dfrac{L_{cj}}{d_{ns} \cdot t_{Pcj} \cdot n_{Pcj} \cdot f_{Pcjs} \cdot K_{nms}}}$$

where:

A_c = the area of diffusive connection c [m2];

L_{ci} = diffusive length for connection c in cell i [m];
L_{cj} = diffusive length for connection c in cell j [m];
d_{ms} = diffusivity for species s for fluid m (in cell i) [m2/yr];
d_{ns} = diffusivity for species s for the fluid n (in cell j) [m2/yr];
tp_{ci} = tortuosity for the porous medium defined for connection c in cell i (≤ 1);
tp_{cj} = tortuosity for the porous medium defined for connection c in cell j (≤ 1);
$fp_{ci}s$ = fraction of available porosity for species s for the porous medium defined for connection c in cell i (≤ 1);
fp_{cjs} = fraction of available porosity for species s for the porous medium defined for connection c in cell j (≤ 1);
np_{ci} = porosity for the porous medium defined for connection c in cell i;
np_{cj} = porosity for the porous medium defined for connection c in cell j; and
K_{nms} = partition coefficient between fluid medium n (in cell j) and fluid medium m (in cell i) for species s [m3 medium m / m3 medium n].

In this problem, the accessible porosity in each solid is defined as a variable, taking on the following values:

	$\mathbf{f_{clay}}$	$\mathbf{f_{sand}}$
Cell 1	.5	.9
Cell 2	.3	.7

This results in a linear system of equations (similar to those presented in CT_Cells3-01). The resulting concentrations are as follows:

Cell 1

Medium	Am-241 (g/m^3)	Am-242 (g/m^3)	Am-243 (g/m^3)
WATER			
time = 100	2.44	8.61E-1	4.20E+1
time = 1000	1.61	5.68E-1	2.77E+1
time = 10,000	1.45	5.11E-1	2.49E+1

Cell 2

Medium	Am-241 (g/m^3)	Am-242 (g/m^3)	Am-243 (g/m^3)
WATER			
time = 100	2.63E-1	9.27E-2	4.52
time = 1000	1.25	4.42E-1	2.15E+1
time = 10,000	1.45	5.11E-1	2.49E+1

CT_Cells3-17 – Unsaturated Diffusion

This test is designed to test unsaturated diffusion between cells. The test contains two Cell elements. In Cell1 the Aq species has a concentration of 1 in water and 0 in air. The Air species has a concentration of 1e-6 in water and 1 in air.

The amounts of the two fluids vary with time; initially Aq is 90% saturated and Air is 10%, until time > 50s, when Aq is 10% saturated and Air is 90%.

The porous medium has a porosity of 0.3, so for a 100% saturated fluid the diffusive flux would be 0.3 g/sec.

The verifier should confirm that the Aq species, diffusing through the water medium, initially diffuses at a rate of 90% * 0.3 g/sec = 0.27 g/sec, and subsequently at 10% * 1 g/sec = 0.03 g/sec. The Air species, diffusing through the air medium, should have the opposite pattern. This result can be confirmed by ensuring that the Fluxes plot corresponds with the plot in Figure CT_Cells3-17a below.

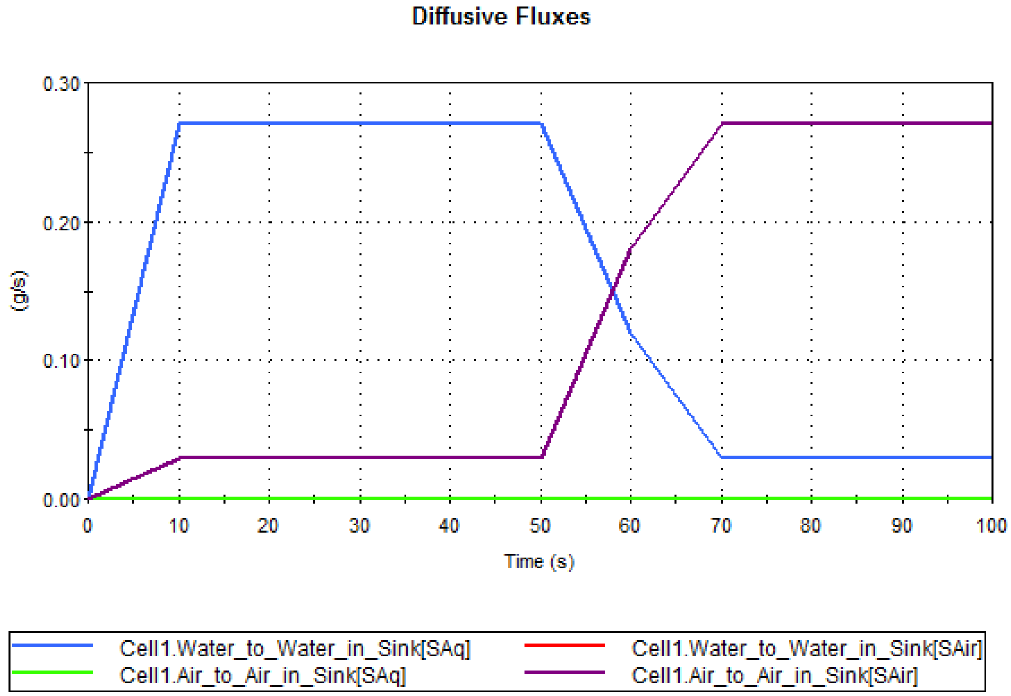


Figure CT_Cells3-17a

CT_Cells4 – Decay Calculations in Cells

These test problems are specifically targeted at verifying the radioactive decay algorithms in RIP. All problems in this group are run with radioactive decay. A 100 yr timestep is used for all problems unless otherwise specified

CT_Cells4-01: Radioactive Decay in a Cell

In this problem, the decay chain starting with Am-241 is examined. The problem is simply looking at decay over the first 1,000 yr. Am-241 decays to Np-237. To test split decay, two daughters are specified for Np-237, each receiving 50% of the mass. U-233a and U-233b each have identical properties. The analytical solutions for Am-241, Np-237 and U-233 are as follows (note that decay in the containers is a function of the timestep, with smaller timesteps producing more accurate results. A 2 year timestep is used in this case to exactly reproduce the analytical solution:

$$M(\text{Am-241}) = M_0(\text{Am-241})\, e^{-k_1 t}$$

$$M(\text{Np-237}) = \frac{M_0(\text{Am-241}) \dfrac{AW(\text{Np-237})}{AW(\text{Am-241})} k_1 \; A_2}{(k_2 - k_1)\; A_1} \left[e^{-k_1 t} - e^{-k_2 t} \right]$$

$$M(\text{U-233}) = \frac{A_3 \; k_1 \; k_2 \; M_0(\text{Am-241}) \dfrac{AW(\text{U-233})}{AW(\text{Am-241})}}{A_1} \times$$
$$\left[\frac{e^{-k_1 t}}{(k_2 - k_1)(k_3 - k_1)} + \frac{e^{-k_2 t}}{(k_1 - k_2)(k_3 - k_2)} + \frac{e^{-k_3 t}}{(k_1 - k_3)(k_2 - k_3)} \right]$$

where:

k_1	=	decay rate for Am-241 = 1.603E-03 yr^{-1},
k_2	=	decay rate for Np-237 = 3.238E-07 yr^{-1},
k_3	=	decay rate for U-233a and b = 4.372E-06 yr^{-1},
M_0(Am-241)=		Curies of Am-241 at TIME 0 = 10,000,
AW	=	atomic weight (amu), taken as 241, 237 and 233 respectively,
A_1	=	specific activity of Am-241 = 3.44 Ci/g,
A_2	=	specific activity of Np-237 = 7.06E-04 Ci/g, and
A_3	=	specific activity of U-233 = 9.69E-03 Ci/g.

Using t = 1,000 yr and the above constants, the results are 2,013 Ci for Am-241, 1.613 Ci for Np-237, and 4.423E-03 Ci for U-233. Since the U-233 portion is split evenly between two daughters, U-233a and U-233b each receive 2.2116E-3 Ci.

CT_Cells4-02: Radioactive Decay in a Cell with Solubility Limit

This problem is identical to T9P5, but a solubility constraint is imposed such that initially the cell is saturated. After some decay has taken place, it drops below the solubility limit.

Am-241 is given a solubility limit of 1,000 g/ m^3 in water. The concentration of Am-241 in the cell is in excess of this limit until sometime between 600 and 700 years.

CT_Cells4-03: Competing Decay Rates

In this problem, species A decays to species B, and species B decays to species A. This simulates an equilibrium between two species. The magnitude of the decay rates determines the ratio of species present in the cell. The stochiometry of the reaction is that A ⇔ B.

To solve for the actual concentration of each species over time, the following equations can be used:

$$MA(t) = -k_f*mA(t) + k_r*(AWA/AWB)* mB(t)$$

$$MB(t) = -k_r*mB(t) + k_f*(AWB/AWA)* mA(t)$$

where:

k_f	=	the forward reaction rate = 0.001 (1/yr);
k_r	=	the reverse reaction rate = 0.0005 (1/yr);
AWA	=	the atomic weight of species A = 200 (g/mole);
AWB	=	the atomic weight of species B = 200 (g/mole);
mA(0)	=	the initial mass of species A = 0 (g);
mB(0)	=	the initial mass of species B = 400 (g).

The resulting masses should be:

Time, yr	**A**	**B**
100	18.6	381.4
1,000	103.6	296.4
10,000	133.3	266.7

CT_Cells4-04: Stoichiometry

In this problem, species A decays to species B. The stoichiometry of the reaction is that A ⇔ 2B. There are initially 400g of A in the cell, with a decay rate of 0.001/yr.

To solve for the actual concentration of each species over time, the following equations can be used:

$$mA(t) = mA(0) \exp(-kf*t)$$

$$mB(t) = mB(0) + (b/a) * mA(0) * (1 - \exp(-kf*t))$$

The resulting masses should be:

Time, yr	**A**	**B**
100	361.9	76.1
1,000	147.2	505.7

10,000	0.0182	800

CT_Cells4-05: Time-varying Decay Rate

In this problem, species A decays to species B. The decay rate is specified as a function of both time and local environment, as follows:

Decay = IF(Time < 500, Var, 0)

The cell environments are specified as follows:

Environment	Var	Cell Used
ENVT1	0.01	Cell 2
ENVT2	0.001	Cell 3
NONE (default)	0	Cell 1

An initial mass of 1 gram is defined in each of the three cells and each cell has a volume of 1 m^3. To solve for the actual concentration of each species over time, the following equations can be used:

mA(t) = mA(0) exp(-kf*t)

\Default\Cell1:

There is no decay in Cell1.

\ENVT1\Cell2:

m(100) = 1 * e-0.01 * 100 = 3.68E-1 g

m(500) = 1 * e-0.01 * 500 = 6.74E-3 g

m(1000) = m(500)

\ENVT2\Cell3:

m(100) = 1 * e-0.001 * 100 = 9.05E-1 g

m(500) = 1 * e-0.001 * 500 = 6.07E-1 g

m(1000) = m(500)

CT_Cells4-06: Time-varying Decay Rates, Stoichiometry, Four Daughters

In this problem, species A1 decays to species A2, A3, A4 and A5. The decay of A1 does not start until time 10 seconds, and ceases at 70 seconds. During the decay period, the stoichiometry is varied so that A2 is the daughter during 10 – 20 seconds, A3 is the daughter during 30 – 40 seconds, and so on. Starting at 70 seconds, all of the daughters decay rapidly back into A1.

In the array-view result elements the final concentration values should be negligible for all but species A1. The values should be: Water total concentration 2 g/l, dissolved concentration 1 g/l. Non-suspended solid concentration 8 g/kg, suspended-solid concentration 1 g/kg, and PrecipMass 0.7g

The time histories should show A1 decaying starting at 10 seconds, with the daughter product switching successively through the other species. Starting at 70 seconds, all of the daughters should decay back into A1.

CT_Cells5 - Time Variable Partitioning and Mass Transfer

In these problems, parameters controlling partitioning and mass transfer are time variable.

CT_Cells5-01 - Time Variable Partitioning Between Media in a Cell

This problem is identical to CT_Cells1-01, but at 5000 years, the partition coefficients change as follows:

Medium	**Partition Coefficient relative to WATER** (m^3/m^3) for fluids; (m^3/kg) for solids
WATER	1
OIL	0.2
SAND	0.4
CLAY	10

The resulting concentrations, before and after the change, are as follows:

Medium	Am-241 (g/m^3) or (g/kg)	Am-242 (g/m^3) or (g/kg)	Am-243 (g/m^3) or (g/kg)
WATER			
time = 4,900	2.59E-1	9.13E-2	4.45
time = 5,100	1.35E-1	4.78E-2	2.33
OIL			
time = 4,900	2.59E-2	9.13E-3	4.45E-1
time = 5,100	2.71E-2	9.56E-3	4.66E-1
SAND			
time = 4,900	5.17E-2	1.83E-2	8.90E-1
time = 5,100	5.41E-2	1.91E-2	9.32E-1
CLAY			
time = 4,900	1.29	4.57E-1	2.23E+1
time = 5,100	1.35	4.78E-1	2.33E+1

CT_Cells5-02 - Time Variable Advection

This problem is identical to CT_Cells3-01, but at 5000 years, the flow rate is reduced from 0.1 m^3/yr to 0.01 m^3/yr.

The concentration in WATER in Cell 1 over time is shown in the following table. Note that a lower precision than normal is acceptable for the small final values at time 10,000:

Medium	Am-241 (g/m^3)	Am-242 (g/m^3)	Am-243 (g/m^3)
WATER			
time = 100	2.37E-1	8.35E-2	4.07
time = 1000	1.06E-1	3.75E-2	1.83
time = 10,000	1.95E-3	6.87E-4	3.35E-2

CT_Cells5-03 - Time Variable Diffusion

This problem is identical to T6P3-1, but at 5000 years, the diffusive lengths, area, tortuosities and porosities change as follows:

	transport medium	diffusive length (m)	tortuosity	porosity
Connection 1	WATER			
Cell 1		0.01	0.2 (SAND)	0.6 (SAND)
Cell 2		0.01	0.3 (CLAY)	0.8 (CLAY)

The diffusive area changes to 10 m^2. The diffusivity changes from 1E-3 m^2/yr to 2E-3 m^2/yr.

The resulting concentrations are as follows:

Cell 1

Medium	Am-241 (g/m^3)	Am-242 (g/m^3)	Am-243 (g/m^3)
WATER			
time = 100	2.54E-1	8.97E-2	4.37
time = 1000	2.20E-1	7.76E-2	3.79
time = 6,000	1.31E-1	4.61E-2	2.25

Sink

Medium	Am-241 (g/m^3)	Am-242 (g/m^3)	Am-243 (g/m^3)
WATER			
time = 100	4.52E-3	1.59E-3	7.77E-2
time = 1000	3.87E-2	1.37E-2	6.66E-1
time = 6,000	1.28E-1	4.52E-2	2.20

Precision and Algorithm tests: Rerun CT_Cells5-03 specifically testing the medium and low accuracy options as selected in the Model/Options dialog. Confirm that the results are equivalent.

CT_Cells5-03 – Changing Volume

This test verifies that when the volume of water changes at a time step, the Cell uses an effective amount equal to 3/8 of the previous amount plus 5/8 of the new amount.

The initial outflow rate from Cell1 of 1e-6 m3/s should give a fraction released of 1e-6 per timestep, or approximately 1g per timestep.

At 10s the Cell1's volume changes from 1 to 2 m3, so the weighted average is 13/8 m3. The fraction released for that time step should be 8/13 = 0.615 e-6, or 0.615g released.

From then up to 19s the fraction released should be 0.5e-6 or 0.5 g per step.

At 20s Cell1's volume changes from 2 m3 to 1 m3, so the weighted average is 11/8 m3. The fraction released for that time step should be 8/11 = 0.727 e-6, o3 0.727g released.

The tester should run the model and confirm that the flux rates match these values, which are summarized in Table CT_Cells5-04-1 below.

Time/Time Range	Expected Release
0-9s	1g
10s	0.615g
11s-19s	0.5g
20s	0.727g
21s-100s	1g

Table CT_Cells5-04-1

CT_Cells6 – Pseudo-Reference Fluids and Multiple Cell Nets

In these problems, GoldSim's capability to apply multiple solubilities within a given cell network and to diffuse mass among multiple cell networks is verified.

CT_Cells6-01 – Pseudo-Reference Fluids

This problem verifies that pseudo-reference fluids function properly within GoldSim's Cell Pathways. The problem consists of three Cells connected by diffusive pathways and each having a different reference fluid. Two species, A and B, exist initially in Cell1. The solubility limit for each species is different in each cell. The following tables summarizes the problem setup and initial conditions:

Cell	**Reference Fluid**	**Volume (m^3)**	**Diffusive connections to:**
Cell1	Sol_1_50 (pseudo)	1.0	Cell2
Cell2	Sol_10_50	1.0	Cell1, Cell3
Cell3	Sol_10_100 (pseudo)	1.0	Cell2

Species	**Solubility Limit in Cell (mg/l):**			**Original Amount and Location**
	Cell1	Cell2	Cell3	
A	1	10	10	100g in Cell1
B	50	50	100	100g in Cell1

This test uses 'pseudo-reference fluids' to define variable solubility within a single cell network.

Species A has sufficient mass to reach the solubility limits of 1, 10, 10 g/m3 in the three cells. The remaining 79g should stay as precipitate in Cell1.

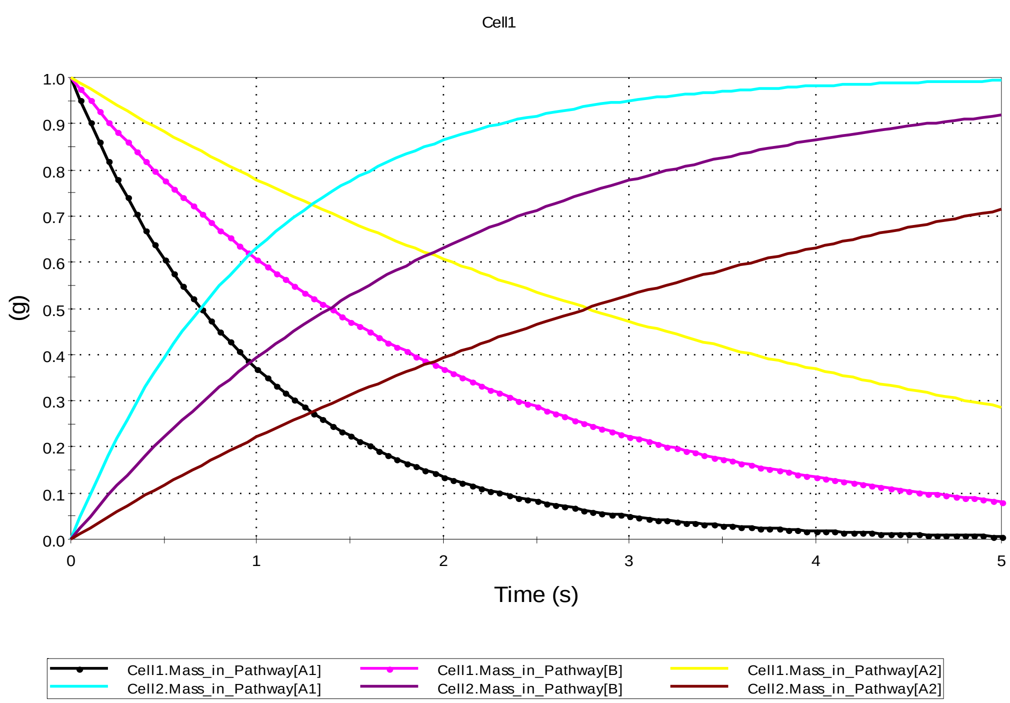
Species B has only enough mass to reach half of the solubility limits in the cells: 25, 25, and 50 g/m3 respectively.

Check that when the model is run, the dissolved concentrations and precipitate mass converge to the correct values.

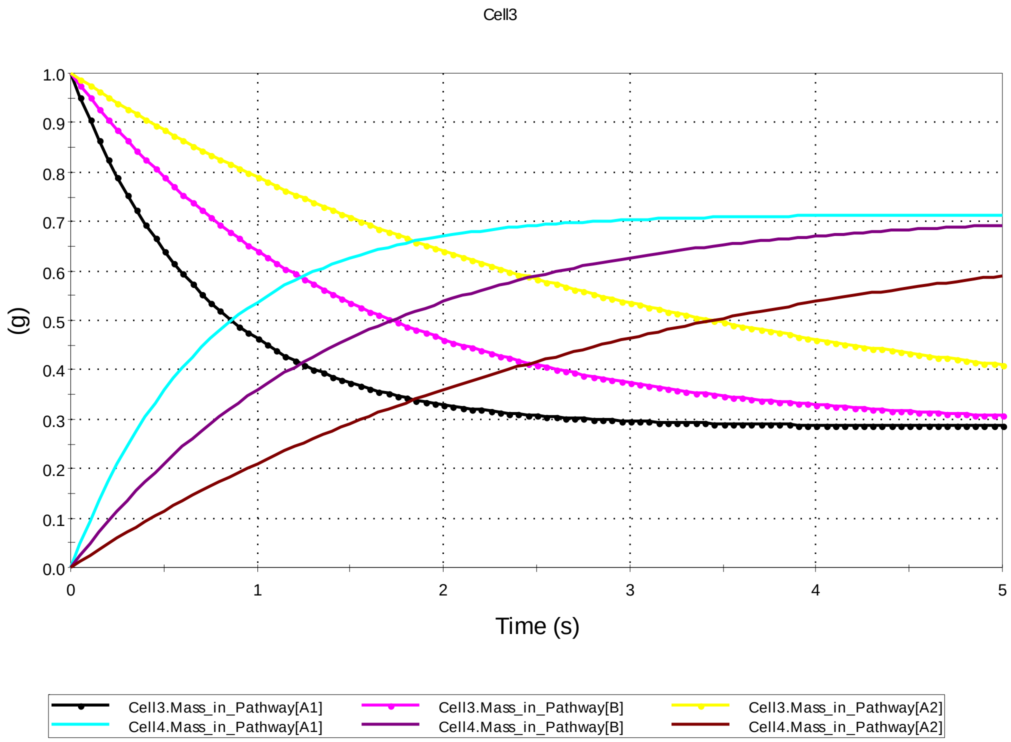
CT_Cells7-01 – Cell Outflows using Direct Transfer Rates

In this problem two pairs of Cells are linked using direct transfer rate flux links. There are three species, and simulations are run in two ways: once using distinct species, and once having the first and third species act as isotopes.

For the distinct species case, the transfer of mass between Cell1 and Cell2 should be exponentially-decaying, with the transfer rates being 1 sec^{-1}, 0.5 sec^{-1}, and 0.25 sec^{-1} for each species:



The transfer between Cell3 and Cell4 is two-way, so while these Cells initially behave identically as the amount of mass in Cell4 builds up the system approaches equilibrium. Nearing equilibrium the mass in Cell3 should approach 0.29g, and Cell4 should approach 0.71g:



CT_Cells7-02 – Cell Outflows using Precipitate and Filter Transfer Rates

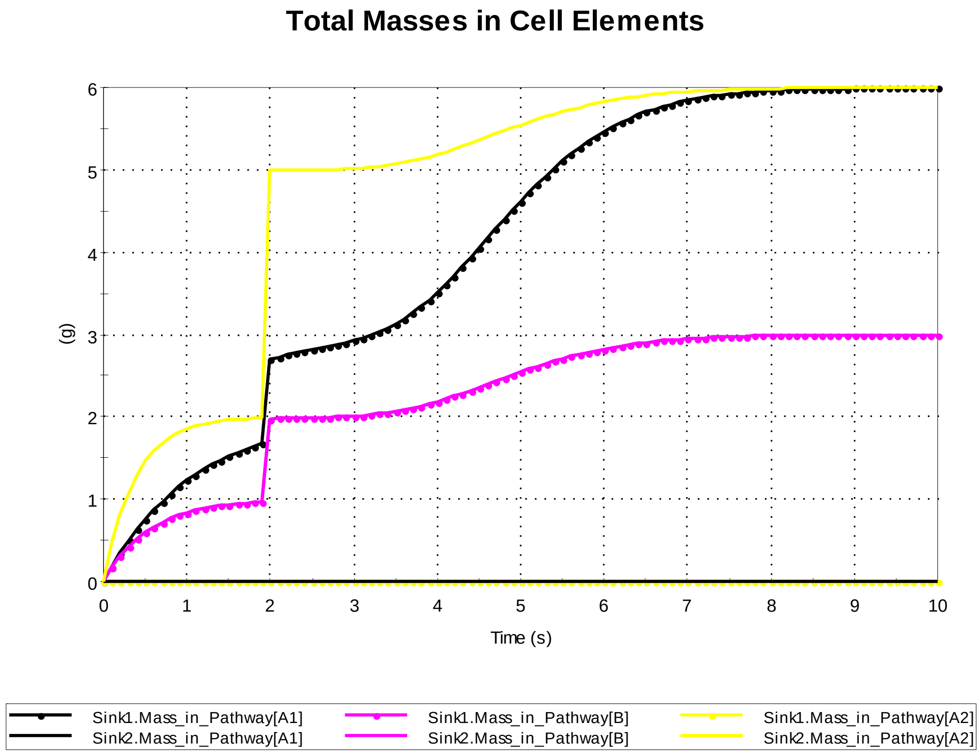
In this test problem Container FilterTest contains a small model that tests the capabilities of the 'Fraction of inflows' filter-type flux link, and Container PrecipTest contains a small model that tests the capabilities of the 'Precipitate transfer' flux link.

Run the model, and then compare the results in each Container to those shown in the model (and below). The results should be as follows.

<u>FilterTest</u>:

The total amount of mass added to Sink1 is 6g of each species. Of this, 0% of A1, 50% of B, and 100% of A2 should be intercepted and sent to Cell Sink2. Check the total masses in Sink1 and Sink2 at the end of the simulation to confirm this.

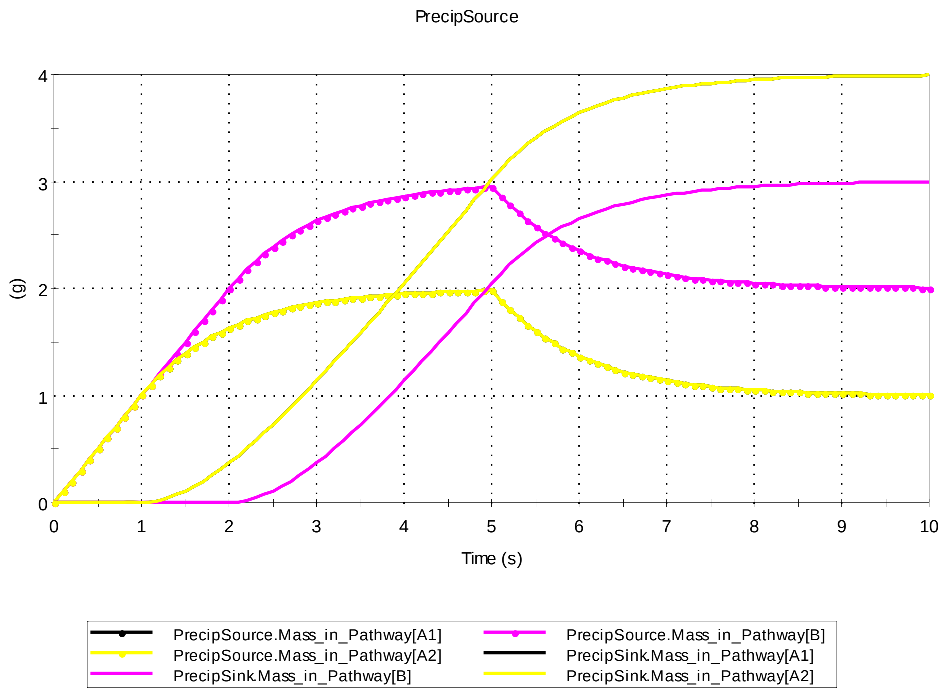
The time-history record should look like this:



<u>PrecipTest</u>:

Species A1 & A2 reach their solubility limit at 1s, and their precipitate is gradually moved to PrecipSink. Species B reaches its limit at 2s. After the external input stops at 5s, the remaining excess precipitate should be flushed into PrecipSink. At the end, PrecipSource should contain 1g, 2g, 1g of the species (A1, B, A2). PrecipSink should contain 4g, 3g, 4g.

The time-history record should look like this:


PrecipSource
(g)
Time (s)
0
1
2
3
4
0
1
2
3
4
5
6
7
8
9
10
PrecipSource.Mass_in_Pathway[A1]
PrecipSource.Mass_in_Pathway[B]
PrecipSource.Mass_in_Pathway[A2]
PrecipSink.Mass_in_Pathway[A1]
PrecipSink.Mass_in_Pathway[B]
PrecipSink.Mass_in_Pathway[A2]

4.3 EXTERNAL PATHWAY TESTS

CT_ExtPath-01

This test uses a simple external pathway function XF002 inside the test dll file cfstubs.dll. It has a single input and output. Two species are input using the cumulative input field, with species A being constant at 3 g/day, and species B being 3 g/day from 6 to 10 days, and 0 at all other times.

In order to test the ability of the external pathway to return an error message, set the Multiplier input from its normal value of 3 to a value of 0, and run the model. You should see an error message indicating that the multiplier is not positive.

Repeat both tests with the external pathway element set to run as a separate process.

Repeat the complete test with 64-bit versions of the test file and DLL (CT_ExtPath-0164.gsm and cfstubs64.dll).

CT_ExPath-02

This test uses the same external pathway, but with two input and two output connections from low-volume cells. One cell loads at the same rate as the cumulative input in CT_ExtPath-01, the other loads at twice the rate.

The external function merges all inputs, and triples them. Thus each output should have three times the input concentrations, which average 1.5, so the output concentrations are 4.5.

Repeat the complete test with 64-bit versions of the test file and DLL (CT_ExtPath-0264.gsm and cfstubs64.dll).

CT_ExtPath-03

This is the same as CT_ExtPath-02, but the inputs are combined and the outputs are split. The external element splits the outputs in proportion to their flow rates. The resulting mass-fluxes should be 3 for the first output, and 6 for the second.

Repeat the complete test with 64-bit versions of the test file and DLL (CT_ExtPath-0364.gsm and cfstubs64.dll).

4.4 NETWORK PATHWAY TESTS

CT_Net-01

This test replicates CT_Pipes-01 using three different series combinations of network-pipes to substitute for the original pipe elements. All three networks should give the same result (Ogata and Banks) as CT_Pipes-01.

CT_Net-02

This test replicates CT_Pipes-01 using three different combinations of network-pipes to substitute for the original pipe elements.

It is similar to CT_Net-01, but tests different combinations of merging inputs and splitting outputs. The three networks do the following:

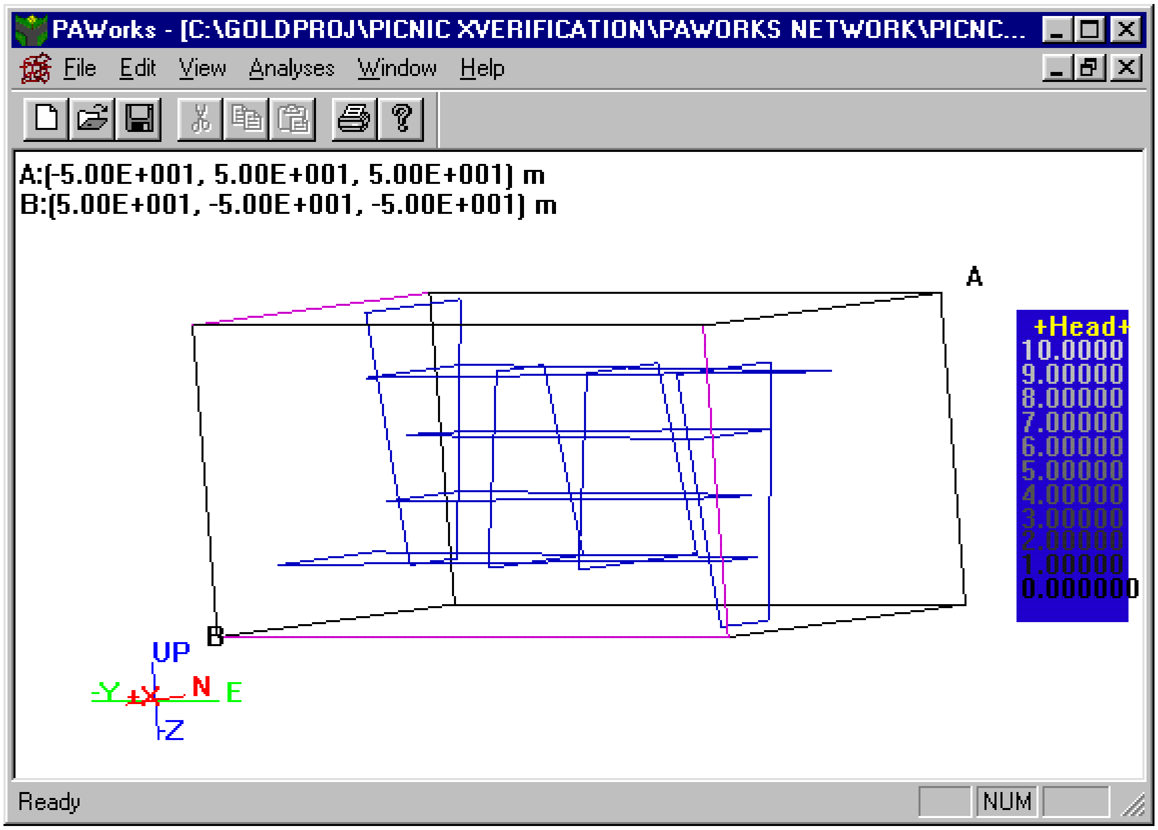
- The first network has a set of three short pipes in series, in parallel with a single full-length pipe.
- The second network has three pipes in parallel, each with the properties from Pipe_40m_Retarded in CT_Pipes-01.
- The third network has five pipes, with two converging into a single pipe which splits into two more. The effective properties of each segment are equivalent to the original pipe in CT_Pipes-01, so again the resulting concentration history should be the same.

CT_Net-03: Fracture Network with Diffusion into Immobile Zones

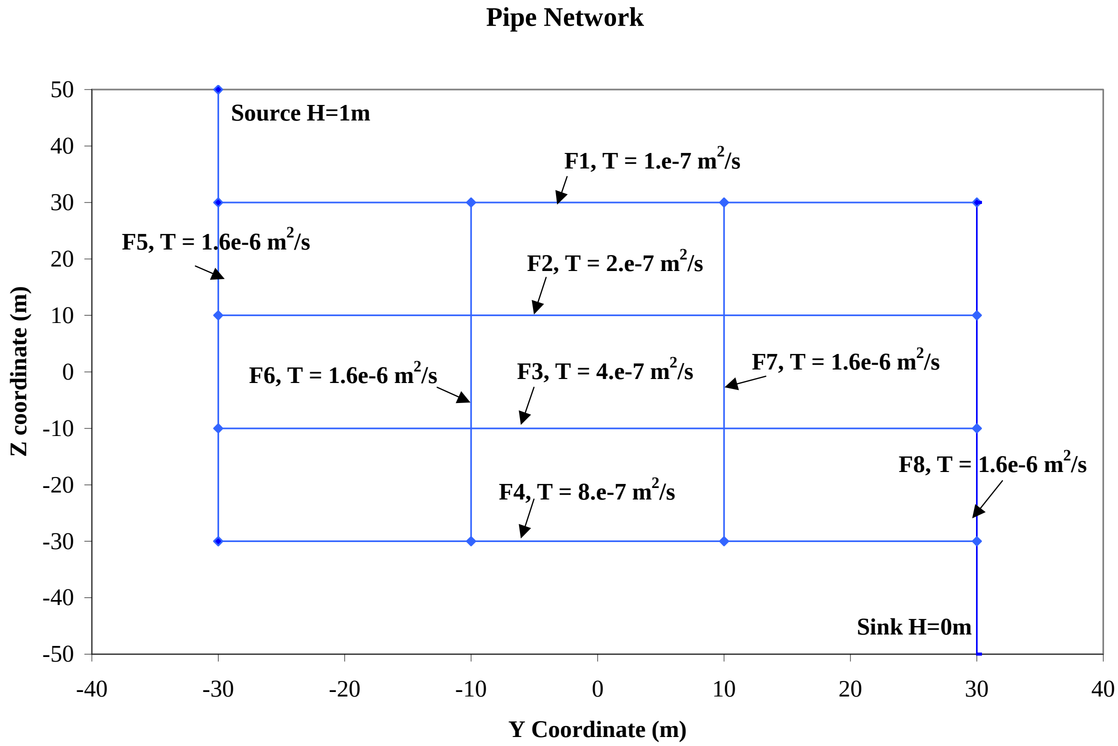
Formerly RIP verification test T8P7-1, this test problem is designed to verify the fracture network pathway. No analytic solutions to complex fracture systems are available; therefore the GoldSim results are verified against the results of an independent code developed by Barten and Robinson (1996) of the Swiss Paul Scherrer Institute (PSI), called PICNIC (Barten. (1996b).

This "grid" network simulation uses a 3x3 fracture network, with differing immobile zone properties attached to each of the fractures. The fracture network is shown below. The fractures vary in width along their length, so that every pipe has a different flow wetted surface. The boundary conditions, transmissivities (T), and fracture numbers (F) are shown in the following figures.

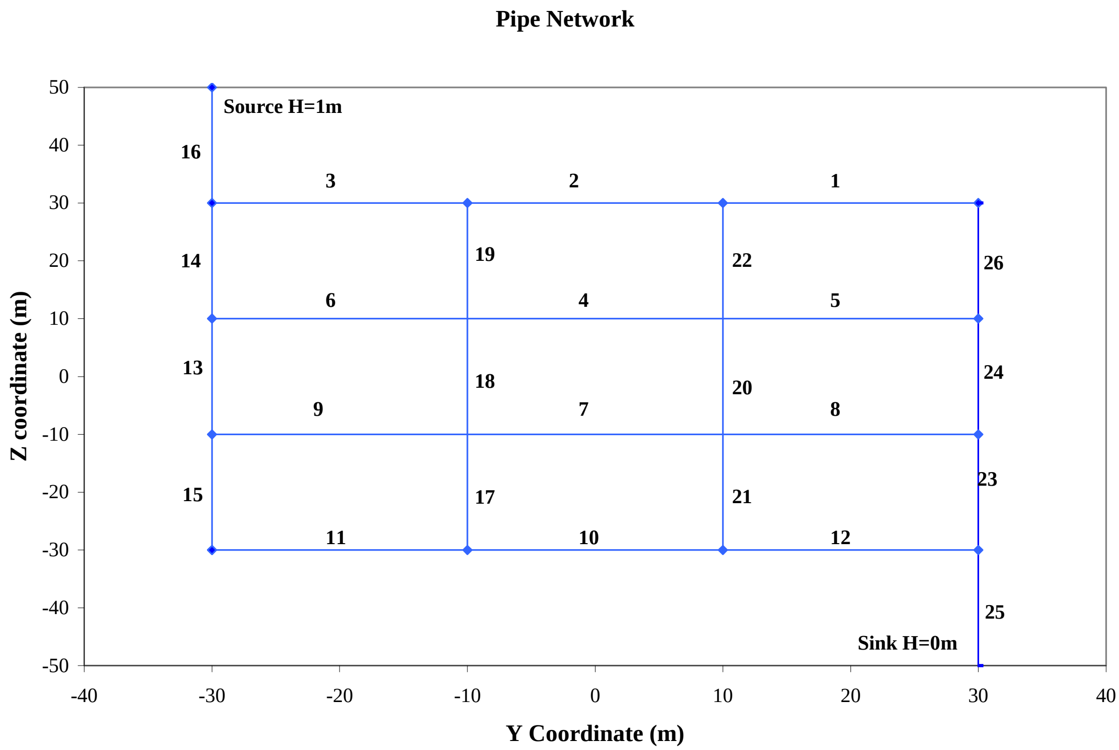
Fracture Network for the 3x3 "Grid" Cross Verification Tests



Fracture Properties and Boundaries for “Grid” Cross Verification Test



Pipe Numbers for “Grid” Cross Verification Test



The aperture (a) of each pipe is related to the fracture transmissivity through the relationship:

$$a = 2T^{0.5}$$

Flow in all pipes is downward and to the right. The velocity and flow area for each of the 26 pipes is given in the following table. The dispersion length (α) is equal to 1.0m and the free water diffusion coefficient (D_0) is equal to 10^{-9} m^2/s.

Pipe Properties for Test Case PNG1

Pipe	**Velocity (m/yr)**	**Area (m^2)**
1	84.93	0.00965
2	68.83	0.01278
3	74.93	0.01746
4	97.07	0.01789
5	120.65	0.02366
6	98.84	0.01212
7	136.33	0.02530
8	175.28	0.01714
9	127.54	0.03058
10	191.41	0.03818
11	172.17	0.04047
12	266.92	0.02508
13	76.66	0.14176
14	66.73	0.18080
15	38.40	0.18144
16	44.79	0.29856
17	1.76	0.19288
18	0.69	0.16000
19	2.88	0.14840
20	6.61	0.16000
21	4.44	0.13784
22	0.35	0.17328
23	80.73	0.08272
24	22.96	0.16000
25	109.25	0.12240
26	5.11	0.16032

In this simulation, two immobile zones are defined. The first immobile zone is attached to fractures 1, 2, 3, 6 and 7 (see above figure for fracture numbering) and is identical to that used in the preceding example.

The second immobile zone is attached to fractures 4, 5 and 8. The porosity of this zone is 0.001, the tortuosity is 1.0, the maximum diffusion distance is 1.0m, and the rock density is 2500 kg/m^3. The immobile zone properties for all fractures are given below (note that for this non-decaying example, only the retardation for species 1 is used).

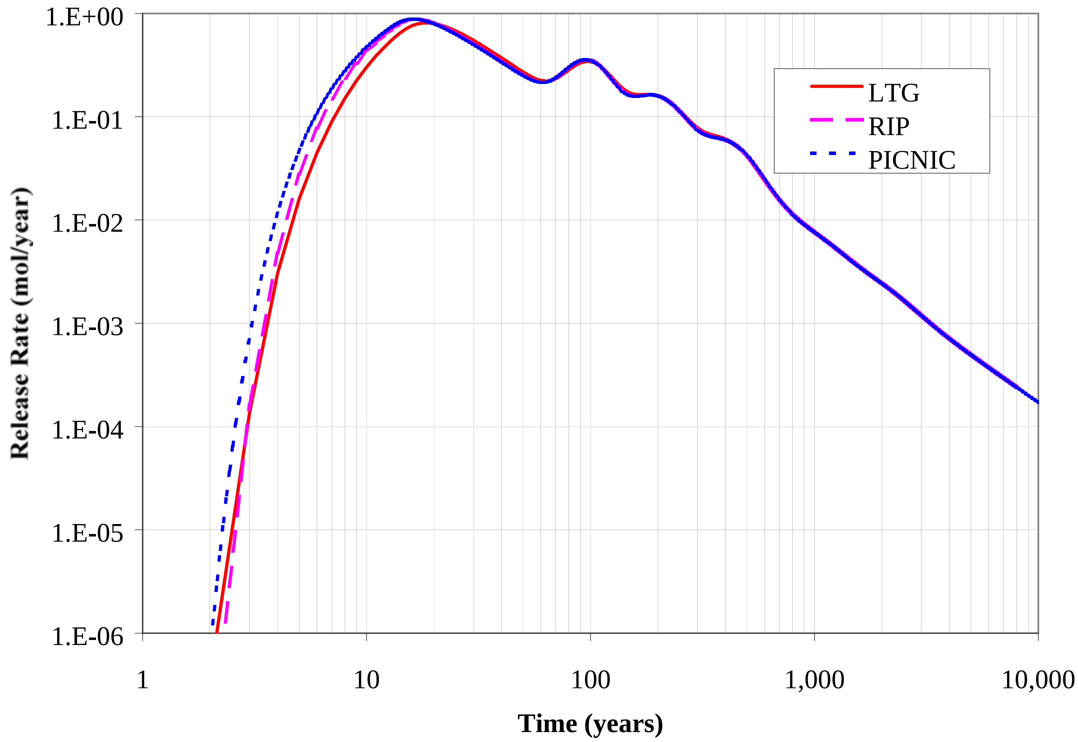
Immobile Zone Properties

Pipe (-)	**Porosity (-)**	**Perimeter (m)**	**Max. Diff. Dist. (m)**	**Tort. (-)**	**Retardation (-)**
1	0.1	30.5	0.05	1	26
2	0.1	40.42	0.05	1	26
3	0.1	55.2	0.05	1	26
4	0.1	40	0.05	1	26
5	0.1	52.9	0.05	1	26
6	0.1	27.1	0.05	1	26
7	0.1	40	0.05	1	26
8	0.1	27.1	0.05	1	26
9	0.1	48.34	0.05	1	26
10	0.001	42.68	1	1	2501
11	0.001	45.24	1	1	2501
12	0.001	28.04	1	1	2501
13	0.001	35.44	1	1	2501
14	0.001	45.2	1	1	2501
15	0.001	45.36	1	1	2501
16	0.001	74.64	1	1	2501
17	0.1	48.22	0.05	1	26
18	0.1	40	0.05	1	26
19	0.1	37.1	0.05	1	26
20	0.1	40	0.05	1	26
21	0.1	34.46	0.05	1	26
22	0.1	43.32	0.05	1	26
23	0.001	20.68	1	1	2501
24	0.001	40	1	1	2501
25	0.001	30.6	1	1	2501
26	0.001	40.08	1	1	2501

The input boundary condition is a Cauchy release (flux rate) equal to 10 moles per year for 10 years, falling to zero for the rest of the simulation.

The resulting downstream release with time for PICNIC is shown graphically in the following figure and table. The time history for total mass discharged (combined over all species, output "Totalflux") in the GoldSim model should essentially match these results.

PICNIC Results for Cross Verification Case PNG3



PICNIC Results for Case PNG3

Time (years)	PICNIC (mol/yr)
10	4.71E-01
45	2.88E-01
100	3.52E-01
450	5.22E-02
1,000	7.63E-03
4,500	5.86E-04

CT_Net-04: Network Watch Groups

This test case is based on CT_Net-03. Element Net3 has two watch groups that use the second (fracture-set property) method of defining Watch Groups. The second of these watches Set_4's output, which should match that of the overall network. Compare the first two outputs in element Compare to verify this, by ensuring that the two histories are identical.

The first Watch Group in Net2, defined using Method 1 (in the pipe table) should match the first Watch Group in Net3, which uses Method 2. This represents a set of internal pipes that contribute to the total discharge. Compare the outputs 3 and 4 in element Compare to verify that they are identical, and that their outputs are smaller than and initially arrive later than those of the first two outputs.

CT_Net-05: Multiple Network Watch Groups

This test case is also based on CT_Net-03. Element Net3 has multiple watch groups that are specified within a .ltx file. Edit the network table and import file CT_Net-05.ltx.

The test compares three different calculations of the total discharge from the last pipe (Pipe 25) . One of these is the actual network pathway discharge, and the other two are separate watch groups both associated with Pipe 25.

1. Edit the fracture network table in element Net1. Delete several pipes randomly. Then import file CT_Net-05.ltx.

2. Run the model.

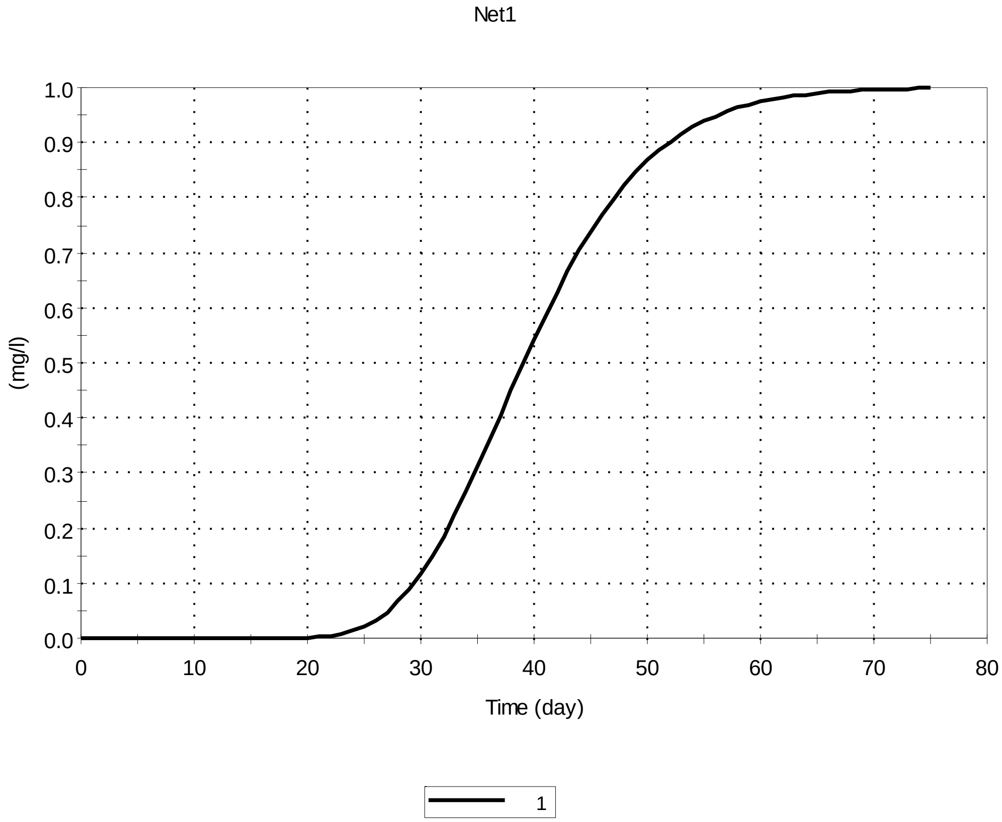
3. Display the history table in element WatchGroups. Confirm that all three results are identical. The results should match those in the table image shown on-screen.

Time (yr)	Net1.Water_to_BG2[Am241] [g/yr]	Net1.Watch25[Am241] [g/yr]	Net1.Watch99[Am241] [g/yr]
0	0	0	0
10	0.3302	0.3302	0.3302
45	0.2037	0.2037	0.2037
100	0.1383	0.1383	0.1383
1000	3.857e-07	3.857e-07	3.857e-07
4500	0	0	0

CT_Net-06: Local Property "Length" in Dispersivity Input Field

This test case is based on a simple pipe subdivided into three segments.

Run the model twice, using two values for the dispersivity in the fracture set element: "1m" and "1m + ~Length * 025". Confirm that the results for the 1m value match those shown below. Confirm that the results for the higher dispersivity show significantly increased dispersion.



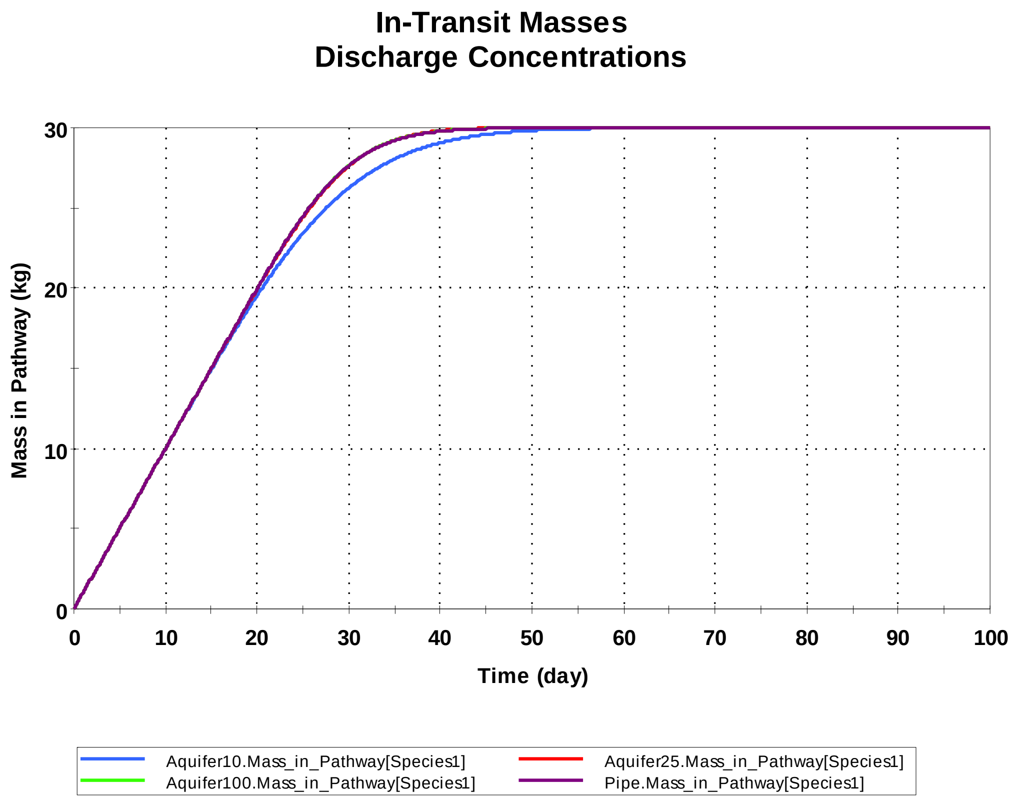
Time (day)	Net1.Concentration[A1] [mg/l]
18	0.00017
19	0.0004483
20	0.001052
21	0.002233
22	0.004351
23	0.007865
24	0.01332
25	0.02131
26	0.03242
27	0.04718
28	0.06601
29	0.08916
30	0.1167
31	0.1486
32	0.1844
33	0.2238
34	0.2661
35	0.3107
36	0.3569
37	0.4039
38	0.451

39	0.4975
40	0.5428

4.5 AQUIFER PATHWAY TESTS

CT_Aquifer_01 Dispersion Tests

In this test an aquifer with a length of 100 m and dispersivity of 2 m is simulated using Aquifer element with 100 cells, 25 cells, and 10 cells. In addition to the Aquifer elements, this model sets up a Pipe element with the same flow properties to use as an analytical verification. The tester should run the model and zoom in on the Mass_Concs and Outfluxes graphs to confirm that the three aquifer elements give similar results to the Pipe element, with the results of the aquifer of 100 cells most closely aligning with the Pipe's results. In addition, the tester should enter the Mass_Balance_Verification container and confirm that the elements Percent_Error10, Percent_Error25, and Percent_Error100 all have very small absolute values (<1e-6%). These elements confirm that the integral of mass loading into the aquifers equals the integral of outflux from the aquifer plus the mass stored in the aquifer.



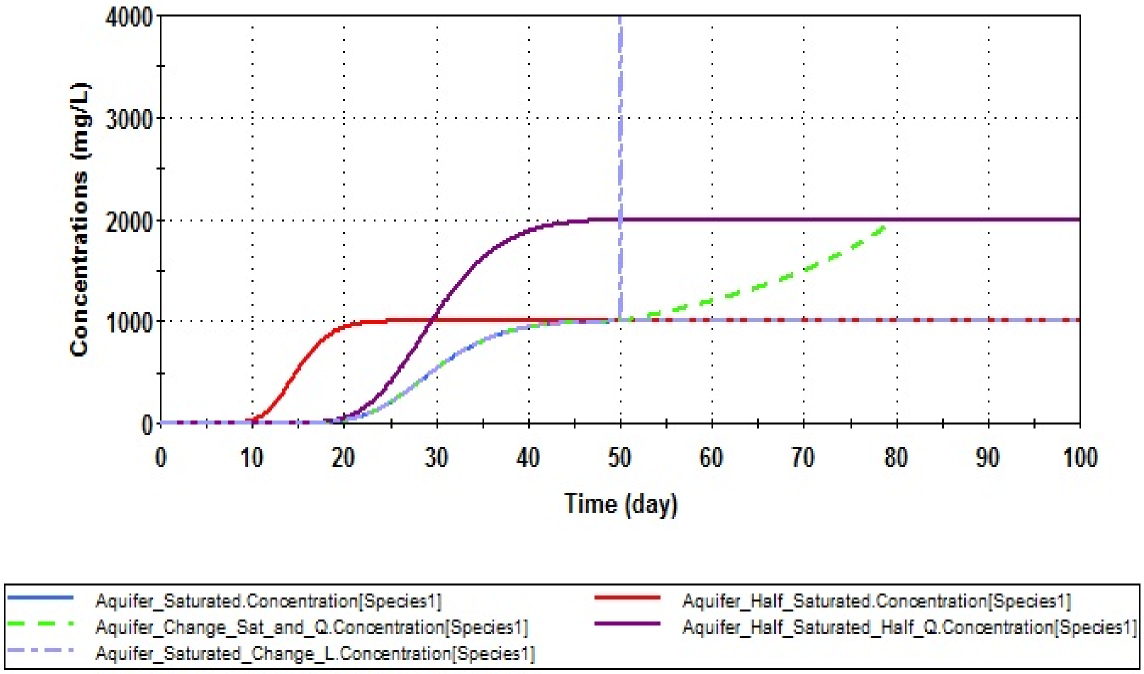
CT_Aquifer_02 ChangingProperties

This test qualitatively examines the effect of saturation, flow rate, and aquifer length on breakthrough curves, including a test of length, flow rates and saturation that change during the simulation. All other aquifer properties are held constant.

The tester should run the model and confirm the graphs (Mass_Concs and Outfluxes) match the images of graphs pasted beside them. The tester should also enter the Mass_Balance_Verification container and confirm the element Maximum_Continuity_Pcent_Error is a very small percentage (<1e-6%).

In the Mass_Concs graph, the blue line, the fully saturated aquifer with an outflow rate of 1 m3/day, should reach its steady state breakthrough concentration at about 45 to 50 days. The half saturated aquifer with the same flow rate (red line) should come to steady state at about 22 to 25 days (half the time). The purple line on the graph, i.e. the aquifer with half saturation and a flow rate of 0.5 m3/day, i.e., should have a breakthough at the same time as the saturated aquifer but the breakthrough concentration should be twice as high. The aquifer with a changing flow rate and saturation level (green line) should have the same concentration output as the saturated aquifer for the first ~50 days, as it is also fully saturated with a flow rate of 1 m3/day during this period. Between 50 and 80 days, the aquifer with changing saturation and flows rates changes these parameters linearly from 1 and 1 m3/day, respectively, to 0.5 and 0.5 m3/day, respectively. By 80 days, the aquifer with changing flow rate and saturation level (green line) should have the same outflow concentration as the purple line, i.e. the aquifer with saturation and flow rates or 0.5 and 0.5 m3/day, respectively. The violet line on the graph is an aquifer that is the same as the saturated aquifer (blue line), except that the length changes from 100 to 99 m at 50 days. The tester should verify a spike in concentration and mass loading occurs in the violet line at day 50 when the length changes.

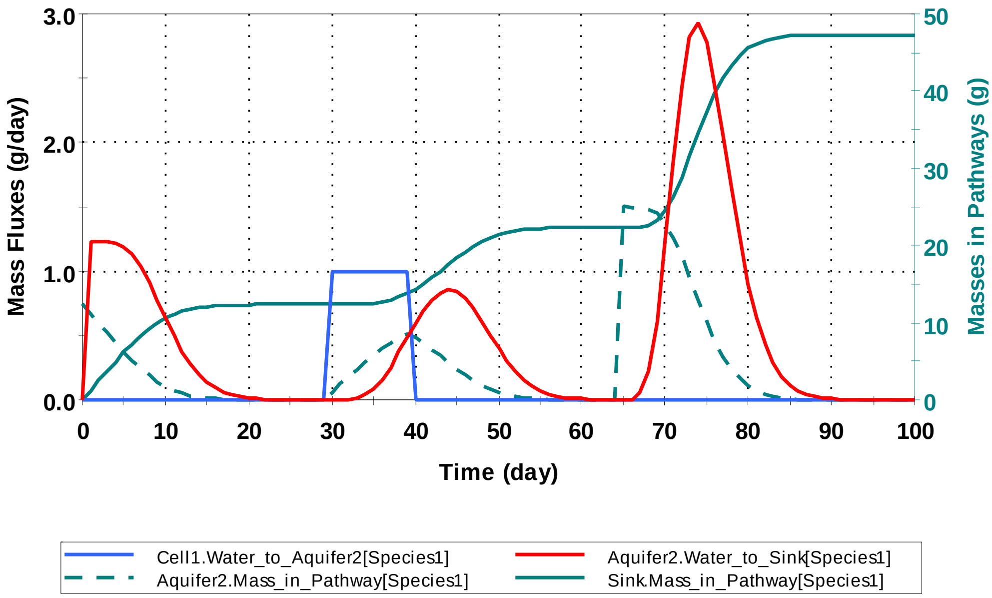
Mass_Concs graph from CT_Aquifer_02_ChangingProperties



CT_Aquifer_03 Changing Boundary Conditions

This file tests the aquifer element under changing boundary conditions. It tests specification of different boundary conditions, changing inflow concentrations, discrete changes. The tester should run the model and compare the graphs to the graph images in the model and shown below. In addition the tester should verify that the final mass in the first sink is 47.34 g and 15 g in the other sinks.

