Department of Energy
Office of Civilian Radioactive Waste Management
Office of Repository Development
P.O. Box 364629
North Las Vegas, NV 89036-8629

QA: N/A

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OVERNIGHT MAIL

Janet R. Schlueter, Chief
High-Level Waste Branch
Division of Waste Management
Office of Nuclear Material Safety
and Safeguards
U.S. Nuclear Regulatory Commission
Two White Flint North
Rockville, MD 20852

TRANSMITTAL OF REPORT ADDRESSING KEY TECHNICAL ISSUE (KTI) AGREEMENT ITEM UNSATURATED AND SATURATED FLOW UNDER ISOTHERMAL CONDITIONS (USFIC) 3.02

This letter transmits a report entitled *Response to USFIC 3.02: Justification of Parameters Used in the Infiltration Uncertainty Analysis*, which provides the basis for closure of the subject KTI agreement. Agreement USFIC 3.02 reads as follows.

> "Provide justification for the parameters in Table 4-1 of the Analysis of Infiltration Uncertainty AMR (for example, bedrock permeability in the infiltration model needs to be reconciled with Alcove 1 results/observations). Also, provide documentation (source, locations, tests, and test results) for the Alcove 1 and Pagany Wash tests.
> DOE will provide justification and documentation in a Monte Carlo analysis document. The information will be available in February 2002."

In response to the agreement, the U.S. Department of Energy (DOE) submits the following response (detailed in the enclosure) that provides the technical basis for justifying the parameter distributions used in the Analysis and Model Report (AMR) *Analysis of Infiltration Uncertainty*, ANL-NBS-HS-000027, Revision 00 (herein referred to as the Infiltration Uncertainty AMR). This technical basis includes: (1) justification of parameters used in the Infiltration Uncertainty AMR based on data and other information available at the time of preparation of the AMR as written in the original agreement; (2) the documentation of Alcove 1 and Pagany Wash test data, which became available after the publication of the AMR; and (3) additional results of a recent Total System Performance Assessment (TSPA) sensitivity study that demonstrate that the current understanding of the infiltration model is adequate given that it has little significance to calculation of the mean annual dose in the first 10,000 years following waste emplacement, which indicates that further technical justification is not required to support a risk-informed assessment of system performance.

The parameters addressed in the report were used to develop infiltration-weighting factors used in the TSPA for Site Recommendation. During the preparation of this response, typographical errors were identified in a table of the Infiltration Uncertainty AMR. In addition, it was identified that the source AMR, *Simulation of Net Infiltration for Modern and Potential Future Climates*, ANL-NBS-HS-000032, Revision 00, ICN 02, was found to contain insufficient justification for the parameter distributions used subsequently in the Infiltration Uncertainty AMR. As a result of these findings, the DOE has issued Deficiency Report BSC(B)-02-D-144 to initiate correction of these discrepancies in accordance with the Project procedures.

Actions to correct the identified errors and deficiencies, including revision of the Infiltration Uncertainty AMR (CRWMS M&O 2000a), are now underway. However, these actions, as demonstrated in the sensitivity study in the enclosed report, will not likely result in any significant changes in the calculated mean annual doses for the compliance period.

The DOE considers USFIC 3.02 to be fully addressed by the enclosed report, and pending review and acceptance by U.S. Nuclear Regulatory Commission, it should be closed.

There are no new regulatory commitments in the body or enclosure to this letter. Please direct any questions concerning this letter and its enclosure to Timothy C. Gunter at (702) 794-1343 or Eric T. Smistad at (702) 794-5073.

for Joseph D. Ziegler, Acting Director
Office of License Application & Strategy

OLA&S:TCG-0002

Enclosure:
Response to USFIC 3.02: Justification of Parameters Used in the Infiltration Uncertainty Analysis (REV 00 ICN 01)

cc w/encl:
J. W. Andersen, NRC, Rockville, MD
D. D. Chamberlain, NRC, Arlington, TX
R. M. Latta, NRC, Las Vegas, NV
H. J. Larson, ACNW, Rockville, MD
W. C. Patrick, CNWRA, San Antonio, TX
Budhi Sagar, CNWRA, San Antonio, TX
J. R. Egan, Egan & Associates, McLean, VA
J. H. Kessler, EPRI, Palo Alto, CA
Steve Kraft, NEI, Washington, DC

cc w/encl: (continued)
W. D. Barnard, NWTRB, Arlington, VA
R. R. Loux, State of Nevada, Carson City, NV
Marjorie Paslov Thomas, State of Nevada, Carson City, NV
Irene Navis, Clark County, Las Vegas, NV
Alan Kalt, Churchill County, Fallon, NV
George McCorkell, Esmeralda County, Goldfield, NV
Leonard Fiorenzi, Eureka County, Eureka, NV
Michael King, Inyo County, Edmonds, WA
Andrew Remus, Inyo County, Independence, CA
Mickey Yarbro, Lander County, Battle Mountain, NV
Lola Stark, Lincoln County, Caliente, NV
Arlo Funk, Mineral County, Hawthorne, NV
L. W. Bradshaw, Nye County, Pahrump, NV
David Chavez, Nye County, Tonopah, NV
Josie Larson, White Pine County, Ely, NV
R. I. Holden, National Congress of American Indians, Washington, DC
Allen Ambler, Nevada Indian Environmental Coalition, Fallon, NV
CMS Coordinator, BSC, Las Vegas, NV
G. L. Smith, DOE/ORD (RW-50W), Las Vegas, NV
OLA&S Library
Records Processing Center = "43"

cc w/o encl:
C. W. Reamer, NRC, Rockville, MD
L. L. Campbell, NRC, Rockville, MD
N. K. Stablein, NRC, Rockville, MD
S. L. Wastler, NRC, Rockville, MD
Margaret Chu, DOE/HQ (RW-1), FORS
R. A. Milner, DOE/HQ (RW-2E), FORS
A. B. Brownstein, DOE/HQ (RW-1), FORS
R. D. Brown, DOE/OQA (RW-3), Las Vegas, NV
Richard Goffi, BAH, Washington, DC
Donald Beckman, BSC, Las Vegas, NV
S. J. Cereghino, BSC, Las Vegas, NV
N. H. Williams, BSC, Las Vegas, NV
R. B. Bradbury, MTS, Las Vegas, NV
R. P. Gamble, MTS, Las Vegas, NV
R. C. Murray, MTS, Las Vegas, NV
R. D. Rogers, MTS, Las Vegas, NV

cc w/o encl: (continued)
J. R. Dyer, DOE/ORD (RW-2W), Las Vegas, NV
W. J. Boyle, DOE/ORD (RW-40W), Las Vegas, NV
D. H. Coleman, DOE/ORD (RW-50W), Las Vegas, NV
A. V. Gil, DOE/ORD (RW-40W), Las Vegas, NV
T. C. Gunter, DOE/ORD (RW-40W), Las Vegas, NV
C. L. Hanlon, DOE/ORD (RW-40W), Las Vegas, NV
G. W. Hellstrom, DOE/ORD (RW-2W), Las Vegas, NV
E. T. Smistad, DOE/ORD (RW-40W), Las Vegas, NV
J. R. Summerson, DOE/ORD (RW-50W), Las Vegas, NV
J. T. Sullivan, DOE/ORD (RW-40W), Las Vegas, NV
D. R. Williams, DOE/ORD (RW-40W), Las Vegas, NV
J. D. Ziegler, DOE/ORD (RW-40W), Las Vegas, NV

RESPONSE TO USFIC 3.02: JUSTIFICATION OF PARAMETERS USED IN THE INFILTRATION UNCERTAINTY ANALYSIS

November 2002

Preparation*:

11/8/02

J.S.Y. Wang, Unsaturated Zone Department Manager — Date

11/11/02

Ming Zhu, License Application Project — Date

Approval:

for

11/11/02

P.R. Dixon, Natural Systems Subproject Manager — Date

Reviewed by:

11/11/02

E.L. Hardin, Natural Systems Subproject Deputy Manager — Date

*With technical contribution from J.A. Hevesi (Infiltration AMR Originator), L.D. Rickertsen (Performance Assessment Strategy and Scope), and D.C. Gillies (U.S. Geological Survey)

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ACRONYMS AND ABBREVIATIONS

AMR	analysis and model report
DOE	U.S. Department of Energy
KTI	Key Technical Issue
LHS	Latin Hypercube Sampling
NRC	U.S. Nuclear Regulatory Commission
TSPA	Total System Performance Assessment
TSPA-SR	Total System Performance Assessment for Site Recommendation
USFIC	Unsaturated and Saturated Flow under Isothermal Conditions
YMRP	Yucca Mountain Review Plan

RESPONSE TO USFIC 3.02: JUSTIFICATION OF PARAMETERS USED IN THE INFILTRATION UNCERTAINTY ANALYSIS

This report presents the technical basis for resolving and closing Key Technical Issue (KTI) Agreement 2 related to Unsaturated and Saturated Flow under Isothermal Conditions (USFIC) Subissue 3, Present-Day Shallow Groundwater Infiltration (USFIC 3.02). The issue that is addressed is the U.S. Department of Energy (DOE)—U.S. Nuclear Regulatory Commission (NRC) agreement that the DOE provide justification for the parameters used in the analysis and model report (AMR) *Analysis of Infiltration Uncertainty* ANL-NBS-HS-000027, Rev 00 (CRWMS M&O 2000a) (herein referred to as the Infiltration Uncertainty AMR). Another related issue that is addressed is documentation for infiltration tests conducted at Alcove 1 and Pagany Wash (Reamer and Williams 2000b).

