BECHTEL SAIC COMPANY, LLC

QA: N/A

February 20, 2002

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CONTRACT NO. DE-AC08-01RW12101 – DOCUMENTS FOR TRANSMITTAL TO THE U. S. NUCLEAR REGULATORY COMMISSION (NRC)

In an e-mail request from Dr. David Esh, NRC, to Veronica Cornell, Bechtel SAIC Company, LLC, dated February 4, 2002, the NRC requested copies of the enclosed documents.

We are ready to assist you in any way that will be beneficial to the Project. Please contact Veronica Cornell at (702) 295-5342 for any additional information you may require.

Nancy H. Williams
Manager of Projects

2-19-02
Date Signed

VC:cg – 0214021485

Enclosures:
1. FEHM Version 2.10, REV01, Validation Test Report 10086-VTR-2.10-01
2. GoldSim Version 6.03, Validation Test Report 10344-VTR-6.03-00
3. INFIL Version 2.0, Validation Test Report 10307-VTR-2.0-00
4. INFIL Version A2.a1, Validation Test Report 10253-VTR-A2.a1.00
5. TOUGHREACT Version 2.3, Software Baseline Request 10396-2.3-00
6. TOUGHREACT Version 2.4, Validation Test Report 10396-VTR-2.4-00

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David Esh <DWE@nrc.gov> on 01/30/2002 07:53:47 AM

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Subject: MOL's

Federal Record Status Not Determined

Veronica,

I am looking for the MOL's (or documents) for the validation test reports (VTR's) for the following software routines referenced in the software impact assessment report:

FEHM Version 2.10
GoldSim Version 6.03
INFIL Version 2.0
TOUGHREACT Version 2.3

Thanks for your time.

Regards,

Dave

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COPY WBS: 1.2.5.4
QA: QA

Civilian Radioactive Waste Management System
Management & Operating Contractor

GoldSim Version 6.03

VALIDATION TEST REPORT

Software Document Number: ~~**10344-SAP-6.03-00**~~ 10344-VTR-6.03-00 (2) 9/21/01

Software Media Number: 10344-PC-6.03-00

Software Tracking Number: 10344-6.03-00

Software Activity Number: LV-2001-155

September 2001

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Civilian Radioactive Waste Management System

Civilian Radioactive Waste Management System
Management & Operating Contractor
GoldSim Version 6.03

VALIDATION TEST REPORT

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Software Tracking Number: 10344-6.03-00

Software Activity Number: LV-2001-155

September 2001

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9/21/2001
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CHANGE HISTORY

Revision Number	Effective Date	Description of Change
00	9/14/01	Initial issue

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1 SOFTWARE IDENTIFICATION

Software GoldSim Version 6.03
Operating Platform PC
Operating System Windows NT Version 4.0

2 VALIDATION TESTER

The validation tester was Norm Graves. The validation tests were conducted in Las Vegas in November 2000.

3 SPECIAL TOOLS AND EQUIPMENT

No special tools or equipment were needed to install the code and run the tests. The software was installed on a network PC, CPU Number 117181, with the Windows NT Version 4.0 operating system.

4 TEST RESULTS LINKED TO THE UNIQUE TEST IDENTIFIER FROM THE VTP

Each test case that follows is uniquely identified and correlated to its associated test case in the VTP.

5 DOCUMENTATION OF ITP AND VTP

5.1 INTRODUCTION

GoldSim is a probabilistic software program that is designed to simulate the release, transport and fate of contaminates in environmental and engineered systems. GoldSim is an update of the Repository Integration Program (RIP) which was used by the Performance Assessment group to evaluate the performance of a potential nuclear waste repository at Yucca Mountain. GoldSim now has a highly graphical user interface and several added features. The *Validation Test Plan for GoldSim Version 6.04.007* describes the validation process.

5.2 ITP DOCUMENTATION

The Installation Test Plan specifies the use of the vendor's User's Manual for installation instructions and an installation test case. The installation instructions in the GoldSim User's Manual (Golder 2000a, Section 1) were followed, and there were no problems encountered during the installation. The installation test problem that was provided with the software was run as described in the User's Manual. The result, shown in Figure 1, is the same as that given in the User's Manual and indicates GoldSim was installed correctly.

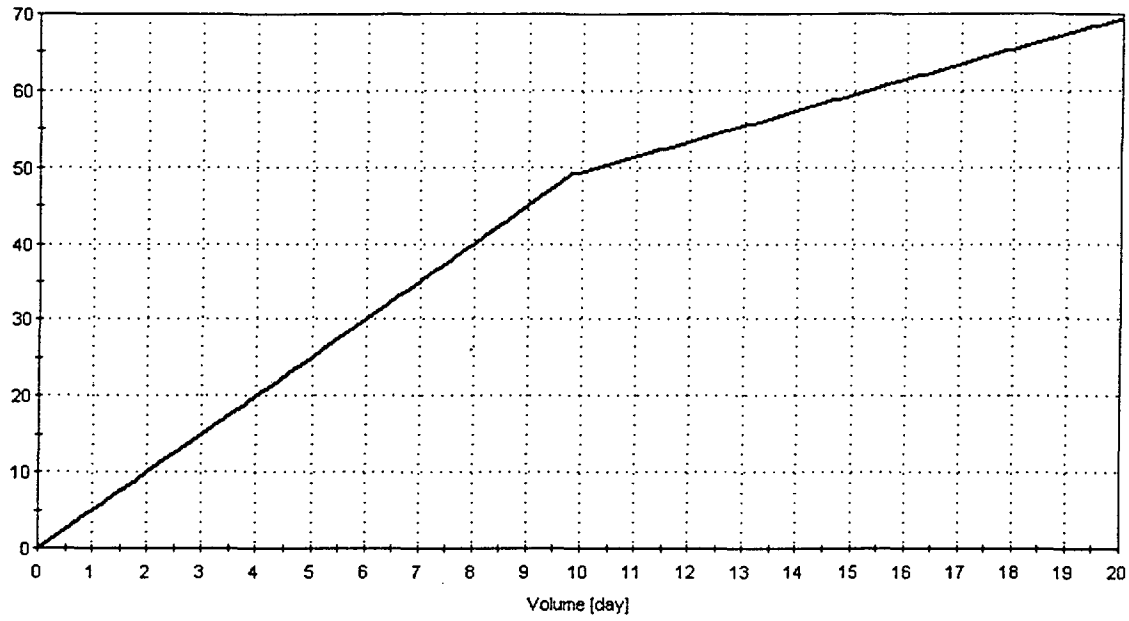

Figure 1. Result of the GoldSim version 6.03 installation test problem.

All validation tests were executed on CPU 117181. The workstation uses the Windows NT 4.0 operating system.

5.3 VTP DOCUMENTATION

The steps to be used for validating GoldSim are delineated in the Validation Test Plan (VTP) for GoldSim Version 6.04.007. The VTP provides six tests that test various capabilities of the software; these tests are designated in the following subsections as Tests 1 through 6. The VTP also instructs the validation tester to select additional tests from those provided by the vendor. The tests selected from those supplied from the vendor should test the functions that were not tested in the six VTP tests. Those functions not tested by the six VTP tests are listed in the VTP.

The VTP has supplied six independent test cases to test some of the computational requirements of GoldSim. These tests were run as described in the VTP, and the results are documented in the following subsections.

5.3.1 Test 1: Diffusive Transport

This test consists of two cases that are designed to test the requirement that GoldSim simulate diffusive mass transport through partially saturated to fully saturated porous media. The test of diffusive mass transport through a fully saturated porous medium (designated as Test 1, Case 1

in the VTP) was simulated as described in the VTP. The expected result is a mass flux rate of 5.0E-03 grams/year (CRWMS M&O 2000a, Section 4.1.1).

The simulation of Case 1 produced the result shown in Figure 2. As the figure shows, the mass flux rate quickly increases from zero to a steady-state flux of 5.0E-03 grams/year.

The time history result table, given in Attachment I, shows that the flux rate reaches a steady state of 4.995E-3 grams/year. The acceptance criteria defined in the VTP for this test case is +/- 10% (4.5E-03 to 5.5E-05 grams/year). This result is within the acceptance criteria range, and indicates that the program is correctly calculating diffusive mass transport flux rates through a fully saturated medium.

The second case of the diffusive mass transport test (designated as Test 1, Case 2 in the VTP) is transport through a partially saturated medium. The VTP states that the expected result for this case is 6.9347E-5 grams/year (CRWMS M&O 2000a, Section 4.1.1). The acceptance criteria given in the VTP for this result is +/- 10% (6.237E-5 to 7.623E-5 grams/year).

Simulation of Case 2 produced the mass flux curve shown in
Figure 3. The curve shows that the mass flux reaches a steady state at just under 7E-05 grams/year.

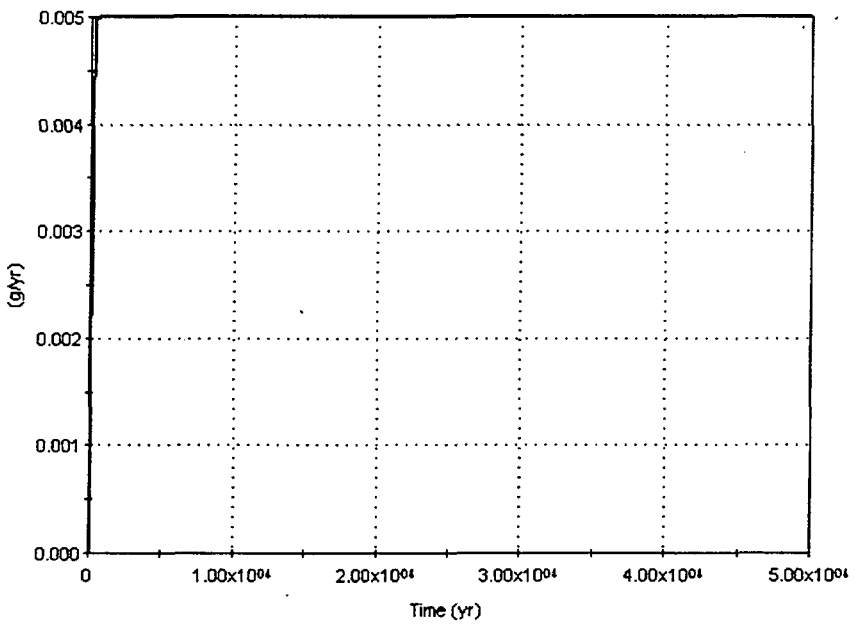

Figure 2. Diffusive mass transport through a fully saturated medium, VTP Test 1, Case 1.

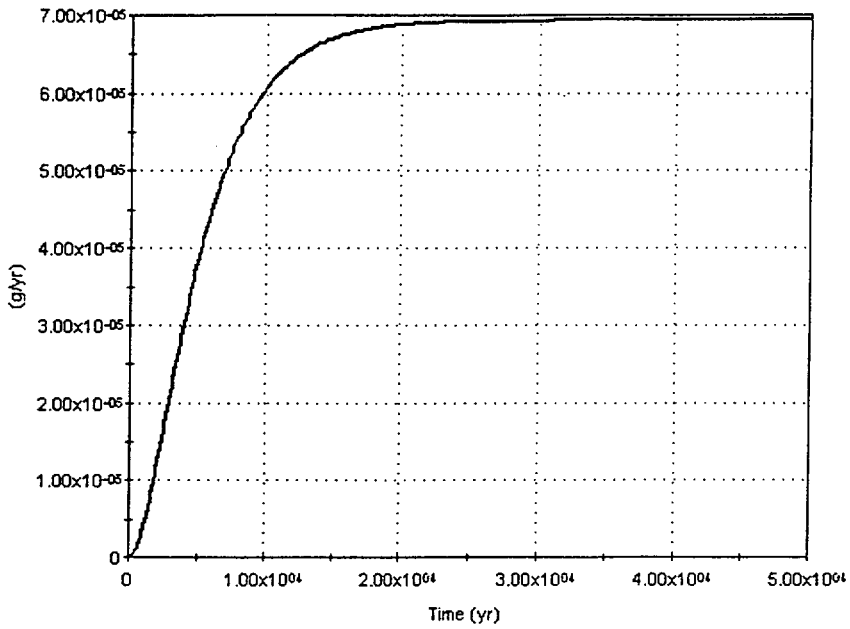

Figure 3. Diffusive mass transport through a partially saturated medium, VTP Test 1, Case 2.

The time history results, given in Attachment I, for Case 2 show that steady state is reached at a mass flux rate of 6.9278E-5 grams/year. The simulation result is within the acceptance criteria range, and this indicates that the program is correctly calculating diffusive mass transport flux rates through a partially saturated medium.

GoldSim passed both cases of VTP Test 1, Diffusive Transport.

Tester's Initials Date 9/14/01

5.3.2 Test 2: Advective Transport

Validation testing of the advective transport capabilities of GoldSim consists of three cases, 1) one-dimensional advection with dispersion, 2) one-dimensional advection with dispersion with the addition of sorbing material within the advective pathway, and 3) advection out of a mixing cell (CRWMS M&O 2000a, Section 4.1.2). The acceptance criterion for all three cases is that the GoldSim results should be within +/- 10% of the expected results (CRWMS M&O 2000a, Section 2.1.2).

The expected results for Case 1, one-dimensional advection with dispersion, are shown in Table 1.

Table 1. Expected Values for Test 2, Case 1: One-dimensional Advection with Dispersion (CRWMS M&O 2000a, Section 4.1.2.1)

Time (years)	Concentration (g/m^3)
500	8.006677
1000	58.52889
1500	87.45247
2000	96.62204
2500	99.12365
3000	99.77509

The results generated by GoldSim for the times shown in Table 1 are given in Table 2. The complete set of GoldSim results is given in Attachment II.

Table 2. GoldSim Results for Test 2, Case 1: One-dimensional Advection with Dispersion

Time (years)	Conc. (g/m3)	Percent Deviation from Expected
500	7.9626	0.55
1000	58.426	0.18
1500	87.349	0.12
2000	96.521	0.10
2500	99.023	0.10
3000	99.675	0.10

These results are all well within the +/- 10% acceptance criteria set in the VTP. It is concluded from this test that GoldSim can correctly calculate advective transport with dispersion.

Case 2 is similar to Case 1 with the addition of a sorbing material. The velocity of the water was increased for this case such that the results for Case 2 would be identical to those of Case 1 (CRWMS M&O 2000a, Section 4.1.2.2). The results generated by GoldSim for this case are given in
Table **3**, and can be compared with the expected results shown in Table 1.

Table 3. GoldSim Results for Test 2, Case 2: One-dimensional Advection with Dispersion and the Addition of a Sorbing Material within the Advective Pathway

Time (years)	Conc. (g/m^3)	Percent Deviation from Expected
500	7.9626	0.55
1000	58.426	0.18
1500	87.349	0.12
2000	96.521	0.10
2500	99.023	0.10

Time (years)	Conc. (g/m^3)	Percent Deviation from Expected
3000	99.676	0.10

The results for Case 2 are all well within the +/- 10% acceptance criteria set in the VTP. It is concluded from this test that GoldSim can correctly calculate advective transport with dispersion through a sorbing material.

The third case tests the advective release from a batch reactor "mixing cell". The expected results for this simulation are given in Table 4.

Table 4. Expected Results for VTP Test 2, Case 3: Advection Out of a Mixing Cell (CRWMS M&O 2000a, Section 4.1.2.3)

Time (years)	Mass in Cell (g)
500	60.653
1000	36.788
2000	13.534
5000	0.674

The results generated by the GoldSim run, shown in **Table 5**, are nearly identical to the expected results (see Attachment II for the full listing of the Case 3 simulation results). Thus, it is concluded that GoldSim can correctly calculate advective release from a batch reactor "mixing cell". GoldSim passed all three cases of Test 2, Advective Transport.

Table 5. GoldSim Results for Test 2, Case 3: Advection Out of a Mixing Cell

Time (years)	Mass in Cell (g)
500	60.653
1000	36.788
2000	13.534
5000	0.6738

GoldSim passed all three cases of Test 2, Advective Transport.

Tester's Initials Date 9/14/01

5.3.3 Test 3: Source Term

This test was designed to test the requirement that GoldSim be capable of simulating a release from three layers of containment – release from a waste matrix, and releases from an inner and an outer barrier (see CRWMS M&O 2000a, Section 4.1.3 for more details).

Source 1 tests the use of the 'inner barrier', which is used to represent the fuel cladding barrier. The inventory is 1.0E+05 g of Species A located outside the waste matrix, but inside the inner barrier. The solubility of Species A is 1 g/m^3. The expected results for unexposed mass at selected times is shown in **Table 6**, and the expected steady-state mass transport of Species A is expected to be 5.0E-03 g/year (CRWMS M&O 2000a, Section 4.1.3.1).

Table 6. Expected Results at Selected Times for VTP Test 3, Source 1: Inner Barrier (CRWMS M&O 2000a, Section 4.1.3.1)

Time (years)	Unexposed Mass (g)
2000	8.0E+04
4000	6.0E+04
6000	4.0E+04
8000	2.0E+04
10000	0.0

The results generated by GoldSim for these selected times are identical to those given in Table 6 above (the results are given in Attachment III). As can be seen in Figure 4, the mass transport rate quickly reaches steady state at about 5.0E-03 grams/year.

The time histories for the mass transport rate, also given in Attachment III, show a steady-state transport rate of 4.995E-03 grams/years. This is well within the +/- 10% acceptance criterion established by the VTP. These results indicate that GoldSim can correctly simulate loss of containment from an 'inner barrier' and the subsequent mass transport rate.

Source 2 was designed to test release from the 'outer barrier'. The outer barrier is used to represent the discrete failure of waste packages. For this validation test, Source 2 contains 10 packages, and each package contains 100 g of Species B. The packages are to fail uniformly from 0 to 10,000 years, refer to CRWMS M&O 2000a, Section 4.1.3.2 for more details. The acceptance criterion for Source 2 is that a single package fails and a pulse of Species B is released at each of the following times: 500, 1500, 2500, 3500, 4500, 5500, 6500, 7500, 8500, and 9500 years (CRWMS M&O 2000a, Section 4.1.3.2).

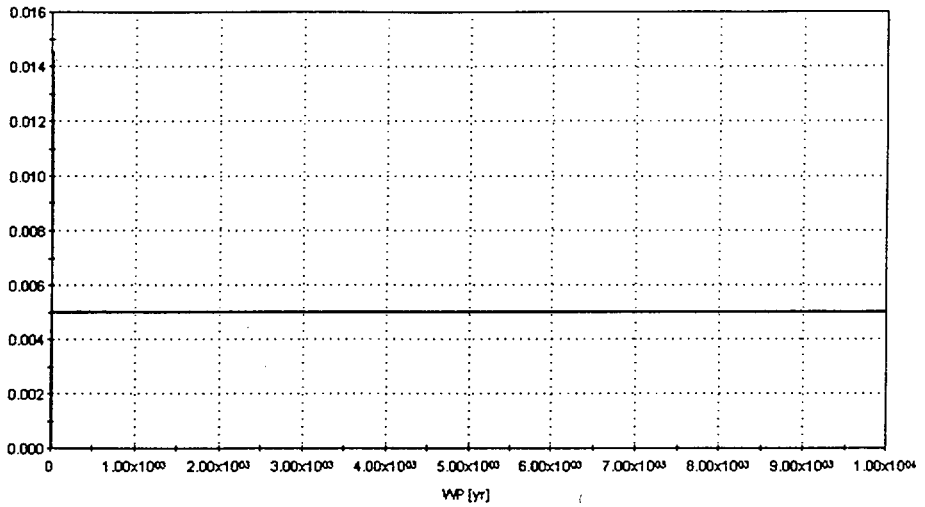

Figure 4. Mass transport rate for Test 3, Source 1.

The results of the GoldSim run for this source are shown in Figure 5. As can be seen from the figure, there are discrete releases at the times expected. The data listing (provided in Attachment III) shows that 10 grams/year of Species B is released for each 10 year time step interval. This result indicates that GoldSim can correctly simulate a release from an outer barrier.

Source 3 was developed to test the matrix degradation of a source term. Source 3 contains a single waste package that has an inventory of 100 grams of Species C within a matrix. A matrix degradation rate of 1.0E-04 per year is defined. Species C is also defined with a decay rate of 1.0E-05 per year. The expect results (CRWMS M&O 2000a, Section 4.1.3.3) are shown in Table 7 along with the results from the GoldSim run (the complete listing of the GoldSim results can be found in Attachment III). The acceptance criterion specified in the VTP is +/- 10%.

Table 7. Comparison of Expected Results with Results Generated in GoldSim, Test 3, Source 3

Time (years)	Unexposed Mass Expected (g)	Unexposed Mass GoldSim (g)	Percent Deviation From Expected
0	100.0	100.0	0.00
100	98.90	99.005	0.11
1000	89.58	89.669	0.10
10000	33.29	33.304	0.04

As can be seen from the table, the GoldSim results are well within the acceptance criteria established in the VTP. This indicates that GoldSim can correctly simulate the release from a matrix. GoldSim passed all three of the cases of Test 3, Source Term.

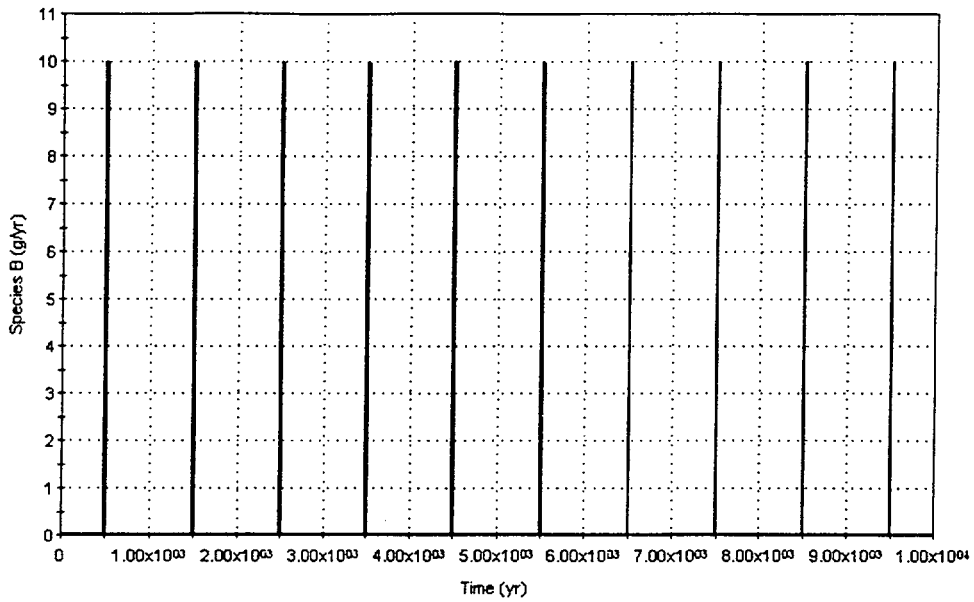

Figure 5. Mass release rate from an outer barrier, Test 3, Source 1.

GoldSim passed all three of the cases of Test 3, Source Term..

Tester's Initials Date 9/14/01

5.3.4 Test 4: Dose Rate

This test was design to test the requirement that GoldSim be able to calculate a dose rate to an individual or a population. This test sums the dose rate from two separate species to give a total dose rate. Species A is defined with the following properties: a decay rate of 3.0E-04 per year, an initial inventory of 100 grams, and a dose conversion factor of 3.0E+03 (rem/year)/(g/m^3). Species B is defined with the following properties: decay rate of 1.0E-03 per year, an initial inventory of 1000 grams, and a dose conversion factor of 5.0E+02 (rem/year)/(g/m^3).

The expected results as given in the VTP (CRWMS M&O 2000a, Section 4.1.4) along with the results generated in GoldSim are given in Table 8. The complete listing of results of the test are given in Attachment IV.

Table 8. Comparison of Expected Results with Results Generated in GoldSim, Test 4

Time (years)	Total Dose Rate Expected (rem/year)	Total Dose Rate GoldSim (rem/year)	Percent Deviation from Expected
0	8.000E+05	8.00E+05	0.00
100	7.435E+05	7.44E+05	0.07
1000	4.062E+05	4.06E+05	0.05

10000	1.495E+04	1.4959E+04	0.06

These results are well within the +/- 10% criterion established for the GoldSim results by the VTP (CRWMS M&O 2000a, Section 4.1.4). These results show that GoldSim can correctly calculate the dose rate to an individual or a population.

GoldSim passed Test 4, Dose Rate.

Tester's Initials Date 9/14/01

5.3.5 Test 5: Stochastic Parameters

VTP Test 5 is used to evaluate the ability of GoldSim to define stochastic parameters and to correlate parameters (CRWMS M&O 2000a, Section 4.1.5). This test consists of two normal distributions that are fully correlated. Distribution "Normal1" is defined with a mean of zero and a standard deviation of one. Distribution "Normal2" is defined with a mean of one and a standard deviation of one. This test simulation was run using random sampling for 100 realizations as described in the VTP. The acceptance criterion specified in the VTP is that the value of "Normal2" be equal to the value of "Normal1" +1 for all 100 realizations. Also, to test the output requirements associated with stochastic parameters and multiple realizations, the following outputs are required by the VTP: 1) a plot of the CDF and CCDF of stochastic parameters, and 2) the ability to save all of the time histories of a parameter to an ASCII file.

Selected simulation results for the correlation of distribution "Normal1" with distribution "Normal2" are shown in Table 9 (the full listing of the results is given in Attachment V).

Table 9. GoldSim Results for Distributions Normal1 and Normal2

Realization	Normal1	Normal2
1	-0.63019	0.36981
25	-1.1797	-0.17968
50	-1.5809	-0.5809
75	0.59879	1.5988
100	0.015646	1.0156

The "Normal2" values are equal to "Normal1" + 1 as expected. The ability of GoldSim to provide CDF and CCDF plots of stochastic parameters is shown in Figure 6 and Figure 7, respectively.

Finally, the last result is the ability of GoldSim to save all of the generated time histories of a parameter to an ASCII file. As described in the VTP (CRWMS M&O 1999a, Section 6.5) an ASCII file was created of the time history results for distribution "Normal3", which is a uniform distribution. The ASCII file of the time histories was created correctly, and is given in Attachment V. GoldSim passed all aspects of VTP Test 5.

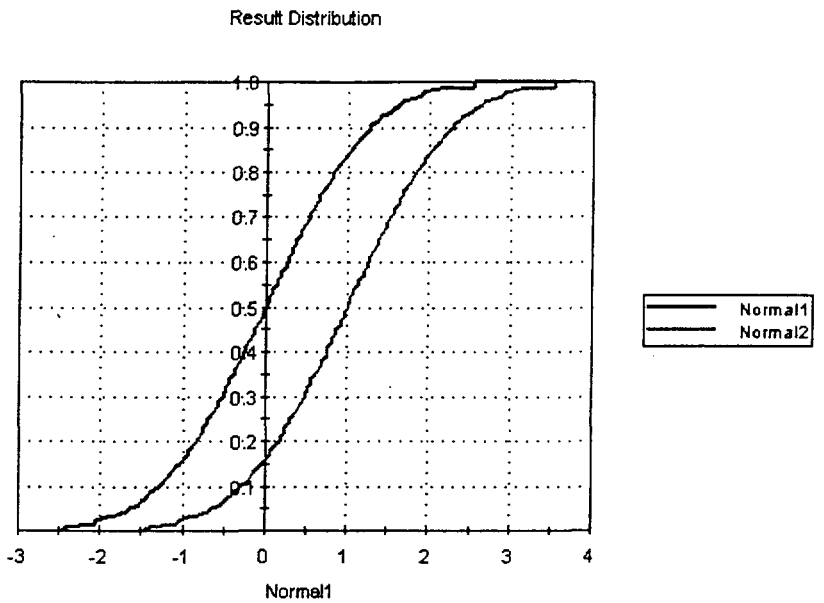

Figure 6. CDF plot of distributions "Normal1" and "Normal2".

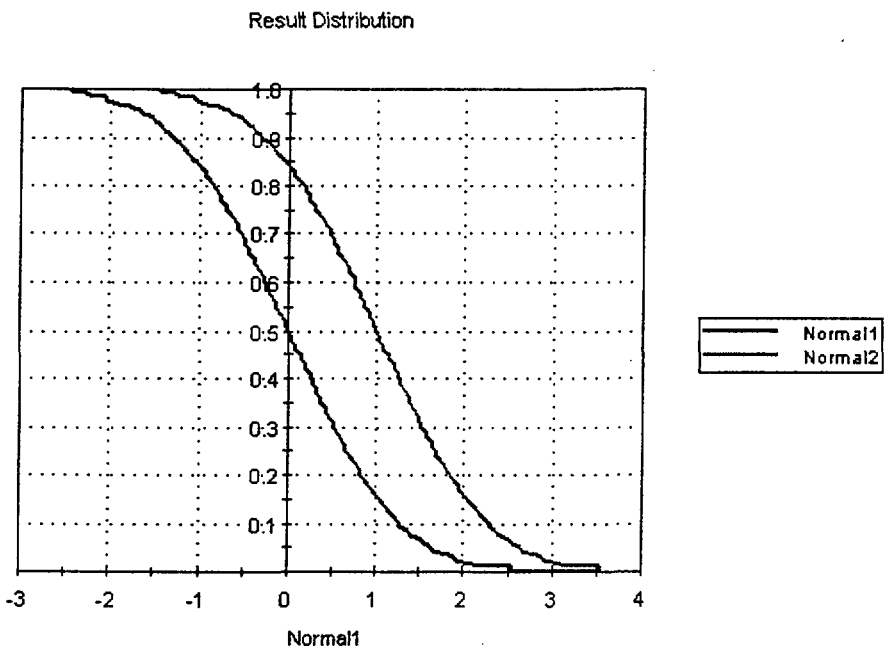

Figure 7. CCDF plot of distributions "Normal1" and "Normal2".

GoldSim passed Test 5.

Tester's Initials Date 9/14/01

5.3.6 Test 6: Loading Values from a Database

This test was designed to evaluate the requirement that GoldSim be able to load values from a database. A Microsoft Access database was created for this test (CRWMS M&O 2000a, Section 4.1.6). GoldSim is to read from the database a constant value, a distribution, a one-dimensional table, and a two-dimensional table. The constant value to be read from the database is the "Area of the Repository Region 1", which is 429314 m^2. The distribution to be read from the database is a uniform distribution that corresponds to the CSNF zircaloy corrosion cladding failure, with a minimum equal to zero meters, and a maximum equal to 1 meter. The one-dimensional table gives the mean seepage fraction in LTA region 1, and the two-dimensional table provides the waste package failure history CDF for no drip packages.

The test case was run as described in VTP Section 6.6 (CRWMS M&O 2000a). The constant value and the distribution type with the minimum and maximum values loaded correctly. The one-dimensional and two-dimensional tables also loaded correctly. Table 10 lists a few of the points for the one-dimensional table (CRWMS M&O 2000a, Section 4.1.6) along with the values obtained from GoldSim. As can seen from Table 10, GoldSim correctly loaded the one-dimensional table values.

Table 10. Comparison of Database Values with the Values Loaded by GoldSim for a One-dimensional Table

Database Values		Values Loaded by GoldSim	
Independent Variable	Dependent Variable	Independent Variable	Dependent Variable
0	0	0	0
2.2	0	2.2	0
3.9	0.00844	3.9	0.00844
9.2	0.0462	9.2	0.0462

Table 11 shows the results for the two-dimensional table. This shows that GoldSim can also correctly load a two-dimensional table from a database.

Table 11. Comparison of Database Values with the Values Loaded by GoldSim for a One-dimensional Table

Database Values				Values Loaded by GoldSim			
	Columns				Columns		
Rows	1	2	3	Rows	1	2	3
0	0	0	0	**0**	0	0	0
794327.2	0	0	0	**794327.2**	0	0	0
794328.2	0.0053	0	1.4022	**794328.2**	0.0053	0	1.4022
803526.1	0.0062	0	2.8174	**803526.1**	0.0062	0	2.8174

GoldSim passed all aspects of Test 6, "Loading Values from a Database".

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5.3.7 Vendor Supplied Test Cases

The VTP instructs the validation tester to select five test cases from the vendor's verification plan to run. The VTP indicates that the test cases from the vendor's verification plan should test the functions listed below:

1. Change in mass of radioactive species due to decay and ingrowth in decay chains
2. Advection through partially saturated media
3. Diffusion through sorptive material
4. Transport of colloids (suspended solids)

5. Interpolation of values between data entries in multidimensional tables

6. Calculation of mathematical expressions to determine the values of derived parameters. Mathematical operations that should be supported include addition, subtraction, multiplication, division, exponents, and logical tests.

7. Calculation of mathematical functions including trigonometric functions, absolute value, exponential, logarithms, modulus, rounding, truncating, and square root functions.

8. Ability to define parameters as distribution functions

9. Ability to use the expected value of all stochastic variables for a given simulation

10. Ability to perform Monte Carlo simulations by sampling all stochastic parameters using Latin Hypercube Sampling (LHS)

11. Ability to perform up to 1000 realizations for a single simulation.

There are not five vendor tests cases that would test all these functions, so seven vendor tests were selected so that all the above functions would be tested. **Table 12** lists the vendor test cases selected for each of the functions to be tested (from the list above).

Table 12. Vendor Test Cases Chosen for GoldSim Verification

Vendor Test Case	Description	Functions Tested
CT_SourceDecay-1	Decay within a source	Decay and ingrowth in decay chains (1)
CT_Pipes-1	Single-porosity test problem	Advection through partially saturated media and transport of colloids (2 and 4)
CT_Cells3-01	Simple diffusion	Diffusion through a sorptive material (3)
GS8_LOOK	Look-up tables	Interpolation in multidimensional tables (5)
GS2_EXP	Expressions and data	Mathematical expressions (6 and 7)
GS4_STOC	Stochastic distributions	Stochastic distributions and expected value simulations (8 and 9)
TMC-02	Monte-Carlo tests	Latin-Hypercube sampling and multiple realizations (10 and 11)

5.3.7.1 Decay Within a Source

This test case is intended to evaluate the ability of GoldSim to calculate the change in mass of radioactive species due to decay and ingrowth in decay chains. This vendor-supplied test is designated as *CT_SourceDecay-1* (Golder 1999b, Section 4.6.4). This test starts with an ^{241}Am source (10,000 Ci) and defines a single daughter, ^{237}Np. To evaluate split decay, ^{237}Np is defined with two equally probable daughters, ^{233}U(a) and ^{233}U(b). The simulation time is 1,000 years.

The results of the GoldSim simulation agree well with the expected results (Golder 1999b, Section 4.6.4). **Table 13** shows the results of the GoldSim simulation along with the expected results.

Table 13. Comparison of GoldSim Results for the Decay of a Radionuclide and the Ingrowth of the Daughters with the Expected Results

Radionuclide	Expected Value (Ci)	GoldSim Result (Ci)	Percent Deviation From Expected
^{241}Am	2029	2012.9	0.8
^{237}Np	1.610	1.613	0.2
^{233}U(a)	2.194E-03	2.2116E-03	0.8
^{233}U(b)	2.194E-03	2.2116E-03	0.8

This result indicates that GoldSim can correctly simulate the decay and ingrowth of radionuclides within decay chains.

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5.3.7.2 Advection Through Partially Saturated Media and Transport of Colloids

The vendor test that contains these problems is *CT_Pipes-1* (Golder 1999b, Section 4.1). For the advection through a partially saturated medium problem, transport is through a pipe element with a flow rate of 1.0 m^3/day. The pipe's flow area is 1.0 m^2, the longitudinal dispersivity is 1.0 m, the constant flux boundary condition is 1 g/day, and the fluid saturation is 10 percent.

For the transport of colloids problem, transport is through a pipe element with a flow rate of 1.0 m^3/day. The pipe's flow area is 1.0 m^2, the longitudinal dispersivity is 0.5 m, the constant flux boundary condition is 1 g/day, and the fluid saturation is 100 percent. The pipe has a 1-mm coating and the suspended solid concentration is 1.78E-03 kg/m^3.

The expected results for both the advection problem and the colloid problem are the same (refer to Golder 1999b, Section 4.1 for details) and are given along with the GoldSim results in **Table 14**. The complete listing of results for this simulation is given in Attachment VI.

Table 14. Advection through Partially Saturated Media and Transport of Colloids

Time (days)	Concentration – Expected Results	GoldSim Results – Advection	GoldSim Results – Colloids
25	0.0215	0.0215	0.0215
50	0.8679	0.8679	0.8679
75	0.9986	0.9986	0.9986

The GoldSim results match the expected results. GoldSim passed the tests for calculation advection through a partially saturated medium and for transport of colloids.

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5.3.7.3 Diffusion Through a Sorptive Material

This vendor test problem is *CT_Cells3-01* – Simple Diffusion. In this problem, two cells each contain two fluid media, water and oil, and two solid media, sand and clay. The initial inventory (cell 1 only) is 100 Ci each of ^{241}Am (29.09 g), ^{242}Am (10.27 g), and ^{243}Am (500.8 g). The solubility of Am in water is unlimited. There is one diffusive connection between the two cells (water to water). **Table 15** gives the volume, masses, and partition coefficients for the media. **Table 16** gives the diffusive connection properties. Refer to Golder 1999b, Section 4.2.3 for more information.

Table 15. Media Properties for *CT_Cells3-01* Test Problem

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

Table 16. Diffusive Connection Properties for *CT_Cells3-01* Test Problem

	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-3m^2/year.

Table 17 gives the expected results for each cell at various times (Golder 1999b, Section 4.2.3).

Table 17. Expected Concentrations in Water for Each Cell

Cell 1			
Time (years)	^{241}Am (g/m^3)	^{242} Am (g/m^3)	^{243} Am (g/m^3)
100	2.54E-1	8.97E-2	4.37
1,000	2.20E-1	7.76E-2	3.79
10,000	1.33E-1	4.70E-2	2.29
Cell2			
Time (years)	^{241}Am (g/m^3)	^{242} Am (g/m^3)	^{243} Am (g/m^3)
100	4.52E-3	1.59E-3	7.77E-2
1,000	3.87E-2	1.37E-2	6.66E-1
10,000	1.26E-1	4.43E-2	2.16

The results produced by GoldSim shown in **Table 18** match the expected results shown above in **Table 17**. The complete output listing for this test case is given in Attachment VII.

Table 18. GoldSim Results for Concentrations in Water for Each Cell

Cell 1			
Time (years)	^{241}Am (g/m^3)	^{242} Am (g/m^3)	^{243} Am (g/m^3)
100	2.54E-1	8.97E-2	4.37
1,000	2.20E-1	7.76E-2	3.79
10,000	1.33E-1	4.70E-2	2.29
Cell2			
Time (years)	^{241}Am (g/m^3)	^{242} Am (g/m^3)	^{243} Am (g/m^3)
100	4.52E-3	1.59E-3	7.77E-2
1,000	3.87E-2	1.37E-2	6.66E-1
10,000	1.26E-1	4.43E-2	2.16

GoldSim passed this test.

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5.3.7.4 Interpolation in Multidimensional Tables

The GoldSim verification problem *GS8_LOOK* is used to test GoldSim's ability to look-up and interpolate data in one, two, and three-dimensional tables (Golder 1999b, Section 3.1).

5.3.7.4.1 One-dimensional Look-up Tables

The verification problems for a one-dimensional table include tests of GoldSim's ability to look-up table values, interpolate between table data points, and extrapolate outside table data points. There are four verification tests for the one-dimensional table look-up as follows:

1. Look-up data point at, between, and outside table data points, linear interpolation and extrapolation.
2. Look-up data point at, between, and outside table data points, linear interpolation and no extrapolation.
3. 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.
4. 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.

The table defined for these one-dimensional look-up tests is shown in Table 19.

Table 19. One-dimensional Look-up Table

Time (s)	Value (dimensionless)
10	1
20	2
30	3
40	4

The test of GoldSim's ability to look-up table values, linear interpolation between table values, and linear extrapolation outside the table values was executed using a 50-second simulation time (0-50) with half-second time steps. The results of the simulation are given in Attachment VIII. It can be seen by inspection that GoldSim correctly performed these functions. The second test was similar, except that no extrapolation was allowed. These results are also given in Attachment VIII. It can be seen that these calculation were carried out correctly, and that values outside those defined by the look-up table, 0-10 and 40-50 were not calculated.

Table 20 gives the expected results (Golder 1999b, Section 3.1, Table *GS8_LOOK*) and GoldSim results for the third test of a one-dimensional look-up table, which uses linear interpolation and extrapolation on the dependent axis, and log interpolation and extrapolation on the independent axis (time). The complete GoldSim result listing is given in Attachment VIII. As can be seen from the table, GoldSim passed this test.

Table 20. Results for Linear Interpolation and Extrapolation on the Dependent Axis and Log Interpolation and Extrapolation on the Independent Axis

Time (s)	Expected Value	GoldSim Results
0	1	1
10	10	10
20	100	100
30	1000	1000
40	10000	10000
50	100000	100000

Table 21 shows the expected results (Golder 1999b, Section 3.1, Table *GS8_LOOK*) and GoldSim results for the fourth test of a one-dimensional look-up table, which uses log interpolation and extrapolation on the dependent axis, and linear interpolation and extrapolation on the independent axis (time). The complete GoldSim result listing is given in Attachment VIII. As can be seen from the table, GoldSim passed this test.

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Table 21. Results for Log Interpolation and Extrapolation on the Dependent Axis and Linear Interpolation and Extrapolation on the Independent Axis

Time (s)	Expected Value	GoldSim Results
0.5	6.9897	6.9897
1	10	10
10	20	20
40	26.021	26.021

5.3.7.4.2 Two-dimensional Look-up Tables

The verification tests for a two-dimensional table includes the following 1) look-up data point at table data point, 2) look-up data point between table data points, 3) look-up data point outside table data point, and 4) time dependent look-up points at, between, and outside table data points. The two-dimensional look-up table defined for these tests is shown in Table 22.

Table 22. Two-dimensional Look-up Table

	10	20
10	1	3
20	3	5
30	5	7

The first two-dimensional look-up table test requires GoldSim to look-up the table value for row value 20 and column value 10. The value obtain by GoldSim is 3, which is the expected value (Golder 1999b, Section 3.1, Table *GS8_LOOK*). The second two-dimensional look-up table test is to obtain the value for row value 15 and column value 15. GoldSim obtain a value of 3, which is the expected value (Golder 1999b, Section 3.1, Table *GS8_LOOK*). The third two-dimensional look-up table test will find a data point outside the table data points; row value 40 and column value 20. The GoldSim result for this test is 7, which is the expected result (Golder 1999b, Section 3.1, Table *GS8_LOOK*).

For the final two-dimensional look-up table test, time histories were saved for a 50-second simulation time (0-50) with half-second time steps. The expected results from the verification plan (Golder 1999b, Section 3.1, Table *GS8_LOOK*) and the GoldSim results are shown in Table 23.

Table 23. Expected Results and GoldSim Results for Time Dependent Two-dimensional Look-up Table

Time (s)	Expected Value	GoldSim Results
< 10	2	2
10	2	2
15	3	3
20	4	4
25	5	5
30	6	6
> 30	6	6

As can be seen from Table 23, GoldSim performed as expected. The complete listing of GoldSim results for this fourth two-dimensional table look-up test is given in Attachment VIII.

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5.3.7.4.3 Three-dimensional Look-up Tables

The verification problems for the three-dimensional look-up tables are 1) look-up data point at table data point, 2) look-up data point between table data points, 3) look-up data point outside table data point, and 4) time dependent look-up points at, between, and outside table data points. The three-dimensional look-up table defined for these tests is shown in Table 24.

Table 24. Three-dimensional Look-up Table

3D Layer = 10	10	20	3D Layer = 20	10	20
10	1	3	10	3	5
20	3	5	20	5	7
30	5	7	30	7	9

For the first test, GoldSim is to look-up a value at table point layer 10, row 10, and column 10. GoldSim obtained the value 1, which is the expected value (Golder 1999b, Section 3.1, Table *GS8_LOOK*). For the second test, GoldSim is to find the value between table data points at layer 15, row 15, and column 15. GoldSim calculated a value of 4, which is the expected value (Golder 1999b, Section 3.1, Table *GS8_LOOK*). In the third test GoldSim is to look-up a value outside the table data points at layer 5, row 5, and column 5. GoldSim calculated a value of 1, which is the expected result (Golder 1999b, Section 3.1, Table *GS8_LOOK*).

The final three-dimensional look-up table test finds time dependent look-up points at, between, and outside the table data points using a layer value of 10, column value of 15, and time values for the row values. The simulation was run for 50 seconds with half-second time steps. The expected results (Golder 1999b, Section 3.1, Table *GS8_LOOK*) and the GoldSim results are shown in Table 25.

Table 25. Expected Results and GoldSim Results for Time Dependent Three-dimensional Look-up Table

Time (s)	Expected Value	GoldSim Result
< 10	2	2
10	2	2
15	3	3
20	4	4
25	5	5
30	6	6

As can be seen from Table 25, GoldSim performed as expected. The complete listing of GoldSim results for this fourth two-dimensional table look-up test is given in Attachment VIII. GoldSim passed all tests of one, two, and three-dimensional table look-up.

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5.3.7.5 Mathematical Expressions

The VTP requires that GoldSim support mathematical operations such as addition, subtraction, multiplication, division, exponents, and logical tests. GoldSim should also support mathematical functions such as trigonometric functions, absolute value, exponential, logarithms, modulus, rounding, truncating, and square root functions. (CRWMS M&O 2000a, Section 4.2)

These functions and operations are tested using vendor test problem *GS2_EXP* – Expressions and Data. The test and the expected results (Golder 1999b, Section 3.1.1, Table GS2_EXP) are shown in Table 26 along with the GoldSim results (note that the financial functions were not tested since they are not planned be used in the TSPA).

Table 26. GoldSim Test Results of Mathematical Operations.

Type	Test	Expected Result	GoldSim Result
Trigonometric Functions	SIN function	0.84147	0.84147
	COS function	0.54030	0.54030
	TAN	1.5574	1.5574
	ASIN	48.590 deg	48.590 deg
	ACOS	41.410 deg	41.410 deg
	ATAN	36.870 deg	36.870 deg
	SINH	0.52110 rad	0.52110 rad
	COSH	1.1276 rad	1.1276 rad
	TANH	0.46212 rad	0.46212 rad
	COT	0.64209 rad	0.64209 rad
Math Functions	Add	5	5
	Subtract	3	3
	Multiply	10	10
	Divide	2.5	2.5
	Square root	2	2
	Power	25	25
	Absolute value	2	2
	Logarithm	2.3463	2.3463
	Minimum value	1	1
	Maximum value	5	5
	Modulus	2	2

Type	Test	Expected Result	GoldSim Result
	Exponential	2.7183	2.7183
	Truncation	1	1
	Rounding	1	1
Special Functions	Bessel function	2.5153e-007	2.5153e-007
	Beta function	0.50000	0.50000
	Error function	0.84271	0.84271
	If function (expression)	1	1
	If function2 (expression)	1	1
Special Operators	Equality operator	0	0
	Inequality operator	1	1
	Greater operator	0	0
	Less than operator	1	1
	Greater than or equal to operator	0	0
	Less than or equal to operator	1	1
	And operator	0	0
	Or operator	1	1
	Not operator	0	0
	Complex dimension change operator	0.86602	0.86602

GoldSim Passed the mathematical functions test.

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5.3.7.6 Stochastic Distributions and Expected Values

The vendor supplied test problem *GS4_STOC* was used to test the stochastic elements supported by GoldSim. The vendor test problem is a model that contains each of the 18 probability distributions supported by GoldSim. The values shown by GoldSim for each of these 18 distributions is compared with analytical results, numerical integration, or results generated from the code At Risk® (refer to Golder 1999b, Section 3.1 for more details). The results generated using the GoldSim Calculator are also verified in these tests. The GoldSim Calculator allows the user to compute the value associated with a particular cumulative probability or the cumulative probability associated with a particular value (refer to Section 4 of the GoldSim user's manual for more details, Golder 2000a).

The 18 distributions supported by GoldSim and verified by this test problem are the following:

- 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

The table in Attachment IX shows the expected values for each distribution (Golder 1999b, Section 3.1, Table *GS4_STOC*) along with the results given by GoldSim. By inspection, it can be seen that the GoldSim results are well within +/-10% of the expected values (it appears that the slight differences are due to rounding of the expected values) for all the distributions except for the probability density in the Boolean distribution. I contacted the vendor about the probability density results given by the Boolean distribution. This is a known bug with the probability density display that will be fixed in a subsequent version of GoldSim. The probability density value is for display purposes only; the cumulative probability values are what are used in the calculations. The cumulative probability values are calculated correctly.
These results also show that GoldSim is correctly calculating the expected value (mean) for these distributions. This test shows that GoldSim can be used to define parameters as distribution functions.

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5.3.7.7 Latin Hypercube Sampling and Multiple Realizations

The vendor test problem *TMC-02* (Monte Carlo Tests) will be used to verify GoldSim's ability to perform Monte Carlo simulations by sampling stochastic parameters using Latin Hypercube Sampling (LHS). This test will also verify GoldSim's ability to run up to 1,000 realizations for a single simulation.

TMC-02 uses a stochastic distribution (Uniform 0-1), and carries out three tests. For the first test, the model is run for 100 realizations with LHS enabled. The expected result is that there be exactly one value between the interval 0.00 – 0.01, one between 0.01 – 0.02, and so on up to 0.99 – 1.00 (Golder 1999b, Section 3.2, TMC-02). The results generated by GoldSim are given in Attachment X.

The second test is to repeat the first test, but without LHS sampling. The GoldSim Verification Plan (Golder 1999b, Section 3.2, *TMC-02* Monte Carlo Test) indicates that there should be on the order of 10 results that lie outside the 5% - 95% confidence bounds, and any number less than 20 is reasonable. The simulation results are given in Attachment X, and they show eight excursions below 5% and one excursion above 95% for a total of nine excursions outside the 5% - 95% confidence bounds.

The final test was to repeat the second test (no LHS sampling) for 5,000 realizations. The expected result is that there should be on the order of 500 excursions outside the 5% - 95% confidence interval, and any value under 1,000 is acceptable (Golder 1999b, Section 3.2, *TMC-02* Monte Carlo Test). This test also verifies that GoldSim can perform "up to 1,000 realizations for a single simulation" as specified in the GoldSim Validation Test Plan (CRWMS M&O 2000a, Section 4.2). The results of this simulation are given in Attachment X. The simulation results show that there are 239 excursions below 5%, and 231 excursions above 95% for a total of 470 excursions outside the 5% - 95% confidence bounds.

These test results show that GoldSim can correctly perform Monte Carlo simulations, including LHS, and run at least 1,000 realizations in a single simulation (this test ran 5,000 realizations).

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6. INDICATION OF PASS FAIL

GoldSim version 6.03 passed all the validation tests given in the VTP and all those selected from the vendor's verification plan. As noted in Section 3.2.6, this version of GoldSim does not display the correct probability density for the Boolean distribution, but this is insignificant because the probability density is not used in any calculations.

7. FAILURE CONDITIONS, OCCURRENCE RESOLUTION

As noted in Section 3.2.6, this version of GoldSim calculates the correct probability density for the Boolean distribution it does not display it correctly. This is of no consequence to the TSPA since the probability density is not used in any calculations. The vendor has been notified of the discrepancy and will correct the problem.

8. OVERALL CONCLUSIONS

GoldSim version 6.03 is validated for the Performance Assessment Department of the Management and Operating (M&O) Contractor of the Civilian Radioactive Waste Management

System (CRWMS) to be used to evaluate the performance of a potential nuclear waste repository. It is recommended that GoldSim version 6.03 be qualified for use for the evaluation of the performance of a potential nuclear waste repository.

9DOCUMENTATION AND JUSTIFICATION OF TEST EXCEPTIONS AND FAILURES

Exceptions are noted in Section 6.

10. SUMMARY OF UNIT TESTING

No unit testing was performed for this software.

11. GENERAL REMARKS

None

12. REFERENCES

CRWMS M&O 2000b. *Installation Test Plan for GoldSim Version 6.04.007*, Software Activity Number (SAN) LV-2000-190, Software Document Number (SDN) 10344-ITP-6.04-000. Las Vegas, Nevada: CRWMS M&O.

Golder Associates 1999b. *Verification Report for GoldSim Version 6.01,* Golder Associates Inc., Redmond Washington, October 1999. ACC: MOL.19991220.0333

Golder Associates 2000a. *GoldSim Graphical Simulation Environment, User's Guide,* Golder Associates Inc., Redmond Washington,

CRWMS M&O 2000a. Validation Test Plan for GoldSim Version 604.007, Software Activity Number (SAN) LV-2000-190, Software Document Number (SDN) 10344-VTP-6.04.007-00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20001120.0185.

Attachment I Results For VTP Test 1, Diffusive Transport

This Attachment lists the GoldSim results for VTP Test 1, Cases 1 and 2. Case 1 is diffusive mass transport flux rates through a fully saturated medium, and Case 2 is diffusive mass transport flux rates through a partially saturated medium.

Time (years)	Fully Saturated Medium Mass Flux Rate (g/year)	Partially Saturated Medium Mass Flux Rate (g/year)	Time (years)	Fully Saturated Medium Mass Flux Rate (g/year)	Partially Saturated Medium Mass Flux Rate (g/year)
0	0	0	25200	0.004995	6.91E-05
200	0.004432	1.19E-07	25400	0.004995	6.92E-05
400	0.004984	5.97E-07	25600	0.004995	6.92E-05
600	0.004995	1.39E-06	25800	0.004995	6.92E-05
800	0.004995	2.45E-06	26000	0.004995	6.92E-05
1000	0.004995	3.72E-06	26200	0.004995	6.92E-05
1200	0.004995	5.17E-06	26400	0.004995	6.92E-05
1400	0.004995	6.76E-06	26600	0.004995	6.92E-05
1600	0.004995	8.46E-06	26800	0.004995	6.92E-05
1800	0.004995	1.02E-05	27000	0.004995	6.92E-05
2000	0.004995	1.21E-05	27200	0.004995	6.92E-05
2200	0.004995	1.40E-05	27400	0.004995	6.92E-05
2400	0.004995	1.59E-05	27600	0.004995	6.92E-05
2600	0.004995	1.78E-05	27800	0.004995	6.92E-05
2800	0.004995	1.97E-05	28000	0.004995	6.92E-05
3000	0.004995	2.16E-05	28200	0.004995	6.92E-05
3200	0.004995	2.35E-05	28400	0.004995	6.92E-05
3400	0.004995	2.54E-05	28600	0.004995	6.92E-05
3600	0.004995	2.72E-05	28800	0.004995	6.92E-05
3800	0.004995	2.90E-05	29000	0.004995	6.92E-05
4000	0.004995	3.07E-05	29200	0.004995	6.92E-05
4200	0.004995	3.24E-05	29400	0.004995	6.92E-05
4400	0.004995	3.40E-05	29600	0.004995	6.92E-05
4600	0.004995	3.56E-05	29800	0.004995	6.92E-05
4800	0.004995	3.71E-05	30000	0.004995	6.92E-05
5000	0.004995	3.86E-05	30200	0.004995	6.92E-05
5200	0.004995	4.01E-05	30400	0.004995	6.92E-05
5400	0.004995	4.14E-05	30600	0.004995	6.92E-05
5600	0.004995	4.27E-05	30800	0.004995	6.93E-05
5800	0.004995	4.40E-05	31000	0.004995	6.93E-05
6000	0.004995	4.52E-05	31200	0.004995	6.93E-05
6200	0.004995	4.64E-05	31400	0.004995	6.93E-05
6400	0.004995	4.75E-05	31600	0.004995	6.93E-05
6600	0.004995	4.86E-05	31800	0.004995	6.93E-05
6800	0.004995	4.96E-05	32000	0.004995	6.93E-05

Time (years)	Fully Saturated Medium Mass Flux Rate (g/year)	Partially Saturated Medium Mass Flux Rate (g/year)	Time (years)	Fully Saturated Medium Mass Flux Rate (g/year)	Partially Saturated Medium Mass Flux Rate (g/year)
7000	0.004995	5.06E-05	32200	0.004995	6.93E-05
7200	0.004995	5.15E-05	32400	0.004995	6.93E-05
7400	0.004995	5.24E-05	32600	0.004995	6.93E-05
7600	0.004995	5.33E-05	32800	0.004995	6.93E-05
7800	0.004995	5.41E-05	33000	0.004995	6.93E-05
8000	0.004995	5.48E-05	33200	0.004995	6.93E-05
8200	0.004995	5.56E-05	33400	0.004995	6.93E-05
8400	0.004995	5.63E-05	33600	0.004995	6.93E-05
8600	0.004995	5.70E-05	33800	0.004995	6.93E-05
8800	0.004995	5.76E-05	34000	0.004995	6.93E-05
9000	0.004995	5.82E-05	34200	0.004995	6.93E-05
9200	0.004995	5.88E-05	34400	0.004995	6.93E-05
9400	0.004995	5.93E-05	34600	0.004995	6.93E-05
9600	0.004995	5.98E-05	34800	0.004995	6.93E-05
9800	0.004995	6.03E-05	35000	0.004995	6.93E-05
10000	0.004995	6.08E-05	35200	0.004995	6.93E-05
10200	0.004995	6.12E-05	35400	0.004995	6.93E-05
10400	0.004995	6.17E-05	35600	0.004995	6.93E-05
10600	0.004995	6.21E-05	35800	0.004995	6.93E-05
10800	0.004995	6.24E-05	36000	0.004995	6.93E-05
11000	0.004995	6.28E-05	36200	0.004995	6.93E-05
11200	0.004995	6.31E-05	36400	0.004995	6.93E-05
11400	0.004995	6.35E-05	36600	0.004995	6.93E-05
11600	0.004995	6.38E-05	36800	0.004995	6.93E-05
11800	0.004995	6.41E-05	37000	0.004995	6.93E-05
12000	0.004995	6.43E-05	37200	0.004995	6.93E-05
12200	0.004995	6.46E-05	37400	0.004995	6.93E-05
12400	0.004995	6.48E-05	37600	0.004995	6.93E-05
12600	0.004995	6.51E-05	37800	0.004995	6.93E-05
12800	0.004995	6.53E-05	38000	0.004995	6.93E-05
13000	0.004995	6.55E-05	38200	0.004995	6.93E-05
13200	0.004995	6.57E-05	38400	0.004995	6.93E-05
13400	0.004995	6.59E-05	38600	0.004995	6.93E-05
13600	0.004995	6.61E-05	38800	0.004995	6.93E-05
13800	0.004995	6.63E-05	39000	0.004995	6.93E-05
14000	0.004995	6.64E-05	39200	0.004995	6.93E-05
14200	0.004995	6.66E-05	39400	0.004995	6.93E-05
14400	0.004995	6.67E-05	39600	0.004995	6.93E-05
14600	0.004995	6.69E-05	39800	0.004995	6.93E-05

Time (years)	Fully Saturated Medium Mass Flux Rate (g/year)	Partially Saturated Medium Mass Flux Rate (g/year)	Time (years)	Fully Saturated Medium Mass Flux Rate (g/year)	Partially Saturated Medium Mass Flux Rate (g/year)
14800	0.004995	6.70E-05	40000	0.004995	6.93E-05
15000	0.004995	6.71E-05	40200	0.004995	6.93E-05
15200	0.004995	6.72E-05	40400	0.004995	6.93E-05
15400	0.004995	6.73E-05	40600	0.004995	6.93E-05
15600	0.004995	6.74E-05	40800	0.004995	6.93E-05
15800	0.004995	6.75E-05	41000	0.004995	6.93E-05
16000	0.004995	6.76E-05	41200	0.004995	6.93E-05
16200	0.004995	6.77E-05	41400	0.004995	6.93E-05
16400	0.004995	6.78E-05	41600	0.004995	6.93E-05
16600	0.004995	6.79E-05	41800	0.004995	6.93E-05
16800	0.004995	6.80E-05	42000	0.004995	6.93E-05
17000	0.004995	6.80E-05	42200	0.004995	6.93E-05
17200	0.004995	6.81E-05	42400	0.004995	6.93E-05
17400	0.004995	6.82E-05	42600	0.004995	6.93E-05
17600	0.004995	6.82E-05	42800	0.004995	6.93E-05
17800	0.004995	6.83E-05	43000	0.004995	6.93E-05
18000	0.004995	6.83E-05	43200	0.004995	6.93E-05
18200	0.004995	6.84E-05	43400	0.004995	6.93E-05
18400	0.004995	6.84E-05	43600	0.004995	6.93E-05
18600	0.004995	6.85E-05	43800	0.004995	6.93E-05
18800	0.004995	6.85E-05	44000	0.004995	6.93E-05
19000	0.004995	6.86E-05	44200	0.004995	6.93E-05
19200	0.004995	6.86E-05	44400	0.004995	6.93E-05
19400	0.004995	6.86E-05	44600	0.004995	6.93E-05
19600	0.004995	6.87E-05	44800	0.004995	6.93E-05
19800	0.004995	6.87E-05	45000	0.004995	6.93E-05
20000	0.004995	6.87E-05	45200	0.004995	6.93E-05
20200	0.004995	6.88E-05	45400	0.004995	6.93E-05
20400	0.004995	6.88E-05	45600	0.004995	6.93E-05
20600	0.004995	6.88E-05	45800	0.004995	6.93E-05
20800	0.004995	6.88E-05	46000	0.004995	6.93E-05
21000	0.004995	6.89E-05	46200	0.004995	6.93E-05
21200	0.004995	6.89E-05	46400	0.004995	6.93E-05
21400	0.004995	6.89E-05	46600	0.004995	6.93E-05
21600	0.004995	6.89E-05	46800	0.004995	6.93E-05
21800	0.004995	6.89E-05	47000	0.004995	6.93E-05
22000	0.004995	6.90E-05	47200	0.004995	6.93E-05
22200	0.004995	6.90E-05	47400	0.004995	6.93E-05
22400	0.004995	6.90E-05	47600	0.004995	6.93E-05

Time (years)	Fully Saturated Medium Mass Flux Rate (g/year)	Partially Saturated Medium Mass Flux Rate (g/year)	Time (years)	Fully Saturated Medium Mass Flux Rate (g/year)	Partially Saturated Medium Mass Flux Rate (g/year)
22600	0.004995	6.90E-05	**47800**	0.004995	6.93E-05
22800	0.004995	6.90E-05	**48000**	0.004995	6.93E-05
23000	0.004995	6.90E-05	**48200**	0.004995	6.93E-05
23200	0.004995	6.91E-05	**48400**	0.004995	6.93E-05
23400	0.004995	6.91E-05	**48600**	0.004995	6.93E-05
23600	0.004995	6.91E-05	**48800**	0.004995	6.93E-05
23800	0.004995	6.91E-05	**49000**	0.004995	6.93E-05
24000	0.004995	6.91E-05	**49200**	0.004995	6.93E-05
24200	0.004995	6.91E-05	**49400**	0.004995	6.93E-05
24400	0.004995	6.91E-05	**49600**	0.004995	6.93E-05
24600	0.004995	6.91E-05	**49800**	0.004995	6.93E-05
24800	0.004995	6.91E-05	**50000**	0.004995	6.93E-05
25000	0.004995	6.91E-05			

Attachment II Results for VTP Test 2, Advective Transport

This Attachment lists the GoldSim results VTP Test 2, Cases 1, 2, and 3. Case 1 is one-dimensional advection with dispersion, Case 2 is one-dimensional advection with dispersion and the addition of a sorbing material, and Case 3 is the advective release from a batch reactor "mixing cell".

Time (years)	Case 1 Concentration (g/m^3)	Case 2 Concentration (g/m^3)	Case 3 Mass in Cell (g)	Time (years)	Case 1 Concentration (g/m^3)	Case 2 Concentration (g/m^3)	Case 3 Mass in Cell (g)
0	0	0	100	2510	99.047	99.047	8.1268
10	9.31E-14	9.31E-14	99.005	2520	99.07	99.07	8.046
20	1.33E-13	1.33E-13	98.02	2530	99.092	99.092	7.9659
30	1.84E-13	1.84E-13	97.045	2540	99.114	99.114	7.8867
40	2.49E-13	2.49E-13	96.079	2550	99.135	99.135	7.8082
50	3.31E-13	3.31E-13	95.123	2560	99.155	99.155	7.7305
60	4.32E-13	4.32E-13	94.176	2570	99.175	99.175	7.6536
70	8.32E-13	8.32E-13	93.239	2580	99.195	99.195	7.5774
80	2.75E-11	2.75E-11	92.312	2590	99.213	99.213	7.502
90	9.31E-10	9.31E-10	91.393	2600	99.232	99.232	7.4274
100	1.58E-08	1.59E-08	90.484	2610	99.25	99.25	7.3535
110	1.60E-07	1.60E-07	89.583	2620	99.267	99.267	7.2803
120	1.10E-06	1.10E-06	88.692	2630	99.284	99.284	7.2079
130	5.64E-06	5.64E-06	87.81	2640	99.301	99.301	7.1361
140	2.28E-05	2.28E-05	86.936	2650	99.317	99.317	7.0651
150	7.63E-05	7.63E-05	86.071	2660	99.332	99.332	6.9948
160	0.00022	0.00022	85.214	2670	99.348	99.348	6.9252
170	0.000557	0.000557	84.366	2680	99.362	99.362	6.8563
180	0.001273	0.001273	83.527	2690	99.377	99.377	6.7881
190	0.002663	0.002663	82.696	2700	99.391	99.391	6.7206
200	0.005171	0.005171	81.873	2710	99.405	99.405	6.6537
210	0.009414	0.009414	81.058	2720	99.418	99.418	6.5875
220	0.016213	0.016213	80.252	2730	99.431	99.431	6.5219
230	0.026609	0.026609	79.453	2740	99.443	99.443	6.457
240	0.041863	0.041863	78.663	2750	99.456	99.456	6.3928
250	0.063458	0.063458	77.88	2760	99.468	99.468	6.3292
260	0.093077	0.093077	77.105	2770	99.479	99.479	6.2662
270	0.13259	0.13259	76.338	2780	99.49	99.49	6.2039
280	0.18399	0.18399	75.578	2790	99.501	99.501	6.1421
290	0.24942	0.24942	74.826	2800	99.512	99.512	6.081
300	0.33104	0.33104	74.082	2810	99.523	99.523	6.0205
310	0.43109	0.43109	73.345	2820	99.533	99.533	5.9606
320	0.55176	0.55176	72.615	2830	99.543	99.543	5.9013
330	0.69521	0.69521	71.892	2840	99.552	99.552	5.8426

Time (years)	Case 1 Concentration (g/m^3)	Case 2 Concentration (g/m^3)	Case 3 Mass in Cell (g)	Time (years)	Case 1 Concentration (g/m^3)	Case 2 Concentration (g/m^3)	Case 3 Mass in Cell (g)
340	0.86348	0.86348	71.177	2850	99.562	99.562	5.7844
350	1.0585	1.0585	70.469	2860	99.571	99.571	5.7269
360	1.2822	1.2822	69.768	2870	99.579	99.579	5.6699
370	1.536	1.536	69.073	2880	99.588	99.588	5.6135
380	1.8215	1.8215	68.386	2890	99.596	99.596	5.5576
390	2.1398	2.1398	67.706	2900	99.605	99.605	5.5023
400	2.4921	2.4921	67.032	2910	99.613	99.613	5.4476
410	2.8792	2.8792	66.365	2920	99.62	99.62	5.3934
420	3.3016	3.3016	65.705	2930	99.628	99.628	5.3397
430	3.7598	3.7598	65.051	2940	99.635	99.635	5.2866
440	4.2539	4.2539	64.404	2950	99.642	99.642	5.234
450	4.7841	4.7841	63.763	2960	99.649	99.649	5.1819
460	5.3501	5.3501	63.128	2970	99.656	99.656	5.1303
470	5.9515	5.9515	62.5	2980	99.662	99.662	5.0793
480	6.5879	6.5879	61.878	2990	99.669	99.669	5.0288
490	7.2585	7.2585	61.263	3000	99.675	99.675	4.9787
500	7.9626	7.9626	60.653	3010	99.681	99.681	4.9292
510	8.6993	8.6993	60.05	3020	99.687	99.687	4.8801
520	9.4674	9.4674	59.452	3030	99.693	99.693	4.8316
530	10.266	10.266	58.861	3040	99.698	99.698	4.7835
540	11.094	11.094	58.275	3050	99.704	99.704	4.7359
550	11.949	11.949	57.695	3060	99.709	99.709	4.6888
560	12.831	12.831	57.121	3070	99.714	99.714	4.6421
570	13.738	13.738	56.553	3080	99.719	99.719	4.5959
580	14.669	14.669	55.99	3090	99.724	99.724	4.5502
590	15.622	15.622	55.433	3100	99.729	99.729	4.5049
600	16.595	16.595	54.881	3110	99.733	99.733	4.4601
610	17.588	17.588	54.335	3120	99.738	99.738	4.4157
620	18.599	18.599	53.794	3130	99.742	99.742	4.3718
630	19.626	19.626	53.259	3140	99.746	99.746	4.3283
640	20.667	20.667	52.729	3150	99.75	99.75	4.2852
650	21.722	21.722	52.205	3160	99.754	99.754	4.2426
660	22.789	22.789	51.685	3170	99.758	99.758	4.2004
670	23.866	23.866	51.171	3180	99.762	99.762	4.1586
680	24.952	24.952	50.662	3190	99.766	99.766	4.1172
690	26.046	26.046	50.158	3200	99.769	99.769	4.0762
700	27.147	27.147	49.659	3210	99.773	99.773	4.0357
710	28.252	28.252	49.164	3220	99.776	99.776	3.9955
720	29.361	29.361	48.675	3230	99.78	99.78	3.9558

Time (years)	Case 1 Concentration (g/m^3)	Case 2 Concentration (g/m^3)	Case 3 Mass in Cell (g)	Time (years)	Case 1 Concentration (g/m^3)	Case 2 Concentration (g/m^3)	Case 3 Mass in Cell (g)
730	30.474	30.474	48.191	**3240**	99.783	99.783	3.9164
740	31.587	31.587	47.711	**3250**	99.786	99.786	3.8774
750	32.701	32.701	47.237	**3260**	99.789	99.789	3.8388
760	33.815	33.815	46.767	**3270**	99.792	99.792	3.8006
770	34.927	34.927	46.301	**3280**	99.795	99.795	3.7628
780	36.036	36.036	45.841	**3290**	99.798	99.798	3.7254
790	37.143	37.143	45.384	**3300**	99.801	99.801	3.6883
800	38.244	38.244	44.933	**3310**	99.803	99.803	3.6516
810	39.341	39.341	44.486	**3320**	99.806	99.806	3.6153
820	40.432	40.432	44.043	**3330**	99.808	99.808	3.5793
830	41.516	41.516	43.605	**3340**	99.811	99.811	3.5437
840	42.593	42.593	43.171	**3350**	99.813	99.813	3.5084
850	43.662	43.662	42.742	**3360**	99.816	99.816	3.4735
860	44.722	44.722	42.316	**3370**	99.818	99.818	3.439
870	45.774	45.774	41.895	**3380**	99.82	99.82	3.4048
880	46.815	46.815	41.478	**3390**	99.822	99.822	3.3709
890	47.847	47.847	41.066	**3400**	99.824	99.824	3.3373
900	48.868	48.868	40.657	**3410**	99.826	99.826	3.3041
910	49.878	49.878	40.252	**3420**	99.828	99.828	3.2712
920	50.877	50.877	39.852	**3430**	99.83	99.83	3.2387
930	51.864	51.864	39.455	**3440**	99.832	99.832	3.2065
940	52.84	52.84	39.063	**3450**	99.834	99.834	3.1746
950	53.803	53.803	38.674	**3460**	99.836	99.836	3.143
960	54.753	54.753	38.289	**3470**	99.837	99.837	3.1117
970	55.691	55.691	37.908	**3480**	99.839	99.839	3.0807
980	56.616	56.616	37.531	**3490**	99.841	99.841	3.0501
990	57.527	57.527	37.158	**3500**	99.842	99.842	3.0197
1000	58.426	58.426	36.788	**3510**	99.844	99.844	2.9897
1010	59.311	59.311	36.422	**3520**	99.845	99.845	2.9599
1020	60.183	60.183	36.06	**3530**	99.847	99.847	2.9305
1030	61.041	61.041	35.701	**3540**	99.848	99.848	2.9013
1040	61.885	61.885	35.345	**3550**	99.85	99.85	2.8725
1050	62.716	62.716	34.994	**3560**	99.851	99.851	2.8439
1060	63.533	63.533	34.646	**3570**	99.852	99.852	2.8156
1070	64.337	64.337	34.301	**3580**	99.854	99.854	2.7876
1080	65.127	65.127	33.96	**3590**	99.855	99.855	2.7598
1090	65.903	65.903	33.622	**3600**	99.856	99.856	2.7324
1100	66.666	66.666	33.287	**3610**	99.857	99.857	2.7052
1110	67.414	67.414	32.956	**3620**	99.858	99.858	2.6783

Time (years)	Case 1 Concentration (g/m^3)	Case 2 Concentration (g/m^3)	Case 3 Mass in Cell (g)	Time (years)	Case 1 Concentration (g/m^3)	Case 2 Concentration (g/m^3)	Case 3 Mass in Cell (g)
1120	68.15	68.15	32.628	**3630**	99.859	99.859	2.6516
1130	68.872	68.872	32.303	**3640**	99.861	99.861	2.6252
1140	69.581	69.581	31.982	**3650**	99.862	99.862	2.5991
1150	70.276	70.276	31.664	**3660**	99.863	99.863	2.5733
1160	70.958	70.958	31.349	**3670**	99.864	99.864	2.5477
1170	71.627	71.627	31.037	**3680**	99.865	99.865	2.5223
1180	72.284	72.284	30.728	**3690**	99.866	99.866	2.4972
1190	72.927	72.927	30.422	**3700**	99.867	99.867	2.4724
1200	73.558	73.558	30.119	**3710**	99.867	99.867	2.4478
1210	74.176	74.176	29.82	**3720**	99.868	99.868	2.4234
1220	74.781	74.781	29.523	**3730**	99.869	99.869	2.3993
1230	75.375	75.375	29.229	**3740**	99.87	99.87	2.3754
1240	75.956	75.956	28.938	**3750**	99.871	99.871	2.3518
1250	76.525	76.525	28.65	**3760**	99.872	99.872	2.3284
1260	77.083	77.083	28.365	**3770**	99.872	99.872	2.3052
1270	77.629	77.629	28.083	**3780**	99.873	99.873	2.2823
1280	78.163	78.163	27.804	**3790**	99.874	99.874	2.2596
1290	78.686	78.686	27.527	**3800**	99.874	99.874	2.2371
1300	79.198	79.198	27.253	**3810**	99.875	99.875	2.2148
1310	79.698	79.698	26.982	**3820**	99.876	99.876	2.1928
1320	80.188	80.188	26.714	**3830**	99.876	99.876	2.171
1330	80.667	80.667	26.448	**3840**	99.877	99.877	2.1494
1340	81.136	81.136	26.185	**3850**	99.878	99.878	2.128
1350	81.595	81.595	25.924	**3860**	99.878	99.878	2.1068
1360	82.043	82.043	25.666	**3870**	99.879	99.879	2.0858
1370	82.481	82.481	25.411	**3880**	99.879	99.879	2.0651
1380	82.91	82.91	25.158	**3890**	99.88	99.88	2.0445
1390	83.329	83.329	24.908	**3900**	99.881	99.881	2.0242
1400	83.738	83.738	24.66	**3910**	99.881	99.881	2.0041
1410	84.138	84.138	24.414	**3920**	99.882	99.882	1.9841
1420	84.529	84.529	24.171	**3930**	99.882	99.882	1.9644
1430	84.911	84.911	23.931	**3940**	99.883	99.883	1.9448
1440	85.285	85.285	23.693	**3950**	99.883	99.883	1.9255
1450	85.649	85.649	23.457	**3960**	99.883	99.883	1.9063
1460	86.005	86.005	23.224	**3970**	99.884	99.884	1.8873
1470	86.353	86.353	22.993	**3980**	99.884	99.884	1.8686
1480	86.693	86.693	22.764	**3990**	99.885	99.885	1.85
1490	87.025	87.025	22.537	**4000**	99.885	99.885	1.8316
1500	87.349	87.349	22.313	**4010**	99.886	99.886	1.8133

Time (years)	Case 1 Concentration (g/m^3)	Case 2 Concentration (g/m^3)	Case 3 Mass in Cell (g)	Time (years)	Case 1 Concentration (g/m^3)	Case 2 Concentration (g/m^3)	Case 3 Mass in Cell (g)
1510	87.665	87.665	22.091	4020	99.886	99.886	1.7953
1520	87.974	87.974	21.871	4030	99.886	99.886	1.7774
1530	88.276	88.276	21.654	4040	99.887	99.887	1.7598
1540	88.57	88.57	21.438	4050	99.887	99.887	1.7422
1550	88.858	88.858	21.225	4060	99.887	99.887	1.7249
1560	89.138	89.138	21.014	4070	99.888	99.888	1.7077
1570	89.412	89.412	20.805	4080	99.888	99.888	1.6907
1580	89.679	89.679	20.598	4090	99.888	99.888	1.6739
1590	89.939	89.939	20.393	4100	99.889	99.889	1.6573
1600	90.194	90.194	20.19	4110	99.889	99.889	1.6408
1610	90.442	90.442	19.989	4120	99.889	99.889	1.6245
1620	90.684	90.684	19.79	4130	99.89	99.89	1.6083
1630	90.92	90.92	19.593	4140	99.89	99.89	1.5923
1640	91.15	91.15	19.398	4150	99.89	99.89	1.5764
1650	91.375	91.375	19.205	4160	99.89	99.89	1.5608
1660	91.594	91.594	19.014	4170	99.891	99.891	1.5452
1670	91.808	91.808	18.825	4180	99.891	99.891	1.5299
1680	92.017	92.017	18.637	4190	99.891	99.891	1.5146
1690	92.22	92.22	18.452	4200	99.891	99.891	1.4996
1700	92.418	92.418	18.268	4210	99.892	99.892	1.4846
1710	92.612	92.612	18.087	4220	99.892	99.892	1.4699
1720	92.8	92.8	17.907	4230	99.892	99.892	1.4552
1730	92.984	92.984	17.728	4240	99.892	99.892	1.4408
1740	93.164	93.164	17.552	4250	99.892	99.892	1.4264
1750	93.338	93.338	17.377	4260	99.893	99.893	1.4122
1760	93.509	93.509	17.205	4270	99.893	99.893	1.3982
1770	93.675	93.675	17.033	4280	99.893	99.893	1.3843
1780	93.837	93.837	16.864	4290	99.893	99.893	1.3705
1790	93.995	93.995	16.696	4300	99.893	99.893	1.3569
1800	94.148	94.148	16.53	4310	99.894	99.894	1.3434
1810	94.298	94.298	16.365	4320	99.894	99.894	1.33
1820	94.445	94.445	16.203	4330	99.894	99.894	1.3168
1830	94.587	94.587	16.041	4340	99.894	99.894	1.3037
1840	94.726	94.726	15.882	4350	99.894	99.894	1.2907
1850	94.861	94.861	15.724	4360	99.894	99.894	1.2778
1860	94.993	94.993	15.567	4370	99.895	99.895	1.2651
1870	95.122	95.122	15.412	4380	99.895	99.895	1.2525
1880	95.247	95.247	15.259	4390	99.895	99.895	1.2401
1890	95.369	95.369	15.107	4400	99.895	99.895	1.2277

Time (years)	Case 1 Concentration (g/m^3)	Case 2 Concentration (g/m^3)	Case 3 Mass in Cell (g)	Time (years)	Case 1 Concentration (g/m^3)	Case 2 Concentration (g/m^3)	Case 3 Mass in Cell (g)
1900	95.488	95.488	14.957	**4410**	99.895	99.895	1.2155
1910	95.604	95.604	14.808	**4420**	99.895	99.895	1.2034
1920	95.716	95.716	14.661	**4430**	99.895	99.895	1.1915
1930	95.826	95.826	14.515	**4440**	99.895	99.895	1.1796
1940	95.934	95.934	14.37	**4450**	99.896	99.896	1.1679
1950	96.038	96.038	14.227	**4460**	99.896	99.896	1.1562
1960	96.14	96.14	14.086	**4470**	99.896	99.896	1.1447
1970	96.239	96.239	13.946	**4480**	99.896	99.896	1.1333
1980	96.335	96.335	13.807	**4490**	99.896	99.896	1.1221
1990	96.429	96.429	13.67	**4500**	99.896	99.896	1.1109
2000	96.521	96.521	13.534	**4510**	99.896	99.896	1.0998
2010	96.61	96.61	13.399	**4520**	99.896	99.896	1.0889
2020	96.697	96.697	13.266	**4530**	99.896	99.896	1.0781
2030	96.782	96.782	13.134	**4540**	99.897	99.897	1.0673
2040	96.864	96.864	13.003	**4550**	99.897	99.897	1.0567
2050	96.944	96.944	12.874	**4560**	99.897	99.897	1.0462
2060	97.023	97.023	12.745	**4570**	99.897	99.897	1.0358
2070	97.099	97.099	12.619	**4580**	99.897	99.897	1.0255
2080	97.173	97.173	12.493	**4590**	99.897	99.897	1.0153
2090	97.245	97.245	12.369	**4600**	99.897	99.897	1.0052
2100	97.316	97.316	12.246	**4610**	99.897	99.897	0.99518
2110	97.384	97.384	12.124	**4620**	99.897	99.897	0.98528
2120	97.451	97.451	12.003	**4630**	99.897	99.897	0.97548
2130	97.516	97.516	11.884	**4640**	99.897	99.897	0.96577
2140	97.579	97.579	11.765	**4650**	99.897	99.897	0.95616
2150	97.641	97.641	11.648	**4660**	99.898	99.898	0.94665
2160	97.701	97.701	11.533	**4670**	99.898	99.898	0.93723
2170	97.759	97.759	11.418	**4680**	99.898	99.898	0.9279
2180	97.816	97.816	11.304	**4690**	99.898	99.898	0.91867
2190	97.872	97.872	11.192	**4700**	99.898	99.898	0.90953
2200	97.926	97.926	11.08	**4710**	99.898	99.898	0.90048
2210	97.978	97.978	10.97	**4720**	99.898	99.898	0.89152
2220	98.029	98.029	10.861	**4730**	99.898	99.898	0.88265
2230	98.079	98.079	10.753	**4740**	99.898	99.898	0.87387
2240	98.128	98.128	10.646	**4750**	99.898	99.898	0.86517
2250	98.175	98.175	10.54	**4760**	99.898	99.898	0.85656
2260	98.221	98.221	10.435	**4770**	99.898	99.898	0.84804
2270	98.265	98.265	10.331	**4780**	99.898	99.898	0.8396
2280	98.309	98.309	10.228	**4790**	99.898	99.898	0.83125

Time (years)	Case 1 Concentration (g/m^3)	Case 2 Concentration (g/m^3)	Case 3 Mass in Cell (g)	Time (years)	Case 1 Concentration (g/m^3)	Case 2 Concentration (g/m^3)	Case 3 Mass in Cell (g)
2290	98.351	98.351	10.127	**4800**	99.898	99.898	0.82298
2300	98.393	98.393	10.026	**4810**	99.898	99.898	0.81479
2310	98.433	98.433	9.9261	**4820**	99.898	99.898	0.80668
2320	98.472	98.472	9.8274	**4830**	99.898	99.898	0.79865
2330	98.51	98.51	9.7296	**4840**	99.898	99.898	0.79071
2340	98.547	98.547	9.6328	**4850**	99.899	99.899	0.78284
2350	98.583	98.583	9.5369	**4860**	99.899	99.899	0.77505
2360	98.619	98.619	9.442	**4870**	99.899	99.899	0.76734
2370	98.653	98.653	9.3481	**4880**	99.899	99.899	0.7597
2380	98.686	98.686	9.2551	**4890**	99.899	99.899	0.75214
2390	98.719	98.719	9.163	**4900**	99.899	99.899	0.74466
2400	98.75	98.75	9.0718	**4910**	99.899	99.899	0.73725
2410	98.781	98.781	8.9815	**4920**	99.899	99.899	0.72991
2420	98.811	98.811	8.8922	**4930**	99.899	99.899	0.72265
2430	98.84	98.84	8.8037	**4940**	99.899	99.899	0.71546
2440	98.868	98.868	8.7161	**4950**	99.899	99.899	0.70834
2450	98.896	98.896	8.6294	**4960**	99.899	99.899	0.70129
2460	98.923	98.923	8.5435	**4970**	99.899	99.899	0.69432
2470	98.949	98.949	8.4585	**4980**	99.899	99.899	0.68741
2480	98.974	98.974	8.3743	**4990**	99.899	99.899	0.68057
2490	98.999	98.999	8.291	**5000**	99.899	99.899	0.6738
2500	99.023	99.023	8.2085				

Attachment III Results for VTP Test 3, Source Term

This Attachment lists the GoldSim results for VTP Test 3, Sources 1, 2, and 3. Source 1 tests the use of the inner barrier of source term containment, often defined as cladding for nuclear fuel. The GoldSim results for Source 1 show the amount of "unexposed mass" and the mass transport rate. Source 2 tests the use of the outer barrier, used to represent discrete failures of waste packages. The GoldSim results for Source 2 show the release from discrete waste package failures. The third source represents the release from a matrix, and the source also decays radioactively. The GoldSim results give the amount of "unexposed mass" of radioactive Species C.

Time (years)	Source 1 Unexposed Mass (grams)	Source 1 Mass Transport Rate (g/yr)	Source 2 Outer Barrier Releases (g/yr)	Source 3 Unexposed Mass of Species C (grams)	Time (years)	Source 1 Unexposed Mass (grams)	Source 1 Mass Transport Rate (g/yr)	Source 2 Outer Barrier Releases (g/yr)	Source 3 Unexposed Mass of Species C (grams)
0	1.00E+05	0	0	100	**5010**	49900	0.004995	0	57.675
10	99900	0.01456	0	99.99	**5020**	49800	0.004995	0	57.611
20	99800	0.004995	0	99.88	**5030**	49700	0.004995	0	57.548
30	99700	0.004995	0	99.77	**5040**	49600	0.004995	0	57.485
40	99600	0.004995	0	99.66	**5050**	49500	0.004995	0	57.421
50	99500	0.004995	0	99.551	**5060**	49400	0.004995	0	57.358
60	99400	0.004995	0	99.441	**5070**	49300	0.004995	0	57.295
70	99300	0.004995	0	99.332	**5080**	49200	0.004995	0	57.232
80	99200	0.004995	0	99.223	**5090**	49100	0.004995	0	57.169
90	99100	0.004995	0	99.114	**5100**	49000	0.004995	0	57.106
100	99000	0.004995	0	99.005	**5110**	48900	0.004995	0	57.044
110	98900	0.004995	0	98.896	**5120**	48800	0.004995	0	56.981
120	98800	0.004995	0	98.787	**5130**	48700	0.004995	0	56.918
130	98700	0.004995	0	98.678	**5140**	48600	0.004995	0	56.856
140	98600	0.004995	0	98.57	**5150**	48500	0.004995	0	56.793
150	98500	0.004995	0	98.461	**5160**	48400	0.004995	0	56.731
160	98400	0.004995	0	98.353	**5170**	48300	0.004995	0	56.668
170	98300	0.004995	0	98.245	**5180**	48200	0.004995	0	56.606
180	98200	0.004995	0	98.137	**5190**	48100	0.004995	0	56.544
190	98100	0.004995	0	98.029	**5200**	48000	0.004995	0	56.481
200	98000	0.004995	0	97.921	**5210**	47900	0.004995	0	56.419
210	97900	0.004995	0	97.813	**5220**	47800	0.004995	0	56.357
220	97800	0.004995	0	97.706	**5230**	47700	0.004995	0	56.295
230	97700	0.004995	0	97.598	**5240**	47600	0.004995	0	56.233
240	97600	0.004995	0	97.491	**5250**	47500	0.004995	0	56.171
250	97500	0.004995	0	97.384	**5260**	47400	0.004995	0	56.11
260	97400	0.004995	0	97.277	**5270**	47300	0.004995	0	56.048
270	97300	0.004995	0	97.17	**5280**	47200	0.004995	0	55.986
280	97200	0.004995	0	97.063	**5290**	47100	0.004995	0	55.925

Time (years)	Source 1 Unexposed Mass (grams)	Source 1 Mass Transport Rate (g/yr)	Source 2 Outer Barrier Releases (g/yr)	Source 3 Unexposed Mass of Species C (grams)	Time (years)	Source 1 Unexposed Mass (grams)	Source 1 Mass Transport Rate (g/yr)	Source 2 Outer Barrier Releases (g/yr)	Source 3 Unexposed Mass of Species C (grams)
290	97100	0.004995	0	96.956	5300	47000	0.004995	0	55.863
300	97000	0.004995	0	96.849	5310	46900	0.004995	0	55.802
310	96900	0.004995	0	96.743	5320	46800	0.004995	0	55.74
320	96800	0.004995	0	96.636	5330	46700	0.004995	0	55.679
330	96700	0.004995	0	96.53	5340	46600	0.004995	0	55.618
340	96600	0.004995	0	96.424	5350	46500	0.004995	0	55.557
350	96500	0.004995	0	96.318	5360	46400	0.004995	0	55.496
360	96400	0.004995	0	96.212	5370	46300	0.004995	0	55.434
370	96300	0.004995	0	96.106	5380	46200	0.004995	0	55.374
380	96200	0.004995	0	96	5390	46100	0.004995	0	55.313
390	96100	0.004995	0	95.895	5400	46000	0.004995	0	55.252
400	96000	0.004995	0	95.789	5410	45900	0.004995	0	55.191
410	95900	0.004995	0	95.684	5420	45800	0.004995	0	55.13
420	95800	0.004995	0	95.579	5430	45700	0.004995	0	55.07
430	95700	0.004995	0	95.474	5440	45600	0.004995	0	55.009
440	95600	0.004995	0	95.369	5450	45500	0.004995	0	54.949
450	95500	0.004995	0	95.264	5460	45400	0.004995	0	54.888
460	95400	0.004995	0	95.159	5470	45300	0.004995	0	54.828
470	95300	0.004995	0	95.054	5480	45200	0.004995	0	54.767
480	95200	0.004995	0	94.95	5490	45100	0.004995	0	54.707
490	95100	0.004995	0	94.845	5500	45000	0.004995	10	54.647
500	95000	0.004995	10	94.741	5510	44900	0.004995	1.00E-12	54.587
510	94900	0.004995	1.00E-12	94.637	5520	44800	0.004995	0	54.527
520	94800	0.004995	0	94.533	5530	44700	0.004995	0	54.467
530	94700	0.004995	0	94.429	5540	44600	0.004995	0	54.407
540	94600	0.004995	0	94.325	5550	44500	0.004995	0	54.347
550	94500	0.004995	0	94.221	5560	44400	0.004995	0	54.287
560	94400	0.004995	0	94.117	5570	44300	0.004995	0	54.228
570	94300	0.004995	0	94.014	5580	44200	0.004995	0	54.168
580	94200	0.004995	0	93.91	5590	44100	0.004995	0	54.108
590	94100	0.004995	0	93.807	5600	44000	0.004995	0	54.049
600	94000	0.004995	0	93.704	5610	43900	0.004995	0	53.99
610	93900	0.004995	0	93.601	5620	43800	0.004995	0	53.93
620	93800	0.004995	0	93.498	5630	43700	0.004995	0	53.871
630	93700	0.004995	0	93.395	5640	43600	0.004995	0	53.812
640	93600	0.004995	0	93.292	5650	43500	0.004995	0	53.752
650	93500	0.004995	0	93.19	5660	43400	0.004995	0	53.693
660	93400	0.004995	0	93.087	5670	43300	0.004995	0	53.634

Time (years)	Source 1 Unexposed Mass (grams)	Source 1 Mass Transport Rate (g/yr)	Source 2 Outer Barrier Releases (g/yr)	Source 3 Unexposed Mass of Species C (grams)	Time (years)	Source 1 Unexposed Mass (grams)	Source 1 Mass Transport Rate (g/yr)	Source 2 Outer Barrier Releases (g/yr)	Source 3 Unexposed Mass of Species C (grams)
670	93300	0.004995	0	92.985	5680	43200	0.004995	0	53.575
680	93200	0.004995	0	92.883	5690	43100	0.004995	0	53.516
690	93100	0.004995	0	92.78	5700	43000	0.004995	0	53.457
700	93000	0.004995	0	92.678	5710	42900	0.004995	0	53.399
710	92900	0.004995	0	92.576	5720	42800	0.004995	0	53.34
720	92800	0.004995	0	92.475	5730	42700	0.004995	0	53.281
730	92700	0.004995	0	92.373	5740	42600	0.004995	0	53.223
740	92600	0.004995	0	92.271	5750	42500	0.004995	0	53.164
750	92500	0.004995	0	92.17	5760	42400	0.004995	0	53.106
760	92400	0.004995	0	92.068	5770	42300	0.004995	0	53.047
770	92300	0.004995	0	91.967	5780	42200	0.004995	0	52.989
780	92200	0.004995	0	91.866	5790	42100	0.004995	0	52.931
790	92100	0.004995	0	91.765	5800	42000	0.004995	0	52.872
800	92000	0.004995	0	91.664	5810	41900	0.004995	0	52.814
810	91900	0.004995	0	91.563	5820	41800	0.004995	0	52.756
820	91800	0.004995	0	91.463	5830	41700	0.004995	0	52.698
830	91700	0.004995	0	91.362	5840	41600	0.004995	0	52.64
840	91600	0.004995	0	91.261	5850	41500	0.004995	0	52.582
850	91500	0.004995	0	91.161	5860	41400	0.004995	0	52.524
860	91400	0.004995	0	91.061	5870	41300	0.004995	0	52.467
870	91300	0.004995	0	90.961	5880	41200	0.004995	0	52.409
880	91200	0.004995	0	90.861	5890	41100	0.004995	0	52.351
890	91100	0.004995	0	90.761	5900	41000	0.004995	0	52.294
900	91000	0.004995	0	90.661	5910	40900	0.004995	0	52.236
910	90900	0.004995	0	90.561	5920	40800	0.004995	0	52.179
920	90800	0.004995	0	90.462	5930	40700	0.004995	0	52.121
930	90700	0.004995	0	90.362	5940	40600	0.004995	0	52.064
940	90600	0.004995	0	90.263	5950	40500	0.004995	0	52.007
950	90500	0.004995	0	90.163	5960	40400	0.004995	0	51.95
960	90400	0.004995	0	90.064	5970	40300	0.004995	0	51.892
970	90300	0.004995	0	89.965	5980	40200	0.004995	0	51.835
980	90200	0.004995	0	89.866	5990	40100	0.004995	0	51.778
990	90100	0.004995	0	89.767	6000	40000	0.004995	0	51.721
1000	90000	0.004995	0	89.669	6010	39900	0.004995	0	51.664
1010	89900	0.004995	0	89.57	6020	39800	0.004995	0	51.608
1020	89800	0.004995	0	89.471	6030	39700	0.004995	0	51.551
1030	89700	0.004995	0	89.373	6040	39600	0.004995	0	51.494
1040	89600	0.004995	0	89.275	6050	39500	0.004995	0	51.438

Time (years)	Source 1 Unexposed Mass (grams)	Source 1 Mass Transport Rate (g/yr)	Source 2 Outer Barrier Releases (g/yr)	Source 3 Unexposed Mass of Species C (grams)	Time (years)	Source 1 Unexposed Mass (grams)	Source 1 Mass Transport Rate (g/yr)	Source 2 Outer Barrier Releases (g/yr)	Source 3 Unexposed Mass of Species C (grams)
1050	89500	0.004995	0	89.177	**6060**	39400	0.004995	0	51.381
1060	89400	0.004995	0	89.078	**6070**	39300	0.004995	0	51.324
1070	89300	0.004995	0	88.98	**6080**	39200	0.004995	0	51.268
1080	89200	0.004995	0	88.883	**6090**	39100	0.004995	0	51.212
1090	89100	0.004995	0	88.785	**6100**	39000	0.004995	0	51.155
1100	89000	0.004995	0	88.687	**6110**	38900	0.004995	0	51.099
1110	88900	0.004995	0	88.59	**6120**	38800	0.004995	0	51.043
1120	88800	0.004995	0	88.492	**6130**	38700	0.004995	0	50.987
1130	88700	0.004995	0	88.395	**6140**	38600	0.004995	0	50.931
1140	88600	0.004995	0	88.298	**6150**	38500	0.004995	0	50.875
1150	88500	0.004995	0	88.201	**6160**	38400	0.004995	0	50.819
1160	88400	0.004995	0	88.104	**6170**	38300	0.004995	0	50.763
1170	88300	0.004995	0	88.007	**6180**	38200	0.004995	0	50.707
1180	88200	0.004995	0	87.91	**6190**	38100	0.004995	0	50.651
1190	88100	0.004995	0	87.813	**6200**	38000	0.004995	0	50.595
1200	88000	0.004995	0	87.717	**6210**	37900	0.004995	0	50.54
1210	87900	0.004995	0	87.62	**6220**	37800	0.004995	0	50.484
1220	87800	0.004995	0	87.524	**6230**	37700	0.004995	0	50.429
1230	87700	0.004995	0	87.427	**6240**	37600	0.004995	0	50.373
1240	87600	0.004995	0	87.331	**6250**	37500	0.004995	0	50.318
1250	87500	0.004995	0	87.235	**6260**	37400	0.004995	0	50.262
1260	87400	0.004995	0	87.139	**6270**	37300	0.004995	0	50.207
1270	87300	0.004995	0	87.043	**6280**	37200	0.004995	0	50.152
1280	87200	0.004995	0	86.948	**6290**	37100	0.004995	0	50.097
1290	87100	0.004995	0	86.852	**6300**	37000	0.004995	0	50.042
1300	87000	0.004995	0	86.757	**6310**	36900	0.004995	0	49.987
1310	86900	0.004995	0	86.661	**6320**	36800	0.004995	0	49.932
1320	86800	0.004995	0	86.566	**6330**	36700	0.004995	0	49.877
1330	86700	0.004995	0	86.471	**6340**	36600	0.004995	0	49.822
1340	86600	0.004995	0	86.375	**6350**	36500	0.004995	0	49.767
1350	86500	0.004995	0	86.28	**6360**	36400	0.004995	0	49.712
1360	86400	0.004995	0	86.186	**6370**	36300	0.004995	0	49.658
1370	86300	0.004995	0	86.091	**6380**	36200	0.004995	0	49.603
1380	86200	0.004995	0	85.996	**6390**	36100	0.004995	0	49.548
1390	86100	0.004995	0	85.901	**6400**	36000	0.004995	0	49.494
1400	86000	0.004995	0	85.807	**6410**	35900	0.004995	0	49.44
1410	85900	0.004995	0	85.713	**6420**	35800	0.004995	0	49.385
1420	85800	0.004995	0	85.618	**6430**	35700	0.004995	0	49.331

Time (years)	Source 1 Unexposed Mass (grams)	Source 1 Mass Transport Rate (g/yr)	Source 2 Outer Barrier Releases (g/yr)	Source 3 Unexposed Mass of Species C (grams)	Time (years)	Source 1 Unexposed Mass (grams)	Source 1 Mass Transport Rate (g/yr)	Source 2 Outer Barrier Releases (g/yr)	Source 3 Unexposed Mass of Species C (grams)
1430	85700	0.004995	0	85.524	**6440**	35600	0.004995	0	49.277
1440	85600	0.004995	0	85.43	**6450**	35500	0.004995	0	49.222
1450	85500	0.004995	0	85.336	**6460**	35400	0.004995	0	49.168
1460	85400	0.004995	0	85.242	**6470**	35300	0.004995	0	49.114
1470	85300	0.004995	0	85.149	**6480**	35200	0.004995	0	49.06
1480	85200	0.004995	0	85.055	**6490**	35100	0.004995	0	49.006
1490	85100	0.004995	0	84.961	**6500**	35000	0.004995	10	48.952
1500	85000	0.004995	10	84.868	**6510**	34900	0.004995	1.00E-12	48.898
1510	84900	0.004995	1.00E-12	84.775	**6520**	34800	0.004995	0	48.845
1520	84800	0.004995	0	84.681	**6530**	34700	0.004995	0	48.791
1530	84700	0.004995	0	84.588	**6540**	34600	0.004995	0	48.737
1540	84600	0.004995	0	84.495	**6550**	34500	0.004995	0	48.684
1550	84500	0.004995	0	84.402	**6560**	34400	0.004995	0	48.63
1560	84400	0.004995	0	84.309	**6570**	34300	0.004995	0	48.577
1570	84300	0.004995	0	84.217	**6580**	34200	0.004995	0	48.523
1580	84200	0.004995	0	84.124	**6590**	34100	0.004995	0	48.47
1590	84100	0.004995	0	84.031	**6600**	34000	0.004995	0	48.416
1600	84000	0.004995	0	83.939	**6610**	33900	0.004995	0	48.363
1610	83900	0.004995	0	83.847	**6620**	33800	0.004995	0	48.31
1620	83800	0.004995	0	83.754	**6630**	33700	0.004995	0	48.257
1630	83700	0.004995	0	83.662	**6640**	33600	0.004995	0	48.204
1640	83600	0.004995	0	83.57	**6650**	33500	0.004995	0	48.151
1650	83500	0.004995	0	83.478	**6660**	33400	0.004995	0	48.098
1660	83400	0.004995	0	83.387	**6670**	33300	0.004995	0	48.045
1670	83300	0.004995	0	83.295	**6680**	33200	0.004995	0	47.992
1680	83200	0.004995	0	83.203	**6690**	33100	0.004995	0	47.939
1690	83100	0.004995	0	83.112	**6700**	33000	0.004995	0	47.887
1700	83000	0.004995	0	83.02	**6710**	32900	0.004995	0	47.834
1710	82900	0.004995	0	82.929	**6720**	32800	0.004995	0	47.781
1720	82800	0.004995	0	82.838	**6730**	32700	0.004995	0	47.729
1730	82700	0.004995	0	82.747	**6740**	32600	0.004995	0	47.676
1740	82600	0.004995	0	82.656	**6750**	32500	0.004995	0	47.624
1750	82500	0.004995	0	82.565	**6760**	32400	0.004995	0	47.571
1760	82400	0.004995	0	82.474	**6770**	32300	0.004995	0	47.519
1770	82300	0.004995	0	82.383	**6780**	32200	0.004995	0	47.467
1780	82200	0.004995	0	82.293	**6790**	32100	0.004995	0	47.415
1790	82100	0.004995	0	82.202	**6800**	32000	0.004995	0	47.362
1800	82000	0.004995	0	82.112	**6810**	31900	0.004995	0	47.31

Time (years)	Source 1 Unexposed Mass (grams)	Source 1 Mass Transport Rate (g/yr)	Source 2 Outer Barrier Releases (g/yr)	Source 3 Unexposed Mass of Species C (grams)	Time (years)	Source 1 Unexposed Mass (grams)	Source 1 Mass Transport Rate (g/yr)	Source 2 Outer Barrier Releases (g/yr)	Source 3 Unexposed Mass of Species C (grams)
1810	81900	0.004995	0	82.021	**6820**	31800	0.004995	0	47.258
1820	81800	0.004995	0	81.931	**6830**	31700	0.004995	0	47.206
1830	81700	0.004995	0	81.841	**6840**	31600	0.004995	0	47.154
1840	81600	0.004995	0	81.751	**6850**	31500	0.004995	0	47.103
1850	81500	0.004995	0	81.661	**6860**	31400	0.004995	0	47.051
1860	81400	0.004995	0	81.571	**6870**	31300	0.004995	0	46.999
1870	81300	0.004995	0	81.482	**6880**	31200	0.004995	0	46.947
1880	81200	0.004995	0	81.392	**6890**	31100	0.004995	0	46.896
1890	81100	0.004995	0	81.302	**6900**	31000	0.004995	0	46.844
1900	81000	0.004995	0	81.213	**6910**	30900	0.004995	0	46.793
1910	80900	0.004995	0	81.124	**6920**	30800	0.004995	0	46.741
1920	80800	0.004995	0	81.034	**6930**	30700	0.004995	0	46.69
1930	80700	0.004995	0	80.945	**6940**	30600	0.004995	0	46.638
1940	80600	0.004995	0	80.856	**6950**	30500	0.004995	0	46.587
1950	80500	0.004995	0	80.767	**6960**	30400	0.004995	0	46.536
1960	80400	0.004995	0	80.679	**6970**	30300	0.004995	0	46.485
1970	80300	0.004995	0	80.59	**6980**	30200	0.004995	0	46.434
1980	80200	0.004995	0	80.501	**6990**	30100	0.004995	0	46.382
1990	80100	0.004995	0	80.413	**7000**	30000	0.004995	0	46.331
2000	80000	0.004995	0	80.324	**7010**	29900	0.004995	0	46.28
2010	79900	0.004995	0	80.236	**7020**	29800	0.004995	0	46.23
2020	79800	0.004995	0	80.148	**7030**	29700	0.004995	0	46.179
2030	79700	0.004995	0	80.059	**7040**	29600	0.004995	0	46.128
2040	79600	0.004995	0	79.971	**7050**	29500	0.004995	0	46.077
2050	79500	0.004995	0	79.883	**7060**	29400	0.004995	0	46.027
2060	79400	0.004995	0	79.796	**7070**	29300	0.004995	0	45.976
2070	79300	0.004995	0	79.708	**7080**	29200	0.004995	0	45.925
2080	79200	0.004995	0	79.62	**7090**	29100	0.004995	0	45.875
2090	79100	0.004995	0	79.533	**7100**	29000	0.004995	0	45.824
2100	79000	0.004995	0	79.445	**7110**	28900	0.004995	0	45.774
2110	78900	0.004995	0	79.358	**7120**	28800	0.004995	0	45.724
2120	78800	0.004995	0	79.27	**7130**	28700	0.004995	0	45.673
2130	78700	0.004995	0	79.183	**7140**	28600	0.004995	0	45.623
2140	78600	0.004995	0	79.096	**7150**	28500	0.004995	0	45.573
2150	78500	0.004995	0	79.009	**7160**	28400	0.004995	0	45.523
2160	78400	0.004995	0	78.922	**7170**	28300	0.004995	0	45.473
2170	78300	0.004995	0	78.835	**7180**	28200	0.004995	0	45.423
2180	78200	0.004995	0	78.749	**7190**	28100	0.004995	0	45.373

Time (years)	Source 1 Unexposed Mass (grams)	Source 1 Mass Transport Rate (g/yr)	Source 2 Outer Barrier Releases (g/yr)	Source 3 Unexposed Mass of Species C (grams)	Time (years)	Source 1 Unexposed Mass (grams)	Source 1 Mass Transport Rate (g/yr)	Source 2 Outer Barrier Releases (g/yr)	Source 3 Unexposed Mass of Species C (grams)
2190	78100	0.004995	0	78.662	**7200**	28000	0.004995	0	45.323
2200	78000	0.004995	0	78.576	**7210**	27900	0.004995	0	45.273
2210	77900	0.004995	0	78.489	**7220**	27800	0.004995	0	45.223
2220	77800	0.004995	0	78.403	**7230**	27700	0.004995	0	45.173
2230	77700	0.004995	0	78.317	**7240**	27600	0.004995	0	45.124
2240	77600	0.004995	0	78.23	**7250**	27500	0.004995	0	45.074
2250	77500	0.004995	0	78.144	**7260**	27400	0.004995	0	45.025
2260	77400	0.004995	0	78.058	**7270**	27300	0.004995	0	44.975
2270	77300	0.004995	0	77.973	**7280**	27200	0.004995	0	44.926
2280	77200	0.004995	0	77.887	**7290**	27100	0.004995	0	44.876
2290	77100	0.004995	0	77.801	**7300**	27000	0.004995	0	44.827
2300	77000	0.004995	0	77.716	**7310**	26900	0.004995	0	44.777
2310	76900	0.004995	0	77.63	**7320**	26800	0.004995	0	44.728
2320	76800	0.004995	0	77.545	**7330**	26700	0.004995	0	44.679
2330	76700	0.004995	0	77.459	**7340**	26600	0.004995	0	44.63
2340	76600	0.004995	0	77.374	**7350**	26500	0.004995	0	44.581
2350	76500	0.004995	0	77.289	**7360**	26400	0.004995	0	44.532
2360	76400	0.004995	0	77.204	**7370**	26300	0.004995	0	44.483
2370	76300	0.004995	0	77.119	**7380**	26200	0.004995	0	44.434
2380	76200	0.004995	0	77.034	**7390**	26100	0.004995	0	44.385
2390	76100	0.004995	0	76.95	**7400**	26000	0.004995	0	44.336
2400	76000	0.004995	0	76.865	**7410**	25900	0.004995	0	44.287
2410	75900	0.004995	0	76.78	**7420**	25800	0.004995	0	44.239
2420	75800	0.004995	0	76.696	**7430**	25700	0.004995	0	44.19
2430	75700	0.004995	0	76.612	**7440**	25600	0.004995	0	44.141
2440	75600	0.004995	0	76.527	**7450**	25500	0.004995	0	44.093
2450	75500	0.004995	0	76.443	**7460**	25400	0.004995	0	44.044
2460	75400	0.004995	0	76.359	**7470**	25300	0.004995	0	43.996
2470	75300	0.004995	0	76.275	**7480**	25200	0.004995	0	43.948
2480	75200	0.004995	0	76.191	**7490**	25100	0.004995	0	43.899
2490	75100	0.004995	0	76.107	**7500**	25000	0.004995	10	43.851
2500	75000	0.004995	10	76.024	**7510**	24900	0.004995	1.00E-12	43.803
2510	74900	0.004995	1.00E-12	75.94	**7520**	24800	0.004995	0	43.754
2520	74800	0.004995	0	75.857	**7530**	24700	0.004995	0	43.706
2530	74700	0.004995	0	75.773	**7540**	24600	0.004995	0	43.658
2540	74600	0.004995	0	75.69	**7550**	24500	0.004995	0	43.61
2550	74500	0.004995	0	75.607	**7560**	24400	0.004995	0	43.562
2560	74400	0.004995	0	75.523	**7570**	24300	0.004995	0	43.514

Time (years)	Source 1 Unexposed Mass (grams)	Source 1 Mass Transport Rate (g/yr)	Source 2 Outer Barrier Releases (g/yr)	Source 3 Unexposed Mass of Species C (grams)	Time (years)	Source 1 Unexposed Mass (grams)	Source 1 Mass Transport Rate (g/yr)	Source 2 Outer Barrier Releases (g/yr)	Source 3 Unexposed Mass of Species C (grams)
2570	74300	0.004995	0	75.44	**7580**	24200	0.004995	0	43.467
2580	74200	0.004995	0	75.357	**7590**	24100	0.004995	0	43.419
2590	74100	0.004995	0	75.274	**7600**	24000	0.004995	0	43.371
2600	74000	0.004995	0	75.192	**7610**	23900	0.004995	0	43.323
2610	73900	0.004995	0	75.109	**7620**	23800	0.004995	0	43.276
2620	73800	0.004995	0	75.026	**7630**	23700	0.004995	0	43.228
2630	73700	0.004995	0	74.944	**7640**	23600	0.004995	0	43.18
2640	73600	0.004995	0	74.861	**7650**	23500	0.004995	0	43.133
2650	73500	0.004995	0	74.779	**7660**	23400	0.004995	0	43.086
2660	73400	0.004995	0	74.697	**7670**	23300	0.004995	0	43.038
2670	73300	0.004995	0	74.615	**7680**	23200	0.004995	0	42.991
2680	73200	0.004995	0	74.533	**7690**	23100	0.004995	0	42.944
2690	73100	0.004995	0	74.451	**7700**	23000	0.004995	0	42.896
2700	73000	0.004995	0	74.369	**7710**	22900	0.004995	0	42.849
2710	72900	0.004995	0	74.287	**7720**	22800	0.004995	0	42.802
2720	72800	0.004995	0	74.205	**7730**	22700	0.004995	0	42.755
2730	72700	0.004995	0	74.124	**7740**	22600	0.004995	0	42.708
2740	72600	0.004995	0	74.042	**7750**	22500	0.004995	0	42.661
2750	72500	0.004995	0	73.961	**7760**	22400	0.004995	0	42.614
2760	72400	0.004995	0	73.879	**7770**	22300	0.004995	0	42.567
2770	72300	0.004995	0	73.798	**7780**	22200	0.004995	0	42.52
2780	72200	0.004995	0	73.717	**7790**	22100	0.004995	0	42.474
2790	72100	0.004995	0	73.636	**7800**	22000	0.004995	0	42.427
2800	72000	0.004995	0	73.555	**7810**	21900	0.004995	0	42.38
2810	71900	0.004995	0	73.474	**7820**	21800	0.004995	0	42.334
2820	71800	0.004995	0	73.393	**7830**	21700	0.004995	0	42.287
2830	71700	0.004995	0	73.312	**7840**	21600	0.004995	0	42.24
2840	71600	0.004995	0	73.232	**7850**	21500	0.004995	0	42.194
2850	71500	0.004995	0	73.151	**7860**	21400	0.004995	0	42.148
2860	71400	0.004995	0	73.071	**7870**	21300	0.004995	0	42.101
2870	71300	0.004995	0	72.99	**7880**	21200	0.004995	0	42.055
2880	71200	0.004995	0	72.91	**7890**	21100	0.004995	0	42.009
2890	71100	0.004995	0	72.83	**7900**	21000	0.004995	0	41.962
2900	71000	0.004995	0	72.75	**7910**	20900	0.004995	0	41.916
2910	70900	0.004995	0	72.67	**7920**	20800	0.004995	0	41.87
2920	70800	0.004995	0	72.59	**7930**	20700	0.004995	0	41.824
2930	70700	0.004995	0	72.51	**7940**	20600	0.004995	0	41.778
2940	70600	0.004995	0	72.43	**7950**	20500	0.004995	0	41.732

Time (years)	Source 1 Unexposed Mass (grams)	Source 1 Mass Transport Rate (g/yr)	Source 2 Outer Barrier Releases (g/yr)	Source 3 Unexposed Mass of Species C (grams)	Time (years)	Source 1 Unexposed Mass (grams)	Source 1 Mass Transport Rate (g/yr)	Source 2 Outer Barrier Releases (g/yr)	Source 3 Unexposed Mass of Species C (grams)
2950	70500	0.004995	0	72.351	**7960**	20400	0.004995	0	41.686
2960	70400	0.004995	0	72.271	**7970**	20300	0.004995	0	41.64
2970	70300	0.004995	0	72.191	**7980**	20200	0.004995	0	41.595
2980	70200	0.004995	0	72.112	**7990**	20100	0.004995	0	41.549
2990	70100	0.004995	0	72.033	**8000**	20000	0.004995	0	41.503
3000	70000	0.004995	0	71.954	**8010**	19900	0.004995	0	41.458
3010	69900	0.004995	0	71.874	**8020**	19800	0.004995	0	41.412
3020	69800	0.004995	0	71.795	**8030**	19700	0.004995	0	41.366
3030	69700	0.004995	0	71.716	**8040**	19600	0.004995	0	41.321
3040	69600	0.004995	0	71.637	**8050**	19500	0.004995	0	41.275
3050	69500	0.004995	0	71.559	**8060**	19400	0.004995	0	41.23
3060	69400	0.004995	0	71.48	**8070**	19300	0.004995	0	41.185
3070	69300	0.004995	0	71.401	**8080**	19200	0.004995	0	41.139
3080	69200	0.004995	0	71.323	**8090**	19100	0.004995	0	41.094
3090	69100	0.004995	0	71.244	**8100**	19000	0.004995	0	41.049
3100	69000	0.004995	0	71.166	**8110**	18900	0.004995	0	41.004
3110	68900	0.004995	0	71.088	**8120**	18800	0.004995	0	40.959
3120	68800	0.004995	0	71.01	**8130**	18700	0.004995	0	40.914
3130	68700	0.004995	0	70.931	**8140**	18600	0.004995	0	40.869
3140	68600	0.004995	0	70.853	**8150**	18500	0.004995	0	40.824
3150	68500	0.004995	0	70.776	**8160**	18400	0.004995	0	40.779
3160	68400	0.004995	0	70.698	**8170**	18300	0.004995	0	40.734
3170	68300	0.004995	0	70.62	**8180**	18200	0.004995	0	40.689
3180	68200	0.004995	0	70.542	**8190**	18100	0.004995	0	40.644
3190	68100	0.004995	0	70.465	**8200**	18000	0.004995	0	40.6
3200	68000	0.004995	0	70.387	**8210**	17900	0.004995	0	40.555
3210	67900	0.004995	0	70.31	**8220**	17800	0.004995	0	40.51
3220	67800	0.004995	0	70.232	**8230**	17700	0.004995	0	40.466
3230	67700	0.004995	0	70.155	**8240**	17600	0.004995	0	40.421
3240	67600	0.004995	0	70.078	**8250**	17500	0.004995	0	40.377
3250	67500	0.004995	0	70.001	**8260**	17400	0.004995	0	40.332
3260	67400	0.004995	0	69.924	**8270**	17300	0.004995	0	40.288
3270	67300	0.004995	0	69.847	**8280**	17200	0.004995	0	40.244
3280	67200	0.004995	0	69.77	**8290**	17100	0.004995	0	40.2
3290	67100	0.004995	0	69.693	**8300**	17000	0.004995	0	40.155
3300	67000	0.004995	0	69.617	**8310**	16900	0.004995	0	40.111
3310	66900	0.004995	0	69.54	**8320**	16800	0.004995	0	40.067
3320	66800	0.004995	0	69.464	**8330**	16700	0.004995	0	40.023

Time (years)	Source 1 Unexposed Mass (grams)	Source 1 Mass Transport Rate (g/yr)	Source 2 Outer Barrier Releases (g/yr)	Source 3 Unexposed Mass of Species C (grams)	Time (years)	Source 1 Unexposed Mass (grams)	Source 1 Mass Transport Rate (g/yr)	Source 2 Outer Barrier Releases (g/yr)	Source 3 Unexposed Mass of Species C (grams)
3330	66700	0.004995	0	69.387	**8340**	16600	0.004995	0	39.979
3340	66600	0.004995	0	69.311	**8350**	16500	0.004995	0	39.935
3350	66500	0.004995	0	69.235	**8360**	16400	0.004995	0	39.891
3360	66400	0.004995	0	69.159	**8370**	16300	0.004995	0	39.847
3370	66300	0.004995	0	69.083	**8380**	16200	0.004995	0	39.803
3380	66200	0.004995	0	69.007	**8390**	16100	0.004995	0	39.76
3390	66100	0.004995	0	68.931	**8400**	16000	0.004995	0	39.716
3400	66000	0.004995	0	68.855	**8410**	15900	0.004995	0	39.672
3410	65900	0.004995	0	68.779	**8420**	15800	0.004995	0	39.629
3420	65800	0.004995	0	68.703	**8430**	15700	0.004995	0	39.585
3430	65700	0.004995	0	68.628	**8440**	15600	0.004995	0	39.541
3440	65600	0.004995	0	68.552	**8450**	15500	0.004995	0	39.498
3450	65500	0.004995	0	68.477	**8460**	15400	0.004995	0	39.454
3460	65400	0.004995	0	68.402	**8470**	15300	0.004995	0	39.411
3470	65300	0.004995	0	68.326	**8480**	15200	0.004995	0	39.368
3480	65200	0.004995	0	68.251	**8490**	15100	0.004995	0	39.324
3490	65100	0.004995	0	68.176	**8500**	15000	0.004995	10	39.281
3500	65000	0.004995	10	68.101	**8510**	14900	0.004995	1.00E-12	39.238
3510	64900	0.004995	1.00E-12	68.026	**8520**	14800	0.004995	0	39.195
3520	64800	0.004995	0	67.952	**8530**	14700	0.004995	0	39.152
3530	64700	0.004995	0	67.877	**8540**	14600	0.004995	0	39.109
3540	64600	0.004995	0	67.802	**8550**	14500	0.004995	0	39.066
3550	64500	0.004995	0	67.728	**8560**	14400	0.004995	0	39.023
3560	64400	0.004995	0	67.653	**8570**	14300	0.004995	0	38.98
3570	64300	0.004995	0	67.579	**8580**	14200	0.004995	0	38.937
3580	64200	0.004995	0	67.504	**8590**	14100	0.004995	0	38.894
3590	64100	0.004995	0	67.43	**8600**	14000	0.004995	0	38.851
3600	64000	0.004995	0	67.356	**8610**	13900	0.004995	0	38.809
3610	63900	0.004995	0	67.282	**8620**	13800	0.004995	0	38.766
3620	63800	0.004995	0	67.208	**8630**	13700	0.004995	0	38.723
3630	63700	0.004995	0	67.134	**8640**	13600	0.004995	0	38.681
3640	63600	0.004995	0	67.06	**8650**	13500	0.004995	0	38.638
3650	63500	0.004995	0	66.986	**8660**	13400	0.004995	0	38.596
3660	63400	0.004995	0	66.913	**8670**	13300	0.004995	0	38.553
3670	63300	0.004995	0	66.839	**8680**	13200	0.004995	0	38.511
3680	63200	0.004995	0	66.766	**8690**	13100	0.004995	0	38.468
3690	63100	0.004995	0	66.692	**8700**	13000	0.004995	0	38.426
3700	63000	0.004995	0	66.619	**8710**	12900	0.004995	0	38.384

Time (years)	Source 1 Unexposed Mass (grams)	Source 1 Mass Transport Rate (g/yr)	Source 2 Outer Barrier Releases (g/yr)	Source 3 Unexposed Mass of Species C (grams)	Time (years)	Source 1 Unexposed Mass (grams)	Source 1 Mass Transport Rate (g/yr)	Source 2 Outer Barrier Releases (g/yr)	Source 3 Unexposed Mass of Species C (grams)
4090	59100	0.004995	0	63.82	**9100**	9000	0.004995	0	36.771
4100	59000	0.004995	0	63.75	**9110**	8900	0.004995	0	36.731
4110	58900	0.004995	0	63.68	**9120**	8800	0.004995	0	36.69
4120	58800	0.004995	0	63.61	**9130**	8700	0.004995	0	36.65
4130	58700	0.004995	0	63.54	**9140**	8600	0.004995	0	36.61
4140	58600	0.004995	0	63.47	**9150**	8500	0.004995	0	36.569
4150	58500	0.004995	0	63.4	**9160**	8400	0.004995	0	36.529
4160	58400	0.004995	0	63.33	**9170**	8300	0.004995	0	36.489
4170	58300	0.004995	0	63.261	**9180**	8200	0.004995	0	36.449
4180	58200	0.004995	0	63.191	**9190**	8100	0.004995	0	36.409
4190	58100	0.004995	0	63.121	**9200**	8000	0.004995	0	36.369
4200	58000	0.004995	0	63.052	**9210**	7900	0.004995	0	36.329
4210	57900	0.004995	0	62.983	**9220**	7800	0.004995	0	36.289
4220	57800	0.004995	0	62.913	**9230**	7700	0.004995	0	36.249
4230	57700	0.004995	0	62.844	**9240**	7600	0.004995	0	36.209
4240	57600	0.004995	0	62.775	**9250**	7500	0.004995	0	36.169
4250	57500	0.004995	0	62.706	**9260**	7400	0.004995	0	36.129
4260	57400	0.004995	0	62.637	**9270**	7300	0.004995	0	36.09
4270	57300	0.004995	0	62.568	**9280**	7200	0.004995	0	36.05
4280	57200	0.004995	0	62.499	**9290**	7100	0.004995	0	36.01
4290	57100	0.004995	0	62.431	**9300**	7000	0.004995	0	35.971
4300	57000	0.004995	0	62.362	**9310**	6900	0.004995	0	35.931
4310	56900	0.004995	0	62.293	**9320**	6800	0.004995	0	35.892
4320	56800	0.004995	0	62.225	**9330**	6700	0.004995	0	35.852
4330	56700	0.004995	0	62.156	**9340**	6600	0.004995	0	35.813
4340	56600	0.004995	0	62.088	**9350**	6500	0.004995	0	35.773
4350	56500	0.004995	0	62.02	**9360**	6400	0.004995	0	35.734
4360	56400	0.004995	0	61.952	**9370**	6300	0.004995	0	35.695
4370	56300	0.004995	0	61.883	**9380**	6200	0.004995	0	35.655
4380	56200	0.004995	0	61.815	**9390**	6100	0.004995	0	35.616
4390	56100	0.004995	0	61.747	**9400**	6000	0.004995	0	35.577
4400	56000	0.004995	0	61.679	**9410**	5900	0.004995	0	35.538
4410	55900	0.004995	0	61.612	**9420**	5800	0.004995	0	35.499
4420	55800	0.004995	0	61.544	**9430**	5700	0.004995	0	35.46
4430	55700	0.004995	0	61.476	**9440**	5600	0.004995	0	35.421
4440	55600	0.004995	0	61.409	**9450**	5500	0.004995	0	35.382
4450	55500	0.004995	0	61.341	**9460**	5400	0.004995	0	35.343
4460	55400	0.004995	0	61.274	**9470**	5300	0.004995	0	35.304

Time (years)	Source 1 Unexposed Mass (grams)	Source 1 Mass Transport Rate (g/yr)	Source 2 Outer Barrier Releases (g/yr)	Source 3 Unexposed Mass of Species C (grams)	Time (years)	Source 1 Unexposed Mass (grams)	Source 1 Mass Transport Rate (g/yr)	Source 2 Outer Barrier Releases (g/yr)	Source 3 Unexposed Mass of Species C (grams)
4470	55300	0.004995	0	61.206	**9480**	5200	0.004995	0	35.265
4480	55200	0.004995	0	61.139	**9490**	5100	0.004995	0	35.226
4490	55100	0.004995	0	61.072	**9500**	5000	0.004995	10	35.188
4500	55000	0.004995	10	61.004	**9510**	4900	0.004995	1.00E-12	35.149
4510	54900	0.004995	1.00E-12	60.937	**9520**	4800	0.004995	0	35.11
4520	54800	0.004995	0	60.87	**9530**	4700	0.004995	0	35.072
4530	54700	0.004995	0	60.803	**9540**	4600	0.004995	0	35.033
4540	54600	0.004995	0	60.736	**9550**	4500	0.004995	0	34.995
4550	54500	0.004995	0	60.67	**9560**	4400	0.004995	0	34.956
4560	54400	0.004995	0	60.603	**9570**	4300	0.004995	0	34.918
4570	54300	0.004995	0	60.536	**9580**	4200	0.004995	0	34.879
4580	54200	0.004995	0	60.47	**9590**	4100	0.004995	0	34.841
4590	54100	0.004995	0	60.403	**9600**	4000	0.004995	0	34.803
4600	54000	0.004995	0	60.337	**9610**	3900	0.004995	0	34.764
4610	53900	0.004995	0	60.27	**9620**	3800	0.004995	0	34.726
4620	53800	0.004995	0	60.204	**9630**	3700	0.004995	0	34.688
4630	53700	0.004995	0	60.138	**9640**	3600	0.004995	0	34.65
4640	53600	0.004995	0	60.072	**9650**	3500	0.004995	0	34.612
4650	53500	0.004995	0	60.006	**9660**	3400	0.004995	0	34.573
4660	53400	0.004995	0	59.94	**9670**	3300	0.004995	0	34.535
4670	53300	0.004995	0	59.874	**9680**	3200	0.004995	0	34.497
4680	53200	0.004995	0	59.808	**9690**	3100	0.004995	0	34.46
4690	53100	0.004995	0	59.742	**9700**	3000	0.004995	0	34.422
4700	53000	0.004995	0	59.676	**9710**	2900	0.004995	0	34.384
4710	52900	0.004995	0	59.611	**9720**	2800	0.004995	0	34.346
4720	52800	0.004995	0	59.545	**9730**	2700	0.004995	0	34.308
4730	52700	0.004995	0	59.48	**9740**	2600	0.004995	0	34.27
4740	52600	0.004995	0	59.414	**9750**	2500	0.004995	0	34.233
4750	52500	0.004995	0	59.349	**9760**	2400	0.004995	0	34.195
4760	52400	0.004995	0	59.284	**9770**	2300	0.004995	0	34.157
4770	52300	0.004995	0	59.218	**9780**	2200	0.004995	0	34.12
4780	52200	0.004995	0	59.153	**9790**	2100	0.004995	0	34.082
4790	52100	0.004995	0	59.088	**9800**	2000	0.004995	0	34.045
4800	52000	0.004995	0	59.023	**9810**	1900	0.004995	0	34.007
4810	51900	0.004995	0	58.958	**9820**	1800	0.004995	0	33.97
4820	51800	0.004995	0	58.893	**9830**	1700	0.004995	0	33.933
4830	51700	0.004995	0	58.829	**9840**	1600	0.004995	0	33.895
4840	51600	0.004995	0	58.764	**9850**	1500	0.004995	0	33.858

Time (years)	Source 1 Unexposed Mass (grams)	Source 1 Mass Transport Rate (g/yr)	Source 2 Outer Barrier Releases (g/yr)	Source 3 Unexposed Mass of Species C (grams)	Time (years)	Source 1 Unexposed Mass (grams)	Source 1 Mass Transport Rate (g/yr)	Source 2 Outer Barrier Releases (g/yr)	Source 3 Unexposed Mass of Species C (grams)
4850	51500	0.004995	0	58.699	**9860**	1400	0.004995	0	33.821
4860	51400	0.004995	0	58.635	**9870**	1300	0.004995	0	33.784
4870	51300	0.004995	0	58.57	**9880**	1200	0.004995	0	33.746
4880	51200	0.004995	0	58.506	**9890**	1100	0.004995	0	33.709
4890	51100	0.004995	0	58.441	**9900**	1000	0.004995	0	33.672
4900	51000	0.004995	0	58.377	**9910**	900	0.004995	0	33.635
4910	50900	0.004995	0	58.313	**9920**	800	0.004995	0	33.598
4920	50800	0.004995	0	58.249	**9930**	700	0.004995	0	33.561
4930	50700	0.004995	0	58.185	**9940**	600	0.004995	0	33.524
4940	50600	0.004995	0	58.121	**9950**	500	0.004995	0	33.488
4950	50500	0.004995	0	58.057	**9960**	400	0.004995	0	33.451
4960	50400	0.004995	0	57.993	**9970**	300	0.004995	0	33.414
4970	50300	0.004995	0	57.929	**9980**	200	0.004995	0	33.377
4980	50200	0.004995	0	57.866	**9990**	100	0.004995	0	33.34
4990	50100	0.004995	0	57.802	**10000**	0	0.004995	0	33.304
5000	50000	0.004995	0	57.738					

Attachment IV Results for VTP Test 4, Dose Rate

This Attachment lists the GoldSim results for VTP Test 4, Calculation of Dose Rate. This test requires that GoldSim calculate the total dose rate to an individual from two different radioactive species. The results are given below for a 10,000 year simulation with 10 year time steps.