Masses and fluxes graph from CT_Aquifer_03 first test:



4.6 RECEPTOR TESTS

CT_Recept-01 Impact to a Receptor

Test CT_Recept-01 computes the impact to a receptor in terms of hazard index, dose, and risk. Over the simulation, the concentration of S1 goes from 1 to 0, while S2 goes from 0 to 1.

The allowable concentration for S1 is 0.1g/m3, for S2 it is 0.2g/m3. Thus S1's HI should change from 10 down to 0, while S2's changes from 0 to 5.

The risk/concentration ratio for S1 is 1.0{(yr-1)/(g/m3)}; S2's is twice as much. Thus, the risk due to S1 should start at 1/yr and diminish to 0, while that for S2 should start at 0 and increase to 2/yr.

The Dose is calculated using a dose-conversion factor of 1e7(Sv/yr)/(g/m3) for S1, and twice as great for S2. The dose due to S1 should thus start at 1e7Sv/r and diminish to 0, while that due to S2 should start at 0 and increase to 2e7Sv/yr.

4.7 SOURCE TESTS

These problems test all aspects of the Sources, including associated cells linked to a source.

Basic Source Term Functionality

These test problems are specifically targeted at verifying the basic source term functionality, including distributing and releasing mass to specified associated cells, sources in localized containers, and simple release from associated cells. In all cases the test problem files are set up with a single, non-decaying species. Each of 10,000 packages is assigned an inventory of 1 g.

Distributing and Releasing Mass

These test problems verify that GoldSim distributes mass to and releases mass from specified associated cells.

CT_SourceBasic-01: Distribute Mass to Multiple Parallel Cells

In this problem, the mass at the source is exposed immediately and distributed evenly (in parallel) to four associated cells. Each of these cells in turn discharges to a different unassociated cell. The links between cells are all advective with very high flow rates small cell volumes and infinite solubility cell solubility limits, insuring immediate release.

The cumulative release from the source to each of the cells should be equal to 2500g. The final mass in each of the unassociated cells should equal 2500 g.

CT_SourceBasic-02: Distribute Mass to a Single Cell

This problem is identical to CT6-1, but the mass is only distributed to the first of the four associated cells.

The cumulative release to the first cell should be 10,000g. The final mass in the first unassociated cell should be 10,000g, and 0g in the other unassociated cells.

CT_SourceBasic-03: Distribute Mass to Four Cells in a Series

In this problem, the mass in the source is exposed immediately and distributed evenly to four associated cells, which are connected in series. Each of the associated cells is connected to a separate unassociated cell. Each of the first three associated cells releases half of its output to the next associated cell in series, and half to its unassociated cell. The final associated cell in the series releases all of its mass to its unassociated cell. The connections between cells are all advective with very high flow rates, small cell volumes and an infinite cell solubility limit, ensuring immediate release.

The mass in each of the four unassociated cells should be as follows:

Cell1: (0.5)(2500) = 1250 g

Cell2: (0.5)(2500 + 1250) = 1875 g

Cell3: (0.5)(2500 + 1875) = 2187.5 g

Cell4: 2500 + 2187.5 = 4687.5 g

CT_SourceBasic-04: Distribute Mass to First Cell in a Series

In this problem, the mass in the source is exposed immediately and distributed to a single associated cell. This cell discharges to three other associated cells connected in series. Each of the associated cells is connected to a separate unassociated cell. Each of the first three associated cells releases half of its output to the next associated cell in series, and half to its unassociated cell. The final associated cell in the series releases all of it mass to its unassociated cell. The connections between cells are all advective with very high flow rates, small cell volumes and an infinite cell solubility limit, insuring immediate release.

The mass in each of the four unassociated cells should be as follows:

Cell1: (0.5)(10,000) = 5000 g

Cell2: (0.5)(5000) = 2500 g

Cell3: (0.5)(2500) = 1250 g

Cell4: 1250 g

Releases from Associated Cells

CT_SourceBasic-05: Simple Advective Release from Associated Cells

In this problem a source discharges to a single associated cell. It tests the scaling of advective fluxes from associated cells. The source contains 10,000 packages which fail uniformly over 50 years. The cell contains 10 m^3 of water, which discharges at a rate of 4 m^3/yr. The solubility is specified as very small (such that release is linearly controlled by the advective release, which is in turn scaled by the number of failed containers). The simulation is run for 100 years. The time history of the source release rate should increase linearly with time, and become constant at 50 years.

The release rate from the source, M(t) [g/yr], at time t for an associated cell with a single media and a concentration above the saturation limit is computed as follows:

$$M(t)= Q*C_{sat}* NFail(t)$$

where:

Q = the flow rate of the advective connection [m^3/yr] = 4;

Csat = the saturation concentration for species A1 [g/ m^3] = 1E-6;

NFail(t) = the rate of container failure [-]
= 10,000/50*t = 200*t for 0 <= t <= 50;
= 10,000 otherwise.

M(10) = $(4\ [m^3/yr])*(1E\text{-}10\ [g/\ m^3])*(200*10) = 8.0E\text{-}7$ g/yr

M(20) = $(4\ [m^3/yr])*(1E\text{-}10\ [g/\ m^3])*(200*20) = 1.6E\text{-}6$ g/yr

M(50) = $(4\ [m^3/yr])*(1E\text{-}10\ [g/\ m^3])*(200*50) = 4.0E\text{-}6$ g/yr

Note that GoldSim results may be off at the third decimal place, since when a solubility limit is reached, the solubility can be fixed at 0.999 of the solubility limit.

CT_SourceBasic-06: Simple Diffusive Release from Associated Cells

This problem is similar to CT_BasicSource-5, but the associated cell is linked to a pipe diffusively. It tests the scaling of diffusive fluxes from associated cells. The diffusion parameters are defined such that the diffusive flux is small. The solubility is also specified as being small. As shown below, the time history of release from the associated cell should increase linearly with time, and become constant at 50 years.

For a diffusive link through a common fluid (with no porous media) from a cell to a pipe, the total mass flux can be calculated as follows, assuming that the cell concentration is above the solubility limit :

$$M(t) = D*Csat*NFail$$

$$D = \frac{A_c\, d}{L}$$

where:

d = the diffusivity for the species in water [m2/yr] = 0.03156;

A_c = the diffusive area [m2] = 1;

L = diffusive length in cell [m] = 0.1;

Csat = the solubility for the species[g/ m^3] = 1E-10;

NFail(t) = the rate of container failure [-]
= 10,000/50*t = 200*t for 0 <= t <= 50
= 10,000 otherwise.

M(10) = $(0.3156\ m^3/yr)*(1E\text{-}10\ g/\ m^3)*(200*10) = 6.312E\text{-}8$ g/yr

M(20) = $(0.3156\ m^3/yr)*(1E\text{-}10\ g/\ m^3)*(200*20) = 1.262E\text{-}7$ g/yr

M(50) = $(0.3156\ m^3/yr)*(1E\text{-}10\ g/\ m^3)*(200*50) = 3.156E\text{-}7$ g/yr

Note that GoldSim results may be off at the third decimal place, since when a solubility limit is reached, the solublity can be fixed at 0.999 of the solubility limit.

CT_SourceBasic-07: Scaling of Volumes and Masses in Associated Cells, High Solubility

This problem tests the scaling of media volumes and masses in associated cells. The source contains 100 packages, each containing a single gram of mass. A single associated cell contains 10 m^3 of water and 10 kg of sand. The partition coefficient between sand and water is equal to 1, such that the mass is partitioned equally between the two media. The solubility limit is equal to 0.5 g/ m^3.

The containers fail uniformly over 50 years. Hence, after 50 years, 100 g of mass is partitioned equally between 10 x 100 m^3 of water and 10 x 100 kg of sand (since the media volumes and masses are scaled with the number of failed packages). Similarly, after n years (n < 50), n g of mass is partitioned equally between 10 x n $m^3$of water and 10 x n kg of sand.

Because the associated cells are scaled, the solubility limit is not exceeded. The concentration in the water should be 0.5g * n/10 m^3*n = 0.05 g/ m^3, and the concentration in the sand should be 0.5g*n/10kg *n = 0.05 g/kg.

CT_SourceBasic-08: Scaling of Volumes and Masses in Associated Cells, Low Solubility

This problem is similar to CT_BasicSource-7, except that a very low solubility limit (1E-10 g/ m^3) is imposed. As a result, the concentration in the water in the associated cell should always be fixed at 1E-10 g/ m^3. All of the precipitated mass is assumed to be part of the solid. Hence, the concentration in the sand should be 1g*n/10kg*n = 0.1 g/kg.

CT_SourceBasic-09: Scaling of Volumes and Masses in Associated Cells, Excluded Cells

This problem ensures that cells are located in a container with a source, but are specified to not be associated with the source do not have their properties scaled.

The file contains two sources. Both sources contain 100 packages with 1g of mass in each package. The packages fail immediately and are connected to a single associated cell with 10 m^3 of water. The solubility of the species is very low (1E-10 g/ m^3).

In the first source(Source_A), the associated cell has two advective links: one to an unassociated cell in the source container, and a second to a cell outside the source container. Both of these cells have a very large volume (1E6 m^3), such that the solubility limit is not reached. The advective flow rate is 2 m^3/yr. Hence, the flux to each cell is (2 m^3/yr)(100 packages)(1E-10 g/ m^3) = 2E-8 g/yr. The concentration in the two cells should behave identically, increasing linearly, reaching (2E-6 g)/(1E6 m^3) = 2E-12 g/ m^3after 100 years (i.e., the unassociated cell in the source should not have it's volume scaled).

In the second source (Source_B), the associated cell has only a single link to an unassociated cell in the same container. This unassociated cell has a very small volume (1E-10 m^3), such that it is immediately saturated. It then discharges to a cell outside of the source container at a rate of 2 m^3/yr. The flux rate from the unassociated cell in the source container should be (1E-10 g/ m^3)(2 m^3/yr) = 2E-10 g/yr (i.e., the flux should not be scaled).

CT_SourceBasic-10: Scaling of Volumes and Diffusive Area, No Solubility Constraint

In this problem, the barriers fail uniformly over 5000 years. A single associated cell is connected to a single unassociated cell. Since the release from the associated cellis diffusive, the release will continue to rise linearly until equilibrium is reached, at which time the release will remain constant. There is no solubility constraint, no porous medium, and no resistance in the unassociated cell.

The governing equations are listed below:

$$M_{1s} = D_{cs}*(-P_{1,Water,e}*m_{1s} + P_{2,Water,e}*m_{2s}) + Nfail \ (1g)$$

$$M_{2s} = D_{cs}*(P_{1,Water,e}*m_{1s} - P_{2,Water,e}*m_{2s})$$

where

NFail = 2 yr-1 for 0 <= t <= 5,000 yr;

$P_{1,Water}$ = 1/(1*NFail) m-3 for cell 1;

$P_{2,Water}$ = 1/(1*10,000) = 1e-4 m-3 for cell 2;

m_0 = 0 for both cell 1 and cell 2.

The diffusive conductance, D_{cs}, increases linearly with time between 0 and 5000 years:

$$D_{cs} = \frac{NFail\ A_c\ d}{L}$$

where:

d = the diffusivity for the species in water [m2/yr] = 0.03156;

A_c = the diffusive area [m2] = 0.01;

L = diffusive length in cell [m] = 0.1;

The solution (reached using Matlab) is as follows:

Acell1

Medium	Am-241 (g/m^3)
WATER	
time = 100	8.59E-1
time = 1000	3.70E-1
time = 4000	4.59E-1
time = 10,000	5.00E-1

Cell 1

Medium	Am-241 (g/m^3)
WATER	
time = 100	2.84E-3
time = 1000	1.26E-1
time = 4000	4.33E-1
time = 10,000	5.00E-1

Number of Packages

CT_BasicSource-11: Stochastic Number of Packages

This test ensures that the number of packages can be specified stochastically, and that the number of packages can be specifed as zero. In the test, all packages fail immediately. The number of packages is specified as a function. The function is defined as follows:

If(Packages>1, Packages, 0)

"Packages" is a stochastic, defined as a uniform distribution between -100 and 100. Hence, about half of the time, the number of packages will be 0. The remainder of the realizations will be between 1 and 100.

N_Packages should be compared to Failed_Packages. Failed_Packages should be a rounded version of N_Packages. Furthermore, the cumulative amount of mass exposed should be equal to zero for those realizations in which the number of packages is zero.

Barrier Failure

Simple Outer Barrier Failure

All of these problems were run for 10,000 years, with 10,000 packages and 1 g of species in each package.

CT_SourceBarriers-1: Outer Barrier Failure with Multiple Weibull Modes

In this test, all of the mass is in the outer fraction, and there are three Weibull failure modes:

Mode	Probability	Mean Lifetime (yrs)	Slope
1	0.75	4000*0.8862	2
2	0.25	5000*0.8862	2
3	0.00	5000	2

The cumulative amount exposed should be:

$$\text{Exposed} = \text{NWP} * \left[1 - \prod_{i=1}^{N} \left(1 - P_i * F_i(10{,}000) \right) \right]$$

where:

Exposed	=	cumulative amount of mass exposed (g),
NWP	=	total number of packages,
$F_i(10{,}000)$	=	cumulative probability of failure mode i by time 10,000,
P_i	=	fraction of packages which can fail by mode, and
N	=	number of failure modes = 3.

$F_i(10{,}000)$ is simply the integral (from 0 to 10,000) of the failure distribution for mode i. For the purposes of this verification, this integration was computed by creating a Weibull stochastic, and viewing that Cumulative Probability at a level of 10,000. Note that since only an integral number of primary containers can fail, the value is rounded. In this case, the total exposed mass is equal to 8103g (10,000 – 8103).

CT_SourceBarriers-2: Outer Barrier Failure with Multiple Uniform Modes

This test is identical to CT_SourceBarriers-1, except that it uses three uniform failure modes:

Mode	**Probability**	**Duration (yrs)**
1	0.75	5000
2	0.25	6000
3	0.00	6000

The total exposed mass is equal to 8125 g.

CT_SourceBarriers-3: Outer Barrier Failure with Multiple Exponential Modes

This test is identical to CT_SourceBarriers-1, except that it uses three exponential failure modes:

Mode	**Probability**	**Expected Lifetime (yrs)**
1	0.75	4000
2	0.25	5000
3	0.00	5000

The total exposed mass is equal to 7558 g.

CT_SourceBarriers-4: Outer Barrier Failure with Multiple Degenerate Modes

This test is identical to CT_SourceBarriers-1, except that it uses three degenerate failure modes:

Mode	Probability	Start Time (yrs)
1	0.75	4000
2	0.25	5000
3	0.00	5000

The total exposed mass is equal to 8125 g.

CT_SourceBarriers-5: Outer Barrier Failure with Mixed Modes: Weibull and Exponential

This test is identical to CT_SourceBarriers-1, except that it uses two mixed failure modes:

Mode	Type	Probability	Mean Lifetime (yrs)	Slope
1	Weibull	0.75	4000*0.8862	2
2	Exponential	0.25	4000	NA

The total exposed mass is equal to 8063 g.

CT_SourceBarriers-6: Outer Barrier Failure with Mixed Modes: Uniform and Exponential

This test is identical to CT_SourceBarriers-1, except that it uses two mixed failure modes:

Mode	Type	Probability	Mean Lifetime (yrs)	Duration (yr)
1	Exponential	0.75	4000	NA
2	Uniform	0.25	5000	NA

The total exposed mass is equal to 7663 g.

Simple Inner Barrier Failure

CT_SourceBarriers-7: Inner Barrier Failure with Multiple Weibull Modes

This test is identical to CT_SourceBarriers-1, except that all mass is placed inside the inner barrier, the failure distributions are defined for the inner barrier, and the outer barrier fails immediately.

Note that because inner barriers are not discretized, the result is not truncated. The total exposed mass is equal to 8102.63g .

CT_SourceBarriers-8: Inner Barrier Failure with Multiple Uniform Modes

This test is identical to CT_SourceBarriers-2, except that all mass is placed inside the inner barrier, the failure distributions are defined for the inner barrier, and the outer barrier fails immediately.

The total exposed mass is equal to 8125 g .

CT_SourceBarriers-9: Inner Barrier Failure with Multiple Exponential Modes

This test is identical to CT_SourceBarriers-3, except that all mass is placed inside the inner barrier, the failure distributions are defined for the inner barrier, and the outer barrier fails immediately.

Note that because inner barriers are not discretized, the result is not truncated. The total exposed mass is equal to 7557.86 g .

CT_SourceBarriers-10: Inner Barrier Failure with Multiple Degenerate Modes

This test is identical to CT_SourceBarriers-4, except that all mass is placed inside the inner barrier, the failure distributions are defined for the inner barrier, and the outer barrier fails immediately.

Note that because inner barriers are not discretized, the result is not truncated. The total exposed mass is equal to 8125 g.

4.8 SOURCE TESTS: ADVANCED OUTER AND INNER BARRIER FAILURE

CT_SourceBarriers-11: Outer Barrier Failure with Start Time

In this problem, all of the mass is in the outer fraction, and the outer barrier has a single uniform failure mode with a duration of 10,000 years (the same as the simulation length). The effective time is defined such that the failure mode does not start until 1050 years:

Effective Time = Max(0{yrs}, Time-1050{yrs})

This should result in the failure of 8950 packages, and a total of 8950g of exposed mass.

CT_SourceBarriers-12: Outer Barrier Failure with Accelerated Failure Rate

In this problem, all of the mass is in the outer fraction, and the outer barrier has a single uniform failure mode with a duration of 10,000 years (the same as the simulation length). The failure rate is accelerated between years 1000 and 3000 by defining the effective time as follows:

Effective Time = Cumulative_Time

where Cumulative_Time is a Integrator, with an initial value of 0 yrs, and a rate defined as:

Rate of Change = If(time<1000{yrs} OR time>3000{yrs}, 1, 2)

This should result in a time history of failure in which 1000 packages have failed by 1000 years, 4900 have failed by 3000 years, and all of the packages have failed by 8000 years.

CT_SourceBarriers-13: Inner Barrier Failure Linked to Outer Barrier Failure

This problem is identical to CT_SourceBarriers-11, except all of the mass is assigned to the inner fraction, the outer barrier fails according to a degenerate distribution at 1050 yrs, and the inner barrier failure is linked to the outer barrier. This should result in a total of 8950g of exposed mass.

CT_SourceBarriers-14: Inner Barrier Failure with Start Time, Exposure Delayed by Outer Barrier

This problem is identical to CT_SourceBarriers-13, except that the inner barrier is not linked to the outer barrier, and is assigned a start time of 0. As a result, at time = 1100 yrs (the next timestep after the outer barrier fails), the cumulative amount of mass exposed is 1100g. It then increases linearly, such that at 5000 yrs, 5000 g have been exposed, and at 10,000 yrs, 10,000g have been exposed.

CT_SourceBarriers-15: Inner Barrier Failure with Start Time

This problem is similar to CT_SourceBarriers-14, except that the inner barrier is not linked to the outer barrier, and is assigned a start time of 1050yrs. The outer barrier fails immediately. This should result in a total of 8950g of exposed mass.

<u>User-Defined Outer and Inner Barrier Failure</u>

CT_SourceBarriers-16: Outer Barrier Failure with Multiple User-Defined Modes

This problem is identical to CT_SourceBarriers-2, except that the uniform failure rate is specifed using a User-Defined failure mode. The fraction failed is specified as follows:

Fraction Failed = If(time<=Duration, time/Duration,1)

The total exposed mass should be the same as in CT_SourceBarriers-2 (8125 g).

CT_SourceBarriers-17: User-Defined Outer Barrier Failure Defined by a Table

In this problem, all of the mass is in the outer fraction, and the outer barrier has a single user-defined failure mode. The failure mode is defined using a 1D Table as follows:

Time	**Fraction Failed**
0	0
1000	0
6000	0.5
10000	1

The cumulative release should be 0 at time = 1000 yrs, 5000g at time = 6000 yrs, and 10,000 g at time =10,000 yrs.

CT_SourceBarriers-18: Inner Barrier Failure with Multiple User-Defined Modes

This test is identical to CT_SourceBarriers-16, except that all mass is placed inside the inner barrier, the failure distributions are defined for the inner barrier, and the outer barrier fails immediately.

The total exposed mass is equal to 8125 g.

CT_SourceBarriers-19: User-Defined Inner Barrier Failure Linked to Outer Barrier Failure

This problem is identical to CT_SourceBarriers-13 (in which the outer barrier fails at 1050 yrs), except that the uniform failure rate for the inner barrier is specifed using a User-Defined failure mode. The fraction failed is specified as follows:

Fraction Failed = If(time<=10000, time/10000,1)

Theoretically, this should result in a total of 8950g of exposed mass. However, because user-defined distributions are only computed at the discrete timesteps, the barriers are assumed to fail over the entire timestep, rather than just a fraction of a timestep. Hence, 9000 g of mass are exposed.

CT_SourceBarriers-20: User-Defined Inner Barrier Failure Not Linked to Outer Barrier, but Exposure Delayed by Outer Barrier

This problem is identical to CT_SourceBarriers-19, except that the inner barrier is not linked to the outer barrier, and hence begins failing immediately. As a result, at time = 1100 yrs (the next timestep after the outer barrier fails), the cumulative amount of mass exposed is 1100g. It then increases linearly, such that at 5000 yrs, 5000 g have been exposed, and at 10,000 yrs, 10,000g have been exposed.

CT_SourceBarriers-21: User Defined Inner Barrier Failure Not Linked to Outer Barrier

In this problem, the outer barrier fails immediately, and the user-defined inner barrier failure rate is defined as follows:

Fraction Failed = If(time<1050, 0, (time-1050)/10000)

This should result in a total of 8950g of exposed mass.

CT_SouceBarriers-22: Uniform Outer Barrier Failure with Rounding/Truncating Failure Times

In this problem, the outer barriers of ten packages fail uniformly over 100 years according to a uniform distribution. The user should test the option (Model/Options/Mass Transport) to round versus truncate the failure times.

With rounding the packages should fail at 5, 15, 25… 95 years. With truncation they should fail at 10, 20, 30… 100 years.

CT_SouceBarriers-23: Outer Barrier Failure with Multiple Weibull Modes and Disruptive Event

This test is identical to CT_SourceBarriers-01, except that there is a defined disruptive event which occurs and fails 1,000 packages suddenly at 2,000 years.

The Tester should confirm that both the number of failed packages and the cumulative mass exposed jump by 1,000 at 2,000 years.

Sampled Failure Modes

CT_SourceSampledFailure-1: Uniform Outer Barrier Failure with Random Failures

In this problem, the outer barriers of 10,000 packages fail uniformly over 100 years according to a uniform distribution. Failure is simulated by assuming a random failure time. Five realizations are carried out.

All five realizations for the time history of the number of failed packages (Failed_Packages) should have nearly the same shape: a relatively straight line from 0 to 10,000. Table view, however, should indicate that the curves are not identical.

Failure Using an External Table

All of these problems were run for 100 years with 100packages and 1 g of species in each package. They all use an external table defined as follows:

time(yr)	fraction
1	0
2	0.01
5	0.1
10	0.2
25	0.3
50	0.5

CT_SourceTableFailure-01: Outer Barrier Failure using an External Table

In this test, all mass is in the outer fraction, and there is a single external table outer failure mode. The probability of failure is 0.5.

The cumulative amount exposed should be 50 g x 0.5 = 25 g at time 50 yrs.

CT_SourceTableFailure-02: Inner Barrier Failure using an External Table

In this test, all mass is in the inner fraction, and there is a single external table inner failure mode. The probability of failure for the inner barrier is 0.5. The outer barrier fails immediately (probability of failure = 1.0).

The cumulative amount exposed should be 25 g at time 50 yrs.

CT_SourceTableFailure-03: Outer Barrier Failure using an External Table with a Start Time

This test is identical to CT_SourceTableFailure-01, except that the failure mode does not begin until 20 years:

Effective Time = Max(0{yrs}, ETime - 20{yrs})

The cumulative amount of mass exposed should be 25 g at time 69 yrs.

CT_SourceTableFailure-04: Outer Barrier Failure using an External Table with Decelerated Failure

This test is identical to CT_SourceTableFailure-01, except that the failure mode is decelerated after 25 years as follows:

Effective Time = Cumulative_Time

where Cumulative_Time is a Integrator, with an initial value of 0 yrs and a rate defined as:

Rate of Change = if(Time< 25 {yrs}, 1, 0.5)

At time 25 yrs, the amount of exposed mass is (fraction from table)(original mass)(probability of failure) = (0.3)(0.5)(100) = 15 g. After time 49 yrs, the amount exposed is 15g + (0.5)[(0.5-0.3)*100g] = 25g.

CT_SourceTableFailure-05: Inner Barrier Failure using an External Table with Inner Linked to Outer

This test is similar to CT_SourceTableFailure-02, except that the probability of inner failure is 1 and the inner barrier failure is linked to outer barrier failure. The outer barrier fails immediately at 50 years.

Under these conditions, GoldSim would actually start the failure in the middle of the previous timestep (i.e., at 49.5 years). This results in 50.5 years of failure. During the first years of the distribution, 50 g are exposed. During the last 50 years, 0.4g/yr is exposed. As a result, 50.5 years of failure results in a total of 50.4 g being exposed. The verifier should ensure that the cumulative amount to Cell A1 is 50g at 100 years.

CT_SourceTableFailure-06: Inner Barrier Failure using an External Table with Inner Delayed by Outer

This test is identical to CT_SourceTableFailure-05, except that rather than being linked to the outer barrier, the inner failure mode starts immediately. The outer barrier, however, does not fail until 50 years. At Time = 50 yrs, 50 g should be exposed immediately.

CT_SourceTableFailure-07: Outer Barrier Failure using an External Table with Random Failures

This test is identical to CT_SourceTableFailure-01, except that failure is simulated assuming a random failure time. Five realizations are carried out.

All five realizations should have roughly the same shape, and approximately 25 g (say, between 22 and 28g) should be exposed by 50 yrs. The curves, however, should not be identical (due to the random sampling).

<u>Source Term Exposure Rates</u>

CT_SourceExposure-1: Bound Exposure with Slow Degradation Rate

In this problem, all mass is assigned to the bound fraction, and the outer and inner containers fail immediately. Exposure is therefore controlled by the matrix degradation rate. Analytically, the release rate can be computed as follows:

$$\text{cumulative release} = \int_{t=0}^{10,000} N_c \times M_{uu}(t) \times k \times I_b(t)\, dt$$

where:

N_c = number of containers = 10,000;
$I_b(t)$ = bound inventory of a single container = 1 g;
$M_{uu}(t)$ = fraction of unprotected, unaltered matrix; and
k = fractional degradation rate of the matrix = 4.75E-5 yrs-1.

In this example, since all of the containers fail instantaneously, $M_{uu}(t)$ can be expressed as follows:

$$M_{uu}(t) = \exp(-kt)$$

GoldSim assumes that degenerate failures occur in the middle of the timestep (i.e., the barriers cannot fail at time = 0). Hence, the matrix only degrades for 9950 years. The cumulative release is:

$$\text{cumulative release} = -N_c \times e^{-kt} \times I_b \Big|_0^{9950} = 3766\,\text{g}$$

CT_SourceExposure-2: Bound Exposure with Delayed Inner Barrier Start Time

This problem is identical to CT_SourceExposure-1, except that the inner barrier does not fail until TIME = 2,050 yr. This results in 7950 yrs of release. The analytical solution for the problem is:

$$\int_0^{8,000} Muu\,(k)\,(I)\,(Nc) = -(I)\,(Nc)\,e^{-kt} \Big|_0^{7950} = 3,145\text{ g}$$

CT_SourceExposure-3: Bound Exposure with Uniform Outer Failure Distribution

This problem is similar to CT_SourceExposure-1, except that rather than failing the primary containers immediately, they all failed uniformly over 10,000 yr. Under these circumstances, the solution for for $M_{uu}(t)$ is as follows:

$$M_{uu}(t) = \frac{g}{k}\left(1 - e^{-kt}\right)$$

The term g is the rate at which the matrix becomes unprotected (equal to a constant value of 1/10,000 in this problem).

Hence, the cumulative release is:

$$\int_0^{10,000} Muu\,(k)\,(I)\,(Nc) = (I)\,(Nc)(g\,t \;+\; \frac{g}{k}\; e^{-kt})\Big|_0^{10,000} = 2040\text{ g}$$

CT_SourceExposure-4: Multiple Inventory Exposure

The outer containers for this test fail uniformly over 500 to 1,500 years, and the inner fail uniformly over 500 years, starting when the outer containers fail. There are four inventories, with each having a total of 1,000g of a unique species:

1. The first inventory is ‘free’, and so is simply released uniformly as the outer containers fail, over 500 to 1,500 years.
2. The second inventory is bound in a waste matrix, in the ‘outer’ region. Its decay rate is 0.00139/year (half-life of 500 years). The release curve for this inventory should start at time 500, and follow inventory 1 but lagging with a half-life of 500 years.
3. The third inventory is in the ‘gap’, should start to be exposed at 1,500 years, and should lag inventory one by a variable amount never greater than 2,000 years, the time for all inner containers to fail.
4. The fourth inventory is bound in a matrix within the inner container. The matrix decays at 0.000693/year. The release curve for this inventory should lag that of the third inventory, with a half-life of 1,000 years.

The Verifier should display a time-history of releases plot, and confirm visualy that each inventory’s pattern matches the description above.

CT_SourceExposure-5: Congruent Dissolution of the Waste Matrix

10% of the matrix mass (100g) should be dissolved when the container fails, at 10+ years. After that the balance should dissolve at 100g/yr over 9 years until it is all dissolved. The concentration will then start to drop exponentially as the Cell is flushed.

The contaminant should follow the same path, but with one thousand times lower values. Some overshoot of the dissolved concentration is expected at early times, by a few percentage points, because slightly more matrix is 'dissolved' than the minimum required to reach the solubility limit.

The verifier should run the model and compare the results in the MatrixResults and ContResults plots to Figure CT_SourceExposure-5a and CT_SourceExposure-5b below.

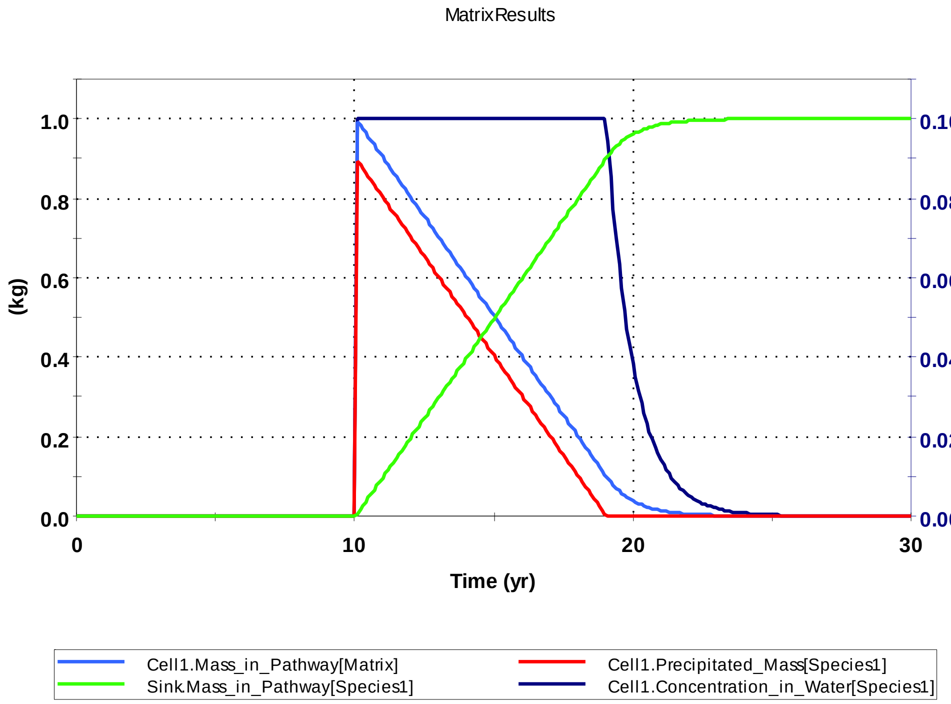


Figure CT_SourceExposure-5a

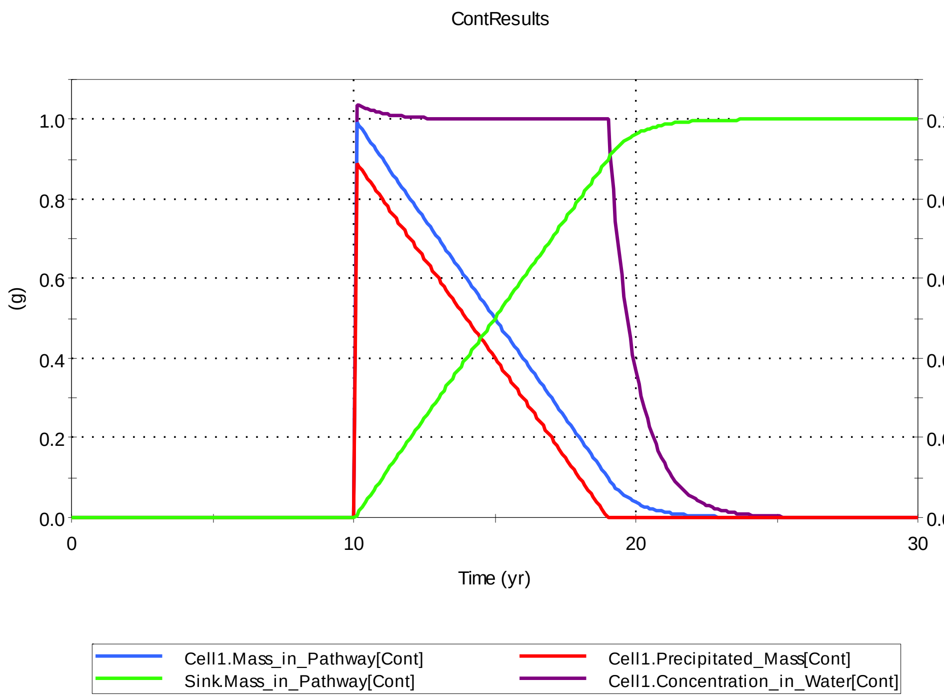


Figure CT_SourceExposure-5b

Decay Within Sources and Associated Cells

CT_SourceDecay-1: Decay within a Source

In this problem, the decay chain starting with Am-241 is examined. Mass is exposed and then released instantaneously from the containers at TIME = 1,000. Therefore, the problem is simply looking at decay within the source over the first 1,000 yr. Am-241 decays to Np-237. To test split decay, two daughters are specified for Np-237, each recieving 50% of the mass. U-233 and V-233 each have identical properties.

The analytical solutions for Am-241, Np-237, U-233 and V-233 are as follows:

$$M(\text{Am-241}) = M_0(\text{Am-241})\, e^{-k_1 t}$$

$$M(\text{Np-237}) = \frac{M_0(\text{Am-241})\, \frac{AW(\text{Np-237})}{AW(\text{Am}-241)} k_1\ A_2}{(k_2 - k_1)\ A_1} \left[e^{-k_1 t} - e^{-k_2 t}\right]$$

$$M(\text{U-233}) = \frac{A_3\ k_1\ k_2\ M_0(\text{Am-241}) \frac{AW(\text{U}-233)}{AW(\text{Am-241})}}{A_1} \times$$

$$\left[\frac{e^{-k_1 t}}{(k_2 - k_1)(k_3 - k_1)} + \frac{e^{-k_2 t}}{(k_1 - k_2)(k_3 - k_2)} + \frac{e^{-k_3 t}}{(k_1 - k_3)(k_2 - k_3)}\right]$$

where:

k1	=	decay rate for Am-241 = 1.603E-03 yr-1,
k2	=	decay rate for Np-237 = 3.238E-07 yr-1,
k3	=	decay rate for U-233a and b = 4.372E-06 yr-1,
M_0(Am-241) = Curies of Am-241 at TIME 0 = 10,000,		
AW	=	atomic weight (amu), taken as 241, 237 and 233 respectively,
A1	=	specific activity of Am-241 = 3.44 Ci/g,
A2	=	specific activity of Np-237 = 7.06E-04 Ci/g, and
A3	=	specific activity of U-233 = 9.69E-03 Ci/g.

Note that within the source, the mass that is released during a timestep is only decayed for half of that timestep. A 10 year timestep is used in this case. Using t = 995 yr and the above constants, the results for "exposed mass" are 2,029 Ci for Am-241, 1.610 Ci for Np-237, and 2.194E-03 Ci for U-233 and V-233. The associated cell, however, decays the mass for the balance of the timestep in which it is received (990 to 1000yrs). As a result, the mass in the cell at 1000 yrs should equal the exact solution of 2,012.9 Ci for Am-241, 1.613 Ci for Np-237, and 2.212E-03 Ci for U-233 and V-233.

This model should be run in two ways. In the first run, U233 should have no daughters. Run the test and confirm the results are close to the exact results.

In the second run, make Am241 a daughter of U233, with a stoichiometry factor of zero. Repeat the test. (This tests the full-matrix iterative solver).

4.9 SOURCES AFFECTED BY DISRUPTIVE EVENTS

CT_SourceEvent-01

This file ensures that Source Elements function properly when waste-container failure is induced by a disruptive event. The file contains four tests:

Test Containers Test1 and Test1a - 500 waste containers fail normally at 10 days, and 450 more due to the disruptive Discrete Change at 15 days. The first 500 containers release 500 grams gradually over 3 days as their inner barriers fail uniformly. The disruptive Discrete Change should immediately release an additional 450 g from the disrupted inner barriers. The total mass released is 950g. Note that the difference between the tests in Containers 1 and 1a is simply that in Test1 a condition-triggered Discrete Change Element is used to disrupt the Source, whereas in Test1a a Timed Event is used to trigger the Discrete Change Element. The results for both test Containers should be essentially identical.

Test Containers Test2 and Test2a - 500 waste containers fail normally at 10 days, and 450 more due to the disruptive Discrete Change at 15 days. There is no release due to the initial failures, as the inner barriers do not fail unless disrupted. The Discrete Change should immediately cause the release of 900 grams from the inner containers of the failed packages. Note that the difference between the tests in Containers 2 and 2a is simply that in Test2 a condition-triggered Discrete Change is used to disrupt the Source, whereas in Test1a an Timed Event is used to trigger the Discrete Change. The results for both test Containers should be essentially identical.

4.10MISCELLANEOUS CONTAMINANT TRANSPORT TESTS

CT_Clone3: Cloned CT Models

The purpose of this file is to ensure that cloned environmental elements work properly.
This file contains a simple model made up of Source, Pipe, Cell, and Receptor Elements. The original model is contained in Buried_Drum_Example. The entire model has been cloned and is contained in Buried_Drum_Example_1. Tests include the following:

1. First, run the model to see results. The dose received by Receptor1 is of interest. The time history of the dose for the cloned receptor should be the same for the original model (it is assumed that the calculated results are accurate based on separate verification tests for the contaminant-transport elements). Expected results for this test are shown in Figure CT_Clone3.1.

2. Next, in one version of the model (either the original or the clone), change/edit an element (e.g., the number of source packages;). Re-run the model. Results for the original model and the clone should still be identical, although the results will likely be different from the previous model run(s). Repeat by changing several more elements.

3. Make sure to undo changes, then re-save the model file.

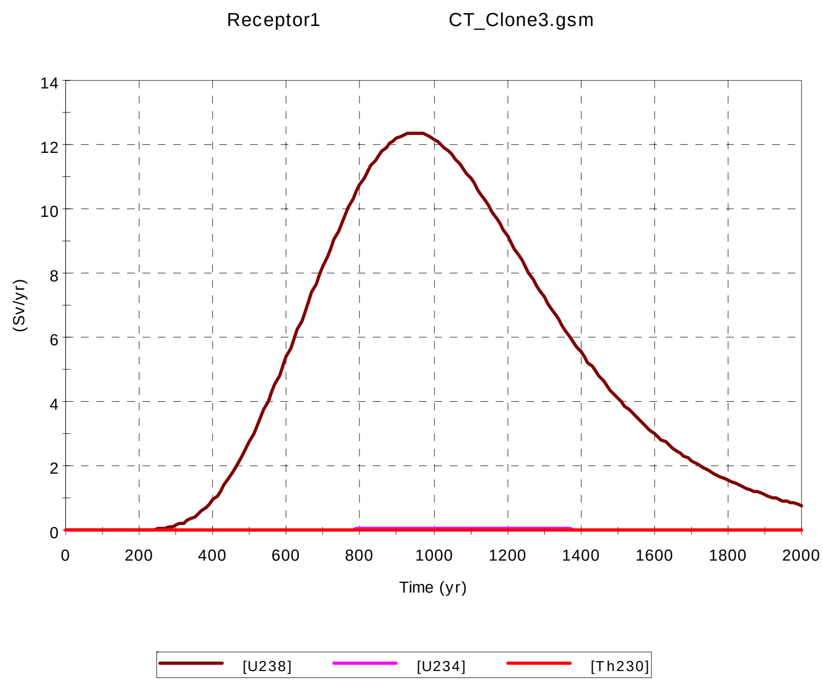


Figure CT_Clone3.1. Expected results for Receptor1 for the initial test.

CT_Timestep: Variable Timesteps for CT Elements

This file verifies that GoldSim models containing contaminant-transport elements run correctly when variable timesteps are used. Run the model to see results. Expected outputs are obtained by running the same models with uniform timesteps. The results using uniform timesteps are assumed to be accurate based on separate verification of the Cell and Pipe Pathway Elements. Tests include the following:

1. A test to verify that a model based on cell pathways within a container runs properly when variable timesteps are defined. The timestep phases are 0 - 1000 days (0.938-day step); 1001 - 10000 days (1.88-day step); and 10000 - 30000 days (15-days step). Model_with_Cells is the model of interest. Expected results for the Pond and Outflow_Stream elements are shown in a table in the file and in Table CT_TIMESTEP.1.

2. A test to verify that a model based on a pipe pathway within a container still functions properly when variable timesteps are used. Model_with_Pipe is the model of interest. Expected results for the GW_Discharge element is shown in a table in the file and in Table CT_TIMESTEP.2.

Table CT_TIMESTEP.1 (Elements Pond and Outflow_Stream)

Day	Pond	Outflow_Stream

	Mass of Species A (g)	Concentration of Species A (mg/l)	Mass of Species A (g)	Concentration of Species A (mg/l)
1	10	1 x 10^{-5}	0	0
3,615			6.6 x 10^{-2}	6.6 x 10^{-4}
30,000	0	0	0	0
	Declines exponentially with time		Curve shape resembles a lognormal distribution with peak at 3615 days	

Table CT_TIMESTEP.2 (Element GW_Discharge)

Day	Mass of Species A (g)	Concentration of Species A (mg/l)
2,750	2.0 x 10^{-4}	2.0 x 10^{-7}
6,400	151	0.151
30,000	2.7 x 10^{-1}	2.7 x 10^{-4}
	Curve shape resembles a lognormal distribution with peak at 6375 days	

CT_Conditionality1: CT elements inside conditional containers

This file verifies that environmental elements function properly inside of conditional containers. An environmental model resides inside Container1, which is an unconditional container. The same model has been cloned and placed inside of
Container2, which is a conditional container that activates at a time of 100 years. Run the model. The time history for the result element CiPlot should be identical for both models, but the time history for the model in Container2 should be delayed by 100 years.

CT_Plume

This file verifies the plume function. The test problem considers several combinations of source and aquifer geometry for a dissolved-contaminant groundwater plume. Other input parameters for the plume function are contained in the test file. GoldSim's plume function is verified by comparing results to those obtained from TPlume (Golder 1991), which uses the Domenico and Robbins (1985) solution.

The test proceeds as follows. Run the model. View the results shown in **Table CT_PLUME_FUNCTION_1** below and ensure that the results match the expected GoldSim results.

Table CT_PLUME_FUNCTION_1

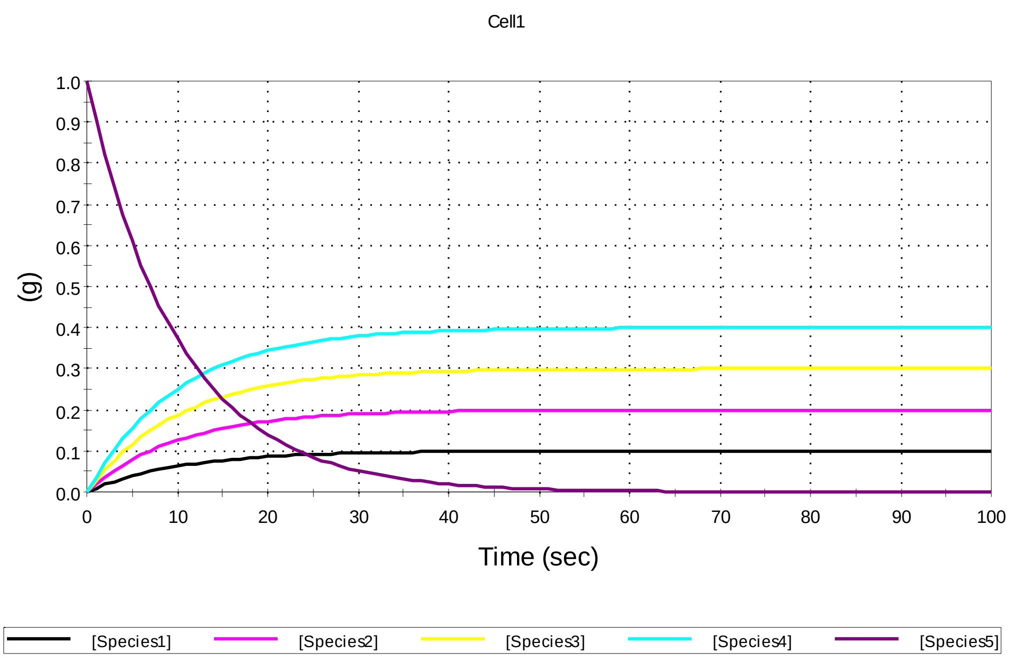
Container	Element	Expected GoldSim output at 1,000 days (g/m^3)	TPlume value at 1,000 days (g/m^3)
PointSource_ThickAquifer	XConc	0.0154	0.0154
PointSource_ThinAquifer	XConc	0.0461	0.0477
AreaSource_ThickAquifer	XConc	0.0154	0.0153
AreaSource_ThinAquifer	XConc	0.0462	0.0478

The verifier should also ensure that the Vector_Check Expression element replicates the results from each container in a vector format (it performs an identical calucation by combining the source thickness, source width, acquifer thickness and concentration into vector inputs to a vector-type plume function).

Notes:
1. GoldSim differs from TPlume for the thin-aquifer case because GoldSim has a more accurate solution for thin aquifers (i.e., reflections vs. assumed vertical mixing).
2. The assumed source geometry is a point source at the groundwater table (PointSource), or a vertical rectangle with a depth equal to half the width, oriented perpendicular to the flow direction, and with the top at the groundwater table.
3. The observation point for the concentration is 50 m downgradient from the source, 25 m off the plume centerline horizontally, and 10 m below the groundwater table (i.e., x = 50m, y = 25m, and z = 10m).
4. This verification includes no decay or retardation.

CT_Decay_4: Four Daughter Products for CT Species

This file verifies that four daughter products are correctly produced by the decay calculations in the Cell and in the Pipe element. The parent is Species5, and the four daughters are produced at the same rate (0.1 sec^{-1}) but with different stoichiometry. The resulting mass-time charts should look like the following figure:



CT_Locking_and_Sealing

This file verifies that CT elements behave properly inside sealed or locked containers. This file does not verify sealed and locked containers (see the GoldSim User Interface test). The test proceeds as follows:

1. Seal the container named CT_Elements.

2. Enter CT_Elements. Open the properties dialog for each element, and then click in each field and try to edit the field. Be sure to open each tab and click each expansion button in the properties dialog. Each time, a message box should appear stating that the container is sealed, and asking if you want to continue and break the seal. Click “No” to cancel the action each time. Note if any fields are alterable.

3. Remove the seal and then lock the container CT_Elements.

4. Enter CT_Elements. Open the properties dialog for each element. Within each, explore all of the properties tabs and expansion buttons. None of the fields should be active (i.e., they should all be “greyed out”). The only active button on any dialogs should be the Close button. Note if any fields are active.

5. The inputs and outputs for each CT element should also be inactive. Verify this by trying to access them via the element’s input and output ports (Exception: you should be able to invoke the link cursor from an output and make a link to the input of an element outside the container CT_Elements. Try this by attempting to link to Data4 outside the container).

6. Unlock the container and save the file.

CT_MeshGenerator

This file verifies the correct functioning of the CT CellNet Generator. There are four mesh tests, and the verifier should follow this procedure for the four CellNet Generator elements in the test:

1. Delete any existing cell elements in the container housing the CellNet Generator.
2. Open the property dialog for the CellNet Generator being tested and click the “Generate Cells” button.
3. Verify that the generated network corresponds with the expected characteristics pasted in the container. Repeat the test with the orientation of the generated cells rotated (so that the direction that was horizontal is now vertical). Confirm the result again with the rotated network.

CT_Species_Import_Elements

This test verifies that the Species spreadsheet import functions are working correctly, and also checks to ensure that the Elements array label set functions correctly.
There are four spreadsheet import functions - Replace All, Update Only, Add & Update, and Add Only.
To run the test open the CT_Species_Import.gsm file and proceed through the following steps:
1. Go to the Species element. Delete all of the species except for the first (Ag). Go to the Array Labels dialog and ensure that the Elements list has been updated so that it only shows Ag. Import species information from CT_Species_Import.xls. Select Replace All. View the Elements array label set again, and ensure it has been updated to show Ag, Am, Np, and Pu. Exit the Species element’s property dialog and run the model.
2. Change to edit mode and go to the Species element. Delete all of the species except for the first (Ag). Import species information from CT_Species_Import.xls. Select Add Only. Exit the Species element’s property dialog and run the model.
3. Return to edit mode and reopen the Species element. Edit all of the species - change the Isotope flag, daughter products, molecular weights, decay rates and daughter products. Import species data from Excel using an Update only operation (the Replace All, Add Only and Add &

Update import options should be greyed out). Exit the Species element's dialog and run the model.
4. Change to edit mode and open the Species element and delete the two Americium species. Check that this is reflected in the Elements array label set. Edit the remaining species - change the Isotope flag, daughter products, molecular weights, decay rates and daughter products. Import species information from CT_Species_Import.xls (select the Update Only option). No species should be added and the verifier should ensure the Elements array label set is unchanged. Close the dialog and run the model .
5. Return to edit mode and reopen the species element. Import species information from CT_Species_Import.xls (select the Add Only option). The two Americium species should be added to the Species list and Am should be added to the Elements list. Close the Species element's dialog and run the model.
6. Change to edit mode, open the Species element and delete the two Americium species. Edit the remaining species - change the Isotope flag, daughter products, molecular weights, decay rates and daughter products. Import species information from CT_Species_Import.xls (select the Add and Update option). The two Americium species should be added to the species list and Am should be added to the Elements list.
7. Return to edit mode, open the species element and attempt to import CT_Bad_Import_Data.xls. GoldSim should not crash, but you should be prevented from running the model.

CT_Species_Import_Export

This test verifies the correct export and import of species data to and from Microsoft Excel. The test is in two parts: the first verifies that these features function correctly for species data specified using decay rates, and the second verifies that the features function correctly for species data specified using half-lives.

1. Open the file called CT_Species_Import_Export_Decay.gsm. Open the Species element's property dialog and export species data to a new spreadsheet called Export_Decay.xls. To verify that the data was correctly exported, import the data (using an Update All operation) back into the species element. Run the model and ensure the Cell1_Plot and Cell2_Plot correspond with the graphs pasted in the model.

2. Return to edit mode. Switch the drop down in the species element so that decay is now specified using half-lives. Try to run the model. The model should not run.

3. Open the file called CT_Species_Import_Export_HL.gsm. Open the Species element's property dialog and export species data to a new spreadsheet called Export_HL.xls. To verify that the data was correctly exported, import the data (using an Update All operation) back into the species element. Run the model and ensure the Cell1_Plot and Cell2_Plot correspond with the graphs pasted in the model.

4. Return to edit mode. Switch the drop down in the species element so that decay is now specified using decay rates. Try to run the model. The model should not run.

CT_Polymorphic

This test verifies the correct functioning of polymorphic inputs to media elements. It consists of four model files, with each model file defining media properties using a different combination of species/element property vectors and solubility units. Each model file should produce identical results.

The verifier should ensure that the Result element agrees with the plot in Figure CT_Polymorphic-1 below.

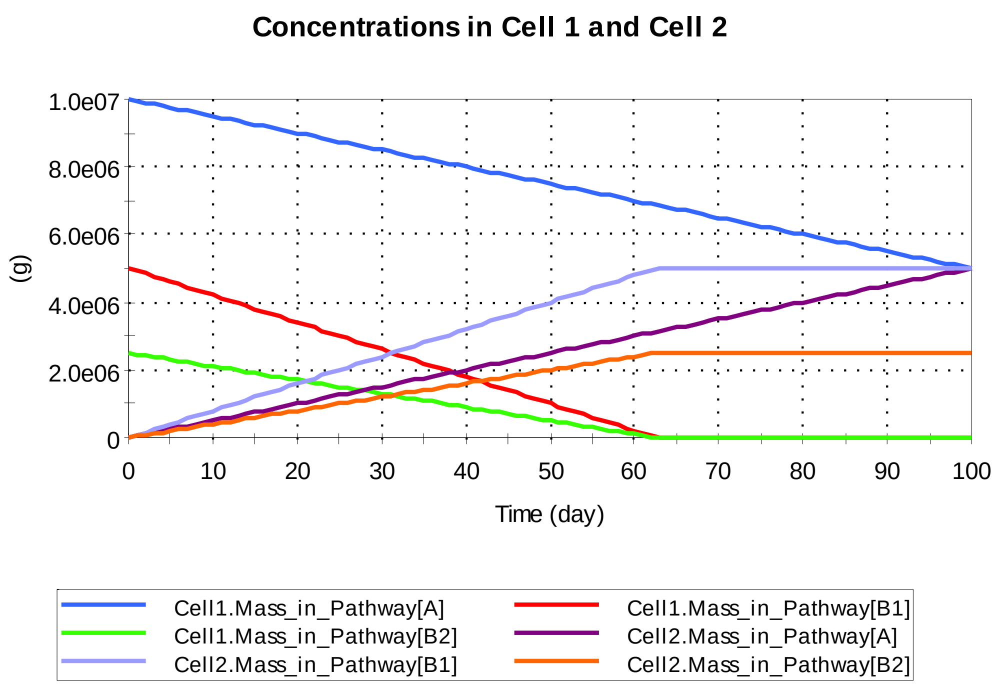


Figure CT_Polymorphic-1

The Verifier should then enter the Material container and ensure that the following outputs display the following expected values:

Element	Output	Expected Value
Water	Relative Diffusivity	[0.10 0.15 0.15]
Water	Solubility	[50 100 200] mg/L or [50 10 0.2] mol/m3
Fluid_1	Partition Coefficients	[0.2 0.23 0.23]
Fluid_1	Relative Diffusivity	[0.07 0.10 0.10]
Fluid_2	Solubilities	[0.02 0.04 0.08] kg/m3 [20 4 4] mol/m3
Solid	Partition Coefficients	[2.0E-5 2.5E-5 2.5E-5] m3/kg
Solid	Porosities	0.3

CT_Inconsistent_Properties

This test checks that GoldSim identifies inconsistent properties between different isotopes of the same species.

The verifier should begin the test by opening the Water element. They should confirm that the Solubilities field is equal to Sol_Ref_Fluid_Species_Mass, and that the Relative Diffusivities field is set to Ref_Fluid_Diff_Fact_Species. In the Fluid_2 element they should ensure that the Solubilities field is set to Sol_Fluid_Species_Mass. Run the model - five warnings should be added to the run log. The Water element should warn that the Solubilities are inconsistent, while Fluid_1 should warn that Partition Coefficients are inconsitent, and Fluid_2 should warn that the specified Solubilities are inconsistent. Solid_1 should warn about its Partition Coefficients are inconsistent, and Solid_2 should report that the specified Porosities are inconsistent.

For the next step open the Water element and link the Solubilities field to Sol_Ref_Species_Mol. Link the Fluid_2 element to Sol_Fluid_Species_Mol. Rerun the model - the same five errors should be generated.

For the final step open the Water element and connect the Solubilities field to Sol_Ref_Fluid_Element_Mass, and the Relative Diffusivities field to Ref_Fluid_Diff_Fact_Species. Rerun the model. Again five errors should be generated, but the Water element should now warn that the Relative Diffusivities are inconsistent.

5. DASHBOARD AUTHORING MODULE TESTS <SUPERCEDED BY GS46>

6. RELIABILITY MODULE TESTS

General Tests

Note that because the Reliability component of GoldSim is a separate module, the user may have to use the File/Extension Modules menu to enable it.

The tester should verify that the "Insert Reliability Element" item is added to the Insert menu, and also to the context-sensitive menu in the graphics pane when the Reliability Module is enabled. After inserting a reliability element of the tester's choosing, the user should deactivate the reliability module, and a warning message informing the user that any reliability elements will be removed should appear. Click yes to continue unloading the Reliability Module, and ensure that "Insert Reliability Element" no longer appears in the Insert menu or in the context-sensitive menu in the graphics pane.

RL_01_Failure_Modes

Open the test file RL_01_FailureModes. This file tests the functioning of all RL failure modes. This test file was designed to run 1000 realizations and to save time histories up to the 200th realization, as defined in the Model Simulation Settings dialog box.

To perform the test, first run the model. Then verify that the CCDF of result 1 matches that shown in **Figure RL01-1 (also reproduced in the model).**

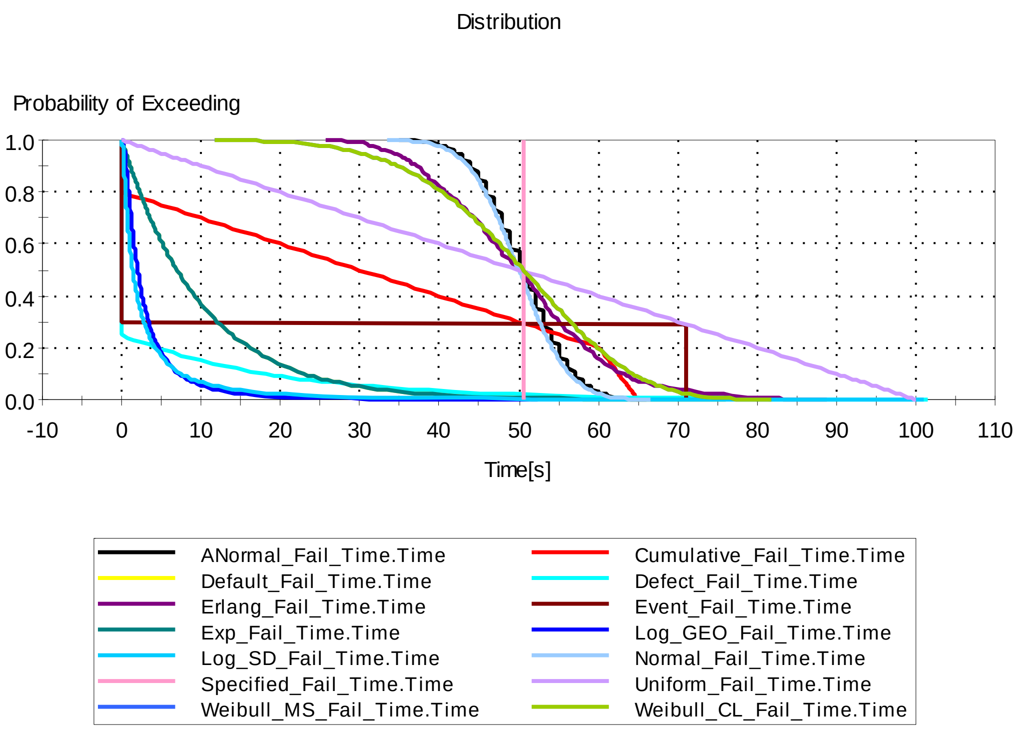


Figure RL01-1

The verification results are presented in **Table RL01-1**. A verifier should check that the MTTF of the specified failure times listed in **Table RL01-1** are within the range of 90% confidence value, from 5% to 95%, of those given by the result distribution elements in each distribution's container. Note: the 5% and 95% limits are confidence bounds *on the mean value*. Thus, for any of the test elements in Table RL01-1, there is a 10% chance that the MTTF will lie outside these bounds.