Section 1 of this report contains an introduction, and Section 2 is a description of regulatory requirements and agreement status. Section 3 presents the response to the agreement, based on preliminary analyses conducted after the issuance of the Infiltration Uncertainty AMR (CRWMS M&O 2000a). The response consists of the following three parts, which when combined constitute the technical basis for closure of USFIC 3.02:

- Section 3.1 presents, as originally agreed upon, justification of parameters used in the Infiltration Uncertainty AMR (CRWMS M&O 2000a). This information supplements the AMR, although it was available at the time the AMR was prepared. This information is being used as partial input for ongoing revision of this AMR.

- Section 3.2 presents, also as agreed upon, the documentation of test data from Alcove 1 and Pagany Wash, which became available after the publication of the Infiltration Uncertainty AMR (CRWMS M&O 2000a).

- Section 3.3 presents results from a recent Total System Performance Assessment (TSPA) sensitivity study which demonstrate that the details of the infiltration model are not important to the calculation of mean annual dose in the first 10,000 years after waste emplacement. This demonstration indicates that further technical justification is not required to support a risk-informed assessment of system performance.

During the preparation of this response, typographical errors were identified in a table of the Infiltration Uncertainty AMR (CRWMS M&O 2000a). Also, the source AMR which developed the infiltration model (USGS 2001) was found to contain insufficient justification for the parameter distributions used subsequently in the Infiltration Uncertainty AMR. As a result of these findings, the DOE issued Deficiency Report BSC(B)-02-D-144 to initiate correction of these discrepancies in accordance with project procedures (see Section 3.4).

1. BACKGROUND

USFIC 3.02 is related to the Monte Carlo analyses conducted as part of the infiltration uncertainty analysis supporting the Total System Performance Assessment for Site Recommendation (TSPA-SR), which is documented in *Total System Performance Assessment for the Site Recommendation* (CRWMS M&O 2000b). At the USFIC KTI Technical Exchange in August, 2000 (Reamer and Williams 2000a) the NRC questioned the values assigned by the DOE to the weight-multipliers for upper-bound mean annual infiltration. At the USFIC Technical Exchange on October 31 –November 2, 2000 (Reamer and Williams 2000b), the NRC also requested justification of parameters used in Table 4-1 of *Analysis of Infiltration Uncertainty* (CRWMS M&O 2000a) (Table 4-1 of that AMR is reproduced as Tables 1A and 1B herein, showing corrections for typographical errors). At the latter meeting, the NRC also requested documentation of the infiltration tests conducted at Alcove 1 and Pagany Wash. In these meetings the DOE agreed to provide justification of the parameters and documentation of the tests.

Table 1A. Uncertain Input Parameter Distributions for Glacial Transition Climate (Reproduced from Table 4-1 of *Analysis of Infiltration Uncertainty* [CRWMS M&O 2000a] with Errors Highlighted in Bold in the Mean Column)

Idpram	Mean	Low Range	High Range	Distribution Type	Units
BRPERM	1.000	0.05	20.0	LOGNORMAL	NONE
BRPOROS	**10.030**	0.0000	0.040	NORMAL	NONE
BRZDEPTH	3.000	1.0000	5.000	NORMAL	METERS
ETCOEFFA	**1.00**	-5.000	-15.0	NORMAL	NONE
ETCOEFFB	1.040	0.540	1.540	NORMAL	NONE
FLAREA	**100**	0.01	0.490	NORMAL	NONE
POTETMUL	**1.04.000**	0.6000	1.400	NORMAL	NONE
PRECIPM	**-10.000**	0.6000	1.400	NORMAL	NONE
SNOPAR1	1.78	0.78	2.78	UNIFORM	NONE
SOILDEPM	**3.000**	0.5000	1.500	NORMAL	NONE
SOILPERM	1.000	0.05	20.0	LOGNORMAL	NONE
SUBPAR1	0.1	0	.2	UNIFORM	NONE

DTN: GS000308311221.008

NOTES: Idpram (uncertain input parameter) values are defined in Table 4-3 of *Analysis of Infiltration Uncertainty* (CRWMS M&O 2000a). For lognormal and normal distributions Latin Hypercube Sampling (LHS) assumes that the low and high values in the range are at the 1.0 and 99.0 percentile (CRWMS M&O 2000a, Section 5.3).

Recently, the Bechtel SAIC Company, LLC has conducted a series of sensitivity studies using the latest version of the TSPA model and concluded that the sensitivity of the mean annual dose to the effects of infiltration is not significant, which indicates that the degree of waste isolation provided by the repository system is not sensitive to the details of the infiltration model, including the assessment of remaining uncertainties in the parameters used in the infiltration uncertainty analysis.

1.1 NRC INITIAL COMMENTS

In discussions of Subissue 3 (Present-Day Shallow Groundwater Infiltration) at the USFIC KTI Technical Exchange on August 16 and 17, 2000, in Berkeley, California (Reamer and Williams 2000a), the NRC staff noted apparent bias in upper bound mean annual infiltration multipliers and expressed concern that the DOE upper-bound estimates of shallow infiltration for present-day and future climates may not be great enough to encompass the uncertainty inherent in the infiltration model parameters and assumptions. In the follow-up discussion of the same subissue at the USFIC KTI Technical Exchange on October 31–November 2, 2000, in Albuquerque, New Mexico (Reamer and Williams 2000b), the NRC raised issues with the consistency of the Alcove 1 permeability measurements with model parameters and the lack of justification for parameter distributions presented in Table 4-1 of *Analysis of Infiltration Uncertainty* (CRWMS M&O 2000a).

Table 1B. Uncertain Input Parameter Distributions for Glacial Transition Climate (Modified from Table 4-1 of *Analysis of Infiltration Uncertainty* [CRWMS M&O 2000a] with Errors Corrected and Highlighted in Bold in the Mean Column)

Idpram	Mean	Low Range	High Range	Distribution Type	Units
BRPERM	1.00	0.05	20.0	LOGNORMAL	NONE
BRPOROS	**0.02**	0.00	0.04	NORMAL	NONE
BRZDEPTH	3.00	1.00	5.00	NORMAL	METERS
ETCOEFFA	**-10.0**	-5.00	-15.0	NORMAL	NONE
ETCOEFFB	1.04	0.54	1.54	NORMAL	NONE
FLAREA	**0.25**	0.01	0.49	NORMAL	NONE
POTETMUL	**1.00**	0.60	1.40	NORMAL	NONE
PRECIPM	**1.00**	0.60	1.40	NORMAL	NONE
SNOPAR1	1.78	0.78	2.78	UNIFORM	NONE
SOILDEPM	**1.00**	0.50	1.50	NORMAL	NONE
SOILPERM	1.00	0.05	20.0	LOGNORMAL	NONE
SUBPAR1	0.10	0.00	0.20	UNIFORM	NONE

DTN: GS000308311221.008

NOTES: Idpram values are defined in Table 4-3 of *Analysis of Infiltration Uncertainty* (CRWMS M&O 2000a).
For lognormal and normal distributions LHS assumes that the low and high values in the range are at the 1.0 and 99.0 percentile (CRWMS M&O 2000a Section 5.3).

1.2 DOE INITIAL RESPONSE

In response to the NRC comments, the DOE agreed at the KTI Technical Exchange on October 31–November 2, 2000 (Reamer and Williams 2000b) to provide the justification of parameter distributions shown in Table 4-1 of *Analysis of Infiltration Uncertainty* (CRWMS M&O 2000a) and to provide documentation of the Alcove 1 and Pagany Wash tests.

1.3 DEFINITION OF TERMS

Significant - an increase in magnitude of the expected annual dose, as a result of the omission of a feature, event, or process or the omission or failure of an engineered barrier, that is more than a small fraction of the numerical limits associated with the postclosure performance objectives in 10 CFR 63.113.

2. APPLICABLE NUCLEAR SAFETY STANDARDS/REQUIREMENTS/GUIDANCE

2.1 APPLICABLE REGULATORY REQUIREMENTS/GUIDANCE

The following 10 CFR Part 63 requirements and *Yucca Mountain Review Plan, Draft Report for Comment* (YMRP) guidelines (NRC 2002) are considered applicable to USFIC 3.02, which is related to the justification of data and parameters used in a process model supporting the TSPA calculations.

- 10 CFR 63.21 (c) (9): An assessment to determine the degree to which those features, events, and processes of the site that are expected to materially affect compliance with § 63.113 - whether beneficial or potentially adverse to performance of the geologic repository - have been characterized, and the extent to which they affect waste isolation. Investigations must extend from the surface to a depth sufficient to determine principal pathways for radionuclide migration from the underground facility. Specific features, events, and processes of the geologic setting must be investigated outside of the site if they affect performance of the geologic repository.

- 10 CFR 63.21 (c) (14): An evaluation of the natural features of the geologic setting and design features of the engineered barrier system that are considered barriers important to waste isolation as required by § 63.115.

- 10 CFR 63.114 (a): Include data related to the geology, hydrology, and geochemistry (including disruptive processes and events) of the Yucca Mountain site, and the surrounding region to the extent necessary, and information on the design of the engineered barrier system used to define parameters and conceptual models used in the assessment.

- 10 CFR 63.114 (b): Account for uncertainties and variabilities in parameter values and provide for the technical basis for parameter ranges, probability distributions, or bounding values used in the performance assessment.

- 10 CFR 63.114 (g): Provide the technical basis for models used in the performance assessment such as comparisons made with outputs of detailed process-level models and/or empirical observations (e.g., laboratory testing, field investigations, and natural analogs).

