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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

January 25, 1995

MEMORANDUM TO: John Austin, Chief
Performance Assessment & Hydrology Branch

THROUGH: Norman Eisenberg, Section Leader
Performance Assessment Section, PAHB

FROM: Richard Codell
Performance Assessment Section, PAHB

RC

SUBJECT: EPRI PERFORMANCE ASSESSMENT MEETING

I attended a meeting at the Electric Power Research Institute (EPRI) headquarters in Palo Alto, California on December 12 and 13, 1994, which was for the purpose of bringing together people working on the performance assessments (PA) for the Yucca Mountain repository, especially with regard to hydrologic and transport issues. There are currently four PA's underway; DOE-Sandia, DOE-M&O, NRC and EPRI. There were representatives from Sandia National Laboratories (Mike Wilson) and myself for NRC, but the M&O was not represented. Linda Lehman represented the State of Nevada, although EPRI paid for her travel and accommodations. The remaining attendees represented EPRI and its contractors who developed IMARC, the EPRI PA model.

EPRI is funded by utilities to conduct research on their behalf. High-level and low-level waste are considered to be among the most important topics for EPRI research. Their general goal for Yucca Mountain research will focus on developing an independent capability to identify the most important technical issues, demonstrate PA techniques and approaches, and assist DOE, EPA and NRC in resolving licensing issues. They feel strongly that PA is the best tool to assess the importance of technical issues, prioritizing site characterization needs, and determining site suitability.

IMARC differs in a number of important respects from the other three PA models. Among the biggest differences in IMARC is the use of a "decision tree" approach to propagate model uncertainty, parameter uncertainty, and alternative design choices. The other three PA's employ Monte Carlo sampling. Robin McGuire, of Decision Engineering Inc., explained that there were some advantages to the approach they took in evaluating sensitivities. In their current model, there appears to be potentially 30,000 possible combinations of decision pathways. However, the branches in the decision tree that proved to have consequences too small to be important could be truncated.

Mike Wilson gave a synopsis of the Sandia TSPA-93. Frank Schwartz of the University of Ohio gave an overview of hydrologic concerns at the Yucca Mountain site and the models adopted in EPRI's approach.

Linda Lehman discussed some results from an analysis of site characterization for Yucca Mountain that might be considerations in the hydrologic models used

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in PA. She presented an interpretation of temperatures measured in wells near the site. There is an apparent temperature anomaly in these wells that she postulates shows a significant flow of colder water from the region of the high hydraulic gradient to the northwest through fault zones like Solitario Canyon, Drill Wash Fault, and Ghost Dance Fault. I had several questions about the data and her interpretation: (1) Do the measured temperatures represent the top of the water table, or at least a consistent depth below it; (2) Are the temperature anomalies partially explained by the geothermal gradient alone, given that the water table depth below land surface varies widely from well to well; and (3) How much water would have to be flowing in the fault zones to account for the temperature differences. Linda commented that the she did not account for the geothermal gradient difference, but that some of the coldest water occurred where the depth to the water table was greatest, which is opposite from the expected effect. She did not perform any calculations on point 3 however. I commented that it would be interesting and not difficult to calculate the flow of water necessary to explain the temperature differences, and from this result, one could see if water flow is a viable mechanism. My first impression is that the temperature differences are too great to be explained by water flow because most heat transfer underground is dominated by thermal conduction. Alternative explanations would include data measurement errors, perched water, differences in thermal conductivity, and conduction or upwelling from concentrated sources of geothermal heat.

Dr. Edward Sudicky, an EPRI consultant from the University of Waterloo, commented that the models for flow and transport in the EPRI model could be improved significantly. His specialty is the development of hydrologic models for flow and transport in saturated and unsaturated media. He is using and is aware of some very powerful methods for use in numerical simulation of hydrologic and transport problems that can improve run speeds by orders of magnitude and reduce convergence problems in mathematical simulations. Waterloo offers several unique codes at moderate cost (approximately $5000 U.S.) for unsaturated flow and transport. These codes in my estimation would be cost-effective, considering that they are already in a high state of development and are designed to solve problems in which we are interested, such thermal effects of waste heat on hydrology, matrix diffusion, and dual continua.

Dr. Sudicky also told me about a package of codes that he worked on for the Environmental Protection Agency. These codes, which are in the public domain, are a collection of analytical steady state flow and transport models for the unsaturated zone, including chain decay, and a numerical simulation for three-dimensional flow and transport in the saturated zone. These codes might be useful for updating the current NRC models for flow and transport in the Phase 3 Iterative Performance Assessment (IPA). Since returning, I have contacted Dr. Zubair Saleem at EPA and acquired documentation on the codes.

The focus of the meeting was hydrologic concerns in the PA's, so I brought along material in this area from IPA Phase 2, and continuing development of methodologies from the NRC and CNWRA. The NRC approach to flow and transport had similarities to the other approaches discussed, but there are also major differences. It was interesting to see that the EPRI model took lateral diversion of infiltrating groundwater into account in almost the same way that the NRC model did. EPRI used a transient analytical solution for unsaturated groundwater flow based on a linearization of Richard's equation by an appropriate choice of the constitutive properties. However the choices of the parameters in this model were very restrictive, which led to unrealistic infiltration conditions. Dr. Sudicky is suggesting a more realistic model, even if it involves a numerical solution, that would allow more common constitutive relationships like the Van Genuchten curves.

Dr. Thomas Pigford, U.C. Berkeley (retired), consults for EPRI, and is also involved with the National Academy of Sciency panel on the revised EPA high level waste regulations. We had several interesting discussions concerning the revised EPA rule. I shared my thoughts with him on how uncertain results from PA's should be compared to deterministic standards. I discussed NRC's choice of the model for evaluating dose to humans from the Yucca Mountain site. The other PA's had difficulty in representing the end-user concentrations for water for their dose assessments, because they had to assume specific mixing mechanisms in the saturated zone. NRC's model neatly avoided this problem by defining the users as a farm family with an irrigated plot of land located downgradient from the site. All radionuclides released from the repository (corrected for decay) would be drawn into the irrigation well pumping 1 million gallons per day. The NRC model assumed that the saturated zone has reasonable vertical communication, so the concentration in the well could be calculated simply from the water withdrawal and the radionuclide release. Dr Pigford seemed to be very interested in this example, because the panel was apparently bothered by the inability to define future scenarios for water use near the site. I commented that I thought any plans to obtain water from the site for use elsewhere would be short-sighted, and that the valley could sustain only about 10 million gallons per day without water mining (greater than sustainable yield of the aquifer). The limited water availability also would severely restrict growth in the valley, and could bound the future scenario for the dose assessments.

The group discussed how complex the models needed to be in a PA. Current practices range from CAMCON for the WIPP site, in which the full, non-abstracted models are all included in the analyses, to assessments where nearly all of the codes are highly abstracted in order to run efficiently on small computers. One disadvantage of the CAMCON approach, other than the large cost involved, was model transparency. The process is so complicated that it is almost impossible to tell if the results make sense. I commented that this was the case with many large system codes, many of which contain millions of lines of code. In many cases, it is impossible to come up with an abstraction to the system, simple enough for it to be transparent. If the models are not transparent, then confidence in the models may depend on strict adherence to software quality assurance. Most attendees agreed with the approach of using abstracted models, but with justification provided by more robust analyses. Dr. Sudicky commented that paying attention to advances in numerical computer algorithms and fast, cheap workstations allows increasingly more complicated problems to be solved. He cited several examples of complex multiphase flow and transport problems that are routinely solved on workstations in seconds to minutes of computer time. I commented that we were working on parallel computation of Monte Carlo problems in low- level PA using a large cluster of Sun workstations that have the equivalent power of a sizable supercomputer.

Since the models incorporated in the EPRI PA are generally highly simplified, there was considerable discussion on how to improve the system within EPRI's limited budget and mandate. The EPRI system does not allow for stratigraphic layers in the unsaturated zone, and does not include chain decay. Furthermore, the codes could not handle explicitly the interaction of coupled matrix/fracture flow and transport, although there were empirical corrections for strong or weak coupling between fractures and matrix. The group therefore recommended that the updated model include both considerations of layers, dual continua, and chain decay. Dr. Pigford urged that the complexity of the model should be somewhat guided by the bottom line; e.g. dose. Improvements that do not affect the final result substantially may not be worth the added developmental and run costs.

There was a discussion on Monte Carlo techniques used in most PA's to propagate parameter and even model uncertainty. I commented that input parameter distributions for PA models were often thought of as "degrees of belief" from expert judgement. Alternatively, these parameter distributions could be constructed from considerations of factors of safety or unbiasedness (e.g., the Maximum Entropy formalism), rather than expressions of actual data distributions. Even the degree of belief in the conceptual model itself could be factored into the PA analysis formally, although this practice has been discouraged by NRC and others. Dr. David Hodgekinson of Intera U.K. commented that some people disagree that the Monte Carlo PA approach is correct, and that his company is working on alternative approaches using fuzzy set theory to deal with parameter and model uncertainty in decision-making. While he did not expand on the details of the method, I suggested that a useful product from EPRI would be a dissertation of the various methods being used for uncertainty propagation in repository PA's, along with the pros and cons and an EPRI recommendation. The experience of EPRI in dealing with reactor PA's would assist them in this effort.

Dan Gilles, of the US Geological Survey discussed the current state of knowledge on the geology and hydrology of the Yucca Mountain site. It was mostly a synopsis of presentations from other recent U.S. Geological Survey and DOE presentations. One interesting piece of information he presented was the fact that isotope concentrations recently found at depth near the site came from a borehole in the imbricate fault zone, and may not be representative of the site in general.

Conclusions and Recommendations

The meeting was a fully worthwhile exchange of ideas between the various groups working on PA's for the Yucca Mountain repository. I learned of a number of worthwhile approaches to various parts of the PA's, including improved codes for flow and transport that might be useful for the Phase 3 IPA. I also felt that I contributed good information to the group, which will help the other PA modelers improve their assessment codes. I am in the process of evaluating the documentation of the codes I obtained from EPA on the advice of Dr. Sudicky. I would also recommend that NRC or the CNWRA obtain some of the flow and transport codes being offered by Waterloo to evaluate their possible usefulness for low-level and high-level PA's.

I will bring Linda Lehman's model for the temperature differences in the wells to the attention of suitable NRC and CNWRA staff in order to determine whether her explanations are reasonable and if there are alternative models.

EPRI is planning a similar meeting in late February 1995 to cover issues of source term models for Yucca Mountain PA's. I recommend that someone from NRC or CNWRA attend this meeting.

Attachments:
(1) Meeting Agenda
(2) EPRI's Interest in Yucca Mountain and its Hydrology (J. Kessler)
(3) Review of Conceptual Hydrologic Models of Yucca Mountain (F. Schwartz)
(4) Hydrology and Transport Modeling for Performance Assessment at Sandia (M. Wilson)
(5) Review of IMARC Hydrologic Models (F. Schwartz)
(6) Alternative Infiltration Scenarios for Yucca Mountain (L. Lehman)

see enclosure in Shelf

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EPRI
Electric Power
Research Institute

FAX MESSAGE

To: Richard Codell

Fax Number: 301/415-5399

Number of Pages: 4

From: Sara Ennis/Fuel Reliability, S&D

Date: Tuesday, December 6, 1994

Message:
Attached is the correct agenda for the hydrology workshop; sorry for any convenience.

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Proposed Agenda
EPRI Hydrologic Workshop
Palo Alto CA
12-13 December 1994

Monday, 12 December - Morning

1.	Why is EPRI Involved with the Yucca Mountain Project?	Kessler
2.	IMARC Overview and Demonstration	McGuire
3.	Review of the Conceptual Hydrologic Model of Yucca Mountain	Schwartz
4.	Review of IMARC Hydrologic Model (Schwartz on formulation and data; McGuire on implementation in IMARC)	Schwartz/ McGuire
5.	Other PA Approaches	Sandia/ Intera

Monday, 12 December - Afternoon

6.	Present Illustrative Results of IMARC and Cross-Comparisons	McGuire
7.	Discussion of the Nature of Hydraulic Data Available to Support Hydrologic Modeling at Yucca Mountain	Gillies/USGS

Examination of Issues - General

8.	Group Discussion: Can simple PA models capture complex hydraulic behavior for the purposes of site suitability evaluation and licensing?	Schwartz

Tuesday, 13 December - Morning

Examination of Issues - IMARC Specific — **Schwartz**

9. Assessment of the Impact of Limitations in Current IMARC Hydrologic Model

   a. Is the current conceptualization of the fractured rock system adequate for PA calculations? If not, what other conceptual models should be considered? Must we wait for more field data to answer this question?
   b. Is there any benefit at the present time in creating a more

rigorous model of the saturated zone given the lack of detailed information concerning important features?

c. What are the implications of simplified approaches within IMARC?
   i. neglecting dispersion in saturated and unsaturated zones
   ii. neglecting the ingrowth of daughter products
   iii. treating unsaturated flow and transport as one-dimensional
   iv. simplified stratigraphy and rock properties?
d. To what extent do data limitations impact the performance of IMARC?
e. What is the consensus on how to prioritize 9a. through d.?

Tuesday, 13 December - Afternoon (Schwartz and McGuire leaders)

10. Within the scope of the EPRI mission (and limited budget), are there supporting activities that would complement the existing efforts, and ultimately lead to an improvement of IMARC? Examples may be:

    a. Corroboration of conceptual modeling approaches using chlorine and tritium isotopic data.
    b. Regional scale hydrologic modeling calibrated to carbon-14.
    c. Reappraisal of geologic and hydrogeologic data base.
    d. More detailed evaluation of near-field thermo-mechanical effects and their impact on performance.
    e. Other.

11. More general discussion on the direction of DOE efforts in performance assessment.

    a. Is the emphasis toward incorporating more and more complicated processes models justified given the available data?
    b. What are the ultimate project needs in hydrology and will they be realized?

12. Are there any unidentified gaps especially in relation to regulatory issues?

    a. For example, how will hydrologic modeling be abstracted without sufficient data to corroborate the detailed hydrologic process models? What guidance can be provided in selecting data to be obtained and where expert judgment will suffice for hydrologic modeling?

List of Attendees:

EPRI:
- John Kessler
- Rosa Yang

USGS: Dan Gillies

SNL: Mike Wilson

M&O (Intera): Bill Nelson (tentative)

L. Lehman and Associates: Linda Lehman (tentative)

NRC (tentative): Dick Codell

NWTRB:
- Vic Palciauskas
- Pat Domenico (tentative)

Tom Pigford

Consultants:
- Frank Schwartz (Ohio State)
- Robin McGuire (Risk Engineering)
- David Hodgkinson (Intera, UK)
- Les Smith
- Ed Sudicky (U. Waterloo)

EPRI

EPRI's Interest In Yucca Mountain And Its Hydrology

John Kessler
Manager, Spent Fuel and HLW Disposal Program

EPRI / NPG

Background

- EPRI is funded by utilities to conduct research on their behalf
- Nuclear Power Group within EPRI focuses on members with nuclear plants
- Spent fuel handling, storage, and disposal a significant concern for those utilities
  - of 36 nuclear power research topics at EPRI, execs ranked these areas high in importance
  - #3: HLW repository issue resolution
  - #7: spent fuel storage and transportation

Fuel Reliability, Storage & Disposal

HWs 12/94 -1-

EPRI / NPG

EPRI's General Goals in Conducting a Research Program for Yucca Mountain

- Develop an independent capability to identify important technical issues at Yucca Mountain and assess their importance
- Selective demonstration of assessment techniques, technical approaches and solutions
- Assist DOE, EPA, and NRC in resolving difficult licensing issues from a technical standpoint

Fuel Reliability, Storage & Disposal

HWs 12/94 -2-

EPRI / NPG

EPRI's Total System Performance Assessment (TSPA) Effort

EPRI feels that TSPA

- is the best tool for assessing the real importance of technical issues
- can prioritize an efficient site characterization strategy
- will be the centerpiece of DOE's license application to the NRC
- should be used in DOE's Technical Site Suitability (TSS) determination, too

Fuel Reliability, Storage & Disposal

HWs 12/94 -3-

EPRI / NPG

EPRI TSPA Development History

1989:

- EPRI forms small team of experts (11 people) to develop subsystem models
  - infiltration model: Austin Long
  - hydrology and mass transport model: Frank Schwartz
- Event tree approach, rather than Monte Carlo, chosen for probabilistic assessment

1990: model completed, preliminary studies conducted and report issued

1991-1992:

- Model improved using a small group of experts (14 people)
  - infiltration model: Stuart Childs
  - climate-related water table change model: Frank Schwartz
  - hydrology and mass transport model: Frank Schwartz
- Focused on 10,000 year EPA release criterion

Fuel Reliability, Storage & Disposal

HWs 12/94 -4-

EPRI / NPG

EPRI TSPA Development History

1993:

- Model extended to 100,000 years (no change in hydrology model)
- Dose assessment capability added
  - requires calculating concentrations, so mixing zone added
  - biosphere model added

1994:

- sorption in the saturated zone added
- SZ porosity adjusted
- key transuranic specie solubilities adjusted

Fuel Reliability, Storage & Disposal

HWs 12/94 -5-

EPRI / NPG

EPRI's TSPA Model Is Necessarily More Abstract That DOE's Models

- EPRI TSPA budget is 1-2% of DOE TSPA budget
- EPRI goal is demonstration of a viable TSPA model developed for a fraction of the cost
  - necessary reliance on expert opinion
  - must look hard at *why* models should be made more complex before making the effort

Fuel Reliability, Storage & Disposal

HWs 12/94 -6-

EPRI / NPG

Regulations Requiring The Use Of Hydrology Models

Efficiently meeting the regulations drives EPRI's interests

Does each regulation require a different hydrologic modeling approach?

Substantially Complete Containment

- 300-1000 years of ≤1% container "failure"
- contaminent transport model not required
- probably need to know upper bounds on:
  - number of containers contacted by water
  - temperature and geochemistry of contacting water
  - water contact time

Fuel Reliability, Storage & Disposal

HWe 12/94 -7-

EPRI / NPG

Regulations Requiring The Use Of Hydrology Models (continued)

Groundwater Travel Time

Minimum of 1000 years from edge of "disturbed zone"

Stochastic or deterministic approach?

- DOE intends to go stochastic
  - argues that the range of possible transport times is very wide and real
  - proposes that a small fraction of realizations <1000 years will be acceptable
- Recent NRC proposal blends stochastic with a worst case bounding approach
  - concern about model differences obscuring NRC intent
  - just look at shortest travel time only from each set of realizations for each model type

Currently forbidden to consider contaminant transport

- No dispersion
- No solubility
- No sorption

Fuel Reliability, Storage & Disposal

HWe 12/94 -8-

EPRI / NPG

Regulations Requiring The Use Of Hydrology Models (continued)

EPA Release criterion at 10,000 years (may be thrown out)

- Only a certain fraction of the 1,000 year inventory may pass the site boundary in 10,000 years
- 10,000 year standard places great demands on the hydrology submodel

Parts of the model that matter:

- control on container failure
- control on leach rate from container
- unsaturated zone transport
- saturated zone transport
- space- and time-dependent daughter ingrowth?