Time (years)	Total Dose Rate (rem/year)	Time (years)	Total Dose Rate (rem/year)	Time (years)	Total Dose Rate (rem/year)	Time (years)	Total Dose Rate (rem/year)
0	8.00E+05	2510	1.82E+05	5020	69841	7530	31605
10	7.94E+05	2520	1.81E+05	5030	69609	7540	31508
20	7.88E+05	2530	1.80E+05	5040	69378	7550	31412
30	7.83E+05	2540	1.79E+05	5050	69147	7560	31316
40	7.77E+05	2550	1.79E+05	5060	68918	7570	31221
50	7.71E+05	2560	1.78E+05	5070	68689	7580	31125
60	7.66E+05	2570	1.77E+05	5080	68462	7590	31030
70	7.60E+05	2580	1.76E+05	5090	68235	7600	30936
80	7.54E+05	2590	1.75E+05	5100	68009	7610	30841
90	7.49E+05	2600	1.75E+05	5110	67784	7620	30747
100	7.44E+05	2610	1.74E+05	5120	67560	7630	30653
110	7.38E+05	2620	1.73E+05	5130	67337	7640	30560
120	7.33E+05	2630	1.72E+05	5140	67115	7650	30467
130	7.28E+05	2640	1.72E+05	5150	66893	7660	30374
140	7.22E+05	2650	1.71E+05	5160	66673	7670	30281
150	7.17E+05	2660	1.70E+05	5170	66453	7680	30189
160	7.12E+05	2670	1.69E+05	5180	66234	7690	30097
170	7.07E+05	2680	1.69E+05	5190	66016	7700	30005
180	7.02E+05	2690	1.68E+05	5200	65799	7710	29913
190	6.97E+05	2700	1.67E+05	5210	65583	7720	29822
200	6.92E+05	2710	1.66E+05	5220	65368	7730	29731
210	6.87E+05	2720	1.66E+05	5230	65153	7740	29641
220	6.82E+05	2730	1.65E+05	5240	64939	7750	29551
230	6.77E+05	2740	1.64E+05	5250	64726	7760	29460
240	6.72E+05	2750	1.63E+05	5260	64514	7770	29371
250	6.68E+05	2760	1.63E+05	5270	64303	7780	29281
260	6.63E+05	2770	1.62E+05	5280	64092	7790	29192
270	6.58E+05	2780	1.61E+05	5290	63883	7800	29103
280	6.54E+05	2790	1.61E+05	5300	63674	7810	29015
290	6.49E+05	2800	1.60E+05	5310	63466	7820	28926
300	6.45E+05	2810	1.59E+05	5320	63258	7830	28838
310	6.40E+05	2820	1.59E+05	5330	63052	7840	28751
320	6.36E+05	2830	1.58E+05	5340	62846	7850	28663
330	6.31E+05	2840	1.57E+05	5350	62641	7860	28576
340	6.27E+05	2850	1.57E+05	5360	62437	7870	28489

Time (years)	Total Dose Rate (rem/year)	Time (years)	Total Dose Rate (rem/year)	Time (years)	Total Dose Rate (rem/year)	Time (years)	Total Dose Rate (rem/year)
350	6.22E+05	2860	1.56E+05	5370	62234	7880	28402
360	6.18E+05	2870	1.55E+05	5380	62031	7890	28316
370	6.14E+05	2880	1.55E+05	5390	61829	7900	28230
380	6.10E+05	2890	1.54E+05	5400	61628	7910	28144
390	6.05E+05	2900	1.53E+05	5410	61428	7920	28058
400	6.01E+05	2910	1.53E+05	5420	61228	7930	27973
410	5.97E+05	2920	1.52E+05	5430	61029	7940	27888
420	5.93E+05	2930	1.51E+05	5440	60831	7950	27803
430	5.89E+05	2940	1.51E+05	5450	60634	7960	27719
440	5.85E+05	2950	1.50E+05	5460	60437	7970	27634
450	5.81E+05	2960	1.49E+05	5470	60242	7980	27550
460	5.77E+05	2970	1.49E+05	5480	60047	7990	27467
470	5.73E+05	2980	1.48E+05	5490	59852	8000	27383
480	5.69E+05	2990	1.47E+05	5500	59659	8010	27300
490	5.65E+05	3000	1.47E+05	5510	59466	8020	27217
500	5.61E+05	3010	1.46E+05	5520	59273	8030	27134
510	5.58E+05	3020	1.46E+05	5530	59082	8040	27052
520	5.54E+05	3030	1.45E+05	5540	58891	8050	26970
530	5.50E+05	3040	1.44E+05	5550	58701	8060	26888
540	5.47E+05	3050	1.44E+05	5560	58512	8070	26806
550	5.43E+05	3060	1.43E+05	5570	58323	8080	26725
560	5.39E+05	3070	1.43E+05	5580	58135	8090	26644
570	5.36E+05	3080	1.42E+05	5590	57948	8100	26563
580	5.32E+05	3090	1.41E+05	5600	57761	8110	26482
590	5.29E+05	3100	1.41E+05	5610	57575	8120	26402
600	5.25E+05	3110	1.40E+05	5620	57390	8130	26322
610	5.22E+05	3120	1.40E+05	5630	57206	8140	26242
620	5.18E+05	3130	1.39E+05	5640	57022	8150	26162
630	5.15E+05	3140	1.39E+05	5650	56839	8160	26083
640	5.11E+05	3150	1.38E+05	5660	56656	8170	26004
650	5.08E+05	3160	1.37E+05	5670	56474	8180	25925
660	5.05E+05	3170	1.37E+05	5680	56293	8190	25846
670	5.01E+05	3180	1.36E+05	5690	56113	8200	25768
680	4.98E+05	3190	1.36E+05	5700	55933	8210	25690
690	4.95E+05	3200	1.35E+05	5710	55754	8220	25612
700	4.91E+05	3210	1.35E+05	5720	55575	8230	25534
710	4.88E+05	3220	1.34E+05	5730	55397	8240	25457
720	4.85E+05	3230	1.34E+05	5740	55220	8250	25380
730	4.82E+05	3240	1.33E+05	5750	55043	8260	25303
740	4.79E+05	3250	1.33E+05	5760	54868	8270	25226

Time (years)	Total Dose Rate (rem/year)	Time (years)	Total Dose Rate (rem/year)	Time (years)	Total Dose Rate (rem/year)	Time (years)	Total Dose Rate (rem/year)
750	4.76E+05	3260	1.32E+05	5770	54692	8280	25150
760	4.73E+05	3270	1.31E+05	5780	54518	8290	25073
770	4.70E+05	3280	1.31E+05	5790	54343	8300	24997
780	4.67E+05	3290	1.30E+05	5800	54170	8310	24922
790	4.64E+05	3300	1.30E+05	5810	53997	8320	24846
800	4.61E+05	3310	1.29E+05	5820	53825	8330	24771
810	4.58E+05	3320	1.29E+05	5830	53654	8340	24696
820	4.55E+05	3330	1.28E+05	5840	53483	8350	24621
830	4.52E+05	3340	1.28E+05	5850	53312	8360	24546
840	4.49E+05	3350	1.27E+05	5860	53143	8370	24472
850	4.46E+05	3360	1.27E+05	5870	52973	8380	24398
860	4.43E+05	3370	1.26E+05	5880	52805	8390	24324
870	4.41E+05	3380	1.26E+05	5890	52637	8400	24250
880	4.38E+05	3390	1.25E+05	5900	52470	8410	24177
890	4.35E+05	3400	1.25E+05	5910	52303	8420	24104
900	4.32E+05	3410	1.24E+05	5920	52137	8430	24031
910	4.30E+05	3420	1.24E+05	5930	51971	8440	23958
920	4.27E+05	3430	1.23E+05	5940	51807	8450	23886
930	4.24E+05	3440	1.23E+05	5950	51642	8460	23813
940	4.22E+05	3450	1.22E+05	5960	51478	8470	23741
950	4.19E+05	3460	1.22E+05	5970	51315	8480	23669
960	4.16E+05	3470	1.21E+05	5980	51153	8490	23598
970	4.14E+05	3480	1.21E+05	5990	50991	8500	23526
980	4.11E+05	3490	1.21E+05	6000	50829	8510	23455
990	4.09E+05	3500	1.20E+05	6010	50668	8520	23384
1000	4.06E+05	3510	1.20E+05	6020	50508	8530	23313
1010	4.04E+05	3520	1.19E+05	6030	50348	8540	23243
1020	4.01E+05	3530	1.19E+05	6040	50189	8550	23173
1030	3.99E+05	3540	1.18E+05	6050	50030	8560	23103
1040	3.96E+05	3550	1.18E+05	6060	49872	8570	23033
1050	3.94E+05	3560	1.17E+05	6070	49715	8580	22963
1060	3.92E+05	3570	1.17E+05	6080	49558	8590	22894
1070	3.89E+05	3580	1.16E+05	6090	49402	8600	22824
1080	3.87E+05	3590	1.16E+05	6100	49246	8610	22755
1090	3.84E+05	3600	1.16E+05	6110	49090	8620	22687
1100	3.82E+05	3610	1.15E+05	6120	48936	8630	22618
1110	3.80E+05	3620	1.15E+05	6130	48781	8640	22550
1120	3.78E+05	3630	1.14E+05	6140	48628	8650	22481
1130	3.75E+05	3640	1.14E+05	6150	48475	8660	22413
1140	3.73E+05	3650	1.13E+05	6160	48322	8670	22346

Time (years)	Total Dose Rate (rem/year)	Time (years)	Total Dose Rate (rem/year)	Time (years)	Total Dose Rate (rem/year)	Time (years)	Total Dose Rate (rem/year)
1150	3.71E+05	**3660**	1.13E+05	**6170**	48170	**8680**	22278
1160	3.69E+05	**3670**	1.13E+05	**6180**	48018	**8690**	22211
1170	3.66E+05	**3680**	1.12E+05	**6190**	47867	**8700**	22144
1180	3.64E+05	**3690**	1.12E+05	**6200**	47717	**8710**	22077
1190	3.62E+05	**3700**	1.11E+05	**6210**	47567	**8720**	22010
1200	3.60E+05	**3710**	1.11E+05	**6220**	47417	**8730**	21944
1210	3.58E+05	**3720**	1.10E+05	**6230**	47268	**8740**	21877
1220	3.56E+05	**3730**	1.10E+05	**6240**	47120	**8750**	21811
1230	3.54E+05	**3740**	1.10E+05	**6250**	46972	**8760**	21745
1240	3.52E+05	**3750**	1.09E+05	**6260**	46824	**8770**	21680
1250	3.49E+05	**3760**	1.09E+05	**6270**	46678	**8780**	21614
1260	3.47E+05	**3770**	1.08E+05	**6280**	46531	**8790**	21549
1270	3.45E+05	**3780**	1.08E+05	**6290**	46385	**8800**	21484
1280	3.43E+05	**3790**	1.08E+05	**6300**	46240	**8810**	21419
1290	3.41E+05	**3800**	1.07E+05	**6310**	46095	**8820**	21354
1300	3.39E+05	**3810**	1.07E+05	**6320**	45951	**8830**	21290
1310	3.37E+05	**3820**	1.06E+05	**6330**	45807	**8840**	21226
1320	3.35E+05	**3830**	1.06E+05	**6340**	45663	**8850**	21161
1330	3.34E+05	**3840**	1.06E+05	**6350**	45520	**8860**	21098
1340	3.32E+05	**3850**	1.05E+05	**6360**	45378	**8870**	21034
1350	3.30E+05	**3860**	1.05E+05	**6370**	45236	**8880**	20970
1360	3.28E+05	**3870**	1.04E+05	**6380**	45094	**8890**	20907
1370	3.26E+05	**3880**	1.04E+05	**6390**	44954	**8900**	20844
1380	3.24E+05	**3890**	1.04E+05	**6400**	44813	**8910**	20781
1390	3.22E+05	**3900**	1.03E+05	**6410**	44673	**8920**	20718
1400	3.20E+05	**3910**	1.03E+05	**6420**	44533	**8930**	20656
1410	3.19E+05	**3920**	1.02E+05	**6430**	44394	**8940**	20593
1420	3.17E+05	**3930**	1.02E+05	**6440**	44256	**8950**	20531
1430	3.15E+05	**3940**	1.02E+05	**6450**	44118	**8960**	20469
1440	3.13E+05	**3950**	1.01E+05	**6460**	43980	**8970**	20408
1450	3.11E+05	**3960**	1.01E+05	**6470**	43843	**8980**	20346
1460	3.10E+05	**3970**	1.01E+05	**6480**	43706	**8990**	20285
1470	3.08E+05	**3980**	1.00E+05	**6490**	43570	**9000**	20223
1480	3.06E+05	**3990**	99880	**6500**	43434	**9010**	20162
1490	3.05E+05	**4000**	99516	**6510**	43299	**9020**	20102
1500	3.03E+05	**4010**	99155	**6520**	43164	**9030**	20041
1510	3.01E+05	**4020**	98795	**6530**	43029	**9040**	19981
1520	3.00E+05	**4030**	98436	**6540**	42895	**9050**	19920
1530	2.98E+05	**4040**	98080	**6550**	42762	**9060**	19860
1540	2.96E+05	**4050**	97725	**6560**	42629	**9070**	19800

Time (years)	Total Dose Rate (rem/year)	Time (years)	Total Dose Rate (rem/year)	Time (years)	Total Dose Rate (rem/year)	Time (years)	Total Dose Rate (rem/year)
1550	2.95E+05	**4060**	97371	**6570**	42496	**9080**	19741
1560	2.93E+05	**4070**	97020	**6580**	42364	**9090**	19681
1570	2.91E+05	**4080**	96670	**6590**	42232	**9100**	19622
1580	2.90E+05	**4090**	96321	**6600**	42101	**9110**	19563
1590	2.88E+05	**4100**	95974	**6610**	41970	**9120**	19504
1600	2.87E+05	**4110**	95629	**6620**	41840	**9130**	19445
1610	2.85E+05	**4120**	95286	**6630**	41710	**9140**	19386
1620	2.83E+05	**4130**	94944	**6640**	41580	**9150**	19328
1630	2.82E+05	**4140**	94604	**6650**	41451	**9160**	19269
1640	2.80E+05	**4150**	94265	**6660**	41323	**9170**	19211
1650	2.79E+05	**4160**	93928	**6670**	41194	**9180**	19153
1660	2.77E+05	**4170**	93592	**6680**	41067	**9190**	19096
1670	2.76E+05	**4180**	93258	**6690**	40939	**9200**	19038
1680	2.74E+05	**4190**	92925	**6700**	40812	**9210**	18981
1690	2.73E+05	**4200**	92594	**6710**	40686	**9220**	18924
1700	2.71E+05	**4210**	92265	**6720**	40560	**9230**	18867
1710	2.70E+05	**4220**	91937	**6730**	40434	**9240**	18810
1720	2.69E+05	**4230**	91610	**6740**	40309	**9250**	18753
1730	2.67E+05	**4240**	91285	**6750**	40184	**9260**	18696
1740	2.66E+05	**4250**	90962	**6760**	40059	**9270**	18640
1750	2.64E+05	**4260**	90640	**6770**	39935	**9280**	18584
1760	2.63E+05	**4270**	90319	**6780**	39812	**9290**	18528
1770	2.62E+05	**4280**	90000	**6790**	39688	**9300**	18472
1780	2.60E+05	**4290**	89682	**6800**	39566	**9310**	18417
1790	2.59E+05	**4300**	89366	**6810**	39443	**9320**	18361
1800	2.57E+05	**4310**	89051	**6820**	39321	**9330**	18306
1810	2.56E+05	**4320**	88737	**6830**	39200	**9340**	18251
1820	2.55E+05	**4330**	88425	**6840**	39078	**9350**	18196
1830	2.53E+05	**4340**	88115	**6850**	38958	**9360**	18141
1840	2.52E+05	**4350**	87805	**6860**	38837	**9370**	18086
1850	2.51E+05	**4360**	87498	**6870**	38717	**9380**	18032
1860	2.50E+05	**4370**	87191	**6880**	38598	**9390**	17977
1870	2.48E+05	**4380**	86886	**6890**	38479	**9400**	17923
1880	2.47E+05	**4390**	86582	**6900**	38360	**9410**	17869
1890	2.46E+05	**4400**	86280	**6910**	38241	**9420**	17815
1900	2.44E+05	**4410**	85978	**6920**	38123	**9430**	17762
1910	2.43E+05	**4420**	85679	**6930**	38006	**9440**	17708
1920	2.42E+05	**4430**	85380	**6940**	37888	**9450**	17655
1930	2.41E+05	**4440**	85083	**6950**	37772	**9460**	17602
1940	2.39E+05	**4450**	84787	**6960**	37655	**9470**	17549

Time (years)	Total Dose Rate (rem/year)	Time (years)	Total Dose Rate (rem/year)	Time (years)	Total Dose Rate (rem/year)	Time (years)	Total Dose Rate (rem/year)
1950	2.38E+05	4460	84492	6970	37539	9480	17496
1960	2.37E+05	4470	84199	6980	37423	9490	17443
1970	2.36E+05	4480	83907	6990	37308	9500	17391
1980	2.35E+05	4490	83616	7000	37193	9510	17338
1990	2.33E+05	4500	83327	7010	37078	9520	17286
2000	2.32E+05	4510	83039	7020	36964	9530	17234
2010	2.31E+05	4520	82752	7030	36850	9540	17182
2020	2.30E+05	4530	82466	7040	36737	9550	17131
2030	2.29E+05	4540	82181	7050	36624	9560	17079
2040	2.28E+05	4550	81898	7060	36511	9570	17028
2050	2.27E+05	4560	81616	7070	36399	9580	16976
2060	2.25E+05	4570	81335	7080	36287	9590	16925
2070	2.24E+05	4580	81055	7090	36175	9600	16874
2080	2.23E+05	4590	80777	7100	36064	9610	16824
2090	2.22E+05	4600	80500	7110	35953	9620	16773
2100	2.21E+05	4610	80224	7120	35842	9630	16722
2110	2.20E+05	4620	79949	7130	35732	9640	16672
2120	2.19E+05	4630	79675	7140	35622	9650	16622
2130	2.18E+05	4640	79402	7150	35513	9660	16572
2140	2.17E+05	4650	79131	7160	35404	9670	16522
2150	2.16E+05	4660	78861	7170	35295	9680	16472
2160	2.15E+05	4670	78592	7180	35187	9690	16423
2170	2.14E+05	4680	78324	7190	35079	9700	16373
2180	2.13E+05	4690	78057	7200	34971	9710	16324
2190	2.11E+05	4700	77791	7210	34864	9720	16275
2200	2.10E+05	4710	77526	7220	34757	9730	16226
2210	2.09E+05	4720	77263	7230	34650	9740	16177
2220	2.08E+05	4730	77000	7240	34544	9750	16129
2230	2.07E+05	4740	76739	7250	34438	9760	16080
2240	2.06E+05	4750	76479	7260	34332	9770	16032
2250	2.05E+05	4760	76219	7270	34227	9780	15984
2260	2.04E+05	4770	75961	7280	34122	9790	15935
2270	2.03E+05	4780	75704	7290	34017	9800	15888
2280	2.03E+05	4790	75448	7300	33913	9810	15840
2290	2.02E+05	4800	75193	7310	33809	9820	15792
2300	2.01E+05	4810	74940	7320	33705	9830	15745
2310	2.00E+05	4820	74687	7330	33602	9840	15697
2320	1.99E+05	4830	74435	7340	33499	9850	15650
2330	1.98E+05	4840	74184	7350	33397	9860	15603
2340	1.97E+05	4850	73935	7360	33294	9870	15556

Time (years)	Total Dose Rate (rem/year)	Time (years)	Total Dose Rate (rem/year)	Time (years)	Total Dose Rate (rem/year)	Time (years)	Total Dose Rate (rem/year)
2350	1.96E+05	4860	73686	7370	33192	9880	15509
2360	1.95E+05	4870	73438	7380	33091	9890	15463
2370	1.94E+05	4880	73192	7390	32989	9900	15416
2380	1.93E+05	4890	72946	7400	32888	9910	15370
2390	1.92E+05	4900	72701	7410	32788	9920	15324
2400	1.91E+05	4910	72458	7420	32688	9930	15278
2410	1.91E+05	4920	72215	7430	32588	9940	15232
2420	1.90E+05	4930	71973	7440	32488	9950	15186
2430	1.89E+05	4940	71732	7450	32388	9960	15140
2440	1.88E+05	4950	71493	7460	32289	9970	15095
2450	1.87E+05	4960	71254	7470	32191	9980	15049
2460	1.86E+05	4970	71016	7480	32092	9990	15004
2470	1.85E+05	4980	70779	7490	31994	10000	14959
2480	1.84E+05	4990	70543	7500	31896		
2490	1.84E+05	5000	70308	7510	31799		
2500	1.83E+05	5010	70074	7520	31702		

Attachment V Results for Test 5, Stochastic Parameters

This attachment contains the GoldSim results from VTP Test 5 (Stochastic Parameters). The first set of results is the test of the GoldSim correlation function. Two normal distributions ("Normal1" and "Normal2") are defined as fully correlated. "Normal1" is defined with a mean of zero and a standard deviation of one, and "Normal2" is defined with a mean of 1 and a standard deviation of one. The simulation is run for 100 realizations. The acceptance criterion for this test is that the value of "Normal2" should be equal to the value of "Normal1" + 1 for all 100 realizations.

The second set of results tests the ability of GoldSim to output the time histories from a multiple realization run to an ASCII file. These results are shown in the right half of the table below for a parameter defined with a uniform distribution.

	Results of Distribution Correlation		ASCII File Creation Time History Results		
Realization	Normal1	Normal2	0	0.5	1
1	-0.63019	0.36981	0.3958	0.3958	0.3958
2	1.925	2.925	0.69158	0.69158	0.69158
3	-0.2553	0.7447	0.851	0.851	0.851
4	0.51945	1.5195	0.74311	0.74311	0.74311
5	1.0542	2.0542	0.47739	0.47739	0.47739
6	0.64377	1.6438	0.80056	0.80056	0.80056
7	-0.05571	0.94429	0.005464	0.005464	0.005464
8	0.84755	1.8476	0.45277	0.45277	0.45277
9	-2.4453	-1.4453	0.6133	0.6133	0.6133
10	-0.10812	0.89188	0.78313	0.78313	0.78313
11	0.29958	1.2996	0.75036	0.75036	0.75036
12	0.79132	1.7913	0.2405	0.2405	0.2405
13	0.67633	1.6763	0.49438	0.49438	0.49438
14	-0.70149	0.29851	0.46263	0.46263	0.46263
15	-0.00902	0.99098	0.9451	0.9451	0.9451
16	-0.08443	0.91557	0.96773	0.96773	0.96773
17	1.6	2.6	0.31549	0.31549	0.31549
18	1.8287	2.8287	0.36055	0.36055	0.36055
19	-0.48988	0.51012	0.92153	0.92153	0.92153
20	-0.34377	0.65623	0.41309	0.41309	0.41309
21	1.4127	2.4127	0.18563	0.18563	0.18563
22	-0.22206	0.77794	0.83381	0.83381	0.83381
23	-0.91105	0.088945	0.11856	0.11856	0.11856
24	0.96491	1.9649	0.27311	0.27311	0.27311
25	-1.1797	-0.17968	0.3748	0.3748	0.3748
26	-0.58286	0.41714	0.15854	0.15854	0.15854
27	-0.32028	0.67972	0.71736	0.71736	0.71736

	Results of Distribution Correlation		ASCII File Creation Time History Results		
Realization	Normal1	Normal2	0	0.5	1
28	-1.0098	-0.00984	0.35636	0.35636	0.35636
29	0.57434	1.5743	0.95349	0.95349	0.95349
30	-0.37409	0.62591	0.89665	0.89665	0.89665
31	1.6572	2.6572	0.088066	0.088066	0.088066
32	1.2794	2.2794	0.68185	0.68185	0.68185
33	-1.3913	-0.3913	0.93357	0.93357	0.93357
34	0.46785	1.4679	0.1756	0.1756	0.1756
35	1.5128	2.5128	0.54955	0.54955	0.54955
36	-0.93503	0.064969	0.2981	0.2981	0.2981
37	0.1051	1.1051	0.76934	0.76934	0.76934
38	-0.53155	0.46845	0.015893	0.015893	0.015893
39	0.70872	1.7087	0.87581	0.87581	0.87581
40	-2.0598	-1.0598	0.40201	0.40201	0.40201
41	1.1531	2.1531	0.64493	0.64493	0.64493
42	-0.23875	0.76125	0.59678	0.59678	0.59678
43	0.3609	1.3609	0.9984	0.9984	0.9984
44	0.24807	1.2481	0.10171	0.10171	0.10171
45	2.5473	3.5473	0.13052	0.13052	0.13052
46	-1.2609	-0.26086	0.56622	0.56622	0.56622
47	-1.1113	-0.11135	0.093211	0.093211	0.093211
48	0.16499	1.165	0.05749	0.05749	0.05749
49	-1.3316	-0.33161	0.777	0.777	0.777
50	-1.5809	-0.5809	0.44667	0.44667	0.44667
51	0.7668	1.7668	0.52762	0.52762	0.52762
52	-0.14942	0.85058	0.25605	0.25605	0.25605
53	0.050302	1.0503	0.9122	0.9122	0.9122
54	-0.66774	0.33226	0.3233	0.3233	0.3233
55	1.3577	2.3577	0.81956	0.81956	0.81956
56	-0.44786	0.55214	0.55469	0.55469	0.55469
57	0.90674	1.9067	0.22708	0.22708	0.22708
58	0.14065	1.1406	0.16026	0.16026	0.16026
59	-0.75953	0.24047	0.42549	0.42549	0.42549
60	-0.97516	0.024844	0.036655	0.036655	0.036655
61	-0.19341	0.80659	0.071302	0.071302	0.071302
62	-1.7976	-0.79757	0.20373	0.20373	0.20373
63	-1.4402	-0.44021	0.043507	0.043507	0.043507
64	-0.81161	0.18839	0.8667	0.8667	0.8667
65	-1.6925	-0.69254	0.28344	0.28344	0.28344

	Results of Distribution Correlation		ASCII File Creation Time History Results		
Realization	Normal1	Normal2	0	0.5	1
66	1.119	2.119	0.3483	0.3483	0.3483
67	-0.56939	0.43061	0.73213	0.73213	0.73213
68	-0.41131	0.58869	0.12476	0.12476	0.12476
69	0.63743	1.6374	0.51809	0.51809	0.51809
70	-1.1701	-0.17008	0.63009	0.63009	0.63009
71	0.041945	1.0419	0.21152	0.21152	0.21152
72	0.34867	1.3487	0.65823	0.65823	0.65823
73	-0.77368	0.22632	0.72572	0.72572	0.72572
74	0.39095	1.3909	0.98925	0.98925	0.98925
75	0.59879	1.5988	0.33836	0.33836	0.33836
76	2.1191	3.1191	0.58585	0.58585	0.58585
77	-0.43842	0.56158	0.67056	0.67056	0.67056
78	0.21708	1.2171	0.23652	0.23652	0.23652
79	0.46361	1.4636	0.3842	0.3842	0.3842
80	-0.73811	0.26189	0.022108	0.022108	0.022108
81	-0.28165	0.71835	0.43507	0.43507	0.43507
82	-2.0402	-1.0402	0.90058	0.90058	0.90058
83	-0.15082	0.84918	0.82128	0.82128	0.82128
84	1.287	2.287	0.30218	0.30218	0.30218
85	0.93348	1.9335	0.19594	0.19594	0.19594
86	-0.49562	0.50438	0.53116	0.53116	0.53116
87	-0.84888	0.15112	0.48969	0.48969	0.48969
88	0.077948	1.0779	0.79403	0.79403	0.79403
89	-0.03657	0.96343	0.57506	0.57506	0.57506
90	0.82004	1.82	0.066771	0.066771	0.066771
91	0.19849	1.1985	0.88304	0.88304	0.88304
92	-1.4995	-0.49952	0.70891	0.70891	0.70891
93	1.185	2.185	0.14484	0.14484	0.14484
94	0.53255	1.5325	0.62975	0.62975	0.62975
95	-1.0733	-0.07327	0.60937	0.60937	0.60937
96	0.31621	1.3162	0.84438	0.84438	0.84438
97	0.27096	1.271	0.66962	0.66962	0.66962
98	1.0323	2.0323	0.50423	0.50423	0.50423
99	0.42146	1.4215	0.26214	0.26214	0.26214
100	0.015646	1.0156	0.97711	0.97711	0.97711

Attachment VI **Results for Advection through Partially Saturated Media and Transport of Colloids**

This attachment provides the full GoldSim result listing for the advection through a partially saturated medium test and the transport of colloids test. The simulation time was 75 days with 5 day time step intervals.

Time (days)	Concentration (mg/l) Advection	Concentration (mg/l) Colloids
0	0	0
5	1.00E-12	1.00E-12
10	1.68E-11	1.68E-11
15	3.68E-06	3.68E-06
20	0.001063	0.001063
25	0.021469	0.021469
30	0.11731	0.11731
35	0.31183	0.31183
40	0.54407	0.54407
45	0.73921	0.73921
50	0.86787	0.86788
55	0.93932	0.93932
60	0.97422	0.97422
65	0.9897	0.9897
70	0.99609	0.99609
75	0.99857	0.99857

Attachment VII Diffusion through a Sorptive Material

This attachment provides the full GoldSim result listing of the concentrations of ^{241}Am, ^{242}Am, and ^{243}Am in Cells 1 and 2 (Cell 2 is called 'Sink' in the GoldSim file) for the *CT_Cells3-01* test problem. Refer to Section 3.2.2 *Diffusion through a Sorptive Material* for a discussion of this test problem.

	Cell 1			Cell 2		
Time (yr)	^{241}Am (mg/l)	^{242}Am (mg/l)	^{243}Am (mg/l)	^{241}Am (mg/l)	^{242}Am (mg/l)	^{243}Am (mg/l)
0	0.25858	0.091289	4.4516	0	0	0
100	0.25406	0.089695	4.3738	0.004516	0.001594	0.077747
200	0.2497	0.088156	4.2988	0.008874	0.003133	0.15278
300	0.2455	0.086671	4.2264	0.013081	0.004618	0.22519
400	0.24144	0.085238	4.1565	0.01714	0.006051	0.29507
500	0.23752	0.083855	4.089	0.021057	0.007434	0.36251
600	0.23374	0.08252	4.024	0.024838	0.008769	0.42759
700	0.23009	0.081232	3.9612	0.028486	0.010057	0.49041
800	0.22657	0.079989	3.9005	0.032007	0.0113	0.55102
900	0.22317	0.078789	3.842	0.035405	0.0125	0.60952
1000	0.21989	0.077632	3.7856	0.038685	0.013657	0.66598
1100	0.21673	0.076514	3.7311	0.04185	0.014775	0.72046
1200	0.21367	0.075436	3.6785	0.044904	0.015853	0.77304
1300	0.21073	0.074395	3.6278	0.047851	0.016894	0.82379
1400	0.20788	0.073391	3.5788	0.050696	0.017898	0.87276
1500	0.20514	0.072422	3.5315	0.053441	0.018867	0.92002
1600	0.20249	0.071486	3.4859	0.056091	0.019802	0.96563
1700	0.19993	0.070584	3.4419	0.058648	0.020705	1.0096
1800	0.19746	0.069713	3.3994	0.061115	0.021576	1.0521
1900	0.19508	0.068872	3.3584	0.063496	0.022417	1.0931
2000	0.19278	0.068061	3.3189	0.065795	0.023228	1.1327
2100	0.19057	0.067278	3.2807	0.068012	0.024011	1.1709
2200	0.18842	0.066522	3.2438	0.070153	0.024767	1.2077
2300	0.18636	0.065793	3.2083	0.072218	0.025496	1.2433
2400	0.18437	0.065089	3.174	0.074212	0.0262	1.2776
2500	0.18244	0.06441	3.1408	0.076136	0.026879	1.3107
2600	0.18059	0.063754	3.1089	0.077992	0.027535	1.3427
2700	0.17879	0.063122	3.078	0.079784	0.028167	1.3735
2800	0.17706	0.062511	3.0483	0.081513	0.028778	1.4033
2900	0.1754	0.061922	3.0195	0.083182	0.029367	1.432
3000	0.17378	0.061353	2.9918	0.084793	0.029935	1.4598
3100	0.17223	0.060805	2.965	0.086347	0.030484	1.4865
3200	0.17073	0.060275	2.9392	0.087847	0.031014	1.5123
3300	0.16928	0.059764	2.9143	0.089295	0.031525	1.5373

	Cell 1			Cell 2		
Time (yr)	^{241}Am (mg/l)	^{242}Am (mg/l)	^{243}Am (mg/l)	^{241}Am (mg/l)	^{242}Am (mg/l)	^{243}Am (mg/l)
3400	0.16789	0.059271	2.8903	0.090692	0.032018	1.5613
3500	0.16654	0.058795	2.867	0.09204	0.032494	1.5845
3600	0.16524	0.058336	2.8446	0.093341	0.032953	1.6069
3700	0.16398	0.057892	2.823	0.094597	0.033397	1.6285
3800	0.16277	0.057464	2.8022	0.095808	0.033824	1.6494
3900	0.1616	0.057052	2.782	0.096978	0.034237	1.6695
4000	0.16047	0.056653	2.7626	0.098107	0.034636	1.689
4100	0.15938	0.056269	2.7438	0.099196	0.03502	1.7077
4200	0.15833	0.055897	2.7258	0.10025	0.035391	1.7258
4300	0.15732	0.055539	2.7083	0.10126	0.03575	1.7433
4400	0.15634	0.055194	2.6914	0.10224	0.036095	1.7601
4500	0.15539	0.05486	2.6752	0.10319	0.036429	1.7764
4600	0.15448	0.054538	2.6595	0.1041	0.036751	1.7921
4700	0.1536	0.054228	2.6443	0.10498	0.037061	1.8072
4800	0.15275	0.053928	2.6297	0.10583	0.037361	1.8219
4900	0.15193	0.053638	2.6156	0.10665	0.03765	1.836
5000	0.15114	0.053359	2.602	0.10744	0.03793	1.8496
5100	0.15038	0.05309	2.5888	0.1082	0.038199	1.8627
5200	0.14964	0.05283	2.5762	0.10894	0.038459	1.8754
5300	0.14893	0.052579	2.5639	0.10965	0.03871	1.8876
5400	0.14824	0.052336	2.5521	0.11033	0.038952	1.8995
5500	0.14758	0.052103	2.5407	0.111	0.039186	1.9109
5600	0.14694	0.051877	2.5297	0.11163	0.039412	1.9219
5700	0.14633	0.051659	2.5191	0.11225	0.039629	1.9325
5800	0.14573	0.051449	2.5088	0.11285	0.03984	1.9427
5900	0.14516	0.051247	2.499	0.11342	0.040042	1.9526
6000	0.1446	0.051051	2.4894	0.11398	0.040238	1.9621
6100	0.14407	0.050862	2.4802	0.11451	0.040427	1.9714
6200	0.14355	0.05068	2.4713	0.11503	0.040609	1.9802
6300	0.14305	0.050504	2.4627	0.11552	0.040785	1.9888
6400	0.14257	0.050334	2.4545	0.11601	0.040955	1.9971
6500	0.14211	0.05017	2.4465	0.11647	0.041119	2.0051
6600	0.14166	0.050012	2.4388	0.11692	0.041277	2.0128
6700	0.14123	0.04986	2.4313	0.11735	0.041429	2.0202
6800	0.14081	0.049712	2.4241	0.11777	0.041576	2.0274
6900	0.14041	0.04957	2.4172	0.11817	0.041719	2.0343
7000	0.14002	0.049433	2.4105	0.11856	0.041856	2.041
7100	0.13965	0.049301	2.4041	0.11893	0.041988	2.0475

	Cell 1			Cell 2		
Time (yr)	^{241}Am (mg/l)	^{242}Am (mg/l)	^{243}Am (mg/l)	^{241}Am (mg/l)	^{242}Am (mg/l)	^{243}Am (mg/l)
7200	0.13928	0.049173	2.3978	0.11929	0.042116	2.0537
7300	0.13893	0.04905	2.3918	0.11964	0.042239	2.0597
7400	0.1386	0.048931	2.386	0.11998	0.042358	2.0655
7500	0.13827	0.048816	2.3804	0.12031	0.042473	2.0711
7600	0.13796	0.048705	2.375	0.12062	0.042584	2.0765
7700	0.13766	0.048598	2.3698	0.12092	0.04269	2.0817
7800	0.13736	0.048495	2.3648	0.12121	0.042794	2.0868
7900	0.13708	0.048396	2.3599	0.1215	0.042893	2.0916
8000	0.13681	0.0483	2.3553	0.12177	0.042989	2.0963
8100	0.13655	0.048207	2.3507	0.12203	0.043082	2.1008
8200	0.13629	0.048117	2.3464	0.12228	0.043172	2.1052
8300	0.13605	0.048031	2.3422	0.12253	0.043258	2.1094
8400	0.13581	0.047948	2.3381	0.12277	0.043341	2.1135
8500	0.13558	0.047867	2.3342	0.12299	0.043422	2.1174
8600	0.13536	0.047789	2.3304	0.12321	0.043499	2.1212
8700	0.13515	0.047715	2.3267	0.12343	0.043574	2.1248
8800	0.13495	0.047642	2.3232	0.12363	0.043647	2.1284
8900	0.13475	0.047572	2.3198	0.12383	0.043716	2.1318
9000	0.13456	0.047505	2.3165	0.12402	0.043784	2.135
9100	0.13438	0.04744	2.3133	0.1242	0.043849	2.1382
9200	0.1342	0.047377	2.3103	0.12438	0.043911	2.1413
9300	0.13403	0.047317	2.3073	0.12455	0.043972	2.1442
9400	0.13386	0.047258	2.3045	0.12472	0.04403	2.1471
9500	0.1337	0.047202	2.3017	0.12488	0.044087	2.1498
9600	0.13355	0.047148	2.2991	0.12503	0.044141	2.1525
9700	0.1334	0.047095	2.2965	0.12518	0.044194	2.155
9800	0.13325	0.047044	2.294	0.12532	0.044244	2.1575
9900	0.13312	0.046996	2.2917	0.12546	0.044293	2.1599
10000	0.13298	0.046948	2.2894	0.1256	0.044341	2.1622

Attachment VIII Look-Up Tables

One-dimensional Tables

The complete listing of GoldSim results for the four one-dimensional look-up table tests are given below. Shown in the "Value" columns are the look-up table results for tests one through four.

Time (s)	Value [a]	Value [b]	Value [c]	Value [d]	Time (s)	Value [a]	Value [b]	Value [c]	Value [d]
0	0	1	1	10	**25.5**	2.55	2.55	354.81	24.065
0.5	0.05	1	1.122	6.9897	**26**	2.6	2.6	398.11	24.15
1	0.1	1	1.2589	10	**26.5**	2.65	2.65	446.68	24.232
1.5	0.15	1	1.4125	11.761	**27**	2.7	2.7	501.19	24.314
2	0.2	1	1.5849	13.01	**27.5**	2.75	2.75	562.34	24.393
2.5	0.25	1	1.7783	13.979	**28**	2.8	2.8	630.96	24.472
3	0.3	1	1.9953	14.771	**28.5**	2.85	2.85	707.95	24.548
3.5	0.35	1	2.2387	15.441	**29**	2.9	2.9	794.33	24.624
4	0.4	1	2.5119	16.021	**29.5**	2.95	2.95	891.25	24.698
4.5	0.45	1	2.8184	16.532	**30**	3	3	1000	24.771
5	0.5	1	3.1623	16.99	**30.5**	3.05	3.05	1122	24.843
5.5	0.55	1	3.5481	17.404	**31**	3.1	3.1	1258.9	24.914
6	0.6	1	3.9811	17.782	**31.5**	3.15	3.15	1412.5	24.983
6.5	0.65	1	4.4668	18.129	**32**	3.2	3.2	1584.9	25.052
7	0.7	1	5.0119	18.451	**32.5**	3.25	3.25	1778.3	25.119
7.5	0.75	1	5.6234	18.751	**33**	3.3	3.3	1995.3	25.185
8	0.8	1	6.3096	19.031	**33.5**	3.35	3.35	2238.7	25.25
8.5	0.85	1	7.0795	19.294	**34**	3.4	3.4	2511.9	25.315
9	0.9	1	7.9433	19.542	**34.5**	3.45	3.45	2818.4	25.378
9.5	0.95	1	8.9125	19.777	**35**	3.5	3.5	3162.3	25.441
10	1	1	10	20	**35.5**	3.55	3.55	3548.1	25.502
10.5	1.05	1.05	11.22	20.212	**36**	3.6	3.6	3981.1	25.563
11	1.1	1.1	12.589	20.414	**36.5**	3.65	3.65	4466.8	25.623
11.5	1.15	1.15	14.125	20.607	**37**	3.7	3.7	5011.9	25.682
12	1.2	1.2	15.849	20.792	**37.5**	3.75	3.75	5623.4	25.74
12.5	1.25	1.25	17.783	20.969	**38**	3.8	3.8	6309.6	25.798
13	1.3	1.3	19.953	21.139	**38.5**	3.85	3.85	7079.5	25.855
13.5	1.35	1.35	22.387	21.303	**39**	3.9	3.9	7943.3	25.911
14	1.4	1.4	25.119	21.461	**39.5**	3.95	3.95	8912.5	25.966
14.5	1.45	1.45	28.184	21.614	**40**	4	4	10000	26.021
15	1.5	1.5	31.623	21.761	**40.5**	4.05	4	11220	26.075
15.5	1.55	1.55	35.481	21.903	**41**	4.1	4	12589	26.128
16	1.6	1.6	39.811	22.041	**41.5**	4.15	4	14125	26.18
16.5	1.65	1.65	44.668	22.175	**42**	4.2	4	15849	26.232
17	1.7	1.7	50.119	22.304	**42.5**	4.25	4	17783	26.284
17.5	1.75	1.75	56.234	22.43	**43**	4.3	4	19953	26.335

Time (s)	Value [a]	Value [b]	Value [c]	Value [d]	Time (s)	Value [a]	Value [b]	Value [c]	Value[d]
18	1.8	1.8	63.096	22.553	**43.5**	4.35	4	22387	26.385
18.5	1.85	1.85	70.795	22.672	**44**	4.4	4	25119	26.435
19	1.9	1.9	79.433	22.788	**44.5**	4.45	4	28184	26.484
19.5	1.95	1.95	89.125	22.9	**45**	4.5	4	31623	26.532
20	2	2	100	23.01	**45.5**	4.55	4	35481	26.58
20.5	2.05	2.05	112.2	23.118	**46**	4.6	4	39811	26.628
21	2.1	2.1	125.89	23.222	**46.5**	4.65	4	44668	26.675
21.5	2.15	2.15	141.25	23.324	**47**	4.7	4	50119	26.721
22	2.2	2.2	158.49	23.424	**47.5**	4.75	4	56234	26.767
22.5	2.25	2.25	177.83	23.522	**48**	4.8	4	63096	26.812
23	2.3	2.3	199.53	23.617	**48.5**	4.85	4	70795	26.857
23.5	2.35	2.35	223.87	23.711	**49**	4.9	4	79433	26.902
24	2.4	2.4	251.19	23.802	**49.5**	4.95	4	89125	26.946
24.5	2.45	2.45	281.84	23.892	**50**	5	4	1.00E+05	26.99
25	2.5	2.5	316.23	23.979					

NOTES: [a] This column shows the results for obtaining values at, between, and outside a look-up table using linear interpolation and linear extrapolation.

[b] This column shows the results for obtaining values at, between, and outside a look-up table using linear interpolation, but no extrapolation.

[c] This column shows the results for linear interpolation and extrapolation on the dependent axis, log interpolation and extrapolation on the independent axis (time).

[d] This column shows the results for log interpolation and extrapolation on the dependent axis, linear interpolation and extrapolation on the independent axis (time).

Two-dimensional Table

The table below gives the results for the fourth two-dimensional look-up table test, time dependent look-up points at, between, and outside table data points.

Time (s)	2-D Look-up Value	Time (s)	2-D Look-up Value	Time (s)	2-D Look-up Value
0	2	17	3.4	34	6
0.5	2	17.5	3.5	34.5	6
1	2	18	3.6	35	6
1.5	2	18.5	3.7	35.5	6
2	2	19	3.8	36	6
2.5	2	19.5	3.9	36.5	6
3	2	20	4	37	6
3.5	2	20.5	4.1	37.5	6
4	2	21	4.2	38	6
4.5	2	21.5	4.3	38.5	6
5	2	22	4.4	39	6
5.5	2	22.5	4.5	39.5	6
6	2	23	4.6	40	6
6.5	2	23.5	4.7	40.5	6
7	2	24	4.8	41	6
7.5	2	24.5	4.9	41.5	6
8	2	25	5	42	6
8.5	2	25.5	5.1	42.5	6
9	2	26	5.2	43	6
9.5	2	26.5	5.3	43.5	6
10	2	27	5.4	44	6
10.5	2.1	27.5	5.5	44.5	6
11	2.2	28	5.6	45	6
11.5	2.3	28.5	5.7	45.5	6
12	2.4	29	5.8	46	6
12.5	2.5	29.5	5.9	46.5	6
13	2.6	30	6	47	6
13.5	2.7	30.5	6	47.5	6
14	2.8	31	6	48	6
14.5	2.9	31.5	6	48.5	6
15	3	32	6	49	6
15.5	3.1	32.5	6	49.5	6
16	3.2	33	6	50	6
16.5	3.3	33.5	6		

Three-dimensional Look-up Table

The table below gives the results for the fourth three-dimensional look-up table test, time dependent look-up points at, between, and outside table data points.

Time (s)	3-D Look-up Value	Time (s)	3-D Look-up Value	Time (s)	3-D Look-up Value
0	2	17	3.4	34	6
0.5	2	17.5	3.5	34.5	6
1	2	18	3.6	35	6
1.5	2	18.5	3.7	35.5	6
2	2	19	3.8	36	6
2.5	2	19.5	3.9	36.5	6
3	2	20	4	37	6
3.5	2	20.5	4.1	37.5	6
4	2	21	4.2	38	6
4.5	2	21.5	4.3	38.5	6
5	2	22	4.4	39	6
5.5	2	22.5	4.5	39.5	6
6	2	23	4.6	40	6
6.5	2	23.5	4.7	40.5	6
7	2	24	4.8	41	6
7.5	2	24.5	4.9	41.5	6
8	2	25	5	42	6
8.5	2	25.5	5.1	42.5	6
9	2	26	5.2	43	6
9.5	2	26.5	5.3	43.5	6
10	2	27	5.4	44	6
10.5	2.1	27.5	5.5	44.5	6
11	2.2	28	5.6	45	6
11.5	2.3	28.5	5.7	45.5	6
12	2.4	29	5.8	46	6
12.5	2.5	29.5	5.9	46.5	6
13	2.6	30	6	47	6
13.5	2.7	30.5	6	47.5	6
14	2.8	31	6	48	6
14.5	2.9	31.5	6	48.5	6
15	3	32	6	49	6
15.5	3.1	32.5	6	49.5	6
16	3.2	33	6	50	6
16.5	3.3	33.5	6		

Attachment IX Stochastic Distributions and Expected Values

The table below lists the expected values and the GoldSim results for the vendor test problems, which verify the correct functioning of the stochastic elements supported by GoldSim. These results are for test problem GS4_STOC, and the expected results are from Section 3.1, Table GS4_STOC of the GoldSim Verification Plan (Golder, 1999b).

Distribution Type	Result Type	Expected Values	GoldSim Results
Uniform		Mean=500 St. Dev. = 289 5%: x = 50.0 25%: x = 250 50%: x = 500 75%: x = 750 90%: x = 900	Mean = 500 St. Dev. = 288.675 5%: x= 50 25%: x = 250 50%: x = 500 75%: x = 750 90%: x = 900
	calculator value input 900	Cum. Prob. =0.900 Prob. Density = 0.001	Cum. Prob. = 0.9 Prob. Density = 0.001
	calculator cumulative probability input 0.9	Value = 900 Prob. Density =0.001	Cum. Prob. = 900 Prob. Density = 0.001
Log-Uniform		Mean = 215 St. Dev. = 250 5%: x = 12.6 25%: x = 31.6 50%: x=100 75%: x = 316 90%: x=631	Mean = 214.976 St. Dev. = 249.696 5%: x= 12.58925 25%: x = 31.62278 50%: x = 100 75%: x = 316.2278 90%: x = 630.9573
	calculator value input 100	Cum. Prob. = 0.500 Prob. Density =0.00217	Cum. Prob. = 0.5 Prob. Density = 0.00217147
	calculator cumulative probability input 0.9	Value = 631 Prob. Density = 0.000344	Cum. Prob. = 630.957 Prob. Density = 0.000344155
Triangular		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	Mean = 46.6667 St. Dev. = 19.2931 5%: x= 19.48683 25%: x = 31.26136 50%: x = 43.87514 75%: x = 60.31373 90%: x = 74.9002
	calculator value input 50	Cum. Prob. = 0.603 Prob. Density = 0.0159	Cum. Prob. = 0.603175 Prob. Density = 0.015873
	calculator cumulative probability input 0.9	Value = 74.9 Prob. Density = 0.00797	Value = 74.9002 Prob. Density = 0.00796819
Log-Triangular		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	Mean = 34.688 St. Dev. = 16.7297 5%: x= 14.27099 25%: x = 22.1498 50%: x = 30.80978 75%: x = 43.49589 90%: x = 59.06559

Distribution Type	Result Type	Expected Values	GoldSim Results
	calculator value input 50	Cum. Prob. = 0.827 Prob. Density = 0.01	Cum. Prob. = 0.826692 Prob. Density = 0.0100012
	calculator cumulative probability input 0.9	Value = 59.1 Prob. Density = 0.00643	Value = 59.0656 Prob. Density = 0.00643101
Normal		5%: x= 67.1 25%: x = 86.5 50%: x = 100 75%: x = 113 90%: x = 126	5%: x= 67.09577 25%: x = 86.51622 50%: x = 100 75%: x = 113.4838 90%: x = 125.6346
	calculator value input 80	Cum. Prob. = 0.159 Prob. Density = 0.0121	Cum. Prob. = 0.158876 Prob. Density = 0.0120985
	calculator cumulative probability input 0.9	Value = 126 Prob. Density = 0.00877	Value = 125.635 Prob. Density = 0.00877292
Log-Normal		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	geo. Mean = 89.44273 geo. St. Dev. = 1.603808 5%: x= 41.11743 25%: x = 65.04794 50%: x = 89.44273 75%: x = 122.9862 90%: x = 163.8682
	calculator value input 80	Cum. Prob. = 0.407 Prob. Density = 0.0103	Cum. Prob. = 0.406704 Prob. Density = 0.0102663
	calculator cumulative probability input 0.9	Value = 164 Prob. Density = 0.00227	Value = 163.868 Prob. Density = 0.00226667
Normal-Truncated		5%: x= 70.6 25%: x = 87.2 50%: x = 100 75%: x = 113 90%: x = 124	5%: x= 70.52407 25%: x = 87.21854 50%: x = 100 75%: x = 112.7815 90%: x = 123.698
	calculator value input 80	Cum. Prob. = 0.142 Prob. Density = 0.0127	Cum. Prob. = 0.142755 Prob. Density = 0.0126703
	calculator cumulative probability input 0.9	Value = 124 Prob. Density = 0.0104	Value = 123.698 Prob. Density = 0.0103529
Log-Normal-Truncated		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	geo. Mean = 89.4427 geo. St. Dev. = 1.60381 5%: x= 54.48063 25%: x = 69.61232 50%: x = 87.98693 75%: x = 110.7303 90%: x = 130.3778
	calculator value input 80	Cum. Prob. = 0.395 Prob. Density = 0.0136	Cum. Prob. = 0.39464 Prob. Density = 0.0136229

Distribution Type	Result Type	Expected Values	GoldSim Results
	calculator cumulative probability input 0.9	Value = 130 Prob. Density = 0.00624	Value = 130.378 Prob. Density = 0.00625286
Beta		5%: x= 9.76 25%: x = 24.3 50%: x = 38.6 75%: x = 54.4 90%: x = 68.0	5%: x= 9.760884 25%: x = 24.30354 50%: x = 38.57638 75%: x = 54.37435 90%: x = 67.96383
	calculator value input 30	Cum. Prob. = 0.348 Prob. Density = 0.0176	Cum. Prob. = 0.348262 Prob. Density = 0.01764
	calculator cumulative probability input 0.9	Value = 68.0 Prob. Density = 0.00837	Value = 67.9636 Prob. Density = 0.00837037
Binomial		Mean = 25.0 St. Dev. = 4.33 5%: x= 18 25%: x = 22 50%: x = 25 75%: x = 28 90%: x = 31	Mean = 25 St. Dev. = 4.33013 5%: x= 18 25%: x = 22 50%: x = 25 75%: x = 28 90%: x = 31
	calculator value input 20	Cum. Prob. = 0.149 Prob. Density = 0.0493	Cum. Prob. = 0.148831 Prob. Density = 0.0493006
	calculator cumulative probability input 0.9	Value = 31 Prob. Density = 0.0344	Value = 31 Prob. Density = 0.0344383
Boolean		Mean = 1 5%: x= 0 25%: x = 1 50%: x = 1 75%: x = 1 90%: x = 1	Mean = 1 5%: x= 0 25%: x = 1 50%: x = 1 75%: x = 1 90%: x = 1
	calculator value input 0	Cum. Prob. = 0.25 Prob. Density = 0.25	Cum. Prob. = 0.25 Prob. Density = 0
	calculator cumulative probability input 0.25	Value = 1 Prob. Density = 0.75	Value = 1 Prob. Density = 1
Cumulative		Mean = 50 5%: x= 5 25%: x = 25 50%: x = 50 75%: x = 75 90%: x = 90	Mean = 50 5%: x= 5 25%: x = 25 50%: x = 50 75%: x = 75 90%: x = 90
	calculator value input 60	Cum. Prob. = 0.60 Prob. Density = 0.01	Cum. Prob. = 0.6 Prob. Density = 0.01
	calculator cumulative probability input 0.9	Value = 90 Prob. Density = 0.01	Value = 90 Prob. Density = 0.01

Distribution Type	Result Type	Expected Values	GoldSim Results
Discrete		Mean = 50 St. Dev. = 28.4 5%: x= 5 25%: x = 25 50%: x = 50 75%: x = 75 90%: x = 95	Mean = 50 St. Dev. = 28.377 5%: x= 5 25%: x = 25 50%: x = 50 75%: x = 75 90%: x = 95
	calculator value input 26	Cum. Prob. = 0.252 Prob. Density = 0	Cum. Prob. = 0.252 Prob. Density = 0
	calculator cumulative probability input 0.9	Value = 95 Prob. Density = 0.200	Value = 95 Prob. Density = 0.2
Gamma		5%: x= 5.47 25%: x = 10.1 50%: x = 14.7 75%: x = 20.4 90%: x = 26.7	5%: x= 5.465274 25%: x = 10.14128 50%: x = 14.68824 75%: x = 20.43768 90%: x = 26.72313
	calculator value input 20	Cum. Prob. = 0.735 Prob. Density = 0.0351	Cum. Prob. = 0.734974 Prob. Density = 0.0350935
	calculator cumulative probability input 0.9	Value = 26.7 Prob. Density = 0.0156	Value = 26.7231 Prob. Density = 0.0155899
Gamma-Truncated		5%: x= 6.43 25%: x = 10.1 50%: x = 13.8 75%: x = 18.1 90%: x = 21.6	5%: x= 6.429784 25%: x = 10.06941 50%: x = 13.82705 75%: x = 18.0994 90%: x = 21.59638
	calculator value input 20	Cum. Prob. = 0.838 Prob. Density = 0.0422	Cum. Prob. = 0.837909 Prob. Density = 0.042206
	calculator cumulative probability input 0.9	Value = 21.6 Prob. Density = 0.0357	Value = 21.5964 Prob. Density = 0.0356535
Poisson		Mean = 25 St. Dev. = 5.00 5%: x= 17 25%: x = 22 50%: x = 25 75%: x = 28 90%: x = 32	Mean = 25 St. Dev. = 5 5%: x= 17 25%: x = 22 50%: x = 25 75%: x = 28 90%: x = 32
	calculator value input 20	Cum. Prob. = 0.185 Prob. Density = 0.0519	Cum. Prob. = 0.185492 Prob. Density = 0.0519175
	calculator cumulative probability input 0.9	Value = 32 Prob. Density = 0.0286	Value = 32 Prob. Density = 0.0286119
Weibull		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	Mean = 18.8625 St. Dev. = 4.63263 5%: x= 12.26486 25%: x = 15.36374 50%: x = 18.32576 75%: x = 21.77441 90%: x = 25.17467

Distribution Type	Result Type	Expected Values	GoldSim Results
	calculator value input 25	Cum. Prob. = 0.895 Prob. Density = 0.0316	Cum. Prob. = 0.894588 Prob. Density = 0.0316218
	calculator cumulative probability input 0.9	Value = 25.2 Prob. Density = 0.0303	Value = 25.1747 Prob. Density = 0.0303478
Weibull-Truncated		Mean = 17.7 5%: x= 12.1 25%: x = 15.0 50%: x = 17.7 75%: x = 20.5 90%: x = 22.8	Mean = 17.7004 5%: x= 12.1392 25%: x = 15.0315 50%: x = 17.7004 75%: x = 20.5431 90%: x = 22.7887
	calculator value input 20	Cum. Prob. = 0.707 Prob. Density = 0.0822	Cum. Prob. = 0.706583 Prob. Density = 0.0822455
	calculator cumulative probability input 0.9	Value = 22.8 Prob. Density = 0.0557	Value = 22.7887 Prob. Density = 0.0557129

Attachment X Latin Hypercube Sampling and Multiple Realizations

The table below gives the results of the first Monte Carlo test where 100 realizations were run with LHS enabled. As expected, there is a single value in each interval (0.00 – 0.01, 0.01 – 0.02, etc.).

No.	Value	No.	Value	No.	Value	No.	Value
1	0.008648	26	0.25838	51	0.50114	76	0.7573
2	0.016932	27	0.26875	52	0.51427	77	0.76374
3	0.021075	28	0.27215	53	0.52051	78	0.77381
4	0.034111	29	0.28597	54	0.53082	79	0.7844
5	0.044781	30	0.29325	55	0.54451	80	0.79873
6	0.051513	31	0.30017	56	0.55628	81	0.80859
7	0.066765	32	0.31744	57	0.56001	82	0.81728
8	0.075811	33	0.32824	58	0.57471	83	0.82529
9	0.086451	34	0.33074	59	0.58686	84	0.83629
10	0.096334	35	0.34601	60	0.5969	85	0.84208
11	0.10137	36	0.35106	61	0.60938	86	0.85852
12	0.11184	37	0.36471	62	0.61025	87	0.86069
13	0.12222	38	0.37965	63	0.62808	88	0.87791
14	0.13326	39	0.38049	64	0.63511	89	0.88964
15	0.14425	40	0.39781	65	0.64877	90	0.89204
16	0.15239	41	0.4	66	0.6527	91	0.90854
17	0.16439	42	0.41729	67	0.66399	92	0.91634
18	0.1786	43	0.42946	68	0.67941	93	0.92738
19	0.18824	44	0.43954	69	0.68457	94	0.93072
20	0.19138	45	0.44179	70	0.6913	95	0.9479
21	0.2007	46	0.45385	71	0.70669	96	0.95939
22	0.21611	47	0.46417	72	0.71804	97	0.96981
23	0.22687	48	0.47944	73	0.72917	98	0.97135
24	0.23435	49	0.48549	74	0.7304	99	0.98925
25	0.2451	50	0.4983	75	0.74261	100	0.99309

This table shows the results for the second Monte Carlo test where 100 realizations were run without LHS enabled. The GoldSim Verification Plan (Golder 1999b, Section 3.2, TMC-02 Monte Carlo Test) indicates that there should be on the order of 10 results that lie outside the 5% - 95% confidence bounds, and any number less than 20 is reasonable. The simulation results given in the table below show eight excursions below 5% and one excursion above 95% for a total of nine excursions outside the 5% - 95% confidence bounds.

No.	Value	No.	Value	No.	Value	No.	Value
1	0.005957	26	0.21407	51	0.4334	76	0.74237
2	0.006942	27	0.21505	52	0.43725	77	0.75739
3	0.011513	28	0.22863	53	0.44469	78	0.76147
4	0.023162	29	0.2288	54	0.45675	79	0.7639
5	0.031003	30	0.23447	55	0.47313	80	0.77106
6	0.03968	31	0.23778	56	0.47571	81	0.78208
7	0.040646	32	0.24768	57	0.47912	82	0.81274
8	0.043155	33	0.26306	58	0.50108	83	0.81637
9	0.075204	34	0.27643	59	0.51258	84	0.84182
10	0.083816	35	0.30236	60	0.51275	85	0.84818
11	0.083885	36	0.30976	61	0.51598	86	0.85282
12	0.090291	37	0.32117	62	0.53785	87	0.86152
13	0.10474	38	0.33625	63	0.55969	88	0.86448
14	0.12408	39	0.34	64	0.57681	89	0.86696
15	0.12791	40	0.36811	65	0.5801	90	0.8687
16	0.13699	41	0.36921	66	0.60347	91	0.87018
17	0.1557	42	0.37006	67	0.60608	92	0.88515
18	0.1575	43	0.37606	68	0.61934	93	0.90033
19	0.16266	44	0.39042	69	0.66389	94	0.9062
20	0.1753	45	0.39246	70	0.66543	95	0.90902
21	0.18594	46	0.39688	71	0.70708	96	0.93346
22	0.19289	47	0.39905	72	0.71796	97	0.93874
23	0.19416	48	0.4102	73	0.73324	98	0.94348
24	0.20511	49	0.42369	74	0.74156	99	0.95412
25	0.21223	50	0.43021	75	0.74182	100	0.98086

This table shows the results of the third Monte Carlo test where 5000 realizations were run without LHS enabled. The GoldSim Verification Plan (Golder 1999b, Section 3.2, TMC-02 Monte Carlo Test) indicates that there should be on the order of 500 results that lie outside the 5% - 95% confidence bounds, and any number less than 1000 is reasonable. The simulation results given in the table below show 239 excursions below 5% and 231 excursions above 95% for a total of 470 excursions outside the 5% - 95% confidence bounds.

No.	Value	No.	Value	No.	Value	No.	Value	No.	Value	No.	Value
1	0.000249	835	0.16918	1669	0.33369	2503	0.4953	3337	0.66222	4171	0.83162
2	0.000271	836	0.16938	1670	0.33375	2504	0.49533	3338	0.66243	4172	0.83227
3	0.000896	837	0.16971	1671	0.33399	2505	0.49546	3339	0.66257	4173	0.83229
4	0.001029	838	0.17004	1672	0.33404	2506	0.49551	3340	0.66313	4174	0.83267
5	0.001085	839	0.17007	1673	0.3345	2507	0.49602	3341	0.66317	4175	0.83331
6	0.001143	840	0.17015	1674	0.33492	2508	0.49646	3342	0.66326	4176	0.83339
7	0.001186	841	0.17024	1675	0.3351	2509	0.49646	3343	0.66381	4177	0.8336
8	0.001251	842	0.17029	1676	0.33533	2510	0.49701	3344	0.66408	4178	0.83385
9	0.001273	843	0.17073	1677	0.33666	2511	0.49712	3345	0.66467	4179	0.83426
10	0.00138	844	0.17113	1678	0.33683	2512	0.49762	3346	0.66477	4180	0.83434
11	0.00162	845	0.1713	1679	0.33685	2513	0.49763	3347	0.66492	4181	0.83445
12	0.001666	846	0.17152	1680	0.33696	2514	0.49812	3348	0.66494	4182	0.83486
13	0.002038	847	0.17218	1681	0.33742	2515	0.49825	3349	0.66549	4183	0.83496
14	0.002108	848	0.17268	1682	0.33787	2516	0.49863	3350	0.66591	4184	0.83544
15	0.002232	849	0.17281	1683	0.33801	2517	0.49878	3351	0.66599	4185	0.83547
16	0.002555	850	0.17284	1684	0.33801	2518	0.4988	3352	0.66602	4186	0.83562
17	0.002649	851	0.17309	1685	0.33858	2519	0.49941	3353	0.6661	4187	0.83567
18	0.003325	852	0.17353	1686	0.33859	2520	0.50007	3354	0.66611	4188	0.83583
19	0.003386	853	0.1738	1687	0.33876	2521	0.50025	3355	0.66627	4189	0.83587
20	0.003441	854	0.17399	1688	0.33883	2522	0.50035	3356	0.66637	4190	0.83594
21	0.003716	855	0.17425	1689	0.3389	2523	0.50071	3357	0.66647	4191	0.83613
22	0.003966	856	0.17461	1690	0.33896	2524	0.50097	3358	0.6669	4192	0.83632
23	0.003998	857	0.17502	1691	0.33897	2525	0.50134	3359	0.66693	4193	0.83632
24	0.004012	858	0.17532	1692	0.33907	2526	0.50221	3360	0.66721	4194	0.83662
25	0.004172	859	0.17536	1693	0.33921	2527	0.50254	3361	0.66724	4195	0.83694
26	0.004212	860	0.17569	1694	0.33936	2528	0.50314	3362	0.66734	4196	0.837
27	0.004371	861	0.17604	1695	0.33978	2529	0.50324	3363	0.66745	4197	0.83718
28	0.004677	862	0.1761	1696	0.33981	2530	0.50326	3364	0.66751	4198	0.8376
29	0.005018	863	0.17676	1697	0.3407	2531	0.50379	3365	0.66782	4199	0.83775
30	0.00522	864	0.17709	1698	0.34071	2532	0.50381	3366	0.66784	4200	0.83791
31	0.005274	865	0.17711	1699	0.34123	2533	0.50386	3367	0.66797	4201	0.83791
32	0.005454	866	0.17717	1700	0.34131	2534	0.50397	3368	0.66805	4202	0.8384
33	0.005618	867	0.17729	1701	0.34141	2535	0.5041	3369	0.66811	4203	0.83884
34	0.005736	868	0.17732	1702	0.34165	2536	0.50448	3370	0.66883	4204	0.83922
35	0.006063	869	0.17739	1703	0.34167	2537	0.50463	3371	0.66898	4205	0.83924

No.	Value	No.	Value	No.	Value	No.	Value	No.	Value	No.	Value
36	0.00607	870	0.17746	1704	0.34168	2538	0.50479	3372	0.6691	4206	0.83934
37	0.006199	871	0.17748	1705	0.34174	2539	0.50485	3373	0.66927	4207	0.83951
38	0.006232	872	0.17783	1706	0.34203	2540	0.50487	3374	0.66929	4208	0.83965
39	0.007191	873	0.17814	1707	0.34207	2541	0.50541	3375	0.67071	4209	0.83978
40	0.007209	874	0.17854	1708	0.34249	2542	0.50551	3376	0.67102	4210	0.84016
41	0.007793	875	0.1786	1709	0.34271	2543	0.50561	3377	0.67103	4211	0.84038
42	0.007987	876	0.17919	1710	0.34296	2544	0.50639	3378	0.67105	4212	0.84077
43	0.008265	877	0.17971	1711	0.34335	2545	0.5066	3379	0.6711	4213	0.84084
44	0.008421	878	0.17972	1712	0.34339	2546	0.50684	3380	0.67122	4214	0.84116
45	0.008449	879	0.17977	1713	0.3435	2547	0.5069	3381	0.67127	4215	0.84126
46	0.008569	880	0.17982	1714	0.34356	2548	0.50693	3382	0.67145	4216	0.84167
47	0.009179	881	0.17984	1715	0.34358	2549	0.50696	3383	0.67166	4217	0.84202
48	0.009814	882	0.17991	1716	0.34434	2550	0.50741	3384	0.67176	4218	0.84202
49	0.010005	883	0.17992	1717	0.34443	2551	0.50752	3385	0.67197	4219	0.84269
50	0.010188	884	0.18015	1718	0.34454	2552	0.50784	3386	0.672	4220	0.84272
51	0.010232	885	0.18061	1719	0.34468	2553	0.5079	3387	0.67221	4221	0.84285
52	0.010795	886	0.18094	1720	0.3448	2554	0.5083	3388	0.67222	4222	0.84347
53	0.010824	887	0.18107	1721	0.34487	2555	0.50849	3389	0.67241	4223	0.8441
54	0.010977	888	0.18121	1722	0.34496	2556	0.5086	3390	0.67281	4224	0.84417
55	0.011165	889	0.1814	1723	0.34497	2557	0.50864	3391	0.67301	4225	0.84434
56	0.011334	890	0.18192	1724	0.34513	2558	0.50867	3392	0.67306	4226	0.84467
57	0.0115	891	0.18193	1725	0.3452	2559	0.50876	3393	0.67306	4227	0.84474
58	0.011621	892	0.1823	1726	0.34523	2560	0.50902	3394	0.67321	4228	0.8451
59	0.011992	893	0.18272	1727	0.34575	2561	0.50937	3395	0.6733	4229	0.84523
60	0.012228	894	0.18278	1728	0.34577	2562	0.50939	3396	0.6734	4230	0.84526
61	0.012288	895	0.1829	1729	0.34581	2563	0.5094	3397	0.6735	4231	0.84536
62	0.01309	896	0.18301	1730	0.34587	2564	0.50952	3398	0.67363	4232	0.84539
63	0.013188	897	0.18333	1731	0.34623	2565	0.5097	3399	0.67388	4233	0.84572
64	0.013459	898	0.18335	1732	0.34649	2566	0.50984	3400	0.67405	4234	0.84583
65	0.014183	899	0.18357	1733	0.34651	2567	0.51024	3401	0.67411	4235	0.84595
66	0.01431	900	0.18359	1734	0.34743	2568	0.51047	3402	0.67421	4236	0.84606
67	0.014376	901	0.18376	1735	0.34756	2569	0.51063	3403	0.67431	4237	0.84644
68	0.01439	902	0.18394	1736	0.3477	2570	0.51063	3404	0.67453	4238	0.84649
69	0.01471	903	0.18432	1737	0.34806	2571	0.5109	3405	0.67453	4239	0.84652
70	0.01486	904	0.18459	1738	0.34815	2572	0.51107	3406	0.67494	4240	0.84714
71	0.015064	905	0.18467	1739	0.34825	2573	0.51131	3407	0.67508	4241	0.84728
72	0.015228	906	0.18524	1740	0.34853	2574	0.51147	3408	0.67514	4242	0.84729
73	0.01525	907	0.18532	1741	0.34918	2575	0.51209	3409	0.6756	4243	0.84743
74	0.015493	908	0.18573	1742	0.34954	2576	0.51221	3410	0.67562	4244	0.84805
75	0.016177	909	0.18615	1743	0.34968	2577	0.51224	3411	0.67562	4245	0.84883
76	0.01618	910	0.187	1744	0.35015	2578	0.51252	3412	0.67572	4246	0.84889

No.	Value	No.	Value	No.	Value	No.	Value	No.	Value	No.	Value
77	0.016391	**911**	0.18736	**1745**	0.35017	**2579**	0.51259	**3413**	0.67573	**4247**	0.84889
78	0.016507	**912**	0.18746	**1746**	0.35025	**2580**	0.51284	**3414**	0.67583	**4248**	0.84949
79	0.01668	**913**	0.1875	**1747**	0.35036	**2581**	0.51301	**3415**	0.67591	**4249**	0.8495
80	0.016713	**914**	0.18754	**1748**	0.35051	**2582**	0.51304	**3416**	0.67608	**4250**	0.84963
81	0.017012	**915**	0.1879	**1749**	0.35052	**2583**	0.5133	**3417**	0.67618	**4251**	0.84979
82	0.017324	**916**	0.18806	**1750**	0.35057	**2584**	0.51334	**3418**	0.67628	**4252**	0.84984
83	0.017468	**917**	0.18811	**1751**	0.35058	**2585**	0.5136	**3419**	0.67655	**4253**	0.85004
84	0.017765	**918**	0.18813	**1752**	0.35059	**2586**	0.51416	**3420**	0.67658	**4254**	0.85017
85	0.018042	**919**	0.18816	**1753**	0.35074	**2587**	0.51445	**3421**	0.67728	**4255**	0.85048
86	0.018366	**920**	0.18826	**1754**	0.35102	**2588**	0.51468	**3422**	0.67738	**4256**	0.8507
87	0.018405	**921**	0.18848	**1755**	0.35104	**2589**	0.51485	**3423**	0.67743	**4257**	0.85141
88	0.018536	**922**	0.18893	**1756**	0.35121	**2590**	0.51518	**3424**	0.67759	**4258**	0.85162
89	0.018723	**923**	0.18901	**1757**	0.35151	**2591**	0.51535	**3425**	0.67764	**4259**	0.85179
90	0.018723	**924**	0.18941	**1758**	0.35161	**2592**	0.51578	**3426**	0.67772	**4260**	0.85192
91	0.018794	**925**	0.18983	**1759**	0.35171	**2593**	0.51606	**3427**	0.6779	**4261**	0.852
92	0.018943	**926**	0.19006	**1760**	0.35174	**2594**	0.51631	**3428**	0.67792	**4262**	0.85201
93	0.019071	**927**	0.19026	**1761**	0.35199	**2595**	0.5165	**3429**	0.67891	**4263**	0.85217
94	0.01945	**928**	0.19047	**1762**	0.35204	**2596**	0.51693	**3430**	0.67892	**4264**	0.85288
95	0.019517	**929**	0.19089	**1763**	0.3523	**2597**	0.51698	**3431**	0.67919	**4265**	0.85302
96	0.019896	**930**	0.19103	**1764**	0.35232	**2598**	0.51706	**3432**	0.67921	**4266**	0.85323
97	0.019907	**931**	0.19111	**1765**	0.35273	**2599**	0.5171	**3433**	0.67974	**4267**	0.85346
98	0.019908	**932**	0.19117	**1766**	0.35283	**2600**	0.51731	**3434**	0.67977	**4268**	0.85379
99	0.020026	**933**	0.1914	**1767**	0.35294	**2601**	0.5174	**3435**	0.6799	**4269**	0.85407
100	0.020196	**934**	0.19152	**1768**	0.353	**2602**	0.51781	**3436**	0.67993	**4270**	0.85409
101	0.020448	**935**	0.19171	**1769**	0.35309	**2603**	0.51868	**3437**	0.68003	**4271**	0.8541
102	0.020466	**936**	0.19174	**1770**	0.35395	**2604**	0.51884	**3438**	0.68013	**4272**	0.85418
103	0.020473	**937**	0.1922	**1771**	0.35424	**2605**	0.51926	**3439**	0.6803	**4273**	0.85422
104	0.020818	**938**	0.19318	**1772**	0.35433	**2606**	0.5195	**3440**	0.68054	**4274**	0.85427
105	0.021096	**939**	0.19331	**1773**	0.35444	**2607**	0.51977	**3441**	0.68066	**4275**	0.85437
106	0.021286	**940**	0.19339	**1774**	0.35468	**2608**	0.51999	**3442**	0.68102	**4276**	0.85514
107	0.021289	**941**	0.19387	**1775**	0.35476	**2609**	0.52006	**3443**	0.68111	**4277**	0.8552
108	0.021308	**942**	0.19448	**1776**	0.35476	**2610**	0.52038	**3444**	0.68133	**4278**	0.8556
109	0.021536	**943**	0.19455	**1777**	0.35504	**2611**	0.52093	**3445**	0.68134	**4279**	0.85585
110	0.021605	**944**	0.19455	**1778**	0.35527	**2612**	0.52094	**3446**	0.68147	**4280**	0.85586
111	0.021805	**945**	0.19457	**1779**	0.35614	**2613**	0.52102	**3447**	0.68149	**4281**	0.85596
112	0.022072	**946**	0.19459	**1780**	0.35614	**2614**	0.52118	**3448**	0.68212	**4282**	0.85597
113	0.022081	**947**	0.19507	**1781**	0.35627	**2615**	0.52126	**3449**	0.68222	**4283**	0.85604
114	0.022496	**948**	0.19512	**1782**	0.35681	**2616**	0.5213	**3450**	0.68225	**4284**	0.8561
115	0.022547	**949**	0.19523	**1783**	0.35693	**2617**	0.52141	**3451**	0.68248	**4285**	0.85638
116	0.022782	**950**	0.19556	**1784**	0.35716	**2618**	0.5215	**3452**	0.68322	**4286**	0.85683
117	0.022981	**951**	0.19615	**1785**	0.35722	**2619**	0.52154	**3453**	0.68335	**4287**	0.85689

No.	Value	No.	Value	No.	Value	No.	Value	No.	Value	No.	Value
118	0.02308	952	0.19618	1786	0.35746	2620	0.52166	3454	0.68349	4288	0.85721
119	0.023477	953	0.1962	1787	0.35812	2621	0.52176	3455	0.6837	4289	0.85726
120	0.02358	954	0.19629	1788	0.35819	2622	0.52194	3456	0.68442	4290	0.85731
121	0.024011	955	0.19646	1789	0.35829	2623	0.52216	3457	0.68455	4291	0.85739
122	0.024097	956	0.19647	1790	0.35849	2624	0.52223	3458	0.68458	4292	0.85765
123	0.024266	957	0.19647	1791	0.35866	2625	0.52261	3459	0.68478	4293	0.85769
124	0.024305	958	0.19668	1792	0.35868	2626	0.52272	3460	0.68489	4294	0.85782
125	0.024752	959	0.19673	1793	0.35869	2627	0.52295	3461	0.68497	4295	0.85796
126	0.025222	960	0.19697	1794	0.35904	2628	0.52308	3462	0.685	4296	0.85798
127	0.025492	961	0.19698	1795	0.35904	2629	0.52323	3463	0.68512	4297	0.85836
128	0.025496	962	0.197	1796	0.35913	2630	0.52334	3464	0.68518	4298	0.85868
129	0.025633	963	0.19702	1797	0.35914	2631	0.52344	3465	0.68586	4299	0.85886
130	0.025766	964	0.19765	1798	0.3595	2632	0.52373	3466	0.68587	4300	0.85941
131	0.026276	965	0.19774	1799	0.36002	2633	0.52379	3467	0.68599	4301	0.85963
132	0.026345	966	0.19782	1800	0.36048	2634	0.52381	3468	0.6861	4302	0.86001
133	0.026392	967	0.19834	1801	0.36057	2635	0.52423	3469	0.6865	4303	0.86025
134	0.026694	968	0.19848	1802	0.36074	2636	0.52424	3470	0.68733	4304	0.86071
135	0.026859	969	0.19857	1803	0.3608	2637	0.52428	3471	0.68736	4305	0.86077
136	0.026952	970	0.19886	1804	0.36101	2638	0.52456	3472	0.68778	4306	0.86084
137	0.02696	971	0.19901	1805	0.36128	2639	0.52457	3473	0.68823	4307	0.86156
138	0.027214	972	0.19904	1806	0.36167	2640	0.5246	3474	0.68833	4308	0.86158
139	0.027336	973	0.19917	1807	0.3622	2641	0.52518	3475	0.68837	4309	0.86176
140	0.027455	974	0.19924	1808	0.36223	2642	0.52523	3476	0.68841	4310	0.86182
141	0.027519	975	0.19963	1809	0.36277	2643	0.52538	3477	0.68865	4311	0.86192
142	0.027538	976	0.19974	1810	0.36307	2644	0.52579	3478	0.68872	4312	0.86219
143	0.02772	977	0.19987	1811	0.36333	2645	0.52605	3479	0.68878	4313	0.86257
144	0.027846	978	0.19987	1812	0.36359	2646	0.52636	3480	0.68915	4314	0.86274
145	0.027909	979	0.19991	1813	0.36375	2647	0.52645	3481	0.68943	4315	0.86283
146	0.028185	980	0.2	1814	0.3642	2648	0.52695	3482	0.68962	4316	0.86324
147	0.028474	981	0.20003	1815	0.36435	2649	0.52719	3483	0.6897	4317	0.86326
148	0.028664	982	0.20037	1816	0.36468	2650	0.52742	3484	0.68974	4318	0.86328
149	0.028918	983	0.20063	1817	0.36516	2651	0.52753	3485	0.68987	4319	0.86366
150	0.029081	984	0.20072	1818	0.36517	2652	0.52764	3486	0.69007	4320	0.86367
151	0.029118	985	0.20074	1819	0.36541	2653	0.52802	3487	0.69008	4321	0.86369
152	0.029605	986	0.20082	1820	0.36575	2654	0.52806	3488	0.69017	4322	0.8637
153	0.029664	987	0.20116	1821	0.36579	2655	0.52867	3489	0.69048	4323	0.8638
154	0.029737	988	0.20122	1822	0.36612	2656	0.52893	3490	0.69056	4324	0.86408
155	0.029929	989	0.20135	1823	0.36673	2657	0.53	3491	0.69103	4325	0.86409
156	0.030057	990	0.20141	1824	0.36721	2658	0.53006	3492	0.69104	4326	0.86425
157	0.030168	991	0.20141	1825	0.36722	2659	0.53015	3493	0.69148	4327	0.86481
158	0.03033	992	0.20199	1826	0.36781	2660	0.53029	3494	0.69148	4328	0.86499

No.	Value	No.	Value	No.	Value	No.	Value	No.	Value	No.	Value
159	0.03052	993	0.20207	1827	0.36794	2661	0.53029	3495	0.69154	4329	0.86513
160	0.030836	994	0.20214	1828	0.36816	2662	0.53055	3496	0.6922	4330	0.86516
161	0.031035	995	0.20233	1829	0.36838	2663	0.53056	3497	0.69309	4331	0.86519
162	0.031693	996	0.2026	1830	0.36926	2664	0.53118	3498	0.69367	4332	0.86529
163	0.031975	997	0.20284	1831	0.36926	2665	0.53139	3499	0.69407	4333	0.86553
164	0.032032	998	0.20289	1832	0.36932	2666	0.53147	3500	0.69422	4334	0.86562
165	0.032195	999	0.20291	1833	0.36934	2667	0.53162	3501	0.69497	4335	0.86583
166	0.0326	1000	0.20302	1834	0.36939	2668	0.53162	3502	0.69517	4336	0.86614
167	0.032681	1001	0.20337	1835	0.36948	2669	0.53216	3503	0.69654	4337	0.86614
168	0.032782	1002	0.20433	1836	0.36978	2670	0.53247	3504	0.69655	4338	0.86621
169	0.033281	1003	0.2044	1837	0.37011	2671	0.53273	3505	0.69673	4339	0.86663
170	0.033343	1004	0.2048	1838	0.37046	2672	0.53311	3506	0.69673	4340	0.86664
171	0.033871	1005	0.20483	1839	0.37103	2673	0.53469	3507	0.69691	4341	0.8668
172	0.033927	1006	0.20549	1840	0.37114	2674	0.53483	3508	0.69773	4342	0.86687
173	0.033954	1007	0.20557	1841	0.37202	2675	0.53498	3509	0.69774	4343	0.86702
174	0.034253	1008	0.20594	1842	0.37227	2676	0.53504	3510	0.69793	4344	0.86746
175	0.034522	1009	0.20601	1843	0.37234	2677	0.53515	3511	0.69819	4345	0.86771
176	0.034584	1010	0.20614	1844	0.37258	2678	0.53538	3512	0.69825	4346	0.86837
177	0.034656	1011	0.20649	1845	0.37286	2679	0.53596	3513	0.69828	4347	0.86844
178	0.03471	1012	0.20655	1846	0.37302	2680	0.53641	3514	0.69832	4348	0.86847
179	0.035559	1013	0.20672	1847	0.37313	2681	0.53669	3515	0.69889	4349	0.86859
180	0.035617	1014	0.20741	1848	0.3735	2682	0.53717	3516	0.69895	4350	0.86878
181	0.035806	1015	0.2076	1849	0.37358	2683	0.53725	3517	0.69933	4351	0.86926
182	0.035838	1016	0.20818	1850	0.37364	2684	0.53728	3518	0.6995	4352	0.86929
183	0.035977	1017	0.20818	1851	0.37367	2685	0.53735	3519	0.69952	4353	0.86937
184	0.03643	1018	0.20846	1852	0.37387	2686	0.53793	3520	0.69954	4354	0.86937
185	0.036491	1019	0.20848	1853	0.37399	2687	0.53813	3521	0.69973	4355	0.86945
186	0.036773	1020	0.20885	1854	0.37414	2688	0.53815	3522	0.69973	4356	0.86952
187	0.03683	1021	0.20929	1855	0.37447	2689	0.5386	3523	0.69983	4357	0.86969
188	0.036873	1022	0.20929	1856	0.3746	2690	0.53861	3524	0.69991	4358	0.86986
189	0.037123	1023	0.20939	1857	0.3749	2691	0.53874	3525	0.70001	4359	0.87078
190	0.037254	1024	0.20953	1858	0.37509	2692	0.539	3526	0.70017	4360	0.87084
191	0.037731	1025	0.20981	1859	0.37511	2693	0.53914	3527	0.7003	4361	0.87092
192	0.037768	1026	0.21036	1860	0.3753	2694	0.53927	3528	0.70049	4362	0.87096
193	0.038741	1027	0.21041	1861	0.37563	2695	0.53947	3529	0.70066	4363	0.87105
194	0.038954	1028	0.21066	1862	0.3758	2696	0.53983	3530	0.70089	4364	0.87111
195	0.039323	1029	0.21068	1863	0.37583	2697	0.53991	3531	0.7009	4365	0.87121
196	0.039687	1030	0.21086	1864	0.37587	2698	0.54006	3532	0.70098	4366	0.87122
197	0.039956	1031	0.21087	1865	0.3765	2699	0.54012	3533	0.70155	4367	0.87126
198	0.041185	1032	0.21103	1866	0.37697	2700	0.54019	3534	0.70165	4368	0.87131
199	0.041242	1033	0.21139	1867	0.37721	2701	0.5403	3535	0.7018	4369	0.87138

No.	Value	No.	Value	No.	Value	No.	Value	No.	Value	No.	Value
200	0.041639	1034	0.21155	1868	0.37724	2702	0.54085	3536	0.70188	4370	0.87141
201	0.041791	1035	0.21158	1869	0.37759	2703	0.54093	3537	0.70207	4371	0.87156
202	0.042109	1036	0.21163	1870	0.3778	2704	0.54106	3538	0.70232	4372	0.87158
203	0.042325	1037	0.21174	1871	0.37784	2705	0.54142	3539	0.70243	4373	0.87172
204	0.042484	1038	0.21176	1872	0.3784	2706	0.54164	3540	0.70257	4374	0.87226
205	0.042747	1039	0.21184	1873	0.37885	2707	0.54193	3541	0.70261	4375	0.87236
206	0.04313	1040	0.21194	1874	0.379	2708	0.54256	3542	0.7029	4376	0.8726
207	0.043285	1041	0.21258	1875	0.37925	2709	0.54264	3543	0.70293	4377	0.87282
208	0.043358	1042	0.21276	1876	0.37926	2710	0.54283	3544	0.70307	4378	0.87327
209	0.043513	1043	0.2128	1877	0.37945	2711	0.54286	3545	0.70307	4379	0.87376
210	0.043897	1044	0.21308	1878	0.37957	2712	0.54305	3546	0.70308	4380	0.87393
211	0.044145	1045	0.21309	1879	0.37963	2713	0.54308	3547	0.70338	4381	0.87406
212	0.044175	1046	0.21329	1880	0.37974	2714	0.54315	3548	0.70352	4382	0.87412
213	0.044724	1047	0.21334	1881	0.37977	2715	0.54357	3549	0.70368	4383	0.87417
214	0.044763	1048	0.2135	1882	0.37981	2716	0.54369	3550	0.70381	4384	0.87421
215	0.044942	1049	0.21359	1883	0.37993	2717	0.54377	3551	0.70414	4385	0.87433
216	0.0451	1050	0.2141	1884	0.38014	2718	0.54412	3552	0.70427	4386	0.87477
217	0.045111	1051	0.21415	1885	0.38033	2719	0.54432	3553	0.70428	4387	0.87509
218	0.045278	1052	0.21421	1886	0.38071	2720	0.54432	3554	0.70437	4388	0.87514
219	0.045315	1053	0.21464	1887	0.38079	2721	0.54433	3555	0.70442	4389	0.87519
220	0.045372	1054	0.21486	1888	0.38092	2722	0.54472	3556	0.70461	4390	0.87573
221	0.045781	1055	0.21518	1889	0.38097	2723	0.54472	3557	0.70492	4391	0.87577
222	0.046117	1056	0.21523	1890	0.38104	2724	0.54526	3558	0.70521	4392	0.876
223	0.046128	1057	0.21557	1891	0.38133	2725	0.54533	3559	0.70522	4393	0.87698
224	0.046367	1058	0.21587	1892	0.38159	2726	0.54537	3560	0.70529	4394	0.87718
225	0.046699	1059	0.2163	1893	0.38171	2727	0.54555	3561	0.7054	4395	0.8772
226	0.046906	1060	0.21637	1894	0.38205	2728	0.54571	3562	0.7065	4396	0.87722
227	0.047434	1061	0.21657	1895	0.38251	2729	0.54574	3563	0.70665	4397	0.87725
228	0.047515	1062	0.21713	1896	0.3827	2730	0.54584	3564	0.70675	4398	0.87729
229	0.047759	1063	0.21787	1897	0.38275	2731	0.54598	3565	0.70696	4399	0.87748
230	0.047926	1064	0.21789	1898	0.38293	2732	0.54601	3566	0.70721	4400	0.8776
231	0.048295	1065	0.21791	1899	0.38299	2733	0.54636	3567	0.70749	4401	0.87798
232	0.048347	1066	0.2185	1900	0.38321	2734	0.54639	3568	0.70888	4402	0.87821
233	0.048766	1067	0.21869	1901	0.38346	2735	0.54646	3569	0.70889	4403	0.87827
234	0.048812	1068	0.21875	1902	0.38367	2736	0.54668	3570	0.70927	4404	0.87829
235	0.049076	1069	0.21891	1903	0.38395	2737	0.54668	3571	0.7093	4405	0.87829
236	0.049373	1070	0.21917	1904	0.38405	2738	0.54718	3572	0.70946	4406	0.87843
237	0.049448	1071	0.21991	1905	0.38407	2739	0.54759	3573	0.70947	4407	0.87843
238	0.049686	1072	0.22012	1906	0.38424	2740	0.54802	3574	0.70987	4408	0.87846
239	0.049718	1073	0.22017	1907	0.38428	2741	0.54826	3575	0.71014	4409	0.87857
240	0.05014	1074	0.22049	1908	0.38433	2742	0.54827	3576	0.71019	4410	0.87862

No.	Value	No.	Value	No.	Value	No.	Value	No.	Value	No.	Value
241	0.050326	1075	0.22058	1909	0.38445	2743	0.54835	3577	0.71031	4411	0.87868
242	0.050438	1076	0.22061	1910	0.38463	2744	0.54855	3578	0.71051	4412	0.87891
243	0.050466	1077	0.22068	1911	0.38517	2745	0.54876	3579	0.71053	4413	0.87926
244	0.050519	1078	0.22098	1912	0.38523	2746	0.54878	3580	0.71079	4414	0.87934
245	0.050926	1079	0.22099	1913	0.38555	2747	0.54882	3581	0.71115	4415	0.87948
246	0.051465	1080	0.22117	1914	0.38597	2748	0.54901	3582	0.71195	4416	0.87978
247	0.051576	1081	0.2217	1915	0.38682	2749	0.54907	3583	0.71219	4417	0.87984
248	0.051895	1082	0.22175	1916	0.38693	2750	0.54921	3584	0.71242	4418	0.88037
249	0.052076	1083	0.2218	1917	0.38788	2751	0.54937	3585	0.71247	4419	0.88041
250	0.052219	1084	0.22253	1918	0.38794	2752	0.54984	3586	0.71261	4420	0.88046
251	0.052285	1085	0.22292	1919	0.38863	2753	0.54987	3587	0.71342	4421	0.88066
252	0.0524	1086	0.223	1920	0.38929	2754	0.55011	3588	0.71369	4422	0.88079
253	0.052448	1087	0.22307	1921	0.38947	2755	0.55021	3589	0.71399	4423	0.88089
254	0.052725	1088	0.22335	1922	0.38954	2756	0.55024	3590	0.71404	4424	0.88107
255	0.052758	1089	0.22363	1923	0.38989	2757	0.55088	3591	0.7141	4425	0.88136
256	0.052904	1090	0.2237	1924	0.39046	2758	0.55136	3592	0.71411	4426	0.88147
257	0.053675	1091	0.22372	1925	0.39069	2759	0.55142	3593	0.71443	4427	0.88204
258	0.053804	1092	0.22386	1926	0.39084	2760	0.55176	3594	0.71447	4428	0.88253
259	0.054077	1093	0.22399	1927	0.39086	2761	0.55187	3595	0.71454	4429	0.88254
260	0.054112	1094	0.22403	1928	0.39088	2762	0.5519	3596	0.71487	4430	0.88275
261	0.054417	1095	0.22451	1929	0.39098	2763	0.55225	3597	0.715	4431	0.8829
262	0.054964	1096	0.22465	1930	0.39115	2764	0.55246	3598	0.71562	4432	0.88306
263	0.055083	1097	0.22469	1931	0.39128	2765	0.55282	3599	0.71566	4433	0.88328
264	0.05556	1098	0.2247	1932	0.39136	2766	0.55302	3600	0.71582	4434	0.88336
265	0.055599	1099	0.2251	1933	0.39139	2767	0.55328	3601	0.71659	4435	0.88345
266	0.055631	1100	0.22512	1934	0.39161	2768	0.55334	3602	0.71681	4436	0.88351
267	0.056993	1101	0.22524	1935	0.39169	2769	0.55352	3603	0.71686	4437	0.88387
268	0.057202	1102	0.22582	1936	0.39218	2770	0.55394	3604	0.71687	4438	0.88389
269	0.05735	1103	0.22597	1937	0.39249	2771	0.55406	3605	0.71716	4439	0.88461
270	0.057495	1104	0.22632	1938	0.39282	2772	0.55415	3606	0.71728	4440	0.88482
271	0.0576	1105	0.22655	1939	0.39297	2773	0.55435	3607	0.71762	4441	0.88583
272	0.057805	1106	0.22667	1940	0.39306	2774	0.55435	3608	0.7179	4442	0.88588
273	0.057905	1107	0.2269	1941	0.39312	2775	0.55461	3609	0.71792	4443	0.88629
274	0.057957	1108	0.22734	1942	0.39325	2776	0.55472	3610	0.71806	4444	0.88646
275	0.058516	1109	0.22781	1943	0.39325	2777	0.55475	3611	0.71816	4445	0.88708
276	0.058695	1110	0.22848	1944	0.39325	2778	0.55493	3612	0.71846	4446	0.88714
277	0.058749	1111	0.22853	1945	0.39334	2779	0.5551	3613	0.71851	4447	0.88725
278	0.058889	1112	0.22889	1946	0.39337	2780	0.55553	3614	0.71874	4448	0.88753
279	0.059003	1113	0.22892	1947	0.3934	2781	0.55555	3615	0.7188	4449	0.88758
280	0.059081	1114	0.22903	1948	0.3935	2782	0.55668	3616	0.72008	4450	0.88764
281	0.059357	1115	0.22948	1949	0.39375	2783	0.55683	3617	0.72023	4451	0.88784

No.	Value	No.	Value	No.	Value	No.	Value	No.	Value	No.	Value
282	0.059402	1116	0.22953	1950	0.39377	2784	0.5569	3618	0.72049	4452	0.88796
283	0.059823	1117	0.22958	1951	0.3939	2785	0.55695	3619	0.72055	4453	0.88801
284	0.060447	1118	0.2296	1952	0.39391	2786	0.55708	3620	0.72097	4454	0.88805
285	0.060607	1119	0.22985	1953	0.394	2787	0.55727	3621	0.72118	4455	0.88808
286	0.060928	1120	0.23072	1954	0.394	2788	0.55754	3622	0.7213	4456	0.88843
287	0.061029	1121	0.23083	1955	0.39409	2789	0.55789	3623	0.72176	4457	0.88874
288	0.061638	1122	0.23085	1956	0.39416	2790	0.55799	3624	0.72199	4458	0.88908
289	0.061931	1123	0.23113	1957	0.39469	2791	0.5584	3625	0.72208	4459	0.88928
290	0.061947	1124	0.23143	1958	0.3949	2792	0.55845	3626	0.72216	4460	0.88931
291	0.062037	1125	0.23165	1959	0.395	2793	0.55856	3627	0.72248	4461	0.88958
292	0.062909	1126	0.23166	1960	0.39518	2794	0.5588	3628	0.72254	4462	0.89002
293	0.063064	1127	0.23173	1961	0.39601	2795	0.55882	3629	0.72303	4463	0.89006
294	0.063491	1128	0.23179	1962	0.39603	2796	0.55882	3630	0.72317	4464	0.89067
295	0.063671	1129	0.23185	1963	0.39612	2797	0.55947	3631	0.7232	4465	0.89096
296	0.06386	1130	0.23253	1964	0.39617	2798	0.5595	3632	0.72322	4466	0.89132
297	0.063918	1131	0.23254	1965	0.3962	2799	0.55954	3633	0.7233	4467	0.89137
298	0.063919	1132	0.23258	1966	0.39641	2800	0.55961	3634	0.72333	4468	0.89163
299	0.064129	1133	0.2326	1967	0.39653	2801	0.55971	3635	0.72346	4469	0.89178
300	0.064138	1134	0.23267	1968	0.397	2802	0.55988	3636	0.72366	4470	0.89189
301	0.064364	1135	0.23268	1969	0.39719	2803	0.55999	3637	0.7237	4471	0.89191
302	0.064451	1136	0.23298	1970	0.39722	2804	0.56019	3638	0.72384	4472	0.89223
303	0.064563	1137	0.23312	1971	0.39744	2805	0.56044	3639	0.72407	4473	0.89265
304	0.064667	1138	0.23315	1972	0.39761	2806	0.56053	3640	0.72418	4474	0.89267
305	0.064829	1139	0.23357	1973	0.39763	2807	0.56075	3641	0.72444	4475	0.8928
306	0.064989	1140	0.23374	1974	0.39785	2808	0.56096	3642	0.72468	4476	0.89288
307	0.065272	1141	0.23412	1975	0.39785	2809	0.56113	3643	0.72499	4477	0.89304
308	0.065293	1142	0.23413	1976	0.39819	2810	0.56126	3644	0.7251	4478	0.89306
309	0.065833	1143	0.23439	1977	0.39839	2811	0.56127	3645	0.72514	4479	0.8933
310	0.065925	1144	0.23468	1978	0.39842	2812	0.56142	3646	0.72527	4480	0.89348
311	0.065941	1145	0.23494	1979	0.39848	2813	0.56158	3647	0.72529	4481	0.89349
312	0.066036	1146	0.23495	1980	0.39856	2814	0.56173	3648	0.72561	4482	0.89395
313	0.066887	1147	0.235	1981	0.39857	2815	0.56174	3649	0.726	4483	0.89427
314	0.067209	1148	0.23509	1982	0.39864	2816	0.56208	3650	0.726	4484	0.89429
315	0.06738	1149	0.2353	1983	0.39872	2817	0.56239	3651	0.72629	4485	0.89475
316	0.06739	1150	0.23545	1984	0.39883	2818	0.56246	3652	0.72629	4486	0.89482
317	0.067425	1151	0.23549	1985	0.39901	2819	0.56248	3653	0.72634	4487	0.8949
318	0.067536	1152	0.23577	1986	0.39923	2820	0.5626	3654	0.72655	4488	0.89511
319	0.067705	1153	0.23584	1987	0.39946	2821	0.56329	3655	0.72675	4489	0.89528
320	0.067761	1154	0.23599	1988	0.39949	2822	0.56347	3656	0.72677	4490	0.89552
321	0.067771	1155	0.23604	1989	0.39953	2823	0.56352	3657	0.72694	4491	0.89575
322	0.068038	1156	0.23627	1990	0.39969	2824	0.56363	3658	0.72732	4492	0.89578

No.	Value	No.	Value	No.	Value	No.	Value	No.	Value	No.	Value
323	0.068339	1157	0.23631	1991	0.40087	2825	0.56373	3659	0.72737	4493	0.8958
324	0.068381	1158	0.23643	1992	0.40112	2826	0.56381	3660	0.72743	4494	0.8961
325	0.068448	1159	0.23648	1993	0.40114	2827	0.5642	3661	0.7279	4495	0.89672
326	0.068736	1160	0.23662	1994	0.40126	2828	0.56428	3662	0.728	4496	0.89688
327	0.06883	1161	0.23689	1995	0.40131	2829	0.56433	3663	0.72833	4497	0.89711
328	0.068942	1162	0.23696	1996	0.40139	2830	0.56442	3664	0.72839	4498	0.89729
329	0.069387	1163	0.23702	1997	0.40147	2831	0.56448	3665	0.72852	4499	0.898
330	0.06971	1164	0.23718	1998	0.40148	2832	0.56449	3666	0.72867	4500	0.89808
331	0.069905	1165	0.23745	1999	0.40152	2833	0.56467	3667	0.72905	4501	0.89859
332	0.069973	1166	0.23746	2000	0.40188	2834	0.56503	3668	0.72946	4502	0.89859
333	0.070167	1167	0.23757	2001	0.40224	2835	0.56507	3669	0.72953	4503	0.89868
334	0.070454	1168	0.2377	2002	0.40252	2836	0.56509	3670	0.72967	4504	0.89871
335	0.070546	1169	0.2379	2003	0.40257	2837	0.56528	3671	0.72997	4505	0.89898
336	0.070759	1170	0.23847	2004	0.40274	2838	0.5653	3672	0.73005	4506	0.89909
337	0.071066	1171	0.23868	2005	0.40289	2839	0.56543	3673	0.73027	4507	0.89911
338	0.071095	1172	0.23883	2006	0.40298	2840	0.56577	3674	0.73032	4508	0.89924
339	0.072092	1173	0.23883	2007	0.40322	2841	0.56585	3675	0.73055	4509	0.89962
340	0.072131	1174	0.23929	2008	0.40344	2842	0.56595	3676	0.73132	4510	0.89974
341	0.07232	1175	0.23931	2009	0.40369	2843	0.56636	3677	0.73133	4511	0.90018
342	0.072566	1176	0.23962	2010	0.40386	2844	0.56653	3678	0.73136	4512	0.90044
343	0.072586	1177	0.23963	2011	0.40391	2845	0.56718	3679	0.73144	4513	0.90047
344	0.072594	1178	0.23966	2012	0.40447	2846	0.56744	3680	0.73145	4514	0.90069
345	0.072601	1179	0.23966	2013	0.40454	2847	0.56749	3681	0.73146	4515	0.90079
346	0.072907	1180	0.23969	2014	0.40457	2848	0.56753	3682	0.73147	4516	0.9008
347	0.072936	1181	0.23984	2015	0.40461	2849	0.56764	3683	0.73147	4517	0.90089
348	0.07313	1182	0.23999	2016	0.40461	2850	0.56764	3684	0.73152	4518	0.90095
349	0.073277	1183	0.24018	2017	0.40484	2851	0.56772	3685	0.73158	4519	0.90098
350	0.073819	1184	0.24022	2018	0.40535	2852	0.56792	3686	0.7318	4520	0.90115
351	0.073834	1185	0.24041	2019	0.40539	2853	0.56805	3687	0.73192	4521	0.90132
352	0.073894	1186	0.24066	2020	0.40553	2854	0.56805	3688	0.73203	4522	0.90136
353	0.07397	1187	0.24081	2021	0.40558	2855	0.56812	3689	0.73214	4523	0.90164
354	0.074014	1188	0.24091	2022	0.40586	2856	0.56816	3690	0.73215	4524	0.90212
355	0.074062	1189	0.24109	2023	0.40595	2857	0.56816	3691	0.73223	4525	0.90235
356	0.07416	1190	0.24125	2024	0.40611	2858	0.56883	3692	0.73239	4526	0.90238
357	0.074311	1191	0.24144	2025	0.40639	2859	0.56909	3693	0.73245	4527	0.90249
358	0.074372	1192	0.24147	2026	0.40696	2860	0.56922	3694	0.73278	4528	0.90266
359	0.07505	1193	0.24163	2027	0.40724	2861	0.56924	3695	0.73306	4529	0.90285
360	0.075254	1194	0.24169	2028	0.40745	2862	0.56944	3696	0.73328	4530	0.90313
361	0.075857	1195	0.24175	2029	0.40771	2863	0.56945	3697	0.73331	4531	0.90417
362	0.076057	1196	0.24262	2030	0.40772	2864	0.56966	3698	0.73351	4532	0.90418
363	0.076142	1197	0.24288	2031	0.40806	2865	0.56968	3699	0.73357	4533	0.90423

No.	Value	No.	Value	No.	Value	No.	Value	No.	Value	No.	Value
364	0.076299	1198	0.24289	2032	0.40821	2866	0.57019	3700	0.73397	4534	0.9044
365	0.076359	1199	0.24296	2033	0.40836	2867	0.57023	3701	0.73409	4535	0.90441
366	0.076618	1200	0.2431	2034	0.4084	2868	0.5705	3702	0.73462	4536	0.90448
367	0.076687	1201	0.24329	2035	0.40844	2869	0.57084	3703	0.73538	4537	0.90452
368	0.076864	1202	0.2434	2036	0.40845	2870	0.57089	3704	0.73553	4538	0.90461
369	0.077041	1203	0.24403	2037	0.40848	2871	0.57144	3705	0.7356	4539	0.90473
370	0.077198	1204	0.24408	2038	0.40865	2872	0.57161	3706	0.7356	4540	0.90562
371	0.07769	1205	0.24452	2039	0.40881	2873	0.57176	3707	0.73563	4541	0.90565
372	0.077727	1206	0.24476	2040	0.40882	2874	0.57177	3708	0.7357	4542	0.906
373	0.077727	1207	0.24498	2041	0.40898	2875	0.57209	3709	0.73581	4543	0.90602
374	0.07783	1208	0.24518	2042	0.40904	2876	0.57217	3710	0.73592	4544	0.9061
375	0.07791	1209	0.24539	2043	0.40923	2877	0.57227	3711	0.73606	4545	0.90626
376	0.078252	1210	0.24543	2044	0.40958	2878	0.57251	3712	0.73609	4546	0.90631
377	0.078422	1211	0.24585	2045	0.40965	2879	0.57252	3713	0.73644	4547	0.90663
378	0.078467	1212	0.24614	2046	0.40974	2880	0.57254	3714	0.73709	4548	0.90695
379	0.07902	1213	0.24628	2047	0.40984	2881	0.57258	3715	0.73709	4549	0.90716
380	0.079074	1214	0.24655	2048	0.4101	2882	0.57293	3716	0.73712	4550	0.90728
381	0.079206	1215	0.24655	2049	0.4106	2883	0.57296	3717	0.73713	4551	0.90747
382	0.079581	1216	0.24671	2050	0.41082	2884	0.57299	3718	0.73748	4552	0.90781
383	0.079684	1217	0.24719	2051	0.4109	2885	0.57315	3719	0.7385	4553	0.908
384	0.080102	1218	0.24731	2052	0.41108	2886	0.57362	3720	0.73856	4554	0.90801
385	0.080103	1219	0.24738	2053	0.41136	2887	0.57403	3721	0.73868	4555	0.90811
386	0.080121	1220	0.24753	2054	0.41191	2888	0.57442	3722	0.7388	4556	0.90819
387	0.080147	1221	0.24766	2055	0.4121	2889	0.57453	3723	0.73936	4557	0.90856
388	0.080187	1222	0.2478	2056	0.41214	2890	0.57456	3724	0.73937	4558	0.90921
389	0.080351	1223	0.24787	2057	0.41253	2891	0.57474	3725	0.73941	4559	0.90933
390	0.08069	1224	0.24804	2058	0.41268	2892	0.57505	3726	0.73941	4560	0.90965
391	0.081137	1225	0.2492	2059	0.41269	2893	0.57511	3727	0.73959	4561	0.91002
392	0.081318	1226	0.24922	2060	0.41285	2894	0.57515	3728	0.74019	4562	0.91013
393	0.081446	1227	0.2494	2061	0.41296	2895	0.57517	3729	0.74021	4563	0.91019
394	0.081825	1228	0.24946	2062	0.41301	2896	0.57534	3730	0.74083	4564	0.91055
395	0.081827	1229	0.25003	2063	0.41303	2897	0.5754	3731	0.74112	4565	0.9109
396	0.081934	1230	0.25015	2064	0.41317	2898	0.57544	3732	0.74113	4566	0.9109
397	0.081936	1231	0.25074	2065	0.41319	2899	0.57573	3733	0.74153	4567	0.91133
398	0.082016	1232	0.2511	2066	0.41362	2900	0.5763	3734	0.74179	4568	0.91169
399	0.082156	1233	0.25126	2067	0.41365	2901	0.57675	3735	0.74216	4569	0.91183
400	0.082313	1234	0.25128	2068	0.41375	2902	0.57682	3736	0.74329	4570	0.91193
401	0.082684	1235	0.25146	2069	0.41387	2903	0.57732	3737	0.74357	4571	0.91225
402	0.083072	1236	0.25152	2070	0.41395	2904	0.57742	3738	0.74419	4572	0.9123
403	0.083208	1237	0.25155	2071	0.41398	2905	0.57792	3739	0.74428	4573	0.91246
404	0.083252	1238	0.25202	2072	0.41439	2906	0.57792	3740	0.74445	4574	0.91315

No.	Value	No.	Value	No.	Value	No.	Value	No.	Value	No.	Value
405	0.083369	1239	0.25231	2073	0.41469	2907	0.57797	3741	0.7445	4575	0.91318
406	0.083669	1240	0.25258	2074	0.41522	2908	0.57809	3742	0.7448	4576	0.91362
407	0.084322	1241	0.25259	2075	0.41559	2909	0.57828	3743	0.74505	4577	0.91377
408	0.084364	1242	0.2527	2076	0.41562	2910	0.57867	3744	0.74522	4578	0.91408
409	0.084428	1243	0.25275	2077	0.41572	2911	0.57869	3745	0.74551	4579	0.9143
410	0.084613	1244	0.25285	2078	0.41572	2912	0.5787	3746	0.74567	4580	0.91449
411	0.084836	1245	0.25291	2079	0.41579	2913	0.57921	3747	0.74587	4581	0.91458
412	0.084975	1246	0.2533	2080	0.41606	2914	0.57927	3748	0.74613	4582	0.91476
413	0.085328	1247	0.25341	2081	0.41637	2915	0.57956	3749	0.74618	4583	0.91495
414	0.085559	1248	0.25346	2082	0.41668	2916	0.57978	3750	0.74622	4584	0.91505
415	0.085811	1249	0.25363	2083	0.41672	2917	0.57982	3751	0.74636	4585	0.91526
416	0.08584	1250	0.25379	2084	0.41682	2918	0.57997	3752	0.74693	4586	0.91553
417	0.085844	1251	0.25387	2085	0.41701	2919	0.57999	3753	0.74707	4587	0.91577
418	0.086021	1252	0.25405	2086	0.41702	2920	0.5806	3754	0.74719	4588	0.9159
419	0.086054	1253	0.25422	2087	0.41713	2921	0.58061	3755	0.74723	4589	0.91616
420	0.086949	1254	0.25438	2088	0.41724	2922	0.58085	3756	0.74736	4590	0.91618
421	0.087234	1255	0.25453	2089	0.41728	2923	0.58094	3757	0.7475	4591	0.91642
422	0.087471	1256	0.25461	2090	0.41748	2924	0.58109	3758	0.74759	4592	0.91649
423	0.087502	1257	0.25466	2091	0.41754	2925	0.58117	3759	0.7476	4593	0.91649
424	0.08767	1258	0.25474	2092	0.41783	2926	0.58167	3760	0.74774	4594	0.91673
425	0.088264	1259	0.25475	2093	0.41801	2927	0.58168	3761	0.74814	4595	0.91688
426	0.088545	1260	0.25517	2094	0.41812	2928	0.58184	3762	0.74848	4596	0.91708
427	0.089112	1261	0.25529	2095	0.41847	2929	0.5822	3763	0.74864	4597	0.9171
428	0.089141	1262	0.2553	2096	0.41877	2930	0.58224	3764	0.7487	4598	0.91726
429	0.0892	1263	0.25553	2097	0.41921	2931	0.58224	3765	0.74903	4599	0.9175
430	0.08935	1264	0.25628	2098	0.41927	2932	0.58227	3766	0.74947	4600	0.91755
431	0.089475	1265	0.25629	2099	0.41935	2933	0.58231	3767	0.74952	4601	0.91758
432	0.089523	1266	0.25645	2100	0.41944	2934	0.58235	3768	0.74984	4602	0.91763
433	0.090341	1267	0.25677	2101	0.41996	2935	0.583	3769	0.75003	4603	0.91767
434	0.090344	1268	0.25682	2102	0.41996	2936	0.58369	3770	0.75025	4604	0.91768
435	0.090436	1269	0.25685	2103	0.42036	2937	0.58369	3771	0.75028	4605	0.91773
436	0.090541	1270	0.25726	2104	0.42069	2938	0.58384	3772	0.75037	4606	0.91787
437	0.090549	1271	0.25759	2105	0.4207	2939	0.58415	3773	0.75041	4607	0.9182
438	0.090814	1272	0.25778	2106	0.42078	2940	0.58418	3774	0.7508	4608	0.91825
439	0.090839	1273	0.25821	2107	0.42085	2941	0.58427	3775	0.7509	4609	0.91834
440	0.090916	1274	0.25857	2108	0.42111	2942	0.58432	3776	0.75092	4610	0.91859
441	0.09094	1275	0.25865	2109	0.42112	2943	0.58485	3777	0.75096	4611	0.91863
442	0.091043	1276	0.25866	2110	0.42115	2944	0.58488	3778	0.75103	4612	0.91904
443	0.09126	1277	0.25919	2111	0.4212	2945	0.58509	3779	0.75186	4613	0.91911
444	0.091349	1278	0.25944	2112	0.42124	2946	0.58542	3780	0.75187	4614	0.91913
445	0.0917	1279	0.25954	2113	0.4214	2947	0.58571	3781	0.75195	4615	0.91932

No.	Value	No.	Value	No.	Value	No.	Value	No.	Value	No.	Value
446	0.091963	1280	0.25978	2114	0.42186	2948	0.58601	3782	0.75202	4616	0.91975
447	0.09247	1281	0.26046	2115	0.42196	2949	0.5866	3783	0.75211	4617	0.9208
448	0.092588	1282	0.2605	2116	0.42253	2950	0.5869	3784	0.75231	4618	0.92081
449	0.09385	1283	0.2606	2117	0.42292	2951	0.58705	3785	0.75277	4619	0.92095
450	0.094062	1284	0.26092	2118	0.42298	2952	0.58723	3786	0.75347	4620	0.92117
451	0.094101	1285	0.26163	2119	0.42318	2953	0.58745	3787	0.75365	4621	0.92142
452	0.094499	1286	0.26206	2120	0.42326	2954	0.58795	3788	0.75392	4622	0.92146
453	0.094829	1287	0.26228	2121	0.42342	2955	0.58801	3789	0.75414	4623	0.92154
454	0.094932	1288	0.26229	2122	0.42363	2956	0.58809	3790	0.75423	4624	0.92227
455	0.095096	1289	0.26246	2123	0.42369	2957	0.58815	3791	0.75427	4625	0.92229
456	0.095293	1290	0.26247	2124	0.42376	2958	0.58822	3792	0.75447	4626	0.92254
457	0.095898	1291	0.26248	2125	0.4239	2959	0.58829	3793	0.75458	4627	0.92282
458	0.09657	1292	0.26253	2126	0.42397	2960	0.58847	3794	0.7549	4628	0.92301
459	0.096649	1293	0.26254	2127	0.42403	2961	0.58854	3795	0.75517	4629	0.9231
460	0.0967	1294	0.26254	2128	0.42403	2962	0.58889	3796	0.75531	4630	0.92349
461	0.096826	1295	0.2626	2129	0.4243	2963	0.58894	3797	0.75543	4631	0.92357
462	0.097004	1296	0.26279	2130	0.42445	2964	0.58895	3798	0.75554	4632	0.92375
463	0.097266	1297	0.26292	2131	0.42454	2965	0.58904	3799	0.75573	4633	0.92376
464	0.097442	1298	0.26309	2132	0.42463	2966	0.58935	3800	0.75579	4634	0.92382
465	0.097539	1299	0.26345	2133	0.42479	2967	0.58941	3801	0.75618	4635	0.92463
466	0.097565	1300	0.26346	2134	0.42486	2968	0.58961	3802	0.75654	4636	0.92475
467	0.097597	1301	0.26357	2135	0.42487	2969	0.58975	3803	0.75656	4637	0.92527
468	0.097648	1302	0.26376	2136	0.42511	2970	0.59013	3804	0.75684	4638	0.92588
469	0.098272	1303	0.26401	2137	0.42522	2971	0.59055	3805	0.75702	4639	0.92599
470	0.098353	1304	0.26417	2138	0.42523	2972	0.59088	3806	0.75721	4640	0.92609
471	0.098456	1305	0.26438	2139	0.42543	2973	0.59112	3807	0.75721	4641	0.92652
472	0.099407	1306	0.26461	2140	0.42556	2974	0.5917	3808	0.7573	4642	0.92697
473	0.099579	1307	0.26468	2141	0.42557	2975	0.59186	3809	0.75754	4643	0.92722
474	0.099757	1308	0.26472	2142	0.42694	2976	0.59189	3810	0.75759	4644	0.9273
475	0.099786	1309	0.26481	2143	0.42709	2977	0.592	3811	0.75812	4645	0.92778
476	0.099952	1310	0.26522	2144	0.42721	2978	0.5921	3812	0.75815	4646	0.92791
477	0.099994	1311	0.26552	2145	0.42804	2979	0.59217	3813	0.75833	4647	0.92792
478	0.1002	1312	0.26554	2146	0.42809	2980	0.5922	3814	0.7587	4648	0.92795
479	0.10076	1313	0.26562	2147	0.42838	2981	0.59224	3815	0.7588	4649	0.92812
480	0.10092	1314	0.26576	2148	0.42859	2982	0.5928	3816	0.75902	4650	0.92824
481	0.10107	1315	0.26576	2149	0.4293	2983	0.59293	3817	0.75909	4651	0.92827
482	0.10121	1316	0.26578	2150	0.42943	2984	0.59293	3818	0.75911	4652	0.92834
483	0.10125	1317	0.26602	2151	0.42944	2985	0.593	3819	0.75929	4653	0.92846
484	0.10143	1318	0.26608	2152	0.42944	2986	0.59318	3820	0.75935	4654	0.92869
485	0.10146	1319	0.26613	2153	0.42982	2987	0.59337	3821	0.75941	4655	0.92929
486	0.10153	1320	0.26626	2154	0.42986	2988	0.59342	3822	0.75941	4656	0.92943