- 10 CFR 63.304 (4): Focuses performance assessments and analyses on the full range of defensible and reasonable parameter distributions rather than only upon extreme physical situations and parameter values.

- Draft YMRP Revision 2, Section 4.2.1.3.5, Model Abstraction for Climate and Infiltration, Acceptance Criterion 2 – Data are sufficient for model justification.

- Draft YMRP Revision 2, Section 4.2.1.3.5, Model Abstraction for Climate and Infiltration, Acceptance Criterion 3 – Data uncertainty is characterized and propagated through model abstraction.

2.2 KTI AGREEMENT

USFIC 3.02 reads as follows. "Provide justification for the parameters in Table 4-1 of the Analysis of Infiltration Uncertainty AMR (for example, bedrock permeability in the infiltration model needs to be reconciled with Alcove 1 results/observations). Also, provide documentation (source, locations, tests, test results) for the Alcove 1 and Pagany Wash tests. DOE will provide justification and documentation in a Monte Carlo analysis document. The information will be available in February 2002."

2.3 STATUS OF AGREEMENT

The NRC lists the status of this agreement as "not received." This report provides a sufficient technical basis to justify closing the agreement upon the review and acceptance by the NRC.

3. BASIS FOR REGULATORY COMPLIANCE STATEMENT

This section provides the technical basis for the resolution of USFIC 3.02 consisting of the following:

- Documentation justifying the parameter distributions used in the infiltration uncertainty analysis (Section 3.1)
- Documentation of Alcove 1 and Pagany Wash test data (Section 3.2)
- TSPA sensitivity study (Section 3.3).

As described previously, the first two items are specific to the agreement, and the last item is the result of additional sensitivity studies conducted using the latest version of the TSPA model.

3.1 DEVELOPMENT OF PARAMETER DISTRIBUTIONS USED IN THE AMR ANALYSIS OF INFILTRATION UNCERTAINTY

The purpose of the uncertainty analysis originally documented in *Analysis of Infiltration Uncertainty* (CRWMS M&O 2000a) was an estimate of the uncertainty in infiltration rates over the repository footprint and to use the associated uncertainty distributions to provide direct input for TSPA. The uncertainty measure was provided by a complementary cumulative distribution function resulting from a set of 100 realizations (or vectors) each of which provided a unique representative infiltration rate. This representative rate, the metric in this analysis, was obtained by calculating the spatial average for the corresponding infiltration rate map, averaged over a rectangular region, including the loaded footprint of the repository (CRWMS M&O 2000a).

3.1.1 Uncertainty Parameters

The uncertainty analysis required estimates of upper and lower bounds and corresponding distribution types for selected model input parameters considered potentially significant to model sensitivity for INFIL V2.0 (USGS 2001, Section 6.10). The parameters were identified in *Simulation of Net Infiltration for Modern and Potential Future Climates* (USGS 2001) and used in the sensitivity analyses of *Analysis of Infiltration Uncertainty (*CRWMS M&O 2000a). The input parameter uncertainty distributions were intended only for an initial, preliminary analysis of modeled infiltration uncertainty based on initial assumptions of model sensitivity and input parameter uncertainty. The analysis did not account for uncertainty in all aspects of the infiltration model because: 1) an analysis of uncertainty that included the complete set of uncertain model inputs would have been unwieldy and was not attempted, and 2) uncertainty in the model itself (e.g., the accuracy of representing infiltration using the field capacity approach) was not considered (USGS 2001). However, the analysis did provide useful information on infiltration uncertainty that was incorporated in the TSPA.

One approach for quantifying uncertainty in the infiltration model results due to uncertainty in spatially variable model inputs would be to include multiple input realizations distributed spatially across all grid cells. A simpler approach was adapted for *Simulation of Net Infiltration for Modern and Potential Future Climates* (USGS 2001). Only those parameters that could be uniformly scaled using inputs included in the model control file were considered for the uncertainty analysis. A description of the selected parameters and distribution types included in the model control file is shown in Table 2. For some parameters, such as effective bedrock porosity (BRPOROS), the input parameter distribution could be defined using actual values. In other cases, the input parameter distribution was defined using a scaling factor (multiplier) which was then applied to the actual parameter value distributed across all grid cells of the infiltration model. For input distributions defined using multipliers, the actual parameter values varied from cell to cell. Distribution types for all parameters were selected in *Simulation of Net Infiltration for Modern and Potential Future Climates* (USGS 2001) to be one of three types. normal, lognormal, and uniform. Where possible and appropriate, selection of an appropriate distribution was based on results from prior studies (e.g., lognormal distribution for hydraulic conductivity; see *Analysis of Hydrologic Properties Data* [BSC 2001f, Section 6.2.1, p. 48]).

Table 2. Description of Uncertain Input Parameters

Parameter	Description	Distribution
BRPOROS	Bedrock effective root-zone porosity (actual value –unitless)	NORMAL
BRZDEPTH	Bedrock root-zone thickness (actual value – meters)	NORMAL
SOILDEPM	Soil zone thickness (multiplier)	NORMAL
PRECIPM	Daily precipitation (multiplier)	NORMAL
POTETMUL	Daily evapotranspiration (multiplier)	NORMAL
BRPERM	Bedrock bulk saturated hydraulic conductivity (multiplier)	LOGNORMAL
SOILPERM	Soil saturated hydraulic conductivity (multiplier)	LOGNORMAL
ETCOEFFA	First coefficient in expression for evapotranspiration (actual value – unitless)	NORMAL
ETCOEFFB	Second coefficient in expression for evapotranspiration (actual value – unitless)	NORMAL
FLAREA	Surface flow runoff area (actual value – unitless)	NORMAL
SNOPAR1	Snow-melt parameter (actual value – unitless)	UNIFORM
SUBPAR1	First term ("A1") in snow loss (sublimation) equation for temperature regime below freezing (i.e. $T_k \leq 0.0\ ^{\circ}C$) (actual value – unitless)	UNIFORM

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NOTE: Parameters SNOPAR1 and SUBPAR1 were not used in the modern climate scenario uncertainty analysis in *Analysis of Infiltration Uncertainty* CRWMS M&O (2000a). All 12 parameters were used in the analyses for the infiltration rate uncertainty for the glacial-transition climate scenario in *Analysis of Infiltration Uncertainty* CRWMS M&O (2000a).

Upper and lower bounds for the parameters were determined using a combination of absolute bounds defined by the physical limits of the parameter (i.e., BRPOROS, BRZDEPTH, SOILDEPM, PRECIPM, POTETMUL, BRPERM, SOILPERM, FLAREA, SNOPAR1, and SUBPAR1 could not be negative, and BRPOROS and FLAREA could not be greater than 1). Development of the parameter input distributions followed an iterative approach where an initial "best estimate" input distribution for modern climate was tested using the LHS procedure and equations 6-2 through 6-4 in *Analysis of Infiltration Uncertainty* (CRWMS M&O 2000a). The criteria applied to the LHS test run was that the calculated weighting factors (w1, w2, w3 in equation 6-2) were defensible for the application of lower, medium, and upper bound infiltration rate maps, for a given climate scenario, as analogs for modeled infiltration uncertainty. Due to the practical constraints involved in the TSPA-SR (i.e., the same weighting factors had to be used for all three climate scenarios), the uncertainty analysis required the development of a single set of weights for all three climate scenarios (CRWMS M&O 2000a). This required the assumption that the developed weighting factors would be appropriate for all three climate scenarios (modern, monsoon, and glacial-transition) and that the upper and lower bound climate scenarios would be appropriate as an indication of modeled infiltration uncertainty. To ensure that the upper and lower bound climate scenarios could be used as analogs for infiltration uncertainty, w2 needed to be greater than w1 and w3. Although the modern climate scenario was used for the initial test run, the glacial transition climate scenario was used in *Analysis of Infiltration Uncertainty* (CRWMS M&O 2000a) to develop the final weighting factors because this climate scenario was predicted to have a longer duration relative to the modern and monsoon climate scenarios (USGS 2000).

3.1.2 Input Distributions Developed for the Modern Climate Scenario

For the modern climate LHS test run, initial input distributions were developed for a set of 10 parameters (Table 3) that were selected on the basis of model sensitivity and parameter uncertainty considerations (CRWMS M&O 2000a). The BRPOROS parameter is multiplied by the BRZDEPTH parameter to define the total storage capacity in bedrock available for transpiration. The BRZDEPTH term defines the maximum root zone thickness in bedrock. Due to a lack of prior studies quantifying these parameters for arid environments, there was no supporting information available for defining the input distributions. The value of BRPOROS was assigned to have a mean value of 0.02 and to vary between a lower bound value of 0 and an upper bound value that was considered to be representative of the average maximum effective fracture porosity, and which was set to 0.04. The water storage capacity of the root zone in bedrock was thus set to be less than the fracture porosity. (Note that BRPOROS range is the same for both modern and glacial-transition climate scenrios). For the modern climate scenario, BRZDEPTH was assigned a mean value of 2 meters varying between 0 and 4 meters. BRZDEPTH might vary according to climate, with lower values for drier climates and higher values for wetter climates. The initial input distributions of BRPOROS and BRZDEPTH for modern climate were considered reasonable based on the results of model calibration. The actual mean thickness of the root zone in bedrock for the modern climate scenario, averaged across all model grid cells, is less than 2 meters as calculated using equation 17 of *Simulation of Net Infiltration for Modern and Potential Future Climates* (USGS 2001, Section 6.7.2) with the soil depth map (DTN: GS000308311221.004). For model grid cells, the root zone thickness in bedrock decreases as the thickness of soil increases. In addition, the root density in bedrock is only a fraction of the root density in soil, which decreases as a function of depth below surface (USGS 2001, Section 6.8.3, p.56).