Parts of the model that do not matter

- dispersion
- sorption
- space- and time-dependent daughter ingrowth

Fuel Reliability, Storage & Disposal

HWs 12/94 -9-

EPRI / NPG

Regulations Requiring The Use Of Hydrology Models (continued)

Maximum allowable health or dose risk

- No upper time limit ("when doses peak"). Could be a few million years
  - Does this stretch hydrology model credibility too far?
  - Is a different approach required due to the long time frames?
- Parts of the model that matter:
  - control on leach rate from container
  - unsaturated zone transport
  - saturated zone transport
  - dilution in the saturated zone
  - realistic estimates of concentration
- Parts of the model that MAY not matter
  - dispersion
  - sorption
  - space- and time-dependent daughter ingrowth

Fuel Reliability, Storage & Disposal

HWs 12/94 -10-

General Goals of This Meeting

- Identify the components of hydrology model(s) that are *essential* to demonstration of the regulatory goals
  - how complex before you can see what is essential?
  - issue of model "validation" (corroboration)
- Identify any clarification of the regulatory requirements necessary prior to choosing the correct model(s)
- Identify parts of the EPRI hydrology model requiring improvement and specific recommendations for improving them on a limited budget

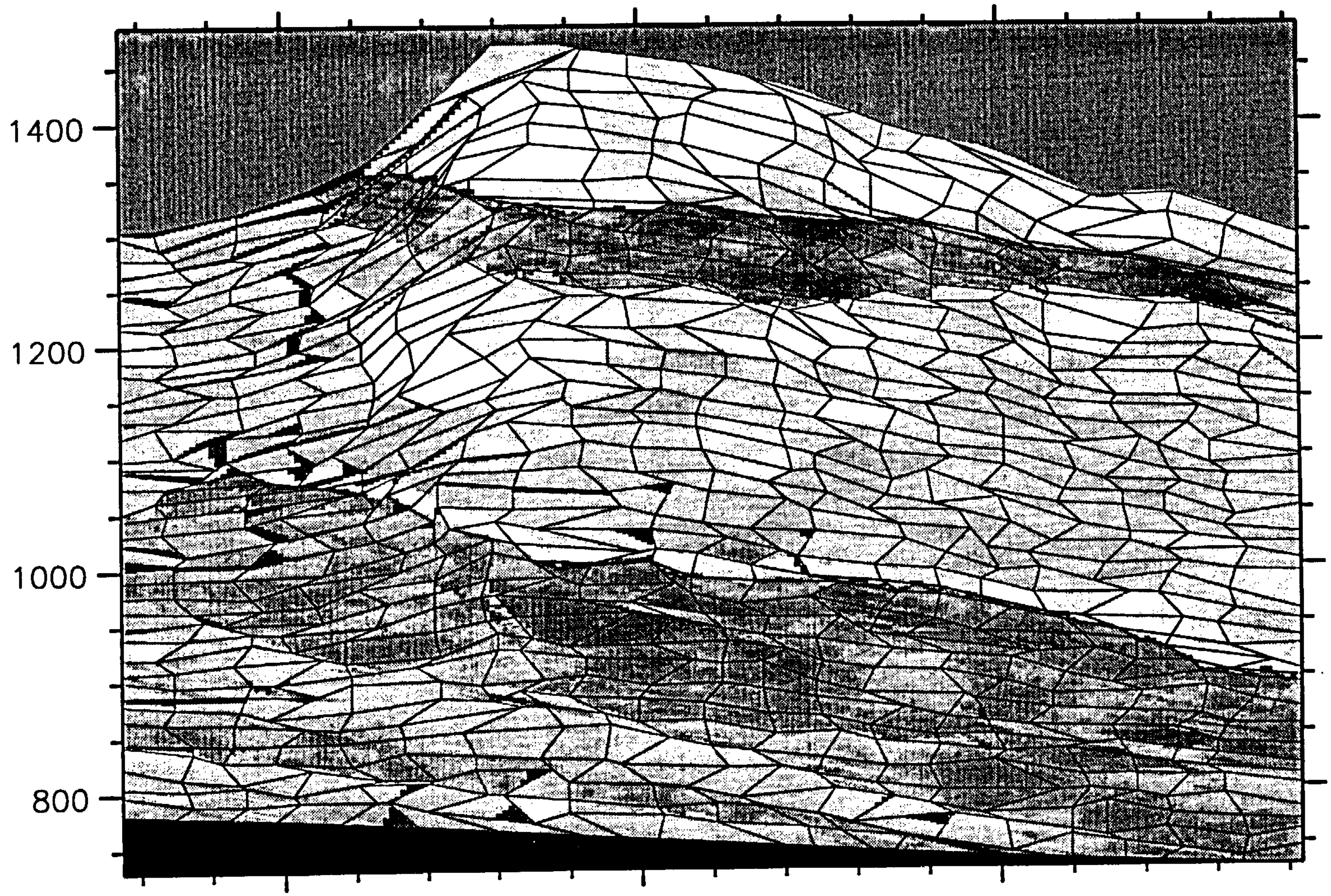
Hydrology (and Transport) Modeling for Performance Assessment at Sandia

Michael L. Wilson
Sandia National Laboratories

Levels of complexity

- Detailed (GWTT)
  - two dimensions
  - complicated geometry, heterogeneity
  - isothermal, single phase, steady state
- Simplified (TSPA composite-porosity model)
  - one dimension
  - simple layered stratigraphy
  - isothermal, single phase
  - sequence of steady states

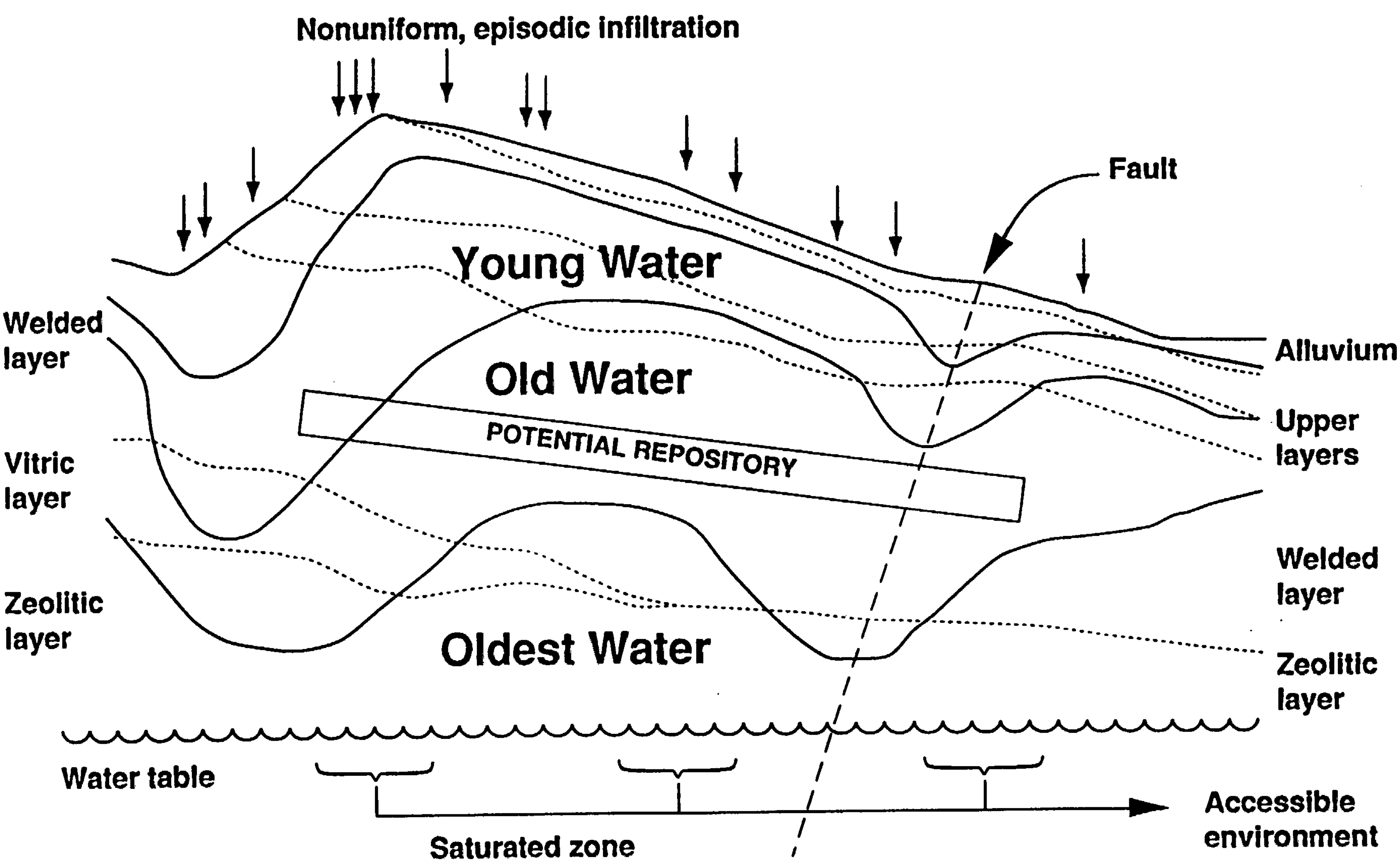
2-D calculation with heterogeneity



Levels of complexity (cont.)

- Really simplified (TSPA weeps model)
  - probabilistic calculation of discrete-fracture flow
  - single phase
  - simple approximation of thermal effects
  - dynamic

Composite-porosity model



Composite-porosity model

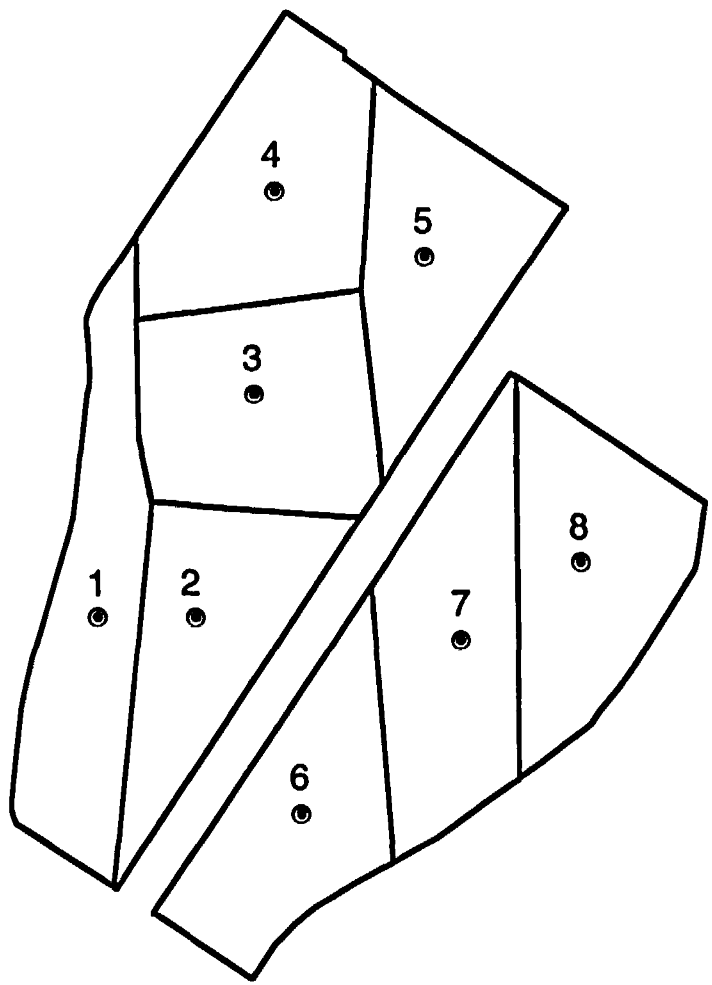
- Flow solved using Darcy's Law
- Need stratigraphy (could be distributions)
- Need percolation distribution, water-table location (could be distribution)

Composite-porosity model (cont.)

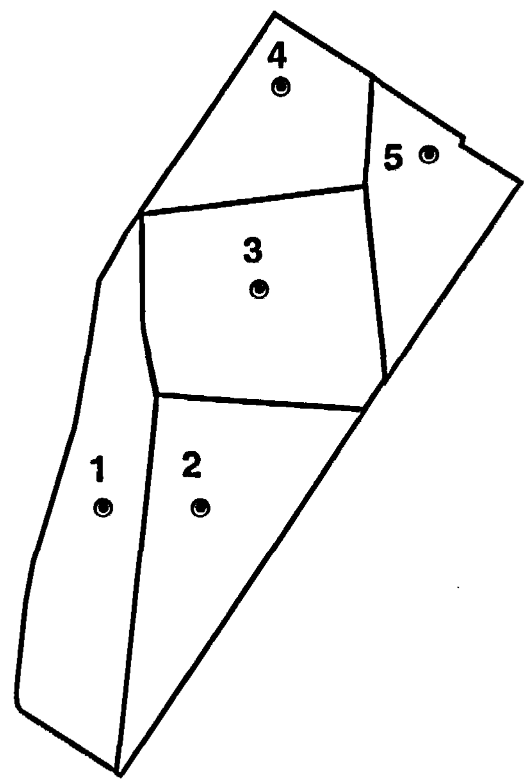
- Need material-property (matrix and fracture) distributions
  - porosity, density
  - saturated hydraulic conductivity
  - saturation-curve parameters (van Genuchten)
  - sorption coefficients
  - dispersivity
- For saturated zone, also need SZ thickness and water flux

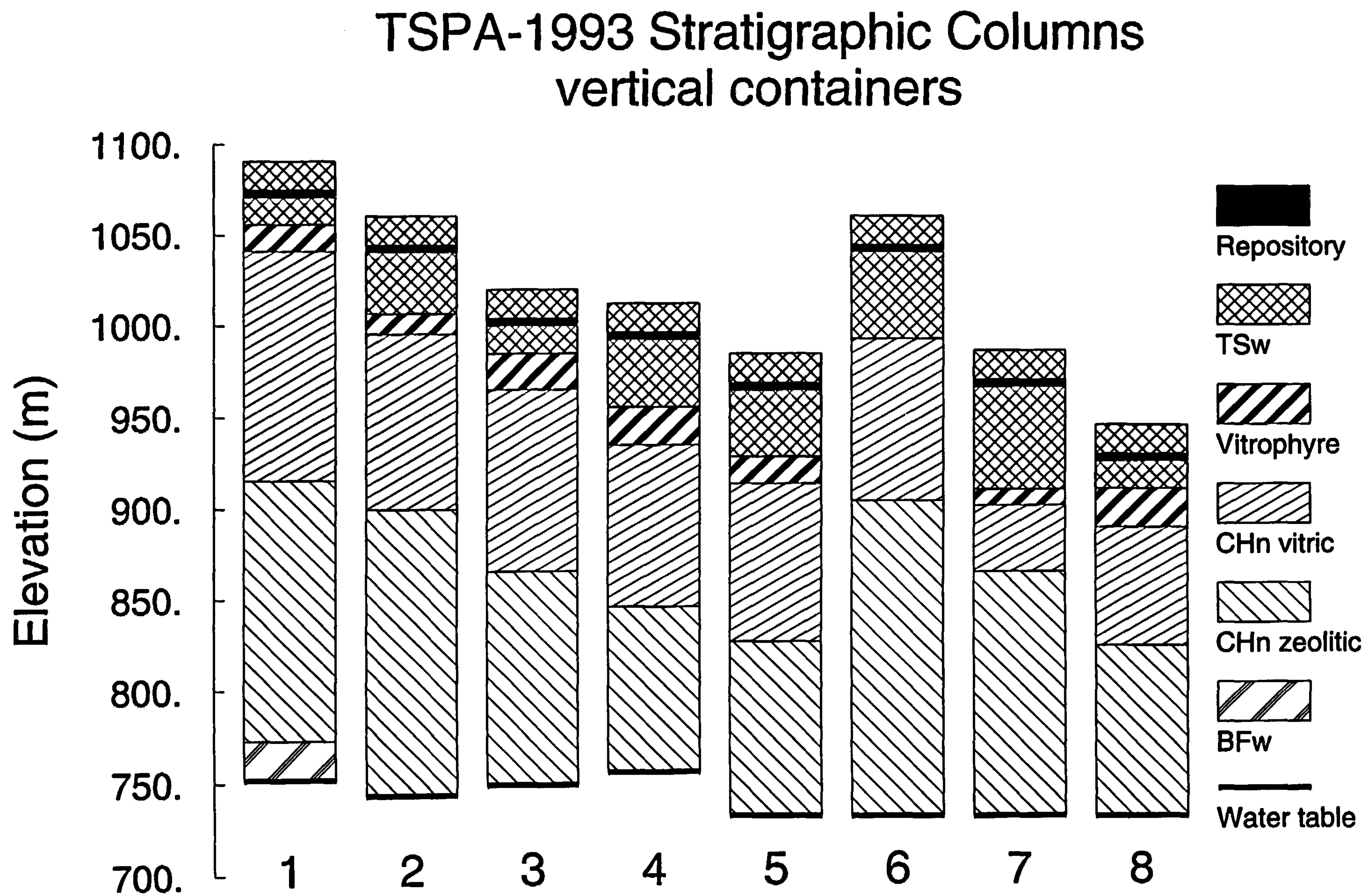
Division of repository into columns

57 kW/acre



114 kW/acre



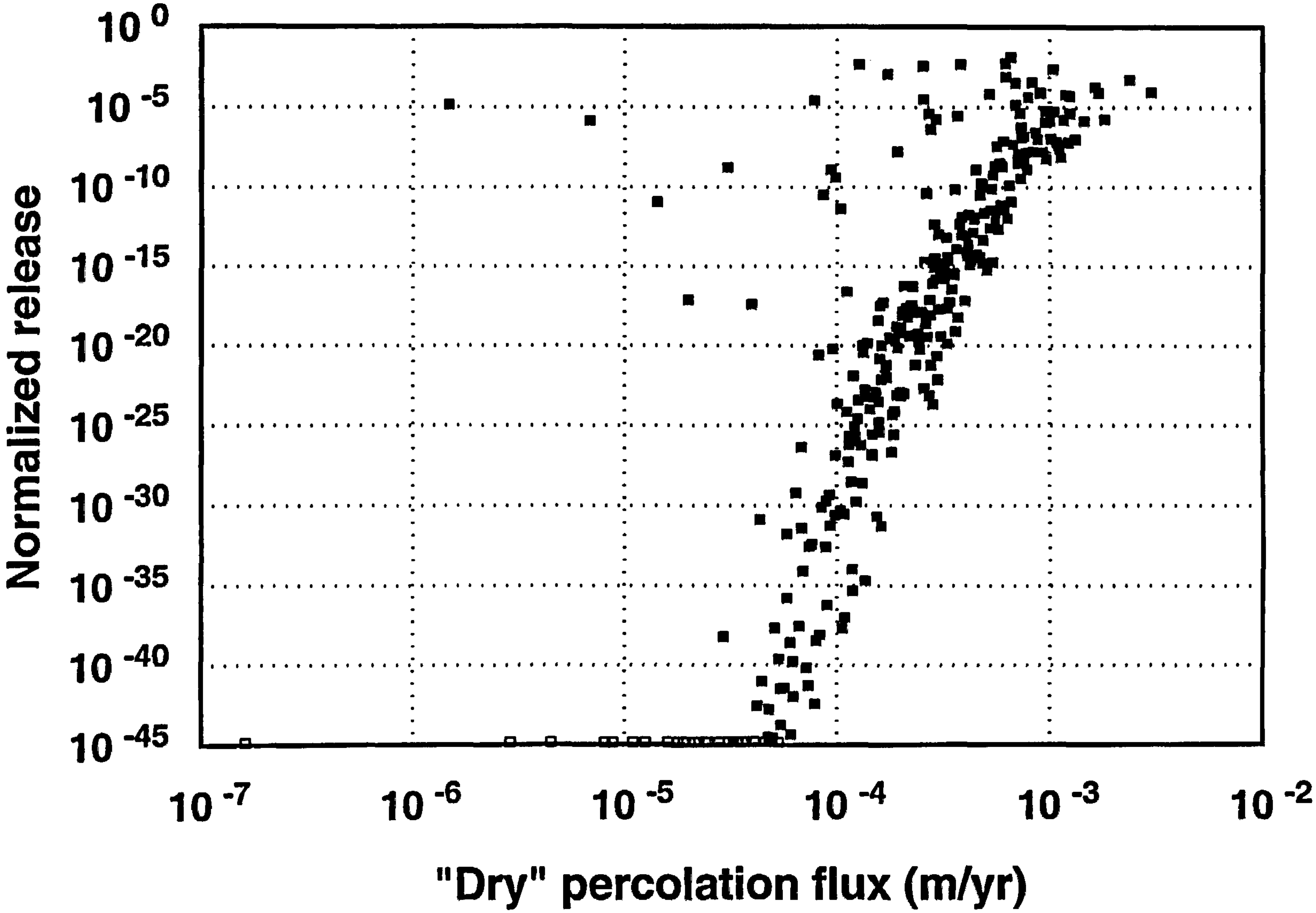


TSPA-1993 Stratigraphic Columns
vertical containers
Elevation (m)
1100.
1050.
1000.
950.
900.
850.
800.
750.
700.
1
2
3
4
5
6
7
8
Repository
TSw
Vitrophyre
CHn vitric
CHn zeolitic
BFw
Water table

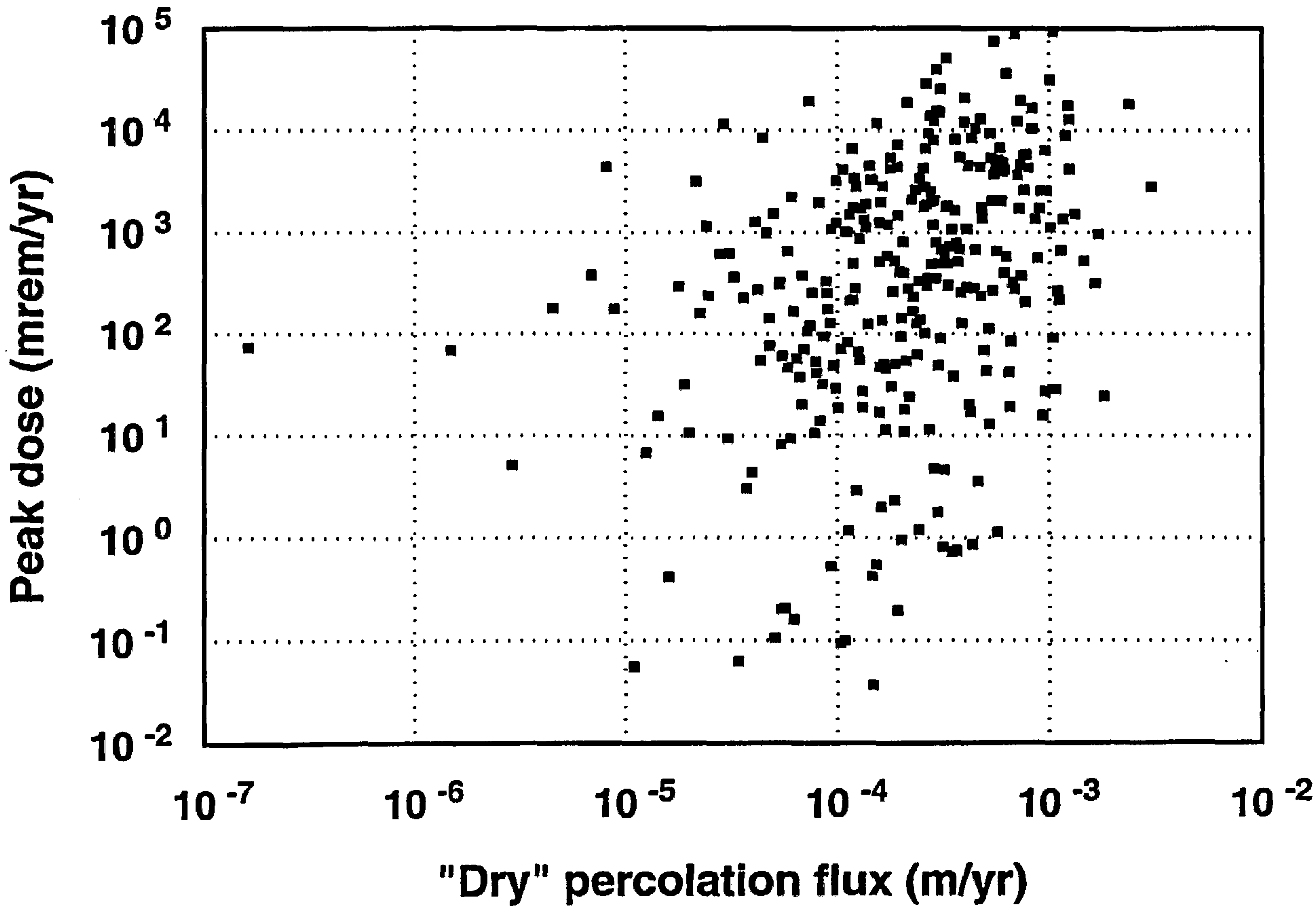
Important parameters for composite-porosity model