No.	Value	No.	Value	No.	Value	No.	Value	No.	Value	No.	Value
487	0.1017	1321	0.26659	2155	0.43005	2989	0.59347	3823	0.75972	4657	0.92973
488	0.10172	1322	0.26703	2156	0.43057	2990	0.59357	3824	0.75984	4658	0.92974
489	0.10172	1323	0.26736	2157	0.43058	2991	0.59359	3825	0.75989	4659	0.92995
490	0.10177	1324	0.26747	2158	0.4306	2992	0.5936	3826	0.76016	4660	0.93032
491	0.10191	1325	0.26761	2159	0.43068	2993	0.59375	3827	0.76074	4661	0.93064
492	0.10272	1326	0.26764	2160	0.43101	2994	0.59378	3828	0.76093	4662	0.93094
493	0.10312	1327	0.26777	2161	0.43115	2995	0.59405	3829	0.76095	4663	0.93111
494	0.10315	1328	0.26799	2162	0.43133	2996	0.59412	3830	0.76102	4664	0.93135
495	0.10343	1329	0.2683	2163	0.43137	2997	0.59423	3831	0.76134	4665	0.93142
496	0.10367	1330	0.26844	2164	0.43159	2998	0.59442	3832	0.76177	4666	0.93143
497	0.1037	1331	0.26851	2165	0.43163	2999	0.5946	3833	0.76209	4667	0.93144
498	0.10386	1332	0.26852	2166	0.43185	3000	0.59477	3834	0.76234	4668	0.93144
499	0.1045	1333	0.26897	2167	0.43196	3001	0.59492	3835	0.76287	4669	0.93154
500	0.10458	1334	0.26927	2168	0.43228	3002	0.59503	3836	0.76314	4670	0.93173
501	0.10537	1335	0.26935	2169	0.43236	3003	0.59517	3837	0.76342	4671	0.93203
502	0.10591	1336	0.26965	2170	0.43276	3004	0.59553	3838	0.76342	4672	0.93212
503	0.106	1337	0.26987	2171	0.43288	3005	0.59591	3839	0.76348	4673	0.93271
504	0.10605	1338	0.2699	2172	0.43314	3006	0.59594	3840	0.7637	4674	0.93297
505	0.10659	1339	0.27021	2173	0.43333	3007	0.59604	3841	0.7638	4675	0.93325
506	0.10668	1340	0.27027	2174	0.43334	3008	0.59627	3842	0.76396	4676	0.93325
507	0.10668	1341	0.27029	2175	0.43354	3009	0.59638	3843	0.76398	4677	0.93368
508	0.10687	1342	0.2704	2176	0.43368	3010	0.59663	3844	0.76478	4678	0.93437
509	0.1069	1343	0.27083	2177	0.43433	3011	0.59678	3845	0.76481	4679	0.93441
510	0.10691	1344	0.27084	2178	0.43464	3012	0.59697	3846	0.76524	4680	0.93446
511	0.10703	1345	0.27129	2179	0.43492	3013	0.5971	3847	0.76553	4681	0.93457
512	0.10704	1346	0.27149	2180	0.43502	3014	0.59724	3848	0.76564	4682	0.93465
513	0.10713	1347	0.27152	2181	0.43504	3015	0.59754	3849	0.76569	4683	0.93473
514	0.10724	1348	0.27183	2182	0.43591	3016	0.59756	3850	0.76577	4684	0.93477
515	0.10726	1349	0.27206	2183	0.43616	3017	0.5976	3851	0.76598	4685	0.93494
516	0.10782	1350	0.27219	2184	0.43617	3018	0.59864	3852	0.76599	4686	0.93504
517	0.10798	1351	0.27222	2185	0.43668	3019	0.59875	3853	0.76603	4687	0.93516
518	0.10809	1352	0.27225	2186	0.4367	3020	0.59876	3854	0.7663	4688	0.93518
519	0.10817	1353	0.27252	2187	0.43677	3021	0.59878	3855	0.76663	4689	0.93521
520	0.10836	1354	0.27313	2188	0.43691	3022	0.59893	3856	0.76693	4690	0.93526
521	0.10871	1355	0.27316	2189	0.43701	3023	0.59909	3857	0.76697	4691	0.93548
522	0.10879	1356	0.27348	2190	0.43717	3024	0.59929	3858	0.76719	4692	0.93568
523	0.10883	1357	0.27361	2191	0.43729	3025	0.59935	3859	0.76746	4693	0.93604
524	0.1089	1358	0.2741	2192	0.43731	3026	0.59962	3860	0.76788	4694	0.93652
525	0.10929	1359	0.2742	2193	0.43764	3027	0.59989	3861	0.76802	4695	0.93658
526	0.11005	1360	0.27433	2194	0.43771	3028	0.59994	3862	0.76874	4696	0.93713
527	0.11035	1361	0.27434	2195	0.43771	3029	0.60001	3863	0.76895	4697	0.93756

No.	Value	No.	Value	No.	Value	No.	Value	No.	Value	No.	Value
528	0.11047	**1362**	0.27462	**2196**	0.4379	**3030**	0.60005	**3864**	0.76919	**4698**	0.93756
529	0.11075	**1363**	0.27482	**2197**	0.4379	**3031**	0.6002	**3865**	0.76966	**4699**	0.93758
530	0.11147	**1364**	0.27496	**2198**	0.43807	**3032**	0.60039	**3866**	0.76992	**4700**	0.93763
531	0.11159	**1365**	0.27498	**2199**	0.43867	**3033**	0.6004	**3867**	0.77013	**4701**	0.93786
532	0.11159	**1366**	0.27521	**2200**	0.43906	**3034**	0.60053	**3868**	0.77019	**4702**	0.93791
533	0.11173	**1367**	0.27539	**2201**	0.43919	**3035**	0.60072	**3869**	0.77028	**4703**	0.93804
534	0.11208	**1368**	0.27566	**2202**	0.43933	**3036**	0.6008	**3870**	0.77038	**4704**	0.93829
535	0.11215	**1369**	0.27586	**2203**	0.43966	**3037**	0.60102	**3871**	0.77098	**4705**	0.93841
536	0.11222	**1370**	0.27632	**2204**	0.44008	**3038**	0.60105	**3872**	0.77102	**4706**	0.93857
537	0.11277	**1371**	0.27707	**2205**	0.44032	**3039**	0.60119	**3873**	0.77103	**4707**	0.93866
538	0.11295	**1372**	0.27752	**2206**	0.44096	**3040**	0.60128	**3874**	0.77116	**4708**	0.93877
539	0.11297	**1373**	0.27753	**2207**	0.441	**3041**	0.60129	**3875**	0.77136	**4709**	0.93895
540	0.11302	**1374**	0.27764	**2208**	0.44104	**3042**	0.60131	**3876**	0.77161	**4710**	0.93947
541	0.11308	**1375**	0.27795	**2209**	0.44105	**3043**	0.60145	**3877**	0.77168	**4711**	0.9397
542	0.1133	**1376**	0.2785	**2210**	0.44109	**3044**	0.60162	**3878**	0.7717	**4712**	0.93987
543	0.11363	**1377**	0.27871	**2211**	0.44138	**3045**	0.60186	**3879**	0.77181	**4713**	0.93995
544	0.11365	**1378**	0.27873	**2212**	0.44144	**3046**	0.60186	**3880**	0.77183	**4714**	0.94024
545	0.11378	**1379**	0.27884	**2213**	0.44164	**3047**	0.60232	**3881**	0.77216	**4715**	0.9403
546	0.1138	**1380**	0.27917	**2214**	0.44201	**3048**	0.60233	**3882**	0.77226	**4716**	0.94033
547	0.11386	**1381**	0.27942	**2215**	0.44213	**3049**	0.60328	**3883**	0.77238	**4717**	0.94048
548	0.11406	**1382**	0.28007	**2216**	0.44222	**3050**	0.60332	**3884**	0.77297	**4718**	0.94075
549	0.11443	**1383**	0.28014	**2217**	0.44224	**3051**	0.60349	**3885**	0.77298	**4719**	0.94094
550	0.11448	**1384**	0.28044	**2218**	0.4424	**3052**	0.60362	**3886**	0.773	**4720**	0.94097
551	0.11451	**1385**	0.28064	**2219**	0.44254	**3053**	0.60363	**3887**	0.77319	**4721**	0.94151
552	0.11491	**1386**	0.2807	**2220**	0.44282	**3054**	0.60373	**3888**	0.77344	**4722**	0.9416
553	0.11588	**1387**	0.28077	**2221**	0.44292	**3055**	0.60385	**3889**	0.77351	**4723**	0.94167
554	0.1164	**1388**	0.28097	**2222**	0.44319	**3056**	0.60413	**3890**	0.77363	**4724**	0.94207
555	0.11644	**1389**	0.28116	**2223**	0.44337	**3057**	0.60487	**3891**	0.77367	**4725**	0.94224
556	0.11665	**1390**	0.28119	**2224**	0.44341	**3058**	0.60496	**3892**	0.77383	**4726**	0.94245
557	0.11679	**1391**	0.28138	**2225**	0.44381	**3059**	0.60497	**3893**	0.7744	**4727**	0.94274
558	0.11683	**1392**	0.28147	**2226**	0.44394	**3060**	0.60518	**3894**	0.77469	**4728**	0.94283
559	0.11712	**1393**	0.28188	**2227**	0.4441	**3061**	0.60535	**3895**	0.77482	**4729**	0.94289
560	0.11735	**1394**	0.28201	**2228**	0.44449	**3062**	0.60578	**3896**	0.77498	**4730**	0.94325
561	0.11758	**1395**	0.2822	**2229**	0.44468	**3063**	0.60579	**3897**	0.7751	**4731**	0.94336
562	0.11773	**1396**	0.28225	**2230**	0.44473	**3064**	0.60583	**3898**	0.77515	**4732**	0.94342
563	0.11782	**1397**	0.28243	**2231**	0.44493	**3065**	0.60596	**3899**	0.77518	**4733**	0.94354
564	0.11804	**1398**	0.28266	**2232**	0.44501	**3066**	0.60639	**3900**	0.77523	**4734**	0.94365
565	0.11858	**1399**	0.28293	**2233**	0.44531	**3067**	0.60681	**3901**	0.77527	**4735**	0.94371
566	0.1186	**1400**	0.28301	**2234**	0.44568	**3068**	0.60701	**3902**	0.77609	**4736**	0.94377
567	0.11876	**1401**	0.2834	**2235**	0.44577	**3069**	0.60742	**3903**	0.77623	**4737**	0.94383
568	0.11915	**1402**	0.28345	**2236**	0.44588	**3070**	0.60754	**3904**	0.77651	**4738**	0.94383

No.	Value	No.	Value	No.	Value	No.	Value	No.	Value	No.	Value
569	0.11928	1403	0.28386	2237	0.44618	3071	0.60766	3905	0.77677	4739	0.94384
570	0.11949	1404	0.28389	2238	0.44621	3072	0.60817	3906	0.77678	4740	0.94449
571	0.1199	1405	0.28407	2239	0.44647	3073	0.60826	3907	0.77728	4741	0.94461
572	0.12051	1406	0.28436	2240	0.44651	3074	0.60828	3908	0.77793	4742	0.94468
573	0.12057	1407	0.28452	2241	0.44687	3075	0.60828	3909	0.77795	4743	0.94492
574	0.12092	1408	0.28514	2242	0.44705	3076	0.60829	3910	0.77845	4744	0.94538
575	0.12095	1409	0.28549	2243	0.44724	3077	0.60831	3911	0.77886	4745	0.94548
576	0.12132	1410	0.28558	2244	0.4476	3078	0.60859	3912	0.77909	4746	0.94551
577	0.12148	1411	0.28573	2245	0.44778	3079	0.60864	3913	0.77929	4747	0.94563
578	0.12156	1412	0.28579	2246	0.44779	3080	0.60935	3914	0.77933	4748	0.94571
579	0.12171	1413	0.28604	2247	0.44791	3081	0.60944	3915	0.77957	4749	0.94583
580	0.12172	1414	0.28635	2248	0.44799	3082	0.60973	3916	0.77957	4750	0.94635
581	0.12174	1415	0.28646	2249	0.4484	3083	0.61021	3917	0.77968	4751	0.94636
582	0.12174	1416	0.28665	2250	0.44848	3084	0.61041	3918	0.77986	4752	0.94662
583	0.12186	1417	0.28686	2251	0.44862	3085	0.61048	3919	0.78001	4753	0.94665
584	0.12197	1418	0.28748	2252	0.44864	3086	0.61084	3920	0.78007	4754	0.94673
585	0.12205	1419	0.28776	2253	0.4488	3087	0.61102	3921	0.78056	4755	0.94673
586	0.12206	1420	0.2878	2254	0.44883	3088	0.61145	3922	0.7808	4756	0.94696
587	0.12255	1421	0.28801	2255	0.44917	3089	0.61162	3923	0.78111	4757	0.94705
588	0.12258	1422	0.28865	2256	0.44963	3090	0.61162	3924	0.78114	4758	0.94712
589	0.12267	1423	0.2888	2257	0.44971	3091	0.61192	3925	0.78119	4759	0.94737
590	0.12277	1424	0.28887	2258	0.4498	3092	0.61237	3926	0.78132	4760	0.94741
591	0.12329	1425	0.2889	2259	0.4501	3093	0.6124	3927	0.7817	4761	0.94802
592	0.12347	1426	0.28918	2260	0.45025	3094	0.61264	3928	0.78175	4762	0.94813
593	0.12397	1427	0.28948	2261	0.45026	3095	0.61298	3929	0.78183	4763	0.94836
594	0.12411	1428	0.28956	2262	0.45027	3096	0.61336	3930	0.78184	4764	0.9485
595	0.12419	1429	0.28961	2263	0.45028	3097	0.6136	3931	0.78184	4765	0.94877
596	0.12449	1430	0.2899	2264	0.45048	3098	0.6142	3932	0.78211	4766	0.94891
597	0.12464	1431	0.28996	2265	0.45071	3099	0.61448	3933	0.78224	4767	0.9496
598	0.12469	1432	0.29013	2266	0.45113	3100	0.6149	3934	0.78255	4768	0.94978
599	0.12503	1433	0.29016	2267	0.45115	3101	0.61503	3935	0.78258	4769	0.95014
600	0.12517	1434	0.29026	2268	0.45153	3102	0.61503	3936	0.78266	4770	0.95018
601	0.12535	1435	0.2903	2269	0.45193	3103	0.61521	3937	0.78288	4771	0.95028
602	0.12539	1436	0.29047	2270	0.45223	3104	0.61522	3938	0.78303	4772	0.95054
603	0.12542	1437	0.29048	2271	0.45237	3105	0.61576	3939	0.78314	4773	0.95088
604	0.12551	1438	0.29059	2272	0.45251	3106	0.61582	3940	0.78314	4774	0.95098
605	0.12569	1439	0.29059	2273	0.45269	3107	0.61627	3941	0.78334	4775	0.95113
606	0.12594	1440	0.29078	2274	0.45276	3108	0.61633	3942	0.78342	4776	0.95124
607	0.126	1441	0.29124	2275	0.4528	3109	0.61637	3943	0.78375	4777	0.95124
608	0.1261	1442	0.29141	2276	0.45287	3110	0.61695	3944	0.78409	4778	0.95129
609	0.12614	1443	0.29158	2277	0.45353	3111	0.61715	3945	0.78547	4779	0.95139

No.	Value	No.	Value	No.	Value	No.	Value	No.	Value	No.	Value
610	0.12625	1444	0.29161	2278	0.45385	3112	0.61716	3946	0.78549	4780	0.9519
611	0.12684	1445	0.29191	2279	0.45421	3113	0.61732	3947	0.78562	4781	0.95192
612	0.12692	1446	0.29196	2280	0.4545	3114	0.61772	3948	0.78579	4782	0.95201
613	0.12701	1447	0.29204	2281	0.45452	3115	0.61773	3949	0.78582	4783	0.9526
614	0.12721	1448	0.29223	2282	0.45464	3116	0.61776	3950	0.78584	4784	0.95274
615	0.12736	1449	0.29271	2283	0.45479	3117	0.61782	3951	0.78615	4785	0.9528
616	0.12749	1450	0.29283	2284	0.45486	3118	0.61815	3952	0.78616	4786	0.95284
617	0.12797	1451	0.29311	2285	0.45494	3119	0.61826	3953	0.7862	4787	0.95291
618	0.12848	1452	0.29313	2286	0.45539	3120	0.61842	3954	0.78659	4788	0.953
619	0.12896	1453	0.2934	2287	0.45568	3121	0.61851	3955	0.78668	4789	0.95329
620	0.12937	1454	0.29344	2288	0.45584	3122	0.61852	3956	0.78669	4790	0.95359
621	0.12957	1455	0.2935	2289	0.4559	3123	0.61871	3957	0.78671	4791	0.95393
622	0.12965	1456	0.29354	2290	0.45606	3124	0.61936	3958	0.78777	4792	0.95442
623	0.13023	1457	0.29392	2291	0.4562	3125	0.61937	3959	0.78815	4793	0.95446
624	0.13027	1458	0.2942	2292	0.45633	3126	0.61958	3960	0.78827	4794	0.95446
625	0.13053	1459	0.29427	2293	0.45637	3127	0.61963	3961	0.78837	4795	0.9545
626	0.13062	1460	0.29436	2294	0.45638	3128	0.61968	3962	0.78838	4796	0.9546
627	0.13065	1461	0.29466	2295	0.45679	3129	0.61968	3963	0.78873	4797	0.95498
628	0.1314	1462	0.29491	2296	0.45784	3130	0.61978	3964	0.78875	4798	0.95542
629	0.1315	1463	0.29503	2297	0.45794	3131	0.61983	3965	0.78889	4799	0.95615
630	0.13157	1464	0.2951	2298	0.45806	3132	0.62004	3966	0.78893	4800	0.95656
631	0.1317	1465	0.29522	2299	0.45823	3133	0.62023	3967	0.789	4801	0.95684
632	0.1319	1466	0.29523	2300	0.45829	3134	0.62032	3968	0.7893	4802	0.95697
633	0.13226	1467	0.29524	2301	0.45843	3135	0.62038	3969	0.78949	4803	0.95703
634	0.13228	1468	0.29548	2302	0.45873	3136	0.62042	3970	0.78957	4804	0.95707
635	0.13304	1469	0.29561	2303	0.45877	3137	0.62065	3971	0.79001	4805	0.95708
636	0.13316	1470	0.29561	2304	0.45887	3138	0.6207	3972	0.79029	4806	0.9576
637	0.13336	1471	0.29563	2305	0.45909	3139	0.62088	3973	0.79032	4807	0.95815
638	0.1334	1472	0.29566	2306	0.45917	3140	0.62117	3974	0.79034	4808	0.95819
639	0.13353	1473	0.29577	2307	0.45924	3141	0.62145	3975	0.79061	4809	0.95826
640	0.13367	1474	0.29604	2308	0.45952	3142	0.62148	3976	0.7908	4810	0.95837
641	0.13369	1475	0.29604	2309	0.45973	3143	0.62157	3977	0.79081	4811	0.95917
642	0.13402	1476	0.29624	2310	0.4598	3144	0.62157	3978	0.79082	4812	0.95925
643	0.13425	1477	0.29635	2311	0.46047	3145	0.62203	3979	0.79093	4813	0.9594
644	0.13444	1478	0.29636	2312	0.46048	3146	0.62282	3980	0.79097	4814	0.95982
645	0.13458	1479	0.29638	2313	0.46129	3147	0.62288	3981	0.79105	4815	0.95987
646	0.13459	1480	0.2966	2314	0.46134	3148	0.62289	3982	0.79146	4816	0.96019
647	0.13465	1481	0.29686	2315	0.46138	3149	0.62367	3983	0.79159	4817	0.96028
648	0.13501	1482	0.29688	2316	0.46148	3150	0.62396	3984	0.79162	4818	0.96051
649	0.13503	1483	0.29692	2317	0.46155	3151	0.62398	3985	0.7917	4819	0.96089
650	0.1351	1484	0.29718	2318	0.46174	3152	0.62408	3986	0.79176	4820	0.96106

No.	Value	No.	Value	No.	Value	No.	Value	No.	Value	No.	Value
651	0.13511	1485	0.29766	2319	0.46212	3153	0.62412	3987	0.79182	4821	0.96123
652	0.13511	1486	0.29779	2320	0.46275	3154	0.62412	3988	0.79194	4822	0.96143
653	0.13513	1487	0.29798	2321	0.46299	3155	0.62437	3989	0.79217	4823	0.96149
654	0.13545	1488	0.29879	2322	0.46299	3156	0.62438	3990	0.79268	4824	0.9617
655	0.13566	1489	0.29901	2323	0.46303	3157	0.62514	3991	0.79318	4825	0.96188
656	0.13588	1490	0.29925	2324	0.46317	3158	0.62522	3992	0.79357	4826	0.96205
657	0.13589	1491	0.29928	2325	0.46318	3159	0.62529	3993	0.79364	4827	0.96219
658	0.13593	1492	0.2995	2326	0.46327	3160	0.62529	3994	0.79402	4828	0.96232
659	0.136	1493	0.29952	2327	0.46344	3161	0.62545	3995	0.79467	4829	0.96239
660	0.13607	1494	0.29952	2328	0.46357	3162	0.6257	3996	0.79467	4830	0.96249
661	0.1364	1495	0.29967	2329	0.46359	3163	0.62593	3997	0.79476	4831	0.96262
662	0.13643	1496	0.2999	2330	0.46359	3164	0.62596	3998	0.79526	4832	0.96263
663	0.13657	1497	0.30031	2331	0.46372	3165	0.62626	3999	0.79542	4833	0.96277
664	0.13658	1498	0.30049	2332	0.46379	3166	0.62631	4000	0.79552	4834	0.96296
665	0.13663	1499	0.30049	2333	0.46394	3167	0.62632	4001	0.79582	4835	0.96307
666	0.13668	1500	0.30054	2334	0.46394	3168	0.62634	4002	0.79595	4836	0.96382
667	0.13685	1501	0.30065	2335	0.46395	3169	0.62729	4003	0.796	4837	0.9639
668	0.13721	1502	0.30071	2336	0.46455	3170	0.62751	4004	0.79618	4838	0.96409
669	0.13734	1503	0.3008	2337	0.46459	3171	0.62855	4005	0.79626	4839	0.96416
670	0.13743	1504	0.30139	2338	0.46472	3172	0.62867	4006	0.79629	4840	0.96433
671	0.13743	1505	0.30141	2339	0.46505	3173	0.62878	4007	0.79649	4841	0.96446
672	0.13754	1506	0.30147	2340	0.46525	3174	0.62908	4008	0.7967	4842	0.96488
673	0.13763	1507	0.30181	2341	0.46559	3175	0.62908	4009	0.79679	4843	0.96511
674	0.13818	1508	0.30196	2342	0.46566	3176	0.62912	4010	0.79684	4844	0.96555
675	0.1387	1509	0.30202	2343	0.46573	3177	0.62914	4011	0.79714	4845	0.96583
676	0.13877	1510	0.30214	2344	0.46592	3178	0.62954	4012	0.7972	4846	0.96614
677	0.13901	1511	0.30291	2345	0.46625	3179	0.62976	4013	0.79763	4847	0.96637
678	0.1391	1512	0.30309	2346	0.46643	3180	0.6299	4014	0.79776	4848	0.96639
679	0.13955	1513	0.30329	2347	0.46655	3181	0.62998	4015	0.79801	4849	0.96675
680	0.13997	1514	0.30344	2348	0.46667	3182	0.63049	4016	0.79811	4850	0.96693
681	0.14034	1515	0.3036	2349	0.46696	3183	0.63085	4017	0.79823	4851	0.96727
682	0.14037	1516	0.30362	2350	0.46703	3184	0.63088	4018	0.79826	4852	0.96727
683	0.14057	1517	0.30381	2351	0.46703	3185	0.63125	4019	0.79827	4853	0.96739
684	0.14082	1518	0.30441	2352	0.46714	3186	0.63137	4020	0.79864	4854	0.96746
685	0.14135	1519	0.30478	2353	0.46715	3187	0.63156	4021	0.79889	4855	0.96758
686	0.1415	1520	0.30519	2354	0.46737	3188	0.63162	4022	0.79896	4856	0.96767
687	0.14166	1521	0.30535	2355	0.46737	3189	0.63163	4023	0.79912	4857	0.96768
688	0.14179	1522	0.30539	2356	0.46771	3190	0.63194	4024	0.79968	4858	0.96773
689	0.1418	1523	0.30548	2357	0.46796	3191	0.63198	4025	0.79969	4859	0.96806
690	0.14182	1524	0.30558	2358	0.4684	3192	0.63203	4026	0.7999	4860	0.96849
691	0.14237	1525	0.30582	2359	0.46858	3193	0.63206	4027	0.80013	4861	0.96863

No.	Value	No.	Value	No.	Value	No.	Value	No.	Value	No.	Value
692	0.1425	1526	0.30605	2360	0.46878	3194	0.63231	4028	0.80022	4862	0.96874
693	0.14261	1527	0.30607	2361	0.46903	3195	0.63237	4029	0.80029	4863	0.96914
694	0.14272	1528	0.30647	2362	0.46911	3196	0.63244	4030	0.80053	4864	0.96919
695	0.14332	1529	0.30654	2363	0.46937	3197	0.6328	4031	0.80194	4865	0.96953
696	0.14363	1530	0.30692	2364	0.46967	3198	0.6328	4032	0.80231	4866	0.96991
697	0.14369	1531	0.30696	2365	0.46976	3199	0.63306	4033	0.8026	4867	0.96996
698	0.14396	1532	0.30701	2366	0.46994	3200	0.63313	4034	0.80264	4868	0.97047
699	0.1444	1533	0.3071	2367	0.47016	3201	0.63352	4035	0.80319	4869	0.97047
700	0.14465	1534	0.30718	2368	0.47027	3202	0.63409	4036	0.80343	4870	0.97065
701	0.14488	1535	0.30732	2369	0.47065	3203	0.63446	4037	0.8038	4871	0.97088
702	0.14498	1536	0.30744	2370	0.47096	3204	0.63452	4038	0.80432	4872	0.97102
703	0.14529	1537	0.30802	2371	0.47107	3205	0.6347	4039	0.80468	4873	0.97181
704	0.14538	1538	0.30809	2372	0.47119	3206	0.63477	4040	0.80592	4874	0.97186
705	0.14567	1539	0.30818	2373	0.47124	3207	0.63486	4041	0.80628	4875	0.97192
706	0.14583	1540	0.30829	2374	0.47163	3208	0.6353	4042	0.80675	4876	0.9721
707	0.14592	1541	0.30847	2375	0.47198	3209	0.63581	4043	0.8068	4877	0.97221
708	0.14598	1542	0.30848	2376	0.47219	3210	0.63584	4044	0.8073	4878	0.9727
709	0.14675	1543	0.3086	2377	0.47293	3211	0.63586	4045	0.80769	4879	0.97275
710	0.14701	1544	0.30872	2378	0.47344	3212	0.63616	4046	0.8077	4880	0.97278
711	0.14711	1545	0.30908	2379	0.47369	3213	0.6364	4047	0.80775	4881	0.97284
712	0.14757	1546	0.30923	2380	0.47375	3214	0.63667	4048	0.80803	4882	0.97304
713	0.14786	1547	0.3096	2381	0.47403	3215	0.63688	4049	0.80815	4883	0.97375
714	0.14788	1548	0.30965	2382	0.47414	3216	0.63696	4050	0.8082	4884	0.97391
715	0.14811	1549	0.30971	2383	0.47442	3217	0.63708	4051	0.80884	4885	0.9742
716	0.14848	1550	0.30985	2384	0.47443	3218	0.63734	4052	0.80907	4886	0.97496
717	0.14865	1551	0.31003	2385	0.47494	3219	0.63745	4053	0.80945	4887	0.97513
718	0.14901	1552	0.31035	2386	0.47496	3220	0.63771	4054	0.80978	4888	0.97516
719	0.14902	1553	0.31053	2387	0.47507	3221	0.638	4055	0.80984	4889	0.97521
720	0.14942	1554	0.31056	2388	0.47511	3222	0.63811	4056	0.80992	4890	0.97522
721	0.14972	1555	0.31109	2389	0.47601	3223	0.63859	4057	0.81006	4891	0.97532
722	0.14973	1556	0.31109	2390	0.47623	3224	0.63868	4058	0.81006	4892	0.97559
723	0.14981	1557	0.31119	2391	0.47625	3225	0.63941	4059	0.81015	4893	0.97602
724	0.14985	1558	0.31121	2392	0.47626	3226	0.63986	4060	0.81017	4894	0.97643
725	0.15026	1559	0.31125	2393	0.47644	3227	0.63993	4061	0.81018	4895	0.97646
726	0.15029	1560	0.31126	2394	0.47644	3228	0.64056	4062	0.8108	4896	0.97664
727	0.15041	1561	0.31154	2395	0.47647	3229	0.64159	4063	0.81086	4897	0.97696
728	0.15045	1562	0.3117	2396	0.47651	3230	0.64205	4064	0.81108	4898	0.97717
729	0.15049	1563	0.3118	2397	0.47694	3231	0.64239	4065	0.8113	4899	0.97723
730	0.15077	1564	0.31181	2398	0.47704	3232	0.64245	4066	0.81141	4900	0.9777
731	0.15078	1565	0.31198	2399	0.47707	3233	0.64258	4067	0.81143	4901	0.97774
732	0.15097	1566	0.31228	2400	0.47729	3234	0.64296	4068	0.81146	4902	0.97803

No.	Value	No.	Value	No.	Value	No.	Value	No.	Value	No.	Value
733	0.15113	1567	0.31252	2401	0.47733	3235	0.6441	4069	0.81154	4903	0.97853
734	0.15161	1568	0.31259	2402	0.47739	3236	0.64416	4070	0.8116	4904	0.97855
735	0.15162	1569	0.3128	2403	0.47742	3237	0.64447	4071	0.81192	4905	0.97872
736	0.15182	1570	0.31288	2404	0.47757	3238	0.64459	4072	0.81197	4906	0.9788
737	0.15228	1571	0.31291	2405	0.47784	3239	0.64511	4073	0.81208	4907	0.97888
738	0.15239	1572	0.31302	2406	0.47788	3240	0.64535	4074	0.81216	4908	0.97911
739	0.15247	1573	0.31307	2407	0.47793	3241	0.64537	4075	0.81219	4909	0.97948
740	0.15255	1574	0.31355	2408	0.47799	3242	0.64575	4076	0.81245	4910	0.9797
741	0.15262	1575	0.31386	2409	0.47827	3243	0.64622	4077	0.81289	4911	0.97971
742	0.15275	1576	0.31388	2410	0.47841	3244	0.64624	4078	0.81293	4912	0.9801
743	0.15279	1577	0.31396	2411	0.47908	3245	0.64644	4079	0.81314	4913	0.9805
744	0.15305	1578	0.31418	2412	0.47925	3246	0.64648	4080	0.81331	4914	0.98111
745	0.15317	1579	0.3142	2413	0.47936	3247	0.64667	4081	0.81355	4915	0.98111
746	0.15329	1580	0.31422	2414	0.47953	3248	0.64691	4082	0.81356	4916	0.98116
747	0.15343	1581	0.31427	2415	0.47976	3249	0.64693	4083	0.81374	4917	0.98122
748	0.15378	1582	0.31456	2416	0.47992	3250	0.64718	4084	0.81388	4918	0.98148
749	0.15451	1583	0.31489	2417	0.48035	3251	0.64725	4085	0.81406	4919	0.98183
750	0.15493	1584	0.31515	2418	0.48039	3252	0.64749	4086	0.81415	4920	0.98195
751	0.15518	1585	0.31571	2419	0.48045	3253	0.64756	4087	0.81446	4921	0.98232
752	0.15533	1586	0.31572	2420	0.48066	3254	0.6476	4088	0.8147	4922	0.98239
753	0.1555	1587	0.31577	2421	0.48077	3255	0.64762	4089	0.81493	4923	0.98249
754	0.15558	1588	0.31587	2422	0.48086	3256	0.64763	4090	0.81495	4924	0.98342
755	0.15573	1589	0.31605	2423	0.48119	3257	0.64811	4091	0.81527	4925	0.98385
756	0.15579	1590	0.31672	2424	0.48143	3258	0.6482	4092	0.81549	4926	0.98393
757	0.15585	1591	0.31696	2425	0.4816	3259	0.64838	4093	0.81561	4927	0.98413
758	0.15602	1592	0.31724	2426	0.48169	3260	0.64841	4094	0.81565	4928	0.98426
759	0.15626	1593	0.31729	2427	0.48177	3261	0.64886	4095	0.81578	4929	0.98437
760	0.15627	1594	0.31811	2428	0.48205	3262	0.64887	4096	0.81652	4930	0.98469
761	0.15653	1595	0.31861	2429	0.48233	3263	0.64887	4097	0.81674	4931	0.98472
762	0.1566	1596	0.31867	2430	0.48245	3264	0.6496	4098	0.81698	4932	0.9848
763	0.15663	1597	0.31956	2431	0.48254	3265	0.64971	4099	0.81698	4933	0.98491
764	0.15682	1598	0.3199	2432	0.48265	3266	0.64973	4100	0.81699	4934	0.98508
765	0.15693	1599	0.32062	2433	0.483	3267	0.64987	4101	0.81731	4935	0.98532
766	0.15726	1600	0.32068	2434	0.48302	3268	0.65018	4102	0.81741	4936	0.98553
767	0.15732	1601	0.3207	2435	0.48305	3269	0.65076	4103	0.81748	4937	0.9856
768	0.1576	1602	0.32087	2436	0.4831	3270	0.65081	4104	0.81759	4938	0.9862
769	0.15784	1603	0.32103	2437	0.48373	3271	0.65105	4105	0.81765	4939	0.98631
770	0.15802	1604	0.32142	2438	0.48406	3272	0.65108	4106	0.81782	4940	0.98677
771	0.15831	1605	0.3215	2439	0.48417	3273	0.65115	4107	0.81798	4941	0.98681
772	0.15832	1606	0.32171	2440	0.48432	3274	0.65121	4108	0.8183	4942	0.98691
773	0.1584	1607	0.32205	2441	0.48453	3275	0.65135	4109	0.8188	4943	0.98707

No.	Value	No.	Value	No.	Value	No.	Value	No.	Value	No.	Value
774	0.15863	**1608**	0.32234	**2442**	0.48473	**3276**	0.65158	**4110**	0.81884	**4944**	0.98739
775	0.15874	**1609**	0.32235	**2443**	0.48502	**3277**	0.65159	**4111**	0.81927	**4945**	0.98775
776	0.15878	**1610**	0.32243	**2444**	0.48514	**3278**	0.65168	**4112**	0.8195	**4946**	0.98793
777	0.15891	**1611**	0.32248	**2445**	0.48515	**3279**	0.652	**4113**	0.81951	**4947**	0.98806
778	0.15893	**1612**	0.32283	**2446**	0.48526	**3280**	0.65274	**4114**	0.81974	**4948**	0.98809
779	0.15915	**1613**	0.3237	**2447**	0.48549	**3281**	0.65283	**4115**	0.81976	**4949**	0.98819
780	0.15942	**1614**	0.32382	**2448**	0.48564	**3282**	0.65291	**4116**	0.81977	**4950**	0.98862
781	0.15961	**1615**	0.32408	**2449**	0.48571	**3283**	0.65312	**4117**	0.81994	**4951**	0.98924
782	0.15966	**1616**	0.32463	**2450**	0.48632	**3284**	0.65342	**4118**	0.82005	**4952**	0.98929
783	0.1597	**1617**	0.32468	**2451**	0.48642	**3285**	0.65369	**4119**	0.82027	**4953**	0.98938
784	0.1602	**1618**	0.32487	**2452**	0.48643	**3286**	0.65383	**4120**	0.8204	**4954**	0.98977
785	0.16021	**1619**	0.32501	**2453**	0.48652	**3287**	0.65388	**4121**	0.82043	**4955**	0.98986
786	0.16049	**1620**	0.32516	**2454**	0.48667	**3288**	0.6539	**4122**	0.82061	**4956**	0.9901
787	0.16059	**1621**	0.32528	**2455**	0.48675	**3289**	0.65395	**4123**	0.82073	**4957**	0.99025
788	0.16061	**1622**	0.32542	**2456**	0.48675	**3290**	0.65397	**4124**	0.82073	**4958**	0.99031
789	0.16078	**1623**	0.32546	**2457**	0.48706	**3291**	0.65472	**4125**	0.82118	**4959**	0.99035
790	0.16122	**1624**	0.3255	**2458**	0.48709	**3292**	0.65483	**4126**	0.82124	**4960**	0.99067
791	0.16123	**1625**	0.32612	**2459**	0.48711	**3293**	0.65486	**4127**	0.82222	**4961**	0.9907
792	0.16138	**1626**	0.3263	**2460**	0.48746	**3294**	0.65487	**4128**	0.8225	**4962**	0.99089
793	0.16163	**1627**	0.3263	**2461**	0.48762	**3295**	0.65523	**4129**	0.82318	**4963**	0.99096
794	0.16188	**1628**	0.32646	**2462**	0.4877	**3296**	0.65565	**4130**	0.82325	**4964**	0.99102
795	0.16221	**1629**	0.32653	**2463**	0.48799	**3297**	0.65581	**4131**	0.82338	**4965**	0.99144
796	0.1623	**1630**	0.32692	**2464**	0.48815	**3298**	0.65599	**4132**	0.82408	**4966**	0.99214
797	0.1624	**1631**	0.32725	**2465**	0.48816	**3299**	0.656	**4133**	0.82409	**4967**	0.99323
798	0.16256	**1632**	0.32759	**2466**	0.48824	**3300**	0.65613	**4134**	0.82436	**4968**	0.99333
799	0.16266	**1633**	0.32808	**2467**	0.48834	**3301**	0.65621	**4135**	0.8245	**4969**	0.99338
800	0.16266	**1634**	0.32818	**2468**	0.48856	**3302**	0.65634	**4136**	0.82455	**4970**	0.9935
801	0.16274	**1635**	0.32835	**2469**	0.48859	**3303**	0.65641	**4137**	0.82512	**4971**	0.99378
802	0.16282	**1636**	0.32869	**2470**	0.48864	**3304**	0.65646	**4138**	0.82538	**4972**	0.994
803	0.16313	**1637**	0.32875	**2471**	0.48871	**3305**	0.65675	**4139**	0.82542	**4973**	0.9942
804	0.16329	**1638**	0.32885	**2472**	0.48933	**3306**	0.65697	**4140**	0.82543	**4974**	0.9945
805	0.16356	**1639**	0.32951	**2473**	0.48948	**3307**	0.65713	**4141**	0.82546	**4975**	0.99525
806	0.16383	**1640**	0.32959	**2474**	0.48975	**3308**	0.65723	**4142**	0.82581	**4976**	0.99587
807	0.1645	**1641**	0.32985	**2475**	0.49001	**3309**	0.6574	**4143**	0.82583	**4977**	0.9959
808	0.16452	**1642**	0.32996	**2476**	0.49006	**3310**	0.6576	**4144**	0.82584	**4978**	0.99625
809	0.16458	**1643**	0.33013	**2477**	0.49009	**3311**	0.65776	**4145**	0.82586	**4979**	0.99635
810	0.16471	**1644**	0.33022	**2478**	0.49109	**3312**	0.65783	**4146**	0.82599	**4980**	0.99645
811	0.16497	**1645**	0.33026	**2479**	0.4911	**3313**	0.65787	**4147**	0.826	**4981**	0.99676
812	0.16499	**1646**	0.33054	**2480**	0.49116	**3314**	0.65802	**4148**	0.82617	**4982**	0.99678
813	0.16502	**1647**	0.33057	**2481**	0.49152	**3315**	0.65814	**4149**	0.82636	**4983**	0.99704
814	0.16518	**1648**	0.33063	**2482**	0.49189	**3316**	0.65829	**4150**	0.82684	**4984**	0.9972

No.	Value	No.	Value	No.	Value	No.	Value	No.	Value	No.	Value
815	0.16527	**1649**	0.33071	**2483**	0.49208	**3317**	0.65829	**4151**	0.82695	**4985**	0.99728
816	0.16543	**1650**	0.33088	**2484**	0.49239	**3318**	0.65843	**4152**	0.82697	**4986**	0.99728
817	0.16561	**1651**	0.33116	**2485**	0.49247	**3319**	0.65885	**4153**	0.82737	**4987**	0.99732
818	0.16622	**1652**	0.33123	**2486**	0.49258	**3320**	0.65941	**4154**	0.82743	**4988**	0.99735
819	0.16643	**1653**	0.33128	**2487**	0.49263	**3321**	0.65942	**4155**	0.82761	**4989**	0.9978
820	0.16644	**1654**	0.33135	**2488**	0.4927	**3322**	0.65963	**4156**	0.82765	**4990**	0.99785
821	0.16649	**1655**	0.33146	**2489**	0.49282	**3323**	0.6602	**4157**	0.82862	**4991**	0.99802
822	0.1667	**1656**	0.3317	**2490**	0.49284	**3324**	0.66026	**4158**	0.82866	**4992**	0.99831
823	0.16671	**1657**	0.33172	**2491**	0.49343	**3325**	0.66046	**4159**	0.82886	**4993**	0.99849
824	0.16732	**1658**	0.33181	**2492**	0.49357	**3326**	0.66066	**4160**	0.82915	**4994**	0.99904
825	0.16736	**1659**	0.33183	**2493**	0.49362	**3327**	0.66095	**4161**	0.82922	**4995**	0.99905
826	0.16759	**1660**	0.33207	**2494**	0.4937	**3328**	0.66131	**4162**	0.82948	**4996**	0.9991
827	0.16763	**1661**	0.33214	**2495**	0.49382	**3329**	0.66136	**4163**	0.83008	**4997**	0.9993
828	0.16767	**1662**	0.33222	**2496**	0.49387	**3330**	0.6615	**4164**	0.83018	**4998**	0.99954
829	0.16776	**1663**	0.33243	**2497**	0.49396	**3331**	0.66151	**4165**	0.83037	**4999**	0.99976
830	0.16821	**1664**	0.33247	**2498**	0.494	**3332**	0.66175	**4166**	0.83042	**5000**	0.99981
831	0.16835	**1665**	0.33248	**2499**	0.49419	**3333**	0.66185	**4167**	0.83108		
832	0.16889	**1666**	0.33254	**2500**	0.49453	**3334**	0.66193	**4168**	0.83122		
833	0.16896	**1667**	0.33271	**2501**	0.49513	**3335**	0.66202	**4169**	0.83134		
834	0.16915	**1668**	0.33283	**2502**	0.49522	**3336**	0.66216	**4170**	0.83149		

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WBS: 1.2.22.6.3
QA: QA

Civilian Radioactive Waste Management System
Management & Operating Contractor

INFIL
VERSION A_2.a1

VALIDATION TEST REPORT

SAN: SNL-2001-247
STN: 10253-A_2.a1-00
SMN: 10253-DEC-A_2.a1-00
SDN: 10253-VTR-A_2.a1-00

November 2001

Prepared for:

U.S. Department of Energy
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Civilian Radioactive Waste Management System
Management & Operating Contractor

INFIL
VERSION A_2.a1

VALIDATION TEST REPORT

SAN: SNL-2001-247
STN: 10253-A_2.a1-00
SMN: 10253-DEC-A_2.a1-00
SDN: 10253-VTR-A_2.a1-00

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Responsible Manager

Reviewed:

ITSMA — 11/21/01 Date
EDWARD MILLER

CHANGE HISTORY

Revision Number	Interim Change No.	Effective Date	Description of Change
0	0	11/21/2001	Initial issue

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ACRONYMS AND ABBREVIATIONS

AMR	Analysis and Model Report
DD	Design Document
DEC	Digital Equipment Corporation
ITP	Installation Test Plan
ITSMA	Information Technology Software Management Analyst
PC	Personal Computer
RD	Requirements Document
SAP	Software Activity Plan
SBRF	Software Baseline Request Form
SNL	Sandia National Laboratories
UM	Users' Manual
USGS	U.S. Geological Survey
VMS	Virtual Memory System (DEC operating system)
VTP	Validation Test Plan
VTR	Validation Test Report

1. SOFTWARE IDENTIFICATION

The software being qualified in this Validation Test Report (VTR) is INFIL Version A_2.a1. It is being qualified on the DEC Alpha platform using the operating system open VMS AXP V7.2-1, at Sandia National Laboratories (SNL).

2. INDEPENDENT VALIDATION TESTERS

While INFIL Version A_2.a1 is the code being qualified, the qualification process depends directly on comparisons of the results of INFIL Version A_2.a1, and the results from the qualified code INFIL Version 2.0 for the same test case. Two independent validation testers participated in this effort.

For INFIL Version A_2.a1, the independent validation tester at SNL is Harold Iuzzolino, whose position is Senior Scientist with GRAM, Inc., contractor to Sandia National Laboratories.

For runs with the qualified code INFIL Version 2.0, the independent validation tester at the M&O in Las Vegas was William E. Tracy who is in the Software Configuration Management organization.

3. SPECIAL TOOLS AND EQUIPMENT

Since the qualified code INFIL Version 2.0 is validated for the PC platform, and INFIL Version A_2.a1 is being qualified for use on the DEC Alpha platform, both computer platforms were used in the qualification effort. Specifics are provided as follows:

PC Platform

Type nomenclature:	Dual Pentium, 600 Mhz running NT 4.0, SP5
Model number:	Dell Precision 420
Serial number:	H6PJ00B, CPU tag # 114902
Location:	YMP, Las Vegas, Nevada, Summerlin Office 504F

DEC Alpha Platform

Type nomenclature:	DEC Alpha with Open VMS AXP 7.2-1 OS
Model number:	Not applicable
Serial numbers:	S712688, S712689, S712690, S715504, S715505, S773104, S778392, S778614, S778615, S794667, S794668, S797512, S797513.
Location:	Sandia National Laboratories, Albuquerque, New Mexico

4. TEST RESULTS LINKED TO THE UNIQUE TEST IDENTIFIER FROM THE VTP

There is one test identified in the VTP. The unique test identifier assigned to that test is **TEST #1.**

5. DOCUMENTATION RESULTS OF ITP AND VTP

This section provides the documentation of the results of the execution of the individual test steps within the ITP and VTP.

5.1 COMPARISON OF OUTPUTS BETWEEN VERSIONS

Table 1 is a comparison between Summary Output results from execution of the code INFIL Version A_2.a1 on the DEC ALPHA using the operating system open VMS AXP V7.2-1 at Sandia National Laboratories and the qualified code INFIL Version 2.0 using Windows NT 4.0 on a PC platform. Table 1 shows the difference in the results to be negligible. Sections 5.12 and 5.13 below show output details.

5.1.1 Results of TEST #1

These listings indicate that the PC (Windows NT) version predicts a net infiltration of 21.305166 and the DEC Alpha (VMS) version predicts a net infiltration of 21.305163. The difference is less than 0.15 parts per million (ppm). This satisfies the acceptance criterion for **TEST # 1** of less than 1 ppm difference.

Table 1. Comparison of Summary Output Results from INFIL Version A_2.a1 and INFIL Version 2.0

	Version		
Output Parameter	**V A_2.a1**	**V 2.0**	**Relative Error**
Precipitation	290.532770	290.532762	2.75356E-08
Rain	233.901757	233.901750	2.99271E-08
Snowfall	56.631013	56.631012	1.76582E-08
Snow-cover	631.284972	631.285751	1.23399E-06
Snow-melt	50.640619	50.640612	1.38229E-07
Sublimation	5.261948	5.261954	1.14026E-06
Potential Evapotranspiration	832.586015	832.585923	1.10499E-07
Actual Evapotranspiration	262.509388	262.509371	6.47596E-08
Change in Soil Moisture	0.727825	0.727825	0
*Net Infiltration**	21.305163	21.305166	1.40811E-07
Runoff Generation	0.690760	0.690760	0
Cumulative Daily Run-on	0.094091	0.094091	0

NOTE: Net Infiltration is the output parameter of importance.

5.1.2 Output from INFIL Version A_2.a1

Summary Output Produced on DEC Alpha platform running Open VMS AXP V7.2-1

```
INFIL2a1.ctl: Solitario East, Tule Lake, se10-2a1-gm1-k2-w20 (11/18/1999)
Daily precipitation input:          Tulelake.inp
Watershed modeling domain parameters: se10.w20
Average daily mass balance terms:    se10-gm1.2a1
24-hour mass balance map:            se10-gm1.2a2
Annual mass balance map:             se10-gm1.1
Average annual mass balance map:     se10-gm1.2a4
```

Summary statistics output: se10-gm1.2a3
Debugging output: se10-gm1.2a5
Total number of days read in - 12053
Total daily precip - 9660.7
Average annual precip (mm) - 292.8
Maximum daily precip (mm) - 51.3
TOTAL NUMBER OF LOCATIONS - 69
AVERAGE ELEVATION OF SAMPLE - 1339.3
MAXIMUM ELEVATION OF SAMPLE - 1377.0
MINIMUM ELEVATION OF SAMPLE - 1301.0
AVERAGE SOIL DEPTH (M) - 2.124
AVERAGE SLOPE OF SAMPLE - 12.8
MAXIMUM SLOPE OF SAMPLE - 23.0
NUMBER OF ACTIVE LOCATIONS - 17

Yr	Dy	Precip	Rain	Snow	Sn-cover	Snowmelt	Sublim	PET	PETRS	Evapotrs	Del-soil	Net-inf	Runoff	Out-flow	Mass-balance
1950	365	288.823	218.232	70.591	432.356	60.488	5.658	835.723	663.272	242.653	36.067	0.000	0.000	0.000	-0.896813276E-10
1951	365	212.451	120.978	91.473	736.623	54.355	7.819	842.857	668.934	194.543	-19.922	0.711	0.000	0.000	-0.670113706E-09
1952	366	271.664	232.269	39.395	354.124	64.979	4.581	812.532	644.867	292.275	-8.315	13.289	0.000	0.000	-0.118735058E-08
1953	365	367.872	313.935	53.937	178.650	51.584	5.932	799.670	634.659	315.938	37.982	11.599	0.000	0.000	-0.161001923E-08
1954	365	212.451	135.956	76.495	495.140	53.006	7.244	813.631	645.739	223.574	-55.092	20.480	0.000	0.000	-0.254417724E-08
1955	365	254.902	127.629	127.273	1372.195	91.170	8.873	832.747	660.911	156.121	58.930	3.748	0.000	0.000	-0.116435381E-09
1956	366	310.147	281.781	28.367	1903.177	65.457	6.385	828.810	657.786	324.945	-38.969	61.261	8.775	0.000	-0.183099313E-08
1957	365	381.163	363.570	17.592	37.571	15.850	1.742	845.560	671.079	327.175	36.173	16.072	0.000	0.000	-0.249317704E-08
1958	365	341.291	301.092	40.198	154.009	29.814	3.133	818.516	649.616	358.730	-51.929	24.106	0.000	0.000	-0.363462775E-08
1959	365	120.607	110.988	9.619	86.665	14.498	2.372	862.267	684.339	156.361	-30.875	0.000	0.000	0.000	-0.408099911E-08
1960	366	282.276	271.893	10.384	33.734	8.881	1.503	845.880	671.334	218.626	61.323	0.826	0.000	0.000	-0.741168510E-10
1962	365	338.712	312.850	25.862	224.619	22.460	3.402	830.644	659.242	267.587	36.307	31.416	0.176	0.000	-0.634508074E-09
1963	365	233.379	179.558	53.821	1076.487	39.313	9.210	811.546	644.085	260.099	-53.651	12.423	0.000	0.000	-0.143827826E-08
1964	366	378.187	225.224	152.963	1169.237	47.514	4.296	825.651	655.279	254.243	14.771	3.723	0.000	0.000	-0.201924445E-08
1966	365	232.387	189.844	42.543	2289.880	128.425	9.780	843.435	669.393	229.022	41.116	48.131	0.000	0.000	-0.403216082E-08
1967	365	206.302	174.810	31.492	232.016	38.340	3.713	852.245	676.385	279.375	-83.650	17.425	0.000	0.000	-0.648956358E-09
1968	366	290.905	277.997	12.908	34.296	10.462	2.565	839.402	666.192	247.988	40.471	0.000	0.000	0.000	-0.852496186E-09
1969	365	333.356	234.815	98.541	1113.232	29.055	4.130	845.652	671.152	264.208	-17.865	17.527	0.000	0.000	-0.138001286E-08
1970	365	258.175	179.126	79.049	1328.668	124.590	8.793	833.578	661.570	228.047	30.552	45.117	1.920	0.000	-0.350565337E-08
1971	365	281.384	242.377	39.006	323.340	45.848	4.291	836.134	663.598	291.648	-13.915	10.492	0.000	0.000	-0.431267944E-08
1974	365	167.323	131.266	36.057	171.037	31.414	4.643	837.322	664.541	187.377	-26.855	2.157	0.000	0.000	-0.259751234E-09
1975	365	267.498	230.968	36.530	91.871	31.777	4.753	830.917	659.458	262.708	-3.118	3.155	0.000	0.000	-0.708225371E-09
1976	366	227.329	194.598	32.731	545.162	27.352	5.379	822.342	652.653	241.625	-19.755	0.080	0.000	0.000	-0.103352604E-08
1977	365	313.618	235.905	77.713	498.200	31.490	3.201	834.295	662.139	230.039	37.357	0.000	0.000	0.000	-0.137197357E-08
1978	365	257.877	208.165	49.713	721.268	87.363	5.371	849.230	673.992	271.385	-17.794	41.937	0.000	0.000	-0.283669747E-08
1979	365	313.519	282.240	31.280	67.986	29.239	2.041	843.151	669.167	227.781	69.200	14.497	0.000	0.000	-0.261695151E-09
1980	366	257.877	237.226	20.651	128.283	18.391	2.150	857.524	680.574	289.409	-69.175	35.383	0.299	0.000	-0.280423179E-08
1981	365	390.486	276.116	114.370	406.011	72.334	8.066	814.972	646.803	254.882	71.770	21.798	0.000	0.000	-0.366651546E-08
1982	365	328.694	297.352	31.342	446.031	55.426	4.752	816.770	648.230	346.565	-25.551	31.765	0.000	0.000	-0.594888706E-08
1983	365	450.889	307.306	143.583	1341.380	70.336	8.617	813.936	645.981	297.566	29.337	50.739	0.464	0.000	-0.843875677E-08
1987	365	238.933	199.277	39.656	1924.282	94.977	7.509	848.007	673.021	294.840	-52.029	51.443	5.062	0.000	-0.210783399E-08
1995	365	412.604	368.866	43.738	277.639	46.667	4.115	824.088	654.038	312.516	50.800	52.217	0.237	0.000	-0.439056246E-08
1996	366	364.301	254.389	109.912	636.803	78.251	7.623	825.734	655.345	312.781	-39.681	59.540	5.863	0.000	-0.763445402E-08

Global Summary Statistics (mm/year):

```
Precipitation..................      290.532770
Rain...........................      233.901757
Snowfall.......................       56.631013
Snow-cover.....................      631.284972
Snow-melt......................       50.640619
Sublimation....................        5.261948
Potential Evapotranspiration....     832.586015
Actual Evapotranspiration.......     262.509388
Change in Soil Moisture........        0.727825
Net Infiltration...............       21.305163
Runoff Generation..............        0.690760
Cumulative Daily Run-on........        0.094091
Outflow........................        0.000000
Average Mass Balance Error......   -0.264155E-12
Average Max Daily Error (mm/dy).   -0.386456E-13
```

5.1.3 Output from INFIL Version 2.0

Summary Output File Produced on PC Platform using Windows NT 4.0

INFIL2a1.ctl: Solitario East, Tule Lake, se10-2a1-gm1-k2-w20 (11/18/1999)
Daily precipitation input: Tulelake.inp
Watershed modeling domain parameters: se10.w20
Average daily mass balance terms: se10-gm1.2a1
24-hour mass balance map: se10-gm1.2a2
Annual mass balance map: se10-gm1.1
Average annual mass balance map: se10-gm1.2a4
Summary statistics output: se10-gm1.2a3
Debugging output: se10-gm1.2a5

Total number of days read in - 12053
Total daily precip - 9660.7
Average annual precip (mm) - 292.8
Maximum daily precip (mm) - 51.3

TOTAL NUMBER OF LOCATIONS - 69
AVERAGE ELEVATION OF SAMPLE - 1339.3
MAXIMUM ELEVATION OF SAMPLE - 1377.0
MINIMUM ELEVATION OF SAMPLE - 1301.0
AVERAGE SOIL DEPTH (M) - 2.124
AVERAGE SLOPE OF SAMPLE - 12.8
MAXIMUM SLOPE OF SAMPLE - 23.0
NUMBER OF ACTIVE LOCATIONS - 17

Yr	Dy	Precip	Rain	Snow	Sn-cover	Snowmelt	Sublim	PET	PETRS	Evapotrs	Del-soil	Net-inf	Runoff	Out-flow	Mass-balance
1950	365	288.823	218.232	70.591	432.356	60.488	5.658	835.723	663.272	242.653	36.067	0.000	0.000	0.000	0.175624822E-09
1951	365	212.451	120.978	91.473	736.625	54.355	7.819	842.857	668.934	194.543	-19.922	0.711	0.000	0.000	0.218118841E-09
1952	366	271.664	232.269	39.395	354.124	64.979	4.581	812.532	644.867	292.275	-8.315	13.289	0.000	0.000	0.192151030E-09
1953	365	367.872	313.935	53.937	178.650	51.584	5.932	799.670	634.659	315.938	37.982	11.599	0.000	0.000	0.263993153E-09
1954	365	212.451	135.956	76.495	495.141	53.006	7.244	813.631	645.739	223.574	-55.092	20.480	0.000	0.000	0.241319896E-09
1955	365	254.902	127.629	127.273	1372.197	91.170	8.873	832.747	660.910	156.121	58.930	3.748	0.000	0.000	-0.112246360E-09
1956	366	310.147	281.781	28.367	1903.180	65.457	6.385	828.810	657.786	324.945	-38.969	61.261	8.775	0.000	-0.156601933E-09
1957	365	381.162	363.570	17.592	37.572	15.850	1.742	845.560	671.079	327.175	36.173	16.072	0.000	0.000	-0.164860299E-09
1958	365	341.291	301.092	40.198	154.009	29.814	3.133	818.516	649.616	358.730	-51.929	24.106	0.000	0.000	0.444154606E-10
1959	365	120.607	110.988	9.619	86.666	14.498	2.372	862.267	684.339	156.361	-30.875	0.000	0.000	0.000	0.187447951E-09
1960	366	282.276	271.893	10.384	33.734	8.881	1.503	845.880	671.334	218.626	61.323	0.826	0.000	0.000	-0.364036219E-10
1962	365	338.712	312.850	25.862	224.620	22.460	3.402	830.644	659.241	267.587	36.307	31.416	0.176	0.000	0.156433114E-09
1963	365	233.379	179.558	53.821	1076.488	39.313	9.210	811.546	644.084	260.099	-53.651	12.423	0.000	0.000	0.137249349E-09
1964	366	378.187	225.224	152.963	1169.237	47.514	4.296	825.651	655.279	254.243	14.771	3.723	0.000	0.000	0.531510373E-10
1966	365	232.387	189.844	42.543	2289.883	128.425	9.780	843.435	669.393	229.022	41.116	48.131	0.000	0.000	-0.619987124E-10
1967	365	206.302	174.810	31.492	232.017	38.340	3.713	852.245	676.385	279.375	-83.650	17.425	0.000	0.000	0.923037274E-10
1968	366	290.905	277.997	12.908	34.296	10.462	2.565	839.402	666.192	247.988	40.471	0.000	0.000	0.000	0.614522354E-10
1969	365	333.356	234.815	98.541	1113.233	29.055	4.130	845.652	671.152	264.208	-17.865	17.527	0.000	0.000	0.656519736E-10
1970	365	258.175	179.126	79.049	1328.669	124.590	8.793	833.578	661.570	228.047	30.552	45.117	1.920	0.000	-0.883941765E-10
1971	365	281.384	242.377	39.006	323.340	45.848	4.291	836.133	663.598	291.648	-13.915	10.492	0.000	0.000	-0.168360502E-09
1974	365	167.323	131.266	36.057	171.037	31.414	4.643	837.322	664.541	187.377	-26.855	2.157	0.000	0.000	-0.687992874E-10
1975	365	267.498	230.968	36.530	91.871	31.777	4.753	830.917	659.458	262.708	-3.118	3.155	0.000	0.000	-0.182410852E-09
1976	366	227.329	194.598	32.731	545.162	27.352	5.379	822.342	652.653	241.625	-19.755	0.080	0.000	0.000	-0.218551604E-09
1977	365	313.618	235.905	77.713	498.201	31.490	3.201	834.295	662.139	230.039	37.357	0.000	0.000	0.000	-0.180917354E-09
1978	365	257.877	208.165	49.713	721.270	87.363	5.371	849.229	673.992	271.385	-17.794	41.937	0.000	0.000	-0.114093109E-09
1979	365	313.519	282.240	31.280	67.986	29.239	2.041	843.151	669.167	227.781	69.200	14.497	0.000	0.000	0.100798462E-09
1980	366	257.877	237.226	20.651	128.283	18.391	2.150	857.524	680.574	289.409	-69.175	35.383	0.299	0.000	0.193833364E-09
1981	365	390.486	276.116	114.370	406.012	72.334	8.066	814.972	646.803	254.882	71.770	21.798	0.000	0.000	0.557352754E-10
1982	365	328.694	297.352	31.342	446.031	55.426	4.752	816.770	648.230	346.565	-25.551	31.765	0.000	0.000	-0.160379148E-09
1983	365	450.889	307.306	143.583	1341.381	70.336	8.617	813.935	645.981	297.566	29.337	50.739	0.464	0.000	-0.492668107E-09
1987	365	238.933	199.277	39.656	1924.285	94.977	7.509	848.007	673.021	294.840	-52.029	51.443	5.062	0.000	-0.710995995E-10
1995	365	412.604	368.866	43.738	277.639	46.667	4.115	824.088	654.038	312.516	50.800	52.217	0.237	0.000	-0.251104930E-09
1996	366	364.301	254.389	109.912	636.804	78.251	7.623	825.734	655.345	312.781	-39.681	59.540	5.863	0.000	-0.259870723E-09

```
Global Summary Statistics (mm/year):
------------------------------------------------

Precipitation.................          290.532762
Rain..........................          233.901750
Snowfall......................           56.631012
Snow-cover....................          631.285751
Snow-melt.....................           50.640612
Sublimation...................            5.261954
Potential Evapotranspiration....        832.585923
Actual Evapotranspiration.......        262.509371
Change in Soil Moisture........           0.727825
Net Infiltration...............          21.305166
Runoff Generation..............           0.690760
Cumulative Daily Run-on........           0.094091
Outflow........................           0.000000
Average Mass Balance Error......     -0.998939E-13
Average Max Daily Error (mm/dy).     -0.109569E-13
```

6. INDICATION OF PASS/FAIL

Code INFIL Version A_2.a1 passed the installation and validation tests.

6.1 INSTALLATION TEST

In the ITP, the user is required to check that that the output file designated in the model control file is created, and that the results provided in that output file match the results contained in Attachment A of the ITP.

The installation test produced output file SE10-GM1.2A3. That is the correct output file as specified in the model control file. As required by the ITP, the file contents matched the file listed in Attachment A of the ITP; therefore, the installation was successful.

6.2 VALIDATION TEST

As specified in the VTP, the code is required to read data from the model control file. Using these data, the code is required to read specified input files, calculate the net infiltration rate and provide output data to a file specified in the model control file. Meeting the acceptance criterion when comparing output files from INFIL Version 2.0 and INFIL Version A_2.a1 shows that requirements are met. The acceptance criterion is that the resulting net mean infiltration rate is different by less than 1 part in a million (i.e., have a relative error less that 10E-6)

The net infiltration rates from Version 2.0 on the PC platform and Version A_2.a1 on the DEC Alpha (VMS) platform differ by less than 1 part per million; therefore, the validation test was successful. See Section 5.11 above for details of the test.

6.3 TEST LOG

6.3.1 Installation Test

Passed Failed Initials HNJ Date 11/21/01

Initialed for Harold Iuzzolino by Hong Nian Jou

initialed for Harold Irizzolino

6.3.2 Validation test by Hong-Nian Jow

Passed Failed Initials HNJ Date 11/21/01

7. DESCRIPTION OF FAILURE CONDITIONS, OCCURRENCE, RESOLUTION

Not applicable. The execution of all installation and validation tests was satisfactory.

8. OVERALL CONCLUSIONS

INFIL Version A_2.a1 passed all of the installation and validation tests. Comparisons with the output of the qualified code INFIL Version 2.0 meet the acceptance criterion specified in the VTP. Due to the limited use of INFIL Version A_2.a1 in the AMR ANL-NBS-HS-000027 Rev 00 (Analysis of Infiltration Uncertainty) there are restrictions on the validation of INFIL Version A_2.a1. These are discussed below in Section 11 of this VTR.

9. DOCUMENTATION AND JUSTIFICATION OF REMAINING TEST EXCEPTIONS OR FAILURES

Not applicable. The execution of all installation and validation tests was satisfactory.

10. SUMMARY OF UNIT TESTING

Not applicable. No unit testing was necessary for this qualification effort.

11. GENERAL REMARKS

As noted above, the use of INFIL VERSIONA_2.a1 in the "Analysis of Infiltration Uncertainty" AMR was limited to calculations of spatially averaged infiltration rates over watersheds located in the region of the repository footprint. Since this information was used, for the uncertainty analysis of infiltration, directly with infiltration rates calculated by INFIL VERSION2.0 for AMR "Simulation of Net Infiltration for Modern and Potential Future Climates", it was required that INFIL VERSIONA_2.a1 produce equivalent infiltration rate results over this region. The modifications resulting in the differences in these two versions were made so that the code would execute successfully on the computer platform used and satisfy the requirement above. A 'diff' was run on INFIL Version 2.0 and INFIL Version A_2.a1. The only difference of substance between the two codes is that in INFIL Version 2.0 the parameter OPTMASSB is read as input, in INFIL Version A_2.a1 this parameter is hardwired to be 1. In order to account for this difference when comparing output of the two codes, OPTMASSB is set to 1 in the input control file for INFIL Version 2.0 before running the comparison test. The remaining differences between the code are cosmetic in nature (changes in comment lines), and to account for platform dependent differences in file open statements.

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
SOFTWARE BASELINE REQUEST

QA: QA

Complete Only Applicable Items

1. Software Tracking Number:	2. Software Name and Version:	3. Software Activity Number:
10396-2.3-00	TOUGHREACT V. 2.3	LBNL-2000-242

SECTION I - Software Activity Designation (Description of software project [users of software, user location, CPU and platform identification]

This activity will consist of the unqualified use planning, testing and close-out documentation of TOUGHREACT V2.3. The qualified version of this code will be designated as TOUGHREACT V 2.4 in order to differentiate the versions. The qualification of TOUGHREACT V2.4 will be accomplished under another activity.

End Users: Nicolas Spycher, Eric Sonnenthal, Tianfu Xu, Patrick Dobson

Computer Platform: SUN and DEC-Alpha with UNIX

User Location: Lawrence Berkeley National Laboratory (LBNL) Computer Platform ID: Unknown

SECTION II - Software Identification (Supplier/Source Name, Address, and Point of Contact and Telephone number (if available):

5. Source:

☐ Acquired

x☐ Developed or Modified

6. Media Number: 10396-MED-2.3-00 (unqualified)

Media Type: ☐ Tape - Specify x☐ CD ROM

☐ Disk - Specify ☐ Other

Software Baseline Documentation Numbers:

7. Title and version number:		Number:
TOUGHREACT V. 2.3	Software Grading Classification	1 x☐ 2 ☐ 3 ☐
TOUGHREACT V. 2.3	☐ SMR or x☐ SAP	10396-SAP-2.3-00
TOUGHREACT V2.4	☐ SDR or ☒ RD	10396-RD-2.4-00
TOUGHREACT V2.4	DD	10396-DD-2.4-00
TOUGHREACT V2.4	ITP	10396-ITP-2.4-00
TOUGHREACT V2.4	VTP	10396-VTP-2.4-00
TOUGHREACT V2.4	☐ SIR or ☒ UM	10396-UM-2.4-00
TOUGHREACT V2.4	VTR	10396-VTR-2.4-00
	~~VTR~~ 10/31/01	

8. Responsible Manager Name:	Responsible Managers Organization:	Date:
Nick Spycher	Lawrence Berleley National Laboratory	10/23/01

9. Software Configuration Management (SCM) Name:	Date:
Jeff Mason	10/26/2001

10. ITSMA Representative Name:	Date:
Lyle Southworth	10/26/2001

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
SOFTWARE BASELINE REQUEST

QA: QA

Complete Only Applicable Items

1. Software Tracking Number:	2. Software Name and Version:	3. Software Activity Number:
10396-2.3-00	TOUGHREACT V. 2.3	LBNL-2000-242

11. x☐ **SECTION III - Control Point 1, Planning and Requirements and Design Phase Baselining**

12. ☐ **SECTION IV - Control Point 2, Implementation and Validation Phase Baselining**

X ☐ Add to Baseline	☐ Change to Baseline	☐ Superseded by Previous Version
☐ Retire from Baseline	☐ Canceled from Baseline	☐ Remove from Baseline

13. Description of Baseline Activity:

This SBRF is intended to bring closure to the unqualified use of this code at LBNL. This package includes the submittal of the Record-Copy of the unqualified use SAP and close-out testing documentation for TOUGHREACT V2.3 in accordance with Section 5.10.3.e of AP-SI.1Q, Rev.3, ICN1.

14. Rationale for Baseline Activity:

This work is required in support of the YMP Analysis and Modeling Report (AMR) N0120/U0110, *Drift Scale Coupled Processes (DST,THC Seepage) Models* (MDL-MNBS-HS-000001), Rev.01 and Rev.01, ICN1. The work is authorized under Work Package number 4301213UMH as part of the TWP for UZ Flow and Transport Report, TWP-NBS-HS-000001, Rev.00. As prescribed in the unqualified use SAP (record-copy attached), comparison testing was performed to determine the impact of using the unqualified software. The attached SBRF continuation page documents this testing.

15. Request the Following Documents to be Controlled:

1) SBRF for SAP, 10396-SAP-2.3-00
2) SBRF Continuation Page -Comparison of Unqualified TOUGHREACT V2.3 with Qualified TOUGHREACT V2.4
3) Record-copy of unqualified use SAP, 10396-SAP-2.3-00
4) Resubmittal of media 10396-MED-2.3-00 for TOUGHREACT V2.3

16. Remarks: Such as Known Copyright and License Issues, Abstract etc:

Uses proprietory Harwell subroutine MA28. LBNL has purchased limited rights for the use of this software by YMP staff. The specific provisions of this agreement are in the LBNL-AEA Technology Engineering Software Ltd. License agreement which was submitted to SCM on August 17, 2001.

Justification for the differences that exist between TOUGHREACT V2.3 and TOUGHREACT V2.4 is included on the attached SBRF Continuation Page.

17. Responsible Manager Name and Organization: Nicolas Spycher, LBNL	Responsible Manager Signature:	Date: 10/24/01
18. ITSMA Representative Name: Lyle Southworth	ITSMA Representative Signature:	Date: 10/26/01
19. SCM Representative Name: Jeff Mason	SCM Representative Signature: Jeff Mason	Date: 10/26/2001
20. Software Management Name: Steve Splawn	Software Management Signature:	Date: 10/26/01

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
SOFTWARE BASELINE REQUEST

QA: QA

Complete Only Applicable Items

1. Software Tracking Number:	2. Software Name and Version:	3. Software Activity Number:
10396-2.3-00	TOUGHREACT V. 2.3	LBNL-2000-242

SECTION V - Software Baselining and Release for Use

21. Remarks:

It is intended that TOUGHREACT V2.3 be baselined and then immediately retired.

Baseline Approved

Date/Int.: 10/26/01 [illegible]

AP-SI.1Q Rev. 3
eff. 04/01/01

Level: 1 2 3

22. Disposition:

- [x] Approved
- [ ] Rejected
- [ ] Canceled
- [ ] Removed
- [x] Retired
- [ ] Disapproved
- [ ] Change to Baseline
- [ ] Superseded by Previous version
- [ ] Removed for use by Software Defect Notification
- [ ] Software Defect Notification Resolved Approved for use

23. SCM Status Accounting Name:	SCM Status Accounting Signature:	Date:
Jeff Mason	JH Mason	10/26/2001
24. SQA Software Verification Name:	**SQA Software Verification Signature:**	**Date:**
Lyle C. Southworth	Lyle C. Southworth	10/26/01

25. SCM Library Baseline Elements Processed Date: 10/26/2001

26. Software Management Manager Name:	Software Management Manager Signature:	Date:
Steve Spaw	[illegible]	10/26/01

The unqualified version of TOUGREACT V2.3 that was submitted to Software Configuration Management (SCM) by LBNL on 11/17/00 (an updated UnQ media was subsequently submitted on 5/30/01) was used to support two separate modeling activities: 1) Analysis/Model Report (AMR) N0120/U0110 (MDL-NBS-HS-000001), *Drift-Scale Coupled Processes (DST, THC Seepage) Models,* Rev.01, and Rev.01, ICN1, and 2) FY01 Supplemental Science and Performance Analyses (SSPA) Report, Volume 1 (TDR-MGR-MD-000007), Rev.00. An upgraded, qualified, TOUGHREACT V2.4 of the software has since been baselined, obtained from SCM and installed on all applicable machines at LBNL. As outlined in the Interim Unqualified Use Software Activity Plan (SAP) for TOUGHREACT V2.3 (Software Activity Number [SAN]: LBNL-2000-242), the following comparison testing was performed to determine the impact of using unqualified software prior to full qualification.

This write up is broken into three sections: 1.0 Summary of Unqualified Use and Impact, 2.0 Validation Criteria, and 3.0 Validation Testing and Results

1.0 Summary of Unqualified Use and Impact

The unqualified TOUGHREACT V2.3 has been tested against the qualified TOUGHREACT V2.4 by Nicolas Spycher. The unqualified version of TOUGHREACT V2.3 was used for simulations (cases without backfill) presented in AMR N0120/U0110, Rev.01 and Rev.01/ICN1, and all post-Rev.01, ICN1 THC simulations in the SSPA report. These simulations include all the post-Rev.00 Drift Scale Test and THC seepage simulations (no-backfill scenario and repository host units in either the middle non-lithophysal hydrogeologic unit (Tptpmn) or lower lithophysal hydrogeologic unit (Tptpll) of the Tpopopah Spring Tuff were used).

Changes made to TOUGHREACT V2.4 since V2.3, affected primarily new features not used in the AMR or SSPA-related work. In this respect, results of original V2.3 simulations presented in AMR and SSPA-related work should be similar to reruns with V2.4, within ranges discussed below.

The method for weighting thermal conductivities between matrix and fractures was originally changed in V2.3, compared to older versions, but was then changed back in V2.4 to the same method used in pre-V2.3 versions for consistency with currently qualified TOUGH2 modules. For this reason, reruns of V2.3 simulations using V2.4 will yield slightly different predicted temperatures (within a couple degrees). This will have some effect on predicted liquid saturations and fluid chemistries, most primarily in near-dryout conditions. Another anticipated difference between V2.3 and V2.4 relates to water density. Water compositions output by V2.4 are in mol/l (molar) and are converted from mol/kg (molal) taking into account the true water density, which departs from 1 l/kg at elevated temperatures (e.g. ~0.95 l/kg at 100 C). In V2.3, the conversion from molality to molarity assumes a solution density of 1 l/kg. Other significant differences in results between V2.3 and V2.4 are not anticipated. It should be noted that the unqualified V2.3 of the software was validated (but not qualified) against measured data from the Drift Scale Test and laboratory experiments, with results presented in AMR N0120/U0110, Rev.01 and Rev.01, ICN1.

2.0 Validation Criteria

Given the considerations discussed in Section 1.0 above, the criteria for validating the unqualified TOUGHREACT V2.3 against the qualified V2.4 were established as follows:

(1) Rerun with V2.4 one complete THC seepage simulation presented in AMR N0120/U0110 or the SSPA report.

Here we choose the high-temperature simulation *thc6_ht1* discussed in Section 6.3 of the SSPA report because this simulation:

a) Covers the typical temperature and liquid saturation ranges simulated to date for the Yucca Mountain project

b) Takes into account all complex coupled THC processes simulated to date for the project

c) Uses the same setup as another high-temperature THC seepage simulation (*thc6_16_25_g4)* presented in Section 6.6 of AMR N0120/U0110, Rev.01, and Rev.01, ICN1, thus providing validation of the AMR work in addition to the SSPA work.

This simulation considers a waste-emplacement drift in the main repository host unit (Tptpll) at a location near the center of the repository.

(2) Plot time profiles for pH, CO2 gas, aqueous species, and temperature, liquid saturation and other THC parameters such as those presented in AMR N0120/U0110 Rev.01and Rev.01, ICN1 and in Section 6.3 of the SSPA report, and compare with results of V2.3. These plots are for points located at the crown, side, and base of the drift and cover a 100,000-year time window.

(3) Verify that predicted temperature and liquid saturation profiles are similar between V2.3 and V2.4, within ranges that can be accounted for by the difference in thermal conductivity calculations between versions (in this case, no more than 5% difference in temperatures, liquid saturations, or air mass fractions). Note that for saturations directly following or preceding dryout, greater differences could possibly occur due to the temperature difference.

(4) Verify that predicted trends and values of CO2 and aqueous species concentrations are similar between versions. Because of the slightly different temperatures computed with V2.3 and V2.4, and their effect on liquid saturations near dryout conditions, a rigorous criteria for acceptance cannot be established. Nevertheless, concentrations should be within an order of magnitude (within the model uncertainty), and trends should be nearly identical. Note that the model uncertainty cannot be quantified exactly because of the large number of uncertain input parameters.

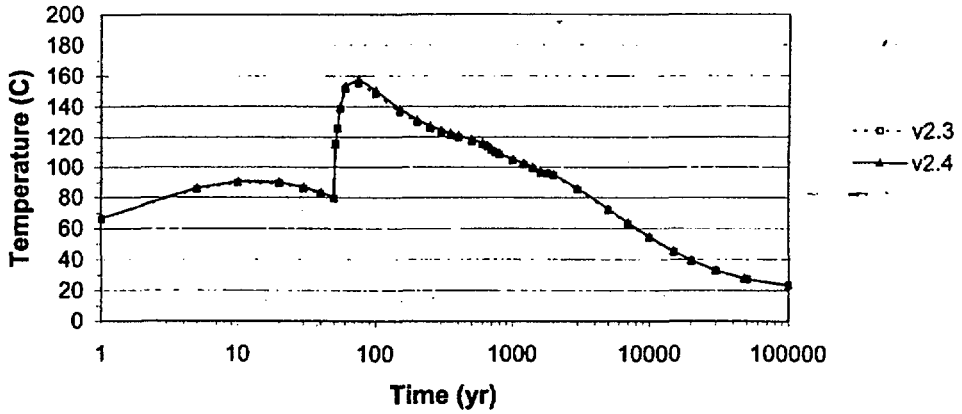
3.0 Validation Testing and Results

Steps 1 though 4 in Section 2.0 were performed. Time profiles for various predicted THC parameters such as temperature, liquid saturation, CO2 gas concentrations, pH, and

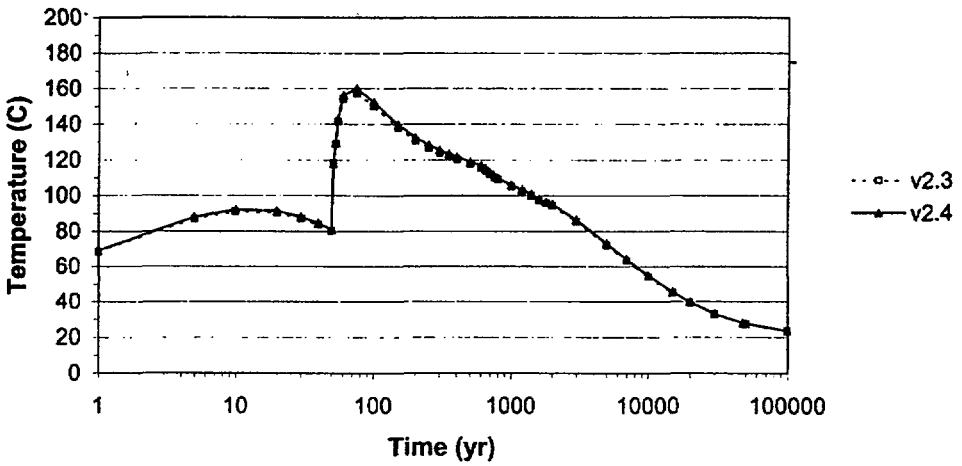
aqueous species concentrations were generated for a time window of 100,000 years (covering the range of data presented in AMR N0120/U0110 and in the SSPA report) (Figures 1 through 12). Profiles calculated with the unqualified version (labeled V2.3) and with the qualified version (labeled V2.4) were plotted on the same graphs for comparison. Blank parts on some of the curves indicate times of dryout when no water is present; values on these curves are shown to indicate the first output saturation after rewetting. There are slight differences in predicted temperatures, liquid saturations, and air mass fractions (Figures 1 to 4), but these do not generally exceed 5 %, except at the time of rewetting because this time changes somewhat due to the change in thermal conductivity weighting discussed in Section 1. A difference in liquid saturations greater than 5% is noticeable for one point at the drift crown at 100,000 years on Figure 2 (fractures only). Such difference can easily be caused by slight differences in precipitated minerals amounts and has no significance on predicted water compositions. Small differences exist in predicted concentrations of CO_2 and aqueous species because of the slight difference in predicted temperatures mentioned in Section 1 (Figures 5 to 12). These differences are mostly observed directly preceding or following dryout conditions. These differences remain within the model uncertainty and criteria established in Section 2.0. Therefore, it can be concluded that simulations with unqualified V2.3 are verified with the qualified V2.4 and, for this reason, a full impact analysis (as per step 3.2 in the SAP) is not required.

Fractures (Tptpll)

Crown



Side



Base

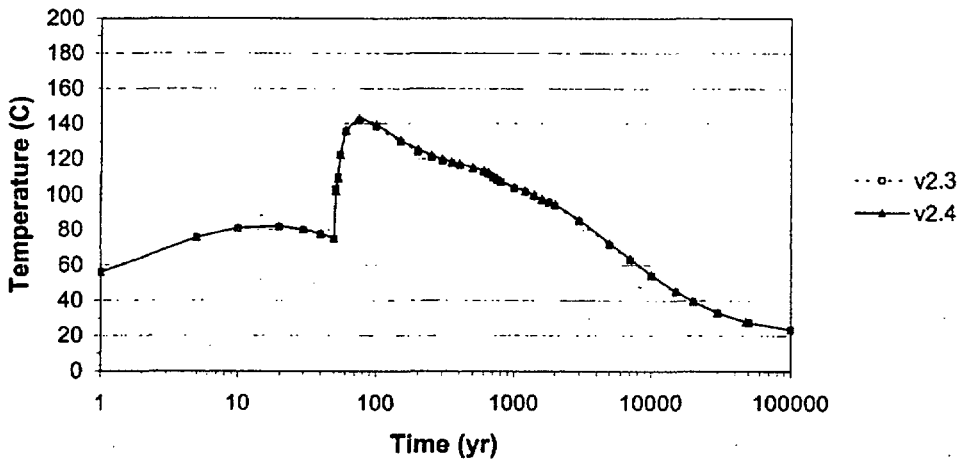
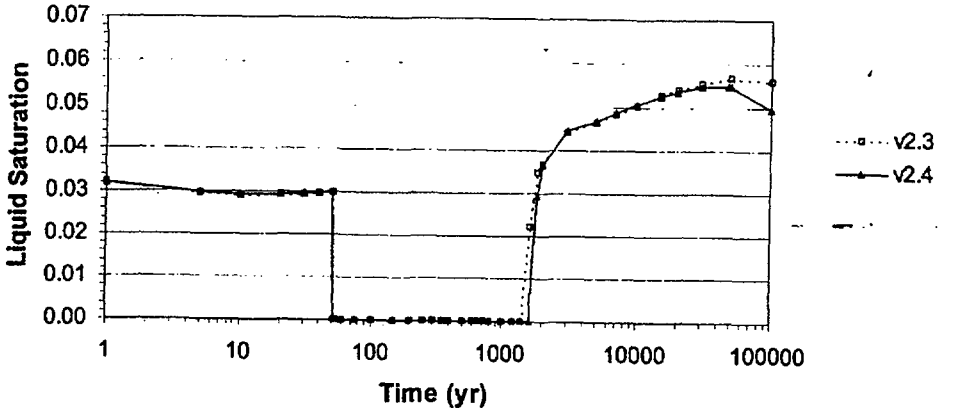


Figure1

Fractures (Tptpll)

Crown



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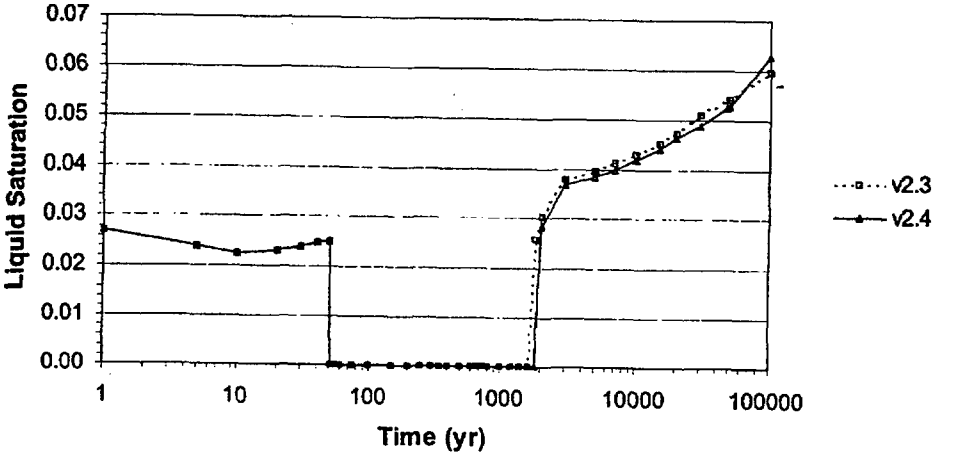

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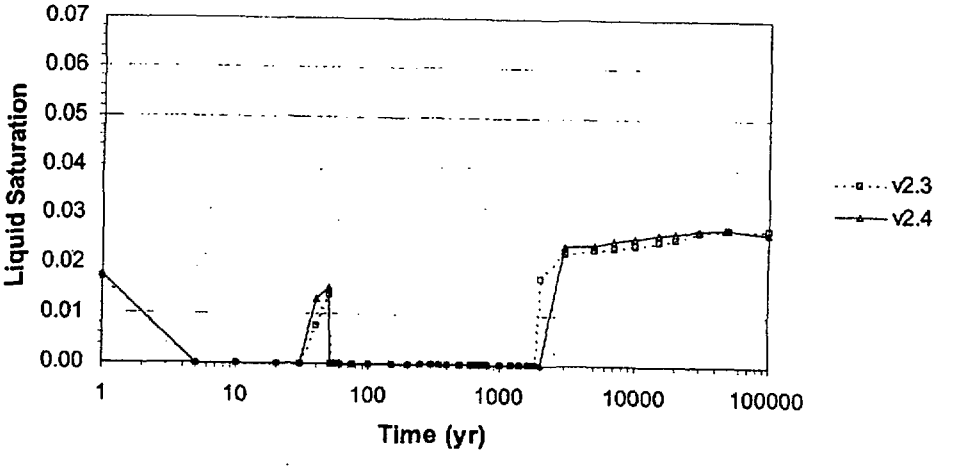
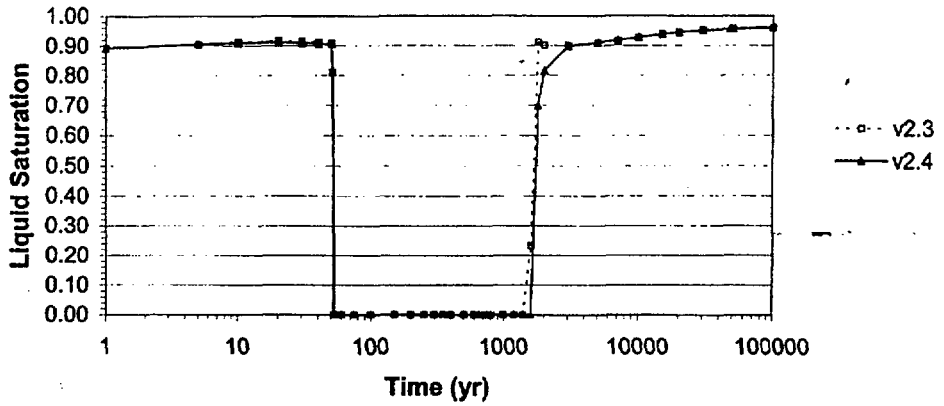


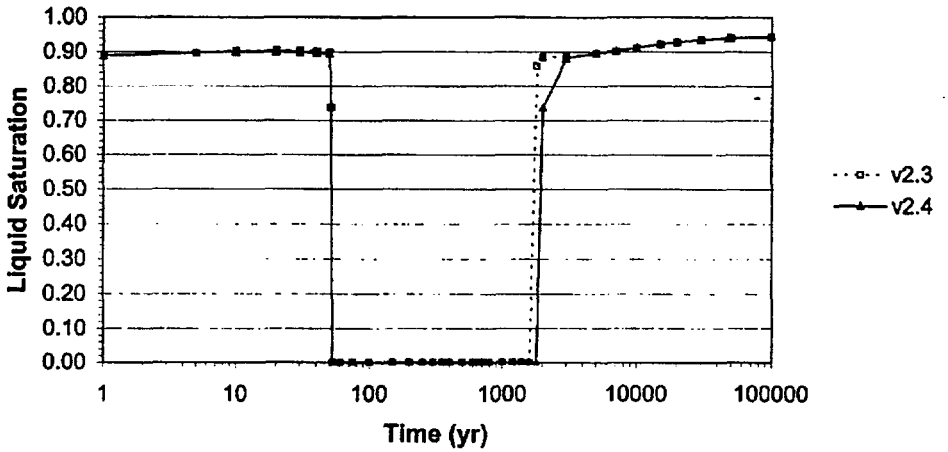
Figure 2

Matrix (Tptpll)

Crown



Side



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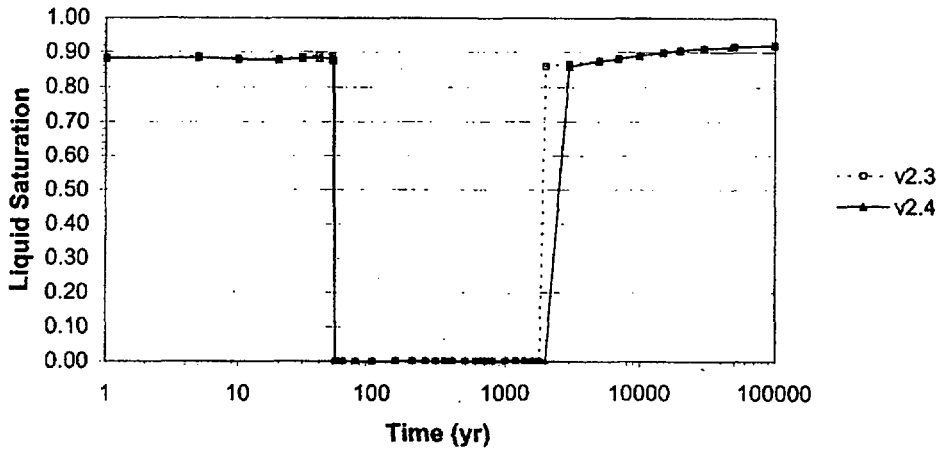
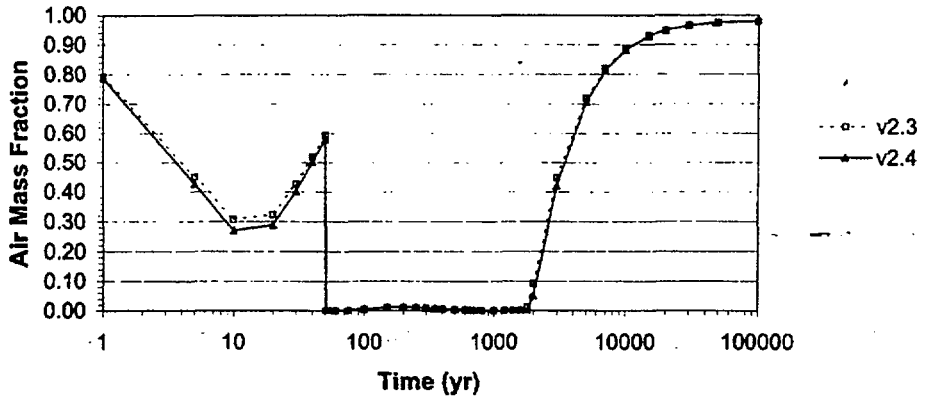


Figure 3

Fractures (Tptpll)

Crown



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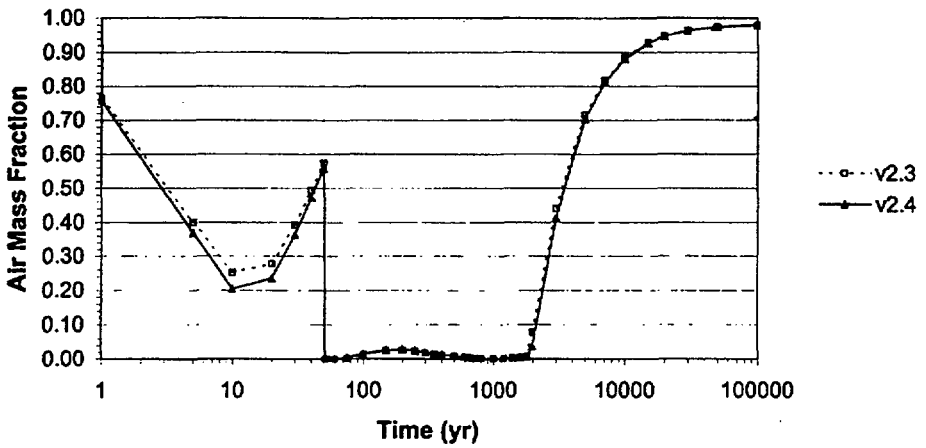

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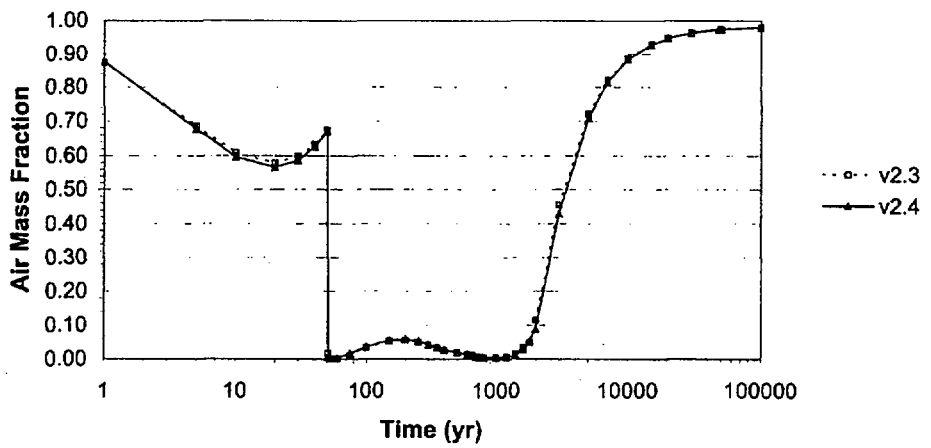
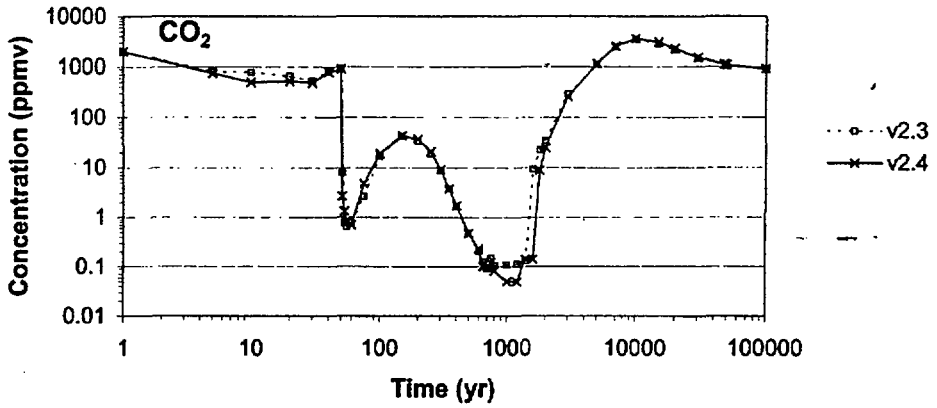


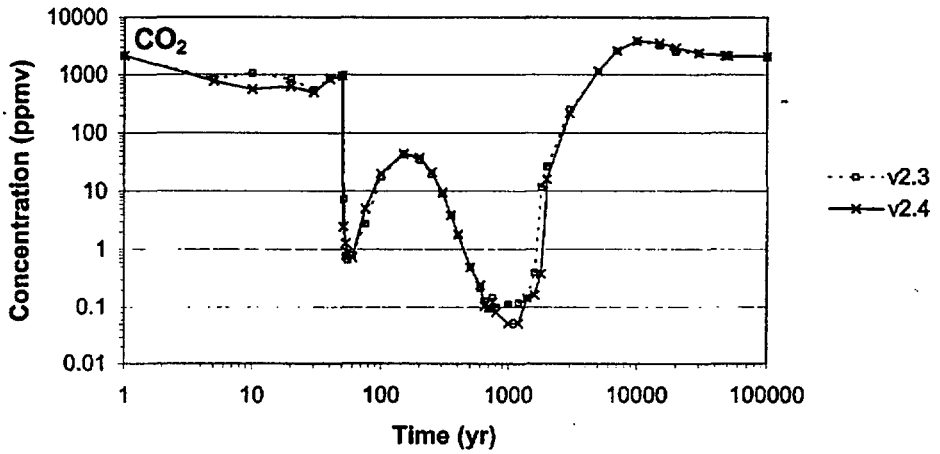
Figure4

Fractures (Tptpll)

Crown



Side



Base

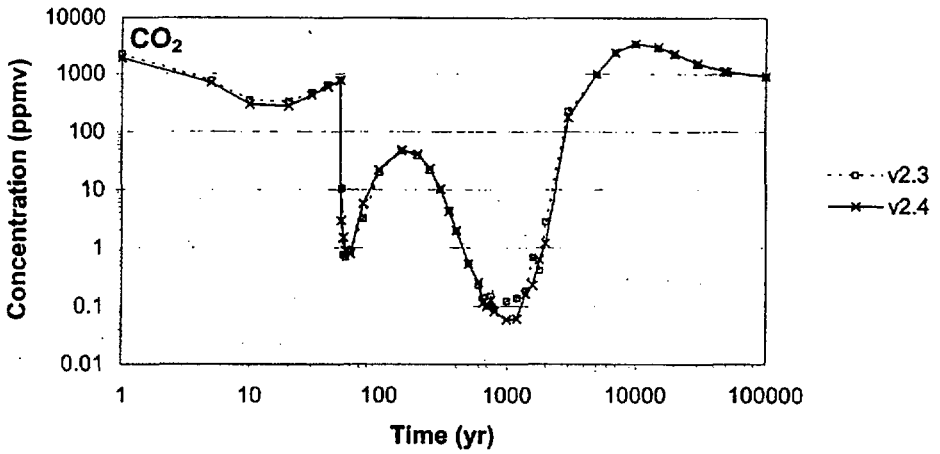


Figure5

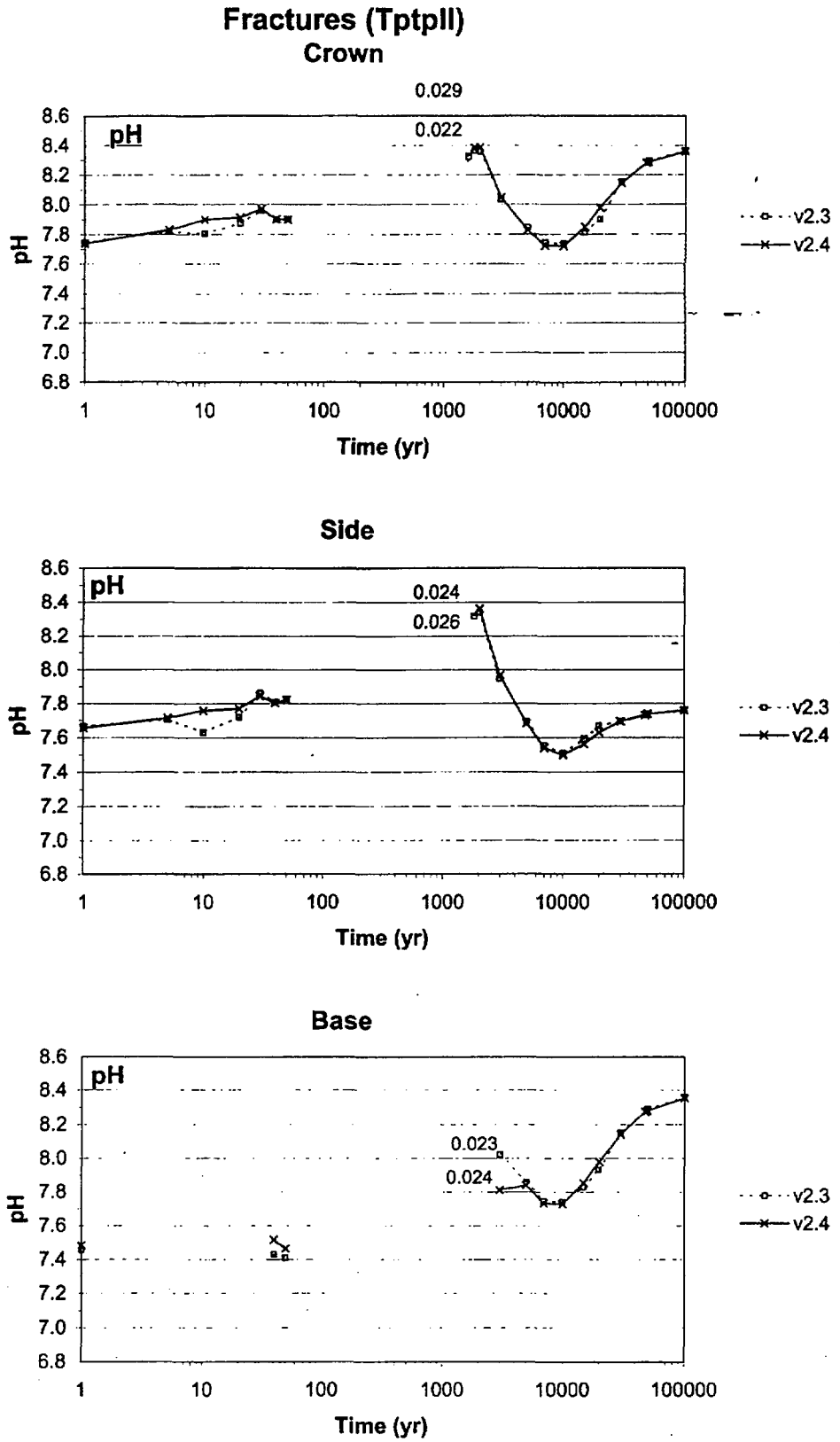
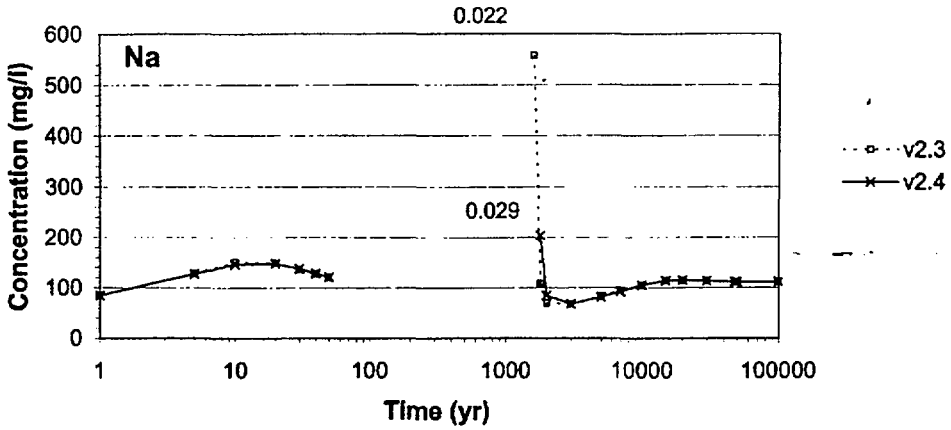

Fractures (Tptpll)
Crown
pH
0.029
0.022
v2.3
v2.4
Time (yr)
Side
pH
0.024
0.026
v2.3
v2.4
Time (yr)
Base
pH
0.023
0.024
v2.3
v2.4
Time (yr)

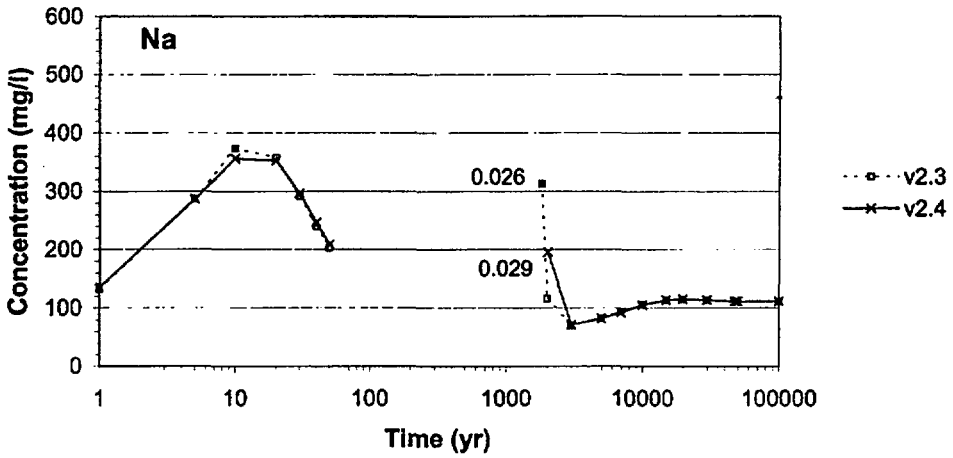
Figure6

Fractures (Tptpll)

Crown



Side



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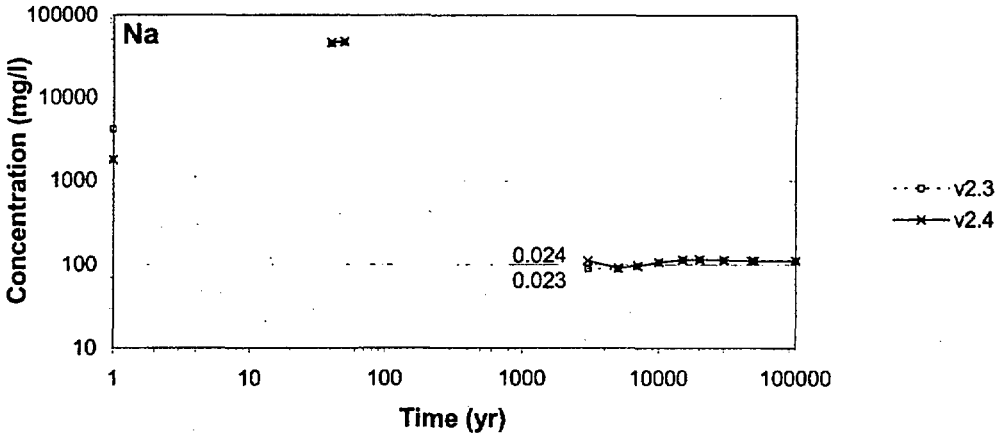
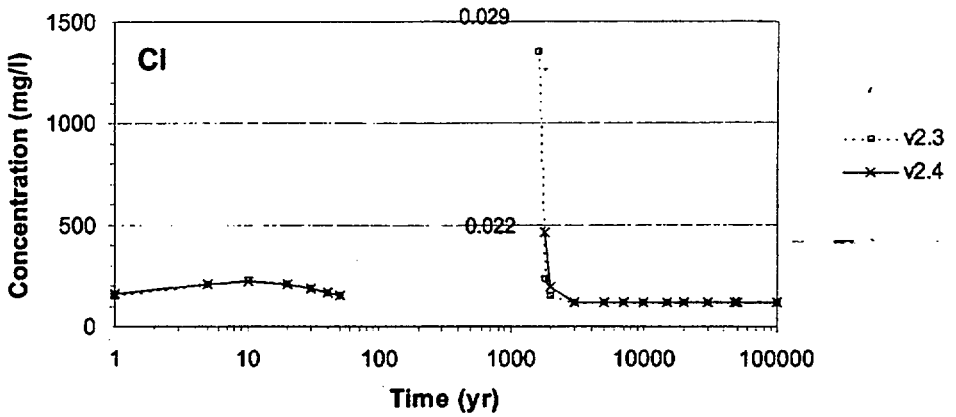


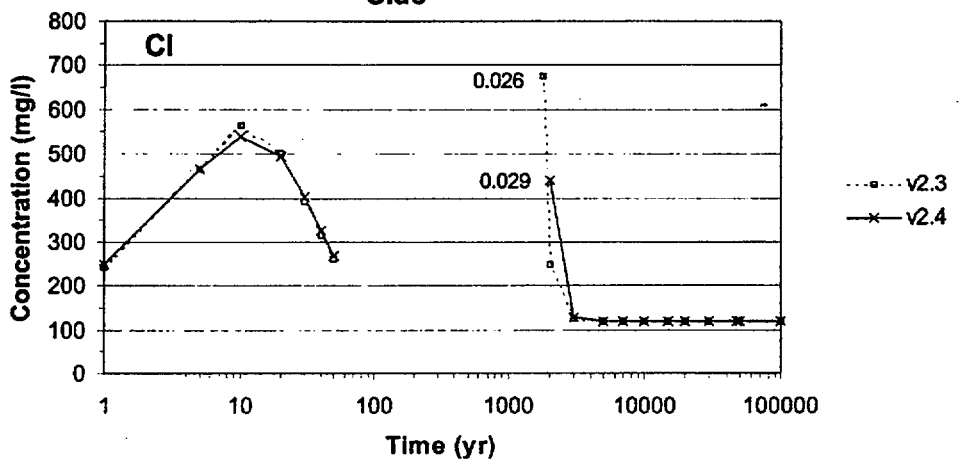
Figure7

Fractures (Tptpll)

Crown



Side



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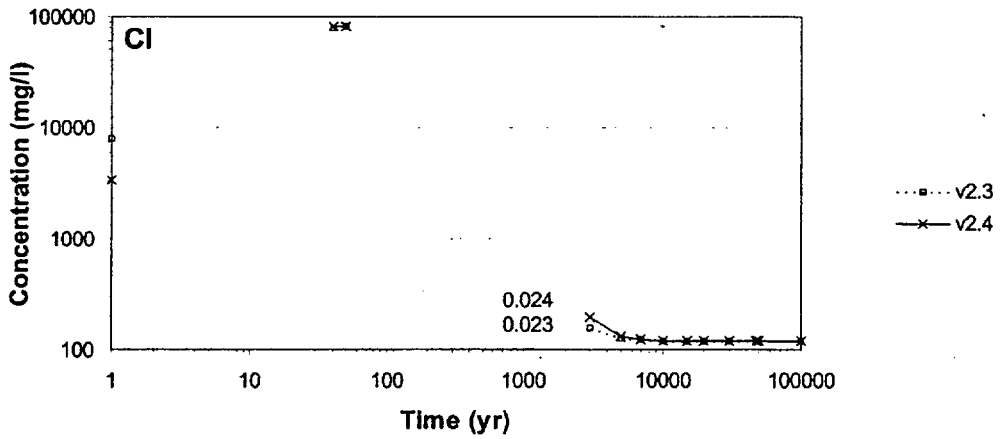
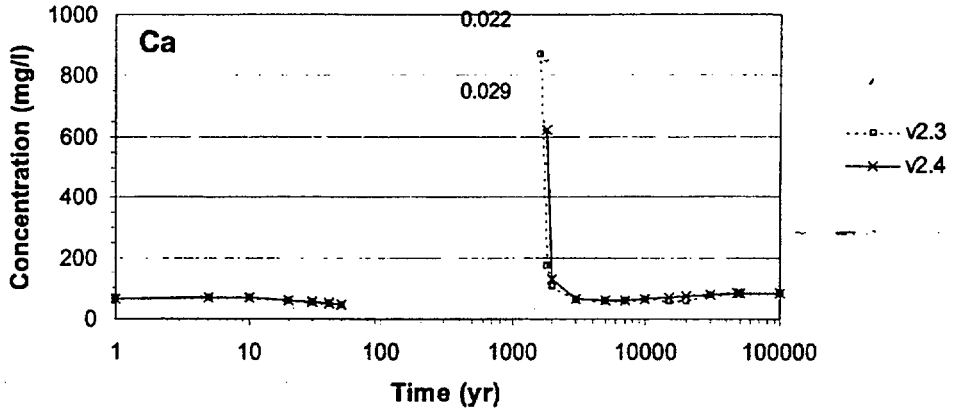


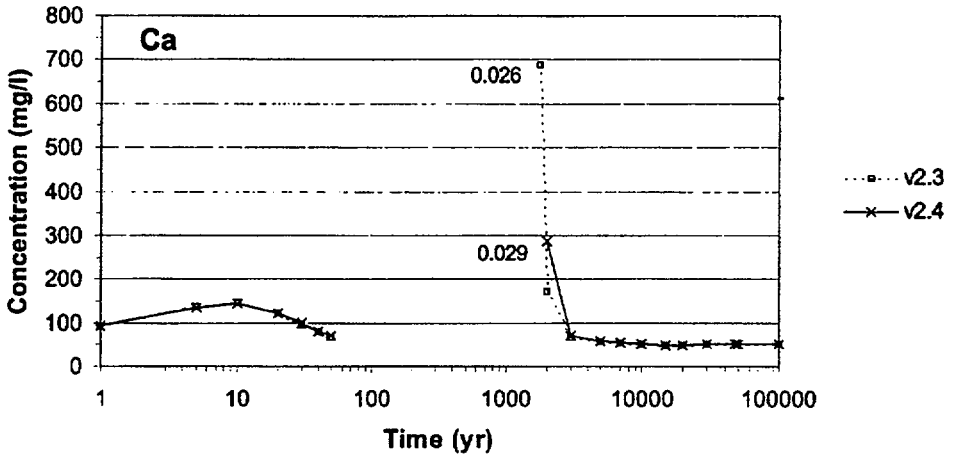
Figure8

Fractures (Tptpll)

Crown



Side



Base

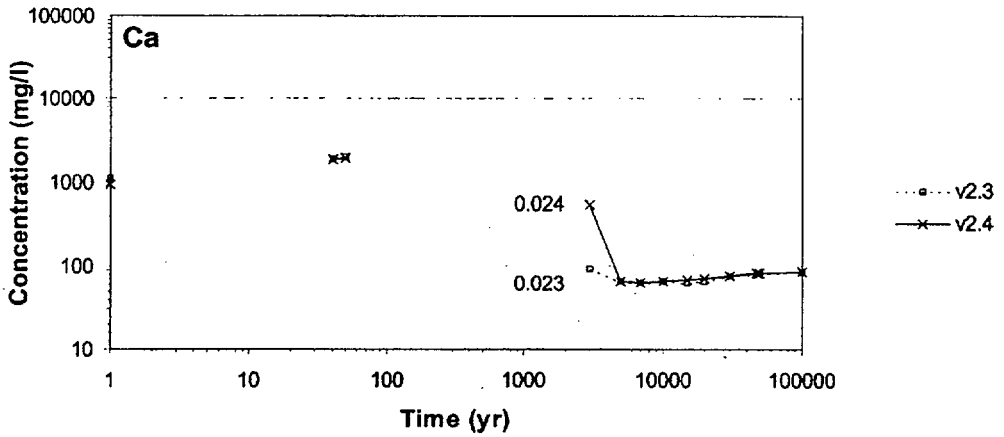
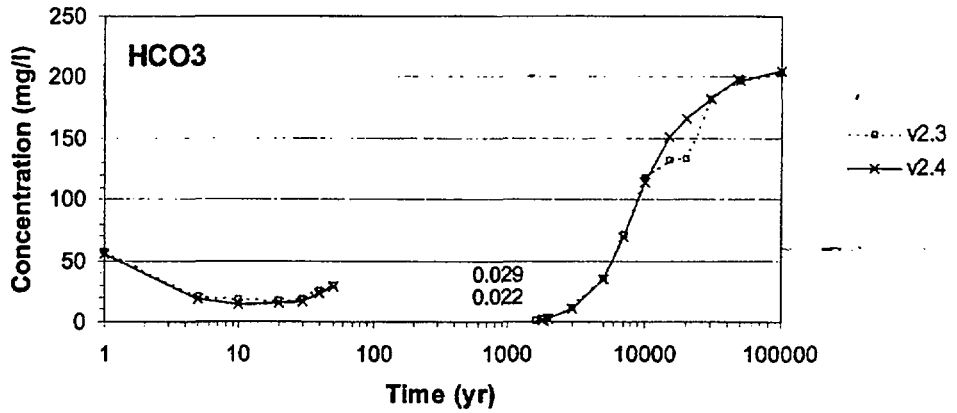


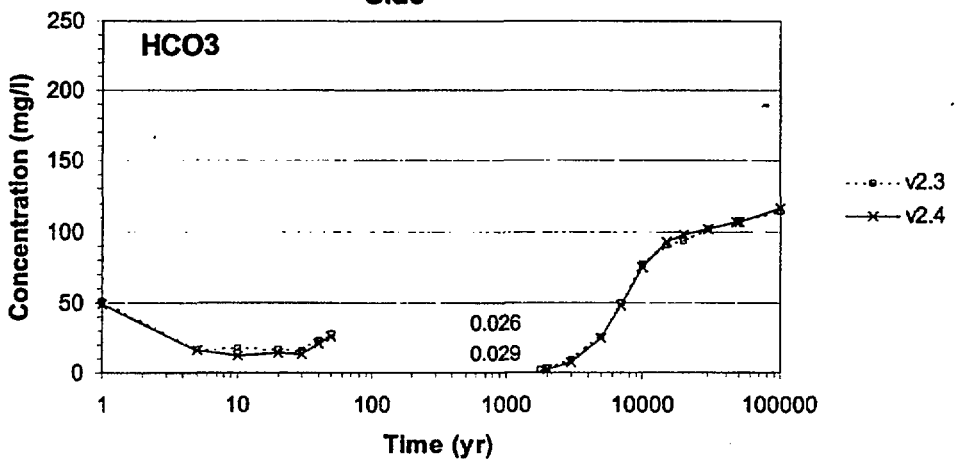
Figure 9

Fractures (Tptpll)

Crown



Side



Base

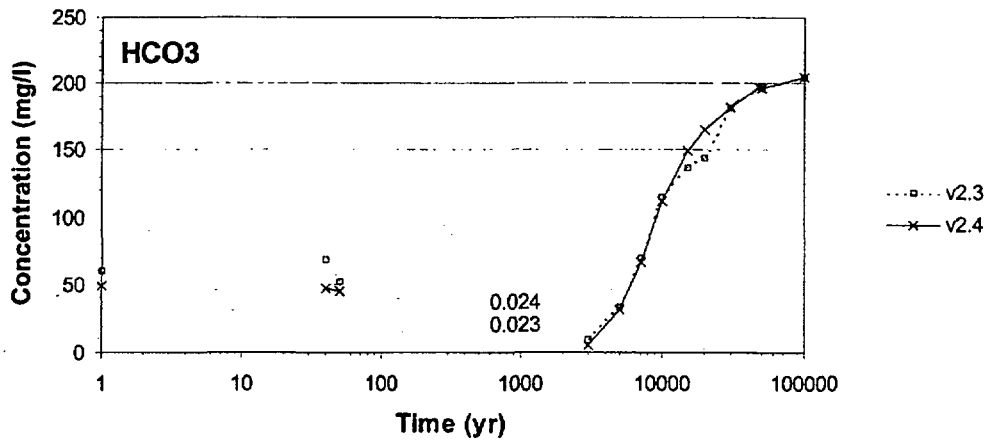
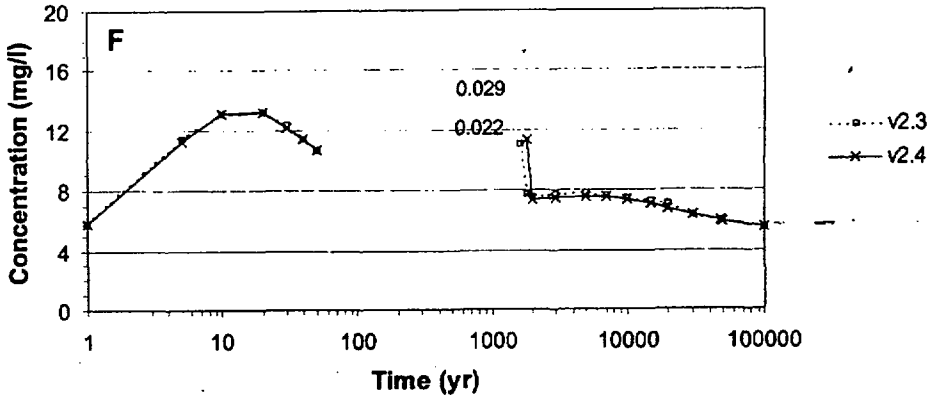


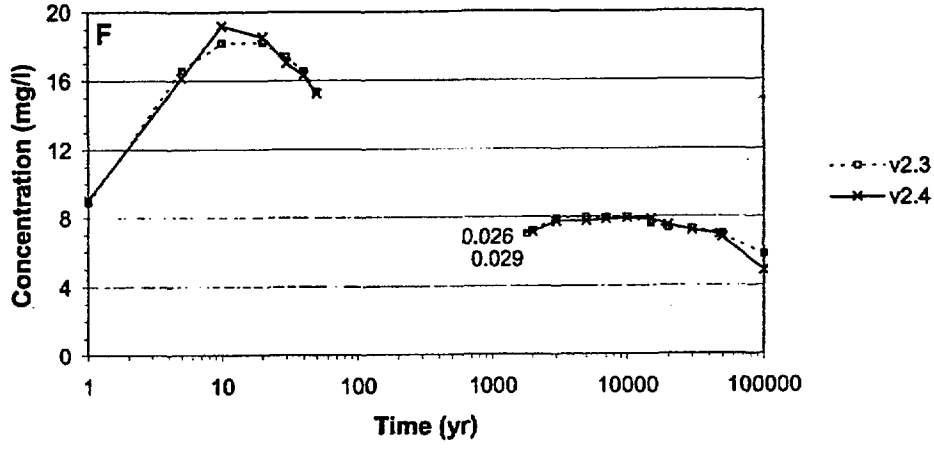
Figure 10

Fractures (Tptpll)

Crown



Side



Base

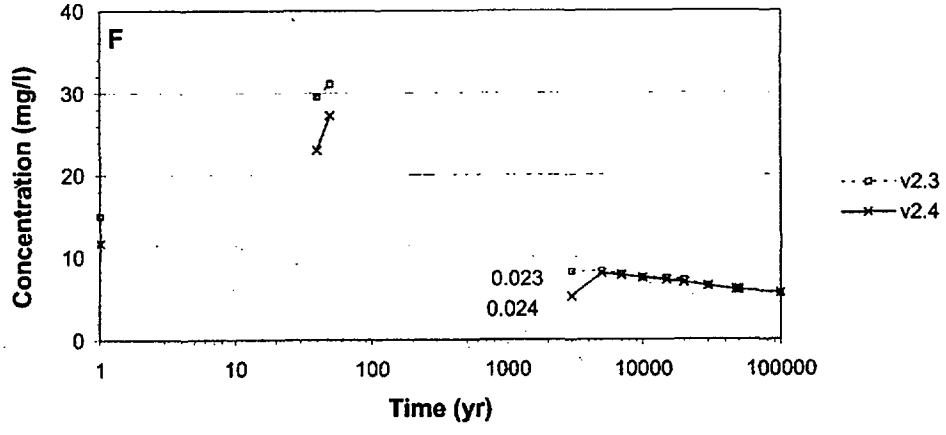


Figure 11

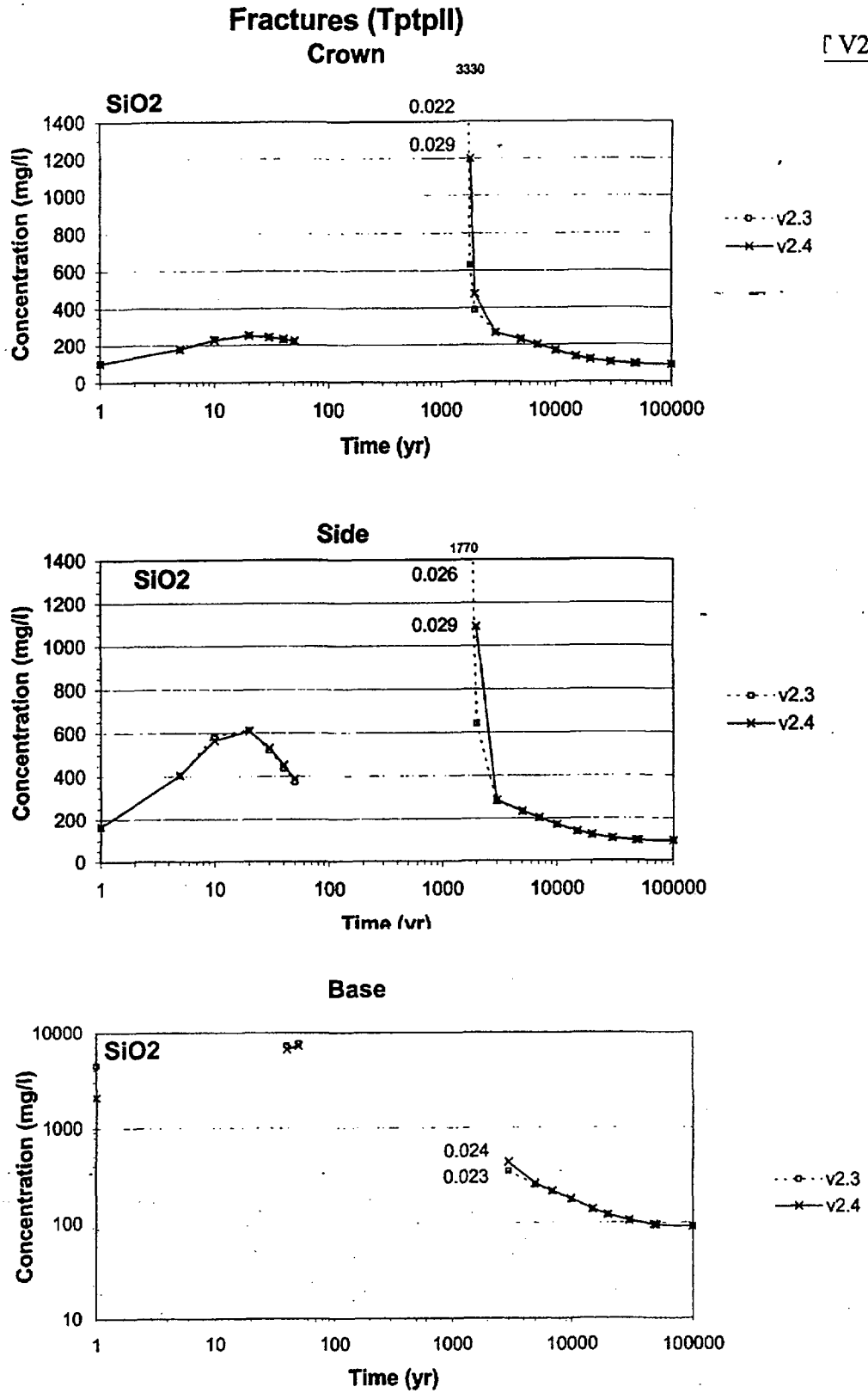

Fractures (Tptpll)
Crown
3330
SiO2
0.022
0.029
Concentration (mg/l)
Time (yr)
v2.3
v2.4
Side
1770
SiO2
0.026
0.029
Concentration (mg/l)
Time (yr)
v2.3
v2.4
Base
SiO2
0.024
0.023
Concentration (mg/l)
Time (yr)
v2.3
v2.4

Figure 12

QA: QA

MOL.20011030.0452

VALIDATION TEST REPORT (VTR)
for
TOUGHREACT V2.4

SAN: LBNL-2001-169
Document Identifier: 10396-VTR-2.4-00
STN: 10396-2.4-00
SMN: 10396-MED-2.4-00

Prepared by: _____ Date 9/28/01
Eric Sonnenthal
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Randall Hedegaard
Management Reviewer

Approved by: _____ for G.S. Bodvarsson Date 9/28/01
G. S. Bodvarsson
Responsible Manager Supervisor

Reviewed by: _____ Date 09/28/01
~~Dianne Spence~~ EDWARD MILLER 09/28/01
Information Technology
Software Management Analyst (ITSMA)

CHANGE HISTORY

Revision Number	Effective Date	Description of Change
00	9/28/01	Initial issue.