Comparing the test results to Figure 7-1 and Table 7.1 ensures that each of the failure modes that can reference time has the MTTF that would be expected, and that the dispersion of failure times for each of those failure modes is correct.

Test Element	**Expected Result**
ExpDefault	MTTF=10s
Exponential	MTTF=10 s
Uniform	MTTF=50 s
Normal	MTTF=50 s
Weibull	MTTF=50 s
Log_SD	MTTF=3.3 s
Log_GEO	MTTF=3.3 s
Cumulative	20% of the components should fail after the first timestep. By 60 s, 80% of components should have failed. All components should fail by 65 s.
Specified	Fails between 50 and 51 s
Event	30% failure at 70 s.
Anormal	MTTF between 50s and 51s (Triggered by an event that occurs once per second)
Defect	Only 25% fail, and for that 25%, mean failure time = 20 s (GoldSim will report a mean *operating time* of approximately 79 s [this can be viewed in the causal analysis result of the RL element] for the entire population; the CDF of the Fail_Result Result Distribution shows that 25% failed to operate for the full duration)
Erlang	Mean failure time = 50 s, standard deviation = 10 s.

Table 6-1

The verifier should then enter the Unreliable container and verify that the Time History of Result 2 corresponds directly with the graph in Figure RL01-2, and that the average Cum_Emitted at 100s is between 0.95 and 1.05. As the unreliable failure mode does not fail (it simply causes a triggered action to fail), this portion of the test verifies that the correct proportion of actions are unsuccessful when an Unreliable failure mode is specified. The Action element is triggered 20 times with and is 95% reliable, meaning that there should be 1 unreliable action per realization.

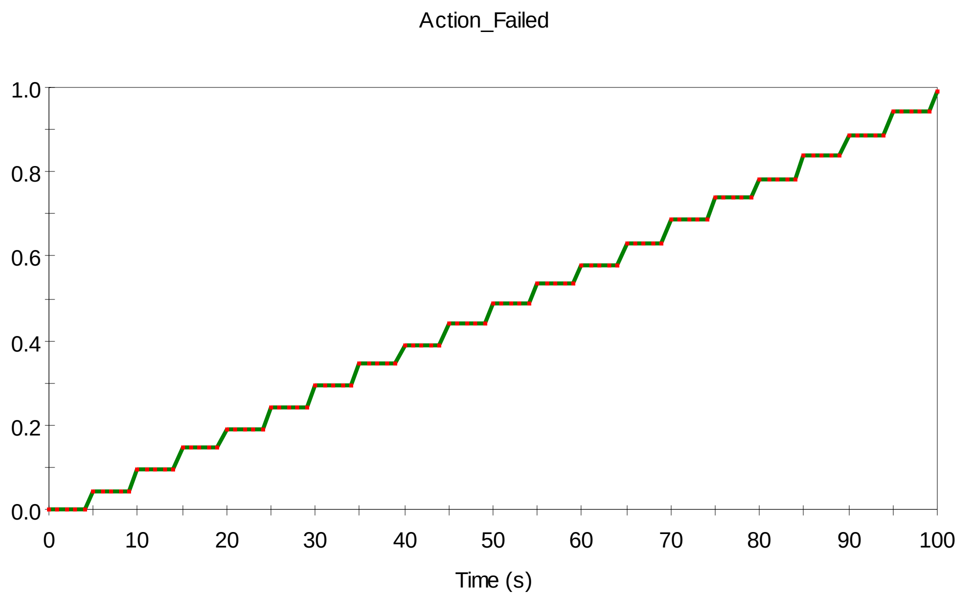


Figure RL01-2

The functioning of the Demand>Capacity failure mode should be verified by entering the Demand_Capacity container and ensuring that the 90 % confidence interval on the mean value of Reliability in the Performance Analysis section of the Results tab includes 0.209853.

This test verifies that an action element with a Demand>Capacity failure mode produces the failure rate that would be expected from a stochastic Demand (Normal distribution, mean 10, standard deviation 2) and stochastic Capacity (Normal distribution, mean 13, standard deviation 2) after the element has been triggered 10 times. Each action has a 0.144556 probability of failure, and since 10 actions are triggered, this means that the element should have a mean Reliability value of (1-0.144556)^10=0.209853.

RL_02_FMCV

This model verifies the correct functioning of the four different FMCVs available in GoldSim(Operating time since PM, Total time, Number of actions completed and User-defined FMCV). Each of these FMCVs is tested inside a normal container, a conditional container, and within a parent reliability element.

The Number of actions completed FMCV is driven by an action that occurs once per second. The User-defined FMCV is in meters, but is actually also proportional to time (it is equal to ETime*20s).

All elements have a specified value exceeded failure mode that occurs at 50s (for Op time and Total time FMCVs), at 50 actions for the Number of Actions mode, and at 1000m for the User-defined mode.

Each container has 5 RL elements, each with different intial ages and acceleration factors. These are:

Normal – no acceleration, new at the start of the simulation
Accelerated – new at the start of the simulation, accelerated by a factor of 2
Decelerated – new at the start of the simulation, accelerated by a factor of 0.5 (ages one half as fast as the normal case).
Initial – 20% aged at the start of the simulation
Initial_Acc – 20% aged at the start of the simulation, accelerated by a factor of 2.

To conduct the test, open and run the model entitled RL_02FMCV.gsm Enter the four containers inside the normal container, the conditional container, and the reliability element. Verify that the time history inside the container corresponds with the graph pasted in this document (and reproduced inside the model), and ensure that failure occurs at the times listed in each container.

Standard Conditions

Because they are in a standard container, and all age at the same rates, all of the FMCVs in the Standard_Conditions container should display the same behavior. The time history results should correspond with Figure RL02-1 below for all four FMCVs.

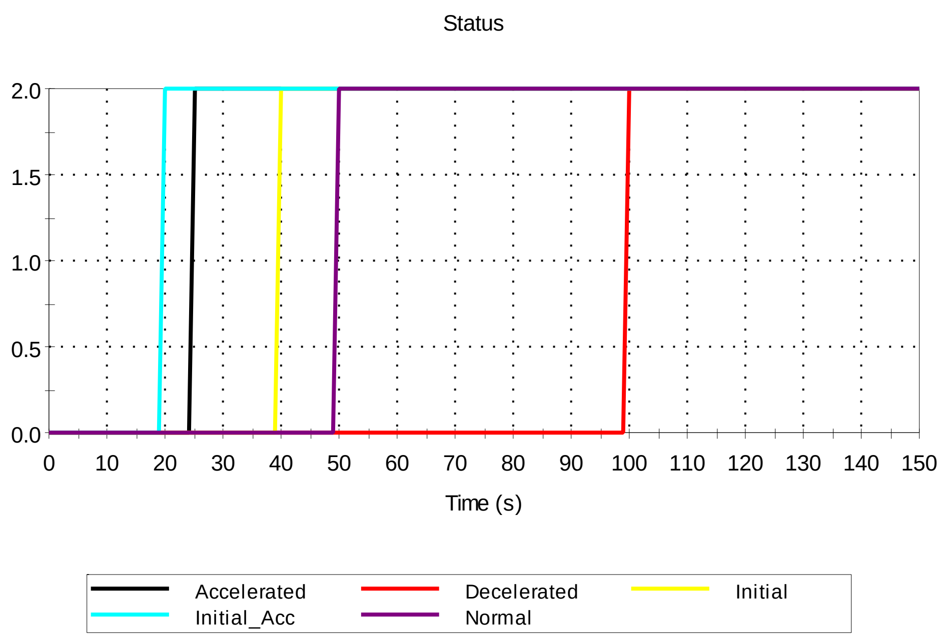


Figure RL02-1

Conditional Container

The same elements are now reproduced inside a conditional container that is activated at 10s,. Graphs should correspond with Figure RL02-2 ,RL02-3. and RL02-3b. Note that failure modes within conditional containers do not age until the container's first activation.

Operating Time, Total Time and User-defined

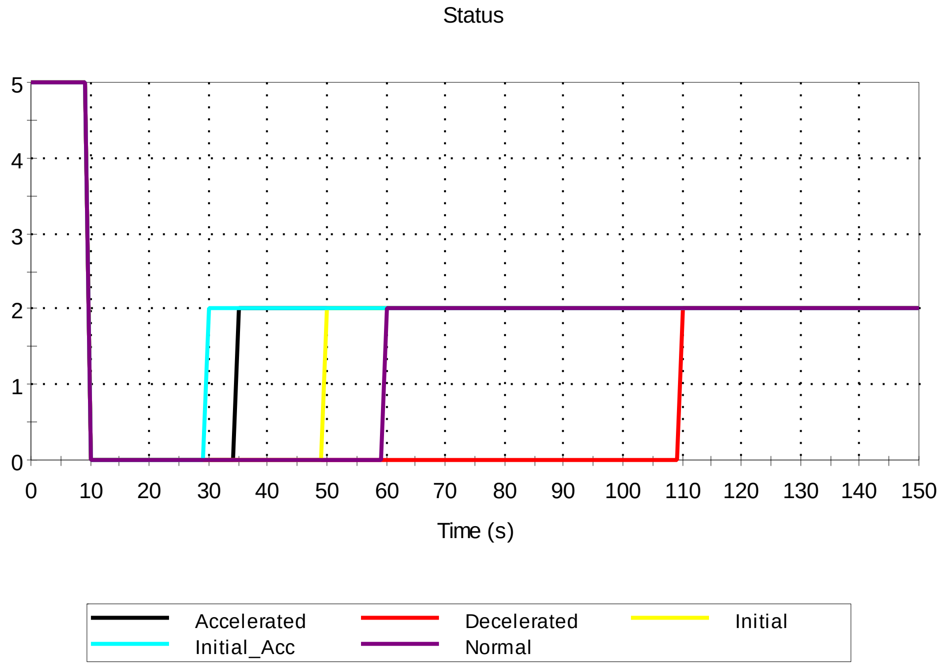


Figure RL02-2

Number of Actions Completed

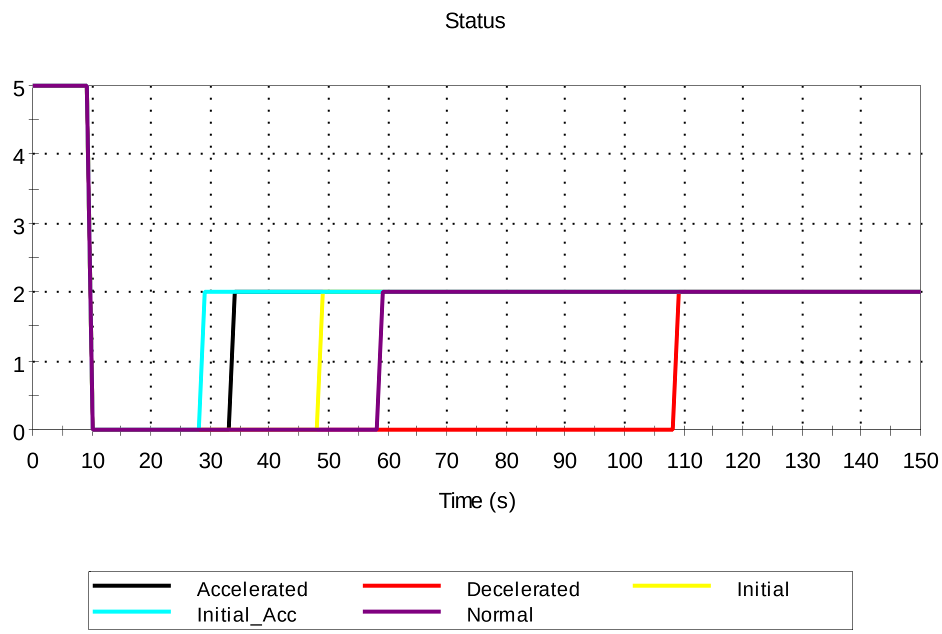


Figure RL02-3

Reliability Element

The same elements are now reproduced inside a reliability element that is activated at 10s, deactivated at 40s and reactivated at 50s. Graphs should correspond with Figure RL02-4, RL02-5 and RL03-5b.

Operating Time and User-defined

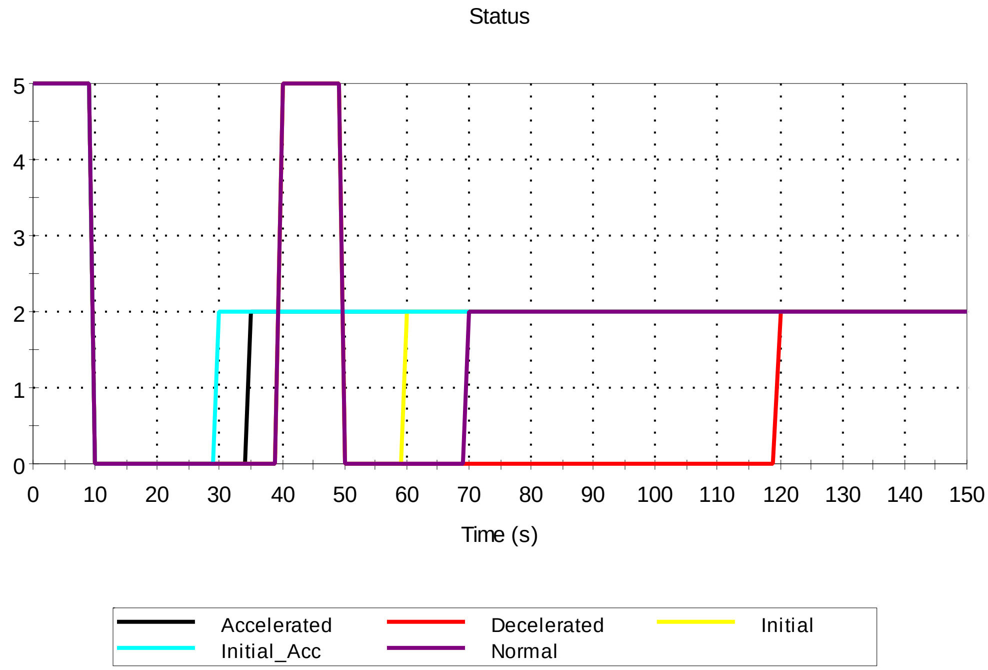


Figure RL02-4

Total Time

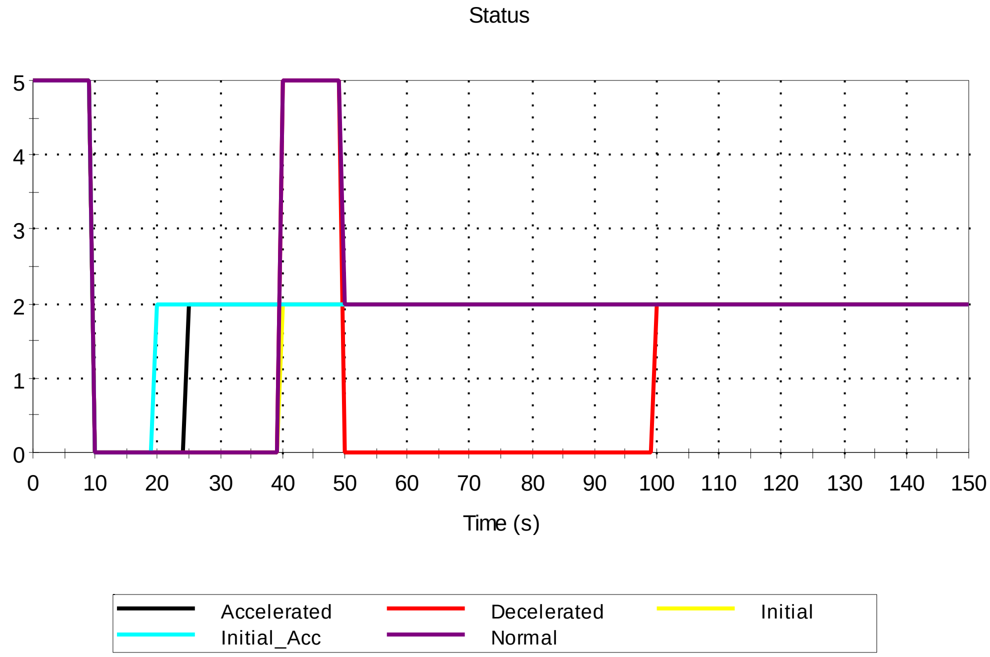


Figure RL02-5

Number of Actions Completed

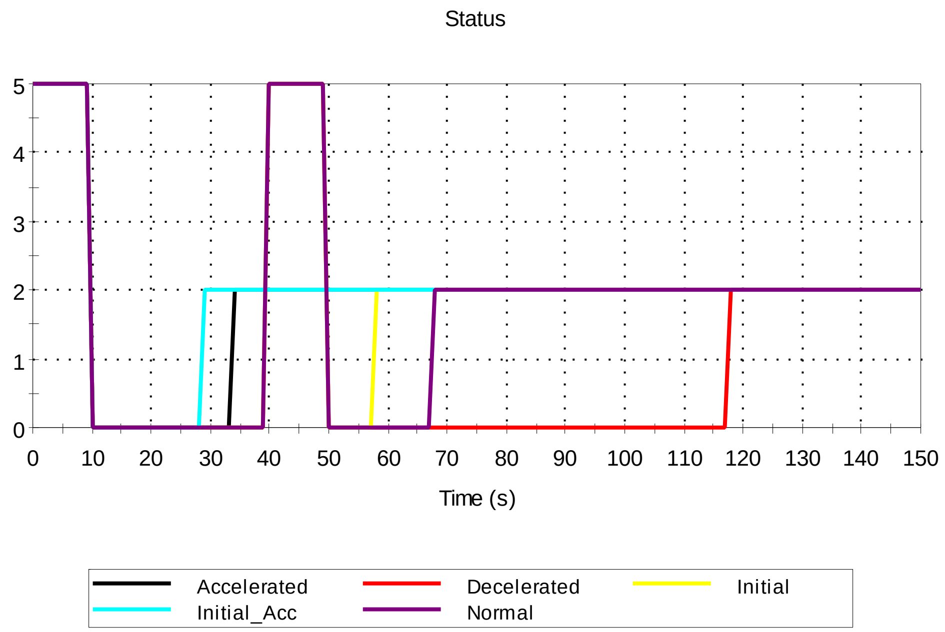


Figure RL02-5b

The final test involves verifying the correct functioning of the Uncertain initial value functionality. To conduct this test, open the file entitled RL_02b_UncertainInitialValue and run the model. Ensure that the graph of Result1 matches Figure RL02-6 (the graph is also reproduced inside the model).

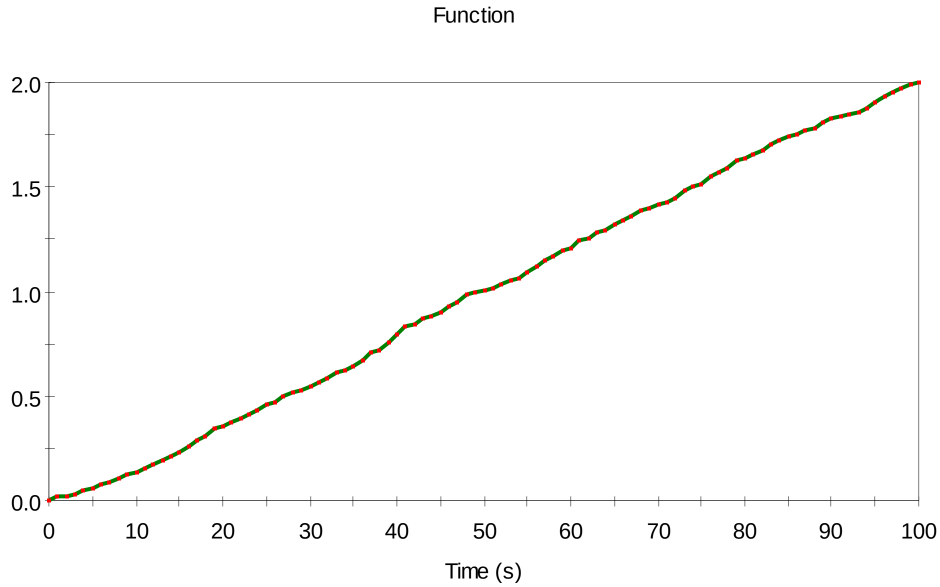


Figure RL02-6

This test uses a specified value exceeded failure mode that fails at 100s with an uncertain initial age value. When an uncertain initial value is selected, GoldSim selects an age value from a uniform distribution that ranges between new and failed. This is why the mean status increases linearly between 0 (operating) and 2 (failed) over the course of the simulation.

RL_03_Automatic_Repair_Distributions

The test is designed to verify that the 'Automatically Repair Failure' options and distributions are operating correctly by comparing them with the exact repair time distributions.

To perform the test, open and run the model entitled RL_03_Automatic_Repair_Distributions. Verify that the Reliable outputs of all four function elements drop to zero at time=50s (all are graphed in the RelHistories time history element and one of them should also be checked using its Results/Performance Analysis option), and that the Operating time history corresponds directly with the Figure RL03-1 pasted below and in the model.

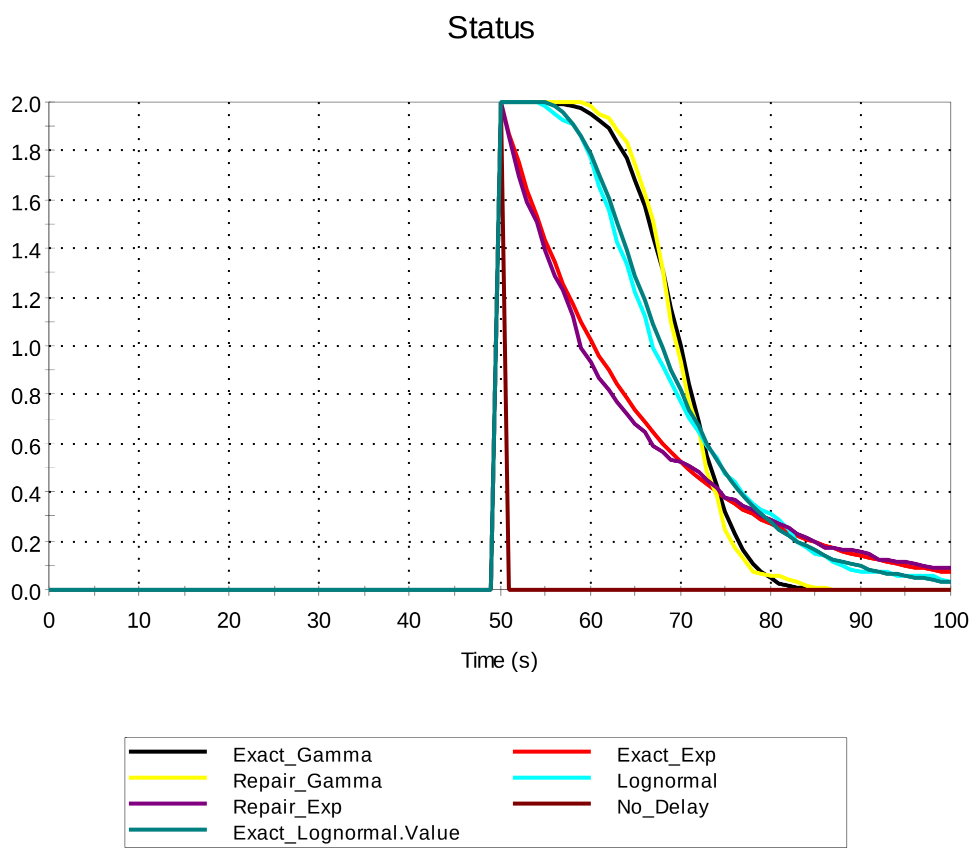


Figure RL03-1

RL_04_Outputs

This test is designed to verify the proper functioning of the reliability element outputs and local properties.

To conduct the test, open the file entitled RL_04_Outputs and run the model. Ensure that the Status graph corresponds with Figure RL04-1 below (also pasted below the element in the model).

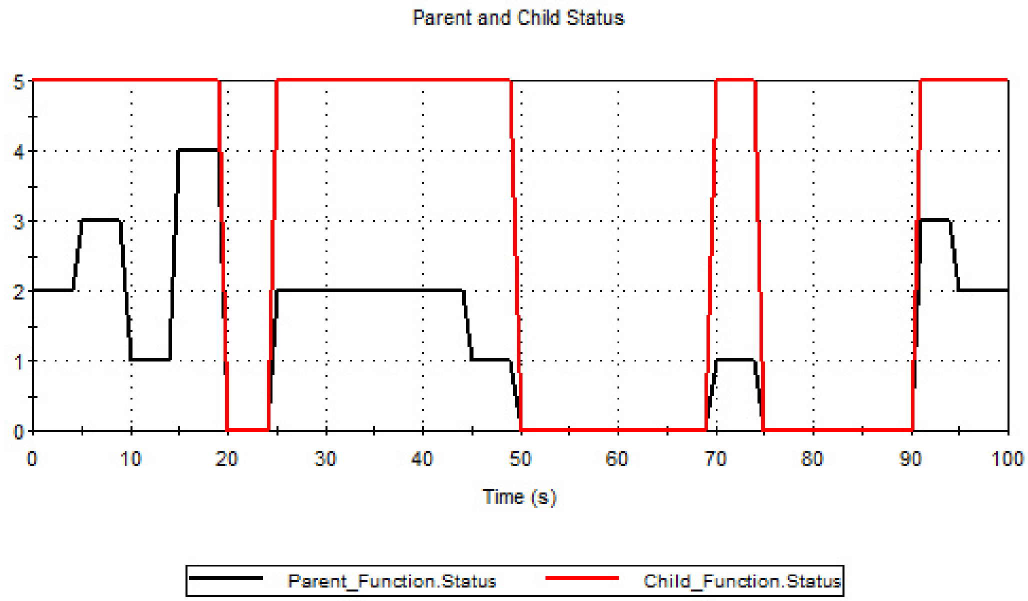


Figure RL04-1

Enter the Parent_Function RL element and ensure that Result3 corresponds with Figure RL04-2 below (also pasted to the right of the element in the model).

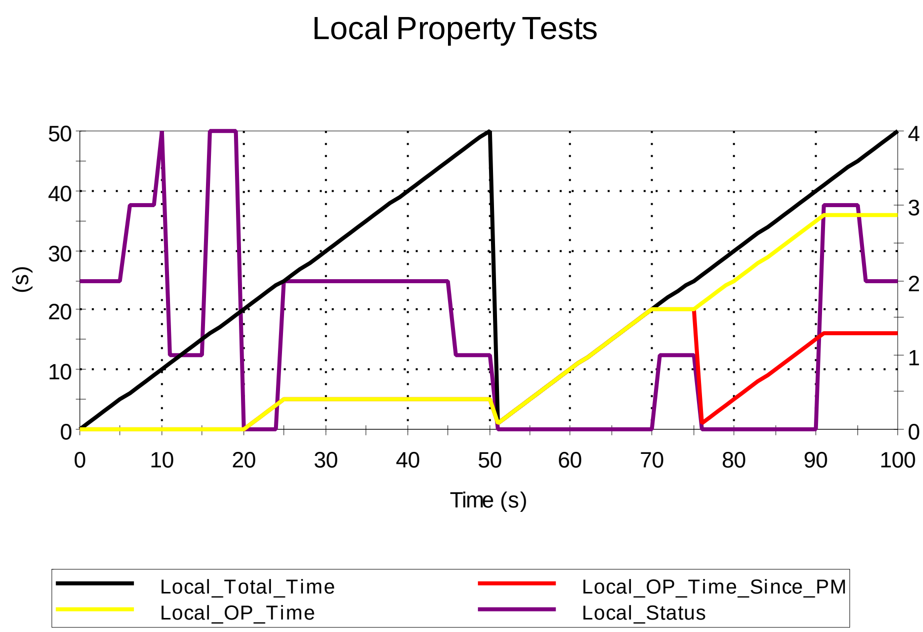


Figure RL04-2

Enter the Function container and ensure that Result1 corresponds with Figure RL04-3 below (also pasted to the right of the element in the model).

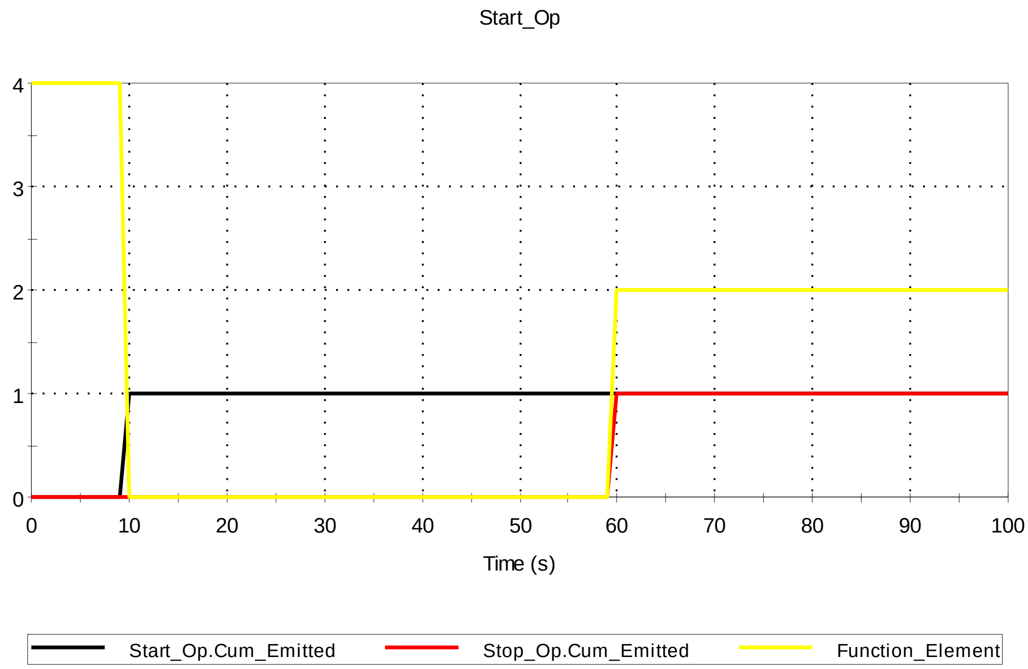


Figure RL04-3

Return to the top level of the model and enter the Action container. Ensure that Result1 corresponds with Figure RL04-4 and that Result2 corresponds with Figure RL04-5. Both graphs are also reproduced in the model.

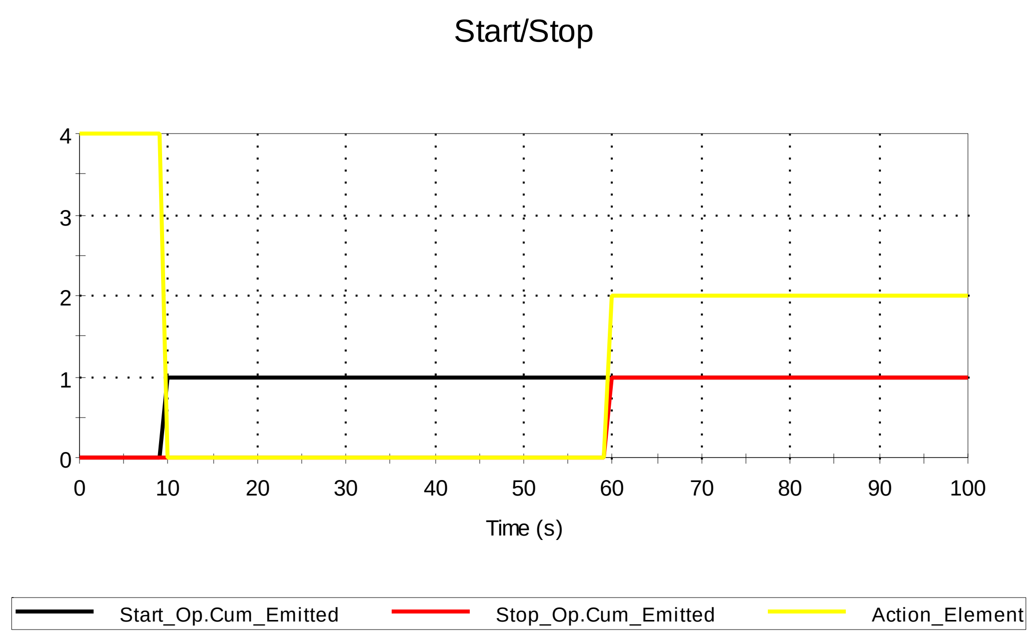


Figure RL04-4

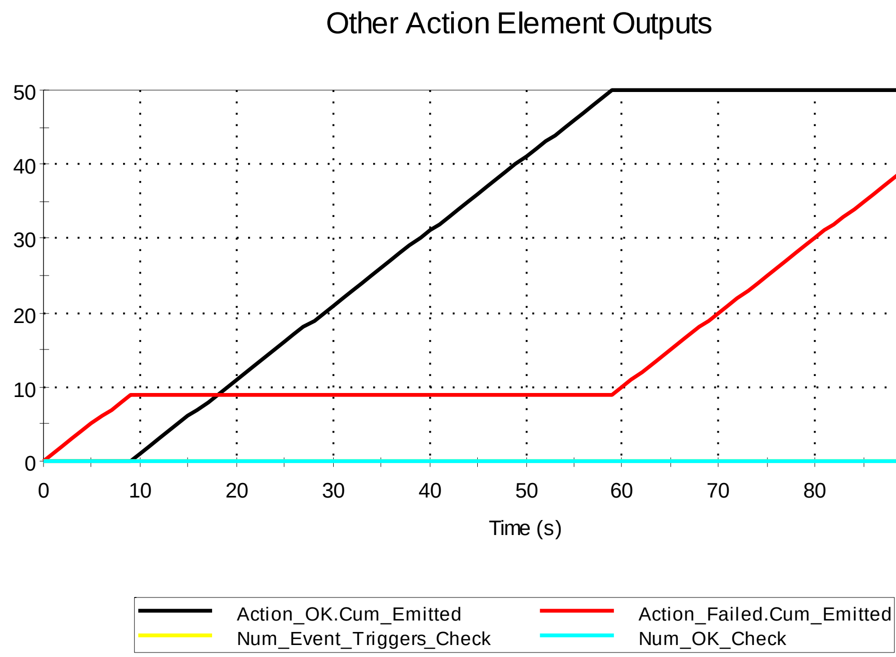


Figure RL04-5

Return to the top level of the model and enter the CustomOutputs container. Ensure that ExposedLocalProperties corresponds with Figure RL04-6 and that ExposedOutput corresponds with Figure RL04-7. Both graphs are also reproduced in the model.

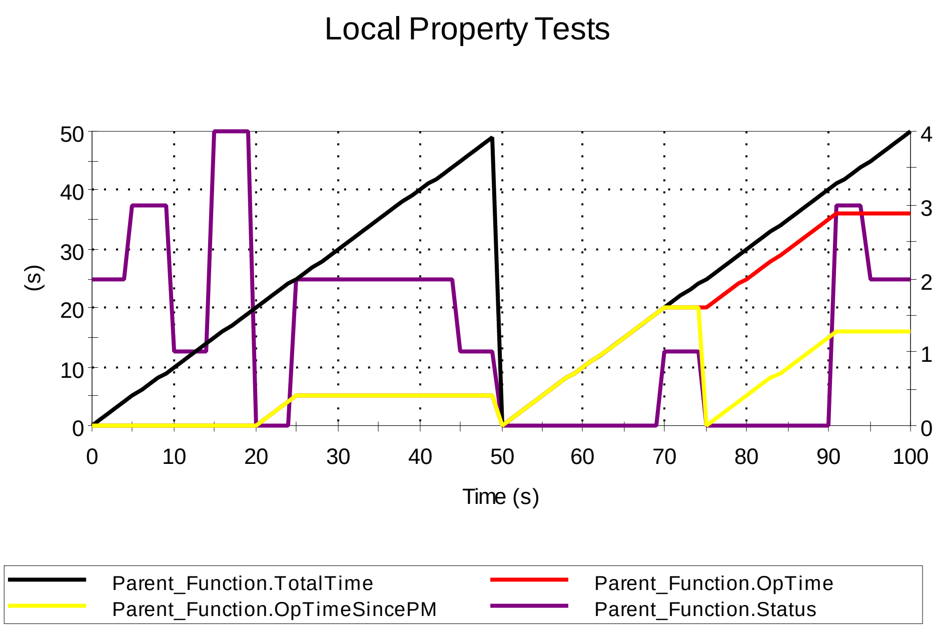


Figure RL04-6

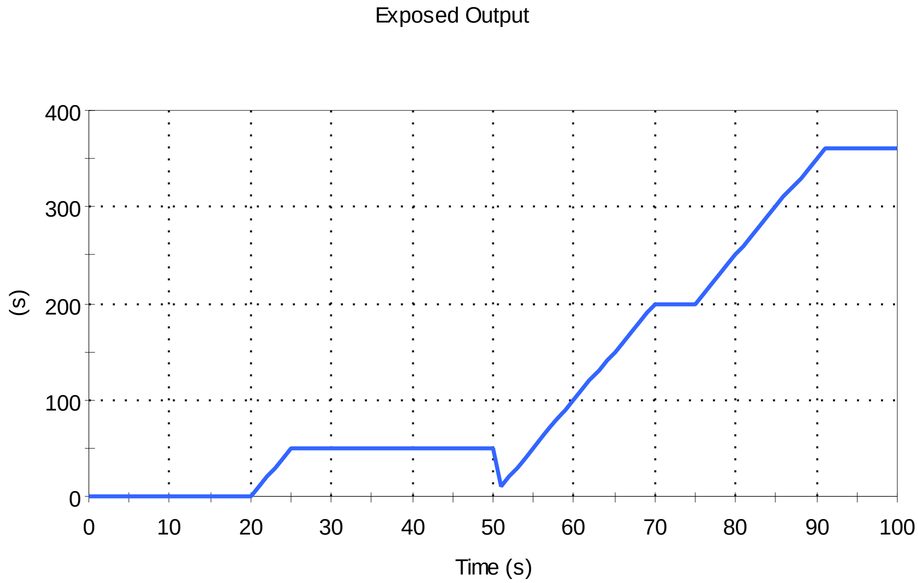
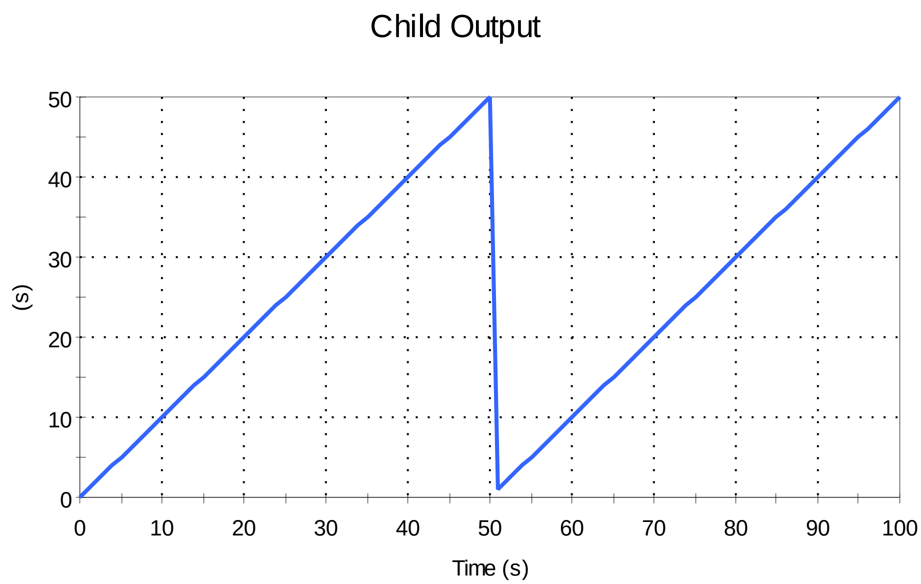


Figure RL04-7

Enter the Parent_Function element and ensure that the Child_Output plot matches Figure RL04-8 below:



RL_05_LogicTrees

This test verifies the proper functioning of the logic-tree nodes, and also the proper functioning of the conversion from one type of logic-tree to another.

To complete the test, open the file entitled RL_05_LogicTrees and run the model. Ensure that each reliability element starts functioning at t = 50s. Then enter each reliability element and change the logic tree type to fault-tree. Run the model again and check that the same result is obtained. Re-enter each reliability element and switch the logic-tree type back to a requirements-tree. Run the model and ensure that each element still starts operating at t = 50s.

RL_06_PMReplace

This test verifies the proper functioning of both types of PM failure modes and the replace trigger, along with their associated options.

There are three reliability elements in the top level: Function, Parent_Function, and Parent_Function_Replace.

Function and the two child elements in Parent_Function and Parent_Function_Replace have two failure modes – an Operating time since PM failure mode that fails at 41s, and a Total time failure mode that fails at 75s and is not repaired by when a PM:Preventive Maintenance event occurs. At 50s the first failure mode is repaired to an age of 25s by a PM:Preventive maintenance mode that takes 5s to complete. This failure mode is either directly triggered, or triggered by the parent.

Function, and Parent_Function are replaced at 95s by a PM:Replace that takes 5s to complete. Parent_Function_Replace is replaced by a Replace trigger at 100s.

To complete the test the verifier should run the model and ensure that the graph of Result1 corresponds with the graph pasted in Figure RL06-1 below (also reproduced in the model).

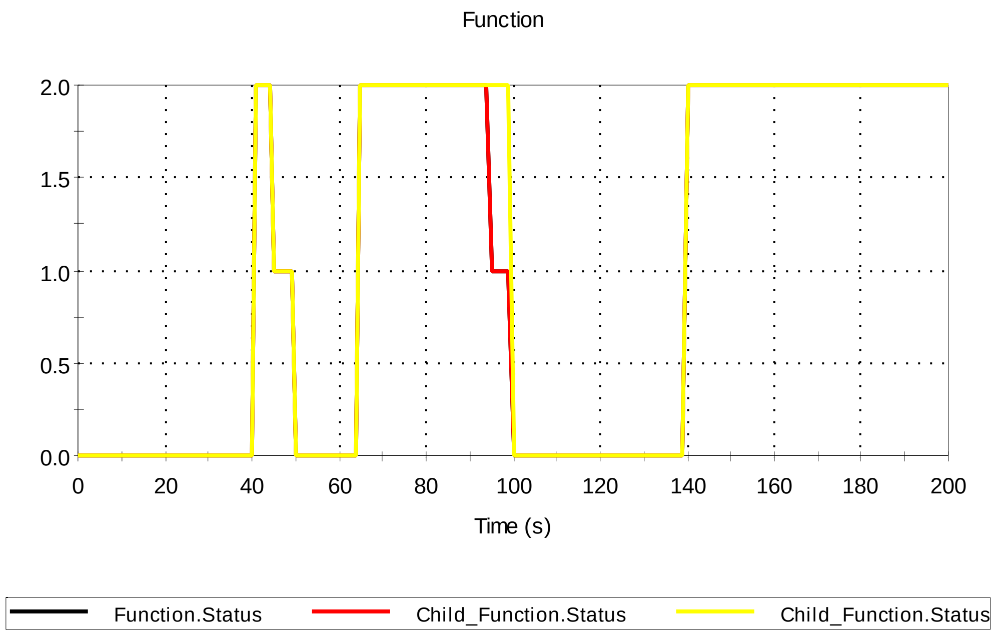


Figure RL06-1

RL_07_Combined_Failure_Modes

This test verifies that multiple failure modes operate correctly.

It uses a reliability element with three exponential failure modes, with mean failure rate of 0.01/s, 0.02/s and 0.07/s.
Because Poisson distributions are unaffected by aggregation, this means that the combined effect of these three failure modes would be equivalent to a Poisson failure mode with a mean failure rate of 0.1/s (corresponds with a mean time to failure of 10s).

To conduct the test, open the file entitled RL_07_CombinedFailureModes and run the model. It should be verified that the graph of the Function_Element's Operating parameter matches the shape of the analytical solution (exponential with mean failure rate of 0.1/s) in Result 1. The correct operation of the three failure modes should also be confirmed by verifying that the 90% confidence bound on the mean failure time in the result distribution includes the expected mean value (10s).

RL_08_Cloning

This test verifies that cloning works properly with the two types of reliability elements.

The verifier should open the file entitled RL_08_Cloning and make a number of changes to all of the settings of both Function and Action. The verifier should ensure that these changes are reflected in Function_1 and Action_1. They should then make a number of changes to Function_1 and Action_1 and ensure they are reflected in Function and Action. Finally, the verifier should free Function_1 and Action_1 and make changes to Function and Action. They should ensure that none of these changes are reflected in Function_1 and Action_1.

These changes should include:

- Switching back and forth between the simple failure mode and advanced failure modes
- Adding and deleting failure modes, changing FMCV and repair settings.
- Altering the logic tree (switching types, adding and deleting nodes, especially to other elements using the RL node browse functionality).

As part of the test, the verifier should create and run a valid model. The model should run successfully to completion and results should be available for all elements in the model.

The tester should also attempt to edit the tree of a child from the property dialog of its cloned parent. A message should be displayed stating that the child element’s dialog must be edited locally. The tree of the child should be edited locally and the verifier should ensure that the changes are correctly reflected in the cloned child element.

The tester should also edit the requirements tree of Function2 and confirm the changes appear in the cloned Function2b. One of the changes should be to add a Not RL Component for the child element Function3.

RL_09_Dynamic_Fields

This test verifies that dynamic fields in the reliability module respond as expected when their value changes.

The verifier should open the model entitled RL_09_DynamicFields and run the model. They should then confirm that the results graphs in each of the 6 containers correspond with the graphs pasted to the right of each result element.

In the first container (EXP_Dynamic), the function element EXP_Dynamic has a dynamic failure mode which has a failure rate of 0.05 1/s for the first 15s of the simulation, and then a failure rate of 0 1/s for the remainder of the simulation. Result 1 should correspond directly with Figure RL09-1 below.

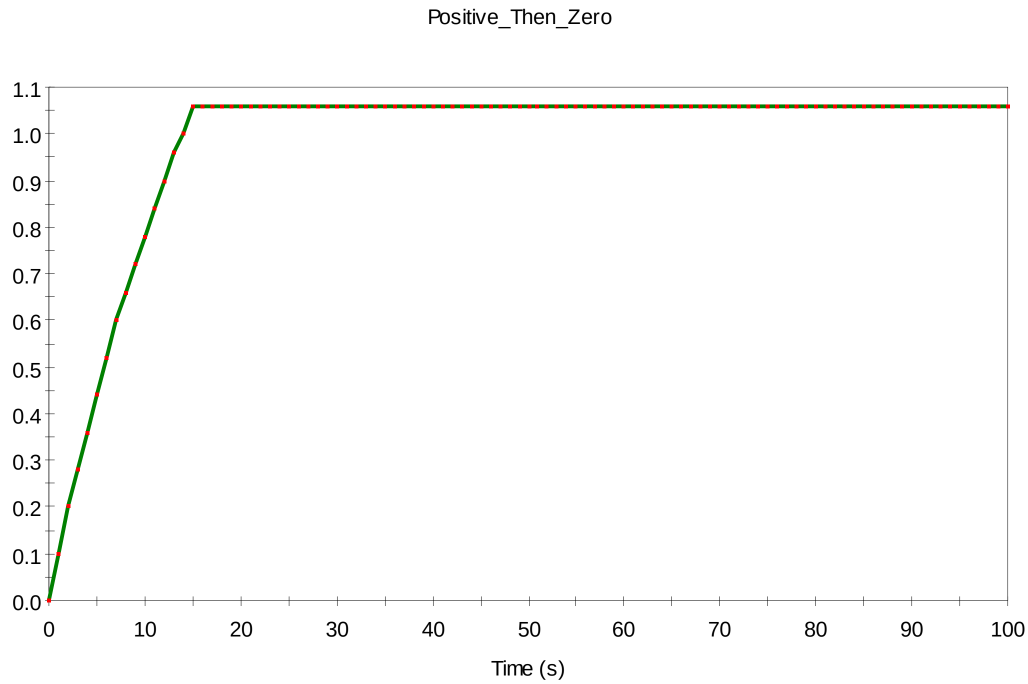


Figure RL09-1

The Engine element has a dynamic failure mode whose failure rate increases, then decreases as the simulation proceeds. The verifier should ensure that the Reliability Time History element corresponds with Figure RL09-1b below:

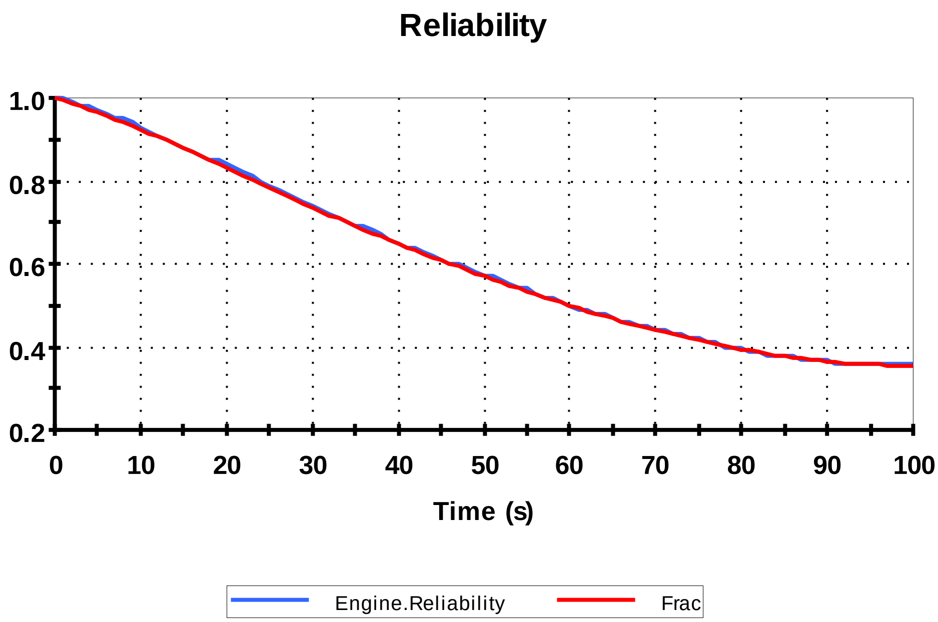
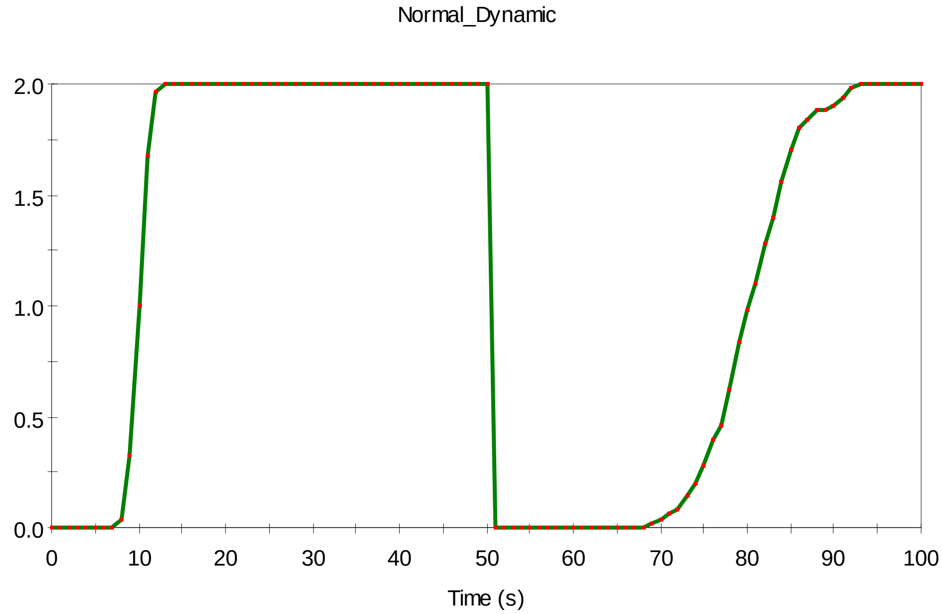


Figure RL09-1b

In Normal_Dynamic, the reliability element initially has a Normal failure mode with a mean time to failure of 10s and a standard deviation of 1s. For the rest of the simulation, the failure mode has a mean time to failure of 30s and a standard deviation of 5s. A successful test is indicated when Result1 corresponds with Figure RL09-2.



.

Figure RL09-2

In Gamma_Repair, the reliability element has a triggered failure at 0s and 50s. It is automatically repaired by a gamma repair distribution that initially has a mean 10s and a standard deviation of 5s, but which has a repair distribution with mean 30s and standard deviation 10s for the remainder of the simulation. A successful test is indicated when Result2 corresponds with Figure RL09-3.

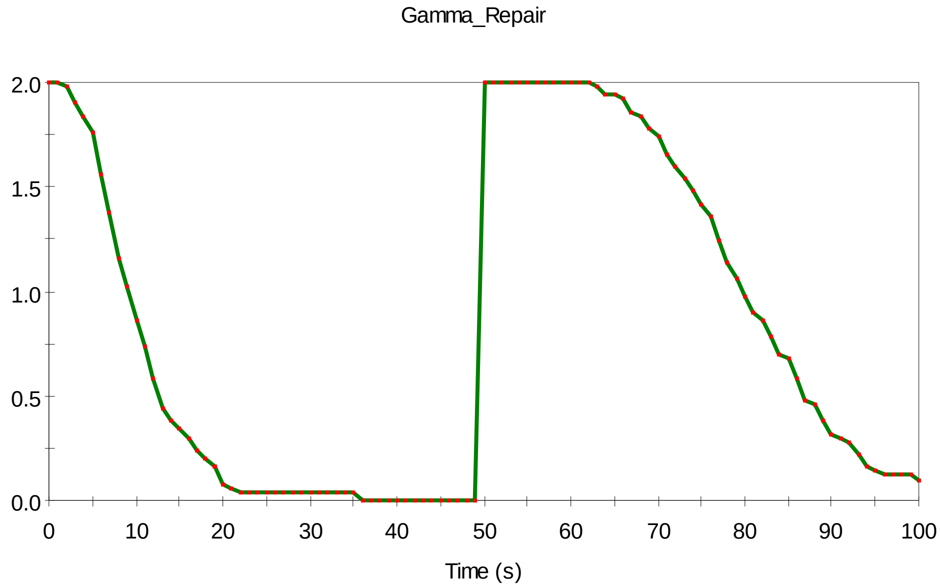


Figure RL09-3

In Repair_to_Age, the reliability element has a specified value exceeded failure mode that fails at 40s. It is repaired after 10s to an age of 20s, a process that takes 10s (gamma repair, 10s mean delay, no standard deviation), meaning it will still fail at an age of 40s. At 50s, it is repaired again (with a 10s delay), but this time to an age of 30s, meaning it will fail again at 70s. A successful test is indicated when Result3 corresponds with Figure RL09-4.

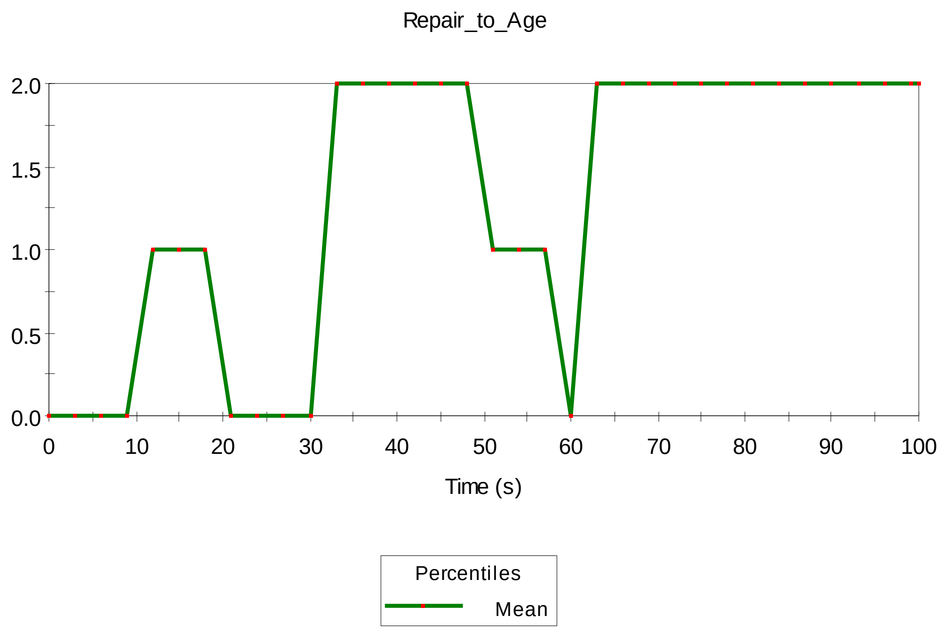


Figure RL09-4

In Repair_if_True, the reliability element has a uniform failure mode that fails between 10s and 20s. The reliability element also has a preventative maintenance mode, triggered at 40s and 80s, which takes 5s, and repairs the uniform failure mode if ETime is less than 50s. Therefore, the element would be expected to fail between 10s and 20s, be repaired at 45s, and then fail again between 55s and 65s. A successful test is indicated when Result4 corresponds with Figure RL09-5.

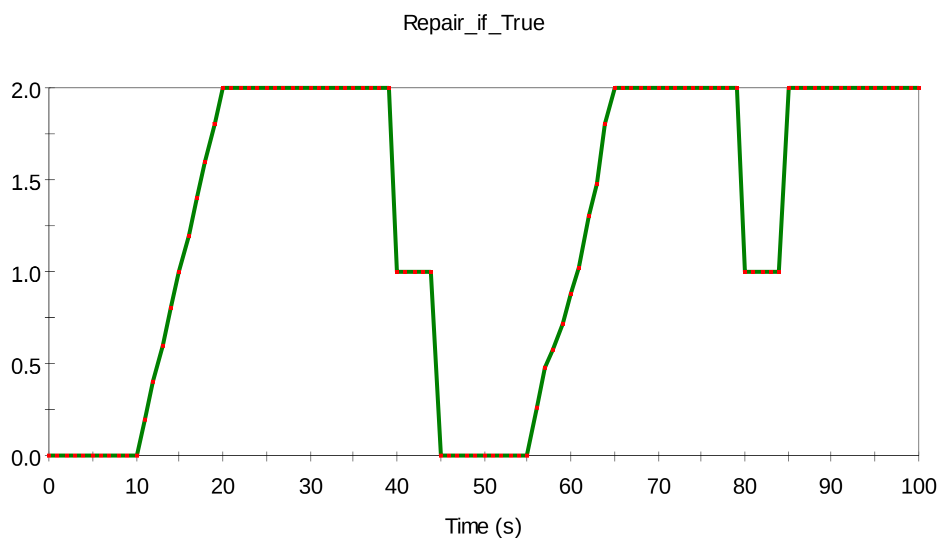
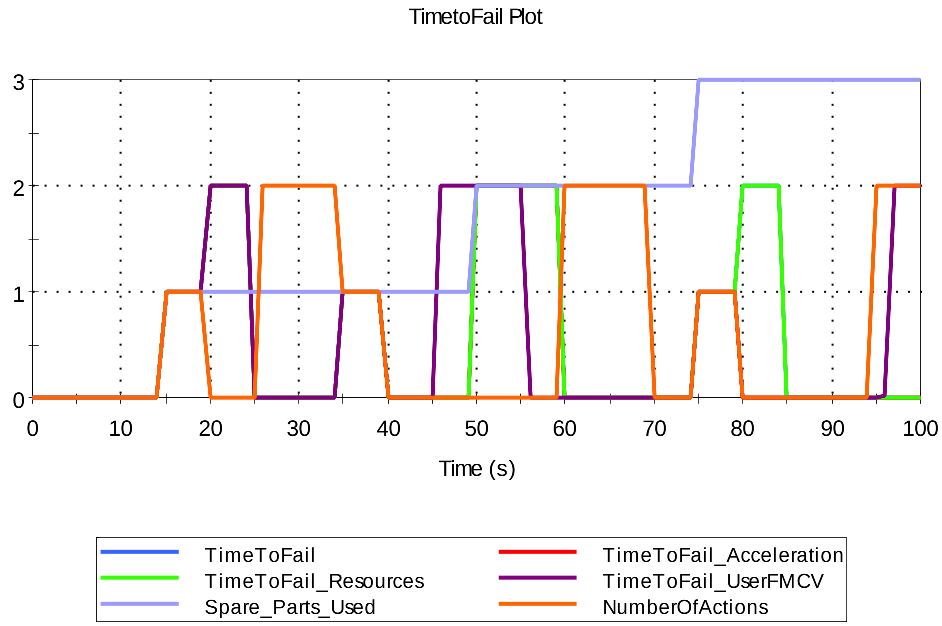


Figure RL09-5

There is an additional container within Repair_if_True (RL_TimeToFail) that tests the ~RL_TimetoFail local property. The test consists of a number of RL elements, each with a specified value exceeded mode and a PM:Preventative Maintenance mode that repairs the specified value exceeded mode if the time to failure is 5 seconds or less. This is tested using various FMCVs, resources and acceleration. The verifier should ensure that the TimetoFail_Plot matches Figure RL09-6 below.