The value of SOILDEPM was used to uniformly scale estimates of soil depth across all model grid cells. A deviation of ±0.9 was used to define the lower and upper bound estimates of 0.1 and 1.9 for SOILDEPM. This distribution was considered appropriate because the soil depth estimates were developed within the ranges of the soil depth classes used in the original INFIL model (Flint et al. 1996; DTN: GS960508312212.007). For most grid locations, the bounding values of the input distribution were within the ranges of the soil depth class map (USGS 2001, Section 6.6.3 and Figure 6-13). Furthermore, the spatial distribution of estimated soil depth (USGS 2001, Section 6.7.1 and Figure 6-16) indicates relatively thin soils less than 0.2 meter deep along steep sideslopes and thicker upland soils of 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 6-meter soil depth represents only the depth of the root zone, not the actual soil depth. In addition to consistency with data used in the original INFIL model, the input distribution was considered to be consistent with soil thickness data from *State Soil Geographic (STATSGO) Data Base, Data Use Information* (USDA 1994) in the vicinity of Yucca Mountain, which was found to range from approximately 0.2 to 1.0 meters for various different upland soil types.

For the normally distributed multipliers for precipitation and potential evapotranspiration, PRECIPM and POTETMUL, a deviation of ±0.4 was used to define the lower and upper bound values for the PRECIPM distribution, and a deviation of ±0.5 was used to define the lower and upper bound values for the POTETMUL distribution. The multipliers scale the daily precipitation and potential evapotranspiration rates. The uncertainty defined by the input distribution is used to represent variability in the average current climate conditions (long-term precipitation and evapotranspiration rates). Uncertainty arises due to limitations in the available climate records (period of record, location of data points) for representing modern climate conditions, the empirical elevation-precipitation correlation used to model spatial variability in precipitation and air temperature, and the deterministic modeling of potential evapotranspiration primarily as a function of clear-sky solar radiation. The distribution for the PRECIPM parameter was consistent with the observed variability in estimated average annual precipitation for the Yucca Mountain area (French 1983; Hevesi et al. 1992). The PRECIPM and POTETMUL input distributions from *Simulation of net Infiltration for Modern and Potential Future Climates* (USGS 2001), used in *Analysis of Infiltration Uncertainty* (CRWMS M&O 2000a), are not intended to account for the temporal and spatial variability in daily precipitation and meteorological conditions controlling potential evapotranspiration. For the mean modern climate scenario, simulated precipitation averaged 196.9 mm/year over the 4.7-km^2 area of the 1999 design potential repository area, and simulated evapotranspiration averaged 189.9 mm/year (USGS 2001, Table 6-10).

Table 3. Uncertain Input Parameter Distributions for Modern Climate

Idpram	Mean	Low Range	High Range	Distribution Type	Units
BRPOROS	0.020	0.0000	0.040	NORMAL	NONE
BRZDEPTH	2.000	0.0000	4.000	NORMAL	METERS
SOILDEPM	1.000	0.1000	1.900	NORMAL	NONE
PRECIPM	1.000	0.6000	1.400	NORMAL	NONE
POTETMUL	1.000	0.5000	1.500	NORMAL	NONE
BRPERM	1.000	0.01	100.0	LOGNORMAL	NONE
SOILPERM	1.000	0.01	100.0	LOGNORMAL	NONE
ETCOEFFA	-10.00	-0.100	-19.9	NORMAL	NONE
ETCOEFFB	1.040	0.540	1.540	NORMAL	NONE
FLAREA	0.500	0.01	0.990	NORMAL	NONE

DTN. GS000308311221.008

NOTE: Idpram (uncertain input parameter) described in Table 2.

The lognormal distribution was assigned to conductivity parameters (BRPERM, SOILPERM), based on a summary of previous studies (Freeze and Cherry 1979, p. 30- 31). For BRPERM, the upper and lower bound values were set to be 2 orders of magnitude within the mean value (where the mean value is defined by BRPERM = 1). This range was considered reasonable based on a summary of results provided by Freeze and Cherry (1979, p. 31), indicating that the standard deviation of the log of hydraulic conductivity is usually in the range of 0.5 – 1.5. The variability of ±2(log K) is likely representative of the internal heterogeneous variations in hydraulic conductivity within each rock type at Yucca Mountain, based on variations in fracture aperture and fracture filling (Flint et al. 1996, Table 2). The estimated input distribution does not represent additional sources of variability such as variations in lithology and fracture density within mapped units or uncertainty in measured rock matrix hydraulic conductivity. The rock matrix mean saturated hydraulic conductivity and estimated fracture density were also based on values provided in Table 2 of Flint et al. (1996). The range of ±2(log K) variability is qualitatively supported by the range in estimated saturated hydraulic conductivity, for a given rock unit, for filled and unfilled fractures of varying widths (Flint et al. 1996, Table 2). The mean saturated hydraulic conductivity for each rock unit is similar to the value given for the 250 μm filled fractures in Table 2 of Flint et al. (1996). In other words, the ±2(log K) variability refers to the range represented by uncertainty in fracture width and filling for a given rock type, not the variability between the rock types. The uncertainty analysis was based on the relative differences in permeability between rock types defined by the inputs in Table 2 of Flint et al. (1996). Thus, the bedrock bulk saturated hydraulic conductivity was set to be approximately consistent with the values for the 250 μm filled fractures provided in that table.

The distribution for SOILPERM is considered to be representative of both field-scale variability within mapped soil types and uncertainty in estimated values provided in Flint et al. (1996, Table 4), which indicates that soil saturated hydraulic conductivity ranges from 5.6×10^{-6} to 3.8×10^{-5} m/s. The deviation of ±2 (log K) used in the analysis is wider than the variation in estimated saturated hydraulic conductivity between different soil types ranging from sand to clay (Campbell 1985, Table 6.1). The wider distribution was considered appropriate because the soils at Yucca Mountain have a high percentage of coarse material (grain sizes > 2 mm) (Flint et al. 1996) with very high permeability, but they can also contain layers cemented with calcium carbonate having a very low permeability.

The normal distributions for the parameters ETCOEFFA and ETCOEFFB are used in the modified Priestley-Taylor equation (Priestley and Taylor 1972) for the estimation of bare-soil evaporation. The mean values for both parameters (-10.00 for ETCOEFFA and 1.04 for ETCOEFFB) are consistent with values reported in Flint and Childs (1991). The ranges of ±9.9 for ETCOEFFA and ±0.5 for ETCOEFFB were used to represent uncertainty in estimates of vegetation cover (bare soil evaporation component is inversely related to vegetation cover) and uncertainty in the advective component of the energy balance calculation in *Simulation of Net Infiltration for Modern and Potential Future Climates* (USGS 2001) and in Flint and Childs (1991).

A normal distribution was used for the FLAREA parameter, which defines the fraction of each grid cell in the infiltration model that is affected by overland flow and channel flow during the routing of runoff. For modern climate, overland flow processes are considered to be the primary component of surface water flow, with a mean value of 0.5 assigned to FLAREA. The mean value of 0.5 was also defined as part of the model calibration process to match stream flow records. A wide distribution of ±0.49 was used for defining a lower bound of 0.01 and an upper bound of 0.99, representing a high degree of variability and uncertainty in this parameter (only values between 0 and 1 are valid for FLAREA). The FLAREA parameter is expected to exhibit a high degree of both spatial and temporal variability.

3.1.3 Input Distributions Developed for the Glacial-Transition Climate Scenario

The LHS results for the initial modern climate input distributions indicated that the mean and upper-bound climate scenarios would not be appropriate as analogs for model uncertainty in the TSPA because the calculated weighting factor w3 for the upper bound climate was greater than the weighting factor w2 for the mean (CRWMS M&O 2000a, Section 6.3). To ensure that the net infiltration maps for the climate scenarios could be used to represent model uncertainty, the initial input distributions for the modern climate scenario were modified. A final input distribution was developed for the glacial-transition climate scenario because this scenario had the greatest total duration for the 10,000-year prediction (CRWMS M&O 2000a).

Based on a combination of the results from the modern climate LHS test run, and assumptions concerning future climate conditions, adjustments were made to the initial input distributions for the following five parameters: SOILDEPM, PRECIPM, BRPERM, SOILPERM, and ETCOEFFA. In addition to these adjustments, the distributions for BRZDEPTH and FLAREA were adjusted based on estimated changes in root zone and channel characteristics for the glacial-transition future climate relative to the modern climate scenario. Table 1B indicates the final input distributions for the 12 selected parameters, including SNOPAR1 and SUBPAR1, which were added in order to utilize the snow module in the infiltration model (USGS 2001).