This Validation Test Report (VTR) is based upon the Software Activity Plan (SAP) 10396-SAP-2.4-00, Requirements Document (RD) 10396-RD-2.4-00, the Design Document (DD) 10396-DD-2.4-00, the Installation Test Plan (ITP) 10396-ITP-2.4-00, and the Validation Test Plan (VTP) 10396-VTP-2.4-00 in accordance with the Office of Civilian Radioactive Waste Management (OCRWM) Administrative Procedure (AP)-SI.1Q, *Software Management*, Rev. 3, ICN 1, ECN 1. TOUGHREACT V2.4 is an
upgrade of TOUGHREACT V2.2 (STN: 10154-2.2-00).

1. SOFTWARE IDENTIFICATION

This report documents the installation and validation testing of TOUGHREACT V2.4 on the following platforms, operating systems and compilers listed:

SunOS 5.5.1 and Fortran 77 v5.0 on SUN system
Compaq Tru64 UNIX v5.0A and Compaq Fortran v5.3 on DEC-Alpha system
DEC OS1 V4.0 and Compaq Fortran 77 on DEC-Alpha system

2. INDEPENDENT VALIDATION TESTER

Guoping Lu confirmed the tests at Lawrence Berkeley National Laboratory.

3. SPECIAL TOOLS AND EQUIPMENT

No special tools or equipment was used in conducting the validation test.

4. TEST RESULTS LINKED TO VTP

The results of the execution of the validation test cases are documented in Appendix A. Within Appendix A, a unique identifier is provided in column 1 of Table 1 which corresponds to the test number identified in the Validation Test Plan (VTP).

5. TEST RESULTS

The results of the execution of the validation test cases are documented in Appendix A. The results for all platforms listed in Section 1 are identical. The results of the execution of the test steps within the ITP are provided below:

1. Pre-installation tasks completed (independent machines identified, target directories established, files transferred, and files extracted properly)
2. Installation and testing completed (makefiles executed and test cases run on target platforms)
3. Acceptance Criteria met for all platforms (no difference between contents of newly created TIME.DAT and reference TIME.DAT)

6. INDICATION OF PASS/FAIL

The results of the validation test cases are documented in Appendix A. The pass/fail annotation with initial and date are provided in the margin of Table 1 next to each test case number.

7. FAILURE CONDITIONS, OCCURRENCE, RESOLUTION

No installation or validation failure condition(s) were found to exist while executing the ITP & VTP.

8. OVERALL CONCLUSIONS

The overall conclusion of these tests is that the software adequately and correctly performs all intended functions and does not perform any unintended functions either by itself or in combination with other functions.

9. DOCUMENTATION AND JUSTIFICATION OF REMAINING TEST EXCEPTIONS OR FAILURES

On the DEC platforms error messages appear when running Test #1 (floating-point exception underflow) and Test #3 (divide by zero). On the SUN platform error messages appear when running Test #1. These errors do not affect output results. There are no other remaining test exceptions or failures based on the execution of these tests.

10. SUMMARY OF UNIT TESTING

For the purposes of this validation effort, no unit tests were performed by the developer.

11. GENERAL REMARKS

None

APPENDIX A- TOUGHREACT V2.4 Validation Test Documentation

This appendix presents the results of verification and validation tests to confirm that TOUGHREACT V2.4 meets the requirements set forth in the Validation Test Plan. Table 1 summarizes testing results. Part of the testing of TOUGHREACT V2.4 relies on running validation/verification tests developed for previous qualified versions of TOUGHREACT, and ensuring that V2.4 produces equivalent results. New test problems are developed to verify new V2.4 features listed below:

1) Supersaturation "windows" for kinetically inhibited minerals.
2) New HKF (1981) activity coefficient model
3) Ideal solid solutions for minerals
4) New k-ϕ aperture model for mineral precipitation
5) Ability to input initial heterogeneous k and ϕ field
6) Permeability law zones
7) Precipitation of amorphous silica into dry nodes

Table 1. Summary of Validation Testing for TOUGHREACT V2.4

Test Status	#	Requirements	Problem Type	Acceptance Criteria	Dimension	Reference/Test Problem Name
GL-9/28/01 Pass	1	Verification of equivalence to TOUGH2 EOS3. Run with V2.4 previous test problems used to qualify V2.1. Ensure both versions yield results within the acceptance criteria.	(a) Flow to a geothermal well (b) Transient heat pipe (c) Two-phase flow	Match results of V2.1 (within 0.1%)	3-D, cylindrical 3-D, cylindrical 1-D, linear	Test Problem 1 in Spycher et al. (1999)/ no_outer_ring out-ring geothermal2.4 heat-pipe2.4
GL-9/28/01 Pass	2	Verification of proper chemical mass-balance and mass-action for the chemical solver (no transport) for an unsaturated case. Run with V2.4 previous test problems used to qualify V2.1. Ensure both versions yield results within the acceptance criteria.	Heat water and gas (two-phase) from 25 to approximately 100°C at near atmospheric pressure.	Match results of V2.1 within 5%, after correction for water density changes not accounted for in V2.1.	1 grid block (no transport)	Test Problem 2b in Spycher et al. (1999)/ heat_unsat1_2.4
GL-9/28/01 Pass	3	Verification of evaporative concentration due to boiling. Run with V2.4 a previous test problem used to qualify V2.1. Ensure both versions yield results within the acceptance criteria.	Boil water near 100°C at pressure approximately atmospheric.	Match results of V2.1 for chloride (within 1%), after correction for water density changes not accounted for in V2.1	2 grid blocks (steam transport only)	Test Problem 3 in Spycher et al. (1999)/ boil100_2.4
GL-9/28/01 Pass	4	Verification of aqueous transport (advection/diffusion). Run with V2.4 previous test problems used to qualify V2.1. Ensure both versions yield results within the acceptance criteria.	Simulate transport of a chemical tracer at 25°C, 1 bar (version 1.0 test problem 4).	Match results of V2.1 (within 1%) (correction for water density changes not needed at the considered temperature)	1-D, linear	Test Problem 4 in Spycher et al. (1999)/ aqtrans_2.4
GL-9/28/01 Pass	5	Verification of gas transport (advection/diffusion). Run with V2.4 previous test problems used to qualify V2.2. Ensure both versions yield results within the acceptance criteria.	Simulate CO_2 transport in a constant, steady state flow field, with option set to calculate the CO_2 diffusion coefficient.	Match results of V2.2 (within 1%) for concentration ratios ($C/C_{initial}$)	1-D, linear	Test Problem 8 in Spycher et al. (1999), as rerun for V2.2 qualification./ gas_diffus_2.4
GL-	6	Verification of activity coefficients and water activity calculation.	Simulate chemical speciation (no flow) in a one-block problem for	Plot calculated mean salt activities, activity	1 grid block (no transport)	This report/ qa_hkf81

9/28/01 Pass			electrolyte solutions of various composition and ionic strengths for which activity coefficients and water activity have been independently determined.	coefficients, and water activities and compare with measured data. For NaCl, match calculated and measured activities within 10% up to 6M NaCl. For other salts, plot results and qualitatively compare results against measured data (no strict criteria can be set because the method assumes NaCl-dominant solutions).		
GL- 9/28/01 Pass	7	Verification of supersaturation window	Run quartz plug flow reactor using arbitrary rate such that equilibrium is reached quickly, then vary supersaturation window. Repeat for equilibrium case.	Hand-calculate solubility for given saturation window and ensure these values match within 1% the values calculated by V2.4.	1-D, linear, liquid saturated	This report/ supsatwin2.4
GL- 9/28/01 Pass	8	Verification of ideal solid solution option	Run problem similar to test#2 using clay minerals in solid solution and under kinetic constraints. Use arbitrary rate such that equilibrium is reached quickly.	Check output to verify that the sum of Q/K values of each endmember equals zero at equilibrium (within 0.1%).	1 grid block (no transport)	This report/ solid_sol2.4
GL- 9/28/01 Pass	9	Verification of correct fracture permeability calculations (permeability law 3 – cubic law)	Run 1-D fracture plugging problem using permeability law 3.	Use porosity change to hand calculate permeability change. Check that permeability change is within 0.1% of calculated value based on porosity change	1-D vertical fracture plugging problem – nonisothermal, boiling and complete dryout	This report/ test_boilfrac_1
GL- 9/28/01 Pass	10	Verification of correct fracture permeability calculations (permeability law 4 – fracture aperture law)	Run 1-D fracture plugging problem using permeability law 4. Use a range of possible *a* and *b* parameters (Based on range of AMR N0120 values; Sonnenthal and Spycher, 2001) and porosity change to hand calculate permeability change	Use porosity change to hand calculate permeability change. Check that permeability change is within 1.0% of calculated value based on *a* and *b* parameters and porosity change	1-D vertical fracture plugging problem – nonisothermal, boiling and complete dryout	This report/ test_boilfrac_2 test_boilfrac_3 test_boilfrac_4

GL-9/28/01 Pass	11	Verification of correct permeability porosity coupling for permeability law 1 (Carman-Kozeny law)	Run quartz plug flow reactor and hand check permeability changes and porosity changes	Use porosity change to hand calculate permeability change. Check that permeability change is within 0.1% of calculated value based on porosity change	1-D, linear, liquid saturated, plug flow reactor problem	This report/ k-phicoupling
GL-9/28/01 Pass	12	Verification of correct input of heterogeneous porosity and permeability fields	Restart of 1-D fracture plugging problem after strong initial heterogeneity in permeability and porosity has developed	Show that after restart, with no permeability-porosity coupling that the output permeabilities and porosities in the SAVE file are identical to those input in the INCON file	1-D vertical fracture problem – nonisothermal, boiling and complete dryout	This report/ test_boilfrac_5
GL-9/28/01 Pass	13	Verification of correct input of permeability zones	Run 1-D fracture plugging problem, using zones block in CHEMICAL.INP and in SOLUTE.INP	Show that permeability zone is correctly assigned to grid blocks, with correct permeability law (associated with problems 9, 10, and 11)	1-D vertical fracture problem – nonisothermal, boiling and complete dryout	This report/ Same problems as tests # 11 through # 15
GL-9/28/01 Pass	14	Verification of correct match to analytical solution for 1-D reaction-transport, for V2.4 consideration of liquid density changes in reaction calculations	Run quartz plug flow reactor compare concentrations to that of analytical solution	Compare results to analytical solution. Check that output concentrations match within 5 % of analytical solution.	1-D, linear, liquid saturated, plug flow reactor problem	This report/ nok-phicoupling
GL-9/28/01 Pass	15	Verification of option to precipitate amorphous silica into dry nodes	Run 1-D fracture plugging problem setting flag 4 (after mineral name) to 1 and using permeability laws 3 and 4. All other minerals must have their flag set to zero	Show that amorphous silica precipitates in the dry node that is just ahead of the first wet node in the boiling front and that the mass balance for silica precipitated in the entire system is within 5% of the input value (in Mbalance.out)	1-D vertical fracture problem – nonisothermal, boiling and complete dryout	This report/ test_boilfrac_1 test_boilfrac_2 test_boilfrac_3 test_boilfrac_4 test_boilfrac_5

is unique software validation test problem number

A. Test Problem Results

A.1 TOUGHREACT V2.4 Verification Against TOUGH2 EOS3 (Test Problem 1)

Test problem 1 in Table 1 has three test problems: (a) flow to a geothermal well; (b) transient heat pipe; and (c) two-phase flow. In the two-phase flow, two tests were performed, the test "outer-ring" includes 100 extra elements in the test "outer ring" in the computational mesh to simulate a constant temperature ring around the core created by the oven. Test problems were run with version V2.4, produced results consistent with those of V2.2 and met the acceptance criteria listed in that table. In each of the four tests, the output file FLOW.OUT run with V2.4 was renamed as FLOW.OUTq2.4, and output with V2.1 as FLOW.OUTq2.1. The results are identical for both versions with the exception of the differences because of output format. Examples of these differences include code's internal assigned array sizes, time steps, notes of version updates, simulation run's elapsed time. The tests meet the acceptance criteria in Table 1.

A.2 Verification of Proper Chemical Mass Balance and Mass Action (Test Problem 2)

Test problem 2 in Table 1 was run with version V2.4. The results were corrected for water density changes at elevated temperature (V2.4). Results from V2.4 were matched with those of V2.1 within 5%. Output files chdump.dat and TIME.DAT were checked for several minerals and CO_2 gas, and mass balances of several component species. The test met the acceptance criteria listed in that table.

Test folder and data files used:

heat_unsat1:	FLOW.INP	input
	SOLUTE.INP	input
	CHEMICAL.INP	input
	thermok2.dat	input
	TIME.DAT	output
	FLOW.OUT	output

This test is the same as Test #2b in the qualification documents of V2.1. This test was rerun with the same input files as for V2.1 but modified for any new V2.4 format requirements. Calculated concentrations with V2.1 and V2.4 were compared. Because aqueous concentrations calculated with V2.4 are output in mol/L, while V2.1 output is in mol/kg (ppm), concentrations from V2.1 were multiplied by the water density (from the FLOW.OUT file) before the comparison was made. The difference in concentrations calculated between V2.4 and V2.1 was less than 5%, as shown in Table A-1. The difference is more pronounced for double charged species such as calcium because of the activity coefficient changes in V2.4 compared to V2.1 (See Test #6).

Table A-1

T (C)	density		Calcium				Sodium		
	(kg/l)	V2.1	V2.1	V2.4	%diff	V2.1	V2.1	V2.4	%diff
		(mol/kg)	(mol/L)	(mol/L)		(mol/kg)	(mol/L)	(mol/L)	
33.338	0.9947	8.973E-05	8.93E-05	9.111E-05	-2.08	1.61E-02	1.597E-02	1.59E-02	0.34
61.470	0.9824	1.164E-04	1.14E-04	1.161E-04	-1.53	1.10E-02	1.085E-02	1.08E-02	0.05
103.105	0.9559	1.615E-04	1.54E-04	1.580E-04	-2.34	4.32E-03	4.125E-03	4.06E-03	1.50

A.3 Verification of Evaporative Concentration due to Boiling (Test Problem 3)

This test problem was to verify evaporative concentration due to boiling. It was set up in a two grid blocks. One was used to simulate heating of an initially liquid-saturated at 100°C near atmospheric pressure (Problem 3 in Table 1). This grid block was connected to another large grid block containing essentially gas. As water in the first block was evaporated, steam was displaced from the first block into the second block, thus resulting in decreasing the liquid saturation in the first block. The chloride concentrations $C/C_{initial}$ from V2.4 were corrected for water density changes and matched well with those of V2.1. The run with version V2.4 met the acceptance criteria listed in that table.

Test folder and data files used:

boil100_2.4	FLOW.INP	input
	SOLUTE.INP	input
	CHEMICAL.INP	input
	thermok2.dat	
	time.dat	output

This test is the same as Test #3 in the qualification documents of V2.1. This test was rerun with the same input files as for V2.1 but modified for any new V2.4 format requirements. Using output data from the TIME.DAT file, chloride concentrations were plotted as C/Co versus liquid saturation for both V2.1 and V2.4 results, where Co is the initial concentration (Figure A-1). The results of V2.1 and V2.4 overlap and match within < 1%, and therefore the acceptance criteria is met.

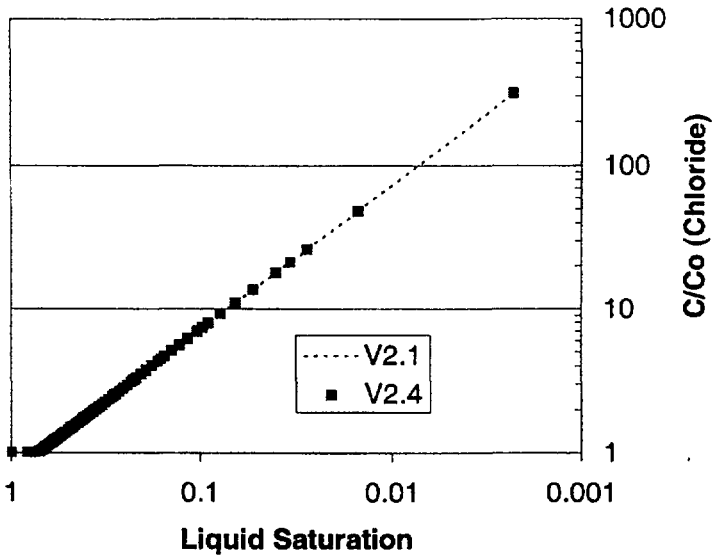

Figure A-1

A.4 Verification of Aqueous Transport (Advection/Diffusion) (Test Problem 4)

This test problem (Test problem 4 in Table 1) was to test the transport of aqueous species (Wu et al., 1999) by advection and diffusion (for T = 25°C). This test is the same as Test #4 in the qualification documents of V2.1. This test was rerun with the same input files as for V2.1 but modified for any new TOUGHREACTV2.4 format requirements. It was run with version V2.4 and the result was shown in the file TEC_CONC.DAT.

Test folder and data files used:

aqtrans_2.4	FLOW.INP	input
	SOLUTE.INP	input
	CHEMICAL.INP	input
	thermok2.dat	input
	TEC_CONC.DAT	output

Calculated concentrations with V2.1 and V2.4 were compared by plotting calculated C/Co values for both versions (Figure A-2) as a function of distance. Both curves overlap and the difference in concentrations is less than 1%, and therefore the acceptance criteria are met.

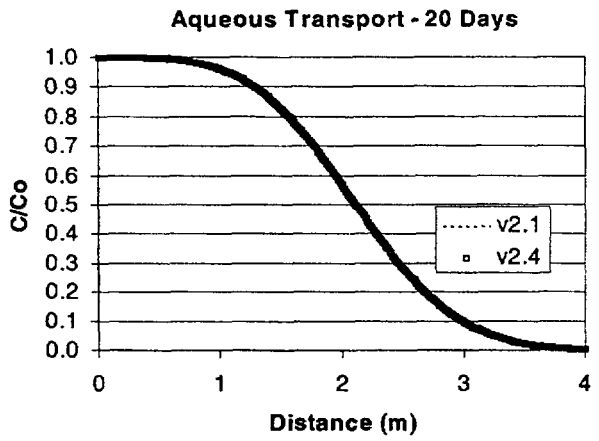

Figure A-2

A.5 Verification of Gas Diffusion Coefficient and Gas Transport (Test Problem 5)

This problem (Test problem 5 in Table 1) verifies the calculation of effective gas diffusion coefficients.

Test folder and data files used:

	ThermoU2.07dat	
gas_diffus_2.4		
	FLOW.INP	input
	SOLUTE.INP	input
	CHEMICAL.INP	input
	TIME.DAT	
	TEC_GAS.DAT	output

This test is the same as Test #8 in the qualification documents of V2.2. This test was rerun with the same input files as for V2.2 but modified for any new V2.4 format requirements. Calculated gas concentrations from the TEC_GAS.DAT files of both versions and were identical (i.e. the unix "diff" command showed that these files were identical), and therefore the acceptance criteria are met.

A.6 Verification of Activity Coefficients and Water Activity Calculation (Test Problem 6)

Test problem 6 simulates chemical speciation (no transport) in a one-block problem for electrolyte solutions of various compositions and ionic strengths for which activity coefficients and water activity have been independently determined in Table 1. The test was run with version V2.4 and met the acceptance criteria listed in that table.

Test folder and data files used:

qa_hkf81/	FLOW.INP	input
	CHEMICAL.INP	input
	SOLUTE.INP	input
	thermok2.07.dat	input
	chdump.dat	output

Testing of activity coefficient calculation subroutines (hkfpar and dh_hkf81) was originally carried out by the developer by calculating activity coefficients and water activities with V2.2.3 for various electrolyte solutions, and comparing with values measured by Robinson and Stokes (1965).. Calculated and measured data for NaCl solutions are shown as an example in Figures A-3 and A-4 (see scientific notebook YMP-LBNL-YWT-NS-1.2 p. 28-30 and p.32 which was included on media with test case).

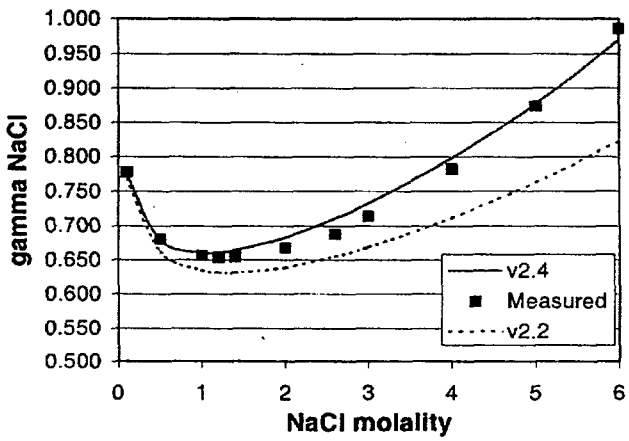

Figure A-3

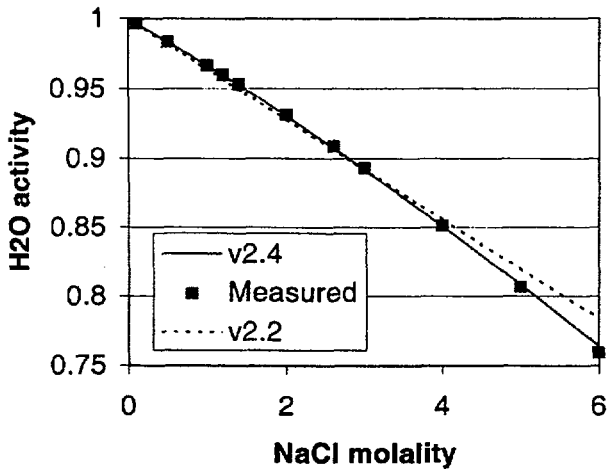

Figure A-4

To verify the correct implementation of the activity coefficient routines in V2.4, activities and activity coefficients of dissolved species and water activity were computed with V.4 for a 6m NaCl solution. The results were compared with existing results as well as with the data measured by Robinson and Stokes. Water activity and NaCl activities calculated with V2.4 were identical to those calculated with the existing results provided, as expected, and within 10% of the Robinson and Stokes values, as shown below.

From ouput data in the chdump.dat file, we get:

a H_2O = 0.7644 (note, output gamma H_2O is activity for water)

a Na^+ = $10^{0.739}$ = 5.48

• Na^+ = 0.913

a Cl^- = $10^{0.791}$ = 6.18

• Cl^- = 1.029

To check against the measured data, we need to calculate mean activities and mean activity coefficients as follows:

• $_{\pm}$NaCl = $(\bullet\ Na^+ \cdot \bullet\ Cl^-)^{1/2}$ = 0.9693
a NaCl = $(m\ NaCl \cdot \bullet\ {}_{\pm}NaCl)^2 = (6 \cdot 0.9693)^2 = 33.8$

Robinson and Stokes give the following values:

a H_2O = 0.7598

• $_{\pm}$NaCl = 0.986

which gives a NaCl = $(m\ NaCl \cdot \bullet\ {}_{\pm}NaCl)^2 = 35.0$

The data computed by V2.4 are within 10% of these values, and therefore the acceptance criteria is met.

A.7 Verification of Supersaturation Window (Test Problem 7)

This test problem Table 1 was run with a quartz plug flow reactor (Spycher et al., 1999) using an arbitrary rate such that equilibrium is reached quickly, then varying the supersaturation window. Tests were repeated for the equilibrium case. The test problem 7 was run with version V2.4 and met the acceptance criteria listed in that table.

This new test made use of the same general setup as Test #11 (quartz plug-flow reactor, also similar to one of the V2.2 sample problems). Here, we use amorphous silica instead of quartz, using arbitrary, very high, precipitation and dissolution rates such that equilibrium is reached quickly. The temperature is maintained constant at 200°C. We first run a simulation without a supersaturation window, and verify that equilibrium is quickly reached by checking that log(Q/K) for amorphous silica becomes zero. The SiO_2 solubility is hand-calculated and compared to the computed value. The test is then repeated for two cases of superaturation windows.

<u>1) Check without saturation window</u>

Test folder and data files used:

supsatwin2.4/ssq0/	FLOW.INP	] input
	SOLUTE.INP	] input
	CHEMICAL.INP	] input
	thermok3.dat	
	FLOW.OUT	output
	TIME.DAT	output

Setup: 200°C
log(K) for amorphous silica = -1.819 (given input data)
This log(K) value is for the reaction: $SiO_{2am(s)} <=> SiO_{2(aq)}$

Therefore: a $SiO_{2(aq)} \sim m\ SiO_{2(aq)} = 10^{-1.819} = 1.51705$ E-2 mol/kg

Water density from the FLOW.OUT file (here in kg/l – i.e., divided by 1000)

time	=	100 sec	d = 0.86998
		1000 sec	d = 0.87142

From the TIME.DAT file we get the following computed solubilities:

At t = 100 sec (0.115741 E-2 days) m $SiO_{2(aq)}$ = 0.1318 E-1 mol/l
Convert to mol/kg: 0.1318 E-1/0.86998 = 0.15150 E-1 mol/kg

At t = 1000 sec (0.115741 E-1 days) m $SiO_{2(aq)}$ = 0.1323 E-1 mol/l
Convert to mol/kg: 0.1323 E-1/0.87142 = 1.5180 E-2 mol/kg

Hand-calculated and computed solubilities match within 1%, and therefore the acceptance criteria are met.

2) Check with saturation window = 1.5

Test folder and data files used:

supatwin2.4/ssq-1.5/	FLOW.INP	input
	SOLUTE.INP	input
	CHEMICAL.INP	input
	thermok3.dat	input
	FLOW.OUT	output
	TIME.DAT	output

Set the supersaturation window (ssq) = 1.5
Set T_1 = 200° C and T_2 = 300° C. These temperatures are the brackets for the supersaturation window (i.e., at T_1 ssq=1.5 and at T_2 ssq=ssq/100). Here, the run temperature is 200° C, therefore the full window (=1.5) is used.

Set inlet SiO_2 high, at 1 m/kg (arbitrary concentration to force precipitation)
Set reactor SiO_2 at 0.5 m/kg (arbitrary concentration to force precipitation)
Run at T = 200° C so we get full window of 1.5 (see above)

We should get log (Q/K) = 1.5 (can be verified in the chdump.dat file)

Therefore, log(Q) = log(K) + 1.5 = log (m SiO_2)
$\Rightarrow$ m $SiO_2 = 10^{(-1.819+1.5)}$ = 0.4973 E-1 m/kg

From the TIME.DAT file we get the following computed solubility:
At t = 1000 sec m $SiO_{2(aq)}$ = 0.4175 m/l
Convert to mol/kg: 0.4175/0.87142 = 0.4791 m/kg

Hand-calculated and computed solubilities match within 1%, and therefore the acceptance criteria was met.

3) Check as before (ssq = 1.5) but consider temperature effect on ssq

Test folder and data files used:

supsatwin2.4/ssq_1.5a/	FLOW.INP	input
	SOLUTE.INP	input
	CHEMICAL.INP	input
	thermok3.dat	input
	FLOW.OUT	output
	TIME.DAT	output

This is the same test as 2) above but we set the temperature brackets such that the supersaturation window value (ssq) changes as function of temperature:

Set $T_1 = 100°C$ and $T_2 = 300°C$, with ssq = 1.5

The value of ssq decreases exponentially between T_1 and T_2, such that at T_1 ssq=1.5 (full value) and at T_2 ssq = 1/100 of original value. The equation implemented in V2.4 to achieve this exponential decrease is (see YMP-LBNL-YWT-NS-1.2 p.33):

$$ssq_{(T)} = ssq \cdot e\left[-4.61 \cdot \left(\frac{T-T1}{T2-T1}\right)\right]$$

The run temperature is T = 200°C and because ssq=1.5, we have:

$$ssq_{(200°C)} = 1.5\, e\left[-4.61 \cdot \left(\frac{200-100}{300-100}\right)\right] = 0.1496$$

Therefore, the log (Q/K) should be 0.1496. We write, as before:

$\log(Q) = 0.1496 + \log(K) = 0.1496 - 1.819 = 1.6694 = \log(m\ SiO_2)$

$\Rightarrow m\ SiO_2 = 10^{-1.6694} = 0.2141$ E–1 mol/kg

From the TIME.DAT file we get the following computed solubility:

At t = 1000 sec: $SiO_{2(aq)} = 0.1861$E–1 mol/l

Convert to mol/kg: 0.1861E–1/0.87142 = 0.2136E–1 mol/kg

Hand-calculated and computed solubilities match within 1%, and therefore the acceptance criteria is met.

A.8 Verification of Ideal Solid Solution Option (Test Problem 8)

Test problem 8 in Table 1 is similar to test problem 2 using clay minerals in solid solution and under kinetic constraints. An arbitrary rate was used such that equilibrium is reached quickly. The test was run with version V2.4 and met the acceptance criteria listed in that table.

This test uses a one-block setup (actually, there are two connected identical blocks, because at least one connection is needed for the code to compute surface areas; the two blocks, each with identical properties and initial conditions, can be regarded as one larger block). The block is heated up from 25° C to ~ 130° C. The initial solution composition is arbitrarily chosen as a Yucca Mountain pore water, and the block mineralogy corresponds to a tuff, with an arbitrarily elevated percentage of smectite minerals. We set the precipitation and dissolution rates of smectites very high (~10-5 mol/s·m2) such that equilibrium is quickly reached.

1) Baseline verification of clay saturation without solid solution

Test folder and data files used:

solid_sol2.4/no_ss

FLOW.INP
SOLUTE.INP
CHEMICAL.INP
ThermoU2.07.dat
] input

chdump.dat
TIME.DAT
] output

There are no solid solutions in this first test. We examine the log(Q/K) values in the chdump.dat file and precipitated/dissolved amounts in the TIME.DAT file for smectite end-members as individual minerals. The following log(Q/K) values are computed:

Table A-2

Log Q/K			
T (°C)	smect-ca	smect-na	smect-mg
28	0.0837	-0.246	0.0837
129.077	0.000	0.000	0.000
	precipitates	dissolves	precipitates

Equilibrium is reached when log Q/K = 0 for each individual mineral, and the precipitated/dissolved trends are consistent with original log (Q/K) values.

2) Verify saturation of smectite ideal solid solution

Test folder and data files used:

solid_sol2.4/clay_ss

FLOW.INP
CHEMICAL.INP
SOLUTE.INP
ThermoU2.07.dat
] input

chdump.dat
] output

Here, we run the same simulation as in 1) above, but specify the smectite minerals (Na-, Ca-, and Mg-smectite) as an ideal solid solution. Because we treat the smectites as an ideal solid solution, saturation of the solid solution should occur when the sum of the (Q/K) values for each end-member equals 1 (• $(Q/K)_i = 1$). We examine log(Q/K) values in the chdump.dat file, as previously:

Table A-3

Log (Q/K)			
T (°C)	smect-ca	smect-na	smect-mg
27.084	-0.3935	-0.7388	-0.3836
	• $(Q/K)_i = 10^{-.3935} + 10^{-.7388} + 10^{-.3836} = 1.00$		
51.052	-0.3989	-0.8100	-0.3506
	• $(Q/K)_i = 10^{-.3989} + 10^{-.8100} + 10^{-.3506} = 1.00$		
103.105	-0.4057	-0.9410	-0.3076
	• $(Q/K)_i = 10^{-.4057} + 10^{-.9410} + 10^{-.3076} = 1.00$		
129.077	-0.4026	-0.9898	-0.2994
	• $(Q/K)_i = 10^{-.4026} + 10^{-.9898} + 10^{-.2994} = 1.00$		

Equilibrium is reached when • $(Q/K)_i = 1$, as expected. Also, in this case, the smectite solid solution originally precipitates, even though each individual end member is undersaturated (as would be expected). Hand-calculated and computed saturation indexes match within 0.1%, and therefore the acceptance criteria is met.

A.9 Verification of Correct Fracture Permeability Calculations (Permeability Law 3 – Cubic Law)

Test problem 9 (test_boilfrac_1) was run with V2.4 using permeability law 3 and the option to change porosity and permeability over time. At grid block **A 1** at the last time step, porosity has changed from the initial value of 0.08 to 0.7999. This decrease in porosity is in good agreement with the mineral volume fraction 0.1154e-4 (precipitation). The permeability has changed from the initial value of 0.133e-13 to 0.13294e-13. This is also supported by permeability law 3, which yields a value of 0.13294e-13. The acceptance criterion in Table 1 was met.

A.10 Verification of Correct Fracture Permeability Calculations (Permeability Law 4 – Fracture Aperture Law)

Test problem 10 is comprised of 3 test simulations (test_boilfrac_2-4) that were run with V2.4 using permeability law 4 and the option to change porosity and permeability over time. In test_boilfrac_2, the porosity of a node at the last time step has changed from the initial value of 0.08 to 0.07711. This decrease in porosity is in good agreement with the mineral volume fraction change 0.2887e-2 (precipitation). A permeability change from 0.13300e-15 m2 to 0.10605e-15 m2 was observed, with a hand-calculated value of 0.10590e-15. These results meet the acceptance criterion in Table 1.

A.11 Verification of Correct Permeability Porosity Coupling for Permeability Law 1 (Carman-Kozeny Law)

Test problem 11 in Table 1 was run with V2.4. The concentration of SiO_2(aq) read at the end of TIME.DAT at the outlet (grid block rk 31) is 0.3139e-2 mol/lliquid. This is equivalent to 0.3827e-2 mol/l, after the density of the liquid 0.82021 g/l at elevated temperature 239°C for the experiment (density read from file FLOW.OUT as DL) is factored in. This simulated concentration 0.3827e-2 mol/l is close to analytical value of 0.3774e-2 mol/l (equivalent to 106 ppm Si) and meets acceptance criteria (5%). Furthermore, changes in porosity and permeability were also checked. At outlet at grid block rk 31, the porosity has changed from an initial value of 0.425002 to 0.425442 (read from file SAVE), an increase of 0.442e-4. The change in mineral amount is –0.442e-4 (volume fraction) (negative means dissolution) (read from file TEC_MIN.DAT). The identical numbers in mineral (quartz) dissolution is translated into an increase in porosity. The hand calculated permeability is calculated with Karmen-Kozeny law:

$$k = k_0 \times \frac{(1-\varphi_0)^2}{(1-\varphi)^2} = 0.651e-11 \times \frac{(1-0.425000)^2}{(1-0.425442)^2} = 0.65110e-11$$

where k, k_0 are simulated and initial permeabilities (m^2), φ, φ_0 are simulated and initial porosities. This is identical to the simulated permeability of 0.65110e-11. Acceptance criteria for porosity and permeability changes are both met.

A.12 Verification of Correct Input of Heterogeneous Porosity and Permeability Fields

Test problem 12 in Table 1 was run with V2.4. This option was tested by restarting the output of test problem 9 (1-D fracture plugging problem) that had previously developed heterogeneity in permeability and porosity. The value of kcpl in the SOLUTE.INP file was changed such that no subsequent changes would occur to porosity or permeability. The simulation was restarted and stopped after a few iterations. The permeability and porosity values were compared at all nodes in the input INCON and the output SAVE file using the UNIX "diff" command. The values were identical. Acceptance criteria for porosity and permeability changes are therefore both met.

A.13 Verification of Correct Input of Permeability Zones

Test problem 13 in Table 1 was run with version 2.4. This is the same 1-D fracture plugging problem as used in test problems 11 through 15. Zones blocks were used in CHEMICAL.INP and in SOLUTE.INP. The successful tests for the permeability equations in A.9, A.10, and A.11 demonstrate that the permeability zones were assigned correctly to grid blocks.

A.14 Verification of Correct Match to 1-D Reaction Transport

Test problem 14 was run with version V2.4. The permeability porosity coupling flag kcpl in SOLUTE.INP is set to "0". The concentration at outlet (grid block rk 31) is 0.3140e-2 mol/l_{liquid}. This is equivalent to 0.3828e-2 mol/l, after the density of the liquid 0.82021 g/l at elevated temperature 239°C for the experiment (density read from FLOW.OUT as DL) is considered. This simulated concentration is close to analytical value of 0.3774e-2 mol/l and meets acceptance criteria (<5%).

A.15 Verification of Option to Precipitate Amorphous Silica into Dry Nodes

Test problem 15 was run with V2.4. This was tested with 1-D fracture plugging problem setting flag 4 (after mineral name) to 1 and using permeability law 3 and 4. All other minerals must have their flags set to zero. It must be checked that amorphous silica precipitates in the dry node that is just ahead of the first wet node in the boiling front and that the mass balance for silica precipitated in the entire system is within 5% of the input value (in Mbalance.out). The initial condition is that the nodes are wet down to '**A 8**', with '**A 9**' being the first dry node below the boiling front. Checking the output tec_min.dat file, amorphous silica is found to precipitate in the first dry node. Checking the Mbalance.out file for the mass balance of SiO_2, we get:

	Input+Initial	Output+Current	Difference	Rel. Dif.(%)	Del Solid/liq %
sio2(aq)	0.4075E+00	0.4075E+00	-0.2033E-04	-0.4989E-02	-0.1000E+01

Therefore, the mass balance for all SiO_2 in the system (under Rel. Dif.(%)) is about -0.005% and the balance for the amount of solid precipitated/dissolved compared to the changes in solute concentrations is 1%. Hence the criteria for less than 5% mass balance error on the amount of amorphous silica precipitated is met.

5. References

Spycher, N., Sonnenthal, E., Ahlers, R., and Xu, T., *TOUGHREACT V2.1 Software Qualification*, 1999. MOL.20000216.0113

Robinson and Stokes 1965. Electrolyte Solutions, 2nd ed., Butterworth, 571p.

Sonnenthal, E., and Spycher, N. 2001. Drift-scale coupled processes (DST and THC seepage) models, MDL-NBS-HS—000001 REV01 ICN01. Bechtel SAIC Company (BSC), Las Vegas, Nevada.

Wu, Y.S., Haukwa, C., and Mukhopadyay S., TOUGH2 V1.4 and T2R3D V1.4: Verification and Validation Report and User's Manual, Rev 00, 1999. MOL 20000216.0111

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Civilian Radioactive Waste Management System
Management & Operating Contractor

FEHM, V2.10
REV 01

VALIDATION TEST REPORT

Software Document Number: 10086-VTR-2.10-01

Software Media Number: 10086-PC-2.10-01

Software Tracking Number: 10086-2.10-01

Software Activity Number: LV-2001-158

AUGUST 2001

Prepared for:

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AUGUST 2001

Verified by:

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EDWARD MILLER

CHANGE HISTORY

Revision Number	Effective Date	Description of Change
00	12/11/2000	Initial issue.
01	08/27/2001	Sections 1-12 were extensively revised to qualify the FEHM V2.10 program for Windows NT 4.0 environment.

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ATTACHMENT 1: Comparison of the Test Results between

Windows 2000 and Windows NT 4.0 1-1

ACRONYMS AND ABBREVIATIONS

ECM Equivalent Continuum Method
EKM Double Porosity/Double Permeability Method
LANL Los Alamos National Laboratory
RIS Record Information System
SAP Software Activity Plan
SCM Software Configuration Management
TSPA Total System Performance Assessment
VTR Validation Test Report

1. SOFTWARE IDENTIFICATION

FEHM Version 2.10 was originally installed and verified for PC/Windows 2000 platform and the validation test plan 10086-VTP-2.10-00 was conducted for that platform. Per AP-SI.1Q section 5.8.4, this VTR is generated to qualify it on the Windows NT 4.0 operating system. The same VTP that was used Windows 2000 is applicable to Windows NT 4.0 platform.

2. VALIDATION TESTER

Bradley Gundlach of Los Alamos National Laboratory (LANL) performed the validation tests. Mr. Gundlach was assigned to support TSPA project and retest the FEHM V2.10 code with the PC/Windows NT 4.0 platform and document the test results.

3. SPECIAL TOOLS AND EQUIPMENT

Validation tests were conducted at LANL using PC/Windows NT 4.0 platform. An installation test per the ITP was performed at BSC in Las Vegas, NV to verify the installation test. The CPU number that the installation test was performed is 112371.

4. TEST RESULTS LINKED TO THE UNIQUE TEST IDENTIFIER FROM THE VTP

FEHM version 2.10 was previously qualified using PC/Windows 2000 platform. MOL.20001219.0100 and MOL.20001219.0102 provide the RIS Accession numbers for the VTP and VTR qualifications of code, respectively, using PC/Windows 2000 platform.

Per section 5.8.4 of AP-SI.1Q procedure (Operating Environment Changes), regression testing was performed at LANL using the PC/Windows NT4.0 platform. Table 1 summarizes the test identifier, description and the results of the tests. A summary of the regression tests is given in Attachment 1.

Table 1 – Summary of the Results		
Test Identifier and Description	Pass	Fail
1. Thermodynamic Functions	✓	
2. heat Conduction	✓	
3. Temperature in a Wellbore	✓	
4. Hydraulic Head	✓	
5. Pressure Transient Analysis	✓	
6. Infiltration into a One Dimensional, Layered, Unsaturated Medium	✓	
7. Vapor Extraction from an Unsaturated Reservoir	✓	
8. Barometric Pumping Mechanisms	✓	
9. Dual Porosity	✓	
10. Heat and Mass Transfer in Porous Media	✓	
11. Toronyl Two-Phase Problem	✓	
12. DOE Code Comparison Project Problem Five, Case A	✓	
13. Dry-out of a Partially Saturated Medium	✓	
14. One Dimensional Reactive Solute Transport	✓	
15. Henry's Law Species	✓	
16. Fracture Transport with Matrix Diffusion	✓	
17. Movement of a Dissolved Mineral Front	✓	
18. Multi-Solute Transport with Chemical Reaction	✓	
19. Three dimensional Radionuclide Transport	✓	
20. Streamline Particle Tracking Model	✓	
21. Cell-Based particle Tracking Model	✓	

5. DOCUMENTATION OF ITP AND VTP (ANY ADDITIONAL PLATFORMS OR OPERATING SYSTEMS)

Per section 5.8.4 of AP-SI.1Q procedure, the existing ITP and VTP (MOL.20001219.0099 and MOL.20001219.0100) are valid for the present VTR. No new ITP and VTP are required for the present VTR.

Installation Test

In order to verify the installation, the ITP was repeated in the PC/Windows NT 4.0 environment. The ITP consists of using Explorer in Windows NT 4.0 system to complete the installation tasks.

Testing the installation test is accomplished by running a test case (One Dimensional Reactive Transport Model test number 14 in Table 1). From Windows NT, a directory was made as:

C:\FEHMNT

The executable **FEHM_V2_10.exe,** and the dynamic link library (DLL) files of **fehmn.dll, Dforrt.dll, Msvcrt.dll** and all sorption files were installed from the Fehm/Bin directory of the media into the above directory.

From Windows NT, the executable was run by typing: **FEHM_V2_10.exe**

In response to interactive query, "**sorption.files**" was used.

The input file is: **sorption.in**

Execution of the test problem generates the following output files: **sorption.out, sorption.trc.**

sorption.out is the output file for all 5 isotherm cases of:

Conservative,

Linear,

Langmuir,

Freundlich, and

Modified Freundlich

sorption.trc contains the data for plotting the concentration at the outlet node of each species versus time.

Since the output file is very large, only the results for time of 39.966 seconds (randomly picked) was extracted from **sorption.trc** and is repeated here:

```
4.625708999999980E-004          1
0.997870209755906
4.625708999999980E-004          2
6.891537624976829E-002
4.625708999999980E-004          3
0.541263629606992
4.625708999999980E-004          4
0.551999291477854
4.625708999999980E-004          5
1.000000000000000E-090
```

Note that the time unit is in days for 4.6257089999E-4 (or 39.966 seconds) and the values are the concentration for the five species.

Validation Test

The following section summarizes the results of each test step for each validation test contained in the VTP for FEHM 2.10. These tests were performed by Bradley Gundlach at Los Alamos National Laboratory.

6. INDICATION OF PASS/FAIL

Indicate the Pass/Fail, initial, and date for each Validation Test Plan (VTP) test step:

Test Identifier: 1. Thermodynamic Functions

Step 1 (Enthalpy): PASS — Initial and Date: G 13 Jun 2001
Step 2 (Density): PASS — Initial and Date: G 13 Jun 2001
Step 3 (Compressibility): PASS — Initial and Date: G 13 Jun 2001
Step 4 (Viscosity): PASS — Initial and Date: G 13 Jun 2001
Step 5 (Pressure & Temperature): PASS — Initial and Date: G 13 Jun 2001

Test Identifier: 2. Infiltration into a One Dimensional, Layered, Unsaturated Medium

Step 1 (2-D heat Conduction): PASS — Initial and Date: G 13 Jun 2001
Step 2 (3-D Heat Conduction): PASS — Initial and Date: G 13 Jun 2001

Test Identifier: 3. Temperature in a Wellbore

Step 1 (Injection in a Wellbore): PASS — Initial and Date: G 13 Jun 2001

Test Identifier: 4. Hydraulic Head

Step 1 (Head Pressure): PASS — Initial and Date: G 13 Jun 2001

Test Identifier: 5. Pressure Transient Analysis

Step 1 (Radial Flow): PASS — Initial and Date: G 13 Jun 2001

Test Identifier: 6. Infiltration into a One Dimensional, Layered, Unsaturated Medium

Step 1 (Infiltration using ECM): PASS — Initial and Date: G 13 Jun 2001
Step 2 (Infiltration using DKM): PASS — Initial and Date: G 13 Jun 2001

Test Identifier: 7. Vapor Extraction from an Unsaturated Reservoir

Step 1 (Vapor Extraction): PASS — Initial and Date: G 13 Jun 2001

Test Identifier: 8. Barometric Pumping Mechanisms

Step 1 (Pore-Scale Velocity): PASS — Initial and Date: G 13 Jun 2001
Step 2 (Contaminant Mass Transfer): PASS — Initial and Date: G 13 Jun 2001

Test Identifier: 9. . Dual Porosity

Step 1 (Dual Porosity): PASS — Initial and Date: G 13 Jun 2001

Test Identifier: 10. Heat and Mass Transfer in Porous Media

Step 1 (1-D Radial Aquifer): PASS — Initial and Date: G 13 Jun 2001

Test Identifier: 11. Toronyl Two-Phase Problem

Step 1 (2-D Phase Problem): PASS — Initial and Date: G 13 Jun 2001

Test Identifier: 12. DOE Code Comparison Project Problem Five, Case A
Step 1 (DOE Code Comparison): PASS Initial and Date: G 13 Jun 2001

Test Identifier: 13. Dry-out of a Partially Saturated Medium
Step 1 (Without Pressure Lowering): PASS Initial and Date: G 13 Jun 2001
Step 2 (With Pressure Lowering): PASS Initial and Date: G 13 Jun 2001

Test Identifier: 14. One Dimensional Reactive Solute Transport
Step 1 (Reactive Tracer Transport): PASS Initial and Date: G 13 Jun 2001

Test Identifier: 15. Henry's Law Species
Step 1 (Air Movement): PASS Initial and Date: G 13 Jun 2001
Step 2 (Water Movement): PASS Initial and Date: G 13 Jun 2001

Test Identifier: 16. Fracture Transport with Matrix Diffusion
Step 1 (No Sorption): PASS Initial and Date: G 13 Jun 2001
Step 2 (Sorption in the Matrix): PASS Initial and Date: G 13 Jun 2001
Step 3 (Sorption in the Fracture&Matrix): PASS Initial and Date: G 13 Jun 2001
Step 4 (Dual Porosity): PASS Initial and Date: G 13 Jun 2001

Test Identifier: 17. . Movement of a Dissolved Mineral Front
Step 1 (Calcite Dissolution in 1-D System): PASS Initial and Date: G 13 Jun 2001

Test Identifier: 18. Multi-Solute Transport with Chemical Reaction
Step 1 (Cobalt Transport): PASS Initial and Date: G 13 Jun 2001

Test Identifier: 19. Three dimensional Radionuclide Transport
Step 1 (Decay Chain Transport): PASS Initial and Date: G 13 Jun 2001

Test Identifier: 20. Streamline Particle Tracking Model
Step 1 (Breakthrough Curve): PASS Initial and Date: G 13 Jun 2001
Step 2 (Situ Concentration Profile): PASS Initial and Date: G 13 Jun 2001

Test Identifier: 21. Cell-Based particle Tracking Model
Step 1 (Breakthrough Curve): PASS Initial and Date: G 13 Jun 2001
Step 2 (Sorbing & Matrix Diffusion Model): PASS Initial and Date: G 13 Jun 2001
Step 3 (Sorption of Intermediate Species): PASS Initial and Date: G 13 Jun 2001
Step 4 (GoldSim Interface): PASS Initial and Date: G 13 Jun 2001

7. FAILURE CONDITIONS, OCCURRENCE, RESOLUTION

None

8. OVERALL CONCLUSIONS

FEHM V2.10 did not require any source code modification or recompilation to run Windows NT 4.0 operating system. The same executable that was used for Windows 2000 was used for Windows NT 4.0. Comparison of the test results (Attachment 1) shows that they are identical using the two operating systems.

9. DOCUMENTATION AND JUSTIFICATION OF TEST

A copy of the validation tests for FEHM V2.10 using Windows NT 4.0 operating system are provided in Attachment 1.

10. SUMMARY OF UNIT TESTING

Results of the reinstallation of FEHM V2.10 on the PC/Windows NT 4.0 operating system indicate that the change in operating system did not change the results of the software to properly execute when compared to that of the same tests using the baseline qualified PC/Windows 2000 operating system.

11. GENERAL REMARKS

The FEHM V2.10 computer program has previously been tested and qualified using PC/Windows 2000 platform (MOL.20001219.0095). An impact assessment was performed by LANL for FEHM V2.10 to run on the Windows NT version 4.0 operating system and it was concluded that the results were identical for Windows 2000 and Window NT 4.0 operating systems (See Reference below). The comparison was performed without any changes to the source code.

> *"Impact Assessment for Software FEHM Version 2.10 (Windows NT, Version 4.0 Operating System," Z.V. Dash, B. Robinson, August 2001.*

The present VTR supports qualification of the code using PC/Windows NT 4.0 platform. No changes to the code were accomplished by the effort. The testing and qualification were accomplished in accordance with AP-SI.1Q section 5.8.

ATTACHMENT 1

Comparison of the Test Results between Windows 2000 and Windows NT 4.0

Results of FEHM Version 2.10 Comparison Tests
PC Windows NT

SUMMARY of COMPARISON TESTS for FEHM V2.10PC00-10-26 run 010613

********** AVDONIN **********

Avdonin Radial Heat and Mass Transfer Problem
Comparison of Model and Analytical Solution for Temperature vs Time
At R coordinate (m) 37.5000

Test Case	Maximum Error	Maximum % Error	RMS Error
84 nodes	1.2560	0.7744	3.162E-04
400 nodes	0.4036	0.2470	6.951E-05
800 nodes	0.3892	0.2380	6.744E-05

Avdonin Radial Heat and Mass Transfer Problem
Comparison of Model and Analytical Solution for Temperature vs Position
At Time 0.100000E+10

Test Case	Maximum Error	Maximum % Error	RMS Error
84 nodes	0.5233	0.3239	1.746E-04
400 nodes	0.2818	0.1745	3.417E-05
800 nodes	0.2819	0.1746	2.214E-05

********** BAROMETRIC **********

Barometric Pumping Test - effects on pore-scale velocity
Comparison of Model and Analytical Solution for Velocity vs Depth during cycle

Test Case	Maximum Error	Maximum % Error	RMS Error
Time 1.75 days	2.936E-08	33.0800	6.577E-03
Time 3.5 days	3.937E-08	48.9900	3.644E-03
Time 5.25 days	1.451E-08	40.8400	4.018E-03
Time 7 days	4.666E-08	47.9800	3.503E-03

Barometric Pumping Test - Contaminant Transport
Comparison of Model and Analytical Solution for MFR vs Time

Test Case	Maximum Error	Maximum % Error	RMS Error
Alpha 0.0	3.779E-03	0.3978	5.803E-04
Alpha 0.1	2.699E-03	0.3033	4.158E-04
Alpha 0.2	1.088E-03	0.1137	2.261E-04

********** CELLBASED **********

Cell-Based Particle Tracking w/Advection, Dispersion & Matrix Diffusion
Comparison of Model and Analytical Solution for Breakthrough Conc. vs Time

Test Case	Maximum Error	Maximum % Error	RMS Error
No Sorption	3.948E-02	10.9800	7.055E-03
Matrix Sorption	4.073E-02	9.5000	6.158E-03
Diffusion, Matrix&Fracture Sorption	8.112E-03	3.3980	6.206E-04

Cell-Based Particle Tracking - Decay-chain Test
Comparison of Model and CHAIN Solution for Concentration vs Time

Test Case	Maximum Error	Maximum % Error	RMS Error
Species 1	806.3000	38.6100	3.534E-02
Species 2	240.6000	34.8300	2.931E-02
Species 3	156.0000	18.7200	1.111E-02
Species 4	138.6000	43.9200	3.656E-02

********** DISSOLUTION **********

Calcite Dissolution in a One-Dimensional System
Comparison of Model and Analytical Solution for Dissolution Front vs Time

Test Case	Maximum Error	Maximum % Error	RMS Error
Time 20000. seconds	2.161E-03	3.3250	3.325E-02
Time 60000. seconds	3.323E-03	1.6530	1.653E-02
Time 100000. seconds	6.281E-04	0.1875	1.875E-03

********** DOE **********

DOE Code Comparison Project, Problem 5, Case A
Comparison of FEHM and Other Code Solutions for Temperature vs Time
At X, Y coordinates (m) 62.5000 62.5000

Test Case	Maximum Error	Maximum % Error	RMS Error
Code 1	1.3560	0.6532	7.746E-04
Code 2	1.5190	0.6471	1.070E-03
Code 3	1.6230	0.6867	1.259E-03
Code 4	2.0030	0.8528	1.139E-03
Code 5	1.4980	0.7299	9.932E-04
Code 6	1.3680	0.5906	1.379E-03

DOE Code Comparison Project, Problem 5, Case A
Comparison of FEHM and Other Code Solutions for Pressure vs Time
At X, Y coordinates (m) 62.5000 62.5000

Test Case	Maximum Error	Maximum % Error	RMS Error
Code 1	5.124E-02	1.5810	1.908E-03
Code 2	6.127E-02	2.0220	3.137E-03
Code 3	5.347E-02	1.7700	3.234E-03
Code 4	6.233E-02	2.0570	3.017E-03
Code 5	2.149E-02	0.7164	1.199E-03
Code 6	2.828E-02	0.9395	1.637E-03

DOE Code Comparison Project, Problem 5, Case A
Comparison of FEHM and Other Code Solutions for Pressure vs Time
At X, Y coordinates (m) 162.500 137.500

Test Case	Maximum Error	Maximum % Error	RMS Error
Code 1	2.530E-02	0.7312	8.878E-04
Code 2	2.534E-02	0.7610	7.676E-04
Code 3	1.656E-02	0.4842	8.250E-04
Code 4	2.215E-02	0.6651	7.065E-04
Code 5	3.449E-02	1.0420	1.879E-03
Code 6	3.445E-02	1.0410	2.547E-03

********** DRYOUT **********

Dry-Out of a Partially Saturated Medium
Comparison of Dryout Front vs Time without Vapor Pressure Lowering

Test Case	Maximum Error	Maximum % Error	RMS Error
Time 100 days	4.637E-05	0.1903	1.903E-03
Time 200 days	2.889E-04	0.5927	5.927E-03
Time 300 days	6.240E-04	0.8534	8.534E-03
Time 400 days	1.064E-03	1.0910	1.091E-02
Time 500 days	1.571E-03	1.2890	1.289E-02

Dry-Out of a Partially Saturated Medium
Page 2

Comparison of Dryout Front vs Time with Vapor Pressure Lowering

Test Case	Maximum Error	Maximum % Error	RMS Error
Time 200 days	2.813E-04	1.1540	1.154E-02
Time 400 days	2.582E-04	0.5297	5.297E-03
Time 600 days	4.542E-05	6.212E-02	6.212E-04
Time 800 days	2.941E-04	0.3017	3.017E-03
Time 1000 days	7.099E-04	0.5826	5.826E-03

********** DUAL **********

Dual Porosity Problem
Comparison of Model and Analytical Solution - Pressure vs Time (nondimensional)
At R coordinate (m) 0.139800

Test Case	Maximum Error	Maximum % Error	RMS Error
Case 1	3.784E-02	1.1770	7.994E-04
Case 2	1.858E-02	0.6075	5.318E-04
Case 3	1.995E-02	0.6331	5.482E-04

********** FRACTURE_TRANSPORT **********

Fracture Transport with Matrix Diffusion
Comparison of Model and Analytical Solution for Concentration vs Time
At X, Y coordinates (m) 0.00000 5000.00

Test Case	Maximum Error	Maximum % Error	RMS Error
No Sorption	2.804E-02	9.0820	1.410E-03
Matrix Sorption	1.758E-02	13.3700	2.204E-03
Matrix & Fracture Sorption	1.707E-02	4.6630	2.108E-03

Fracture Transport with Matrix Diffusion - GDPM formulation
Comparison of Model and Analytical Solution for Concentration vs Time
At X, Y coordinates (m) 5000.00 0.00000

Test Case	Maximum Error	Maximum % Error	RMS Error
No Sorption	3.043E-02	11.7200	1.553E-03
Matrix Sorption	2.357E-02	19.1600	2.662E-03

********** HEAD **********

Head Pressure Problem
Comparison of Head and Pressure Formulation for Pressure vs Position
At Time 365.000

Test Case	Maximum Error	Maximum % Error	RMS Error
Depth 0 meters	4.116E-04	3.010E-02	1.505E-04
Depth 25 meters	2.606E-04	2.321E-02	1.160E-04
Depth 50 meters	1.419E-04	1.614E-02	8.071E-05
Depth 75 meters	5.531E-05	8.714E-03	4.357E-05
Depth 100 meters	9.260E-07	2.371E-04	1.185E-06
Node by node comparison	4.116E-04	3.010E-02	1.702E-05

********** HEAT2D **********

2-D Heat Conduction Problem
Comparison of Model and Analytical Solution for Temperature vs Time
At X, Y coordinates (m) 0.00000 0.00000

Test Case	Maximum Error	Maximum % Error	RMS Error
3-node Triangles	0.5805	0.4162	7.661E-05
4-node Quadrilaterals	0.7140	0.3666	4.060E-05

Mixed Elements	0.5530	0.2915	5.129E-05
Refined Elements	0.9345	0.4313	4.253E-05

2-D Heat Conduction Problem
Comparison of Model and Analytical Solution for Temperature vs Position
At Time 21600.0

Test Case	Maximum Error	Maximum % Error	RMS Error
3-node Triangles	0.5978	0.3423	7.415E-04
4-node Quadrilaterals	0.7066	0.3649	8.162E-04
Mixed Elements	0.6671	0.3466	7.644E-04
Refined Elements	0.8615	0.4452	8.725E-04

********** HEAT3D **********
3-D Heat Conduction Problem
Comparison of Model and Analytical Solution for Temperature vs Time
At X, Y, Z coordinates (m) 0.00000 0.00000 0.00000

Test Case	Maximum Error	Maximum % Error	RMS Error
6-node Triangular Prisms	0.7860	0.5670	1.164E-04
8-node Quadrilateral Polyhedrons	1.0190	0.5275	6.811E-05
4-node Tetrahedrals	1.2450	0.6520	7.690E-05
Mixed Elements	0.8470	0.4349	7.936E-05
Refined Elements	1.2670	0.6632	7.874E-05
Polyhedrons, Finite Volume Option	1.0190	0.5275	6.811E-05
Ref. Elements, Finite Volume Option	1.0320	0.5343	6.892E-05

3-D Heat Conduction Problem
Comparison of Model and Analytical Solution for Temperature vs Position
At Time 21600.0

Test Case	Maximum Error	Maximum % Error	RMS Error
6-node Triangular Prisms	0.7957	0.5284	1.056E-03
8-node Quadrilateral Polyhedrons	0.9912	0.5200	1.065E-03
4-node Tetrahedrals	1.2430	0.6523	1.157E-03
Mixed Elements	0.8211	0.4403	9.982E-04
Refined Elements	1.2650	0.6634	1.124E-03
Polyhedrons, Finite Volume Option	0.9912	0.5200	1.065E-03
Ref. Elements, Finite Volume Option	1.0050	0.5273	1.075E-03

********** HENRYS_LAW **********
1-D Henry's Law Species
Comparison of Model and Analytical Solution for Concentration vs Time
At R coordinate (m) 1.00000

Test Case	Maximum Error	Maximum % Error	RMS Error
Air Movement Through Stagnant Water	9.947E-03	7.4640	4.910E-04
Water Movement Through Stagnant Air	7.292E-03	2.7220	2.904E-04

********** INFILTRATION **********
Infiltration Problem using the Equivalent Continuum Method
Comparison of FEHM and TOUGH2 Solution for Saturation vs Elevation
At Time 0.100000E+10

Test Case	Maximum Error	Maximum % Error	RMS Error
ECM	5.639E-02	8.1690	1.423E-03

Infiltration Problem using the Double Porosity/Double Permeability Method

Comparison of FEHM and TOUGH2 Solution for Saturation vs Elevation
At Time 0.100000E+10

Test Case	Maximum Error	Maximum % Error	RMS Error
DPM - matrix	8.151E-02	17.1200	2.069E-03
DPM - fracture	1.022E-02	355.0000	3.679E-02

********** MULTI_SOLUTE **********
Multi-Solute Transport with Chemical Reaction
Comparison of FEHM and PDREACT Solution for Concentration vs Time
At R coordinate (m) 10.0000

Test Case	Maximum Error	Maximum % Error	RMS Error
Species Co_aq	3.916E-06	0.7115	3.879E-04
Species Fe_aq	1.652E-15	1.0250	1.031E-03
Species EDTA_aq	9.630E-13	11.2100	5.986E-03
Species CoEDTA_aq	1.442E-04	3.6850	2.222E-03
Species FeEDTA_aq	3.667E-05	2.6400	1.747E-03
Species CoEDTA_s	7.826E-05	5.8390	3.178E-03
Species Co_s	1.866E-05	0.9680	6.416E-04
Species FeEDTA_s	1.438E-05	3.2470	2.229E-03

********** RAMEY **********
Temperature in a Wellbore (Ramey) Problem
Comparison of Model and Analytical Solution for Temperature vs Time

Test Case	Maximum Error	Maximum % Error	RMS Error
Depth 0. meters	2.573E-02	0.1286	3.112E-05
Depth 1000. meters	1.3450	2.8150	1.556E-03
Depth 2000. meters	1.0570	1.3580	1.061E-03

Temperature in a Wellbore (Ramey) Problem
Comparison of Model and Analytical Solution for Temperature vs Depth
At Time 0.216000E+07

Test Case	Maximum Error	Maximum % Error	RMS Error
Time 25 days	0.6971	1.0260	5.203E-04

********** SORPTION **********
One Dimensional Reactive Solute Transport
Comparison of FEHM and SORBEQ for Concentration vs Time
At R coordinate (m) 1.00000

Test Case	Maximum Error	Maximum % Error	RMS Error
Isotherm: Conservative	9.711E-03	9.4930	2.902E-04
Isotherm: Linear	4.509E-03	2.2250	1.787E-04
Isotherm: Langmuir	9.151E-03	5.4050	2.385E-04
Isotherm: Freundlich	1.166E-02	2.1270	2.504E-04
Isotherm: Modified Freundlich	2.568E-02	8.0140	7.802E-04

********** STREAMLINE **********
Streamline Particle Tracking w/Advection, Dispersion & Matrix Diffusion
Comparison of Model and Analytical Solution for Concentration vs Time

Test Case	Maximum Error	Maximum % Error	RMS Error
No Sorption	9.481E-02	54.4000	2.993E-03
Matrix Sorption	9.437E-02	45.0500	5.560E-03
Matrix Diffusion, No Sorption	4.811E-02	21.7400	3.973E-03

Streamline Particle Tracking w/Longitudinal & Tranverse Dispersion
Comparison of Model and Analytical Solution for Concentration Profiles

Test Case	Maximum Error	Maximum % Error	RMS Error
Profile at 4800 m 10,000 Particles	1.192E-02	4.6640	1.350E-02
Profile at 4800 m 100,000 Particles	5.900E-03	11.7900	1.916E-02
Profile at 10000 m 10,000 Particles	2.524E-02	10.2200	1.914E-02
Profile at 10000 m 100,000 Particles	7.824E-03	6.2610	1.273E-02

********** THEIS **********
Pressure Transient Analysis (Theis) Problem
Comparison of Model and Analytical Solution for Pressure vs Time

Test Case	Maximum Error	Maximum % Error	RMS Error
Radius 0.00144 meters	1.101E-05	1.100E-03	6.681E-08
Radius 3.44825 meters	6.010E-06	6.010E-04	7.722E-08

Pressure Transient Analysis (Theis) Problem
Comparison of Model and Analytical Solution for Pressure vs Position
At Time 86400.0

Test Case	Maximum Error	Maximum % Error	RMS Error
Time 1 day	2.843E-06	2.842E-04	1.742E-07

********** THERMODYNAMICS **********
Comparison of Steam Table vs FEHM Values
Thermodynamic property as a Function of Pressure and Temperature

Test Case	Maximum Error	Maximum % Error	RMS Error
Liquid enthalpy	2.100E-03	0.1319	1.732E-05
Vapor enthalpy	9.000E-05	3.125E-03	3.130E-06
Liquid density	1.5220	0.2482	2.018E-05
Vapor density	2.550E-02	5.794E-02	6.295E-05
Liquid compressibility	2.160E-03	16.0000	5.182E-03
Vapor compressibility	1.2870	0.1297	4.074E-04
Liquid viscosity	3.224E-06	0.5244	9.222E-05
Vapor viscosity	3.650E-08	0.1601	1.687E-04
Saturation pressures	2.575E-02	0.3000	4.687E-04
Saturation temperatures	1.1000	0.4000	5.943E-04

********** TORONYI **********
Toronyi Two-phase Problem
Comparison of FEHM and Thomas & Pierson Solution for Final Saturation
At Time 78.3000

Test Case	Maximum Error	Maximum % Error	RMS Error
Node by node comparison	1.542E-03	1.3180	7.719E-04

********** TRANSPORT3D **********
Three-Dimensional Radionuclide Transport Problem
Comparison of FEHM and TRACRN for Concentration vs Time

Test Case	Maximum Error	Maximum % Error	RMS Error
Conservative Tracer, Point 1	5.296E-02	6.6030	1.308E-03
Conservative Tracer, Point 2	1.607E-02	10.7800	1.813E-03
Conservative Tracer, Point 3	3.646E-03	4.5320	8.533E-04
Conservative Tracer, Point 4	1.016E-03	2.8520	1.261E-03

Am Tracer, Point 1	4.800E-02	7.2750	1.523E-03
Am Tracer, Point 2	1.589E-02	14.8100	3.423E-03
Am Tracer, Point 3	1.042E-03	12.6900	3.293E-03
Am Tracer, Point 4	1.992E-05	15.0200	4.231E-03

********** VAPOR_EXTRACTION **********

Vapor Extraction from an Unsaturated Reservoir

Comparison of Model and Analytical Solution for Vapor Pressure vs Position

Test Case	Maximum Error	Maximum % Error	RMS Error
Isotropic	1.983E-03	2.1950	8.938E-05
Anisotropic	3.066E-03	3.3110	1.436E-04

NOTE: Tests executed on system running Windows NT Version 4.0

Results of FEHM Version 2.10 Comparison Tests
PC Windows 2000

SUMMARY of COMPARISON TESTS for FEHM V2.10PC00-10-26 run 001101

********** AVDONIN **********

Avdonin Radial Heat and Mass Transfer Problem
Comparison of Model and Analytical Solution for Temperature vs Time
At R coordinate (m) 37.5000

Test Case	Maximum Error	Maximum % Error	RMS Error
84 nodes	1.2560	0.7744	2.162E-04
400 nodes	0.4036	0.2470	6.951E-05
800 nodes	0.3892	0.2380	6.744E-05

Avdonin Radial Heat and Mass Transfer Problem
Comparison of Model and Analytical Solution for Temperature vs Position
At Time 0.100000E+10

Test Case	Maximum Error	Maximum % Error	RMS Error
84 nodes	0.5233	0.3239	1.746E-04
400 nodes	0.2818	0.1745	3.417E-05
800 nodes	0.2619	0.1746	2.214E-05

********** BAROMETRIC **********

Barometric Pumping Test - effects on pore-scale velocity
Comparison of Model and Analytical Solution for Velocity vs Depth during cycle

Test Case	Maximum Error	Maximum % Error	RMS Error
Time 1.75 days	2.936E-08	33.0800	6.577E-03
Time 3.5 days	3.937E-08	48.9900	3.644E-03
Time 5.25 days	1.451E-08	40.8400	4.018E-03
Time 7 days	4.666E-08	47.9800	3.503E-03

********** CELLBASED **********

Cell-Based Particle Tracking w/Advection, Dispersion & Matrix Diffusion
Comparison of Model and Analytical Solution for Breakthrough Conc. vs Time

Test Case	Maximum Error	Maximum % Error	RMS Error
No Sorption	3.948E-02	10.9800	7.055E-03
Matrix Sorption	4.073E-02	9.5000	6.158E-03
Diffusion, Matrix&Fracture Sorption	8.112E-03	3.3980	6.206E-04

********** DISSOLUTION **********

Calcite Dissolution in a One-Dimensional System
Comparison of Model and Analytical Solution for Dissolution Front vs Time

Test Case	Maximum Error	Maximum % Error	RMS Error
Time 20000. seconds	2.161E-03	3.2250	3.225E-02
Time 60000. seconds	3.323E-03	1.6530	1.653E-02
Time 100000. seconds	6.281E-04	0.1875	1.875E-03

********** DOE **********

DOE Code Comparison Project, Problem 5, Case A
Comparison of FEHM and Other Code Solutions for Temperature vs Time
At X, Y coordinates (m) 62.5000 62.5000

Test Case	Maximum Error	Maximum % Error	RMS Error
Code 1	1.3560	0.6532	7.746E-04
Code 2	1.5190	0.6471	1.070E-03
Code 3	1.6230	0.6867	1.259E-03
Code 4	2.0030	0.8528	1.139E-03
Code 5	1.4980	0.7299	9.932E-04
Code 6	1.3680	0.5906	1.379E-03

DOE Code Comparison Project, Problem 5, Case A
Comparison of FEHM and Other Code Solutions for Pressure vs Time
At X, Y coordinates (m) 62.5000 62.5000

Test Case	Maximum Error	Maximum % Error	RMS Error
Code 1	5.124E-02	1.5810	1.908E-03
Code 2	6.127E-02	2.0220	3.137E-03
Code 3	5.347E-02	1.7700	3.234E-03
Code 4	6.233E-02	2.0570	3.017E-03
Code 5	2.149E-02	0.7164	1.199E-03
Code 6	2.828E-02	0.9395	1.637E-03

DOE Code Comparison Project, Problem 5, Case A
Comparison of FEHM and Other Code Solutions for Pressure vs Time
At X, Y coordinates (m) 162.500 137.500

Test Case	Maximum Error	Maximum % Error	RMS Error
Code 1	2.530E-02	0.7312	8.878E-04
Code 2	2.534E-02	0.7610	7.676E-04
Code 3	1.656E-02	0.4842	8.250E-04
Code 4	2.215E-02	0.6651	7.065E-04
Code 5	3.449E-02	1.0420	1.879E-03
Code 6	3.445E-02	1.0410	2.547E-03

********** DRYOUT **********
Dry-Out of a Partially Saturated Medium
Comparison of Dryout Front vs Time without Vapor Pressure Lowering

Test Case	Maximum Error	Maximum % Error	RMS Error
Time 100 days	4.637E-05	0.1903	1.903E-03
Time 200 days	2.889E-04	0.5927	5.927E-03
Time 300 days	6.240E-04	0.8534	8.534E-03
Time 400 days	1.064E-03	1.0910	1.091E-02
Time 500 days	1.571E-03	1.2890	1.289E-02

Dry-Out of a Partially Saturated Medium
Comparison of Dryout Front vs Time with Vapor Pressure Lowering

Test Case	Maximum Error	Maximum % Error	RMS Error
Time 200 days	2.813E-04	1.1540	1.154E-02
Time 400 days	2.582E-04	0.5297	5.297E-03
Time 600 days	4.542E-05	6.212E-02	6.212E-04
Time 800 days	2.941E-04	0.3017	3.017E-03
Time 1000 days	7.099E-04	0.5826	5.826E-03

********** DUAL **********
Dual Porosity Problem
Comparison of Model and Analytical Solution - Pressure vs Time (nondimensional)
At R coordinate (m) 0.139800

Test Case	Maximum Error	Maximum % Error	RMS Error
Case 1	3.784E-02	1.1770	7.994E-04
Case 2	1.858E-02	0.6075	5.318E-04
Case 3	1.995E-02	0.6331	5.482E-04

********** FRACTURE_TRANSPORT **********
Fracture Transport with Matrix Diffusion
Comparison of Model and Analytical Solution for Concentration vs Time
At X, Y coordinates (m) 0.00000 5000.00

Test Case	Maximum Error	Maximum % Error	RMS Error
No Sorption	2.804E-02	9.0820	1.410E-03
Matrix Sorption	1.758E-02	13.3700	2.204E-03

Matrix & Fracture Sorption	1.707E-02	4.6630	2.105E-03

Fracture Transport with Matrix Diffusion - GDPM formulation
Comparison of Model and Analytical Solution for Concentration vs Time
At X, Y coordinates (m) 5000.00 0.00000

Test Case	Maximum Error	Maximum % Error	RMS Error
No Sorption	3.043E-02	11.7200	1.553E-03
Matrix Sorption	2.357E-02	19.1600	2.662E-03

********** HEAD **********
Head Pressure Problem
Comparison of Head and Pressure Formulation for Pressure vs Position
At Time 365.000

Test Case	Maximum Error	Maximum % Error	RMS Error
Depth 0 meters	4.116E-04	3.010E-02	1.505E-04
Depth 25 meters	2.606E-04	2.321E-02	1.160E-04
Depth 50 meters	1.419E-04	1.614E-02	8.071E-05
Depth 75 meters	5.531E-05	8.714E-03	4.357E-05
Depth 100 meters	9.260E-07	2.371E-04	1.185E-06
Node by node comparison	4.116E-04	3.010E-02	1.702E-05

********** HEAT2D **********
2-D Heat Conduction Problem
Comparison of Model and Analytical Solution for Temperature vs Time
At X, Y coordinates (m) 0.00000 0.00000

Test Case	Maximum Error	Maximum % Error	RMS Error
3-node Triangles	0.5805	0.4162	7.661E-05
4-node Quadrilaterals	0.7140	0.3666	4.060E-05
Mixed Elements	0.5530	0.2815	5.129E-05
Refined Elements	0.8345	0.4313	4.253E-05

2-D Heat Conduction Problem
Comparison of Model and Analytical Solution for Temperature vs Position
At Time 21600.0

Test Case	Maximum Error	Maximum % Error	RMS Error
3-node Triangles	0.5978	0.3423	7.415E-04
4-node Quadrilaterals	0.7066	0.3649	8.162E-04
Mixed Elements	0.6671	0.3466	7.644E-04
Refined Elements	0.8615	0.4452	8.725E-04

********** HEAT3D **********
3-D Heat Conduction Problem
Comparison of Model and Analytical Solution for Temperature vs Time
At X, Y, Z coordinates (m) 0.00000 0.00000 0.00000

Test Case	Maximum Error	Maximum % Error	RMS Error
6-node Triangular Prisms	0.7860	0.5670	1.164E-04
8-node Quadrilateral Polyhedrons	1.0190	0.5275	6.811E-05
4-node Tetrahedrals	1.2450	0.6520	7.690E-05
Mixed Elements	0.8470	0.4349	7.936E-05
Refined Elements	1.2670	0.6632	7.874E-05
Polyhedrons, Finite Volume Option	1.0190	0.5275	6.811E-05
Ref. Elements, Finite Volume Option	1.0320	0.5343	6.892E-05

3-D Heat Conduction Problem
Comparison of Model and Analytical Solution for Temperature vs Position
At Time 21600.0

Test Case	Maximum Error	Maximum % Error	RMS Error

6-node Triangular Prisms	0.7957	0.5284	1.056E-03
8-node Quadrilateral Polyhedrons	0.9912	0.5200	1.065E-03
4-node Tetrahedrals	1.2430	0.6523	1.157E-03
Mixed Elements	0.8211	0.4403	9.982E-04
Refined Elements	1.2650	0.6634	1.124E-03
Polyhedrons, Finite Volume Option	0.9912	0.5200	1.065E-03
Ref. Elements, Finite Volume Option	1.0050	0.5273	1.075E-03

********** HENRYS_LAW **********
1-D Henry's Law Species
Comparison of Model and Analytical Solution for Concentration vs Time
At R coordinate (m) 1.00000

Test Case	Maximum Error	Maximum % Error	RMS Error
Air Movement Through Stagnant Water	9.947E-03	7.4640	4.910E-04
Water Movement Through Stagnant Air	7.292E-03	2.7220	2.904E-04

********** INFILTRATION **********
Infiltration Problem using the Equivalent Continuum Method
Comparison of FEHM and TOUGH2 Solution for Saturation vs Elevation
At Time 0.100000E+10

Test Case	Maximum Error	Maximum % Error	RMS Error
ECM	5.639E-02	6.1690	1.423E-03

Infiltration Problem using the Double Porosity/Double Permeability Method
Comparison of FEHM and TOUGH2 Solution for Saturation vs Elevation
At Time 0.100000E+10

Test Case	Maximum Error	Maximum % Error	RMS Error
DPM - matrix	8.151E-02	17.1200	2.068E-03
DPM - fracture	1.022E-02	355.0000	3.679E-02

********** MULTI_SOLUTE **********
Multi-Solute Transport with Chemical Reaction
Comparison of FEHM and PDREACT Solution for Concentration vs Time
At R coordinate (m) 10.0000

Test Case	Maximum Error	Maximum % Error	RMS Error
Species Co_aq	3.916E-06	0.7115	3.879E-04
Species Fe_aq	1.652E-15	1.0250	1.031E-03
Species EDTA_aq	9.630E-13	11.2100	5.986E-03
Species CoEDTA_aq	1.442E-04	3.6850	2.222E-03
Species FeEDTA_aq	3.667E-05	2.6400	1.747E-03
Species CoEDTA_s	7.826E-05	5.8390	3.178E-03
Species Co_s	1.866E-05	0.9680	6.416E-04
Species FeEDTA_s	1.438E-05	3.2470	2.229E-03

********** RAMEY **********
Temperature in a Wellbore (Ramey) Problem
Comparison of Model and Analytical Solution for Temperature vs Time

Test Case	Maximum Error	Maximum % Error	RMS Error
Depth 0. meters	2.573E-02	0.1286	3.112E-05
Depth 1000. meters	1.3450	2.8150	1.556E-03
Depth 2000. meters	1.0570	1.3580	1.061E-03

Temperature in a Wellbore (Ramey) Problem
Comparison of Model and Analytical Solution for Temperature vs Depth
At Time 0.216000E+07

Test Case	Maximum Error	Maximum % Error	RMS Error
Time 25 days	0.6971	1.0260	5.203E-04

********** SORPTION **********
One Dimensional Reactive Solute Transport
Comparison of FEHM and SORBEQ for Concentration vs Time
At R coordinate (m) 1.00000

Test Case	Maximum Error	Maximum % Error	RMS Error
Isotherm: Conservative	9.711E-03	9.4930	2.902E-04
Isotherm: Linear	4.509E-03	2.2250	1.787E-04
Isotherm: Langmuir	9.151E-03	5.4050	2.385E-04
Isotherm: Freundlich	1.166E-02	2.1270	2.504E-04
Isotherm: Modified Freundlich	2.568E-02	8.0140	7.802E-04

********** STREAMLINE **********
Streamline Particle Tracking w/Advection, Dispersion & Matrix Diffusion
Comparison of Model and Analytical Solution for Concentration vs Time

Test Case	Maximum Error	Maximum % Error	RMS Error
No Sorption	9.481E-02	54.4000	2.993E-03
Matrix Sorption	9.437E-02	45.0500	5.560E-03
Matrix Diffusion, No Sorption	4.811E-02	21.7400	3.973E-03

Streamline Particle Tracking w/Longitudinal & Tranverse Dispersion
Comparison of Model and Analytical Solution for Concentration Profiles

Test Case	Maximum Error	Maximum % Error	RMS Error
Profile at 4800 m 10,000 Particles	1.192E-02	4.6640	1.350E-02
Profile at 4800 m 100,000 Particles	5.900E-03	11.7900	1.918E-02
Profile at 10000 m 10,000 Particles	2.524E-02	10.2200	1.914E-02
Profile at 10000 m 100,000 Particles	7.824E-03	6.2610	1.273E-02

********** THEIS **********
Pressure Transient Analysis (Theis) Problem
Comparison of Model and Analytical Solution for Pressure vs Time

Test Case	Maximum Error	Maximum % Error	RMS Error
Radius 0.00144 meters	1.101E-05	1.100E-03	6.681E-08
Radius 3.44825 meters	6.010E-06	6.010E-04	7.722E-08

Pressure Transient Analysis (Theis) Problem
Comparison of Model and Analytical Solution for Pressure vs Position
At Time 86400.0

Test Case	Maximum Error	Maximum % Error	RMS Error
Time 1 day	2.843E-06	2.842E-04	1.742E-07

********** THERMODYNAMICS **********
Comparison of Steam Table vs FEHM Values
Thermodynamic property as a Function of Pressure and Temperature

Test Case	Maximum Error	Maximum % Error	RMS Error
Liquid enthalpy	2.100E-03	0.1319	1.732E-05
Vapor enthalpy	9.000E-05	3.125E-03	3.130E-06
Liquid density	1.5220	0.2482	2.018E-05
Vapor density	2.550E-02	5.794E-02	6.295E-05
Liquid compressibility	2.160E-03	16.0000	5.182E-03
Vapor compressibility	1.2870	0.1297	4.074E-04
Liquid viscosity	3.224E-06	0.5244	9.222E-05
Vapor viscosity	3.650E-08	0.1601	1.687E-04
Saturation pressures	2.575E-02	0.3000	4.687E-04
Saturation temperatures	1.1000	0.4000	5.943E-04

********** TORONYI **********

SUMMARY_RPT.001101

Toronyi Two-phase Problem
Comparison of FEHM and Thomas & Pierson Solution for Final Saturation
At Time 78.3000

Test Case	Maximum Error	Maximum % Error	RMS Error
Node by node comparison	1.542E-03	1.3180	7.719E-04

********** TRANSPORT3D **********
Three-Dimensional Radionuclide Transport Problem
Comparison of FEHM and TRACRN for Concentration vs Time

Test Case	Maximum Error	Maximum % Error	RMS Error
Conservative Tracer, Point 1	5.296E-02	6.6030	1.308E-03
Conservative Tracer, Point 2	1.607E-02	10.7800	1.813E-03
Conservative Tracer, Point 3	3.646E-03	4.5320	8.533E-04
Conservative Tracer, Point 4	1.016E-03	2.8520	1.261E-03
Am Tracer, Point 1	4.800E-02	7.2750	1.523E-03
Am Tracer, Point 2	1.589E-02	14.8100	3.423E-03
Am Tracer, Point 3	1.042E-03	12.6900	3.293E-03
Am Tracer, Point 4	1.992E-05	15.0200	4.231E-03

********** VAPOR_EXTRACTION **********
Vapor Extraction from an Unsaturated Reservoir
Comparison of Model and Analytical Solution for Vapor Pressure vs Position

Test Case	Maximum Error	Maximum % Error	RMS Error
Isotropic	1.983E-03	2.1950	8.838E-05
Anisotropic	3.066E-03	3.3110	1.436E-04

NOTE: Tests executed on system running Microsoft Windows 2000 [Version 5.00.2195]

WBS 1.2.21.3U
QA: QA

COPY

Civilian Radioactive Waste Management System
U.S. Geological Survey

INFIL V2.0

VALIDATION TEST REPORT

SDN:10307-VTR-2.0-00
STN: 10307-2.0-00
SMN: 10307-PC-2.0-00
SAN:USGS-2000-~~014~~ 114 WBS 9/28/01

27 July 2001

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Civilian Radioactive Waste Management System
U.S. Geological Survey
INFILV2.0

VALIDATION TEST REPORT

SDN:10307-VTR-2.0-00

SAN:USGS-2000-014

27 July 2001

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CHANGE HISTORY

Revision Number	Effective Date	**Description of and Reason for Revision**
0	8/29/2000	Initial Release

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1. PURPOSE

The Validation Test Report (VTR) that follows is part of the software baseline documentation that the U.S. Geological Survey-Yucca Mountain Project Branch (USGS-YMPB) must submit to qualify the use of INFIL V2.0 to support the Analysis Model Report (AMR) *Similuation of Net Infiltration for Modern and Potential Future Climates* (USGS 2001). The VTR has been developed to meet the requirements described in Requirements Document 10307-RD-2.0-00 (RD) and Design Document 10307-DD-2.0-00 (DD). The primary function of the INFIL V2.0 program is to perform a root-zone water balance from which net infiltration can be derived. It is noted that this approach does not necessarily represent the physics of infiltration in soils, but uses a water volume calculation approach in the mathematical and numerical models. This model has been compared successfully to several independent approaches to estimating net infiltration and recharge, and more rigorous methods based, for example, on detailed numerical solution of the differential equations of ground-water and surface-water flow are not feasible for use in this large-scale application. The sum of results for net infiltration simulations are to be presented in USGS (2001). These calculations are dependent on post-processing routines discussed in the cited AMR.

INFIL V2.0 supports the net infiltration model and analysis to be documented in USGS (2001), that are concerned specifically with estimating the spatial distribution of net infiltration in the vicinity of the potential Yucca Mountain repository under present-day and projected future climatic conditions. In accordance with the screening criteria listed in Software Categorization, Section 5.1 of AP-SI.1Q, *Software Management,* the net infiltration model and analysis are of Level 2 importance in addressing the factors of the post-closure safety case for the potential repository in the unsaturated zone at Yucca Mountain. The net infiltration model is founded on the application of INFIL V2.0 based on standard distributed-parameter water-balance methods to estimate net infiltration as discussed, for example, in Hatton (1998). On this basis, the software program, INFIL V2.0 is deemed to be appropriate for providing estimates of net infiltration that serve as input to and the upper boundary condition for the site-scale UZ flow and transport model.

2. VALIDATION OF INFIL V2.0

2.1 METHOD

This validation test report describes the result for re-execution of the Installation Test Plan 10307-ITP-2.0-00 (ITP), and execution of the Validation Test Plan 10307-VTP-2.0-00 (VTP) submitted for INFIL V2.0. The ITP and the appropriate tests from the controlled VTP were executed to validate the software program INFIL V2.0 performs according to specifications in the RD and DD regarding functionality.

In general, the intended level of precision for most estimates of net infiltration, which is the principal output from INFIL V2.0, is 0.01 mm. The precision and functionality of the calculations performed by the program are validated by ensuring that the water volume balance equation is satisfied (the solution to the water balance equation must be 0, within the level of machine and variable precision). The set of validation tests designed for this VTP are only capable of validating that the software is functioning as intended and within the level of precision intended. The accuracy of model results cannot be validated by the validation tests described in this document. The accuracy of results generated by INFIL V2.0 depends on the accuracy of model inputs, the appropriateness of the assumptions applied in model

development, and the adequacy of the model in representing the true physical processes being modeled. More detailed information for intended levels of precision is provided for each test case description.

The collection of test cases assembled for this VTP is designed to ensure that the 16 functionality requirements listed in Section 1.1.2 of the RD and in Section 2.2 of this VTR have been satisfied. Each test case includes a listing of one or more criteria that are used to validate one or more functionality requirements. Each functionality requirement is validated multiple times within the set of test cases. The purpose of multiple validation is to ensure that the functionality requirements are validated across a broad range of conditions that are likely to arise during model application. It is not possible to validate all functionality requirements for all possible combinations of model inputs and run-time conditions; however, the set of test cases used for this VTR is assumed to be provide a sufficient validation for the functionality requirements.

The validation test cases are organized into 6 test sequences. Each test sequence contains multiple test cases that are generally ordered by the complexity of model functionality. The simplest level of model functionality is where all inputs are either turned off or set to zero, and all model components have been de-activated. Simplifying model functionality allows for the validation of the most basic water volume balance calculation (there is no water in the system, thus all outputs must be zero). The complexity of model functionality is progressively increased as model components are activated and additional model inputs are incorporated. This allows for a systematic validation of the various model components and functions. For example, model functionality is simplified if evapotranspiration is enabled but daily precipitation is set to zero, potential evapotranspiration is set to a constant rate of 1 mm/day, and net infiltration and surface water flow routing are disabled. In this example the simplified conditions are designed to test only the loss of water from the root zone as a function of modeled evapotranspiration and the initial water content of the root zone. The level of complexity is increased if daily precipitation and air temperature input are allowed, spatial variability in geospatial input parameters is allowed, and all model functions such as net infiltration, coupled surface water routing, and snow accumulation – snow melt, are all enabled. In this example, the level of model complexity has been increased to test the interaction of the various model components

The organization of multiple validation test cases allows for comparison of results from progressively more complex test cases with results from a sequence of previous tests developed from the simplest "base-case" test condition. Thus, in most cases, the results from later test cases are intended to build on the results of previous test cases in a logical progression from simplified conditions that are restrictive relative to conditions expected during model application, to the actual conditions intended for use during model application.

Validation for each test case is conducted by a visual inspection of the output files generated by INFILv2 using an ASCII text editor, word processing application, or spreadsheet application, and also by hand calculations that can be performed using a spreadsheet application (such as EXCEL). The absence of remarks or checks in the "Fail" column of the matrix for the Validation Test Results (Appendix 2, Table A2-2), is confirmation that all tests passed the acceptance criteria.

2.2 FUNCTIONAL REQUIREMENTS

Net infiltration is the component of infiltrated precipitation, snowmelt, or surface water run-on that has percolated below the zone of evapotranspiration as defined by the depth of the effective root zone, the average depth below the ground surface (at a given location) from which water is removed by evapotranspiration. The estimates of net infiltration are used for defining the upper boundary condition for the site-scale 3-dimensional Unsaturated-Zone Flow and Transport (UZ flow and transport) Model (CRWMS M&O 2000a). Output from this model provides the upper boundary condition for the UZ flow and transport model that is used to generate flow fields for evaluating potential radionuclide transport through the unsaturated zone.

The output from INFIL V2.0 is post-processed to create raster-based, 2-dimensional grids of spatially distributed, time-averaged rates for three different climate stages estimated as likely conditions for the next 10,000 years beyond the present. Each climate stage is represented using a lower bound, a mean, and an upper bound climate, and the corresponding net-infiltration scenario for representing uncertainty in the characterization of daily climate conditions for each climate stage, as well as potential climate variability within each climate stage. The set of nine raster grid maps provide spatially detailed representations of the magnitude and distribution of net-infiltration rates that are used to define specified flux upper boundary conditions for the UZ flow and transport model.

The RD describes the hierarchical structure of INFIL V2.0, and provides the functional requirements that the program calculate infiltration into the root zone, evapotranspiration, net infiltration, and runoff based on identification of watershed domains, climate, soil layer depths, and hydrologic properties of the underlying bedrock. The processes, and therefore the functional requirements of INFIL V2.0 must be satisfied to ensure that the software functions as designed and fulfills the purpose of the application. The specific functionality requirements stated in the VTP that conform to those in the RD are that INFIL V2.0 properly functions to perform the following:

1. Accept input from pre-processing software routines that are documented in USGS (2001) (the pre-processing routines are used to develop the daily climate input and the geospatial parameter input files), as well as from a model control file documented in the User's Manual 10307-UM-2.0-00 (UM) for INFIL V2.0 (see Appendix 1-A). The input formats for daily climate parameters must include an option to allow daily air temperature to either be provided as input in the daily climate input file or be modeled internally by the program as a function of the day-of-year. The input formats for daily climate input must include a format compatible with the output generated by the FORTRAN routine DAILY09, as documented in USGS (2001). The input format for the geospatial parameter file must be compatible with the format of the output generated by the FORTRAN routine WATSHD20, as described in USGS (2001).

2. Apply a multi-layered root zone model for calculating daily net infiltration, evapotranspiration, and runoff. Partition the root zone into 4 layers and define the thickness of each root-zone layer, including the depth to which the root zone extends into bedrock, as a function of the soil depth input parameter and user specified model parameters.

3. Model potential evapotranspiration as an hourly energy balance based on incoming solar radiation, the average daily air temperature, estimated ground heat flux, and topographic parameters included in the geospatial parameter input file. If average daily air temperature is not provided as input, model

-daily air temperature as a function of the day-of-year and user specified parameters in the model control file. Model incoming solar radiation on an hourly basis using topographic parameters and the day of year provided as input from the daily climate model.

4. Model the spatial distribution of daily precipitation, air temperature, and potential evapotranspiration as a function of spatially distributed parameters provided by the geospatial parameter input file.

5. Estimate daily snowfall and snowmelt as a function of average daily air temperature. Estimate sublimation as a function of daily potential evapotranspiration.

6. Initiate the daily water balance calculation using an estimate of root zone water content for soil layers at all model nodes.

7. Solve the daily water volume balance equation (equation 1 in the RD and equation 3-3 in this VTR) for all model nodes for all days simulated. All components of the daily water balance must sum to zero (water is conserved), within the expected level of output precision (0.01 mm). The components of the calculation include precipitation (either rain or snow), snowmelt, sublimation, evapotranspiration, change in root zone water storage, runoff, run-on, and drainage (net infiltration) below the root zone.

8. Perform the daily water balance calculation for all grid locations, including surface water routing across all model nodes if runoff is generated at any node in the model domain. Repeat the water balance calculation for all successive days of a continuous simulation period based on the modeled root zone water content of the previous day and the daily climate input for the new day.

9. Estimate daily evapotranspiration as a function of the root zone water content, root density, and modeled potential evapotranspiration.

10. Calculate net infiltration as a function of the root zone water content for the bottom root zone layer, the saturated hydraulic conductivity of the soil, and the bulk saturated hydraulic conductivity of the bedrock or soil underlying the root zone, and evapotranspiration from the bottom root zone layer.

11. Distribute runoff laterally across all model nodes as surface water flow. Couple the surface water routing model component to the root zone water balance model component by allowing surface water run-on to infiltrate into the root zone as a function of the root zone hydraulic conductivity and the available root zone storage capacity. Include the infiltrated run-on as the new root zone water content for the next day simulated.

12. Calculate daily surface water outflow from the model domain and from specified model nodes as daily mean discharge, in cubic-feet-per-second.

13. Output the main components of the daily water volume balance, averaged across all model nodes, for each day of the simulation. This is a primary model output that includes daily precipitation (both rain and snowfall), snow-melt, sublimation, evapotranspiration, change in root zone water storage, runoff, infiltrated run-on, surface water outflow, and drainage (net infiltration) below the root zone. The output terms indicate the daily water volume for each component of the water balance as a spatially averaged water depth, in mm, across the total area of the model domain (the water depth

across all model nodes is averaged). Include as part of the output a check of the daily water balance for all days simulated.

14. Output a summary of the main components of the daily water balance as annual totals and calculated average annual rates, averaged across all model nodes. This is a primary output that indicates the daily water volume for each component of the water balance as a spatially averaged water depth, in mm, across the total area of the model domain.

15. Output the main components of the water balance as average annual rates calculated for all model nodes. This is a primary output that indicates a time-averaged rate, in mm/year, for each component of the water balance, for all nodes in the model domain. The time-averaged rates are calculated using the daily water balance results at each node. Include as part of the output a check of the average annual water balance at all model nodes. The output must include the x-y coordinate of each model node so that the results can be easily mapped, and must be in the correct format to be used as input for the post-processing routine MAPADD20, as described in USGS (2001).

16. Output additional information that can be used for model testing and analysis of model results. The additional information is secondary output where the generation of output files is optional and is controlled by user-defined options in the model control file. The optional output files include map files for annual totals or multi-annual averages, map files for the daily water balance results for specified days of the simulation period, and a map file of root zone layer parameters calculated by the program. Although the secondary output is non-essential for the intended model application, some of the optional output is used as part of model validation.

As noted elsewhere, the test cases used for program validation are organized into a set of 6 test sequences (Test Sequence 0 through Test Sequence 5) designed to validate that the software program correctly performs all functional requirements. Test sequence 0 provides an overall test of the model inputs intended for use during model application. This test sequence validates that the program will process the model inputs as intended, model functions are performed as intended, and the water volume balance is satisfied. Test sequence 1 consists of a modified set of conditions to allow a more focused validation of the layered root zone system in response to initial conditions and variations in soil and bedrock properties only. Daily climate input is disabled (precipitation and evapotranspiration are set to 0) to allow for a direct validation of specific root zone functions. Test sequence 2 consists of validating the response of the layered root zone system to various conditions defined by controlling potential evapotranspiration. Daily precipitation is still disabled and thus the test sequence involves model validation based on initial conditions. Test sequence 3 consists of applying controlled conditions in terms of both daily precipitation and daily potential evapotranspiration for a more integrated test of the intended multi-layered root zone functions. Test sequence 4 focuses on validating the coupled surface water routing model component based on applying controlled model conditions in terms of a combination of modified daily climate input, geospatial input parameters, and root zone properties. Test sequence 5 is used to validate the snowfall – snow-melt model component by controlling daily air temperature input.

3. CONCEPTUAL MODEL OF INFILTRATION: SCIENTIFIC APPROACH

3.1 NUMERICAL REPRESENTATION OF THE CONCEPTUAL MODEL

3.1.1 Mathematical Concepts

The numerical model is a digital representation of the mathematical concepts that describe the conceptual model of net infiltration described in Section 6.1. In most cases, an exact mathematical formulation of the physical processes being modeled is not required and in many cases is not possible. An application of approximate mathematical formulations is an essential requirement for computational efficiency and practical applicability of the numerical model. The level of accuracy needed for an approximate representation depends on the sensitivity of the UZ flow and transport models to net infiltration, in conjunction with the level of accuracy needed for results obtained with the models to evaluate potential repository performance (CRWMS M&O, 2000a).

From the documentation for INFIL, version 1, the water balance at user specified site locations is shown to be based on the principle of the conservation of mass of water:

$$P + A + U + \Delta Ws + \Delta Ss + \Delta Bs + Li + Ron - Roff - D - E - T - Lo - Ex = 0 \qquad \text{(Eq. 3-1)}$$

where P is precipitation, A is applied water (man induced), U is upward flow, ΔW_s is change in soil water storage, ΔS_s is change in surface storage, ΔB_s is change in above ground biomass storage, L_i is lateral flow in, R_{on} is surface run-on, R_{off} is surface runoff, D is deep drainage or percolation, E is evaporation, T is transpiration, L_o is lateral flow out, and $-E_x$ is extraction of water (man-induced). Equation 3-3 states that the sum of all inputs, outputs, and changes in storage in the hydrologic system must equal zero. To be applied, the equation must be defined over some arbitrary time interval and over some arbitrary volume or depth in the soil. In most cases, the general form of the water-balance equation can be greatly simplified by assuming one or more of the terms to be zero or negligible in magnitude. The authors have simplified Eq. 3-1 as shown in Eq. 3-2. The term B_s and E_x can often be set to zero, R_{on} and R_{off} are combined into a single term R, and E and T can be combined into a single term for evapotranspiration (ET).

$$P + \Delta W_s - D - ET - R = 0 \qquad \text{(Eq. 3-2)}$$

The current (1999) model development supplements and enhances a preceding 1996 model, particularly with respect to evapotranspiration from the root zone and the infiltration of surface run-on in the channels of washes. In addition, the current (1999) model uses updated model inputs for bedrock geology and soil depth. INFIL V2.0 implements the same approach for calculating the water balance, with Equation 3-2 rewritten to provide more detail with respect to the components of precipitation. The governing equation for the root zone water volume balance at each node is written as:

$$Prs - SF + SM + IR - CRZWC - ET - NI - O = 0 \qquad \text{(Eq. 3-3)}$$

where *Prs* is precipitation (rain or snow), *SF* is snowfall, *SM* is snowmelt, *IR* is infiltrated surface water run-on, *CRZWC* is the change in root zone water content, *ET* is evapotranspiration, *NI* is net infiltration, and *O* is surface water outflow. The parameters included in Equation 3-3 are developed through the software program functional requirements and may be considered to constrain the design of the software.

The process of sublimation of accumulated snowfall is also included in the model and is provided as an output term. To include the sublimation term in the root zone water balance, Equation 3-3 is modified to:

$$Pr + SF - CSP - S + IR - CRZWC - ET - NI - O = 0 \qquad \text{(Eq. 3-4)}$$

where *Pr* is precipitation as rain only and *CSP* is the change in snow pack depth and S is sublimation.

All model nodes have equivalent areas and thus the water volume balance calculation is reduced to a water depth balance for a daily time step, in units of millimeters per day. Water contents for each root zone layer at each node are converted to water depths using layer thickness, which depends on soil depth and is thus variable from node to node. Equations 3-3 and 3-4 state that the sum of all inputs, outputs and changes in storage in the hydrologic system must equal zero.

Equation 3-4 is solved using the daily climate input and modeled potential evapotranspiration. Daily climate input may or may not include daily air temperature, but must at minimum include daily precipitation (although all daily precipitation input values can equal 0), the year number, and the day of year number. If daily air temperature is not provided as input, it is modeled by the program as a daily mean air temperature using an annual sine-wave function:

$$T\alpha = [17.3 - 11.74\, SIN\, [(DN/366) * 2 * \Pi - 1.3)\} - 273.15 \qquad \text{(Eq. 3-5)}$$

where *DN* is the day of the year and $T\alpha$ is the modeled daily mean air temperature in Kelvins (*K*).

Air temperature and the day of year are needed model potential evapotranspiration using the equation developed by Priestley and Taylor (1972)

$$\lambda E = \alpha S/(S+\gamma) \qquad \text{(Eq. 3-6)}$$

where α, an empirical coefficient, S is the slope of the saturation vapor pressure-temperature curve, γ is the psychrometric constant, R_n is net radiation, G is soil-heat flux. The term α, was determined to be 1.26 for freely evaporating surfaces (Priestley and Taylor, 1972; Stewart and Rouse, 1977; and Eichinger and others, 1996). The Priestley-Taylor equation has been modified by several researchers to relate their empirical coefficient, α, to seasonal changes in soil water content (Davies and Allen, 1973; Flint and Childs, 1991), and has been described as successfully used in arid and semi-arid environments (deBruin, 1988; Stannard, 1993). This equation has the added benefit of minimal data requirements. For soil-water-limited conditions the relation between α and soil water content is empirical but works well for many surface conditions (Davies and Allen, 1973; Flint and Childs, 1991).

The evapotranspiration subroutine calculates actual evapotranspiration using a modified Priestley-Taylor equation (Eq. 3-6) where α is replaced with α' which is modeled as:

$$\alpha' = \alpha\ (1 - e^{\beta\Theta}) \qquad \text{(Eq. 3-7)}$$

where α is taken as 1.26, β is a fitting parameter ranging from approximately -1.5 to –10.0 and Θ is relative saturation:

$$\Theta = (\theta - \theta_r)/(\theta_s - \theta_r) \qquad \text{(Eq. 3-8)}$$

where θ is soil-water content, θ_s is porosity, θ_r is residual saturation for plant transpiration (soil-water content at -60 bars water potential, which is the approximate mean minimum xylem potential for the plants in the Yucca Mountain area). The parameter $s/(s+\gamma)$, extracted from Table A.3 in Campbell (1977), is modeled as:

$$S/(S+\gamma) = -13.281 = (0.083684/K)T\alpha - (0.00012375/K^2)\,T\alpha^2 \qquad \text{(Eq. 3-9)}$$

Net radiation (R_n, w/m^2) is modeled as:

$$R_n = -71 + 0.72 * K\downarrow \qquad \text{(Eq. 3-10)}$$

where $K\downarrow$ is modeled incoming solar radiation (w/m^2). Soil-heat flux (G, w/m^2) is modeled as:

$$G- = -20 + 0.386\,R_n \qquad \text{(Eq. 3-11)}$$

Solar radiation, net radiation and soil heat flow are solved on an hourly basis and summed over the period of one day. Evapotranspiration is calculated at the end of the day and the change in water content (θ) is updated at the beginning of the next day. This modification of the Priestley-Taylor equation allows for the soil-water content to limit evapotranspiration. If moisture conditions change due to precipitation then α' approaches 1.26 allowing evapotranspiration to approach the equilibrium evaporation rate.

It is important to note that runoff, not net infiltration, is calculated as the solution to the water-balance equation. A unit gradient is assumed and net infiltration is incorporated in the water-balance formulation as a temporary potential net-infiltration term and is limited by the field-scale-saturated hydraulic conductivity of the soil or bedrock underlying the root zone.

The net-infiltration modeling process requires a combination of applications using Geographic Information System (GIS) applications, field measurements (or acquisition of existing field data), parameter estimation, visualization and analysis, and the application of developed FORTRAN codes. The FORTRAN codes are used for pre-processing model input, the implementation of process modeling using INFIL V2.0 for simulating net infiltration, and for post-processing of model results, which includes the development of net-infiltration estimates for a given climate scenario by averaging separate model simulation results. The process modeling for net infiltration consists primarily of an hourly energy balance and a daily water balance simulation for a continuous multi-year period. The daily net-infiltration rates are averaged over the duration of the simulation for each model node to obtain spatially distributed, time-averaged net-infiltration rates.

3.1.2 Accuracy and Precision of Model Calculations

The simulation of net infiltration primarily involves a water-balance calculation and the application of the conservation of mass principle. All water-balance calculations are performed as water-depth balances (which are easily converted to volume balances[1]), and thus an assumption is made that calculation errors due to temperature effects on water density are negligible relative to the level of precision needed for net-infiltration estimates.

[1] Model calculations are performed as water-depth balances, and are converted to volume balances based on model grid cell area, which is 900 square meters for all model grid cells.

Model calculations are performed using double precision variables and standard FORTRAN77 programming language. The model code performs several internal mass balance checking calculations that are used to test the precision of the overall water-balance simulation (program testing and software validation are described thoroughly in the software qualification documentation). For estimated average annual net-infiltration rates, model results are provided for each model grid cell to the nearest 0.00001-millimeter (mm) water depth for all components of the water balance to allow for additional mass-balance checking using post-processing procedures. This level of internal precision does not indicate the level of expected precision in model results. Based on the average number of significant figures in model input, the number of significant figures that can be applied to model results should not exceed two. This degree of output precision is subjectively based on the average level of precision in model inputs.

3.2 CONCEPTUAL MODEL OF INFILTRATION

The conceptual model defines net infiltration as water that has percolated from the land surface to below the root zone. The root zone herein is defined as the zone from the ground surface to some variable depth in soil or bedrock from which infiltrated water is readily removed on an annual or seasonal basis by evapotranspiration. The depth of the root zone can be estimated from field studies but cannot be defined precisely. In addition, the depth of the root zone depends on variable climate and surface conditions controlling vegetation and other factors affecting evapotranspiration and is thus transient and spatially variable. Infiltration is the movement of water across the air/soil or air/bedrock interface, and percolation is defined as the downward movement of water within the unsaturated zone.

The current conceptual model of infiltration at Yucca Mountain identifies effective precipitation, which is the ratio of precipitation to potential evapotranspiration, as the most significant environmental factor controlling net infiltration at Yucca Mountain. Precipitation averages 170 mm/yr over the study area but is temporally and spatially variable (Hevesi et al., 1992). On an annual basis effective precipitation is low because potential evapotranspiration is much higher than precipitation. However, on a daily basis, effective precipitation can be high, particularly during periods with large and frequent winter storms. For example, the average penetration depth of infiltration[2] into the soil/bedrock profile fluctuates on a seasonal basis for a given location, but tends to be greatest in the winter due to lower evapotranspiration demands, higher amounts of precipitation, and slow snow melt.

The second most significant environmental factor controlling net infiltration is soil depth. When there is sufficient precipitation to produce net infiltration, the spatial distribution is generally defined by the spatial variability of soil depth. Field measurements indicate that when the soil/bedrock contact reaches near-saturated conditions (see Figure 6-6A), fracture flow is initiated in the bedrock (as evidenced by changes in water content profiles), increasing the hydraulic conductivity by several orders of magnitude. Soils exceeding 6 meters in thickness eliminate the infiltration of water to the soil/bedrock contact except in channels (Flint and Flint, 1995). Storage capacity in the soil profile is large enough that most water from precipitation is held in the root zone and removed by evapotranspiration processes. Soils that are less than 6 meters deep do not have enough storage capacity to store the volume of precipitation, and often allow near-ponding conditions to occur at the soil/bedrock contact, particularly when the soil depth is less than 0.5 meters.

[2] The penetration depth of infiltration is identified by the maximum depth at which a wetting front is observed based on geophysical logs.

The third factor controlling net infiltration is bedrock permeability. At Yucca Mountain welded tuffs of the Tiva Canyon welded (TCw) hydrogeologic unit, and nonfractured, nonwelded tuffs of the Paintbrush nonwelded (PTn) hydrogeologic unit are the principal rock types present in surface exposures or directly under soils.. The saturated hydraulic conductivity of the nonwelded PTn matrix is higher than the TCw matrix (Flint, 1998, Table 7). The fractures in the welded tuff increase the saturated hydraulic conductivity of those rocks but due to channeling and the presence of inactive as well as active fractures (Liu et al., 1998), the unsaturated bulk conductivity is generally not more than that of the matrix of the nonwelded tuffs. The lower storage capacity of the fractured, welded tuffs allows moisture that has infiltrated to penetrate more deeply than in the nonwelded tuffs. Hydraulic properties of fractures calculated for this study depend on fracture aperture and whether or not the fractures are open or filled with calcium carbonate or siliceous materials. Based on numerical simulations of water flow through a block of variably saturated fractured tuff, Kwicklis et al. (1998, p. 60) suggest that the infiltration of water into a fractured welded tuff, such as the TCw, will be controlled by the water potential at the soil-bedrock interface. Because the apertures and the air-entry water potentials of unfilled fractures (Kwicklis et al., 1998) are larger than the overlying soils, the initiation of fracture flow should occur only under saturated or near-saturated conditions. Fracture densities and matrix permeabilities are variable among the geologic units at Yucca Mountain.

Shallow infiltration processes at Yucca Mountain can be described on the basis of four infiltration zones that can be identified based on the manner in which volumetric water content changes with depth and time (Flint and Flint, 1995). The zones, which correlate with topographic position, are described as follows: (1) Ridgetops are flat to gently sloping, of higher elevation than the other zones, and have thin soils composed of both eolian deposits and soils developed in place from the weathering process. These soils often have higher clay content and higher water-holding capacity compared to soils on sideslopes and alluvial terraces. The ridgetops generally are located where the bedrock is moderately to densely welded and fractured. The presence of thin soil and fractured bedrock results in the deeper penetration of moisture following precipitation compared to other topographic positions. In some locations where runoff is channeled, large volumes of water can infiltrate. For the present-day arid climate, runoff generally is restricted to the upper headwater portions of drainages and to locations downstream of areas that have very thin soils underlain by relatively impermeable bedrock. (2) Sideslopes are steep, commonly have thin to no soil cover, and are usually developed in welded, fractured tuff. The steepness of the slopes creates conditions conducive to rapid runoff. The low storage capacity of the thin soil cover and the exposure of fractures at the surface may enable small volumes of water to infiltrate to greater depths, especially on slopes with north-facing exposures and therefore lower evapotranspiration demands. Shallow alluvium at the bases of the slopes can easily become saturated and initiate flow into the underlying fractures. (3) Alluvial terraces are flat, broad deposits of layered rock fragments and fine soil with a large storage capacity. Little runoff is generated on the terraces and the precipitation that falls there does not move below a depth of one to two meters before it is removed evapotranspiration. Consequently, this zone contributes the least to net infiltration in the drainage basin. (4) Active channels are similar to the terraces but are located in a position to collect and concentrate runoff that, although occurring infrequently, can penetrate deeply. Although local net infiltration can be high for some channel locations, under the current arid climate this mechanism is not considered a major contributor to the total volume of net infiltration at Yucca Mountain, because runoff is infrequent and because the channels areas include only a very small percentage of the total drainage basin area.

3.3 HYDROLOGIC CYCLE

In the conceptual model, the hydrologic cycle is used to identify, define, and separate the various field-scale components and processes controlling net infiltration (Figure 3-1). The hydrologic cycle is a basic conceptual tool used to visualize and define the various components of the field-scale water balance (Maidment, 1993, Figure 1.2.1, p. 1.4; Freeze and Cherry, 1979, Figure 1.1, p. 3). The hypothetical starting point of the hydrologic cycle is precipitation, which for current (modern) climate at Yucca Mountain occurs primarily as rain but can also occur as snow. Precipitation can accumulate on the ground surface,[3] infiltrate the soil or exposed bedrock[4] surfaces, contribute to runoff, or accumulate as snow. The contribution of precipitation to runoff generation depends on precipitation intensity relative to soil and exposed bedrock hydraulic conductivity, and also on the available storage capacity of soil and shallow bedrock with thin or no soil cover. Water accumulated in the snow pack can sublimate into the atmosphere or become snowmelt, which can then infiltrate, evaporate, or contribute to runoff. Rain or snowmelt that becomes runoff accumulates in surface depressions and basins or contributes to surface water flow, which is routed to downstream locations as run-on.[5] Run-on contributes to either infiltration or accumulated surface-water run-on at downstream locations. Infiltrated water percolates through the root zone as either saturated or unsaturated ground water and is subject to evapotranspiration. Water percolating through the root zone is available as potential net infiltration, but the actual net-infiltration rate is limited by the bulk (or field-scale) saturated hydraulic conductivity of the bedrock or soil underlying the root zone. In the conceptual model, the bulk saturated hydraulic conductivity represents a weighted averaging of the field-scale matrix and fracture saturated hydraulic conductivity. Estimates of saturated hydraulic conductivity were calculated using these measured values of fracture conductivity for the percentage of area covered by the fracture per square meter of rock, given the fracture density and aperture size available for water to flow through. This was added to the saturated hydraulic conductivity of the rock matrix and weighted averages of bulk saturated hydraulic conductivity of bedrock, on the basis of percentages of matrix and fractures, were calculated by lithostratigraphic unit (see Appendix 1-C, B, Part 2). When infiltration from rain, snowmelt, or surface-water run-on occurs at a rate greater than the bulk saturated hydraulic conductivity of a subsurface layer, water will begin to fill the available storage capacity of the overlying soil. When the total storage capacity is exceeded, runoff is generated. While runoff can occur while the subsurface is still unsaturated due to precipitation exceeding the saturated hydraulic conductivity of the soil, this is on a small scale, and irrelevant to modeling of 30m x 30m grid blocks.

Figure 3-1. Field-scale water balance and processes controlling net infiltration. (Appendix 3)

[3]Some precipitation can also be intercepted and temporarily stored by vegetation surfaces, but this component of the hydrologic cycle is negligible at the study site.

[4]In this report, bedrock is used as a general term referring to all consolidated rock material that is either exposed (outcropping) or overlain by unconsolidated soil material.

[5]In this report, runoff is specifically defined as the volume or depth of water accumulation on the ground surface prior to being routed as surface-water flow, whereas run-on is defined as the volume or depth of the routed surface-water flow.

In the Yucca Mountain area, the hydrologic cycle can be limited to atmospheric, surface, and shallow sub-surface processes because contributions from ground water discharge and the deep unsaturated zone are insignificant relative to the other components of the cycle[6] (there is no perennial stream flow at the site).

3.3.3 Evapotranspiration

Evapotranspiration is the combined process of bare-soil evaporation and transpiration (excluding evaporation from open water bodies) (Freeze and Cherry, 1979, p. 4). Transpiration is the uptake and transfer of water to the atmosphere by vegetation. Transpiration is much more efficient than bare-soil evaporation in removing water from sub-surface soils and fractured bedrock. Evapotranspiration is a function of the potential evapotranspiration rate, the availability of water at the ground surface and within the root zone, vegetation characteristics such as timing of plant growth and root density, and the chemical and hydrologic properties of the root zone. The processes are not independent, but in general the primary factors controlling evapotranspiration are potential evapotranspiration, water availability, vegetation density, and seasonal vegetation growth. The more saturated the soil (or fractured bedrock) and the denser the vegetation, the closer the transpiration rate is to the potential evapotranspiration rate. If the soil (or fractured bedrock) becomes drier than what is conceptually referred to as the wilting point, transpiration will not occur even though there may be some residual water in the root zone. The redistribution of water within the root zone affects the total evapotranspiration rate because bare-soil evaporation extends approximately depths of only 10 to 30 cm, and the density and growth of roots within the root zone in general is typically observed to decrease with depth. The estimate of the depth of bare-soil evaporation is based on field measurements of water potential with depth. At above about 20-30 cm the water potential values are too dry for extraction by plant roots. The more quickly water redistributes to lower depths the greater the potential for net infiltration to occur because the overall susceptibility of water in the root zone to removal by evapotranspiration decreases with depth. At depths greater than the root zone vapor flow and matric suction potentials can result in upward unsaturated flow or exfiltration back into the root zone; but total water losses from these processes are considered negligible relative to evapotranspiration within the relatively thin root zone.

The potential evapotranspiration rate is determined by the energy balance and depends primarily on net radiation, air temperature, ground heat flux, the slope of the saturation-vapor density curve, and advective energy from wind (McNaughton and Spriggs, 1989; Priestley and Taylor, 1972; Flint and Childs, 1991). Net radiation depends primarily on solar radiation and surface characteristics including topography and albedo. For the current climate at Yucca Mountain, the average annual potential evapotranspiration rate is approximately six times greater than the average annual precipitation rate (Hevesi et al., 1994b, p. 2326); thus, on an annual basis, most of the precipitation is removed from the site by evapotranspiration. However, on a daily basis, the precipitation, snowmelt, or surface-water run-on rate, can be much higher than the potential evapotranspiration rate, especially during the winter when the potential evapotranspiration rate is at a minimum.

[6] Vapor flow enhanced by barometric pumping and temperature gradients also contributes to the water balance at the site but has been shown to be insignificant relative to precipitation, evapotranspiration, runoff, and net infiltration.

3.3.4 Net Infiltration

Net infiltration at Yucca Mountain is dominantly an episodic process that tends to occur only under wetter than average conditions or in response to isolated but intense storms (Flint et al., 1996; Flint and Flint, 1995; Hevesi et al., 1994a). For upland areas having thin soils and rooting depths, the occurrence of net infiltration requires saturated or near-saturated conditions at the soil/bedrock interface and within shallow bedrock fractures to initiate flow through open or filled fractures (see Section 6.1.2). Assuming that active roots can extend into bedrock along open or partially filled fractures, a maximum effective rooting depth of approximately two meters is estimated for fractured bedrock, with a much lower root density and water storage capacity relative to soils. For locations with thick soils, the occurrence of net infiltration requires percolation through a deeper average rooting depth that is estimated to be approximately 6 meters (Flint et al., 1996; Flint and Flint, 1995).