RL_10_Action_Delay

This test verifies the proper function of the Action element's delay features.

To perform the test the verifier should open the file called RL_10_ActionDelay and run the model. At least 250 run log errors should be generated, and the verifier should ensure that the run log contains entries stating that the Max_Events element has 500 action triggers left to process. After checking the run log, the verifier should ensure that the Result elements in the Specified_Delay, Parent_and_Child, Erlang, SD and Action_Failed containers and within the Action_Event system correspond with the graphs pasted in each container.

In the Specified_Delay container, the action element has a specified delay of 50s, and is triggered at the start of the simulation – the expected result is that the action event is emitted at 50s.

In the Parent_and_Child container, there is a parent element, triggered at the start of the simulation with a specified delay of 50s, and a child element with a specified delay of 20s. Therefore, the expected result is that the action events are emitted at 70s.

The Erlang container contains three action elements with Erlang delay dispersions, with shape factors of 1, 10 and 100. The graph inside the Erlang container should correspond with Figure RL10-1.

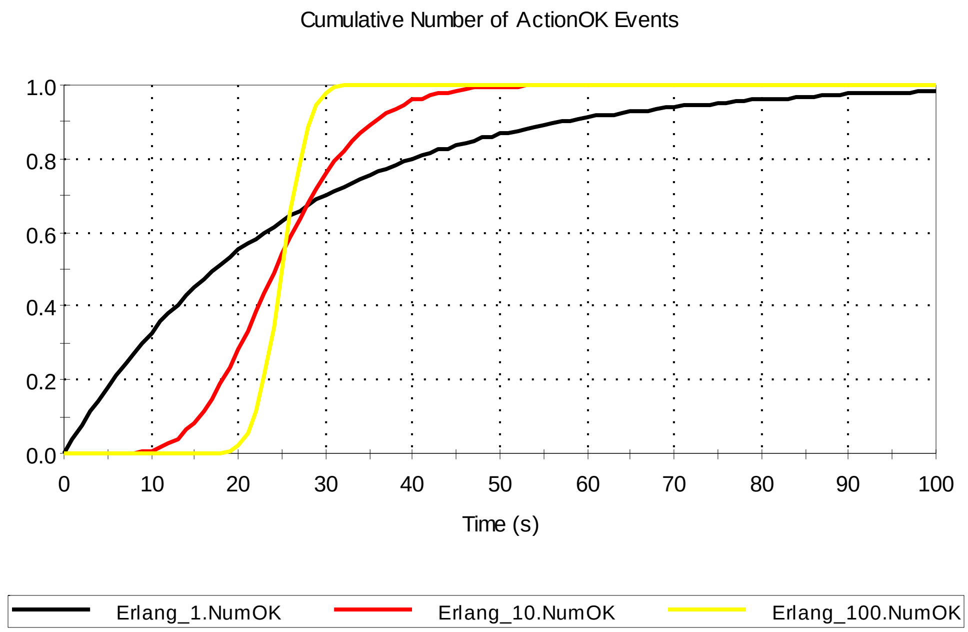


Figure RL10-1

The SD container contains three action elements with standard deviation delay dispersions, with standard deviations of 0s, 5s and 10s. The graph inside the SD container should correspond with Figure RL10-2.

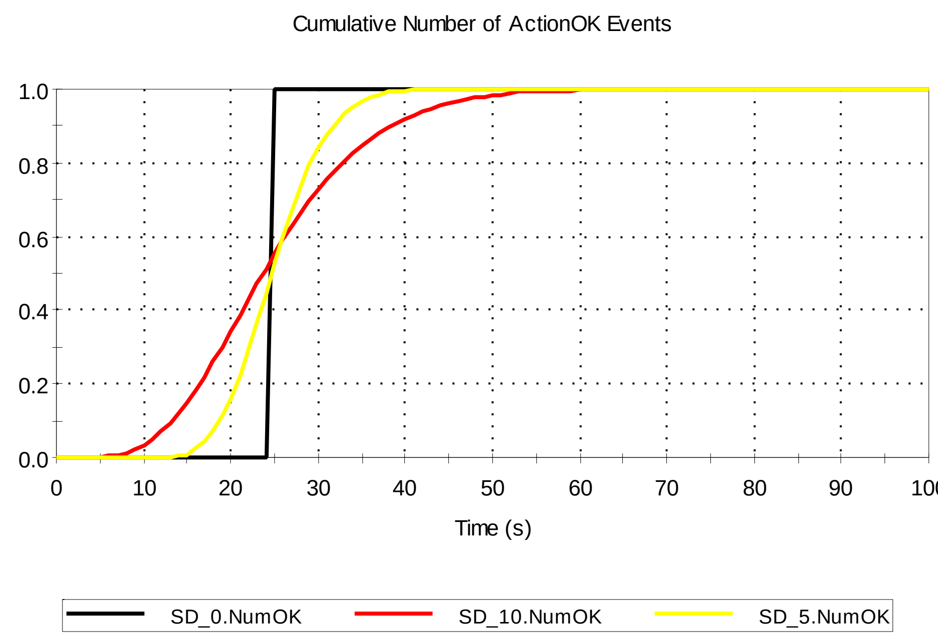


Figure RL10-2

Inside the Action_Failed container, there is a Action element which fails at the start of the simulation, and whose action is triggered at 10s. It should emit an ActionFailed output at 10s, and Result 1 should correspond with Figure RL10-3 below.

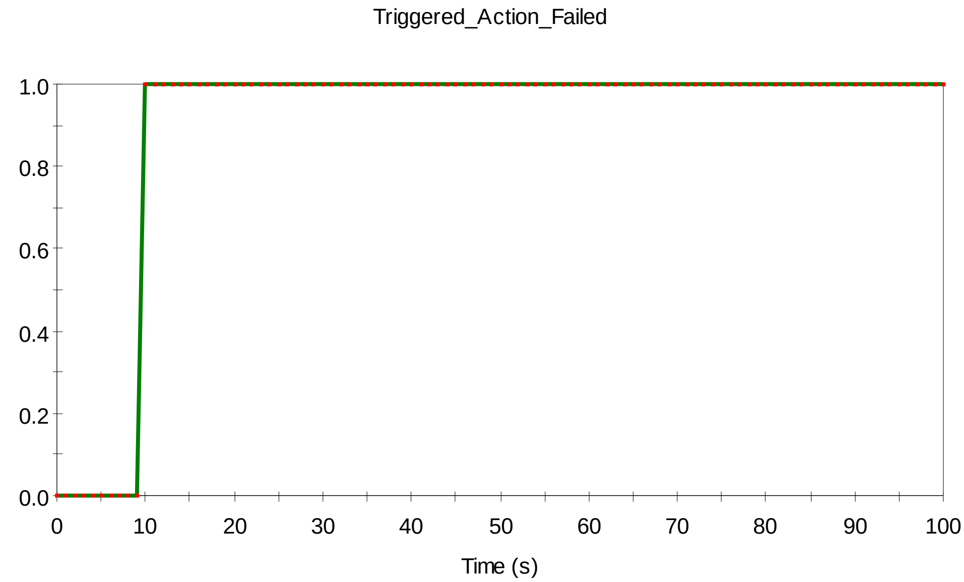


Figure RL10-3

Inside the In_Process_Failure container, there are two Action elements. The In_Process_Fail element is triggered at 10s, but fails at 25s (midway through the Action's delay). An Action_Failed event should be issued at 25s, and an ActionOK event should never be issued. The In_Process_Child has no failures of its own, but handles the Action internally with an Action element with a delay that again fails after 25s. Again, an Action_Failed event should be issued at 25s.

The verifier can confirm expected behavior by ensuring that the result element in the In_Process_Failure container corresponds directly with the plot shown in Figure RL10-4 below:

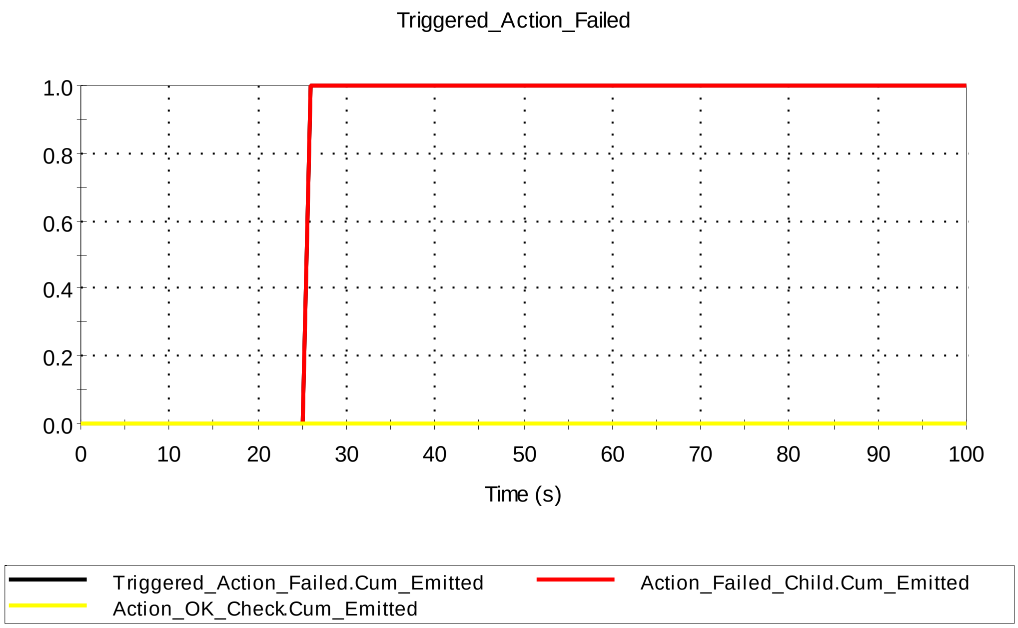


Figure RL10-4

The verifier should then enter the Action_Event system. Inside the system is a Triggered_Event, which uses the ~Action_Event local property. This is connected to a Random Choice element, which routes the output of the Triggered Event back to the parent Action element. The verifier simply needs to confirm that one event is emitted during all 250 realizations. This can be confirmed by verifying that the Result plot matches the plot below in Figure RL10-5.

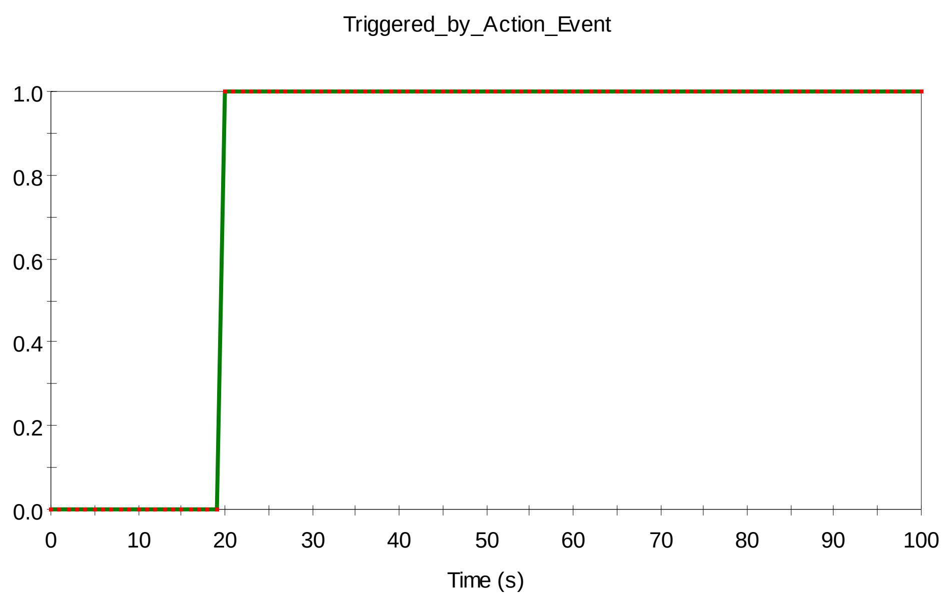


Figure RL10-5

RL_11_Static_Model

This test verifies the correct functioning of failure modes in a static reliability model.

The verifier should open the model called RL_11_StaticModel and run the model. For each failure mode confirm that the 90% confidence interval on the mean value of Operational and Inherent Availability includes the analytic solution (0.714 for all failure modes).

The expected mean Availabilities are calculated using the same formula as the static calculation uses:

(MTTF)/(MTTF+MTTR)

In this case, all failure modes have a mean time to failure of 50d and a mean repair time of 20d, resulting in a mean availability of 0.714.

RL_12_Reliability_Availability

This test verifies the correct calculation of reliability and availability statistics for reliability elements. The verifier should open the model called RL_12_Reliability_Availability and run the model.

In the model, two function elements below both fail according to a uniform distribution based on total time with a lower bound of 0s and an upper bound of 200s.

In both cases, the mean reliability of the component should have a mean of 0.5. The verifier should check that the values in the Summary Section, Performance Analysis Dialog and the Exposed outputs are all identical, and that they correspond with the expected value. In addition they should verify that the decline in reliability is approximately a straight line, decreasing from 1 to 0.5.

Because of the uniform failure mode, components that fail during the simulation have an expected availability of 50s. This means that half of the components fail at a mean time of 50s, and the other half operate for the full 100s. The expected average inherent availability of both components would be 0.75. However, since the Availability outputs are based on a moving average of availability over the proceeding two fixed timesteps, the Inherent Availability output will track the Reliability output and drop in an approximately linear fashion from 1 to 0.5.

The two function elements differ slightly in their Operational Availability results. The Function1_1 element is actually turned off at ETime = 50s. Therefore, the Operational Availability is actually equal to 0.5*(Availability in the first 50s) + 0.5*0. The availability during the first 50s is equal to 0.875 (realibility decreases in a straight line to 0.75 at 50s), so the Operational Availability should be equal to 0.4375. Again the verifier should ensure that the results summary displays a value that corresponds with the expected value. The Operational Availability output should show a straight line decline up until T=50s, at which point the instantaneous operational availability should drop over two timesteps to zero.

RL_13_Failure_Repair

This test verifies that the elements correctly calculate Failure Time and Repair Time statistics.

In the test file, a Function element that fails according to a Uniform (0-100) distrubution and repaired with a Gamma distribution of (10, 2) is placed in the root level of the model and inside a second Function element with no failure modes, where it is an Internal Requirement (this is done to test that GoldSim correctly treats unmet Internal Requirements as failures). A similar test is repeated with an Action element that fails according to a Normal (50, 10) distribution and is repaired according to a Gamma distribution with parameters (1, 0.1).

Run the model and display the results failure and repair time distributions. Confirm that the mean and standard deviation of the Normal and Gamma distributions are correct, and that the Failure and Repair time charts for Function1, Function2, Action1 and Action2 match those shown below the elements in the graphics pane..

RL_14_Tree_States

This test verifies that GoldSim correctly reports the amount of time spent in each status. This model runs a parent, child and grandchild through statuses from -5 to 5.

The verifier should open RL_14_Tree_States.gsm and run the model. The values displayed in the causal analysis by time in state should correspond with figures RL14-1 to RL14-3 below (also reproduced in the test file) for both the Requirements_Parent_Function and the Fault_Parent _Function.

For the Parent Element:

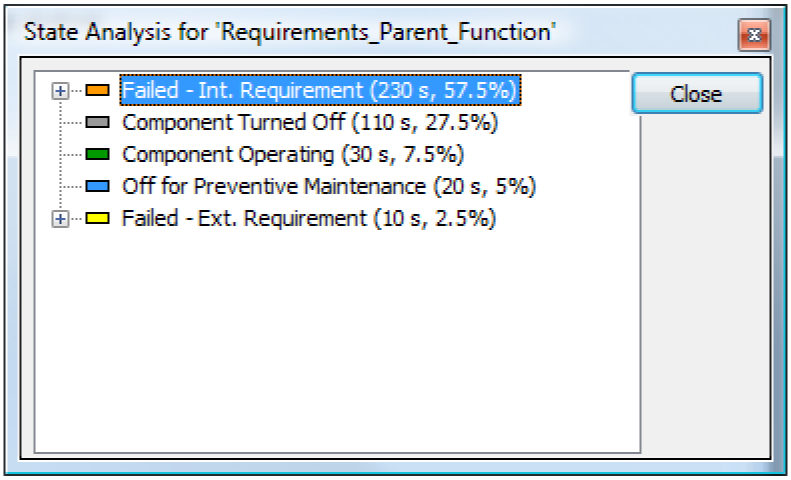


Figure RL14-1

For the Child Element:

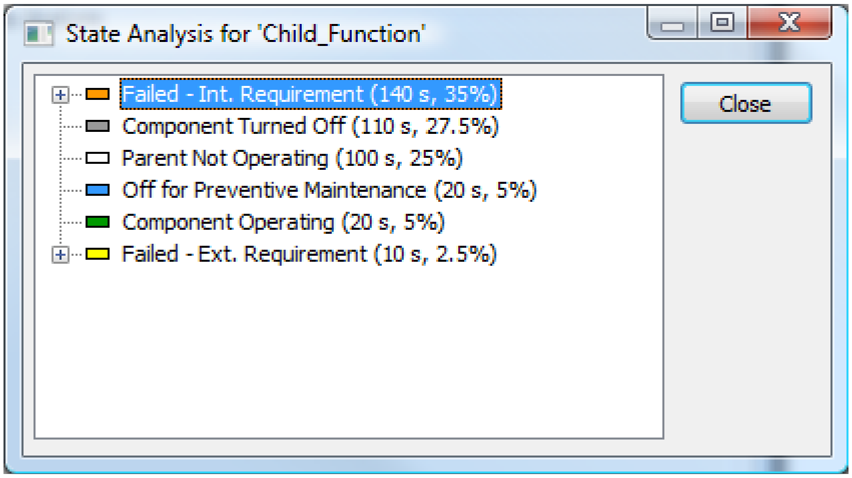


Figure RL14-2

For the Grandchild Element:

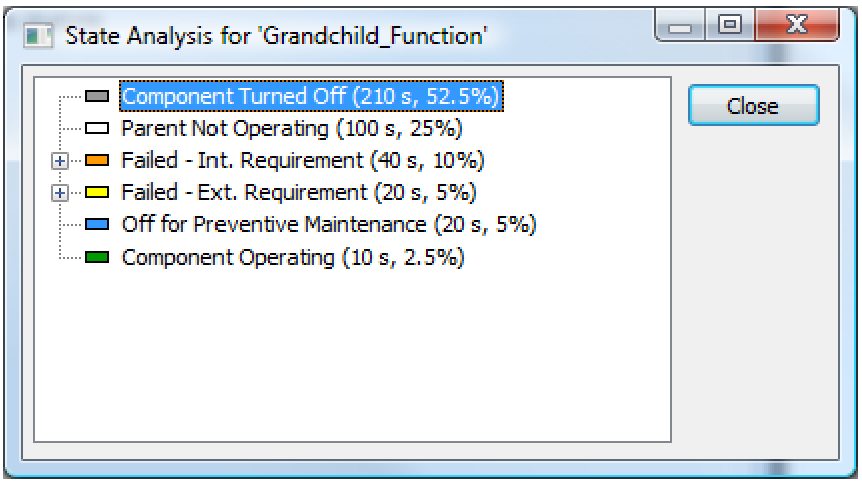


Figure RL14-3

RL_14b_Tree_States_All_Other_States

This test ensures that GoldSim can correctly handle a large number of states (>100 unique internal and external requirements trees).

The verifier should open RL_14b_Tree_States_All_Other_States.gsm and run the model. The causal analysis entries for Internal and External requirements should both display an entry labeled "All Other States".

RL_15_Root_Cause_Analysis

This test verifies the correct functioning of the RL module’s root cause analysis features. The verifier should open the model called RL_15_Root_Cause_Analysis.gsm run it. Results for elements using fault - and requirements-trees should match the results pasted in the test file.

RL16_Event_Driven_System

This test verifies that GoldSim correctly simulaties event driven systems (where results should be identical whether the simulation is run with 1 or 100000 timesteps).

To run the test, the verifier should run the model with 1, 10 and 1000 timesteps. The final value of Lost_Production should be identical in all three cases, and the 90%confidence interval on the final value should include the expected result. The expected availability would be MTTF/(MTTF+MTTR) = 1000/1000.25 = 0.99975. Thus one would expect 0.00025 of each pump's output over 25 years to be lost. A perfect pump would output 3330bbl/day * 365 days * 25 or 30,386,250 bbl. Thus the expected lost production from the three pumps would be 0.00025 * 3 * 30,386,250 bbl or 22790 bbl over 25 years.

RL17_Failed_Output

This test verifies the correct functioning of the Failed output and ~Failed available property. Event triggered failure modes are triggered 10s apart and repaired after 5s.

The verifier should run the model and confirm that the Failed_Output plot matches Fig. RL17-1 below.

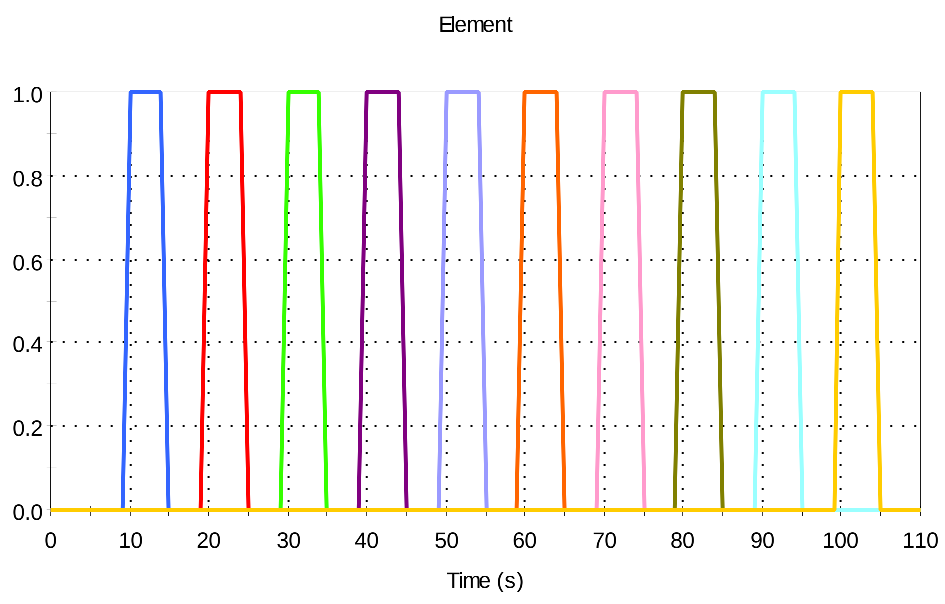


Figure RL17-1

The verifier should then confirm that the Failed_Local_Property plot matches Fig. RL17-2 below. Note that the local property will lag the output by one timestep (as elements within a Reliabilty system are updated prior to their parent’s failure modes being checked).

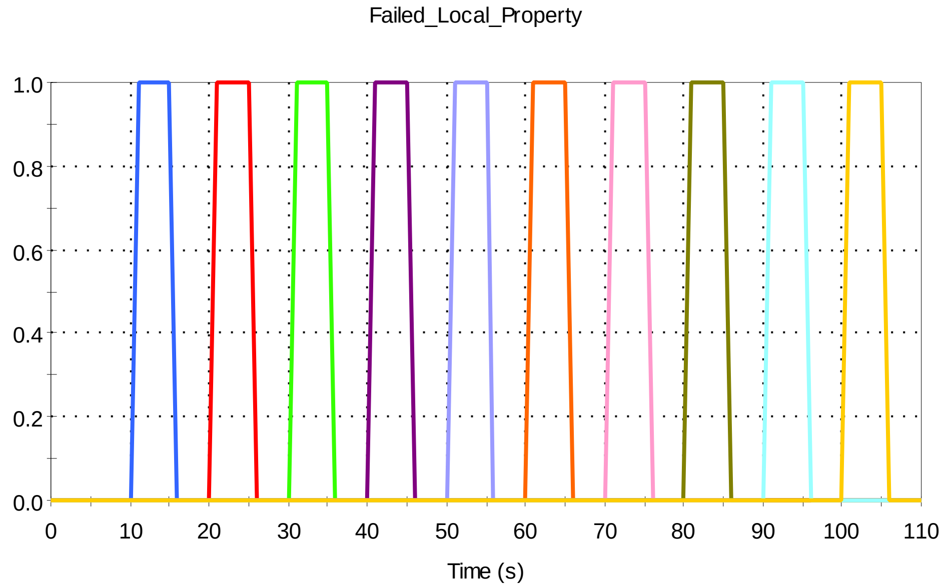


Figure RL17-2

RL18_RL_Export

This test checks that export of high-level reliability results to Excel works correctly.

The verifier should run the model and then open the RL18_Export_Check.xls spreadsheet. Values from the exported spreadsheet (RL18_Export.xls) should be pasted into the Paste Here worksheet and the verifier should confirm that the sheet displays the expected result by going to the Check worksheet. If the Check value is 0 the feature is working correctly.

RL19_FM_Import

This test verifies that the Failure Mode data import from spreadsheets works correctly.

First the tester should delete some of the failure modes for the pump, but not failure mode 5. Then the verifier should open the Pump element and manually import Failure Mode data using the Import Now button. They should then go to the Reliability tab of the Model|Options dialog and ensure that the automatic import option is selected for failure mode import. The model should then be run. The verifier should confirm that that root cause analysis results for the pump match the expected results in Figure RL_19 below. In addition, the tester should enter the Pump's failure modes dialog to confirm that failure mode 5, Cumulative test, has resource requirements that are not deleted during the failure mode import. Finally the testeer should compare the reliability elements' failure modes to those of the spreadsheet to confirm the import worked correctly.

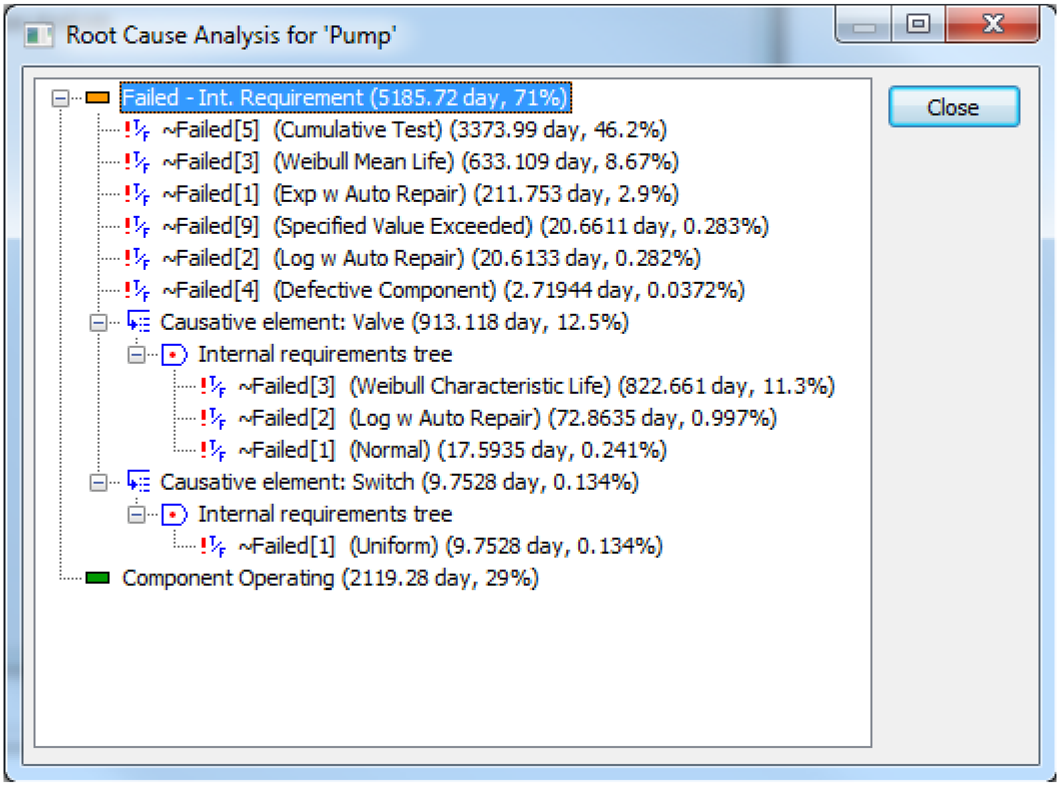


Figure RL19

RL20_Resources

This test verifies the proper functioning of Resources features in the Reliability elements.

In the test there are a number of stores, both global and local, and two Reliability elements (a Function and an Action element). Each uses an AutoOn trigger, but requires one or more "StartCartridges" to turn on - which are not delivered until ETime>=10d. Both components should begin operating at that time, and consume fuel from their local stores while they are operational. They will run out of their initial stockpile of fuel, then shutdown. After 40d, they begin to recieve fuel at the same rate it is consumed, and restart. They then fail at the same time (65d) . A maintenance worker is shared between the two elements, so one is repaired while the other waits. Both eventually return to service.

In addition to the status of the elements, the behavior of triggered Actions using resources is also tested. Each triggered action requires a unit of Catalyst. There is an initial stockpile of 5 units, and this is replenished at day 10. A regular Timed Event triggers the Action once per day. The Action fails 5 times (as their is catalyst available, but the unit is not on), then immediately issues 5 Actions when the store of Catalyst is replenished at day 10. One Action per day is then successful until day 20.

Run the model and compare the Results in the Status, Action and Replace_Status plots to RL20_1 through RL20_3 below. Note that in Figure RL20_1 the Action element's output is shifted by 1 day. Both exact agreement or a one timestep shift are acceptable.

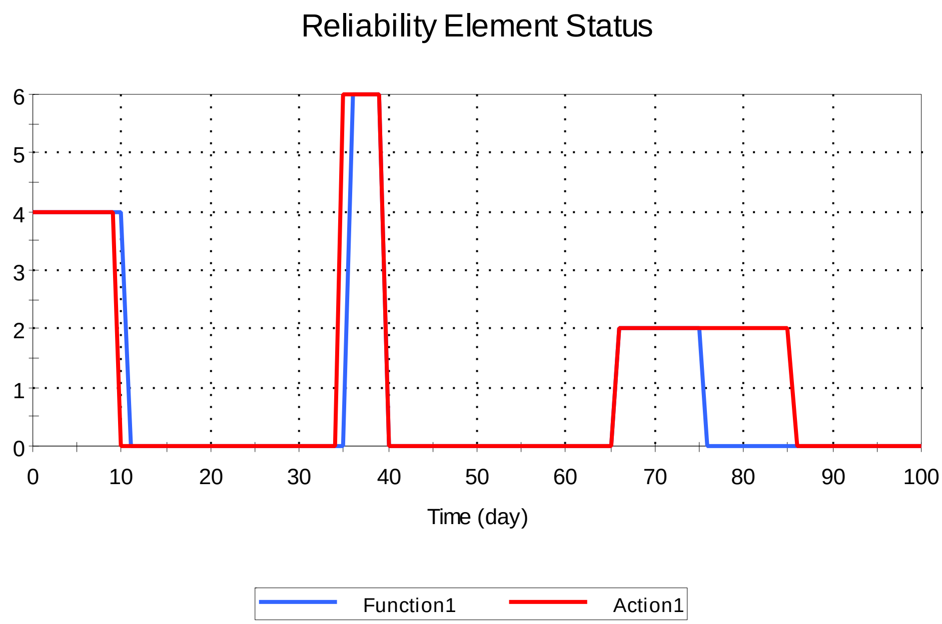


Figure RL20_1

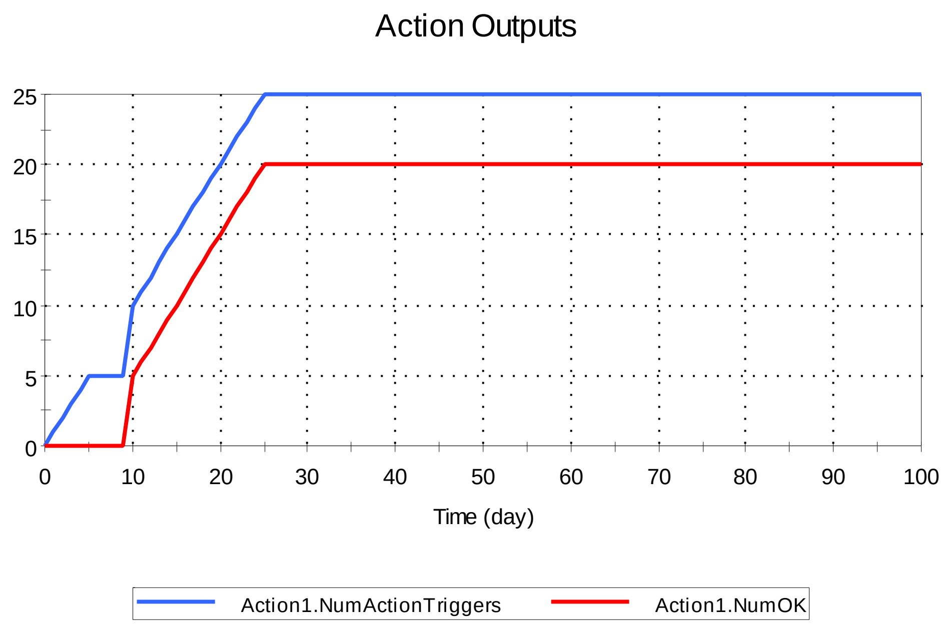


Figure RL20_2

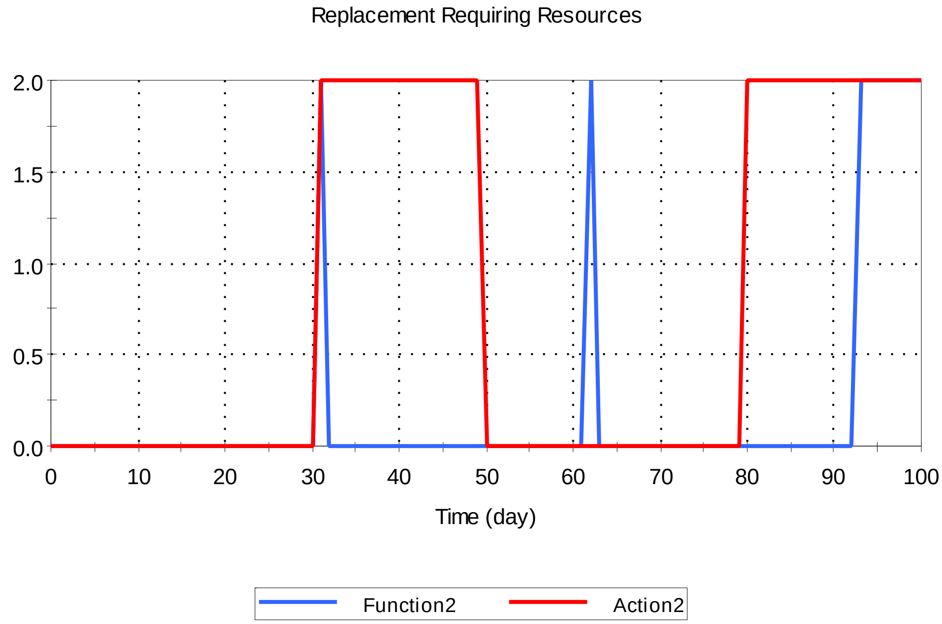


Figure RL20_3

7. OPTIMIZATION MODULE TESTS

Access the Optimization dialog by going to Run|Optimization. Test the Optimization dialogs to ensure that all buttons, drop-downs, and fields work as expected, in both the Define Optimization Settings and Run Optimization tabs.

OP_01_Maximum_Minimum

Open the test file “OP_01_Maximum_Minimum” and follow the instructions in the file. This file tests GoldSim’s ability to locate a minimum and a maximum within a specified range.

The tester should select the High precision level and optimize the model with the goal set to Maximize, and then with the goal set to Minimize. The tester should also confirm that selecting “Copy optimized values to element definitions” after closing the optimization dialog, and then running a deterministic simulation provides the same objective function value.

A successful test is indicated by locating a maximum at X=0.22488 with F(X)= .788685, and a minimum at X=0.72488 with F(X)=-0.47836. Test results should correspond with the actual results to four significant figures.

OP_02_Boolean_Integer_Conversion

Open the test file “OP_02_Boolean_Integer_Conversion” and follow the instructions in the file. This file tests GoldSim’s ability to use both integer and Boolean optimization variables, and also ensures the proper conversion between different units. This test also checks that optimized values are correctly propagated as local properties when the "Copy optimized values to element definitions " option is selected.

The tester should ensure that the start values for X, Y, and TF are set to their defaults (0, 0, and false respectively). They should then run the optimizer with Precision set to Low through five optimization cycles (it should first be verified that the “Randomize Optimization Sequence” option is checked), selecting “Copy optimized values to initial values of optimization variables” when closing the optimization dialog at the end of each optimization run. After the fifth cycle choose the “Copy optimized values to element definitions” option and then run a deterministic simulation to check that the objective function corresponds with its optimized value (thus verifying that the controlled elements have been assigned the optimized values). The tester should ensure that the results are acceptable, as described in the next paragraph, and then repeat the procedure (without copying optimized values) for Precision settings of Medium and High.

This problem has a strict optimum of F=0.000762m, with X=1.2345 ft/0.37628m, Y=9 and TF equal to true.

For the Low precision setting, an acceptable result after five optimization runs is indicated by F<0.1.

For the Medium precision setting, an acceptable result after five optimization runs is indicated by F<0.01.

For the High precision setting, an acceptable result after five optimization runs is indicated by F<0.001.

The optimized variables for the High precision level should also correspond closely with the optima listed above. The optimized value for X should correspond to 4 decimal places, and values for Y and TF should be equal to the optimal values.

OP_03_Conditions

Open the test file "OP_03_Conditions" and follow the instructions in the file. This test is designed to test the optimizer's ability to locate an overall maximum, as well as the "Require this condition to be true" feature in the optimizer.

The tester should first ensure the following initial settings:

Sphere	X-coordinate	Y-coordinate	Z-coordinate	Radius
1	X1 = 1	Y1 = 8	Z1 = 4	R1 = 2
2	X2 = -2	Y2 = -2	Z2 = -2	R2 = 7
3	X3 = 10	Y3 = 0	Z3 = 0	R3 = 4

In the simulation settings dialog "Repeat sampling sequences" should be unchecked, and the optimizer should be set to the High precision level.

1) Run the optimizer with the following settings for the reject region: Xreject=0, Yreject=1 and Rreject=3. The optimizer should report an optimum solution of 5.9999 or greater at a point within the square between [0.99, 7.99] and [1.01, 8.01]).

2) Run the optimizer with the following settings for the reject region: Xreject=1, Yreject=8 and Rreject=1 (this places a small reject region inside of sphere 1). The optimizer should report an optimum solution of 4.99 or greater, but this is not the true maximum. Up to 10 further optimization runs should be conducted to ensure that the optimizer reports a maximum value of 5.73 or greater at a point along the perimeter of the reject region.

3) Run the optimizer with the following settings for the reject region: Xreject=1, Yreject=8 and Rreject=2 (this eliminates sphere 1 from consideration). The optimizer should report an optimum solution of 4.99 or greater (at a point within the square between [-2.01, -2.01] and [-1.99, -1.99]).

4) Run the optimizer with the following settings for the reject region: Xreject=-1, Yreject=0 and Rreject=10 (this eliminates sphere 1 and 2 from consideration). The optimizer should report an optimum solution of 3.99 or greater (at a point within the square between [9.99, -0.0001] and [10, 0.01]).

OP_04_Maximum

This test ensures the correct functioning of the Maximum optimization option.

The test uses an Objective Function that is likely to require a high number of realizations before the optimizer will converge. The upper limit of the expression is 0.2 and the lower limit is -0.2.

The verifier should run the model with the Optimizer set to Maximize and the Precision set to High. The optimization should then be rerun with the precision set to Maximum. Both optimizations should converge to an optimum value close to the 0.2 limit for the equation (>0.199 is acceptable in both cases).

The test should then be repeated for High and Maximum precision settings with the Optimizer set to Minimize. Again, both optimizations should converge to an optimum value close to the -0.2 limit for the equation (<-0.199 is acceptable in both cases).

When running a Maximum precision optimization the verifier can terminate the optimization before it converges if more than 5000 realizations have been run and the Objective Function value is within the acceptable range.

OP_05_Submodel

This test embeds test OP_01_Maximum_Minimum within a SubModel element to ensure that submodel optimization performas as expected.

The user should run the model, and confirm that the SubModel executes at time 10 days, and returns a value close to 0.72488.

8. LICENSING TESTS

Supercedes licensing tests in GS0.

See the document entitled GoldSim_Licensing_Tests.doc. In SourceSafe, this document is located in $/Verification/GoldSim.

9. FINANCIAL MODULE

See the document entitled FN Vplan.doc. In SourceSafe, this document is located in $/Verification/GoldSim/Financial.

10. REFERENCES

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APPENDIX I: TEST FILES

File Names	Description
CT_Cells1-01 – CT_Cells1-07	Cells: partitioning/Solubility
CT_Cells2-01 – CT_Cells2-10	Cells: advective links
CT_Cells3-01 – CT_Cells3-16	Cells: diffusive links
CT_Cells4-01 – CT_Cells4-05	Cells: decay
CT_Cells5-01 – CT_Cells5-03	Cells: time-varying
CT_Cells6-01 – CT_Cells6-02	Cells: cell nets
CT_ExtPath-01 – CT_ExtPath-03	External pathways
CT_Pipes-01 – CT_Pipes-09	Pipe pathways
CT_Net01 – CT_Net03	Network pathways
CT_Result-01 – CT_Result-07	Results
CT_SourceSampledFailure-01	Random source-term failures
CT_SourceTableFailure-01 – CT_SourceTableFailure-07	Source failure using table-defined failure distributions
CT_SourceBasic01 – CT_SourceBasic11	Basic source-term tests
CT_SourceBarriers01 – CT_SourceBarriers23	Source-term barrier tests
CT_SourceDecay-01	Source-term decay calculation
CT_SourceExposure-01 – CT_SourceExposure-04	Source term- exposure
CT_Species_Import	Spreadsheet import of species data (half-lives and decay rates)
CT_Species_Import_Export	Spreadsheet import and export of species data (half-lives and decay rates)
CT_Clone3	Tests cloning of all CT elements
CT_Conditionality1	Conditionality of environmental elements
CT_Timestep	Variable timestep for CT elements
CT_Recept-01	Receptor Element
TimeMonteCarlo-01 – TimeMonteCarlo-07	Time & Monte Carlo tests
GS0_Run_Controller	Tests the GoldSim Run Controller
GS00_User_Interface_Tests	Tests GoldSim user interface
GS00a_FilterGraphicsOptions	Tests filtering and custom influences
GS01_Spreadsheet	Spreadsheet
GS02_expressions	Expressions
GS03_array	Arrays
GS04_Stochastics ,GS04a_Stoc_Array, GS04b_Conditional_Tail_Expectation	Stochastic elements
GS05_Integrator1	Integrator elements
GS06-Integrator2	Integrator elements
GS07_selectors	Selector elements
GS08_look	Lookup-table elements
GS09a_dbas, GS09b_dbas, and GS09aFile_Element	Database connection
GS10_Clone1	Clone elements
GS11_Clone2	Clone elements
GS12_ext	External element

GS13_Sum	Sum element
GS14_Extrema	Extrema element
GS15_logical	And, Or, Not elements
GS16a_Event and Discrete Change Delays GS16b_Information and Material Delays	Delay elements
GS17_Timed_Events_and_Discrete_Changes	Timed events and Discrete Change elements
GS18_Random_Timed_Events	Timed Event element
GS19_Reservoir	Reservoir element
GS19a_Reservoir2	Reservoir element
GS20_Element_Activation	Activation, deactivation, and reactivation of containers and elements
GS21_Conditional_Containers	Container Conditionality tests
GS22_Datetime	Date/time based runs
GS23_Elapsetime	Elapsed time runs
GS24_Timestep	Timestep phases
GS25a_Multiprocessor_Dynamic	Test multiprocessor solution for dynamic models
GS25b_Multiprocessor_Static	Test multiprocessor solution for static models
GS26_Event_Substep	Updating Event during timestep
GS27_Triggering	Triggering
GS28_Deterministic Options	Deterministic simulation settings
GS29_External2	Table-definition output for external elements
GS30_Table_Function	Tests table-call function
GS31_Param_Import_Samp	Importance sampling of parameters
GS32_Save_Results	Result Saving
GS33_Previous_Timestep_Value	Tests Previous-Timestep Operator (~)
GS34_Modify_Units_and_Sets	Ordinal sets and user-defined units
GS35_Dynamic_Export	Result Export
GS36_Static_Export	Result Export
GS37_Initial_Values_and_Previous-Value_Links	Initial values and feedback links
GS38_Changed_and_Occurs	Changed() and Occurs()
GS39_Decision_Milestone_Status	Decision, Milestone, and Status elements
GS40_Information_Time_Series	Information Time Series elements
GS40b_TimeSeriesExcelSupport	Excel support for time history elements
GS41_Material_Time_Series	Material Time Series elements
GS42_Date_Time_Series	Date/Time simulations for Time Series elements
GS43_Versioning	Versioning of model files
GS44_External_File_Locking	File locking of external files
GS45_Command-Line_Arguments	Command Line Arguments
GS46_Dashboard_and_Player 1 and 2, GS46a_Dynamic_Dashboard	Dashboard element and GoldSim Player
GS47_Masterclock_Outputs	Outputs of the Masterclock
GS48_Convolution and GS48b_Truncated_Convolution	Convolution elements

GS49_RandomChoice	Random choice element
GS50_LookupTables	Lookup table elements
GS51_Looping	Looping subsystems
GS52_InternalClocks	Submodels with internal clocks
GS53_Sensitivity	Sensitivity Analysis
GS54_Splitter	Splitter elements
GS55_Allocator	Allocator Elements
GS56_History_Generator	History Generator elements
GS57_Interrupt	Interrupt elements
GS58_Currencies	Currency dialog/conversion
GS59a through GS59i	Submodel Tests
GS60_TimeSeries	Time Series Elements
GS60b_TimeSeriesExcelSupport	Time Series Excel Links
OP_01_Maximum_Minimum	Ability to locate a maximum and minimum
OP_02_Boolean_Integer_Condition	Tests optimization of Boolean and integer varables, and respect of a user-defined condition
OP_03_Conditions	Tests user-defined conditions and restrictions on optimized values
OP_04_Maximum	Tests maximum optimization option
Result-01 to Result-14	Result display
RL_01_Failure_Modes	Tests all of the reliability element failure modes
RL_02_FMCV	Tests built in and user defined failure mode control variables
RL_03_Automatic_Repair_Distributions	Tests automatic repair distributions
RL_04_Outputs	Tests reliability element outputs
RL_05_Requirements	Tests requirements trees
RL_06_PMReplace	Tests PM modes
RL_07_Combined_Failure_Modes	Tests multiple failure modes
RL_08_Cloning	Tests cloning of RL elements
RL_09_Dynamic_Fields	Tests dynamic fields in RL elements
RL_10_Action_Delay	Tests the delay features of the Action RL element
RL_11_Static_Model	Tests the operation of RL elements in a static model
RL_12_Reliability_Availability	Tests reliability and availability statistics
RL_13_Failure_Repair	Tests time to failure and time to repair statistics
RL_14_Tree_States	Tests that RL element states are correctly identified and catalogued
RL_15_Root_Cause_Analysis	Tests root cause analysis functionality
RL_16_Event _Driven_System	Tests that results for event driven systems are calculated correctly.

APPENDIX II AUTOMATIC TEST FILES
(Updated for GoldSim 10.10)

```
//Automatic Tests for GoldSim's Ctrl-F8 Test Procedure


//Normal parsing of numbers
9
9.
9.2
.9
0.9
9E3
9.E3
9.2E3
9E-3
9.E-3
9.2E-3
9.222E-15
1.23456789012345
1.2345678901234545

//Parse-errors in numbers
9876543210987654321.5
2.1098765432109876543
0.9876543210987654321
5E-10000
5E10000
A.
A.1
1.XA
.A
0.XA
9EA
AE3
9.87654321A9876543
9876543210987654321.0XA
9.876543210987654321XA9
98.76   54321

//Normal parsing of identifiers
GEE+2*GEE-GEE*3+SQRT(GEE^2)   gee
GEE/2 gee
GEE   gee
Gee   gee

//Parse-errors in identifiers
GEE+2 gee
GEE-2 gee
GEE*  gee
GEE/0 gee
GEE/  gee
Sqrt(gee)   gee
SQRT-GEE    gee
2^GEE gee
GEEE  gee
```

```
Gee.  gee

//Normal parsing of binary operators
5+2
5-2
5*2
5/2
5^2
5>2
5>=2
2<5
2<=5
5=5
5==5
5!=2
5<>2
5    +        2
(1==1) and (1==1) or (1==1)
(1==1) and (1==2)
(1==1) and (1==1) or (1==2)
(1=1) and (1=1) or (1=2)
5<2
5==2
5<>5

//Parse-errors in binary operators
5>>2
5?0
5=!2
5=>2

//Normal parsing of unary operators
NOT (1==1)
-5
-(-5)
-5^2
(-5)^2
!(1==1)
!(1==2)
NOT (1==1)
NOT NOT (1==1)
NOT (1==2)
--5
---5
-0

//Parse-errors in unary operators
!!5
-b
!B
5!
NOT^2
!^2
-^2
(!)5
(NOT (1==2))^2
- 5
```

```
//Normal parsing of func1()
SIN(1)
COS(1)
TAN(1)
COT(1)
SINH(0.5)
COSH(0.5)
TANH(0.5)
ASIN(0.75)  deg
ACOS(0.75)
ATAN(0.75)
ATAN(5)
LN(0.5)
LOG(222)
ABS(5)
ABS(-2)
SIN(5{deg})
SIN(pi/2)
COS(3*(pi/4))
SINH(5)
COSH(5)
TANH(5)
Round(1.4999)
Round(-1.4999)
Trunc(1.4999)
Trunc(-1.4999)
Sqrt(10^2)
Floor(1.6)
Floor(-1.6)
Floor(3.999999999999)
Ceil(1.6)
Ceil(-1.6)
Ceil(4.000000000001)
gm2cm(.05)
cm2gm(.05)

//Errors in func1()
ASIN(5)
ACOS(5)
LN(-2)
LOG(-2)
SIN(2A)
COS(9876543210987654321.01)
SIN(5{ft})
Sqrt(-2)
Exp(ln(2

//Normal parsing of fun2(,)
BESS(2,10)
BESS(10,10)
BESS(100,50)
BESS(-5,10)
BESS(15.1,2)
MIN(1,5)
MIN(BESS(2,10),BESS(10,10))
MAX(1,5)
MAX(BESS(2,10),BESS(10,10))
```

```
MOD(8,3)
MOD(-2,5)
MIN(2,2)
MAX(2,2)
min(1,5)
max(1,5)
mod(8,3)
0.5*erf(1.96/sqrt(2))
beta(1,2)
beta(3,4)
Ftop(.05,10)
Ptof(.05,10)
Atop(.05,10)
Atof(.05,10)
Ptoa(.05,10)
pc2cc(.05,10)
cc2pc(.05,10)
ari2cm(.05,.10)
ari2vol(.05,.10)
geo2vol(.05,.10)

//Errors in func2(,)
BESS(5,-10)
MIN(BESS(5,-10),BESS(2,10))
MAX(BESS(-5,10),BESS(2,10
MOD(2,0)
BSS(2,10)
MN(1,2)
MX(2,3)
MAD(2,10)
MIN(2, )
MAX( ,3)
MIN(2,3
MAX3,4
Beta(-1,2)


//Normal func3(,,)
if((1==1),2,3)
if((1==2),1,2)
if((1==1),5,3)
if     ((1==1),2,3)
if((1==1) and (1==1),3,4)
if((1==2) or (1==1),2,3)
if((1==2) and (1==1),2,3)
If((1==1),2,3)
IF((1==1),2,3)
If((1==1) then 2 else 3)


//Errors in func3(,,)
if{(1==1),2,3}
if((1==1),2)
if((1==1))
if((1==1), , )
if(1*,2,3)
if(A,2,3)
```

```
iff((1==1),2,3)
if1,2,3

//Normal parsing of units
2{m2} m2
2{m^2}      m2
5{g/l}      g/l
5{lbf-ft2}  lbf-ft2
5{(m2/sec)/(ft-lbf)}    (m2/sec)/(ft-lbf)
5{(g)/(l)}  g/l
5{(g/l)}    g/l
5{(lbf)-(ft2)}    lbf-ft2
5{lbf-ft2}  lbf-ft2
3{in}*5{lbf}
(6{ft})|in|
"3/11/98 23:30:00"-"3/11/98 10:00:00"     day
"3/11/98" - "12/25/2001"      day
-10C  K
 (-10C)     K
-10F  R
 (-10F)     R

//Parse-errors in units
2{(m)2}     m2
2{m(2)}     m22m2 m2
2m^2  m2
2{(m)^2}    m2
2{m^(2)}    m2
2{{m2}}     m2
5{g//l}     g/l
3{in}+5{lbf}
3{in}^5{lbf}
"3/11/98 25:30:00"-"3/11/98 10:00:00"
"3/11/98 - "12/25/2001"


//Normal precedence
(-2)^2/4*2+8-5>2 or (1==1) and (1==2)
(2*(-2)^3/4)^2-8
-(2*5)/5*4
(80-3*4*(2^3+2)/5>6/3)
```

File UnitsEcho0.txt:

```
GoldSim Version 9.29.975
1{$}        $           1
1{'}        m           0.3048
1{"}                    Missing closing "" for date operator
1{°}        rad         0.0174532925199433
1{a}        s           31557600
1{ac}       m2          4046.8564224
1{acre}     m2          4046.8564224
1{af}       m3          1233.48183754752
1{afd}      m3/s        0.0142764101568
1{amp}      amp         1
1{pamp}     amp         1e-012
1{namp}     amp         1e-009
1{uamp}     amp         1e-006
1{mamp}     amp         0.001
1{kamp}     amp         1000
1{Mamp}     amp         1000000
1{Gamp}     amp         1000000000
1{Tamp}     amp         1000000000000
1{Ang}      m           1e-010
1{atm}      kg/m-s2     101325
1{bar}      kg/m-s2     100000
1{pbar}     kg/m-s2     1e-007
1{nbar}     kg/m-s2     0.0001
1{ubar}     kg/m-s2     0.1
1{mbar}     kg/m-s2     100
1{kbar}     kg/m-s2     100000000
1{Mbar}     kg/m-s2     100000000000
1{Gbar}     kg/m-s2     100000000000000
1{Tbar}     kg/m-s2     1e+017
1{bbl}      m3          0.1589873
1{bbldry}   m3          0.11563
1{bblliq}   m3          0.11924
1{bpd}      m3/s        1.84013078703704e-006
1{Bq}       1/s         1
1{pBq}      1/s         1e-012
1{nBq}      1/s         1e-009
1{uBq}      1/s         1e-006
1{mBq}      1/s         0.001
1{kBq}      1/s         1000
1{MBq}      1/s         1000000
1{GBq}      1/s         1000000000
1{TBq}      1/s         1000000000000
1{BTU}      kg-m2/s2    1055.056
1{bushel}   m3          0.03523907
1{C}        K           274.15
1{cal}      kg-m2/s2    4.1868
1{pcal}     kg-m2/s2    4.1868e-012
1{ncal}     kg-m2/s2    4.1868e-009
1{ucal}     kg-m2/s2    4.1868e-006
1{mcal}     kg-m2/s2    0.0041868
1{kcal}     kg-m2/s2    4186.8
1{Mcal}     kg-m2/s2    4186800
1{Gcal}     kg-m2/s2    4186800000
1{Tcal}     kg-m2/s2    4186800000000
1{cc}       m3          1e-006
1{cd}       cd          1
1{pcd}      cd          1e-012
1{ncd}      cd          1e-009
1{ucd}      cd          1e-006
1{mcd}      cd          0.001
1{kcd}      cd          1000
```

1{Mcd}	cd	1000000
1{Gcd}	cd	1000000000
1{Tcd}	cd	1000000000000
1{Cdeg}	K	1
1{cfs}	m3/s	0.028316846592
1{Ci}	1/s	37000000000
1{cm}	m	0.01
1{Co}	s-amp	1
1{pCo}	s-amp	1e-012
1{nCo}	s-amp	1e-009
1{uCo}	s-amp	1e-006
1{mCo}	s-amp	0.001
1{kCo}	s-amp	1000
1{MCo}	s-amp	1000000
1{GCo}	s-amp	1000000000
1{TCo}	s-amp	1000000000000
1{cp}	kg/m-s	0.001
1{cup}	m3	0.00023658825
1{cycle}	rad	6.28318530717959
1{d}	s	86400
1{Darcy}	m2	9.86923266716013e-013
1{day}	s	86400
1{deg}	rad	0.0174532925199433
1{dyne}	kg-m/s2	1e-005
1{eV}	kg-m2/s2	1.60217733e-019
1{peV}	kg-m2/s2	1.60217733e-031
1{neV}	kg-m2/s2	1.60217733e-028
1{ueV}	kg-m2/s2	1.60217733e-025
1{meV}	kg-m2/s2	1.60217733e-022
1{keV}	kg-m2/s2	1.60217733e-016
1{MeV}	kg-m2/s2	1.60217733e-013
1{GeV}	kg-m2/s2	1.60217733e-010
1{TeV}	kg-m2/s2	1.60217733e-007
1{F}	K	255.927777777778
1{Fa}	s4-amp2/kg-m2	1
1{fath}	m	1.8288
1{Fdeg}	K	0.555555555555556
1{flng}	m	201.168
1{floz}	m3	2.957353125e-005
1{fpm}	m/s	0.00508
1{fps}	m/s	0.3048
1{ft}	m	0.3048
1{g}	kg	0.001
1{pg}	kg	1e-015
1{ng}	kg	1e-012
1{ug}	kg	1e-009
1{mg}	kg	1e-006
1{kg}	kg	1
1{Mg}	kg	1000
1{Gg}	kg	1000000
1{Tg}	kg	1000000000
1{gal}	m3	0.003785412
1{gali}	m3	0.00454609
1{galus}	m3	0.003785412
1{gee}	m/s2	9.80665
1{gf}	kg-m/s2	0.00980665
1{gpm}	m3/s	6.30902e-005
1{Gy}	m2/s2	1
1{pGy}	m2/s2	1e-012
1{nGy}	m2/s2	1e-009
1{uGy}	m2/s2	1e-006
1{mGy}	m2/s2	0.001
1{kGy}	m2/s2	1000
1{MGy}	m2/s2	1000000

1{GGy}	m2/s2	1000000000
1{TGy}	m2/s2	1000000000000
1{ha}	m2	10000
1{hp}	kg-m2/s3	745.699920901874
1{hr}	s	3600
1{Hz}	1/s	1
1{pHz}	1/s	1e-012
1{nHz}	1/s	1e-009
1{uHz}	1/s	1e-006
1{mHz}	1/s	0.001
1{kHz}	1/s	1000
1{MHz}	1/s	1000000
1{GHz}	1/s	1000000000
1{THz}	1/s	1000000000000
1{in}	m	0.0254
1{J}	kg-m2/s2	1
1{pJ}	kg-m2/s2	1e-012
1{nJ}	kg-m2/s2	1e-009
1{uJ}	kg-m2/s2	1e-006
1{mJ}	kg-m2/s2	0.001
1{kJ}	kg-m2/s2	1000
1{MJ}	kg-m2/s2	1000000
1{GJ}	kg-m2/s2	1000000000
1{TJ}	kg-m2/s2	1000000000000
1{K}	K	1
1{pK}	K	1e-012
1{nK}	K	1e-009
1{uK}	K	1e-006
1{mK}	K	0.001
1{kK}	K	1000
1{MK}	K	1000000
1{GK}	K	1000000000
1{TK}	K	1000000000000
1{kgf}	kg-m/s2	9.80665
1{kip}	kg-m/s2	4448.22190946
1{kp}	kg/m-s2	98066.5
1{kph}	m/s	0.277777777777778
1{kt}	m/s	0.514444444444444
1{kwh}	kg-m2/s2	3600000
1{l}	m3	0.001
1{pl}	m3	1e-015
1{nl}	m3	1e-012
1{ul}	m3	1e-009
1{ml}	m3	1e-006
1{kl}	m3	1
1{Ml}	m3	1000
1{Gl}	m3	1000000
1{Tl}	m3	1000000000
1{lamb}	cd/m2	10000
1{lbf}	kg-m/s2	4.44822190946
1{lbm}	kg	0.4535924
1{lm}	cd	0.0795774715459477
1{lx}	cd/m2	1
1{ly}	m	9.4607304725808e+015
1{m}	m	1
1{pm}	m	1e-012
1{nm}	m	1e-009
1{um}	m	1e-006
1{mm}	m	0.001
1{km}	m	1000
1{Mm}	m	1000000
1{Gm}	m	1000000000
1{Tm}	m	1000000000000
1{md}	m2	9.86923266716013e-016

1{MGD}	m3/s	0.0438126388888889
1{mgf}	kg-m/s2	9.80665e-006
1{mi}	m	1609.344
1{mil}	m	2.54e-005
1{min}	s	60
1{minarc}	rad	0.000290888208665722
1{mol}	mol	1
1{pmol}	mol	1e-012
1{nmol}	mol	1e-009
1{umol}	mol	1e-006
1{mmol}	mol	0.001
1{kmol}	mol	1000
1{Mmol}	mol	1000000
1{Gmol}	mol	1000000000
1{Tmol}	mol	1000000000000
1{mon}	s	2629800
1{mpg}	1/m2	425143.683171079
1{mph}	m/s	0.44704
1{N}	kg-m/s2	1
1{pN}	kg-m/s2	1e-012
1{nN}	kg-m/s2	1e-009
1{uN}	kg-m/s2	1e-006
1{mN}	kg-m/s2	0.001
1{kN}	kg-m/s2	1000
1{MN}	kg-m/s2	1000000
1{GN}	kg-m/s2	1000000000
1{TN}	kg-m/s2	1000000000000
1{naut}	m	1852
1{ohm}	kg-m2/s3-amp2	1
1{pohm}	kg-m2/s3-amp2	1e-012
1{nohm}	kg-m2/s3-amp2	1e-009
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6. REQUEST TO INSTALL PRODUCTION WELL IN SECTION 29 (Envirocare, 2005)

ENVIROCARE OF UTAH, LLC.
SAFE AND SECURE

CD05-0171

April 11, 2005

Dane Finerfrock, Executive Secretary
State of Utah
Division of Water Quality
168 North 1950 West
P.O. Box 144850
Salt Lake City, Utah 84114-4850

Re: Request to install production well – submittal of revised modeling

Dear Mr. Finerfrock:

Envirocare of Utah, LLC (Envirocare) has a Groundwater Quality Discharge Permit UGW450005 (GWQDP) issued by the Division of Water Quality (DWQ) and administered by the Division of Radiation Control (DRC). Condition I.E.18 of the GWQDP requires that Envirocare receive approval prior to installing a pumping well. On September 8, 2004, Envirocare submitted for DWQ review and approval a groundwater model to demonstrate pumping effects on the shallow, unconfined aquifer. On December 17, 2004, DWQ's consultant, URS, provided comments on the model and on February 11, 2005, a conference call was held to discuss a path forward. The enclosed modeling report incorporates changes agreed upon during the February 11, 2005, conference call. Envirocare has also attached a Technical Memorandum specifically addressing the December 17, 2004, Interrogatories.