For the glacial-transition input distribution in *Analysis of Infiltration Uncertainty* (CRWMS M&O 2000a), the BRPOROS distribution was left unchanged under the assumption that effective fracture porosity would remain constant for all climates. Although the BRZDEPTH mean was increased from 2 to 3 meters, the distribution range was not changed. The increase in BRZDEPTH was selected because the root zone thickness in fractured bedrock will increase when precipitation increases; the selection was not based on the LHS modern climate test run. The SOILDEPM distribution range was reduced from ±0.9 to ±0.5 about the mean, which was left unchanged. The new distribution was defined by a lower bound of 0.5 and an upper bound of 1.5. The modified distribution is considered to be representative of variability in mean soil depths as defined by the soil-depth class map (USGS 2001, Section 6.6.3 and Figure 6-13), where the mean soil depth is approximately defined as the average of the upper and lower soil depth values defining the four soil-depth classes (0 – 0.5 m, 0.5 – 3 m, 3 – 6 m, and ≥6 m). The PRECIPM distribution range was reduced (bounds were moved closer to the mean) by a small percentage, to improve the defensibility of weighting factors developed for TSPA-SR. Although the LHS results indicated a strong sensitivity of net infiltration to the PRECIPM parameter, the adjustment was considered reasonable because total variability in long-term precipitation is taken into account by the lower and upper-bound climate scenarios. In addition, the analog climate records used to develop the mean glacial transition climate scenario for the uncertainty analysis consisted of a longer period of record compared to the climate records used to develop the modern climate scenario for Yucca Mountain (USGS 2001, Tables 6-1, 6-5, and 6-6). The

PRECIPM input distribution accounts only for variability in long-term precipitation within the lower bound, mean, or upper bound climate scenario. The POTETMUL distribution was left unchanged in *Analysis of Infiltration Uncertainty* (CRWMS M&O 2000a). For the mean glacial-transition climate scenario, simulated precipitation averaged 323.1 mm/year over the 4.7-km^2 area of the 1999 design potential repository area, and simulated evapotranspiration averaged 287.8 mm/year (USGS 2001, Table 6-19).

The BRPERM and SOILPERM distribution ranges were narrowed by a relatively large amount in that the ±2 (log K) deviation was reduced to ±1.3 (log K) for *Analysis of Infiltration Uncertainty* (CRWMS M&O 2000a). For BRPERM, this adjustment was justified based on the approximation that all fractures can be considered as filled and that variability depends chiefly on variations in fracture aperture (Flint et al. 1996, Table 2). This rationale is supported by field observations in which fractures at the surface of Yucca Mountain are commonly observed to be filled with calcite. Furthermore, if open fractures are considered, the bulk bedrock saturated hydraulic conductivity would be much larger. This leads to difficulties in performing model calibration to data for precipitation or runoff events. For example, to simulate the observed 1995 streamflow events (Flint et al. 1996), bedrock permeability must be sufficiently low to allow for the soil profile to become fully saturated due to a combination of low winter evapotranspiration rates and a sequence of precipitation and snow melt events. Trial and error fitting during model calibration indicated that simulating the observed streamflow as Hortonian overland flow, not saturated overland flow (Maidment 1993, p. 9.2), required unreasonably low values for soil hydraulic conductivity, or unreasonably high estimates of precipitation rates that were not supported by the higher resolution (15-minute and hourly) precipitation data (DTN. GS010408312111.001). For SOILPERM, the narrower distribution was considered reasonable based on results from double-ring infiltrometer tests at Yucca Mountain (Hofmann et al. 2000, Table 4) and hydraulic conductivity values provided in Flint et al. (1996, Table 4). In other words, the refined SOILPERM input distribution for *Analysis of Infiltration Uncertainty* (CRWMS M&O 2000a) represents the field-scale variability in hydraulic conductivity for a given soil type, and does not account for uncertainty in average hydraulic conductivity values provided in Flint et al. (1996), which are estimates based on average soil texture for a given mapped soil unit and equations in Campbell (1985). The distribution range was considered to be reasonable based on the range in estimated saturated hydraulic conductivity for various soil textures (Campbell 1985, Table 6.1).

For the parameters controlling bare soil evaporation, the distribution for ETCOEFFA was narrowed, while the distribution for ETCOEFFB was left unchanged from the modern climate scenario to the glacial-transition climate scenario. The adjustment to the ETCOEFFA distribution was considered reasonable based on results from Flint and Childs (1991). The range of the FLAREA input distribution was narrowed from ±0.49 about the mean to ±0.24 about the mean, and the mean was reduced from 0.5 to 0.25. The new distribution was defined by a lower bound value of 0.01 (same as for modern climate) and an upper bound value 0.49 (about one-half that used for modern climate). The reasoning used to develop the new distribution was that a greater proportion of total surface water flow for the wetter glacial-transition climate would occur as channelized stream flow as opposed to widespread overland flow. A supporting assumption was also made that drainage networks would be better established for a wetter climate, and surface features would include better defined rill features on sideslopes and in headwater areas of drainages, which in turn would serve to better concentrate overland flow.

For the glacial-transition climate, the parameters SNOPAR1 and SUBPAR1 were added to the input parameter set to utilize the snow module of the infiltration model. A uniform distribution was used for both parameters, with SNOPAR1 defining the snowmelt rate and SUBPAR1 defining the sublimation rate (SNOPAR1 is equivalent to "A" in equation 7, and SUBPAR1 is equivalent to "A1" in equation 6 in USGS 2001, p. 38). The uniform distribution was selected for both parameters because of a lack of data defining input distributions. The mean value of 1.78 for SNOPAR1 was based on the temperature-index expression for light open forest during April (Sierra Nevada, California) obtained from Maidment (1993, Table 7.3.7). The upper-bound value of 2.78 and the lower-bound value of 0.78 used in *Analysis of Infiltration Uncertainty* (CRWMS M&O 2000a) were defined using a distribution range of ±1.0 for SNOPAR1, based on a qualitative assessment of various temperature-index expressions provided in Maidment (1993, Table 7.3.7).

Parameter values in Maidment (1993) range from minimum values of 0.58 (Boreal forest, midseason) and 0.9 (Southern Manitoba) to maximum values of 4.58 (Montana Rockies, May), 3.3 (Western Cascades, May), and 5.7 (Southern Ontario). In the literature, there is no equivalent for a temperature-index expression to estimate changes in the snowpack caused by sublimation and advective processes (saltation and turbulent diffusion). Existing studies indicate a high dependency on wind direction and speed, in addition to air temperature, relative humidity, and elevation (Maidment 1993, pp. 7.5 through 7.10 and Figure 7.2.4). To include the sublimation component of the snowpack water balance in the infiltration model (USGS 2001), a model was developed using an assumed energy-index expression, where the energy for sublimation/advection is defined using the adjusted Priestley-Taylor potential evapotranspiration rate (USGS 2001, p. 39). This hypothetical sublimation/advection model assumes that there is no snow accumulation due to advection. Given that wind characteristics are not parameters in the infiltration model, adding a sublimation/advection component to the uncertainty analysis is speculative but was considered necessary for a more complete characterization of the snowpack water balance.

Given a conceptual understanding that sublimation (including saltation and turbulent diffusion) of snow is a component of the snowpack water balance, the parameter was assigned a range such that it would be small compared to the snow-melt parameter. To be conservative in the infiltration uncertainty analysis the mean percentage of snowpack loss due to sublimation/advection was assumed to be considerably less than the maximum values of 41 to 34 percent indicated by field studies (Maidment 1993, p. 7.8).

3.2 ALCOVE 1 AND PAGANY WASH TEST DATA

To further address USFIC 3.02 on infiltration parameter distributions, specifically to reconcile bedrock permeability in the infiltration model with test results and observations at Alcove 1 and Pagany Wash, this section presents a preliminary analysis that compares the bulk bedrock saturated hydraulic conductivities of Tiva Canyon Tuff with Alcove 1 data and model values and the conductivity of alluvial deposits with Pagany Wash model values. The bedrock conductivities are based on the values in *Simulation of Net Infiltration for Modern and Potential Future Climates* (USGS 2001). The uncertainty range for the bedrock conductivity multiplier is 0.05 to 20, according to *Analysis of Infiltration Uncertainty* (CRWMS M&O 2000a). For locations and general descriptions of these tests conducted at Alcove 1 and Pagany Wash, see

"Selected Pages from Scientific Notebook SN-USGS-SCI-0108-V1 & V2 for Data Package. Tracer Data for the Alcove 1 Infiltration Experiment, Phase II May 9, 1999 to July 5, 2000." (Barck 2000, pp. 6 and 7, which are included in Attachment I of this report) and LeCain et al. (2002, pp. 1 through 6, Figures 2 and 4).

3.2.1 Alcove 1

Alcove 1 is located in the upper lithophysal zone of the Tiva Canyon Tuff. The specific bedrock conductivity tabulated in *Simulation of Net Infiltration for Modern and Potential Future Climates* (USGS 2001, Table IV-3, pp. IV-11 to IV-15) for the upper lithophysal unit is 1.13 mm/d (1.33×10^{-15} m^2). All the bedrock conductivities in USGS (2001) are based on bulk values for 250-micron-aperture fractures filled with in-fill materials. An assumption in USGS (2001) for the purpose of evaluating infiltration is that the fracture flow is maintained only through the thickness of the Tiva Canyon Tuff within the root-zone, which is estimated to be less than 2 meters (USGS 2001, Section 6.3.4, p. 33).

In the Alcove 1 experiment water infiltrated into the bedrock directly above the alcove. The range of flux was from 0 to 30 mm/d (3.54×10^{-14} m^2) during February 19, 1999, to December 15, 1999 (Flint 2000). The range of 18 mm/d (2.12×10^{-14} m^2) to 25 mm/d (2.95×10^{-14} m^2) was maintained from September 21, 1999, to October 15, 1999 before a test with tracer application began. In both the Phase I test (from March 8, 1998, to December 4, 1998, see DTN: GS990108312242.006) and the Phase II test (from January 29, 1999, to June 20, 2000, see DTN: GS000808312242.006) water application was controlled such that no surface runoff occurred. Therefore, an infiltration rate over 30 mm/d could induce surface runoff with the bedrock layer saturated. The flux range of 18 to 25 mm/d corresponds to a factor of 16 to 22 larger than the Net Infiltration Model value of 1.13 mm/d (USGS 2001). This range of multiplying factor is close to the value of 20, the upper value of uncertainty range for the bedrock conductivity multiplier used in *Analysis of Infiltration Uncertainty* (CRWMS M&O 2000a).