For larger storm or snowmelt events, water can accumulate in the root zone more rapidly than it can be removed by evapotranspiration. This is especially true during winter when potential evapotranspiration is at a minimum due to shorter days, lower sun angle, and lower air temperatures and root activity is either diminished or dormant. The downward percolation rate through the root zone under these conditions depends primarily on the storage capacity of the root zone and the field capacity and hydraulic conductivity of the soil and bedrock. The total storage capacity of the soil is defined as the porosity minus the residual water content multiplied by the soil depth. Field capacity is defined as the water content of the near surface soil profile (i.e., the root zone) at which drainage becomes negligible (several orders of magnitude less than the saturated flux rate) (Jury et al., 1991, p. 150). Field capacity is an old soil physics concept intended to provide a characteristic index of how much water may be retained from a rainfall event after redistribution has ceased. In actual field conditions, water drains continually under gravity. However, in coarse-textured soils such as those found at Yucca Mountain, the drainage rate falls to an insignificant level within a few days, after which the water content is changing at such a slow rate that a field capacity concept has practical value (Jury et al., 1991, p. 150). In skeletal soils found in southwestern Oregon, the water content at a measured mean value of -0.07 bars for field capacity was obtained (Flint and Childs, 1984). Flint and Childs (1984) argued that the water content at close to –0.1 bars was more appropriate for field capacity than the assumption of –0.33 bars that was commonly used, based on soil textures common to agricultural fields. This publication and other large scale studies conducted in major metropolitan water districts in southern California and regional watershed studies in Japan, provide support for the use of the field capacity concept in the gravelly sandy soils located at Yucca Mountain. For thick soils, reaching or exceeding field capacity at a depth of 6 meters tends to occur only for locations subject to concentrated surface-water flow, such as active stream channels and the base of steep sideslopes. For upland areas with thin soils, the percolation rate through the root zone depends on the field-scale storage capacity, and once exceeded, the hydraulic conductivity of bedrock. Thus, the effective field capacity of the root zone in upland areas is determined by bedrock lithology, fracture characteristics (density, aperture, filling), and the characteristics of the soil/bedrock interface, in addition to the characteristics of the overlying soil. The water potential that corresponds to the volumetric water content measured at field capacity is considered to be –0.1 bars and is shown for the soils used for modeling infiltration at Yucca Mountain in Appendix I-C.

Two exercises are conducted to illustrate the negligible value of drainage at water contents below the field capacity value of –0.1 bars. Using values of soil properties listed in Appendix 1-C, Table A1-6, unsaturated hydraulic conductivity was calculated for soils with average water potentials at 0.025 bars, -0.1 bars (field capacity), and -0.5 bars. At 0.025 bars the unsaturated hydraulic conductivity is reduced

about 2 orders of magnitude below that of the saturated hydraulic conductivity, with a value of 10.7 mm/day. At field capacity the rate drops to 4 orders of magnitude, with an unsaturated hydraulic conductivity of 0.25 mm/day. Once below field capacity, at 0.5 bars, the rate drops to 6 orders of magnitude, which is 0.003 mm/day. As the evapotranspiration rate at about –0.2 bars is approximately 2-3 mm/day, the soil dries quickly to very low drainage rates.

A calculation of drainage for measured soil water contents was done for a borehole located in an active channel, illustrating relatively wet conditions. For borehole N1, located in Pagany Wash where the channel is about 3 m in cross-section, and the soil is 8.3 m deep, drainage from the soil was calculated as the unsaturated hydraulic conductivity at an average volumetric water content from below an estimated zone of evapotranspiration, 3 m, to the bottom of the alluvium. For monthly measurements made for the period of 1984 through 1995, the drainage was calculated to be 0.5 mm/yr in this active channel with periodic runoff. Flux was calculated as described in Section 6.3.4 for this borehole, using the average water content for 2 m of soil below 6 m in depth. Increases in average water content between monthly measurements were summed for values that were greater than the measurement error of 0.006 m^3/m^3. The total flux calculated for the 10 year period was 83.5 mm/yr (when distributed over a 30 m grid cell, this equates to about 10 mm/yr.). The drainage due to gravity from the soil for this borehole was 0.6% of the total flux calculated for the borehole. Boreholes located in topographic locations where runoff is unlikely, such as terraces, have soils that are generally much drier, potentially reducing the drainage by several orders of magnitude below that calculated for this borehole. As the net infiltration flux calculated in these locations also is much lower, the contribution of drainage to the total flux in the borehole would be higher, but the drainage, even at somewhat moist ranges of between –1 bar and –5 bars, the drainage ranges from 0.2 mm/yr to 0.001 mm/yr.

In general, the volume of net infiltration occurring at Yucca Mountain under conditions of unsaturated ground-water flow when the root zone is drier than field capacity either in upland areas with thin soils or in locations with thick soils is considered negligible compared to the volume of net infiltration occurring as saturated flow through bedrock fractures or through thick soils that have reached or exceeded field capacity (Flint et al., 1996; Flint and Flint, 1995; Hevesi et al., 1994b; Nichols, 1987).

4. ASSUMPTIONS, CONSTRAINTS, BOUNDS, AND LIMITS

The assumptions pertaining to use of INFIL V2.0 are grouped according to the following types of investigations conducted: (1) development of the conceptual model of net infiltration, (2) development of the numerical model of net infiltration, (3) model calibration and comparison to independent methods, and (4) development of estimated input parameter distributions and climate inputs in support of the net infiltration uncertainty analysis documented in CRWMS M&O (2000b).

The numerical representation of the conceptual model depends on the assumption that simplification of physical processes characterized by the conceptual model can be achieved while maintaining a sufficient level of accuracy in the mathematical approximation of these physical processes. This assumption is supported, in part, by model calibration and model validation.

It is assumed on the basis of numerous YMP peer reviews and several publications (e.g. Hatton, 1998, pp. 5-7, 16), that the use of INFIL V2.0, which uses a distributed parameter, quasi-three-dimensional water-balance approach, and associated assumptions, is appropriate for the complexity of this analysis of net infiltration and is relevant in this large-scale application of providing the upper boundary condition to the UZ flow and transport model. It is noted that this approach does not necessarily represent the physics of infiltration in soils, but uses a water volume calculation approach in the mathematical and numerical models. This model has been compared successfully to several independent approaches to estimating net infiltration and recharge, and more rigorous methods based, for example, on detailed numerical solution of the differential equations of ground-water and surface-water flow are not feasible for use in this large-scale application.

The infiltration model and analysis are based on the assumption that the 1996 infiltration model, which was based on the distributed-parameter, water-balance approach and was calibrated using a variety of field data collected from 1984 through 1995, adequately represents the major features and processes controlling present-day and future infiltration at Yucca Mountain. The principal basis for the assumptions, discussed below, is that the resulting net-infiltration model quantitatively accounts for all major water inflow and outflow processes on a cell-by-cell basis and strictly imposes the conservation of total water mass within each model cell. The calculation results do not account for error propagation from the various components of the mass balance, such as measurement error associated with the various model inputs.

Within each cell of the model domain, water is assumed to move vertically downward within soil and bedrock, and that on a 30m x 30m grid block basis, there is no lateral diversion within the root zone. This is a viable assumption based on several calculations of specific conditions at the site. Given a land surface slope of approximately 4 to 6 degrees, the sine of the gravity vector is 0.07 to 0.10. The saturated hydraulic conductivity of the alluvium is 5.6E-6 m/s to 6.7E-6 m/s and the porosity is 35 percent. Using Darcy's equation and assuming fully saturated flow in a lateral downslope direction, with a perched system at the bedrock/alluvium contact that parallels the soil surface, the distance that lateral flow would travel in 30 days is approximately 3 to 6 m, thereby not moving beyond the 30m x 30m grid block area. If the slope were 45 degrees, the distance would be an order of magnitude greater. According to Hatton (1998), 1-dimensional, distributed-parameter, water-balance models are appropriate for use unless the excess rainfall generates overland flow (which is accommodated by flow routing in INFIL V2.0), or with the development of saturated conditions in soil profiles on slopes. The above calculation, and the fact that slopes have very thin soil cover and the underlying fractured bedrock has a high saturated hydraulic conductivity, negate this as a significant concern. On the other hand, if water were to move from one grid block downslope to the next grid block at the soil/bedrock contact, in a three-dimensional model configuration, this volume would be additive and would continue downslope until the slope was reduced, resulting in a shorter lateral travel distance. The total slope would only be affected in the uppermost and lowermost grid blocks. This component of error is considered to be insignificant relative to the spatial resolution required for the site-scale UZ ground water flow model.

Net infiltration is assumed to occur as fracture flow through the Tiva Canyon welded hydrogeologic unit (TCw) that is considered within the root zone. This assumption is based on relative changes in measured water content profiles that indicates that the penetration rates of the wetting front exceeded that calculated from the saturated hydraulic conductivity of the matrix alone. An assumption is also made that saturated fracture flow is maintained only for the duration that saturated conditions are maintained along the soil-bedrock interface. This assumption is based on interpretations of relative changes in the

time series of water content profiles measured in boreholes by neutron logging (Flint and Flint, 1995), and corresponding nearby measurements of water potential at the soil/bedrock contact indicating saturated or near saturated conditions. The net infiltration rate for the time periods when net infiltration is occurring is assumed to be numerically equivalent to the bulk saturated hydraulic conductivity of the bedrock. This model does not use pressure gradients to induce flow and does not consider positive pressure heads.

The evapotranspiration coefficients given in DTN: GS000300001221.009 are assumed to be representative of conditions at Yucca Mountain. The values used (alpha for saturated surfaces (1.26) and bare soil surface (1.04) and B (-10)) are based on measurements at other locations and are commonly used and regarded as appropriate within the scientific community (Priestley and Taylor, 1972 and Flint and Childs, 1991).

The stream-flow routing algorithm is not an approximate solution to the governing partial differential equations of surface water flow (various forms of the St. Venant equations). Kinematic and inertia effects, flood waves and backwater effects are not being modeled. Additional factors not being considered are density changes due to temperature changes throughout the water profile, gravitational acceleration, resistance terms, viscosity changes due to sediment load, phase changes, changes in fluid hydraulics due to shifts from turbulent to laminar flow, flow dispersion and dynamic shifts in channel geometry due to concurrent stream bed erosion and deposition. The only physical process being represented by this model is the lateral redistribution and subsequent infiltration of the runoff water volume and it is assumed that this can be adequately modeled based on elevation alone. In addition, the details of positive heads in active channels are insignificant relative to the uncertainty of available input parameters required to accurately define stream channel geometry for the entire stream channel network represented by this model.

It is assumed that changes in liquid properties, such as viscosity and density, on the saturated field-scale hydraulic conductivity of soil and bedrock are insignificant. This assumption is justified because temperature variations in the near-surface environment that could affect the viscosity or density of water are expected to be small and because dissolved constituents that could affect the density of water are expected to be present in insignificant concentrations.

While there is evidence that there is negligible downward flow occurring during long time-periods of no precipitation, it is included as an assumption. Very small changes in volumetric water content cannot be measured using neutron logging, which assumes that changes less than 0.006 m^3/m^3 are within the error of the measurement. Drainage under a unit gradient during time periods when soil water content is below field capacity can be calculated and an example is included in Section 6.1.5.

Model uncertainty is being addressed through parameter input distributions that are being developed as a part of the net infiltration model uncertainty analysis (CRWMS M&O 2000b). Input distributions are developed for 12 selected parameters (estimated a-priori as being potentially significant) from those included in the model control file. The developed distributions are based on assumptions of upper and lower bounds for each of the selected parameters. Additionally, the distribution type for each selected parameter is assumed. CRWMS M&O (2000b) should be consulted for complete documentation of the assumptions and their bases.

5. MODELING PROCEDURE

5.1 DISTRIBUTED-PARAMETER WATER-BALANCE MODEL

The distributed-parameter, water-balance model developed as the FORTRAN program INFIL V2.0 follows the conceptual model of infiltration discussed in Section 3.0, and is represented using a storage volume approach for modeling the root-zone. The total root-zone water storage capacity is calculated using the 30m x 30m area of each grid cell multiplied by the depth of the root-zone (including soil and bedrock layers) . The root-zone water balance calculation used to model net infiltration is illustrated by Figure 5-1. Infiltration into the root-zone and net infiltration through the root-zone is calculated independently for all grid cells and corresponding root-zone storage volumes. Because all grid cells have equal areas, the root-zone water storage terms are calculated as 1-dimensional vertical storage depths, which can easily be converted to volumes based on grid cell areas. The components of the root-zone water balance are determined for each layer using the water content of each layer. For water contents less than or equal to the water content at field capacity, infiltration is set to zero and water loss due to evapotranspiration from that layer is modeled as an empirical function of relative saturation (with relative saturation based on porosity and the residual water content) and potential evapotranspiration (Flint and Childs, 1991). For water contents greater than the water content at field capacity, water losses due to both infiltration and evapotranspiration from the layer are calculated. Infiltration into the underlying layer is set equal to the bulk saturated hydraulic conductivity of that layer (in millimeters per day). If the available water for net infiltration (calculated based on the amount of water remaining after evapotranspiration losses have been calculated) is less than the maximum infiltration amount determined using saturated hydraulic conductivity, water loss to infiltration is set equal to the amount of available water in the layer. For the lowermost root-zone layer in thick (6 meters or greater) soils, the daily water loss to infiltration is used to determine net infiltration. For upland areas with shallow soils where the root-zone is modeled as having a lowermost layer in bedrock, the amount of water available to evapotranspiration losses is calculated using the fracture porosity and the thickness of the bedrock layer. Once the water content of the bedrock layer has reached the limit defined by the fracture porosity, if water continues to infiltrate or percolate into the bedrock layer, net infiltration is calculated based on either the saturated hydraulic conductivity of the bedrock layer or the amount of available water (whichever determines the lower net infiltration amount).

On a daily basis, precipitation, snowmelt, and surface water run-on are added (as water depth) to the top layer of the root-zone profile at each grid cell. The surface water run-on depth is calculated as runoff generated and routed from upstream grid cells. If the amount of precipitation, snowmelt, and run-on added to the top layer exceeds the maximum daily amount calculated using the saturated hydraulic conductivity of the soil, then runoff (set equal to the amount of excess water) occurs at that grid cell location and is routed to the downstream grid cell. Surface-water flow depths are routed as part of an instantaneous flow routing algorithm representing a daily water balance. All overland flow is routed as a time-independent flow depth for each grid cell within a 24-hour time step (the physics of overland flow are not considered in this type of model). Daily surface water flow volumes are calculated using grid cell areas and converted to standard stream discharge units (cubic-feet-per-second) for comparison with measured stream flow records.

For locations where the lowermost root-zone layer is in bedrock, net infiltration is numerically equal to the bulk saturated hydraulic conductivity of the underlying bedrock (in millimeters/day) for the period of time where the water content of the lowermost root-zone layer exceeds the field capacity of that layer.

Net infiltration is simulated as the bulk saturated hydraulic conductivity of the underlying bedrock when the water content of the bedrock root-zone layer equals the fracture porosity of that layer. This condition is maintained only as long as the field capacity of the bottom soil layer (the soil layer above the bedrock layer) is exceeded. Thus, for upland areas with shallow soils, net infiltration is simulated as an episodic process requiring saturated conditions at the soil/bedrock interface and throughout the effective flow path of the bedrock layer included in the root-zone.

For locations with thick (greater than 6 meters) soil, net infiltration does not require saturated conditions at the bottom of the root zone, but does require that the water content of the bottom soil layer exceeds the field capacity of the layer. For upland areas, it is assumed that water ponded at the soil/bedrock interface and saturating the effective flow path through the bedrock root-zone layer percolates below the root-zone as net infiltration on a daily basis under a unit gradient. In all cases, water losses due to evapotranspiration are simulated for all root zone layers having a water content greater than residual prior to the calculation of net infiltration. During winter when potential evapotranspiration is at a minimum, ponded or saturated conditions at the soil/bedrock interface and throughout the effective flow path of the bedrock root-zone layer may exist for several days. Thus the total net infiltration is calculated as approximately the saturated hydraulic conductivity multiplied by the number of days net infiltration occurred. For days when the amount of water available for net infiltration is less than the limit set by the saturated hydraulic conductivity of the bedrock (this condition applies only to the last day of an extended net infiltration event), net infiltration equals the amount of water available to net infiltration in the lowermost root-zone layer.

The daily water balance model is applied over a continuous multi-year period and is driven by the continuous daily climate input provided for the total simulation period. The daily net infiltration rates calculated for each grid cell location are used to calculate an average annual net infiltration rate for each grid cell based on the total simulation period. The average annual net infiltration rate is calculated in units of length per time (millimeters per year), and can be directly applied as a specified flux upper boundary condition for the UZ flow and transport model.

Figure 5-1. The daily root-zone water-balance used to model net infiltration. (Appendix 3)

5.2 MODELING PROCESS

The net infiltration modeling process begins with building a geospatial input parameter base grid using the selected digital elevation model (DEM) to define the base-grid geometry. The development of the geospatial input parameter base grid and the separate watershed modeling domains requires the application of Geographic Information Systems (GIS) to transfer available digitized map data, which is in a vector-based format, onto the grid-cell of the raster-based format of the DEM (a process referred to as rasterization). The vector-based map coverages used as input by the net infiltration model include bedrock geology and soil type maps. In addition to the rasterization procedure, GIS applications are also used for calculating slope and aspect as well as latitude and longitude coordinates for all grid cells. Geospatial parameters that are not available as either raster-based or vector-based map coverages are developed using a series of FORTRAN routines that are applied sequentially. The routines are used to overlay three separate bedrock geology maps (after rasterization), estimate soil thickness, calculate the blocking ridge parameters, calculate surface water flow routing parameters, and extract the watershed model domains.

The DEM (DTN: GS000308311221.006) selected for defining the grid geometry is the composite DEM used for the original net infiltration model (Flint et al., 1996) that was developed from two standard USGS 7.5 minute 30-meter DEMs (Busted Butte and Topopah Spring NW). The two DEMs (DTN:GS000200001221.003) were combined into a composite DEM (DTN: GS000308311221.006) by using the ARCINFO, ARC-EDIT, ARC-PLOT, and ARC-GRID modules, utilizing a series of standard commands within the various modules. The grid geometry of the composite DEM (DTN: GS000308311221.006) is based on the Universal Transverse Mercator (UTM) projection (zone 11, NAD27) and consists of 691 rows in the north-south direction and 367 columns in the east-west direction covering a rectangular area centered over Yucca Mountain and the potential repository site, with the following corner coordinates:

Northwest corner:	544,661 meters easting, 4,087,833 meters northing
Northeast corner:	555,641 meters easting, 4,087,833 meters northing
Southeast corner:	555,641 meters easting, 4,067,133 meters northing
Southwest corner:	544,661 meters easting, 4,067,133 meters northing

The elevation provided by the composite DEM (253,597 values) is the primary geospatial parameter used by the net infiltration model. Elevation is used to define the surface-water flow-routing network, which is in turn used to define watershed-modeling domains which are extracted from the base grid and modeled separately as closed hydrologic systems. Elevation is used to define slope, aspect, and blocking ridge parameters for modeling incoming solar radiation that is in turn used in an energy balance calculation for modeling potential evapotranspiration. The calculated slope is also used to model soil thickness. Additional uses of elevation values in the net infiltration model include estimation of spatially distributed daily climate input (precipitation and air temperature).

In addition to the geospatial input parameters, the daily climate input and the model parameter inputs are defined prior to application of the net infiltration model. Daily climate input includes precipitation and air temperature. Model parameters include soil properties, bedrock properties, and root-zone parameters. An initial condition consisting of the root-zone water content is also defined prior to model application. Following the development of the base grid, the following 11 steps summarize the net-infiltration modeling procedure used for this analysis:

1. Acquisition and/or development of GIS map coverages and the application of ARCINFO V6.1.2 (USGS 2000) for the rasterization of geospatial parameters onto the base grid defined by the digital elevation model (DEM) for Yucca Mountain. Conversion of grid cell coordinates to both UTM zone 11 and geographic (latitude and longitude) using ARCINFO V6.1.2.

2. Calculation of topographic parameters, including grid cell slope and aspect using ARCINFO V6.1.2, and 36 blocking-ridge angles for each grid cell using the routine BLOCKR7 V1.0 (the blocking-ridge angles used in the geospatial-parameter input file for INFIL V2.0 are the same as those used in the input file for the 1996 INFIL V1.0 model).

3. Estimation of soil depth and refinement of bedrock geology (rock-type identification) using the programs GEOMAP7 V1.0, GEOMOD4 V1.0, and SOILMAP6 V1.0.

4. Calculation of surface-water flow routing parameters for each model grid cell using the DEM and the programs SORTGRD1 V1.0 and CHNNET16 V1.0.

5. Identification of watershed outflow locations using TRANSFORM[7] V3.3 for raster data visualization and output from CHNNET16 V1.0. Extraction of watershed modeling domains, including calibration modeling domains, using the DEM, the identified outflow locations, the calculated surface-water flow-routing parameters, and the program WATSHD20 V1.0.

6. Development of a daily climate input file (mod3-ppt.dat) for model calibration and modern climate simulations using available precipitation records from monitoring sites within the study area and in the proximity of Yucca Mountain. Development of mod3-ppt.dat is performed within an EXCEL spreadsheet (mod3-ppt.xls) using a linear interpolation method.

7. Estimation of pre-calibration model coefficients and initial conditions for root-zone water contents.

8. Calibration of root-zone model coefficients included as input in model control file for modeling program INFIL V2.0 by comparing simulation results for calibration watersheds against streamflow records.

9. Development of 100-year daily climate input files for modern climate scenarios using available precipitation records from the Nevada Test Site stations 4JA and Area 12 Mesa and the programs MARKOV V1.0 (STN 10142-1.0-00) and PPTSIM V1.0. (STN 10143-1.0-00) Development of daily climate input for future climate scenarios using the routine DAILY09 V1.0 and seven selected analog records from the EARTHINFO[8] database.

10. Application of INFIL V2.0 (STN 10307-2.0-00) using developed daily climate input (mod3-ppt.dat, 4ja.s01, area12.s01, nogales.inp, hobbs.inp, rosalia.inp, spokane.inp, stjohn.inp, beowawe.inp, and delta.inp), calibrated or estimated root-zone model coefficients, and watershed modeling domains for net-infiltration simulations.

INFIL V2.0 output is used to develop net-infiltration estimates for nine separate climate scenarios by averaging or sampling from individual net-infiltration simulations using the routine MAPADD20 V1.0. Output also is used to development of descriptive statistics for results over the areas of the potential repository boundary and the UZ flow and transport-modeling domain and development of model results as GIS coverages.

6. MODEL COMPONENTS

6.1 OVERVIEW

The INFIL V2.0 model algorithm consists of three main loops for performing a daily simulation of net infiltration over all model cells comprising a watershed model domain. Figure 6-1 provides a generalized illustration of the various model components required for simulating spatially distributed net-infiltration rates.

Figure 6-1. Major components of the net-infiltration modeling process. (Appendix 3)

[7] TRANSFORM is a registered trademark of Fortner Software LLC, 100 Carpenter Dr, Sterling, VA 20164.
[8] EARTHINFO is a registered trademark of EarthInfo Inc., 5541 Central Avenue, Boulder, CO 80301.

Figure 6-2. Flow chart of the model algorithm used for simulating net infiltration (Appendix 3).

Figure 6-2 provides a flow chart illustration of the general model algorithm and the primary loop (day-of-year loop), which is driven by the daily climate input file and carries the simulation through the time domain. Nested within the primary loop is a grid cell loop for performing a daily water balance calculation at each grid cell location and within each layer of the root zone. [The root zone was subdivided into layers based on the estimated maximum depth of bare-soil evaporation and an estimated variation in root density. In general, the layering represents a decrease in root density with increased depth in the root zone, particularly at locations with thick soils (greater than 6 meters).] The daily root-zone water balance consists of simulating precipitation, snowmelt, sublimation, evapotranspiration, changes in water content for each root-zone layer, net infiltration, and runoff generation. Nested within the water-balance loop is an hourly loop for modeling potential evapotranspiration based on the simulation of incoming solar radiation and effects on total solar radiation due to blocking ridges using the SOLRAD sub-model and the routine BLOCKR7 (Flint et al., 1996; Flint and Childs, 1987).

After the completion of the water-balance loop, a surface-water flow-routing subroutine is called if runoff was generated at any grid cell. Surface-water flow is routed at the end of the day as a time-independent (instantaneous) total daily flow depth across each grid cell. The routing algorithm connects all grid cells horizontally using surface-water flow-routing parameters included in the geospatial parameter input file. Surface-water flow is coupled to the water-balance calculation by allowing surface water to infiltrate into downstream grid cells according to the available root-zone storage capacity, soil hydraulic conductivity, and estimates for effective surface-water flow area and stream flow duration. The infiltrated water is added to the grid cell's antecedent root-zone water-content term used in the following day's water-balance calculation. The surface-water flow depth routed across the grid cell defining the outflow location of the watershed is converted to a daily mean discharge flow rate, in cubic feet per second (cfs),[9] which can be compared to measured stream flow for model calibration.

Time-averaged net-infiltration rates are calculated by accumulating the simulated daily net-infiltration amounts obtained at the end of the daily water-balance loop. Time average rates also are calculated for the remaining components of the water balance (precipitation, snowmelt, sublimation, evapotranspiration, infiltrated run-on, root-zone water-content change, and runoff) for all model grid cells and are included in the main output file used for developing the net-infiltration results. The time-averaged rates for all components of the water balance simulated at each grid cell are averaged over the watershed model domain and compared against the time-averaged watershed outflow to check the consistency of the simulated water balance for the entire watershed.

Output from INFIL V2.0 also includes spatially averaged daily water-balance terms for all components of the water balance. The daily output indicates the average inflow, outflow, and change in storage rates over the area of the watershed being simulated. The spatially averaged daily water balance is compared against the simulated daily outflow to provide a water-balance check for each day simulated. The simulated daily water balance rates are averaged over time and compared against the spatially averaged water-balance rates simulated at each grid cell as an additional method of checking the consistency of the simulated water balance for the entire watershed.

6.2 DAILY WATER AND ENERGY BALANCE

[9] Cubic feet per second is a standard unit used for volume discharge rates in surface water hydrology

The estimation of spatially distributed net-infiltration rates consists of a daily simulation of net infiltration in response to a daily water- and energy-balance calculation performed separately for all model elements within a watershed bounded by surface-water flow divides. The daily water-balance calculation used in INFIL V2.0 is:

$$R_{off}' = P - SF + IR_{on} + SM - SB - SW - ET - I \qquad \text{(Eq. 6-1)}$$

where I = net infiltration, P = precipitation (rain and snow), SF = snowfall, SB = sublimation, SM = snowmelt, SW = change in water-content storage within the root zone, ET = evapotranspiration, IR_{on} = infiltrated surface-water run-on, and R_{off} = surface-water runoff generated by excess precipitation, snowmelt, or run-on. It is important to note that runoff, not net infiltration, is calculated as the solution to the water-balance equation. A unit gradient is assumed and net infiltration is incorporated in the water-balance formulation as a temporary potential net-infiltration term and is limited by the field-scale-saturated hydraulic conductivity of the soil or bedrock underlying the root zone.

The daily water-balance calculation performed for a root zone is illustrated in Figure 5-1, which was discussed in Section 5. In this figure water balance of the root zone is schematically represented for a single soil layer. In modeling the daily water-balance, parameters affecting the daily water balance, such as soil thickness, soil and bedrock properties, and various surface and vegetation characteristics, are uniquely defined for each grid cell. The difference between field capacity and residual water content is commonly referred to as available water capacity in soil science terms and that is the water available for plants. Therefore this is the zone in which the transpiration part of evapotranspiration processes take place. The infiltration rate of precipitation, snowmelt, or surface-water run-on into the root zone from the land surface is limited by the saturated hydraulic conductivity of the grid cell soil type (or the bulk saturated hydraulic conductivity of the grid cell bedrock type in cases of no soil cover). Precipitation and surface-water flow rates are defined using an estimated 2-hour storm duration for summer storm events and an estimated 12-hour storm duration for winter storm events. If the precipitation or snowmelt rate exceeds the saturated hydraulic conductivity of the top root-zone layer, the excess precipitation or snowmelt is added to the runoff term for that grid cell. During the simulation of surface-water flow, the infiltration of surface-water run-on is also limited by the saturated hydraulic conductivity of the top root-zone layer. Surface-water run-on exceeding the saturated hydraulic conductivity of the top root-zone layer is added to the runoff term routed to the downstream grid cell.

As noted in Figure 5-1, infiltration is represented as equal to recharge. This is not entirely the case because in a deep unsaturated zone there are several mechanisms that may remove a small amount of water and the timing of recharge is not accounted for. At Yucca Mountain there are unsaturated zone groundwater ages of over 7,000 years.

6.3 DAILY CLIMATE INPUT

Infiltration occurs in response to daily precipitation that occurs in particular temporal and spatial patterns. Stochastic representations of infiltration would be required to predict infiltration for long time periods without daily input; however, no infiltration data are available for the development of long-term patterns. Therefore, using stochastic representations of precipitation and daily input to simulate infiltration is appropriate.

The daily climate input file is the primary control for the timing and duration of the simulation. The daily climate input file defines the time domain through which the simulation occurs by providing a real-time sequential input of daily climate parameters. The file is ASCII column formatted and at minimum consists of the year number, the day of year number, and the total daily precipitation amount but can also consist of maximum, minimum, and average daily air temperature, along with total daily snowfall accumulation.

The primary input provided by the daily climate-input file is total daily precipitation, in millimeters, and this drives the daily water-balance calculation. Average daily air temperature, in degrees Celsius, is not required as input, but if not provided in the daily climate input file, this parameter is modeled internally by INFIL V2.0 using Equation 20 from Flint et al. (1996):

$$T = T1 - T2 \{\mathrm{Sin}[(D/366)*2*\pi + 1.3]\} \qquad \text{(Eq. 6-2)}$$

where T = modeled daily air temperature, D = day of year number, T1 = mean annual air temperature, and T2 = mean seasonal variation of average daily air temperatures above the mean during summer and below the mean during winter (the ½ amplitude of the sine wave). T1 and T2 were calculated as 17.3 and 11.74 degrees Celsius, respectively, using measured air temperature data from Yucca Mountain (DTN: GS000208312111.002).

The daily climate input file provides point values of total daily precipitation and average daily air temperature for a given day of the simulation. These values are representative of the conditions at locations having elevations of approximately 1,400 meters, which represents the approximate average elevation of the land surface above the potential repository. Precipitation and air temperature are distributed spatially across all model grid cells using empirical elevation models. The precipitation/elevation correlation, caused by the adiabatic cooling of air masses interacting with mountainous terrain, has been studied in the southern Nevada region and correlation models between elevation and annual as well as seasonal precipitation amounts have been defined (French, 1983; Hevesi et al., 1992; Hevesi and Flint, 1998). The precipitation/elevation correlation model used in INFIL V2.0 for modern climate was from Hevesi and Flint (1998, Table 4, DTN: GS960108312111.001) for the sample of 114 precipitation stations with a minimum of 8 years of record, where the coefficients in the table are based on mean annual precipitation transformed as ln(MAP) x 1,000. The model estimated mean annual precipitation distributions using the relation:

$$P_d^k = P_d * \exp(0.0006458*E + 4.317)/MAP \qquad \text{(Eq. 6-3)}$$

where P_d^k = the elevation-corrected daily precipitation estimate (in millimeters) for day d at model element k, P_d = the point precipitation estimated for day d provided by the daily climate input file, E = elevation (in meters), and MAP = mean annual precipitation (in millimeters). For the monsoon and glacial transition climate scenarios, the slope defined by Equation 6-3 was adjusted to account for assumed changes in the precipitation/elevation correlation based on estimates of precipitation-elevation correlations presented by Thompson et al. (1999), indicating a reduction in orographic effects on precipitation for wetter paleoclimates.

Atmospheric pressure decreases with increasing altitude. Consequently, stirring of an atmospheric layer causes rising parcels of air to cool by adiabatic expansion, and sinking parcels to correspondingly warm by compression. The net effect of this is a vertical decrease in temperature with increase in elevation

called the adiabatic lapse rate. The adiabatic lapse rate, or air temperature/elevation correlation is cited in numerous references as about 9.8 degrees C per kilometer and was cited for this work using Maidment (1993, p. 2.27):

$$T_d^k = 0.0098 * (1400.-E^k) + T_d \qquad \text{(Eq. 6-4)}$$

where T_d^k is the elevation-adjusted air temperature for grid cell k based on elevation E and daily air temperature T_d (either provided in the daily climate-input file or simulated using Equation 6-2). The elevation E is subtracted from the estimated mean elevation for the potential repository area that is indicated in the equation as 1,400 m. This is the approximate average ground surface elevation of the potential repository.

Cloud cover is a variable affecting the energy-balance calculation and is indirectly accounted for in the model as an empirical function of daily precipitation magnitude. For days with precipitation, the modeled clear-sky potential evapotranspiration rate is reduced according to:

$$APET_d = PET_d/[(4*P_d/25.4) + 1] \qquad \text{(Eq. 6-5)}$$

where APET = adjusted potential evapotranspiration for day d (in millimeters), PET_d = the Priestley-Taylor modeled clear-sky potential evapotranspiration for day d (PET is discussed further in Section 6.4.4), and P_d = modeled daily precipitation for day d. The coefficient 25.4 converts inches to millimeters, and the value 4 is an estimate that reduces the PET by approximately 25 percent due to cloud cover that exists whenever it rains. The assumption is that the energy for ET is reduced in the presence of clouds (associated with precipitation) and the more rain there is, the less ET there is. The model is fairly insensitive to this value.

6.4 SNOW PACK SUB-MODEL

Precipitation is simulated as snowfall for a grid cell location if the average air temperature is less than or equal to 0 degrees Celsius. When snowfall occurs, all precipitation for that day is assumed to occur as snow at that location. However, because air temperature is distributed spatially using the elevation correlation model, snowfall and snow pack accumulation may occur at higher elevation cells while rain occurs at lower elevations within the same watershed.

Snowfall is accumulated into a snow pack storage term and is removed from the root-zone water balance. If snow pack exists and the air temperature is less than 0 degrees Celsius, water is removed from the snow pack by using an empirical sublimation-saltation-suspension model under the assumption that in upland areas advective wind-transport processes tend to cause snow removal rather than deposition over most areas. The three processes are grouped into a single empirical "sublimation" model that also includes evaporation of snowmelt and sublimation (but not saltation and suspension) when the air temperature exceeds 0 degrees Celsius:

$$SB^k = A1 * APET^k,\ T^k <= 0 \text{ (sublimation/advective losses)} \qquad \text{(Eq. 6-6)}$$
$$SB^k = A2 * APET^k,\ T^k > 0 \text{ (evaporation of snowmelt and sublimation)}$$

where SB^k = total snow pack losses to the atmosphere (in millimeters), $APET^k$ is the cloud cover adjusted Priestley-Taylor potential evapotranspiration rate[10], (in millimeters/day), and T^k is the average air temperature simulated for grid cell k (in degrees Celsius). The model coefficients were estimated based on limited information indicating the average percentage of snow pack losses due to sublimation and advective energy processes (Maidment, 1993, pp. 7.4-7.10). For all simulations using the snow pack sub-model, A1 was set to 0.1 and A2 was set to 0.3 in the model control file. This is an assumed relation to account for an increase in snow pack losses to the atmosphere when the average daily air temperature is above freezing. If a snow pack exists and air temperature is greater than 0 degrees Celsius, a combined sublimation of snow and evaporation of snowmelt is simulated, and the APET term is reduced by the sublimation/evaporation rate SB to provide a potential transpiration rate for the root zone. Thus, the model allows reduced transpiration to occur when a snow pack exists but only if air temperature is higher than 0 degrees. For all days when air temperature is 0 degrees or less, transpiration is set to zero, and only sublimation can occur, provided a snow pack exists.

If air temperature is greater than 0 degrees Celsius, snowmelt is simulated as an empirical linear function of average daily air temperature (Maidment, 1993, pp. 7.4-7.10) using a standard temperature index modeling approach:

$$SM^k = A * T^k \qquad \text{(Eq. 6-7)}$$

where SM is the modeled snowmelt (in millimeters) for grid cell k; T is the modeled average daily air temperature (degrees Celsius) for grid cell k; and A was set to 1.78, which is the coefficient used for modeling snowmelt in the Sierra Nevada during April (Maidment, 1993, Table 7.3.7, p. 7.24) The simulated snowmelt is carried back into the root-zone water-balance calculation as an influx term.

6.5 POTENTIAL EVAPOTRANSPIRATION AND THE NET RADIATION SUB-MODEL

Total daily potential evapotranspiration is modeled for each grid cell using the Priestley-Taylor equation (Priestley and Taylor, 1972):

$$PET_d^k = \alpha * [s/(s + \gamma)_d^k * (RN_d^k - GH_d^k) / 2.45*10^6] \qquad \text{(Eq. 6-8)}$$

where PET_d^k is potential evapotranspiration (in millimeters) on day d for grid cell k; S is the slope of the saturation vapor pressure-temperature curve; γ is the psychometric constant; RN is modeled net radiation; and GH is estimated ground-heat flux, which is modeled using Equation 22 from Flint et al. (1996):

$$GH = -20 + 0.386(RN) \qquad \text{(Eq. 6-9)}$$

and $2.45*10^6$ converts the energy units to millimeters of water. In Equation 6-8, α is used as an empirical scaling factor to account for the missing advective energy term in the Priestley-Taylor

[10] The potential evapotranspiration rate used in the sublimation model uses a Priestley-Taylor α coefficient value of 1.26 to account empirically for the advective component of the total energy balance and is not necessarily equivalent to the values of the coefficient used in the root-zone model.

equation. For wet conditions having freely evaporating surfaces, α is often set to 1.26 (Priestley and Taylor, 1972; Flint and Childs, 1991; DTN: GS000300001221.009). For dry conditions, available moisture becomes the limiting factor controlling actual evapotranspiration, and α can be modeled as an empirical scaling function, α', using a relative saturation term (Flint and Childs, 1991). In the root-zone water-balance sub-model, α' is defined as an empirical function of relative saturation within the root zone by using a method described in Section 6.4.6.

The $s/(s+\gamma)$ term is modeled as a function of average daily air temperature by using Equation 19 from Flint and et al. (1996):

$$s/(s+\gamma)_d^k = -13.281 + 0.083864 * TA_d^k - 0.00012375 * (TA_d^k)^2 \qquad \text{(Eq. 6-10)}$$

where TA^k is the average daily air temperature on day d for grid cell k, in Kelvins. Equation 6-10 was defined using parameter values obtained from performing a regression on data from Campbell (1977, Table A.3), and provides an indication of the relative effect of air temperature on potential evapotranspiration, which varies for different temperature ranges. In Figure 6-3, Equation 6-10 is compared with selected values taken from (Campbell, 1977, Table A.3) to illustrate the greater relative change in the $s/(s+\gamma)$ term for the lower air temperatures in the range –5 to 5 degrees Celsius as compared to temperatures in the range of 25 to 35 degrees Celsius. For example, a decrease in air temperature from 5 to 0 degrees Celsius results in a 17 percent reduction in $s/(s+\gamma)$ and thus potential evapotranspiration, while a decrease in air temperature from 35 to 30 degrees Celsius causes only a 5 percent reduction in the $s/(s+\gamma)$ term.

Figure 6-3. Relative effect of air temperature change on the modeled $s/(s+\gamma)$ term of the Priestley-Taylor equation used for estimating potential evapotranspiration (Appendix 3).

Total daily net radiation is the primary component of the energy balance determining potential evapotranspiration and is modeled using Equation 21 from Flint et al. (1996):

$$RN_d^k = -71 + 0.72 * K_d^k\downarrow \qquad \text{(Eq. 6-11)}$$

where RN is total net radiation, in w/m^2, on day d for model element k, and $K\downarrow$ is simulated incoming solar radiation which is modeled using a version of the SOLRAD program developed by Flint and Childs (1987). To account for seasonal changes in the solar trajectory as well as terrain effects across model elements, SOLRAD calculates solar position on an hourly[11] basis from sunrise to sunset as a function of the day of year and geographic position of each grid cell (Flint and Childs, 1987). Terrain effects (blocking ridges) on incoming solar radiation are modeled using topographic parameters calculated from the DEM and included as input in the geospatial parameter file. Topographic parameters include grid cell slope, aspect, and 36 blocking ridge angles that define shading effects and reductions in skyview for every 10 degrees in the horizontal plane, starting with the UTM northing axis as the 0-degree azimuth. Shading causes a reduction in direct beam radiation, and diminished skyview decreases diffuse radiation. These effects can become important in rugged mountainous terrain.

[11] The time step is a user-specified option included in the model control file. Although a 1-hour time step is allowed, a 2-hour time step was used to reduce simulation run time.

6.6 ROOT-ZONE SUB-MODEL: INFILTRATION, PERCOLATION, AND REDISTRIBUTION

Water infiltrating and percolating through the multi-layered root-zone system is modeled as a cascading piston-flow process. Downward percolation is modeled as a "forward" cascade initiated by adding the total volume of water infiltrating the top layer of the root zone to the antecedent water content of the layer. The new water content is calculated using the layer thickness and compared against the field capacity defined by the grid cell soil type. The volume of water exceeding the field capacity becomes downward percolation that is added to the antecedent water content of the underlying layer, and the new water content of the underlying layer is compared against the field capacity of that layer. If the potential percolation volume exceeds the saturated soil hydraulic conductivity or the saturated bulk bedrock hydraulic conductivity of the underlying layer, the downward percolation rate is set equal to the saturated hydraulic conductivity of the underlying layer, and the excess water volume is added to a temporary storage term for the overlying layer. The process is repeated for each soil and bedrock layer in the root zone (in the case of the model used in this analysis/modeling activity, a maximum of three soil layers and one bedrock layer was used) until the bottom layer is reached, which completes the forward cascade.

The volume of water that has percolated into the bottom bedrock layer (which may be zero if the field capacity of an overlying layer was not exceeded) is compared against the effective root-zone storage capacity of the bedrock. If a bedrock layer exists in the root zone, the effective root-zone storage capacity of the bedrock layer is calculated based on the estimated root-zone depth, the estimated soil depth, and the estimated effective fracture porosity of the rock. The volume of water exceeding the bedrock storage capacity is the potential net-infiltration volume. For thick soils, there is no bedrock layer in the root zone. The thickness of the bedrock root-zone layer is set to zero, the effective fracture porosity for the bottom bedrock layer becomes zero, and all water exceeding the field capacity of the bottom soil layer (the third soil layer) is potential net infiltration unless limited by the saturated bulk hydraulic conductivity of the underlying soil or bedrock. For locations where the soil depth is estimated to be 6 meters or greater, the underlying bedrock properties are defined using alluvium/colluvium properties. Based on analysis of neutron moisture meter data (Flint and Flint, 1995), the maximum depth of infiltration in non-channel alluvial locations is 6 meters, therefore there is no need to provide bedrock properties in these locations. The actual net-infiltration volume is calculated after evapotranspiration is simulated throughout the root zone and is limited by the bulk saturated hydraulic conductivity of the underlying rock type. The potential net-infiltration volume exceeding the bulk saturated hydraulic conductivity is added to the temporary storage term of the bottom root-zone layer.

Starting with the bottom root-zone layer, a reverse cascade is performed to determine if runoff is generated. The volume of water in the temporary storage term is compared against the total storage capacity of each layer defined by the porosity (or effective fracture porosity in the case of bedrock) and layer thickness. If the volume of water in the temporary storage term exceeds the storage capacity, the excess water is added to the temporary storage term of the overlying layer. The process is repeated until the top layer is reached, completing the reverse cascade. The volume of water in the temporary storage term exceeding the storage capacity of the top layer is added to the potential runoff volume calculated for that grid cell. The final runoff volume is calculated following the simulation of evapotranspiration from the root zone.

6.7 ROOT-ZONE SUB-MODEL: EVAPOTRANSPIRATION, RUNOFF, AND NET INFILTRATION

After the completion of the reverse cascade and the placement of excess water into temporary storage terms, evapotranspiration is simulated for each root-zone layer using a dynamic root-zone weighting function and the modified Priestley-Taylor. Evapotranspiration is simulated only for days with air temperature greater than 0 degrees Celsius. The dynamic weighting is based on calculated relative saturations for each root-zone layer and the relative distribution of water (based on saturation) throughout all layers. The purpose of the dynamic weighting is to increase root activity for the wettest layer. Static root density weights are also incorporated into the dynamic weighting function, setting an upper limit on root activity within each layer. For the top soil layer, the bare-soil evaporation term is added to the transpiration term. Using the calculated weighting terms, evapotranspiration is simulated by applying a form of the modified Priestley-Taylor equation developed by Flint and Childs (1991, coefficients in DTN: GS000300001221.009) to each layer of the root zone:

$$ET^k = \alpha' * PET^k \qquad \text{(Eq. 6-12)}$$
$$\alpha' = \sum_i \{wgt_i * [a^k (1-\exp(b^k * relsat_i^k))]\}$$

where ET^k is total root-zone evapotranspiration for grid cell k; PET^k is the adjusted clear-sky simulated equilibrium[12] potential evapotranspiration rate for grid cell k; $relsat_i^k$ is the relative saturation calculated for layer i within grid cell k; a^k and b^k are the Priestley-Taylor model coefficients for grid cell k supplied as soil- and rock-type input parameters in the model control file (in this analysis, the coefficients were identical for all soil and rock types but were varied between different climate scenarios and between soils and rocks). After water contents for each layer are reduced according to the calculated evapotranspiration rates, the final runoff and net-infiltration terms are calculated, and the new water-content terms for each root-zone layer are up-dated for the following day's water-balance calculation.

6.8 SURFACE-WATER FLOW-ROUTING SUB-MODEL

At the completion of the root-zone water balance loop, the surface-water flow sub-model is called if the runoff accumulation term is greater than zero (at least one grid cell has generated runoff). The sub-model uses an instantaneous flow routing (IFR) method to perform an efficient time-independent simulation of surface-water flow. The purpose of the routing algorithm is to calculate the lateral redistribution of water throughout the watershed domain and to allow for the infiltration of surface water as it is routed. The surface water flow routing algorithm is fully coupled with the algorithm used to calculate infiltration into the root zone. There is no need to predict a flood wave, peak flows, or backwater effects, and thus a finite difference approximation of the St. Venant equations is not required. The IFR method assumes that the duration of surface-water flow at Yucca Mountain is less than 24 hours, which is generally supported by the available stream flow records and field observations (Savard, 1995; Flint et al., 1996, Figure 23; DTN: GS960908312121.001). For the purpose of calculating daily net infiltration, it is not necessary to perform surface water flow routing at time steps less then the daily water balance, especially when stream flow events are known to be episodic and have duration less then 24 hours (at least for current climate conditions).

[12] The equilibrium potential evapotranspiration rate is calculated using $\alpha = 1.0$, and is used to represent the non-advective component of the energy balance.

The routing is performed using parameters calculated by the routine CHNNET16 V1.0 and included in the geospatial parameter input file. The routing parameters identify downstream cell connections for all cells in the model domain. The flow routing routine determines which of eight surrounding grid cells is the lowest in elevation and calculates the flow directions for each grid cell by first sorting the entire base-grid based on elevation, then using a standard D8 convergent flow routing algorithm in the routine. Multiple cells are allowed to route to a single cell, but any given cell can route to only one downstream grid cell (as opposed to two in cases of flow dispersion). In this way, channels are defined for every watershed. In general it is adequate to drive all flow along one connected node pair. The flow routing algorithm models convergent flow only. Inaccuracies resulting from a lack of flow dispersion are not significant within the area of the potential repository, and are not significant within most areas of the UZ flow and transport model. Inaccuracies resulting from a lack of flow dispersion tend to increase as flow is routed across more gently sloping alluvial fans, particularly in cases where the stream channel becomes braided or is not well defined.

The IFR sub-model repeats the infiltration and percolation simulation performed in the water- balance loop, providing a 2-dimensional coupling of surface-water flow and infiltration. As with precipitation and snowmelt, infiltration of run-on is a function of the storage capacity and hydraulic conductivity of the underlying soils and bedrock. The fraction of the total grid cell area affected by surface-water flow is defined in the model control file and is used to scale the bulk hydraulic conductivity of the grid cell as a means of limiting total infiltration volumes along the width of the active channel. The scaling is performed by using an estimate of the average fraction of the total grid cell area wetting by surface water flow. For example, if the scaling factor is 0.1, only 10 percent of the 30m x 30m area of the grid cell is wetted, on average, by surface water. Thus the effective saturated hydraulic conductivity used to limit the volume of water infiltrating into the grid cell is multiplied by 0.1 to account for the reduction in area. Saturated conditions along the active channel are assumed for estimated storm duration of 2 hours for summer storms and 12 hours for winter storms. Positive pressure heads are assumed to be negligible and are not included in the calculation of infiltration volumes. The increase in water content for each layer in the root zone is stored and included in the following day's root-zone water-balance calculation.

Surface water that is routed off the model grid is stored as an outflow term. For watershed model domains, there is only one outflow point and the outflow term represents stream discharge from the watershed. The outflow term is incorporated into a global mass-balance calculation using:

$$D = \sum R_{off}{}^{k} - \sum IR_{on}{}^{k} = \sum P^{k} + \sum SM^{k} - \sum SB^{k} - \sum SW^{k} - \sum ET^{k} - \sum I^{k} \qquad \text{(Eq. 6-13)}$$

where D is the watershed outflow, P is defined for this equation as rainfall, and the water balance terms defined in Equation 6-1 are summed for all grid cells k in the watershed. Equation 6-13 is calculated for each day of the simulation as a means of verifying the mass balance over the modeling domain.

7. MODEL INPUT

User-defined model inputs for INFIL V2.0 consist of four general groups: (1) geospatial parameters, (2) hydrologic properties, (3) empirical model coefficients, and (4) daily climate input. Additional model coefficients are defined within the model source code The data acquired or developed and used as input for modeling net infiltration consist of either ASCII digital data or proprietary formats for acquired software applications (ARCINFO map coverages, EARTHINFO data formats).

7.1 STANDARD INPUT

7.1.1 Accuracy of Input Parameters

The accuracy of all model inputs could not be fully quantified at the time of this activity. Uncertainty in model inputs was not incorporated into the results developed in this report. A preliminary uncertainty analysis is provided by CRWMS M&O (2000b), and will be used in the UZ Flow and Transport Process Model Report (CRWMS M&O 2000a) to provide a limited evaluation of model accuracy and uncertainty based on estimated bounds and distributions for a few selected input parameters. The development of input distributions for the selected parameters is discussed in Section 4.

7.1.2 Data Requirements

Input and Output Data Defaults

There are no data defaults. Because the program is free format, the user must enter a place-holder value for all read statement parameters. It is the user's responsibility to recognize realistic and correct data.

File Formats

Most data variables are entered in free format (list directed input/output). The variable order is included in Appendices 1, 2, and 3.

Allowable/Tolerable Ranges for Inputs and Outputs

There are no data defaults. Because the program is free format, the user must enter a place-holder value for all read statement parameters. It is the user's responsibility to recognize realistic and correct data.

All model input required directly for simulating net infiltration using the developed model code INFIL V2.0 is provided by three separate ASCII files. These are the model control file, geospatial parameter input file, and the daily climate input file. The model control file specifies input and output options, input and output file names, modeling options, simulation period, model coefficients, and hydrologic properties. The Geospatial Parameter Input File is used for modeling grid geometry and watershed modeling domains.

Table A1-1 indicates the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for tests. Any special conditions or modifications made to the input files used for a test case will be identified.

7.2 MODEL CONTROL INPUT FILE

The model control file specifies input and output options, input and output file names, modeling options, simulation period, model coefficients, and hydrologic properties. See Appendix 1 for detailed description and example file.

7.3 DAILY CLIMATE INPUT FILE.

As discussed in Section 6.3, the daily climate input file is the primary control for the timing and duration of the simulation. The daily climate input file defines the time domain through which the simulation occurs by providing a real-time sequential input of daily climate parameters. The file is ASCII column

formatted and at minimum consists of the year number, the day of year number, and the total daily precipitation amount but can also consist of maximum, minimum, and average daily air temperature, along with total daily snowfall accumulation.

The reader is referred to Appendix 1-B for a detailed description and example of the Daily Climate Input File.

7.4 GEOSPATIAL PARAMETER INPUT

The net infiltration modeling procedure begins with building a geospatial input parameter base grid using the selected digital elevation model (DEM) to define the base-grid geometry. The parameters included in the geospatial-parameter input file defining each watershed model domain are: grid cell identifier, UTM easting (meters), UTM northing (meters), latitude (decimal degrees), longitude (decimal degrees), row identifier, column identifier, downstream grid cell identifier, number of upstream cells, elevation (meters), slope (degrees inclination from horizontal), aspect (degrees from north), and other physical attributes, including soil-type identifier, soil depth class identifier, soil depth (meters), rock-type identifier, topographic position identifier, vegetation-type identifier, percent vegetation cover, and 36 blocking-ridge angles.

7.4.1 Topographic Parameters (Slope, Aspect, and Blocking Ridges)

Topographic parameters, such as the flow-routing parameters, are calculated directly from the DEM and included in the geospatial-parameter input file. Additional topographic parameters include slope, aspect, and blocking ridge angles, which are required by the SOLRAD routine in the potential evapotranspiration sub-model. The 36 blocking ridge angles (degrees of inclination above horizontal) are calculated at each 10-degree horizontal arc (with the azimuth aligned in the UTM northing direction) for each grid cell using the routine BLOCKR7 V1.0. Calculations were performed using the DEM as input and a technique for approximating the 10-degree horizontal angles based on northing and easting grid cell distances. The blocking ridge parameters cannot account for topographic influences outside of the DEM, and thus the blocking ridge effect is only partly accounted for along the perimeter of the DEM. Slope is also a required input parameter for estimating soil depths using the routine SOILMAP6 V1.0. Slope and aspect were calculated for the 1996 version of the net-infiltration model (Flint et al., 1996) using standard GIS applications in ARCINFO V6.1.2.

7.4.2 Soil and Bedrock Classification

Soil-Depth Classes

A soil-depth-class map consisting of four separate soil-depth classes was developed for the 1996 net-infiltration model (Flint et al., 1996, Figure 13; DTN: GS960508312212.007). The four depth classes represent different ranges in actual soil depths that were estimated using a combination of Quaternary geologic maps, field observations, and soil depth recorded at borehole sites (Flint and Flint, 1995, Table 2). Depth class #1 identifies locations with soil depths ranging from 0 to 0.5 meter and primarily occurs in rugged upland areas. Depth class #2 identifies deeper soils ranging from 0.5 to 3.0 meters occurring at mid to lower side-slope locations in upland areas affected by slumps, slides, and other mass-wasting processes. Depth class #3 identifies locations in the transition zone between upland areas and alluvial fans or basins with intermediate soil depths ranging from 3 to 6 meters. Depth class #4 identifies soils

with depths of 6 meters or greater. The soil-depth classes were used to estimate soil depths based on calculated slope and an empirical soil-depth model described Appendix 1-C.

Soil Types

A soil-type classification map is defined in Flint et al. (1996; Figure 14, DTN: GS960508312212.007). The soil-type classification is based on a recombination of mapped Quaternary surficial deposits and defines 10 unique soil types based primarily on differences in soil texture. Soil texture and porosity data were obtained using field samples and laboratory measurements (DTN: GS950708312211.002) as described in Flint et al. (1996; p. 42). Soil hydrologic properties consisting of hydraulic conductivity, residual water content, and field capacity were both measured and estimated using the soil texture data as described in Flint et al. (1996, p. 41) and Appendix 1-C. The soil hydrologic properties included directly as model input (using the model control file) for INFIL V2.0 consist of porosity, field capacity, residual water content, and saturated hydraulic conductivity, and are the same as the properties used in the 1996 version of the net-infiltration model (INFIL V1.0) which are listed in Flint et al. (1996, Table 4, p. 42).

7.4.3 Bedrock Geology

Bedrock geology was defined for each grid element using three different ARCINFO map coverages and a vector to raster conversion performed by ARCINFO. Figure 7-1 indicates the areal coverage of the three maps: the 1:6,000-scale Bedrock Geologic Map of the central block area by Day et al. (1998, DTN: GS971208314221.003), the Preliminary Geologic Map of Yucca Mountain by Scott and Bonk (1984, DTN: MO0003COV00095.000), and the Geologic Map of the Topopah Spring Northwest Quadrangle by Sawyer et al. (1995, DTN: GS000300001221.010). Within the UZ flow and transport model area, bedrock geology for the net-infiltration model (which is defined as a unique integer identifier for each rock type in the geospatial-parameter input file) is primarily defined by Day et al. (1998). Bedrock geology for the northern and southern perimeter sections of the UZ flow and transport model area is defined by Scott and Bonk (1984).

Figure 7-1. Overlay of the three geologic maps used to define rock types underlying the root zone and included in the bottom root-zone layer. (Appendix 3)

Bedrock geology for the 1996 version of the net-infiltration model was defined by the Scott and Bonk (1984; DTN: MO0003COV00095.000) and the Sawyer et al. (1995, DTN: GS000300001221.010) map coverages (Flint et al., 1996, Figure 10). To incorporate the Day et al. (1998) geology for INFIL V2.0, the rasterized version of the Day et al. (1998) map coverage (DTN: GS971208314221.003) was integrated with the bedrock geology defined by the 1996 version of the geospatial input file (DTN: GS000308311221.004) using the routine GEOMAP7 V1.0. For some locations within the Day et al. (1998) geologic map coverage, bedrock geology for the net-infiltration model is defined by GEOMAP7 V1.0 using the Scott and Bonk (1984) geologic map (DTN: MO0003COV00095.000). The purpose of including the Scott and Bonk (1984) geology (DTN: MO0003COV00095.000) within the Day et al. (1998) map coverage (DTN: GS971208314221.003) is to estimate bedrock geology for some locations mapped by Day et al. (1998) as alluvium or colluvium and having intermediate soil depths less than 6 meters (as defined by the soil depth class map from Flint et al. (1996, Figure 13; DTN: GS960508312212.007). Locations having intermediate soil depths primarily occur in the transition from upland areas to alluvial fans and basins. Assigning a bedrock type of colluvium or alluvium to grid cells having a soil depth less than 6 meters was considered problematic in terms of modeling net infiltration.

Conceptually, all grid cells with a soil depth less than 6 meters should be underlain by a consolidated bedrock type to avoid inconsistency in terms of the assigned soil depth and the estimated root-zone depth. The available geologic maps, however, are representations of the surface geology and do not necessarily indicate bedrock geology for locations having one to 6 meters of soil cover. In general, the consolidated bedrock geology defined by Scott and Bonk (1984) extends farther into the intermediate soil-depth areas then the consolidated bedrock geology defined by Day et al. (1998) and thus was substituted by GEOMAP7 V1.0 for the colluvium or alluvium defined by Day et al. (1998) at many locations with intermediate soil depths.

To ensure that a consolidated rock type was defined as the bedrock geology for all grid cells having less than 6 meters of soil, the routine GEOMOD4 V1.0 was applied to the geospatial parameter file created by GEOMAP7 V1.0. GEOMOD4 V1.0 also performs a modification of the depth-class #3 boundary defined in Flint et al. (1996, p. 40) for all cases where the boundary was found to be inconsistent with the updated bedrock geology. The algorithm creates a new buffer zone of intermediate soil depths defined by depth class #3 using the updated alluvium/colluvium – consolidated bedrock boundary. The result is that the modified depth-class parameters defined by GEOMOD4 V1.0 do not allow for grid cells with depth class #4 (thick soils) to be adjacent to grid cells with thin soils (depth classes #1 and #2). All thin soils are separated from the thick soils by at least one grid cell assigned to depth class #3. Once the soil-depth classes are finalized, GEOMOD4 V1.0 identifies all grid cells having less than 6 meters of soil and alluvium or colluvium as bedrock and interpolates the bedrock geology based on the most prevalent consolidated rock type found within a search neighborhood of one to two grid cell layers.

Bedrock geology is represented in the geospatial-parameter-input file using a unique integer identifier for each rock type (see Appendix 1-C for details). The identifier is linked to an estimated bulk (field-scale) saturated hydraulic conductivity in the model control file. The bulk saturated hydraulic conductivity represents a combination of the saturated hydraulic conductivity of the matrix (Flint, 1998, DTN: GS000308312231.002) and the saturated hydraulic conductivity of fracture-fill material (DTN: GS950708312211.003) based on the fracture density of the particular rock type. The saturated hydraulic conductivity of the fracture fill material was measured in the laboratory and averaged 43.2 mm/d (DTN: GS950708312211.003) (see Appendix 1-C). Estimates of saturated hydraulic conductivity were calculated using these values of fracture conductivity for the percentage of area covered by the fracture per square meter of rock, given the fracture density and size of aperture available through which water can flow. This was added to the saturated hydraulic conductivity of the rock matrix and weighted averages of bulk bedrock saturated hydraulic conductivity were calculated on the basis of percentages of matrix and fractures by lithostratigraphic unit. These calculations are also provided in Flint et al. (1996, Table 2), in DTN: GS000308311221.004, and in Appendix 1-C. Bulk saturated hydraulic conductivity values for the updated Day et al. (1998) geology rock types were defined using lithologic correlations with the Scott and Bonk (1984) geology (DTN: MO0003COV00095.000). In general, the number of unique bedrock units with different bulk hydraulic conductivity values decreased with the incorporation of the Day et al.(1998) geology. The bulk saturated hydraulic conductivities range from a minimum of less than 10 mm/year for densely welded tuffs with low matrix hydraulic conductivity and relatively small fracture densities to a maximum of more than 100,000 mm/year for alluvium and colluvium.

7.4.4 Estimated Root-Zone Depth

Estimated Soil Depth

Soil depth is estimated using a combination of the soil-depth class map and an estimated linear relation between soil depth and slope within each depth class. The empirical soil-depth model is based on an assumed soil depth/slope correlation (DTN: GS000308311221.004), Appendix 1-C, within the soil depth classes defined for the 1996 version of the net-infiltration model (Flint et al., 1996; DTN: GS960508312212.007). The conceptual soil-depth model for depth class #1 assumes that soils are thinnest at summit and ridge-crest areas as well as steep side slopes. Thicker soils are expected to occur at the relatively gently sloping shoulder areas that define the transition between summit or ridge-crest areas and steep sideslope areas. Thicker soils are also expected to occur for more gently sloping foot-slope locations. The model for soil-depth class 1 is defined by:

$$D = 0.03 * S + 0.1, S \leq 10 \qquad \text{(Eq. 6-14)}$$
$$D = 0.013 * (10 - S) + 0.4, 10 < S < 40$$
$$D = 0.01, S \geq 40$$

where D = soil depth (in meters), and S = slope (degrees). The model for depth class #2 is defined by:

$$D = 2 - (0.05 * S), \quad S < 32 \qquad \text{(Eq. 6-15)}$$
$$D = 0.4, \quad S \geq 32$$

and the model for depth class #3 is defined by:

$$D = 6 - (0.16 * S), \quad S \leq 25 \qquad \text{(Eq. 6-16)}$$
$$D = 2.0$$

For depth class #4, soil depth is set to a uniform depth of 6 meters.

Figure 7-2 shows the spatial distribution of estimated soil depth (DTN: GS000308311221.004) with relatively thin soils less than 0.2 meter deep along steep sideslopes, and thicker upland soils 0.3 to 0.4 meter along ridge-top and shoulder areas. All locations having a soil depth of 6 meters are underlain by alluvium or colluvium rock-types. The six-meter soil depth represents only the depth of the root zone, not the actual soil depth.

Figure 7-2. Estimated soil depth using the 1996 soil-depth class map and calculated land-surface slope (Appendix 3).

Estimated Root-Zone Depth

The estimated soil-depth map is used to estimate the depth of the root zone by using an empirical model based on field observations and neutron moisture meter data analyses:

$$RZ^k = SD^k + [RZc - (SD^k/RZd)], \quad [RZc - (SD^k/RZd)] \geq 0 \qquad \text{(Eq. 6-17)}$$
$$RZ^k = SD^k, \quad [RZc - (SD^k/RZd)] \leq 0$$

where RZ is the estimated root-zone depth (in meters) at grid location k; SD is the estimated soil depth at grid location k; and RZc and RZd are coefficients supplied as input in the model control file. The coefficients are used to adjust the depth of the root zone extending into bedrock for locations with thin soils. For example, for the modern climate simulations, RZc and RZd were both set to 2, and thus the

extension of the root zone into bedrock was limited to locations with soil depth less than four meters. Using Equation 6-17, the root zone extends two meters into bedrock for locations having no soil, one meter into bedrock for locations having two meters soil depth, and 1.5 meters into bedrock for locations having one meter soil depth. The empirical model defined by Equation 6-17 is consistent with the estimated root-zone depth defined in Flint et al. (1996, Table 5) and is derived on the basis of field observations of rooting depth into bedrock, and evaluation of measurements of extraction of water within the estimated root zone in bedrock, using neutron moisture meters.

7.4.5 Estimated Root-Zone Layering and Root-Zone Density

Root-zone layers are defined to represent differences in root-zone density, storage capacity, and hydrologic properties affecting evapotranspiration and percolation within the root zone. The layers are used to model vertical percolation and redistribution of water in the root zone. The top layer is used to model both bare-soil evaporation and shallow transpiration. Three lower root-zone layers, which include two soil layers and the bottom bedrock layer, are used for modeling transpiration only. The thickness of each of the four root-zone layers is variable and is defined by the soil-depth map. The thickness of the bottom bedrock layer, $RZ4^k$, is the extension of the root zone into bedrock, as defined using Equation 6-17 above. The thickness of each of the three soil root-zone layers is defined using:

$$
\begin{aligned}
RZ1^k &= SD^k \qquad SD^k \leq RZa \qquad\qquad \text{(Eq. 6-18)}\\
RZ2^k &= 0\\
RZ3^k &= 0\\
RZ1k &= Rza \qquad RZa \leq SDk \leq RZb\\
RZ2^k &= SD^k - RZa\\
RZ3^k &= 0\\
RZ1^k &= RZa \qquad RZb \geq SD^k\\
RZ2^k &= RZb - RZa\\
RZ3^k &= SD^k - RZb
\end{aligned}
$$

where RZ1 is the top root-zone layer thickness (in meters) for grid cell k; RZ2 is the second soil layer thickness; and RZ3 is the third soil layer thickness. Model coefficients RZa and RZb define the maximum thickness of the soil layers. For example, for the modern climate scenarios, RZa = 0.3 and RZb = 1.5, and thus the maximum thickness of the top layer is 0.3 meter, the maximum thickness of the second layer is 1.2 meters, and the maximum thickness of the third layer is 4.5 meters. According to this model, root zones in upland locations with thin soils less than 1.5 meters deep consist of one or two soil layers and one bedrock layer, while alluvial fan terraces having 6 meters or greater soil thickness have three soil layers and no bedrock layer.

The multi-layered root-zone model represents variable root-zone properties (model control file) between layers by using a set of model coefficients specific to each layer. The model coefficients consist of two root-density-weighting factors for each layer (including the bedrock layer) and are defined in the model control file. These root-density-weighting factors were assumed, but are partially based on field observations of root distributions of various plant types at Yucca Mountain. Soil storage capacities are defined for the three soil layers using the soil-type ID assigned to each grid cell in the geospatial-parameter input file, soil porosity, and soil thickness. The bedrock fracture porosity (a coefficient included in the model control file) and the thickness of the bedrock layer define the storage capacity of the bedrock layer. For all simulations, a fracture porosity of 0.02 was determined for the modern climate

during model calibration based on comparisons of simulated versus measured stream flow. This value is consistent with model results from CRWMS M&O (2000a, Section 2.5.2.3). The total water-storage capacity of the root zone is a function of the estimated root-zone depth, soil depth, soil porosity, and the bedrock fracture porosity. Figure 7-3 illustrates the calculated total water-storage capacity of the root zone. Minimum storage capacities of approximately 40 mm occur in upland areas with very thin soils and indicate the root-zone water storage capacity of fractured bedrock. Maximum storage capacities of more than 1,000 mm occur at locations with thick alluvium and no bedrock layer included in the root zone.

The reader is referred to Appendix 1 for detailed description and example of the geospatial input file.

Figure 7-3. Total water-storage capacity of the modeled root zone, including bedrock and soil layers Appendix 3).

8. RESULTS of VALIDATION and INSTALLATION TEST PLANS for INFIL V2.0

The results of performing the Validation Test Plan (VTP) and Installation Test Plan (ITP) validate the functionality and performance of INFIL V2.0. The validation tester for INFIL V2.0 was Jennifer Curtis. The platform for testing was a PC, on a Windows NT 4 operating system. The identification number for the CPU on which the test was run is 3337779850003776. The installation test is run as part of the VTP. The correct installation acceptance/rejection criteria are described in the ITP, 10307-ITP-2.0-00 (Table A2-1 in Appendix 2).

8.1 ACCEPTANCE CRITERIA

As stated in the VTP, the acceptance criterion for Test Sequence(s) O, 1, 2, 3, 4, and 5 is that the conditions (program output(s) stated in each sequence subset(s)) are met. Each condition requires a specific program output. For example, Test Sequence O includes test subsets OA, OB, OC, and OD. Within each subset, one or more conditions (program output(s)) are required. In the case of Test Sequence O, Subset OA, there are 12 conditions (program requirements) that must be met.

Confirmation by a reviewer of correct results is performed by review and/or comparison of output in one or more of the output files identified in the subset conditions. Table A2-2 in Appendix 2 is provided to assist in the technical review process.

8.2 TEST SEQUENCE

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for tests. Any special conditions or modifications made to the input files used for a test case are identified. The model setup is identical to the setup intended for model application, as documented in USGS (2001).

8.2.1 Test Sequence 0: Validation of model functions based on inputs and conditions intended for model application

Test sequence 0 consists of 4 test cases (test 0A through test 0D) used to check that the inputs and input file formats intended for model application are being processed correctly by the program, and that the

correct output files and formats are being generated. The program performs several internal calculations as part of the model initialization process during which all model inputs are read in, the root zone layers are defined, and the initial root zone water contents are calculated for all layers at all nodes. In addition to validating that the model inputs are being correctly processed, the test cases in this test sequence are also used to validate that the intended output files are generated according to options defined in the model control file, and that the intended results are included in the output. This test sequence is used only as a general validation of the intended output and also that the various model components have been integrated into the daily water balance calculation as intended. The primary purpose of this test sequence is to validate the program under the same conditions that will be used for the intended model application. A more rigorous validation of specific model functions is provided by other test sequences, but these will use modified model inputs in order to generate the conditions necessary for the test cases.

Test 0A: Validation of Mod3-ppt.dat Daily Climate Input Format

Test description: Test 0A is performed to validate RD requirements 1, 2, 3, 4, 7, 8, 13, 14, 15, and 16 (see Section 2.2). The daily climate input file used to run test 0A is mod3-ppt.dat, which is one of the daily climate input files used to generate results in USGS (2001). The model run period is set to equal the full period defined by mod3-ppt.dat (1/1/1980 – 10/1/95). The geospatial parameter file specified in the model control file is T1.w20. The file T1.w20 is a small subset of the geospatial parameters defined for the full model domain documented in USGS (2001). The file consists of a total of 125 grid nodes, including 75 active nodes and 50 boundary nodes. Boundary nodes are used only as input to the surface water routing algorithm; the nodes are not included in the calculation of daily averages or annual totals, and are not included in the average annual map file. All parameters defined by T1.w20 are fully documented in USGS (2001) (these input parameters are the same as those used to develop the model results documented in USGS (2001)). Soil and bedrock properties for the various soil and rock types defined in the geospatial parameter file are designated in the model control file, and are identical to the properties used to develop model results in USGS (2001).

Test 0A is designed to check that model inputs are correctly read-in and processed, the intended outputs are generated, and the water volume balance is satisfied when using model inputs intended for model application. The test results also indicate consistency between the three primary output files (daily averages, annual totals, and average annual rates are being calculated correctly based on daily results modeled at each grid node). All model inputs used in this test are the same inputs used in model application for developing the lower-bound modern climate and the mean modern climate results documented in USGS (2001).

Test 0B: Validation of 4JA.S01 Daily Climate Input Format

Test description: Test 0b is performed to validate RD requirements 1, 7, 8, 11, 13, 14, and 15 (see Section 2.2). The daily climate input file is 4JA.s01, and the geospatial parameter input file is T1.w20. The file 4JA.s01 is one of the daily climate input files documented in USGS (2001). The test conditions are identical to those defined for test 0a with the exception that the file 4ja.s01 is used for the daily climate input file, the simulation period is set to 100 years, and output file options are modified. The file 4ja.s01 is generated as a stochastic simulation of daily precipitation using the qualified program PPTSIM V1.0, as documented in USGS (2001). The test is used to validate that the input format for 4ja.s01 (which is slightly different from the input format of mod3-ppt.dat) is correctly processed by the program. The test is also used to validate that the water volume balance is satisfied for a 100-year simulation, and that the model results are consistent between the three primary output files. All model

inputs used in this test are the same inputs used in model application for developing the lower-bound modern climate and the mean modern climate results documented in USGS (2001).

Table A1-1 of Apendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 0b. There are no special conditions or modifications made to the input files used for this test case. The model setup is identical to the setup intended for model application. The following provides a description of the critical differences in the model control file for test 0b relative to test 0a:

1. The daily climate input file is set to 4ja.s01, and the input format option is set to read in the file format for output generated by PPTSIM V1.0 (PPTFILE = "4ja.s01", IPPTDAT = 1)

2. The simulation period is set to follow the arbitrary 100-year period defined by the time sequence parameters provided by 4ja.s01 (YRBEG = 1, DNBEG = 1, YREND = 100, DNEND = 365)

3. The output options for the annual summary map files are set to generate 10 10-year averages for the 100-year simulation (TYEAR1 = 1, TYEAR2 = 10)

Test 0C: Validation of Rosalia.inp Daily Climate Input Format

Test description: Test 0C is performed to validate RD requirements 1, 3, 4, 5, 7, 8, 11, 13, 14, and 15 (see Section 2.2). The daily climate input file is Rosalia.inp, and the geospatial parameter input file is T1.w20. The test conditions are similar to those defined for test 0B. The file Rosalia.inp is used for the daily climate input file, and the simulation period is set from 1951 through 1997. The file Rosalia.inp is generated as output from the routine DAILY09, which is documented in USGS (2001). The root zone parameters and ET model coefficients are modified to represent an increase in vegetation density and root depths. The test is used to validate that the input format for Rosalia.inp, which includes daily air temperature inputs, is correctly processed by the program. The test includes a validation that the time series defined by Rosalia.inp, which includes missing years due to incomplete records, is processed correctly by the program and that missing years do not cause errors. The test is also used to validate that the daily air temperature inputs are correctly used to model evapotranspiration, snowfall, snowmelt, and sublimation. All model inputs used in this test are the same inputs used in model application for developing the upper-bound glacial transition climate results documented in USGS (2001).

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 0C. There are no special conditions or modifications made to the input files used for this test case. The model setup is identical to the setup intended for model application. The following provides a description of the critical differences in the model control file for test 0C relative to test 0B:

Test 0D: Validation of the Average Annual Map Output File Format for Post-Processing Application using the Software Routine MAPADD20

Test description: Test 0D is performed to validate RD requirements 1 and 6 (see Section 2.2). The daily climate input file is Rosalia.inp. The simulation period is set to 1980 through 1985. For this test, three geospatial parameter input files are used (Jr2.w20, Jr3.w20, and Sc2.w20), and thus 3 separate simulations are run (Test 0D1, Test 0D2, and Test 0D3). With the exception of the geospatial parameter input files, the output file names, and the specified simulation period, all parameters in the model control file are identical to Test 0C. The primary purpose of this test is to validate that the average annual map

files (Test0d1.v24, Test0d2.v24, and Test0d3.v24) are in the correct format and can be used as input for the post-processing routine MAPADD20. The test includes an application of the routine MAPADD20, and inspection of the output generated by MAPADD20 to validate that the inputs were correctly processed. This test is only used to validate the output generated by INFIL v2.0. Validation and documentation of the routine MAPADD20 is provided in USGS (2001). All model inputs used in this test are the same inputs used in model application for developing the upper-bound glacial transition climate results documented in USGS (2001).

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for tests 0D1 through 0D3. Results for the three test simulations are obtained, and the output files Testd1.v24, Test0d2.v24, and Test0d3.v24, are defined as input for MAPADD20 using the routine control file MAPADD20.ctl. The following is a listing of the routine control file MAPADD20.ctl that is used for this test case:

mapadd20.ctl: INFIL v2.0 validation test 0d, model gu1-5os-v2-w20 (9/20/99)

```
test0d.out
test0d.dat
test0d.sum
test0d.err
1
3  1  1.0e-08
jr2-gu1-5os-v2-w20
1   test0d1.v24
jr3-gu1-5os-v2-w20
1   test0d2.v24
sc2-gu1-5os-v2-w20
1   test0d3.v24
```

A complete description of the routine MAPADD20, including an explanation of routine functions, intended applications, and a description of input and output files and file formats, is provided in USGS (2001). The model setup for all three simulations used in this test case is identical to the setup intended for model application. The following provides a description of the critical differences in the model control files for test 0D relative to test 0C:

1. The simulation period is set to a 6-year period, 1980 through 1985, within the complete time sequence defined by Rosalia.inp (YRBEG = 1980, DNBEG = 1, YREND = 1985, DNEND = 1)

2. The output options for the annual summary map files are set to generate 1-year totals for each of the 6 years. (TYEAR1 = 0, TYEAR2 = 1)

3. For Test 0D1, the geospatial parameter input file is set to Jr2.w20. For Test 0D2, the geospatial parameter input file is set to Jr3.w20. For Test 0D3, the geospatial parameter input file is set to Sc2.w20. (INFILE = Jr2.w20, Jr3.w20, SC2.w20)

8.2.2 Test Sequence 1: Validation of Infiltration and Net Infiltration Functions using a Multi-layered Root Zone Model

This test sequence consists of 6 tests (test 1a through 1f) used to check the internal water volume balance calculation performed by the program. The test cases provided a basic check that equations 1 and 2 in the RD are satisfied (to within the limitations of machine precision and the number of significant figures carried by the output). All tests performed in this test sequence are based on evaluation of model calculations using only the specified initial conditions for the root zone water content, along with variations in the specified model options and input parameters.

All test conditions are defined by modifying parameter values in the model control file (INFILv2.ctl). Daily precipitation and potential evapotranspiration are set to 0 for all test cases in this test sequence. By de-activating precipitation input, the model results are simplified because the water volume balance calculation is based only on the specified initial condition and water loss from the root zone due to net infiltration. For some test cases, the initial root zone water content is set to exceed soil porosity to ensure that the soil profile is fully saturated. If the initial root zone water content exceeds the root zone storage capacity, excess water is generated, and runoff and surface water routing will occur on the first day of the simulation. Thus, setting the initial water content to exceed the root zone storage capacity is conceptually and numerically equivalent to a large rainfall or snowmelt event on the first day of the simulation, except that potential evapotranspiration is modeled under a clear sky condition.

All test cases in this test sequence use the geospatial parameter input file T1.w20, which is a subset of input parameters used to obtain results documented in USGS (2001). This allows for the validation of spatially distributed model parameters within each test case. The test criteria are based on evaluation of the daily water balance, the water balance for the average annual rates calculated for each model grid node, and on the average results for the entire model grid.

Test 1A: Basic Water Volume Balance Check

Test description: Test 1A is performed to validate RD requirements 1, 7, 13, 14, and 15 (see Section 2.2). The test is designed to check the internal water volume calculation performed by the model. This test is based on the criteria for RD requirement 1 that water cannot be generated or removed internally by the main model algorithm, which calculates daily averages and average annual rates for all terms of the water volume balance. The test results also indicate consistency between the three primary output files (daily averages, annual totals, and average annual rates are being calculated correctly based on daily results modeled at each grid node). Finally, the test indicates that the input from pre-processing routines is being properly read-in, and that the correct output files are being generated properly.

The daily climate input file used to run test 1a is mod3-ppt.dat, which is one of the daily climate input files used to generate results in USGS (2001). This input is used only to drive the model run through the time domain (the PPTFACT term causes all precipitation amounts in mod3-ppt.dat to be 0), and to check that the program is correctly reading in this type of daily climate input format. The model run period is set to equal the full period defined by mod3-ppt.dat (1/1/1980 – 10/1/95). The geospatial parameter file specified in the model control file is T1.w20. The file T1.w20 is a small subset of the geospatial parameters defined for the full model domain documented in USGS (2001). The file consists of a total of 125 grid nodes, including 75 active nodes and 50 boundary nodes. Boundary nodes are not included in the calculation of daily averages or annual totals, and are not included in the average annual map file. All parameters defined by T1.w20 are fully documented in USGS (2001) (these input parameters are the

same as those used to develop the model results documented in USGS (2001)). Soil and bedrock properties for the various soil and rock types defined in the geospatial parameter file are designated in the model control file, and are identical to the properties used to develop model results in USGS (2001).

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 1a. The following provides a description of the critical parameters used to define test 2a:

1. All climate inputs are set to 0 in the model control file (Infilv2.ctl) by setting PPTFACT and ETFACT = 0.

2. The root-zone is made impermeable by setting SKSFACT = 0.

3. The underlying bedrock is made impermeable by setting IMBFACT = 0.

4. SDFACT and RKPOR are set to 0, which causes the water storage capacity of the root-zone to be 0.

5. Surface water flow routing is de-coupled from the root-zone sub-model by setting IROUT = 0.

6. The initial soil water content is set to a constant value of 0 by setting IVWCFLG = 0 and VWCFACT = 0.

Test 1B: Basic Water Volume Balance Check with Saturated Initial Conditions

Test description: Test 1b is identical to test 1a, except that the initial soil water content is set to 10 times the wilting point for all soil types designated in T1.w20. The daily climate input file is Mod3-ppt.dat, and the geospatial parameter input file is T1.w20. The thickness of all root zone layers is set to 0 except for layer 3, which is set equal to the soil thickness. This test is a continuation of the basic evaluation of the internal water balance calculation performed by the model. This test is also designed to check that water is not being generated or removed internally by the main model algorithm. The test is a variation of test 1a to show that if precipitation, evapotranspiration, and net infiltration are de-activated, all daily water balance terms will be 0 even when the root is fully saturated (with the exception of the first day when runoff is generated).

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 1b. For test 1b, all parameters are identical to the parameters used for test 1a except for the following modifications:

1. The surface water flow routing component is de-coupled from the root zone model component (IROUT = 0)

2. The simulation time is shortened to 5 years (YREND = 1985, DNEND = 365)

3. Soil depths are set to equal the soil depths designated by the geospatial parameter input file T1.w20 (SDFACT = 1)

4. The thickness of all root zone layers is set to 0, except layer 3, which is set to equal soil depth. This modification causes the root zone to be defined as a 1-layer model that does not extend into underlying bedrock. (RDEPTH1 = 0, RDEPTH2 = 0, RDEPTH4 = 0, RDEPTHF = 2)

5. The initial soil water content is set to 10 times the wilting point for each soil (VWCFACT = 10)

6. The daily map file is set to be generated for the first day of the simulation (IRDAY = 1, NYROUT = 1980)

Test 1C: Basic Water Volume Balance Check with Saturated Initial Conditions
Test description: This test is a continuation of the basic evaluation of the internal water balance calculation performed by the model, and the processing of the geospatial input parameters to develop a multi-layered root zone model. The daily climate input file is Mod3-ppt.dat, and the geospatial parameter input file is T1.w20. The test is a variation of test 1b to show that water is not created or subtracted when net infiltration and surface water processes are enabled using a single layer root zone model. For this test, the initial water content is set equal to 20 times the wilting point of each soil type. To validate that infiltration rates are being correctly calculated throughout the duration of the simulation period, a series of daily map files are generated as output. A positive test result indicates that water is not being generated or removed internally by the code, and that the root zone functions are performing as intended under the specified conditions of the test case.

Test 1C is similar to test 1b, with the following modifications in the model control file:

1. Coupled surface water flow routing is enabled (IROUT = 1)

2. The soil and bedrock hydraulic conductivity for each soil and rock type in the model is set equal to the values defined in the model control file. This allows for net infiltration to occur at the bottom of the root zone. (IMBFACT, SKSFACT = 1)

3. The root zone is modeled as a single layered system, with the thickness of the top layer equal to the soil thickness (RDEPTH1 = 3, RDEPTH2 = 0, RDEPTH4 = 0, RDEPTHF = 0).

4. The initial soil water content is set equal to 20 times the wilting point for each soil type (VWCFACT = 20)

5. A set of 4 daily map files are designated as output files. (NDAYMAP = 4)

Test 1D: Basic Water Volume Balance Check with Layered Root Zone
Test description: This test is a continuation of the basic evaluation of the internal water balance calculation performed by the model, the processing of the geospatial input parameters to develop a multi-layered root zone model, and the intended function of the multi-layered root zone model. The daily climate input file is Mod3-ppt.dat, and the geospatial parameter input file is T1.w20. Test 1d is a variation of test 1c to show that the water volume balance is satisfied when the root zone is modeled as a layered system. A positive test result indicates that water is not being generated or removed internally by the code under the specified conditions of the test case, and that daily net infiltration rates are correctly calculated by the program.

Test 1D is similar to test 1c, with the following modification in the model control file:

The root zone is modeled as a multi-layered system by setting RDEPTH = 0.1, RDEPTH2 = 0.2, RDEPTH4 = 0.5, and RDEPTHF = 1.

Test 1E: Basic Water Volume Balance Check with Layered Root Zone
Test description: This test is a continuation of the basic evaluation of the internal water balance calculation performed by the model, the processing of the geospatial input parameters to develop a multi-layered root zone model, and the intended function of the multi-layered root zone model.

The daily climate input file is Mod3-ppt.dat, and the geospatial parameter input file is T1.w20. Test 1e is identical to test 1d, except that an effective storage capacity term of 0.10 is enabled for the rock layer in the root zone profile. This is accomplished by changing RKPOR from 0 to 0.1 (all other parameters are left unchanged). The initial condition for the rock layer is always set to 0 (the specified initial conditions only affect the soil water content), and thus some of the excess water developed by the specified initial soil water content is infiltrated into the available storage capacity of the rock layer. The effective storage capacity of the bedrock layer is defined based on the effective bedrock porosity term (RKPOR) and the thickness of the bedrock layer, which is modeled as an empirical function of soil thickness using the parameters RDEPTH4 and RDEPTHF. The purpose of Test 1e is to show that the water volume balance is satisfied when the root zone is modeled as a layered system, and the bedrock layer (layer 4) is given an effective storage capacity. The effective storage capacity of the bedrock layer allows evapotranspiration from the bedrock layer before net infiltration is calculated, and thus the root zone is allowed to extend into bedrock. A positive test result indicates that water is not being generated or removed internally by the code under the specified conditions of the test case, and that daily net infiltration rates are correctly calculated by the program.

Test 1E is similar to test 1d, with the following modification in the model control file:

The root zone is modeled as a multi-layered system with root extending into the bottom bedrock layer by setting RKPOR = 0.1 (10% effective porosity).

Test 1F: Basic Water Volume Balance Check with Layered Root Zone
Test description: This test is a continuation of the basic evaluation of the internal water balance calculation performed by the model, the processing of the geospatial input parameters to develop a multi-layered root zone model, and the intended function of the multi-layered root zone model.

The daily climate input file is Mod3-ppt.dat, and the geospatial parameter input file is T1.w20. Test 1f is identical to test 1e, except that the soil saturated hydraulic conductivity has been decreased by 4 orders of magnitude. The purpose of this test is to validate that net infiltration and infiltration through the root zone is dependent on soil properties as well as the soil or bedrock underlying the root zone. A positive test result indicates that the multi-layered root zone model is functioning as intended.

Test 1F is similar to test 1e, with the following modification in the model control file:

The soil saturated hydraulic conductivity of the root zone is decreased by 4 orders of magnitude by setting SKSFACT = 0.0001.

8.2.3 Test Sequence 2: Validation of Evapotranspiration Functions Coupled with Infiltration and Net Infiltration using a Multi-layered Root Zone

Test sequence 2 consists of 11tests (test 2a through test 2k) used to evaluate the internal water volume calculation performed by the program, in response to a specified set of initial conditions and daily evapotranspiration conditions. The test sequence is designed to show that the model components applied to calculate potential evapotranspiration, evaporation, transpiration, evapotranspiration, infiltration (through a layered root zone), and net infiltration, are performing the intended functions and that specific components of the root zone water volume balance calculations are being correctly executed. The modeled root zone functions are evaluated based on variations in parameters defining root zone layering, root density, vegetation cover, and both soil and bedrock properties.

The test sequence is similar to test sequence 1 in that the simulations set daily precipitation input to 0, so that each test case is simplified to show the model response to the initial water content of the root zone. By de-activating precipitation input, the model results are simplified because the water volume balance calculation is based only on the specified initial condition and water loss from the root zone due to net infiltration and evapotranspiration. For some test cases, the initial root zone water content is set to exceed soil porosity to ensure that the soil profile is fully saturated. If the initial root zone water content exceeds the root zone storage capacity, excess water is generated, and runoff and surface water routing will occur on the first day of the simulation. Thus, setting the initial water content to exceed the root zone storage capacity is conceptually and numerically equivalent to a large rainfall or snowmelt event on the first day of the simulation, except that potential evapotranspiration is modeled under a clear sky condition.

All test conditions are defined by modifying parameter values in the model control file (INFILv2.ctl). Some test cases require modifications to the parameters in the daily climate input file Mod3-ppt.dat or the parameters in the geospatial parameter file T1.w20. The modified versions of Mod3-ppt.dat are Test2d.dat and Test2e.dat, and the modifications are made to the day of year number. The modified version of T1.w20 is T1a.w20, where the parameters for soil type, soil depth, and rock type are set to uniform values.

Test 2A: Potential Evapotranspiration Functions

Test description: This test case provides a basic check of the potential evapotranspiration function. The daily climate input file is Mod3-ppt.dat and the geospatial parameter input file is T1.w20. Test conditions are set so that there is no water available for evapotranspiration in the layered root zone. This is accomplished by disabling precipitation input and setting the initial soil water content to equal the wilting point (note: setting the initial water content to less than the wilting point will cause meaningless output on the first day of the simulation period). All water balance components should be 0 throughout the simulation period, even though evapotranspiration and net infiltration are allowed, and the root zone is modeled as a multi-layered system. Potential evapotranspiration should be correlated with air temperature and the day of year. A positive test result indicates that the potential evapotranspiration component of the model is functioning as intended.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 2a. Test case 2a uses the same model inputs as test case 0a with the following modifications to the model control file:

1. The simulation period is shortened to 6 years (YREND = 1985, DNEND = 365)

2. Precipitation input is disabled (PPTFACT = 0)

3. Initial conditions are set to equal the wilting point for all soil layers (VWCFACT = 1.0)

Test 2B: Potential Evapotranspiration and Evapotranspiration Functions
Test description: This test case is a modified version of test 2a in which the seasonal variation in air temperature is removed by setting daily air temperature to a constant value equal to the average daily temperature in test 2a. The daily climate input file is Mod3-ppt.dat and the geospatial parameter input file is T1.w20. This test is used to validate the intended effect of air temperature on potential evapotranspiration. The test results should indicate a decrease in the seasonal variability of modeled potential evapotranspiration, and a slight decrease in the average annual potential evapotranspiration rate (the effect of air temperature on modeled potential evapotranspiration is non-linear).

In addition to testing the potential evapotranspiration function, test 2b is used to perform a general validation of the integrated response of the evapotranspiration, the surface water routing, and the net infiltration functions based on the initial root zone water content and geospatial model parameters intended for model application. A positive test result indicates that the evapotranspiration function is performing as intended when integrated with other model components and when used with model parameters intended for model application.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 2b. All input parameters values are identical to the values used in test 2a with the exception of the following modifications:

1. Daily air temperature is set to a constant value (ATEMP2 = 0)

2. The initial root zone water content is set to 20 times the wilting point for all soil layers (VWCFACT = 20)

Test 2C: Potential Evapotranspiration and Evapotranspiration Functions
Test description: This test case is a modified version of test 2b in which the average daily air temperature is reduced to approximately 0 degrees C. The daily climate input file is Mod3-ppt.dat and the geospatial parameter input file is T1.w20. The decrease in air temperature should cause a decrease in both the potential evapotranspiration rate and the actual evapotranspiration rate, along with an increase in net infiltration. Seasonal variability in air temperature is still disabled and thus daily air temperature should be constant for each day of the simulation. Daily potential evapotranspiration should still be correlated to the day of year, and annual potential evapotranspiration should still show variability across model nodes due to variability in topographic parameters included in the geospatial parameter file. A positive test result validates that the potential evapotranspiration and the evapotranspiration model components are functioning as intended.

In addition to testing the potential evapotranspiration function, test 2c is a continuation of a general validation of the integrated response of the evapotranspiration, the surface water routing, and the net infiltration functions based on the initial root zone water content and geospatial model parameters intended for model application. A positive test result indicates that the evapotranspiration function is

performing as intended when integrated with other model components and when used with model parameters intended for model application.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 2c. All input parameters values are identical to the values used in test 2b with the exception of the following modification:

Daily air temperature is set to a constant value of approximately 0 degrees C (ATEMP1 = 0.0).

Test 2D: Potential Evapotranspiration and Evapotranspiration Functions

Test description: This test case is a modified version of test 2c in which the daily climate input file (mod3-ppt.dat) is modified (the modified file is Test2d.dat) so that the day of year number is a constant value of 355 (December 21st) for all days simulated. The geospatial parameter input file is T1.w20. This test is used to validate the intended effect of topographic parameters on modeled potential evapotranspiration by disabling the effects of variable daily air temperature and the day of year. The test conditions force a minimum sun angle (thus maximizing shading effects from surrounding topography) for all days simulated, and the duration of daylight hours is at a minimum. The expected result is an increase in the spatial variability of potential evapotranspiration relative to results obtained for all previous test cases in this test sequence (tests 2a, 3b, 2c). For the period 1980-85, the daily and annual potential evapotranspiration rates should be less relative to results obtained for test 2c for all days and years simulated, while the net infiltration rate should be higher for this same period. A positive test result indicates that the solar radiation algorithm of the potential evapotranspiration model component is functioning as intended, and the slope, aspect, and 36 blocking ridge angles defined for each model node in the geospatial parameter input file are being processed correctly by the model.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 2d. All input parameters values are identical to the values used in test 2c with the exception of the following modification:

The daily climate input file is set to Test2d.dat. (PPTFILE = Test2d.dat)

Test 2E: Potential Evapotranspiration and Evapotranspiration Functions

Test description: This test case is a modified version of test 2c in which the daily climate input file (mod3-ppt.dat) is modified (the modified file is Test2e.dat) so that the day of year number is a constant value of 171 (June 19th) for all days simulated. The daily climate input file is Mod3-ppt.dat and the geospatial parameter input file is T1.w20. This test is used to validate the intended effect of topographic parameters on modeled potential evapotranspiration by disabling the effects of variable daily air temperature and the day of year. The test conditions force a maximum sun angle (thus minimizing shading effects from surrounding topography) for all days simulated, and the duration of daylight hours is at a maximum. The expected result is a decrease in the spatial variability of potential evapotranspiration relative to results obtained for all previous test cases in this test sequence (tests 2a, 2b, 2c, and 2d). For the period 1980-85, the daily and annual potential evapotranspiration rates should be greater relative to results obtained for test 2c for all days and years simulated, while the net infiltration rate should be lower for this same period. A positive test result indicates that the solar radiation algorithm of the potential evapotranspiration model component is functioning as intended, and the slope, aspect, and 36 blocking ridge angles defined for each model node in the geospatial parameter input file are being processed correctly by the model.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 2e. All input parameters values are identical to the values used in test 2d with the exception of the following modification:

The daily climate input file is set to Test2e.dat. (PPTFILE = Test2e.dat)

Test 2F: Potential Evapotranspiration and Evapotranspiration Functions

Test description: This test case is a modified version of test 2a in which the geospatial parameter input file (t1.w20) is modified to set a uniform soil depth, soil type, and rock type for all model nodes (the modified file is T1a.w20). The daily climate input file is Mod3-ppt.dat. Initial conditions are set to fully saturate the root zone profile, while daily precipitation input is still disabled, and daily potential evapotranspiration is set to a constant rate of 5 mm/day. The root zone parameters are similar to parameters used in model application for the modern climate simulations in USGS (2001). Soil saturated hydraulic conductivity for the uniform soil type 10 is increased to allow free drainage at field capacity. To facilitate a hand calculation check of the root zone water contents, both the wilting point and the field capacity for soil type 10 are set to 0.1, and the porosity is set to 0.3 by modifying the soil properties parameters in the model control file. A uniform rock type is defined for the model grid (rock type 500 in the model control file), and the bulk saturated bedrock hydraulic conductivity is set to 1 mm/day. To facilitate checking of actual evapotranspiration rates relative to potential evapotranspiration rates, the alpha parameter in the modified Preistley-Taylor function used in the evapotranspiration model is set to 1.0 for bare soil, bare rock, vegetated soil, and vegetated rock.

The purpose of this test case is to validate that the evapotranspiration model component of the multi-layered root zone model is functioning as intended in terms of a dynamic partitioning of water contents and evapotranspiration rates, integrated with surface water run-on, root zone percolation, and net infiltration. The test criteria are designed to show that when soil permeability is high, drainage into the lower root zone layers maintains full saturation for those layers even though evapotranspiration losses and net infiltration are removing water from the root zone system. In addition, the root is modeled as having a decreasing root density with depth, so that evapotranspiration rates are maximized at the top layer, as long as the water content of the top layer remains relatively high. Through time the top layers dry out more rapidly than the bottom layers of the root zone (especially if free drainage is allowed into the bottom layers). As the water content for the top layers approaches the wilting point, the evapotranspiration rates for the bottom layers increases because a dynamic weighting function allows evapotranspiration to adjust to the distribution of water contents across the root zone layers.

This test is designed to show the expected changes in water contents for root zone layers based on inspection of a series of daily map files, in conjunction with inspection of the daily output file. A series of 7 daily map files are generated by setting user-defined options in the model control file. A positive test result indicates that the dynamic evapotranspiration functions in the multi-layered root zone model are performing as intended.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 2f. All input parameters values are identical to the values used in test 2a with the exception of the following modifications:

1. Daily potential evapotranspiration is set to a constant rate of 5 mm/day (IETTEST = 1, ETTEST = 5).

2. The alpha parameter for bare soil evaporation is changed from 1.04 to 1 (BARSOIL2 = 1).

3. The initial water content is set to 4 times the soil wilting point (VWCFACT = 4).

4. A uniform soil depth, soil type, and rock type is defined for all model nodes by modifying the geospatial parameter input file T1.w20 (the modified file is named T1a.w20). In the modified geospatial parameter input file, the soil type is set to 10, and the rock type is set to 500 (INFILE = T1a.w20).

5. The number of daily map output files is set to 7 (NDAYMAP = 7). The simulation days for which each successive daily map file is generated are: 01/01/80, 01/02/80, 01/10/80, 2/26/80, 2/27/80, 2/28/80, and 12/31/85 (IRDAY(1) = 1, NYROUT(1) = 1980, IRDAY(2) = 2, NYROUT(2) = 1980, IRDAY(3) = 10, NYROUT(3) = 1980, IRDAY(4) = 57, NYROUT(4) = 1980, IRDAY(5) = 58, NYROUT(5) = 1980, IRDAY(6) = 59, NYROUT(6) = 1980, IRDAY(7) = 365, NYROUT(7) = 1985).

6. For soil type 10, the wilting point is set to 0.1, the field capacity is set to 0.2, and the porosity is set to 0.3 (FIELDCAP = 0.1, SOILRESID = 0.1, SOILPOR = 0.3).

7. For soil type 10, the wilting point is set to 0.1, the field capacity is set to 0.2, and the porosity is set to 0.3 (FIELDCAP = 0.1, SOILRESID = 0.1, SOILPOR = 0.3).

8. Rock type 500 is added to the model control file (NROCKID = 130). The bulk saturated hydraulic conductivity of rock type 500 is set to 1 mm/day (IMBIBE(500) = 1.0).

Test 2G: Potential Evapotranspiration and Evapotranspiration

Test description: This test case is a modified version of test 2f in which the soil saturated hydraulic conductivity is reduced by a factor of 0.000001. This modification decreases the rate of drainage of the saturated soil profile into the underlying rock layer (which has an effective water content of 0 at the start of the simulation). The daily climate input file for this test is Mod3-ppt.dat, and the geospatial parameter input file is T1a.w20. For the conditions defined in this test case, transpiration from the rock layer continually removes the water that slowly infiltrates from the overlying soil layers. The transpiration prevents the water content of the rock layer from reaching the effective storage capacity of 30 mm, and the occurrence of net infiltration is prevented.

The purpose of this test case is to validate that the transpiration model component of the multi-layered root zone model is functioning as intended in terms of a dynamic partitioning of water contents and transpiration rates, integrated with surface water run-on, root zone percolation, and net infiltration. Although drainage into the bottom bedrock layer of the root zone is allowed, the drainage rate is too slow to allow the water content of the bedrock layer to reach the effective storage capacity. Thus, the test conditions are designed to show that when soil permeability is low, transpiration "catches up" with the water percolating through the root zone and eventually removes all water from the bottom root zone layer before net infiltration can occur. A positive test result indicates that the dynamic transpiration functions in the multi-layered root zone model are performing as intended.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 2g. All input parameters values are identical to the values used in test 2g with the exception of the following modification:

The soil saturated hydraulic conductivity is reduced by a factor of 0.000001 (SKSFACT = 0.000001)

Test 2H: Potential Evapotranspiration and Evapotranspiration Functions
Test description: This test case is a modified version of test 2g in which the soil saturated hydraulic conductivity is increased by a factor of 10 (a factor of 0.00001 decrease relative to the soil saturated hydraulic conductivity used for test 2f). This modification slightly increases the rate of drainage of the saturated soil profile into the underlying rock layer. For the conditions defined in this test case, transpiration from the rock layer continually removes the water that slowly infiltrates from the overlying soil layers, but the effective storage capacity of the rock layer is eventually filled. Net infiltration does not occur until approximately 1 month after the beginning of the simulation, and only lasts for a period of approximately 2 weeks.

The purpose of this test case is to validate that the transpiration model component of the multi-layered root zone model is functioning as intended in terms of a dynamic partitioning of water contents and transpiration rates, integrated with surface water run-on, root zone percolation, and net infiltration. Although drainage into the bottom bedrock layer of the root zone is allowed and net infiltration does occur, the total net infiltration depth is relatively small because most water is removed by transpiration as the water slowly drains through the rock layer of the root zone.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 2h. All input parameters values are identical to the values used in test 2g with the exception of the following modification:

The soil saturated hydraulic conductivity is reduced by a factor of 0.00001 (SKSFACT = 0.00001)

Test 2I: Potential Evapotranspiration and Evapotranspiration Functions
Test description: This test case is a modified version of test 2h in which the potential evapotranspiration rate is reduced to 2 mm/day. This modification is intended to greatly increases the duration of net infiltration, but should not greatly increase the net infiltration rate because this is still limited by the low soil permeability, in addition to transpiration from the rock layer. The occurrence of net infiltration should still be delayed, but the net infiltration rate should be slightly greater than the results for test 2h because transpiration is reduced and thus removes a smaller fraction of water from net infiltration. The purpose of this test case is to validate that the transpiration model component of the multi-layered root zone model is functioning as intended in terms of a dynamic partitioning of water contents and transpiration rates, integrated with surface water run-on, root zone percolation, and net infiltration. The daily climate input file used for this test is Mod3-ppt.dat, and the geospatial parameter input file used for this test is T1a.w20.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 2i. All input parameters values are identical to the values used in test 2h with the exception of the following modification:

1. The potential evapotranspiration rate is set to 2 mm/day (ETTEST = 2.0)

Test2J: Potential Evapotranspiration and Evapotranspiration Functions
Test description: This test case is a modified version of test 2i in which the soil depth is increased to 2 meters. The root zone layering is defined to include all 4 layers (the 3 soil layers and the underlying rock layer all have layer a thickness greater then 0 meters). Potential evapotranspiration is held constant at 2

mm/day. The root density weighting factors are defined to represent very low vegetation cover, with roots extending into the top layer only. The field capacity for the soil layers is increased from 0.1 to 0.2 to allow testing of the root density weighting functions. Net infiltration should be maximized because transpiration is greatly reduced. The daily climate input file used for this test is Mod3-ppt.dat, and the geospatial parameter input file used for this test is T1a.w20. The purpose of this test case is to validate that the transpiration model component of the multi-layered root zone model is functioning as intended, and that root density is correctly controlled using parameters in the model control file.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 2j. All input parameters values are identical to the values used in test 2i with the exception of the following modifications:

1. The soil depth is increased to 2 meters (SDFACT = 2m)

2. The root density weighting factors are set to 1 for the top layer, and to 0 for all other layers. (ROOTF1 = 1, ROOTF2 = 0, ROOTF3 = 0, ROOTF4 = 0, MAXWGT1 = 1, MAXWGT2 = 0, MAXWGT3 = 0, MAXWGT4 = 0)

3. Layer 3 is set to a thickness of 1 meter, and the rock layer is set to a thickness of 2 meters. (RDEPTH1 = 0.3, RDEPTH2 = 1, RDEPTH4 = 3, RDEPTHF = 2)
   This confines the root zone to the top layer only.

4. The soil field capacity for soil type 10 is set 0.2 (FIELDCAP(10) = 0.2)

5. The soil saturated hydraulic conductivity is set to 1E-4 kg*sec/m^3

Test2K: Potential Evapotranspiration and Evapotranspiration Functions
Test description: This test case is a modified version of test 2j in which the root density weighting factors are defined so that bare-soil evaporation does not occur and transpiration occurs from layers 2 and 4 only. Net infiltration should be decreased relative to results for test 2j. The purpose of this test case is to validate that the transpiration model component of the multi-layered root zone model is functioning as intended, and that root density is correctly controlled using parameters in the model control file. The daily climate input file used for this test is Mod3-ppt.dat, and the geospatial parameter input file is T1a.w20.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 2k. All input parameters values are identical to the values used in test 2g with the exception of the following modifications:

The root density weighting factors are set to 1 for the second soil layer and the rock layer (layers 2 and 4), and 0 for the top layer and the third soil layer (evapotranspiration is disabled for those layers). (ROOTF1 = 0, ROOTF2 = 1, ROOTF3 = 0, ROOTF4 = 1, MAXWGT1 = 0, MAXWGT2 = 1, MAXWGT3 = 0, MAXWGT4 = 1)

8.2.4 Test Sequence 3: Validation of Evapotranspiration, Infiltration, and Net Infiltration Functions in Response to Daily Precipitation Input

Test sequence 3 consists of 7 tests (test 3a through test 3g) used to evaluate the internal water volume calculation performed by the program, in response to a specified set of initial conditions and controlled daily precipitation input. The test conditions are similar to those used in test sequence 2, except that daily precipitation input is incorporated, and for all test cases the initial root zone water content is set to the wilting point water content for the root zone. Thus, where test sequence 2 is used to validate model functions in terms of initial wet conditions and the drying out of the root zone, test sequence 3 is designed to validate model functions in terms of initially dry conditions and the wetting up of the root zone. The test sequence is designed to show that the model components applied to calculate potential evapotranspiration, evaporation, transpiration, evapotranspiration, infiltration (through a layered root zone), and net infiltration, are performing the intended functions and that specific components of the root zone water volume balance calculations are being correctly executed. The modeled root zone functions are evaluated based on variations in parameters defining root zone layering, root density, vegetation cover, and both soil and bedrock properties. For most test cases, model results should indicate that a steady state condition has been reached in response to a steady state precipitation input.

All test conditions are defined by modifying parameter values in the model control file (INFILv2.ctl). All test cases require a modified version of the geospatial parameter file T1.w20. The modified version of T1.w20 is T1a.w20, where the parameters for soil type, soil depth, and rock type are set to uniform values. Although all test cases use the daily climate input file Mod3-ppt.dat to drive the simulation through time, the daily precipitation input is set to a constant rate by using model options in the model control file.

Test 3A: Evapotranspiration, Infiltration, and Net Infiltration Functions in Response to Daily Precipitation Input

Test description: This test case uses the same setup for root zone layering and soil depth that was used in tests 2h – 2k (4-layered root zone system, with 2 meters of soil and 2 meters of rock). The thickness of the top soil layer is set to 0.3 meter, the middle layer is set to 0.7 meter, and the third layer is to 1 meter. Evapotranspiration is disabled, and thus the purpose of the test is to validate that once the soil profile and bedrock layer have become fully saturated, daily precipitation input must equal the sum of net infiltration and outflow. The net infiltration rate must equal the bulk saturated hydraulic conductivity of the rock layer, because the precipitation rate is set to exceed the bedrock conductivity.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 3a. The daily climate input file used for this test is Mod3-ppt.dat, and the geospatial parameter input file used for this test is T1a.w20. All input parameters values are identical to the values used in test 2k with the exception of the following modifications:

1. Coupled flow routing is enabled for the last day of the simulation (OPTMASSB = 0)
2. Daily precipitation input is set to a constant value of 10 mm/day (IPPTEST = 1, PPTTEST = 10, PPTFACT = 1)
3. Daily evapotranspiration is disabled (IETTEST = 0, ETFACT = 0)
4. Initial conditions are set to the soil wilting point water content (VWCFACT = 1)

Test 3B: Evapotranspiration, Infiltration, and Net Infiltration Functions in Response to Daily Precipitation Input

Test description: This test uses the same setup as test 3a except that the soil saturated hydraulic conductivity is reduced by a factor 0f 0.0001 to prevent net infiltration from occurring within the simulation period. The root zone very gradually increases in saturation at a rate determined by storm duration and the soil saturated hydraulic conductivity (0.0001 x 84.672 = 0.0084672 mm/day). Storm duration is assumed to be 2 hours for summer storms (occurring between days 183 and 247 and 12 hours for winter storms (occurring between the days of 184 and 246 of the following year). If runoff is generated, the duration of surface water flow is assumed equivalent to storm duration, but occurs after precipitation. Thus, if both infiltration of precipitation and infiltration of run-on are allowed, the maximum infiltration rate for a summer storm should be 2 x (0.0084672/12) = 0.001411 mm/day and the maximum infiltration rate for a winter storm should be 2 x (0.0084672/2) = 0.0084672. The purpose of the test is to validate that net infiltration rate is limited by both the permeability of the soil and the permeability of the underlying bedrock. In addition, the test is used to validate that net infiltration does not occur until the effective storage capacity of the bedrock layer has been exceeded (if the root zone extends into bedrock), and that storm duration is being correctly incorporated into the calculation of maximum infiltration rates into the root zone profile.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 3b. The daily climate input file used for this test is Mod3-ppt.dat, and the geospatial parameter input file used for this test is T1a.w20. All input parameters values are identical to the values used in test 3a with the exception of the following modification:

1. Coupled flow routing is disabled for the last day of the simulation (OPTMASSB = 1).

2. The saturated hydraulic conductivity of the soil is reduced by 4 orders of magnitude (SKSFACT = 0.0001).

Test 3C: Evapotranspiration, Infiltration, and Net Infiltration Functions in Response to Daily Precipitation Input

Test description: This test uses the same setup as test 3b except that the soil depth is set to a uniform depth of 0.1 meters and the root zone storage capacity in the bedrock layer is set to 0.001. By setting the soil depth to 0.1 meters, the thickness of soil layers 2 and 3 is 0 meters, the thickness of the top soil layer is 0.1 meters, and the thickness of the bottom rock layer is 2.95 meters. Thus, the storage capacity of the soil layer is 30 mm, and the storage capacity of the rock layer is 2.95 mm. The purpose of the test is to validate that net infiltration will not occur until the root zone storage capacity in the bedrock layer has been exceeded, and that net infiltration rate is limited by the permeability of the soil as well as the permeability of the underlying bedrock. The test conditions are designed to show that after the root zone profile has been fully saturated and net infiltration is allowed to occur, the net infiltration rate is limited by the minimum saturated hydraulic conductivity of the root zone (as defined by either soil or bedrock). In this case, the minimum hydraulic conductivity is defined by the soil. A positive test result will show that once the water content of the root zone is at full capacity, steady state conditions are maintained for the remainder of the simulation.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 3c. The daily climate input file used for this test is Mod3-ppt.dat, and the

geospatial parameter input file used for this test is T1a.w20. All input parameters values are identical to the values used in test 3b with the exception of the following modification:

1. Soil depth is set to 0.1 meters (SDFACT = 0.1)

2. The effective storage capacity of the bedrock layer is set to 0.001 (RKPOR = 0.001)

Test 3D: Evapotranspiration, Infiltration, and Net Infiltration Functions in Response to Daily Precipitation Input

Test description: This test uses the same setup as test 3c except that the daily potential evapotranspiration rate is set to 2 mm/day for all days simulated. The purpose of the test is to validate that transpiration removes water from the bottom of the root zone, which in this case includes the bedrock layer, before net infiltration is calculated. For these test conditions, the potential evapotranspiration rate is set to 2 mm/day. Because the root zone density parameters for the soil layer are set to 0, only transpiration from the rock layer can occur. The transpiration rate cannot exceed the maximum infiltration rate into the rock layer, which in this case is defined by the saturated hydraulic conductivity of the soil overlying the rock layer. As the water content of the rock layer increases, the transpiration rate also increases. When the transpiration rate equals the infiltration rate, steady state conditions are maintained for the remainder of the simulation.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 3d. The daily climate input file used for this test is Mod3-ppt.dat, and the geospatial parameter input file used for this test is T1a.w20. All input parameters values are identical to the values used in test 3c with the exception of the following modifications:

1. The potential evapotranspiration rate is set to 2 mm/day (IETTEST = 1, ETTEST = 2)

2. The root density parameters for the top soil layer are set to 0 (ROOTF1 = 0, MAXWGT1 = 0)

Test 3E: Evapotranspiration, Infiltration, and Net Infiltration Functions in Response to Daily Precipitation Input

Test description: This test uses the same setup as test 3d except that the daily potential evapotranspiration rate is set to 5 mm/day, the soil depth is increased to 1 meter, and the bedrock bulk saturated hydraulic conductivity is increased to 5 mm/day. A soil thickness of 1 meter defines 2 soil layers in the root zone, with a 0.3 meter thick top soil layer and a 0.7 meter thick bottom soil layer. The thickness of the rock layer is reduced to 2.5 meters. The root density terms are set to 0 for both soil layers, which forces all evapotranspiration to occur as transpiration only from the rock layer. The purpose of the test is to validate that transpiration removes water from the bottom of the root zone, which in this case includes the bedrock layer, before net infiltration is calculated. A positive result indicates that the transpiration rate exceeds the net infiltration rate because all transpiration is forced to occur in the bottom rock layer, and transpiration is calculated before net infiltration.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 3e. The daily climate input file used for this test is Mod3-ppt.dat, and the geospatial parameter input file used for this test is T1a.w20. All input parameters values are identical to the values used in test 3d with the exception of the following modifications:

1. The potential evapotranspiration rate is set to 5 mm/day (IETTEST = 1, ETTEST = 5).

2. The root density parameters for the top 2 soil layers are set to 0 (ROOTF1 = 0, ROOTF2 = 0, MAXWGT1 = 0, MAXWGT2 = 0).

3. The bedrock bulk saturated hydraulic conductivity is increased to 5 mm/day (IMBFACT = 5).

4. The soil thickness is set to a uniform thickness of 1 meter (SDFACT = 1).

5. The soil saturated hydraulic conductivity is set to 84.672 mm/day (SKSFACT = 1).

Test 3F: Evapotranspiration, Infiltration, and Net Infiltration Functions in Response to Daily Precipitation Input

Test description: This test uses the same setup as test 3e except that the root zone density terms are set to allow evapotranspiration from the top soil layer and transpiration from the second soil layer. Transpiration from the rock layer is also allowed but is reduced relative to conditions for test case 3e. For this test case, both the evapotranspiration rate and the net infiltration rate should increase relative to test case 3e, while the runoff rate decreases relative to results for test 3e. The purpose of the test is to validate that the transpiration and net infiltration terms are calculated before the runoff term when runoff is generated because the root zone profile has become fully saturated. A positive result also indicates that when transpiration removes water from the soil profile, surface water run-on can infiltrate into the soil profile during the routing process. The purpose of the test is also to validate that the daily root-zone mass balance is satisfied under conditions involving a steady precipitation and potential evapotranspiration rate, with the precipitation rate exceeding the combined potential evapotranspiration and maximum net infiltration rates. For these test conditions, steady state conditions should be established once the root zone is fully saturated.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 3f. The daily climate input file used for this test is Mod3-ppt.dat, and the geospatial parameter input file used for this test is T1a.w20. All input parameters values are identical to the values used in test 3e with the exception of the following modifications:

The root density parameters for the top 2 soil layers are set to 1, and the root density parameters for the bottom rock layer are reduced to 0.1 (ROOTF1 = 1, ROOTF2 = 1, ROOTF4 = 0.1, MAXWGT1 = 1, MAXWGT2 = 1, MAXWGT = 0.1).

Test 3G: Evapotranspiration, Infiltration, and Net Infiltration Functions in Response to Daily Precipitation Input

Test description: This test uses the same setup as test 3f except that the soil thickness is increased to 2 meters at all nodes. The increase in soil depth decreases the thickness of the rock layer to 2 meters. The soil profile is divided into 3 root zone layers; a top layer having a thickness of 0.3 meters, a second layer having a thickness of 0.7 meters, and a bottom soil layer having a thickness of 1 meter. Thus, the root zone is modeled as a 4-layered profile having a total thickness of 4 meters.

In addition to increasing the soil thickness, the root zone density terms are set to define a decreasing root density with depth. Although transpiration from the rock layer is enabled, the root density is reduced by an order of magnitude relative to the root density used for test 3f. The purpose of the test is to validate that the transpiration and net infiltration terms are calculated before the runoff term when runoff is

generated because the root zone profile in a 4-layered root zone system has become fully saturated. The purpose of the test is also to show that when the infiltration rate through the root zone profile exceeds the bedrock bulk saturated hydraulic conductivity, the bottom root zone layers become fully saturated first, while the water content of the top soil is maintained at slightly less than field capacity. A positive test result should indicate that both evapotranspiration and net infiltration are increased relative to results obtained for test 3f, while the runoff and run-on terms are reduced. Evapotranspiration should increase because the thickness of the root zone has been increased. Net infiltration should increase because the root density has been decreased in the rock layer. For these test conditions, steady state conditions should be established once the root zone is fully saturated.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 3g. The daily climate input file used for this test is Mod3-ppt.dat, and the geospatial parameter input file used for this test is T1a.w20. All input parameters values are identical to the values used in test 3f with the exception of the following modifications:

1. The soil thickness is increased to 2 meters for all nodes (SDFACT = 2).
2. The root density parameters for the top soil layer are set to 1 (ROOTF1 = 1, MAXWGT1 = 1).
3. The root density parameters for the second soil layer are set to 0.5 (ROOTF2 = 0.5, MAXWGT2 = 0.5).
4. The root density parameters for the third soil layer are set to 0.1 (ROOTF3 = 0.1, MAXWGT3 = 0.1).
5. The root density parameters for the rock layer are set to 0.01 (ROOTF4 = 0.01, MAXWGT4 = 0.01).
6. The effective water storage capacity of the rock layer is increased (RKPOR = 0.02)

8.2.5 Test Sequence 4: Validation of Evapotranspiration, Infiltration, Net Infiltration, and Surface Water Routing Functions in Response to Variable Daily Precipitation Input and Geospatial Parameters

Test sequence 4 consists of 6 tests (test 4a through test 4f) used to evaluate the internal water volume calculation performed by the program, in response to a specified set of initial conditions, controlled daily precipitation input, and specified geospatial input parameters. The test conditions are similar to those used in test sequence 3, except that variable daily precipitation input is incorporated using modified versions of the daily climate input file mod3-ppt.dat. For all test cases the initial root zone water content is set to the wilting point water content for the root zone. All test conditions are defined by modifying parameter values in the model control file (INFILv2.ctl). All test cases require a modified version of the geospatial parameter file T1.w20, T1b.w20, where the parameters for soil type, soil depth, and rock type are specified separately for upland and channel nodes. Two different soil depths are defined using the geospatial input file T1b.w20. The "upland" soil depth is set to 1 meter for all model nodes having less than 5 upstream nodes. The "channel" soil depth is set to 6 meters for all model nodes having 5 or more upstream nodes. A unique soil type and rock type is defined for upland and channel nodes. All upland nodes are assigned soil type 10 and rock type 500, whereas all channel nodes are

assigned soil type 11 and rock type 400. The hydrologic properties for these fictitious soil and rock types are controlled using the model parameters in the model control file.

The test sequence is designed to show that the model components applied to calculate potential evapotranspiration, evaporation, transpiration, evapotranspiration, infiltration (through a layered root zone), and net infiltration, are performing the intended functions and that specific components of the root zone water volume balance calculations are being correctly executed. The modeled root zone functions are evaluated based on variations in parameters defining root zone layering, root density, vegetation cover, and both soil and bedrock properties.

Test 4A: Infiltration and Coupled Surface Water Flow Routing
Test description: The conditions for test case 4a are defined by setting the bedrock bulk saturated hydraulic conductivity to 0 mm/day for all nodes and by disabling evapotranspiration.

The purpose of the test is to validate that coupled surface water flow routing is initiated when the water storage capacity of the root zone is exceeded for any node in the model domain. For these test conditions, outflow from the watershed does not occur when runoff is initiated because the channel nodes have enough available storage capacity to allow the routed surface water to infiltrate. Because evapotranspiration and net infiltration are disabled, runoff must equal outflow once the root zone has become fully saturated.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 4a. The daily climate input file used for this test is Mod3-ppt.dat, and the geospatial parameter input file used for this test is T1b.w20. All input parameters values are identical to the values used in test 3g with the exception of the following modifications:

1. Using the modified geospatial parameter input file T1b.w20, the soil thickness is set to 1 meter for upland nodes, and 6 meters for channel nodes (SDFACT = 1).

2. Using the modified geospatial parameter input file T1b.w20, the soil type is set to 10 for all upland nodes, and 11 for all channel nodes, where a channel node is defined as any node with 5 or more upstream nodes.

3. Using the modified geospatial parameter input file T1b.w20, the rock type is set to 500 for all upland nodes, and 400 for all channel nodes, where a channel node is defined as any node with 5 or more upstream nodes.

4. Evapotranspiration is disabled (IETTEST = 0, ETFACT = 0).

5. Net Infiltration is disabled (IMBFACT = 0)

6. The effective bedrock porosity is set to 0.1 (RKPOR = 0.1)

Test 4B: Infiltration, Net Infiltration, and Coupled Surface Water Flow Routing
Test description: This test uses the same setup as test 4a except that the bedrock bulk saturated hydraulic conductivity for channel nodes is set to 5 mm/day. The soil saturated hydraulic conductivity is increased by a factor of 1000, and the effective surface water flow area is set to 1. These conditions allow all run-on to infiltrate at all model nodes as long as the root zone is not fully saturated. The

purpose of the test is to validate that coupled surface water flow routing is initiated when the water storage capacity of the root zone is exceeded for any node in the model domain. In addition, a positive test result indicates that even though runoff is generated and routed downstream as run-on, the occurrence of outflow from the watershed is dependent on the available root zone storage capacity and the hydraulic conductivity of the soil and bedrock. For these test conditions, outflow from the watershed does not occur when runoff is initiated because the channel nodes have enough available storage capacity to allow the routed surface water to infiltrate, and the effective soil hydraulic conductivity is not a limiting factor. Although net infiltration at channel nodes decreases the outflow rate relative to test case 4a, the bedrock bulk saturated hydraulic conductivity is not high enough to prevent outflow from the watershed.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 4b. The daily climate input file used for this test is Mod3-ppt.dat, and the geospatial parameter input file used for this test is T1b.w20. All input parameters values are identical to the values used in test 4a with the exception of the following modifications:

1. The bedrock bulk saturated hydraulic conductivity of the channel nodes is set to 5 mm/day, while the bedrock for the upland nodes is made impermeable (IMBFACT = 1, IMBIBE(400) = 5 mm/day, IMBIBE(500) = 0 mm/day).

2. The soil saturated hydraulic conductivity is increased by a factor of 1000 (SKSFACT = 1000).

3. The effective flow area for surface water flow is set to 100% of the node surface area (FLAREA = 1).

Test 4C: Infiltration, Net Infiltration, and Coupled Surface Water Flow Routing

Test description: This test uses the same setup as test 4b except that the effective surface water flow area is set to 0.0001 (surface water flow affects only 0.01% of the area of each model node). These conditions allow all run-on to infiltrate at all model nodes as long as the root zone is not fully saturated, but the infiltration rate is limited because the infiltration capacity of the wetted area cannot be exceeded. The purpose of the test is to validate that the infiltration of routed surface water is dependent on the estimated wetted area of downstream cells. For these test conditions, a positive test result indicates that when runoff is generated within the watershed, outflow also occurs because the runoff cannot completely infiltrate into the channel nodes. In contrast to results for test 4b, results for test 4c should show that outflow from the watershed occurs before net infiltration has been initiated, and the duration for which routed surface water infiltrates into channel nodes is longer.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 4c. The daily climate input file used for this test is Mod3-ppt.dat, and the geospatial parameter input file used for this test is T1b.w20. All input parameters values are identical to the values used in test 4b with the exception of the following modification:

The effective surface water flow area is reduced to 0.01% of the node area (FLAREA = 0.00001).