Also discussed during the conference call was the preparation of a "post-model audit plan". The purpose of this plan is to evaluate how the production well affects the shallow, unconfined aquifer beneath the site. The remainder of this letter provides the requested information.

The groundwater model demonstrates that the production wells will not impact groundwater flow in the shallow, unconfined aquifer. The results of the model indicate that a production well screened from 550 to 600 feet below ground surface (bgs), pumped at 200 gallons per minute, 24 hours per day, 4 months per year (122 days), would create approximately 0.5 feet of drawdown in the upper aquifer after 20 years. This drawdown will not affect the hydraulic gradient beneath the facility.

Condition I.H.2.c)2. of the GWQDP specifies hydraulic gradient limits for all disposal facilities at the Envirocare facility. Specifically, the limits are as follows:

ENVIROCARE

Disposal Cell	Horizontal Hydraulic Gradient Limit
Class A	1.00 E-3
LARW	9.67 E-4
Mixed Waste	9.67 E-4
11e.(2)	3.29 E-3

These limits were used in the previous modeling exercises to demonstrate compliance with the Groundwater Protection Levels. Envirocare is required [Conditions I.F.5.a), I.F.5.b), and I.H.2.a)] to measure and report groundwater elevations on a monthly basis and calculate fresh-water and salt-water gradients. It is important to note that based on the conservative fate and transport modeling (HELP, UNSAT-H, and PATHRAE), contaminants from the disposal cell won't reach the water table for many years. Any effects from the production wells will have attenuated before any transport can occur.

Even though the MOD-FLOW model demonstrates little to no impact on the shallow, unconfined aquifer, Envirocare commits that should production wells cause the average gradients beneath any of the disposal embankments to go above the specified horizontal hydraulic gradient. Envirocare will shut down the production wells until either:

1) the average hydraulic gradient returns to below the specified value, or
2) Envirocare remodels the disposal cell using the new average gradient value and demonstrates that the groundwater protection levels are met.

In addition, Envirocare commits to the installation of two observation wells in the immediate vicinity of the production well north of our current operations. Monitoring wells G-19A (screened from 18 to 28 feet bgs), GW-19B (screened from 79 to 99 feet bgs), and piezometer PZ-1 (screened from 19 to 29 feet bgs) will fulfill this requirement for the production well near the southwest corner pond. These wells will also be monitored on a monthly basis, which will provide information to evaluate if the production well is affecting the vertical gradient in the shallow, unconfined aquifer and deeper, confined aquifer.

Envirocare is located in a groundwater discharge area. Condition I.H.2.b)2. requires that the upper gradient be calculated on a monthly basis. The two new observation wells installed with northern production well can be added to this condition for reporting. Should the vertical gradient be reversed, Envirocare will immediately notify the DWQ and provide an evaluation of how this reversal will impact the long-term performance of the facility.

ENVIROCARE Summary

Envirocare currently uses approximately 20,000,000 gallons of salt water for dust control at our Clive facility. This water is trucked from a production well located north of Interstate-80. Envirocare requests that the DRC approve the installation and use of the two production wells to reduce truck traffic and costs associated with hauling water. Envirocare commits to monitor and report the effects of the production wells on the shallow, unconfined aquifer as part of the monthly monitoring program. Should the operation change the hydraulic gradient beneath the disposal sites to an un-analyzed condition, Envirocare commits to stopping production. Envirocare also commits to installing and monitoring one shallow and one intermediate depth well for the northern production well in order to evaluate the vertical gradient.

Envirocare is committed to protecting human health and the environment. Although there are no known receptors for the groundwater beneath the facility, Envirocare will continue to protect this groundwater as if there were an end use. The conservative nature of the modeling coupled with the poor groundwater quality beneath the facility means that there is little risk in allowing Envirocare to install the proposed production wells.

Should you have any questions regarding this letter or if you would like to discuss the content or substance of this letter, please feel free to contact me at (801) 532-1330.

Sincerely,

Daniel B. Shrum
Director of Safety and Compliance

Enclosures

Cc: Bob Baird, URS, w/ attachments

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Whetstone Associates

Technical Memorandum

To:	Dan Shrum, Envirocare of Utah, Inc.	**4101U**
From:	Susan Wyman, P.E., P.G., Whetstone Associates, Inc.	
Date:	**March 15, 2005**	
Subject:	Response to Interrogatories, Pumping Well Modeling	

On behalf of UDEQ DRC, URS Corporation submitted comments on the numerical groundwater models created to assess the potential drawdown in the surficial aquifer from production well(s) at the Envirocare facility located at Clive, Utah. The Modflow modeling was performed by Whetstone Associates and presented in two technical memoranda dated April 9, 2003 and September 7, 2004. The interrogatory comments were received in December 2004, and a conference call was held between Envirocare, Envirocare's consultant (Whetstone Associates), and DRC's consultant (URS). This memorandum addresses the interrogatories presented in the December 2004 URS memo, as clarified in the February 2005 conference call.

Interrogatory #1A. *Please provide discussion on regional groundwater flow and how the present local flow model dovetails into it.*

> *Background. Some discussion and quantification of regional flow is necessary because of the artificial boundaries (upgradient and downgradient) used in the model. Also note that the development of a quantitative regional model is sometimes useful to help set such boundaries.*

Interrogatory #1B. *Please provide a discussion and graphic of the conceptual model with an emphasis on hydrostratigraphic units and natural boundary conditions (or lack thereof). Aquifer parameters and model layers should be identified/characterized within this context. If newer data have augmented or modified earlier interpretation then this should be discussed. If not, relate the current conceptual model (and MODFLOW implementation) to the previous conceptual model.*

> *Background. There is no discussion of the conceptual model. Instead, the narrative (partially) documents a MODFLOW implementation. In addition, the present conceptual model—implicit in the 'Model Domain' discussion—appears to be inconsistent with the information provided in earlier reports, e.g., Pentacore 2000 and Bingham 1996. Earlier reports and modeling consider four (4) units—the upper most being unsaturated.*
>
> *The statement that "model layers represent geologic material encountered during drilling at the site (p.3)..." is about as close as the memorandum gets to a discussion of the conceptual flow model for the site.*
>
> *The present model (conceptual aspects) and its parameterization should specifically incorporate the four geohydrological units identified in these earlier reports. (Note, however, the unsaturated zone is not of interest here.)*

Response. A description of the regional hydrologic system has been added to the revised report, along with brief discussion of the four hydrostratigraphic units described in previous hydrogeology reports about the site (Bingham [1991, 1992], Pentacore [2000]). As described in the revised report, the regional aquifer comprises the Great Salt Lake Desert sub-basin of the West Desert Basin, a closed basin that drains to the Great Salt Lake. The MODFLOW model represents 4% (234 square miles) of the 6,250 square miles of the Great Salt Lake Desert sub-basin.

The hydrostratigraphic units mapped at the Envirocare site represent the shallow subsurface in a localized area of the model domain. Four units have been identified. The upper unit (Unit 4) is unsaturated. Unit 3 averages 15 ft in thickness and is only partially saturated. Unit 2 averages 15 ft and is typically saturated. The thickness of Unit 1 has not been determined, because few of the wells installed on site are drilled to depths greater than 55 ft. The four hydrostratigraphic units together represent the upper 30 - 50 ft of the aquifer and are incorporated into Layer 1 of the 1,000-ft thick model.

More than 5 deep monitoring wells and piezometers have been installed to depths of 100 – 250 ft. The hydraulic properties of model layers 2-11 and 13-20 were based on information from these borings.

Table 1. Thickness of Upper Hydrostratigraphic Units

HSU	Minimum Thickness (ft)	Maximum Thickness (ft)	Average thickness (ft)	Saturation
Unit 4	6 to 16.5	16.5	10	Unsaturated
Unit 3	7 to 25	25	15	Partially saturated
Unit 2	2.5 to 25	25	15	Saturated
Unit 1	>10	ND	ND	Saturated

Notes: ND = not determined

Interrogatory #2A. Please...explain why changes in bedrock elevation do not need to be incorporated into the present model—be that by means of direct incorporation of some variability of the depth in the model, e.g., through the use inactive Fcells in some of the lower layers, or more simply via sensitivity analyses.

> *Background. It is clear in earlier reports that the depth to bedrock is variable, e.g., in the 1996 Bingham report: "Because of the lack of detailed subsurface data concerning the bedrock, the exact depth to and relationships of various bedrock units are unknown, however, the presence of nearby outcrops and the regional block-faulted basins suggest that the valley-fill deposits are relatively thin within the area of the site. ..."*
>
> *Given reasonable estimates for the range of depths to bedrock over the modeled area and in the vicinity of the site, resulting variation in transmissivity may impact the drawdown.*
>
> *Other possible impacts—bedrock outcrops represent interior no flow areas and also may result in some recharge at interior locations, e.g., one mile to the west and two miles to from the vicinity of Lone Mountain to the south and east.*

Response. Changes in bedrock were not incorporated into the April 2003 and September 2004 modeling submissions because:

- Bedrock has not been encountered in any drill holes at the site, as the modeling reports described. The modeling reports provided data for the Cox Construction well and the Broken Arrow well, which were drilled to depths of 350 ft and 620 ft, respectively. (Note that since the Broken Arrow well was drilled in 1996, the same year that the Bingham report was published, the data from this well may not have been included in the Bingham report. The model is based on the more current information, which indicates that the depth to bedrock in the vicinity of the site exceeds 620 ft.)
- In a report on basin-and-range aquifers, the USGS (Robson and Banta, 1995) reported that "the thickness of the basin fill is not well known in some basins, but ranges from about 1,000 to 5,000 feet in many basins, and may exceed 10,000 in a few deep basins in Utah and south-central Arizona."
- The Utah Division of Water Resources reports that in the Great Salt Lake Desert region, groundwater in bedrock is hydrologically connected the alluvial basins (DWR, 2001). The Utah State Water Plan for the West Desert Basin states that:

  > "Many of the fault block mountains are underlain by carbonate rocks which provide groundwater flow paths between basins. Therefore much of the southern Great Salt Lake Desert is hydrologically connected in what Gates (1987) calls the 'Great Salt Lake Desert flow system.' This system ultimately discharges to Fish Springs Flat, the margins of the Bonneville Salt Flats and the Great Salt Lake."

- The USGS (Robson and Banta, 1995) also reports that groundwater in the basin-and-range aquifers may flow between the basins by passing through the carbonate rocks in the bedrock ranges:

  > "Carbonate rocks predominate in a 20,000- to 30,000-foot thick sequence of Paleozoic and Lower Mesozoic rocks in an extensive area of western Utah … and southern and eastern Nevada…. The location of solution-altered zones of enhanced permeability within these carbonate rocks is poorly known. However, some data indicate that ground water might flow between basins through permeable carbonate rocks in the mountains of west-central Utah, and water might flow from recharge areas in the mountains to local basins through permeable carbonate rocks bordering the northeastern part of the aquifer system."

For these reasons, changes in bedrock elevation were not incorporated into the base case model. Sensitivity analyses have been added to the revised report to evaluate the effects of an impermeable bedrock high (sensitivity analysis PW-BH) and a shallower (600 ft) depth to bedrock (sensitivity analysis PW-6F).

Interrogatory #2B. Provide more work on the constant head upgradient and downgradient boundary conditions. Why were no sensitivity analyses on the constant heads performed? Also provide alternative model formulations and calculations employing constant flux boundary conditions.

Background. When non-natural hydrological boundary conditions are employed, it is common to both examine constant head and constant flux boundaries conditions, and to perform sensitivities analyses. Similar results across the board demonstrate decoupling of transient effects from the boundaries under question.

Response. It is true that the boundary conditions in the model do not coincide with the physical boundaries of the regional aquifer. The regional aquifer is bounded by the Great Salt Lake to the north, the Cedar Mountains to the east, and by mountain ranges in the state of Nevada to the west. It is impractical to include such a large area in the groundwater model, a fact that is recognized by Anderson and Woessner (1992) and Rumbaugh (2002). Anderson and Woessner state that:

> "It may not be possible or convenient to design a grid that includes the physical boundaries of the system if the focus of interest is far removed from the boundaries."

Rumbaugh states:

> "It is desirable to include only natural hydrologic boundaries as boundary conditions in the model. Most numerical models, however, employ a grid that must end somewhere. Thus, it is often unavoidable to specify artificial boundaries at the edges of the model. When these grid boundaries are sufficiently remote from the area of interest, the artificial conditions on the grid boundary do not significantly impact the predictive capabilities of the model."

The smaller model domain was carved out from the regional system, and hydraulic boundaries, rather than physical boundaries, were applied to the smaller model domain. In this common approach to modeling, "hydraulic boundaries may be defined from a water table map of the area to be modeled," (Anderson and Woessner, 1992) and no-flow boundaries are located along flow lines with constant head boundaries along equipotential lines. The important consideration is that the simulation must be structured so that pumping from the well will not affect heads or fluxes near the hydraulic boundaries.

Sensitivity analyses have been added to the revised modeling report, investigating lower and higher hydraulic gradients, by setting higher and lower constant heads in cells along the downgradient model boundary. However, since gradient was perhaps the most important component of the model (from which impacts to gradient were determined), the base case model is more applicable for evaluating impacts due to pumping. It should be noted that neither the high nor low-gradient sensivitity analyses indicated unacceptable changes in hydraulic gradient below the individual embankments or below the site as a whole.

Constant flux boundaries (a.k.a. specified flow boundaries) are typically used for physical boundaries such as underflow through a river channel. Fluxes must be generally well defined. In the present model, the source of flow data from which to specify fluxes at every boundary node would have to be derived from the model itself, which was set up using constant heads. Reading the cell-by-cell flows and applying the flows to the boundary cells would be indistinguishable from the constant head boundary solution. Also, Anderson and Woessner (1992) state that, "Although hydrogeologically defensible, exclusive use of flux boundaries generally should be avoided for the following mathematical reason. The governing equation is written in terms of derivatives, or differences in head, so that the solution will be nonunique if the boundary conditions are also specified as derivatives. Steady-state problems require at least one boundary node with a specified head in order to give the model a reference elevation from which to calculate heads." Because constant flux boundaries would be non-unique, they were not used in the model.

Interrogatory #3. Provide the rationale for use of a large, full 3D model as opposed to a quasi-3D model.

> *Background. It is recognized that the use of a true 3D model is not incorrect. However, the full 20 layer 3D model is unwieldy, both from the perspective of input preparation and review of output. If a much more manageable quasi-3D model provides similar results, it would be an easier tool to use in sensitivity analyses (discussed below). Also, the sophistication of a 3D model here may convey an unwarranted sense of accuracy to the untrained observer. What are the reasons for the larger 20 layer 3D model? Please provide the appropriate discussion.*
>
> *Typically the use of three dimensions in a model reflects either known spatial complexity in the aquifer properties and/or boundary conditions. Or, a finer-grained discretization might be required for purely numerical reasons. However, the distribution of aquifer properties in the current model—a single high conductivity 50-foot layer (12) embedded in a lower conductivity material (11 layers above and 8 layers below)—exhibits less 'real' site-specific complexity than even the four unit configuration used in earlier reports. The current model is essentially a big box having homogeneous aquifer properties with the exception of layer 12.*
>
> *The bottom line is that the present model appears to be quasi-generic, hydrologically simpler than earlier models, numerically more complex, and not well-related to the accepted hydrostratigraphy. Envirocare should either (1) clearly justify the use of this modeling approach using 'new' findings and updated hydrostratigraphic knowledge, or (2) develop and apply a new, numerically simpler, more geohydrologically 'realistic' model.*

Response. The system was modeled using a three-dimensional model grid to answer the question of spatial changes in hydraulic gradient. Anderson and Woessner (1992) state that "Profile or full three-dimensional models are used to simulate unconfined aquifers when vertical head gradients are important." This is the case at the Envirocare site, where the proposed wells would pump from a depth of 550 – 600 feet and the issue of critical concern is the effect on heads and gradients at the water table. Hydrogeologic data from the site have shown that the aquifer is vertically stratified (as would be expected in lacustrine deposits) and the three-dimensional model was required to determine the changes in vertical hydraulic gradient and horizontal hydraulic gradient across the site. Twenty 50-ft thick layers were used to minimize the effects of numerical averaging of heads in the vertical direction. By defining 20 layers, the vertical head gradients could be calculated between any of 20 elevations.

The hydraulic properties of Layer 1 and Layer 12 differ from each other and from those in Layers 2-11 and 13 – 20. It was not our intent to imply that each model layer has different hydraulic properties or that the model represents a very complicated system. The 20 layers serve to provide a more useful three-dimensional view of model results.

Interrogatory #4. Provide a complete description of model input organized around the MODFLOW packages used in the model.

Background. The current presentation is a narrative which provides model configuration along with many but not all of the aquifer parameters. Verifying model input as described in the report is awkward at best. Because the MODFLOW model is the focus of this effort, a complete and transparent description of input parameters is needed. Presenting the input organized around the MODFLOW packages results in a complete description of the input and a direct linkage to the conceptual model.

Also, some inputs to MODFLOW are calculated—specifically the VCONT (leakage) array—and have been omitted in the current document. The calculation is straightforward, using other input aquifer/model parameters—cell/layer vertical hydraulic conductivities and layer thicknesses. Detailing VCONT calculations will document consistency between the conductivities, layer thicknesses and leakages.

Response. A section has been added to the report documenting each of the Modflow packages used in the model, including the calculation of the VCONT array. In summary, leakance between model layers (VCONT) was calculated using the following equation:

$$VCONT = \frac{1}{\left[\frac{0.5T_o}{Kv_o}\right] + \left[\frac{0.5T_u}{Kv_u}\right]}$$

Where:

T_o is the thickness (ft) of the overlying layer.
Kv_o is the vertical hydraulic conductivity (ft/d) of the overlying layer.
T_u is the thickness (ft) of the underlying layer.
Kv_u is the vertical hydraulic conductivity (ft/d) of the underlying layer.

The vertical hydraulic conductivity values that were used to calculate VCONT are summarized in Table 2.

Table 2. Calculation of MODFLOW VCONT Array

Layer	Geologic Unit	Thickness	K_h (ft/d)	K_h (cm/sec)	K_v (ft/d)	V_{cont}
1	Silts, silty clays, sandy silts	varies	1.73	6.1E-04	0.173	varies
2	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
3	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
4	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
5	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
6	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
7	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
8	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
9	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
10	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
11	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	6.88E-03
12	Gravel	50	283	1.0E-01	28.3	6.88E-03
13	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
14	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
15	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
16	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
17	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
18	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
19	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
20	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	N/A

Interrogatory #5. Provide a section on the calibration of the model.

> *Background. Model calibration has not been addressed in the memorandum. The acceptance of model predictions is predicated on calibration of the model. The role of and proposed implementation of a post-model audit should also be addressed. Develop an appendix reviewing the present working inventory of wells, their applicability vis-à-vis location, screening, etc., to the post-model audit activities, and identifying additional monitoring which may be required to fill in gaps in the present well configuration. A preliminary monitoring protocol—location, depth, frequency—and decision tree should also be a part of this effort.*

Response. A section has been added to the report, discussing model calibration. In summary:

Calibration of a flow model refers to a demonstration that the model is capable of producing field-measured heads and flows which are known as calibration targets. Calibration is an inverse problem, which involves finding a set of hydraulic parameters, boundary conditions, and stresses that produce simulated heads and fluxes that match the field-measured values within a specified range of error. The model was run as a forward simulation, rather than an inverse calibration. An inverse calibration would require both field measured head and flux values, because head values alone produce non-unique model solutions. Since the 243-square mile model is "carved out" of the larger regional aquifer, field measurements of fluxes across the model domain are not available. In the forward problem, system parameters such as hydraulic conductivity, specific storage, and hydrologic stresses such as recharge rate are specified and the model calculates heads. Although Anderson and Woessner (1992) report that "*most* field problems require solving an inverse problem," in this case the forward problem is believed to be appropriate.

A Post-Model Audit has been proposed by Envirocare, as a separate document from the modeling report. Because the model is intended as a screening tool for decision-making, the Post-Model Audit focuses on actual field measurements of head and gradient, comparing those field values to the allowable hydraulic gradients specified in the GWQDP.

Interrogatory #6. Provide a section on the sensitivity analyses.

> *Background. There are by necessity a number of qualitative uncertainties, e.g., the conceptual model, location of boundary conditions, etc., and quantitative uncertainties, e.g., aquifer properties, spatial variability, etc. incorporated into the present model. Sensitivity analyses are needed to bound the predictions of the model, and to identify those uncertainties that significantly impact predictions. In particular, please assess the effects of variations in hydraulic properties, recharge, hydrostratigraphy, and boundary conditions. In regard to the last item: significant variation in the depth of the transmissive zone, i.e., the depth of the no-flow bottom of the model as a function of location, and a comparison of constant head and flux boundary conditions should be examined.*
>
> *The variation of the depth is of interest because the site is one mile square and yet bedrock surfaces one mile west of the site. There may be an as-yet undetermined decrease in depth to bedrock (assumed to be a no-flow boundary?) underneath western portions of the site and almost certainly within a mile of the site. This will impact flow at the site. (Indeed one earlier model implements a model-extent limiting, no-flow boundary along the perimeter of that daylighting bedrock.) Finally, as noted above, constant head and flux boundary conditions are often compared when non-natural boundary conditions are needed.*

Response. A section on sensitivity analysis has been added to the report. Several sensitivity analyses were performed to investigate the effects of differing aquifer thicknesses and boundary conditions. The file names and conditions are summarized in Table 3. The following sensitivity analyses were run:

- PW-6F. Sensitivity analyses evaluated a 600-ft thick aquifer, which is 60% of the thickness used in the base case model.
- PW-ST. Sensitivity analyses evaluated higher storage coefficients. Values were 8.2 times (Layer 12), 30.4 times (Layers 2-11 and 13-20) and 114 times (Layer 1) the values used in the base case model.
- PW-LG. Sensitivity analyses using a lower hydraulic gradient. Gradient in the sensitivity analysis (4.95×10^{-4}) was 89% of the value used in the base case model (5.57×10^{-4}).
- PW-HG. Sensitivity analyses using a higher hydraulic gradient. Gradient in the sensitivity analysis (6.06×10^{-4}) was 109% of the value used in the base case model (5.57×10^{-4}).

- PW-HG. Sensitivity analyses evaluated a bedrock high, which was assumed to be impermeable and was modeled as no-flow cells. Although the conceptual hydrologic model of the regional aquifer indicates that the bedrock and alluvium act as a single hydrologic unit (DWR, 2001; Gates, 1987), the sensitivity analysis assumes that the bedrock does not transmit water.

Table 3. Sensitivity Analyses

CASE	Model Run (File Name)	Model Thickness	Boundary Conditions	Gradient	Specific Storage
Base Case	Model20	1000 ft	Constant Head (4275 -> 4230)	5.57E-04	1.98E-4, 5.3E-5, 2.66E-5
Bedrock Ridge	PW-BH	Variable: 1000 ft with bedrock high	Constant Head (4275 -> 4230)	5.57E-04	1.98E-4, 5.3E-5, 2.66E-5
Shallow Bedrock	PW-6F	600 ft	Constant Head (4275 -> 4230)	5.57E-04	1.98E-4, 5.3E-5, 2.66E-5
Higher Storage	PW-ST	1000 ft	Constant Head (4275 -> 4230)	5.57E-04	6.0E-3, 1.6E-3, 8.1E-4
Lower Gradient	PW-LG	1000 ft	Constant Head (4275 -> 4235)	4.95E-04	1.98E-4, 5.3E-5, 2.66E-5
Higher Gradient	PW-HG	1000 ft	Constant Head (4275 -> 4226)	6.06E-04	1.98E-4, 5.3E-5, 2.66E-5

Interrogatory #7. Provide a complete description—discussion and input—of the steady state calculations (no well) used to generate the starting heads using in the well calculations.

> *Background. This steady-state calculation is the basis for all following calculations. It is the 'present case' describing the system prior to pumping and can be used for model calibration.*
>
> *Also, MODFLOW models with pumping are realized as relatively simple extensions to the steady-state model via the addition of the well package and time-dependence. Finally, the steady-state model is the implementation that most directly and clearly relates to the conceptual flow model.*

Response. The original submissions and the revised report contained a discussion of the calculation of steady-state heads. In summary, the groundwater flow model was first run without pumping to arrive at the steady-state solution, using the PCG2 solver and the 16-digit precision code. The heads from the steady-state model were saved in the binary file PW16ssdp.hds and used as starting heads for the transient simulation.

The report descriptions of model domain, model grid, aquifer hydraulic properties, constant heads, recharge, etc apply to the steady state model. The additional components that apply to the transient model include aquifer storage, pumping rates, and stress periods.

Interrogatory #8. Please address salinity effects in a separate section in the report.

> *Background. Because the salinity of the groundwater, some density effects are expected to be important. Discuss where and how these effects might be anticipated, how they impact model predictions, and how or if they are accommodated in the model.*

The reports indicate that no attempt was made to reproduce vertical gradients—and this may be entirely reasonably due to limitations of MODFLOW. However, vertical gradients are important in performance assessment and so some discussion on the limitations of the present modeling approach in this regard would be helpful. What other approach might be needed in this context? What recommendations result from the evaluations?

Salinity of the water in this system and its implications on density driven flow and the role of vertical gradients in performance assessments are important topics. Envirocare should address these matters separately in evaluating its proposal to develop production wells at the Clive site?

Response. The section of the report discussing freshwater heads has been expanded. Envirocare routinely measures actual (saltwater) head and calculates the freshwater equivalent head for each monitoring well. Both saltwater and freshwater heads are reported monthly. Saltwater and freshwater equivalent gradients are also calculated and reported, including horizontal ground water flow direction and velocity and vertical hydraulic gradients at well pairs.

At the Envirocare facility, the differences between the elevation of the unadjusted saline water phreatic surface elevation and the calculated fresh water equivalent head elevation at the midpoints of the saturated filter packs are relatively minor, averaging 0.15 feet. Similarly, the ground water flow directions and gradients as seen on the ground water elevation contour maps are essentially identical (Pentacore, 2004).

The MODFLOW model was developed based on freshwater equivalent heads and hydraulic gradients calculated and reported by Envirocare. The use of freshwater heads and gradients ensures the numerically correct implementation of the model, since the flow equations solved by MODFLOW inherently incorporate a standard density of water.

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Whetstone Associates, 2004. Evalution of Potential Pumping Well Drawdown in the Shallow Aquifer, technical memorandum from Susan Wyman (Whestone Associates) to Dan Shrum, Envirocare of Utah. Unpublished consultant's report prepared for Envirocare of Utah, September 7, 2004. 13 pp. plus figures.

EVALUATION OF POTENTIAL DRAWDOWN AND GRADIENT CHANGES RESULTING FROM PUMPING TWO DEEP WELLS AT THE ENVIROCARE FACILITY

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April 7, 2005

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1. INTRODUCTION

Envirocare of Utah proposes to install two production wells to provide groundwater for operational use at the Clive, Utah low-level radioactive waste disposal facility. Envirocare's Ground Water Quality Discharge permit (GWQDP) # UGW450005 requires that Envirocare receive approval from the Division of Water Quality (DWQ) prior to installing any pumping wells at the site. At issue is whether pumping from the proposed deep wells would affect the hydraulic gradients in the shallow aquifer, and potentially change the assumptions used in previous fate and transport models on which the existing facility permits are predicated.

To support decision-making, a three-dimensional finite difference groundwater flow model was developed to evaluate the potential drawdown and gradient changes that could be associated with pumping from two water supply production wells. The analysis was performed using the United States Geological Survey (USGS) MODFLOW software (McDonald and Harbaugh, 1988) and the Groundwater Vistas 3.0 pre/post-processor (Rumbaugh, 2002). The purpose of this report is to describe the conceptual model, the numerical model input parameters, model assumptions, and results.

1.1 Location and Site Description

The Envirocare facility is located in Section 32, T1S, R11W near Clive, Utah approximately 80 miles west of Salt Lake City. Envirocare began waste disposal at the facility in 1988, and currently operates four disposal embankments: the Mixed Waste, LARW, 11e.(2), and Class A embankments. The Mixed Waste embankment is currently being expanded to the north, the LARW embankment is nearing final cover and completion, the Class A embankment is being expanded west and north, and the 11e.(2) embankment is being expanded to the west. In the northeast corner of Section 32, the U.S. Department of Energy (DOE) disposed of the Vitro Uranium Mill tailings; this area is owned and monitored by the DOE.

The facility, including DOE's Vitro tailings disposal cell, is one square mile in size and encompasses all of Section 32 (Figure 1). The facility is located at an average elevation of approximately 4,270 feet above mean seal level (amsl). The natural topography slopes slightly toward the southwest with approximately 10 feet of relief over one mile. The area is semi-arid, with an average precipitation of approximately 7.8 inches per year and average pan evaporation of 49.5 inches per year (MSI, 2003).

1.2 Previous Modeling

Two previous technical memoranda documented numerical groundwater flow modeling of a single production well (Whetstone, 2003) and two production wells (Whetstone, 2004) at the Envirocare site. These memoranda were reviewed by URS Corporation on behalf of UDEQ DRC. URS Corporation submitted interrogatory comments in December 2004, and a conference call was held between Envirocare, Envirocare's consultant (Whetstone Associates), and DRC's consultant (URS) in February 2005. The interrogatory comments and the conference call conveyed DRC's desire for additional model documentation and sensitivity analyses.

The current report expands the technical memoranda to:

- Clarify the purpose and scope of the modeling exercise
- Describe the regional hydrologic system,
- Provide more information about the conceptual model
- Document additional model input parameters, including leakance (VCONT)
- Provide additional interpretation of model results
- Include sensitivity analyses on aquifer thickness, gradient, and boundary conditions

Envirocare of Utah
Pumping Well Evaluation

FIGURE 1
SITE LOCATION MAP

Date: 3/14/05

Project/File: 4101U

Drawn/Checked By: SW / SE

Whetstone

The modeling results presented as the "Base Case" model are identical to those presented in the September 7, 2004 submission. The MODFLOW files (model20.nam, model20.bas, model20.bcf, model20.wel, model20.rch, model20.oc, model20.pcg, and pw16ssdp.hds) have not been modified, although additional data extraction targets were set up in the Groundwater Vistas pre/post-processor to assist in interpreting the results.

1.3 Model Purpose and Scope

The purpose of the modeling exercise is to determine whether pumping from two production wells would affect the hydraulic gradient beneath the facility. Condition I.H.2.c)2. of the GWQDP specifies hydraulic gradient limits for all disposal facilities at the Envirocare site (Table 1). These limits were used in the previous PATHRAE fate and transport modeling exercises to demonstrate compliance with the Groundwater Protection Levels.

Table 1. Horizontal Hydraulic Gradient Limits Specified in the GWQDP

Disposal Cell	Horizontal Hydraulic Gradient Limit
Class A	1.00 E-3
LARW	9.67 E-4
Mixed Waste	9.67 E-4
11e.(2)	3.29 E-3

The MODFLOW model is designed to be a feasibility-level screening analysis to support decision-making by Envirocare and DRC. Envirocare desires to determine whether any unacceptable changes in hydraulic gradients beneath the site may occur, before investing capital in the construction of two deep water supply wells. Similarly, DRC requires an evaluation of the effects of pumping on the site hydraulic gradient before the production wells can be approved. The model is intended to provide a "best estimate" of expected drawdown and gradient changes resulting from pumping. Although the model, like any groundwater model, possesses inherent uncertainties, the level of uncertainty is considered acceptable for the purpose of decision-making.

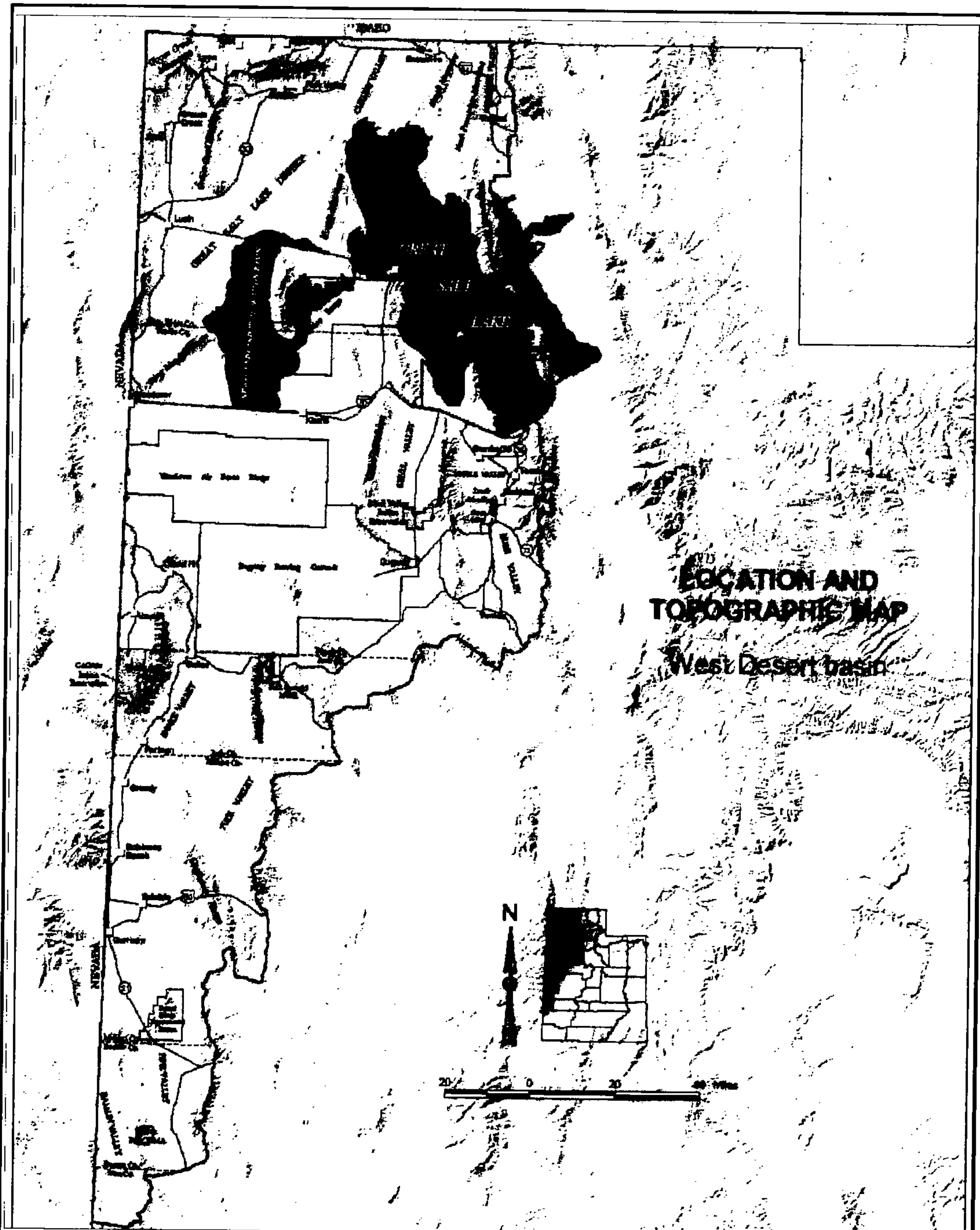
Uncertainties in the modeling will be addressed by a Post-Model Audit (PMA) plan, in which Envirocare proposes to monitor and report water levels and hydraulic gradients. Envirocare is currently required to measure and report groundwater elevations on a monthly basis and calculate fresh-water and salt-water gradients. Additional monitoring locations for horizontal and vertical hydraulic gradients would be implemented as part of the PMA, and contingencies or mitigation strategies would be developed. Tying the pumping permit to real-world conditions will help to address the issue of model uncertainty.

2. CONCEPTUAL MODEL

2.1 Geologic Setting

2.1.1 Regional Geologic Setting

The Envirocare facility is located in the West Desert Basin, a region that has no external drainage and is characterized by small fault-block mountains and intervening alluvial valleys (DWR, 2001). The regional topography is shown in Figure 2.



SOURCE: Division of Water Resources (DWR), 2001. Utah State Water Plan, West Desert Basin, April 2001

Envirocare of Utah
Pumping Well Evaluation

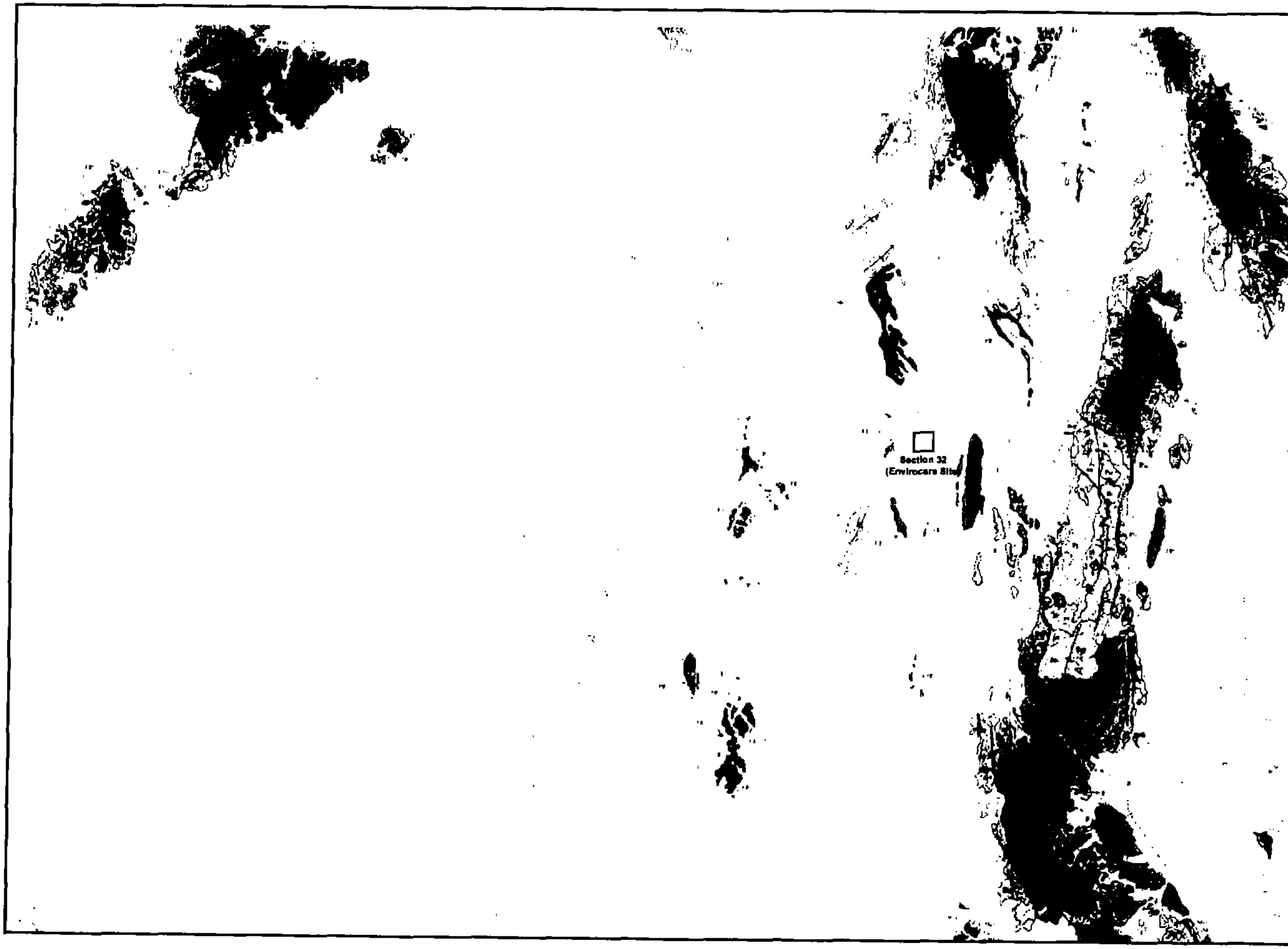
FIGURE 2
TOPOGRAPHIC MAP AND LOCATION
WEST DESERT BASIN

Whetstone

Date: 3/14/05

Project/File: 4101U

Drawn/Checked By: SW / SE



EXPLANATION

Tb? Basalt and basaltic andesite flows and shallow intrusives (Miocene and Pliocene)

PPsc Calcareous sandstone, quartzite, limestone, and dolomite (Lower Permian and Upper Pennsylvanian)

Qa = Quaternary alluvial deposits including lacustrine deposits, alluvium, and colluvium

NORTH

0 5 10
Scale (Miles)

SOURCE: Moore, William J., and Sorenson, Martin L., 1979. Geologic Map of the Tooele 1° by 2° Quadrangle, Utah. U.S. Geological Survey, Miscellaneous Investigations Series, Map I-1132

Envirocare of Utah
Pumping Well Evaluation

FIGURE 3
REGIONAL GEOLOGIC MAP

Scale: 1" = 5 miles	Date 4/5/05
Project No. 4101U	File
Whetstone	Drawn By SW
	Checked By SE

The West Desert Basin is part of the Basin and Range geologic province. The Basin and Range province is characterized by north-south trending mountain ranges with alluvium-filled intermontane valleys. The mountains are mainly Paleozoic-age sedimentary and metamorphic rock, but can also be comprised of volcanic rocks. The intermountain troughs are primarily filled with unconsolidated alluvial, lacustrine, fluvial, and evaporite deposits; but pyroclastics, aeolian sediments, and basalt flows also occur (Bingham Environmental, 1996; Dames & Moore, 1982, 1987; Stephens, 1974). Sediments near the mountains are predominately of colluvial and alluvial origin, and are generally coarser than the lacustrine deposits found in the center of the valleys. A regional geologic map, excerpted from the USGS Tooele 1°by 2° geologic map (Moore and Sorenson, 1979) is presented in Figure 3.

The Envirocare facility is located on Quaternary-age lacustrine lake bed deposits associated with the former Lake Bonneville. Beneath the facility, the sediments consist of interbedded silt, sand, and clay with occasional gravel lenses. The depth of the valley fill beneath the facility is at least 700 feet, although its total depth is unknown (Envirocare, 2004). The deepest borehole at the facility (well SC-1) was drilled to a depth of 250 feet below ground surface (bgs) without encountering bedrock. An exploratory borehole for a potential water-supply well in Section 29 (north of the Envirocare site) was drilled to 700 feet bgs and did not encounter bedrock.

The Grayback Hills begin approximately four miles north of the facility and are composed mainly of basalt flows and pyroclastics. The Cedar Mountains are found about 10 miles to the east-southeast and consist primarily of limestone, dolomite, and shale (Stephens, 1974).

2.2 Hydrogeologic Setting

2.2.1 Regional Hydrogeologic Setting

The hydrology and hydrogeology of the West Desert Basin is described in detail in the Utah State Water Plan, West Desert Basin (DWR, 2001). The report describes the West Desert Basin, a region that has no external drainage and is characterized by small fault-block mountains and intervening alluvial valleys. The West Desert Basin is divided into four sub-basins for the purpose of water planning: Box Elder County, Great Salt Lake Desert, Tooele/Rush Valley and the Great Salt Lake (Figure 4). The Envirocare facility is located in the Great Salt Lake Desert sub-basin.

The Great Salt Lake Desert sub-basin includes the area west of the Great Salt Lake, south of the Box Elder County line, west of the Stansbury Mountains and the Sevier Lake Basin, and north of the Escalante Valley (Cedar-Beaver Basin). The southern end of the sub-basin contains mountains rising above 10,000 feet in elevation that generate ephemeral streams and small perennial streams which provide recharge locally to Pilot Valley, Wah Wah Valley, Pine Valley, Tule (White) Valley, and Snake Valley. The northern eastern portion of the sub-basin drains directly to the Great Salt Lake.

The mountain blocks are composed mostly of rocks of Paleozoic and Precambrian age. These hard, brittle rocks are permeable when fractured, and can provide groundwater aquifers (DWR, 2001). The Paleozoic formations include several limestone and dolomite units, which constitute an important regional aquifer system (DWR, 2001). The centers of the valleys and basins are typically underlain with lacustrine silt and clay, which have low permeability, and contain water with high dissolved solids. The alluvial slopes fringing the mountain blocks are composed of more permeable sand and gravel, and form important local aquifers.

Although local aquifers may exist at the flanks of the bedrock mountains, the bedrock and valley fill deposits in the Great Salt Lake Desert act as a single hydrogeologic system on a regional scale. DWR (2001) states that:

> "Many of the fault block mountains are underlain by carbonate rocks which provide groundwater flow paths between basins. Therefore much of the southern Great Salt Lake

> Desert is hydrologically connected in what Gates (1987) calls the "Great Salt Lake Desert flow system." This system ultimately discharges to Fish Springs Flat, the margins of the Bonneville Salt Flats and the Great Salt Lake."

The USGS (Robson and Banta, 1995) also reports that groundwater in the basin-and-range aquifers may flow between the basins by passing through the carbonate rocks in the bedrock ranges:

> "Carbonate rocks predominate in a 20,000- to 30,000-foot thick sequence of Paleozoic and Lower Mesozoic rocks in an extensive area of western Utah ... and southern and eastern Nevada.... The location of solution-altered zones of enhanced permeability within these carbonate rocks is poorly known. However, some data indicate that ground water might flow between basins through permeable carbonate rocks in the mountains of west-central Utah, and water might flow from recharge areas in the mountains to local basins through permeable carbonate rocks bordering the northeastern part of the aquifer system."

In the 5,000 square mile area that includes the Envirocare facility, the fault block mountains and valley fill were mapped as a single undifferentiated unit (Figure 5). Gates (1987) and DWR (2001) identified several coarse alluvial aquifers and carbonate aquifers in the West Desert Basin. However, the broad region of the Great Salt Lake Desert was not identified as a principle aquifer.

The thickness of the Lake Bonneville sediments in the Great Salt Lake Desert has not been thoroughly mapped. In a report on basin-and-range aquifers, the USGS (Robson and Banta, 1995) reported that "the thickness of the basin fill is not well known in some basins but ranges from about 1,000 to 5,000 feet in many basins and may exceed 10,000 in a few deep basins in Utah and south-central Arizona."

Groundwater exploration occurred in the Great Salt Lake Desert as early as 1902, when the Southern Pacific Railroad drilled test wells to depths of 1,000 feet in search of fresh water for its steam locomotives. Although the test wells proved unproductive, they provide valuable information about subsurface strata and groundwater to depths of 1,000 feet in the central part of the basin (Schreiber, 1954). In their reconnaissance of the southern Great Salt Lake Desert, south of Interstate 80, Gates and Kruer (1981) state that large amounts of groundwater occur, but much of it is of poor quality, and much of it is in fine-grained deposits that will not yield more than a few gallons per minute.

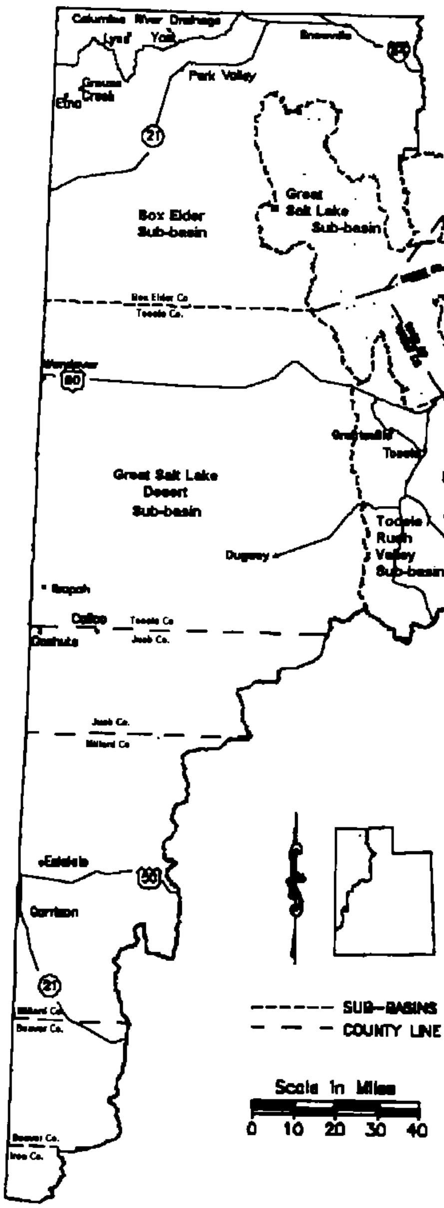
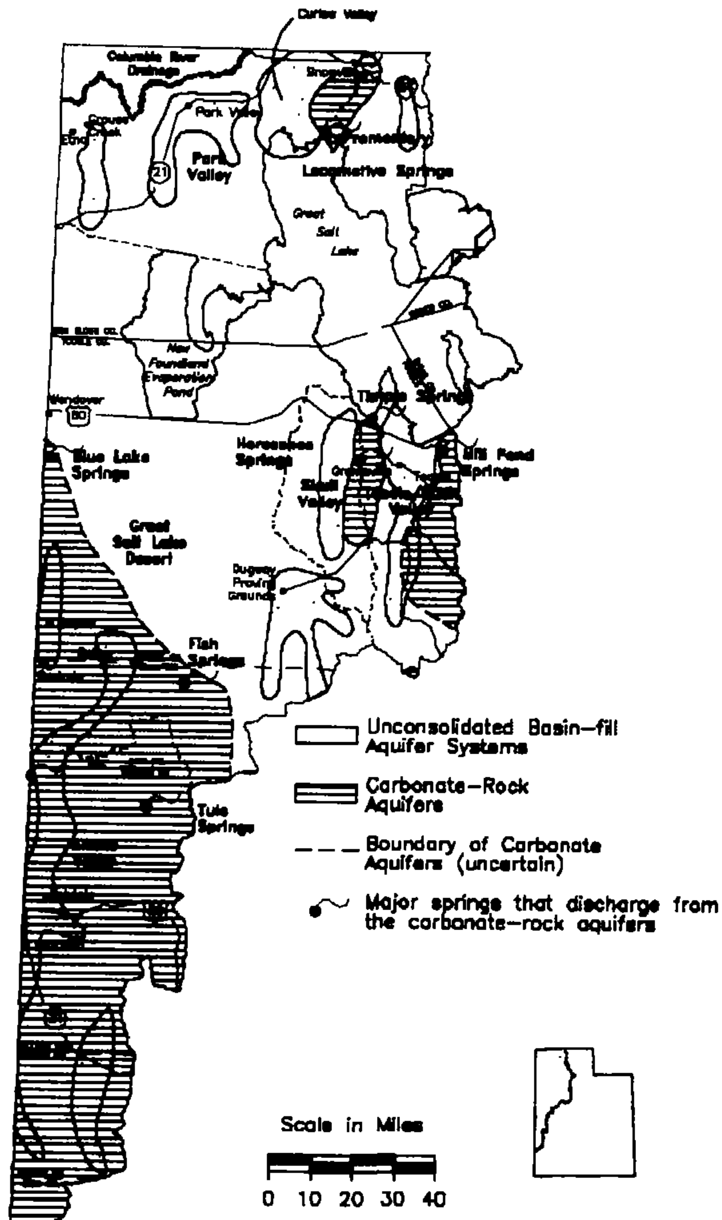


Figure 4. Sub-Basins of the West Desert Basin



Adapted from Gates (1987) Figure 3, as published in DWR (2001)

Figure 5. Principal Aquifers of the West Desert Basin

Although the West Desert Basin has no streams that flow perennially to the Great Salt Lake, the general trend of both surface water and groundwater is toward the basin's lowest point, the Great Salt Lake.

2.2.2 Site Hydrogeologic Setting

Much information is available on the shallow aquifer at the Envirocare site. Approximately 100 monitoring wells and piezometers have been completed to depths of 55 feet or less at the site. In contrast, relatively few borings have been drilled to greater depths at the site. Those borings include 5 deep monitoring wells and piezometers that have been installed to depths between 100 and 250 feet.

Four hydrostratigraphic units have been identified at the site. The upper three units have a combined average total thickness of 40 feet (Table 2). The unconfined water-bearing zone occurring in Unit 3 (and the upper part of Unit 2) has been designated as the "shallow aquifer". The lower unit (Unit 1) is of unknown thickness and is referred to as the "deep aquifer" which is locally confined.

Table 2. Thickness of Upper Hydrostratigraphic Units

HSU	Min imum Thickness (ft)	Maximum Thickness (ft)	Average Thickness (ft)	Lithology	Saturation
Unit 4	6 to 16.5	16.5	10	Silt and clay	Unsaturated
Unit 3	7 to 25	25	15	Silty sand with interbedded silt and clay layers	Partially saturated
Unit 2	2.5 to 25	25	15	Silty clay with interbedded silts and sand lenses	Saturated
Unit 1	>10	ND	ND	Silty sand interbedded with clay and silt layers	Saturated

Notes: ND = not determined

Drilling logs and well drillers reports (Appendix A) indicate that the aquifer may be more permeable at depth. Geologic logs from deep test holes and production wells in the area including the following wells:

1. A 9 7/8-inch boring that was drilled to a depth of 620 feet for Broken Arrow, Inc., in Section 29 (directly north of the Envirocare facility.) The well was drilled from January 9 – 18, 1996 and the hole was abandoned on January 31 of that year. Gravel and cobble zones were identified from 483 – 487 ft, 497-495 ft, and 505-545 ft. A mixture of gravel and clay was logged from 182 – 483 ft. The lower gravel layer was 40 feet thick (505-545 ft) and was surrounded by clay above and below. The boring was drilled to 620 feet and did not encounter bedrock.
2. A water supply well that was drilled to a depth of 350 ft in Section 18, T1S, R11W (about 5 miles north of the Envirocare facility.) The hole was completed as an industrial well for Cox Construction Co in 1969, and encountered clay, clayey gravel, and sandstone at depth, according to the driller's log. The well yielded 600 gpm with a drawdown of 120 ft after 10 hours, from a screened interval of 185 – 350 ft.

3. NUMERICAL MODEL SET UP

3.1 Model Code

The model was developed using the USGS MODFLOW code (McDonald and Harbaugh, 1988) and the Groundwater Vistas pre/post-processor (Rumbaugh, 2002). The MODFLOW input files (Table 3) were created in Groundwater Vistas and run from an external, stand-alone, double-precision (16-digit) version of MODFLOW (modflowdp.exe). The double-precision executable was compiled from the standard, public-domain MODFLOW96 source code which was downloaded from the USGS website (http://water.usgs.gov/nrp/gwsoftware/modflow.html). The numerical accuracy of the double precision code was necessary to simulate the extremely low gradient across the site.

Table 3. MODFLOW Modules and Files

Name file	NAM	MODEL20.nam
Basic package	BAS 1	MODEL20.bas
Block-centered flow package	BCF 11	MODEL20.bcf
Well file	WEL 12	MODEL20.wel
Recharge file	RCH 18	MODEL20.rch
Output control file	OC 22	MODEL20.oc
Solver	PCG 19	MODEL20.pcg
Starting heads	DATA(BINARY) 10	PW16ssdp.hds

3.2 Model Domain and Grid

3.2.1 Model Domain

The regional aquifer is bounded by the Great Salt Lake to the north, the Cedar Mountains to the east, and by mountain ranges in the state of Nevada to the west. It is impractical to include such a large area in the groundwater model, a fact that is recognized by Anderson and Woessner (1992) and Rumbaugh (2002). Anderson and Woessner state that:

> "It may not be possible or convenient to design a grid that includes the physical boundaries of the system if the focus of interest is far removed from the boundaries."

Rumbaugh states:

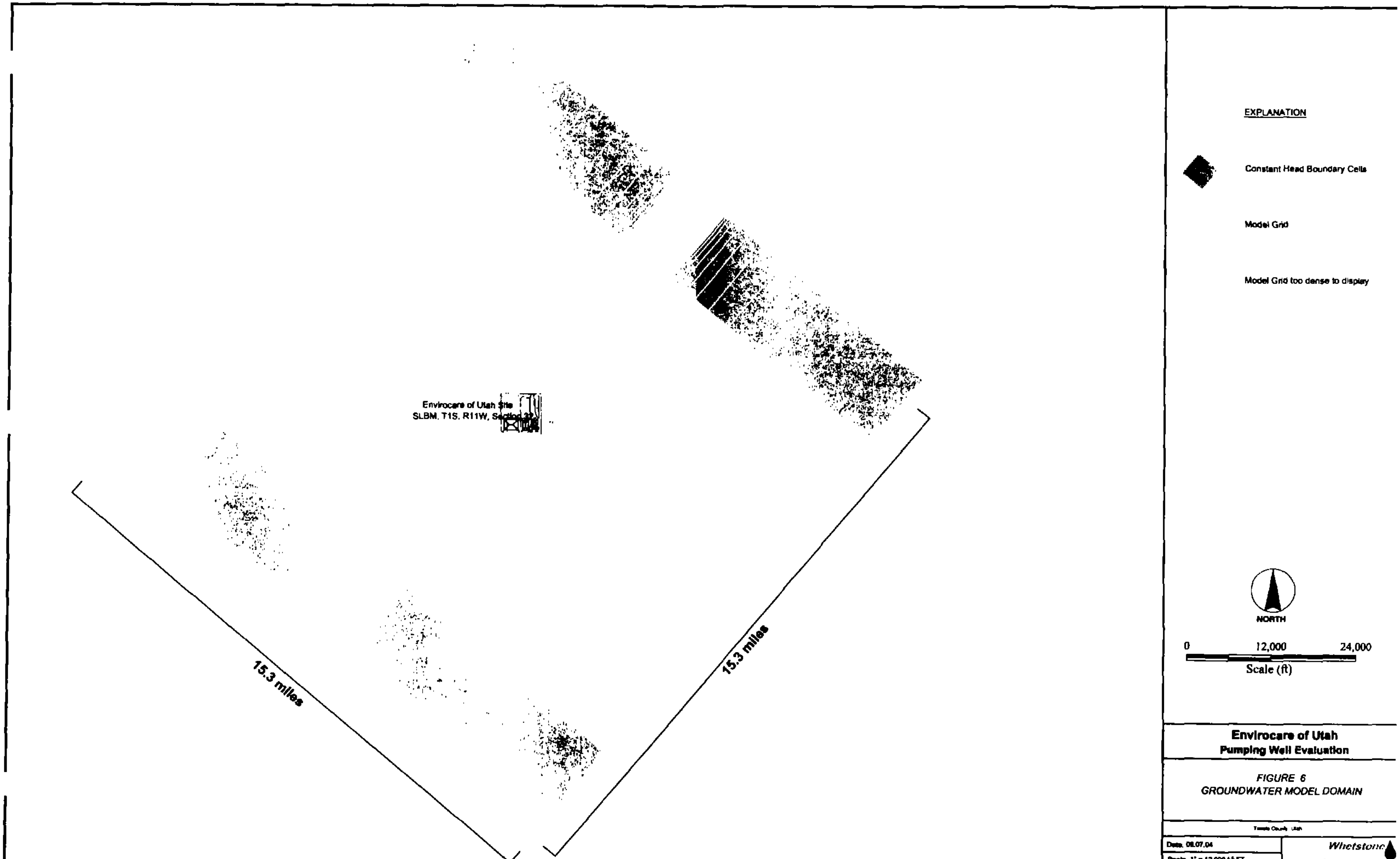
> "It is desirable to include only natural hydrologic boundaries as boundary conditions in the model. Most numerical models, however, employ a grid that must end somewhere. Thus, it is often unavoidable to specify artificial boundaries at the edges of the model. When these grid boundaries are sufficiently remote from the area of interest, the artificial conditions on the grid boundary do not significantly impact the predictive capabilities of the model."