It is likely that the conductivities for fractures without filling are greater than for filled fractures with the same aperture. This is one of possible reason why the permeability values measured by air injection in Alcove 1 (along underground boreholes drilled from the alcove, and situated below surface covers) are much higher than the value tabulated in *Simulation of Net Infiltration for Modern and Potential Future Climates* (USGS 2001). The overall infiltration, percolation, seepage, and transport processses between the surface and alcove are likely controlled by the permeability of fractures in the bulk rock in response to artificial injections.

The Alcove 1 artificial infiltration test results are used for model validation in the AMR UZ Flow Models and Submodels (BSC 2001d, Section 6.8.1, pp. 140 through 147, Table 6-34; see also Liu et al. 2002). The vertical fracture permeability calibrated with the seepage data in the AMR has the value of 2.74×10^4 mm/d (3.23×10^{-11} m^2), 4 orders of magnitude higher than the value of 1.13 mm/d reported in *Simulation of Net Infiltration for Modern and Potential Future Climates* (USGS 2001). The calibration starts with the Alcove 1 measured values from air-injection tests in boreholes drilled from the interior of the alcove, ranging from 169 mm/d (0.2×10^{-12} m^2) to 7.20×10^4 mm/d (85.0×10^{-12} m^2), with the geometric mean of 1.36×10^4 mm/d (16.0×10^{-12} m^2) (LeCain 1998, p. 1 and Tables 1-3).

It is also noted that most (20 out of 32 table entries) bedrock conductivities of Tiva Canyon Tuff in *Simulation of Net Infiltration for Modern and Potential Future Climates* (USGS 2001) have the minimum value of 0.06 mm/d (7.08×10^{-17} m^2), while the bedrock conductivity for the upper lithophysal has the higher value 1.13 mm/d. The maximum value in USGS (2001) for Tiva Canyon Tuff is 13.8 mm/d (1.63×10^{-14} m^2). If we use the minimum value of 0.06 mm/d, the ratio between the filled fracture value in USGS (2001) with the Alcove 1 fracture permeability value (2.74×10^4 mm/d) is even greater than 4 orders of magnitude.

3.2.2 Pagany Wash

Pagany Wash is an alluvium/colluvium filled channel located northeast of Yucca Mountain. An analytical estimation of infiltration was made using the temperature data between sensors at 3.0 and 6.1 m below the surface in borehole UZ #4 (LeCain et al. 2002, Table 1, p. 18). The hydraulic conductivity used in the solution is 149 mm/d (1.75×10^{-13} m^2). One data value is listed in *Simulation of Net Infiltration for Modern and Potential Future Climates* (USGS 2001) for alluvium/colluvium deposits: 500 mm/d (5.9×10^{-13} m^2). The model value of 149 mm/d is approximately 30 percent of the value of 500 mm/d used in USGS (2001). While alluvium layers could have higher and lower hydraulic conductivities, this analytically estimated value is within the uncertainty range of 0.05 to 20 in the *Analysis of Infiltration Uncertainty* (CRWMS M&O 2000a, Table 4-1, p. 14).

3.2.3 Implication of Permeability Differences

For fractured tuff locations such as Alcove 1, there may be large differences between the bedrock conductivity values representing filled fractures as applied in *Simulation of Net Infiltration for Modern and Potential Future Climates* (USGS 2001), and measured values from boreholes intersecting open fractures, as discussed in Section 3.2.1. The filled fractures may control the infiltration through the bedrock under nominal climate conditions, while the open fractures control the flow paths for air movement and liquid flow below the bedrock in response to high-rate injection, such as that conducted during the Alcove 1 artificial infiltration tests. Changes in many other parameters, processes, and conditions, in addition to bedrock conductivities, determine the infiltration distribution. Additional sensitivity studies have been conducted to assess the potential impact of remaining uncertainties of the infiltration model on total system performance, and results of these studies are presented in Section 3.3.

For alluvium locations such as at the Pagany Wash, representation of the bedrock as a porous medium, like the alluvium, is supported by the agreement obtained between the bedrock conductivity value used in *Simulation of Net Infiltration for Modern and Potential Future Climates* (USGS 2001) and an independent estimate derived from the interpretation of temperature data from an infiltration test.

3.2.4 Discussion of Permeability Ranges

The range of Alcove 1 air-permeability (k) is 2.63 orders of magnitude, with the range determined by $\log_{10} (k_{max}/k_{min})$. This range for a Tiva Canyon welded tuff site is comparable to the ranges of two Topopah Spring welded tuff sites: range of 2.75 at Niche 3107 and range of 2.68 at Niche 4788 (BSC 2001e, Table 6.1.2-1). In fractured welded tuff locations, these permeability ranges are between the multiplier range of 2.60 for the glacial transition climate (multiplier from 0.05 to 20) and the multiplier range of 4.0 for the modern climate (multiplier from 0.01 to 100) (CRWMS M&O 2000a, Table 4-1, p. 14, and DTN: GS00030831221.004). (It is noted from the range definition that the measure of spatial variability with permeability ratio is sensitive to the presence of outliers with extreme high or low values, as in the case of Niche 3650 in the vicinity of the Sundance Fault.)

The dependence of the permeability range on climate is likely associated with the dependence of spatial heterogeneity of fracture in-fill material on climate. Heavy or long-term precipitation tends to promote more extensive saturated conditions at the soil-bedrock interface. Net infiltration through fracture flow is initiated when the soil-bedrock interface reaches saturation or near-saturation condition (Hevesi et al. 2002, p. 13; Flint et al. 2000; Flint et al. 2001). This is the basis for the net infiltration model that has been developed from studies at Yucca Mountain site and applied to the Death Valley regional flow system. The evaluation of studies of near-surface caliche and other mineral deposits in paleo-climate stages could substantiate or refute the hypothesis about infiltration control by spatial distribution of filled fractures under different climate stages.

3.3 TSPA SENSITIVITY STUDY

To further address uncertainties in the parameter distributions for the infiltration model, this section presents results of a sensitivity study that has been conducted to provide insight into the importance of these uncertainties in the assessment of postclosure performance. This study examines the impact of net infiltration on the ability to demonstrate compliance with the individual protection requirement of 10 CFR 63.113(b) and takes into account uncertainties in the net infiltration model in this evaluation.

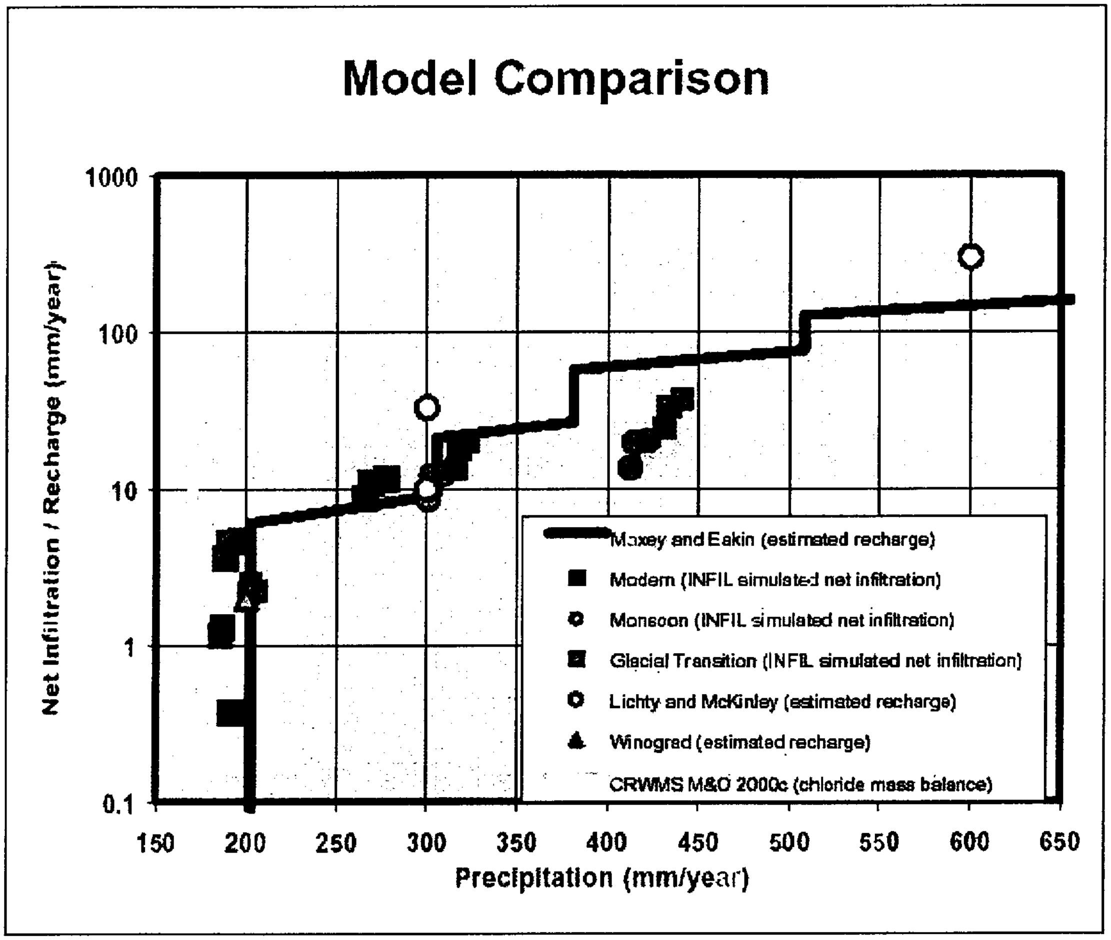
The net infiltration model is used to calculate infiltration rates that are used as boundary conditions for the unsaturated zone flow model, which is used to generate flow fields to predict the amount of flux and the transport of radionuclides in the unsaturated zone under various climatic conditions. The flow fields are developed based on the infiltration projected to occur over the next 10,000 years. Uncertainties in the infiltration may therefore affect the representation of the flow fields and these effects could therefore be translated into uncertainties in the assessment of repository performance. The flow can potentially affect performance in the following ways. First, it can potentially affect the estimated amount of seepage into the emplacement drifts and the resulting amount of water that might contact the waste packages. In principle, this could play a role in affecting degradation of the waste package. However, detailed analyses based upon experimental measurements indicate that degradation of the corrosion-resistant waste package material shows little sensitivity to amount of water contacting the waste package (CRWMS M&O 2000c, Section 5.2). Accordingly, uncertainties in the net infiltration model are expected to be unimportant to performance of the waste package.