- Percolation flux and climate-change time
- Source-term parameters
- Saturated-zone thickness, for doses
- Bulk permeability, for gaseous releases

10,000-year cumulative releases
Composite-porosity model



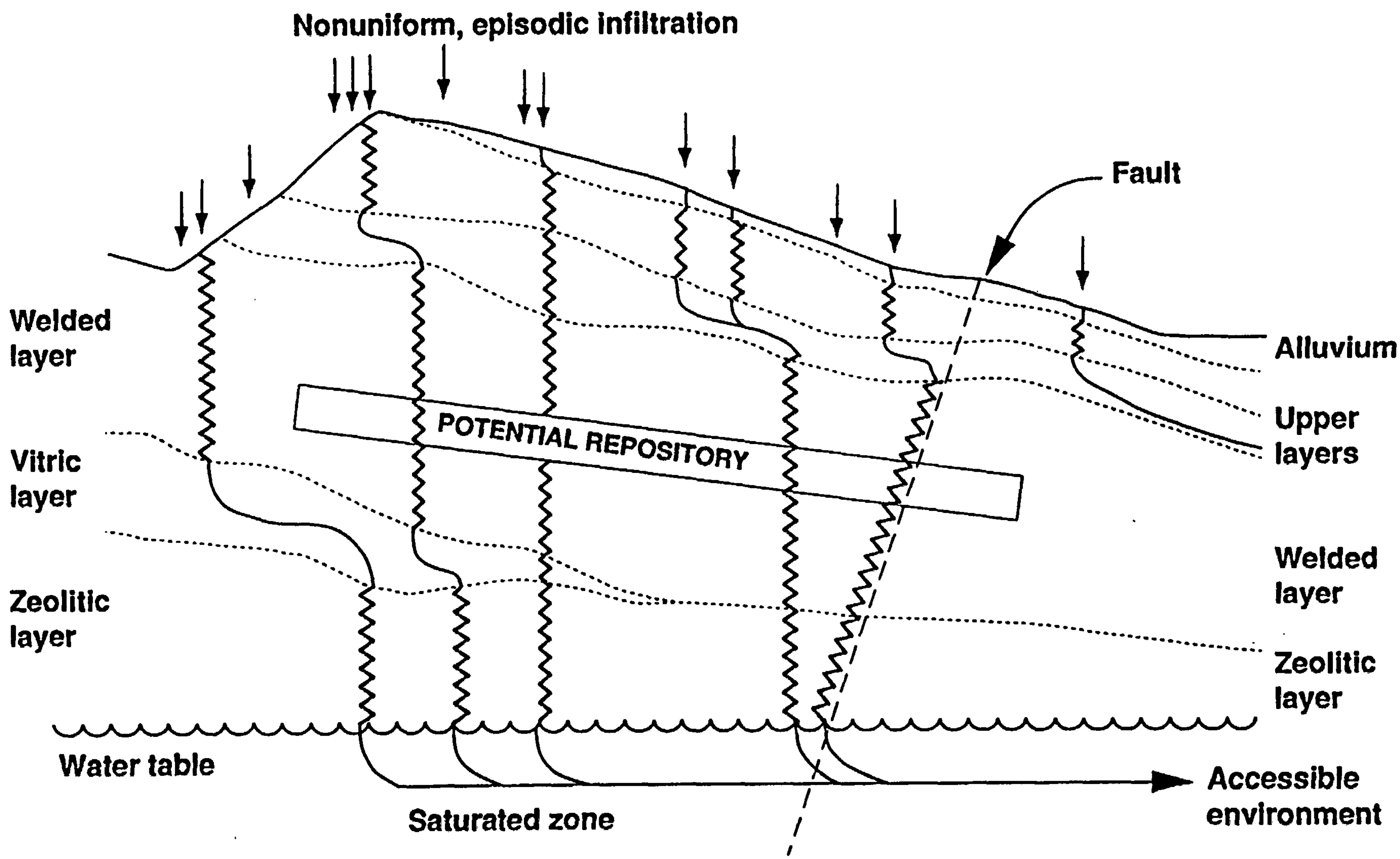
1,000,000-yr peak doses
Composite-porosity model



Extensions of composite-porosity model (present and future work)

- Investigate reduction of matrix/fracture coupling
  - large effective fracture spacing
  - fracture coatings
- Dual-permeability model?
- 2-D? Nonisothermal? Multi-phase?

Weeps model

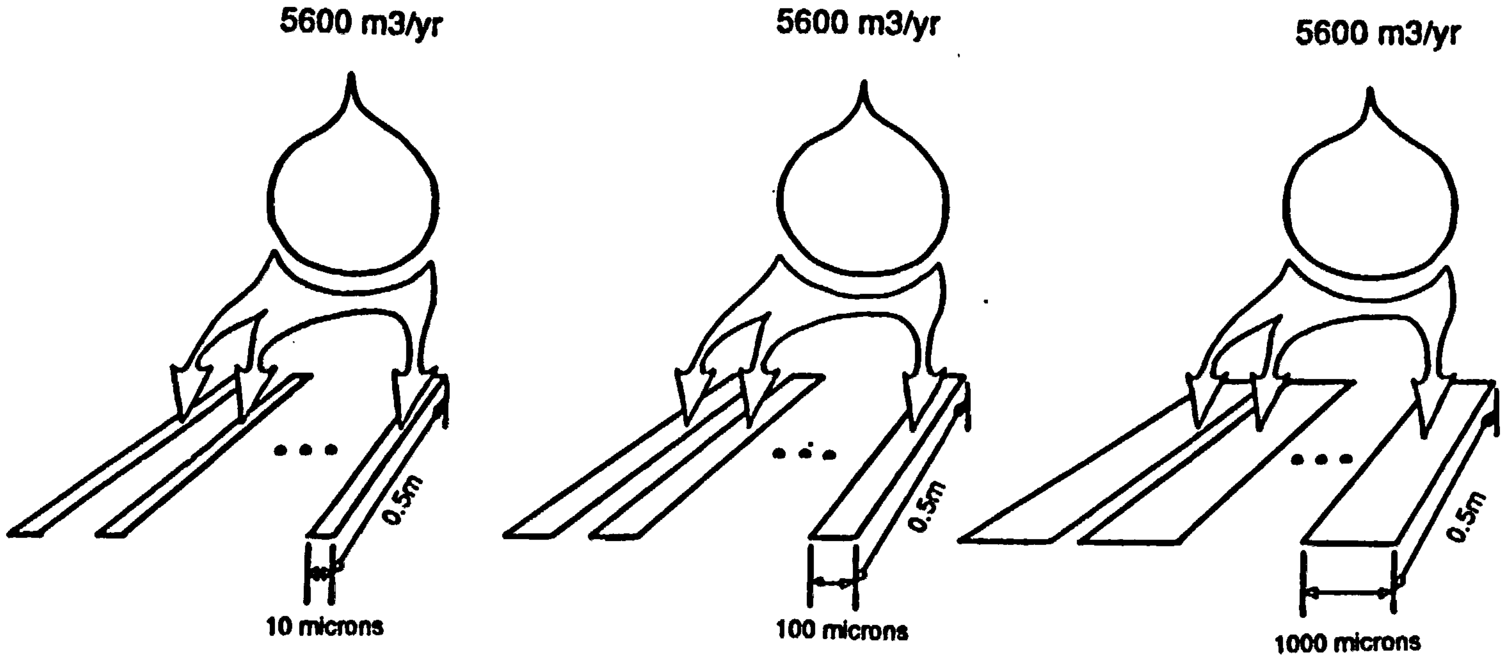


Nonuniform, episodic infiltration
Fault
Welded layer
Vitric layer
Zeolitic layer
POTENTIAL REPOSITORY
Alluvium
Upper layers
Welded layer
Zeolitic layer
Water table
Saturated zone
Accessible environment

Weeps model

- No actual flow calculation, only water balance (travel time to water table taken to be zero)
- Need percolation and episodity distributions
- Need fracture-property distributions—effective aperture and width (to calculate flow volume)

How Many Flowing Fractures Does it Take for 5600m^3/yr of Water?

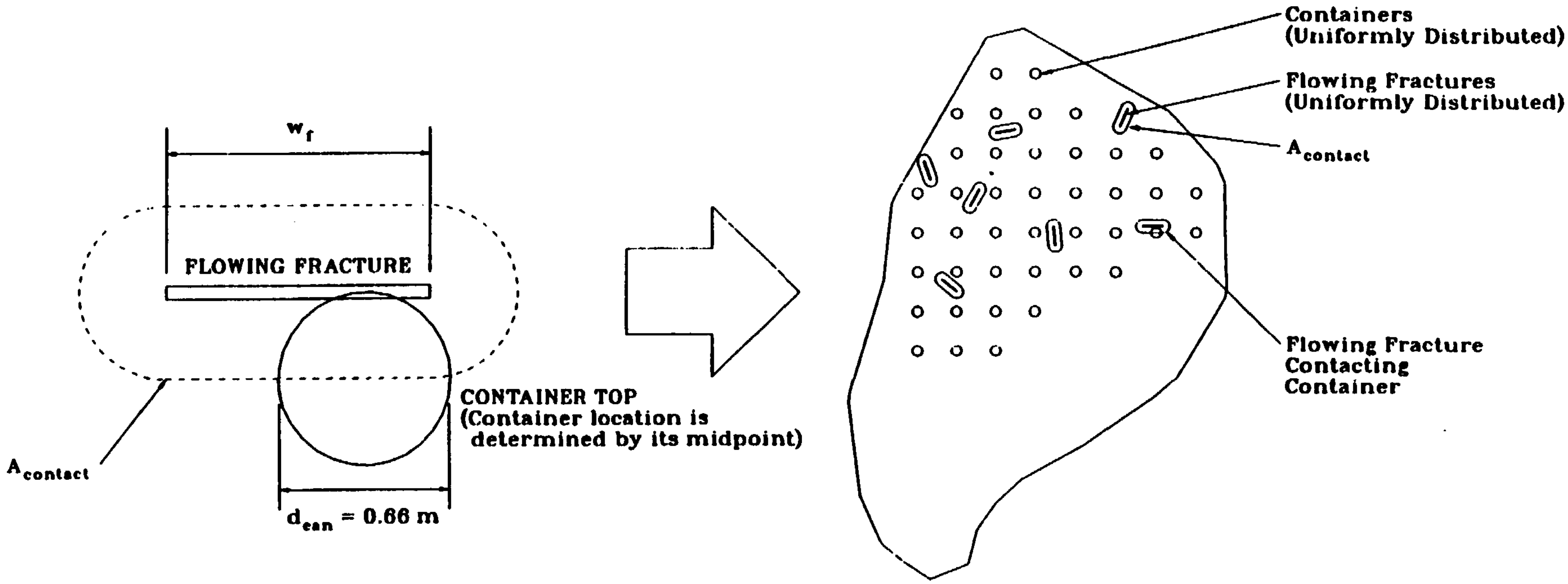


4,600,000
10-micron fractures

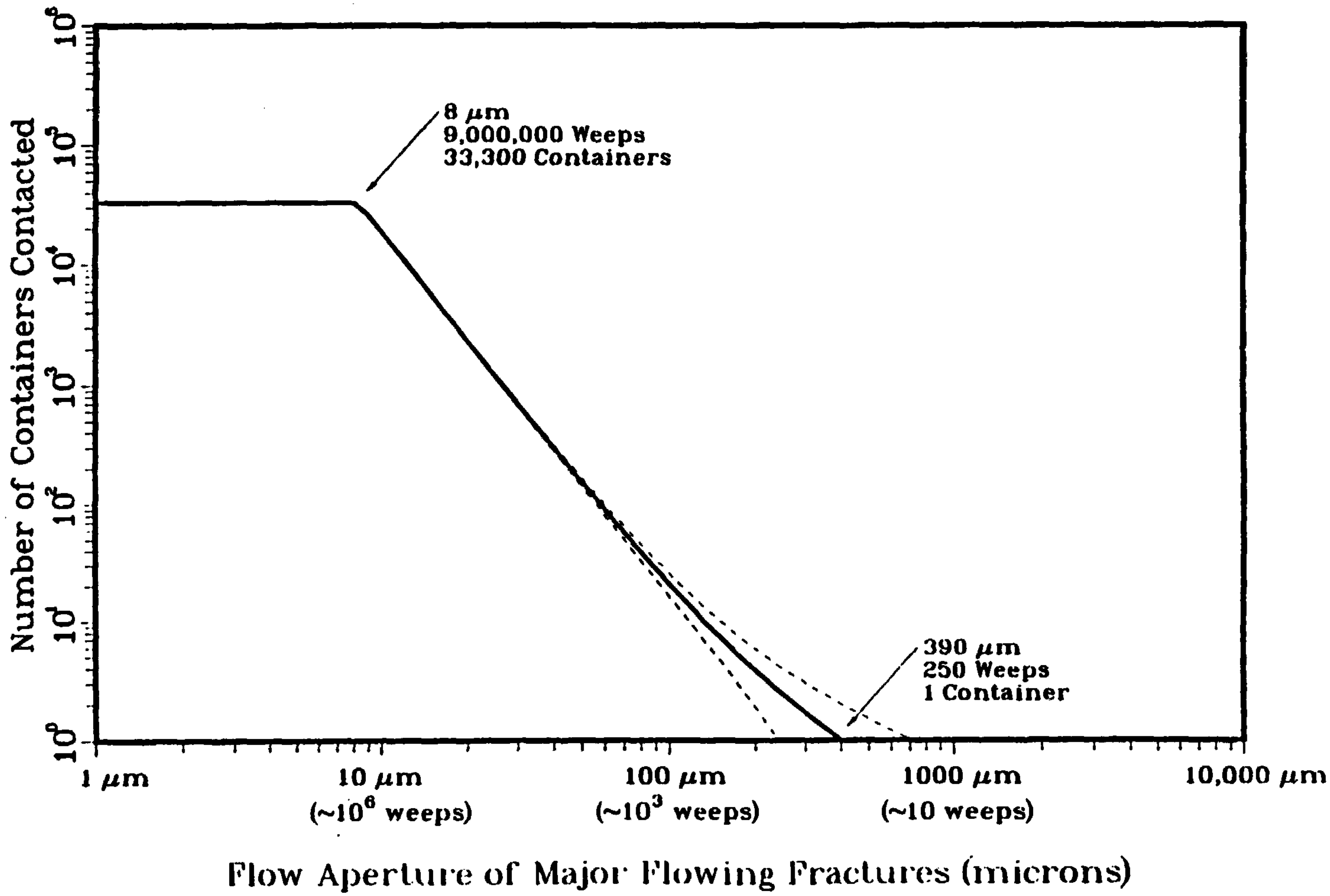
5,200
100-micron fractures

55
1000-micron fractures

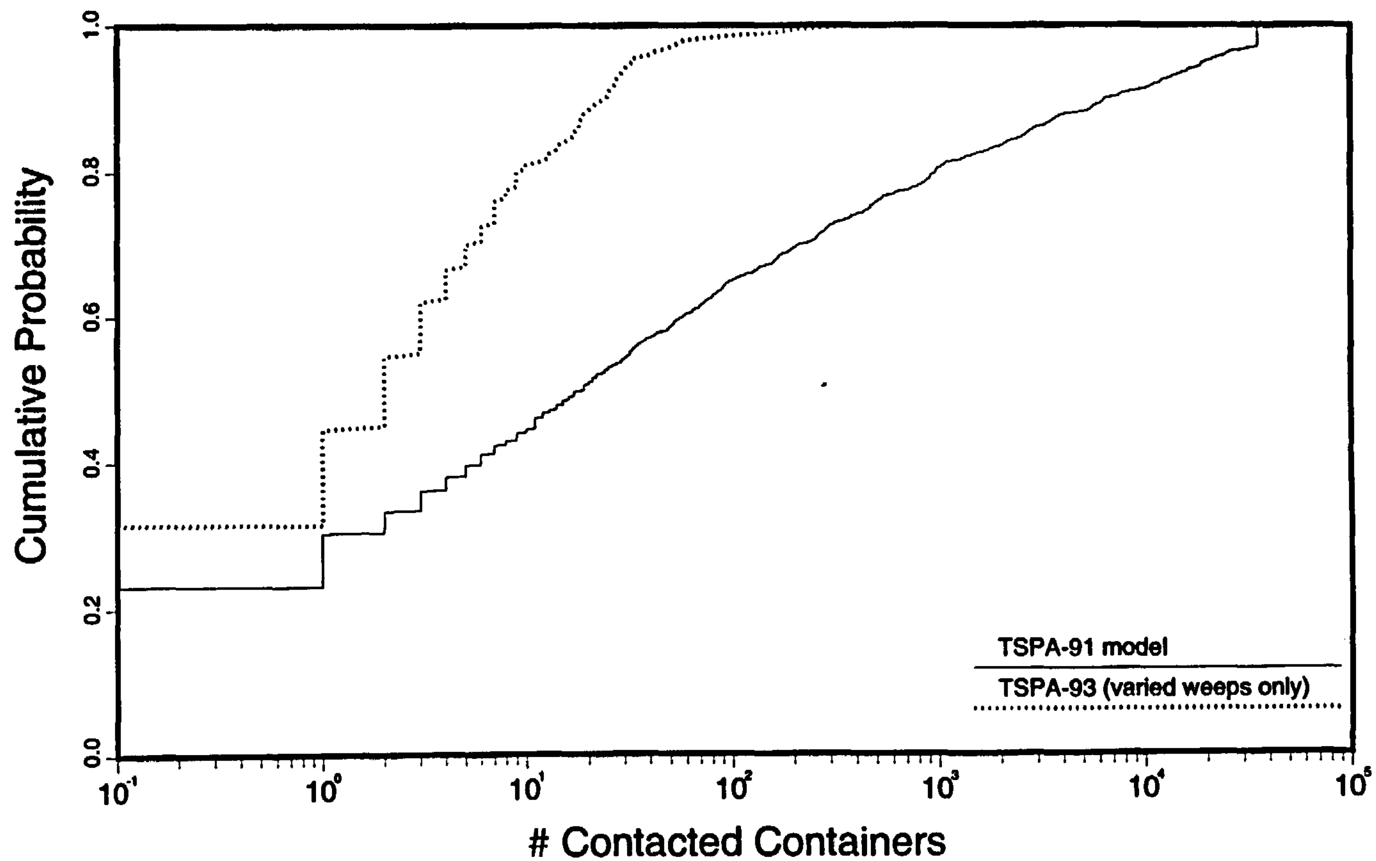
How Many of the Flowing Fractures Contact Waste Containers?



Flow Aperture vs Contacted Containers
Average Case



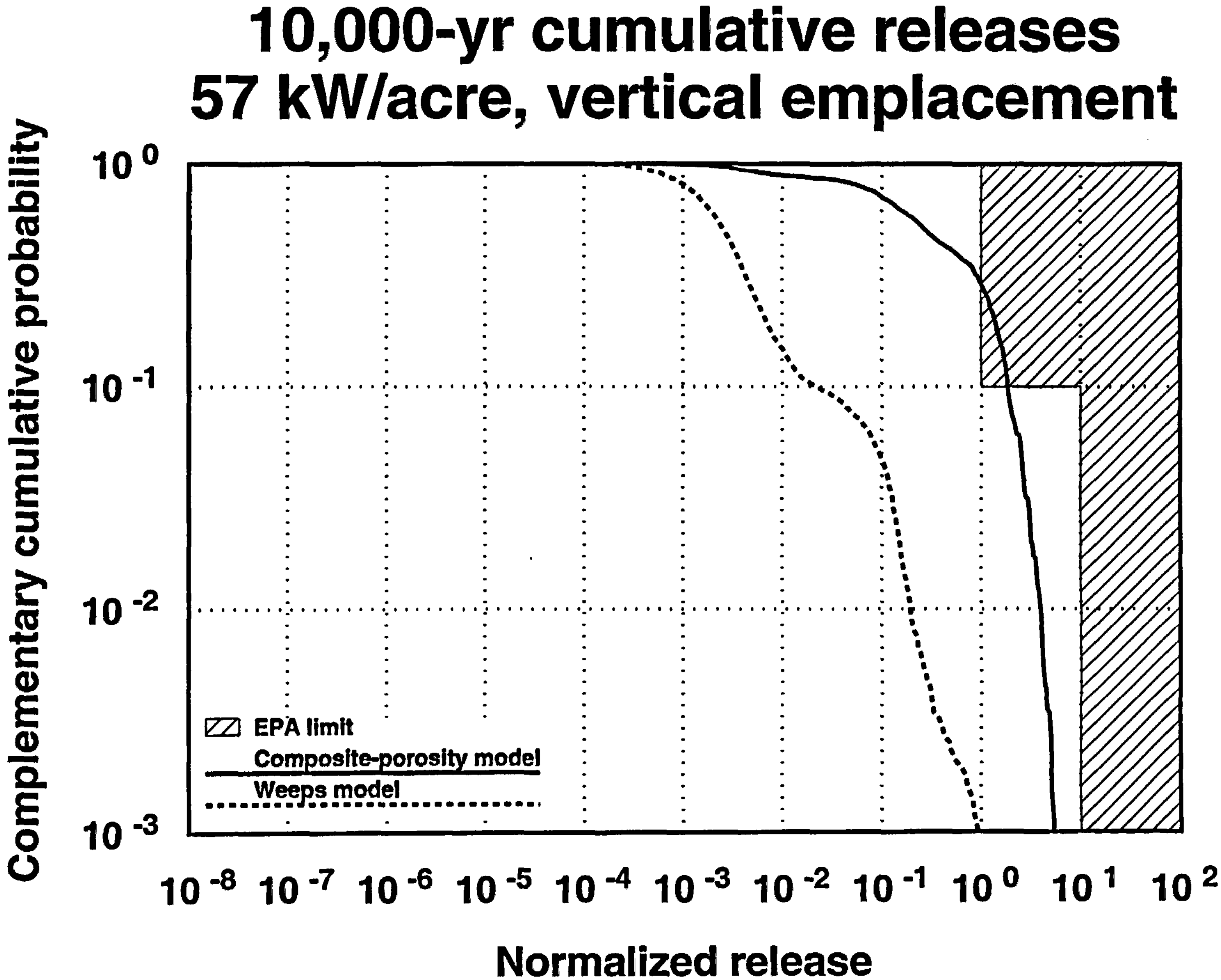
Distribution of Containers Contacted by Weeps