Although the Great Salt Lake Desert sub-basin occupies 4 million acres (6,250 square miles), less than 4% of this area is covered by the model. The model domain encompasses a rectangle of 15 miles by 15 miles, or about 234 square miles (Figure 6). This sizable domain was selected to avoid the effects of transient stresses (i.e., pumping) unrealistically encountering model boundaries.

3.2.2 Model Grid

The model uses a telescoping grid with 102 cells in the x-direction and 102 cells in the y-direction. The horizontal grid spacing ranges from a minimum of 100 feet near the proposed pumping wells to a maximum of 12,000 feet near the model boundaries. The model domain is 1,000 feet thick, and is divided into 20 layers of uniform (50-ft) thickness (Table 4). The model contains 208,080 active cells.

The system was modeled using a three-dimensional model grid to answer the question of spatial changes in hydraulic gradient. Anderson and Woessner (1992) state that "Profile or full three-dimensional models are used to simulate unconfined aquifers when vertical head gradients are important." This is the case at the Envirocare site, where the proposed wells would pump from a depth of 550 – 600 feet and the issue of critical concern is the effect on heads and gradients at the water table. Hydrogeologic data from the site have shown that the aquifer is vertically stratified (as would be expected in lacustrine deposits) and the three-dimensional model was required to determine the changes in vertical hydraulic gradient and horizontal hydraulic gradient across the site. Twenty 50-ft thick layers were used to minimize the effects of numerical averaging of heads in the vertical direction.



Envirocare of Utah
Pumping Well Evaluation

FIGURE 6
GROUNDWATER MODEL DOMAIN

Tooele County, Utah

Date: 08.07.04

Scale: 1" = 12,000 FEET

Whetstone

Table 4. Model Layers

Layer	Depth to top (ft)	Depth to bottom (ft)	Top Elevation (ft amsl)	Bottom Elevation (ft amsl)	Geologic Material
1	0	50	4275	4225	Silts, silty clays, sandy silts
2	50	100	4225	4175	Silts, silty clays, sandy silts
3	100	150	4175	4125	Silts, silty clays, sandy silts
4	150	200	4125	4075	Silts, silty clays, sandy silts
5	200	250	4075	4025	Silts, silty clays, sandy silts
6	250	300	4025	3975	Silts, silty clays, sandy silts
7	300	350	3975	3925	Silts, silty clays, sandy silts
8	350	400	3925	3875	Silts, silty clays, sandy silts
9	400	450	3875	3825	Silts, silty clays, sandy silts
10	450	500	3825	3775	Silts, silty clays, sandy silts
11	500	550	3775	3725	Silts, silty clays, sandy silts
12	550	600	3725	3675	Gravel
13	600	650	3675	3625	Silts, silty clays, sandy silts
14	650	700	3625	3575	Silts, silty clays, sandy silts
15	700	750	3575	3525	Silts, silty clays, sandy silts
16	750	800	3525	3475	Silts, silty clays, sandy silts
17	800	850	3475	3425	Silts, silty clays, sandy silts
18	850	900	3425	3375	Silts, silty clays, sandy silts
19	900	950	3375	3325	Silts, silty clays, sandy silts
20	950	1000	3325	3275	Silts, silty clays, sandy silts

NOTES: amsl = above mean sea level

A sensitivity analysis (Section 5.3) was also performed to evaluate a 600-ft thick aquifer, which is 60% of the thickness used in the base case model.

3.3 Hydraulic Gradient

The model boundaries in all layers were set to constant heads of 4,375 feet at the upgradient boundary (model north) and 4,230 feet at the downgradient boundary (model south). The constant head cells establish a very small uniform gradient of 0.000654 ft/ft[1] (6.54×10^{-4}) in the steady-state model (Table 5).

Table 5. Constant Head Boundaries and Steady-State Uniform Gradient

Upgradient Constant Head (model north)	4,275	ft
Downgradient Constant Head (model south)	4,230	ft
Distance (from center of boundary nodes)[1]	68,822	ft
Uniform Gradient	0.000654	

Sensitivity analyses were performed using lower and higher hydraulic gradients, as described in Section 5.3.

[1] The uniform hydraulic gradient of 6.54×10^{-4} cm/sec was reported as 5.57×10^{-4} cm/sec in previous modeling reports, based on a model distance of 80,822 ft. Because MODFLOW assigns the constant head to the center of the boundary nodes (which are 12,000 ft wide), the actual distance between constant heads is 68,822 ft and the resulting gradient is 17% greater. This gradient calculation occurs external to the model, and no changes to the Base Case model were made from the previous submission.

3.3.1 Freshwater Equivalent Heads

Envirocare routinely measures actual (saltwater) head and calculates the freshwater equivalent head for all monitoring wells. Both saltwater and freshwater heads are reported monthly. Saltwater and freshwater equivalent gradients are also calculated and reported, including horizontal ground water flow direction and velocity and vertical hydraulic gradients at well pairs.

At the Envirocare facility, the differences between the elevation of the unadjusted saline water phreatic surface elevation and the calculated fresh water equivalent head elevation at the midpoints of the saturated filter packs are relatively minor, averaging 0.15 feet. Similarly, the ground water flow directions and gradients as seen on the ground water elevation contour maps are essentially identical (Envirocare, 2004).

The MODFLOW model was developed based on freshwater equivalent heads and hydraulic gradients calculated and reported by Envirocare. The use of freshwater heads and gradients ensures the numerically correct implementation of the model, since the flow equations solved by MODFLOW inherently incorporate a standard density of water.

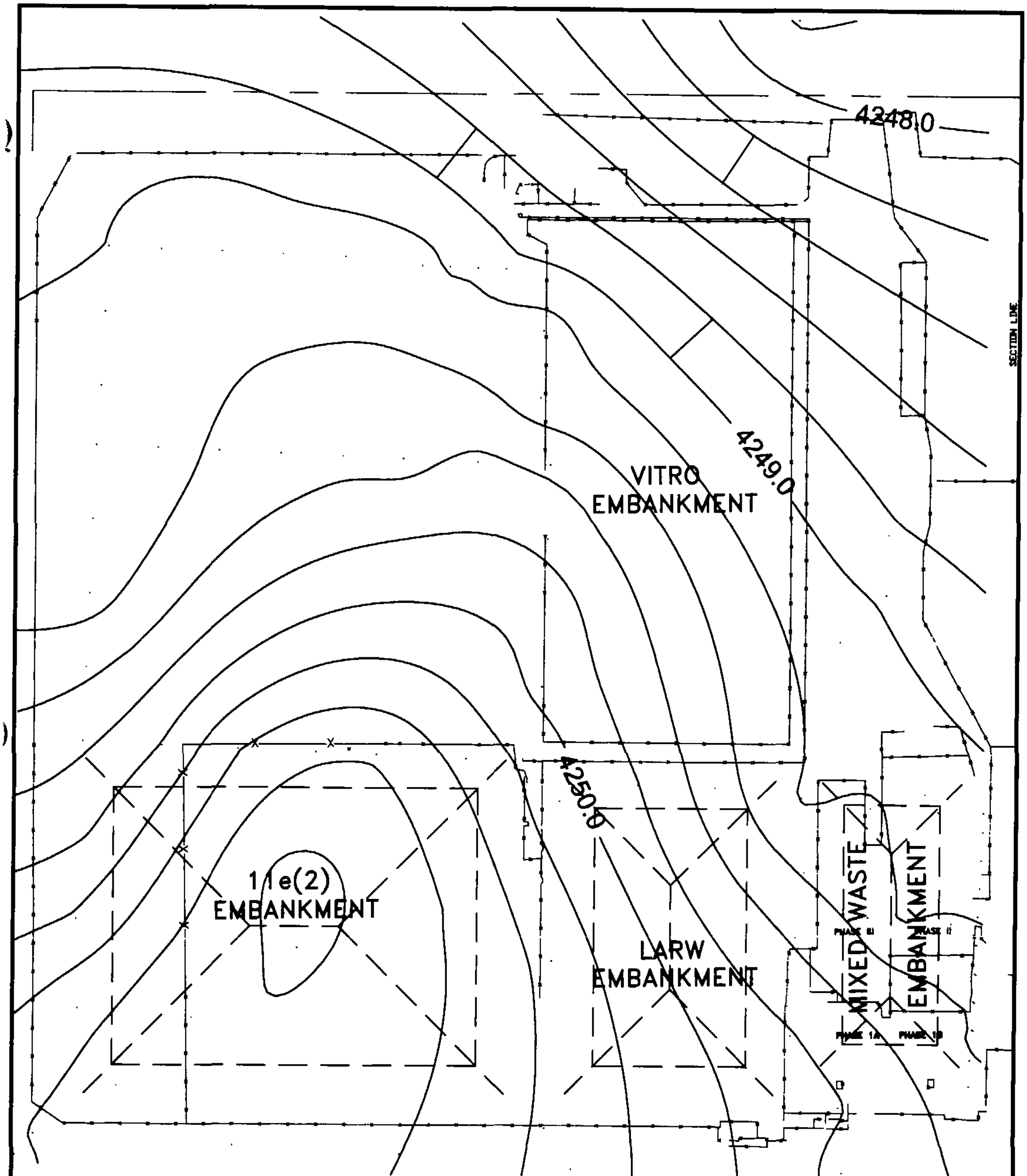
3.3.2 Hydraulic Gradient

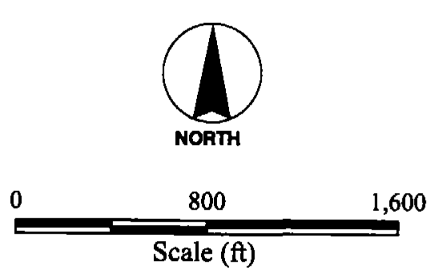
The hydraulic gradient used in the model (6.54×10^{-4}) approximates the actual site-specific hydraulic gradient, and is 24% higher than the average gradient measured at the site in all unconfined wells during January 2003 (Table 6). Variable, rather than uniform, gradients exist across the site, due primarily to human-influenced perturbations resulting in changes in infiltration and evaporation from shallow groundwater (Figure 7). Hydraulic gradients have declined in recent years in some areas of the site. Pentacore (2000) reported that the average hydraulic gradient across the site was 0.001 (1×10^{-3}), which is half an order of magnitude higher than the more recent measurements.

Table 6. Hydraulic Gradients at the Envirocare Site, January 2003

Area	Water Type	Maximum	Minimum	Average
All unconfined wells	Fresh	2.27E-03	9.39E-06	4.96E-04
	Salt	2.60E-03	5.82E-06	4.87E-04
LARW	Fresh	8.10E-04	1.10E-04	5.73E-04
	Salt	9.09E-04	4.67E-05	5.91E-04
Class A	Fresh	1.13E-03	1.06E-04	6.41E-04
	Salt	1.06E-03	1.51E-04	6.18E-04
11e.(2)	Fresh	1.11E-03	3.48E-05	4.57E-04
	Salt	1.04E-03	5.82E-06	4.59E-04
Mixed Waste	Fresh	2.27E-03	8.15E-05	5.04E-04
	Salt	2.60E-03	1.77E-05	5.41E-04
Deep	Fresh	3.31E-04	8.45E-05	2.29E-04
	Salt	2.99E-04	4.49E-05	1.74E-04
B & C	Fresh	1.06E-03	1.54E-05	3.33E-04
	Salt	8.55E-04	9.13E-05	3.44E-04

Early hydrogeologic reports for the Envirocare site identified very slight upward vertical gradients based on freshwater elevations and downward or mixed, vertical gradients based on saltwater heads. However, the most recent hydrogeologic report (Envirocare, 2004) identified no significant vertical gradients. Envirocare (2004) evaluated vertical hydraulic gradients by analyzing head differences between monitoring wells completed in the "shallow" (Unit 2) and "deep" (Unit 1) aquifers at the site. Envirocare identified slight downward vertical gradients near well pair GW-19A/GW-19B, located in the southwest corner of the facility, and slight upward gradients near wells I-3-30/I-3-100, north of the Mixed Waste Landfill. Because





Envirocare of Utah
Pumping Well Evaluation

FIGURE 7
Water Level Contours in the Shallow Aquifer
January, 2003

Tooele County, Utah

Date: 03.14.03

Scale: 1" = 800 FEET

Whetstone Associates

vertical gradient elsewhere beneath the facility were of very low magnitude, the report concluded that "vertical flow is not significant either upward or downward". The steady-state model produced almost negligible vertical gradients (0.00000132 downward), which is considered consistent with overall site conditions.

The sides of the domain (model east and model west) are no-flow boundaries. The groundwater flow direction in the shallow aquifer at the site is approximately N40°E. The grid (and results) were rotated and oriented in the prevailing flow direction, corresponding to site conditions.

3.4 Hydraulic Properties

3.4.1 Hydraulic Conductivity

The hydraulic conductivities applied to model layers represent geologic material encountered during drilling at the site. Large quantities of site-specific data have been collected from monitoring wells installed to less than 55 ft depth in the shallow aquifer. In addition, more than 5 deep monitoring wells and piezometers have been installed to depths of 100 – 250 feet.

Hydraulic conductivity values are derived from boring logs and slug tests conducted at the site. The horizontal hydraulic conductivity of the silts, silty clays, and sandy silts is based on slug tests performed in 69 wells on site. The geometric mean hydraulic conductivity of the 69 tests is 6.09×10^{-4} cm/sec (1.726 ft/day), as shown in Table 7. The vertical hydraulic conductivity of these materials is assumed to be ten times lower than the horizontal hydraulic conductivity, or 6.09×10^{-5} cm/sec (0.1726 ft/day). For comparison, Pentacore (2000) assumed a vertical hydraulic conductivity, K_v, of 0.00283 ft/day (1×10^{-6} cm/sec). The use of this lower vertical hydraulic conductivity in the model would have produced less drawdown in the upper aquifer.

The hydraulic conductivity of the gravel zone was conservatively assigned to the lowest end of the range for gravel (0.1 – 100 cm/sec) given by Freeze and Cherry (1979, table 2.2). A specific capacity analysis of the Cox Construction well (located about five miles north of Section 32 and screened from 185 – 350 feet in clay, gravel, and sand) produced a hydraulic conductivity of 0.1 cm/sec based on an unconfined specific storage of 0.1 and 0.2 cm/sec based on a confined specific storage of 0.00001. The gravel layer in the model corresponds to the gravel layer in the Broken Arrow abandoned hole, directly north of Section 32, which was logged as a clean gravel and would therefore be expected to have a higher hydraulic conductivity than the Cox Construction well. The use of a higher K for the gravel layer in the model would produce less drawdown at the well and a more widespread cone of depression.

Table 7. Hydraulic Conductivity Values

Lithology	Parameter	Value (cm/sec)	Value (ft/day)	Data Source
Silts, silty clays, sandy silts	K_h	6.09E-04	1.7263	Average of 69 slug tests
	K_v	6.09E-05	0.1726	Assume $K_h = 10K_v$
Gravel layer	K_h	1.00E-01	283	lower range in Freeze & Cherry
	K_v	1.00E-02	28.3	Assume $K_h = 10K_v$

Notes: K_h = horizontal hydraulic conductivity
K_v = vertical hydraulic conductivity

3.4.2 Specific Storage and Specific Yield

The specific yield and specific storage values used in the model are shown in Table 8. Specific storage was calculated using the formula derived by Jacob (1940):

$$S_s = \rho_w g \cdot (n\beta_w + \beta_p)$$

where: S_s = specific storage (1/ft)
ρ_w = density of water (lb/ft^3)
n = porosity (unitless)
g = acceleration due to gravity (ft/sec^2)
β_w = compressibility of water (ft^2/lb)
β_p = compressibility of pores (ft^2/lb)

In this equation, the density of water (ρ_w), acceleration due to gravity (g), and compressibility of water (β_w) were assumed to be known constants of 62.4 lb/ft^3, 32.2 ft/sec^2, and 2.30x10^{-8} ft^2/lb, respectively. The porosity of the shallow site materials (0.29) was derived from laboratory testing, while the porosity was assumed to decrease by 30% to 0.20 for underlying dense silty sands. The effective porosity of gravel (0.13) was derived as a weighted average of gravel and silty clay, from a table of default values. Vertical compressibility values for the various aquifer materials were selected from a table developed by Domenico and Mifflin (1965), reprinted in Domenico and Schwartz (1990).

Table 8. Specific Yield and Specific Storage Values

Material	Units	Silty sand	Dense silty sand	Dense sandy gravel
S_y	unitless	0.15	0.12	0.07
ρ_w	(lb/ft^3)	62.4	62.4	62.4
g	ft/sec^2	32.2	32.2	32.2
n	unitless	0.29	0.20	0.13
β_w	ft^2/lb	2.30E-08	2.30E-08	2.30E-08
β_p	ft^2/lb	3.00E-06	8.00E-07	4.00E-07
Calculated S_s	/ft	6.04E-03	1.62E-03	8.10E-04
Modeled S	unitless	1.98E-04	5.3E-05	2.66E-04
Applied to		Layer 1	Layers 2-11, 13-20	Layer 12

The storage coefficients (S) used in the base case model were lower than those calculated by multiplying S_s (in Table 8) times layer thickness, which caused the model to conservatively over-estimate drawdown. A sensitivity analysis was performed by increasing S values to those calculated in Table 8.

3.4.3 Leakance

Leakance between model layers (VCONT) was calculated using the following equation:

$$VCONT = \frac{1}{\left[\frac{0.5T_o}{Kv_o}\right] + \left[\frac{0.5T_u}{Kv_u}\right]}$$

Where:

T_o is the thickness (ft) of the overlying layer.
Kv_o is the vertical hydraulic conductivity (ft/d) of the overlying layer.
T_u is the thickness (ft) of the underlying layer.
Kv_u is the vertical hydraulic conductivity (ft/d) of the underlying layer.

The vertical hydraulic conductivity values that were used to calculate VCONT are summarized in Table 9.

Table 9. Calculation of MODFLOW VCONT Array

Layer	Geologic Unit	Thickness	K_h (ft/d)	K_h (cm/sec)	K_v (ft/d)	V_{cont}
1	Silts, silty clays, sandy silts	varies	1.73	6.1E-04	0.173	Varies
2	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
3	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
4	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
5	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
6	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
7	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
8	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
9	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
10	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
11	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	6.88E-03
12	Gravel	50	283	1.0E-01	28.3	6.88E-03
13	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
14	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
15	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
16	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
17	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
18	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
19	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
20	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	N/A

3.5 Recharge

Recharge was applied to Layer 1 of the model at a rate of 2.283×10^{-6} ft/day (0.01 inches/yr). Lower recharge would result in higher drawdown of the aquifer. Higher recharge would result in less drawdown.

4. STEADY-STATE FLOW MODELING

4.1 Steady-State Model Runs

The groundwater flow model was first run without pumping to arrive at the steady-state solution. A double-precision (16-digit) version of the MODFLOW96 code (modflowdp.exe) was run external to the Groundwater Vistas pre/post-processor. The numerical accuracy of the double precision code was necessary to simulate the extremely low gradient across the site. The model utilized the pre-conditioned conjugate gradient (PCG2) solver.

The steady-state model (PW16ss) produced a flow field having a uniform hydraulic gradient of $6.54x10^{-4}$. The heads in model Layer 1 are shown in Figure 8. Steady-state heads in Layers 2 – 20 were identical to Layer 1 in the steady-state simulation. The heads from the steady-state model were saved in the binary file PW16ssdp.hds. Steady-state heads were also generated for each sensitivity analysis, as discussed in Section 5.3.

4.2 Calibration

Calibration of a flow model refers to a demonstration that the model is capable of producing field-measured heads and flows which are known as calibration targets. Calibration is an inverse problem, which involves finding a set of hydraulic parameters, boundary conditions, and stresses that produce simulated heads and fluxes that match the field-measured values within a specified range of error. The model was run as a forward simulation, rather than an inverse calibration. An inverse calibration would require both field measured head and flux values, because head values alone produce non-unique model solutions. Since the 243-square mile model is "carved out" of the larger regional aquifer, field measurements of fluxes across the model domain are not available. In the forward problem, system parameters such as hydraulic conductivity, specific storage, and hydrologic stresses such as recharge rate are specified and the model calculates heads. Although Anderson and Woessner (1992) report that "*most* field problems require solving an inverse problem," in this case the forward problem is believed to be appropriate.

5. TRANSIENT FLOW MODELING

The heads from the steady-state simulation (PW16ss.hds) were used as starting heads for the transient simulation, which was also run using double precision. The transient model included the wells and stress periods described below.

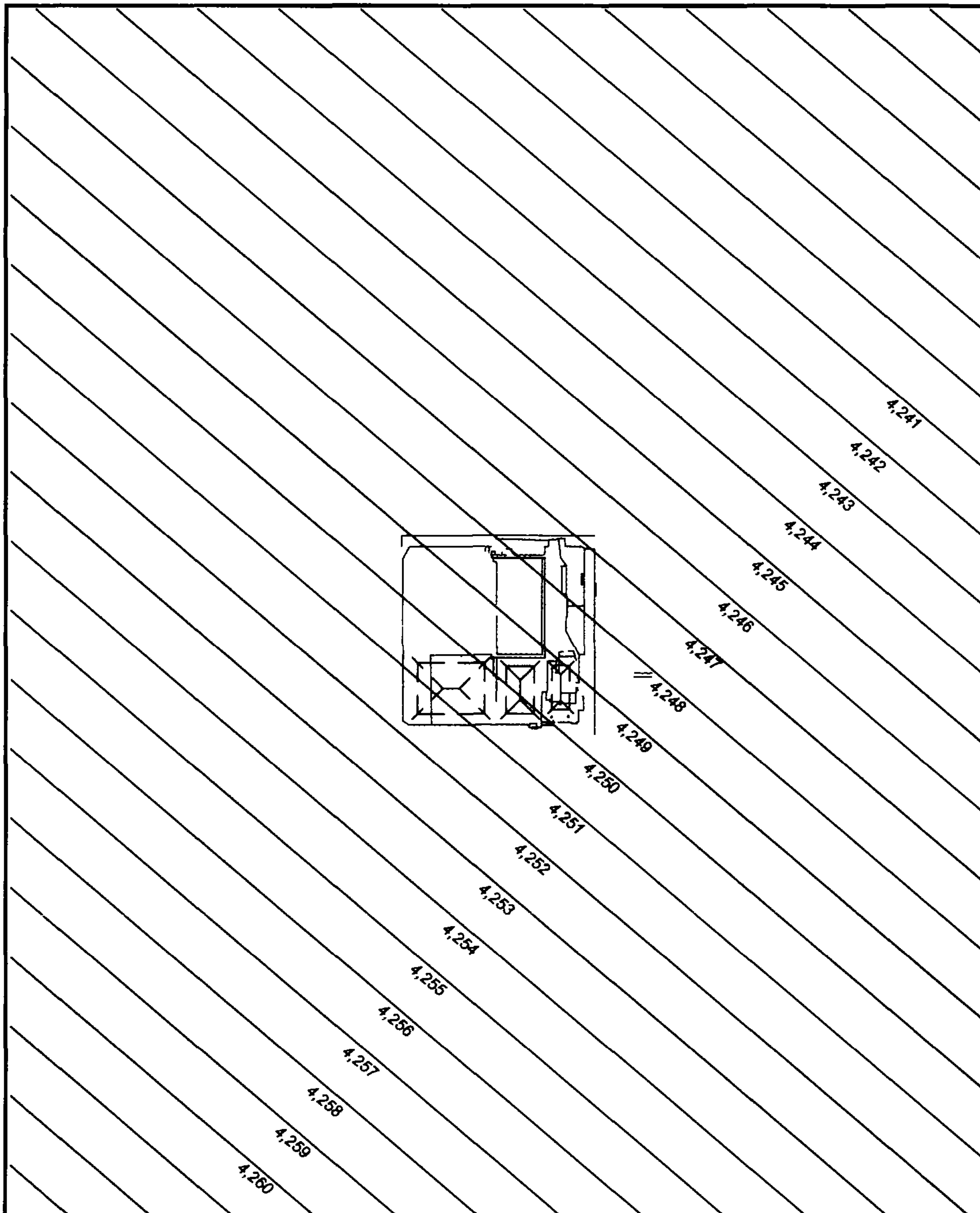
5.1 Pumping Well Set Up

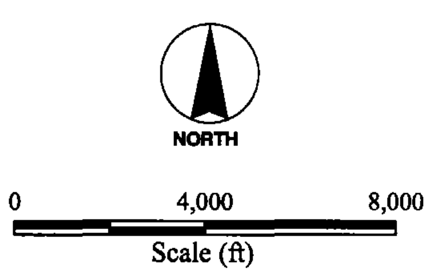
The model simulated pumping from two proposed production wells. The first pumping well is modeled as pumping from the southwest corner of the site, near existing monitoring wells GW-19A, GW-19B, and PZ-1. The second pumping well is modeled located in Section 29, east of the existing pond (Figure 9). In this report, the wells are referred to as the Southwest Pond Well and the Section 29 Well, respectively. The site coordinates and model grid coordinates are provided in Table 10.

Table 10. Pumping Well Coordinates

WELL	SITE NORTHING	SITE EASTING	MODEL ROW	MODEL COLUMN	MODEL LAYER
Section 29 Well	15,870	14,137	87	53	12
Southwest Pond Well	9,868	10,032	17	45	12

The wells simulated as being pumped from a 50-ft thick gravel layer, which corresponds to the gravel layer identified in the Broken Arrow abandoned test well. The pumping wells are in model Layer 12, and simulate pumping from 550 to 600 ft below ground surface (3,725 to 3,775 ft elevation).





Envirocare of Utah
Pumping Well Evaluation

FIGURE 8
Water Level Contours in Model Layer 1
Steady State (Pre-pumping)

Tooele County, Utah

Date: 09.07.04

Scale: 1" = 4,000 FEET

Whetstone Associates

Figure 9. Aerial Photographs Showing Location of (a) Proposed Section 29 Well and (b) Proposed Southwest Pond Well

The model simulates a pumping rate of 200 gallons per minute (gpm) from each well for 4 months of the year (June 1 to September 30). The wells are modeled as pumping for 122 days at a rate of 38,503 ft^3/day per well, or 77,006 ft^3/day total. The wells are turned off from October 1 to May 31 (243 days). This equates to an average annual withdrawal of 107.8 acre-ft per well, or a total of 215.7 acre-ft per year (Table 11).

Table 11. Pumping Rate Used in Transient Simulation

	Flow Rate (gpm)	Flow Rate (ft^3/day)	Months Pumped	Days Pumped	Annual Volume Pumped (acre-ft/yr)	Average Annual Pumping Rate (gallons/year)
Per Well	200	38,503	4	122	107.8	35,136,000
Total	400	77,006	4	122	215.7	70,272,000

5.2 Stress Period Set Up

The transient simulation was run for 52 stress periods, 40 of which simulated 20 years of pumping and 12 of which simulated 20 years of water level recovery. Pumping rates and time discretization for stress periods 1 – 40 are shown in Table 12. Time discretization for stress periods 41 – 52, which simulate water level recovery without pumping, is summarized in Table 13.

Table 12. Pumping Rate per Transient Stress Period

Stress Period Number	Stress Period Length	Cumulative Time	Pumping Rate Per Well	Pumping Rate Per Well	Pumping Rate Total	Pumping Rate Total
	(Days)	(Years)	(ft³/day)	(gpm)	(ft³/day)	(gpm)
1	150	0.41	0	0	0	0
2	122	0.75	38,503	200	77,005	400
3	243	1.41	0	0	0	0
4	122	1.75	38,503	200	77,005	400
5	243	2.41	0	0	0	0
6	122	2.75	38,503	200	77,005	400
7	243	3.41	0	0	0	0
8	122	3.75	38,503	200	77,005	400
9	243	4.41	0	0	0	0
10	122	4.75	38,503	200	77,005	400
11	243	5.41	0	0	0	0
12	122	5.75	38,503	200	77,005	400
13	243	6.41	0	0	0	0
14	122	6.75	38,503	200	77,005	400
15	243	7.41	0	0	0	0
16	122	7.75	38,503	200	77,005	400
17	243	8.41	0	0	0	0
18	122	8.75	38,503	200	77,005	400
19	243	9.41	0	0	0	0
20	122	9.75	38,503	200	77,005	400
21	243	10.41	0	0	0	0
22	122	10.75	38,503	200	77,005	400
23	243	11.41	0	0	0	0
24	122	11.75	38,503	200	77,005	400
25	243	12.41	0	0	0	0
26	122	12.75	38,503	200	77,005	400
27	243	13.41	0	0	0	0
28	122	13.75	38,503	200	77,005	400
29	243	14.41	0	0	0	0
30	122	14.75	38,503	200	77,005	400
31	243	15.41	0	0	0	0
32	122	15.75	38,503	200	77,005	400
33	243	16.41	0	0	0	0
34	122	16.75	38,503	200	77,005	400
35	243	17.41	0	0	0	0
36	122	17.75	38,503	200	77,005	400
37	243	18.41	0	0	0	0
38	122	18.75	38,503	200	77,005	400
39	243	19.41	0	0	0	0
40	122	19.75	38,503	200	77,005	400

Table 13. Transient Stress Periods for Water Level Recovery

Stress Period Number	Stress Period Length (Days)	Cumulative Time (Days)	Cumulative Time (Years)
41	8	7215	19.767
42	32	7247	19.855
43	128	7375	20.205
44	256	7631	20.907
45	365	7996	21.907
46	365	8361	22.907
47	730	9091	24.907
48	730	9821	26.907
49	730	10551	28.907
50	1095	11646	31.907
51	1460	13106	35.907
52	1825	14931	40.907

5.3 Sensitivity Analysis

Several sensitivity analyses were performed to investigate the effects of variations in aquifer thicknesses and boundary conditions. The file names and conditions are summarized in Table 14. The following sensitivity analyses were run:

- PW-6F. Sensitivity analysis PW-6F evaluated a 600-ft thick aquifer, which is 60% of the thickness used in the base case model.
- PW-ST. Sensitivity analysis PW-ST evaluated higher storage coefficients. Values were 8.2 times (Layer 12), 30.4 times (Layers 2-11 and 13-20) and 114 times (Layer 1) the values used in the base case model.
- PW-LG. Sensitivity analysis PW-LG used a lower hydraulic gradient. The gradient in the sensitivity analysis (5.81×10^{-4}) was 89% of the value used in the base case model (6.54×10^{-4}).
- PW-HG. Sensitivity analyses PW-HG used a higher hydraulic gradient. The gradient in the sensitivity analysis (7.82×10^{-4}) was 109% of the value used in the base case model (6.54×10^{-4}).
- PW-BH. Sensitivity analysis PW-BH evaluated a bedrock high, which was assumed to have a permeability ten times lower than that of the lacustrine sedimentary deposits. Although the conceptual hydrologic model of the regional aquifer (Section 2.2.1) indicates that the bedrock and alluvium act as a single hydrologic unit (DWR, 2001; Gates, 1987), the sensitivity analysis assumes that the bedrock transmits very little water (Table 15.)

Table 14. Sensitivity Analyses

CASE	Model Run (File Name)	Model Thickness	Boundary Conditions	Gradient	Specific Storage
Base Case	Model20	1000 ft	Constant Head (4275 -> 4230)	6.54E-04	1.98E-4, 5.3E-5, 2.66E-5
Thinner Aquifer	PW-6F	600 ft	Constant Head (4275 -> 4230)	6.54E-04	1.98E-4, 5.3E-5, 2.66E-5
Higher Storage	PW-ST	1000 ft	Constant Head (4275 -> 4230)	6.54E-04	6.0E-3, 1.6E-3, 8.1E-4
Lower Gradient	PW-LG	1000 ft	Constant Head (4275 -> 4235)	5.81E-04	1.98E-4, 5.3E-5, 2.66E-5
Higher Gradient	PW-HG	1000 ft	Constant Head (4275 -> 4226)	7.12E-04	1.98E-4, 5.3E-5, 2.66E-5
Bedrock Ridge	PW-BH	Variable: 1000 ft with bedrock high	Constant Head (4275 -> 4230)	6.54E-04	1.98E-4, 5.3E-5, 2.66E-5

Table 15. Hydraulic Conductivity Values for Sensitivity Analysis of Low-Permeability Bedrock High

Lithology	Parameter	Value (cm/sec)	Value (ft/day)	Data Source
Silts, silty clays, sandy silts	K_h	6.09E-04	1.7263	Average of 69 slug tests
	K_v	6.09E-05	0.1726	Assume $K_h = 10K_v$
Gravel layer	K_h	1.00E-01	283	lower range in Freeze & Cherry
	K_v	1.00E-02	28.3	Assume $K_h = 10K_v$
PPsc Bedrock	K_h	6.09E-05	0.1726	Assumed 1 o.o.m. lower than Ql
	K_v	6.09E-06	0.01726	Assume $K_h = 10K_v$

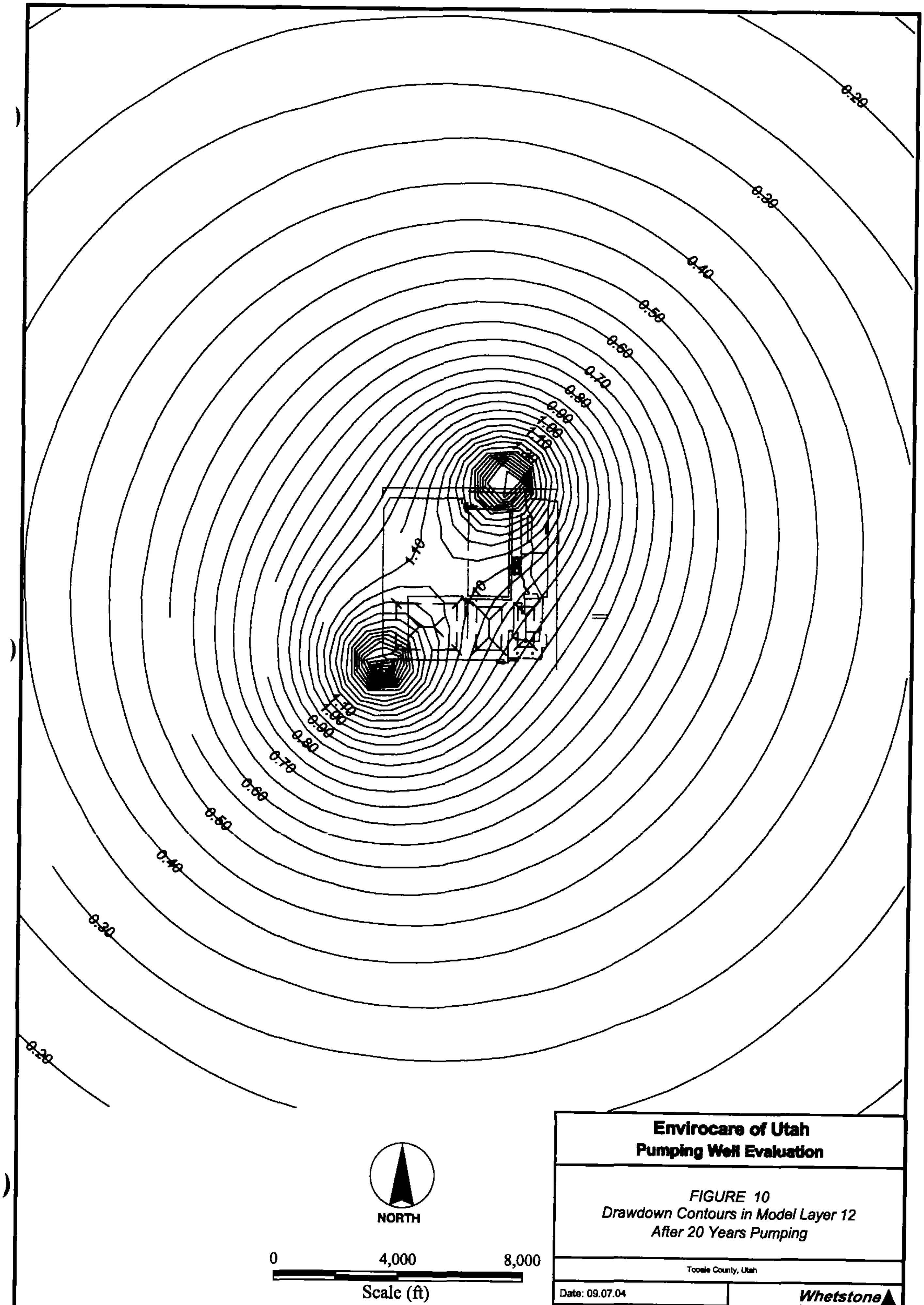
Notes: K_h = horizontal hydraulic conductivity
K_v = vertical hydraulic conductivity
PPsc = Pennsylvanian / Permian Calcareous sandstone, quartzite, limestone, and dolomite. (Lower Permian and Upper Pennsylvanian). Also includes Basalt and basaltic andesite flows and shallow intrusives (Miocene and Pliocene).
Ql = Quaternary lacustrine deposits
o.o.m. = order of magnitude

6. MODELING RESULTS

6.1 Base Case Model Results

6.1.1 Heads and Drawdown

The drawdown resulting from pumping at a rate of 200 gpm each from two wells for 4 months of each year for 20 years is shown in Table 16. These drawdown values are from the 100-ft wide model cells at the pumping wells (Row 87, Column 53, Layer 12 and Row 17, Column 45, Layer 12), directly above the pumping well (Layers 1 and 5), and directly below the pumping well (Layer 20). The drawdown is greatest at the pumping well in Layer 12 of the model, where a maximum drawdown of 3.034 ft is predicted at the Southwest Pond Well, and 3.029 ft is predicted at the Section 29 Well at the end of 20 years pumping (Figure 10).



Envirocare of Utah
Pumping Well Evaluation

FIGURE 10
Drawdown Contours in Model Layer 12
After 20 Years Pumping

Tooele County, Utah

Date: 09.07.04
Scale: 1" = 4,000 FEET

Whetstone Associates

Table 16. MODFLOW Model Results: Drawdown at the Pumping Wells During 20 Years of Pumping

Stress Period	Time (days)	Time (yrs)	Drawdown above SW Pumping Well in Layer 1	Drawdown above SW Pumping Well in Layer 5	Drawdown at SW Pumping Well in Layer 12	Drawdown below SW Pumping Well in Layer 20	Drawdown above Sec 29 Pumping Well in Layer 1	Drawdown above Sec 29 Pumping Well Layer 5	Drawdown at Sec 29 Pumping Well in Layer 12	Drawdown below Sec 29 Pumping Well in Layer 20
R1	150	0.41	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
R2	272	0.75	0.223	0.551	2.704	1.014	0.223	0.551	2.699	1.014
R3	515	1.41	0.155	0.117	0.065	0.065	0.156	0.118	0.065	0.065
R4	637	1.75	0.352	0.650	2.761	1.069	0.353	0.650	2.755	1.069
R5	880	2.41	0.252	0.194	0.112	0.112	0.253	0.195	0.112	0.112
R6	1002	2.75	0.436	0.717	2.804	1.112	0.437	0.718	2.799	1.112
R7	1245	3.41	0.318	0.249	0.150	0.149	0.319	0.249	0.150	0.149
R8	1367	3.75	0.494	0.767	2.839	1.147	0.495	0.767	2.834	1.147
R9	1610	4.41	0.365	0.290	0.180	0.179	0.366	0.290	0.180	0.179
R10	1732	4.75	0.537	0.804	2.867	1.175	0.539	0.805	2.862	1.175
R11	1975	5.41	0.402	0.322	0.205	0.204	0.403	0.323	0.205	0.204
R12	2097	5.75	0.571	0.834	2.891	1.198	0.572	0.835	2.886	1.198
R13	2340	6.41	0.431	0.348	0.226	0.225	0.432	0.349	0.226	0.225
R14	2462	6.75	0.598	0.858	2.911	1.218	0.599	0.859	2.906	1.218
R15	2705	7.41	0.454	0.369	0.244	0.243	0.456	0.370	0.245	0.243
R16	2827	7.75	0.620	0.878	2.928	1.235	0.622	0.879	2.923	1.236
R17	3070	8.41	0.474	0.388	0.260	0.259	0.476	0.389	0.260	0.259
R18	3192	8.75	0.639	0.896	2.943	1.250	0.640	0.897	2.938	1.251
R19	3435	9.41	0.491	0.403	0.274	0.272	0.493	0.404	0.274	0.273
R20	3557	9.75	0.655	0.911	2.956	1.264	0.657	0.912	2.951	1.264
R21	3800	10.41	0.506	0.417	0.286	0.285	0.507	0.418	0.287	0.285
R22	3922	10.75	0.669	0.924	2.968	1.275	0.671	0.925	2.963	1.275
R23	4165	11.41	0.519	0.429	0.297	0.295	0.520	0.430	0.297	0.296
R24	4287	11.75	0.681	0.936	2.979	1.286	0.683	0.937	2.974	1.286
R25	4530	12.41	0.530	0.440	0.307	0.305	0.532	0.441	0.307	0.306
R26	4652	12.75	0.692	0.946	2.988	1.295	0.694	0.947	2.983	1.295
R27	4895	13.41	0.541	0.450	0.316	0.314	0.542	0.451	0.316	0.314
R28	5017	13.75	0.702	0.956	2.997	1.304	0.704	0.957	2.992	1.304
R29	5260	14.41	0.550	0.459	0.324	0.322	0.551	0.460	0.324	0.322
R30	5382	14.75	0.711	0.964	3.004	1.311	0.713	0.965	2.999	1.312
R31	5625	15.41	0.558	0.467	0.331	0.329	0.560	0.468	0.331	0.330
R32	5747	15.75	0.719	0.972	3.011	1.318	0.721	0.973	3.006	1.319
R33	5990	16.41	0.565	0.474	0.338	0.336	0.567	0.475	0.338	0.336
R34	6112	16.75	0.726	0.979	3.018	1.325	0.728	0.980	3.013	1.325
R35	6355	17.41	0.572	0.480	0.344	0.342	0.574	0.481	0.344	0.342
R36	6477	17.75	0.733	0.985	3.024	1.331	0.735	0.986	3.019	1.331
R37	6720	18.41	0.579	0.486	0.349	0.347	0.580	0.487	0.350	0.348
R38	6842	18.75	0.739	0.991	3.029	1.336	0.741	0.992	3.024	1.336
R39	7085	19.41	0.584	0.492	0.354	0.353	0.586	0.493	0.355	0.353
R40	7207	19.75	0.744	0.996	3.034	1.341	0.746	0.997	3.029	1.341

Drawdown in the shallow aquifer (Model Layer 1) reaches a maximum of 0.75 ft at the end of 20 years. Drawdown in Layer 1, directly above the pumping wells, varies between about 0.59 ft and 0.75 ft during the final years of pumping as the well is cycled on and off (Figure 11.) Contours of the maximum drawdown in Layer 1 (in Year 20, at the end of pumping) are shown in Figure 12. The water levels in Layer 1 decline slightly over time, as shown in Figure 13.

These water level declines result in a very slight perturbation in the groundwater flow field (Figure 14) as the contours are deflected around the pumping wells.

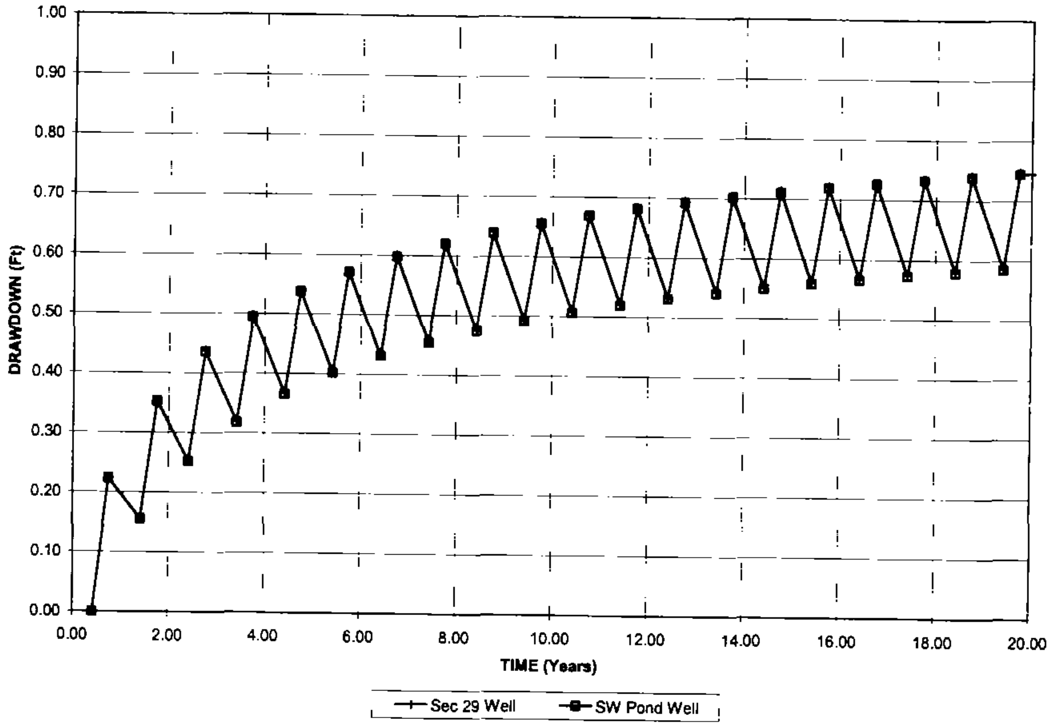


Figure 11. MODFLOW Model Results: Drawdown vs. Time in the Shallow Aquifer (Model Layer 1)

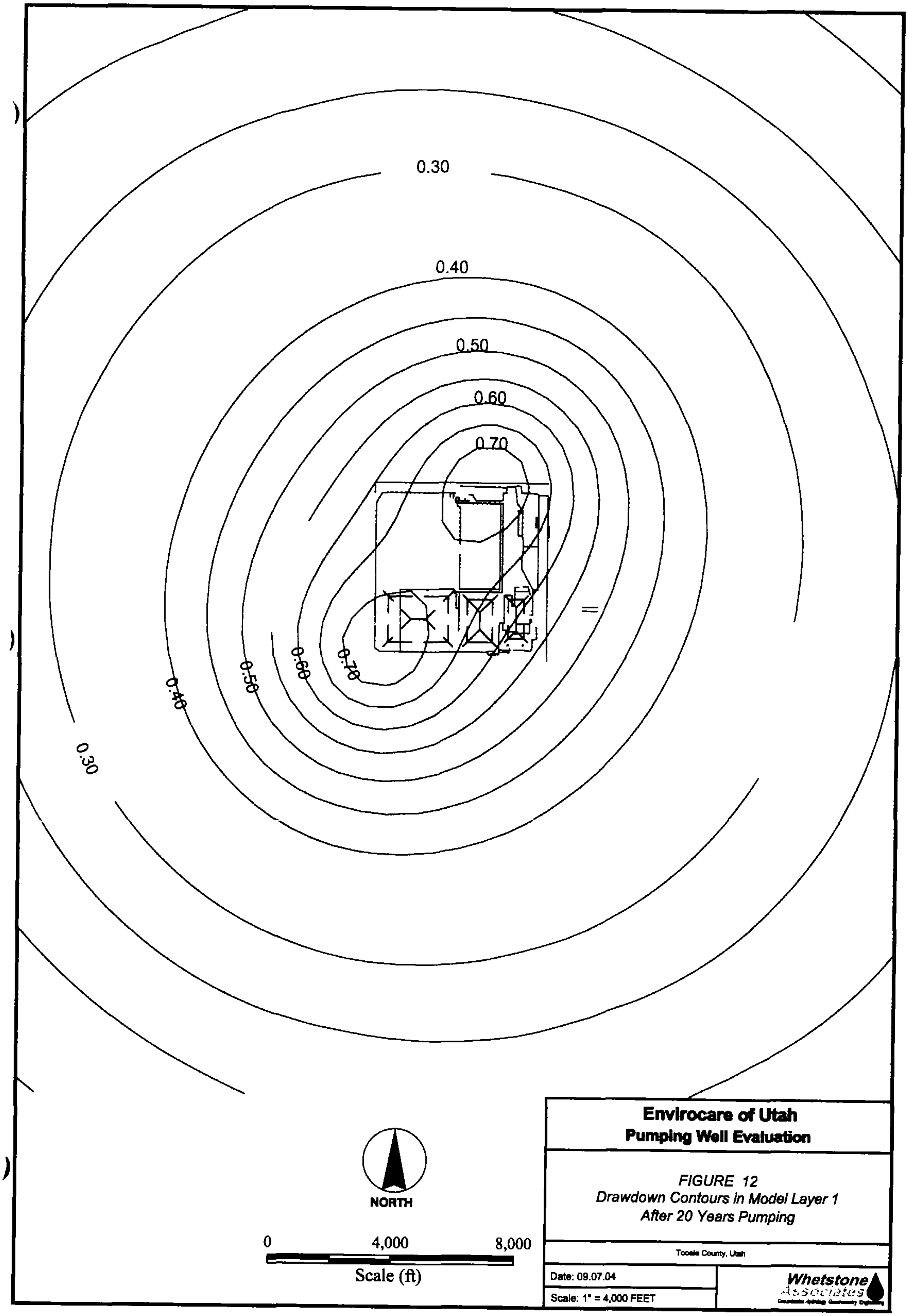


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FIGURE 12
Drawdown Contours in Model Layer 1
After 20 Years Pumping

Tooele County, Utah

Date: 09.07.04
Scale: 1" = 4,000 FEET

Whetstone Associates

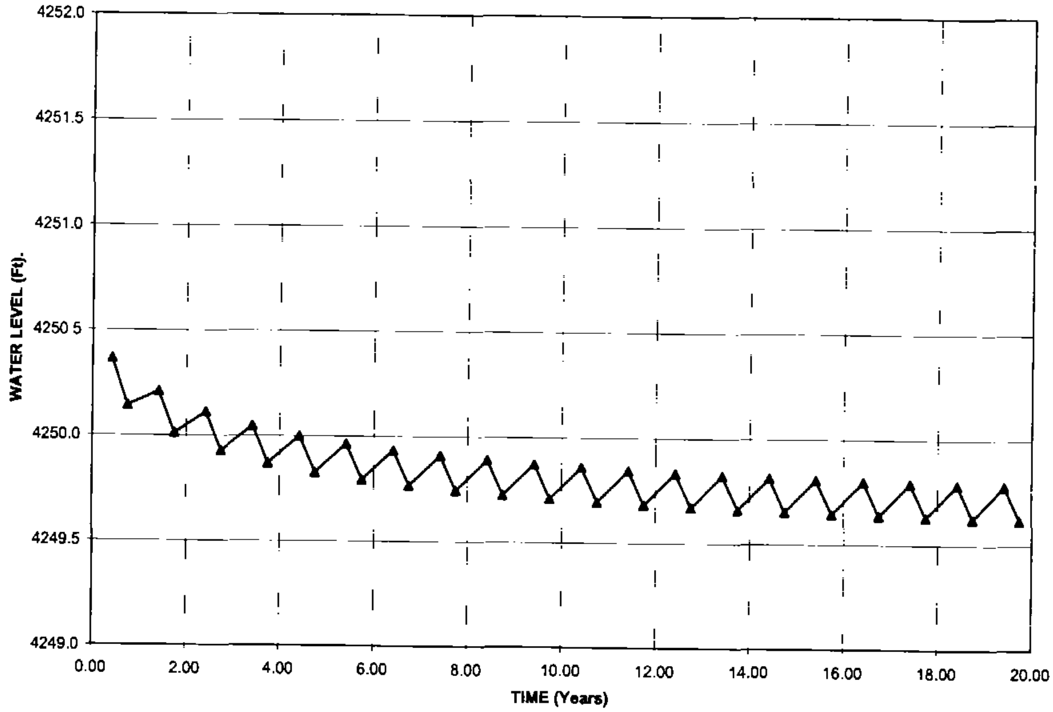
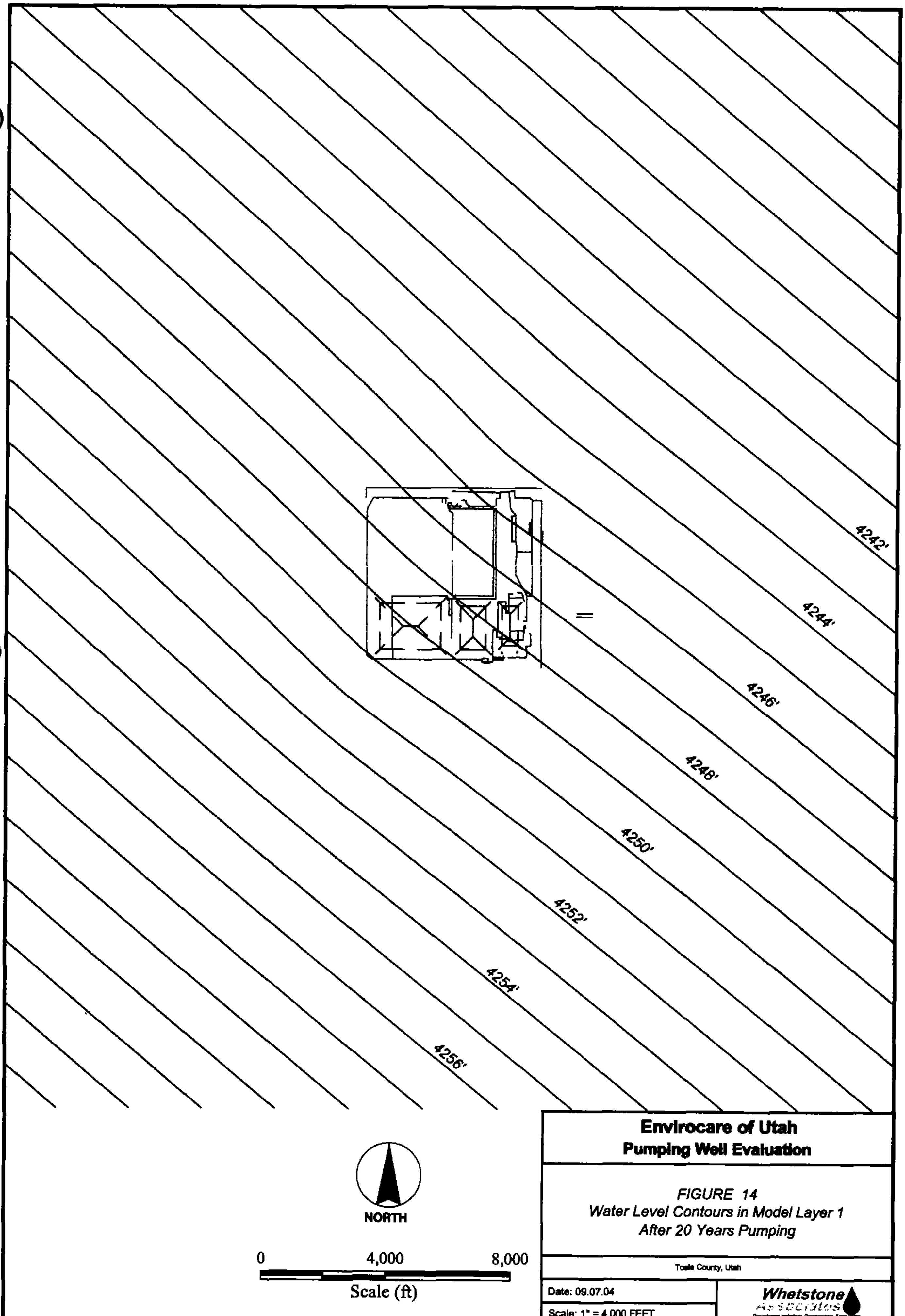


Figure 13. Model Results: Water Level vs. Time in the Shallow Aquifer (Model Layer 1)

6.1.2 Horizontal Hydraulic Gradients

Hydraulic gradients in the shallow aquifer *decrease* across the site in response to pumping from the two modeled production wells. Gradients beneath the embankments (Figure 15) are lowest during pumping and return to pre-pumping conditions within 3 years after the cessation of pumping (Figure 16). The gradients are lowest across the 11e.(2) cell, which is closest to the proposed Southwest Pond pumping well (Table 17, Figure 15). Although the gradient decreases in response to pumping, it is never reversed. The hydraulic gradient increases slightly upgradient of the Southwest Pond pumping well. The effect of these small changes in hydraulic gradient in the shallow aquifer would be to slow the potential rate of migration of constituents in groundwater downgradient of the site. The existing fate and transport modeling performed for waste disposal cells at the site would be even more conservative, and would over-predict constituent migration rates in the shallow aquifer.