Second, the flow could potentially affect the amount of water contacting waste in waste packages that have breached and therefore affect the mobilization of radionuclides in these waste packages. Third, the flow could affect transport of radionuclides released from the waste packages and that reach the rock in the unsaturated zone. The issue is the extent to which the uncertainties in the net infiltration model could be translated in effects on mobilization and transport of radionuclides sufficient to affect compliance with the individual or groundwater protection requirements.

Careful consideration of the information already available, as shown below, indicates that the details of the unsaturated zone flow model do not play a significant role in the estimate of individual and groundwater protection provided by the system. There are two scenarios in which the unsaturated zone flow might play a role. (1) the nominal scenario (the scenario for expected conditions in which igneous activity does not occur) and (2) the igneous activity groundwater release scenario. The nominal scenario describes expected conditions for all the elements of the system. The radionuclides that dominate the estimate of mean annual dose for this scenario are highly soluble (CRWMS M&O 2000b, Table 3.5-8, p. 3-119) so that their release does not depend strongly on the amount of water that is present. This conclusion holds even considering flow focusing or episodicity effects in which locally high flows might occur. Uncertainties in the net infiltration model are therefore not likely to have a significant effect on the estimate of mean annual dose for the nominal scenario.

The igneous activity groundwater release assumes that igneous activity occurs and intruding magma damages waste packages and drip shields, exposing the waste to water flowing down through the unsaturated zone. In this scenario, the repository does not benefit from diversion of water by the engineered barriers; consequently, the significance of variations and uncertainties in the flow system may be more clearly ascertained. The radionuclides that dominate the estimate of the probability-weighted mean annual dose for the igneous activity groundwater release scenario includes radionuclides that are less soluble. The release of these radionuclides could be affected by the amount of water present and uncertainties in the net infiltration model could therefore translate into effects on the estimate of mean annual dose. However, the estimate of mean annual dose in this case is so low that it is not likely that these effects could result in an estimate exceeding the regulatory standard. Accordingly, while uncertainties in the net infiltration model can play a role in understanding the flow model, significant effects on compliance with the individual protection requirement are not expected.

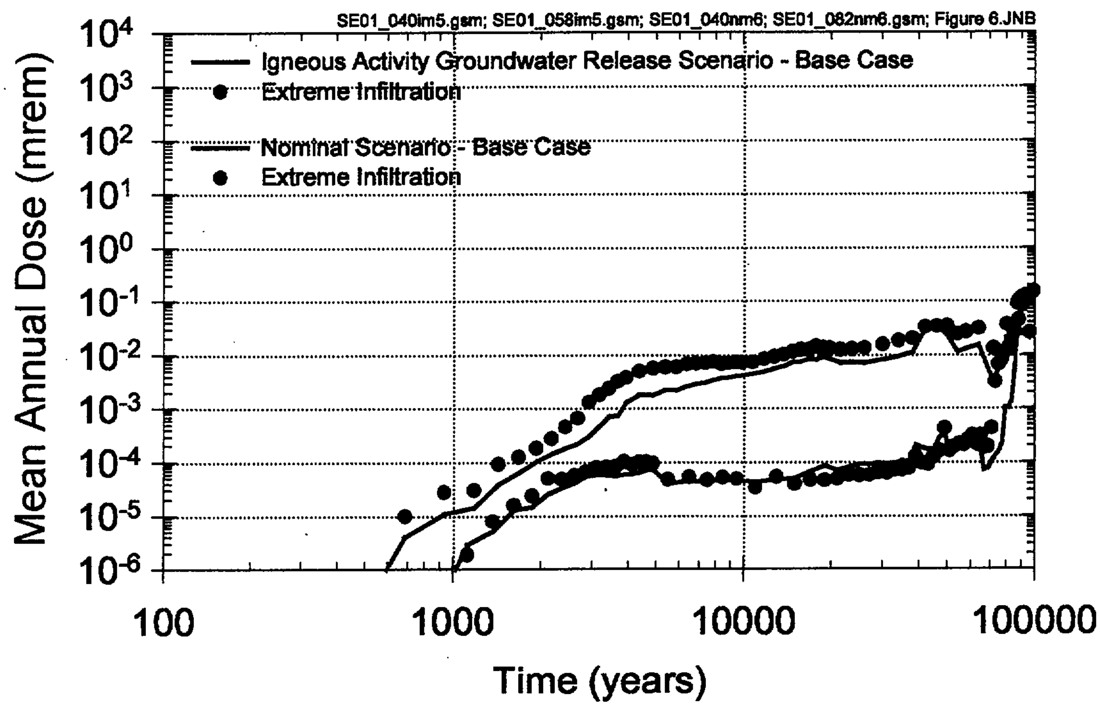
A TSPA sensitivity study has been conducted to quantify these effects and to confirm these physical arguments. The study has been conducted using a TSPA model that is described in the risk prioritization report (BSC 2002a, Section 3.1, p. 3-1). In this sensitivity study, the results using the current unsaturated zone flow model are compared with the results using an extreme representation for the unsaturated zone flow. Precipitation onto Yucca Mountain averages about 190 mm/year under current conditions, and the maximum average is estimated to be no more than 310 mm/year over the next 10,000 years (BSC 2001a, Table 3.3.1-1, p. 3T-1). The corresponding net infiltration flux in the current model averages about 4.6 mm/year under present day conditions and about 12 mm/year over the next 10,000 years (BSC 2001a, Table 3.3.2-1, p. 3T-5). The flux in the extreme model considered in the sensitivity analysis averages about 150 mm/year (BSC 2001a, Table 3.3.2-3, p 3T-7), more than an order of magnitude greater than the infiltration flux of the current model and only a factor of 2 below the maximum precipitation projected for the next 10,000 years. That this infiltration flux represents a reasonable bound to the uncertainties in the flux is indicated in Figure 1. This figure shows the results of alternative approaches to estimating net infiltration or recharge flux for different precipitation rates at the Yucca Mountain site and other locations (BSC 2001b, Figure 6-41). These results generally indicate that, for a precipitation rate well beyond the maximum of 310 mm/year estimated for the next 10,000 years, 150 mm/year provides a useful bound to the average infiltration flux.



Source: USGS 2001, Figure 6-41

Figure 1. Comparison of INFIL V2.0 Simulated Average Net-Infiltration Rates (DTN. GS000308311221.005) at Yucca Mountain (Upper Bound, Lower Bound, and Mean for Three Climates)

Estimates of mean annual dose for the two net infiltration models are shown in Figure 2. The results for the nominal scenario show little change to the estimate of mean annual dose. For the nominal scenario, the change in mean annual dose in the first 10,000 years is estimated to be less than 0.0001 mrem/year and is considered to be insignificant. The reason this change is small is that the mean annual dose is dominated by carbon-14 and technetium-99, highly soluble radionuclides whose release is not significantly affected by the amount of water present. These results confirm the physical arguments for the nominal scenario discussed at the beginning of this section of the document.



NOTE: Each mean annual dose curve is a probability-weighted average.

Figure 2. Sensitivity of Mean Annual Dose to the Infiltration and Unsaturated Zone Flow Models as Defined for Base-Case and Extreme Infiltration Fluxes

The results for the igneous activity groundwater release scenario also confirm the physical arguments. The release in this case is dominated by solubility-limited radionuclides, neptunium-237, plutonium-239, and plutonium-240, and the estimate of mean annual dose is higher due to increased flux through the unsaturated zone. However, the change in the probability-weighted mean annual dose in the first 10,000 years is still less than 0.01 mrem/year and considered to be insignificant. Thus, the conclusion remains that uncertainties in the particular representation of the unsaturated zone flow system play little role in determining whether the repository system would meet the individual protection requirement of 15 mrem/year. These results indicate that in the presence of waste packages and other engineered barriers, the potential remaining uncertainties in the bedrock permeability used in the infiltration model are not important to a risk-informed performance assessment. Therefore, the TSPA sensitivity study results also support the closure of USFIC 3.02.