Test 4D: Infiltration, Net Infiltration, and Coupled Surface Water Flow Routing

Test description: The setup for Test 4d consists of a specified sequence of daily precipitation amounts using a modified version of the daily climate input file mod3-ppt.dat. The modified file, Test4d.dat, has a precipitation amount of 500 mm for days 1 and 200 of each year. All remaining days have no precipitation. The soil depth and the geospatial parameter input file is the same as for test 4c, but the bedrock bulk saturated hydraulic conductivity is set to 1 mm/day for both rock types 400 and 500. The soil saturated conductivity for soil type 11 (the soil type for channel nodes) is increased by a factor of 100 (to 8467.2 mm/day). The soil saturated hydraulic conductivity for the upland nodes is left unchanged at 84.672 mm/day. The thickness of the top soil layer is reduced to 0.1 meters, thus increasing the thickness of the second soil layer to 0.9 meters. These test conditions are designed to show that the occurrence of runoff and runon are dependent on storm intensity relative to the soil saturated hydraulic conductivity. The infiltration rate during a given storm event is limited because the infiltration capacity cannot exceed the soil saturated hydraulic conductivity, even if the root zone has available storage capacity. The infiltration capacities are dependent on the estimated storm duration, where the duration of winter storms is estimated to be 12 hours and the duration of summer storms is estimated to be 2 hours. Thus, for a soil having a saturated hydraulic conductivity of 84.672 mm/day, the infiltration capacity for precipitation during a summer storm is 84.672 x (2/24) = 7.056 mm, while the infiltration capacity for precipitation during a winter storm is 84.672 x (12/24) = 42.336 mm. Summer storms are assumed to occur between day number 185 and day 274 of each year, and winter storms are assumed for all remaining days. Storm duration applies to both the duration of precipitation and the duration of surface water flow following the precipitation event. For storms resulting in the generation of runoff, the maximum daily infiltration capacity from both precipitation and surface water run-on is 2 x 7.056 = 14.112 mm for summer storms and 2 x 42.336 = 84.672 mm for winter storms for a soil having a saturated hydraulic conductivity of 84.672 mm/day.

The purpose of the test is to validate that the infiltration of routed surface water is dependent on the estimated storm duration, in conjunction with the soil saturated hydraulic conductivity. In addition, the test results should show that runoff is generated at upland nodes because the infiltration capacity of the soil layers has been exceeded. This is in contrast to conditions for test 4c in which runoff is generated at upland nodes because the root zone has become fully saturated. A positive test result should show that net infiltration at channel nodes occurs early in the simulation in response to surface water run-on, while net infiltration at upland nodes is delayed because of the lower saturated hydraulic conductivity of the soil for upland nodes. For upland nodes along the watershed divide that are not affected by surface water run-on (there are no upstream nodes), net infiltration should not occur until the final storm events in the simulation.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 4d. The daily climate input file used for this test is Test4d.dat, and the geospatial parameter input file used for this test is T1b.w20. All input parameters values are identical to the values used in test 4c with the exception of the following modifications:

1. Daily precipitation is defined using the daily precipitation amounts provided by the daily climate input file Test4d.dat (IPPTTEST = 0, PPTFILE = Test4d.dat).

2. Soil saturated hydraulic conductivity is set to 84.672 mm/day for upland nodes with soil type 10 and 8467.2 mm/day for channel nodes with soil type 11 (SKSFACT = 1, SOILKS(10) = 0.00001, SOILKS(11) = 0.001).

3. The thickness of the top soil layer is set to 0.1 meters (RDEPTH1 = 0.1).

4. The effective surface water flow area is increased to 100% of the node area (FLAREA = 1).

5. The bedrock bulk saturated hydraulic conductivity is set to 1 mm/day for both rock type 400 and rock type 500 (IMBIBE(400) = 1, IMBIBE(500) = 1).

Test 4E: Infiltration, Net Infiltration, Evapotranspiration, and Coupled Surface Water Flow Routing

Test description: This test uses a modified version of the geospatial parameter input file, T1b.w20. The modified version of the file, T1c.w20, defines a new soil and rock type for all model nodes along the watershed boundary. These nodes are within the model domain, but do not have upstream nodes, and thus do not receive surface water run-on. Using the file T1c.w20, the soil type number for upland nodes along the watershed boundary is set to 12, with a saturated hydraulic conductivity of 8467.2 mm/day defined in the model control file. The rock type number for the upland nodes along the watershed boundary is set to 450, with a bedrock bulk saturated hydraulic conductivity of 10 mm/day. The soil type number for upland nodes downstream of other upland nodes (and thus affected by surface water run-on) is set to 10, with a saturated hydraulic conductivity of 84.672 mm/day. As in test case 4d, upland nodes are defined as nodes having less then 5 upstream nodes, whereas channel nodes have 5 or more upstream nodes. The rock type number for these upland nodes with 1 to 4 upstream nodes is 500, with a bedrock bulk saturated hydraulic conductivity of 1 mm/day. The soil type number for channel nodes is 11, with a saturated hydraulic conductivity of 846.72 mm/day. The rock type number for channel nodes is 400, with a bedrock bulk saturated hydraulic conductivity of 100 mm/day. The soil depths in T1c.w20 are set to 0 for upland nodes along the watershed divide, 1 meter for downstream upland nodes, and 6 meters for channel nodes. In addition to the modified geospatial parameter inputs and corresponding soil and bedrock hydrologic properties, a constant daily evapotranspiration rate of 5 mm/day is defined using parameter options in the model control file.

For these test conditions, the infiltration of precipitation and surface water into the root zone is limited by the infiltration capacities of the soil and bedrock. Infiltration capacities are determined by the estimated storm duration, where the duration of winter storms is estimated to be 12 hours and the duration of summer storms is estimated to be 2 hours. Summer storms are assumed to occur between day number 185 and day 274 of each year, and winter storms are assumed for all remaining days. Storm duration applies to both the duration of precipitation and the duration of surface water flow following the precipitation event. During summer storms, infiltration of precipitation and surface water run-on should be limited by the lower infiltration capacity (as defined by the shorter storm duration). Thus, net infiltration in response to summer storm events should not occur until the end of the simulation period when upland nodes along the watershed divide have exceeded the water storage capacity of the rock layer, which does not contain roots and thus slowly wets up throughout the simulation. For these test conditions, evapotranspiration from soil layers is enabled, and this limits net infiltration amounts at all nodes with soil cover. The purpose of the test is to validate that the infiltration of precipitation and routed surface water is dependent on the estimated storm duration, in conjunction with watershed characteristics such as soil depth, root density, soil saturated hydraulic conductivity, and bedrock bulk saturated hydraulic conductivity. A positive test result also shows that net infiltration is dependent on the combined effects of evapotranspiration and the rate of infiltration through the root zone. In contrast to results for test 4d, results for test 4e should show that for the higher intensity summer storm events, net infiltration does not occur at model nodes with soil cover because the smaller amount of water infiltrated

is removed by evapotranspiration. For upland nodes with no soil cover, evapotranspiration does not occur and thus net infiltration eventually occurs in response to infiltrated precipitation once the water content of the rock layer has reached the effective water storage capacity.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 4e. The daily climate input file used for this test is Test4d.dat, and the geospatial parameter input file used for this test is T1c.w20. All input parameters values are identical to the values used in test 4d with the exception of the following modifications:

1. Using the modified geospatial parameter input file T1c.w20, the soil thickness is set to 0 for all upland nodes along the watershed divide (nodes with no upstream nodes). Soil thickness is set to 1 meter for all upland nodes with 1 to 4 upstream nodes, and 6 meters for all channel nodes with 5 or more upstream nodes (SDFACT = 1, INFILE = T1c.w20).

2. Using the modified geospatial parameter input file T1c.w20, the soil type is set to 12 for all upland nodes along the watershed divide, 10 for all upland nodes downstream of the watershed divide, and 11 for all channel nodes (INFILE = T1c.w20).

3. Using the model control file Infilv2.ctl, the soil saturated hydraulic conductivity is set to 1E-4 Kg-sec/m^3 (84.672 mm/day) for soil type 10, 1E-3 Kg-sec/m^3 (846.72 mm/day) for soil type 11, and 1E-2 Kg-sec/m^3 (8467.2 mm/day) for soil type 12 (SKSFACT = 1, SOILKS(10) = 1E-4, SOILKS(11) = 1E-3, SOILKS(12) = 1E-2).

4. Using the modified geospatial parameter input file T1c.w20, the rock type is set to 450 for all upland nodes along the watershed divide, 500 for all upland nodes downstream of the watershed divide, and 400 for all channel nodes. (INFILE = T1c.w20).

5. Using the model control file, the bedrock bulk saturated hydraulic conductivity is set to 100 mm/day for rock type 400, 10 mm/day for rock type 450, and 1 mm/day for rock type 500 (IMBFACT = 1, IMBIBE(400) = 100, IMBIBE(450) = 10, IMBIBE(500) = 1).

6. Evapotranspiration is enabled and potential evapotranspiration is set to a constant rate of 5 mm/day (IETTEST = 1, ETFACT = 5).

7. Root density is set to 100% for the first soil layer, 50% for the second soil layer, 10% for the third soil layers, and 0% for the rock layer (ROOTF1 = 1, ROOTF2 = 0.5, ROOTF3 = 0.1, ROOTF4 = 0, MAXWGT1 = 1, MAXWGT2 = 0.5, MAXWGT3 = 0.1, MAXWGT4 = 0).

Test 4F: Infiltration, Net Infiltration, Evapotranspiration, and Coupled Surface Water Flow Routing

Test description: This test uses the same setup used for test 4e, except that the root density terms are reversed so that the maximum root density occurs at the bottom of the root zone, and evapotranspiration is disabled for the first soil layer. For these test conditions, the transpiration rate from the rock layer should prevent the water content of the layer from exceeding the effective water storage capacity at all upland nodes, preventing the occurrence of net infiltration at upland nodes. Although episodic infiltration through the overlying soil does occur in response to both summer and winter storm events, the infiltration events cannot overcome transpiration losses from the lower root zone. Net infiltration

should occur at channel nodes because of the much higher run-on rates as compared to upland nodes, and because of the higher soil hydraulic conductivity relative to upland nodes affected by run-on.

The purpose of the test is to validate that the root density functions are performing as intended, and that net infiltration is dependent on parameters controlling evapotranspiration as well as other watershed characteristics such as soil depth, soil permeability, bedrock permeability, and topography. A positive test result also shows that average annual evapotranspiration, runoff, run-on, and infiltrated run-on rates are all increased relative to results for test 4e, while average annual net infiltration and the change in root zone water content rates are decreased relative to results for test 4e. The differences occur because the water content of the first soil layer is on average higher than results obtained for test 4e, while the water content of the bottom soil layer and rock layer are on average lower than results for test 4e.

Table A1-1 of Appendix 1 lists the input parameters used in the model control file (INFILv2.ctl) for defining the conditions for test 4f. The daily climate input file used for this test is Test4d.dat, and the geospatial parameter input file used for this test is T1c.w20. All input parameters values are identical to the values used in test 4e with the exception of the following modifications:

1. The root density parameters for the top soil layer are set to 0 (ROOTF1 = 0, MAXWGT1 = 0).
2. The root density parameters for the second soil layer are set to 0.1 (ROOTF2 = 0.1, MAXWGT2 = 0.1).
3. The root density parameters for the third soil layer are set to 0.5 (ROOTF3 = 0.5, MAXWGT3 = 0.5).
4. The root density parameters for the rock layer are set to 1.0 (ROOTF4 = 1.0, MAXWGT4 = 1.0).

8.2.6 Test Sequence 5: Validation of Evapotranspiration, Infiltration, Net Infiltration, and Surface Water Routing Functions in Response to the modeling of Snowfall, Snow-Melt, and Sublimation.

This test sequence consists of 4 test cases used to test the functionality of the snow-module, the interaction of the snow-module with other model components, and the interaction of the snow-module with the daily climate input parameters. The test sequence is also used to test the PET module performance in response to the simulation day-of-year number and various daily air temperature and precipitation inputs. The test criteria are based mostly on the expected response of the snow-module to daily precipitation and air temperature input, and the response of modeled ET, sublimation, and snowmelt to daily precipitation, air temperature, and day number. All test cases are evaluated by visual inspection of the two primary output files generated by INFILv2: the average daily output (daily results for all model nodes are averaged for each day of the simulation) and the average annual map file (the average annual rate for all terms of the water-balance is calculated for all model nodes).

Test 5A: Snow Cover Accumulation

Test description: This is the basic test for the snow-cover accumulation term. A positive test result indicates that precipitation occurs as snowfall and is stored as accumulated snow-cover, as long as the average daily air temperature is below freezing. For this test case, only the precipitation, snowfall, and snow-cover terms should have values greater than 0. Although sublimation is enabled, sublimation does not occur because the average daily air temperature is set to a very low value of –50 C. If the test

criteria are met, this test indicates that the snow module is functioning properly because for extreme cold potential evapotranspiration = 0 and all precipitation occurs as snow, which does not sublimate or melt, and thus there is no water input to other components of the water balance.

Table A1-1 of Appendix 1 provides a complete list of all parameter values in the model control file used for this test. The test simulation is run from 1/1/1980 through 12/31/1985 using mod3-ppt.dat as the daily climate input file and t1a.w20 as the geospatial parameter input file. Using parameters in the model control file (Infilv2.ctl):

1. Precipitation input is set to a constant value of 1 mm/day (IPPTTEST = 1, PPTTEST = . 2. Daily air temperature is set to a constant value of –50 C by setting the daily air temperature model parameters (IAIRTEMP =1, ATEMP1 = -50, ATEMP2 = 0).

2. The potential evapotranspiration (PET) module is enabled by setting IETTEST = 0 and ETFACT = 1.

Test 5B: Sublimation

Test description: This is a continuation of the basic test for the snow-cover accumulation term. This test is a slightly modified version of test 5a for the purpose of testing the sublimation function. If the test criteria are met, this test indicates that the snow module and the sublimation function are performing properly because potential evapotranspiration is greater than 0, and sublimation is modeled as an empirical function of potential evapotranspiration. However, because air temperature is less than 0 degree C for all days simulated, rain or snow-melt does not occur, and thus there is no water input to other components of the water balance.

Table A1-1 of Appendix 1 provides a complete list of all parameter values in the model control file used for this test:

1. The test simulation is run from 1/1/1980 through 12/31/1985 using mod3-ppt.dat as the daily climate input file and t1a.w20 as the geospatial parameter input file.

2. Precipitation input is set to a constant value of 1 mm/day (IPPTTEST = 1, PPTTEST = 1).

3. Daily air temperature is set to a constant value of –10 C by setting the daily air temperature model parameters (IAIRTEMP =1, ATEMP1 = -10, ATEMP2 = 0).

4. The potential evapotranspiration (PET) module is enabled by setting IETTEST = 0 and ETFACT = 1.

5. The surface water routing module is de-coupled (IROUT = 0).

Test 5C: Snowfall and Snow Cover Distribution

Test description: This is a basic test of the spatial distribution of snow-fall and snow-cover terms based on the modeled air-temperature-elevation correlation, and the range of elevations included in the geospatial parameter file (t1a.w20). If the test criteria are met, this test indicates that the spatial distribution of snowfall and snow cover, which are dependent on air temperature, is correctly being modeled as a function of elevation and average air temperature on a daily basis. Because air temperature for model nodes at 1464 m and higher remain below 0 C throughout the entire simulation,

only those nodes below the snow-line are affected by processes such as infiltration, evapotranspiration, net infiltration, and surface water flow.

Table A1-1 of Appendix 1 provides a complete list of all parameter values in the model control file used for this test:

1. Precipitation input is set to a constant value of 2 mm/day (IPPTTEST = 1, PPTTEST = 2).

2. Daily air temperature is set to a constant value of –0.6 C by setting the daily air temperature model parameters (IAIRTEMP =1, ATEMP1 = -0.6, ATEMP2 = 0).

3. The potential evapotranspiration module is enabled by setting IETTEST = 0 and ETFACT = 1.

4. The test simulation is run using mod3-ppt.dat as the daily climate input and t1a.w20 as the geospatial parameter input. The test simulation is run from 1/1/1980 through 12/31/1985.

Test 5D: Spatial and Temporal Distribution of Snowfall and Snow Cover

Test description: This is a basic test of the combined spatial and temporal distribution of snowfall and snow cover terms based on the modeled air-temperature-elevation correlation, and the range of elevations included in the geospatial parameter file (t1a.w20). If the test criteria are met, this test indicates that the combined spatial and temporal distribution of snowfall and snow cover, which are dependent on air temperature, is correctly being modeled as a function of elevation and day of year number. A positive test result indicates that the processes of snow pack development during winter when air temperatures are below freezing and snowmelt during spring as air temperature increases with a subsequent increase in evapotranspiration are being modeled correctly. The spring snowmelt causes a large increase in runoff following the saturation of the root-zone. This is followed by diminished runoff during the summer after the snow pack has melted. The cycle is repeated for each year of the simulation.

Table A1-1 of Appendix 1 provides a complete list of all parameter values in the model control file used for this test. The following list indicates the critical changes made to the model control file:

1. Precipitation input is set to a constant value of 2 mm/day (IPPTTEST = 1, PPTTEST = 2).

2. Daily air temperature is set to an average annual value of –0.6 C with a summer maximum of +19.4 C and a winter minimum of -20.6 C by setting the daily air temperature model parameters (IAIRTEMP =1, ATEMP1 = -0.6, ATEMP2 = 20).

3. The potential evapotranspiration module is enabled by setting IETTEST = 0 and ETFACT = 1.

4. The soil saturated hydraulic conductivity for soil type 10 is set to 1E-3 Kg sec/m^3 (SOILKS(10) = 1E-3).

5. The bedrock bulk saturated hydraulic conductivity is set to 1 mm/day (IMBIBE(500) = 1).

6. The test simulation is run using mod3-ppt.dat as the daily climate input and t1a.w20 as the geospatial parameter input. The test simulation is run from 1/1/1980 through 12/31/1985.

9. CONCLUSION

The no-error (successful) results of the USGS-YMPB execution of the installation test are presented in Appendix 2, Table A2-1. The test run meets the specified criteria indicated in the ITP and the test case output files are consistent with those criteria specified.

Results of the software program functionality validation test described in the USGS-YMPB validation test plan are included as Appendix 2, Table A2-2. As noted elsewhere, a checkmark entered by the validation tester is the indication that the results were checked and found to satisfy the acceptance criteria that all conditions as stated were met. These results confirm successful validation of INFIL V2.0.

To conclude, the test results are found to satisfy the acceptance criteria described in the Validation Test Plan for INFIL V2.0, and meet each of the test sequence requirements listed in Appendix 2 and described in the RD and DD. Correct installation and indication that the software is performing (functioning) as designed further is validated by the successful run of the Installation/Functionality tests. There are no identified remaining test exceptions or failures. In accordance with AP-SI.1Q, section 5.9.3.1, appropriate software validation has been performed to meet the requirements of Section 5.6.

10. DOCUMENTS CITED

Altman, S.J.; Arnold, B.W.; Barnard, R.W.; Barr, G.E.; Ho, C.K.; McKenna, S.A.; and Eaton, R.R. 1996. *Flow Calculations for Yucca Mountain Groundwater Travel Time (GWTT-95).* SAND96-0819. Albuquerque, New Mexico: Sandia National Laboratories. ACC: MOL.19961209.0152.

Buesch, D.C.; Spengler, R.W.; Moyer, T.C.; and Geslin, J.K. 1996. *Proposed Stratigraphic Nomenclature and Macroscopic Identification of Lithostratigraphic Units of the Paintbrush Group Exposed at Yucca Mountain, Nevada.* Open-File Report 94-469. Denver, Colorado: U.S. Geological Survey. ACC: MOL.19970205.0061.

Campbell, G.S. 1977. *An Introduction to Environmental Biophysics.* New York, New York: Springer-Verlag. TIC: 238256.

Campbell, G.S. 1985. *Soil Physics with BASIC Transport Models for Soil-Plant Systems.* Developments in Soil Science 14. Amsterdam, The Netherlands: Elsevier Science B.V. TIC: 214477.

CRWMS M&O 2000a. *Unsaturated Zone Flow and Transport Model Process Model Report.* TDR-NBS-HS-000002 REV 00 ICN 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000831.0280.

CRWMS M&O 2000b. *Analysis of Infiltration Uncertainty.* ANL-NBS-HS-000027 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000525.0377.

CRWMS M&O 2000c. *Analysis of Geochemical Data for the Unsaturated Zone.* ANL-NBS-HS-000017 rev 00 ICN 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20010405.0013

CRWMS M&O 2000d. *Geochemical and Isotopic Constraints on Ground-Water Flow Directions, Mixing, and Recharge at Yucca Mountain, Nevada.* ANL-NBS-HS-000021 REV 00 ICN 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20010123.0120

CRWMS M&O 2000e. *Technical Work Plan for Unsaturated Zone (UZ) Flow and Transport Process Model Report.* TWP-NBS-HS-000001, Rev 01. Las Vegas, Nevada; CRWMS M&O. ACC: MOL.20010404.007

Davies, J.A. and Allen, C.D. 1993. *Equilibrium, potential, and actual evaporation from cropped surfaces in southern Ontario.* Journal of Applied Meteorology, Vol 12, p. 649-657.

Day, W.C.; Potter, C.J.; Sweetkind, D.S.; Dickerson, R.P.; and San Juan, C.A. 1998. *Bedrock Geologic Map of the Central Block Area, Yucca Mountain, Nye County, Nevada.* Map I-2601. Washington, D.C.: U.S. Geological Survey. TIC: 237019.

deBruin, H.A.R. 1988. *Evaporation in arid and semi-arid regions, in,* "Estimation of natural groundwater recharge", ed., Simmers, I., Reidel Publishing Company, Boston, MA., p. 73-88.

Eichinger, W.E.; Parlange, M.B.; and Stricker, H. 1996. "On the Concept of Equilibrium Evaporation and the Value of the Priestley-Taylor Coefficient." *Water Resources Research, 32,* (1), 161-164. Washington, D.C.: American Geophysical Union. TIC: 245924.

Flint, A.L. and Childs, S.W. 1984. "Physical Properties of Rock Fragments and Their Effect on Available Water in Skeletal Soils." Chapter 10 of *Erosion and Productivity of Soils Containing Rock Fragments.* SSSA Special Publication #13. Madison, Wisconsin: Soil Science Society of America. TIC: 247223.

Flint, A.L. and Childs, S.W. 1987. "Calculation of Solar Radiation in Mountainous Terrain." *Agricultural and Forest Meteorology, 40,* (3), 233-249. Amsterdam, The Netherlands: Elsevier Science Publishers B.V. TIC: 225242.

Flint, A.L. and Childs, S.W. 1991. "Use of the Priestley-Taylor Evaporation Equation for Soil Water Limited Conditions in a Small Forest Clearcut." *Agricultural and Forest Meteorology, 56,* (3-4), 247-260. Amsterdam, The Netherlands: Elsevier. TIC: 241865.

Flint, A.L.; Hevesi, J.A.; and Flint, L.E. 1996. *Conceptual and Numerical Model of Infiltration for the Yucca Mountain Area, Nevada.* Milestone 3GUI623M. Denver, Colorado: U.S. Geological Survey. ACC: MOL.19970409.0087.

Flint, L.E. 1998. *Characterization of Hydrogeologic Units Using Matrix Properties, Yucca Mountain, Nevada.* Water-Resources Investigations Report 97-4243. Denver, Colorado: U.S. Geological Survey. ACC: MOL.19980429.0512.

Flint, L.E. and Flint, A.L. 1995. *Shallow Infiltration Processes at Yucca Mountain, Nevada—Neutron Logging Data 1984-93.* Water-Resources Investigations Report 95-4035. Denver, Colorado: U.S. Geological Survey. ACC: MOL.19960924.0577.

Freeze, R.A. and Cherry, J.A. 1979. *Groundwater.* Englewood Cliffs, New Jersey: Prentice-Hall. TIC: 217571.

French, R.H. 1983. "Precipitation in Southern Nevada." *Journal of Hydraulic Engineering, 109,* (7), 1023-1036. New York, New York: American Society of Civil Engineers. TIC: 238300.

Hatton, T. 1998. *Catchment Scale Recharge Modelling.* Part 4 of The Basics of Recharge and Discharge. Zhang, L., ed. Collingwood, Victoria, Australia: CSIRO Publishing. TIC: 247711.

Hevesi, J.A. and Flint, A.L. 1998. "Geostatistical Estimates of Future Recharge for the Death Valley Region." *High-Level Radioactive Waste Management, Proceedings of the Eighth International Conference, Las Vegas, Nevada, May 11-14, 1998.* Pages 173-177. La Grange Park, Illinois: American Nuclear Society. TIC: 237082.

Hevesi, J.A.; Ambos, D.S.; and Flint, A.L. 1994a. "A Preliminary Characterization of the Spatial Variability of Precipitation at Yucca Mountain, Nevada." *High-Level Radioactive Waste Management, Proceedings of the Fifth Annual International Conference, Las Vegas, Nevada, May 22-26, 1994. 4,* 2520-2529. La Grange Park, Illinois: American Nuclear Society. TIC: 210984.

Hevesi, J.A.; Flint, A.L.; and Flint, L.E. 1994b. "Verification of a One-Dimensional Model for Predicting Shallow Infiltration at Yucca Mountain." *High Level Radioactive Waste Management, Proceedings of the Fifth Annual International Conference, Las Vegas, Nevada, May 22-26, 1994. 4,* 2323-2332. La Grange Park, Illinois: American Nuclear Society. TIC: 210984.

Hevesi, J.A.; Flint, A.L.; and Istok, J.D. 1992. "Precipitation Estimation in Mountainous Terrain Using Multivariate Geostatistics. Part II: Isohyetal Maps." *Journal of Applied Meteorology, 31,* (7), 677-688. Boston, Massachusetts: American Meteorological Society. TIC: 225248.

Jury, W.A.; Gardner, W.R.; and Gardner, W.H. 1991. *Soil Physics.* 5th Edition. New York, New York: John Wiley & Sons. TIC: 241000.

Kwicklis, E.M.; Thamir, F.; Healy, R.W.; and Hampson, D. 1998. *Numerical Simulation of Air- and Water-Flow Experiments in a Block of Variably Saturated, Fractured Tuff from Yucca Mountain, Nevada.* Water-Resources Investigations Report 97-4274. Denver, Colorado: U.S. Geological Survey. ACC: MOL.19981215.0103.

Liu, H.H.; Doughty, C.; and Bodvarsson, G.S. 1998. "An Active Fracture Model for Unsaturated Flow and Transport in Fractured Rocks." *Water Resources Research, 34,* (10), 2633-2646. Washington, D.C.: American Geophysical Union. TIC: 243012.

Maidment, D.R., ed. 1993. *Handbook of Hydrology.* New York, New York: McGraw-Hill. TIC: 236568.

McNaughton, K.G. and Spriggs, T.W. 1989. "An Evaluation of the Priestley and Taylor Equation and the Complementary Relationship Using Results from a Mixed-Layer Model of the Convective Boundary Layer." *Estimation of Areal Evapotranspiration, Proceedings of an International Workshop Held During the XIXth General Assembly of the International Union of Geodesy and Geophysics at Vancouver, British Columbia, Canada, 9-22 August, 1987. 177,* 89-104. Wallingford, United Kingdom: International Association of Hydrological Sciences. TIC: 245925.

Nichols, W.D. 1987. *Geohydrology of the Unsaturated Zone at the Burial Site for Low-Level Radioactive Waste Near Beatty, Nye County, Nevada.* Water-Supply Paper 2312. Denver, Colorado: U.S. Geological Survey. ACC: NNA.19920428.0023.

Priestley, C.H.B. and Taylor, R.J. 1972. "On the Assessment of Surface Heat Flux and Evaporation Using Large-Scale Parameters." *Monthly Weather Review, 100,* (2), 81-92. Washington, DC: U.S. Department of Commerce. TIC: 235941.

Savard, C.S. 1995. *Selected Hydrologic Data from Fortymile Wash in the Yucca Mountain Area, Nevada, Water Year 1992.* Open-File Report 94-317. Denver, Colorado: U.S. Geological Survey. ACC: MOL.19941208.0002.

Sawyer, D.A.; Wahl, R.R.; Cole, J.C.; Minor, S.A.; Laczniak, R.J.; Warren, R.G.; Engle, C.M.; and Vega, R.G. 1995. *Preliminary Digital Geological Map Database of the Nevada Test Site Area, Nevada.* Open-File Report 95-0567. Denver, Colorado: U.S. Geological Survey. TIC: 232986.

Scott, R.B. and Bonk, J. 1984. *Preliminary Geologic Map of Yucca Mountain, Nye County, Nevada, with Geologic Sections.* Open-File Report 84-494. Denver, Colorado: U.S. Geological Survey. TIC: 203162.

Stannard, D.I 1993. *Comparison of Penman-Monteith Shuttleworth-Wallance and modified Priestley-Taylor evapotranspiration models for wildland vegetation in semiarid rangeland.* Water Resources Research, 29 (5), p. 1379-1392. American Geophysical Union. Washington, DC.

Stewart, R.B. and Rouse, W.R. 1977. "Substantiation of the Priestley and Taylor Parameter [alpha]=1.26 for Potential Evaporation in High Latitudes." *Journal of Applied Meteorology, 16,* 649-650. [Boston, Massachusetts: American Meteorological Society]. TIC: 245923.

Thompson, R.S.; Anderson, K.H.; and Bartlein, P.J. 1999. *Quantitative Paleoclimatic Reconstructions from Late Pleistocene Plant Macrofossils of the Yucca Mountain Region.* Open-File Report 99-338. Denver, Colorado: U.S. Geological Survey. TIC: 245688.

USGS 1996. *Software Code: MARKOV.* V1.0. 10142-1.0-00.

USGS (U.S. Geological Survey) 2000a. *Simulation of Net Infiltration for Modern and Potential Future Climates AMR.* Development Plan TDP-NBS-HS-000016 REV 01. [Denver, Colorado]: U.S. Geological Survey. ACC: MOL.20000516.0011.

USGS (U.S. Geological Survey) 2000b. *Future Climate Analysis.* ANL-NBS-GS-000008 REV 00. Denver, Colorado: U.S. Geological Survey. ACC: MOL.20000629.0907.

USGS (U.S. Geological Survey) 2001. *Simulation of Net Infiltration for Modern and Potential Future Climates.* ANL-NBS-HS-000032 REV 00 ICN 01. Denver, Colorado: U.S. Geological Survey. ACC: MOL.20010405.0002.

APPENDIX 1

APPENDIX 1-A: INFIL V2.0 MODEL CONTROL FILE

A. Model Control File Variable Order

```
read(7,5) header
read(7,*) optmassb
read(7,*) irout, ifrtol
read(7,*) isnow,isnwmod,snopar1
read(7,*) isublim,subpar1,subpar2
read(7,*) ippttest,ppttest
read(7,*) iettest,ettest
read(7,*) celsize
read(7,*) xcfs,ycfs
read(7,*) yrbeg,dnbeg,yrend,dnend,tyear1,tyear2
read(7,*) pptfact,etfact,imbfact,sksfact
read(7,*) sdfact,ivegc,fvegc
read(7,*) rootf1,rootf2,rootf3,rootf4
read(7,*) maxwgt1,maxwgt2,maxwgt3,maxwgt4
read(7,*) rdepth1,rdepth2,rdepth4,rdepthf
read(7,*) rkpor,rkmmfact,flarea
read(7,*) infmod,etmod,runmod
read(7,*) barsoil1,barsoil2
read(7,*) iairtemp,atemp1,atemp2
read(7,*) hstep
read(7,*) pptyuc,aaprepx,ipptdat
read(7,5) pptfile
read(7,*) depthflg,irtz,delvwcf,moistcr,fracmod
read(7,*) ivwcflg,vwcfact
read(7,5) vwcfile
read(7,5) infile
read(7,*) locstart
read(7,5) Dayall
read(7,*) ndaymap, imap
read(7,*) irday(i),nyrout(i)
read(7,5) daymap(i)
read(7,5) outfile
read(7,5) flxfile
read(7,*) dbgflag,dbgflag2
read(7,5) dbgfile
read(7,*) idebug
read(7,5) dbugout
read(7,*) outyear1
read(7,5) header0
read(7,*) numdepth
```

```
read(7,*) idpth,idpth2,rtza(idpth),rtzb(idpth),
  1         rtzc(idpth),rtzd(idpth),bsoil(idpth),
  2         vwcf2(idpth)
     read(7,5) dumbhead
    read(7,*) nsoilid
     read(7,*) soilid,fieldcap(soilid),soilresid(soilid),
  1          soilporo(soilid),soilalbeta(soilid),
  2          soiltalpha(soilid),soilks(soilid),soilpe(soilid),
  3          soilbval(soilid),salpha(soilid),soilvgn(soilid),
  4          sorp(soilid),soilpond(soilid),potis(soilid)
     read(7,5) dumbhead
    read(7,*) nrockid
     read(7,*) rockid,rockcap(rockid),rockresid(rockid),
  1                  rockporo(rockid),rockalbeta(rockid),
  2         rocktalpha(rockid),rockks(rockid),rockpe(rockid),
  3         rockbval(rockid),ralpha(rockid),rockvgn(rockid),
  4         rockfracks(rockid),imbibe(rockid),potir(rockid)
```

B. Model Control File Input Variables.

Control FileInput Parameter	DESCRIPTION	FORMAT
HEADER	Model run identification: date, input file names, etc.	A (character data)
OPTMASSB	0 to stop runoff routing on last day of simulation	* (list-directed I/O)
IROUT	0 for de-coupled flow routing; 1 for coupled routing;-1 for no flow routing; -2 for no infiltration	*
IFRTOL	Flow routing tolerance term	*
ISNOW	Internal testing options (validation)0 : snow module dissabled; 2 : snow module enabled	*
ISNWMOD	isnwmod = I : snow-cover model type= 1 for setting et = 0 for days at freezing or below= 2 for snow-cover module enabled	*
SNOPAR1	snopar1 = model parameter	*
ISUBLIM	isublim = sublimation model option (0 = off, 1 = on)	*
SUBPAR1	subpar1 = sublimation factor if air temperature less than or equal to 0.	*
SUBPAR2	subpar2 = sublimation factor if air temperature greater than 0	*
IPPTTEST	Internal testing options (validation): ippttest = 1 (for testing)sets precip to constant = ppttest. ippttest = 0 for modeling	*
PPTTEST	Constant precip value for testing	*
IETTEST	Internal testing options (validation): = 1 (for testing) sets et to constant = ettest. Iettest = 0 for modeling	*
ETTEST	Constant et value for testing.	*
CELSIZE	celsize from control file to calculate discharge. Size hard-wired for 30-meter grid.	*
XCFS	X coordinate for generating discharge (cfs) at user specified location (cell)	*
YCFS	Y coordinate for generating discharge (cfs) at user specified location (cell)	*
YRBEG	Simulation starting year. For using measured daily precipitation as input (described below). Gregorian calendar year.	*

Control FileInput Parameter	DESCRIPTION	FORMAT
DNBEG	Integer, (0 ≤ dnn1 ≤ 366). Simulation starting day number (example; 1= January 1, 365 = December 31 for non-leap year). If precipitation input file begins prior to the date represented by the starting year and starting day, this part of the input file will be ignored by the program INFIL. Julian day number.	*
YREND	Simulation ending year. For using measured daily precipitation as input (described below). Gregorian calendar year.	*
DNEND	Integer, (0 ≤ dn2 ≤ 366). Simulation ending day number (example; 1 - January 1, 365 - December 31 for non-leap year). If precipitation input file ends after the date represented by ending year and ending day, this part of the input file will be ignored by the program INFIL.	*
TYEAR1	Determines type of simulation output. Domain of values is 0 or 1. = 0 for straight annual totals. =1 for annual avg. for multi-years	*
TYEAR2	Interval (in years) for calculating multi-year averages from above.	*
PPTFACT	PPTFACT, real, (0 ≤ pptfact). Scaler for increasing or decreasing the magnitude of daily precipitation. Values greater than 1.0 increase precipitation, values less than 1 decrease precipitation.	*
ETFACT	ETFACT, real (0 ≤ etfact). Scaler for increasing or decreasing the magnitude of daily potential evapotranspiration. Values greater than 1.0 increase precipitation, values less than 1 decrease precipitation.	*
IMBFACT	Bedrock permeability (mm/day) scaling factor	*
SKSFACT	Soil permeability scaling factor	*
SDFACT	Soil depth scaling factor	*
IVEGC	Used to invoke vegetation map cover in et calculation when IVEGC = 1	*
FVEGC	constant vegetation cover factor used in et calculation when IVEGC = 0	*
ROOTF1	Upper cascading bucket evapotranspiration weighting function limit	*
ROOTF2	Second cascading bucket evapotranspiration weighting function limit	*
ROOTF3	Third cascading bucket evapotranspiration weighting function limit	*
ROOTF4	Lower cascading bucket evapotranspiration weighting function limit	*
MAXWGT1	Dynamic root zone weighting function for simulation evapotransipiration for layer 1	*
MAXWGT2	Dynamic root zone weighting function for simulation evapotransipiration for layer 2	*
MAXWGT3	Dynamic root zone weighting function for simulation evapotransipiration for layer 3	*
MAXWGT4	Dynamic root zone weighting function for simulation evapotransipiration for layer 4	*
RDEPTH1	Root zone depth 1: Index variable for associating root-zone parameters to soil depth class IDPTH. Values for IDPTH must correspond to depth classes as identified in the location parameter input file.	*
RDEPTH2	Root zone depth 2	*
RDEPTH4	Root zone depth 3	*
RDEPTHF	Estimated root zone depth	*
RKPOR	Rock porosity, id est effective bedrock storage capacity variable	*
RKMMFACT	Initial rock water content condition	*
FLAREA	Effective surface-water flow area	*
INFMOD	Infiltration module. = 1 for slow drainage function, =2 for full darinage.	*
ETMOD	Evapotranspiration module. = 1 if module is on.	*

Control FileInput Parameter	DESCRIPTION	FORMAT
RUNMOD	Run-off routing module. =2,3 to allow slow, of full net infiltration when effective bedrock storage capacity > 0. = 1 to allow simple net infiltration only when effective bedrock storage capacity is exceeded. = 0 allows net infiltration to occur only during infiltration module calculations.	*
BARSOIL1	Bare soil et parameter	*
BARSOIL2	Bare soil et parameter	*
IAIRTEMP	Air temperature model. Domain of values –1, 1, 2, 3, other	*
ATEMP1	ATEMP1 = avg. air temp (deg. C)	*
ATEMP2	ATEMP2 = half amplitude of air temp (seasonal) deviation (deg. C)	*
HSTEP	HSTEP, real, hours (1 ≤ hstep ≤ 4). Time step used in POTEVAP subroutine for simulating potential evapotranspiration using a solar radiation model and an energy balance method. Values of either 1 or 2 are recommended	*
PPTYUC	PPTYUC, integer, (0 ≤ pptyuc ≤ 5). Option for using a function to account for the spatial variability of daily precipitation over Yucca Mountain.pptyuc = 5 for monsoon climatepptyuc = 4 for future climatespptyuc = 3 for Yucca Mt (4JA) using constant scalerpptyuc = 2 for Yucca Mt (4JA) using variable scalerpptyuc= 1 for analog climate simulations (Area 12, etc)pptyuc = (0) for uniform precip distributionvalues used for original 1996 precip model - -3, -2, -1	*
AAPREPX	Average annual precip for site. Use when PPTYUC = 5	*
IPPTDAT	ipptdat = input data type:IPPTDAT = 0 for daily precip data from a single site.IPPTDAT = 1 for simulated precip input from PPTSIM.IPPTDAT = 3 for reading output generated by DAILY09	*
PPTFILE	pptfile (unit 11) = daily precip input file	A
DEPTHFLG	Integer, (0 1). Option used for specifying the root-zone sub-model to be used for simulating evapotranspiration. IRTZ is set to 1 for using a dynamic root-zone sub-model which calculates root-zone weighting factors as a function of root-zone depth and water contect. IRTZ is set to 0 for using a static root-zone sub-model which calculates root-sub-model, evapotranspiration is simulated as a function of potential evapotranspiration, water content, and the root-zone weighting factors. Root-zone weighting factors are not used when the bucket sub-model is used. Unused.	*
IRTZ	Set to 1 for using a dynamic root-zone sub-model which calculates root-zone weighting factors as a function of root-zone depth and water contect. IRTZ is set to 0 for using a static root-zone sub-model which calculates root-sub-model, evapotranspiration is simulated as a function of potential evapotranspiration, water content, and the root-zone weighting factors Unused.	*
DELVWCF	*Not used:* Real, (0< delvwcf). Exponent used in the dynamic root-zone sub-model for controlling the relative effect of changes in water content on root-zone weighting factors. Values less than 1 are used for decreasing the relative effect of water contents, values greater than 1 are used for increasing the relative effect	*
MOISTCR	Integer, (0, 1). Option for selecting the moisture characteristic functions to be used in the Richards equation sub-model. Set to 1 for using a Brooks and Corey type moisture characteristic, 0 for using a van Genuchten type moisture characteristic. The van Genuchten version is not fully functional with the current version of INFIL. This parameter serves only as a place-holder until later versions of INFIL are completed Unused.	*

Control FileInput Parameter	DESCRIPTION	FORMAT
FRACMOD	integer, (0, 1). Option for setting the fracture flow sub-model to be used in the Richards equation sub-model. Set to 1 for using a storage type fracture sub-model which simulates imbibition of fracture flow back into the bedrock matrix. Set to 0 for using a simplified approach which assumes all fracture flow in bedrock becomes net infiltration Unused.	*
IVWCFLG	fromc previous simulation as initial conditions forc next simulationSet = 0 for model simulations	*
VWCFACT	Initial vwc determined by residual VWC and vwcfactsoilvwc(ia) = soilresid(soiltype(ia))*vwcfactif((ivwcflg.eq.1).and.(locid(ia).eq.locid2))buckvwc, initvwc,finalvwc Unused when VWCFACT = 0	*
INFILE	main input file: geospatial input parameters	A
LOCSTART	Not used. (4/30/97 to allow re-start in case of power loss) Set to -1	*
DAYALL	File name variable for daily mass balance terms averaged for all points output.	A
NDAYMAP	Number of 24-hour mass balance results for mapping.maximum of 10 output files	*
IMAP	I = 1 to 10 for number of an individual DAYMAP output file.	*
IRDAY	The number of days for a DAYMAP output	*
NYROUT	The year for the 24-hour mass balance map results	*
DAYMAP	File name for 24-hour mass balance results for mapping output	A
OUTFILE	File name for summary information and annual summary statistics output	A
FLXFILE	File name for average annual mass balance terms output	A
DBGFLAG	Integer, ($1 \leq$ dbgflag ≤ 9). Option for control of output to main output file. Set to 1 for standard simulation results consisting of daily mass balance terms for a specified location. Set to 9 for generating average mass balance terms calculated for all locations. Values in between 1 and 9 are used for testing and debugging purposes	*
DBGFLAG2	Integer, (0, 1) option for generating total yearly mass balance results	*
DBGFILE	File name for 2nd daily mass balance output file	A
IDEBUG	Integer, (-1 < idebug < 3)To check mass balance (if = 0, echo input parameters)	*
DBUGOUT	File name for output file to hold debugging list of inputs. If idebug does not = 0 then write dbugout	A
OUTYEAR1	File name (prefix) for output map – annual totals or multi-year averages	*
HEADER0	Root zone parameter names	A
NUMDEPTH	Number of root-zone parameter lines in control file. Counter.	*
IDPTH	Root-zone parameter line index number	*
IDPTH2	real, meters, ($0 <$ IDPTH2 ≤ 100)	*
RTZA	(idpth), real, (0 < rtza). Estimated or fitted parameter for function defining root density as a function of depth.	*
RTZB	(idpth), real, (0 < rtzb). Estimated or fitted parameter for function defining root density as a function of depth.	*
RTZC	(idpth), real, (0 < rtzc). Estimated or fitted parameter for function defining root density as a function of depth.	*
RTZD	(idpth), real, (0 < rtzd). Estimated or fitted parameter for function defining root density as a function of depth	*
BSOIL	(idpth), real (0 < rtzb). Estimated or fitted parameter for controlling the relative proportion of total evapotranspiration occurring as bare soil evaporation from the top element of the finite difference mesh.	*

Control FileInput Parameter	DESCRIPTION	FORMAT
VWCF2	(IDPTH), real, (0 < vwcf2). Estimated or fitted parameter for function used to condition the dynamic root-zone weighting function so as to decrease the effect of high water contents with increasing depth.	*
DUMBHEAD	Soil property parameter names	A
NSOILID	Number of soil-property parameter lines in control file. Counter.Integer, (1 ≤ nosoilid ≤ 20). Total number of soil types to be used in mass balance calculations for either the Richards equation or the bucket sub-models. This line must be followed by nsoilid lines consisting of parameters for each soil type. All parameters in line 30 must be repeated nsoilid times. The current version of INFIL is dimensioned to allow a maximum of 20 different soil types.	*
SOILID	Soil-property parameter line index number.	*
FIELDCAP	The water content of the near surface soil profile (i.e., the root zone) at which drainage becomes negligible	*
SOILRESID	(soilid), Estimated or measured residual water content for evapotranspiration. Approximately equivalent to the wilting point, but can be set lower as a means of indirectly accounting for vapor flow contributions to evapotranspiration	*
SOILPORO	(soilid), Soil porosity (or effective fracture porosity in the case of bedrock).), Real m^3/m^3, (fieldcap ≤ fieldcap). Estimated or measured soil porosity. Values are seldom less than 0.15 and higher than 0.70 for most field conditions	*
SOILALBETA	(soilid), Real (soilalbeta ≤ 0). Estimated or fitted parameter for defining evapotranspiration as a function of soil water content and potential evapotranspirtation using the modified Priestley-Taylor equation. Increasing the absolute magnitude of soilalbeta increases evapotranspiration for a given water content. Values ranging from 10.0 to -1.5 are recommended for modeling field conditions	*
SOILTALPHA	(soilid), Real, (0 ≤ soiltalpha). Estimated or fitted parameter for defining evapotranspiration as a function of soil water content and potential evapotranspiration using the modified Priestley-Taylor equation. The value of soiltalpha may increase evapotranspiration for a given water content, depending on the value of soilalbeta. Values ranging from 0.60 to 1.26 are recommended for this parameter for modeling most field conditions	*
SOILKS	(soilid), real, J-sec/m^3, (0 ≤ soilks). Estimated or measured hydraulic conductiviity. This parameter is used only in the Richards equation sub-model in the current version of INFIL	*
SOILE	(soilid), real, J/Kg, (soilpe ≤ 0). Estimated or measured air-entry water potential. This parameter is used in the Brooks and Corey type moisture characteristic functions	*
SOILBVAL	(soilid), real, (0 ≤ soilbval). Estimated or fitted shape parameter for defining the shape of the Brooks and Corey type moisture characteristic function	*
SALPHA	(soilid), 1/(J/Kg), (0 ≤ salpha). Estimated or fitted parameter defining the van Genuchten type moisture characteristic function used in the Richards equation sub-model. This parameter serves only as a place holder, and is not used by the current version of the program INFIL	*
SOILVGN	(soilid), real, (0 ≤ soilvgn). Estimated or fitted parameter defining the van Genuchten type moisture characteristic function used in the Richards equation sub-model. This parameter serves only as a place holder, and is not used by the current version of the program INFIL	*
SORP	(soilid), real, J·sec/ m^3,(0≤ sorp). Estimated or fitted measured sorptivity value for soil type. This parameter serves only as a place holder, and is not used by the current version of the program INFIL	*

Control FileInput Parameter	DESCRIPTION	FORMAT
SOILPOND	(soilid), real, m^3/m^3, (0 $\leq$ soilpond $\leq$ soilporo). Estimated or measured parameter used in the Richards equation sub-model for defining the soil water content at which water is stored as excess precipitation and is used as potential runoff in the water balance. Porosity minus the soilpond term determines the water content at which additional moisture is considered excess and is transferred to overlying elements. If excess water is produced in the top element, this water is accumulated in the runoff term of the water balance	*
POTIS	Estimated or measured water potential which is used to define initial conditions	*
DUMBHEAD	Rock-property parameter names.	A
NROCKID	Number of rock-property lines in control file. Counter.Integer, (0$\leq$ rockid $\leq$ 300). Rock type identification number for referencing rock properties data to location parameters specified in the INPUT file. The current version of INFIL allows for a maximum of 300 different rock types. Rockid numbers need not be sequential for the nrockid number of lines.	*
ROCKID	Rock-property parameter line index number.	*
ROCKCAP	(rockid), real, m^3/m^3 ,(rockresid $\leq$ rockcap $\leq$ rockporo). Estimated or measured field capacity term for rock types specified by rockid. This parameter is used only by the Richards equation sub-model for modeling the occurrence of fracture flow.	*
ROCKRESID	(rockid), real m^3/m^3, (0 $\leq$ rockresid $\leq$ rockcap). Estimated or measured residual water content for evapotranspiration. Approximately equivalent to the wilting point for plants having roots extending into open bedrock fractures, but can be set lower as a means of indirectly accounting for vapor flow contributions to evapotranspiration. This parameter is used only by the Richards equation sub-model.	*
ROCKPORO	(rockid), real, m^3/m^3, (rockcap $\leq$ rockporo $\leq$ 1). Estimated or measured rock porosity. Values are seldom less than 0.01 and higher 0.50 for most field conditions. This parameter is used by only by the Richards equation sub-model.	*
ROCKALBETA	(rockid), real, (rockalbeta $\leq$ 0). Estimated or fitted parameter used in the modified Priestley-Taylor equation for defining evapotranspiration as a function of rock-matrix water content and potential evapotranspiration. Increasing the absolute magnitude of rockalbeta increases evapotranspiration for a given water content. Although values ranging from -10.0 to -1.5 are recommended for a modeling field conditions for soils, values for rock materials are less certain at this time. This parameter is used only by the Richards equation sub-model.	*
ROCKTALPHA	(rockid), real, (0 $\leq$ rocktalpha). Esitmated or fitted parameter used in the modified Priestley-Taylor equation for defining evapotranspiration as a function of rock-matrix water content and potential evapotranspiration. The value of rocktalpha determines the upper limit of evapotranspiration as a function of water content and potential evapotranspiration. Increasing the absolute magnitude of rocktalpha may increases evapotranspiration for a given water content, depending on the value of rockalbeta. Values ranging from 0.60 to -1.26 are recommended for this parameter for modeling most field conditions.	*
ROCKKS	(rockid), real, J·sec/m^3, (0 $\leq$ rockks). Estimated or measured hydraulic conductivity for bedrock matrix. This parameter is used only in the Richards equation sub-model in the current version of INFIL.	*
ROCKPE	ROCKPE(rockid), real, J/Kg, (rockpe $\leq$ 0). Estimated or measured air-entry water potential for bedrock matrix. This parameter is used in the Brooks and Corey type moisture characteristic functions of the Richards equation sub-model.	*

Control FileInput Parameter	DESCRIPTION	FORMAT
ROCKBVAL	(rockid), real, (0 ≤ rockbval). Estimated or fitted shape parameter for defining the shape of the Brooks and Corey type moisture characteristic function used in the Richards equation sub-model.	*
RALPHA	(rockid), real, 1(J/Kg), (0 ≤ ralpha). Estimated or fitted parameter defining the van Genuchten type moisture characteristic function used in the Richards equation sub-model.	*
ROCKVGN	(rockid), real, (0 ≤ rockvgn). Estimated or fitted parameter defining the van Genuchten type moisture characteristic function used in the Richards equation sub-model.	*
ROCKFRACKS	(rockid), real, J·sec/m^3, (0 ≤ rockfracks). Estimated or measured parameter used for defining the specified fracture flux as a sink term in the Richards equation sub-model. The specified flux is applied in the governing flow equation if water content becomes greater than rockcap(rockid).	*
IMBIBE	N/A ((rockid), real, mm/day, (0≤ imbibe). Estimated or measured parameter representing the field-scale or bulk (matrix plus fractures) saturated hydraulic conductivity of the bedrock material. Used only by the Bucket sub-model as a potential net infiltration term in the mass balance calculation)	
POTIR	(rockid), real, J/Kg, (potis ≤ 0). Estimated or measured water potential which is used to define initial conditions for bedrock for simulations using the Richards equation sub-model.	*

Table A1-1. Input for test cases: control file parameter values

Control File Input Parameter	Test Case 0A	0B	0C	0D1	0D2	0D3	1A
OPTMASSB	1	1	1	1	1	1	1
IROUT	0	1	1	1	1	1	0
IFRTOL	1.00E-08	1.00E-08	1.00E-08	1.00E-08	1.00E-08	1.00E-08	1.00E-08
ISNOW	2	2	2	2	2	2	2
ISNWDOW	2	2	2	2	2	2	2
SNOWPAR1	1.78	1.78	1.78	1.78	1.78	1.78	1.78
ISUBLIM	3	3	3	3	3	3	3
SUBPAR1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
SUBPAR2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
IPPTTEST	0	0	0	0	0	0	0
PPTTEST	1	1	1	1	1	1	1
IETTEST	0	0	0	0	0	0	0
ETTEST	0	0	0	0	0	0	0
CELSIZE	30	30	30	30	30	30	30
XCFS	544691	547931	547931	547931	547931	547931	544691
YCFS	4074153	4077483	4077483	4077483	4077483	4077483	4074153
YRBEG	1980	1	1951	1980	1980	1980	1980
DNBEG	1	1	1	1	1	1	1
YREND	1995	100	1997	1985	1985	1985	1995
DNEND	274	365	365	365	365	365	274
TYEAR1	0	1	1	1	1	1	0
TYEAR2	1	10	5	5	5	5	1
PPTFACT	0	1	1	1	1	1	0
ETFACT	0	1	1	1	1	1	0
IMBFACT	0	1	1	1	1	1	0
SKSFACT	0	1	1	1	1	1	0
SDFACT	0	1	1	1	1	1	0
IVEGC	0	0	0	0	0	0	0
FVEGC	0.2	0.2	0.6	0.6	0.6	0.6	0.2

Control File Input Parameter	Test Case 0A	0B	0C	0D1	0D2	0D3	1A
ROOTF1	1	1	1	1	1	1	1
ROOTF2	0.5	0.5	1	1	1	1	0.5
ROOTF3	0.2	0.2	0.8	0.8	0.8	0.8	0.2
ROOTF4	0.01	0.01	0.5	0.5	0.5	0.5	0.01
MAXWGT1	1	1	1	1	1	1	1
MAXWGT2	0.8	0.8	1	1	1	1	0.8
MAXWGT3	0.2	0.2	0.8	0.8	0.8	0.8	0.2
MAXWGT4	0.05	0.05	0.25	0.25	0.25	0.25	0.05
RDEPTH1	0.3	0.3	0.15	0.15	0.15	0.15	0.3
RDEPTH2	1.5	1.5	2.5	2.5	2.5	2.5	1.5
RDEPTH4	2	2	3	3	3	3	2
RDEPTHF	2	2	2	2	2	2	2
RKPOR	0.02	0.02	0.02	0.02	0.02	0.02	0
RKMMFACT	1	1	1	1	1	1	1
FLAREA	0.5	0.5	0.15	0.15	0.15	0.15	0.5
INFMOD	1	1	1	1	1	1	1
ETMOD	1	1	1	1	1	1	1
RUNFLOW	0	0	0	0	0	0	0
BARSOIL1	-10	-10	-10	-10	-10	-10	-10
BARSOIL2	1.04	1.04	1.04	1.04	1.04	1.04	1.04
IAIRTEMPT	1	1	3	3	3	3	1
ATEMP1	17.3	17.3	17.3	17.3	17.3	17.3	17.3
ATEMP2	11.74	11.74	11.74	11.74	11.74	11.74	11.74
HSTEP	2	2	2	2	2	2	2
PPTYUC	1	3	5	5	5	5	1
AAPREPX	181	181	181	181	181	181	181
IPPTDAT	0	1	3	3	3	3	0
PPTFILE	mod3-ppt.dat	4ja.s01	Rosalia.inp	Rosalia.inp	Rosalia.inp	Rosalia.inp	mod3-ppt.dat
DEPTHFLG	0	0	0	0	0	0	0
IRTZ	1	1	1	1	1	1	1
DELVWCF	0.5	0.5	0.5	0.5	0.5	0.5	0.5
MOISTCR	1	1	1	1	1	1	1
FRACMOD	1	1	1	1	1	1	1
IVWCFLG	0	0	0	0	0	0	0
VWCFACT	1.2	1.2	2	2	2	2	0
INFILE	t1.w20	t1.w20	t1.w20	Jr2.W20	Jr3.W20	Sc2.W20	t1.w20
LOCSTART	-1	-1	-1	-1	-1	-1	-1
DAYALL	test0a.v21	test0b.v21	test0c.v21	Test0d1.v21	Test0d2.v21	Test0d3.v21	test1a.v21
NDAYMAP	1	1	4	1	1	1	1
IMAP	1	1	1	1	1	1	1
IRDAY	70	70	41	45	45	45	70
NYROUT	1995	1995	1952	1981	1981	1981	1995
DAYMAP	test0a.v22	test0b.v22	test0c1.v22	Test0d1.v22	Test0d2.v22	Test0d3.v22	test1a.v22
OUTFILE	test0a.v23	test0b.v23	test0c.v23	Test0d1.v23	Test0d2.v23	Test0d3.v23	test1a.v23
FLXFILE	test0a.v24	test0b.v24	test0c.v24	Test0d1.v24	Test0d2.v24	Test0d3.v24	test1a.v24
DBGFLAG	1	1	1	1	1	1	1
DBGFLAG2	1	1	1	1	1	1	1
DBGFILE	test0a.v25	test0b.v25	test0c.v25	Test0d1.v25	Test0d2.v25	Test0d3.v25	test1a.v25
IDEBUG	0	0	0	0	0	0	0
DBUGOUT	test0a.v26	test0b.v26	test0c.v26	test0d1.v26	test0d2.v26	test0d3.v26	test1a.v26
OUTYEAR1	test0a	test0b	test0c	test0d1	Test0d2	test0d3	test1a

Control File Input Parameter	Test Case 0A	0B	0C	0D1	0D2	0D3	1A
SOILID(10)	10	10	10	10	10	10	10
FIELDCAP(10)	0.189	0.189	0.189	0.189	0.189	0.189	0.189
SOILRESID(10)	0.028	0.028	0.028	0.028	0.028	0.028	0.028
SOILPORO(10)	0.322	0.322	0.322	0.322	0.322	0.322	0.322
SOILALBETA(10)	-2.5	-2.5	-4.5	-4.5	-4.5	-4.5	-2.5
SOILTALPHA(10)	1.26	1.26	1.26	1.26	1.26	1.26	1.26
SOILKS(10)	5.70E-05	5.70E-05	5.70E-05	5.70E-05	5.70E-05	5.70E-05	5.70E-05
SOILPE(10)	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00
SOILBVAL(10)	3.88	3.88	3.88	3.88	3.88	3.88	3.88
SALPHA(10)	1	1	1	1	1	1	1
SOILVGN(10)	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01
SORP(10)	0.037	0.037	0.037	0.037	0.037	0.037	0.037
SOILPOND(10)	0.05	0.05	0.05	0.05	0.05	0.05	0.05
POTIS(10)	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02
SOILID(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FIELDCAP(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILRESID(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPORO(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILALBETA(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILTALPHA(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILKS(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPE(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILBVAL(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SALPHA(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILVGN(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SORP(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPOND(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
POTIS(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILID(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FIELDCAP(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILRESID(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPORO(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILALBETA(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILTALPHA(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILKS(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPE(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILBVAL(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SALPHA(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILVGN(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SORP(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPOND(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
POTIS(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
NROCKID	129	129	129	129	129	129	129
ROCKALBETA	-1.5	-1.5	-2.5	-2.5	-2.5	-2.5	-1.5
ROCKTALPHA	1.26	1.26	1.26	1.26	1.26	1.26	1.26
IMBIBE(400)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
IMBIBE(450)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
IMBIBE(500)	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Control File Input Parameter	Test Case						
	1B	1C	1D	1E	1F	2A	2B
OPTMASSB	1	1	1	1	1	1	1
IROUT	0	1	1	1	1	1	1
IFRTOL	1.00E-08	1.00E-08	1.00E-08	1.00E-08	1.00E-08	1.00E-08	1.00E-08
ISNOW	2	2	2	2	2	2	2
ISNWDOW	2	2	2	2	2	2	2
SNOWPAR1	1.78	1.78	1.78	1.78	1.78	1.78	1.78
ISUBLIM	3	3	3	3	3	3	3
SUBPAR1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
SUBPAR2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
IPPTTEST	0	0	0	0	0	0	0
PPTTEST	1	1	1	1	1	1	1
IETTEST	0	0	0	0	0	0	0
ETTEST	0	0	0	0	0	0	0
CELSIZE	30	30	30	30	30	30	30
XCFS	544691	544691	544691	544691	544691	547931	547931
YCFS	4074153	4074153	4074153	4074153	4074153	4077483	4077483
YRBEG	1980	1980	1980	1980	1980	1980	1980
DNBEG	1	1	1	1	1	1	1
YREND	1985	1985	1985	1985	1985	1985	1985
DNEND	365	365	365	365	365	365	365
TYEAR1	0	0	0	0	0	0	0
TYEAR2	1	1	1	1	1	1	1
PPTFACT	0	0	0	0	0	0	0
ETFACT	0	0	0	0	0	1	1
IMBFACT	0	1	1	1	1	1	1
SKSFACT	0	1	1	1	0.0001	1	1
SDFACT	1	1	1	1	1	1	1
IVEGC	0	0	0	0	0	0	0
FVEGC	0.2	0.2	0.2	0.2	0.2	0.2	0.2
ROOTF1	1	1	1	1	1	1	1
ROOTF2	0.5	0.5	0.5	0.5	0.5	0.5	0.5
ROOTF3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
ROOTF4	0.01	0.01	0.01	0.01	0.01	0.01	0.01
MAXWGT1	1	1	1	1	1	1	1
MAXWGT2	0.8	0.8	0.8	0.8	0.8	0.8	0.8
MAXWGT3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
MAXWGT4	0.05	0.05	0.05	0.05	0.05	0.05	0.05
RDEPTH1	0	3	0.1	0.1	0.1	0.3	0.3
RDEPTH2	0	0	0.2	0.2	0.2	1.5	1.5
RDEPTH4	0	0	0.5	0.5	0.5	2	2
RDEPTHF	2	0	1	1	1	2	2
RKPOR	0	0	0	0.1	0.1	0.02	0.02
RKMMFACT	1	1	1	1	1	1	1
FLAREA	0.5	0.5	0.5	0.5	0.5	0.5	0.5
INFMOD	1	1	1	1	1	1	1
ETMOD	1	1	1	1	1	1	1
RUNFLOW	0	0	0	0	0	0	0
BARSOIL1	-10	-10	-10	-10	-10	-10	-10
BARSOIL2	1.04	1.04	1.04	1.04	1.04	1.04	1.04
IAIRTEMPT	1	1	1	1	1	1	1
ATEMP1	17.3	17.3	17.3	17.3	17.3	17.3	17.3
ATEMP2	11.74	11.74	11.74	11.74	11.74	11.74	0
HSTEP	2	2	2	2	2	2	2
PPTYUC	1	1	1	1	1	1	1
AAPREPX	181	181	181	181	181	181	181
IPPTDAT	0	0	0	0	0	0	0

Control File Input Parameter	Test Case						
	1B	1C	1D	1E	1F	2A	2B
PPTFILE	mod3-ppt.dat	mod3-ppt.dat	mod3-ppt.dat	mod3-ppt.dat	mod3-ppt.dat	mod3-ppt.dat	mod3-ppt.dat
DEPTHFLG	0	0	0	0	0	0	0
IRTZ	1	1	1	1	1	1	1
DELVWCF	0.5	0.5	0.5	0.5	0.5	0.5	0.5
MOISTCR	1	1	1	1	1	1	1
FRACMOD	1	1	1	1	1	1	1
IVWCFLG	0	0	0	0	0	0	0
VWCFACT	10	20	20	20	20	1	20
INFILE	t1.w20	t1.w20	t1.w20	t1.w20	t1.w20	t1.w20	t1.w20
LOCSTART	-1	-1	-1	-1	-1	-1	-1
DAYALL	test1b.v21	test1c.v21	test1d.v21	test1e.v21	test1f.v21	test2a.v21	test2b.v21
NDAYMAP	1	4	4	4	4	1	1
IMAP	1	1	1	1	1	1	1
IRDAY	1	1	1	1	1	70	70
NYROUT	1980	1980	1980	1980	1980	1995	1995
DAYMAP	test1b.v22	test1c.v22	test1d.v22	test1e.v22	test1f.v22	test2a.v22	test2b.v22
OUTFILE	test1b.v23	test1c.v23	test1d.v23	test1e.v23	test1f.v23	test2a.v23	test2b.v23
FLXFILE	test1b.v24	test1c.v24	test1d.v24	test1e.v24	test1f.v24	test2a.v24	test2b.v24
DBGFLAG	1	1	1	1	1	1	1
DBGFLAG2	1	1	1	1	1	1	1
DBGFILE	test1b.v25	test1c.v25	test1d.v25	test1e.v25	test1f.v25	test2a.v25	test2b.v25
IDEBUG	0	0	0	0	0	0	0
DBUGOUT	test1b.v26	test1c.v26	test1d.v26	test1e.v26	test1f.v26	test2a.v26	test2b.v26
OUTYEAR1	test1b	test1c	Test1d	Test1e	Test1f	test2a	test2b
SOILID(10)	10	10	10	10	10	10	10
FIELDCAP(10)	0.189	0.189	0.189	0.189	0.189	0.189	0.189
SOILRESID(10)	0.028	0.028	0.028	0.028	0.028	0.028	0.028
SOILPORO(10)	0.322	0.322	0.322	0.322	0.322	0.322	0.322
SOILALBETA(10)	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5
SOILTALPHA(10)	1.26	1.26	1.26	1.26	1.26	1.26	1.26
SOILKS(10)	5.70E-05	5.70E-05	5.70E-05	5.70E-05	5.70E-05	5.70E-05	5.70E-05
SOILPE(10)	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00
SOILBVAL(10)	3.88	3.88	3.88	3.88	3.88	3.88	3.88
SALPHA(10)	1	1	1	1	1	1	1
SOILVGN(10)	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01
SORP(10)	0.037	0.037	0.037	0.037	0.037	0.037	0.037
	1B	1C	1D	1E	1F	2A	2B
SOILPOND(10)	0.05	0.05	0.05	0.05	0.05	0.05	0.05
POTIS(10)	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02
SOILID(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FIELDCAP(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILRESID(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPORO(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILALBETA(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILTALPHA(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILKS(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPE(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Control File Input Parameter	Test Case						
	1B	1C	1D	1E	1F	2A	2B
SOILBVAL(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SALPHA(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILVGN(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SORP(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPOND(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
POTIS(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILID(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FIELDCAP(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILRESID(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPORO(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILALBETA(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILTALPHA(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILKS(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPE(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILBVAL(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SALPHA(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILVGN(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SORP(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPOND(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
POTIS(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
NROCKID	129	129	129	129	129	129	129
ROCKALBETA	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5
ROCKTALPHA	1.26	1.26	1.26	1.26	1.26	1.26	1.26
IMBIBE(400)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
IMBIBE(450)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
IMBIBE(500)	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Control File Input Parameter	Test Case 2C	2D	2E	2F	2G	2H	2I
OPTMASSB	1	1	1	1	1	1	1
IROUT	1	1	1	1	1	1	1
IFRTOL	1.00E-08	1.00E-08	1.00E-08	1.00E-08	1.00E-08	1.00E-08	1.00E-08
ISNOW	2	2	2	2	2	2	2
ISNWDOW	2	2	2	2	2	2	2
SNOWPAR1	1.78	1.78	1.78	1.78	1.78	1.78	1.78
ISUBLIM	3	3	3	3	3	3	3
SUBPAR1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
SUBPAR2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
IPPTTEST	0	0	0	0	0	0	0
PPTTEST	1	1	1	1	1	1	1
IETTEST	0	0	0	1	1	1	1
ETTEST	0	0	0	5	5	5	2
CELSIZE	30	30	30	30	30	30	30
XCFS	547931	547931	547931	547931	547931	547931	547931
YCFS	4077483	4077483	4077483	4077483	4077483	4077483	4077483
YRBEG	1980	1980	1980	1980	1980	1980	1980
DNBEG	1	1	1	1	1	1	1
YREND	1985	1985	1985	1985	1985	1985	1985
DNEND	365	365	365	365	365	365	365
TYEAR1	0	0	0	0	0	0	0
TYEAR2	1	1	1	1	1	1	1
PPTFACT	0	0	0	0	0	0	0
ETFACT	1	1	1	1	1	1	1
IMBFACT	1	1	1	1	1	1	1
SKSFACT	1	1	1	1	0.000001	0.00001	0.00001
SDFACT	1	1	1	1	1	1	1
IVEGC	0	0	0	0	0	0	0
FVEGC	0.2	0.2	0.2	0.2	0.2	0.2	0.2
ROOTF1	1	1	1	1	1	1	1
ROOTF2	0.5	0.5	0.5	0.5	0.5	0.5	0.5
ROOTF3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
ROOTF4	0.01	0.01	0.01	0.01	0.01	0.01	0.01
MAXWGT1	1	1	1	1	1	1	1
MAXWGT2	0.8	0.8	0.8	0.8	0.8	0.8	0.8
MAXWGT3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
MAXWGT4	0.05	0.05	0.05	0.05	0.05	0.05	0.05
RDEPTH1	0.3	0.3	0.3	0.3	0.3	0.3	0.3
RDEPTH2	1.5	1.5	1.5	1.5	1.5	1.5	1.5
RDEPTH4	2	2	2	2	2	2	2
RDEPTHF	2	2	2	2	2	2	2
RKPOR	0.02	0.02	0.02	0.02	0.02	0.02	0.02
RKMMFACT	1	1	1	1	1	1	1
FLAREA	0.5	0.5	0.5	0.5	0.5	0.5	0.5
INFMOD	1	1	1	1	1	1	1
ETMOD	1	1	1	1	1	1	1
RUNFLOW	0	0	0	0	0	0	0
BARSOIL1	-10	-10	-10	-10	-10	-10	-10
BARSOIL2	1.04	1.04	1.04	1	1	1	1
IAIRTEMPT	1	1	1	1	1	1	1
ATEMP1	0	0	0	17.3	17.3	17.3	17.3
ATEMP2	0	0	0	11.74	11.74	11.74	11.74
HSTEP	2	2	2	2	2	2	2
PPTYUC	1	1	1	1	1	1	1
AAPREPX	181	181	181	181	181	181	181

Control File Input Parameter	Test Case 2C	2D	2E	2F	2G	2H	2I
IPPTDAT	0	0	0	0	0	0	0
PPTFILE	mod3-ppt.dat	test2d.dat	test2e.dat	mod3-ppt.dat	mod3-ppt.dat	mod3-ppt.dat	mod3-ppt.dat
DEPTHFLG	0	0	0	0	0	0	0
IRTZ	1	1	1	1	1	1	1
DELVWCF	0.5	0.5	0.5	0.5	0.5	0.5	0.5
MOISTCR	1	1	1	1	1	1	1
FRACMOD	1	1	1	1	1	1	1
IVWCFLG	0	0	0	0	0	0	0
VWCFACT	20	20	20	4	4	4	4
INFILE	t1.w20	t1.w20	t1.w20	t1a.w20	t1a.w20	t1a.w20	t1a.w20
LOCSTART	-1	-1	-1	-1	-1	-1	-1
DAYALL	test2c.v21	test2d.v21	test2e.v21	test2f.v21	test2g.v21	test2h.v21	test2i.v21
NDAYMAP	1	1	1	7	7	7	7
IMAP	1	1	1	1	1	1	1
IRDAY	70	70	70	1	1	1	1
NYROUT	1995	1995	1995	1980	1980	1980	1980
DAYMAP	test2c.v22	test2d.v22	test2e.v22	test2f1.v22	test2g1.v22	test2h1.v22	test2i1.v22
OUTFILE	test2c.v23	test2d.v23	test2e.v23	test2f.v23	test2g.v23	test2h.v23	test2i.v23
FLXFILE	test2c.v24	test2d.v24	test2e.v24	test2f.v24	test2g.v24	test2h.v24	test2i.v24
DBGFLAG	1	1	1	1	1	1	1
DBGFLAG2	1	1	1	1	1	1	1
DBGFILE	test2c.v25	test2d.v25	test2e.v25	test2f.v25	test2g.v25	test2h.v25	test2i.v25
IDEBUG	0	0	0	0	0	0	0
DBUGOUT	test2c.v26	test2d.v26	test2e.v26	test2f.v26	test2g.v26	test2h.v26	test2i.v26
OUTYEAR1	test2c	test2d	test2e	test2f	test2g	test2h	test2i
SOILID(10)	10	10	10	10	10	10	10
FIELDCAP(10)	0.189	0.189	0.189	0.1	0.1	0.1	0.1
SOILRESID(10)	0.028	0.028	0.028	0.1	0.1	0.1	0.1
SOILPORO(10)	0.322	0.322	0.322	0.3	0.3	0.3	0.3
SOILALBETA(10)	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5
SOILTALPHA(10)	1.26	1.26	1.26	1	1	1	1
SOILKS(10)	5.70E-05	5.70E-05	5.70E-05	1.00E-01	1.00E-01	1.00E-01	1.00E-01
SOILPE(10)	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00
SOILBVAL(10)	3.88	3.88	3.88	3.88	3.88	3.88	3.88
SALPHA(10)	1	1	1	1	1	1	1
SOILVGN(10)	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01
SORP(10)	0.037	0.037	0.037	0.037	0.037	0.037	0.037
SOILPOND(10)	0.05	0.05	0.05	0.05	0.05	0.05	0.05
POTIS(10)	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02
SOILID(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FIELDCAP(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILRESID(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPORO(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILALBETA(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILTALPHA(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILKS(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPE(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Control File Input Parameter	Test Case						
	2C	2D	2E	2F	2G	2H	2I
SOILBVAL(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SALPHA(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILVGN(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SORP(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPOND(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
POTIS(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILID(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FIELDCAP(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILRESID(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPORO(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILALBETA(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILTALPHA(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILKS(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPE(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILBVAL(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SALPHA(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILVGN(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SORP(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPOND(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
POTIS(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
NROCKID	129	129	129	130	130	130	130
ROCKALBETA	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5
ROCKTALPHA	1.26	1.26	1.26	1	1	1	1
IMBIBE(400)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
IMBIBE(450)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
IMBIBE(500)	N/A	N/A	N/A	1.00	1.00	1.00	1.00

Control File Input Parameter	Test Case 2J	2K	3A	3B	3C	3D	3E
OPTMASSB	1	1	0	1	1	1	1
IROUT	1	1	1	1	1	1	1
IFRTOL	1.00E-08	1.00E-08	1.00E-08	1.00E-08	1.00E-08	1.00E-08	1.00E-08
ISNOW	2	2	2	2	2	2	2
ISNWDOW	2	2	2	2	2	2	2
SNOWPAR1	1.78	1.78	1.78	1.78	1.78	1.78	1.78
ISUBLIM	3	3	3	3	3	3	3
SUBPAR1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
SUBPAR2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
IPPTTEST	0	0	1	1	1	1	1
PPTTEST	1	1	10	10	10	10	10
IETTEST	1	1	0	0	0	1	1
ETTEST	2	2	2	2	2	2	5
CELSIZE	30	30	30	30	30	30	30
XCFS	547931	547931	547931	547931	547931	547931	547931
YCFS	4077483	4077483	4077483	4077483	4077483	4077483	4077483
YRBEG	1980	1980	1980	1980	1980	1980	1980
DNBEG	1	1	1	1	1	1	1
YREND	1985	1985	1985	1985	1985	1985	1985
DNEND	365	365	365	365	365	365	365
TYEAR1	0	0	0	0	0	0	0
TYEAR2	1	1	1	1	1	1	1
PPTFACT	0	0	1	1	1	1	1
ETFACT	1	1	0	0	0	0	0
IMBFACT	1	1	1	1	1	1	5
SKSFACT	1	1	1	0.0001	0.0001	0.0001	1
SDFACT	2	2	2	2	0.1	0.1	1
IVEGC	0	0	0	0	0	0	0
FVEGC	0.2	0.2	0.2	0.2	0.2	0	0
ROOTF1	1	0	1	1	1	0	0
ROOTF2	0	1	1	1	1	1	0
ROOTF3	0	0	1	1	1	1	1
ROOTF4	0	1	1	1	1	1	1
MAXWGT1	1	0	1	1	1	0	0
MAXWGT2	0	1	1	1	1	1	0
MAXWGT3	0	0	1	1	1	1	1
MAXWGT4	0	1	1	1	1	1	1
RDEPTH1	0.3	0.3	0.3	0.3	0.3	0.3	0.3
RDEPTH2	1	1	1	1	1	1	1
RDEPTH4	3	3	3	3	3	3	3
RDEPTHF	2	2	2	2	2	2	2
RKPOR	0.02	0.02	0.02	0.02	0.001	0.001	0.01
RKMMFACT	1	1	1	1	1	1	1
FLAREA	0.5	0.5	0.5	0.5	0.5	0.5	0.5
INFMOD	1	1	1	1	1	1	1
ETMOD	1	1	1	1	1	1	1
RUNFLOW	0	0	0	0	0	0	0
BARSOIL1	-10	-10	-10	-10	-10	-10	-10
BARSOIL2	1	1	1	1	1	1	1
IAIRTEMPT	1	1	1	1	1	1	1
ATEMP1	17.3	17.3	17.3	17.3	17.3	17.3	17.3
ATEMP2	11.74	11.74	11.74	11.74	11.74	11.74	11.74
HSTEP	2	2	2	2	2	2	2
PPTYUC	1	1	1	1	1	1	1
AAPREPX	181	181	181	181	181	181	181

Control File Input Parameter	Test Case 2J	2K	3A	3B	3C	3D	3E
IPPTDAT	0	0	0	0	0	0	0
PPTFILE	mod3-ppt.dat	mod3-ppt.dat	mod3-ppt.dat	mod3-ppt.dat	mod3-ppt.dat	mod3-ppt.dat	mod3-ppt.dat
DEPTHFLG	0	0	0	0	0	0	0
IRTZ	1	1	1	1	1	1	1
DELVWCF	0.5	0.5	0.5	0.5	0.5	0.5	0.5
MOISTCR	1	1	1	1	1	1	1
FRACMOD	1	1	1	1	1	1	1
IVWCFLG	0	0	0	0	0	0	0
VWCFACT	4	4	1	1	1	1	1
INFILE	t1a.w20	t1a.w20	t1a.w20	t1a.w20	t1a.w20	t1a.w20	t1a.w20
LOCSTART	-1	-1	-1	-1	-1	-1	-1
DAYALL	test2j.v21	test2k.v21	test3a.v21	test3b.v21	test3c.v21	test3d.v21	test3e.v21
NDAYMAP	7	7	7	7	7	7	7
IMAP	1	1	1	1	1	1	1
IRDAY	1	1	1	1	1	1	1
NYROUT	1980	1980	1980	1980	1980	1980	1980
DAYMAP	test2j1.v22	test2k1.v22	test3a1.v22	test3b1.v22	test3c1.v22	test3d1.v22	test3e1.v22
OUTFILE	test2j.v23	test2k.v23	test3a.v23	test3b.v23	test3c.v23	test3d.v23	test3e.v23
FLXFILE	test2j.v24	test2k.v24	test3a.v24	test3b.v24	test3c.v24	test3d.v24	test3e.v24
DBGFLAG	1	1	1	1	1	1	1
DBGFLAG2	1	1	1	1	1	1	1
DBGFILE	test2j.v25	test2k.v25	test3a.v25	test3b.v25	test3c.v25	test3d.v25	test3e.v25
IDEBUG	0	0	0	0	0	0	0
DBUGOUT	test2j.v26	test2k.v26	test3a.v26	test3b.v26	test3c.v26	test3d.v26	test3e.v26
OUTYEAR1	test2j	test2k	test3a	test3b	test3c	test3d	test3e
SOILID(10)	10	10	10	10	10	10	10
FIELDCAP(10)	0.2	0.2	0.2	0.2	0.2	0.2	0.2
SOILRESID(10)	0.1	0.1	0.1	0.1	0.1	0.1	0.1
SOILPORO(10)	0.3	0.3	0.3	0.3	0.3	0.3	0.3
SOILALBETA(10)	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5
SOILTALPHA(10)	1	1	1	1	1	1	1
SOILKS(10)	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04
SOILPE(10)	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00
SOILBVAL(10)	3.88	3.88	3.88	3.88	3.88	3.88	3.88
SALPHA(10)	1	1	1	1	1	1	1
SOILVGN(10)	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01
SORP(10)	0.037	0.037	0.037	0.037	0.037	0.037	0.037
SOILPOND(10)	0.05	0.05	0.05	0.05	0.05	0.05	0.05
POTIS(10)	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02
SOILID(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FIELDCAP(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILRESID(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPORO(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILALBETA(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILTALPHA(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILKS(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPE(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILBVAL(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SALPHA(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILVGN(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SORP(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Control File Input Parameter	Test Case						
	2J	2K	3A	3B	3C	3D	3E
SOILPOND(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
POTIS(11)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILID(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FIELDCAP(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILRESID(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPORO(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILALBETA(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILTALPHA(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILKS(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPE(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILBVAL(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SALPHA(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILVGN(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SORP(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOILPOND(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
POTIS(12)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
NROCKID	130	130	130	130	130	130	130
ROCKALBETA	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5
ROCKTALPHA	1	1	1	1	1	1	1
IMBIBE(400)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
IMBIBE(450)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
IMBIBE(500)	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Control File Input Parameter	Test Case 3F	3G	4A	4B	4C	4D	4E
OPTMASSB	1	1	1	1	1	1	1
IROUT	1	1	1	1	1	1	1
IFRTOL	1.00E-08	1.00E-08	1.00E-08	1.00E-08	1.00E-08	1.00E-08	1.00E-08
ISNOW	2	2	2	2	2	2	2
ISNWDOW	2	2	2	2	2	2	2
SNOWPAR1	1.78	1.78	1.78	1.78	1.78	1.78	1.78
ISUBLIM	3	3	3	3	3	3	3
SUBPAR1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
SUBPAR2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
IPPTTEST	1	1	1	1	1	0	0
PPTTEST	10	10	10	10	10	10	10
IETTEST	1	1	0	0	0	0	1
ETTEST	5	5	5	5	5	5	5
CELSIZE	30	30	30	30	30	30	30
XCFS	547931	547931	547931	547931	547931	547931	547931
YCFS	4077483	4077483	4077483	4077483	4077483	4077483	4077483
YRBEG	1980	1980	1980	1980	1980	1980	1980
DNBEG	1	1	1	1	1	1	1
YREND	1985	1985	1985	1985	1985	1985	1985
DNEND	365	365	365	365	365	365	365
TYEAR1	0	0	0	0	0	0	0
TYEAR2	1	1	1	1	1	1	1
PPTFACT	1	1	1	1	1	1	1
ETFACT	0	0	0	0	0	0	0
IMBFACT	5	5	0	1	1	1	1
SKSFACT	1	1	1	1000	1000	1	1
SDFACT	1	2	2	1	1	1	1
IVEGC	0	0	0	0	0	0	0
FVEGC	0	0	0	0	0	0	0
ROOTF1	1	1	1	1	1	1	1
ROOTF2	1	0.5	1	1	1	1	0.5
ROOTF3	1	0.1	1	1	1	1	0.1
ROOTF4	0.1	0.01	0.1	0.1	0.1	0.1	0
MAXWGT1	1	1	1	1	1	1	1
MAXWGT2	1	0.5	1	1	1	1	0.5
MAXWGT3	1	0.1	1	1	1	1	0.1
MAXWGT4	0.1	0.01	0.1	0.1	0.1	0.1	0
RDEPTH1	0.3	0.3	0.3	0.3	0.3	0.1	0.1
RDEPTH2	1	1	1	1	1	1	1
RDEPTH4	3	3	3	3	3	3	3
RDEPTHF	2	2	2	2	2	2	2
RKPOR	0.01	0.02	0.1	0.1	0.1	0.1	0.01
RKMMFACT	1	1	1	1	1	1	1
FLAREA	0.5	0.5	0.5	1	0.00001	1	1
INFMOD	1	1	1	1	1	1	1
ETMOD	1	1	1	1	1	1	1
RUNFLOW	0	0	0	0	0	0	0
BARSOIL1	-10	-10	-10	-10	-10	-10	-10
BARSOIL2	1	1	1	1	1	1	1
IAIRTEMPT	1	1	1	1	1	1	1
ATEMP1	17.3	17.3	17.3	17.3	17.3	17.3	17.3
ATEMP2	11.74	11.74	11.74	11.74	11.74	11.74	11.74
HSTEP	2	2	2	2	2	2	2
PPTYUC	1	1	1	1	1	1	1
AAPREPX	181	181	181	181	181	181	181

Control File Input Parameter	Test Case 3F	3G	4A	4B	4C	4D	4E
IPPTDAT	0	0	0	0	0	0	0
PPTFILE	mod3-ppt.dat	mod3-ppt.dat	mod3-ppt.dat	mod3-ppt.dat	mod3-ppt.dat	Test4d.dat	Test4d.dat
DEPTHFLG	0	0	0	0	0	0	0
IRTZ	1	1	1	1	1	1	1
DELVWCF	0.5	0.5	0.5	0.5	0.5	0.5	0.5
MOISTCR	1	1	1	1	1	1	1
FRACMOD	1	1	1	1	1	1	1
IVWCFLG	0	0	0	0	0	0	0
VWCFACT	1	1	1	1	1	1	1
INFILE	t1a.w20	t1a.w20	t1b.w20	t1b.w20	t1b.w20	t1b.w20	t1c.w20
LOCSTART	-1	-1	-1	-1	-1	-1	-1
DAYALL	test3f.v21	test3g.v21	test4a.v21	test4b.v21	test4c.v21	test4d.v21	test4e.v21
NDAYMAP	7	7	7	7	10	10	10
IMAP	1	1	1	1	1	1	1
IRDAY	1	1	1	1	1	1	1
NYROUT	1980	1980	1980	1980	1980	1980	1980
DAYMAP	test3f1.v22	test3g1.v22	test4a1.v22	test4b1.v22	test4c1.v22	test4d1.v22	test4e1.v22
OUTFILE	test3f.v23	test3g.v23	test4a.v23	test4b.v23	test4c.v23	test4d.v23	test4e.v23
FLXFILE	test3f.v24	test3g.v24	test4a.v24	test4b.v24	test4c.v24	test4d.v24	test4e.v24
DBGFLAG	1	1	1	1	1	1	1
DBGFLAG2	1	1	1	1	1	1	1
DBGFILE	test3f.v25	test3g.v25	test4a.v25	test4b.v25	test4c.v25	test4d.v25	test4e.v25
IDEBUG	0	0	0	0	0	0	0
DBUGOUT	test3f.v26	test3g.v26	test4a.v26	test4b.v26	test4c.v26	test4d.v26	test4e.v26
OUTYEAR1	test3f	test3g	test4a	test4b	test4c	test4d	test4e
SOILID(10)	10	10	10	10	10	10	10
FIELDCAP(10)	0.2	0.2	0.2	0.2	0.2	0.2	0.2
SOILRESID(10)	0.1	0.1	0.1	0.1	0.1	0.1	0.1
SOILPORO(10)	0.3	0.3	0.3	0.3	0.3	0.3	0.3
SOILALBETA(10)	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5
SOILTALPHA(10)	1	1	1	1	1	1	1
SOILKS(10)	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04
SOILPE(10)	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00
SOILBVAL(10)	3.88	3.88	3.88	3.88	3.88	3.88	3.88
SALPHA(10)	1	1	1	1	1	1	1
SOILVGN(10)	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01
SORP(10)	0.037	0.037	0.037	0.037	0.037	0.037	0.037
SOILPOND(10)	0.05	0.05	0.05	0.05	0.05	0.05	0.05
POTIS(10)	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02
SOILID(11)	N/A	N/A	11	11	11	11	11
FIELDCAP(11)	N/A	N/A	0.2	0.2	0.2	0.2	0.2
SOILRESID(11)	N/A	N/A	0.1	0.1	0.1	0.1	0.1
SOILPORO(11)	N/A	N/A	0.3	0.3	0.3	0.3	0.3
SOILALBETA(11)	N/A	N/A	-2.5	-2.5	-2.5	-2.5	-2.5
SOILTALPHA(11)	N/A	N/A	1	1	1	1	1
SOILKS(11)	N/A	N/A	1.00E-04	1.00E-04	1.00E-04	1.00E-02	1.00E-03
SOILPE(11)	N/A	N/A	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00

Control File Input Parameter	Test Case 3F	3G	4A	4B	4C	4D	4E
SOILBVAL(11)	N/A	N/A	3.88	3.88	3.88	3.88	3.88
SALPHA(11)	N/A	N/A	1	1	1	1	1
SOILVGN(11)	N/A	N/A	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01
SORP(11)	N/A	N/A	0.037	0.037	0.037	0.037	0.037
SOILPOND(11)	N/A	N/A	0.05	0.05	0.05	0.05	0.05
POTIS(11)	N/A	N/A	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02
SOILID(12)	N/A	N/A	N/A	N/A	N/A	N/A	12
FIELDCAP(12)	N/A	N/A	N/A	N/A	N/A	N/A	0.2
SOILRESID(12)	N/A	N/A	N/A	N/A	N/A	N/A	0.1
SOILPORO(12)	N/A	N/A	N/A	N/A	N/A	N/A	0.3
SOILALBETA(12)	N/A	N/A	N/A	N/A	N/A	N/A	-2.5
SOILTALPHA(12)	N/A	N/A	N/A	N/A	N/A	N/A	1
SOILKS(12)	N/A	N/A	N/A	N/A	N/A	N/A	1.00E-02
SOILPE(12)	N/A	N/A	N/A	N/A	N/A	N/A	-1.08E+00
SOILBVAL(12)	N/A	N/A	N/A	N/A	N/A	N/A	3.88
SALPHA(12)	N/A	N/A	N/A	N/A	N/A	N/A	1
SOILVGN(12)	N/A	N/A	N/A	N/A	N/A	N/A	5.50E-01
SORP(12)	N/A	N/A	N/A	N/A	N/A	N/A	0.037
SOILPOND(12)	N/A	N/A	N/A	N/A	N/A	N/A	0.05
POTIS(12)	N/A	N/A	N/A	N/A	N/A	N/A	-1.00E+02
NROCKID	130	130	131	131	131	131	132
ROCKALBETA	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5
ROCKTALPHA	1	1	1	1	1	1	1
IMBIBE(400)	N/A	N/A	1.00	5.00	5.00	1.00	100.00
IMBIBE(450)	N/A	N/A	N/A	N/A	N/A	N/A	10.00
IMBIBE(500)	1.00	1.00	1.00	0.00	0.00	1.00	1.00

Control File Input Parameter	Test Case						
	4F	5A	5B	5C	5D		
OPTMASSB	1	0	0	1	1		
IROUT	1	0	0	1	1		
IFRTOL	1.00E-08	1.00E-08	1.00E-08	1.00E-08	1.00E-08		
ISNOW	2	2	2	2	2		
ISNWDOW	2	2	2	2	2		
SNOWPAR1	1.78	1.78	1.78	1.78	1.78		
ISUBLIM	3	3	3	3	3		
SUBPAR1	0.1	0.1	0.1	0.1	0.1		
SUBPAR2	0.3	0.3	0.3	0.3	0.3		
IPPTTEST	0	1	1	1	1		
PPTTEST	10	1	1	2	2		
IETTEST	1	0	0	0	0		
ETTEST	5	1	1	1	1		
CELSIZE	30	30	30	30	30		
XCFS	547931	547931	547931	547931	547931		
YCFS	4077483	4077483	4077483	4077483	4077483		
YRBEG	1980	1980	1980	1980	1980		
DNBEG	1	1	1	1	1		
YREND	1985	1985	1985	1985	1985		
DNEND	365	365	365	365	365		
TYEAR1	0	0	0	0	0		
TYEAR2	1	1	1	1	1		
PPTFACT	1	1	1	1	1		
ETFACT	0	1	1	1	1		
IMBFACT	1	1	1	1	1		
SKSFACT	1	1	1	1	1		
SDFACT	1	1	1	1	1		
IVEGC	0	0	0	0	0		
FVEGC	0	0	0	0	0		
ROOTF1	0	1	1	1	1		
ROOTF2	0.1	1	1	1	1		
ROOTF3	0.5	1	1	1	1		
ROOTF4	1	1	1	1	1		
MAXWGT1	0	1	1	1	1		
MAXWGT2	0.1	1	1	1	1		
MAXWGT3	0.5	1	1	1	1		
MAXWGT4	1	1	1	1	1		
RDEPTH1	0.1	0.1	0.1	0.1	0.1		
RDEPTH2	1	1	1	1	1		
RDEPTH4	3	2	2	2	2		
RDEPTHF	2	2	2	2	2		
RKPOR	0.01	0.1	0.1	0.1	0.1		
RKMMFACT	1	1	1	1	1		
FLAREA	1	0.5	0.5	0.5	0.5		
INFMOD	1	1	1	1	1		
ETMOD	1	1	1	1	1		
RUNFLOW	0	0	0	0	0		
BARSOIL1	-10	-10	-10	-10	-10		
BARSOIL2	1	1	1	1	1		
IAIRTEMPT	1	1	1	1	1		
ATEMP1	17.3	-50	-10	-0.6	-0.6		
ATEMP2	11.74	0	0	0	20		
HSTEP	2	2	2	2	2		
PPTYUC	1	1	1	1	1		
AAPREPX	181	181	181	181	181		

Control File Input Parameter	Test Case 4F	5A	5B	5C	5D		
IPPTDAT	0	0	0	0	0		
PPTFILE	Test4d.dat	mod3-ppt.dat	mod3-ppt.dat	mod3-ppt.dat	mod3-ppt.dat		
DEPTHFLG	0	0	0	0	0		
IRTZ	1	1	1	1	1		
DELVWCF	0.5	0.5	0.5	0.5	0.5		
MOISTCR	1	1	1	1	1		
FRACMOD	1	1	1	1	1		
IVWCFLG	0	0	0	0	0		
VWCFACT	1	1	1	1	1		
INFILE	t1c.w20	t1a.w20	t1a.w20	t1a.w20	t1a.w20		
LOCSTART	-1	-1	-1	-1	-1		
DAYALL	test4f.v21	test5a.v21	test5b.v21	test5c.v21	test5d.v21		
NDAYMAP	10	1	1	1	1		
IMAP	1	1	1	1	1		
IRDAY	1	70	70	70	70		
NYROUT	1980	1995	1995	1995	1995		
DAYMAP	test4f1.v22	test5a.v22	test5b.v22	test5c.v22	test5d.v22		
OUTFILE	test4f.v23	test5a.v23	test5b.v23	test5c.v23	test5d.v23		
FLXFILE	test4f.v24	test5a.v24	test5b.v24	test5c.v24	test5d.v24		
DBGFLAG	1	1	1	1	1		
DBGFLAG2	1	1	1	1	1		
DBGFILE	test4f.v25	test5a.v25	test5b.v25	test5c.v25	test5d.v25		
IDEBUG	0	0	0	0	0		
DBUGOUT	test4f.v26	test5a.v26	test5b.v26	test5c.v26	test5d.v26		
OUTYEAR1	test4f	test5a	test5b	test5c	test5d		
SOILID(10)	10	10	10	10	10		
FIELDCAP(10)	0.2	0.2	0.2	0.2	0.2		
SOILRESID(10)	0.1	0.1	0.1	0.1	0.1		
SOILPORO(10)	0.3	0.3	0.3	0.3	0.3		
SOILALBETA(10)	-2.5	-2.5	-2.5	-2.5	-2.5		
SOILTALPHA(10)	1	1	1	1	1		
SOILKS(10)	1.00E-04	5.70E-05	5.70E-05	5.70E-05	1.00E-03		
SOILPE(10)	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00	-1.08E+00		
SOILBVAL(10)	3.88	3.88	3.88	3.88	3.88		
SALPHA(10)	1	1	1	1	1		
SOILVGN(10)	5.50E-01	5.50E-01	5.50E-01	5.50E-01	5.50E-01		
SORP(10)	0.037	0.037	0.037	0.037	0.037		
SOILPOND(10)	0.05	0.05	0.05	0.05	0.05		
POTIS(10)	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02	-1.00E+02		
SOILID(11)	11	N/A	N/A	N/A	N/A		
FIELDCAP(11)	0.2	N/A	N/A	N/A	N/A		
SOILRESID(11)	0.1	N/A	N/A	N/A	N/A		
SOILPORO(11)	0.3	N/A	N/A	N/A	N/A		
SOILALBETA(11)	-2.5	N/A	N/A	N/A	N/A		
SOILTALPHA(11)	1	N/A	N/A	N/A	N/A		
SOILKS(11)	1.00E-03	N/A	N/A	N/A	N/A		
SOILPE(11)	-1.08E+00	N/A	N/A	N/A	N/A		

Control File Input Parameter	Test Case 4F	5A	5B	5C	5D		
SOILBVAL(11)	3.88	N/A	N/A	N/A	N/A		
SALPHA(11)	1	N/A	N/A	N/A	N/A		
SOILVGN(11)	5.50E-01	N/A	N/A	N/A	N/A		
SORP(11)	0.037	N/A	N/A	N/A	N/A		
SOILPOND(11)	0.05	N/A	N/A	N/A	N/A		
POTIS(11)	-1.00E+02	N/A	N/A	N/A	N/A		
SOILID(12)	12	N/A	N/A	N/A	N/A		
FIELDCAP(12)	0.2	N/A	N/A	N/A	N/A		
SOILRESID(12)	0.1	N/A	N/A	N/A	N/A		
SOILPORO(12)	0.3	N/A	N/A	N/A	N/A		
SOILALBETA(12)	-2.5	N/A	N/A	N/A	N/A		
SOILTALPHA(12)	1	N/A	N/A	N/A	N/A		
SOILKS(12)	1.00E-02	N/A	N/A	N/A	N/A		
SOILPE(12)	-1.08E+00	N/A	N/A	N/A	N/A		
SOILBVAL(12)	3.88	N/A	N/A	N/A	N/A		
SALPHA(12)	1	N/A	N/A	N/A	N/A		
SOILVGN(12)	5.50E-01	N/A	N/A	N/A	N/A		
SORP(12)	0.037	N/A	N/A	N/A	N/A		
SOILPOND(12)	0.05	N/A	N/A	N/A	N/A		
POTIS(12)	-1.00E+02	N/A	N/A	N/A	N/A		
NROCKID	132	130	130	130	130		
ROCKALBETA	-1.5	-1.5	-1.5	-1.5	-1.5		
ROCKTALPHA	1	1	1	1	1		
IMBIBE(400)	100.00	N/A	N/A	N/A	N/A		
IMBIBE(450)	10.00	N/A	N/A	N/A	N/A		
IMBIBE(500)	1.00	0.24	0.24	1.00	1.00		

(N/A, Not applicable)

APPENDIX 1-B. DAILY CLIMATE INPUT FILE:

The daily climate input file is the primary control for the timing and duration of the simulation. The daily climate input file defines the time domain through which the simulation occurs by providing a real-time sequential input of daily climate parameters. The file at minimum consists of the year number, the day of year number, and the total daily precipitation amount but can also consist of maximum, minimum, and average daily air temperature, along with total daily snowfall accumulation. The three options for daily climate input used for the Yucca Mountain Project are as follows:

1. Development of a daily climate input file (mod3-ppt.dat) for model calibration and modern climate simulations using available precipitation records from monitoring sites within the study area and in the proximity of Yucca Mountain. Development of mod3-ppt.dat is performed within an EXCEL spreadsheet (mod3-ppt.xls) using a linear interpolation method.

2. Development of 100-year daily climate input files for modern climate scenarios using available precipitation records from the Nevada Test Site stations 4JA and Area 12 Mesa and the programs MARKOV V1.0 (STN 10142-1.0-00) and PPTSIM V1.0. (STN 10143-1.0-00).

3. Development of daily climate input for future climate scenarios using the routine DAILY09 V1.0 and seven selected analog records from the EARTHINFO[1] database.

A. Precipitation Input Variable Order

```
        open(unit=11,file=pptfile)
            if(ipptdat.eq.3) then
                do i = 1,33
                    read(11,5) header0
                enddo
            endif
                if(ipptdat.eq.3) then
read(11,8011,end=90) icalday,yr(nd),month(nd),day(nd),
            1                dn(nd),ppt(nd),dayflg,maxairt(nd),
            2                dayflg,minairt(nd),dayflg,avgairt(nd),
      3                      dayflg,snowdat,dayflg
    c
    8011                     format(i8,i5,i3,i3,i5,6(f7.1,a3))
    c
                else if(ipptdat.eq.1) then
            read(11,*,end=90) month(nd),day(nd),yr(nd),dn(nd),ppt(nd)
    c
        else
            read(11,*,end=90) yr(nd),dn(nd),ppt(nd)
                              yr(nd) = 1900 + yr(nd)
                              month(nd) = -9
```

[1] EARTHINFO is a registered trademark of EarthInfo Inc., 5541 Central Avenue, Boulder, CO 80301.

```
                    day(nd) = -9
endif
```

B. Daily climate input file variables.

Precipitation InputParameter	Description	Format
[If IPPTDAT = 0]	Variable determining input source selects daily data from a single site.	N/A
YR	Year of measurement	* (List-directed I/O)
DN	Day of year (Julian day)	*
PPT	Precipitation (mm)	*
[If IPPTDAT = 1]	Variable determining input source selects data produced from PPTSIM module.	N/A
MONTH	Month of year	
DAY	Day of year	*
YR	Year of measurement	*
DN	Day of year (Julian day)	*
PPT	Precipitation (mm)	*
[If IPPTDAT = 3]	Variable determining input source selects data produced from DAILY09 module.	N/A
HEADER0	Descriptions of variables below	A (Character data)
ICALDAY	Record day number	FORMAT statement 8011 (see below)
YR	Year of measurement	8011
MONTH	Month of year	8011
DAY	Day of year	8011
DN	Day of year (Julian day)	8011
PPT	Precipitation (mm)	8011
DAYFLG	Data Flags:-999.9 = missing dataM = missing data flagA = accumulated measurement (multiple days)T = trace amount (less than measurement resolution)C1 = calculated value (type 1 calculation)E1 = estimated value (type 1 estimation)E2 = estimated value (type 2 estimation)E3 = estimated value (type 3 estimation)	8011
MAXAIRT	Maximum air temperature (deg. C) of day	8011
DAYFLG	As above.	8011
MINAIRT	Minimum air temperature (deg. C) of day	8011
DAYFLG	As above.	8011
AVGAIRT	Average air temperature (deg. C) of day	8011
DAYFLG	As above.	8011
SNOWDAT	Snow (mm)	8011
DAYFLG	As above.	8011

Note: 8011, format(i8,i5,i3,i3,i5,6(f7.1,a3)

C. Examples for Precipitation Input Data Files.

There are three types of daily climate input files. These are described below.

1. Yucca Mountain 1980-95 Developed Daily Precipitation Record (mod3-ppt.dat)

a. Statement of Intended Use for the Data

The purpose of these data is to provide a temporal record of precipitation at one point on Yucca Mountain for the time period 1980 through 1995. These data represent a point near the center of Yucca Mountain approximately 1400 m in elevation and will be used to spatially distribute precipitation over the site area using correlations with elevation in order to (1) calibrate the net infiltration model, and (2) develop net infiltration results for the modern climate scenarios, which are used as input for UZ ground-water flow and transport models for TSPA.

b. General Information Pertaining to the Data Set

The climate input file used for model calibration, MOD3-PPT.DAT, is the same developed daily precipitation record that was used for calibration of the original 1996 (INFIL V1.0) net infiltration model for Yucca Mountain (Flint et al., 1996, Figure 19, DTN: GS960908312211.003). The file MOD3-PPT.DAT consists of daily precipitation estimates only and was developed using source data of daily precipitation records from 1980 through 1995.

i. Source data (all data used is shown in Excel file MOD3-PPT.xls)

USGS Yucca Mountain precipitation data from weatherstations WX1 and WX3.
GS960908312111.004 (1995 water year)
GS970108312111.001 (Oct. 1- Dec. 3, 1995)
GS000208312111.003 (1987-1989, non-Q)
GS000208312111.001 (1989-1994)

Nevada Test Site (NTS) precipitation data for stations 4JA, 40MN, Rock Valley, Cane Spring, Mid Valley and Tippipah Spring #2. These data are available in DTN: GS000200001221.002.

National Weather Service (NWS) stations at Beatty 8N and Amargosa Farms, from the National Climate Data Center and available through EarthInfo (see information provided in DTN: GS000100001221.001).

ii. Development of daily precipitation record

The developed record of daily precipitation is only an approximate representation of actual conditions over the general location and ground surface elevation of the potential repository area. Daily precipitation estimates for 1988 through 1995 were developed using the mean of the data from the Yucca Mountain weatherstations. For 1980 through 1987, daily precipitation was estimated using a linear interpolation model and available precipitation records from the six Nevada Test Site (NTS) monitoring sites and the two National Weather Service (NWS) monitoring sites located near Yucca Mountain. The model was developed using linear regression of a weighted mean daily precipitation calculated from the eight stations against the mean calculated from the two USGS weather stations for the period July 17, 1987 through September 30, 1994 (this is the period for which the two sets of records overlapped).

Table III-1 in USGS (2001) is the developed data precipitation record for Yucca Mountain that was used directly as input for INFIL V2.0. There is an EXCEL spreadsheet used to generate the developed data that is available in DTN: GS000208311221.001, and an identical spreadsheet formatted to display the formulas that can be printed out as hard copies.

Mod3-ppt1.xls: EXCEL spreadsheet used to perform calculations for developing mod3-ppt.dat, with values in cells shown.

Mod3-ppt2.xls: EXCEL spreadsheet used to perform calculations for developing mod3-ppt.dat, with formulas in cells shown.

c. Spreadsheet calculations

Calculations in the spreadsheet MOD3-PPT.xls are done following a series of steps outlined in the first sheet of the file, and reiterated here.

Step 1: average daily precipitation is calculated for USGS weather stations WX1 and WX3 for the period July 17, 1987 through September 30, 1994. For gaps in the record, a value of zero is estimated.

Step 2: Average annual precipitation is calculated for the six NTS stations and two NWS stations for all records beginning on July 17, 1987 and ending on September 30, 1994. This period of time coincides with the period for which precipitation data is available for USGS weather stations WX1 and WX3 (either stations). For all eight stations, the ratio $B_i = AAP_o/AAP_i$ is calculated, where AAP_i = average annual precipitation for the period July 17, 1987 – July 30, 1994 for station i, and AAP_o = mean average annual precipitation for USGS weather stations WX1 and WX3 (calculated in step 1), rounded to the nearest millimeter. The ratio is then used to scale the daily precipitation records for all eight stations using $PPT_i * \doteq B_i(PPT_i)$, where B_i is the scaling factor, PPT_i is the original daily precipitation record for station i, and PPT_i is the adjusted daily precipitation record. The scaling function is applied to all eight stations for 1/1/80 through 12/31/94.

Step 3: An inverse-distance-squared interpolation is performed to estimate the mean daily precipitation for WX1 and WX3 for the period July 17, 1987 – July 30, 1994. The inverse distance squared interpolation involves the calculation of a linear weighting factor based on the distance between locations. A central location on Yucca Mountain used with UTM coordinates of 548,553 m easting, 4,078,230 m northing. The equation is:

$$\text{Weighting factori} = (1/di2)/(\Sigma i\ (1/(di\ i2))$$

where d_i is the distance of station i from the central location having the indicated coordinates. Station coordinates, calculated distances, and calculated weighting factors are listed in the spreadsheet.

Step 4: The inverse distance squared model defined in step 3 is used to calculate the daily precipitation for the location defined in step 3.

Step 5: A linear model, based on a regression of measured precipitation vs. the adjusted daily precipitation record (the inverse-distance-squared interpolated precipitation), is applied to the results of the inverse-distance-squared interpolation for the period January 1, 1980 through September 30, 1994 using:

$$PPT_{YM} = 0.946546 * ([(1/d_i^2)/\Sigma_i (1/(d_i^2))] PPT_i^*)+0.0821$$

where PPT_{YM} is the estimated daily precipitation amount (to the nearest millimeter only) for the central location defined by the coordinates in step 3, and PPT_i^* is the scaled daily precipitation amount for station i. The results of the linear model are used to define the Yucca Mountain daily precipitation estimates for January 1, 1980 through May 11, 1989 (file mod3-ppt.day). The results of step 1 (to the nearest millimeter only) are used to define the Yucca Mountain daily precipitation estimates for May 11, 1989 through October 1, 1995 (file mod3-ppt.dat).

Example of developed data precipitation record for Yucca Mountain that was used directly as input for INFIL V2.0. (data source: GS000208311221.001)

Year	Day of Year	Daily Precip-itation (mm)	Year	Day of Year	Daily Precip-itation (mm)	Year	Day of Year r	Daily Precip-itation (mm)	Year	Day of Year	Daily Precip-itation (mm)	Year	Day of Year	Daily Precip-itation (mm)
80	1	0	80	74	0	80	147	0	80	220	0	80	293	0
80	2	0	80	75	0	80	148	0	80	221	0	80	294	0
80	3	0	80	76	0	80	149	0	80	222	0	80	295	0
80	4	0	80	77	0	80	150	0	80	223	0	80	296	0
80	5	0	80	78	0	80	151	0	80	224	0	80	297	0
80	6	0	80	79	0	80	152	0	80	225	0	80	298	0
80	7	0	80	80	0	80	153	0	80	226	0	80	299	0

2. Development of Daily Climate Input Using Daily09 V1.0

a. Name of routine/macro with version/OS/hardware environment and user information:
Name of software routine: DAILY09 V1.0
OS and hardware environment: Windows NT 4.0, Pentium Pro PC
Computer Identification: SM321276 with a USGS specific host-name P720dcasr
Software Users: Joseph Hevesi (916-278-3274), Alan Flint (916-278-3221)
User Location: U.S. Geological Survey, Room 5000E, Placer Hall, 6000 J Street, Sacramento, CA 95819-6129

b. Name of commercial software with version/OS/hardware used to develop routine/macro:
The source code for DAILY09 V1.0 was developed using the standard FORTRAN77 programming language. The source code was written, debugged, and compiled (for PC platforms using INTEL processors) using DIGITAL Visual Fortran with Microsoft Developer Studio, v. 5.0.

c. General Description of routine/macro:
DAILY09 V1.0 is a FORTRAN77 routine developed in accordance with AP-SI.1Q, specifically for the analysis/model activity documented in this VTR. The routine source code (DAILY09.FOR), compiled executable file (DAILY09.EXE), routine control file (DAILY09.CTL), input and output files used for routine validation, supplemental files created as part of validation testing, and a copy of this attachment, are located under the directory DAILY09 on a CD-ROM labeled DAYINPUT-1. The routine source code, control file, and the input and output files are ASCII text files that can be read using any standard ASCII text editor and can be imported into standard word processing applications such as Microsoft

Word. The executable file can be used to run DAILY09 V1.0 on any PC with an INTEL processor (with adequate RAM).

- The following electronic files including DAILY09 V1.0 and selected analog input and output files are provided:

DAILY09.CTL:	input file consisting of the input and output file names for BLOCKR7, along with parameters needed to perform the 36 blocking ridge angle calculations.
DAILY09.FOR:	FORTRAN source code listing for the routine BLOCKR7. A printout of the source code is included as part of this attachment.
DAILY09.EXE:	Executable file for the routine BLOCKR7, compiled for INTEL processors.
ROSALIA.DAT:	ASCII text file exported from the EARTHINFO NOAA daily climate records WEST2 database. This file is the input file to DAILY09 V1.0.
ROSALIA.DAY:	Auxiliary output file created by DAILY09 V1.0. The file contains all daily climate data provided by ROSALIA.DAT and is used to test for the proper re-formatting. The calculated average daily air temperature is included. This file is used only as part of the validation test for DAILY09.
ROSALIA.INP:	Primary output file created by DAILY09 V1.0. This file is used directly as input to INFIL V2.0 for defining the daily climate input parameters needed for simulating net infiltration.

d. Supporting Information

- Procedure for running routine:
  To run the routine DAILY09, an executable version of the code and all input files must be placed in the same directory. The routine is executed by typing DAILY09 in a DOS window or by double clicking on the file DAILY09.EXE in Windows NT. The input and output file names and the parameters used for the blocking ridge calculations must be in the correct sequential order as specified in the routine control file DAILY09.CTL (see example listing in this section)

- Example listing of ROSALIA.DAT.
  This ASCII file is exported from EARTHINFO using the NCDC export format option. The data shown in this subset is for maximum daily air temperature (TMAX), followed by precipitation (PRCP), with the record starting in May (5) of 1948, continuing through November (11) of 1948. On the first 2 monthly records it is noted just above the top line how to read the file. Month 5 has no data (-99999) for temperature, month 6 has data in degrees Fahrenheit. (See next page.)

- Example listing of ROSALIA.DAT (from previous page)

```
                Tmax    1948  5 (May)       1 (Day)          2 (Day)          3 (Day)
DLY45718002TMAX F194805999903 10198-99999M10298-99999M10398-99999M10498-
99999M10598-99999M10698-99999M10798-99999M10898-99999M10998-99999M11098-
99999M11198-99999M11298-99999M11398-99999M11498-99999M11598-99999M11698-
99999M11798-99999M11898-99999M11998-99999M12098-99999M12198-99999M12298-
99999M12398-99999M12498-99999M12598-99999M12698-99999M12798-99999M12898-
99999M12998-99999M13098-99999M13198-99999M1
```

Tmax 1948 6 (June) 1 77 (F) 2 81 (F) 3 67 (F)
DLY45718002TMAX F19480699990310198 00077 10298 00081 10398 00067 10498 00066 10598 00079 10698 00084 10798 00088 10898 00086 10998 00087 11098 00077 11198 00069 11298 00074 11398 00071 11498 00076 11598 00071 11698 00066 11798 00069 11898 00073 11998 00077 12098 00065 12198 00061 12298 00069 12398 00075 12498 00069 12598 00077 12698 00077 12798 00081 12898 00086 12998 00091 13098 00083 13198-99999M1

DLY45718002PRCPHI19480599990310198-99999M10298-99999M10398-99999M10498-99999M10598-99999M10698-99999M10798-99999M10898-99999M10998-99999M11098-99999M11198-99999M11298-99999M11398-99999M11498-99999M11598-99999M11698-99999M11798-99999M11898-99999M11998-99999M12098-99999M12198-99999M12298-99999M12398-99999M12498-99999M12598-99999M12698-99999M12798-99999M12898-99999M12998-99999M13098-99999M13198-99999M1

DLY45718002PRCPHI19480699990310198 00000 10298 00000 10398 00000 10498 00017 10598 00001 10698 00000 10798 00000 10898 00000 10998 00000 11098 00040 11198 00000 11298 00057 11398 00005 11498 00002 11598 00000 11698 00046 11798 00012 11898 00000 11998 00000 12098 00000 12198 00034 12298 00005 12398 00004 12498 00000 12598 00005 12698 00005 12798 00000 12898 00000 12998 00000 13098 00002 13198-99999M1

- Example listing of ROSALIA.DAY. DAILY09 uses the EARTHINO data to reformat into *.DAY format prior to identification of gaps, conversions and averaging. When compared to the above EARTHINFO file it indicates that the reformatting done in DAILY09 is correct. This file also includes the conversion of air temperature from Fahrenheit to Celsius. June 1, 1948 in the EARTHINFO file above is 77 (F), June 2 is 81 (F). In file below the conversion results in June 1 = 25(C) and June 2 = 27.2(C), calculated as degrees C = (degrees F – 32) * (5/9).

Output file generated using program DAILY09.FOR
Output file = Rosalia.day
Daily climate record for Rosalia, Washington
GU1 Upper bound glacial transition climate analog (4/12/1999)

- Example listing of ROSALIA.DAY. (continued)

Station ID = 457180

Dy = day
Mo = month
Yr = year
Max = maximum
Min = minimum
Precip = total daily precipitation
Temp = daily air temperature
mm = millimeters
deg C = degrees Celsius

Data Flags:

-999.9 = missing data value
M = missing data flag
A = accumulated measurement (multiple days)
T = trace amount (less than measurement resolution)

Record Day No.	Year	Mo	Day of Mo	Day of Yr	Precip mm	Max Temp deg C	Min Temp deg C	Snow Fall mm
54177	1948	5	1	122	-999.9 M	-999.9 M	-999.9 M	-999.9 M
54178	1948	5	2	123	-999.9 M	-999.9 M	-999.9 M	-999.9 M
54179	1948	5	3	124	-999.9 M	-999.9 M	-999.9 M	-999.9 M
54180	1948	5	4	125	-999.9 M	-999.9 M	-999.9 M	-999.9 M
54181	1948	5	5	126	-999.9 M	-999.9 M	-999.9 M	-999.9 M
54182	1948	5	6	127	-999.9 M	-999.9 M	-999.9 M	-999.9 M
54183	1948	5	7	128	-999.9 M	-999.9 M	-999.9 M	-999.9 M
54184	1948	5	8	129	-999.9 M	-999.9 M	-999.9 M	-999.9 M
54185	1948	5	9	130	-999.9 M	-999.9 M	-999.9 M	-999.9 M
54186	1948	5	10	131	-999.9 M	-999.9 M	-999.9 M	-999.9 M
54187	1948	5	11	132	-999.9 M	-999.9 M	-999.9 M	-999.9 M
54188	1948	5	12	133	-999.9 M	-999.9 M	-999.9 M	-999.9 M
54189	1948	5	13	134	-999.9 M	-999.9 M	-999.9 M	-999.9 M
54190	1948	5	14	135	-999.9 M	-999.9 M	-999.9 M	-999.9 M

- Example listing of ROSALIA.DAY. DAILY09 uses the EARTHINO data to reformat into *.DAY format prior to identification of gaps and averaging, but following conversion from Fahrenheit to Celsius. The file below is precipitation for 1971 (Dec), 1972 (all) and 1973 (Jan and Feb only), following the reformatting and conversion to Celsius. The year 1972 has large gaps and when compared to the final input file will be omitted.

Output file generated using program DAILY09.FOR
Output file = Rosalia.day
Daily climate record for Rosalia, Washington
GU1 Upper bound glacial transition climate analog (4/12/1999)

Station ID = 457180

Dy = day
Mo = month
Yr = year
Max = maximum
Min = minimum
Precip = total daily precipitation
Temp = daily air temperature
mm = millimeters
deg C = degrees Celsius

Data Flags:

-999.9 = missing data value
M = missing data flag
A = accumulated measurement (multiple days)
T = trace amount (less than measurement resolution)

Record Day Number	Year	Mo	Dy of Mo	Dy of Yr	Precip mm	Max Temp deg C	Min Temp deg C	Snow Fall mm
62791	1971	12	1	335	0.0	1.1	-3.9	0.0
62792	1971	12	2	336	0.0	3.9	-2.8	0.0
62793	1971	12	3	337	0.0 T	2.8	-4.4	0.0 T
62794	1971	12	4	338	0.0	1.7	-6.1	0.0
62795	1971	12	5	339	5.1	2.2	-1.7	63.5
62796	1971	12	6	340	0.0	2.8	-5.0	0.0
62797	1971	12	7	341	0.0	-2.8	-16.1	0.0
62798	1971	12	8	342	0.0	-6.7	-15.6	0.0
62799	1971	12	9	343	0.0	2.8	-7.8	0.0
62800	1971	12	10	344	0.0	2.2	-2.2	0.0
62801	1971	12	11	345	7.6	0.0	-8.9	50.8
62802	1971	12	12	346	2.0	1.1	-8.9	25.4

- Example listing of ROSALIA.INP. This is the main output file from DAILY09 V1.0, generated using the exported EARTHINFO record for Rosalia, WA. The file is used directly as input to INFIL V2.0. The file includes 1971 and 1973. As the data from the entire month of June in 1972 was missing in the above file, it is omitted from the final file indicated below. This verifies the omission of years when the gap identified is large (> 10 days for precipitation and > 20 for air temperature). In addition, the following file illustrates the additional column of mean air temperature calculated as (TMAX+TMIN)/2.

Output file generated using program DAILY09.FOR
Output file = Rosalia.inp
Daily climate record for Rosalia, Washington
GU1 Upper bound glacial transition climate analog (4/12/1999)

Station ID = 457180

Dy = day
Mo = month
Yr = year
Max = maximum
Min = minimum
Precip = total daily precipitation
Temp = daily air temperature
mm = millimeters
deg C = degrees Celsius

Data Flags:

-999.9 = missing data
M = missing data flag
A = accumulated measurement (multiple days)
T = trace amount (less than measurement resolution)
C1 = calculated value (type 1 calculation)
E1 = estimated value (type 1 estimation)
E2 = estimated value (type 2 estimation)
E3 = estimated value (type 3 estimation)

Record Day Number	Year	Mo	Dy of Mo	Dy of Yr	Precip mm	Max Temp deg C	Min Temp deg C	Mean Temp deg C	Snow Fall mm
62791	1971	12	1	335	0.0	1.1	-3.9	-1.4 C1	0.0
62792	1971	12	2	336	0.0	3.9	-2.8	0.6 C1	0.0
62793	1971	12	3	337	0.0 T	2.8	-4.4	-0.8 C1	0.0 T
62794	1971	12	4	338	0.0	1.7	-6.1	-2.2 C1	0.0
62795	1971	12	5	339	5.1	2.2	-1.7	0.3 C1	63.5
62796	1971	12	6	340	0.0	2.8	-5.0	-1.1 C1	0.0

- Example listing of ROSALIA.DAY indicating small gaps in precipitation and air temperature data.

Output file generated using program DAILY09.FOR
Output file = Rosalia.day
Daily climate record for Rosalia, Washington
GU1 Upper bound glacial transition climate analog (4/12/1999)

Station ID = 457180

Dy = day
Mo = month
Yr = year
Max = maximum
Min = minimum
Precip = total daily precipitation
Temp = daily air temperature
mm = millimeters
deg C = degrees Celsius

Data Flags:

-999.9 = missing data value
M = missing data flag
A = accumulated measurement (multiple days)
T = trace amount (less than measurement resolution)

Record Day Number	Year	Mo	Dy of Mo	Dy of Yr	Precip mm	Max Temp Deg C	Min Temp Deg C	Snow Fall mm
71263	1995	2	10	41	0.0	8.3	-1.7	0.0
71264	1995	2	11	42,	0.0	6.1	-2.8	0.0
71265	1995	2	12	43	0.0	1.1	-8.9	0.0
71266	1995	2	13	44	-999.9 M	-6.7	-12.2	-999.9 M
71267	1995	2	14	45	0.8	-7.2	-12.2	12.7
71268	1995	2	15	46	0.0	-6.7	-11.7	0.0
71269	1995	2	16	47	3.8	2.2	-999.9 M	50.8
71270	1995	2	17	48	13.7	4.4	0.0	0.0
71271	1995	2	18	49	0.0	7.8	1.1	0.0
71272	1995	2	19	50	8.9	11.1	2.8	0.0
71273	1995	2	20	51	5.8	13.3	8.3	0.0

- Example listing of ROSALIA.INP illustrating that the gap in precipitation is replaced by a zero, and the gap in air temperature is replaced with a linear interpolation between the numbers on either side of the gap.