Envirocare of Utah
Pumping Well Evaluation

FIGURE 14
Water Level Contours in Model Layer 1
After 20 Years Pumping

Tooele County, Utah

Date: 09.07.04

Scale: 1" = 4,000 FEET

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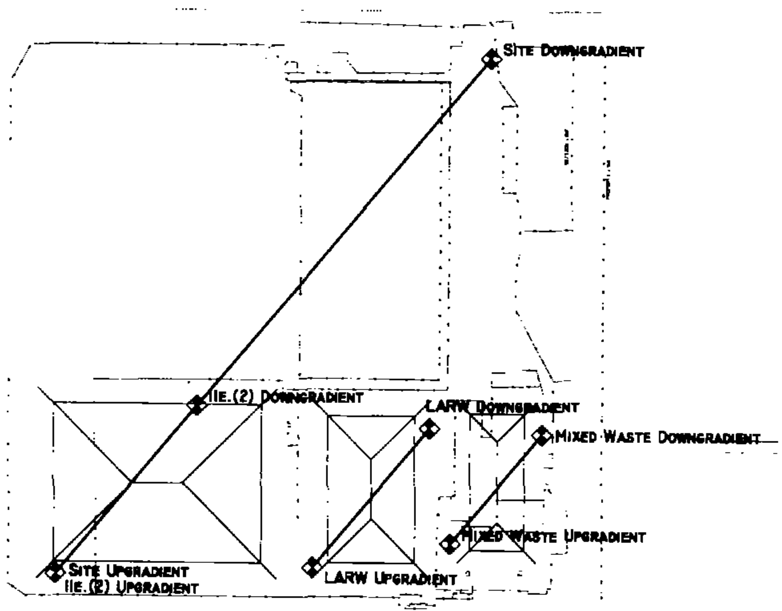

Figure 15. Locations for Horizontal Gradient Calculations

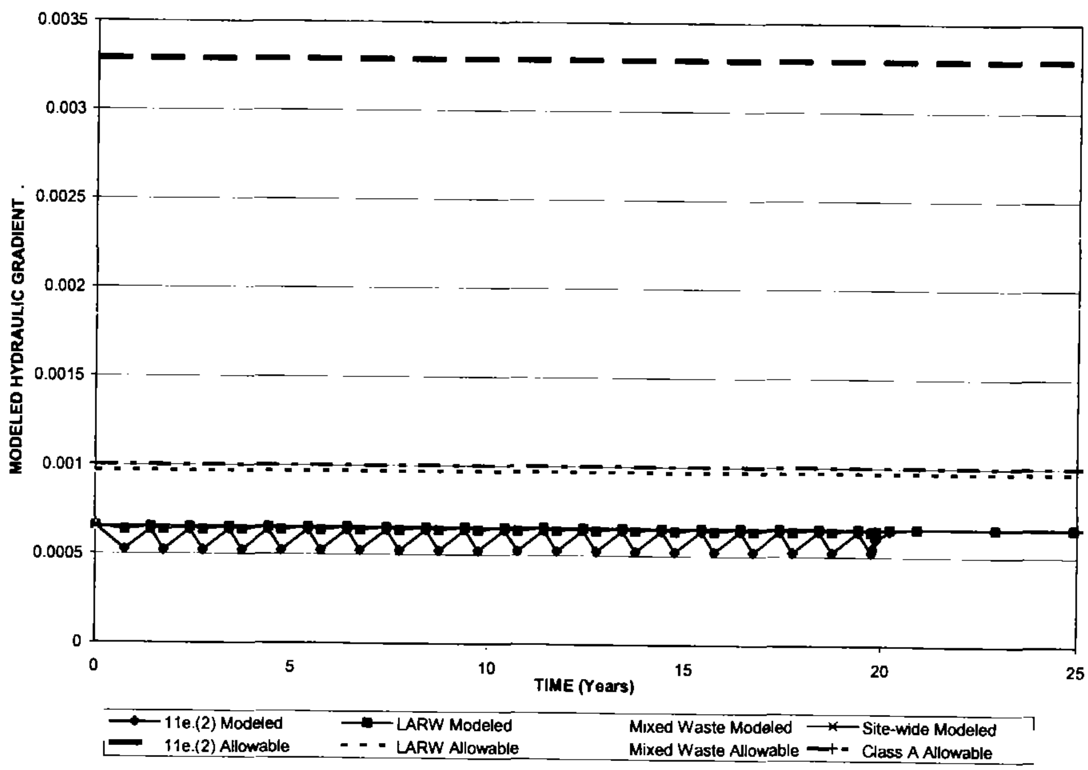

Figure 16. Changes in Site Hydraulic Gradients Over Time

Table 17. MODFLOW Model Results: Changes in Horizontal Hydraulic Gradients Over Time, Site-Wide and Across the 11e.(2), LARW, and Mixed Waste Embankments

Time (Days)	Time (Years)	11e.(2) Upgradient Head	11e.(2) Downgradient Head	Gradient Across 11e.(2)	Percent Change	LARW Upgradient Head	LARW Downgradient Head	Gradient Across LARW	Percent Change
0	0	4254.56	4253.02	0.000654	100.0%	4253.51	4252.40	0.000654	100.0%
272	0.7	4254.34	4252.85	0.000634	97.0%	4253.35	4252.25	0.000648	99.2%
515	1.4	4254.40	4252.88	0.000645	98.7%	4253.39	4252.28	0.000651	99.5%
637	1.7	4254.21	4252.73	0.000629	96.2%	4253.25	4252.15	0.000646	98.8%
880	2.4	4254.30	4252.79	0.000643	98.4%	4253.30	4252.20	0.000649	99.3%
1002	2.7	4254.12	4252.65	0.000628	96.1%	4253.17	4252.07	0.000645	98.7%
1245	3.4	4254.24	4252.72	0.000643	98.4%	4253.24	4252.14	0.000649	99.3%
1367	3.7	4254.06	4252.59	0.000628	96.1%	4253.11	4252.02	0.000645	98.7%
1610	4.4	4254.19	4252.68	0.000643	98.5%	4253.19	4252.09	0.000649	99.3%
1732	4.7	4254.02	4252.54	0.000629	96.2%	4253.07	4251.97	0.000645	98.7%
1975	5.4	4254.15	4252.64	0.000644	98.5%	4253.16	4252.05	0.000649	99.3%
2097	5.7	4253.98	4252.51	0.000629	96.2%	4253.04	4251.94	0.000645	98.7%
2340	6.4	4254.12	4252.61	0.000644	98.5%	4253.13	4252.02	0.000649	99.3%
2462	6.7	4253.96	4252.48	0.000629	96.3%	4253.01	4251.91	0.000645	98.7%
2705	7.4	4254.10	4252.58	0.000644	98.6%	4253.10	4252.00	0.000649	99.3%
2827	7.7	4253.94	4252.46	0.000629	96.3%	4252.99	4251.89	0.000645	98.7%
3070	8.4	4254.08	4252.56	0.000644	98.6%	4253.08	4251.98	0.000649	99.3%
3192	8.7	4253.92	4252.44	0.000629	96.3%	4252.97	4251.87	0.000645	98.7%
3435	9.4	4254.06	4252.55	0.000644	98.6%	4253.06	4251.96	0.000649	99.3%
3557	9.7	4253.90	4252.42	0.000629	96.3%	4252.95	4251.86	0.000645	98.7%
3800	10.4	4254.05	4252.53	0.000645	98.6%	4253.05	4251.95	0.000649	99.3%
3922	10.7	4253.89	4252.41	0.000630	96.3%	4252.94	4251.84	0.000645	98.7%
4165	11.4	4254.03	4252.52	0.000645	98.6%	4253.04	4251.93	0.000649	99.3%
4287	11.7	4253.87	4252.39	0.000630	96.3%	4252.93	4251.83	0.000645	98.7%
4530	12.4	4254.02	4252.51	0.000645	98.7%	4253.03	4251.92	0.000649	99.3%
4652	12.7	4253.86	4252.38	0.000630	96.4%	4252.91	4251.82	0.000645	98.7%
4895	13.4	4254.01	4252.50	0.000645	98.7%	4253.02	4251.91	0.000649	99.3%
5017	13.7	4253.85	4252.37	0.000630	96.4%	4252.90	4251.81	0.000645	98.7%
5260	14.4	4254.00	4252.49	0.000645	98.7%	4253.01	4251.90	0.000649	99.3%
5382	14.7	4253.84	4252.36	0.000630	96.4%	4252.90	4251.80	0.000645	98.7%
5625	15.4	4253.99	4252.48	0.000645	98.7%	4253.00	4251.89	0.000649	99.3%
5747	15.7	4253.84	4252.36	0.000630	96.4%	4252.89	4251.79	0.000645	98.7%
5990	16.4	4253.99	4252.47	0.000645	98.7%	4252.99	4251.89	0.000649	99.3%
6112	16.7	4253.83	4252.35	0.000630	96.4%	4252.88	4251.78	0.000645	98.7%
6355	17.4	4253.98	4252.46	0.000645	98.7%	4252.98	4251.88	0.000649	99.3%
6477	17.7	4253.82	4252.34	0.000630	96.4%	4252.87	4251.78	0.000645	98.7%
6720	18.4	4253.97	4252.46	0.000645	98.7%	4252.98	4251.87	0.000649	99.3%
6842	18.7	4253.82	4252.34	0.000630	96.4%	4252.87	4251.77	0.000645	98.7%
7085	19.4	4253.97	4252.45	0.000645	98.7%	4252.97	4251.87	0.000649	99.3%
7207	19.7	4253.81	4252.33	0.000630	96.4%	4252.86	4251.76	0.000645	98.7%
7215	19.8	4253.82	4252.33	0.000631	96.5%	4252.86	4251.77	0.000645	98.7%
7247	19.9	4253.84	4252.35	0.000635	97.1%	4252.88	4251.78	0.000646	98.9%
7375	20.2	4253.93	4252.42	0.000644	98.5%	4252.94	4251.84	0.000649	99.2%
7631	20.9	4254.05	4252.52	0.000651	99.6%	4253.03	4251.92	0.000651	99.6%
8361	22.9	4254.23	4252.69	0.000655	100.3%	4253.19	4252.08	0.000654	100.0%
9091	24.9	4254.32	4252.78	0.000655	100.2%	4253.27	4252.16	0.000654	100.0%
14931	40.9	4254.50	4252.96	0.000654	100.0%	4253.45	4252.34	0.000654	100.0%

Time (Days)	Time (Years)	M.Waste Upgradient Head	M.Waste Downgradient Head	Gradient Across M.Waste	Percent Change	Site Upgradient Head	Site Downgradient Head	Gradient Across Site	Percent Change
0	0.0	4252.86	4251.97	0.000654	100.0%	4254.56	4250.44	0.000654	100.0%
272	0.7	4252.72	4251.84	0.000652	99.7%	4254.34	4250.23	0.000652	99.7%
515	1.4	4252.75	4251.87	0.000652	99.8%	4254.40	4250.29	0.000653	99.8%
637	1.7	4252.63	4251.75	0.000650	99.5%	4254.21	4250.10	0.000651	99.6%
880	2.4	4252.67	4251.79	0.000652	99.6%	4254.30	4250.19	0.000652	99.8%
1002	2.7	4252.56	4251.68	0.000650	99.4%	4254.12	4250.02	0.000651	99.5%
1245	3.4	4252.61	4251.73	0.000651	99.6%	4254.24	4250.13	0.000652	99.7%
1367	3.7	4252.50	4251.63	0.000649	99.3%	4254.06	4249.96	0.000651	99.5%
1610	4.4	4252.57	4251.69	0.000651	99.5%	4254.19	4250.08	0.000652	99.7%
1732	4.7	4252.46	4251.59	0.000649	99.3%	4254.02	4249.92	0.000651	99.5%
1975	5.4	4252.53	4251.65	0.000651	99.5%	4254.15	4250.04	0.000652	99.7%
2097	5.7	4252.43	4251.55	0.000649	99.3%	4253.98	4249.89	0.000651	99.5%
2340	6.4	4252.50	4251.62	0.000651	99.5%	4254.12	4250.01	0.000652	99.7%
2462	6.7	4252.40	4251.53	0.000649	99.2%	4253.96	4249.86	0.000651	99.5%
2705	7.4	4252.48	4251.60	0.000651	99.5%	4254.10	4249.99	0.000652	99.7%
2827	7.7	4252.38	4251.50	0.000649	99.2%	4253.94	4249.84	0.000651	99.5%

3070	8.4	4252.46	4251.58	0.000650	99.5%	4254.08	4249.97	0.000652	99.7%
3192	8.7	4252.36	4251.48	0.000649	99.2%	4253.92	4249.82	0.000650	99.5%
3435	9.4	4252.44	4251.56	0.000650	99.5%	4254.06	4249.95	0.000652	99.7%
3557	9.7	4252.34	4251.47	0.000649	99.2%	4253.90	4249.80	0.000650	99.5%
3800	10.4	4252.43	4251.55	0.000650	99.5%	4254.05	4249.94	0.000652	99.7%
3922	10.7	4252.33	4251.45	0.000649	99.2%	4253.89	4249.79	0.000650	99.5%
4165	11.4	4252.41	4251.54	0.000650	99.5%	4254.03	4249.93	0.000652	99.7%
4287	11.7	4252.32	4251.44	0.000649	99.2%	4253.87	4249.78	0.000650	99.5%
4530	12.4	4252.40	4251.52	0.000650	99.5%	4254.02	4249.91	0.000652	99.7%
4652	12.7	4252.31	4251.43	0.000649	99.2%	4253.86	4249.76	0.000650	99.5%
4895	13.4	4252.39	4251.51	0.000650	99.5%	4254.01	4249.90	0.000652	99.7%
5017	13.7	4252.30	4251.42	0.000649	99.2%	4253.85	4249.75	0.000650	99.5%
5260	14.4	4252.38	4251.50	0.000650	99.5%	4254.00	4249.89	0.000652	99.7%
5382	14.7	4252.29	4251.41	0.000649	99.2%	4253.84	4249.75	0.000650	99.5%
5625	15.4	4252.37	4251.50	0.000650	99.5%	4253.99	4249.89	0.000652	99.7%
5747	15.7	4252.28	4251.40	0.000649	99.2%	4253.84	4249.74	0.000650	99.5%
5990	16.4	4252.37	4251.49	0.000650	99.5%	4253.99	4249.88	0.000652	99.7%
6112	16.7	4252.27	4251.40	0.000649	99.2%	4253.83	4249.73	0.000650	99.5%
6355	17.4	4252.36	4251.48	0.000650	99.5%	4253.98	4249.87	0.000652	99.7%
6477	17.7	4252.27	4251.39	0.000649	99.2%	4253.82	4249.72	0.000650	99.5%
6720	18.4	4252.35	4251.47	0.000650	99.5%	4253.97	4249.87	0.000652	99.7%
6842	18.7	4252.26	4251.38	0.000649	99.2%	4253.82	4249.72	0.000650	99.5%
7085	19.4	4252.35	4251.47	0.000650	99.5%	4253.97	4249.86	0.000652	99.7%
7207	19.7	4252.25	4251.38	0.000649	99.2%	4253.81	4249.71	0.000650	99.5%
7215	19.8	4252.26	4251.38	0.000649	99.2%	4253.82	4249.72	0.000651	99.5%
7247	19.9	4252.27	4251.39	0.000649	99.3%	4253.84	4249.74	0.000651	99.5%
7375	20.2	4252.32	4251.44	0.000650	99.4%	4253.93	4249.83	0.000652	99.7%
7631	20.9	4252.40	4251.52	0.000651	99.6%	4254.05	4249.94	0.000653	99.8%
8361	22.9	4252.54	4251.66	0.000653	99.9%	4254.23	4250.12	0.000653	99.9%
9091	24.9	4252.62	4251.74	0.000653	99.9%	4254.32	4250.20	0.000654	100.0%
14931	40.9	4252.80	4251.92	0.000654	100.0%	4254.50	4250.38	0.000654	100.0%

6.1.3 Vertical Hydraulic Gradients

Vertical migration of constituents from the shallow aquifer into the pumping well is not expected to occur during the 20 years of pumping. The transport velocity from the shallow to deep aquifer can be calculated as follows:

$$v = \frac{K_v \cdot i_v}{n_e} = \frac{(0.1726 ft/day)(2.29 ft/500 ft)}{0.29} = 0.0027 ft/day = 0.99 ft/yr$$

where: v = transport velocity in the vertical direction (ft/yr)
K_v = vertical hydraulic conductivity (ft/day)
i_v = vertical hydraulic gradient (ft/ft)
n_e = effective porosity (unitless)

Conservatively assuming that the maximum vertical gradient, which occurs in Year 20, applies throughout the 20 years of pumping, a constituent in the shallow aquifer directly above the pumping well would be transported less than 20 feet vertically during the 20 years of pumping. Vertical transport distances would be less, at locations further removed from the pumping well.

6.2 Water Level Recovery

Modeling results indicate that water levels in the shallow aquifer would recover 50% within 2 ½ years and 75% within 7 ¼ years of shutting off the pump (Figure 17). When the pump has been shut off for approximately the same length of time that it operated (20 years), the modeled water levels in the shallow aquifer have recovered to within 0.06 ft of the original static water level.

Water level recovery at depth occurs more quickly (Figure 18) due to the higher hydraulic conductivity in the gravel layer. Water levels in the gravel zone recover 89% in the first year and 90% in two years. Within five years, water levels have recovered to within 0.2 ft of the original static water level.

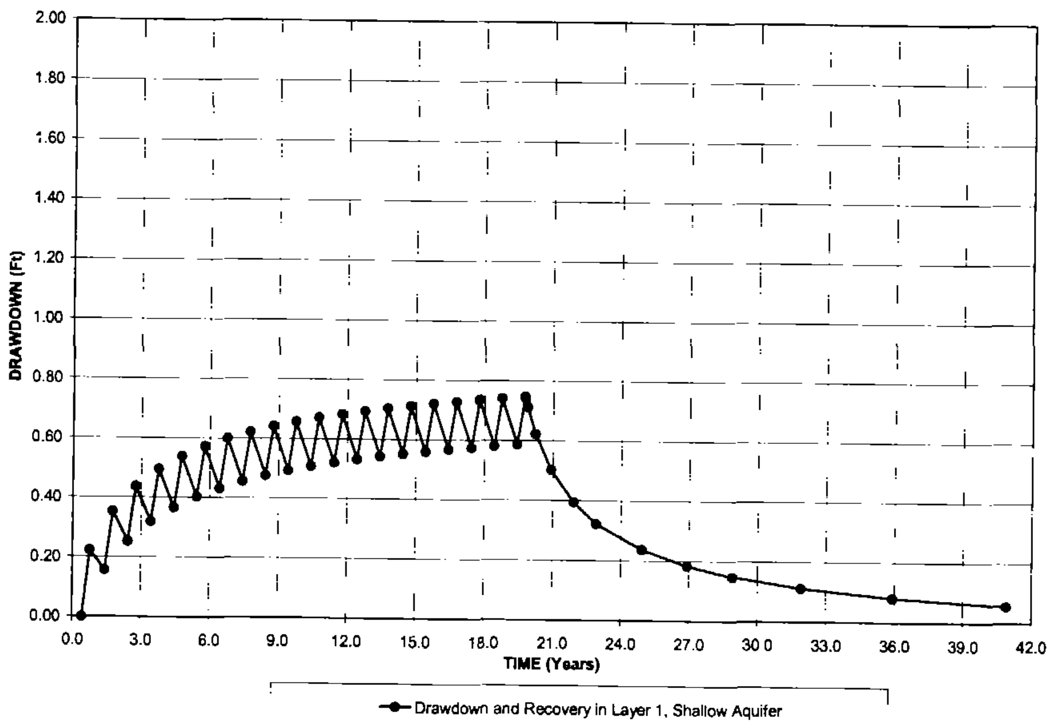

Figure 17. Model Results: Water Level Recovery in the Shallow Aquifer (Model Layer 1)

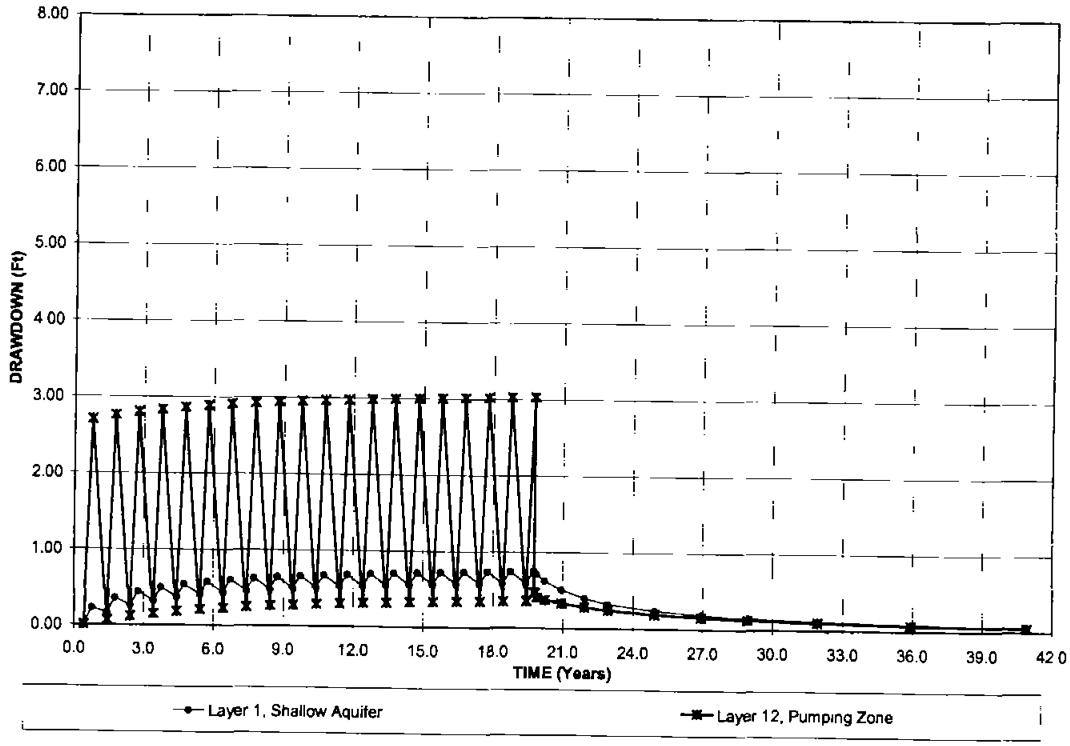

Figure 18. Model Results: Water Level Recovery in the Pumping Well Zone (Model Layer 12)

6.3 Sensitivity Analysis Results

Several sensitivity analyses were performed to investigate the effects of variations in aquifer thicknesses and boundary conditions. The results of the sensitivity analyses are provided in Appendix B. None of the sensitivity analyses resulted in higher gradients during pumping than those than modeled in the steady-state simulation.

The maximum drawdown at both pumping wells was extracted from the model output files. Table 18 summarizes the maximum drawdown in Layer 1 (directly above the pumping well) and Layer 12 (in the pumping zone) for all model cases. The maximum drawdown occurred at the end of pumping (Model Year 20), and ranged from 0.75 to 1.2 feet at the water table directly above the pumping well[2] and from 3.0 – 3.6 feet in the pumping zone (Model Layer 12.)

[2] Model grid spacing is 100-ft in this area, and the drawdown calculated by MODFLOW represents the average drawdown in the 10,000 square-ft cell.

Table 18. Summary of Maximum Drawdown (in feet) for All Sensitivity Analyses Modeled

Well	Zone	Base Case	Thinner Aquifer Sensitivity Analysis	Higher Storativity Sensitivity Analysis	Lower Hydraulic Gradient Sensitivity Analysis	Higher Hydraulic Gradient Sensitivity Analysis	Low-K Bedrock Ridge Sensitivity Analysis
		Model20	**PW-6F**	**PW-ST**	**PW-LG**	**PW-HG**	**PW-BH**
Section 29 Well	Water Table (Layer 1)	0.746	0.774	0.707	0.745	0.747	1.100
Section 29 Well	Pumping Zone (Layer 12)	3.037	3.100	2.907	3.036	3.037	3.436
Southwest Pond Well	Water Table (Layer 1)	0.745	0.772	0.705	0.744	0.745	1.198
Southwest Pond Well	Pumping Zone (Layer 12)	3.051	3.114	2.921	3.051	3.051	3.581

Table 19. Summary of Model-Calculated Hydraulic Gradients (% of Starting Gradient)

Model Run (File Name)	Minimum Gradient Across 11e.(2) Cell	Minimum Gradient Across LARW Cell	Minimum Gradient Across Mixed Waste Cell	Minimum Gradient Across Site
Model20	96.10%	98.66%	99.22%	99.48%
PW-6F	95.99%	98.61%	99.19%	99.46%
PW-ST	96.17%	98.70%	99.25%	99.50%
PW-LG	95.63%	98.50%	99.13%	99.41%
PW-HG	96.40%	98.77%	99.29%	99.52%
PW-BH	85.29%	92.01%	93.59%	93.55%
Model Run (File Name)	**Maximum Gradient Across 11e.(2) Cell**	**Maximum Gradient Across LARW Cell**	**Maximum Gradient Across Mixed Waste Cell**	**Maximum Gradient Across Site**
Model20	100.27%	100.04%	100.00%	100.00%
PW-6F	100.29%	100.04%	100.00%	100.00%
PW-ST	100.29%	100.04%	100.00%	100.00%
PW-LG	100.31%	100.04%	100.00%	100.00%
PW-HG	100.25%	100.03%	100.00%	100.00%
PW-BH	98.39%	98.33%	100.00%	100.00%

The sensitivity analysis results are discussed individually in Section 6.3.1 through 6.3.5.

6.3.1 Sensitivity Analysis PW-6F Results

Sensitivity analysis PW-6F evaluated a 600-ft thick aquifer, which is 60% of the thickness used in the base case model. The hydraulic gradients decrease during pumping, as in the base case, and the reductions in gradient are slightly greater than in the base case (Model20) simulation.

Drawdown at the water table and in the pumping zone is shown in Table 18. The maximum drawdown at the water table in Year 20 of the PW-6F sensitivity analysis was 0.774 ft, which is 3.75% higher than in the Base Case (0.746 ft.) Maximum drawdown in the pumping zone (Layer 12) was 3.114 ft, which is 3.28% greater than in the Base Case

6.3.2 Sensitivity Analysis PW-ST Results

Sensitivity analysis PW-ST evaluated higher storage coefficients. Storage values were 8.2 times (Layer 12), 30.4 times (Layers 2-11 and 13-20) and 114 times (Layer 1) the values used in the base case model. The hydraulic gradients decrease during pumping and are the gradient reductions are comparable to those in the Base Case. The hydraulic gradients across the site and across the individual disposal cells in the PW-ST sensitivity analysis are shown in Appendix B.

Maximum drawdown at the water table and in the pumping zone is summarized in Table 18. The maximum drawdown at the water table in Year 20 of the PW-ST sensitivity analysis was 0.707 ft, which is 5.2% less than in the Base Case (0.746 ft.) Maximum drawdown in the pumping zone (Layer 12) was 2.92 ft, which is 4.5% less than in the Base Case.

6.3.3 Sensitivity Analysis PW-LG Results

Sensitivity analysis PW-LG used a lower hydraulic gradient. The gradient in the sensitivity analysis (5.81×10^{-4}) was 89% of the value used in the base case model (6.54×10^{-4}). The flow field simulated by the PW-LG sensitivity analysis model is nearly identical to the Base Case model

The hydraulic gradients decrease during pumping, and the changes in hydraulic gradients are slightly greater than in the Base Case model results. Drawdown at the water table and in the pumping zone is shown in Table 18. The maximum drawdown at the water table in Year 20 of the PW-LG sensitivity analysis is nearly identical to (and very slightly less than) the Base Case model results.

6.3.4 Sensitivity Analysis PW-HG Results

Sensitivity analysis PW-HG used a higher hydraulic gradient. The gradient in the sensitivity analysis (7.12×10^{-4}) was 109% of the value used in the base case model (6.54×10^{-4}). The flow field simulated by the PW-HG sensitivity analysis model is nearly identical to the Base Case model.

The hydraulic gradients decrease during pumping, as in the base case, and the reductions in gradient are slightly less than in the base case (Model20) simulation. Maximum drawdown at the water table and in the pumping zone in Year 20 of the PW-LG sensitivity analysis is nearly identical to (and very slightly greater than) the Base Case model results (Table 18).

6.3.5 Sensitivity Analysis PW-BH Results

Sensitivity analysis PW-BH evaluated the effects of two bedrock ridges, which were was assumed to have a hydraulic conductivity ten times lower than that of the lacustrine sedimentary deposits. Although the conceptual hydrologic model of the regional aquifer (Section 2.2.1) indicates that the bedrock and alluvium act as a single hydrologic unit (DWR, 2001; Gates, 1987), the sensitivity analysis assumes that the bedrock transmits very little water.

The flow field simulated by the PW-BH sensitivity analysis model was very different from the Base Case model, because the bedrock ridges significantly influence the flow field east and west of the site (Figure 19). Near the Envirocare facility, the modeled flow field is similar to the Base Case model, with a site-wide hydraulic gradient of 2.8×10^{-4} in the steady-state PW-BH simulation compared to 6.54×10^{-4} in the base case model.

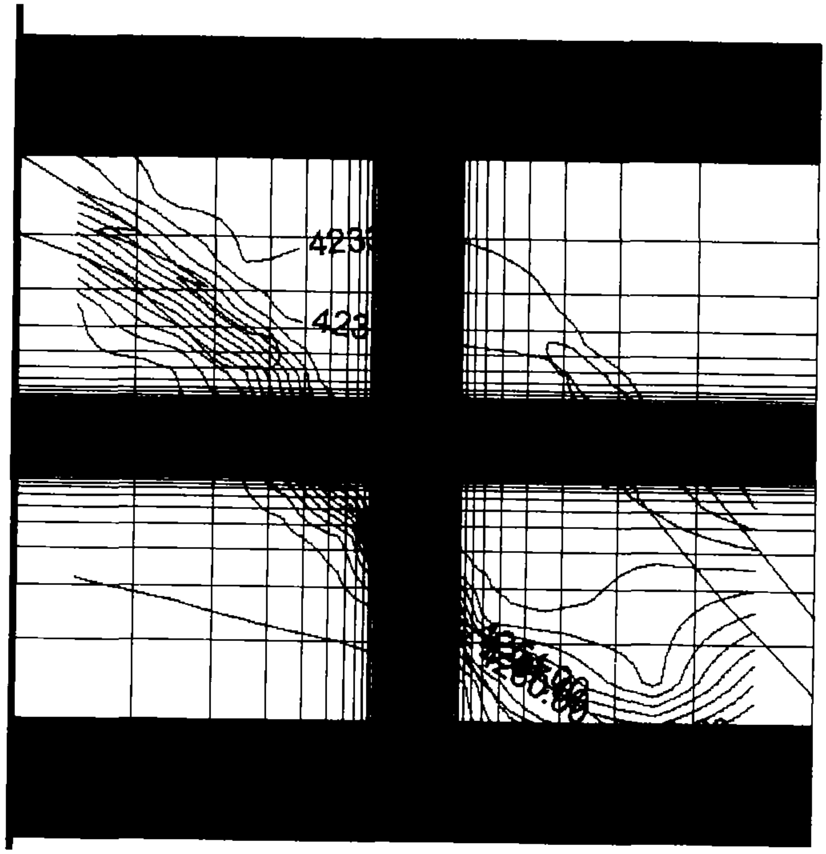

Figure 19. Steady-State Water Table Contours – Model Run PW-BH

The hydraulic gradients decrease during pumping, more so than in the Base Case. For example, the minimum gradient across the 11e.(2) cell during pumping and recovery was 85% of the steady-state calculated gradient. The minimum gradient across the site was approximately 94%, compared to 99.5% in the Base Case simulation (Table 19).

Maximum drawdown at the water table and in the pumping zone is summarized in Table 18. The maximum drawdown at the water table in Year 20 of the PW-BH sensitivity analysis was 1.2 ft, which is 61% higher than in the Base Case (0.746 ft.) Maximum drawdown in the pumping zone (Layer 12) was 3.581 ft, which is 17% greater than in the Base Case.

7. CONCLUSIONS

Model results indicate that pumping from two wells at a depth of 550 feet below ground surface at a combined rate of 400 gpm for 4 months per year for 20 years would result in 0.75 ft drawdown in the overlying shallow aquifer. The drawdown cone would be widespread, and hydraulic gradients would decrease slightly. The flow direction in the shallow aquifer, however, would not reverse. The reduction in gradient would slow the rate of transport of constituents in the aquifer downgradient of the site for the period of pumping and for an additional 10 years of water level recovery. Approximately 20 years after pumping, the water levels would be almost fully recovered and the flow field and transport rates would return to the normal (pre-pumping) condition.

In summary, pumping from two production wells screened from 550 to 600 feet below ground surface (bgs), pumped at 200 gallons per minute, 24 hours per day, 4 months per year (122 days), would create approximately 0.75 feet of drawdown in the upper aquifer after 20 years. This drawdown will not increase the hydraulic gradient beneath the facility.

April 7, 2005
Prepared and submitted by:

Whetstone Associates, Inc.

Susan A. Wyman, P.E., P.G.
Principal Hydrologist / Civil Engineer

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Whetstone Associates

APPENDIX A
WELL DRILLER REPORTS FOR DEEP WELLS

Prepared for:

Envirocare of Utah, Inc.
605 North 5600 West
Salt Lake City, UT 84116

Prepared by

Whetstone Associates, Inc.
137 W. Ryus Street
P.O. Box 1156
La Veta, Colorado 81055
719-742-5155

Document 4101U.050407

April 7, 2005

State of Utah
Division of Water Rights

For additional space, use "Additional Well Data Form" and attach

Well Identification WATER RIGHT APPLICATION: 16-816(A68876)

Owner *Note any changes*

Broken Arrow Incorporated
165 South Main
Tooele, UT 84074

Contact Person/Engineer: ______

Well Location *Note any changes*

COUNTY: Tooele
NORTH 500 feet EAST 3800 feet from the SW Corner of
SECTION 29, TOWNSHIP 1S, RANGE 11W, SLB&M.

Location Description: (address, proximity to buildings, landmarks, ground elevation, local well #) ______

Drillers Activity Start Date: 1-9-96 Completion Date: 1-18-96

Check all that apply: [X] New [ ] Repair [ ] Deepen [ ] Abandon [ ] Replace [ ] Public Nature of Use: OTH

DEPTH (feet) FROM	TO	BOREHOLE DIAMETER (in)	DRILLING METHOD	DRILLING FLUID
0	620	9 7/8	Mud Rotary	Bentonite & Polymer

Well Log

DEPTH (feet) FROM	TO	WATER	PERMEABLE (high/low)	CLAY	SILT	SAND	GRAVEL	COBBLES	BOULDERS	OTHER	ROCK TYPE	COLOR	DESCRIPTIONS AND REMARKS (include comments on water quality if known.)
0	4									X			TopSoil
4	50			X									
80	95					X							
95	182					X					Sandstone		
182	483			X			X						
483	487							X					
487	495						X						
495	505			X									
505	545						X						
545	620			X									

Static Water Level

Date 1-18-96 Water Level 84 feet Flowing? [ ] Yes [X] No

Method of Water Level Measurement Sounder If Flowing, Capped Pressure ______ PSI

Point to Which Water Level Measurement was Referenced Ground level

Height of Water Level reference point above ground surface ______ feet Temperature ______ [ ] °C [ ] °F

Well Log

State of Utah
Division of Water Rights

For additional space, use "Additional Well Data Form" and attach

Well Identification WATER RIGHT APPLICATION: 16-816(A68876)

Owner *Note any changes*
Broken Arrow Incorporated
165 South Main
Tooele, UT 84074

Contact Person/Engineer: ______

Well Location *Note any changes*
COUNTY: Tooele
NORTH 500 feet EAST 3800 feet from the SW Corner of
SECTION 29, TOWNSHIP 1S, RANGE 11W, SLB&M.

Location Description: (address, proximity to buildings, landmarks, ground elevation, local well #) Inactive

Drillers Activity Start Date: 1-30-96 Completion Date: 1-30-96

Check all that apply: ☐ New ☐ Repair ☐ Deepen ☒ Abandon ☐ Replace ☐ Public Nature of Use: OTH

DEPTH (feet) FROM	TO	BOREHOLE DIAMETER (in)	DRILLING METHOD	DRILLING FLUID
0	620	9 7/8	Mud Rotary	Bentonite & Polymer

Well Log

DEPTH (feet) FROM	TO	WATER	PERMEABLE (high / low)	UNCONSOLIDATED: CLAY	SILT	SAND	GRAVEL	COBBLES	CONSOLIDATED: BOULDER	OTHER	ROCK TYPE	COLOR	DESCRIPTIONS AND REMARKS (include comments on *water quality* if known.)

ABANDON

Static Water Level

Date ______ Water Level ______ feet Flowing? ☐ Yes ☐ No

Method of Water Level Measurement ______ If Flowing, Capped Pressure ______ PSI

Point to Which Water Level Measurement was Referenced ______

Height of Water Level reference point above ground surface ______ feet Temperature ______ ☐ °C ☐ °F

Well Log

453 WEST 500 SOUTH
BOUNTIFUL, UTAH 84010
PI Form [illegible]

Examined 3-18-70 V.F.C.
Recorded: B. C 3-18-70 V.F.C. T. B. V.F.C.
Inspection Sheet 3-19-70 [illegible]
Copied

REPORT OF WELL DRILLER
STATE OF UTAH

Application No. A2 39690 (16-545)
Claim No.
Coordinate No. (C-1-11) 18 bcd

GENERAL STATEMENT: Report of well driller is hereby made and filed with the State Engineer, in accordance with the laws of Utah. (This report shall be filed with the State Engineer within 30 days after the completion or abandonment of the well. Failure to file such reports constitutes a misdemeanor.)

(1) WELL OWNER:
Name Cox Construction Co.
Address Manti, Utah

(2) LOCATION OF WELL:
County Tooele Ground Water Basin .... (leave blank)
[redacted] South ~~3000~~ 2100 feet, East ~~West~~ ~~1000~~ 1700 feet from NW Corner of Section 18, T 1 S, R 11 W, SLBM (strike out words not needed)

(3) NATURE OF WORK (check): New Well ☒
Replacement Well ☐ Deepening ☐ Repair ☐ Abandon ☐
If abandonment, describe material and procedure:

(4) NATURE OF USE (check):
Domestic ☐ Industrial ☒ Municipal ☐ Stockwater ☐
Irrigation ☐ Mining ☐ Other ☐ Test Well ☐

(5) TYPE OF CONSTRUCTION (check):
Rotary ☐ Dug ☐ Jetted ☐
Cable ☒ Driven ☐ Bored ☐

(6) CASING SCHEDULE: Threaded ☐ Welded ☒
10 " Diam. from 0 feet to 315 feet Gage STD
8 " Diam. from 210 feet to 350 feet Gage STD
" Diam. from .... feet to .... feet Gage ....
New ☒ Reject ☒ Used ☐

(7) PERFORATIONS: Perforated? Yes ☒ No ☐
Type of perforator used Saw & Mills
Size of perforations 3/8 inches by 6 inches
200 perforations from 185 feet to 210 feet
1000 perforations from 205 feet to 350 feet
perforations from .... feet to .... feet
perforations from .... feet to .... feet
perforations from .... feet to .... feet

(8) SCREENS: Well screen installed? Yes ☐ No ☒
Manufacturer's Name
Type Model No.
Diam. Slot size Set from ...... ft. to ......
Diam. Slot size Set from ...... ft. to ......

(9) CONSTRUCTION:
Was well gravel packed? Yes ☐ No ☒ Size of gravel:
Gravel placed from .... feet to .... feet
Was a surface seal provided? Yes ☒ No ☐
To what depth? 100 feet
Material used in seal Bentonite & clay
Did any strata contain unusable water? Yes ☐ No ☐ ✓
Type of water: Depth of strata
Method of sealing strata off:
Was surface casing used? Yes ☐ No ☒
Was it cemented in place? Yes ☐ No ☐

(10) WATER LEVELS:
Static level 53 feet below land surface Date 12-19-69
Artesian pressure .... feet above land surface Date ....

LOG RECEIVED:

(11) FLOWING WELL:
Controlled by (check) Valve ☐
Cap ☐ Plug ☐ No Control ☐
Does well leak around casing? Yes ☐ No ☒

(12) WELL TESTS: Drawdown is the distance in feet the water level is lowered below static level.
Was a pump test made? Yes ☒ No ☐ If so, by whom? Petersen Bros. Drl
Yield: 600 gal./min. with 130 feet drawdown after 10 hours
Bailer test .... gal./min. with .... feet drawdown after .... hours
Artesian flow .... g.p.m. Date ....
Temperature of water .... Was a chemical analysis made? No ☐ Yes ☐

(13) WELL LOG: Diameter of well 10 inches
Depth drilled 351 feet. Depth of completed well 350 feet.

NOTE: Place an "X" in the space or combination of spaces needed to designate the material or combination of materials encountered in each depth interval. Under REMARKS make any desirable notes as to occurrence of water and the color, size, nature, etc., of material encountered in each depth interval. Use additional sheet if needed.

Depth From	Depth To	Clay	Silt	Sand	Gravel	Cobbles	Boulders	Hardpan	Conglomerate	Redrock	Other	Remarks
0	20	X										White
20	25	X			X							White, small
25	60	X			X							White
60	70	X			X							White harder
70	75			X								Soft mud & water
75	80	X		X								White
80	110	X			X							Hard brown
110	135	X			X							Hard brown
135	160	X										White-little gravel
160	165	X			X							White
165	194	X			X							White
194	203				X							
203	207	X										
207	232											Sandstone
232	240	X			X							
240	245	X			X							Soft
245	252			X								Hard
252	267											Sandstone
267	282											Sandstone
282	292											Sandstone
292	302	X			X							White
302	320	X										White-little gravel
320	325	X			X							White
325	350			X								Hard grey

PETERSEN BROS. DRILLING CO.
453 WEST 500 SOUTH
BOUNTIFUL, UTAH 84010
PHONE 292-1516

Work started 11-15- 1969 Completed 12-19- 1969

(14) PUMP:
Manufacturer's Name Johnstone
Type: Line shaft turbine H. P. 100
Depth to pump or bowles .... feet

Well Driller's Statement:
This well was drilled under my supervision, and this report is true to the best of my knowledge and belief.
Name PETERSEN BROS. DRILLING CO. (Type or print)
Address 453 WEST 500 SOUTH
BOUNTIFUL, UTAH 84010
(Signed) PHONE 292-1506 (Well Driller)
License No. 249 Date 3-5-, 1970

RECEIVED 1970

USE OTHER SIDE FOR ADDITIONAL REMARKS

SCANNED

Whetstone Associates

APPENDIX B
MODEL SENSITIVITY ANALYSIS

Prepared for

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605 North 5600 West
Salt Lake City, UT 84116

Prepared by

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Document 4101U.050407

April 7, 2005

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1. INTRODUCTION

A three-dimensional finite difference groundwater flow model was developed to evaluate the potential drawdown and gradient changes that could be associated with pumping from two water supply production wells proposed for installation near the Envirocare of Utah low-level radioactive waste disposal facility. The analysis was performed using the United States Geological Survey (USGS) MODFLOW software (McDonald and Harbaugh, 1988) and the Groundwater Vistas 3.0 pre/post-processor (Rumbaugh, 2002). The purpose of this appendix is to describe the model sensitivity analysis approach, results, and conclusions.

This appendix is not intended as a stand-alone document. The reader is referred to the main body of the report for a thorough documentation of the conceptual model, numerical model input parameters, and Base Case results.

2. BASE CASE MODEL

The Base Case model is described thoroughly in the main body of the report, and is summarized briefly in this appendix. The three-dimensional finite-difference MODFLOW model uses a telescoping grid with 102 cells in the x-direction, 102 cells in the y-direction, and 20 cells in the z-direction. The horizontal grid spacing ranges from a minimum of 100 feet near the proposed pumping wells to a maximum of 12,000 feet near the model boundaries. The model domain is 1,000 feet thick, is divided into 20 layers of uniform (50-ft) thickness, and contains 208,080 active cells. The electronic data files for the base case model runs are named "Model 20."

The model is oriented in the direction of groundwater flow (approximately N40°E). The model boundaries in all layers of the Base Case model were set to constant heads of 4,375 ft at the upgradient boundary (model north) and 4,230 ft at the downgradient boundary (model south). The constant head cells establish a very small uniform gradient of 0.000654 ft/ft (5.57×10^{-4}) in the steady-state model.

The Base Case model was first run without pumping to arrive at the steady-state solution (PW16ss). A double-precision (16-digit) version of the MODFLOW96 code (modflowdp.exe) was run external to the Groundwater Vistas pre/post-processor, using the pre-conditioned conjugate gradient (PCG2) solver. The numerical accuracy of the double precision code was necessary to simulate the extremely low gradient across the site.

The Base Case model was then run in the transient condition, to simulate pumping from the two proposed production wells, referred to as the Southwest Pond Well and the Section 29 Well. The wells simulate pumping from a 50-ft thick gravel layer located 550 to 600 ft below ground surface (3,725 to 3,775 ft elevation), that corresponds to the gravel layer identified in the Broken Arrow abandoned test well.

The model simulates a pumping rate of 200 gallons per minute (gpm) from each well for 4 months of the year (June 1 to September 30). The wells are modeled as pumping for 122 days at a rate of 38,503 ft^3/day per well, or 77,006 ft^3/day total. The wells are turned off from October 1 to May 31 (243 days). This equates to an average annual withdrawal of 107.8 acre-ft per well, or a total of 215.7 acre-ft per year. The transient simulation was run for 52 stress periods, 40 of which simulated 20 years of pumping and 12 of which simulated 20 years of water level recovery.

The results of the Base Case model indicate that a maximum drawdown of 3.034 ft is predicted at the Southwest Pond Well and 3.029 ft is predicted at the Section 29 Well in the pumping zone (Model Layer 12) at the end of 20 years pumping. Directly above the pumping wells, in Model Layer 1, drawdown in the shallow aquifer reaches a maximum of 0.75 ft at the end of 20 years. In that final year of pumping, drawdown at the water table directly above the pumping wells varies between about 0.59 ft and 0.75 ft as the well is cycled on and off (Figure 1).

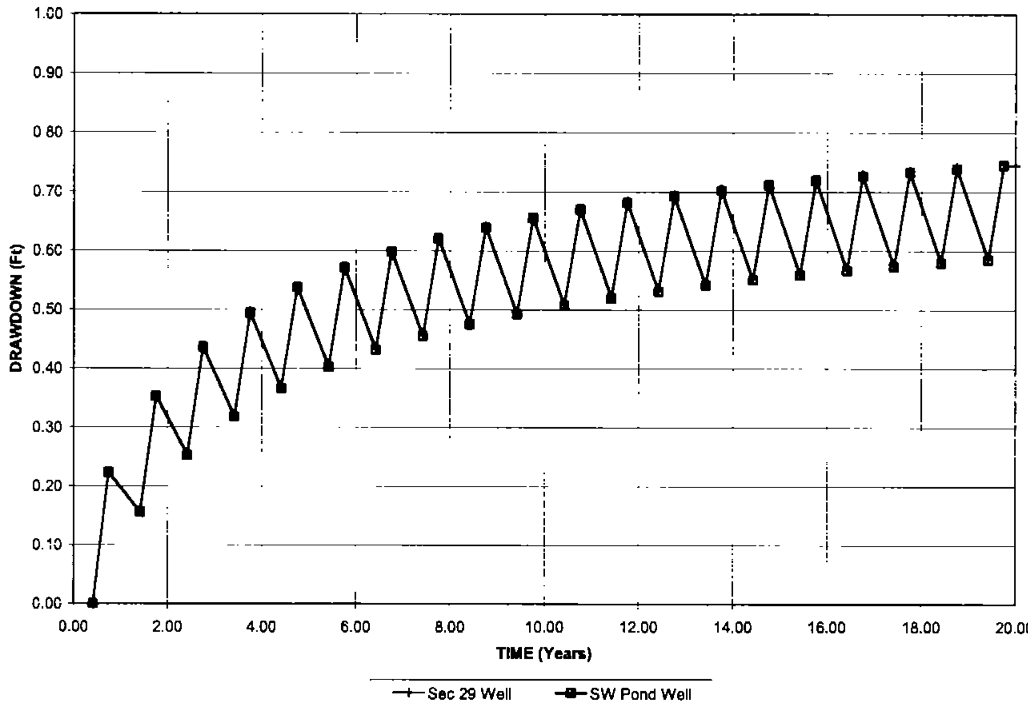

Figure 1. Modflow Model Results: Drawdown vs. Time in the Shallow Aquifer (Model Layer 1)

The water levels (heads) predicted by the Base Case modeling were used to calculate hydraulic gradients across the 11e.(2), LARW, and Mixed Waste disposal facilities and across the entire site, at the locations shown in Figure 2. The calculated gradients were compared to the hydraulic gradient limits specified in Condition I.H.2.c)2. of the Ground Water Quality Discharge Permit (GWQDP) for each disposal facility at the Envirocare site (Table 1). The predicted gradients for the Base Case simulation were well below the allowable limits (Figure 3).

Hydraulic gradients in the shallow aquifer *decrease* across the site in response to pumping from the two modeled production wells. Gradients beneath the disposal embankments are lowest during pumping and return to pre-pumping conditions within 3 years after the cessation of pumping (Figure 3). The gradients are lowest across the 11e.(2) cell, which is closest to the proposed Southwest Pond pumping well. Although the gradient decreases in response to pumping, it is never reversed. The hydraulic gradient increases slightly upgradient of the Southwest Pond pumping well. The effect of these small changes in hydraulic gradient in the shallow aquifer would be to slow the potential rate of migration of constituents in groundwater downgradient of the site. The existing fate and transport modeling performed for waste disposal cells at the site would be even more conservative, and would over-predict constituent migration rates in the shallow aquifer.

Table 1. Horizontal Hydraulic Gradient Limits Specified in the GWQDP

Disposal Cell	Horizontal Hydraulic Gradient Limit
Class A	1.00 E-3
LARW	9.67 E-4
Mixed Waste	9.67 E-4
11e.(2)	3.29 E-3

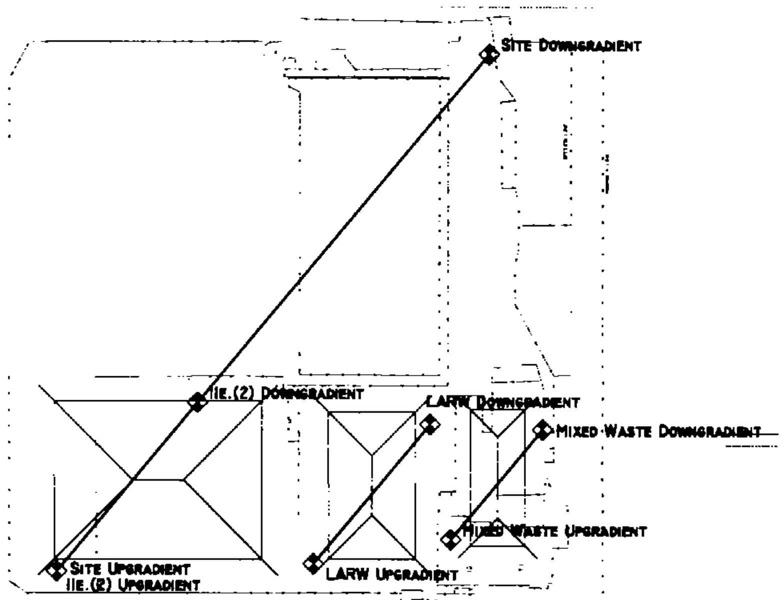

Figure 2. Locations for Horizontal Gradient Calculations

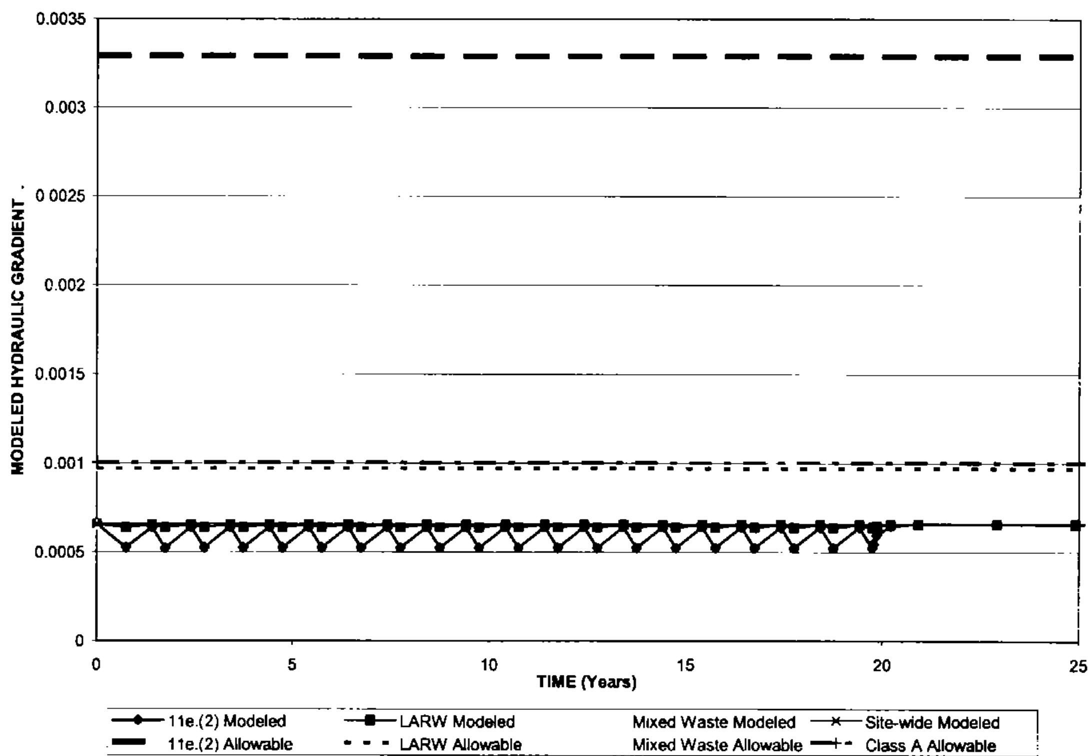

Figure 3. Changes in Site Hydraulic Gradients Over Time – Base Case Simulation

3. SENSITIVITY ANALYSES

Five sensitivity analyses were performed to investigate the effects of variations in aquifer thicknesses and boundary conditions. The file names and conditions are summarized in Table 2, and each case is described individually in the following sections.

Table 2. Sensitivity Analyses

CASE	Model Run (File Name)	Model Thickness	Boundary Conditions	Gradient	Specific Storage
Base Case	Model20	1000 ft	Constant Head (4275 -> 4230)	6.54E-04	1.98E-4, 5.3E-5, 2.66E-5
Bedrock Ridge	PW-BH	Variable: 1000 ft with bedrock high	Constant Head (4275 -> 4230)	6.54E-04	1.98E-4, 5.3E-5, 2.66E-5
Shallow Bedrock	PW-6F	600 ft	Constant Head (4275 -> 4230)	6.54E-04	1.98E-4, 5.3E-5, 2.66E-5
Higher Storage	PW-ST	1000 ft	Constant Head (4275 -> 4230)	5.81E-04	6.0E-3, 1.6E-3, 8.1E-4
Lower Gradient	PW-LG	1000 ft	Constant Head (4275 -> 4235)	7.12E-04	1.98E-4, 5.3E-5, 2.66E-5
Higher Gradient	PW-HG	1000 ft	Constant Head (4275 -> 4226)	6.54E-04	1.98E-4, 5.3E-5, 2.66E-5

3.1.1 Sensitivity Analysis PW-6F

Sensitivity analysis PW-6F evaluated a 600-ft thick aquifer, which is 60% of the thickness used in the base case model. The change in aquifer thickness was implemented by deleting the lower 8 model layers (400 ft), leaving a 12-layer model. No other modifications to the model were made.

3.1.2 Sensitivity Analysis PW-ST

Sensitivity analysis PW-ST evaluated higher storage coefficients. Storage values were 8.2 times (Layer 12), 30.4 times (Layers 2-11 and 13-20) and 114 times (Layer 1) the values used in the base case model. The storage values used in the Base Case model and the PW-ST model runs are shown in Table 3.

Table 3. Storage Values Used in Base Case (Model 20) and Higher Storage (PW-ST) Sensitivity Analysis

Model Case	Description	Silty sand	Dense silty sand	Dense sandy gravel
Model-20	Base Case	6.04E-03 /ft	1.62E-03 /ft	8.10E-04 /ft
PW-ST	Higher Storage Sensitivity Analysis	1.98E-04	5.3E-05	2.66E-04
Applied to		Layer 1	Layers 2-11, 13-20	Layer 12

Lower storage coefficients (such as those used in the base case model) would cause the model to predict higher drawdown. Conversely, higher storage coefficients result in lower predicted drawdown.

3.1.3 Sensitivity Analysis PW-LG

Sensitivity analysis PW-LG used a lower hydraulic gradient. The gradient in the sensitivity analysis ($5.81x10^{-4}$) was 89% of the value used in the base case model ($6.54x10^{-4}$), and corresponds more closely with the average gradient measured at the site in all unconfined wells during January 2003 ($4.96x10^{-4}$). The change in hydraulic gradient was implemented by changing the constant head elevations at the downgradient boundary from 4,230 to 4,235 ft, as shown in Table 4. No other changes were made to the model, and a steady-state simulation (PW-LGSS) was used to generate starting heads for the transient simulation.

Table 4. Calculation of Hydraulic Gradients Used in PW-LG and PW-HG Sensitivity Analyses

	Base Case (Model 20)	Jan 2003 Gradient	PW-LG Sensitivity Analysis	PW-HG Sensitivity Analysis
Upgradient Constant Head	4,275	4,275	4275	4,275
Downgradient Constant Head	4,230	4,234.92	4235	4,226
Distance (from center of boundary nodes)	68,822	68,822	68,822	68,822
Uniform Gradient	6.54E-04	4.96E-04	5.81E-04	7.12E-04
Percent of base case	100%	76%	89%	109%

3.1.4 Sensitivity Analysis PW-HG

Sensitivity analysis PW-HG used a higher hydraulic gradient. The gradient in the sensitivity analysis ($7.12x10^{-4}$) was 109% of the value used in the base case model ($6.54x10^{-4}$). The change in hydraulic gradient was implemented by decreasing the constant head elevations at the downgradient boundary from 4,230 to 4,226 ft, as shown in Table 4. No other changes were made to the model, and a steady-state simulation (PW-HGSS) was used to generate starting heads for the transient simulation.

3.1.5 Sensitivity Analysis PW-BH

Sensitivity analysis PW-BH evaluated the effects of two bedrock ridges, which were was assumed to have a hydraulic conductivity ten times lower than that of the lacustrine sedimentary deposits. Although the conceptual hydrologic model of the regional aquifer (described in the main body of this report) indicates that the bedrock and alluvium act as a single hydrologic unit (DWR, 2001; Gates, 1987), the sensitivity analysis assumes that the bedrock transmits very little water.

The location of the bedrock ridges were determined from geologic maps compiled by Bingham (1991, 1992) and Moore and Sorenson (1979). The Bingham compilation was based on work by Stephens (1974) and U.S. Department of Energy (1983). The bedrock outcrop is overlain on the model grid in Figure 4. The bedrock is exposed in two north-south trending structures. Lone Mountain is located approximately three miles east of the Envirocare site and a series of low-lying hills (50 to 100 ft in height) are located approximately one mile west of the site.

The Bingham (1991) compilation lists these bedrock outcrops as Pzu, chiefly limestone, dolomite and shale which locally includes sandstone, quartzite, and evaporates. Moore and Sorenson (1979) mapped the bedrock as PPsc, Lower Pennsylvanian / Upper Permian calcareous sandstone, quartzite, limestone, and dolomite. Moore and Sorenson (1979) mapped the Grayback Hills, located north-northwest of the Envirocare site, as Miocene and Pliocene basalt and basaltic andesite flows and shallow intrusives. The Bingham (1991, 1992) compilation shows the bedrock outcrops as surrounded by Quaternary alluvium.

Permeability data for the limestone and dolomite in this area were not identified. However, the general literature indicates that limestone and dolomite permeabilities may range from 10^{-7} cm/sec for unfractured limestone and dolomite to 10^{-3} cm/sec for fractured limestone and dolomite to 10 cm/sec for karst. For the model sensitivity analysis, the bedrock was assumed to have a permeability ten times lower than that of Quaternary lacustrine (lake bed) deposits at the site (Table 5).

Table 5. Hydraulic Conductivity Values Used in Sensitivity Analysis of Low-Permeability Bedrock High

Lithology	Parameter	Value (cm/sec)	Value (ft/day)	Data Source
Silts, silty clays, sandy silts	K_h	6.09E-04	1.7263	Average of 69 slug tests
	K_v	6.09E-05	0.1726	Assume $K_h = 10K_v$
Gravel layer	K_h	1.00E-01	283	Lower range in Freeze & Cherry
	K_v	1.00E-02	28.3	Assume $K_h = 10K_v$
Bedrock (PPsc)	K_h	6.09E-05	0.1726	Assumed 1 o.o.m. lower than Ql
	K_v	6.09E-06	0.01726	Assume Kh = 10Kv

Notes: K_h = horizontal hydraulic conductivity
K_v = vertical hydraulic conductivity
PPsc = Pennsylvanian / Permian Calcareous sandstone, quartzite, limestone, and dolomite. (Lower Permian and Upper Pennsylvanian). Also includes Basalt and basaltic andesite flows and shallow intrusives (Miocene and Pliocene).
Ql = Quaternary lacustrine deposits
o.o.m. = order of magnitude

The simulation of lower bedrock hydraulic conductivity was implemented by changing the K values for model cells along the mapped bedrock outcrops in Layers 1 through 10 (Figure 5). The zone of bedrock was expanded in Layers 11 through 20 (Figure 6).