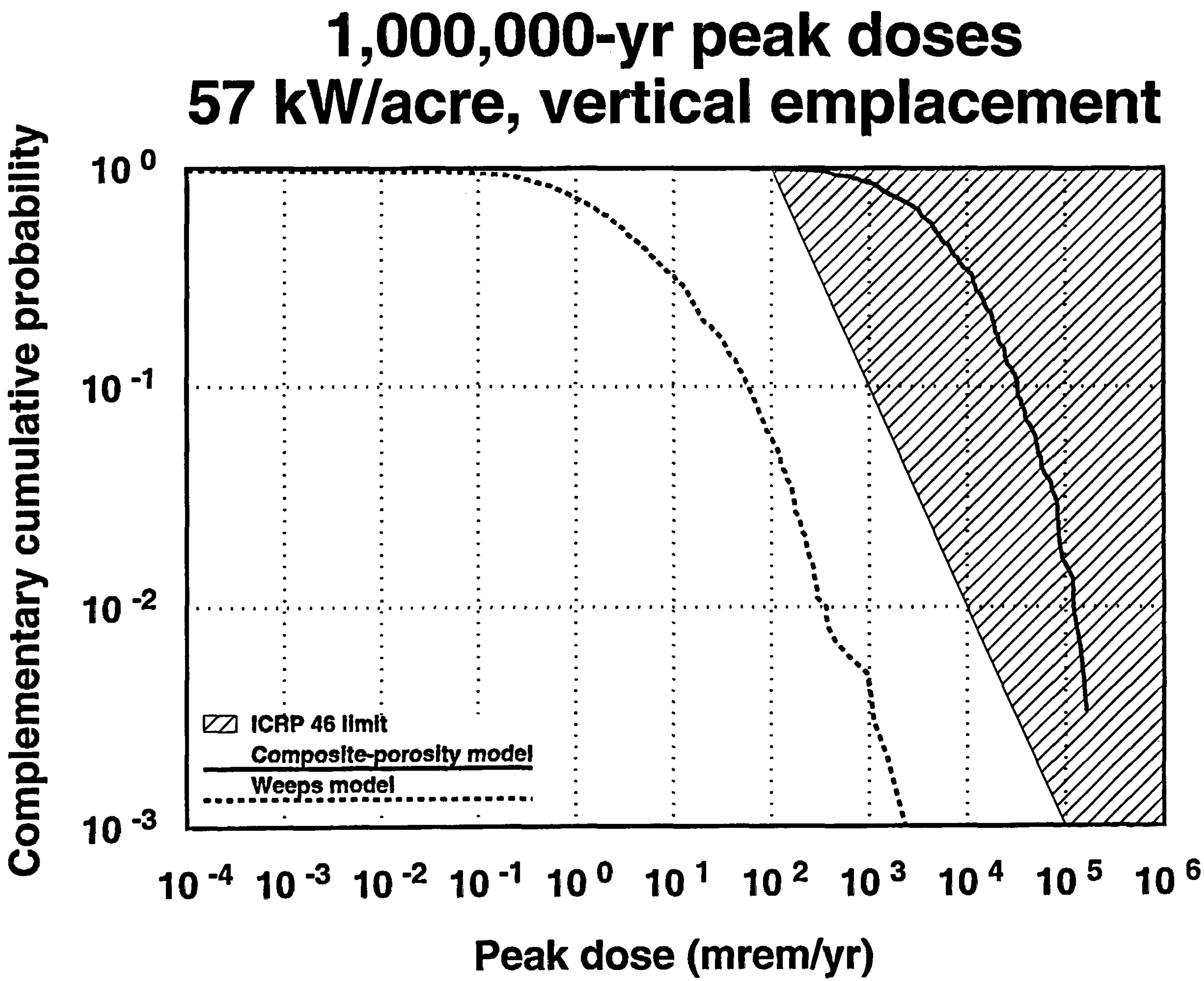
	Label	#Samples	Min	Max	Median	Mean	Std. Dev.
1	TSPA-91 model	1000	0.	3.5580E+04	19.00	2570.	7379.
2	TSPA-93 (varied weeps only)	200	0.	507.0	2.000	10.99	41.44

Important parameters for weeps model

- Weep aperture distribution
- Source-term parameters
- Episodity factor and percolation flux
- Saturated-zone thickness, for doses
- Bulk permeability, for gaseous releases



10,000-yr cumulative releases
57 kW/acre, vertical emplacement
Complementary cumulative probability
10 0
10 -1
10 -2
10 -3
EPA limit
Composite-porosity model
Weeps model
10 -8
10 -7
10 -6
10 -5
10 -4
10 -3
10 -2
10 -1
10 0
10 1
10 2
Normalized release


1,000,000-yr peak doses
57 kW/acre, vertical emplacement
Complementary cumulative probability
10 0
10 -1
10 -2
10 -3
ICRP 46 limit
Composite-porosity model
Weeps model
10 -4
10 -3
10 -2
10 -1
10 0
10 1
10 2
10 3
10 4
10 5
10 6
Peak dose (mrem/yr)

Summary

- Different levels of complexity are useful for different purposes.
- Fracture flow and matrix/fracture coupling are crucial to repository performance.
- A realistic model probably must include "fast paths" (but not too many).

Review of the Conceptual Hydrologic Model of Yucca Mountain

Frank W. Schwartz

EPRI Workshop

December 12 - 13, 1994

Review of Basic Concepts and Issues

- this introductory presentation designed to review the conceptual hydrologic model of Yucca Mountain

- mainly for the purpose of participants in this workshop who have be peripherally involved in the project

- opportunities for all participants to reflect on the validity of "basic truths"

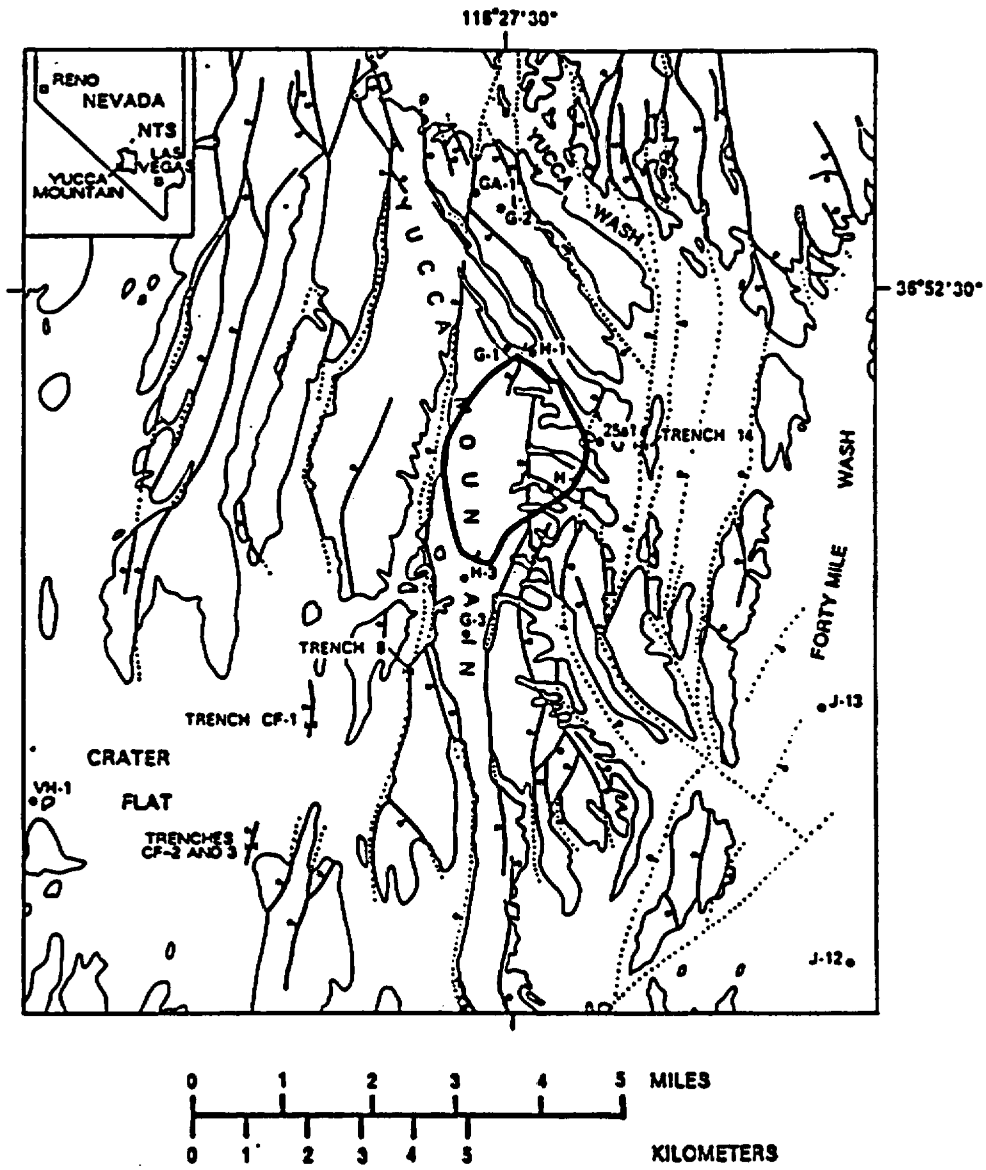
Concept of a Repository at Yucca Mountain

- initially considered a repository for saturated zone

- unsaturated disposal proposed by Winograd in early 1970's and work began in 1982

- features that promote disposal (USGS WRI 84-4345)
    + deep water table (500-700 m)
    + competent rocks for mined openings
    + fractures promote rapid drainage of water
    + unsaturated zone a barrier due to
        - small recharge fluxes
        - non-welded tuffs provide capillary barriers
        - locally zeolites are present to retard transport
    + other barriers in zone of saturation

Location Map



EXPLANATION

G-2 DRILL HOLE

TRENCH

NORMAL FAULT–BAR AND BALL ON DOWNTHROWN SIDE

PERIMETER DRIFT BOUNDARY

Figure 1-23. Map of Yucca Mountain area showing location of selected drillholes and trenches. Modified from Szabo and O'Malley (1985)

Climate

- mid-latitude desert characterized by hot summers, mild winters, and limited precipitation

- modern precipitation
  - annual: 146 mm
  - Summer: 51 mm; Winter 95 mm

- full glacial climate (summary from Bill Wilson)
  - annual: 204 mm
  - Summer: 24 mm; Winter 180 mm

Geologic Setting

- tectonically active area with volcanism, deformation

  faulting, and earthquakes

- comprised of a series of structural blocks bounded

  by westward dipping normal faults

- shallow units a sequence of tuff
  - welded units; lower matrix permeability and porosity, higher fracture densities
  - non-welded units; higher matrix permeability and porosity, lower fracture densities
    - + zeolitic somewhat less permeable
    - + vitric somewhat more permeable

Unit Definitions(from Wilson et al., SAND93-2675)

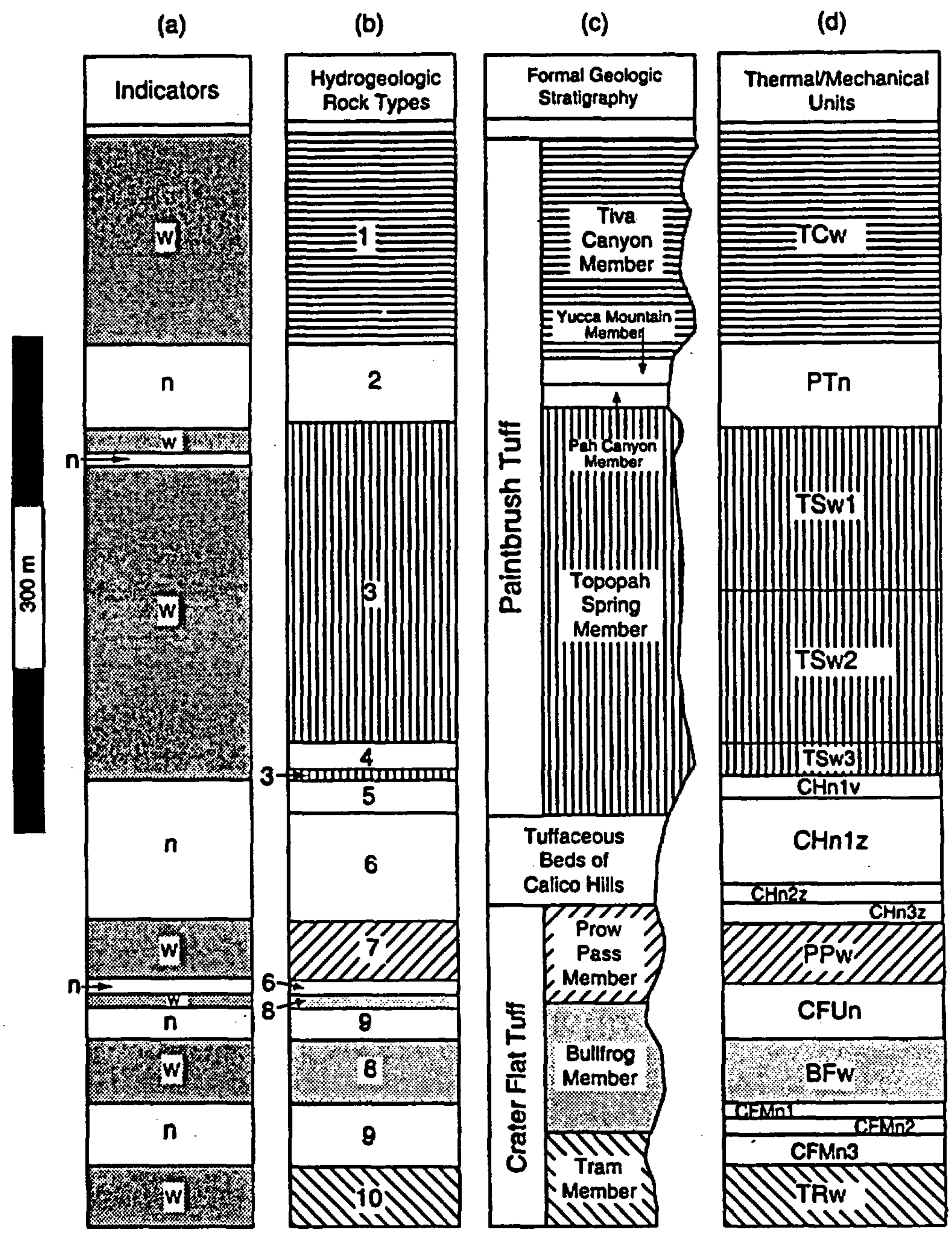
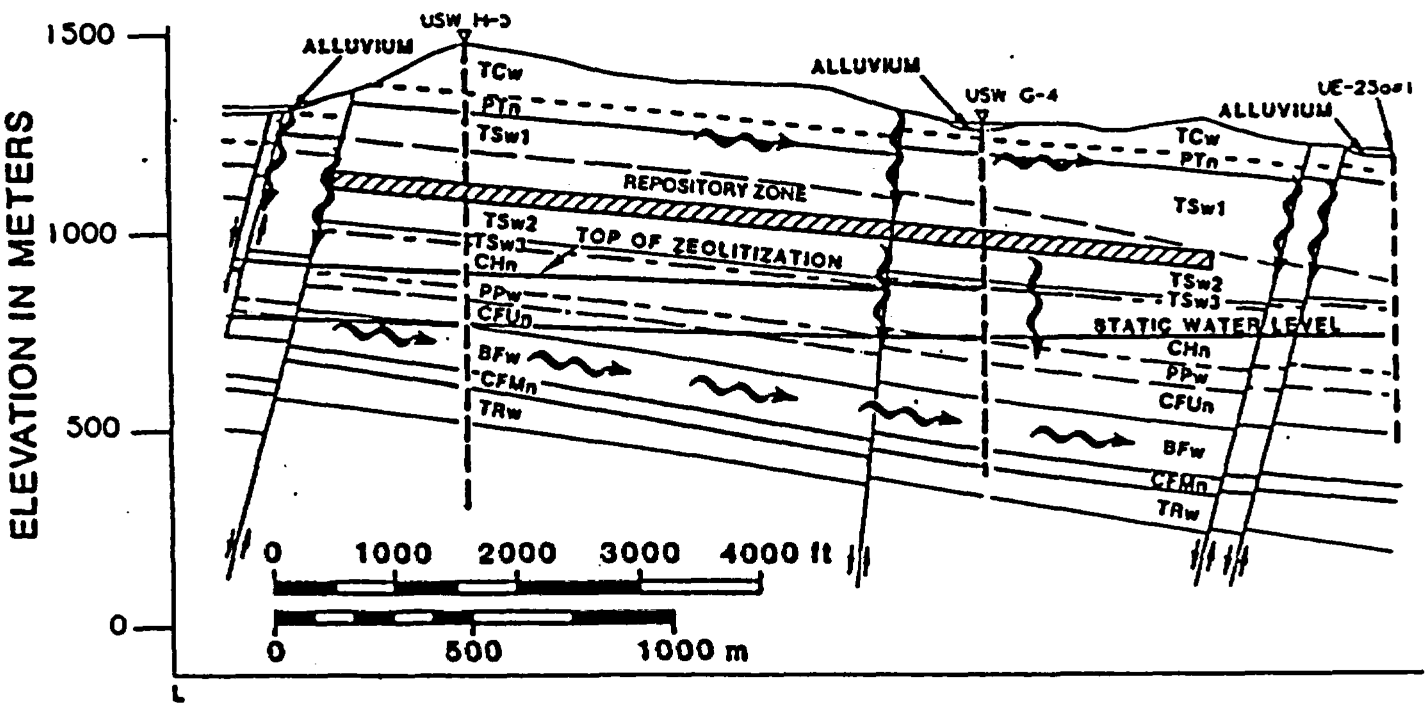


Figure 6-7. Composite vertical profile of Yucca Mountain showing approximate correspondence of indicator lithologic categories (column (a)) with thermal/mechanical units of Ortiz *et al.* (1985) (column (d)), and formal geologic nomenclature as modified from Scott and Bonk (1984) (column (c)). Column (b) shows the hydrogeologic units used in TSPA-93. (Not all of the thin zones at the bottom of Column (b) were modeled.)

Geologic Cross-Section and Conceptual Model of Flow
(from Dudley et al., SAND85-0002)



· overall water flows mainly downward, present-day infiltration fluxes less than 0.5 mm/yr

· lateral diversion may occur within non-welded units to down-dip faults (e.g., PTn and TSw1)

· perched water can occur in the unsaturated zone

Hydrogeologic Properties

- typically properties assumed to be related to the various thermal/mechanical units

- example of tabulations from SAND93-2675

Table 7-11. Hydrogeologic unit matrix, bulk-hydraulic, and fracture parameters comparison for analog bulk saturated hydraulic conductivity.

Unit Unknown Analog	Matrix ϕ	Matrix K_s	Matrix α_{vG}	Matrix β_{vG}	Bulk ρ_b (g/cm^3)	Bulk K_{bs} (m/s)	Fracture F_f[a] (1/m)	Fracture F_f[b] (1/m)
Unit 1 (TCw)	0.087	3.86×10^{-10}	0.0218	1.62	2.366	2.31×10^{-7}	4.50	7.70
Unit 3 (TSw)	0.139	2.37×10^{-11}	0.0299	1.793	2.258	1.17×10^{-5}	3.00	4.25
Unit 8 (BFw)	0.165	4.92×10^{-10}	–	–	2.26	8.00×10^{-6}	3.00	–
Unit 4 (TSwv)	0.065	2.26×10^{-11}	0.0032	2.437	2.308	–	2.50	3.40
Unit 3 (TSw)	0.139	2.37×10^{-10}	0.0299	1.793	2.258	1.17×10^{-5}	3.00	4.25
Unit 5 (CHnv/PPnv)	0.331	1.82×10^{-8}	0.0531	2.75	1.838	–	1.40	0.20
Unit 2 (PTn)	0.421	5.47×10^{-7}	0.2485	2.611	1.714	2.67×10^{-5}	1.40	1.00
Unit 6 (CHnz/PPnz)	0.306	1.93×10^{-10}	0.0193	1.752	1.746	2.81×10^{-6}	1.10	0.20

[a] Data are from Section 7.4 of this document.
[b] Data are from Lin *et al.* (1993).
– Data are either unavailable or inapplicable.