Output file generated using program DAILY09.FOR
Output file = Rosalia.inp
Daily climate record for Rosalia, Washington
GU1 Upper bound glacial transition climate analog (4/12/1999)

Station ID = 457180

Dy = day
Mo = month
Yr = year
Max = maximum
Min = minimum
Precip = total daily precipitation
Temp = daily air temperature
mm = millimeters
deg C = degrees Celsius

Data Flags:

-999.9 = missing data
M = missing data flag
A = accumulated measurement (multiple days)
T = trace amount (less than measurement resolution)
C1 = calculated value (type 1 calculation)
E1 = estimated value (type 1 estimation)
E2 = estimated value (type 2 estimation)
E3 = estimated value (type 3 estimation)

Record Day Number	Year	Mo	Dy of Mo	Dy of Yr	Precip mm	Max Temp deg C	Min Temp deg C	Mean Temp deg C	Snow Fall mm
71263	1995	2	10	41	0.0	8.3	-1.7	3.3 C1	0.0
71264	1995	2	11	42	0.0	6.1	-2.8	1.7 C1	0.0
71265	1995	2	12	43	0.0	1.1	-8.9	-3.9 C1	0.0
71266	1995	2	13	44	0.0 E1	-6.7	-12.2	-9.4 C1	-999.9 M
71267	1995	2	14	45	0.8	-7.2	-12.2	-9.7 C1	12.7
71268	1995	2	15	46	0.0	-6.7	-11.7	-9.2 C1	0.0
71269	1995	2	16	47	3.8	2.2	-5.8 E2	-1.8 C1	50.8

A listing of the source code for DAILY09 V1.0 is included as Attachment V to USGS (2001).

3. Development of Stochastic Simulation Precipitation Data

The data from sites identified as 4ja and Area 12 that was used to develop 100-year period simulations are from work documented and available through a draft Water Resources Investigation Report that was submitted to records and assigned Accession Number MOL.19970409.0087. The data files were submitted as a surrogate record to this report, and assigned the Accession Number MOL.20000317.0164. The standard statistical software programs MARKOV and PPTSIM used to develop this data are qualified and controlled by the OCRWM Software Configuration Management. The developed data are the Mod3-ppt.dat, Mod3ppt1.xls, Mode3ppt2.xls, and Mod3-ppt.text files listed in the surrogate record submitted on CD ROM. For INFIL V2.0, the file for the stochastic data is named PPTSIM (option 1 for IPPTDAT program variable). A summary of developed daily climate input files used for modern climate scenarios used for the AMR ANL NBS HS-000032 is shown below in Table A1-2.

Table A1-2 PPTSIM AND MARKOV [mm, millimeters] (data source: GS000208311221.001)

	Yucca Mountain calibration daily climate input	4JAstochastic simulation	Area 12 MesaStochastic simulation
Filename	Mod3-ppt.dat	4JA.s01	Area12.s01
Beginning of record	01/01/1980	n/a	n/a
Ending of record	10/01/1995	n/a	n/a
Total number of years for simulation	15.75	100	100
Mean annual precipitation (mm)	181	140	328
Maximum daily precipitation (mm)	58	82	76

APPENDIX I-C: GEOSPATIAL INPUT DATA FOR INFIL V2.0 FY99

Model Grid Geometry and Watershed Modeling Domains for the Yucca Mountain Site

The development of the geospatial input parameter base grid and the separate watershed modeling domains requires the application of Geographic Information Systems (GIS) to transfer available digitized map data, which is in a vector-based format, onto the grid-cell of the raster-based format of the DEM (a process referred to as rasterization). The vector-based map coverages used as input by the net infiltration model include bedrock geology and soil type maps. In addition to the rasterization procedure, GIS applications are also used for calculating slope and aspect as well as latitude and longitude coordinates for all grid cells. Geospatial parameters that are not available as either raster-based or vector-based map coverages are developed using a series of FORTRAN routines documented in USGS (2001), that are applied sequentially. The routines are used to overlay three separate bedrock geology maps (after rasterization), estimate soil thickness, calculate the blocking ridge parameters, calculate surface water flow routing parameters, and extract the watershed model domains.

All acquired and estimated geospatial parameters required as input for INFIL V2.0 are combined into a single ASCII file defining the base-grid for all extracted watershed model grids (DTN: GS000308311221.004). The geospatial parameter input files defining watershed model domains are extracted as separate files from the developed base-grid using the routine WATSHD20 V1. All FORTRAN routines (GEOMAP7 V1.0, GEOMOD4 V1.0, SOILMAP6 V1.0, and BLOCKR7 V1.0) are qualified for use in accordance with OCRWM Procedure AP-SI.1Q, Rev 2. The use of the acquired software application ARCINFO V6.1.2 was exempt. The purpose of these data is to provide spatial information and properties for each grid block necessary to calculate net infiltration at each location for the Yucca Mountain site using the model INFIL V2.0.

A. Spatial Discretization and the Base-Grid

The net infiltration modeling procedure begins with building a geospatial input parameter base grid using the selected digital elevation model (DEM) to define the base-grid geometry. The DEM (DTN: GS000308311221.006), selected for defining the grid geometry is the composite DEM used for the original net infiltration model (Flint et al., 1996) that was developed from two standard USGS 7.5 minute 30-meter DEMs (Busted Butte and Topopah Spring NW). The two DEM's (DTN: GS000200001221.003) were combined into a composite DEM (DTN: GS000308311221.006) by using the ARCINFO GRID module. Within this module a command MERGE is used to perform the combining process. Once the two DEM's are combined, it was necessary to convert the projection coordinates from decimal-degrees into UTM coordinates. This was done using the standard ARCINFO PROJECT command. The grid geometry of the composite DEM (DTN: GS000308311221.006) is based on the Universal Transverse Mercator projection (zone 11, NAD27, DTN: GS000200001221.003) and consists of 691 rows in the north-south direction and 367 columns in the east-west direction covering a rectangular area centered over Yucca Mountain and the potential repository site, with the following corner coordinates:

The DEM (DTN: GS000308311221.006) selected for defining the Yucca Mountain grid geometry is the composite DEM used for the original net infiltration model (Flint et al., 1996) that was developed from two standard USGS 7.5 minute 30-meter DEMs (Busted Butte and Topopah Spring NW). The two DEMs (DTN:GS000200001221.003) were combined into a composite

DEM (DTN: GS000308311221.006) by using the ARCINFO, ARC-EDIT, ARC-PLOT, and ARC-GRID modules, utilizing a series of standard commands within the various modules. The grid geometry of the composite DEM (DTN: GS000308311221.006) is based on the Universal Transverse Mercator (UTM) projection (zone 11, NAD27) and consists of 691 rows in the north-south direction and 367 columns in the east-west direction covering a rectangular area centered over Yucca Mountain and the potential repository site, with the following corner coordinates:

Northwest corner:	544,661 meters easting, 4,087,833 meters northing
Northeast corner:	555,641 meters easting, 4,087,833 meters northing
Southeast corner:	555,641 meters easting, 4,067,133 meters northing
Southwest corner:	544,661 meters easting, 4,067,133 meters northing

The elevation provided by the composite DEM (253,597 values) is the primary geospatial parameter used by the net infiltration model. Elevation is used to define the surface-water flow-routing network, which is in turn used to define modeled separately as closed hydrologic systems. Elevation is used to define slope, aspect, and blocking ridge parameters for modeling incoming solar radiation that is in turn used in an energy balance calculation for modeling potential evapotranspiration. The calculated slope is also used to model soil thickness. Additional uses of elevation values in the net infiltration model include estimation of spatially distributed daily climate input (precipitation and air temperature).

Figure A1-1 is a shaded relief representation of the Yucca Mountain DEM and includes the location of the 1999 UZ flow model boundary, the 1999 design potential repository boundary, and the trace of the main Exploratory Studies Facility drift. Also shown are the locations of the neutron borehole sites used to calibrate the 1996 model as well as provide core samples for measuring bedrock hydraulic conductivity. Figure A1-1 illustrates the level of detail provided by the DEM in terms of representing discrete topographic features by using elevation, which is the primary geospatial-input parameter for the net-infiltration model. The DEM has an average elevation of 1,237 meters, a minimum elevation of 918 meters along the southern perimeter, and a maximum elevation of 1,969 meters along the northern perimeter.

Figure A1-1. Yucca Mountain DEM used to define geospatial-input parameters and watershed modeling domains. (Appendix 3)

DEM elevations in the base grid are used for calculating and estimating geospatial-input parameters and are also used directly as an input in the developed geospatial-parameter input file. Section 6.3.2 discusses the application of elevation directly as an input parameter for INFIL V2.0 calculations, which includes estimating the spatial distribution of precipitation and air temperature. Sections 6.5.2 and 6.5.3 discuss the application of DEM elevations for calculating flow-routing parameters and developing watershed model domains using the routines SORTGRD1 V1.0, and CHNNET16 V1.0. Section 6.4.4 describes the application of DEM elevations for calculating topographic parameters, which include slope, aspect, and blocking ridge angles, using ARCINFO V6.1.2 and the routine BLOCKR7 V1.0.

Development of the Surface Drainage Network

To generate watershed-modeling domains, the surface-water drainage network was defined using the base grid supplied as output from SOILMAP6 V1.0 and GEOMOD4 V1.0. Flow directions were calculated for each grid cell using a 2-step process. For the first step, the entire base grid is sorted by elevation using the routine SORTGRD1 V1.0. In the second step, flow-routing directions are calculated

based on a standard D8 routing algorithm (flow is routed to one of eight adjacent grid cells having the lowest elevation) using the routine CHNNET16 V1.0.

CHNNET16 V1.0 is a convergent flow routing algorithm; multiple cells are allowed to route to a single cell, but any given cell can route to only one downstream grid cell (as opposed to two in cases of flow dispersion). The CHNNET16 V1.0 algorithm provides a method for routing through surface depressions in the DEM, which were found to be numerous. The surface depressions are in part a characteristic of poorly established drainage networks across alluvial fans and basins in arid and semiarid environments. Surface depressions are also caused by inaccuracy in the DEM in terms of both elevation values and grid resolution. If the DEM grid is too coarse relative to channel dimensions it cannot accurately capture the natural channel, and this problem tends to be most severe on broad alluvial fans and basins as opposed to upland areas where the drainage network is more accurately defined by the rugged terrain. The CHNNET16 V1.0 routing algorithm allows DEM surface depressions of up to 20 layers deep (20 grid cells need to be crossed before surface flow escapes the depression), and this was found to be greater than the largest depression encountered in the Yucca Mountain DEM. In addition to the flow routing parameters, output from CHNNET16 V1.0 includes a flow accumulation term, which indicates the number of upstream cells for each grid cell in the initial model grid.

Development of Watershed Model Domains

Division of the net-infiltration model domain into a set of smaller, isolated watershed model domains was needed to decrease simulation run-times for INFIL V2.0 by allowing the simulation to be distributed over multiple computer processors. The isolated watershed domains allow for a more efficient analysis of the impact of watershed characteristics on simulation results. Additionally, the smaller, closed modeling systems enable a more efficient mass balance checking because each model domain is a single watershed with only one outflow location.

To develop a composite watershed-modeling domain consisting of all watersheds either overlying or immediately adjacent to the area of the site-scale UZ flow and transport model, the boundary of the UZ model was overlain on the numerically defined drainage networks obtained from CHNNET16 V1.0. The outflow cell (the discharge point for all upstream grid cells) of each major drainage network affecting the UZ model area was identified using TRANSFORM for a visual analysis of the flow accumulation map (Figure A1-2). A total of 10 separate watershed model grids were extracted using the routine WATSHD20 V1.0, which executes a reverse flow-routing algorithm to identify all model cells upstream from the selected outflow cell. The model grid defining the extracted watershed domain includes the active grid cells upstream from the outflow cell and also an outer perimeter layer of inactive cells that are needed as boundary cells during surface-water flow routing. The perimeter cells are also used in the mass-balance checking calculation performed using Equation 6-13 to ensure that outflow is consistent with the cumulative mass balance calculated for all grid cells in the watershed model domain.

Whether or not the calculated flow divides accurately represent the natural system depends on the resolution and accuracy of the DEM, and the accuracy of the flow routing algorithm in capturing the true channel network. An assumption was made that the accuracy of the DEM and the accuracy of the D8 flow routing algorithm was adequate for the purpose of this modeling activity. This assumption was based in part on the knowledge that the model results would be interpolated onto the coarser mesh of the UZ flow and transport model. The assumption was also based on the knowledge that a static DEM was being used to represent topography for the next 10,000 years. In other words, an accurate representation of the present-day channel network at Yucca Mountain is considered to be irrelevant given that the

active channel network is likely to change significantly over a 10,000-year period, particularly if wetter climates develop.

Figure A1-2. Isolation of the drainage networks overlying the area of the UZ flow and transport model. (Appendix 3)

The main watersheds included in the composite watershed model area are Yucca Wash, Drill Hole Wash, Dune Wash, Solitario Canyon #1, and Plug Hill[2]. Additional drainages that were included in the composite model to provide a buffer zone along the western edge of the UZ model are Jet Ridge #1, Jet Ridge #2, Jet Ridge #3, Solitario Canyon #2, and Solitario Canyon #4. The watershed model domains were restricted to the western side of the Fortymile Wash channel because the Yucca Mountain DEM captures only a small part of the lower Fortymile Wash drainage, and complete watersheds cannot be defined for most sections of the DEM east of Fortymile Wash. With the exception of Yucca Wash, and Jet Ridge #1, all watersheds are fully defined by the DEM. For Yucca Wash, northern sections of the watershed are missing because the DEM does not extend far enough north (the northern perimeter of the watershed is defined by the DEM boundary). The missing area is small relative to the total watershed area, and the only potential impact occurs in the Yucca Wash channel along the northeastern perimeter of the UZ flow and transport model area. For Jet Ridge #1, the lowermost segment of the eastern perimeter is defined by the DEM boundary. The missing eastern section of Jet Ridge #1 is an insignificant area that does not affect results obtained for the UZ flow and transport model area.

B. Geospatial Data File

The site location and attribute file contains 19 columns of numbers: location easing (m), slope (degrees), aspect (degrees), elevation (m), latitude (decimal degrees), longitude (decimal degrees), soil type, soil depth class, underlying geologic, geomorphic position and the elevation angle (degrees) of the surrounding topography every identification (unitless), Universal Transverse Mercater (UTM) nothing (m), UTM 10 degrees beginning at 10 degrees with east being 90 degree, south being 180 degrees, west being 270 degrees and north being 360 degrees. In the current version of INFIL, geomorphic position is a place holder for identifying sites located in channels.

<u>Geospatial Input Variable Order:</u>

```
100  read(8,*,end=130) locid(n),easting(n),northing(n),lat(n),lon(n),
     1                 row(n),col(n),iwat(n),totoutc,elev(row(n),col(n)),

     3        sl(n),asp(n),soiltype(n),

     4        dclass,depth(n),rocktype(n),topoid(n),vegt,vegc(n),
     5        (ridge(n,j), j=1,36)
```

[2]The names selected for the extracted watershed modeling domains are not necessarily the established geographic names for these physiographic features. They are used here only as a means of identifying the separate watershed models.

Input Variables

Source data software used for development of geospatial input data are as follows:

Elevation, northing and easting: USGS Digital Elevation Model (DEM) from Topopah Spring West and Busted Butte 7.5-minute quadrangles: DTN: GS000308311221.006, ARCINFO, to produce ASCII file 30MSITE.INP (DTN: GS000308311221.006)

Downstream grid cell: 30MSITE.INP, SORTGRD1 V1.0, CHNNET16 V1.0 (DTN: GS000308311221.006)

Number of upstream cells: 30MSITE.INP, SORTGRD1 V1.0, CHNNET16 V1.0 (DTN: GS000308311221.006)

Slope: 30MSITE.INP, ARCINFO (DTN: GS000308311221.006)

Aspect: 30MSITE.INP, ARCINFO (DTN: GS000308311221.006)

Soil-type: INFIL V2.0 control file INFILS5o.CTL and 30MSITE.INF (DTN: GS960508312212.007, GS000308311221.006)

Soil depth class: soil depth map (DTN: GS960508312212.007), INFIL V2.0 control file INFILS5o.CTL, and 30MSITE.INP (DTN: GS000308311221.006)

Modeled soil depth: soil depth class (DTN: GS960508312212.007), GEOMAP7 V1.0, GEOMOD4 V1.0, and SOILMAP6 V1.0

Rock type: INFIL V2.0 control file INFILS5o.CTL, and README2.DAY [coverage explanations for Day et al. (1998)], (DTN: GS971208314221.003)

Topographic position: INFIL V2.0 control file INFILS5o.CTL

Blocking ridges: 30MSITE.INP (DTN: GS000308311221.006), BLOCKR7 V1.0

Data Set

The data set consists of three parts.

Part 1: Geospatial input for each of 10 drainages

Part one of the data set is a set of 10 files consisting of grid blocks within individual watershed modeling domains and all associated geospatial input listed above. These files are in EXCEL worksheets formatted with descriptive column headers and are available in DTN: GS000308311221.004:

YuccaWash.xls	Solitario4.xls
DuneWash.xls	PlugHill.xls
DrillHole.xls	JetRidge1.xls
Solitario1.xls	JetRidge2.xls
Solitario2.xls	JetRidge3.xls.

The parameters included in each file are grid cell identifier number, UTM easting, UTM northing (m), latitude, longitude (decimal degrees), grid cell row index, grid cell column index, downstream grid cell identifier (used for surface water routing), number of upstream grid cells, elevation (m), slope (degrees inclination from horizontal), aspect (degrees from north), soil-type identifier, soil depth class identifier, modeled soil depth (m), rock-type identifier, topographic position, vegetative type, vegetative cover, 36

blocking ridge angles (decimal degrees, inclination above horizontal) (see Table A1-3). An abbreviated example of the files is shown in Table A1-4.

This input is primarily based on the USGS Digital Elevation Model (DEM) from Topopah Spring West and Busted Butte 7.5-minute quadrangles. The base grid (DTN: GS000308311221.006) was used to define location coordinates for the geospatial parameter input files for the 1996 version of the net infiltration model (Flint et al., 1996). The DEM is a regular 2-dimensional grid of 253,597 cells having dimensions of 30 x 30 meters and elevations to the nearest meter. The 30-meter grid is based on a Universal Transverse Mercator (UTM), zone 11, NAD 1927 projection, consists of 691 northing "rows" (grid cell row index) and 367 easting "columns" (grid cell column index) aligned orthogonal to the UTM coordinate axis, and has a lower left corner coordinate of 544,661 meters easting and 4,067,133 meters northing. Grid locations are also defined using geographic coordinates, latitude and longitude in decimal degrees, which were calculated in ARCINFO and used as input for the SOLRAD sub-model in INFIL V2.0. The row and column location indices are used in the flow routing module in INFIL in the calculation of the surface water run-on term.

Downstream grid cell identifier is the flow routing parameter and determines which of eight surrounding grid cells is the lowest in elevation. A value of –3 indicates the downstream grid cell is a drainage boundary. Flow directions were calculated for each grid cell using a two-step process. For the first step, the entire base-grid is sorted by elevation using the routine SORTGRD V1.0. In the second step, flow routing directions are calculated based on a standard D8 routing algorithm using the routine CHNNET16 V1.0. CHNNET16 V1.0 is a convergent flow routing algorithm; multiple cells are allowed to route to a single cell, but any given cell can route to only one downstream grid cell (as opposed to two in cases of flow dispersion). The CHNNET16 V1.0 algorithm provides a method for routing through surface depressions in the DEM. The number of upstream grid cells is included in each file.

Elevation from mean sea level in meters is included in each file.

Slope is a required input parameter for estimating soil depths. Slope and aspect were calculated for the net infiltration model from the DEM (DTN: GS000308311221.006) using standard GIS applications in ARCINFO.

Soil type is indicated by values of between 1 and 10 (Flint et al., 1996, Table 3, DTN: GS960908312211.003). When encountered in INFIL it uses a lookup table (INFILS5o.CTL) that has all hydrologic parameters for each soil type as listed in Flint et al. (1996). Depth class identifier is a value between 1 and 6 and is used in the preprocessing routine SOILMAP6 V1.0 with depth to bedrock map (DTN: GS960508312212.007, Estimated distribution of geomorphic surfaces and depth to bedrock for the southern half of the Topopah Spring NW 7.5 minute quadrangle and the entire Busted Butte 7.5 minute quadrangle), and slope to calculate soil depth at all grid block locations. Soil depth is estimated using a combination of the soil depth class map and an estimated linear relation between soil depth and slope within each depth class (GEOMAP7 V1.0 and GEOMOD4 V1.0). Soil depth classes represent different ranges in actual soil depths that were estimated using a combination of Quaternary geologic maps, field observations, and soil depth recorded at borehole sites (Flint and Flint, 1995, Table 2). Depth class #1 identifies locations with soil depths ranging from 0 to 0.5 meters and primarily occurs in rugged upland areas. Depth class #2 identifies deeper soils ranging from 0.5 to 3.0 meters occurring at mid to lower side-slope locations in upland areas affected by slumps, slides, and other mass-wasting processes. Depth class #3 identifies locations in the transition zone between upland areas and alluvial fans or basins

with intermediate soil depths ranging from 3 to 6 meters. Depth class #4 identifies deep soils with depths of 6 meters or greater. Depth class #5 is an intermediate depth zone equivalent to Depth class #3, however #3 did not represent field conditions well when the Day et al. (1998) map was incorporated into the model. Depth class #5 is therefore an adjusted version of Depth class #3 where the geology is represented by Day et al. (1998) . Depth class #6 occurs where Scott and Bonk (1984) mapped bedrock and Day et al. (1998) mapped deep alluvium. A compromise for this depth class was chosen as 3-6 m. The soil depth classes were used to estimate soil depths based on calculated slope and an empirical soil-depth model (modeled soil depth, in meters). This model is based on an assumed soil depth – slope correlation within the soil depth classes defined for the 1996 version of the net infiltration model (Flint et al., 1996). The conceptual soil depth model for depth class 1 assumes that soils are thinnest at summit and ridge-crest areas as well as steep side slopes. Deeper soils are assumed to occur at the relatively gently sloping shoulder areas that define the transition between summit or ridge crest areas and steep side slope areas. Deeper soils are also assumed to occur for more gently sloping foot-slope locations. The model for soil depth class 1 is defined by:

$$D = 0.03 * S + 0.1, \quad S \leq 10$$
$$D = 0.013 * (10 - S) + 0.4, \quad 10 < S < 40$$
$$D = 0.01, \quad S \geq 40$$

where D = soil depth (in meters), and S = slope (degrees). The model for depth class #2 is defined by:

$$D = 2 - (0.05 * S), \quad S < 32$$
$$D = 0.4, \quad S \geq 32$$

and the model for depth class # 3 is defined by:

$$D = 6 - (0.16 * S), \quad S \leq 25$$
$$D = 2.0$$

For depth class #4, soil depth is set to a uniform depth of 6 meters.

Rock-type identifier defines the rock type for each grid cell so that the corresponding bulk bedrock permeability can be found in the look up table shown in Table A1-5. Bedrock geology was defined for each grid element using three ARCINFO map coverages and a vector to raster conversion performed by ARCINFO. The three maps used for the bedrock determinations are the 1:6000 scale Bedrock Geologic Map of the Central block area by Day et al. (1998), the Preliminary Geologic Map of Yucca Mountain by Scott and Bonk (1984), and the Geologic Map of the Topopah Spring Northwest Quadrangle by Sawyer et al. (1995) . Within the UZ flow and transport model area, bedrock geology for the net infiltration model (which is defined as a unique integer identifier for each rock-type in the geospatial parameter input file) is primarily defined by Day et al. (1998). Bedrock geology for the northern and southern perimeter sections of the UZ flow and transport model area is defined by Scott and Bonk (1984). Bedrock geology is represented in the geospatial parameter input file using a unique integer identifier for each rock-type. The identifier is linked to a bulk (field-scale) saturated permeability in the model control file (represented in GeoK.xls). Multiple rock-types can be assigned the same bulk permeability value in the model control file.

Topographic position is indicated by values ranging from 1 to 4, corresponding to the classification ridgetop, sideslope, alluvial terrace, and channel discussed in Section 6.1.2 of USGS (2001. This

information was used in INFIL V1.0 to identify channel locations, but as routing is done in version 2.0 this parameter is not used. It is however maintained as a placeholder.

The 36 blocking ridge angles (degrees inclination above horizontal) are calculated at each 10-degree horizontal arc (with the azimuth aligned in the UTM northing direction) for each grid cell using the routine BLOCKR7. Calculations were performed using the DEM as input and a technique for approximating the 10-degree horizontal angles based on grid cell distances. The blocking ridge parameters cannot account for topographic influences outside of the DEM, and thus the blocking ridge effect is only partly accounted for along the perimeter of the DEM.

Part 2: Geologic unit identifier and associated bulk bedrock saturated hydraulic conductivity
The second part of the data set is the lookup table providing properties for each grid. It consists of a spreadsheet called GeoK.xls and consists of rock-type identifier, source, geologic description, hydrogeologic identifier, and bulk bedrock saturated hydraulic conductivity (Table A1-5). The geologic identifier in the first column is a value that allows each grid cell to use this file as a lookup table to identify rock type. The source is the map the rock type was taken from using ARCINFO coverages. The next two columns are geologic descriptions extracted from the sources that, when combined with map location, allow for the interpretation of corresponding lithostratigraphic unit shown in the next column which is represented by nomenclature from Buesch et al. (1996). The determination of corresponding lithostratigraphic unit is typically straightforward based on description. The column with corresponding hydrogeologic unit is based on Flint (1998 Table 1 and DTN: GS000308312231.002) and incorporates data from analyses of samples of most of the rock types for saturated hydraulic conductivity (DTN: GS000308312231.002). Saturated hydraulic conductivity (K_s) on individual core samples was determined on subsamples from several boreholes (DTN: GS990408312231.001, GS960808312231.001, GS960808312231.005). Cores were vacuum saturated, and K_s was measured using a steady-state permeameter that forces water through the core at a measured pressure while weighing the outflow over time. K_s was calculated using Darcy's law. Mean values of saturated hydraulic conductivity for each hydrogeologic unit were determined by using a geometric mean calculation (DTN: GS000308312231.002). The bulk bedrock hydraulic conductivity represents the combined matrix and fracture saturated hydraulic conductivity of each rock-type. Bulk bedrock hydraulic conductivity was calculated using measured saturated hydraulic conductivity of fracture fill material. A value of 43.2 mm/day was selected and used as a preliminary value. However, a value of 46.7 mm/day is the average value calculated from all measurements in DTN: GS950708312211.003, Fracture/Fault Properties For Fast Pathways Model; the difference in calculated bulk hydraulic conductivity between these values is insignificant and results in bulk hydraulic conductivities that are less than 1% different. Additional values used to calculate bulk bedrock hydraulic conductivity included an estimate of the percent area occupied by 250 micron fractures (the assumption of this size fracture is discussed in Flint et al., 1996) and the mean saturated hydraulic conductivity of the bedrock matrix for that rock type (Flint, 1998, Table 7; DTN: GS000308312231.002). The percent area occupied by fractures of 250-microns aperture is equal to 250 microns divided by 1,000,000 microns per meter, multiplied by the fracture densities in fractures per meter. The fracture densities for each rock type that were used to calculate the bulk bedrock hydraulic conductivities were estimated from field observations and, subsequently, were corroborated by the fracture density data from boreholes NRG-4, NRG-5, NRG-6, NRG-7, SD-9 and SD-12 reported in Altman et al. (1996, Table 3-6, DTN: SNSAND96081900.000).

For the development of hydrogeologic units, the data originally collected from laboratory measurements on all samples from 31 surface-based boreholes drilled from 1995 through 1997, were analyzed and data

were submitted in the following data packages: DTN: GS920508312231.012, GS930108312231.006, GS940408312231.004, GS000408312231.004, GS940508312231.006, GS950408312231.004, GS950408312231.005, GS951108312231.009, GS951108312231.011, GS951108312231.010, GS950308312231.002, GS960808312231.004, GS960808312231.001, GS950608312231.008, GS960808312231.005, GS960808312231.003, GS000308312231.001, GS000308312231.002, GS990408312231.001, GS000408312231.003, GS000508312231.005, and GS000508312231.006.

Outliers and inappropriate data have been removed to allow for a better representation of the hydrogeologic units. Physical properties of bulk density, porosity, and particle density; flow properties of saturated hydraulic conductivity and moisture-retention characteristics; and the state variables (variables describing the current state of field conditions) of saturation and water potential were determined for each unit. Units were defined using the data base of physical and hydrologic properties, described lithostratigraphic boundaries and corresponding relations to porosity, recognition of transition zones with pronounced changes in properties over short vertical distances, characterization of the influence of mineral alteration on hydrologic properties such as permeability and moisture-retention characteristics, and a statistical analysis to evaluate where boundaries should be adjusted to minimize the variance within layers.

Part 3: Properties for 10 soil units

The properties in Table A1-6 represent soils located around Yucca Mountain, Nevada. These are measured and calculated properties. Measured properties are bulk density, porosity, and rock fragment content. Saturated hydraulic conductivity, moisture retention curve fit parameters alpha and n, water content at –0.1 bar water potential, and water content at –60 bars water potential were estimated using empirical equations from Campbell (1985). Bulk density, porosity, and rock fragment content were measured using laboratory analyses described in Flint and others (1996, p. 41). The source data for these measured properties were submitted under the following DTNs:

GS950708312211.002 - "FY94 and FY95 Laboratory Measurements of Physical Properties of Surficial Materials at Yucca Mountain, Nevada."

GS960108312211.001 - "FY95 Lab Measurements of Physical Properties of Surficial Material, at Yucca Mountain, NV PART II"

GS960108312211.002 - "Gravimetric and Volumetric Water Content and Rock Fragment Content of 31 Selected Sites at Yucca Mountain, NV: FY95 Laboratory Measurements of Physical Properties of Surficial Material at Yucca Mountain, Part III"

Field and laboratory analyses were conducted on the soils around Yucca Mountain. Large-volume, field bulk-density samples were collected from the surface to 0.3 m by using an irregular-hole, bulk-density device called a bead cone. Bulk density, porosity, rock fragment content, and sand, silt, and clay percentages were determined. Saturated hydraulic conductivity was measured using a double-ring infiltrometer on soils in locations where it could be measured and then compared to conductivity simulated using textural data for the fine-soil fraction (<2 mm) by using Equation 6.12 of Campbell (1985). Log-log water-characteristic curves were determined using Equations 2.15, 2.16, 2.17, 2.18, 5.10, and 5.11 of Campbell (1985) and were converted to van Genuchten curves in Excel. Soil-water contents at -0.1 bar and -60 bars water potential were used as field capacity and residual water content, the difference of which is plant available water content. The soil properties are summarized in Table

A1-6, where the parameters defining the van Genuchten curves (conductivity, alpha, and n) are simulated from texture, rock fragment content, and bulk density measured in the field. Also listed in Table A1-6 are the soil-water contents corresponding to -0.1 and -60 bars water potential for each soil type, calculated using the fitted water-retention van Genuchten curve for each soil type.

To test the validity of using textural analysis as a surrogate for measurements of soil properties, field-measured hydraulic conductivities were compared with the geometric-mean particle diameter using a method discussed in Campbell (1985, eq. 2.15) and with the model predictions of hydraulic properties made using Campbell (1985, eqs. 5.10 and 5.11), which is developed for <2-mm particle sizes. The results indicated an adequate correlation to use textural data for particle sizes < 0.3 mm; however, the presence of rock fragments has a substantial effect on soil properties. To account for the presence of rock fragments, the log of simulated hydraulic conductivity from Campbell (1985) and the gravimetric rock-fragment content were regressed against the log of the measured values of hydraulic conductivity to produce a modified Campbell equation with an r^2 of 0.85. The equation was then applied to each unit in Table A1-6 to determine the saturated hydraulic conductivity. This analysis assumes that textural changes with depth are insignificant and that properties determined from textural sampling from the top 0.3 m of soil represents the entire soil profile. A large percentage of the surficial deposits in the study area are < 0.5 m deep (Flint et al., 1996, Figure 13) and the application of these data for these shallow soils is considered appropriate.

Textural data also were used for the calculation of moisture-retention curves for the surficial soils using Campbell (1985). Six moisture-retention curves were measured in the laboratory on soil units 1, 2, and 4 using tempe cells, pressure pots, and chilled-mirror psychrometers to measure water potential over a full range of saturations (Flint et al., 1996, Figures 16A, 16B, and 16C). Curves were fit to the combined data sets for each soil unit. Curves calculated from the average textural data for the soil units are very similar to the curves from the measured data for the three units. It was considered, therefore, that texture could be used to calculate curves and associated parameters for the remaining five soil units, and all curves are illustrated in Flint et al. (1996, Figure 16D). These parameters are those listed in Table A1-6.

Table A1-3. Description of columns in output files with geospatial input for INFIL V2.0.

Column	Description
1	Grid cell identifier number
2	UTM easting (m)
3	UTM northing (m)
4	Latitude (decimal degrees)
5	Longitude (decimal degrees)
6	Grid cell row index
7	Grid cell column index
8	Downstream grid cell identifier number (used for surface water routing)
9	Number of upstream grid cells
10	Elevation (m)
11	Slope (degrees inclination from horizontal)
12	Aspect (degrees azimuth from the UTM northing axis, in the horizontal plane)
13	Soil type identifier

Column	Description
14	Depth class identifier
15	Modeled soil depth (m)
16	Rock type identifier
17	Topographic position
18	1st of 36 blocking ridge angles (inclination above horizontal, decimal degrees)
54	Last of 36 blocking ridge angles

Table A1-4. Example of output found in files used as geospatial input for INFIL V2.0. (DTN: GS000308311221.004)

Grid cell identifier	UTM Easting (m)	UTM Northing (m)	Latitude (degrees)	Longitude (degrees)	Grid cell row index	Grid cell column index	Downstream grid cell identifier	Number of upstream grid cells	Elevation (m)
59985	545681	4076613	36.8361	116.4877	375	35	-3	0	1393
60288	545681	4076583	36.8359	116.4877	376	35	62707	0	1392
60879	545681	4076553	36.8356	116.4877	377	35	63010	0	1390
61172	545711	4076613	36.8361	116.4874	375	36	-3	0	1389
61179	545681	4076523	36.8353	116.4877	378	35	63573	0	1389
61794	545651	4076613	36.8361	116.488	375	34	-3	0	1387
61795	545711	4076583	36.8359	116.4874	376	36	-3	0	1387
62076	545711	4076553	36.8356	116.4874	377	36	-3	0	1386
62077	545681	4076493	36.835	116.4877	379	35	65103	0	1386
62706	545651	4076583	36.8359	116.488	376	34	-3	1	1384

(Beginning with "Slope", columns continued)

Grid cell identifier	Slope (degrees inclination from horizontal)	Aspect (degrees from northing)	Soil type identifier	Depth class identifier	Modeled soil depth (m)	Rock type identifier	Topographic position	Blocking ridge angle 1	Blocking ridge angle 2
59985	9	197	5	1	0.48	17	4	2	1
60288	9	199	5	1	0.48	17	4	2	1
60879	8	201	5	1	0.46	17	5	2	1
61172	10	109	5	1	0.5	17	4	2	1
61179	8	196	5	1	0.46	17	5	2	1
61794	20	259	5	1	0.33	18	4	3	5
61795	10	108	5	1	0.5	17	4	2	1
62076	10	108	5	1	0.5	17	4	2	1
62077	9	193	5	1	0.48	17	4	2	1
62706	19	259	5	1	0.35	18	4	5	9

Table A1-5. Example from lookup table in INFIL V2.0 providing properties for each grid block, consisting of rock-type identifier, source, geologic description (formation and lithology), corresponding lithostratigraphic unit and hydrogeologic identifier, and estimated fracture density and bulk bedrock saturated hydraulic conductivity based on filled 250-um fractures.[F/m, fractures per meter; mm/d, millimeters per day.] (DTN: GS000308311221.004)

Geologic Identifier	Source	Geologic descriptions from sources		Corres-ponding lithostrati-graphic unit	Corres-ponding hydro-geologic unit	Estimated Fracture density (F/m)	Bulk Bedrock Saturated Hydraulic Conductivity w/filled 250-um fractures (mm/d)
		Formation	Lithology				
2	Scott and Bonk (1984)	Rhyolite of Pinnacles Ridge	Lava flows	Tptrv1	TC	25.0	0.41
3	Scott and Bonk (1984)	Rhyolite of Pinnacles Ridge	Pyroclastic	Tpbt2	BT3	0.5	46.66
4	Scott and Bonk (1984)	Rhyolite of Comb Peak	Lava flows	Tpcpll	CW	7.0	0.09
5	Scott and Bonk (1984)	Rhyolite of Comb Peak	Pyroclastic	Tpbt3	BT3	0.5	46.66
6	Scott and Bonk (1984)	Rhyolite of Vent Pass	Lava flows	Tptrv1	TC	25.0	0.41
7	Scott and Bonk (1984)	Rhyolite of Vent Pass	Pyroclastic	Tpbt3	BT3	0.5	46.66
8	Scott and Bonk (1984)	Rhyolite of Black Glass Canyon	Lava flows	Tpcpll	CW	7.0	0.09
9	Scott and Bonk (1984)	Rhyolite of Black Glass Canyon	Pyroclastic	Tpbt3	BT3	0.5	46.66
10	Scott and Bonk (1984)	Basalt Dikes of Yucca Mountain	Welded	Tpcplnc	CW	7.0	0.09

Table A1-6. Summary of soil properties used as input for INFIL V2.0.
[m/s, meters per second; Pa, pascals; %, percent; g/cm3, grams per cubic centimeter; ------, not applicable] (DTN: GS000308311221.004)

Soil unit	Saturated hydraulic conductivity (simulated, m/s)	alpha (1/Pa)	n	Porosity (%)	Rock fragments (%)	Bulk Density (g/cm3)	Water content at -0.1 bar water potential (%)	Water content at -60 bars water potential (%)
1	5.6×10^{-6}	0.00052	1.24	36.6	10.5	1.60	24.2	5.4
2	1.2×10^{-5}	0.00062	1.31	31.5	11.6	1.73	17.3	2.3
3	1.3×10^{-5}	0.00066	1.36	32.5	18.7	1.70	16.3	1.7
4	3.8×10^{-5}	0.00087	1.62	28.1	21.9	1.81	7.3	0.2
5	6.7×10^{-6}	0.00056	1.28	33.0	15.2	1.69	20.0	3.5
6	2.7×10^{-5}	0.00074	1.40	33.9	11.7	1.66	15.0	1.1
7	5.6×10^{-6}	0.00055	1.26	37.0	17.1	1.58	23.4	4.6
9	5.7×10^{-6}	0.00055	1.30	32.2	19.1	1.72	18.9	2.8

APPENDIX 2. INSTALLATION AND VALIDATION TEST RESULTS FOR INFIL V2.0

Table A2-1. Installation Test Results for INFILV2.0

Documentation of results of execution of the ITP.

Evaluation Tests	Criteria	Met Criteria	Did Not Meet Criteria	Description of Failure
Pre-Installation Test	hard disk size appropriate	Yes		
	CD-ROM available	Yes		
	File transfer system operational	Yes		
	command prompt available	Yes		
	keyboard input accepted	Yes		
Installation Test	files transferred from CD-ROM to hard disk	Yes		
	3 primary output files are produced when infilv2.exe is executed (ITP, Table 1)	Yes		
	18 secondary files are produced when infilv2.exe is executed (ITP, Table 1)	Yes		
	output file ltest3.out matches Table 2	Yes		

Table A2-2. Validation Test Results for INFILV2.0

Test output files commonly are in Notepad. The author has provided those files, and created EXCEL files for the Notepad files used in validation test cases. Supporting information and calculations are provided as an attachment. Examples of the Model Control File (MCF), Geospatial Input file T1.w20, and output files are provided in the attachment to this appendix. Successful results for the validation test steps are indicated by check marks in the "Pass" column. The complete success of all test steps is verified by the signature of the Validation Tester, Jennifer Curtis, as shown on this page.

Test Case	Criteria Description	VTP Test Step	Pass	Fail
Test 0A: Validation of Mod3-ppt.dat Daily Climate Input Format				
0A.1	On successful execution of the program, the following output files have been created: (1) Test0a.1, Test0a.2, Test0a.3, Test0a.3, Test0a.4, Test0a.5, Test0a.6, Test0a.7, Test0a.8, Test0a.9, Test0a.10, Test0a.11, Test0a.12, Test0a.13, Test0a.14, Test0a.15, and Test0a.16. (2) Test0a.v21, Test0a.v22, Test0a.v23, Test0a.v24, Test0a.v25, and Test0a.v26. (RD requirements 1, 13, 14, 15, 16)	(1) Program output, the yearfile.txt file, verifies this activity; (2) Program output, the Test 0a.v23 verifies this and other output of all "v" files.	✓ ✓	
0A.2	The output in the daily water balance output file Test0a.v21 indicates daily water balance results, with each line of output corresponding to the daily time sequence provided by the input file mod3-ppt.dat. The total number of days indicated by the output in Test0a.v21 is 5753. (RD requirements 1, 7, 8, 13)	Review files Test0a.v21 and mod3-ppt.dat.	✓	
0A.3	The output in Test0a.v21 indicates daily variability in air temperature and potential evapotranspiration, as a function of the day-of-year number for each year of the simulation. (RD requirements 1, 3)	Review file Test0a.v21.	✓	
0A.4	(1) The output in the secondary output file Test0a.v26 indicates variable node elevations, soil type, soil depth, and rock type. The set of model nodes are ordered by elevation, with the highest elevation node listed first and the lowest elevation node listed last. (2) The thickness of the root zone layers for each node are defined as a function of soil depth and input parameters in the model control file, as documented in USGS (2001). (3) The soil and rock properties listed for the root zone layers for each node are consistent with the soil and rock parameters defined in the model control file. (4) The root-zone effective water storage capacity (porosity – wilting point) for all layers at all nodes is dependent on the layer thickness and the soil properties at all nodes. (RD requirements 1, 2, 16)	1.) Review output file to verify. 2.) Verify by review of Section 6.7.1-6.7.3 of the AMR, MCF, and Attachment A2-1, Item 2. 3.) Verify by comparison of MCF and T1w.20 file 4.) Review Infilv2.for file for calculation. See Attachment A2-1, Common parameters and definitions.	✓ ✓ ✓ ✓	
0A.5	The output in the summary output file Test0a.v23 provides a listing of the input and output file names specified in the model control file, along with a listing of annual results for each year simulated and average annual rates for the full simulation period. The total number of years listed in Test0a.v23 is 16. (RD requirements 1, 14)	Review Test0a.v23 file Note: The output file for the Annual mass balance map is inadvertently shown as file test0a.1.; the file should be test0a.v25 for all test sequences.	✓	

[illegible] for Jennifer Curtis — April 6, 2001

Signature — Date

Test Case	Criteria Description	VTP Test Step	Pass	Fail
0A.6	(1.) The output in the average annual map file Test0a.v24 corresponds to average annual rates for all water balance terms at all active model nodes defined in the geospatial parameter input file T1.w20. Note: The boundary nodes identified by -3 in the T1.w20 file are not active nodes and are not included in the 0a.v24 file. (2) The format for Test0a.v24 is correct according to input format requirements for the post-processing routine MAPADD20.exe, as documented in USGS (2001). (RD requirement 1, 15)	1.) Review test0a.v24 and T1.w20 files. 2.) Compare Test0a.v24 with Test0d.v24 used as input to input to test with Mapadd20 to ensure comparable format. See Attachment A2-1, Item (4) to confirm successful MAPPADD20 output.	✓ ✓	
0A.7	All Output terms in the average annual map file Test0a.v24 are non-uniform, with the exception of the snowfall, snow-cover, snowmelt, and sublimation terms (these are all 0). (RD requirements 1, 4, 15)	Review test0a.24 file.	✓	
0A.8	(1) The results for the three primary output files (Test0a.v21, Test0a.v23, Test0a.v24) are consistent. For example, the average annual net infiltration rate calculated from the results in the daily output file is equal (to the nearest 0.01 mm) to the spatially averaged net infiltration rate calculated from the average annual map file. (2)The spatial and temporal averages calculated from the results in Test0a.v21 and Test0a.v24 are equal (to the nearest 0.01 mm) to the results provided in the summary output file Test0a.v23 (RD req. 7, 13, 14, 15)	(1) Review output files. (See examples of the calculated averages of parameters in .v24 that confirms comparison with .v23.) (2) Calculate parameter average(s) for year from .v21 and compare (See Attachment A2-1, Item 5)	✓ ✓	
0A.9	The absolute values of the program calculated volume balance terms in the daily output file (mass balance, mass balance 2) do not exceed 1E-8 for any day simulated (RD req. 7, 13)	A hand-calculation check of the results in Test0a.v21 shows that the solutions to both 1 and 2 of the RD have absolute values no greater than 1E-8 for any day simulated	✓	
0A.10	The absolute values of the program calculated volume balance terms in the average annual map file Test0a.v24 (mass-balance, max-balance, mass-balance #2) do not exceed 1E-8 for any model node. (RD req. 7, 15)	Review file.	✓	
0A.11	The absolute value of the program calculated volume balance term in the annual summary file Test0a.v23 (mass-balance) does not exceed 1E-5 for any year simulated (RD requirements 7, 14)	Review file.	✓	
0A.12	(1) For day 5549 of the simulation (day 70 of year 1995) the daily water balance map file Test0a.v22 is consistent with the results in the daily output file Test0a.v21 in terms of precipitation, net infiltration, runoff, and run-on. The average daily precipitation, net infiltration, runoff, and run-on terms in the daily output file must agree (to within 0.0001 mm) with the results calculated using the output from the daily water balance map file. (2) For the results included in the daily water balance map file, the water content of any layer cannot exceed the absolute water storage capacity of that layer (layer porosity times layer thickness). (3) The net infiltration rate at any node cannot exceed the bulk saturated hydraulic conductivity at the base of the root zone. (RD req. 1, 2, 7, 8, 10, 11, 13, 16)	1.) Review and compare files test 0a.v22 and Test0a.v21. See Attachment A2-1, Item 6.. 2.) Review file Test0a.v22. Refer to file test0a.v26 to compare soilmm with scapmm See Attachment A2-1, Common parameters to calculate scapmm. 3.) Compare rocktype imbibe (ksat) (Test0a.v26) to net infil. (Test0a.v22).	✓ ✓ ✓	
Test 0B: Validation of 4JA.S01 Daily Climate Input Format				
0B.1	On successful execution of the program, the following output files have been created: Test0b.1, Test0b.2, Test0b.3, Test0b.4, Test0b.5, Test0b.6, Test0b.7, Test0b.8, Test0b.9, Test0b.10, Test0b.v21, Test0b.v22, Test0b.v23, Test0b.v24, Test0b.v25, and Test0b.v26. (RD requirements 1, 13, 14, 15, 16)	(1) Program output, the yearfile.txt file, verifies this activity; (2) Program output, the Test 0b.v23 verifies this and other output of all "v" files.	✓ ✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
0B.2.	The output in the daily water balance output file Test0b.v21 indicates daily water balance results, with each line of output corresponding to the daily time sequence provided by the input file 4jas01. The total number of days indicated by the output in Test0a.v21 is 36524. (RD requirements 1, 7, 8, 13)	Review files Test0b.v21 and 4jas01. See Attachment A2-1, Item 7, for examples to verify daily time sequence function.	✓	
0B.3.	The output in the summary output file (Test0b.v23) provides a listing of the input and output file names specified in the model control file, along with a listing of annual results for the 100 years simulated and average annual rates for the full simulation period (RD requirement 9).	Review file Test0b.v23	✓	
0B.4.	The output in the average annual map file (Test0b.v24) corresponds to average annual rates for all water balance terms at all active model nodes defined in the geospatial parameter input file T1.w20. All Output terms in the average annual map file (Test0b.v24) are non-uniform (the values vary from node to node), with the exception of the snowfall, snowmelt, and sublimation terms (these are all 0). (RD requirements 1, 4, 15)	Review Test0b.v24 and T1.w20 files to compare. Note: The boundary nodes identified by -3 in the T1.w20 file are not active nodes and are not included in the 0a.v24 file.	✓	
0B.5.	The average annual run-on term shows a general increase in magnitude from higher elevation to lower elevation model nodes (RD req. 1, 11, 15)	Review/compare file Test0b.v24 and Test0b.v26. See Attachment A2-1, Item 8.	✓	
0B.6.	The absolute values of the program calculated volume balance terms in the daily output file (mass balance, mass balance 2) do not exceed 1E-8 for any day simulated (RD req. 7, 13)	Review file..	✓	
0B.7.	The absolute values of the program calculated volume balance terms in the average annual map file Test0b.v24 (mass-balance, max-balance, mass-balance #2) do not exceed 1E-8 for any model node. (RD req. 7, 15)	A hand-calculation check of the results in Test0b.v24 shows that the solution to equations 1 of the RD has an absolute value no greater than 1E-4 for any model node.	✓	
0B.8.	The absolute value of the program calculated volume balance term in the annual summary file Test0b.v23 (mass-balance) does not exceed 1E-5 for any year simulated (RD requirements 7, 14)	Review file.	✓	
Test 0C: Validation of Rosalia.inp Daily Climate Input Format				
0C.1.	On successful execution of the program, the following output files have been created: Test0c.1, Test0c.2, Test0c.3, Test0c.3, Test0c.4, Test0c.5, Test0c.6, Test0c.7, Test0c.8, Test0c.9, Test0c.v21, Test0c1.v22, Test0c2.v22, Test0c3.v22, Test0c4.v22, Test0c.v23, Test0c.v24, Test0c.v25, and Test0c.v26. (RD requirements 1, 13, 14, 15, 16)	(1) Program output, the yearfile.txt file, verifies this activity; (2) Program output, the Test 0c.v23 verifies this and other output of all "v" files.	✓ ✓	
0C.2.	The output in the daily water balance output file Test0c.v21 indicates daily water balance results, with each line of output corresponding to the daily time sequence provided by the input file Rosalia.inp. The total number of days indicated by the output in Test0a.v21 is 16070. (RD requirements 1, 7, 8, 13)	Review files Test0c.v21 and Rosalia.inp.	✓	
0C.3.	The output in the summary output file (Test0c.v23) provides a listing of the input and output file names specified in the model control file, along with a listing of annual results for the all years simulated and average annual rates for the full simulation period. Missing years are not included in the annual results. (RD requirement 9)	Review Test0c.v23 file.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
0C.4.	The output in the average annual map file (Test0c.v24) corresponds to average annual rates for all water balance terms at all active model nodes defined in the geospatial parameter input file T1.w20. Output terms in the average annual map file are non-uniform (results indicate variability from node to node), including the snowfall, snow-melt, and sublimation terms. (RD requirements 1, 4, 5, 15). Note: The boundary nodes identified by -3 in the T1.w20 file are not active nodes and are not included in the 0c.v24 file.	Review test0c.v24 and T1.w20 files.	✓	
0C.5.	The average annual run-on term shows a general increase in magnitude from higher elevation to lower elevation model nodes (RD req. 1, 11, 15)	Review/compare file Test0c.v24 and Test0c.v26.	✓	
0C.6.	The absolute values of the program calculated volume balance terms in the daily output file (mass balance, mass balance 2) do not exceed 1E-8 for any day simulated	Review file.	✓	
0C.7.	The absolute values of the program calculated volume balance terms in the average annual map file Test0b.v24 (mass-balance, max-balance, mass-balance #2) do not exceed 1E-8 for any model node	Review file.	✓	
0C.8.	The absolute value of the program calculated volume balance term in the annual summary file Test0c.v23 (mass-balance) does not exceed 1E-5 for any year simulated (RD requirements 7, 14)	Review file.	✓	
0C.9.	For all days of the simulation where precipitation occurred and the average daily air temperature was < 0 degrees C, some percentage of the total precipitation occurred as snow (RD requirements 4, 5, 13)	Review file.test0c.v21.	✓	
0C.10.	(1) The output in the secondary output file Test0c.v26 indicates the thickness of the root zone layers for each node are defined as a function of soil depth and input parameters in the model control file, as documented in USGS (2001). (2) The soil and rock properties listed for the root zone layers for each node are consistent with the soil and rock parameters defined in the model control file. For example, layer 1 thickness (top layer of root zone) does not exceed RDEPTH1, and layer 4 thickness (bedrock layer of root zone) does not exceed RDEPTH4. (3) The root-zone effective water storage capacity (porosity – wilting point) for all layers at all nodes is dependent on the layer thickness and the soil properties at all nodes. (RD requirements 1, 2, 16)	1.) Review output file to verify. 2.) Verify by comparison of MCF, Test0c.v26, and T1w.20 file. See Attachment A2-1, Item 2. 3.) Review Infilv2.for file for calculation.	✓ ✓ ✓	
0C.11.	For day 406 of the simulation (day 41 of year 1952) the daily water balance map file Test0c1.v22 is consistent with the results in the daily output file Test0c.v21 in terms of precipitation, net infiltration, runoff, and run-on. For example, for day 406, precipitation is 0, but snow-melt is occurring. The root zone layers are close to full saturation at some nodes , and thus runoff is being generated at some nodes.	Review Test0c.v21 and Test0c.v22 files. See Attachment A2-1, Common parameters. Use spreadsheet functions to check for averages for test0c.v22 file parameters (example calculations included in Attachment A2-1, Item 9).	✓	
0C.12.	The average daily net infiltration, runoff, and run-on terms in the daily output file Test0c.v21 must agree (to within 0.0001 mm) with the results calculated using the output from the daily water balance map file for day 406 (Test0c1.v22). (Test0c1.v22 is brought into a spreadsheet, and the results for all nodes are averaged (the columns are averaged). These results must be in agreement with the results for day 406 in the output file test0c.v21.)	Review Test0c1.v21 and .v22 files. See Attachment A2-1, Conversions to convert from mm/day to cfs.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
0C.13.	(1) For the results included in the daily water balance map file, the water content of any layer cannot exceed the absolute water storage capacity of that layer (layer porosity times layer thickness, in mm, as evaluated by the output provided in test0c.v26). (2) The net infiltration rate at any node cannot exceed the bulk saturated hydraulic conductivity at the base of the root zone. (RD req. 1, 2, 7, 8, 10, 11, 13, 16)	1.) Review scapmm (1through4) from test0c.v26 file and soilmm (1 through 4) from test0c.v22 file. 2.) Compare imbibe (ksat) from .v26 with infilmm from file .v22.	✓ ✓	
Test 0D: Validation of the Average Annual Map Output File Format for Post-Processing Application using the Software Routine MAPADD20				
0D.1.	On successful execution of the program for all three test runs, the following output files have been created: Test0d1.1, Test0d1.2, Test0d1.3, Test0d1.3, Test0d1.4, Test0d1.5, Test0d1.6, Test0d1.v21, Test0d1.v22, Test0d1.v23, Test0d1.v24, Test0d1.v25, Test0d1.v26, Test0d2.1, Test0d2.2, Test0d2.3, Test0d2.3, Test0d2.4, Test0d2.5, Test0d2.6, Test0d2.v21, Test0d2.v22, Test0d2.v23, Test0d2.v24, Test0d2.v25, Test0d2.v26, Test0d3.1, Test0d3.2, Test0d3.3, Test0d3.3, Test0d3.4, Test0d3.5, Test0d3.6, Test0d3.v21, Test0d3.v22, Test0d3.v23, Test0d3.v24, Test0d3.v25, and Test0d3.v26. (RD requirement 1)	Review Test0d1, Test0d2, and Test0d3 folders to find program run output files "yearfile" and ".v23". Also can review folder contents to verify presence of all ".v" output files.	✓	
0D.2.	On execution of the post-processing routine MAPADD20 using the files Test0d1.v24, Test0d2.v24, and Test0d3.v24 as input, the output files Test0d.dat, Test0d.err, Test0d.out, and Test0d.sum are generated. (RD requirement 6)	Review the three Test0d ".v24" files and compare to the post-processing Test0d.dat file. Review other post processing output files.	✓	
0D.3.	The results in the summary output file Test0d.sum indicate an average precipitation rate of approximately 517.3 mm/year, an average net infiltration rate of approximately 20.2 mm/year, and an average runoff rate of approximately 32.5 mm/year.	Review file.	✓	
0D.4.	The main output file Test0d.dat lists results for a total of 1574 model nodes (each line of output corresponds to results for a single model node, with the exception of the first line of output which is the header line).	Review the three Test0d ".v24" files and compare to the post-processing Test0d.dat	✓	
0D.5.	The main output file Test0d.dat indicates results that are in agreement with the results in the summary file Test0d.sum. For example, the average precipitation rate across all 1574 model nodes is approximately 517.3 mm/year, the maximum precipitation rate across all model nodes is approximately 548.9 mm/year, and the minimum precipitation rate across all model nodes is 494.1 mm/year.	Review file.	✓	
0D.6.	The second line of output in the file Test0d.dat (first line below the header) corresponds to the second line of output in test0d1.v24. Line 805 in the file Test0d.dat corresponds to the second line of output in test0d2.v24. . Line 1227 in the file Test0d.dat corresponds to the second line of output in test0d3.v24.	Review files. See Attachment A2-1, Item 10 for comparison.	✓	
Test 1A: Basic Water Volume Balance Check				
1A.1.	The following output files have been generated by the code (1) test1a.1, teat1a.2, test1a.3, test1a.3, test1a.4, test1a.5, test1a.6, test1a.7, test1a.8, test1a.9, test1a.10, test1a.11, test1a.12, test1a.13, test1a.14, test1a.15, test1a.16, (2) test1a.v21, test1a.v22, test1a.v23, test1a.v24, test1a.v25, and test1a.v26. (RD requirements 13, 14, 15, 16)	(1) The yearfile.text program output file verifies this. (2) Test1a.v23 output file verifies output of all ".v" files.	✓ ✓	
1A.2.	The output in the daily output file test1a.v21 indicates daily results (each line of output in the file corresponds to the daily time sequence provided by the input file mod3-ppt.dat) and all results are 0. (RD requirements 7, 13)	Review files.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
1A.3.	The output in the summary output file test1a.v23 provides a listing of annual results and average annual rates, and all results are 0. (RD requirements 7, 14).	Review file	✓	
1A.4.	(1) The output in the average annual map file test1a.v24 corresponds to average annual rates for all water balance terms at all active model nodes defined in the geospatial parameter input file T1.w20. (2) The format for test1a.v24 is correct according to input format requirements for the post-processing routine MAPADD20.exe, as documented in USGS (2001). All results in test1a.v24 are 0. (RD requirements 7, 15) Note: The boundary nodes identified by -3 in the T1.w20 file are not active nodes and are not included in the 0a.v24 file.	1.) Review test1a.v24 and T1.w20 files. 2.) Compare test1a.v24 with test0d.v24 used as input to test with Mapadd20 to ensure comparable format. See Attachment A2-1, Item 4 to confirm successful MAPPADD20 output.	✓ ✓	
1A.5.	All output terms in the daily map file Test1a.v22 for day 5549 (day 70, year 1995) are 0 except for the node x-y coordinates and the simulation day number. (RD req. 7, 16)	Review file.	✓	
1A.6	The output in the secondary output file Test1a.v26 indicates that the thickness of the root zone layers for each node is 0. The soil and rock properties listed for the root zone layers for each node are consistent with the soil and rock parameters defined in the model control file. The root-zone effective water storage capacity (porosity – wilting point) for all layers at all nodes is 0 because all layers have a thickness of 0. (RD requirements 1, 7, 16)	Review files. See Attachment A2-1, Item 1, for example of model control file.	✓	
Test 1B: Basic Water Volume Balance Check with Saturated Initial Conditions				
1B.1.	The following output files have been generated by the code: test1b.1, test1b.2, test1b.3, test1b.3, test1b.4, test1b.5, test1b.6, test1b.v21, test1b.v22, test1b.v23, test1b.v24, test1b.v25, and test1b.v26. (RD requirements 1, 13, 14, 15, 16)	1.) The yearfile.text program output file verifies this. 2.) Test1b.v23 output file verifies output of all ".v" files.	✓ ✓	
1B.2.	The absolute value of the average annual rates for the change in root zone water content, runoff, and run-on, in the summary output file Test1b.v23, the average annual map file Test1b.v24, and the daily output file Test1b.v21, are equal (to within 1E-5 mm/year). All other components of the water balance are 0 in all three output files (RD requirements 7, 13, 14, 15)	Review files.	✓	
1B.3.	Except for the first day of the simulation, all terms of the water balance are 0 for all 2192 days simulated. On the first day simulated, the absolute value of the change in root zone water content is equal to both the runoff and run-on terms (to within 1E-9 mm). (RD requirement 6, 7, 8)	Review file test1b.v24	✓	
1B.4.	(1) The daily map file Test1b.v22 indicates that runoff occurred on the first day of the simulation and was routed to downstream nodes. (2) The average runoff generated across all nodes is equal to the average run-on depth calculated based on the outflow from the model domain (to within 1E-9 mm). (RD requirements 6, 7, 8, 13, 16)	1.) Review file. 2.) Review files test1b.v21 and test1b.v22. See Attachment A2-1, Conversions to derive outflow from Test1b.v22 parameters.	✓ ✓	
1B.5.	(1) For all nodes with runoff greater than 0 in the daily map file Test1b.v22, the water content of layer 3 is equal to the total storage capacity of layer 3 for each node. (2) Only the third root zone layer has a water content greater than 0. (3) For all nodes with no runoff, the water content of layer 3 is less than the total storage capacity of layer 3. (Rd requirements 1, 2, 6, 7, 8, 16)	1.) Review files test1b.v22 and test1b.v26 for layer parameters. 2.) Review file test1b.v22 3.) Review file test1b.v22 See Test1b.v26 for scapmm, or Attachment A2-1, Common Parameters, for scapmm calculation.	✓ ✓ ✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
1B.6.	The average runoff and run-on terms calculated from the daily map file Test1b.v22 are equal to the average daily runoff and run-on terms for day 1 in the daily output file Test1b.v21 (to within 1E-9 mm). (RD requirements 7, 8, 13, 16)	See files Test1b.v22 and Test1b.v21. Use spreadsheet functions to calculate averages. (ave. values calculated using spreadsheet function shown to right of data.)	✓	
Test 1C: Basic Water Volume Balance Check with Saturated Initial Conditions				
1C.1.	The following output files have been generated by the code: test1c.1, test1c.2, test1c.3, test1c.3, test1c.4, test1c.5, test1c.6, test1c.v21, test1c1.v22, test1c2.v22, test1c3.v22, test1c4.v22, test1c.v23, test1c.v24, test1c.v25, and test1c.v26. (RD requirements 1, 13, 14, 15, 16)	1.) The yearfile.text program output file verifies this. 2.) Test1c.v23 output file verifies output of all ".v" files.	✓ ✓	
1C.2.	After the first day of the simulation, the average daily change in the root zone water content is equal to the daily net infiltration rate in the daily output file Test1c.v21 (to within 1E-9). (RD requirements 2, 6, 7, 8, 13)	Review file test1c.v21.	✓	
1C.3.	The net infiltration rate decreases throughout the simulation period (the maximum net infiltration rate occurs on the first day, the minimum net infiltration rates occurs on the last day). (RD requirement 2, 6, 7, 8, 13)	Review file test1c.v21	✓	
1C.4.	Although coupled surface water routing is enabled, runoff equals run-on on the first day of the simulation (to within 1E-8 mm) because the root zone profile is fully saturated (RD requirements 2, 6, 7, 8, 13)	Review file Test1c.v21	✓	
1C.5.	1) The daily map file for the first day of the simulation, Test1c1.v22, indicates a fully saturated root zone and net infiltration rates equal to the bulk saturated hydraulic conductivity at the bottom of the root zone for all model nodes (2) The water content for all root zone layers except for layer 1 is 0.(3) Runoff is generated at all nodes, and (4) the run-on term increases as node elevation decreases. (5) The total runoff generated equals the outflow from the model domain. (RD requirements 2, 6, 7, 8, 10, 16)	1.) This is evaluated by a comparison with the output provided in the root-zone parameter file, Test1c.v26. 2.) Review file test1c.v22 3.) Same as (2). 4.) Review files test1c.v22 and test1c.v26 5.) Review output file test1c.v23	✓ ✓ ✓ ✓ ✓	
1C.6.	1) The daily map file for the second day of the simulation, Test1c2.v22, indicates that runoff and run-on are not occurring. (2) The net infiltration rate at each node still equals the bulk saturated hydraulic conductivity. (3) The decrease in the root zone water contents from the first day to the second day of the simulation is equal to the net infiltration rate at each node. (RD requirements 2, 6, 7, 8, 10, 16)	Review files test1c2.v and test1c2.v22	✓	
1C.7.	1) The daily map file Test1c3.v22 for simulation day number 22 indicates that net infiltration is no longer occurring at some model nodes. (2) For these nodes the root zone water content equals the soil field capacity. (3) For all nodes where the root zone water content is greater than the soil field capacity, net infiltration is occurring and is equal to or less than the bulk saturated hydraulic conductivity (imbibe) at the bottom of the root zone. (RD requirements 2, 6, 7, 8, 10, 16)	1.) See file. 2.) See Test1c3.c22 and test1c.v26 files. 3.) Review test1c3.v22 and test1c.v26. See Attachment A2-1, Common Parameters.	✓ ✓ ✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
1C.8.	The daily map file Test1c4.v22 for the last day of the simulation (day number 2192) indicates that net infiltration has stopped at all nodes except for the bottom node at the mouth of the watershed model domain (the lowest elevation node). For all other nodes, the water content of the root zone is equal to the soil field capacity. The water content for the bottom node still exceeds the soil field capacity because this node has thicker soil and thus holds a larger volume of water in the root zone. (RD requirements 2, 6, 7, 8, 10, 16)	1.) See file. 2.) See Test1c3.c22 and test1c.v26 files.	✓ ✓	
Test 1D: Basic Water Volume Balance Check with Layered Root Zone				
1D.1.	The output in the secondary output file Test1d.v26 indicates that the thickness of root zone layers 1 and 2 is 0.1 meters for all nodes. The thickness for root zone layers 3 and 4 is variable and is dependent on soil depth. The thickness of root zone layer 4 is zero when soil depth is 0.5 meters or greater. The total thickness of the root zone is less than or equal to 0.5 meters for all nodes, except for the bottom node at the mouth of the watershed, which has a root zone thickness of 2 meters (RD requirements 1, 2, 7, 16)	Review test1d.v26 file.	✓	
1D.2.	The water storage capacity for the bedrock layer (layer 4) is 0 because the effective root zone porosity term for the bedrock layer (RKPOR) is 0. (RD requirements 1, 2, 16)	Review test1d.v26 file..	✓	
1D.3	All results in the daily output file Test1d.v21 are identical (to within 0.00001 mm/year) to the results in the daily output file for test 1c (Test1c.v21). (RD requirements 2, 6, 7, 8, 10, 13)	Review files	✓	
1D.4.	All results in the average annual map file Test1d.v24 are identical to the results in the average annual map file for test 1c (Test1c.v24). (RD requirements 2, 6, 7, 8, 10, 15)	Review files.	✓	
1D.5.	The daily map file for the first day of the simulation (Test1d1.v22) indicates that the net infiltration rate for day 1 at each node is equal to the bulk saturated hydraulic conductivity at the bottom of the root zone (based on comparison with the results in test1d.v26). (RD requirements 2, 6, 7, 8, 10, 16)	Review files.	✓	
1D.6.	The daily map file for the first day of the simulation (Test1d1.v22) indicates that the water content of all root zone layers in the soil profile at each node is equal to the porosity times layer thickness (in mm) at each node (the soil profile is fully saturated). (RD requirements 2, 6, 7, 8, 10, 13)	Review files 1d1.v22 and 1d.v26	✓	
1D.7.	The daily map file for the 22nd day of the simulation (Test1d3.v22) indicates that the water content of all root zone layers in the soil profile at nodes where net infiltration is 0 is equal to the soil field capacity times layer thickness (in mm). For nodes where net infiltration is greater than 0, the water content for each layer is greater than the field capacity water content but less than or equal to the full saturation water content (porosity times layer thickness). For nodes where net infiltration is greater than 0, the relative saturation of layer 2 is greater than or equal to the relative saturation of layer 1, and the relative saturation of layer 3 is greater than or equal to the relative saturation of layer 2 (RD requirements 2, 6, 7, 8, 10, 13)	Review file test1d.v22 and test1d.v26. See Attachment A2-1, Common Parameters and Item 11 for examples from test. Note: rkpor is user specified input variable which defines effective bedrock storage capacity	✓	
Test 1E: Basic Water Volume Balance Check with Layered Root Zone				
1E.1.	The output in the secondary output file Test1e.v26 indicates that the storage capacity for root zone layer 4 is greater than 0 (RD requirements 1, 2, 7, 16)	Review file. Not true for ia numbers 18 and 123.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
1E.2.	The results in the daily output file Test1e.v21 indicate that the absolute value in the change in the root zone water content, runoff, and run-on, for the first day of the simulation are all less than for the first day of the simulation in test1d. The net infiltration rate on the first day of the simulation is identical for the two test cases. (RD requirements 2, 6, 7, 8, 10, 13)	Review files test1e.v21 and test1d.v21.	✓	
1E.3.	The net infiltration rates in both the daily output file Test1e.v21 and the average annual map file Test1e.v24 are identical to the net infiltration rates obtained for test 1d. (RD requirements 2, 6, 7, 8, 10, 15)	Review test1e.v21, test1e.v24, test1d.v21, and test1d.v24 files.	✓	
1E.4.	The daily map file for the first day of the simulation (Test1e1.v22) indicates that the net infiltration rate for day 1 at each node is equal to the bulk saturated hydraulic conductivity (imbibe) at the bottom of the root zone (as indicated by results in Test1e.v26), and that layer 4 is fully saturated. (RD requirements 2, 6, 7, 8, 10, 16)	Review files.	✓	
1E.5.	1) The daily map file for the 22nd day of the simulation (Test1e3.v22) indicates that the water content of all soil root zone layers at each node where net infiltration is 0 is equal to the soil field capacity times the layer thickness in mm. (2) The water content for layer 4 is equal to the bedrock effective storage capacity times the bedrock layer thickness, in mm. (3) For nodes where net infiltration is greater than 0 the water content for each soil layer is greater than the soil field capacity water content but less than or equal to porosity times layer thickness, in mm (the full saturation water content). For nodes where net infiltration is greater than 0, the average relative saturation of the root zone layers increases from top to bottom. (RD requirements 2, 6, 7, 8, 10, 13)	1.) Review file test1e3.v22 and test1e.v26. See Attachment A2-1, Common Parameters for calculation. 2.) Same as (1) 3.) Same as (1)	✓ ✓ ✓	
1E.6.	The daily map files for days 22 and 2192 indicate that the water content for layer 4 is equal to the effective root zone storage capacity for layer 4 (the relative saturation is 1 for both days). (RD requirements 2, 6, 7, 8, 10, 13)	Review files.	✓	
Test 1F: Basic Water Volume Balance Check with Layered Root Zone				
1F.1.	Comparison of the output files Test1f.v21 and Test1e.v21 indicates that the maximum daily net infiltration rate obtained for test case 1f is less than the maximum daily net infiltration rate obtained for test case 1e. (RD requirements 2, 6, 7, 8, 10, 13)	Review files.	✓	
1F.2.	Comparison of the output files Test1f.v21 and Test1e.v21 indicates that the runoff generated on the first day is greater for test case 1f. (RD requirements 2, 6, 7, 8, 10, 13)	Review files.	✓	
1F.3.	Comparison of the output files Test1f.v24 and Test1e.v24 indicates that the average annual net infiltration rate obtained for test case 1f is less than the average annual net infiltration rate obtained for test case 1e. (RD requirements 2, 6, 7, 8, 10, 15)	Review files. See Attachment A2-1, Item 12 for example of calculated averages.	✓	
1F.4.	1) Inspection of the daily output file Test1f.v21 indicates that the daily net infiltration rate increases from day 1 and reaches a maximum rate after approximately 1 year. (2) The maximum net infiltration rate is approximately equal (to within 2 significant figures) to the spatially average saturated hydraulic conductivity of the soil times 0.0001. (3) After approximately 2 years, the net infiltration rate begins to decrease. (RD requirements 1, 2, 6, 7, 8, 10, 13)	1.) See Attachment A2-1, Item 13. 2.) Review file test1f.v21 to determine max net infil and convert soilks to mm/day to compare. See Attachment A2-1 Item 13 for example. Refer to VTP, Table 1 test soil properties. 3.) Same as (1).	✓ ✓ ✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
1F.5.	1.) The daily map file for the first day of the simulation (Test1f1.v22) indicates that on day 1 net infiltration occurs only at nodes where layer 4 has a thickness of 0 (the root zone does not extend bedrock). (2) For these nodes, the net infiltration rate is equal to 0.0001 times the saturated hydraulic conductivity of the soil. (3) For all other nodes, the increase in the water content for layer 4 is equal to 0.0001 times the saturated hydraulic conductivity of the soil. (RD requirements 1, 2, 6, 7, 8, 10, 16)	1) Review test1f1.v22. 2) Same as Test 1F.4(2). 3) Review test1f1.v22 and VTP, Table 1 for test soil properties.	✓ ✓ ✓	
1F.6.	1.) The daily map file for the 22nd day of the simulation (Test1f2.v22) indicates that the water content for layer 4 has increased relative to the first day, but has not exceeded the effective storage capacity of layer 4 for locations where the thickness of layer 4 is greater than 0. (2) The average net infiltration rate for day 22 is equal to the average net infiltration rate for day 1. (RD requirements 2, 6, 7, 8, 10, 13)	1.) Review files test1f2.v22 and test1f.v26. 2.) Review files test1f1.v22 and test1f2.v22.	✓ ✓	
1F.7.	The daily map file for day 466 (Test1f3.v22) indicates that the water content for layer 4 has increased relative to the 22nd day, and has reached the effective bedrock storage capacity of all nodes in layer 4 except for the first node (the highest elevation node). For all nodes where layer 4 has reached the effective bedrock storage capacity, net infiltration is occurring and is equal to 0.0001 times the saturated hydraulic conductivity of the soil. (RD requirements 2, 6, 7, 8, 10, 13)	1.) Review test 1f3.v22 and test1f.v26 files. 2.) Review test1f.v26 file for rockmm and VTP, Table 1 for soilks.	✓ ✓	
1F.8.	1.) The daily map file for day 2192 (Test1f4.v22) indicates that the water content for layer 4 has increased relative to day 466, and is equivalent to the effective bedrock storage capacity times the layer thickness, in mm, of all nodes. (2) Net infiltration is occurring at only 2 nodes (node 1 and 75), and the water content of layer 3 is greater than field capacity water content for these 2 nodes. (3) The water content of all layers at all other 73 nodes is equal to the field capacity times the layer thickness, in mm times 1000, at each node. (RD requirements 2, 6, 7, 8, 10, 13)	1.) Review test1f4.v22 and test1f.v26 files for rockmm and cdepth4. 2.) Review files test1f4.v22 and test1f.v26. See Attachment A2-1, Common Parameters. 3.) Same as (2).	✓ ✓ ✓	
1F.9.	The results in the annual summary output file (Test1f.v23) are consistent with the results in the daily output file (Test1f.v21) and the average annual map file (Test1f.v24). The average annual rates for the water balance terms calculated using the results in the daily output file are equal (to within 1E-5) to the spatially averaged rates calculated using the results in the average annual map file. (RD requirements 7, 8, 13, 14, 15)	Review files. Use spreadsheet function to calculate averages and see Attachment A2-1, Item 5 as example of comparisons.	✓	
1F.10.	The water volume balance is satisfied using both equations 1 and 2 in the RD (to within 1E-8) for all days simulated based on the daily results in Test1f1.v21. (RD requirements 6, 7, 8, 13)	Review file. See Attachment A2-1, Item 14 for example calculation.	✓	
1F.11.	The water volume balance is satisfied using equation 1 (to within 1E-4 mm/year) for all model nodes based on the average annual results in Test1f.v24. (RD requirements 6, 7, 8, 15)	Review file. See Attachment A2-1, Item 14 for example calculation.	✓	
Test 2A: Potential Evapotranspiration Functions				
2A.1.	The results in the daily output file Test2a.v21 indicate that all components of the daily water balance are 0 throughout the simulation period, with the exception of potential evapotranspiration, which is greater than 0 throughout the simulation period. (RD requirements 1, 3, 13)	Review file.	✓	
2A.2.	The results in the daily output file Test2a.v21 indicate that potential evapotranspiration is correlated to the day of year (this is indicated by a plot of potential evapotranspiration versus day of year). A minimum potential evapotranspiration rate occurs on day 358 of each year, and a maximum potential evapotranspiration rate occurs on day 179 of each year. (RD requirements 1, 3, 13)	Review file. See Attachment A2-1, Item 15 for a plot.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
2A.3.	The results in the annual map file for the first year of the simulation (Test2a.1) indicate that total annual potential evapotranspiration for year 1980 is spatially variable across the model domain (variability is shown from node to node). (RD requirements 1, 4, 16)	Review file.	✓	
2A.4.	The total potential evapotranspiration rate for year 1980 (Test2a.1), averaged across all nodes, is equal to 1.26 times the total potential evapotranspiration term (PETRS) for 1980 in the annual summary file Test2a.v23. (RD requirements 14, 16)	Review files.	✓	
2A.5.	The average annual potential evapotranspiration rate indicated in Test2a.v23 is equal to 1.26 times the average annual potential evapotranspiration rate calculated using the results from the daily output file Test2a.v21. (RD requirements 3, 13, 14)	Review file Test2a.v23 (PET and PETRS)	✓	
Test 2B: Potential Evapotranspiration and Evapotranspiration Functions				
2B.1.	1). The results in the daily output file Test2b.v21 indicate a decrease in the seasonal variability of modeled potential evapotranspiration. (2) The maximum daily potential evapotranspiration rate is less than the maximum for test 2a, and the minimum is greater than the minimum for test 2a. (RD requirement 3)	1.) Review file. This may be verified by visual inspection of file or by a plot of potential evapotranspiration versus day of year. 2.) Compare files test2b.v21 and test2a.v21	✓ ✓	
2B.2.	The average annual potential evapotranspiration rate calculated using the daily output file for test 2b is less than the average annual rate calculated using test 2a. (RD requirement 3)	Compare test2b.v23 and test2a.v23 files.	✓	
2B.3.	The results in the daily output file Test2b.v21 indicate that coupled surface water flow routing and net infiltration have occurred in conjunction with evapotranspiration from the root zone. (Coupled surface water flow routing is indicated by an average infiltrated run-on term greater than 0 for the second day of the simulation, and an average runoff term greater than the average run-on term for the first day of the simulation). (RD requirements 6, 7, 8, 13)	Review file.	✓	
2B.4.	The results of the daily output file Test2b.v21 indicate that the maximum net infiltration rate occurs on the first day of the simulation, and continually decreases for all successive days. The daily net infiltration rate reaches 0 before the last day of the simulation. The maximum evapotranspiration rate does not occur on the first day of the simulation, but increases with an increase in the potential evapotranspiration rate until reaching a maximum rate between day 30 and day 60, and then continually decreases for the remainder of the simulation. (RD requirements 3, 6, 7, 8, 9, 10)	Review file.	✓	
2B.5.	The daily water balance calculated using the results in Test2b.v21 and equations 1 and 2 in the RD is satisfied for all days of the simulation (to within 1E-8 mm/day). (RD requirements 7, 8, 13)	Review file. See Attachment A2-1, Item 14 for example.	✓	
2B.6.	The results of the average annual map file Test2b.v24 indicate that the average annual evapotranspiration rate is variable across model nodes. A maximum evapotranspiration rate occurs for the model node 75 (at the base of the test watershed T1.w20) which has the greatest soil thickness (and thus the greatest root zone thickness). (RD requirements 4, 9, 15)	Review file.	✓	
2B.7.	The average annual water balance calculated using the average annual rates in Test2b.v24 indicate that equation 1 of the RD is satisfied (to within 1E-4 mm/year).	Review file. See Attachment A2-1, Item 14 for example	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
Test 2C: Potential Evapotranspiration and Evapotranspiration Functions				
2C.1.	1.) The results in daily output file Test2c.v21 indicate a constant daily air temperature of 0.7 degrees C, and (2) a decrease in both the average annual potential evapotranspiration rate and the average annual evapotranspiration rate relative to the results obtained for test 2b. (RD requirements 3, 7, 9, 13)	1.) Review file test1c.v21. 2.) Review and compare files test2b.v23 and test1c.v23.	✓ ✓	
2C.2.	The average annual net infiltration rate is greater for test 2c relative to the rate obtained for test 2b. (RD requirements 7, 9, 10, 13)	Review files test1b.v23 and test1c.v23	✓	
2C.3.	The results of the average annual map file Test2c.v24 indicate that the actual average annual evapotranspiration rate is variable across model nodes. A maximum evapotranspiration rate occurs for the model node 75 (at the base of the test watershed T1.w20) which has the greatest soil thickness (and thus the greatest root zone thickness). (RD requirements 4, 9, 15)	Review file test2c.v24, and refer to test2c.v26 for soil cdepth4.	✓	
2C.4.	The results of the average annual map files for test cases 2b and 2c (Test2b.v24 and Test2c.v24) indicate that average annual evapotranspiration rate for test 2b is greater than the rate for test 2c at all nodes. (RD requirements 4, 9, 15)	Review file. See Attachment A2-1, Item 16 for averages.	✓	
2C.5.	The average annual water balance calculated using the average annual rates in Test2b.v24 indicates that equation 1 of the RD is satisfied at all model nodes (to within 1E-4 mm/year). (RD requirements 7, 8, 15)	Review file. See Attachment A2-1, Item 14 for example.	✓	
2C.6.	Comparison of the results in the annual summary files for test cases 2b and 2c (Test2b.v23 and Test2c.v23) indicate that evapotranspiration rates are higher for test case 2b during the first 2 years of the simulation, and higher for test case 2c during the last 2 years of the simulation.	Review files Test2b.v23 and Test2c.v23.	✓	
2C.7.	1.) The results in the annual map file for the first year of the simulation (Test2c.1) indicate that total annual potential evapotranspiration for year 1980 is spatially variable across the model domain (variability is shown from node to node). 2.) Overall variability in potential evapotranspiration for 1980 is decreased relative to the 1980 annual results for test 2a (the variance of potential evapotranspiration calculated using the results for all nodes is less for test 2c relative to the calculated variance for test 2a). results for. (RD requirements 1, 4, 16)	1.) Review file. 2.) Confirm statistical parameter values See Attachment A2-1, Item 18.	✓ ✓	
2C.8.	The total potential evapotranspiration rate for 1980, averaged across all nodes, is equal to 1.26 times the total potential evapotranspiration term (PETRS) for year 1980 in the annual summary file Test2a.v23. (RD requirements 14, 16)	Review file.	✓	
2C.9.	1.) The results in the daily output file Test2c.v21 indicate that potential evapotranspiration is correlated to the day of year. A minimum potential evapotranspiration rate occurs on day 358 of each year, and a maximum potential evapotranspiration rate occurs on day 167 of each year. (RD requirements 1, 3, 13)	Review file. This can be verified by a plot of potential evapotranspiration versus day of year using spreadsheet functions.. See Attachment A2-1, Item 13 for example of plot.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
Test 2D: Potential Evapotranspiration and Evapotranspiration Functions				
2D.1.	1) The results in daily output file Test2d.v21 indicate a constant day of year number equal to 355, and a constant positive daily air temperature close to 0 degrees C (within 1 degree). Daily potential evapotranspiration is a constant for each day of the simulation. (2) Based on calculations made using the first 2192 days simulated (1980-95), the average annual potential evapotranspiration rate calculated using the results from Test2d.v21 is less than the average annual rate calculated using Test2c.v21 (RD requirements 1, 3, 13)	1) Review file test2d.v21 2) Compare files test2d.v23 and test2c.v23	✓ ✓	
2D.2.	Based on calculations made using the first 2192 days simulated, the average annual net infiltration rate calculated using the results from Test2d.v21 is greater for test 2d relative to the rate obtained for test 2c. (RD requirements 7, 9, 10, 13)	Review files test2d.v21 and test2c.v21. Use spreadsheet functions to calculate averages. See Attachment A2-1, Item 17 for calculated averages.	✓	
2D.3.	The results in the daily output file Test2d.v21 indicate that the maximum daily evapotranspiration rate occurs on the first day of the simulation. (RD requirements 6, 7, 8, 9, 13)	Review file. Use spreadsheet function to sort in descending order.	✓	
2D.4.	The results of the annual map file for year 1980 (Test2d.1) indicate that the actual annual evapotranspiration and the annual potential evapotranspiration rates are variable across model nodes. The annual potential evapotranspiration rate shows higher spatial variability (the calculated coefficient of variation is higher) relative to the results obtained for both tests 2c (Test2c.1) and 2a (Test2a.1). (RD requirements 1, 3, 4, 9, 16)	1.) Review file. 2.) Review files. See Attachment A2-1, Item 18 for calculated coefficient of variation.	✓ ✓	
2D.5.	The daily water balance calculated using the results in Test2d.v21 indicate that equations 1 and 2 of the RD is satisfied for all days simulated (to within 1E-8 mm). (RD requirements 7, 13)	Review file Test2d.v23. See Attachment A2-1, Item 14 for example.	✓	
Test 2E: Potential Evapotranspiration and Evapotranspiration Functions				
2E.1.	1.) The results in daily output file Test2d.v21 indicate a constant day of year number equal to 171, and a constant positive daily air temperature close to 0 degrees C (within 1 degree C). Daily potential evapotranspiration is a constant for each day of the simulation. (2) Based on calculations made using the first 2192 days simulated (1980-95), the average annual potential evapotranspiration rate calculated using the results from Test2e.v21 is greater than the average annual rate calculated using Test2c.v21 (RD requirements 1, 3, 13)	1.) Review file. 2.) Review files. See Attachment A2-1, Item 19 for calculated averages.	✓ ✓	
2E.2.	Based on calculations made using the first 2192 days simulated, the average annual net infiltration rate calculated using the results from Test2e.v21 is less than the rate calculated using the results from Test2c.v21 (RD requirements 7, 9, 10, 13)	Review files. See Attachment A2-1, Item 14 for calculated averages.	✓	
2E.3.	The results in the daily output file Test2e.v21 indicate that the maximum daily evapotranspiration rate occurs on the first day of the simulation. (RD requirements 6, 7, 8, 9, 13)	Review file.	✓	
2E.4.	The results of the annual map file for year 1980 (Test2e.1) indicate that the actual annual evapotranspiration and the annual potential evapotranspiration rates are variable across model nodes. The annual potential evapotranspiration rate shows lower spatial variability (the calculated coefficient of variation is lower) relative to the results obtained for all previous tests (Test2a.1, Test2b.1, Test2c.1, and Test2d.1). (RD requirements 1, 3, 4, 9, 16)	Review file. See Attachment A2-1, Item 18 for comparison of variability.	✓	
2E.5.	The daily water balance calculated using the results in Test2e.v21 indicate that equations 1 and 2 of the RD are satisfied for all days simulated (to within 1E-8 mm). (RD requirements 7, 13)	Review file. See Attachment A2-1, Item 14 for example of calculation.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
Test 2F: Potential Evapotranspiration and Evapotranspiration Functions				
2F.1.	The results in daily output file Test2f.v21 indicate a constant potential evapotranspiration rate of 5 mm/day for all days of the simulation. The maximum evapotranspiration rate is less than the potential evapotranspiration rate, and occurs on the first day of the simulation. (RD requirements 1, 3, 6, 7, 9, 13)	Review file.	✓	
2F.2.	The results in daily output file Test2f.v21 indicate that the maximum net infiltration rate is less than the bedrock saturated hydraulic conductivity, and occurs on the first day of the simulation. (Note: The maximum net infiltration rate occurs on the first day of the simulation because evapotranspiration is maximized for the top layer of the root zone. Infiltration into the rock layer from overlying soil layers is replacing water.)	Review file Test2f.v21 and see Attachment A2-1, Item 20.	✓	
2F.3.	1.) The results in daily output file Test2f.v21 indicate that runoff and run-on are generated on the first day of the simulation. (Note: The runoff depth is less than 70 mm because evapotranspiration and net infiltration are calculated first. The run-on depth is less than the runoff depth because coupled surface water routing is enabled and run-on is allowed to infiltrate into the soil profile as downstream routing occurs.) (2) A small amount of storage capacity is available during routing because evapotranspiration has decreased the water content of the top root zone layer (RD requirements 2, 6, 7, 8, 9, 10, 11, 13, 16)	1.) Review file Test2f.v21. 2.) . This is validated by inspection of the daily map file Test2f1.v22 for day 1 of the simulation.	✓ ✓	
2F.4.	The results in daily output file Test2f.v21 indicate that the net infiltration rate reaches 0 within the first year of the simulation (1980), while the evapotranspiration rate continues through approximately 1984 before reaching 0. (RD requirements 6, 7, 9, 10, 13)	Review file.	✓	
2F.5.	The daily water balance calculated using the results in Test2f.v21 indicate that equations 1 and 2 of the RD are satisfied for all days simulated (to within 1E-8 mm/day). (RD requirements 7, 13)	Review file. See Attachment A2-1, Item 14.	✓	
2F.6.	The total change in the zone water content, calculated using the results from the daily output file Test2f.v21, is exactly –300 mm. This is the total amount of water available to evapotranspiration, runoff, and net infiltration, based on the initial root zone water content of 400 mm. (RD requirements 7, 8, 13, 14, 15)	Review file to confirm sum of del-soil is 300mm.	✓	
2F.7.	(1) The daily map file for the first day of the simulation (Test2f1.v22) indicates that the first (top) layer of the root zone has a water content at or very close to the total storage capacity (total storage capacity (saturation) for layer 1 = 0.3 x 0.3 m = 90 mm). (2) The second root zone layer is fully saturated and has a water content of 210 mm at all nodes (the storage capacity for layer 2 = 0.3 x (1.0 - .3 m) = 210 mm). The water content of layer 3 is 0.0 mm at all nodes because the thickness of layer 3 is 0 meters. (3) Layer 4 (the rock layer) has a water content of 30 mm at all nodes, which is equal to the effective root zone storage capacity of the rock layer (0.03 x 1 meter = 30 mm). This indicates that the effective storage capacity of the rock layer has been filled by water infiltrating from the overlying soil, and causes runoff to be approximately 70 mm, not 100 mm. (RD requirements 2, 16)	Review files Test 2f1.v22 and Test 2f.v26 for layer variables.. See Attachment A2-1, Common Parameters.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
2F.8.	The daily map file for the first day of the simulation (Test2f1.v22) indicates all nodes with 0 mm run-on (totout) show a slight decrease in water content for the top layer (this is due to evapotranspiration). All nodes with a run-on term greater than 0 show the water contents for layers 1 and 2 at full saturation (the total soil water content is 300 mm). The runoff depth at all nodes is uniform and slightly less than 70 mm. (RD requirements 2, 3, 4, 7, 8, 9, 16)	Review file.	✓	
2F.9.	The daily map file for the first day of the simulation (Test2f1.v22) indicates that the net infiltration rate at all nodes is uniform and is slightly less than the bulk saturated hydraulic conductivity of the underlying bedrock (1 mm).	Review file and refer to test2f.v26 file or model control file for ksat.	✓	
2F.10.	1.) The daily map file for the second day of the simulation (Test2f2.v22) indicates that the first and second layers of the root zone have water contents slightly less than full saturation (soilporo is 0.3m3/m3), with the relative saturation of layer 2 higher than layer 1. (2) The water contents for layers 1 and 2 are not uniform and reflect higher water contents for nodes having infiltrated run-on from the first day. (3) The water content of the rock layer is still equal to the effective root zone storage capacity of 30 mm. (RD requirements 2, 4, 7, 8, 9, 11, 16)	1. and 3) Review file. 2.) Review file Test2f1.v22 and compare nodes showing runoff (totout) with Test2f2.v22 node layer(s) water content.	✓ ✓	
2F.11.	The daily map file for the second day of the simulation (Test2f2.v22) indicates that the net infiltration rate at all nodes is slightly less than the net infiltration rate for the first day (this is because as the top layer dries the transpiration rate at the bottom of the root zone increases). The net infiltration rates are non-uniform and are higher for nodes where run-on infiltrated from the first day. (RD requirements 2, 4, 7, 8, 9, 10, 11, 16)	Review file.	✓	
2F.12.	1.) The daily map file for the 10th day of the simulation (Test2f3.v22) indicates that the saturation of the top layer is much less (about 50%) than the saturation of layer 2, which is still close to full saturation (about 100%). The net infiltration rate at all nodes has decreased relative to day 2. (2) The water contents of the 2 soil layers are not uniform, with slightly higher water contents occurring at nodes where run-on infiltrated. The water content of the bottom rock layer is still at the effective storage capacity of 30 mm for all nodes, thus net infiltration is still occurring, but has been reduced relative to rates for day 2 (this is because transpiration from the rock layer has increased). (RD requirements 2, 4, 7, 8, 9, 10, 11, 16)	1.) Review files Test2f2.v22 and Test2f3.v22. 2.) Review Test2f3.v22 and compare Test2f3.v22 soilmm(1) and soilmm(2) with totout inTest 2f1.v22.	✓ ✓	
2F.13.	1.) The daily map file for the 57th day of the simulation (Test2f4.v22) indicates that the water content of the top layer has reached the wilting point (and thus the field capacity) of 30 mm water depth (relative saturation of 33.3%) for all nodes (both evapotranspiration and infiltration from the top layer has stopped at all nodes). The water content of layer 2 is still slightly greater than field capacity (70 mm) at all nodes (thus both transpiration and infiltration from layer 2 are still occurring). The water content of the bottom rock layer is still at the effective storage capacity of 30 mm for all nodes. (Thus net infiltration is still occurring, but has been reduced relative to rates for day 10. The reduction is caused by an increase in the transpiration rate from the rock layer as the soil layers have dried up). The net infiltration rate is uniform across all nodes. (RD requirements 2, 4, 7, 8, 9, 10, 16)	1.) Review file Test2f4.v22. See Attachment A2-1, Common Parameters. 2.) Review file.	✓ ✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
2F.14.	The daily map file for the 58th day of the simulation (Test2f5.v22) indicates that the water content of the second layer has reached the wilting point (and thus the fully saturated water content) of 70 mm water depth (relative saturation of 33.3%) for all nodes. Both evapotranspiration and infiltration from the soil profile has stopped at all nodes. The water content of the bottom rock layer is still at the effective storage capacity of 30 mm for all nodes, thus net infiltration is still occurring, but has been reduced relative to rates for day 57. The net infiltration rates are not uniform; nodes where run-on occurred have higher net infiltration rates. (This is the last day that net infiltration can occur). (RD requirements 2, 4, 7, 8, 9, 10, 16)	Review file.	✓	
2F.15.	The daily map file for the 59th day of the simulation (Test2f6.v22) indicates that the water content of the rock layer is uniform and slightly less than the storage capacity of 30 mm at all nodes. The net infiltration is 0, but transpiration is still occurring from the bottom rock layer (this is indicated by the daily output file, Test2f.v21). (RD requirements 2, 4, 7, 8, 9, 10, 16)	Review tiles Test2f6.v22 and Test2f.v21.	✓	
2F.16.	The daily map file for the 2192nd day of the simulation (Test2f7.v22) indicates that the water content of the rock layer is 0. Net infiltration and transpiration have stopped (refer to results in Test2f.v21). There is exactly 100 mm of water in the soil profile at all nodes. (RD requirements 2, 4, 7, 8, 9, 10, 16)	Review tiles Test2f7.v22 and Test2f.v21.	✓	
Test 2G: Potential Evapotranspiration and Evapotranspiration				
2G.1.	The results in daily output file Test2g.v21 indicate that the daily net infiltration rate is 0 for all days of the simulation. The daily evapotranspiration rate is less than the daily potential evapotranspiration rate of 5 mm/day, and the maximum evapotranspiration rate occurs on the first day of the simulation. (RD requirements 6, 7, 8, 9, 10, 13)	Review file.	✓	
2G.2.	The results in the daily output file Test2g.v21 indicate that the runoff depth generated on day 1 is greater than the results for day 1 of test 2f (slightly less than 100 mm), and the total evapotranspiration depth for the simulation period is greater than results for test2f. (RD requirements 6, 7, 8, 9, 10, 11, 13)	Review files test2f.v21 and test2g.v21. See Attachment A2-1, Item 21 for sum of et's.	✓	
2G.3.	The daily map file for the first day of the simulation (Test2g1.v22) indicates that the water content of the soil profile is very close to full saturation (> 99%). The water content of the rock layer is slightly greater than 0 and is equal to the maximum daily infiltration rate from the soil. The water content of the second soil layer and the rock layer are uniform for all nodes, and the runoff depth is uniform across all nodes. (RD requirements 2, 6, 7, 8, 9, 10, 13, 16)	Review file. See Attachment A2-1, Common Parameters.	✓	
2G.4.	1.) The daily map file for day 10 of the simulation (Test2g3.v22) indicates that the saturation of the top layer has been considerably reduced (to about 70% of that for day 1) while the saturation of the second layer is still relatively high (> 90%). 2.) The saturation of the top layer is higher compared to results for day 10 of test 2f, while the saturation of the second layer is lower compared to results for day 10 of test 2f. (RD requirements 2, 6, 7, 8, 9, 10, 13, 16)	1.) Review files Test2g1.v22 and Test2g3.v22. 2.) Review files Test2g3.v22 and Test2f3.v22.	✓ ✓	
2G.5.	The daily map file for day 10 of the simulation (Test2g3.v22) indicates that the water content of the rock layer has increased and is uniform for all nodes, but is much less than 30 mm. (RD requirements 2, 4, 6, 7, 8, 9, 10, 16)	Review file.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
2G.6.	1.) The daily map file for day 57 of the simulation (Test2g4.v22) indicates that the water content of the rock layer has increased relative to results for day 10, but is still much less than 30 mm. (2) The water content of the top layer has reached field capacity, and relative saturation of the second layer is greater than the results for day 57 of test 2f. (RD requirements 2, 6, 7, 8, 9, 10, 13, 16)	1.) Review file. 2.) Review files Test2g4.v22 and Test2f4.v22.	✓ ✓	
2G.7.	The daily map file for day 2192 of the simulation (Test2g7.v22) indicates that the water content of the rock layer is 0, and the soil profile water content is exactly 100 mm, with 30 mm in layer 1 and 70 mm in layer 2. (RD requirements 2, 6, 7, 8, 9, 10, 13, 16)	Review file.	✓	
Test 2H: Potential Evapotranspiration and Evapotranspiration Functions				
2H.1.	The results in daily output file Test2h.v21 indicate that the daily net infiltration rate is 0 for the first 2 to 7 weeks of the simulation. The daily evapotranspiration rate is less than the daily potential evapotranspiration rate of 5 mm/day, and the maximum evapotranspiration rate occurs on the first day of the simulation. (RD requirements 3, 6, 7, 8, 9, 10)	Review file.	✓	
2H.2.	1.) The results in the daily output file Test2h.v21 indicate that the runoff depth generated on day 1 is less than the result for test 2g. (2)The total evapotranspiration depth for the simulation period is greater than result for test 2f, but less than the result for test 2g. The total net infiltration depth is less than the result for test 2f, but greater than the result for 2g. (RD requirements 3, 6, 7, 8, 9, 10)	1.) Review files Test2h.v21 and Test2g.v21. (2) Review files Test2f.v21., Test2g.v21, and Test2h.v21. See Attachment A2-1, Item 21.	✓ ✓	
2H.3.	1.) The daily map file for the first day of the simulation (Test2h1.v22) indicates that the water content of the soil profile is very close to full saturation (> 99%). (2) The water content of the rock layer is 10 times the rock layer water content for test 2g on the first day of the simulation. (RD requirements 2, 3, 6, 7, 8, 9, 16)	1.) Review file Test2h1.v22. 2.) Review file Test2h1.v22 and Test2g1.v22	✓ ✓	
2H.4.	The daily map file for day 10 of the simulation (Test2h3.v22) indicates that the water content of the soil profile is slightly less then results for day 10 of test 2g. The water content of the rock layer is approximately 10 times the rock layer water content for test 2g on the day 10 of the simulation. (RD requirements 2, 3, 6, 7, 8, 9, 16)	Review files Test2h3.v22 and Test2g3.v22.	✓	
2H.5.	1.) The daily map file for day 57 of the simulation (Test2h4.v22) indicates that the water content of the rock layer has reached the effective storage capacity of 30 mm, and net infiltration is occurring. (2) The net infiltration rate is uniform across all model nodes, but is less than the net infiltration rate obtained for day 57 of test 2f because the soil saturated hydraulic conductivity (1E-01) is less than the bedrock bulk saturated hydraulic conductivity (1E00). (RD requirements 3, 6, 7, 8, 9, 10; 16)	1.) Review day 57 for Test2h4.v22 file. 2.) Review day 57 for Test2h.v21 and Test2f.v21 files. Refer to VTP, Table 1 or model control file for soil and rock properties.	✓ ✓	
2H.6.	The daily map file for day 2192 (Test2h7.v22) indicates that the water content of the rock layer has reached 0, and net infiltration is not occurring. The total water content of the soil profile is 100 mm. (RD requirements 2, 3, 6, 7, 8, 9, 10, 11, 16)	Review file.	✓	
Test 2I: Potential Evapotranspiration and Evapotranspiration Functions				
2I.1.	The results in daily output file Test2i.v21 indicate that the daily net infiltration rate is 0 for the first 2 to 7 weeks of the simulation. The daily evapotranspiration rate is less than the daily potential evapotranspiration rate of 2 mm/day, and the maximum evapotranspiration rate occurs on the first day of the simulation. (RD requirements 2, 3, 6, 7, 8, 9, 10, 13)	Review file.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
2I.2.	The daily output file Test2i.v21 indicates that evapotranspiration is still occurring on the last day of the simulation. The minimum evapotranspiration rate occurs on the last day. (RD requirements 3, 6, 7, 8, 9, 13)	Review file.	✓	
2I.3.	The results in the daily output file Test2i.v21 indicate that the total change in root zone water content for the simulation period is slightly less than 300 mm. (RD requirements 2, 3, 6, 7, 8, 9, 10, 13)	Review file.	✓	
2I.4.	The results in the daily output file Test2i.v21 indicate that total net infiltration for the simulation period is greater than results obtained for test 2h. Total evapotranspiration for the simulation period is less than the results obtained for test 2h. (RD requirements 2, 3, 6, 7, 8, 9, 10, 13)	Review file. See Attachment A2-1, Item 21.	✓	
2I.5.	The daily map file for day 57 of the simulation (Test2i4.v22) indicates that the water content of layer 1 has reached field capacity of 30 mm, while the water content of layer 2 is higher than field capacity. The water content of the rock layer is 30 mm (at storage capacity). Net infiltration is occurring and is less than 1 mm/day. (RD requirements 2, 3, 6, 7, 8, 9, 10, 11, 16)	Review file.	✓	
2I.6.	The daily map file for day 2192 (Test2i7.v22) indicates that the water content of the rock layer has decreased to 0.0027 mm, and net infiltration is not occurring. The total water content of the soil profile is 100 mm. (RD requirements 2, 3, 6, 7, 8, 9, 10, 11, 16)	Review file.	✓	
Test2J: Potential Evapotranspiration and Evapotranspiration Functions				
2J.1.	The results in the root zone layer parameter file (Test2j.v26) indicate that the thickness of layer 1 is 0.3 meters, the thickness of layer 2 is 0.7 meters, the thickness of layer 3 is 1.0 meters, and the thickness of layer 4 (the rock layer) is 2.0 meters. (RD requirements 2, 16)	Review file.	✓	
2J.2.	The results in daily output file Test2j.v21 indicate that the daily net infiltration rate is exactly 1 mm/day on the first day of the simulation, and remains at 1 mm/day until the last day that net infiltration occurs in the simulation. (RD requirements 6, 7, 8, 9, 10, 13)	Review file.	✓	
2J.3.	The results in daily output file Test2j.v21 indicate that the daily evapotranspiration rate reaches 0 (ET stops) several weeks prior to the net infiltration rate reaching 0 mm/day (net infiltration stops). The maximum evapotranspiration rate occurs on the first day and is close to the potential evapotranspiration rate of 2 mm/day. (RD requirements 3, 6, 7, 8, 9, 10, 13)	Review file.	✓	
2J.4.	The results in daily output file Test2j.v21 indicate that the total change in the root zone water content for the period of the simulation is –390 mm. (RD requirements 3, 6, 7, 8, 9, 10, 13)	Review file.	✓	
2J.5.	The daily map file for day 1 of the simulation (Test2j1.v22) indicates that the water content of all 4 root zone layers is at the storage capacity of each layer (the root zone, including the bedrock layer, is fully saturated). (Note: Transpiration has not occurred from any layer underlying the top layer, and thus all water contents are uniform for all layers at all nodes). (RD requirements 2, 3, 6, 7, 8, 9, 10, 16)	Review files test2j2.v22 and test2j.v26 (for storage capacity variables). See Attachment A2-1, Item 3 for sample calculation.	✓	
2J.6.	1.) The daily map file for day 2 of the simulation (Test2j2.v22) indicates a decrease in water content for the top layer, but all three of the underlying layers remain at full saturation. (2)The net infiltration rate is exactly 1 mm/day at all nodes, because transpiration is not occurring from the rock layer. (RD requirements 2, 3, 6, 7, 8, 9, 10, 16)	1.) Review file. Compare to day 1 file, test2j1.v22. 2.) Review file.	✓ ✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
2J.7.	1.) The daily map file for day 2192 of the simulation (Test2j7.v22) indicates that the water content of the top layer (layer 1) has reached the wilting point (30 mm). The water content for the 2 underlying soil layers is at field capacity (140 and 200 mm). The water content of the rock layer is equal to the effective storage capacity (40 mm). (2)These results are consistent with the results provided in the root zone layer parameter file (Test2j.v26). (RD requirements 2, 3, 6, 7, 8, 9, 10, 16)	`1.) Review file. 2.) Review files test2j7.v22 and test2j.v26.	✓ ✓	
Test2K: Potential Evapotranspiration and Evapotranspiration Functions				
2K.1.	The results in daily output file Test2k.v21 indicate that the maximum daily net infiltration rate is less than 1 mm/day, and occurs on the first day of the simulation. (RD requirements 6, 7, 8, 10, 13)	Review file.	✓	
2K.2.	The results in daily output file Test2k.v21 indicate that the daily net infiltration rate reaches 0 (net infiltration stops) before the evapotranspiration rate reaches 0 (ET stops). (RD requirements 6, 7, 8, 9, 10, 13)	Review file.	✓	
2K.3.	1.) The results in daily output file Test2k.v21 indicate that the total change in the root zone water content for the period of the simulation is –470 mm. (2) The total net infiltration amount (water depth) is less than the total net infiltration amount for test 2j. The total evapotranspiration amount is greater than the total evapotranspiration amount obtained for test 2j. (RD requirements 6, 7, 8, 9, 10, 13)	1.) Review file. 2.) Review file. See Attachment A2-1, Item 21.	✓ ✓	
2K.4	The daily map file for day 1 of the simulation (Test2k1.v22) indicates a uniform net infiltration rate of approximately 0.2 mm/day for all model nodes. (RD requirements 2, 6, 7, 8, 10, 16)	Review file.	✓	
2K.5.	The daily map file for day 1 of the simulation (Test2k1.v22) indicates the water content of all soil layers is at or slightly less than the total storage capacity (porosity x layer thickness, in mm). The water content of the rock layer (layer 4) is equal to the effective storage capacity of the rock layer (40 mm) at all nodes. (RD requirements 2, 6, 7, 8, 9, 10, 16)	Review file test 2k1.v22 and test2k.v26. See Attachment A2-1, Item 3 for sample calculation of storage capacity.	✓	
2K.6.	The daily map file for day 57 of the simulation (Test2k4.v22) indicates that the water content of the rock layer is less then the effective storage capacity of the rock layer (40 mm), and thus the net infiltration rate is 0 for all nodes. (RD requirements 2, 6, 7, 8, 9, 10, 16)	Review file. Refer to test2k.v26 file for determining effective storage capacity of rock layer (rkmm). See Attachment A2-1, Common Parameters, for calculation.	✓	
2K.7.	The daily map file for day 2192 of the simulation (Test2k7.v22) indicates that the water content of the top layer (layer 1) and the bottom soil layer (layer 3) is equal to the field capacity water content (0.2 times layer thickness of 0.3 m equals 60 mm). The water content of the second soil layer (layer 2) is equal to the field capacity water content (70 mm), and the water content of the rock layer is equal to 0. Water contents are uniform for all nodes. (RD requirements 2, 6, 7, 8, 9, 10, 16)	Review files 2k7.v22 and test2k.v26. See Attachment A2-1, Common Parameters, for example soil water content calculation.	✓	
Test 3A: Evapotranspiration, Infiltration, and Net Infiltration Functions in Response to Daily Precipitation Input				
3A.1.	The results in the daily output file Test3a.v21 indicate that the daily net infiltration rate is equal to the bedrock bulk saturated hydraulic conductivity of 1 mm/day for all days where net infiltration is occurring. (RD requirements 7, 8, 10, 13)	Review file.	✓	
3A.2.	The results in the daily output file Test3a.v21 indicate that net infiltration is 0 mm/day during the first 24 days of the simulation. (RD requirements 7, 8, 10, 13)	Review file.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
3A.3.	The results in the daily output file Test3a.v21 indicate that the root zone has an increase in water content of 240 mm during the first 24 days of the simulation. (RD requirements 3, 7, 8, 10, 13)	Review file.	✓	
3A.4.	The total change in the root zone water content, based on the results in the daily output file Test3a.v21, is 440 mm. (RD requirements 3, 7, 8, 9, 10, 13)	Review file.	✓	
3A.5.	The results in the daily output file Test3a.v21 indicate that after 47 days the root zone is fully saturated and runoff is generated at a constant rate of exactly 9 mm/day. On the 47th day of the simulation, runoff occurs but is less than 9 mm (because the root zone profile is not fully saturated on day 46.) (RD requirements 2, 3, 7, 8, 10, 11, 16)	Review file.	✓	
3A.6.	The results in the daily output file Test3a.v21 indicate that outflow equals runoff for all days having runoff, because the root zone profile is fully saturated and evapotranspiration is disabled. (RD requirements 2, 3, 7, 8, 10, 11, 12, 16)	Review file test3a.v21 and refer to Test3a.v23 for summary run-off and outflow values.	✓	
Test 3B: Evapotranspiration, Infiltration, and Net Infiltration Functions in Response to Daily Precipitation Input				
3B.1.	The results in the daily output file Test3b.v21 indicate that the daily net infiltration rate is 0 for all days in the simulation. (RD requirements 7, 8, 9, 10, 13)	Review file.	✓	
3B.2.	The results in the daily output file Test3b.v21 indicate that the change in the root zone water content is 10 mm/day and runoff is 0 mm/day for the first 6 days of the simulation. (RD requirements 7, 8, 9, 10, 13)	Review file.	✓	
3B.3.	The total change in the root zone water content, based on the results in the daily output file Test3b.v21, is less than 440 mm. (RD requirements 7, 8, 9, 10, 13)	Review file.	✓	
3B.4.	The results in the daily output file Test3b.v21 indicate that after the first 7 days of the simulation, the change in root zone water content is equal to 0.008467 mm/day for all days between (and including) day 275 and day 183 of the following year simulated (winter storms). (RD requirements 7, 8, 9, 10, 13)	Review file.	✓	
3B.5.	The results in the daily output file Test3b.v21 indicate that after the first 7 days of the simulation, the change in root zone water content is equal to 0.001411 mm/day for all days between (and including) day 185 and day 273 of each year simulated (summer storms). (RD requirements 7, 8, 9, 10, 13)	Review file.	✓	
3B.6.	The results in the daily output file Test3b.v21 indicate that outflow is slightly less than runoff for all days having runoff, because infiltration of routed surface water is allowed (the root zone profile is not fully saturated). (RD requirements 7, 8, 9, 10, 11, 12, 13)	Review file. Note: outflow is named run-on in the DAYALL files	✓	
3B.7.	Comparison of results between the daily map files for days 1 and 2 of the simulation (test3b1.v22 and test3b2.v22) indicates a uniform increase of 10 mm in the water content of the top root zone layer. The water content for the remaining layers is unchanged. The net infiltration rate is 0 at all nodes. (RD requirements 2, 8, 9, 10, 13)	Review files test3b1.v22 and test3b2.v22.	✓	
3B.8.	1.) The results of the daily map file for day 48 of the simulation (test3b6.v22) indicates that the top root zone layer is close to full saturation. (2) Runoff is being generated at all nodes and the water content of the second root zone layer has increased slightly (by less than 1 mm relative to day 2 of the simulation). The net infiltration rate is 0 at all nodes.	1.) Review file. 2.) Review file test3b6.v22 and test3b2.v22.	✓ ✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
3B.9.	1.) The results of the daily map file for day 2192 of the simulation (test3b7.v22) indicates that the top root zone layer is at full saturation. (2) Runoff is being generated at all nodes and the water content of the second root zone layer has increased but is still well below the field capacity of 140 mm. The water content of the third root zone layer is equal to the wilting point water content (100 mm), and the water content of the forth root zone layer (the rock layer) is 0. The net infiltration rate is 0 at all nodes.	1.) Review file test 3b.v26 and see Attachment A2-1, Common Parameters for calculation of full saturation. Compare to test3b7.v22. 2.) Review file test3b7.v22	✓ ✓	
Test 3C: Evapotranspiration, Infiltration, and Net Infiltration Functions in Response to Daily Precipitation Input				
3C.1.	The results in the daily output file Test3c.v21 indicate that starting on day 3, runoff is generated for all remaining days of the simulation, and is slightly less than 10 mm on all days. With the exception of the last day of the simulation, runoff is equal to run-on for all days simulated. (RD requirements 7, 8, 11, 12, 13)	Review file.	✓	
3C.2.	The results in the daily output file Test3c.v21 indicate that net infiltration is 0 mm/day during the first 847 days of the simulation. (RD requirements 7, 8, 10, 13)	Review file.	✓	
3C.3.	The results in the daily output file Test3c.v21 indicate that starting on day 4 of the simulation, the change in root zone water content is equal to the maximum infiltration rate, while the net infiltration rate is 0. The maximum infiltration rate is defined by storm duration and the soil saturated hydraulic conductivity (0.004234 mm/day for winter storms, 0.000706 mm/day for summer storms). (RD requirements 2, 6, 7, 8, 11, 12, 13)	Review file. Note explanation of calculation for soil ksat, Attachment A2-1, Item 22.	✓	
3C.4.	1.) The results in the daily output file Test3c.v21 indicate that starting on day 848, net infiltration occurs for the remainder of the simulation, at a rate much less than the bedrock bulk saturated hydraulic conductivity of 1 mm/day. (2) From day 849 on, the net infiltration rate is equal to the maximum soil infiltration rate (0.004234 mm/day for winter storms, and 0.000706 mm/day for summer storms). From day 849 on, the change in the root zone water content is 0 mm/day. (RD requirements 7, 8, 11, 12, 13)	1.) Review files test3c.v21 and test3c.v26 (for ksat (imbibe)). 2.) Review file test3c.v21.	✓ ✓	
3C.5.	The total change in the root zone water content, based on the results in the daily output file Test3c.v21, is 22.95 mm. (RD requirements 6, 7, 8, 10, 13)	Review file.	✓	
3C.6.	Comparison of the daily map files for days 1 and 2 of the simulation (test3c1.v22 and test3c2.v22) indicates a uniform increase of 10 mm in the water content of the root zone (9.9958 mm for layer 1 and 0.0042 mm for layer 4) for day 2 relative to day 1. The water content for all remaining layers is 0. The net infiltration rate is 0 at all nodes. (RD requirements 2, 6, 7, 8, 10, 16)	Review files.	✓	
3C.7.	Comparison of the daily map files for days 2 and 3 of the simulation (test3c2.v22 and test3c3.v22) indicates a uniform increase of approximately 0.004234 mm for the bottom root zone layer. The water content for layer 1 is exactly 30 mm, and a uniform runoff depth of 9.9915 mm is being generated at all model nodes. The water content for all remaining layers is 0. The net infiltration rate is 0 at all nodes. (RD requirements 2, 6, 7, 8, 10, 11, 13)	Review files.	✓	
3C.8.	Comparison of the daily map files for days 847 and 848 of the simulation (test3c4.v22 and test3c5.v22) indicates that the top soil layer has reached full saturation of 30 mm. A uniform net infiltration rate of 0.0008 mm/day is initiated on day 848 for all nodes as the water content of the bottom rock layer reaches the effective water storage capacity of 2.95 mm. The water content for all remaining layers is 0 mm at all nodes. A uniform runoff depth of 9.9958 mm is being generated at all model nodes. (RD requirements 2, 6, 7, 8, 10, 11, 16)	Review files.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
3C.9.	Comparison of the daily map files for days 849 and 2192 of the simulation (test3c6.v22 and test3c7.v22) indicates that the water contents, net infiltration rates, and runoff rates are equivalent at all nodes for both days. The root zone water content is at full capacity (2.95 mm) and the net infiltration rate is ½ the saturated hydraulic conductivity of the soil (0.0042 mm/day). (RD requirements 2, 6, 7, 8, 10, 11, 16)	Review files.	✓	
Test 3D: Evapotranspiration, Infiltration, and Net Infiltration Functions in Response to Daily Precipitation Input				
3D.1.	The results in the daily output file Test3d.v21 indicate that net infiltration is 0 for all days simulated. (RD requirements 6, 10, 13)	Review file.	✓	
3D.2.	The results in the daily output file Test3d.v21 indicate that, with the exception of the last day, runoff equals run-on for all days simulated, and the total runoff for the simulation period equals the total runoff generated for test 3c. (for tests 3c and 3d, runoff generation is controlled by the soil hydraulic conductivity, not by net infiltration or evapotranspiration). (RD requirements 6, 10, 11, 13)	Review files.	✓	
3D.3.	The results in the daily output file Test3d.v21 indicate that the evapotranspiration rate increases during the first several days (day 2 to day 11) of the simulation before reaching a steady rate of 0.004234 mm/day. This rate is maintained until day 184, at which time the rate diminishes over 5 to 10 days to a lower rate of 0.000706 mm/day. The new lower rate is maintained until day 274, at which time the rate gradually increase over the next 5 to 10 days until the higher rate of 0.004234 mm/day is attained. (RD requirements 3, 6, 7, 8, 9, 10, 13)	Review file.	✓	
3D.4.	Comparison of results between the daily map files for days 1 and 2 of the simulation (test3d1.v22 and test3d2.v22) indicates a smaller increase in the water content of layer 4 relative to results obtained for test 3c. The water content for the top soil layer increases from 20 mm on day 1 to 29.9958 mm on day 2 for all nodes. The water content for the bottom rock layer increases from 0 mm on day 1 to 0.0014 mm on day 2. The net infiltration rate is 0 at all nodes. (RD requirements 2, 6, 7, 8, 9, 10, 16)	Review files.	✓	
3D.5.	Comparison of results between the daily map files for days 25 and 46 of the simulation (test3d3.v22 and test3d4.v22) indicates that the water content of the top soil layer is at full saturation (30 mm), while the water content of the rock layer is being maintained at 0.0021 mm. A uniform runoff rate of 9.9958 mm/day is being generated at all nodes for both days. The net infiltration rate is 0 at all nodes for both days. (RD requirements 2, 6, 7, 8, 9, 10, 11, 16)	Review files.	✓	
3D.6.	The results of the daily map file for day 2192 of the simulation (test3d7.v22) indicate that water contents, net infiltration rates, and runoff rates are identical to the results obtained for day 46. (RD requirements 2, 6, 7, 8, 9, 10, 11, 16)	Review file.	✓	
Test 3E: Evapotranspiration, Infiltration, and Net Infiltration Functions in Response to Daily Precipitation Input				
3E.1.	The results in the daily output file Test3e.v21 indicate that net infiltration is 0 for the first 13 days of the simulation. On the 14th day, net infiltration is approximately 1.116 mm/day and remains constant for the remainder of the simulation. (RD requirements 6, 7, 8, 9, 10, 13)	Review file.	✓	
3E.2.	The results in the daily output file Test3e.v21 indicate that, with the exception of the last day, runoff equals run-on for all days simulated. Runoff is 0 mm/day for the first 33 days of the simulation, and is 5 mm/day starting on day 35. The total runoff generated is less than the total runoff generated for test 3d. (RD requirements 6, 7, 8, 9, 10, 11, 12, 13)	Review file.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
3E.3.	The results in the daily output file Test3e.v21 indicate that the evapotranspiration rate is 0 mm/day for the first 10 days of the simulation. From day 11 to 13, the evapotranspiration rate increases to approximately 3.884 mm/day and remains at this rate for the remainder of the simulation. Starting on day 14, the sum of the daily evapotranspiration and net infiltration rate equals 5 mm/day. (RD requirements 3,,6, 7, 8, 9, 10, 13)	Review file.	✓	
3E.4.	The results in the daily output file Test3e.v21 indicate that the change in the root zone water content is 10 mm/day for the first 10 days of the simulation. All other terms of the daily water balance are 0 for the first 10 days, except for precipitation (10 mm/day), rain (10 mm/day), and potential evapotranspiration (5 mm/day). From day 11 to day 15, the change in the root zone water content decreases to 5 mm/day, corresponding to the initiation of evapotranspiration and net infiltration. From day 33 to 35, the change in root zone water content decreases from 5 to 0 mm/day, corresponding to the initiation of runoff. (RD requirements 6, 7, 8, 9, 10, 11, 13)	Review file.	✓	
3E.5.	Comparison of results between the daily map files for days 11 and 13 of the simulation (test3e2.v22 and test3e3.v22) indicates that the water content of layer 4 (the rock layer) is greater than 0. The water content increases from day 11 to day 12 but is less than the effective storage capacity of the rock layer (25 mm). The water content for soil layers 1 and 2 are at the field capacity water content (60 mm and 140 mm). Net infiltration and runoff are 0 at all nodes. (RD requirements 2, 3, 6, 7, 8, 9, 10, 11, 16)	Review files test3e2.v22 and test3e3.v22. See test3e.v26 for effective storage capacity (rkmm) and soil layer field capacities.	✓	
3E.6.	The results of the daily map file for day 14 of the simulation (test3e4.v22) indicates that a uniform net infiltration rate of approximately 1.1 mm/day is occurring at all nodes. The water content of the top soil layer is at the field capacity water content (60 mm) while the water content of the second soil layer has exceeded the field capacity water content (140 mm). The water content of the rock layer is at the effective water storage capacity of the rock layer (25 mm). Runoff and run-on (totout) are 0 at all nodes. (RD requirements 2, 6, 7, 8, 9, 10, 11, 12, 16)	Review file.	✓	
3E.7.	1.) The results of the daily map file for day 34 of the simulation (test3e5.v22) indicate that the water content of the root zone has reached the fully saturated water content of all layers (90 mm for layer 1, 210 mm for layer 2, and 25 mm for layer 4). (2) Runoff is being generated at all model nodes. The net infiltration rate is the same as for day 14. (RD requirements 2, 6, 7, 8, 9, 10, 11, 16)	1.) Review file. 2.) Review file test3e5.v22 and test 3e4.v22.	✓ ✓	
Test 3F: Evapotranspiration, Infiltration, and Net Infiltration Functions in Response to Daily Precipitation Input				
3F.1.	The results in the daily output file Test3f.v21 indicate that evapotranspiration occurs on all days simulated, and the daily evapotranspiration rate is greater than for test case 3e. Starting on day 116 of the simulation, a constant evapotranspiration rate of approximately 4.65 mm/day is maintained for the remainder of the simulation. (RD requirements 3, 6, 7, 8, 9, 10, 13)	Review files.	✓	
3F.2.	1.) The results in the daily output file Test3f.v21 indicate that when runoff is greater than 0 mm/day, runoff is greater than run-on for all days simulated. Runoff and run-on are initiated (values are greater than 0 mm/day) on day 119. After day 121, the runoff and run-on terms are constant for the remainder of the simulation (with the exception of the last day, when run-on equals 0). (2) The maximum runoff rate and the total runoff generated for the simulation is less than results obtained for test case 3e. (RD requirements 6, 7, 8, 9, 10, 11, 12, 13)	1.) Review file test3f.v21 2.) Review files test3f.v21 and test3e.v21	✓ ✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
3F.3.	The results in the daily output file Test3f.v21 indicate that infiltrated run-on (run-infil) occurs starting on day 120. From day 122 on, the infiltrated run-on term remains constant at approximately 1.07 mm/day. (RD requirements 6, 7, 8, 9, 10, 13)	Review file.	✓	
3F.4.	The results in the daily output file Test3f.v21 indicate that net infiltration is initiated on day 22. Starting on day 23, net infiltration remains constant at approximately 4.61 mm/day for the remainder of the simulation. The maximum daily net infiltration rate and the total net infiltration amount for the simulation are greater than results obtained for test case 3e. (RD requirements 6, 7, 8, 9, 10, 13)	Review file.	✓	
3F.5.	The results of the daily map file for day 22 of the simulation (test3f2.v22) indicates that a uniform net infiltration rate of approximately 4.5 mm/day is occurring at all nodes. The water content of the rock layer is at the effective storage capacity of the rock layer (25 mm). The water content of the soil layers is slightly below the field capacity water content of the 2 soil layers (60 mm for layer 1, 140 mm for layer 2). Runoff and run-on are 0 at all nodes. (RD requirements 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 16)	Review file test3f2.v22 and see test3f-v26 for effective storage capacity of rock layer (rkmm) and field capacity water content (fc x cdepth x 1000).	✓	
3F.6.	1.) The results of the daily map file for day 119 of the simulation (test3f4.v22) indicates that a uniform net infiltration rate of approximately 4.6 mm/day is occurring at all nodes.(2) The water content of the bottom soil layer has reached the fully saturated water content of that layer (210 mm). (3) The water content of the top soil layer is slightly less than the fully saturated water content of 90 mm, and is variable across model nodes (this is in response to variable amounts of infiltrated run-on combined with evapotranspiration). (4) A uniform runoff amount of approximately 0.58 mm is being generated at all nodes, but the run-on amount is approximately 0 at all nodes. (RD requirements 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 16)	1.) Review file. 2.) Review file. See Attachment A2-1, Common Parameters for sample calculation of variable. 3.) Same as (2). 4.) Review file.	✓ ✓ ✓ ✓	
3F.7.	1.) The results of the daily map file for day 120 of the simulation (test3f5.v22) indicates that the water content of the top soil layer has reached the fully saturated water content (90 mm) for some, but not all, model nodes. (2) For those nodes with the top soil layer at the saturated water content, the surface water run-on term is greater than 0. (RD requirements 2, 4, 6, 7, 8, 11, 12, 16)	Review file.	✓	
Test 3G: Evapotranspiration, Infiltration, and Net Infiltration Functions in Response to Daily Precipitation Input				
3G.1.	The results in the daily output file Test3g.v21 indicate that evapotranspiration occurs on all days simulated, and the daily evapotranspiration rate is on average greater than for test case 3f. Starting on day 479 of the simulation, a constant evapotranspiration rate of approximately 4.82 mm/day is maintained for the remainder of the simulation. (RD requirements 3, 6, 7, 8, 9, 10, 13)	Review file test3g.v21. See Attachment A2-1, Item 23 for comparison with 3f.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
3G.2.	1.) The results in the daily output file Test3g.v21 indicate that runoff and run-on are initiated on day 493. From day 493 on, runoff and run-on are generated, and runoff is greater than run-on for all days. From day 499 on, runoff and run-on are constant, with runoff approximately 0.68 mm/day and run-on approximately 0.21 mm/day. (2) For all days simulated having runoff and run-on greater than 0, the runoff and run-on rates are less than the runoff and run-on rates generated for test case 3f. (RD requirements 3, 6, 7, 8, 9, 10, 11, 12, 13)	1.) Review file test3g.v21 2.) Review files test3g.v21 and test3f.g21	✓ ✓	
3G.3.	The results in the daily output file Test3g.v21 indicate that net infiltration is initiated on day 43. Starting on day 44, net infiltration remains constant at approximately 4.96 mm/day for the remainder of the simulation, which is greater than the net infiltration rate obtained for test case 3f. (RD requirements 6, 7, 8, 9, 10, 13)	Review files test3g.v21 and test3f.g21.	✓	
3G.4.	1.) The results of the daily map file for day 1 of the simulation (test3g1.v22) indicates water contents greater than 0 for 3 soil layers at all model nodes. The water content for each of the 3 soil layers is uniform across all nodes. (2) The water content of soil layer 1 (the top layer) is approximately 35.9 mm, which shows an increase in water content of less then 10 mm relative to the wilting point water content of 30 mm. The water content of the 2 lower soil layers is at the wilting point water content (70 mm for layer 2, 100 mm for layer 3). (3) The water content of the rock layer is 0 mm. (RD requirements 2, 3, 4, 6, 7, 8, 16)	1.) Review file. 2.) Review file. 3.) Review file.	✓ ✓ ✓	
3G.5.	The results of the daily map file for day 43 of the simulation (test3g2.v22) indicates water contents slightly below the field capacity water content for the top 3 soil layers (60 mm for layer 1, 140 mm for layer 2, and 200 mm for layer 3). The water content of the rock layer is equal to the rock layer storage capacity of 40 mm. A uniform net infiltration rate of approximately 1.55 mm/day is occurring at all model nodes. Runoff and Run-on are 0 at all nodes. (RD requirements 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 16)	Review files test3g2.v22 and test3g.v26.	✓	
3G.6.	The results of the daily map file for day 44 of the simulation (test3g3.v22) indicates water contents slightly below the field capacity water content for the top 2 soil layers (60 mm for layer 1, 140 mm for layer 2). The water content of the 3rd soil layer is slightly greater than the field capacity water content of 200 mm. The water content of the rock layer is equal to the rock layer storage capacity of 40 mm. A uniform net infiltration rate of approximately 4.96 mm/day is occurring at all model nodes. Runoff and Run-on are 0 at all nodes. (RD requirements 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 16)	Review file.	✓	
3G.7.	1.) The results of the daily map file for day 493 of the simulation (test3g5.v22) indicates water contents slightly below the saturated water content of 90 mm for the top soil layer. (2) The water content of the three lower root zone layers is at full saturation for all three layers (210 mm for layer 2, 300 mm for layer 3, 40 mm for layer 4). A uniform net infiltration rate of approximately 4.96 mm/day is occurring at all model nodes. (3) A uniform runoff rate of approximately 0.08 mm/day is occurring at all nodes, while run-on is 0 at all nodes. (RD requirements 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 16)	1.) Review files 3g5.v22 and 3g.v26. 2.) Review file 3g5.v22. 3.) Review file 3g5.v22.	✓ ✓ ✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
3G.8.	The results of the daily map file for day 499 of the simulation (test3g7.v22) indicates water contents slightly below the saturated water content of 90 mm for most nodes in the top soil layer. For those nodes having water contents of 90 mm for the top soil layer, the run-on term is greater than 0 mm. The water content of the three lower root zone layers is at the storage capacity of all three layers (210 mm for layer 2, 300 mm for layer 3, 40 mm for layer 4). A uniform net infiltration rate of approximately 4.96 mm/day is occurring at all model nodes. Runoff is being generated at all model nodes, but is not uniform across all model nodes. (RD requirements 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 16)	Review file.	✓	
Test 4A: Infiltration and Coupled Surface Water Flow Routing				
4A.1.	The results in the daily output file Test4a.v21 indicate that runoff is initiated on day 46. (From day 46 through day 58, outflow (run-on) is less than runoff because surface water flow is allowed to infiltrate into the deeper soils of the channel nodes.) From day 59 on, runoff and run-on equal 10 mm/day and all other terms of the daily water balance (except precipitation and rain) are 0. (Starting on day 59, the root zone profile is fully saturated at all nodes, and run-on equals runoff because net infiltration and evapotranspiration cannot occur.) (RD requirements 4, 6, 7, 8, 11, 12, 13)	Review file.	✓	
4A.2.	The results in the daily output file Test4a.v21 indicate that the infiltrated run-on (run-infil) term is greater than 0 only for days 47 through 59 (this is the period during which routed surface water infiltrates into the deeper soils of the channel nodes). The infiltrated run-on term is 0 for all other days of the simulation. (RD requirements 4, 6, 7, 8, 11, 12, 13)	Review file.	✓	
4A.3.	The results in the average annual map file Test4a.v24 indicate that the average annual infiltrated run-on rate is greater than 0 only for channel nodes (channel nodes are identified as the nodes with 6 meters of soil). The run-on rates are variable across model nodes, and the highest run-on rate of approximately 260,000 mm/year occurs for the node at the mouth of the watershed (the last node listed in the output file), which is a channel node. (RD requirements 4, 6, 7, 8, 11, 12, 15)	Review files Test4a.v24 for run-infil and Test4a.v26 for soil thickness. Note: The channel nodes are identified in lines 25, 34, 43, 45, 53, 62, 68, 71, 73, 74, and 75 of the files.	✓	
4A.4.	The results of the daily map file for day 1 of the simulation (test4a1.v22) indicates water contents greater than 0 for 3 soil layers at all channel nodes. The water content of the top soil layer at all nodes equals the wilting point water content (30 mm) plus 10 mm. The water content for the second soil layer is at the wilting point water content (70 mm) for all nodes, and the water content of the third soil layer for channel nodes is also at the wilting point water content (500 mm). The water content for the bedrock layer is 0 at all model nodes. (RD requirements 2, 4, 6, 7, 8, 9, 16)	Review file. See Test 4A.3, Note, for channel node identification.	✓	
4A.5.	1.) The results of the daily map file for day 45 of the simulation (test4a2.v22) indicates that all upland nodes (nodes with 1 meter soil thickness) are fully saturated. The water content of the two soil layers is at the fully saturated water content (90 mm for layer 1, 210 mm for layer 2). The water content of the rock layer is at the effective storage capacity water content for the rock layer (250 mm). (2) For channel nodes, the water content of the top two soil layers is at the field capacity water content (60 mm for layer 1, 140 mm for layer 2) and the bottom soil layer water content is less than the field capacity water content (1000 mm). Net infiltration and runoff are 0 at all nodes. (RD requirements 2, 4, 6, 7, 8, 9, 10, 11, 12, 16)	1.) Review files test4a2.v22 and test4a.v26. See Test 4A.3, Note, for channel node identification. 2.) See Attachment A2-1, Edit	✓ ✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
4A.6.	1.) The results of the daily map file for day 46 of the simulation (test4a3.v22) indicates a runoff amount of 10 mm at upland nodes, while runoff is 0 at all channel nodes. The run-on terms for all upland nodes are variable in increments of 10 mm, while the run-on terms for channel nodes are in variable increments of less than 10 mm. (2) The layer 3 water content for channel nodes indicates an increase in water content greater than 10 mm relative to day 45 for all channel nodes. (3) The water content of the top soil layer is greater than the field capacity water content of 60 mm for all channel nodes. The run-on term for the node at the mouth of the watershed (the last node listed in the output file) is less than the run-on for the upstream channel node (the second to last node listed in the output file). (RD requirements 2, 4, 6, 7, 8, 9, 10, 11, 12, 16)	1.) Review files test4a3.v22 and test4a.v26. 2.) Review files test4a2.v22 and test4a3.v22. 3.) Review file test4a3.v22. See Test 4A.3, Note, for channel node identification.	✓ ✓ ✓	
4A.7.	The results of the daily map file for day 58 of the simulation (test4a5.v22) indicates that layers 1 and 2 are fully saturated. For channel nodes, layer 3 is fully saturated at a water content of 1,500 mm. For upland nodes, the water content of the rock layer is at the effective storage capacity water content of the rock layer (250 mm). Runoff is not yet occurring at the channel nodes. (RD requirements 2, 4, 6, 7, 8, 9, 11, 12, 16)	Review file. Refer to file test4a.v26 and Attachment A2-1, Common Parameters	✓	
4A.8.	The results of the daily map file for day 59 of the simulation (test4a6.v22) indicates a uniform runoff amount of 10 mm at all model nodes. The root zone is fully saturated, with a water content of 1500 mm for the third soil layer at all channel nodes. The run-on terms are variable in increments of exactly 10 mm for all model nodes, and the highest run-on amount of 740 mm occurs for the node at the mouth of the watershed. (This run-on amount is consistent with 10 mm of runoff being generated at 74 upstream nodes, and an infiltrated run-on rate of 0 mm at all nodes because there is no available storage capacity in the root zone.) (RD requirements 2, 4, 6, 7, 8, 9, 11, 12, 16)	Review file. See Test 4A.3, Note, for channel node identification.	✓	
4A.9.	The results of the daily map file for day 60 of the simulation (test4a7.v22) indicates that all results are equivalent to results obtained for day 59, thus showing that steady-state conditions have been achieved. (RD requirements 2, 4, 6, 7, 8, 9, 10, 11, 12, 16)	Review file.	✓	
Test 4B: Infiltration, Net Infiltration, and Coupled Surface Water Flow Routing				
4B.1.	The results in the daily output file Test4b.v21 indicate that runoff is initiated on day 46, but outflow (run-on) from the watershed does not occur until day 57. Outflow from the watershed increases from day 57 through day 60, and remains constant at approximately 9.3 mm/day for the remainder of the simulation. From day 60 on, outflow (run-on) is equal to runoff. (RD requirements 6, 7, 8, 11, 12, 13)	Review file.	✓	
4B.2.	The results in the daily output file Test4b.v21 indicate that the infiltrated run-on (run-infil) term is greater than 0 only for days 47 through 60 (this is the period during which routed surface water infiltrates into the deeper soils of the channel nodes). The infiltrated run-on term is 0 for all other days of the simulation. (RD requirements 6, 7, 8, 11, 12, 13)	Review file.	✓	
4B.3.	The results in the daily output file Test4b.v21 indicate that from day 46 through day 56, run-on is 0 and runoff is equal to the following day's infiltrated run-on (run-infil). (RD requirements 6, 7, 8, 11, 12, 13)	Review file.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
4B.4.	The results in the daily output file Test4b.v21 indicate that net infiltration is initiated on day 48, 2 days after the initiation of runoff. The net infiltration rate increases from day 48 through day 51. From day 51 on, the net infiltration rate remains constant at approximately 0.73 mm/day. (RD requirements 6, 7, 8, 10, 11, 12, 13)	Review file.	✓	
4B.5.	The results in the average annual map file Test4b.v24 indicate that the average annual infiltrated run-on (run-infil) and net infiltration rates are greater than 0 only for channel nodes (nodes with 6 meters of soil). The net infiltration rates for channel nodes are not uniform. The runoff rate is higher for upland nodes relative to channel nodes. The run-on rates are variable across all model nodes, and the highest run-on rate of approximately 245,000 mm/year occurs for the node at the mouth of the watershed (the last node listed in the output file). (RD requirements 6, 7, 8, 10, 11, 12, 15)	Review file. See Test 4A.3, Note, for channel node identification.	✓	
4B.6.	The results of the daily map file for day 46 of the simulation (test4b2.v22) indicates water contents greater than 0 for the 2 soil layers and the rock layer at all upland nodes, and for 3 soil layers at all channel nodes. For the upland nodes, the root zone profile is fully saturated with a uniform water content of 90 mm for layer 1, 210 mm for layer 2, and 250 mm for layer 4. Runoff is 10 mm at all upland nodes, and 0 mm at all channel nodes. For the channel nodes, the water content of the top 2 soil layers is at the field capacity water content (60 mm for layer 1, 140 mm for layer 2). The water content of the third soil layer is variable across channel nodes, in increments of 10 mm, from a minimum of 880 mm to a maximum of 940 mm. Runoff and run-on are 0 at all channel nodes, while run-on is variable (in increments of 10 mm) for upland nodes. (RD requirements 2, 6, 7, 8, 11, 12, 16)	Review file. See Test 4A.3, Note, for channel node identification.	✓	
4B.7.	1.) The results of the daily map file for day 48 of the simulation (test4b4.v22) indicates net infiltration of 5 mm has occurred at some (but not all) channel nodes. (2.) At all channel nodes where net infiltration is occurring, the water content of the third soil layer is greater than the fully saturated water content of 1000 mm. (3.)Runoff is 10 mm at all upland nodes. Runoff and run-on are 0 at all channel nodes. (RD requirements 2, 6, 7, 8, 10, 11, 12, 16)	1.) Review file 2.) Review file. 3.) Review file. See Test 4A.3, Note, for channel node identification	✓ ✓ ✓	
4B.8.	The results of the daily map file for day 56 of the simulation (test4b5.v22) indicates a net infiltration rate of 5 mm/day for all channel nodes. Some (but not all) of the channel nodes have become fully saturated, with water contents of 90 mm for layer 1, 210 mm for layer 2, and 1500 mm for layer 3. The channel nodes have runoff rates of 5 mm/day, and have variable run-on rates in increments of 5 mm/day. Outflow from the watershed is not occurring because the node at the mouth of the watershed (the last node listed in the output file) has a runoff and run-on rate of 0 mm/day. (RD requirements 2, 6, 7, 8, 10, 11, 12, 16)	Review file. See Test 4A.3, Note, for channel node identification	✓	
4B.9.	The results of the daily map file for day 60 of the simulation (test4b9.v22) indicates that root zone is fully saturated at all model nodes. The water contents are 90 mm for layer 1, 210 mm for layer 2, 1500 mm for layer 3 (channel nodes only), and 250 mm for layer 4 (upland nodes only). All channel nodes have a net infiltration and runoff rate of 5 mm/day. The run-on rates are variable across all model nodes, with increments of 10 mm for upland nodes and 5 mm for channel nodes. The maximum run-on rate of 690 mm/day occurs for the node at the mouth of the watershed (the last node listed in the output file). (RD requirements 2, 6, 7, 8, 10, 11, 12, 16)	Review file. See Test 4A.3, Note, for channel node identification	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
Test 4C: Infiltration, Net Infiltration, and Coupled Surface Water Flow Routing				
4C.1.	The results in the daily output file Test4c.v21 indicate that both runoff and runon are initiated on day 46. From day 46 through day 66, run-on is less than runoff. From day 67 on, run-on equals runoff. (RD requirements 6, 7, 8, 11, 12, 13)	Review file.	✓	
4C.2.	1) The results in the daily output file Test4c.v21 indicate that the infiltrated run-on (run-infil) term is greater than 0 for days 47 through 67 (this is the period during which routed surface water infiltrates into the deeper soils of the channel nodes). The infiltrated run-on term is 0 for all other days of the simulation. (2) The period for which infiltrated run-on occurs is longer compared to results obtained for test 4b. (RD requirements 6, 7, 8, 11, 12, 13)	1.) Review file. 2.) Review files Test4c.v21 and Test4b.v21. See Test 4A.3, Note, for channel node identification	✓ ✓	
4C.3.	The results in the daily output file Test4c.v21 indicate that net infiltration is initiated on day 50, 4 days after the initiation of runoff and run-on. From day 50 on, the net infiltration rate is constant at approximately 0.73 mm/day. (In contrast to results for test 4b, there is no period of increasing net infiltration because channel nodes are uniformly saturated from run-on) (RD requirements 6, 7, 8, 10, 11, 12, 13)	Review file.	✓	
4C.4.	The results in the average annual map file Test4c.v24 indicate that the average annual infiltrated run-on (run-infil) and net infiltration rates are greater than 0 only for channel nodes (nodes with 6 meters of soil). Unlike results obtained for test 4b, the net infiltration rates for channel nodes are uniform. (RD requirements 6, 7, 8, 10, 11, 12, 15)	Review file. See Test 4A.3, Note, for channel node identification	✓	
4C.5.	(1) Comparison of results between the daily map file for day 46 (Test4c2.v22) and 47 (Test4c3.v22) indicates a uniform increase in water content of approximately 40 mm for all channel nodes. All upland nodes are fully saturated and have a uniform runoff rate of 10 mm/day for both days. The run-on rates at all nodes are equivalent for both days. Net infiltration and runoff are 0 at all channel nodes for both days. (2) The water content of the bottom soil layer is uniform (982.1168 mm) across all channel nodes for both days, and is slightly less than fully saturated water content (1000 mm). (RD requirements 2, 6, 7, 8, 10, 11, 12, 16)	1.) Review files Test4c.v22 and Tet4c3.v22. 2.) Review file. See Test 4A.3, Note, for channel node identification	✓ ✓	
4C.6.	1.) The results of the daily map file for day 50 of the simulation (test4c6.v22) indicates a uniform net infiltration rate of 5 mm/day at all channel nodes. (2) Runoff at all channel nodes is 0, and the water content of the third soil layer is uniform (1017.54 mm) and is slightly greater than the fully saturated water content of 1000 mm. (3) The run-on rates for all model nodes are equivalent to the run-on rates obtained for days 46 and 47. The highest run-on rate (305.434 mm) occurs for the node at the mouth of the watershed (the last node listed in the output file). (RD requirements 2, 6, 7, 8, 10, 11, 12, 16)	1.) Review file. 2.) Review file. 3.) Review files Test4c2.v22, Test4c3.v22, and Test4c6.v22 See Test 4A.3, Note, for channel node identification	✓ ✓ ✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
4C.7.	1.) The results of the daily map file for day 65 of the simulation (test4c7.v22) indicates a uniform net infiltration rate of 5 mm/day at all channel nodes. (2) Runoff at all channel nodes is 0, and the water content of the third soil layer is uniform and is equal to the full saturation water content of 1500 mm. (3) The run-on rates for all model nodes are equivalent to the run-on rates obtained for days 46, 47, and 50. (4) Relative to day 47, the water content of the second soil layer has increased uniformly for all channel nodes, but is less than the saturated water content of 210 mm. (RD requirements 2, 6, 7, 8, 10, 11, 12, 16)	1. Review file. 2.) Review files test4c7.v22 , and refer to test4c.v26 for saturated water content calculation variables 3.) Compare files test4c2.v22, test4c3.v22, test4c6,v22 and test4c7.v22. 4.) Review files test4c3.v22 and test4c7.v22. See Test 4A.3, Note, for channel node identification	✓ ✓ ✓ ✓	
4C.8.	The results of the daily map file for day 66 of the simulation (test4c8.v22) indicates that the root zone profile is fully saturated for all model nodes. For upland nodes, the water contents are 90 mm for layer 1, 210 mm for layer 2, and 250 mm for layer 4. For channel nodes, the water contents are 90 mm for layer 1, 210 mm for layer 2, and 1500 mm for layer 3. A uniform net infiltration rate of 5 mm/day is occurring at all channel nodes, but the runoff rate is 0 at all channel nodes. The run-on rates have increased for all channel nodes relative to day 65. (RD requirements 2, 6, 7, 8, 10, 11, 12, 16)	Review file.	✓	
4C.9.	The results of the daily map file for day 67 of the simulation (test4c9.v22) indicates that a uniform net infiltration and runoff rate of 5 mm/day is occurring at all channel nodes. A maximum run-on rate of 690 mm/day occurs for the node at the mouth of the watershed (the last node listed in the output file). The run-on rates are variable across model nodes, with increments of 10 mm/day for upland nodes and 5 mm/day for channel nodes. (RD requirements 2, 6, 7, 8, 10, 11, 12, 16)	Review file.	✓	
Test 4D: Infiltration, Net Infiltration, and Coupled Surface Water Flow Routing				
4D.1.	The results in the daily output file Test4d.v21 indicate that both runoff and run-on occur following all storm events. Runoff is always greater than run-on because some run-on always infiltrates at downstream nodes. (RD requirements 1, 6, 7, 8, 11, 12, 13)	Review file.	✓	
4D.2.	The results in the daily output file Test4d.v21 indicate that infiltrated run-on (run-infil) is always greater following winter storm events (day 2 of each year) compared to infiltrated run-on following summer storm events (day 201 of each year). Infiltrated run-on following the first storm event (day 2 of the simulation) is approximately 120 mm. Infiltrated run-on following all subsequent winter storm events (day 2 of each year) is approximately 25 mm. Infiltrated run-on following all summer storm events (day 201 of each year) is approximately 4.2 mm. (RD requirements 1, 6, 7, 8, 11, 12, 13)	Review file.	✓	
4D.3.	The results in the daily output file Test4d.v21 indicate that the amount of precipitation infiltrating directly into the root zone profile (as indicated by the increase in the del-soil term) is greater during winter storms. Direct infiltration of precipitation during the first storm event (day 1 of the simulation) is approximately 120 mm. Direct infiltration of precipitation during all subsequent winter storm events (day 1 of each year) ranges from approximately 69 mm to approximately 68 mm. Direct infiltration of precipitation during all subsequent summer storm events (day 200 of each year) ranges from approximately 44 mm to approximately 43 mm. (RD requirements 1, 6, 7, 8, 11, 12, 13)	Review file.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
4D.4.	The results in the daily output file Test4d.v21 indicate that from day 2 on, net infiltration occurs for all remaining days of the simulation. During 1980 and 1981 storm events, the net infiltration rate is approximately 0.15 mm/day for all days when net infiltration occurs. Following the 1982 summer storm event (day 201), the maximum net infiltration rate increases to approximately 0.75 mm/day for several days immediately following summer storm events and for several weeks immediately following winter storm events. Following the 1984 summer storm event (day 201), the maximum net infiltration rate increases to 1 mm/day for several days immediately following summer storm events and for several weeks immediately following winter storm events. (RD requirements 6, 7, 8, 10, 11, 12, 13)	Review file.	✓	
4D.5.	1.) The results in the average annual map file Test4d.v24 indicate that the average annual precipitation rate is variable across model nodes and ranges from a maximum of approximately 1156 mm/year to a minimum of approximately 1086 mm/year. The infiltrated run-on rate (run-infil) ranges from a minimum of 0 at upland nodes along the watershed divide (nodes with shallow soils and 0 upstream nodes, as indicated by the parameters in Test4d.v22 (totout) to a maximum of approximately 109 mm/year for the node at the mouth of the watershed (the last node listed in the output file). All upland nodes along the watershed divide have a uniform net infiltration rate of approximately 13 mm/year. All upland nodes affected by surface water run-on have a uniform net infiltration rate of approximately 62 mm/year. (2) All channel nodes have a uniform net infiltration rate of approximately 365 mm/year. (RD requirements 2, 6, 7, 8, 10, 11, 12, 15)	1.) Review file Test4d.v24. (refer to file Test4d.v22 to identify upland nodes). 2.) Review file Test4d.v24 (refer to file test4d.v26 to identify channel nodes; these are lines 25, 34, 43, 45, 53, 62, 68, 71, 73, 74, and 75).	✓ ✓	
4D.6.	The results of the daily map file for day 1 of the simulation (test4d1.v22) indicates that net infiltration has not been initiated in direct response to precipitation (net infiltration is 0 at all nodes). However, the water contents for all channel nodes indicates a fully saturated root zone profile (30 mm for layer 1, 270 mm for layer 2, 1500 mm for layer 3). All upland nodes along the watershed divide have a uniform layer 2 water content of approximately 142 mm, while upland nodes affected by run-on have a higher layer 2 water content of approximately 185 mm. Runoff is 0 at all channel nodes, while for upland nodes runoff ranges from a minimum of approximately 485 mm to a maximum of approximately 516 mm. (RD requirements 2, 6, 7, 8, 10, 11, 12, 16)	Review file. Refer to Test4D.5 for explanation of upland and channel nodes.	✓	
4D.7.	The results of the daily map file for day 2 of the simulation (test4d2.v22) indicates that for all channel nodes the layer 1 water content has decreased to 29 mm, and net infiltration is 1 mm. The layer 2 and 3 water contents remains at full saturation (270 mm for layer 2, 1500 mm for layer 3) at all channel nodes. For upland nodes along the watershed divide, water contents for the two soil layers remain unchanged relative to day 1. For upland nodes affected by run-on, the layer 2 water content has decreased to the field capacity water content of 180 mm, while the layer 4 water content has increased to approximately 5 mm (the soil layer has drained into the rock layer). The layer 1 water content for all upland nodes is at the field capacity water content of 20 mm. (RD requirements 2, 6, 7, 8, 10, 11, 12, 16)	Review file. (Refer to file test4d.v26 for field capacity and cdepth of layers to estimate field capacity water content.)	✓	
4D.8.	The results of the daily map file Test4d3.v22 for day 931 (day 200, 1982) indicates that the root zone is fully saturated at all channel nodes, and net infiltration of 1 mm is occurring in direct response to precipitation. Net infiltration is 0 at all upland nodes, and runoff has been generated at all nodes, including channel nodes. (RD requirements 2, 6, 7, 8, 10, 11, 12, 16)	Review file.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
4D.9.	1.) The results of the daily map file Test4d4.v22 for day 932 (day 201, 1982) indicates that for upland nodes affected by surface water run-on, water from soil layer 2 has drained into the rock layer (this is indicated by a comparison of results between day 931 and 932). The rock layer water content is at the effective storage capacity water content of 250 mm, and net infiltration is 1 mm. (2) For upland nodes along the watershed divide, the bottom soil layer has also drained into the rock layer, but net infiltration is 0 because the water content of the rock layer is below 250 mm. Net infiltration of 1 mm has occurred at all channel nodes, and the water content of the top soil layer has decreased from 30 to 29 mm. (RD requirements 2, 6, 7, 8, 10, 11, 12, 16)	1.) Review files Test4d4.v22 and test4d3.v22. 2.) Review file Test4d4.v22.	✓ ✓	
4D.10	The results of the daily map file Test4d5.v22 for day 1661 (day 200, 1984) indicates a net infiltration rate of 1 mm/day in response to infiltrated precipitation for all nodes except upland nodes along the watershed divide not affected by surface water run-on. For upland nodes affected by run-on, water contents of the two soil layers are above the field capacity water contents (20 mm for layer 1, 180 mm for layer 2), but below the full-saturation water contents (30 mm for layer 1, 270 mm for layer 2). Runoff is being generated at all model nodes. (RD requirements 2, 6, 7, 8, 10, 11, 12, 16)	Review files Test4d5.v22. Refer to file Test4d5.v26 for field capacity and soil porosity used to calculate field capacity water content and full-saturated water content.	✓	
4D.11	The results of the daily map file Test4d6.v22 for day 1662 (day 201, 1984) indicates a net infiltration rate of 1 mm/day at all model nodes. For upland nodes not affected by surface water run-on, drainage from the bottom soil layer into the rock layer has increased the rock layer water content to 250 mm, allowing net infiltration to occur at the maximum rate defined by the bedrock bulk saturated hydraulic conductivity of 1 mm/day. The water content of the top soil layer for all upland nodes is at the field capacity water content of 20 mm. The water content of the second soil layer for all upland nodes is above the field capacity water content of 180 mm but below the full saturation water content of 270 mm. (RD requirements 2, 6, 7, 8, 10, 11, 12, 16)	Review file.	✓	
4D.12	1.) Comparison of results between the daily map file for day 1662 (Test4d6.v22) and 1668 (Test4d7.v22) indicates a uniform decrease in the root zone water content of 6 mm for all nodes affected by surface water run-on (refer to Test4d5.v22), corresponding to a net infiltration rate of 1 mm/day at these nodes. (2) For upland nodes not affected by surface water run-on, the decrease in water content is slightly less than 6 mm, and the net infiltration rate for day 1668 is slightly less than 1 mm/day. The bottom root zone layer is at the full-saturation water content for all nodes (layer 4 has 250 mm for upland nodes, layer 3 has 1500 mm for channel nodes). The water content of the top soil layer is at the field capacity water content of 20 mm for all upland nodes, and 23 mm for all channel nodes. (RD requirements 2, 6, 7, 8, 10, 11, 12, 16)	1.) Review files Test4d6.v22 and Test4d7.v22. 2.) Refer to file Test4d7.v22	✓ ✓	
Test 4E: Infiltration, Net Infiltration, Evapotranspiration, and Coupled Surface Water Flow Routing				
4E.1.	For the first day of the simulation, the results in the daily output file Test4e.v21 indicate an increase in root zone water content of approximately 103 mm, a runoff amount of approximately 457 mm, and outflow (run-on) from the watershed of approximately 369 mm. Evapotranspiration is approximately 3.5 mm on the first day, and net infiltration is 0 mm. (RD requirements 6, 7, 8, 9, 10, 11, 12, 13)	Review file.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
4E.2.	For the second day of the simulation, the results in the daily output file Test4e.v21 indicate that approximately 87.5 mm of run-on has infiltrated into the root zone. There is a net increase of approximately 69.5 mm in the root zone water content, and the net infiltration rate is approximately 14.7 mm/day. The evapotranspiration rate has decreased to approximately 3.35 mm/day. (RD requirements 6,,7, 8, 9, 10, 11, 12, 13)	Review file.	✓	
4E.3.	The results provided in the daily output file Test4e.v21 indicate that, with the exception of the last summer storm occurring on day 2027, the net infiltration rate is 0 for all summer storms (precipitation occurring on day 200 of each year). Infiltrated run-on is approximately 14.6 mm following all summer storms, which is less then the infiltrated run-on of approximately 87 to 86 mm following all winter storms. (RD requirements 6, 7, 8, 10, 11, 12, 13)	Review file.	✓	
4E.4.	The results provided in the average annual map file Test4e.v24 indicate that the average annual evapotranspiration rate is 0 for upland nodes along the watershed divide, approximately 144 mm/year for upland nodes with 1 to 4 upstream nodes, and approximately 330 mm/year for channel nodes. The average annual net infiltration rate is approximately 0.8 mm/year for upland nodes along the watershed divide, approximately 0.2 mm/year for upland nodes having 1 to 4 upstream nodes, and approximately 626 mm/year at all channel nodes. (RD requirements 2, 6, 7, 8, 9, 10, 15)	Review files Test4E.v24, T1c.W20 (to identify upstream nodes), and Test4e.v26 to identify channel and upland nodes. (See file "Test4E additional" created for convenience.) Watershed divide nodes "0" depth: 1through 7; 23, 29 through 31, 35, 37, 38, 42, 44 48, 50, and 52. Channel nodes: 25, 34, 45, 53, 62, 68, 71, 73 through 75.	✓	
4E.5.	1) The results provided in the daily map file for day 1 of the simulation (Test4e1.v22) indicate that net infiltration is 0 mm at all nodes. Thus, net infiltration has not been initiated in direct response to precipitation rates ranging from a maximum of approximately 578 mm/day to a minimum of approximately 543 mm/day. (2) The water content of the rock layer (layer 4) is 5 mm for all upland nodes having no soil cover, and this agrees with the 12-hour maximum infiltration capacity defined by the bedrock bulk saturated hydraulic conductivity of 10 mm/day. For channel nodes, the water contents of the first and second soil layers are at the field capacity water contents (20 mm for layer 1, 180 mm for layer 2), while the water content of the third soil layer is greater than the field capacity water content (1000 mm). (RD requirements 2, 6, 7, 8, 10, 11, 12, 16)	1.) Review file Test4e1.v22. 2.) Review files Test4e1.v22 and Test4e.v26 for cdepth and field capacity values to calculate field water content.	✓ ✓	
4E.6.	1) The results provided in the daily map file for day 1 of the simulation (Test4e1.v22) indicate that total outflow of surface water form the watershed is equal to approximately 27690 mm. This is calculated as the sum of the runoff and run-on for the node at the mouth of the watershed (approximately 96 mm runoff plus 27594 mm run-on, as indicated for the last node listed in Test4e1.v22). The total outflow divided by the number of active model nodes (75) equals the average daily run-on term in the daily output file Test4e.v21 (approximately 369.2 mm). (2) The daily mean discharge rate calculated using the total outflow provided in Test4e1.v22 is approximately 10.2 cubic-feet-per-second, and this agrees with the two discharge rates provided in the daily output file (Test4e.v21). (RD requirements 2, 6, 7, 8, 9, 10, 11, 12, 16)	1.) Review file. 2.) See Attachment A2-1, Conversions.	✓ ✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
4E.7.	Results provided in the daily map file for day 1828 (Test4e7.v22) indicate that net infiltration is occurring in direct response to precipitation at upland nodes with no soil cover and at all channel nodes. Net infiltration at upland nodes with no soil cover is approximately 4.2 mm/day, and net infiltration at all channel nodes is 100 mm/day. Precipitation ranges from a maximum of approximately 578 mm at the highest elevation node (the first node listed in the output) to a minimum of approximately 543 mm at the lowest elevation node (the last node listed). The water contents of the soil layers for all channel nodes are at the full saturation water contents of 30 mm for layer 1, 270 mm for layer 2, and 1500 mm for layer 3. The layer 4 water content for upland nodes with soil cover is slightly less than the effective storage capacity of 25 mm. (RD requirements 2, 6, 7, 8, 9, 10, 16)	Review file.	✓	
4E.8.	Results provided in the daily map file for day 1829 (Test4e8.v22) indicate that net infiltration has stopped at all upland nodes along the watershed divide (nodes with no soil cover). The water content of layer 4 for these nodes is exactly 30 mm. (RD requirements 2, 6, 7, 8, 10, 16)	Review file Test4e8.v22. See file test4e.v26 for cdepth.	✓	
4E.9.	1) Results provided in the daily map file for day 1829 (Test4e8.v22) indicate a net infiltration rate of 1 mm/day for all upland nodes with 1 to 4 upstream nodes (and 1 meter soil cover), in response to infiltrated run-on from the storm of the previous day. (2.) The water content of layer 4 for these nodes is at the effective storage capacity water content of 25 mm, but the water contents of the two overlying soil layers are below the field capacity water contents of 20 mm for layer 1 and 180 mm for layer 2. (RD requirements 2, 6, 7, 8, 10, 11, 16)	1.) Review file Test4e8.v22. and T1c.W20 (See file "Test4E additional" created for convenience.) 2.) Review file Test4e8.v22.	✓ ✓	
4E.10.	Results provided in the daily map file for day 1829 (Test4e8.v22) indicate soil layers 1 and 2 have drained into soil layer 3 at all channel nodes. This is indicated by water contents for the upper soil layers that have decreased from full saturation to slightly below the field capacity water contents. The layer 3 water content has remained at approximately 1500 mm (full saturation), even though net infiltration of 100 mm has occurred at all channel nodes. (RD requirements 2, 6, 7, 8, 9, 10, 11, 16)	Review file.	✓	
4E.11.	Results provided in the daily map file for day 2027 (Test4e9.v22) indicate that net infiltration of approximately 0.83 mm has occurred at upland nodes with no soil cover. The infiltration rate is consistent with the maximum infiltration capacity for a summer storm and a bedrock bulk saturated hydraulic conductivity of 10 mm/day (10*(2/24) = 0.8333). Net infiltration is 0 at all other model nodes. (RD requirements 2, 6, 7, 8, 9, 10, 11, 16)	Review file. See file test4e.v26 for bedrock ks = 10mm/dy. See Infilv2.for for summer storm duration = 2 hours, recognizing 2/24 is the fraction of the day for storm input.	✓	
4E.12.	Results provided in the daily map file for day 2028 (Test4e0.v22) indicate that net infiltration has not occurred in response to infiltrated run-on. The layer 2 water content is below the field capacity water content of 180 mm at all nodes, and thus there has been no drainage of water through the second soil layer. (RD requirements 2, 6, 7, 8, 9, 10, 11, 16)	Review file.	✓	
Test 4F: Infiltration, Net Infiltration, Evapotranspiration, and Coupled Surface Water Flow Routing				
4F.1.	Comparison of results in the daily output files for test 4f (Test4f.v21) and test 4e (Test4e.v21) indicates that runoff, run-on, and infiltrated run-on are slightly higher per storm event for test case 4f relative to 4e. The total runoff for test 4f is approximately 6045 mm, compared to approximately 5923 mm for test 4e. The total run-on for test 4f is approximately 5433 mm, compared to approximately 5316 mm for test 4e. (RD requirements 1, 6, 7, 8, 9, 10, 11, 13)	Review files Test4f.v21 and Test4e.v21. Confirm parameter relationships using spreadsheet summation function. Refer to file, column AB for summations using spreadsheet function.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
4F.2.	1.) Comparison of results in the daily output files for test 4f (Test4f.v21) and test 4e (Test4e.v21) indicates that net infiltration during winter storm events is lower for test 4f compared to test 4e. Starting in 1981, net infiltration on day 1 of each year is approximately 2.3 to 2.6 mm for test 4f, compared to approximately 14.7 to 15.7 mm for test 4e. For test 4f, net infiltration is 0 for the last summer storm event in 1985, compared to 0.2 mm for test 4e. (2) Total net infiltration for test 4f is approximately 361 mm, compared to approximately 552 mm for test 4e. (RD requirements 6, 7, 8, 9, 10, 11, 13)	1.) Review and compare files Test4f.v21 and Test4e.v21. 2.) Sum and compare total net infiltration.	✓ ✓	
4F.3.	Comparison of results in the daily output files for test 4f (Test4f.v21) and test 4e (Test4e.v21) indicates that the maximum evapotranspiration rate in response to each storm event is lower for test 4f compared to test 4e. Maximum evapotranspiration for test 4f is less than 3 mm/day for winter storms and less than 1 mm/day for summer storms, whereas for test 4e maximum evapotranspiration is greater than 3 mm/day for both winter and summer storms. Total evapotranspiration for the entire simulation, however, is greater for test 4f (approximately 920 mm) relative to test 4e (approximately 808 mm). (RD requirements 6, 7, 8, 9, 10, 11, 13)	Review files Test4f.v21 and Test4e.v21. Maximum summer storm is day 200 of every year. Maximum winter storm is day 1 of each year. Refer to file, column AB for summation of evapotranspiration using spreadsheet function.	✓	
4F.4.	Results provided in the average annual map file Test4f.v24 indicate that the average annual evapotranspiration rate is approximately 5.8 mm/year for upland nodes along the watershed divide, approximately 115 mm/year for upland nodes with 1 to 4 upstream nodes, and approximately 566 mm/year for channel nodes. The average annual net infiltration rate is 0 mm/year for all upland nodes, and approximately 410 mm/year at all channel nodes. (RD requirements 6, 7, 8, 9, 10, 11, 15)	Review file Test4f.v24. Refer to Test4E4 for node identification (tests use same geospatial input, T1c.W20).	✓	
4F.5.	1.) Results provided in the daily map file for day 1 of the simulation (Test4f1.v22) indicates that net infiltration has not been initiated in direct response to precipitation (net infiltration is 0 at all nodes). The water content of the rock layer (layer 4) is 0 for all upland nodes having 1 meter of soil cover (upland nodes downstream of the watershed divide). (2) The water content of the rock layer for upland nodes on the watershed divide is approximately 4.2 mm, which is less than the water contents of 5 mm obtained for test 4e on day 1. (RD requirements 2, 6, 7, 8, 10, 16)	1.) Review file. 2.) Review and compare files Test4f1.v22 and Test4e1.v22.	✓ ✓	
4F.6.	1.) Results provided in the daily map file for day 1 of the simulation (Test4f1.v22) indicate that total outflow of surface water form the watershed is equal to approximately 27934 mm. This is calculated as the sum of the runoff and run-on for the node at the mouth of the watershed (approximately 100 mm runoff plus 27834 mm run-on, as indicated for the last node listed in Test4f1.v22). The total outflow divided by the number of active model nodes (75) equals the average daily run-on term in the daily output file Test4f.v21 (approximately 372.4 mm). (2) The daily mean discharge rate calculated using the total outflow provided in Test4f1.v22 is approximately 10.3 cubic-feet-per-second, and this agrees with the discharge rate provided in the daily output file (Test4f.v21). (RD requirements 2, 6, 7, 8, 9, 10, 11, 12, 13, 16)	1.) Review file. 2.) See Attachment A2-1, Conversions	✓ ✓	
4F.7.	1.) Results provided in the daily map file for day 2 (Test4f2.v22) indicate uniform net infiltration rates of 100 mm/day at all channel nodes. (2) The layer 4 water content for all upland nodes is approximately 3.6 mm (this is less than the layer 4 water contents of approximately 4.4 mm obtained for test 4e (Test4e2.v22) on day 2). (RD requirements 2, 6, 7, 8, 10, 16)	1.) Review file. Refer to Test4E4 for node identification (tests use same geospatial input, T1c.W20). 2.) Review and compare files Test4f2.v22 and Test4e2.v22.	✓ ✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
4F.8.	Results provided in the daily map file for day 4 of the simulation (Test4f4.v22) indicate a uniform net infiltration rate of approximately 61 mm/day at all channel nodes, which is less than the results obtained for test 4e. The layer 4 water contents at upland nodes range from approximately 2.4 to 2.5 mm, compared to water contents ranging from 4 to 5 mm obtained for test 4e. The layer 1 water content is 20 mm at all nodes with a soil thickness of 1 or 6 meters, compared to a layer 1 water content of approximately 12 mm for test 4e. (RD requirements 2, 6, 7, 8, 10, 16)	Review and compare files Test4f4.v22 and Test4e4.v22.	✓	
4F.9.	Results provided in the daily map file for day 1828 (Test4f6.v22) indicate net infiltration rates (in direct response to precipitation) of 0 mm/day at all upland nodes and approximately 17 mm/day at all channel nodes. These net infiltration rates are much lower than results obtained for test 4e (Test4e7.v22), which include a net infiltration rate of 100 mm/day at all channel nodes. (RD requirements 2, 6, 7, 8, 10, 16)	Review file Test4f6.v22 and compare with file Test4e7.v22.	✓	
4F.10.	Results provided in the daily map file for day 1828 (Test4f6.v22) indicate water contents for layer 4 at all upland nodes are less than 5 mm, compared to water contents of 22 to 30 mm for test 4e (Test4e7.v22). For test 4f, the water contents of the first and second soil layer at channel nodes are at the field capacity water contents (20 mm for layer 1, 180 mm for layer 2), while the water content of soil layer 3 is approximately 1431 mm. These water contents show a drier root zone profile compared to results obtained for test 4e, which show a fully saturated root zone profile at channel nodes for day 1828. (RD requirements 2, 6, 7, 8, 16)	Review file Test4f6.v22 and compare with file Test4e7.v22.	✓	
4F.11.	1.)Results provided in the daily map file for day 1829 (Test4f7.v22) indicate that the upland nodes with no soil cover have dried relative to day 1828 due to transpiration (the layer 4 water content at all nodes has decreased from approximately 4.2 to 3.6 mm). The layer 4 water content for upland nodes with 1 meter soil cover has increased from approximately 0.007 to 22.3 mm due to drainage from soil layer 2, which still has a water content slightly higher than the field capacity water content of 180 mm. (2) These results are in contrast to results obtained for test 4e (Test4e8.v22), which show the soil layers having water contents slightly less than the field capacity water contents, and a layer 4 water content equal to the effective storage capacity of 25 mm. (RD requirements 2, 6, 7, 8, 9, 16)	`1.)Review and compare files Test4f6.v22 and Test 4f7.v22. 2.) Review and compare files Test4f7.v22 with Test4e8.v22.	✓ ✓	
4F.12.	Results provided in the daily map file for day 1829 (Test4f7.v22) indicate that net infiltration is not occurring at upland nodes, while for test 4e (Test4e8.v22) a net infiltration rate of 1 mm/day occurs at all upland nodes with 1 meter soil cover. Both tests indicate a uniform net infiltration rate of 100 mm/day at all channel nodes, but layer 3 is very close to full saturation (water content of 1500) for test 4e, while layer 3 is drier for test 4f (water content of approximately 1329 mm). For test 4f, the water content for layer 1 remains at the field capacity water content (20 mm) for all nodes with soil cover. The differences in results between the 2 tests are consistent with the differences in the specified root densities for the two tests. (RD requirements 2, 6, 7, 8, 10, 16)	Review and compare files Test4f7.v22 with Test4e8.v22.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
4F.13.	Results provided in the daily map file for day 2027 (Test4f9.v22) indicate that net infiltration is not occurring in response to precipitation during the final summer storm event in the simulation period. This result is in contrast to results obtained for test 4e (Test4e9.v22), which shows the occurrence of net infiltration at upland nodes with no soil cover. For test 4f, the layer 4 water content at all upland nodes is only slightly greater than 0, as compared to results for test 4e which show water contents that are at the effective storage capacity water contents of 25 and 30 mm for upland nodes. (RD requirements 2, 6, 7, 8, 10, 16)	Review and compare files Test4f9.v22 and Test4e9.v22.	✓	
Test 5A: Snow Cover Accumulation				
5A.1.	Results provided in the daily output file Test5a.v21 indicate that all precipitation occurred as snow, with snowfall = precipitation = 1 mm/day for all days simulated. Total precipitation equals total snowfall, which equals 2192 mm. The snow-cover term on the final day of the simulation (day 2192) equals 2192 mm. All remaining water balance terms are 0. (RD requirements 4, 5, 6, 7, 8, 13)	Review file.	✓	
5A.2.	Results provided in the daily output file Test5a.v21 indicate that potential evapotranspiration, and thus sublimation, is 0 for all days simulated. (RD requirements 4, 5, 6, 7, 8, 13)	Review file.	✓	
5A.3.	Results provided in the daily output file Test5a.v21 indicate the daily air temperature is a constant –49.3 C for all days simulated (the –50 C input value is adjusted for elevation). (RD requirements 4, 5, 6, 7, 8, 13)	Review file.	✓	
5A.4.	The average annual map file (Test5a.v24) indicates a precipitation rate and snowfall rate of 365.25 mm/year, and an average annual snow cover term of approximately 400496 mm/year (although this term has no physical meaning, it is used as part of the validation for water balance calculations). All remaining terms in the average annual map file are 0. (RD requirements 4, 5, 7, 8, 15)	Review file.	✓	
Test 5B: Sublimation				
5B.1.	Results provided in the daily output file Test5b.v21 indicate that all precipitation occurred as snow. Snowfall and precipitation are equal to 1 mm/day for all days simulated. Total precipitation and snowfall of 2192 mm is greater than the snow-cover term of approximately 2000 mm on the final day of the simulation, because some of the snow has been lost to sublimation. (RD requirements 4, 5, 6, 7, 8, 13)	Review file.	✓	
5B.2.	Results provided in the daily output file Test5b.v21 indicate that potential evapotranspiration is greater than 0 for all days simulated. Sublimation occurs as a fraction of potential evapotranspiration, and thus is also greater than 0 for all days simulated. Potential evapotranspiration ranges from a minimum of approximately 0.3 mm/day to a maximum of approximately 1 mm/day, while sublimation ranges from a minimum of approximately 0.04 mm/day to a maximum of approximately 0.13 mm/day. (RD requirements 3, 4, 5, 6, 7, 8, 13)	Review file.	✓	
5B.3.	Results provided in the daily output file Test5b.v21 indicate that daily air temperature is a constant –9.3 degrees C for all days simulated (the –10 C input value is adjusted for elevation). (RD requirements 4, 5, 6, 7, 8, 13)	Review file.	✓	
5B.4.	Results provided in the daily output file Test5b.v21 indicate that excluding precipitation, snowfall, snow-cover, sublimation, and potential evapotranspiration, all other daily water balance terms are 0, and the daily water balance check is satisfied for all days simulated. (RD requirements 3, 4, 5, 6, 7, 8, 13)	Review file. Refer to Attachment A2-1, Item 14 for Equation 2.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
5B.5.	Results provided in the average annual map file (Test5b.v24) indicates a precipitation rate equal to the snowfall rate of 365.25 mm/year for all model nodes. (RD requirements 4, 5, 6, 7, 8, 15)	Review file.	✓	
5B.6.	Results provided in the average annual map file (Test5b.v24) indicate that snow-cover and sublimation are variable across model nodes, even though precipitation and snowfall are uniform. Average annual sublimation rates range from a minimum of approximately 29 mm/year to a maximum of approximately 36 mm/year. The variability is due to the combined effects of variability in potential evapotranspiration in response to topographic effects on shading, sun-angle, and intensity of incoming solar radiation, and variability in air temperature as a function of elevation. (RD requirements 3, 4, 5, 6, 7, 8, 15)	Review file.	✓	
5B.7.	Results provided in the average annual map file (Test5b.v24) indicate that except for precipitation, snowfall, snow-cover, and sublimation, all remaining terms in the average annual map file are 0, and the water balance is satisfied for all model nodes. (RD requirements 3, 4, 5, 6, 7, 8, 15)	Review file. Refer to Attachment A2-1, Item 14 for Equation 2.	✓	
Test 5C: Snowfall and Snow Cover Distribution				
5C.1.	Results provided in the daily output file Test5c.v21 indicate a constant daily precipitation rate of 2 mm/day, with approximately 1.25 mm/day occurring as rain and 0.75 mm/day occurring as snow. Average daily air temperature is constant at 0.1 degrees C. (RD requirements 4, 5, 6, 7, 8, 13)	Review file.	✓	
5C.2.	Results provided in the daily output file Test5c.v21 indicate that potential evapotranspiration, actual evapotranspiration, and sublimation are variable through time. Potential evapotranspiration ranges from a minimum of approximately 0.48 mm/day to a maximum of approximately 1.5 mm/day. Sublimation ranges from a minimum of approximately 0.02 mm/day to a maximum of approximately 0.07 mm/day, and evapotranspiration ranges from a minimum of approximately 0.19 mm/day to a maximum of approximately 0.86 mm/day. (RD requirements 3, 4, 5, 6, 7, 8, 13)	Review file.	✓	
5C.3.	Results provided in the daily output file Test5c.v21 indicate that total snow-cover on the last day simulated is approximately 1529.2 mm, which is less than the total snowfall of approximately 1636.7 mm because of sublimation. (RD requirements 4, 5, 6, 7, 8, 13)	Review file.	✓	
5C.4.	Results provided in the daily output file Test5c.v21 indicate that snowmelt is 0 for all days simulated. Infiltrated run-on (run-infil) is 0 for the first 369 days simulated. Net infiltration ranges from a maximum of approximately 0.5 mm/day to a minimum of 0. (RD requirements 4, 5, 6, 7, 8, 9, 10, 11, 13)	Review file.	✓	
5C.5.	Results provided in the average annual map file (Test5c.v24) indicate that the average annual net infiltration rate is 0 for the first 28 model nodes (these nodes are all at higher elevation than the remaining model nodes). For the remaining model nodes (nodes 29 through 75), all precipitation occurs as rain (at a rate of 730.5 mm/year) and the net infiltration rate ranges from a maximum of 249 mm/year to a minimum of 225 mm/year. The average annual snowmelt and infiltrated run-on rates (run-infil) are 0 at all nodes. For nodes 1 through 28, all precipitation occurs as snow, and with the exception of the snow-cover and sublimation terms, all other components of the water balance are 0. (RD requirements 3, 4, 5, 6, 7, 8, 9, 10, 11, 15)	Review File.	✓	