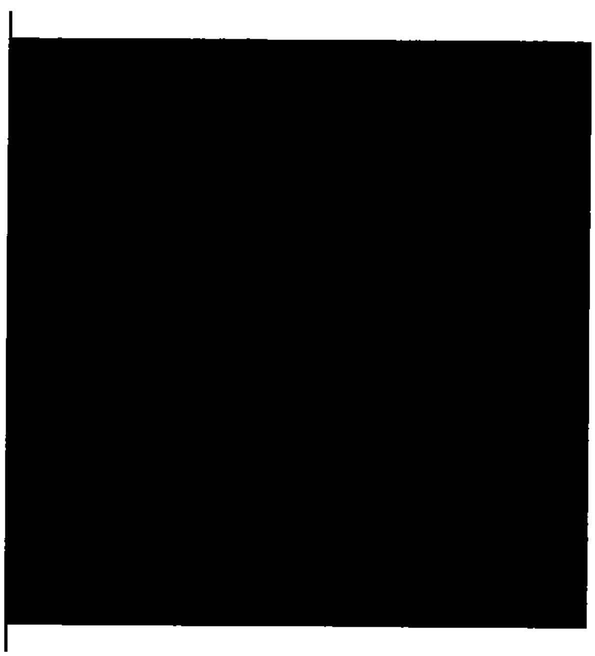

Figure 5. Hydraulic Conductivity Zones Applied to Layers 1-10 of the Low-Permeability Bedrock Sensitivity Analysis (PW-BH)

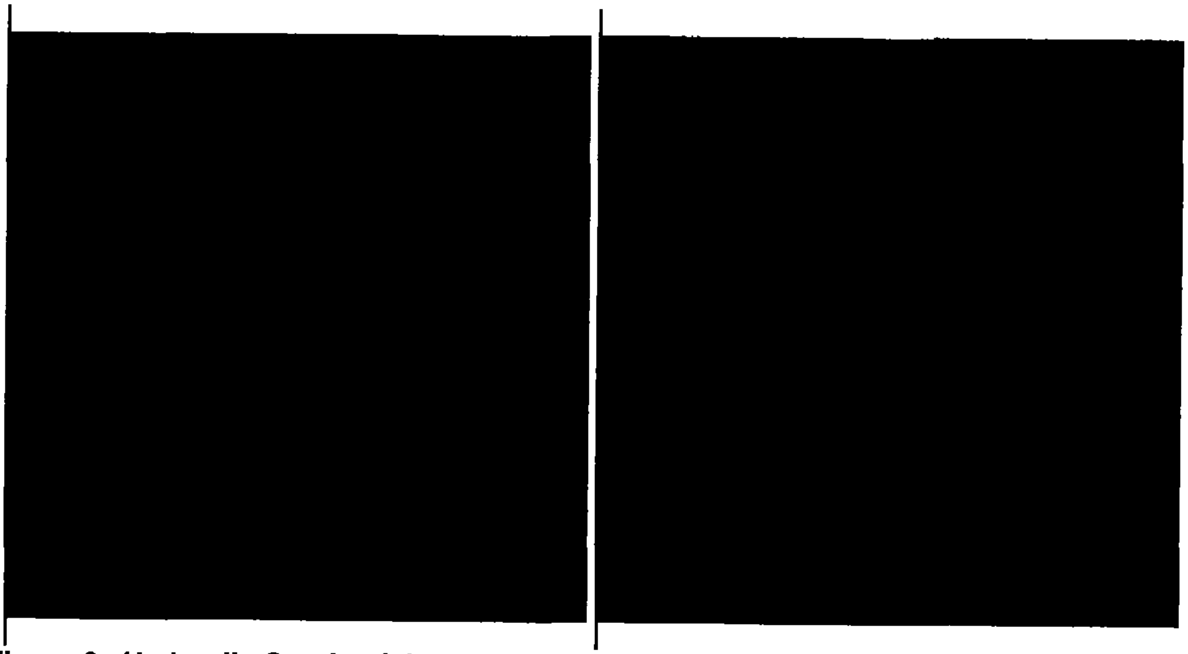

Figure 6. Hydraulic Conductivity Zones Applied to (a) Layer 12 and (b) Layers 11 and 13-20 of the Low-Permeability Bedrock Sensitivity Analysis (PW-BH)

3.2 Sensitivity Analysis Results

The results of the five sensitivity analyses are summarized in Table 6, which presents the maximum and minimum hydraulic gradients at three disposal cells and across the site as a percentage of the steady-state hydraulic gradient. Values less than 100% indicates that gradients decreased from the steady-state (pre-pumping) simulation, while values greater than 100% indicate increases in hydraulic gradient. None of the sensitivity analyses resulted in higher gradients during pumping than those than modeled in the steady-state. After pumping, however, hydraulic gradients across the 11e.(2) and LARW cells increased very slightly above the pre-pumping gradients as water levels rebounded more quickly near the pumping well than at a distance. The highest modeled hydraulic gradient was 100.31% during the post pumping period in the PW-LG simulation. In no case did the modeled gradients exceed the allowable limits specified in the GWQDP.

Table 6. Summary of Model-Calculated Hydraulic Gradients (% of Starting Gradient)

Model Run (File Name)	Minimum Gradient Across 11e.(2) Cell	Minimum Gradient Across LARW Cell	Minimum Gradient Across Mixed Waste Cell	Minimum Gradient Across Site
Model20	96.10%	98.66%	99.22%	99.48%
PW-6F	95.99%	98.61%	99.19%	99.46%
PW-ST	96.17%	98.70%	99.25%	99.50%
PW-LG	95.63%	98.50%	99.13%	99.41%
PW-HG	96.40%	98.77%	99.29%	99.52%
PW-BH	85.29%	92.01%	93.59%	93.55%
Model Run (File Name)	**Maximum Gradient Across 11e.(2) Cell**	**Maximum Gradient Across LARW Cell**	**Maximum Gradient Across Mixed Waste Cell**	**Maximum Gradient Across Site**
Model20	100.27%	100.04%	100.00%	100.00%
PW-6F	100.29%	100.04%	100.00%	100.00%
PW-ST	100.29%	100.04%	100.00%	100.00%
PW-LG	100.31%	100.04%	100.00%	100.00%
PW-HG	100.25%	100.03%	100.00%	100.00%
PW-BH	98.39%	98.33%	100.00%	100.00%

3.2.1 Sensitivity Analysis PW-6F Results

Sensitivity analysis PW-6F evaluated a 600-ft thick aquifer, which is 60% of the thickness used in the base case model. The flow field simulated by the PW-HG sensitivity analysis model was nearly identical to the Base Case model.

The hydraulic gradients decrease during pumping, as in the base case, and the reductions in gradient are slightly greater than in the base case (Model20) simulation. The hydraulic gradients across the site and across the individual disposal cells are shown in Figure 7.

Drawdown at the water table and in the pumping zone is shown in Table 7. The maximum drawdown at the water table in Year 20 of the PW-6F sensitivity analysis was 0.774 ft, which is 3.75% higher than in the Base Case (0.746 ft.) Maximum drawdown in the pumping zone (Layer 12) was 3.114 ft, which is 3.28% greater than in the Base Case.

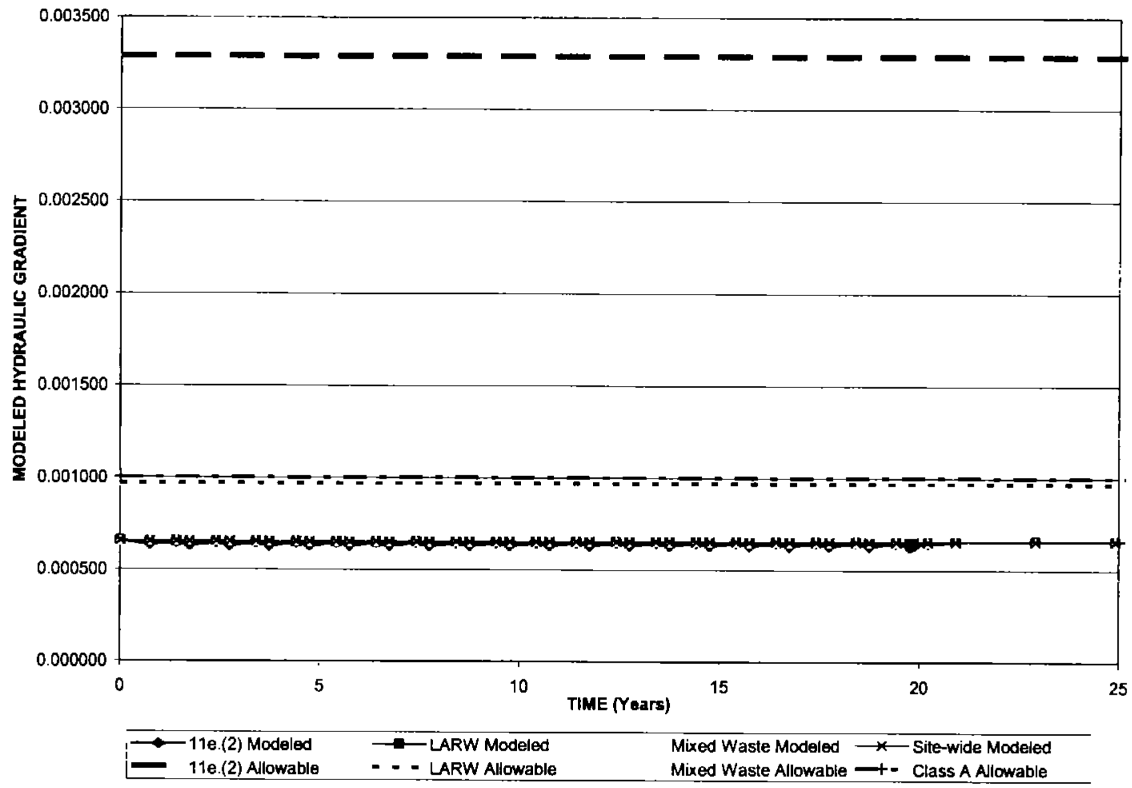

Figure 7. Changes in Site Hydraulic Gradients Over Time – Thinner Aquifer Sensitivity Analysis (Model Run PW-6F)

Table 7. Maximum Drawdown at Pumping Wells – 600-Ft Thick Aquifer Sensitivity Analysis (Model Run PW-6F)

Well	Zone	Maximum Drawdown (ft)
Section 29 Well	Water Table (Layer 1)	0.774
Section 29 Well	Pumping Zone (Layer 12)	3.100
Southwest Pond Well	Water Table (Layer 1)	0.772
Southwest Pond Well	Pumping Zone (Layer 12)	3.114

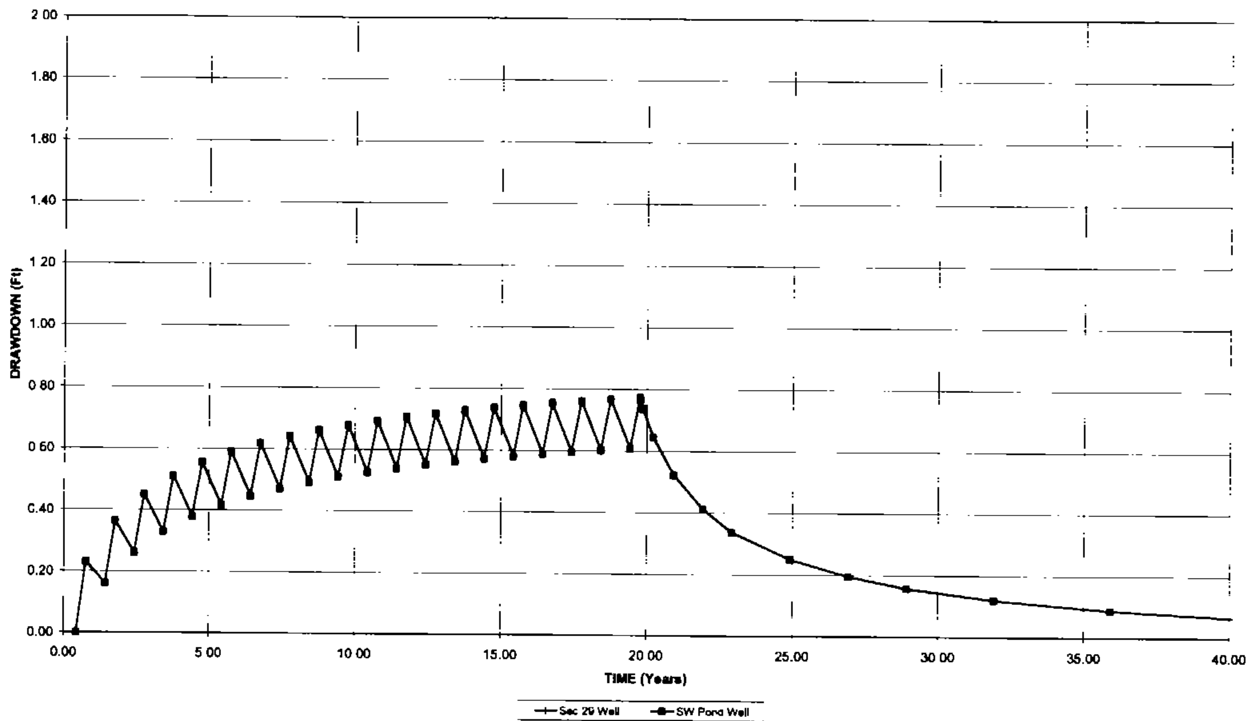

Figure 8. Drawdown and Water Level Recovery in the Shallow Aquifer – Thinner Aquifer Sensitivity Analysis (Model Run PW-6F)

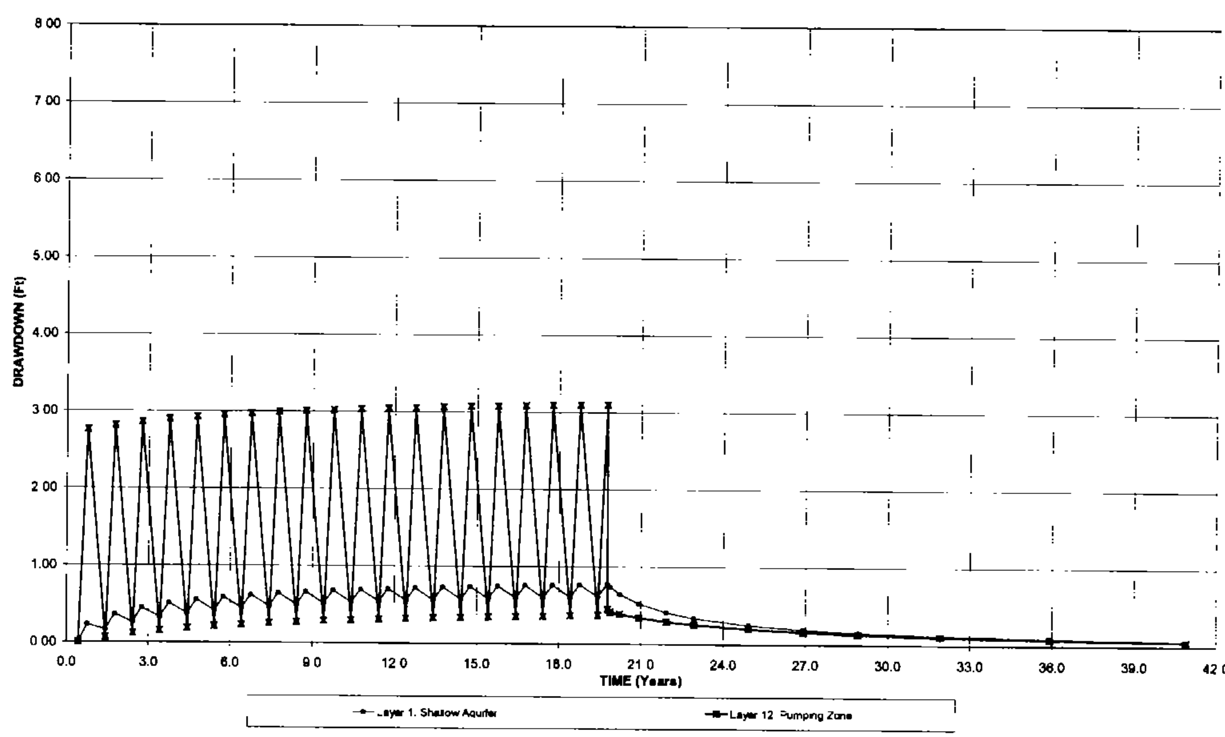

Figure 9. Drawdown and Water Level Recovery in the Pumping Well Zone – Thinner Aquifer Sensitivity Analysis (Model Run PW-6F)

3.2.2 Sensitivity Analysis PW-ST Results

Sensitivity analysis PW-ST evaluated higher storage coefficients. Storage values were 8.2 times (Layer 12), 30.4 times (Layers 2-11 and 13-20) and 114 times (Layer 1) the values used in the base case model. The flow field simulated by the PW-ST sensitivity analysis model was nearly identical to the Base Case model.

The hydraulic gradients decrease during pumping and are the gradient reductions are comparable to those in the Base Case. The hydraulic gradients across the site and across the individual disposal cells in the PW-ST sensitivity analysis are shown in Figure 10.

Drawdown at the water table and in the pumping zone is shown in Table 8. The maximum drawdown at the water table in Year 20 of the PW-ST sensitivity analysis was 0.707 ft, which is 5.2% less than in the Base Case (0.746 ft.) Maximum drawdown in the pumping zone (Layer 12) was 2.92 ft, which is 4.5% less than in the Base Case.

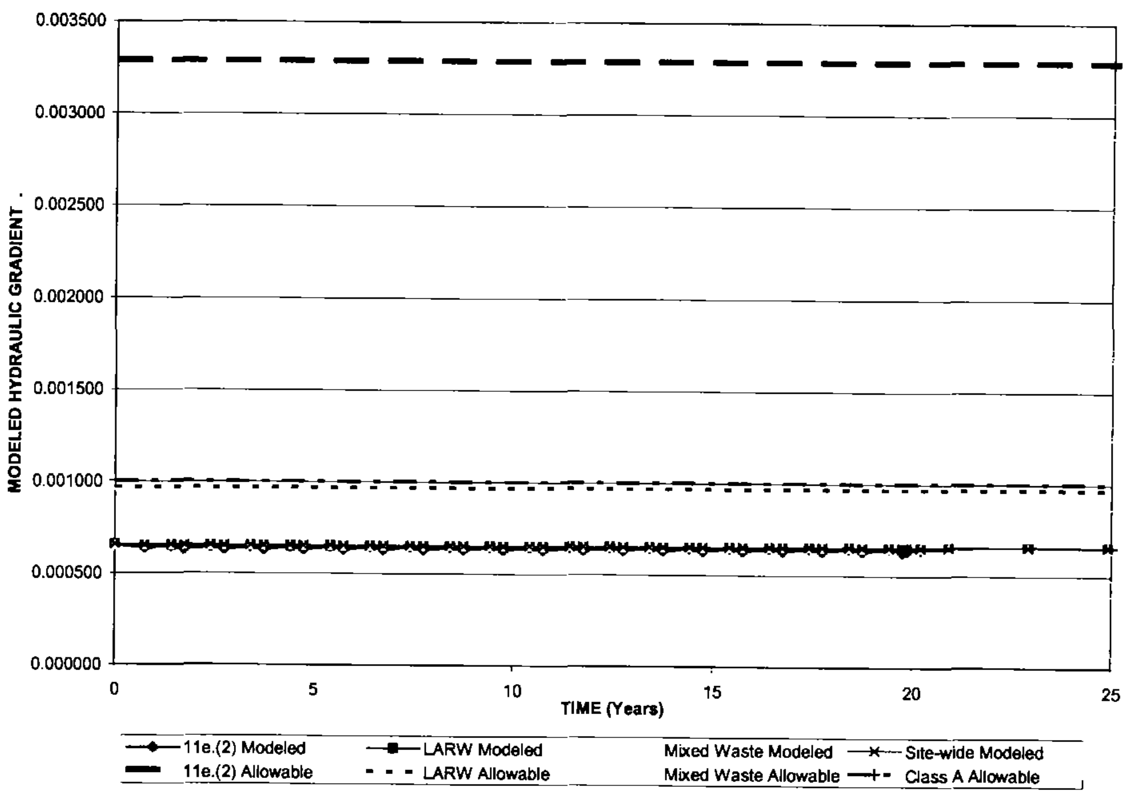

Figure 10. Changes in Site Hydraulic Gradients Over Time – Higher Storage Sensitivity Analysis (Model Run PW-ST)

Table 8. Maximum Drawdown at Pumping Wells – Higher Storativity Sensitivity Analysis (Model Run PW-ST)

Well	Zone	Maximum Drawdown (ft)
Section 29 Well	Water Table (Layer 1)	0.707
Section 29 Well	Pumping Zone (Layer 12)	2.907
Southwest Pond Well	Water Table (Layer 1)	0.705
Southwest Pond Well	Pumping Zone (Layer 12)	2.921

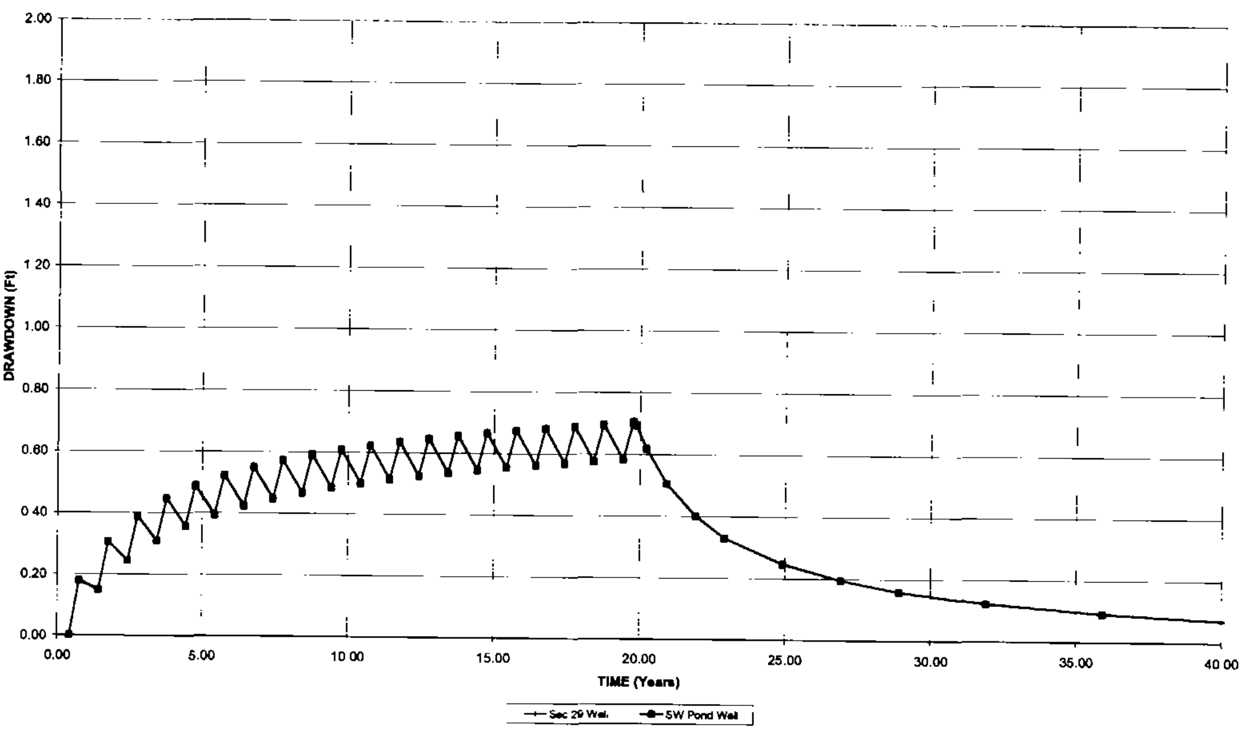

Figure 11. Drawdown and Water Level Recovery in the Shallow Aquifer – Higher Storage Sensitivity Analysis (Model Run PW-ST)

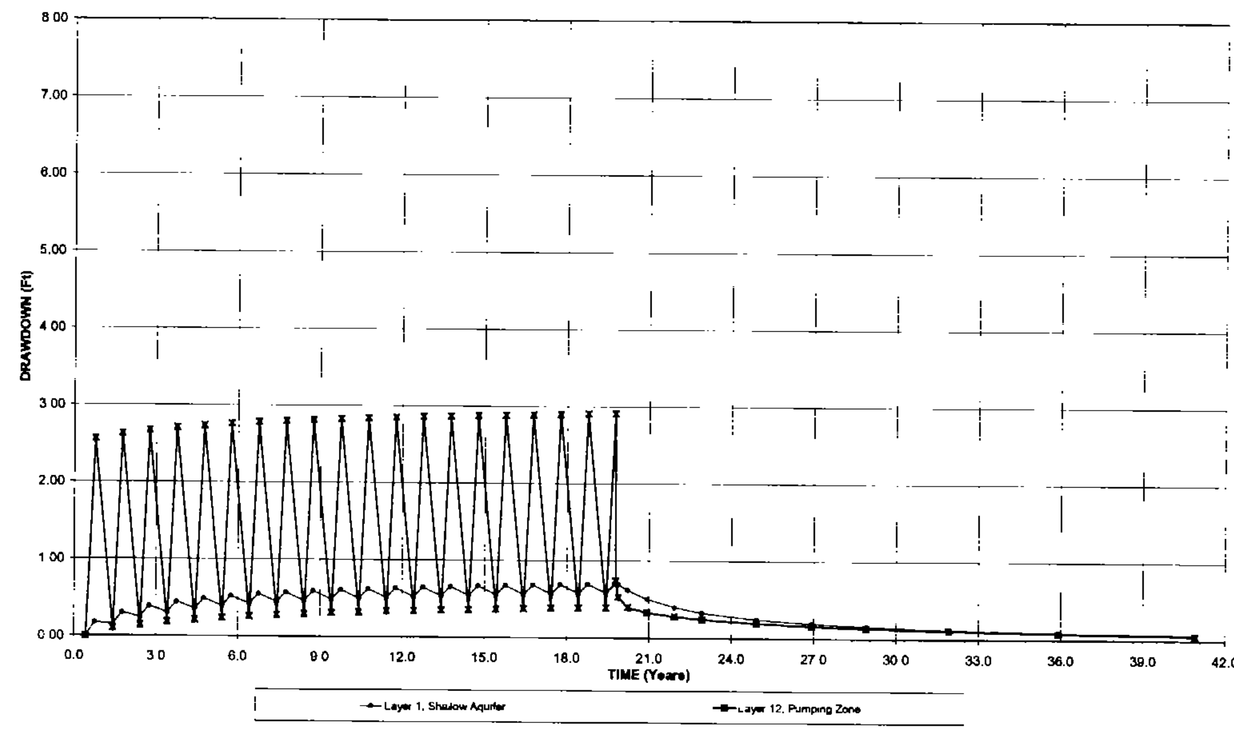

Figure 12. Drawdown and Water Level Recovery in the Pumping Well Zone – Higher Storage Sensitivity Analysis (Model Run PW-ST)

3.2.3 Sensitivity Analysis PW-LG Results

Sensitivity analysis PW-LG used a lower hydraulic gradient. The gradient in the sensitivity analysis ($5.81x10^{-4}$) was 89% of the value used in the base case model ($6.54x10^{-4}$). The flow field simulated by the PW-LG sensitivity analysis model is nearly identical to the Base Case model

The hydraulic gradients decrease during pumping, and the changes in hydraulic gradients are slightly greater than in the Base Case model results. The hydraulic gradients across the site and across the individual disposal cells are shown in Figure 13.

Drawdown at the water table and in the pumping zone is shown in Table 9. The maximum drawdown at the water table in Year 20 of the PW-LG sensitivity analysis is nearly identical to (and very slightly less than) the Base Case model results.

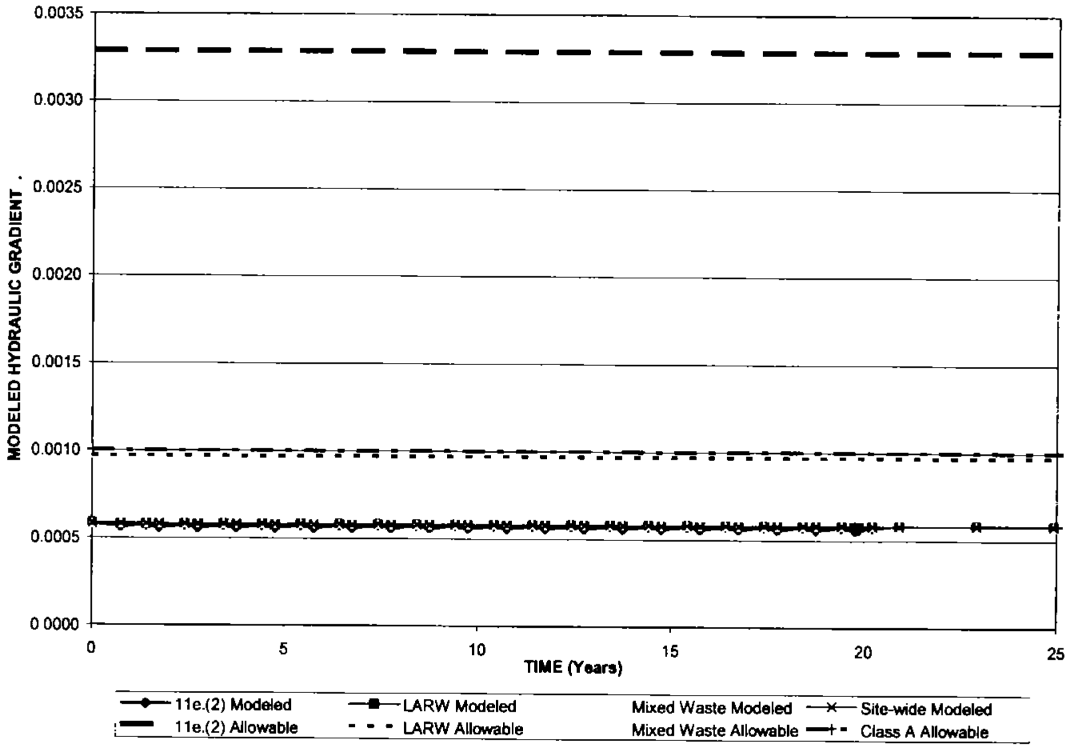

Figure 13. Changes in Site Hydraulic Gradients Over Time – Lower Hydraulic Gradient Sensitivity Analysis (Model Run PW-LG)

Table 9. Maximum Drawdown at Pumping Wells – Lower Hydraulic Gradient Sensitivity Analysis (Model Run PW-LG)

Well	Zone	Maximum Drawdown (ft)
Section 29 Well	Water Table (Layer 1)	0.745
Section 29 Well	Pumping Zone (Layer 12)	3.036
Southwest Pond Well	Water Table (Layer 1)	0.744
Southwest Pond Well	Pumping Zone (Layer 12)	3.051

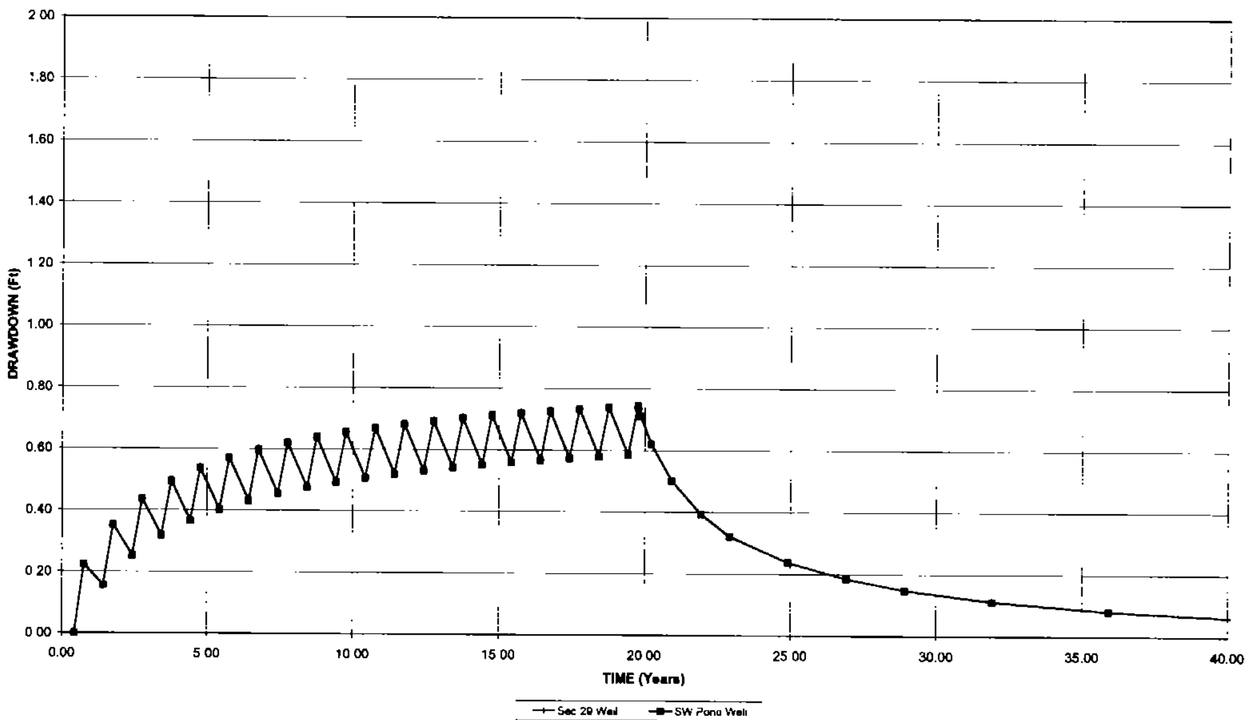

Figure 14. Drawdown and Water Level Recovery in the Shallow Aquifer – Lower Hydraulic Gradient Sensitivity Analysis (Model Run PW-LG)

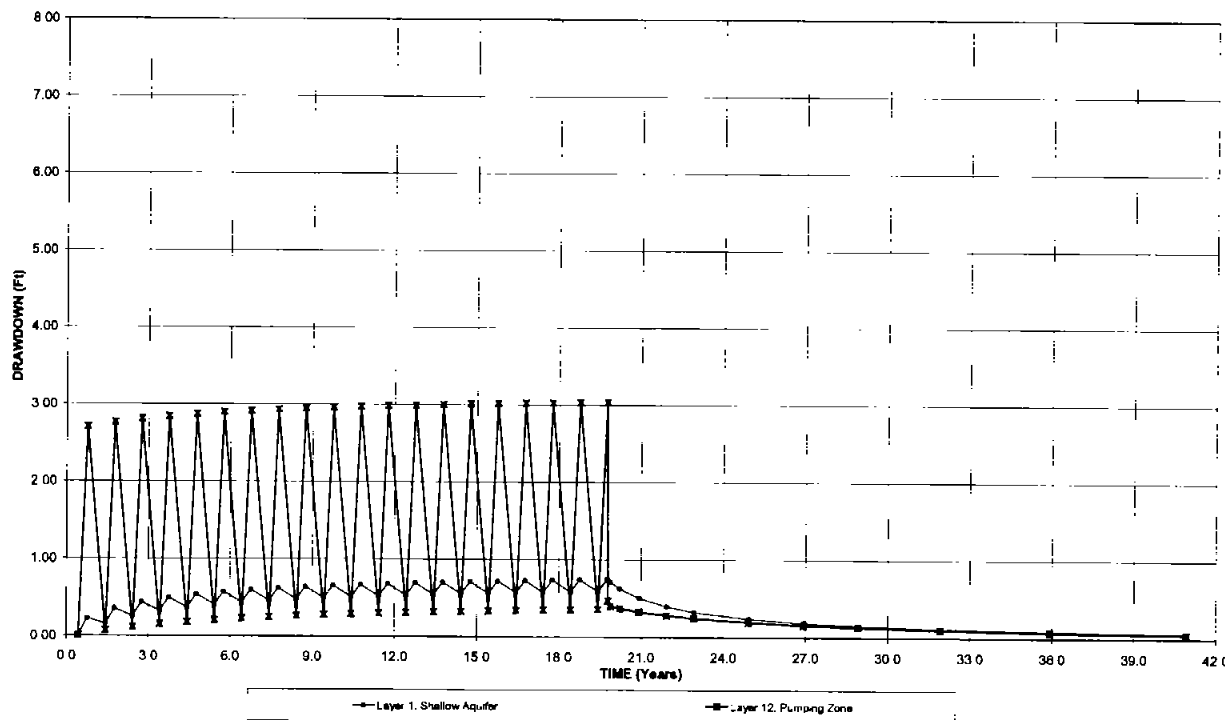

Figure 15. Drawdown and Water Level Recovery in the Pumping Well Zone – Lower Hydraulic Gradient Sensitivity Analysis (Model Run PW-LG)

3.2.4 *Sensitivity Analysis PW-HG Results*

Sensitivity analysis PW-HG used a higher hydraulic gradient. The gradient in the sensitivity analysis (7.12×10^{-4}) was 109% of the value used in the base case model (6.54×10^{-4}). The flow field simulated by the PW-HG sensitivity analysis model is nearly identical to the Base Case model.

The hydraulic gradients decrease during pumping, as in the base case, and the reductions in gradient are slightly less than in the base case (Model20) simulation. The hydraulic gradients across the site and across the individual disposal cells are shown in Figure 16.

Drawdown at the water table and in the pumping zone is shown in Table 10. The maximum drawdown at the water table in Year 20 of the PW-LG sensitivity analysis is nearly identical to (and very slightly greater than) the Base Case model results.

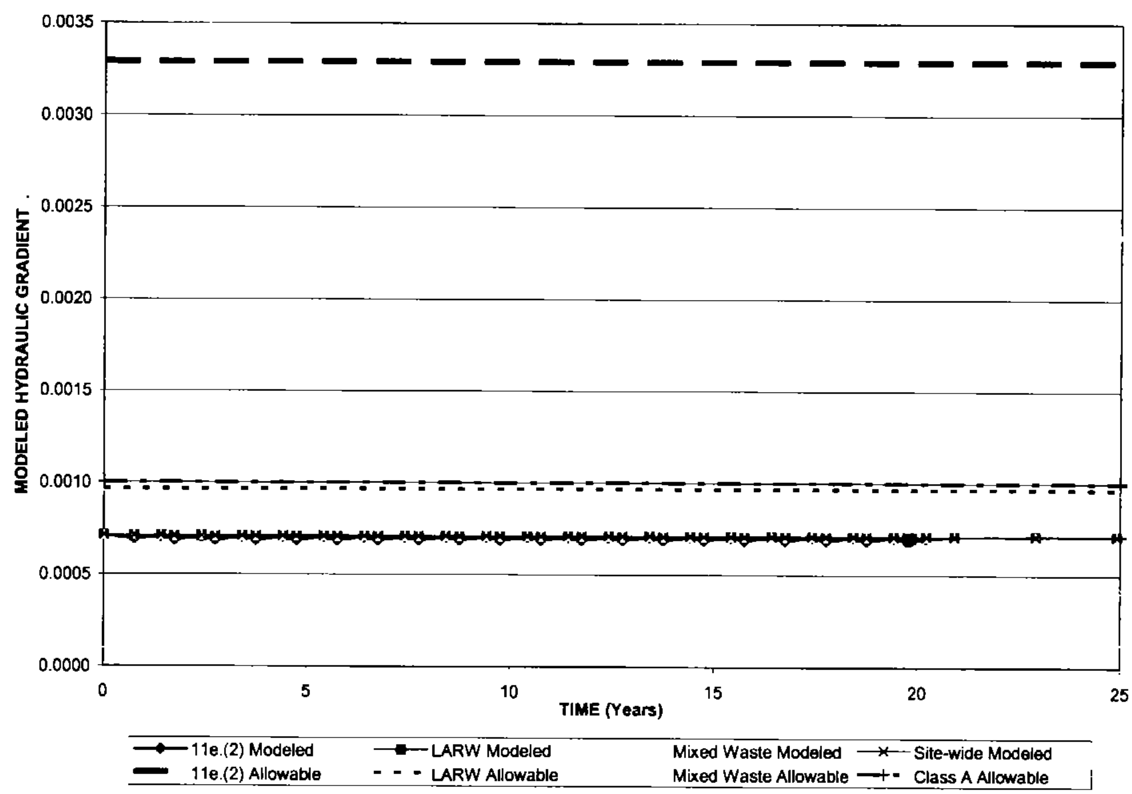

Figure 16. Changes in Site Hydraulic Gradients Over Time – Higher Hydraulic Gradient Sensitivity Analysis (Model Run PW-HG)

Table 10. Maximum Drawdown at Pumping Wells – Higher Hydraulic Gradient Sensitivity Analysis (Model Run PW-HG)

Well	Zone	Maximum Drawdown (ft)
Section 29 Well	Water Table (Layer 1)	0.747
Section 29 Well	Pumping Zone (Layer 12)	3.037
Southwest Pond Well	Water Table (Layer 1)	0.745
Southwest Pond Well	Pumping Zone (Layer 12)	3.051

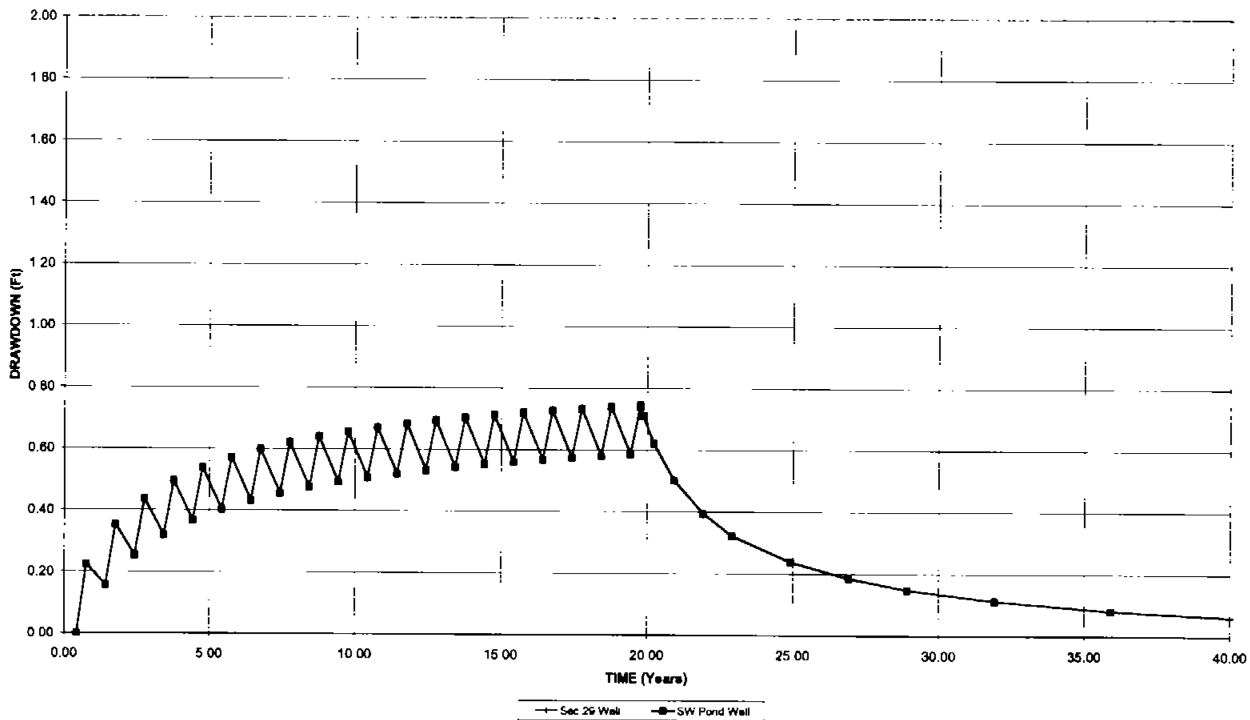

Figure 17. Drawdown and Water Level Recovery in the Shallow Aquifer – Higher Hydraulic Gradient Sensitivity Analysis (Model Run PW-HG)

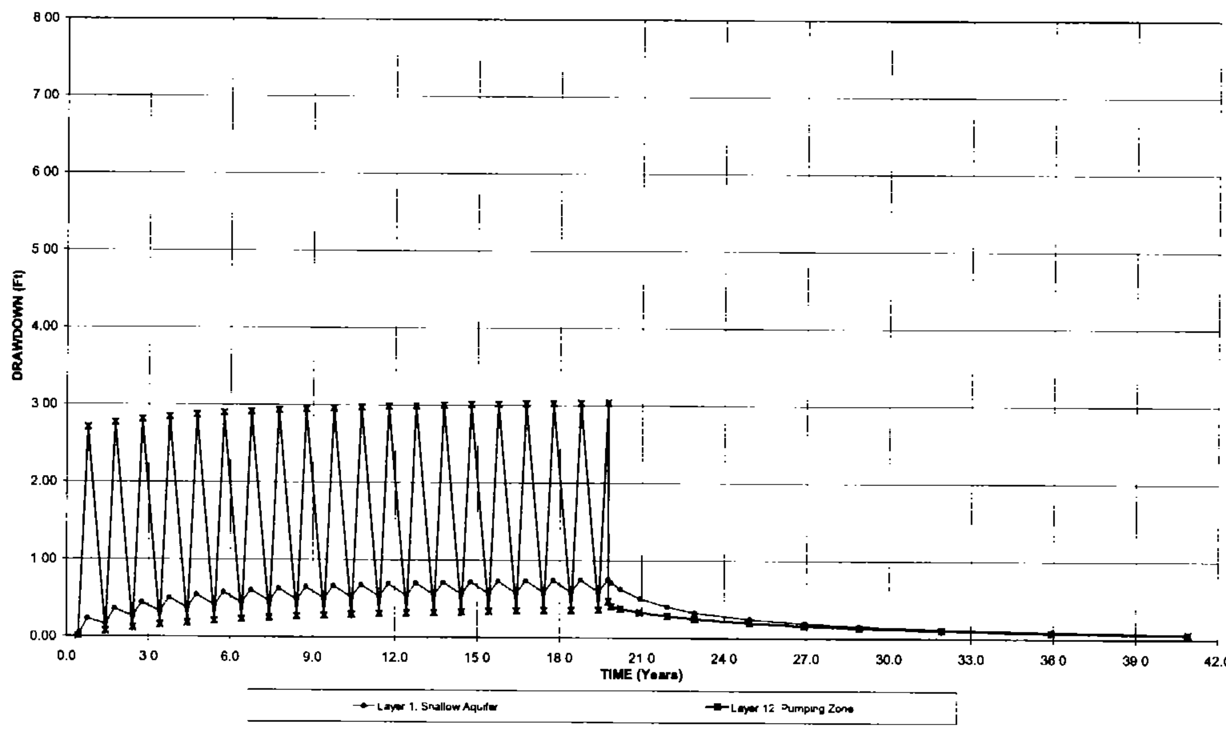

Figure 18. Drawdown and Water Level Recovery in the Pumping Well Zone – Higher Hydraulic Gradient Sensitivity Analysis (Model Run PW-HG)

3.2.5 Sensitivity Analysis PW-BH Results

Sensitivity analysis PW-BH evaluated the effects of two bedrock ridges, which were was assumed to have a hydraulic conductivity ten times lower than that of the lacustrine sedimentary deposits. Although the conceptual hydrologic model of the regional aquifer (described in the main body of this report) indicates that the bedrock and alluvium act as a single hydrologic unit (DWR, 2001; Gates, 1987), the sensitivity analysis assumes that the bedrock transmits very little water.

The flow field simulated by the PW-BH sensitivity analysis model was very different from the Base Case model, because the bedrock ridges significantly influence the flow field east and west of the site (Figure 19). Near the Envirocare facility, the modeled flow field is more similar to the Base Case model, with a site-wide hydraulic gradient of $2.8x10^{-4}$ in the steady-state PW-BH simulation compared to $6.54x10^{-4}$ in the base case model.

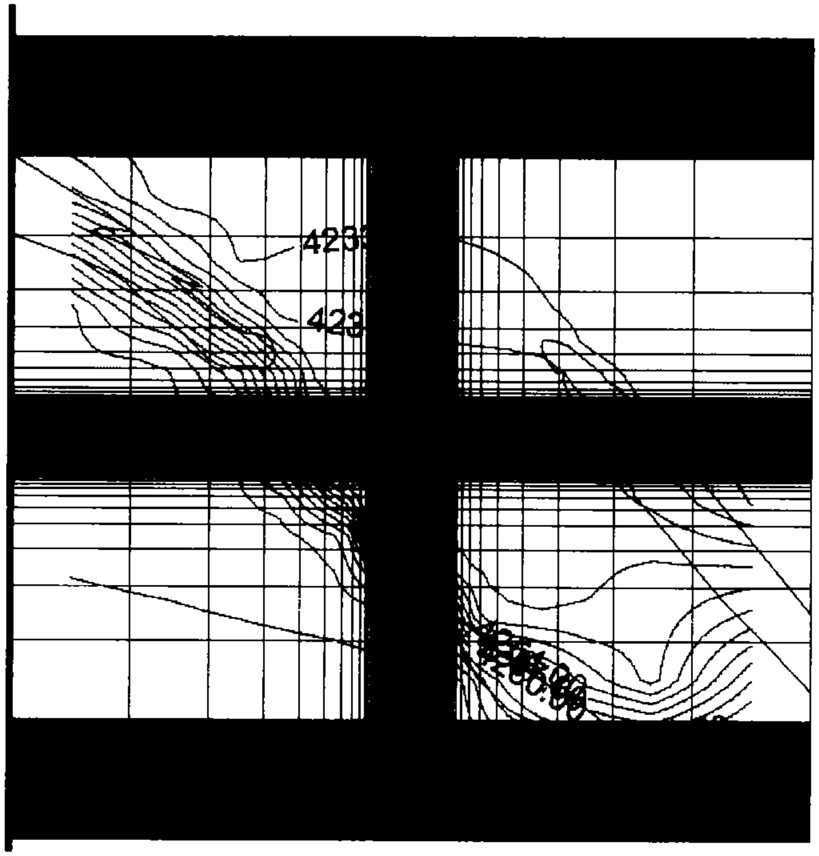

Figure 19. Steady-State Water Table Contours – Model Run PW-BH

The hydraulic gradients decrease during pumping, more so than in the Base Case. For example, the minimum gradient across the 11e.(2) cell during pumping and recovery was 85% of the steady-state calculated gradient. The minimum gradient across the site was approximately 94%, compared to 99.5% in the Base Case simulation. The hydraulic gradients across the site and across the individual disposal cells in the PW-BH sensitivity analysis are shown in Figure 20.

Drawdown at the water table and in the pumping zone is shown in Table 11. The maximum drawdown at the water table in Year 20 of the PW-BH sensitivity analysis was 1.2 ft, which is 61% higher than in the Base Case (0.746 ft.) Maximum drawdown in the pumping zone (Layer 12) was 3.581 ft, which is 17% greater than in the Base Case.

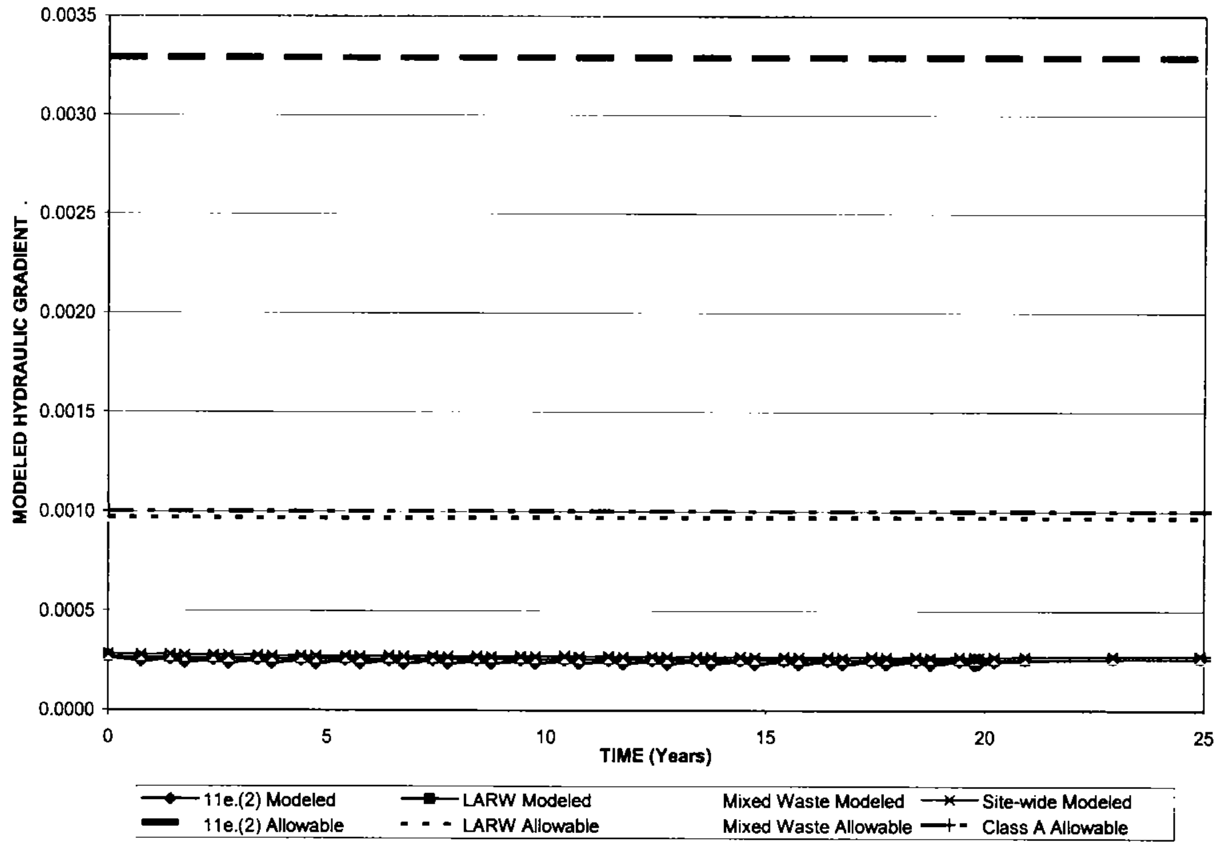

Figure 20. Changes in Site Hydraulic Gradients Over Time – Low-Permeability Bedrock Ridge Sensitivity Analysis (Model Run PW-BH)

Table 11. Maximum Drawdown at Pumping Wells – Low-Permeability Bedrock Ridge Sensitivity Analysis (Model Run PW-BH)

Well	Zone	Maximum Drawdown (ft)
Section 29 Well	Water Table (Layer 1)	1.100
Section 29 Well	Pumping Zone (Layer 12)	3.436
Southwest Pond Well	Water Table (Layer 1)	1.198
Southwest Pond Well	Pumping Zone (Layer 12)	3.581

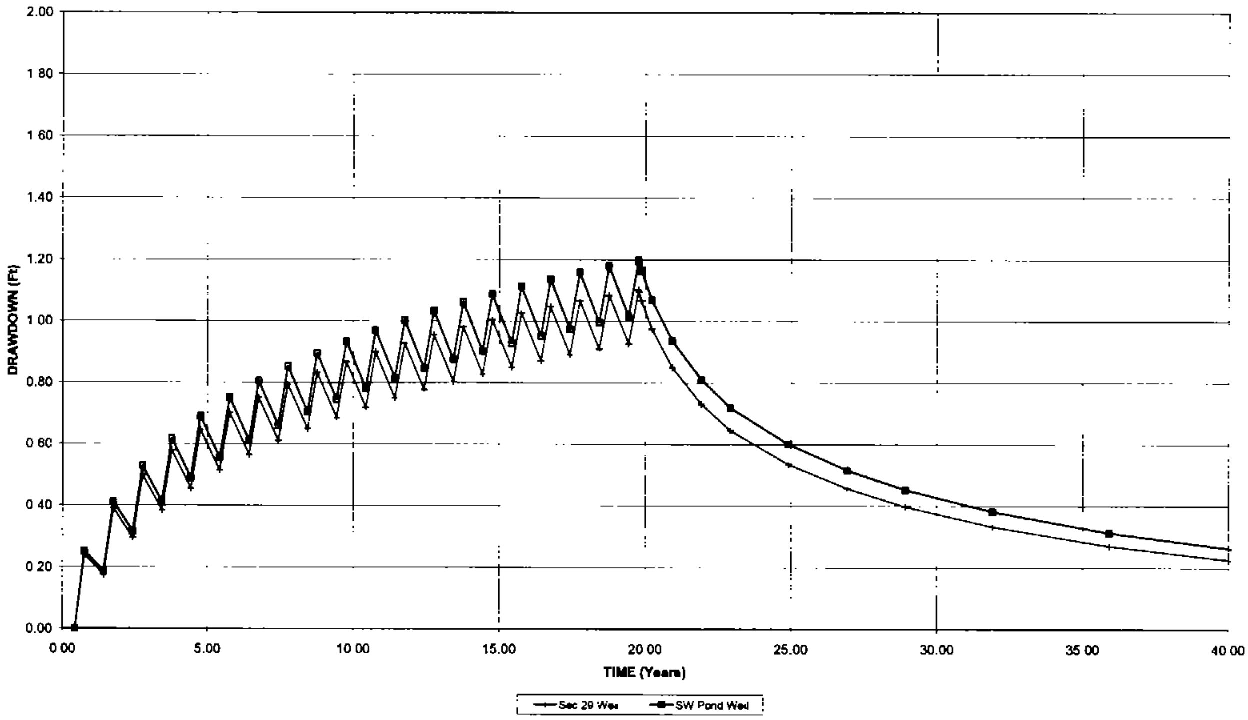

Figure 21. Drawdown and Water Level Recovery in the Shallow Aquifer – Low-Permeability Bedrock Ridge Sensitivity Analysis (Model Run PW-BH)

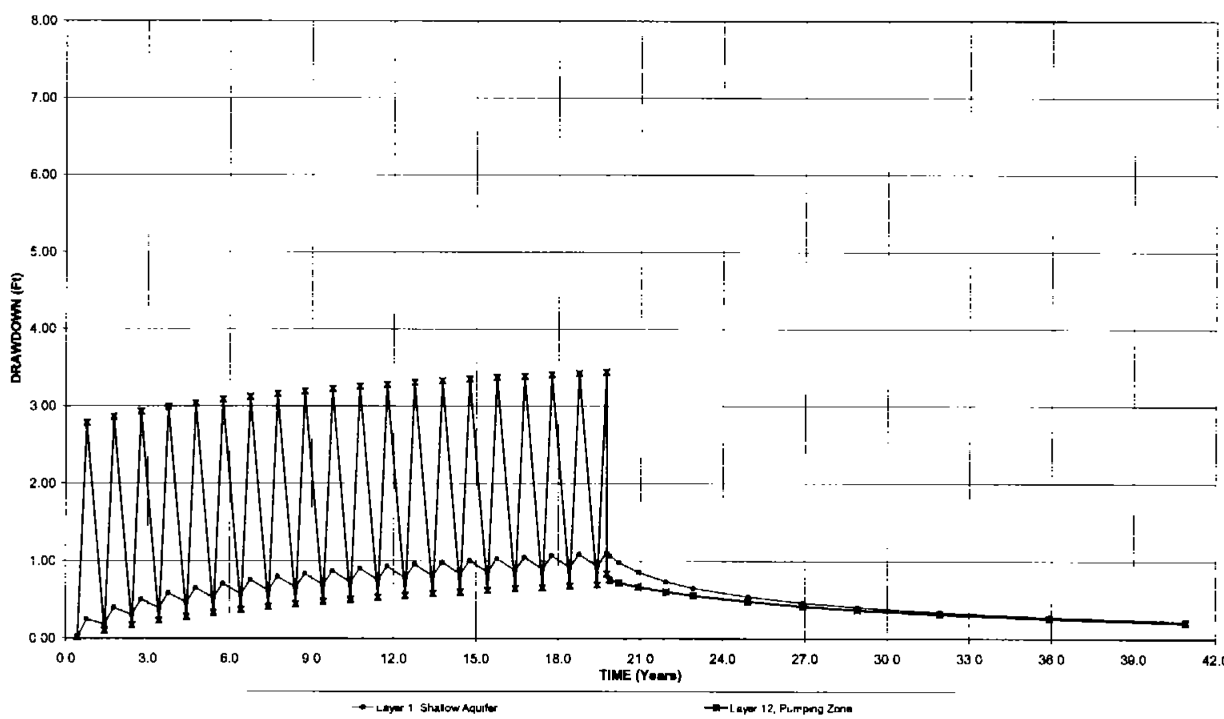

Figure 22. Drawdown and Water Level Recovery in the Pumping Well Zone – Low-Permeability Bedrock Ridge Sensitivity Analysis (Model Run PW-BH)

4. CONCLUSIONS

The results of the sensitivity analysis for the Envirocare Pumping Well Model indicate that changes in aquifer thickness, storage, hydraulic gradient have slight affects on the model results. Hydraulic gradients decrease during pumping in the Base Case and in all sensitivity analyses, in response to pumping from two wells at a depth of 550 feet below ground surface at a combined rate of 400 gpm for 4 months per year for 20 years. The flow direction in the shallow aquifer, however, would not reverse. The reduction in gradient would slow the rate of transport of constituents in the aquifer downgradient of the site for the period of pumping and for an additional 10 years of water level recovery. Approximately 20 years after pumping, the water levels would be almost fully recovered and the flow field and transport rates would return to the normal (pre-pumping) condition in all sensitivity analysis cases.

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APPENDIX C
MODFLOW MODEL
INPUT AND OUTPUT FILES (CDs)

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