Alternative Approaches

- work underway on the development of stochastic simulation approaches

- development of 3-D realizations of lithology conditioned by observed data

(Fig. 6-6; SAND93-2675)

- simulates lithological variability with interfingering of welded and non-welded units

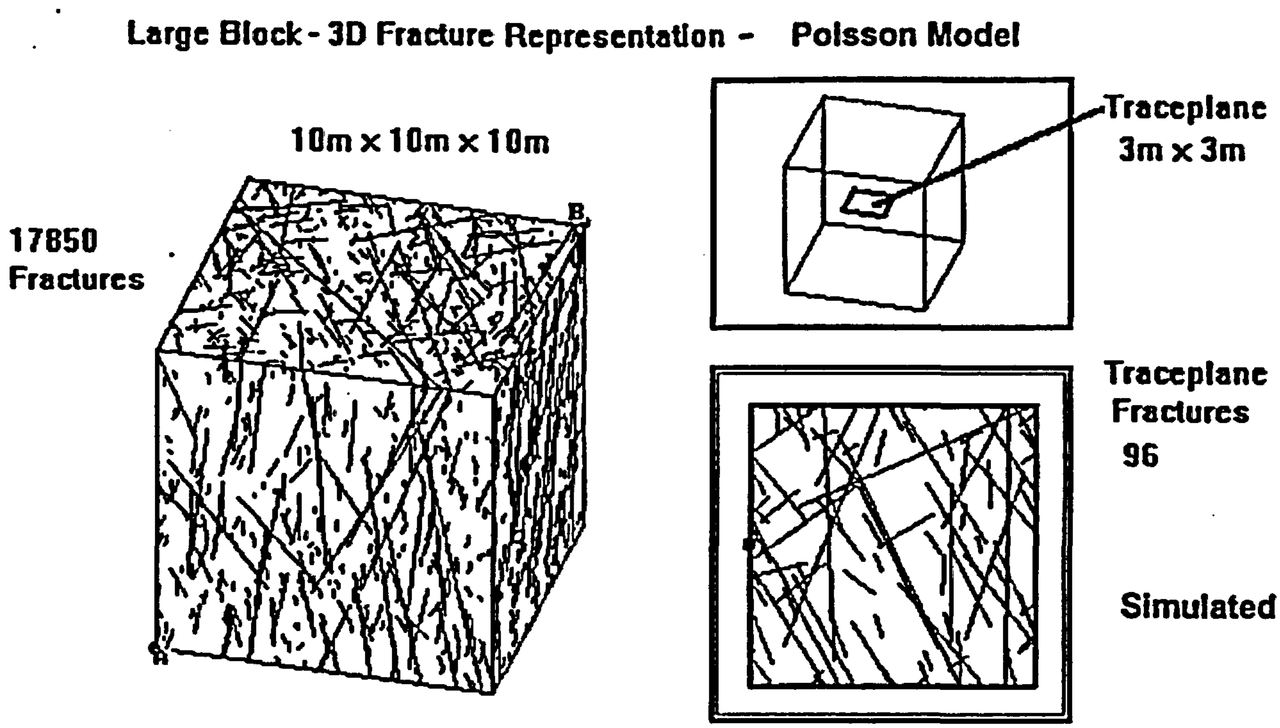
The Fractured Rock Dilemma

- fracturing of the media on all scales provides

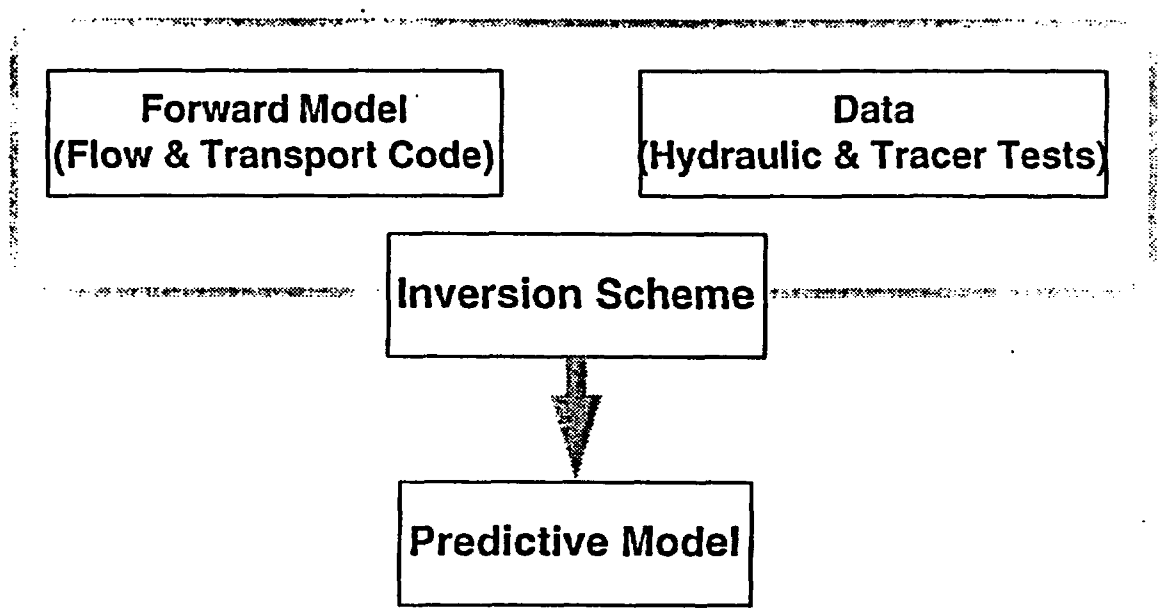
  extreme heterogeneity, beginning to be addressed

- variety of strategies

  - L. Anna, USGS - network model to represent the fundamentals of geometry and connection



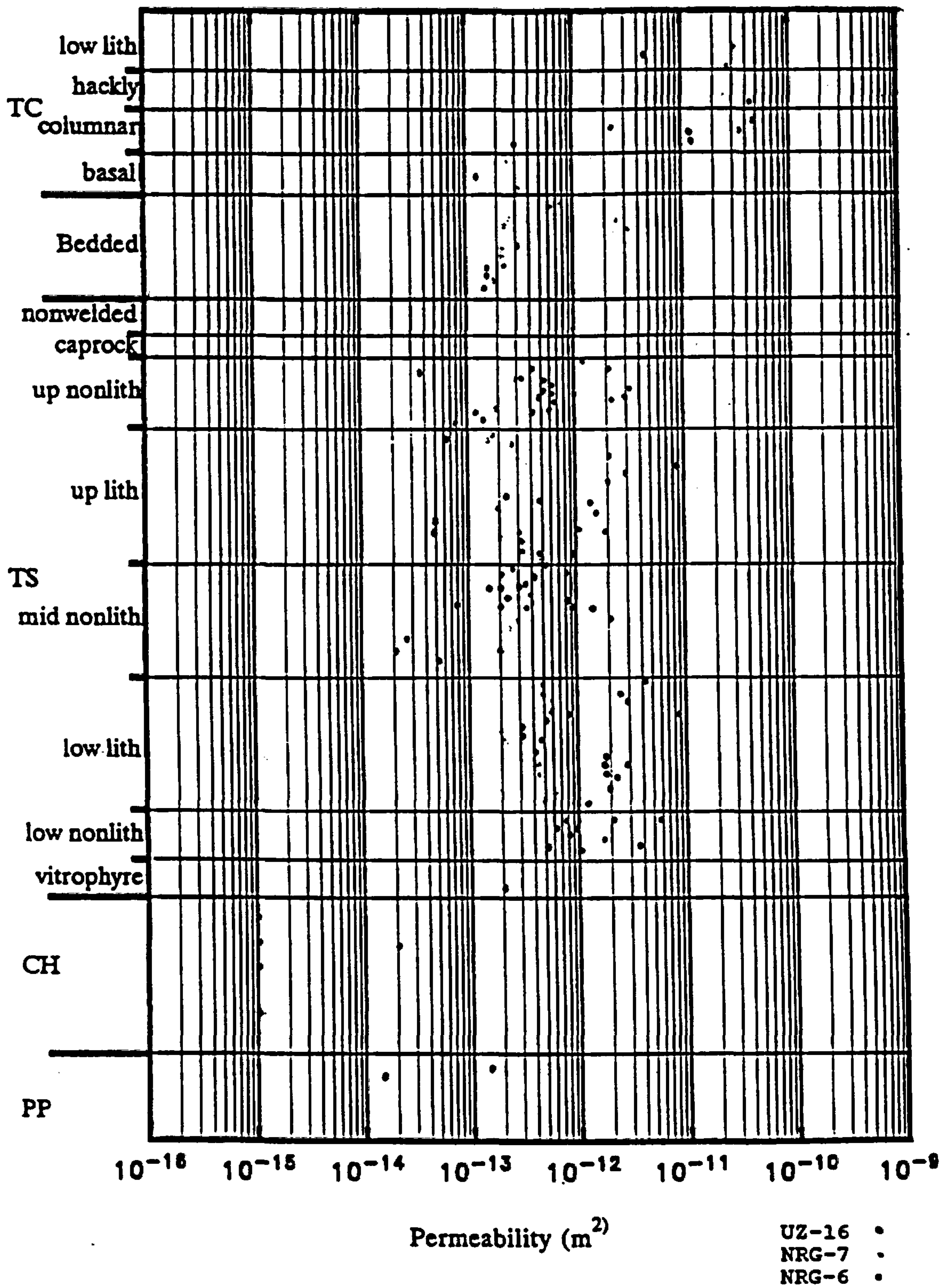
- K. Karasaki, LBL - flow-based alternative to geometric style analyses



Lawrence Berkeley Laboratory

· *in situ* technologies

- air permeability testing G.D. LeCain, USGS



Deep Infiltration of Ground Water

- knowledge about recharge comes from work by the USGS and isotopic measurements

- summary presented by Kwicklis (Sept/94)
    - thick alluvium stores infiltration later evaporated
    - during or following runoff deeper infiltration possible
    - where alluvium thick or absent water can enter fractures and move down 10's of meters
    - infiltration possible from all areas

- isotopic evidence of deep infiltration
    - tritium in Topopah Springs Member
    - ^{14}C of 3500 years in perched water in Calico Hills

In Imbricate zone - may not be pertinent to repository block - UZ/6

Recharge Rates

- remain quite uncertain

- present-day estimates

  - Buscheck and Nitao (1992) estimate rates close to 0.0 up to 0.13 mm/yr, others similar

  - EPRI 0.9 mm/yr

  - Sandia TSPA-93 exponential distribution with mean 0.5 mm/yr

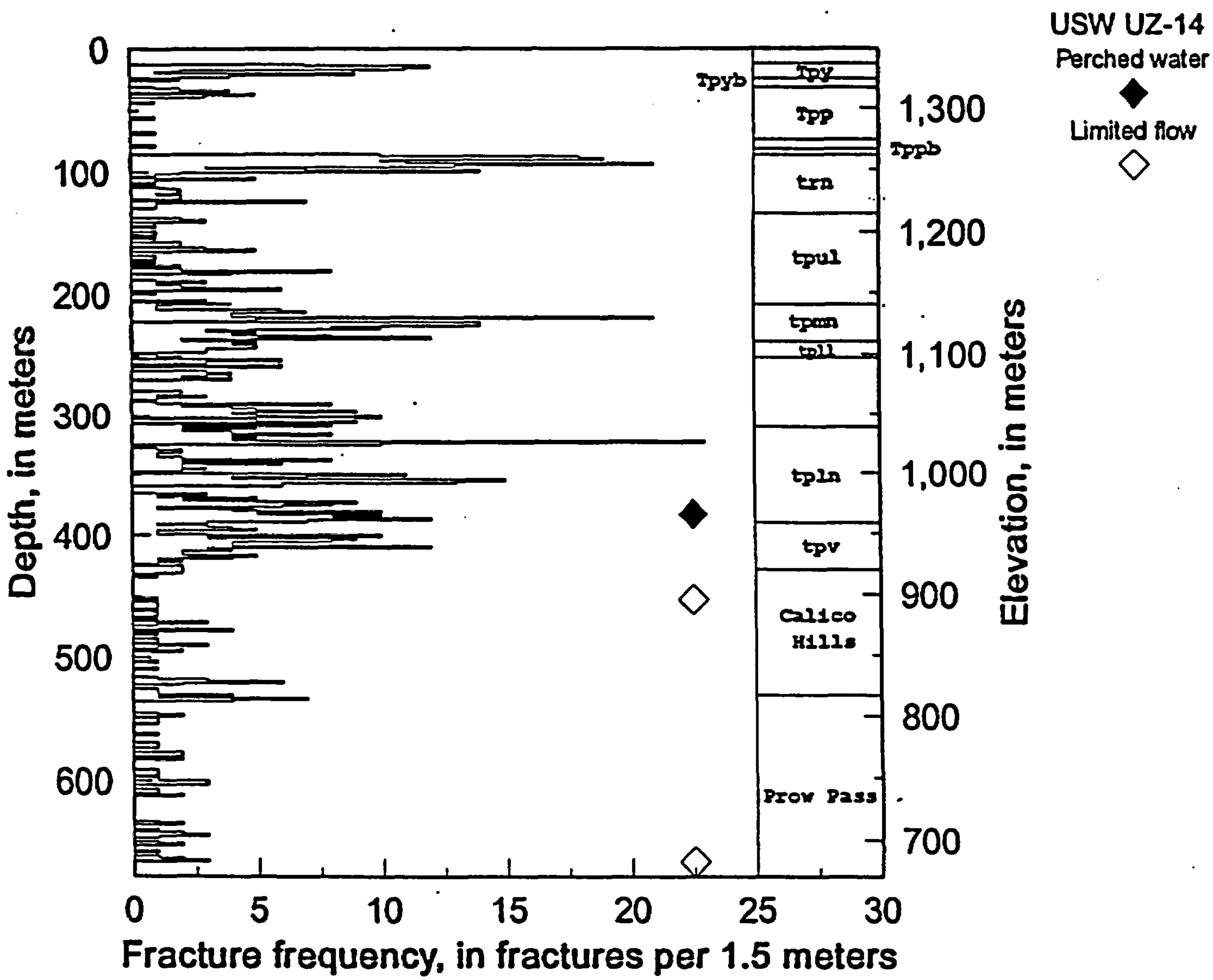
- future climate (pluvial and global warming)

  - EPRI 0.5 mm/yr to 5.4 mm/yr

  - Sandia TSPA-93, exponential, mean 10 mm/yr

Perched Ground Water

- perched conditions in cases where a zone of fracturing was underlain by an interval of low matrix permeability



(from Sept 14/94 presentation by Ed Kwicklis)

Climate-Related Changes in Water-Table Depth

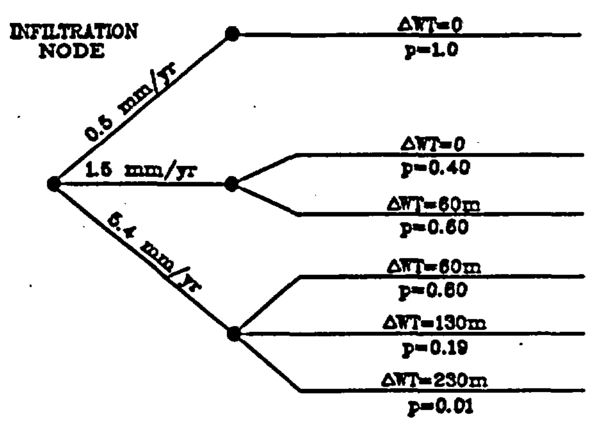
- estimates of previous increases are based on regional and local field observations, studies from computer models

- observations of the carbonate aquifer (Winnograd and Doty, 1980) - 30 m rise during Wisconsin

- distribution of vitric and zeolitized tuff (Levy, 1991) - water-table rise has not exceed 60 m since rocks emplaced

- old model estimate (Czarneki, 1985) - 130 m

- IMARC in 1992 used



Conceptual Models for Ground-Water Flow

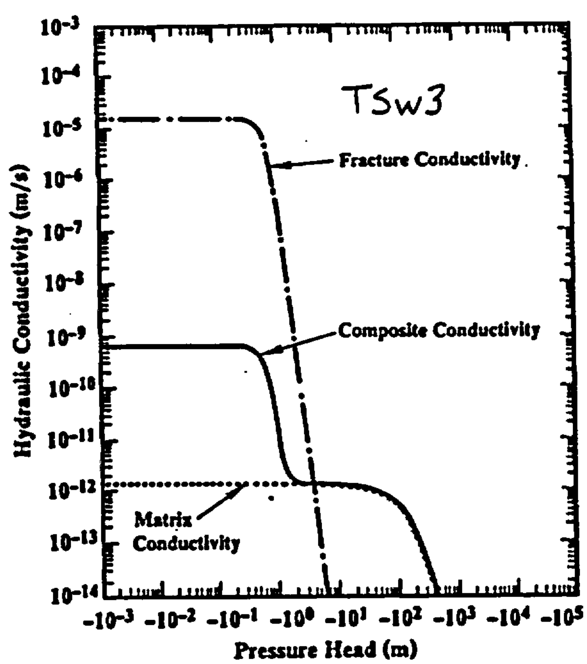
(1) Composite-porosity model for unsaturated flow

- flow in a fractured medium described most completely by solving coupled equations for fractures and matrix

- can simplify approach by assumption that pressure differences instantaneous redistributed, yielding a single equation for flow

- key parameters represented as an equivalent continuum

(from Dudley et al., SAND85-0002)



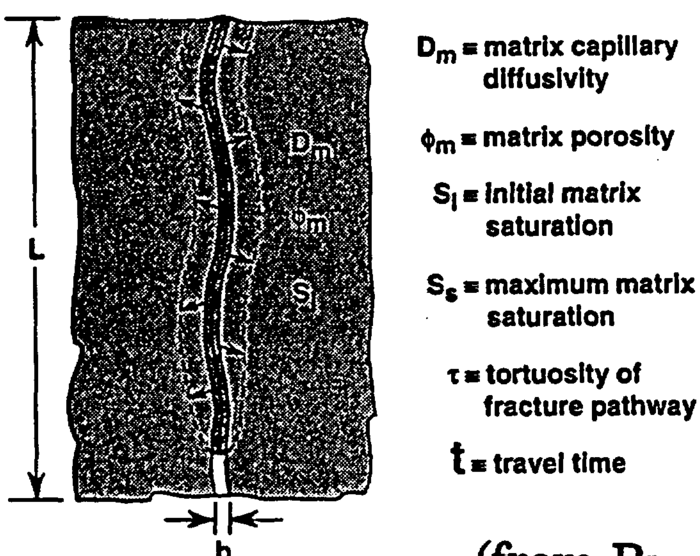
· in effect, hydraulic conductivity and capacitance terms defined in terms of volume weighted contributions from fractures and matrix

· forms the basis of computational models like TOSPAC, SUMO, V-TOUGH

· model forces strong interaction between matrix and fractures and relatively slow velocities

(2) Nonequilibrium Conceptual Models

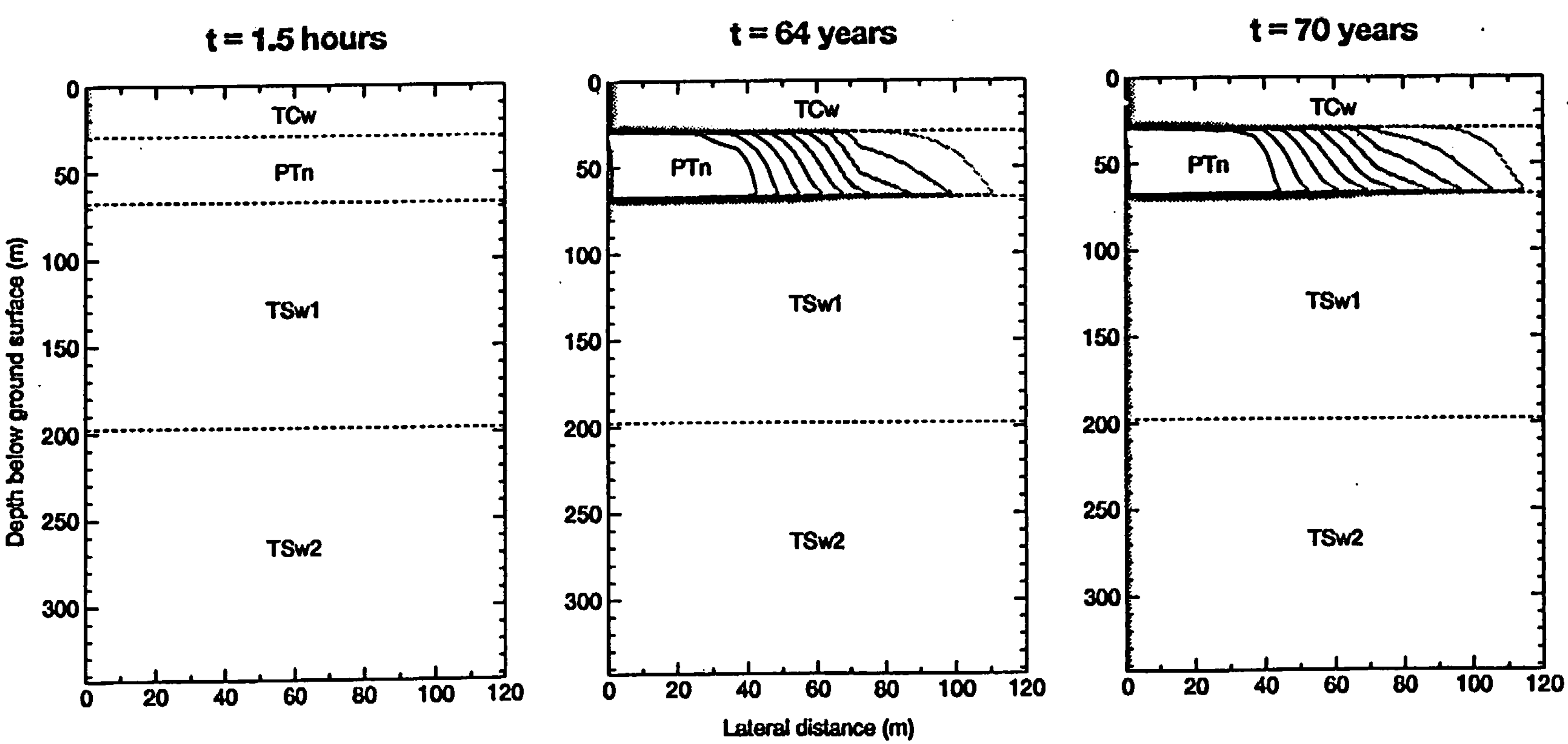
· examined by Buscheck, Nitao and others at LLNL



(from Buscheck, 5/92)

Above the repository, the travel time for liquid flow down a preferential fracture pathway is dominated by matrix flow into the vitric nonwelded Paintbrush tuff unit (PTn)

Dimensionless liquid saturation in the matrix resulting from a wetting event down a 100μm fracture