3.4 QUALITY ASSURANCE

During the preparation of this response, typographical errors were identified in Table 4-1 of *Analysis of Infiltration Uncertainty* (CRWMS M&O 2000a). In addition, it was identified that Section 6.10.2 of *Simulation of Net Infiltration for Modern and Potential Future Climates* (USGS 2001) does not provide sufficient justification for the parameter distributions used in the infiltration uncertainty analysis. Two Technical Error Reports (TER-02-0092 and TER-02-0095) and a deficiency report (BSC-02-D-144) have been initiated to correct the tabulation errors in Table 4-1 of *Analysis of Infiltration Uncertainty* (CRWMS M&O 2000a) and to correct the deficiency in documented justification of the parameters. Data and information presented in Sections 3.1 and 3.2 of this report address the latter part of these issues related to parameter justification, and provide preliminary information for resolution of the deficiencies. Actions to correct the identified errors and deficiencies, including revision of *Analysis of Infiltration Uncertainty* (CRWMS M&O 2000a), are now underway.

The mean values for the following parameters listed in Table 4-1 of *Analysis of Infiltration Uncertainty* (CRWMS M&O 2000a) are different from those provided in Table 4-2 of DTN: GS000308311221.008. BRPOROS, ETCOEFFA, FLAREA, POTETMUL, PRECIPM, and SOILDEPM. These discrepancies are identified to be transcription errors that occurred to the MS Word file of the AMR after its checking was completed. It has been verified that the parameter values provided in DTN: GS000308311221.008 are consistent with those used in the Monte Carlo analyses. Therefore, the typographic errors manifested in Table 4-1 of *Analysis of Infiltration Uncertainty* (CRWMS M&O 2000a) have no impact on the results of the Monte Carlo analyses in the infiltration uncertainty analysis. It was also confirmed that these tabulated parameters were used only in *Analysis of Infiltration Uncertainty* (CRWMS M&O 2000a), and thus the tabulation errors have no impact on any downstream AMRs or on the TSPA-SR.

The analyses presented in Sections 3.1 and 3.2 cited the following DTNs: GS960508312212.007, GS990108312242.006, GS000308311221.004, GS000308311221.008, GS000808312242.006, and GS010408312111.001. Among these, DTNs: GS960508312212.007, GS000308311221.004, GS000308311221.008, and GS010408312111.001 are qualified, whereas DTNs: GS990108312242.006 and GS000808312242.006 are unqualified. These unqualified data are deemed appropriate for use in these preliminary corroborative analyses.

The activity evaluation for the sensitivity study presented in Section 3.3 determined that the prioritization effort to support management decision-making is not subject to quality assurance procedures (BSC 2002b). Consequently, the sensitivity study conducted for this report is considered to be scoping and was not conducted according to such procedures. However, the study was prepared by qualified staff and documented in sufficient detail that it can be verified without recourse to the originator. In addition, the study was conducted using a controlled master TSPA model, and changes to that model are controlled. The sensitivity study calculations were performed using the numerical code, GoldSim, Version 7.17.200 (BSC 2001c). This code is the same as that used for the revised supplemental analysis for the site suitability evaluation (Williams 2001).

4. REFERENCES

4.1 DOCUMENTS CITED

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4.2 CODES, STANDARDS, REGULATIONS, AND PROCEDURES

10 CFR (Code of Federal Regulations) 63. Energy. Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada. Readily Available.

4.3 SOURCE DATA, LISTED BY DATA TRACKING NUMBER

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GS000808312242.006. Pulse Flow Meter Data for the Alcove 1 Infiltration Experiment from 02/19/99 – 06/20/00. Submittal date: 09/07/2000.

GS010408312111.001. Site Meteorology Data for Weather Stations UE-25 WX Stations 1 through 5, 10/1/94 - 10/1/95, Part II. Submittal date: 4/24/2001.

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. Submittal date: 04/21/1996.

GS990108312242.006. Pulse Flow Meter Data for the Alcove 1 Infiltration Experiment from 03/08/98 to 12/04/98. Submittal date: 01/29/1999.

5. ATTACHMENTS

I: SELECTED PAGES FROM SCIENTIFIC NOTEBOOK SN-USGS-SCI-0108-V1 & V2 FOR DATA PACKAGE. TRACER DATA FOR THE ALCOVE 1 INFILTRATION EXPERIMENT, PHASE II MAY 9, 1999 TO JULY 5, 2000 (Barck 2000, pp. 6 and 7)

ATTACH MENT I

SELECTED PAGES FROM SCIENTIFIC NOTEBOOK SN-USGS-SCI-0108-V1 & V2 FOR DATA PACKAGE. TRACER DATA FOR THE ALCOVE 1 INFILTRATION EXPERIMENT, PHASE II MAY 9, 1999 TO JULY 5, 2000 (Barck 2000, pp. 6 and 7)

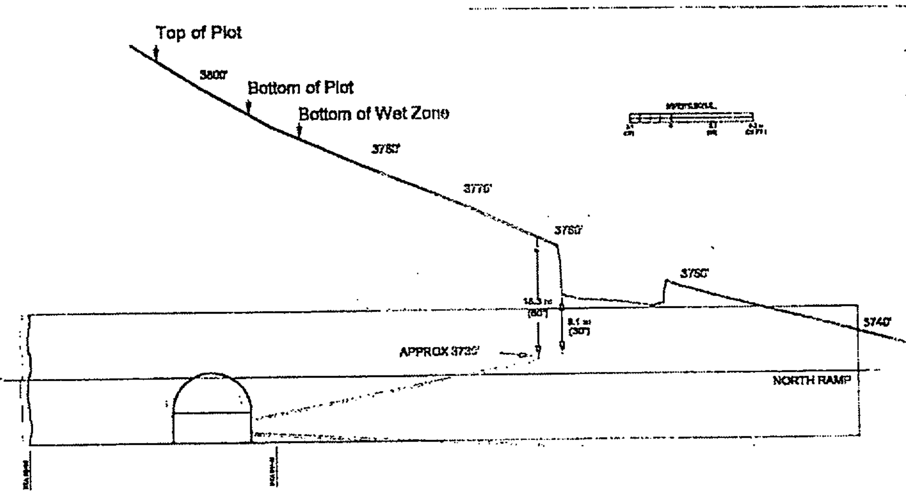
ALCOVE. THE INFILTRATION PLOT WILL EXTENT 26' WEST AND 35' SOUTH FROM THIS CORNER. THE PLOT DIMENSIONS ARE ALSO CONTROLLED BY THE SURFACE GEOLOGY. ALL POSSIBLE EFFORTS ARE BEING MADE TO AVOID PLACING ANY OF THE INFILTRATION PLOT OVER EXPOSED BEDROCK. THIS IS DONE TO AVOID ANY SURFACE RUN OFF OF WATER.

INSTALLATION OF DRIP IRRIGATION EQUIPMENT

THE DOWNSLOPE SIDE OF THE PLOT IS CONTROLLED BY AN OUTCROP OF BOULDERS. THE FIRST IRRIGATION LINE WILL BE JUST ABOVE THIS LOCATION.

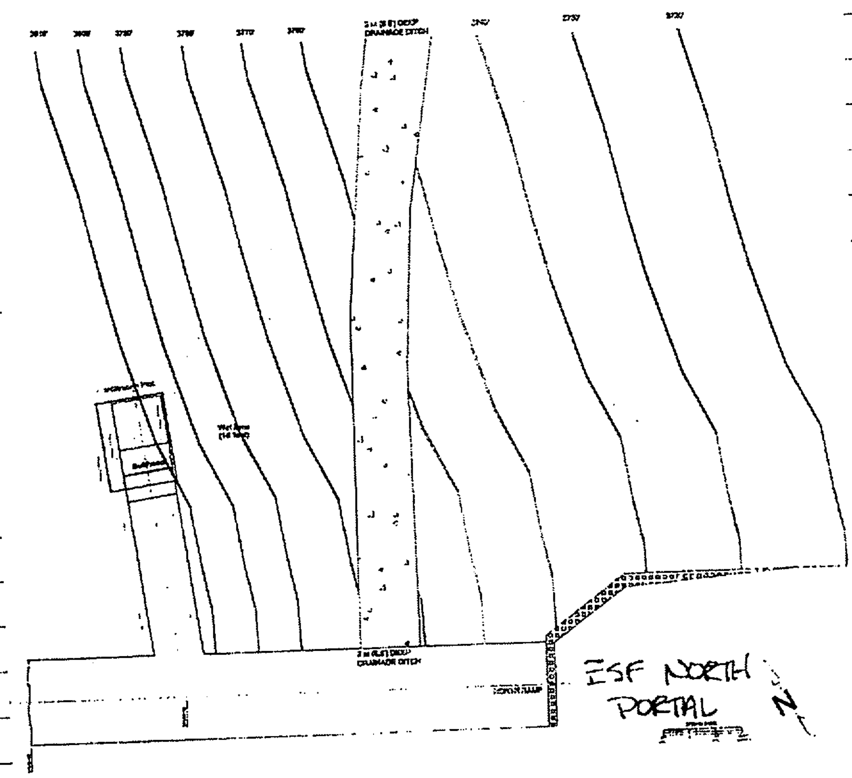
1/19/99 WRG

ALL LARGE BUSHES WILL BE REMOVED FROM THE PLOT



THE FIGURE ON PAGE 29 SHOWS THE RELATIONSHIP OF THE INFILTRATION PLOT TO THE ALCOVE. THE FIGURE BELOW SHOWS THE LOCATION OF THE PLOT & ALCOVE TO THE ESF NORTH PORTAL.

WRG 1/29/99



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