Test Case	Criteria Description	VTP Test Step	Pass	Fail
Test 5D: Spatial and Temporal Distribution of Snowfall and Snow Cover				
5D.1.	Results provided in the daily output file Test5d.v21 indicate a constant daily snowfall rate of 2 mm/day from day 293 through day 105 of the following year, and a corresponding rainfall rate of 0 mm/day. From day 105 through day 109 of each year, snowfall is reduced from 2 mm/day to 0 mm/day while rain is increased from 0 mm/day to 2 mm/day. From day 109 through day 289 of each year, the rainfall rate is constant at 2 mm/day while the snowfall rate is 0 mm/day. (RD requirements 4, 5, 6, 7, 8, 13)	Review file.	✓	
5D.2.	Results provided in the daily output file Test5d.v21 indicate that starting on day 290 of each year except 1980, the snow-cover term shows an accumulating snow pack with a maximum snow pack depth (water equivalent) of approximately 354 to 356 mm (depending on leap year) on day 107 of the following year. From day 108 through day 142, the snow-cover term shows a continuous decrease to 0 mm in response to melting. (RD requirements 4, 5, 6, 7, 8, 13)	Review file.	✓	
5D.3.	Results provided in the daily output file Test5d.v21 indicate a sublimation rate greater than 0 for all days having snow-cover greater than 0. The sublimation rate shows an increase from approximately 0.16 mm/day to more than 0.7 mm/day during the onset of snow-melt and transpiration from the root zone underlying the snowpack. As the air temperature increases to above freezing, the snow-melt term increases from 0 to a maximum rate of approximately 18 to 19 mm/day on day 138 of each year except 1980. (RD requirements 4, 5, 6, 7, 8, 13)	Review file.	✓	
5D.4.	Results provided in the daily output file Test5d.v21 indicate that with the exception of 1980, runoff and run-on are initiated in response to snow melt on day 123 of each year. Run-on is less than runoff for all days on which runoff occurs because surface water is allowed to infiltrate into the root zone. (RD requirements 4, 5, 6, 7, 8, 11, 13)	Review file.	✓	
5D.5.	Results provided in the daily output file Test5d.v21 indicate that with the exception of 1980, net infiltration is initiated on day 106 of each year in response to the combined onset of snowmelt and precipitation occurring as rain. After the period of snowmelt, net infiltration decreases in response to increasing evapotranspiration, then increases as potential evapotranspiration rates decrease with the onset of winter. A maximum net infiltration rate of 1 mm/day occurs on day 293 of each year (except 1980) because evapotranspiration decreases to 0 as air temperature drops below freezing. (RD requirements 4, 5, 6, 7, 8, 9, 10, 13)	Review file.	✓	
5D.6.	Results provided in the average annual map file (Test5d.v24) indicate variable average annual net infiltration rates ranging from a maximum of approximately 147 mm/year to a minimum of approximately 124 mm/year. With the exception of the run-infil and the run-on terms, all components of the water balance are greater than 0 at all nodes, and all components of the water balance show variability across model nodes in response to topographic effects (elevation, blocking ridges, and surface water routing). (RD requirements 3, 4, 5, 6, 7, 8, 9, 10, 11, 15)	Review file.	✓	

Attachment A2-1: Additional information and examples

Background Information

Conversions

i.) mm/day to cfs:
Totout in the output refers to run-on depth, in mm. To compare *.v21 with *.v22, find the sum of the totout + run-off terms in *.v22 at the watershed pour-point cell (last node), convert metric to English, and convert rate to cubic-feet-per-second to compare this value with the discharge value in test0a.v21.

$$\text{cfs} = (\text{mm/day}(\text{grid cell area in m}^3)\ (35.31\ \text{ft}^3)) / ((1000)(24)(60)(60))$$

ii.) Average daily run-on term: The total outflow of surface water form the watershed is equal the sum of the runoff and run-on for the node at the mouth of the watershed (the last node listed in the ".v22" file. The total outflow divided by the number of active model nodes (75) equals the average daily run-on term in the daily output file ".v21". The daily mean discharge rate calculated using the total outflow provided is converted to cubic-feet-per-second, and this agrees with the two discharge rates provided in the daily output file ".v21".

Common Parameters

(Layer thickness is reported as cdepth in meters; the following properties are reported in millimeters)

rkmm = effective bedrock storage capacity = rkpor*cdepth(4,ia)*1000.

scapmm ; soil storage capacity = ((soilporo - soilresid) x cdepth x 1000.)

Example from test1b.v22:

scapmm3	soilmm(3)	soilresid	cd3	soilporo
117.6	112	0.028	0.4	0.322

scapmm3 = (.322 - .028)(.4)(1000) = 117.6

fcmm = soil field capacity = (fc x cdepth x 1000)

soil field capacity = (fc x cdepth x 1000) = 0.2 x 0.3 x 1000

soilmm = soil water content= full saturated water content = (soilporo x depth x 1000)

Example from Test3F.6

soilmm = soil water content= **full saturated water content**
= (soilporo x depth x 1000)
= 0.3 x 0.7 x 1000
= 210

Clarification and Comment

i.) Test "v" output files:
Column labels for test sequence output files were not included in all test output files designated as "v". A guide to these columns is provided in this attachment. Additionally, all test case output files were converted to EXCEL files with labeled columns.

The program run results correctly produce the required output, "v" files for all test cases; however, the file names for some files in the Summary Statistic file differs from that in the INFILv2.CTL file, and the output files identified in the Validation Test Report (VTR) or Requirements Document (RD). The files are identified in the INFILv2.CLT files as follows:

test0a.v21	dayall: (RD: Average daily output/mass balance terms)
test0a.v22	ndaymap, (RD: 24-hour mass balance map)
test0a.v23	daily mass balance (RD: Annual summary/Summary statistics file)
test0a.v24	total daily fluxes (RD: Average annual map output;VTP: Daily output file)
test0a.v25	annual mass balance terms (RD: Secondary daily output)
test0a.v26	new debug file (RD: Root zone layer parameter output)

The Summary Statistics output file identifies the files as follows:

Average daily mass balance terms	test0a.v21
24-hour mass balance map	test0a.v22
Annual mass balance map	test0a.1
Average annual mass balance map:	test0a.v24
Summary statistics output	test0a.v23
Debugging output	test0a.v25

The following example is a comparison of files with different names in the summary output file.

Annual mass balance map: test0a.1 is referred to as a test0a.v25 file.
Average annual mass balance map: test0a.v24 is referred to as test0a.v24.
Debugging output:test0a.v25 is referred to as test0a.v26.

The difference in file names does not impact the functionality of the program. The file names used in the Requirements Document are commonly used in the validation test report.

ii.) For test case criteria requiring verification of summation and simple statistics, the EXCEL version of the file under review includes the summation or statistic in the columns to the right of the data.

Common Parameter Definitions

aaprepx	average annual precip for area of potential repository
BARSOIL	bare soil et parameters
BSOIL (bsoil)	estimated or fitted parameter for relative proportion of total et at bare soil
depth and cdepth:	thickness of root zone (m)
discharge	cfs
drmm (1-4)	drmm1 = soilmm(1,ia)-fcmm1
easting and northing:	(m)
elevation:	(m)
et	evapotranspiration
fcmm(1)	fieldcp*cdepth(1,ia)*1000
fieldcap:	field capacity (m3/m3)
flow-in	sum of all run-on components (contribution from all cells) for a given grid cell
flow-out	surface water that leaves cell and continues downstream
fract-infil	net infiltration interms of fracture flow.
ifrtol	flow routing tolerence term
imbibe:	Ksat (mm/day)
imb2:	imbibe*(365.2)
infilmm(ia)	drmm4 + rinfmm2(ia)
IVEGC	invoke vegetation map cover in et calculation under certain conditions
iwat	downstream identification no.
idepth	(1 - 4); root zone parameter line index number;
petday	potential ET per day
petrsday	total potential ET per day
potis	initital condition water potential
pptloc	average daily precip for each grid cell
RDEPTH	root zone depth (1-4); index variable to associate root zone parameters to soil depth class IDPTH.
RTZA(B, C, and D)	estimated or fitted parameter for function defining root density as a function of depth
rockmm:	Initial rock water content (mm)
rkmm	effective bedrock storage capacity
rkmmfact	initial rock water content condition
run-infil	surface water flow infiltration
outflow	run-off from cell that is being routed to downstream cell (at the receiving cell, it is called run-on)
runoff (run)	water that has not been routed; water that accumulates in surface depressions and basins or contributes to surface water flow (which is routed to downstream locations as run-on)
run-on	flow depth being added to water budget of a cell; water that contributes to either infiltration or accumulated surface-water run-on at downstream locations.(see upstream node)
scapmm	storage capacity (mm)
SCAPMMT	total water storage capacity is the sum of the soil layers' capacities
SDFACT	soil depth scaling factor
skmm:	soil permeability (mm/day); saturated soil ksat (skmm)
sksfact	soil permeability scaling fact
ROCKRESID	(rockid), real m^3/m^3, ($0 \leq$ rockresid $\leq$ rockcap). Estimated or measured residual water content for evapotranspiration.
sl (slope):	measure from horizontal (degrees)

Common Parameter Definitions (cont'd)

soilmm	soil water content: soilvwc(ia)*cdepth(i,ia)*1000.
soilporo	soil porosity (m3/m3)
soilresid:	residual water (mm)
tetday	total annual ET
temperature	degrees centigrade
TotoutC	in the input refers to the number of upstream cells.
Totout	in the output refers to run-on depth, in mm.
upstream node	The surface water run-on depth is calculated as runoff generated and routed from upstream grid cells.
wilting point	soilporo -fieldcap

Explanations and Examples

1. Program Files

A. Test1A, Model Control File

```
INFILv2.ctl: INFIL v2.0 VTP test case 1a, run code t1-1a-v2-w20 (5/27/1999)
1                                   OPTMASSB
0  0.00000001                          IROUT(1 = coupled, 0 = uncoupled, -1 = flow routing off, -2 = infil
off), IFRTOL
2  2    1.78                                        ISNOW, ISNWMOD, SNOPAR1
3  0.1  0.3                          ISUBLIM, SUBPAR1, SUBPAR2
0  1.                                IPPTTEST (1 for testing), PPTTEST = constant
0  .0                                IETTEST (1 for testing), ETTEST = constant
30.0                                 CELSIZE (node spacing (meters): using for flow volume calculations)
544691.0  4074153.0                     xcfs,ycfs: coords for discharge cell
1980  1  1995   274     0   1          yr1 = start year, dnn1 = start day, yr2 = end year, dn2 = end day
0    0   0   0                        multipliers ( pptfact, etfact, imbfact, sksfact)
0.0  0   0.2                          SDFACT (soil depth multiplier), IVEGC (set to 1 for map data),
FVEGC (use if IVEGC = 0)
1.0  0.5  0.2   0.01                  ROOTF1,ROOTF2,ROOTF3,ROOTF4
1.0  0.8  0.2   0.05                  MAXWGT1, MAXWGT2, MAXWGT3, MAXWGT4
 .30  1.5  2.0   2.0                  RDEPTH1,RDEPTH2,RDEPTH3,RDEPTH4,RDEPTHF
0.0  1.0  .5                          RKPOR, RKMMFACT, FLAREA
1  1   0                              INFMOD, ETMOD, RUNMOD
 -10.0  1.04                                 BARSOIL1, BARSOIL2:  bare soil et parameters
1   17.3  11.74                       IAIRTEMP = 1 for new air temp model, ATEMP1 = avg. air temp,
ATEMP2 = air temp seasonal deviation
2                                    HSTEP: time step for PET model (hours)
1  181  0                             PPTYUC (=5 diminished elev. correlation, =2 for 4JA , =1 for simple*
elevation transfer), AAPREPX, IPPTDAT
mod3-ppt.dat                            input file name:  daily precip
   0    1   0.5    1    1             dpthflag, irtz, delvwcf, moistcr, fracmod
   0    0.0                           IVWCFLG,   vwcfact
t1.w20                                input file name:  map parameters (*.inp)
-1
test1a.v21                            dayall: average daily mass balance terms
```

```
1   1                    ndaymap, imap
70  1995
test1a.v22
test1a.v23                 output file name:  daily mass balance
test1a.v24                 output file name:  total daily fluxes
1    1                   dbgflag, dbgflag2
test1a.v25                 output file name:  annual mass balance terms
0                        IDEBUG:  debugging option parameter
test1a.v26                 new debug file
test1a                   map output:  annual totals or mult-year averages
--
```

*The PPTYUC shown , PPTYUC = 5, and the corresponding value of "181" are only a place holders, relict comments from the original file. See Validation Test Plan (10307-VTP-2.0-00), Table A1 to confirm value used.

Model Control File (continued)

Parameters for dynamic root-zone function

	depth (m)	rtza	rtzb	rtzc	rtzd	bsoil	delvwc
4							
1	0.5	15	3	3	2	0.3	0.5
2	1.5	15	4	2	2	0.2	0.5
3	4.5	10	1.5	1	2	0.1	0.5
4	6	10	1.5	1	2	0.05	0.25

Soil Properties (Brooks & Corey/van Genuchten (combined)

	fdcp m^3/m^3	et	residpor m^3/m^3	beta	alpah 1/(J/Kg)	ksat Jsec/m^3	PE J/Kg	B	n	vg-alpha 1/(J/Kg)	sorp J sec/m^3	SOILP	potis J/Kg
10													
1	0.242	0.054	0.366	-2.5	1.26	5.60E-04	-1.19E+00	4.72	1.24	5.20E-01	0.39	0.05	-1.00E+02
2	0.173	0.023	0.315	-2.5	1.26	1.20E-03	-9.41E-01	3.7	1.31	6.20E-01	0.5	0.05	-1.00E+02
3	0.163	0.017	0.325	-2.5	1.26	1.30E-03	-8.60E-01	3.36	1.36	6.60E-01	0.51	0.05	-1.00E+02
4	0.073	0.002	0.281	-2.5	1.26	3.80E-03	-6.22E-01	2.18	1.62	8.70E-01	0.7	0.05	-1.00E+02
5	0.2	0.035	0.33	-2.5	1.26	6.70E-04	-1.07E+00	4.14	1.78	5.60E-01	0.4	0.05	-1.00E+02
6	0.15	0.011	0.339	-2.5	1.26	2.70E-03	-7.55E-01	3.06	1.4	7.40E-01	0.7	0.05	-1.00E+02
7	0.234	0.046	0.37	-2.5	1.26	5.60E-04	-1.10E+00	4.43	1.26	5.50E-01	0.39	0.05	-1.00E+02
8	0.234	0.046	0.37	-2.5	1.26	5.60E-04	-1.10E+00	4.43	1.26	5.50E-01	0.39	0.05	-1.00E+02
9	0.189	0.028	0.322	-2.5	1.26	5.70E-04	-1.08E+00	3.88	1.3	5.50E-01	0.37	0.05	-1.00E+02
10	0.189	0.028	0.322	-2.5	1.26	5.70E-05	-1.08E+00	3.88	1	5.50E-01	0.037	0.05	-1.00E+02

B. Example from geospatial input file: Partial input from test1bt1.w20 file

Grid Cell I.D.	UTM easting (m)	UTM northing (m)	latitude (degrees)	longitude (degrees)	row I.d.	column I.d.	down-stream grid cell I.d. no.	no. of up-stream cells	elevation (m)	slope (degrees inclined from horiz.	aspect (degrees from north)	soil-type I.d.
33982	547571	4077573	36.8447	116.4664	343	98	-3	0	1495	11	215	5
33983	547571	4077543	36.8444	116.4664	344	98	-3	0	1495	8	216	5
34190	547571	4077513	36.8441	116.4664	345	98	-3	0	1494	6	223	10
34379	547601	4077663	36.8455	116.4661	340	99	-3	0	1493	7	221	10
34380	547601	4077633	36.8452	116.4661	341	99	35414	0	1493	5	232	10
34381	547571	4077603	36.845	116.4664	342	98	-3	0	1493	13	210	5
34382	547601	4077603	36.8449	116.4661	342	99	35609	0	1493	5	85	5
34383	547601	4077573	36.8447	116.4661	343	99	36037	0	1493	8	95	5

(continuation of columns for eight rows shown)

soil depth (m)	rock-type I.d.	topo position I.d.	vegetation-type I.d.	percent vegetation cover	these and remaining 34 columns (not shown here) are 36 blocking-ridge angles	
1	0.48	314	4	3	30	1
1	0.46	314	5	3	30	1
1	0.42	314	5	5	30	1
1	0.44	314	5	3	30	1
1	0.4	314	6	3	30	1
1	0.45	314	4	3	30	1
1	0.4	314	6	3	30	1
1	0.46	314	4	3	30	1

C. Example of output files, ".v" with labeled columns:

Output file ".v.21" : The spatially average daily mass balance terms (see Requirements Document ,SDN 10307-RD-2.0-00):
file: DAYALL

day	year	mo	dy	day	temp	precip	rain	snow-fall	snow-cover	snow-melt	sublimation	pot-evaptrs	evapo-trans
1	1980	-9	-9	1	6.6	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.809904751	0.123161550
2	1980	-9	-9	2	6.6	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.817261934	0.118650811
3	1980	-9	-9	3	6.5	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.819999762	0.113509781
4	1980	-9	-9	4	6.5	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.823320038	0.108586165
5	1980	-9	-9	5	6.5	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.826980380	0.103852891
6	1980	-9	-9	6	6.4	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.830679657	0.099279188
7	1980	-9	-9	7	6.4	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.836783570	0.095151856

run-infil	del-soil	net-infil	runoff	run-on	fract-inf	it	discharge-#1	discharge-#2	mass-balance	mass-balance 2
0.000000000	-0.123161550	0.000000000	0.000000000	0.000000000	0.000000000	0	0.00000000	0.00000000	-.166533454E-15	0.00000000
0.000000000	-0.118650811	0.000000000	0.000000000	0.000000000	0.000000000	0	0.00000000	0.00000000	-.235922393E-15	0.00000000
0.000000000	-0.113509781	0.000000000	0.000000000	0.000000000	0.000000000	0	0.00000000	0.00000000	0.971445147E-16	0.00000000
0.000000000	-0.108586165	0.000000000	0.000000000	0.000000000	0.000000000	0	0.00000000	0.00000000	-.138777878E-16	0.00000000
0.000000000	-0.103852891	0.000000000	0.000000000	0.000000000	0.000000000	0	0.00000000	0.00000000	-.152655666E-15	0.00000000
0.000000000	-0.099279188	0.000000000	0.000000000	0.000000000	0.000000000	0	0.00000000	0.00000000	0.971445147E-16	0.00000000
0.000000000	-0.095151856	0.000000000	0.000000000	0.000000000	0.000000000	0	0.00000000	0.00000000	-.180411242E-15	0.00000000

Output file "v.22" : 24-hour mass balance map (see Requirements Document ,SDN 10307-RD-2.0-00):
file: DAYMAP

easting	northin	j	pptloc	soilmm	soilmm (1)	soilmm (2)	rockmm (3)	infilmm	run-off	totout
547601.0	4077633.0	5549	34.6944	96.4880	32.2000	0.0000	36.0000	3.3366	3.9404	0.0000
547601.0	4077603.0	5549	34.6944	98.8914	33.0000	0.0000	36.0000	3.3367	5.3632	0.0000
547601.0	4077573.0	5549	34.6944	96.3742	52.8000	0.0000	35.4000	3.3367	0.0000	0.0000
547601.0	4077543.0	5549	34.6720	93.6052	59.4000	0.0000	35.2000	3.3366	0.0000	0.0000
547631.0	4077693.0	5549	34.5826	93.6563	59.4000	0.0000	35.2000	3.3366	0.0000	0.0000
547631.0	4077663.0	5549	34.5826	90.9970	66.0000	0.0000	35.0000	3.3366	0.0000	0.0000

Output file "v.23" : Summary statistics file for spatially averaged variable(s) value

```
INFILv2.ctl: INFIL v2.0 VTP test 0a, run code t1-4ex-v2-w20 (5/27/1999)
 Daily precipitation input:                mod3-ppt.dat
 Watershed modeling domain parameters:     t1.w20
 Average daily mass balance terms:         test0a.v21
 24-hour mass balance map:                 test0a.v22
 Annual mass balance map:                  test0a.1
 Average annual mass balance map:          test0a.v24
 Summary statistics output:                test0a.v23
 Debugging output:                         test0a.v25

Total number of days read in   =     5753
 Total daily precip            =   2852.0
 Average annual precip (mm)    =    181.1
 Maximum daily precip (mm)     =     58.0

TOTAL NUMBER OF LOCATIONS      =      125
 AVERAGE ELEVATION OF SAMPLE   =   1453.2
 MAXIMUM ELEVATION OF SAMPLE   =   1493.0
 MINIMUM ELEVATION OF SAMPLE   =   1396.0
 AVERAGE SOIL DEPTH (M)        =    0.425
 AVERAGE SLOPE OF SAMPLE       =     15.2
 MAXIMUM SLOPE OF SAMPLE       =     22.0
 NUMBER OF ACTIVE LOCATIONS    =       75
```

Yr	Dy	Precip	Rain	Snow	Sn-cover	Snowmelt	Sublim	PET	PETRS	Evapotrs
1980	366	183.749	183.749	0.000	0.000	0.000	0.000	1040.371	825.692	183.471
1981	365	117.239	117.239	0.000	0.000	0.000	0.000	1049.372	832.835	117.181
1982	365	190.513	190.513	0.000	0.000	0.000	0.000	1031.790	818.881	182.535
1983	365	331.425	331.425	0.000	0.000	0.000	0.000	1024.139	812.809	298.026
1984	366	246.878	246.878	0.000	0.000	0.000	0.000	1034.486	821.020	210.995

Del-soil	Net-inf	Runoff	Out-flow	Mass-balance
0.264	0.015	0.000	0.000	0.209692837E-10
0.058	0.000	0.000	0.000	0.239158189E-10
7.978	0.000	0.000	0.000	-0.525243466E-10
32.361	1.038	0.000	0.000	0.617736307E-10
35.700	0.183	0.000	0.000	-0.295433521E-10

(Output file "v23" continued)

```
Global Summary Statistics (mm/year):
 ---------------------------------------------

 Precipitation..................        204.118706
 Rain...........................        204.118706
 Snowfall.......................          0.000000
 Snow-cover.....................          0.000000
 Snow-melt......................          0.000000
 Sublimation....................          0.000000
 Potential Evapotranspiration....       1047.419091
 Actual Evapotranspiration.......        190.888686
 Change in Soil Moisture.........          0.848292
 Net Infiltration................          8.587232
 Runoff Generation...............          5.171421
 Cumulative Daily Run-on.........         20.074500
 Outflow.........................          3.794496
 Average Mass Balance Error......      0.267996E-13
 Average Max Daily Error (mm/dy).      0.122080E-13
```

Output file "v.24" : Average Annual Map Output file: Average annual map out file consists of the average annual rates of all components of the water balance for all model grid nodes. (see Requirements Document, SDN 10307-RD-2.0-00):
file: FLXFILE (total daily fluxes)

easting	northing	precip	rain	snow-fall	snow-cover	snow-melt	sublimation	evapotrans	run-infil
del-soil	net-infil	runoff							
547601.0	4077633.0	209.40329	209.40329	0.00000	0.00000	0.00000	0.00000	189.33890	0.00000
0.76551	18.34766	0.95122							
547601.0	4077603.0	209.40329	209.40329	0.00000	0.00000	0.00000	0.00000	188.92460	0.00000
0.74201	18.61613	1.12055							
547601.0	4077573.0	209.40329	209.40329	0.00000	0.00000	0.00000	0.00000	190.84591	0.00000
0.69638	17.86100	0.00000							
547601.0	4077543.0	209.26810	209.26810	0.00000	0.00000	0.00000	0.00000	191.67847	0.00000
0.67716	16.91247	0.00000							
547631.0	4077693.0	208.72822	208.72822	0.00000	0.00000	0.00000	0.00000	190.52963	0.00000
0.68640	17.51218	0.00000							
547631.0	4077663.0	208.72822	208.72822	0.00000	0.00000	0.00000	0.00000	191.27580	0.00000
0.66965	16.78277	0.00000							
547631.0	4077633.0	208.72822	208.72822	0.00000	0.00000	0.00000	0.00000	190.75098	0.00000
0.68444	17.29280	0.00000							
run-on	mass-balance	max-balance	mass-balance #2						

0.000000	0.5673240E-13	0.3730349E-13	0.000000
0.000000	-0.1332268E-13	0.3375078E-13	0.000000
0.000000	0.1421085E-13	0.3375078E-13	0.000000
0.000000	-0.1776357E-13	0.4529710E-13	0.000000
0.000000	0.6039613E-13	0.4884981E-13	0.000000
0.000000	0.3197442E-13	0.3352874E-13	0.000000
0.000000	0.6220059E-13	0.6039613E-13	0.000000

Output file "v.25" : Test 0a, "Annual mass balance terms" file (see Requirements Document ,SDN 10307-RD-2.0-00):
file: annual mass balance terms

day	year	mo	ppt (mm/yr)	temp (C)	petday (pot-evaptrs) (mm/yr)	petrsday (evapo-trans) (mm/yr)	tetday (total et) (mm/yr)
1	1980	1	0.0000000	6.629	1.0204800	0.8099048	0.1231616
2	1980	2	0.0000000	6.580	1.0297500	0.8172619	0.1186508
3	1980	3	0.0000000	6.535	1.0331997	0.8199998	0.1135098
4	1980	4	0.0000000	6.493	1.0373832	0.8233200	0.1085862
5	1980	5	0.0000000	6.454	1.0419953	0.8269804	0.1038529
6	1980	6	0.0000000	6.419	1.0466564	0.8306797	0.0992792
7	1980	7	0.0000000	6.387	1.0543473	0.8367836	0.0951519
8	1980	8	0.0000000	6.358	1.0604196	0.8416028	0.0910088

Output file "v.26" : The *.v26 file is an echo of the geospatial input, with some additional model parameters for the separate root-zone layers that are calculated internally by the program. The file gets created before the model starts to run through the daily time series, and so this is not an output of model results, only a verification of model inputs (see Requirements Document ,SDN 10307-RD-2.0-00)

file: new debug file

easting	northing	cdepth4	soiltype (identifier)	ia (ia)	(ia)	row (row(ia), col(ia))	col.	elev.	sl(ia)	depth(ia) (1,ia)	(2,ia)	(3,ia)	cdepth (4,ia)	cdepth	cdepth
547601.0	4077633.0		5	341	99	1493.0	5.0	0.400	0.300	0.100	0.000	1.800	10		
547601.0	4077603.0		7	342	99	1493.0	5.0	0.400	0.300	0.100	0.000	1.800	5		
547601.0	4077573.0		8	343	99	1493.0	8.0	0.460	0.300	0.160	0.000	1.770	5		

skmm (ia)	soilresid (soiltype(ia))	fieldcap (soiltype(ia))	soilporo (soiltype(ia))	scapmm1	scapmm2	scapmm3	rkmm	scapmmt
48.263	0.0280	0.1890	0.3220	88.2000	29.4000	0.0000	36.0000	153.6000
567.302	0.0350	0.2000	0.3300	88.5000	29.5000	0.0000	36.0000	154.0000
567.302	0.0350	0.2000	0.3300	88.5000	47.2000	0.0000	35.4000	171.1000

rocktype	imbibe (rocktype(ia))	imb2
314	3.3400000	1219.9350
314	3.3400000	1219.9350
314	3.3400000	1219.9350

2. Test Case 0A.4 (2):

From the Analysis Model Report, USGS (2001): (Section 6.1.1)
The depth of the root zone can be estimated from field studies but cannot be defined precisely. In addition, the depth of the root zone depends on variable climate and surface conditions controlling vegetation and other factors affecting evapotranspiration and is thus transient and spatially variable. Infiltration is the movement of water across the air/soil or air/bedrock interface, and percolation is defined as the downward movement of water within the unsaturated zone.

The root zone was subdivided into layers based on the estimated maximum depth of bare-soil evaporation and an estimated variation in root density. In general, the layering represents a decrease in root density with increased depth in the root zone, particularly at locations with thick soils (greater than 6 meters).]

The process is repeated for each soil and bedrock layer in the root zone (in the case of the model used in this analysis/modeling activity, a maximum of three soil layers and one bedrock layer were used) until the bottom layer is reached, which completes the forward cascade.

For thick soils, there is no bedrock layer in the root zone. The thickness of the bedrock root-zone layer is set to zero, the effective fracture porosity for the bottom bedrock layer becomes zero, and all water exceeding the field capacity of the bottom soil layer (the third soil layer) is potential net infiltration unless limited by the saturated bulk hydraulic conductivity of the underlying soil or bedrock. For locations where the soil depth is estimated to be 6 meters or greater, the underlying bedrock properties are defined using alluvium/colluvium properties.

The above description describes the process for defining the root zone through implementation of INFILV2.0, and the review of the model control file provided in this attachment (see example) verifies the thickness of the root zone is defined as required by test case 0A.4 (2). The reviewer may also review the Infilv2.for program and perform a word search on key words such as "cdepth" and "root zone".

3. Test 0A.4 (4)
From Infilv2.for
calculate storage capacities for output

```
                scapmm1 = (soilporo(soiltype(ia))
      1                 -soilresid(soiltype(ia)))*cdepth(1,ia)*1000.
```

4 . Test 0A.6 (2)
Results for Test 0d Mapadd20.exe
H:\DATA\SOFTWARE\INFILTRATION MODEL\Life Cycle Docs for Infil V2\INFIL VTP and VTR\TEST 0 sequence\Test 0d>MAPADD20

```
      1      1      1     803     803
      2      1     804    422     1225
      3      1    1226    349     1574

    1000  63.53240
```

(continued)

4). continued.

Total number of cells: 1574

Parameter	Average	Maximum	Minimum
Precipitation (mm/yr):	517.305374	548.880400	494.085810
Rain (mm/yr):	449.347682	456.058310	440.368130
Snow-fall (mm/yr):	67.957692	93.753980	46.453300
Snow cover (mm/yr):	1251.088039	2630.685570	377.092720
Snow-melt (mm/yr):	55.725613	75.409700	39.558410
Sublimation (mm/yr):	5.622712	8.891950	3.283830
Evapotranspiration (mm/yr):	477.000354	708.006040	312.752110
Run-on infiltration (mm/yr):	29.383091	1561.109370	0.000000
Stored water change (mm/yr):	4.688116	192.659760	-28.843570
Net infiltration (mm/yr):	20.246651	1378.709950	0.000000
Run-off (mm/yr):	32.521266	186.960380	0.000000
Run-on (mm/yr):	388.644090	12911.750000	0.000000
Mass balance error (mm/yr):	-0.112473E-12	0.161506E-10	-0.174580E-10
Max daily error (mm/dy):	0.108147E-14	0.724754E-12	-0.767830E-12
Mass balance 2 (mm/yr):	-0.961536E-15	0.241585E-12	-0.241585E-12

5. Test0A.8(1 and 2). Example to verify average values for output files Test0a.v21, Test0a.v23, and Test0a.v24 are comparable. Following are partial printouts of EXCEL worksheets used to calculate averages for 1980 parameter for comparison with Test0a.v23 file and/or example of file provided in this attachment.

(A) Test0A.8(1 and 2)

Average for some parameters from test0a.v21 (file: 0Av21averages1980.xls) to compare with Test0a.v23 output file.

precip	ave. 183.749	net-infil	ave. 0.014852	pot-evaptrs	ave. 8.26E+02	mass-balance 2	ave. 0	del-soil	ave. 0.263543
0		0		0.809905		0		-0.12316	
0		0		0.817262		0		-0.11865	
0		0		0.82		0		-0.11351	
0		0		0.82332		0		-0.10859	

(B) Test0A.8(2)

test0a.v24 file: Statistics calculated from worksheet. (file 0A.v24, global ave.xls) to compare with test0a.v23 output file.

precip	ave. 204.1187	subli-mation	ave. 0	evapotrans-piration	ave. 190.8887	net-infil	ave. 8.587231
209.4033		0		189.3389		18.34766	
209.4033		0		188.9246		18.61613	
209.4033		0		190.8459		17.861	
209.2681		0		191.6785		16.91247	

runoff	ave. 5.171421	run-on	ave. 20.0745	mass-balance	ave. 2.68E-14
0.95122		0		5.67E-14	
1.12055		0		-1.33E-14	
0		0		1.42E-14	
0		0		-1.78E-14	

6. Test0A12(1). Partial EXCEL spreadsheet

From 0a.v22 for day 5549

net-infil	average	run-off	average	pptloc	average
3.3366	1.303965	3.9404	22.57171	34.6944	33.81884
3.3367		5.3632		34.6944	
3.3367		0		34.6944	
3.3366		0		34.672	

From 0a.v21 for day 5549

						ppt	rain	sn	sn	sn
5549	1995	-9	-9	70	11	33.81884	33.81884	0	0	0

(continue columns for 0a.v21 printout)

sub	pot evap	evapotra	run-on	delsoil	net infil	runoff	runon	fract
0	0.295857	0.322948	4.216464	13.83668	1.303961	22.57172	22.3934	0

(continue columns for 0a.v21 printout)

it	dis1	fid2	mb	mb2
3 0	.617914952	0.617915	-1.07E-14	0

7. Test0B.2 (1).

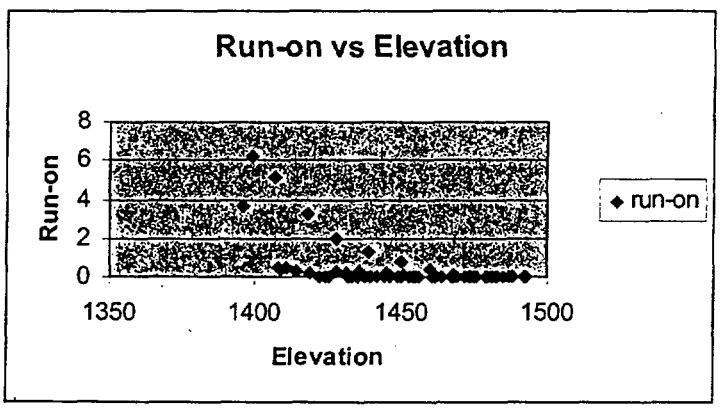
Test0b file 4ja (mod3-ppt.dat (see User Manual))

	Month	Day	Year	Day	Ppt.
Day #30	1	30	1	30	0
Day #52	2	21	1	52	0
Day #12018	11	26	33	330	0
Day #36524	12	30	100	365	0

Test0b.v21

Day	year	mo	dy	day	temp	precip
30	1	1	30	30	6.6	0
52	1	2	21	52	8.5	0
12018	33	11	26	330	10.6	0
36524	100	12	30	365	6.7	0

8. Test0B.5



9. Test0C.11: Compare .v21 and .v22 files: Partial EXCEL worksheet to verify average parameter values for day 41 (from file Test0c.v22, to compare with Test0c.v21 (day 406).

test0c.v22

pptloc	ave.	infilmm	ave.	run-off	ave.
0	0	3.141	1.173952	0	4.381269
0		3.1513		0	
0		3.1493		0	

test0c.v21

day	year	mo	day	day	temp	**precip**	rain
406	1952	2	10	41	3.9	0	0

snow-fall	snow-cover	snow-melt	subli-mation.	pot-evaptrsns	evapotrans	run-infil	del-soil
0	43.20682	6.903746	0.405041	1.0715383	0.70282727	0.248777	0.894476

net-infil	runoff	run-on	fract-inf	it	discharge-#1	discharge-#2	mass-balance	mass-balance 2
1.173953	4.381268	4.254968	0	3 0	.117409986	0.11741	-5.33E-15	0

10) Example for Test0D.6

Test0d.dat file

	easting	northing	precip	rain	snow-fall	snow-covER	snow-melt	sublimation
Line 1	545351	4077993	548.8804	455.1264	93.75398	2630.686	75.06675	8.81757
Line 805	545681	4076553	537.2708	454.7223	82.5485	2058.02	65.70224	7.67204
Line 1227	545621	4075203	502.316	446.9533	55.36266	602.1004	46.11002	4.20585

Test0d.v24 files

	easting	northing	precip	rain	snow-fall	snow-cover	snow-melt	sublimation
0d1.v24, line 2	545351	4077993	548.8804	455.1264	93.75398	2630.686	75.06675	8.81757
0d2.v24, line 2	545681	4076583	537.6208	455.0185	82.60227	2066.477	65.59	7.82131
0d3.v24, line 2	545621	4075233	502.4684	447.0889	55.37945	608.1532	46.28493	3.99887

11. Test 1D.7: Data and example calculations to validate criteria are met.

Test1D.7

fieldcap	cd1	cd2	cd3	cd4	infilmm	water1	water2	water3	water4
						(field capacity x cdepth)			
0.2	0.1	0.1	0.25	0.05	0	0.02	0.02	0.05	0.01
0.2	0.1	0.1	0.25	0.05	0	0.02	0.02	0.05	0.01
0.2	0.1	0.1	0.25	0.05	0	0.02	0.02	0.05	0.01
0.2	0.1	0.1	0.25	0.05	0	0.02	0.02	0.05	0.01
0.2	0.1	0.1	0.23	0.07	0.06	0.02	0.02	0.046	0.014
0.2	0.1	0.1	0.25	0.05	0.06	0.02	0.02	0.05	0.01

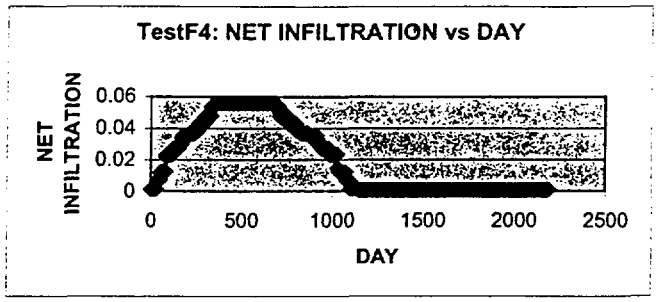
soilmm(1)	soilmm(2)	soilmm(3)	soilporo	full sat. water content (soilporo x cdepth)			
				1	2	3	4
20	20	50	0.33				
20	20	50	0.33				
20	20	50	0.33				
20	20	50	0.33				
31.74	33	75.9	0.33	0.03	0.03	0.0759	0.0231
31.74	33	82.5	0.33	0.03	0.03	0.0825	0.0165

12. Test1F.3: Partial data and calculated average.

1f net infil	ave.	1e net infil	ave.
	7.179947		9.131072
0.09652		9.42118	
7.00786		9.22123	
9.30733		10.52093	
10.07382		10.95417	
10.07382		10.95417	

13) Test 1F.4

(1) and (3): Plot for validation (See next page.)



(2): Convert ks (kg sec /m^3) to mm/day

From Infilv.for file:

c use 86400*9.8 for kgm/sec^2 to mm/day conversion

c mult. by user specified scaler sksfact (1000)

skmm = soilks(soiltype(ia))* 86400. * 9.8 * sksfact

= 0.048mm/day

From test1f.v21, max net infiltration = 0.055

14. Test1F.10

From Requirements Document, 10307-RD-2.0-00:

$$Prs - SF + SM + IR - CRZWC - ET - NI - O = 0 \quad (1)$$

where *Prs* is precipitation (rain or snow), *SF* is snowfall, *SM* is snowmelt, *IR* is infiltrated surface water run-on, *CRZWC* is the change in root zone water content, *ET* is evapotranspiration, *NI* is net infiltration, and *O* is surface water outflow. The parameters included in equation 1 are developed through the software program functional requirements

$$Pr + SF - CSP - S + IR - CRZWC - ET - NI - O = 0 \quad (2)$$

where *Pr* is precipitation as rain only and *CSP* is the change in snow pack depth and S is sublimation.

TEST	easting	northing	precip	rain	snow-fall	snow-cover	snow-melt	subli-mation	evapo-trans
2B.7	547601	4077633	0	0	0	0	0	0	18.96155

	run-infil	del-soil	net-infil	runoff
2B.7	0	-35.4585	7.31946	9.17748

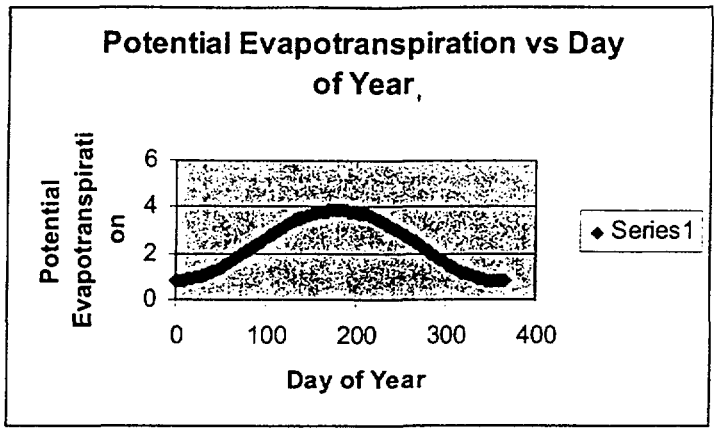
PRS-SF + SM + IR - CRZWC - ET - NI - O = 0

Example: Test 2B.7 (.v24 file):

0 - 0 + 0 + 0 - -35.4585 - 18.9615 - 7.3.1946 - 9.17748 = 0

The values for variables in Equation (2) verify the sum is equal to zero.

15. Test 2A.2



16. Test2C.4: ET average

test2c.v24	test2b.v24
23.03395	23.598268

17. Test2D2

test2d.v21	ave. netinfil	test2c.v21	ave. netinfil
net-infil	0.649936	net-infil	0.649835
1.299871		1.299671	
1.29979		1.299495	
1.299665		1.299326	
1.299534		1.299143	

18. Coefficient of Variation for Potential Evapotranspiration

test2d.1	
Std. Dev.	45.38071
Average:	310.8778
Coeff.Var.	0.146

test2c.1	
Std. Dev.	17.81358
Average:	649.9275
Coeff. Var.	0.0274

Test2a.1	
Std. Dev.:	13.2533
Average:	1098.674
Coeff. Var.:	0.0121

Test2e.1	
Std. Dev.	9.064882
Average:	944.9564
Coeff.Var.	0.0096

Test2b.1	
Std. Dev.	48.3839
Average:	1038.631
Coeff. Var.	0.0466

19.

Test2E.1		Test2E.2	
Ave annual pot et		Ave net infiltration	
test2c.v21	1.410699	test2c.v21	0.011242
test2e.v21	2.049086	test2e.v21	0.007903

20. Test2F.2: Parameter conditions set for test. Refer to the model control file and Validation Test Plan, Document 10307-VTP-2.0-00..

Type	rkcp	et	residpor	beta	alpha	ksat	PE	B	n
500	0.01	0.01	0.10	-1.5	1.00	1.3E-07	-154.6	5.02	1.56

vg-alpha	fracks	imbibe	potir
1560	2.9E-07	1.00	0100

(From 10307-VTP-2.0-00. Refer to Test2f: Test Description, (pp45-46) and Table A1.)

21 Test2G.2;Test2H.2

Test Day 1	Total ET	Total Net Infiltration
test2f	186.6368	48.74017
test2g	203.3789	0
test2h	191.1888	13.09356
test 2l	151.4694	50.84372
test2j	181.6509	51.31624
test2k	303.8083	7.877083

22. Test 3C.3: From Infilv2.for:

```
set infiltration capacity using soil ks
c       and estimated storm duration
c       winter storm = 12 hours, summer storms = 2 hours
        if((dn(j).gt.183).and.(dn(j).lt.274)) then
                skmmp  = skmm/12.
                imbp   = imb/12.
        else
                skmmp  = skmm/2.
                imbp   = imb/2.
```

23. Test 3G.1

TEST	TOTAL RUN-OFF	MAX RUN-OFF	AVE ET
3F	3754.357	1.8111	4.632668
3G			4.769688

APPENDIX 3 FIGURES

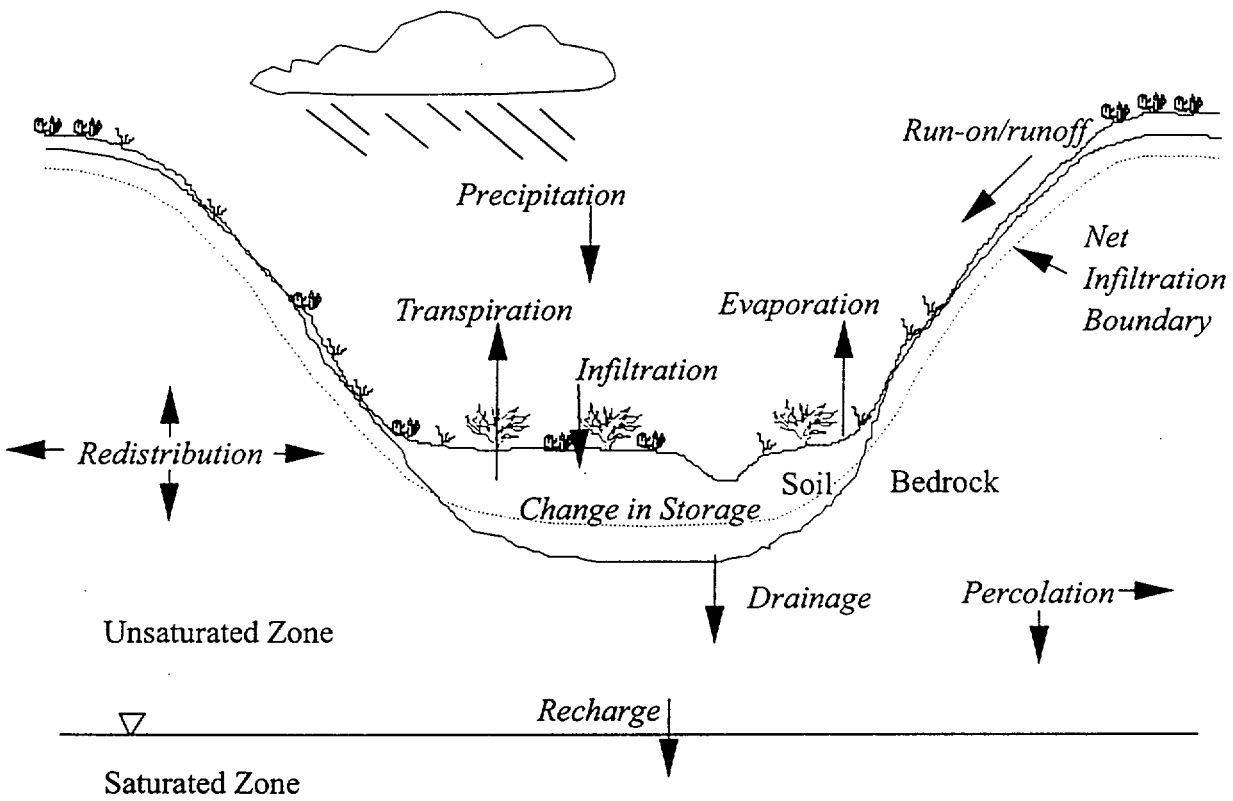
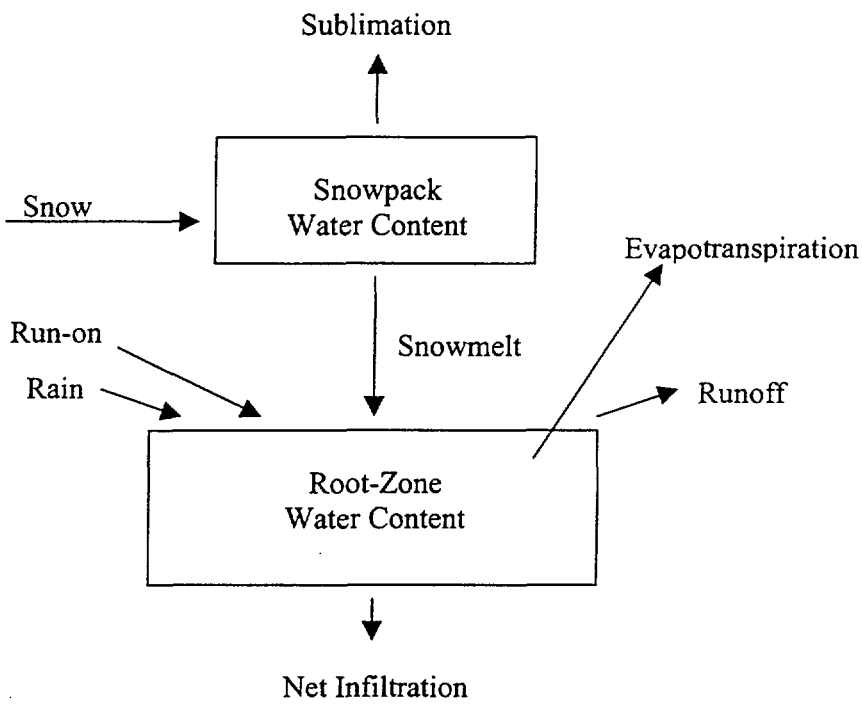


Figure 3-1. Field-scale water balance and processes controlling net infiltration (from Flint et al., 1996, Figure 3).



Change in Root-Zone Water Content:

If water content < water content at field capacity,

change in water content = Rain + Run-on + Snowmelt - Evapotranspiration

If water content < porosity > water content at field capacity,

Figure 5-1. The daily root-zone water-balance used to model net infiltration.

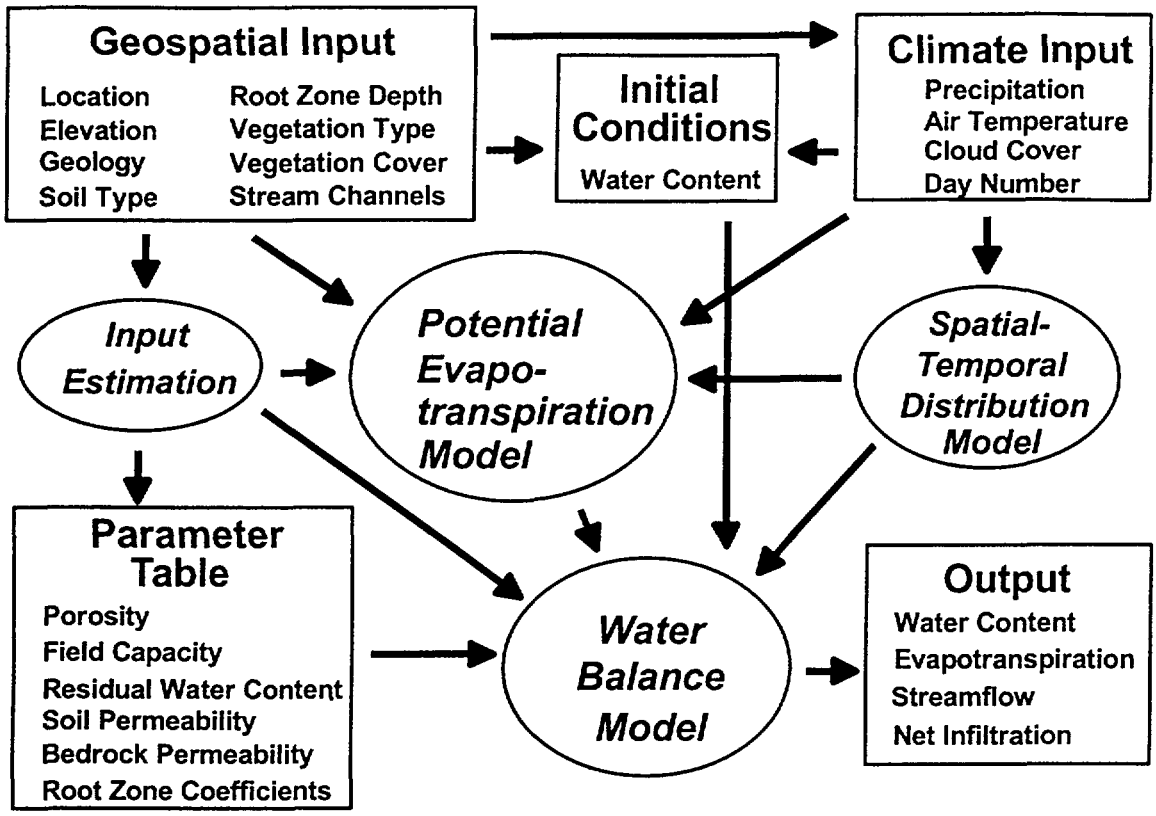


Figure 6-1. Major components of the net-infiltration modeling process.

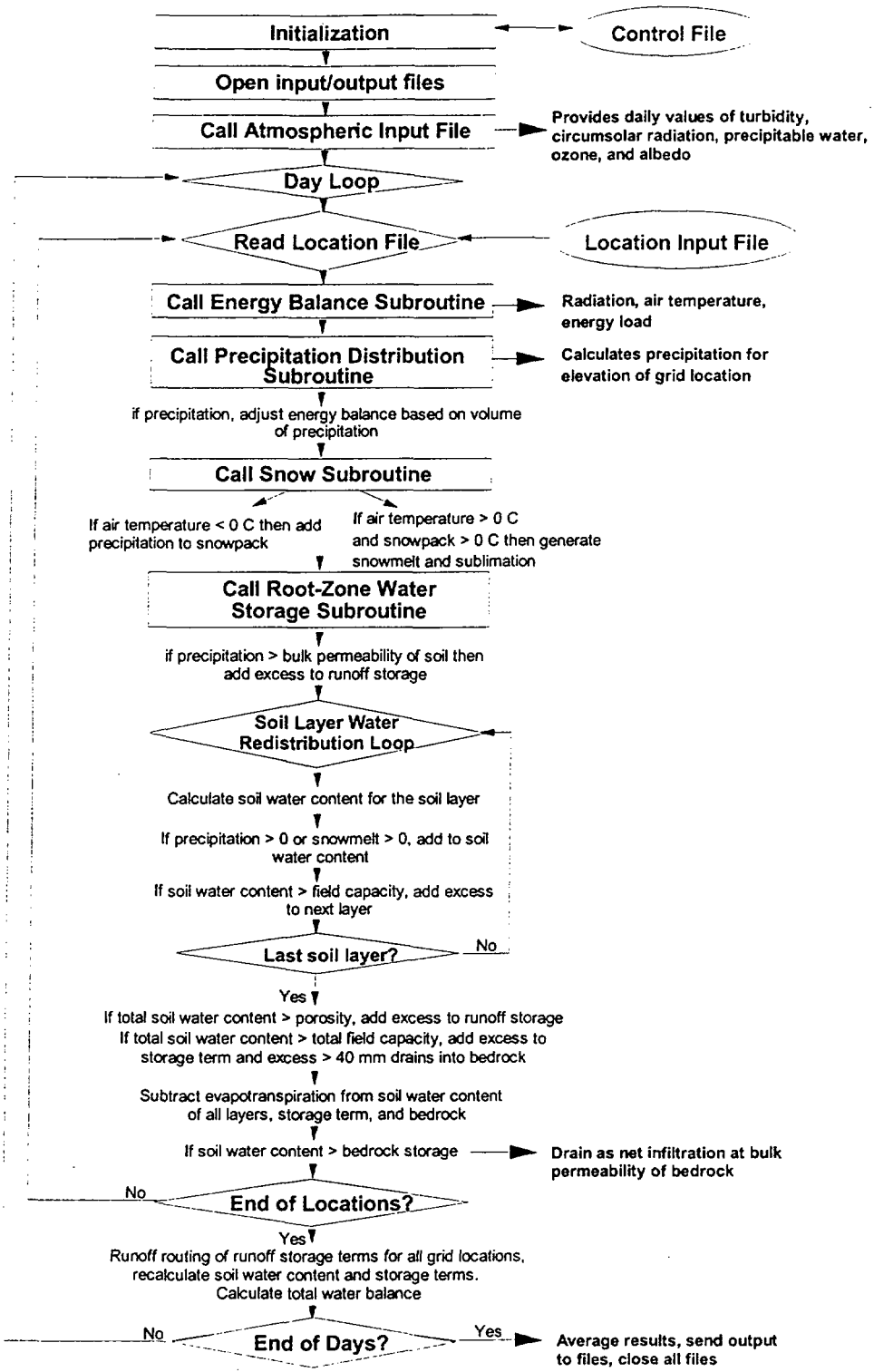


Figure 6-2. Flow chart of the model algorithm used for simulating net infiltration.

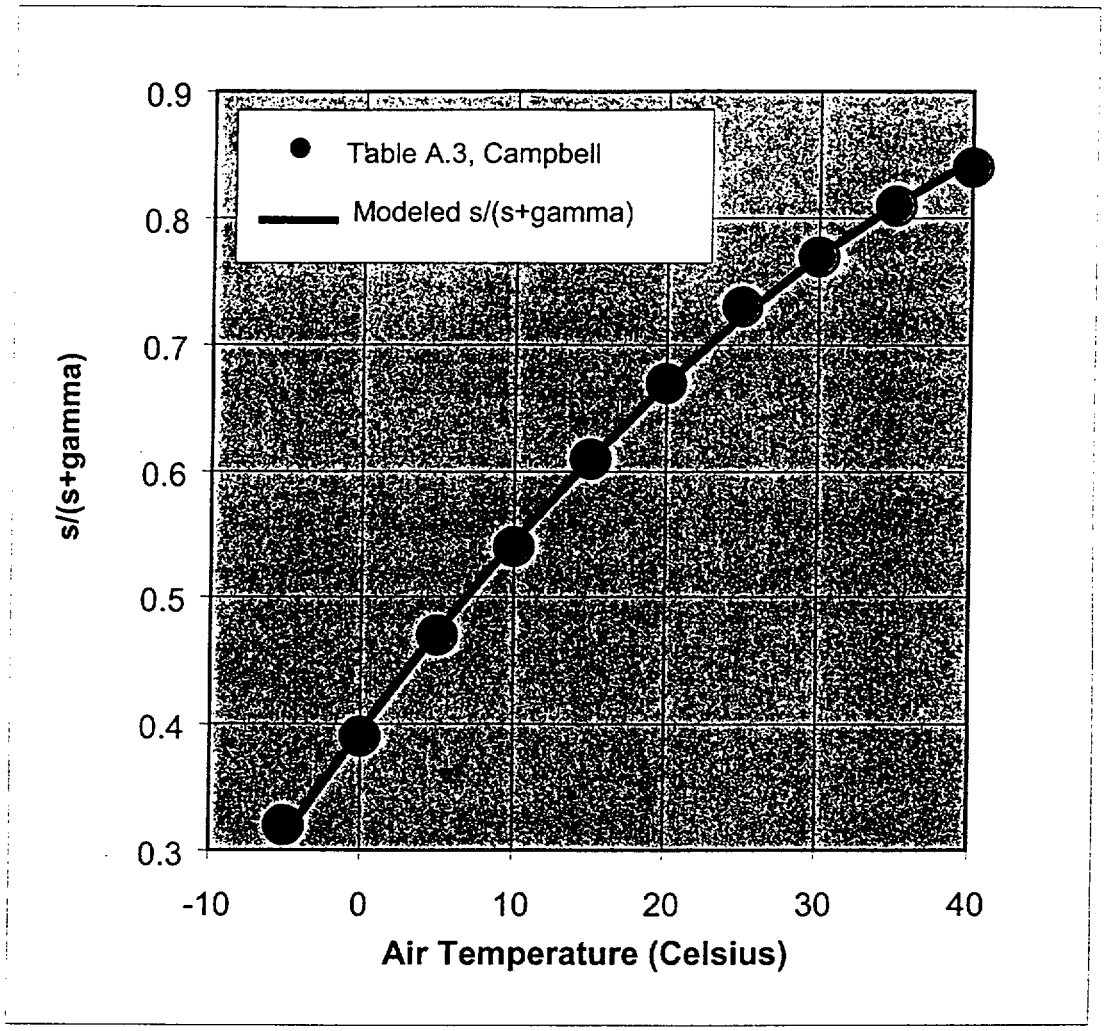


Figure 6-3. Relative effect of air temperature change on the modeled s/(s+γ) term of the Priestley-Taylor equation used for estimating potential evapotranspiration. (DTN: GS000300001221.009)

Figure 7-1. Overlay of the three geologic maps used to define rock types underlying the root zone and included in the bottom root-zone layer (Day et al., 1998, DTN: GS971208314221.003; Scott and Bonk, 1984, DTN: MO0003COV00095.000; Sawyer et al., 1995, DTN: GS000300001221.010)

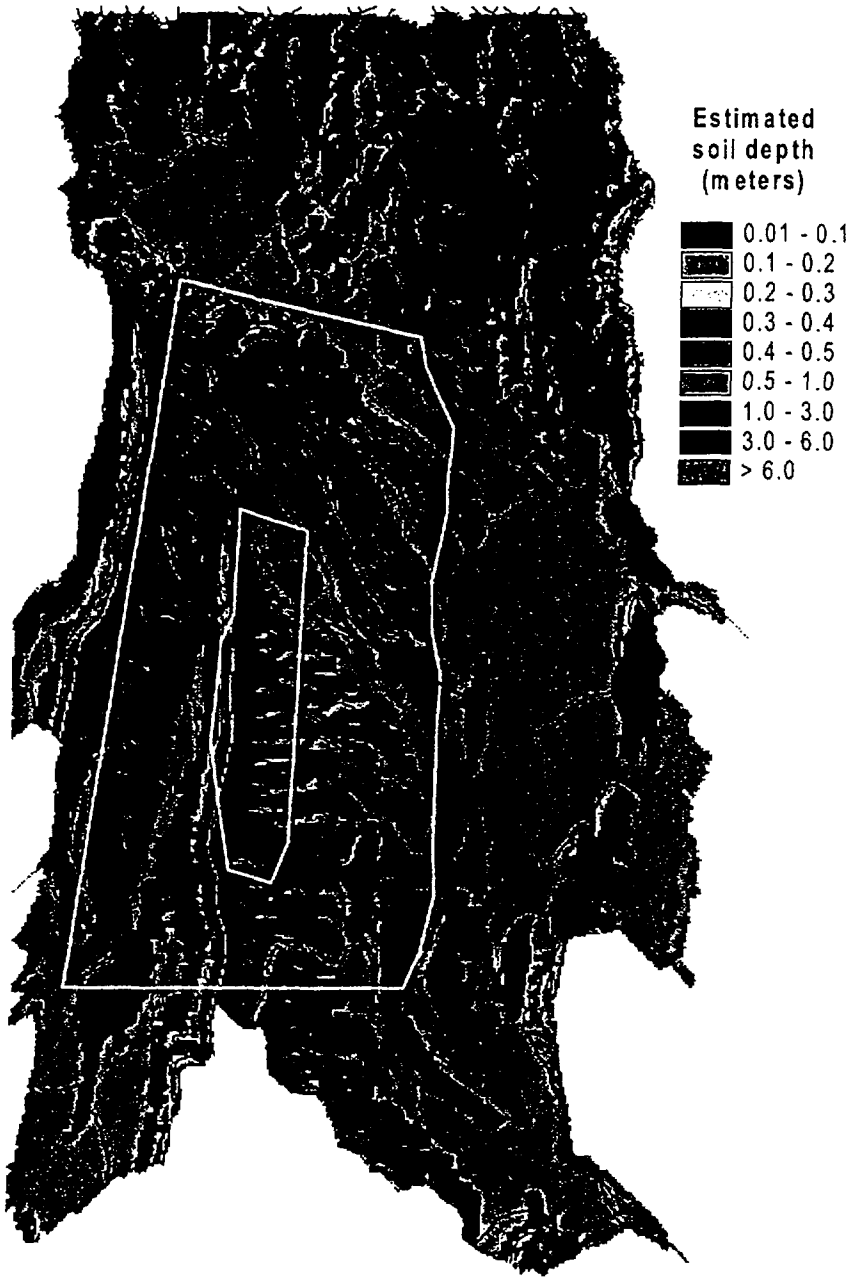


Figure 7-2. Estimated soil depth (DTN: GS960508312212.007) using the 1996 soil-depth class map and calculated land-surface slope (DTN: GS000308311221.004).

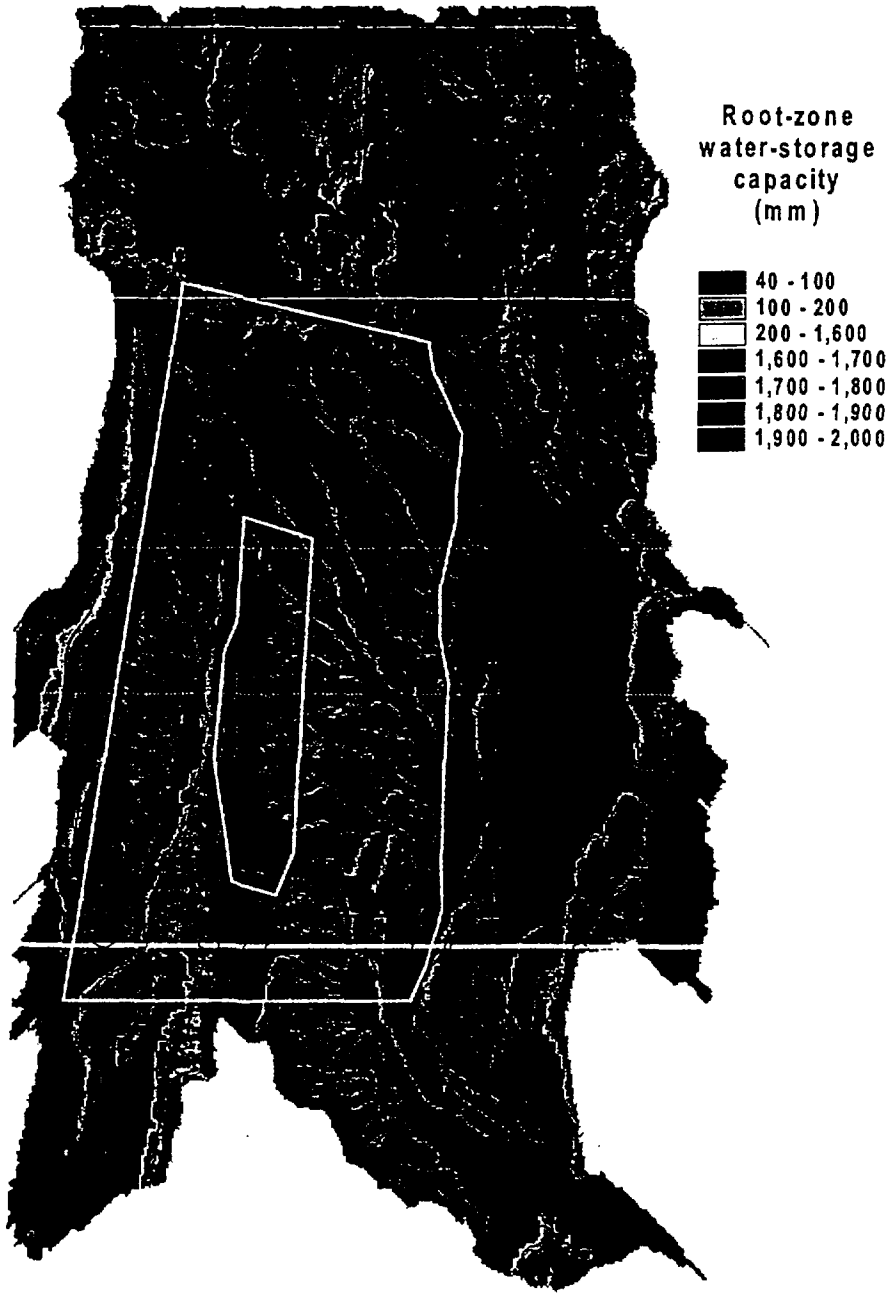


Figure 7-3. Total water-storage capacity of the modeled root zone, including bedrock and soil layers (DTN: GS000308311221.004).

Explanation

Potential repository boundary

Exploratory Studies Facility main drift

UZ flow and transport model area

100 meter elevation contour

S neutron logging boreholes

Figure A1-1. Yucca Mountain DEM used to define the geospatial-input parameters and watershed modeling domains (DTN: GS000308311221.006).

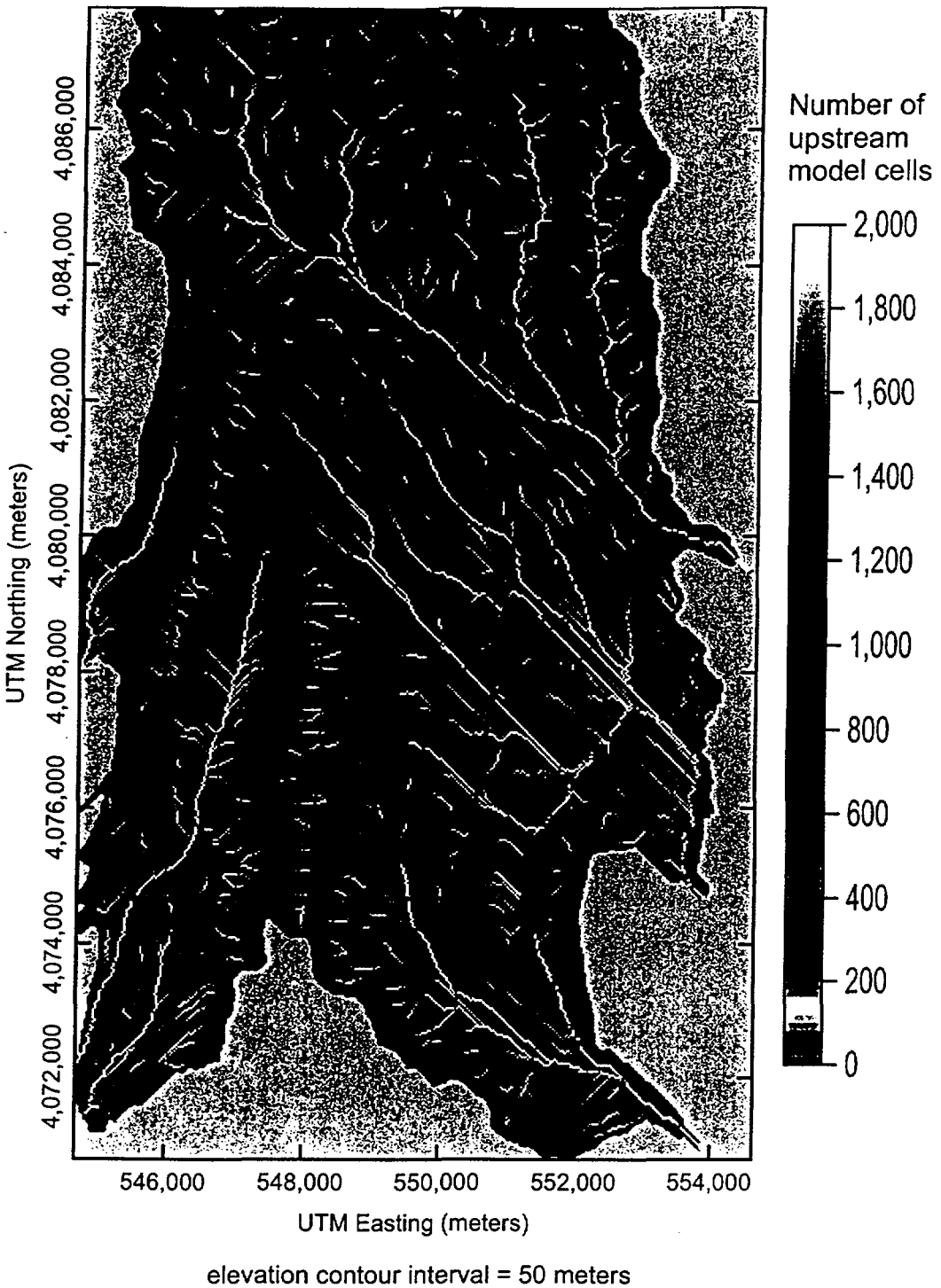


Figure A1-2. Isolation of the drainage networks overlying the area of the UZ flow and transport model.