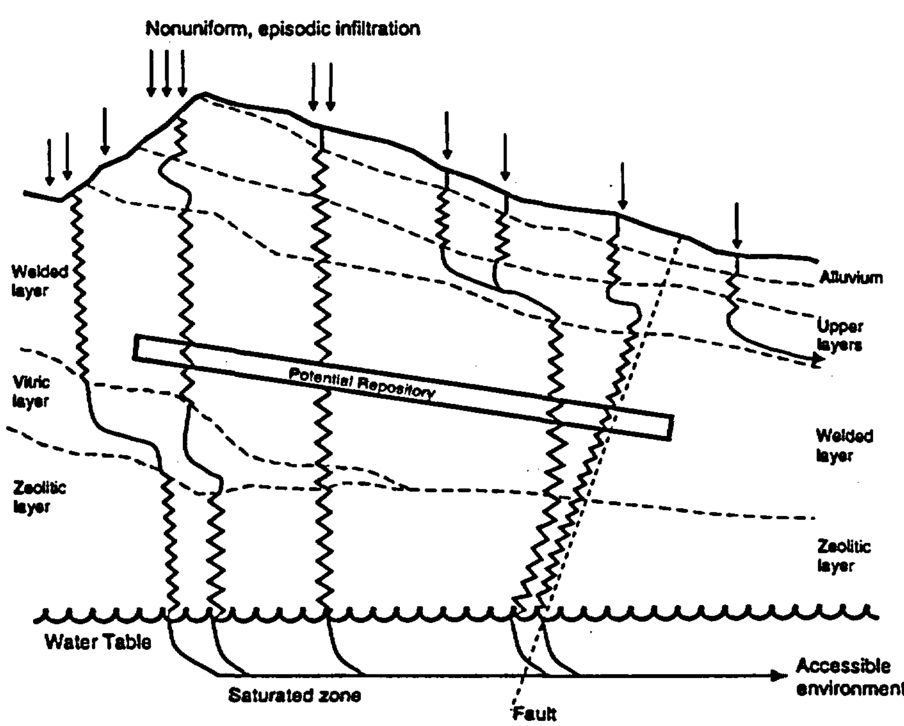


(from Buscheck, 5/92)

Weeps Model (from Gauthier, SNL)

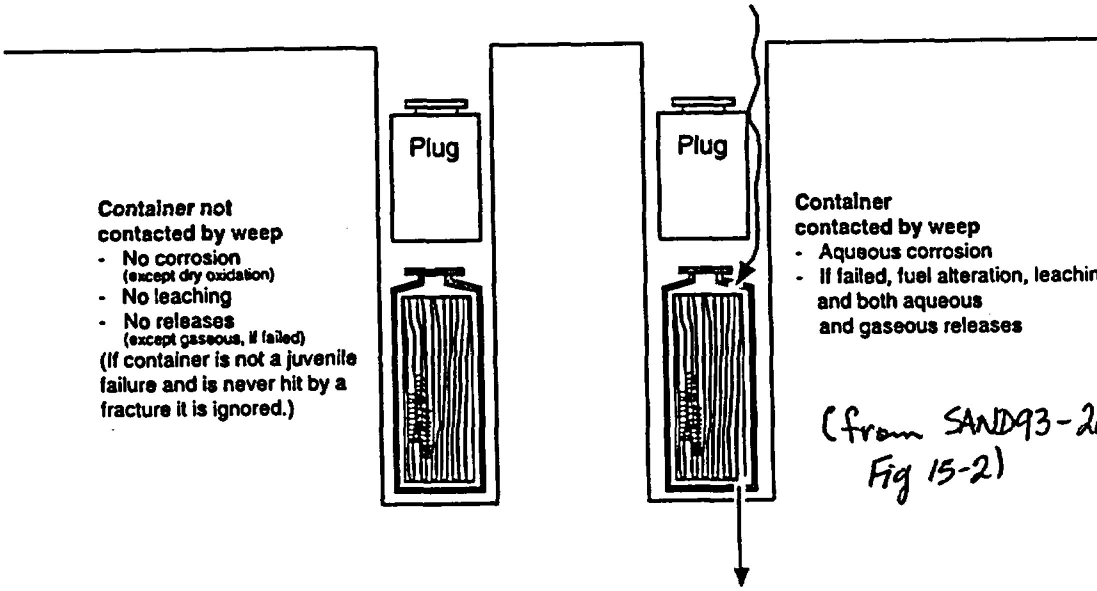
- conceptual model that represents Yucca mountain as a sieve offering containers little protection from episodic fracture flow

- flow conceptualized as vertically downward with negligible capillary effects with the weeps contacting the repository at discrete points



(from SAND93-2675, Fig 15-1)

· containers not contracted by weeps do not corrode



(from SAND93-2675, Fig 15-2)

· description of weep difficult -- analog to Rainier Mesa with episodic flow concentrated in several large faults or fractures

· weep described by an aperture and a width (horizontal length) and total infiltration flow allocated among correct number of weeps

Implementation in PA

· weeps model can account for effects of hot repository

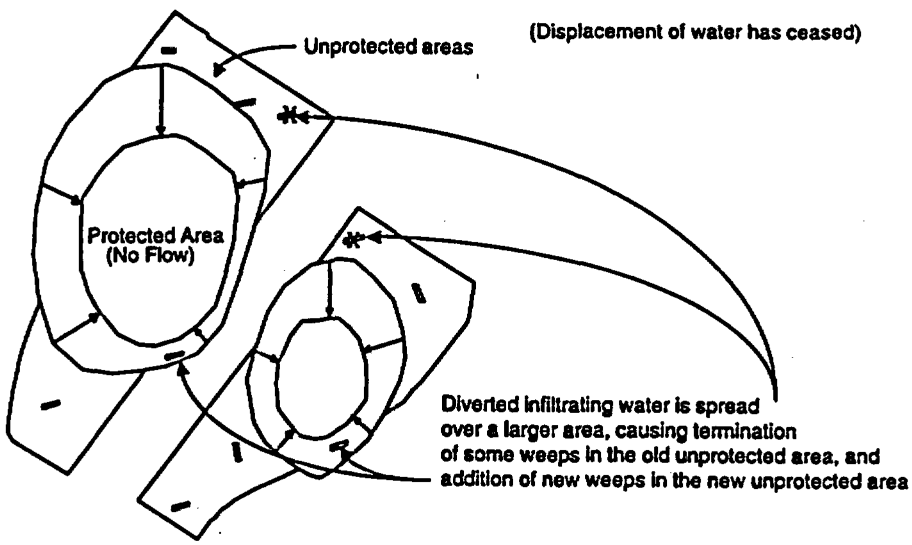


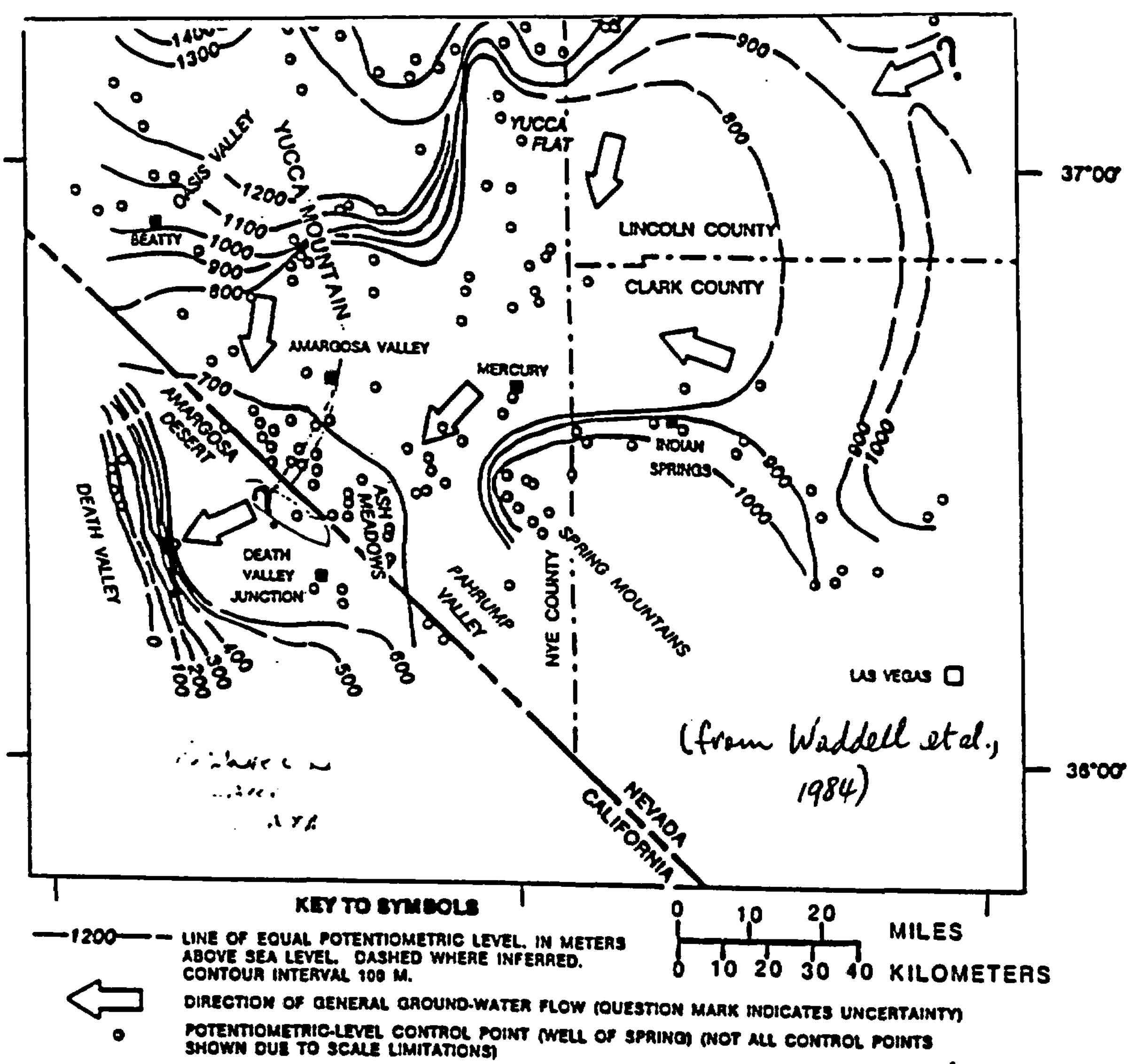
Figure 15-6. Illustration of flow-pattern changes calculated by the weeps model when the dryout zone is contracting.

(from SAND93-2675, Figure 15-6)

Saturated Zone

- saturated zone is a significant component of the g.w. pathway to the accessible environment

- problematic feature is the large hydraulic gradient has been redefined somewhat in newer studies



(from Waddell et al., 1984)

- most studies admit to the complexity and lack of information about the unsaturated zone

- present conceptualization represents the zone of saturation as a fractured and permeable unit
  - linear velocities of the order of 2 to 20 m/yr
  - modest retardation due to sorption

- overall saturated zone as presently conceptualized does not contribute significantly to performance except for strongly sorbed radionuclides

Thermal Loading Initiatives

- scientists at Lawrence Livermore Laboratory propose to utilize heat from the waste as a design variable

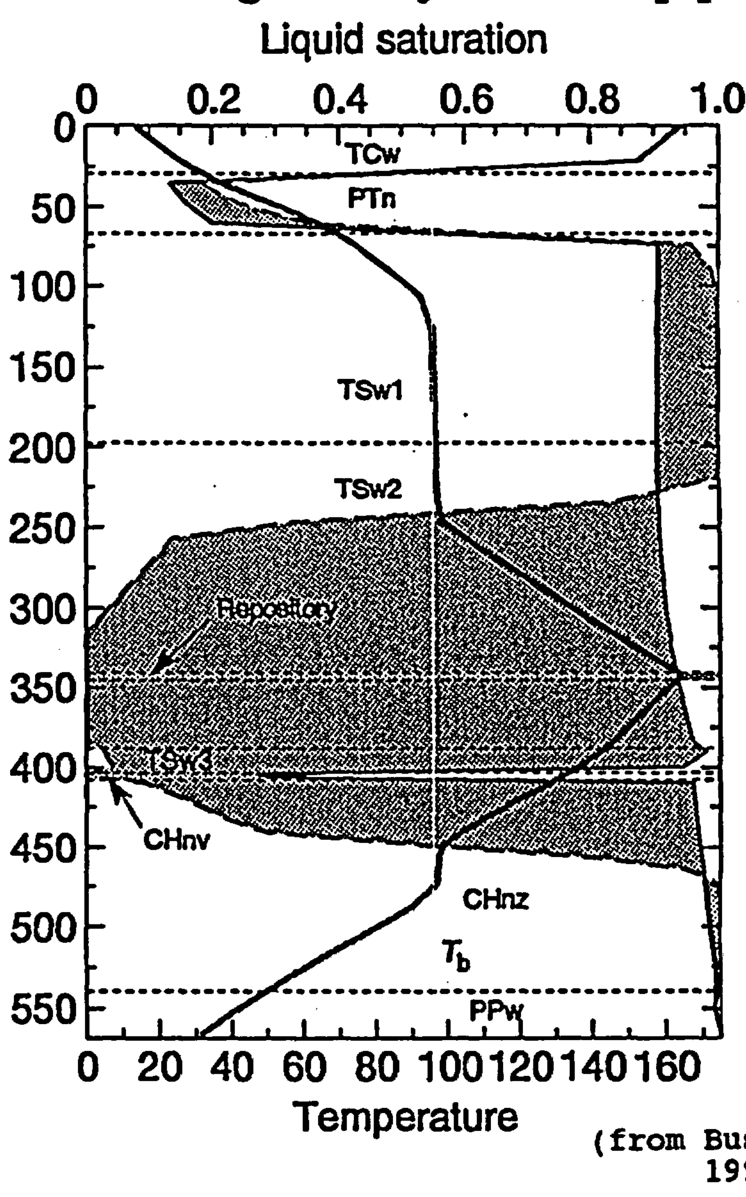
- boil water out of rocks immediately adjacent to containers - performance gains proposed by initially keeping waste from water and later by hydraulic confinement

- three heat-flow regions will develop
  - (1) upper/lower zones of dryout
  - (2) upper/lower heat pipe zones
  - (3) upper/lower zones of heat conduction

- region (1) characterized by moisture contents below gravitational capillary equilibrium

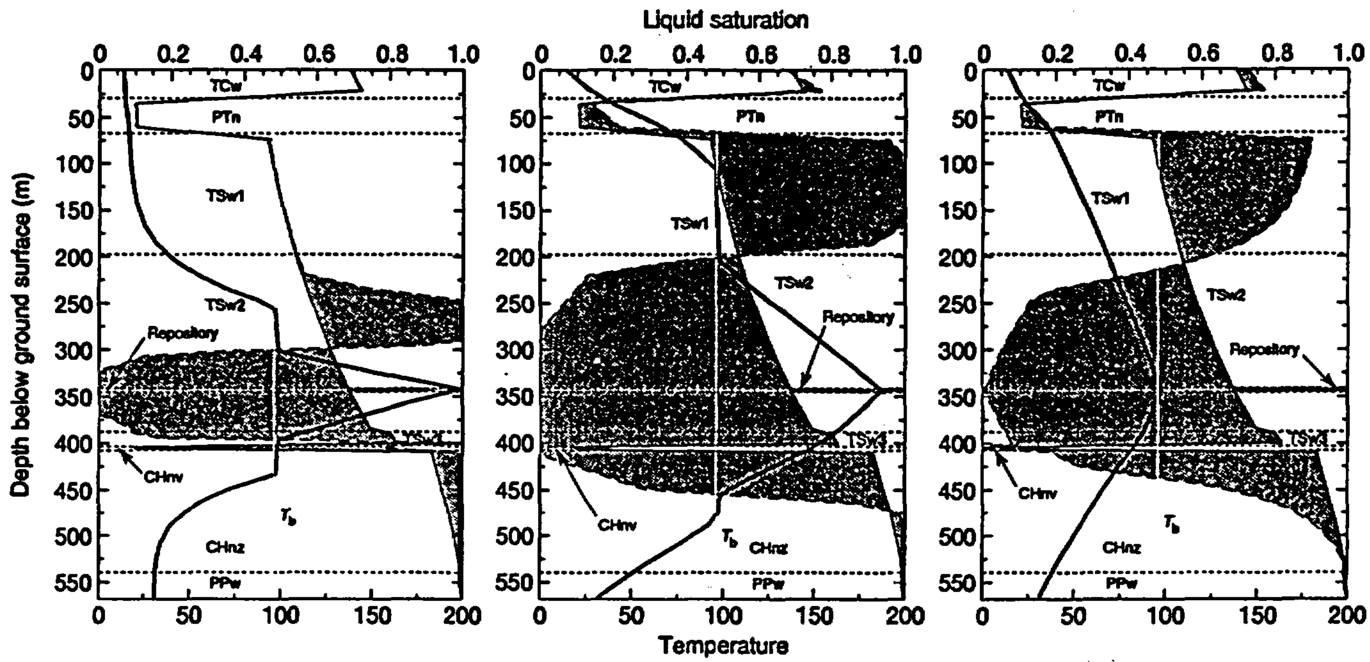
- region (2) vertical zones where temperature is maintained at 100° by heat convection

- region (3) out-regions beyond heat-pipe zone



(from Buscheck presentation, 1992)

· results from Buscheck presentation: (May 5, 1992)

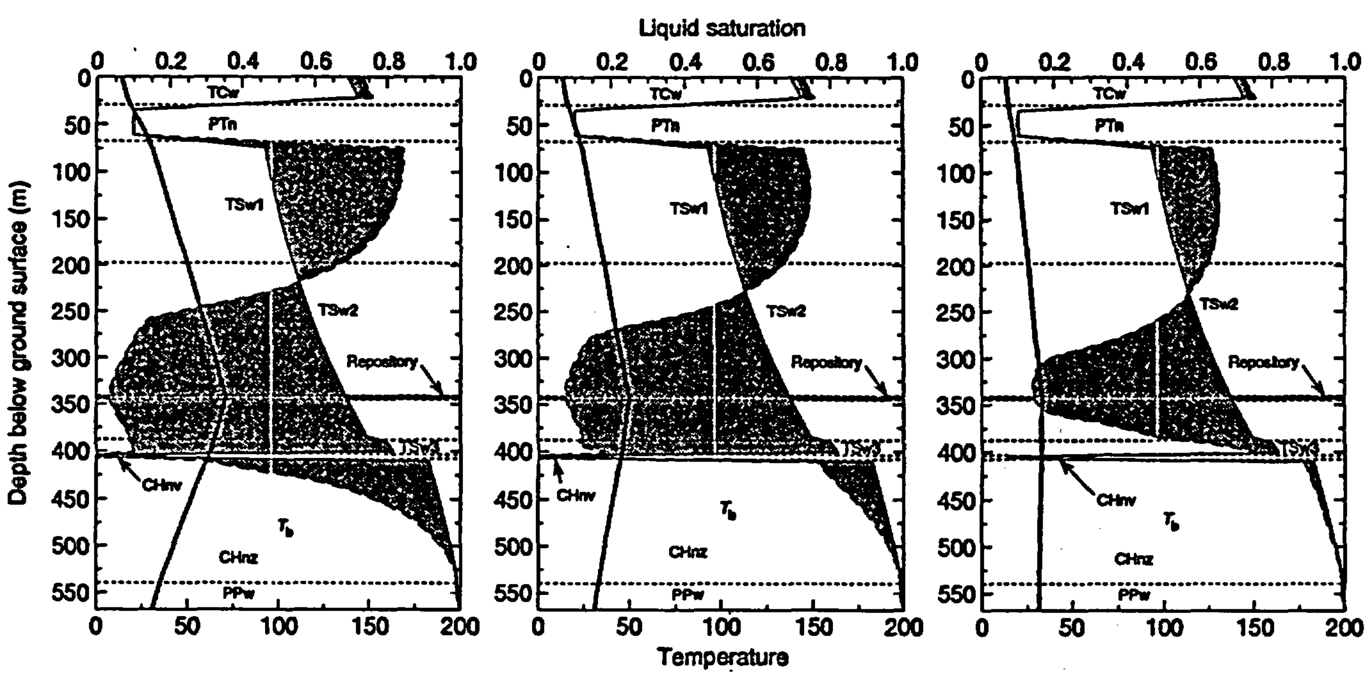


t = 100 yr

t = 1000 yr

t = 5000 yr

Vertical liquid saturation and temperature profiles at the repository center for 30-yr-old fuel, an APD of 114 kW/acre, and a recharge flux of 0.0 mm/yr



t = 10,000 yr

t = 20,000 yr

t = 50,000 yr

Issues in Repository Heating

- potential to mobilize large quantities of silica - subsequent precipitation in fractures may destroy coupling to matrix

- beneficial effects of heating decline with increasing recharge rates - our simple analysis suggests above 0.4 mm/yr resaturation following boiling is extremely rapid

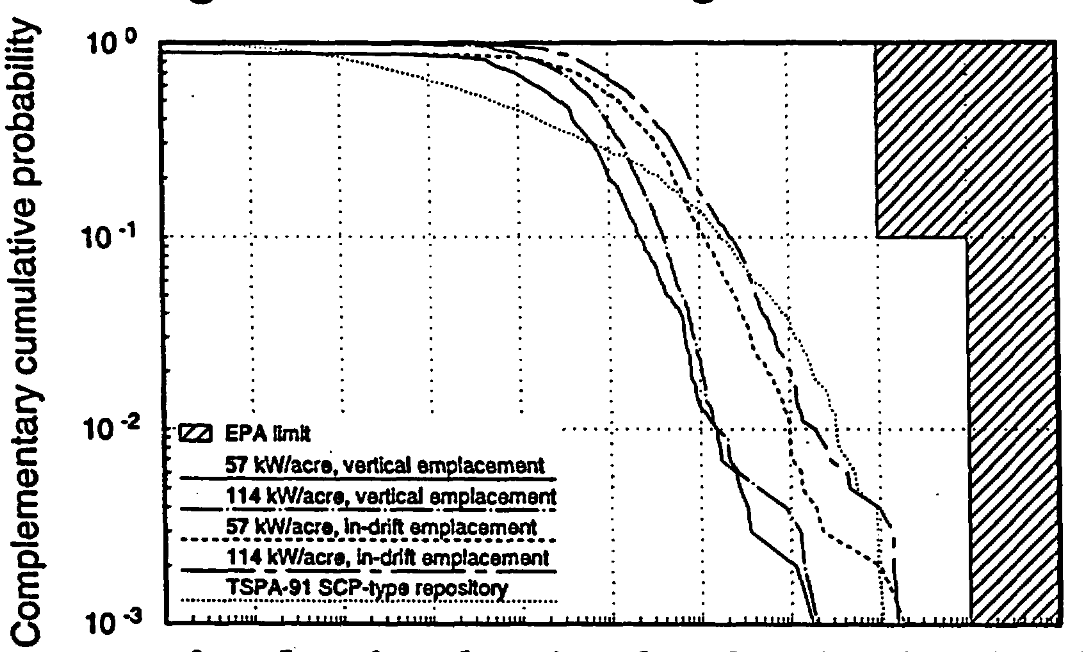
- high temperatures may lead to clay-mineral alteration that reduces sorptive capacity

- the concept has not undergone significant field validation - actual behavior may be quite different from the model predictions

- weeps calculation provides the total amount of water, the area influenced by each weep, and the total number of weeps

- travel times of days to years for transport to the water table when container calculated to fail

- latest versions of the weeps model consider climate change and thermal heating



(from SAND93-2675)

Figure 15-40. Comparison of the conditional CCDFs of cumulative aqueous releases to the accessible environment, at 10,000 years, normalized by the EPA limits, for the four repository cases. Cross-hatching denotes area of noncompliance with the EPA standard.

Review of the IMARC ~~Hydrologic~~ Hydrologic Model

Frank W. Schwartz

EPRI Workshop

December 12 - 13, 1994

<u>Review of IMARC Hydrologic Model</u>

- this presentation reviews the hydrologic model

  contained within IMARC package

- explains the context under which the present code

  was developed

  - modest effort spread across many different
    topical areas

  - goal was to examine process interactions
    which at time not emphasized

  - not our intent to compete with the strong efforts
    underway principally at Sandia

  - examine issues without "project think"
    high recharge rates at the time
    dominant fracture transport
    flooded repository
    skepticism about benefits of heating

- our modeling approach to date built on some assumptions that we propose to revisit in this workshop

(1) performance assessment codes like IMARC and others represent a legitimate analysis tool

- simple models can capture complex system performance

- empirical functions based on observational or model-derived information can represent more complex phenomena (e.g., dryout)

(2) process models like V-TOUGH will be used primarily to understand complexities, and not PA

(3) whichever model is built -- there will be adequate data available - infallibility of approach

Requirements for Flow and Transport Models

(1) must adequately represent the hydrologic system

and proposed disposal concepts

- unsaturated flow in units with widely varying properties
- various types of fracture/matrix coupling
- complex response to changing fluxes
    + time varying climate
    + changing water-table configurations
- lateral saturated flow
- "hot" repository concepts

(2) must accommodate a stochastic approach

- 100's of independent realizations

10,000 + realizations

(2) Continued

- robust in accommodating parameter changes

    + major changes in infiltration rates

    + varying region size due to water-table fluctuations

    + both "hot" and "cool" scenarios in the same simulation

- needs to execute fast on a PC to provide close to real-time demonstrations

(3) Results must be comparable to other modeling approaches (e.g., TOSPAC)

Flow and Transport Modeling

- semi-analytic approach that involves and analytic solution for flow and a numerical solution for transport

- Srivastava and Yeh (1991) solved problem of 1-D transient infiltration into a layered soil

- begin with 1-D for m of Richard's equation

$$\frac{\partial}{\partial z_*}\left[K_*(\psi)\,\frac{\partial(\psi + z_*)}{\partial z_*}\right] = \frac{\partial\theta}{\partial t_*}$$

- assume the following constitutive relationships

$$K_* = K_s e^{\alpha\psi}$$

$$\theta = \theta_r + (\theta_s - \theta_r)e^{\alpha\psi}$$

K_s = saturated hydraulic conductivity
θ_r = residual moisture content
θ_s = saturated moisture content
α = pore size distribution parameter
ψ = pressure head

· these simplified constitutive relationships provide a linearized form of Richard's Equation

$$\frac{\partial^2 K_*}{\partial z_*^2} + \alpha \frac{\partial K_*}{\partial z_*} = \frac{\alpha(\theta_s - \theta_r)}{K_s} \frac{\partial K_*}{\partial t_*}$$

· this form amenable to analytic solution

Advantages and Limitations

· this approach and a number of tricks lets us generally meet the stated requirements

· constitutive relationships idealized and unlike van Genuchten parameters do not represent real media well

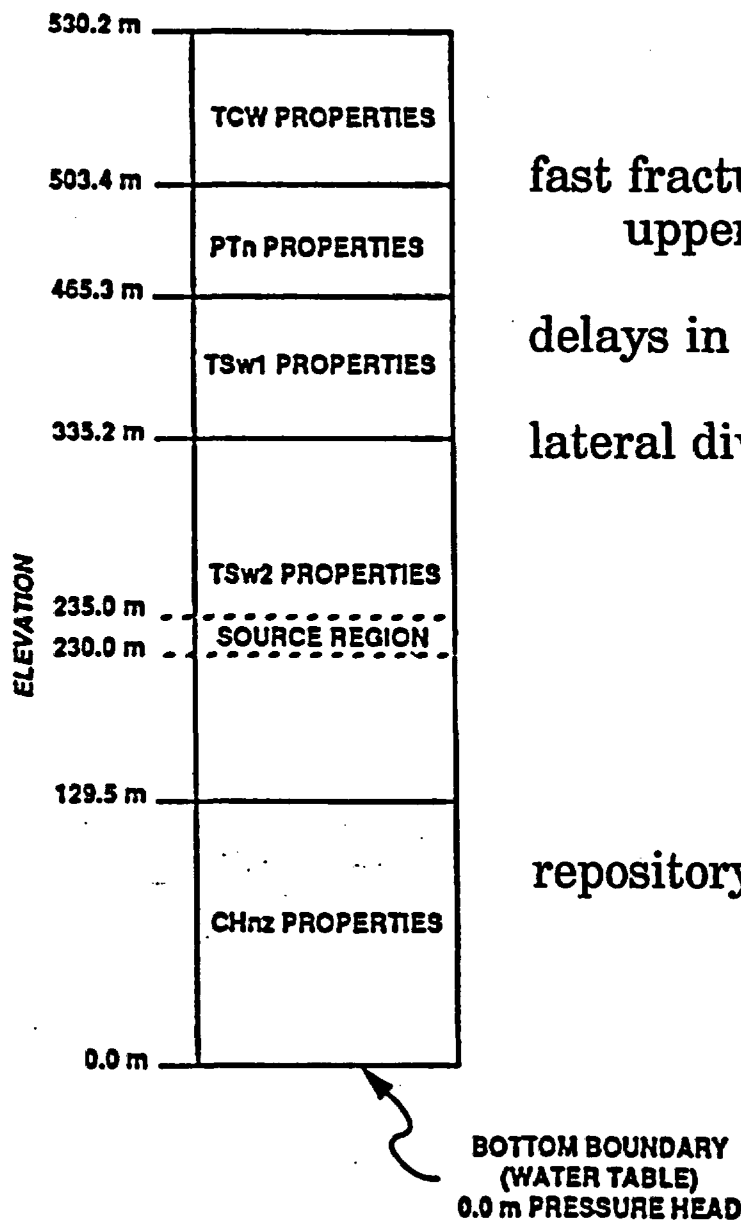
· only possible to represent two layers and one change in infiltration rate

Flow Calculation

· with assumption that flow is vertically downward

there is no explicit need to represent units above the repository

· there are, however, flow effects to consider



fast fracture flow in upper units

delays in flux changes

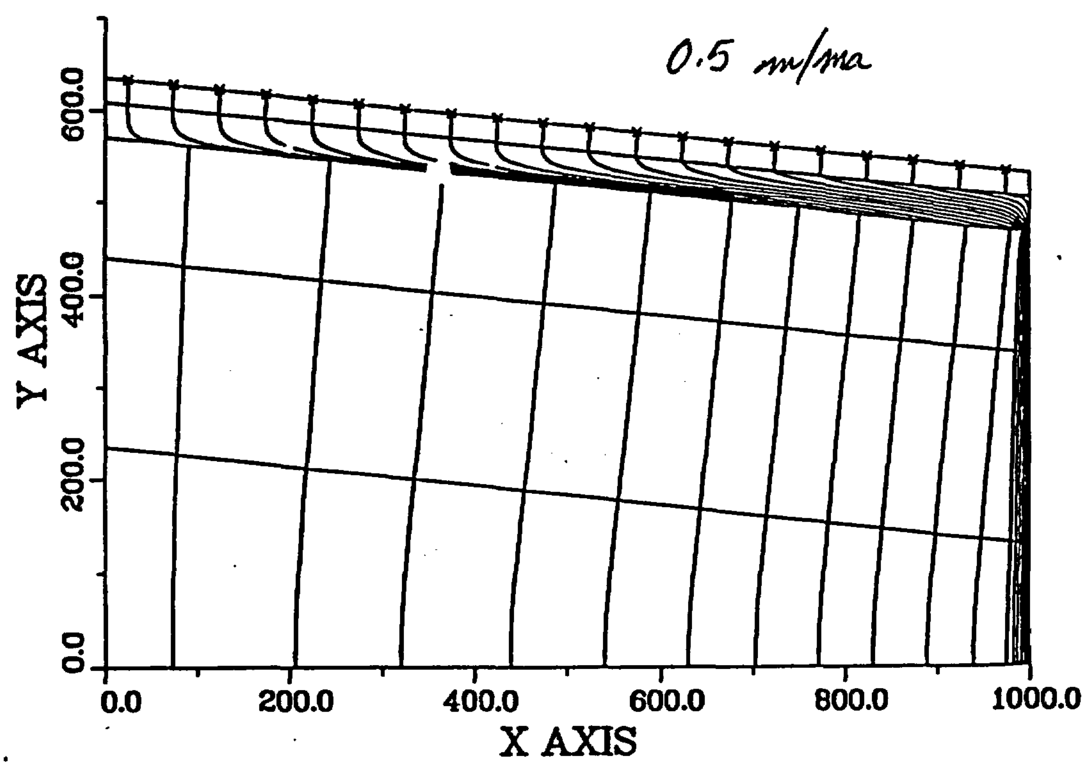
lateral diversions

repository heating

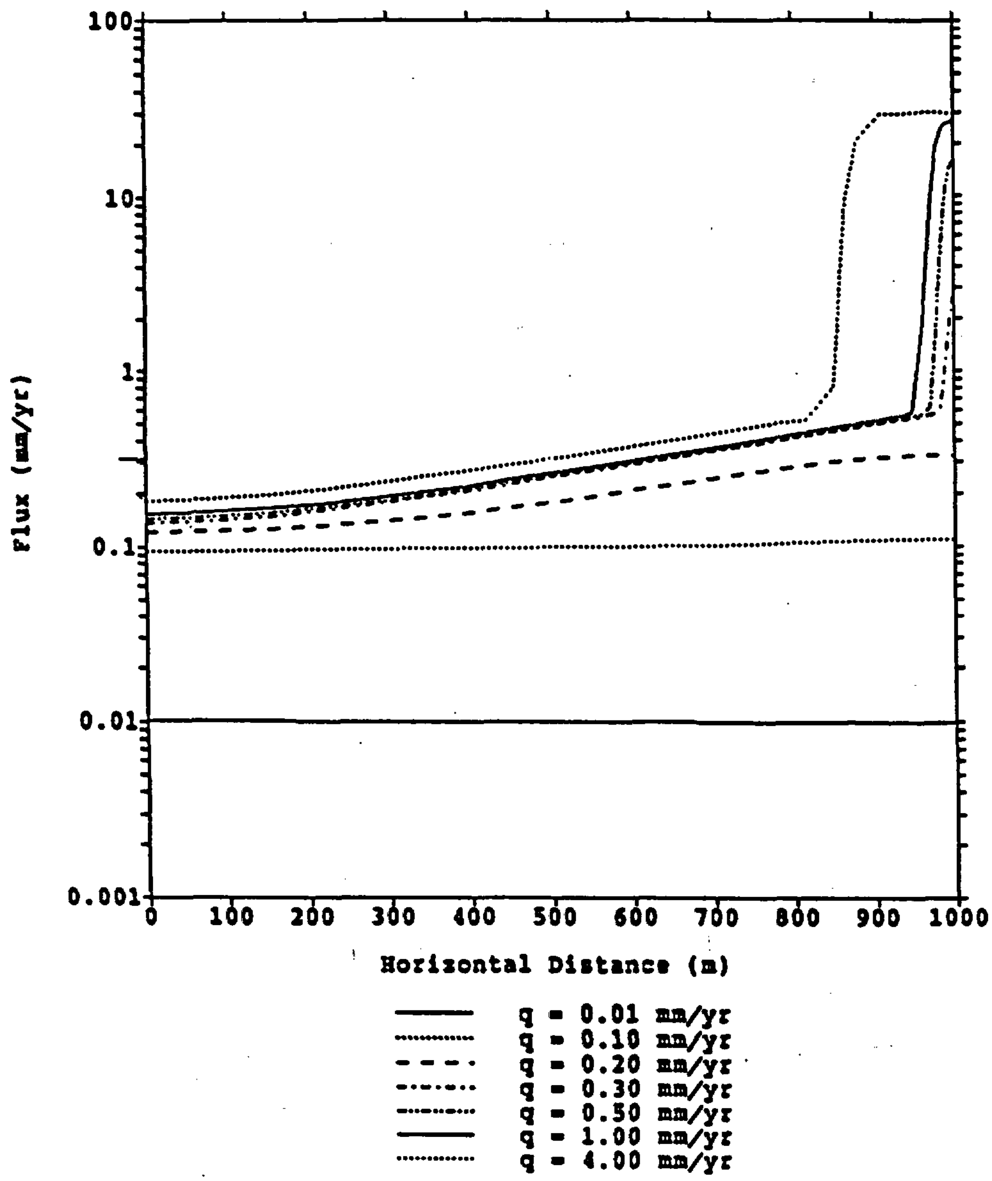
Lateral Diversion of Flow

- two-dimensional modeling trials of Prindle and Hopkins (1989) indicate the possibility of lateral flow diversion to a down-dip fault

- main determinant is contrast in hydraulic conductivity between Paintbrush unit and Topopah Springs unit (upper half)



• results for base case show upper units effective in shielding the repository



(a) no lateral diversion [p=0.45]

$$QA, QB = I_{t1}, I_{t2}$$

where QA = initial flux at repository (m/ma), QB = subsequent flux, I_{t1} = flux at surface, and I_{t2} = subsequent flux.

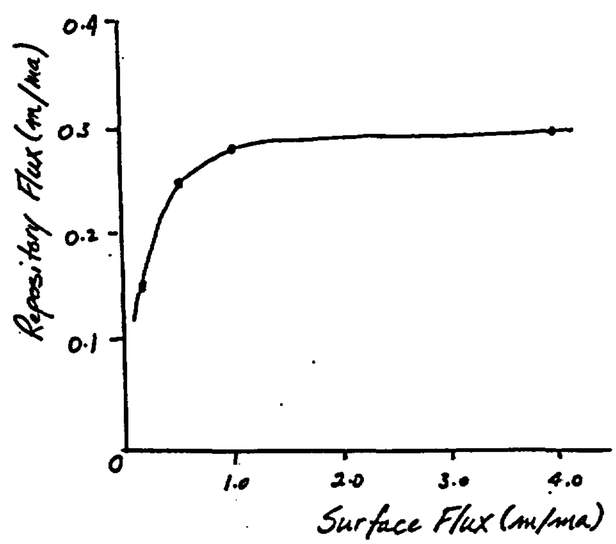
(b) Significant lateral diversion [p=0.55]

$$QA = I_{t1}, \quad \text{when} \quad I_{t1} \leq 0.2 \text{ m/ma}$$
$$QB = I_{t2}, \quad \text{when} \quad I_{t2} \leq 0.2 \text{ m/ma}$$

$$QA = 3I_{t1}/(1 + 10I_{t1}) \quad \text{when} \quad I_{t1} > 0.2 \text{ m/ma}$$
$$QB = 3I_{t2}/(1 + 10I_{t2}) \quad \text{when} \quad I_{t2} > 0.2 \text{ m/ma}$$

- example calculations

I_{t1}	QA
0.20	0.20
0.50	0.25
1.00	0.27
4.00	0.29

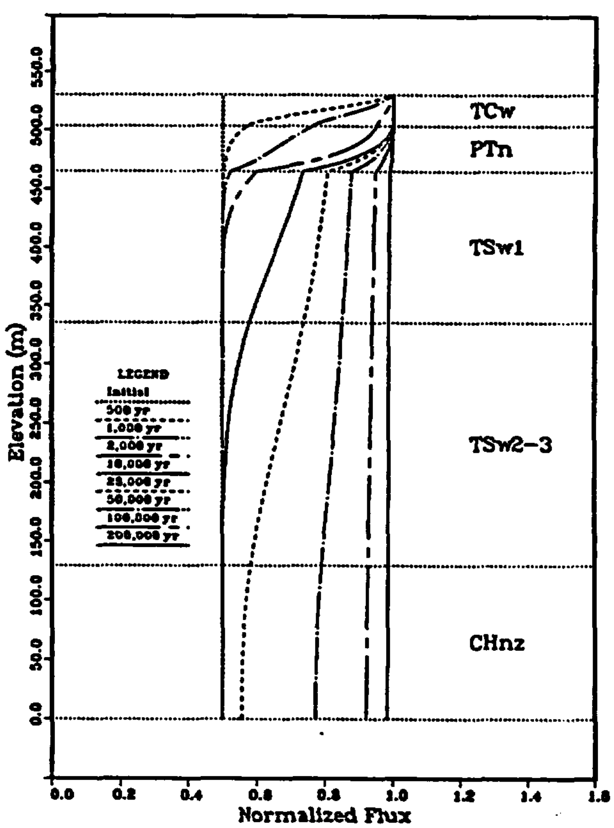


Delays in Flux Changes

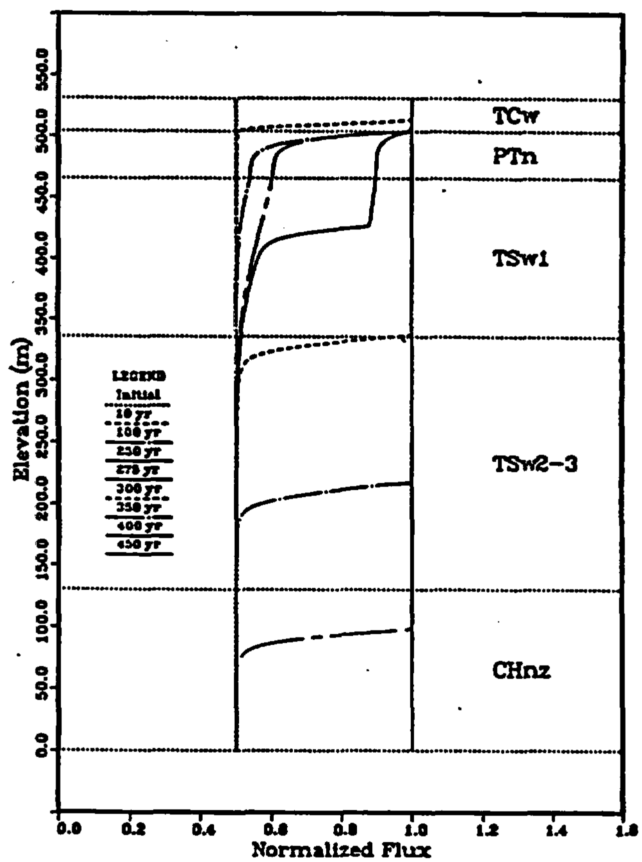
Time lag for flux changes at the repository level

water going into storage in Paintbrush unit

0.1 to 0.2 m/millennium



0.5 to 1.0 m/millennium



· transfer function developed from results of Dudley et al. (1988) to estimate time of flux changes at the repository level

$$t_{rep} = t_{surf} + t_{adj} \qquad \text{where: } t_{adj} = 25 \exp(-I_{t2}/0.22)$$

t_{adj} = time (millennia) lag before a surface infiltration change is felt at the repository level

t_{surf} = time (millennia) when the infiltration flux changes at the surface

I_{t2} = infiltration rate (m/millennia) after t_{surf}

t_{rep} = time (millennia) when the flux changes at the repository

I_{t2}	t_{adj}
0.1	15.8
0.2	10.0
0.5	2.5
1.0	0.2
2.0	0.0

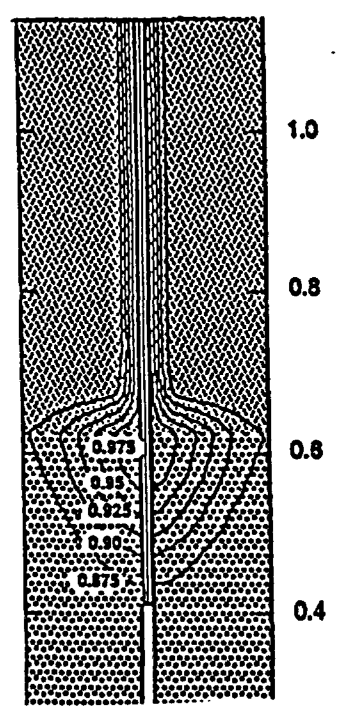
Fast Fracture Flow

- most modeling to date relies on concept of an equivalent continuum

- theoretical calculations suggest that in low permeability rocks water may be slow in moving into the matrix producing fast travel times

- may be responsible for relatively rapid episodic recharge (^{36}Cl) at shallow depth

- requires adjustment in delay times and lateral diversion



Water Table Rise

- IMARC as currently formulated considers various possibilities of water table adjustments given the infiltration rate - most other analyses do not adjust the position of the water table

- infiltration rate 0.5 mm/yr	$\Delta wt = 0$	$p = 1.0$
($p = 0.05$)		
- infiltration rate 1.5 mm/yr	$\Delta wt = 0$	$p = 0.4$
($p = 0.90$)	$\Delta wt = 60m$	$p = 0.6$
- infiltration rate 5.4 mm/yr	$\Delta wt = 60m$	$p = 0.8$
($p = 0.05$)	$\Delta wt = 130m$	$p = 0.19$
floods site	$\Delta wt = 230m$	$p = 0.01$

- the evidence for the extent of water level changes is extremely limited - probable maximum historical change - 60 m - model studies suggest 130 m

- extreme change included in part to assess performance of the facility under flooded conditions - a place holder

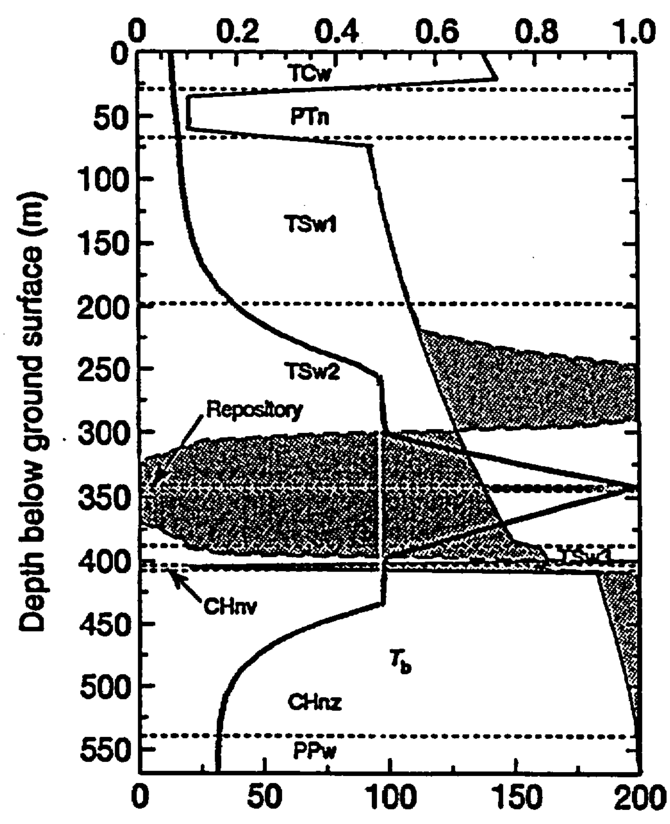
Enhancement Through Heating

- proposal is to improve performance by boiling water out of rocks - delays transport through groundwater because:

  (1) above 96°C surrounding rocks are "dry"

  (2) below 96°C - initially, a hydraulic sink at repository is maintained for some additional time - eventually system slowly resaturates and transport will begin

- calculation for 30-yr-old fuel, an APD of 114 kW/acre, and recharge flux of 0.0 mm/yr (Buscheck presentation, 1992)



100yr

Issues Concerned with Heating

- all of the heating calculations assume the equivalent continuum model for flow - thus model is forced to use small recharge rates (e.g., less than 0.132 mm/yr)

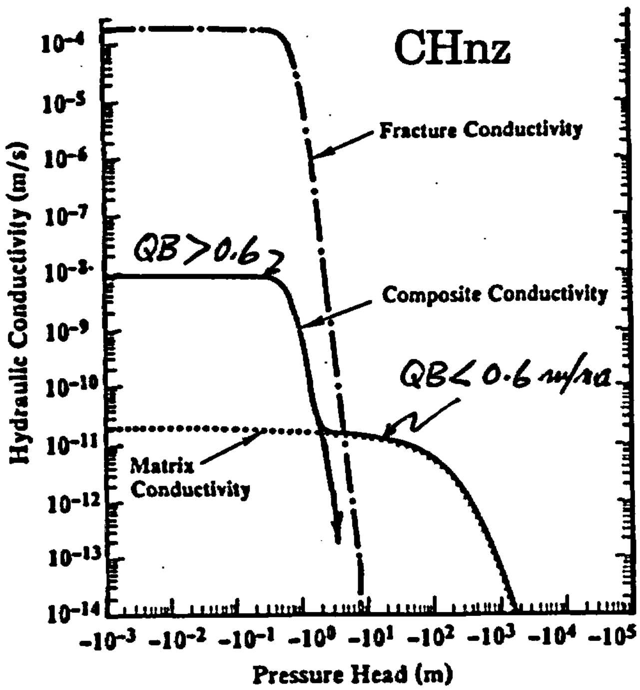
- EPRI conceptualization admits other heating possibilities - all of which reduce the benefits of heating (ref Ben Ross)

- the main benefits of heating are manifest under low recharge rates - main impact on resaturation defined in terms of a delay time (dyt_2; time to saturations one-half of original)

Preliminary summary of delay times related to repository heating.

Recharge Rate (mm/yr)	Thermal Loading (kW/acre-age yrs)	dyt_2(yr) Center	Edge
0.0	114-60	102000	40000
	114-30	90000	27000
	57-30	16000	500
	36-30	0	0
0.132	114-30	38000	3000

Treatment of Composite Properties



- each layer [TSw2-3, CHnz] is characterized by two sets of K_s and α values - a set chosen depending upon QB is less or greater than 0.6 m/ma

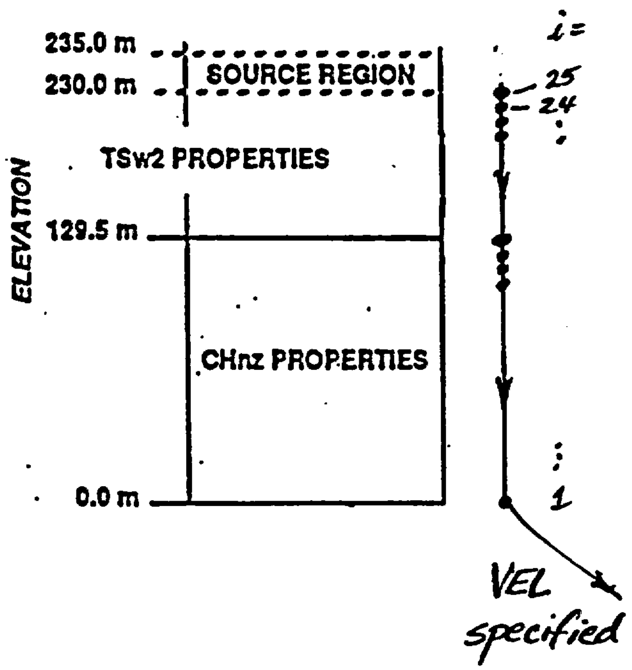
Other Parameters

- QA, QB, and t_{rep} define repository fluxes and timing of flux changes

- θ_s and θ_r define ranges in moisture content

Mass Transport Model

- model provides ψ at a series of locations 10m apart



Darcy equation

$$v_c = (K_*/\theta)\text{grad}(\psi + z)$$

Weak Coupling

$$\theta_{CHnz} = 4.6\text{x}10^{-3}$$

$$\theta_{TSw2\text{-}3} = 18.0\text{x}10^{-3}$$

- transport model uses a moving particle approach to calculate mass outflow at the accessible environment

- accounts for transport of a single constituent subject to advection, sorption, radioactive decay, loading

- each particle defined by z-position and attached mass or activity of nuclide

Saturated Ground Water Flow

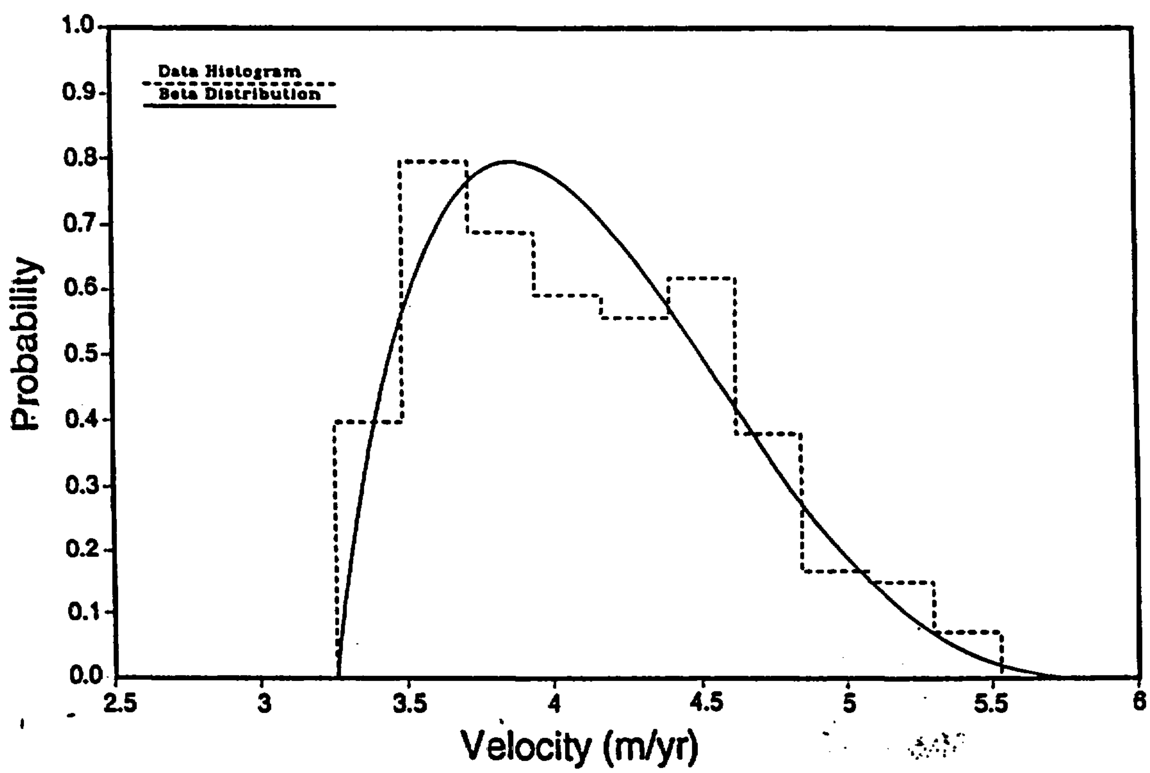
- the original treatment of nuclide transport in the unsaturated zone was conservative

- assumed that no attenuation mechanisms were operative except radioactive decay

    - relatively little information available

    - other treatments ignored saturated system

- advective transport assumed at 1 m/yr and 10 m/yr to reflect uncertainty in the value



(from SAND91-2795; Fig 4-32)

Sorption in the Zone of Saturation

- recently saturated zone model has been modified to include retardation due to sorption

- tuff in saturated zone treated as being devitrified in terms of its sorptive behavior

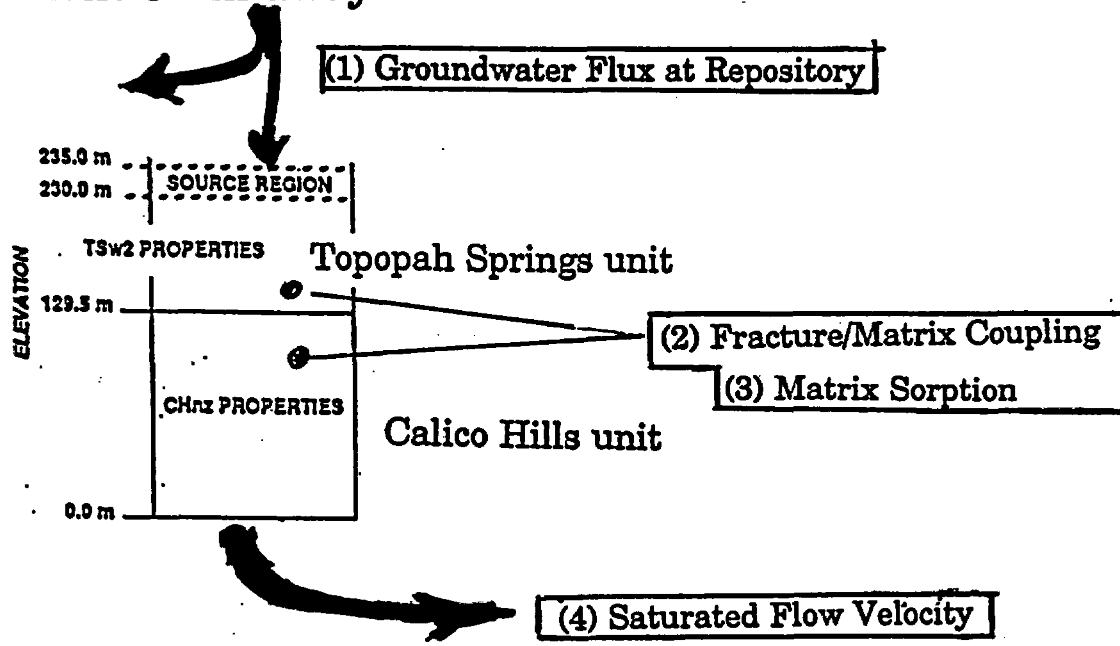
- carries K_d values the same as layer 2 (TSw2)

Nuclide	Base Case $\rho_b K_{d0}$
Pu	117.
Np	12.5
U	3.2
C	0
Se	12.5
I	0
Cs	522.
Tc	.54
Ra	45390.

$\rho_0 = 1.80\ g/cm^3$

Logic Tree For Groundwater System

· groundwater system defined from the repository down to the water table and laterally to the accessible environment 5 km away



* depth to water table and timing of flux changes determined upstream in the logic tree

* depth to the water table changes tomorrow

* flux can be changed once during simulation

* diverted flow along faults does not encounter waste

Code Verification

(1) flow code - trials in Srivastava and Yeh (1991)

(2) total code - cross-verification tests between FLOAT and TOSPAC - Total Performance Assessment Code

SPECTRA Research Institute
Sandia National Labs

- 1-D code to simulate partially saturated flow in a multi-layered sequence - very large code with user information in two volumes

- code made available to us and ported to Risk Engineering VAX

- after the addition of comparable congruent leach model and container failure model, FLOAT is "comparable" to TOSPAC

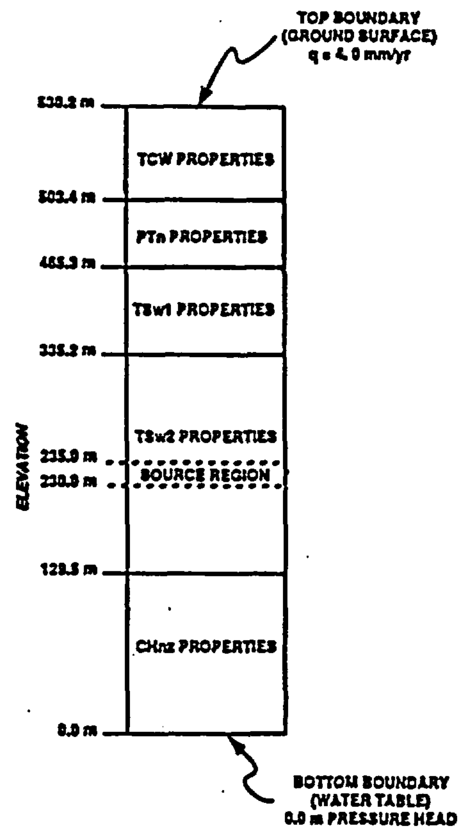
Cross-Verificational Trials

- both codes were utilized on the case discussed earlier

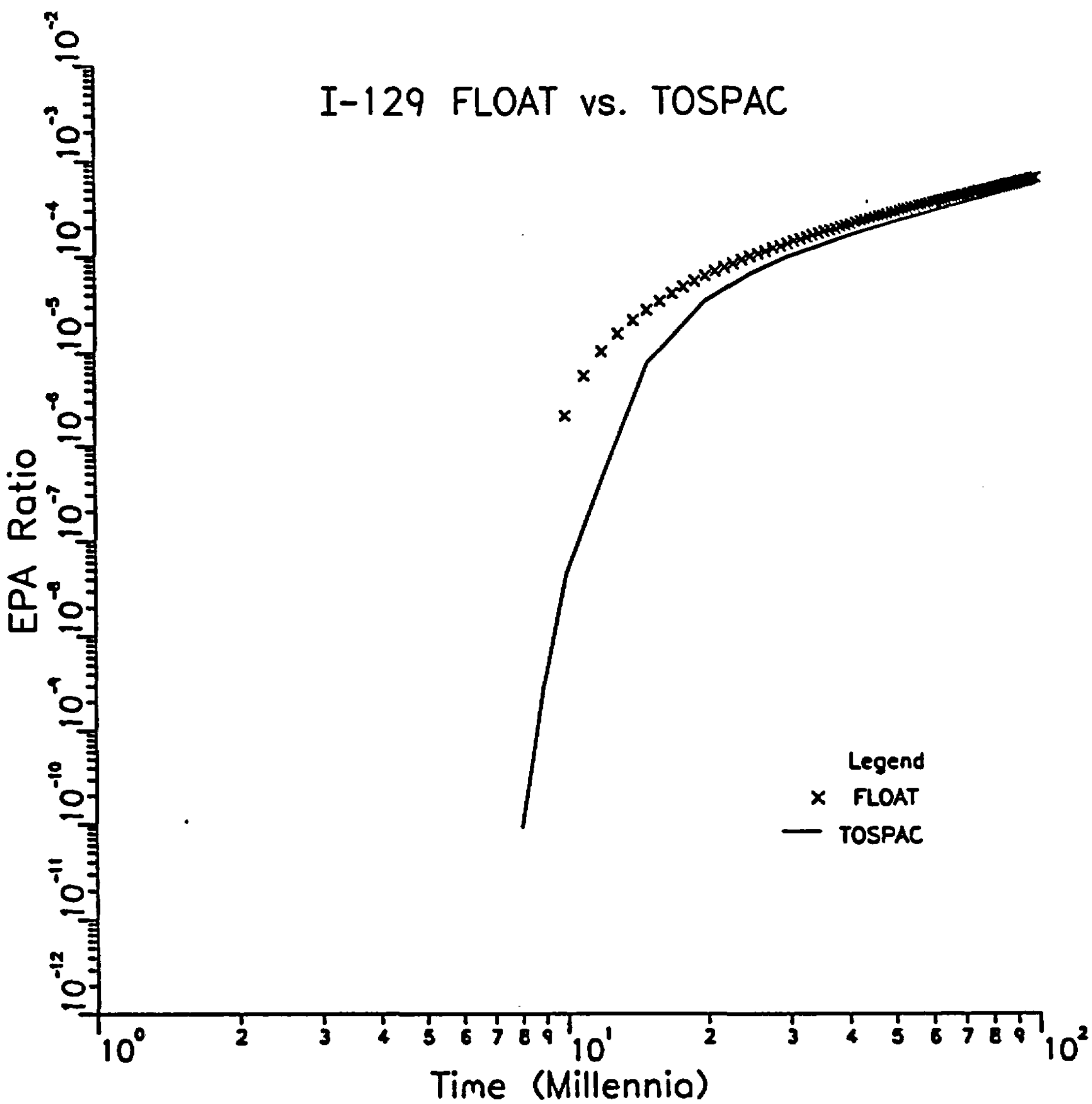
- system only extends to water table

- dispersivity set to 1 m in TOSPAC to reduce the influnce of dispersion

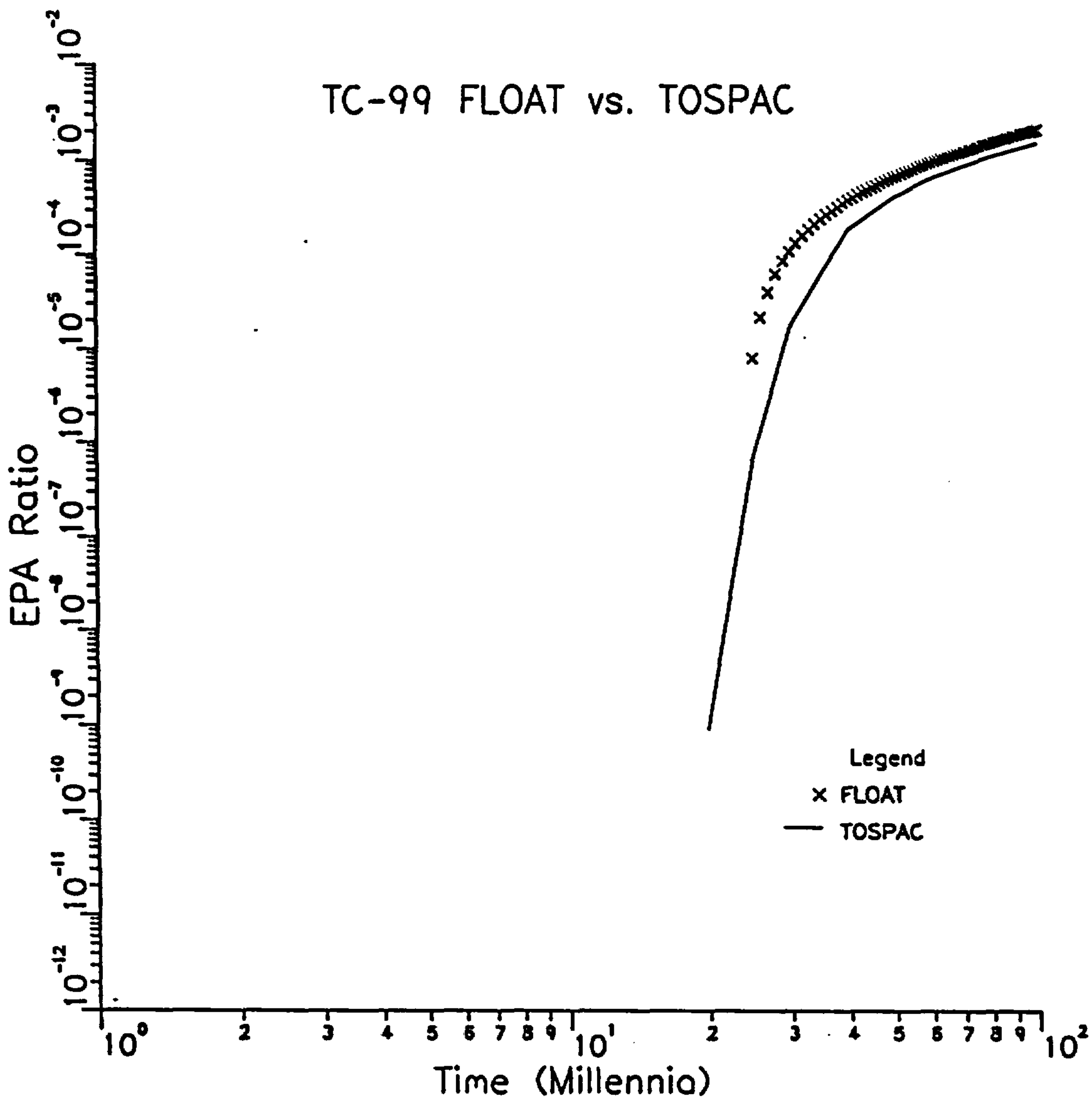
- results plotted as EPA ratio cumulative curies/EPA limit



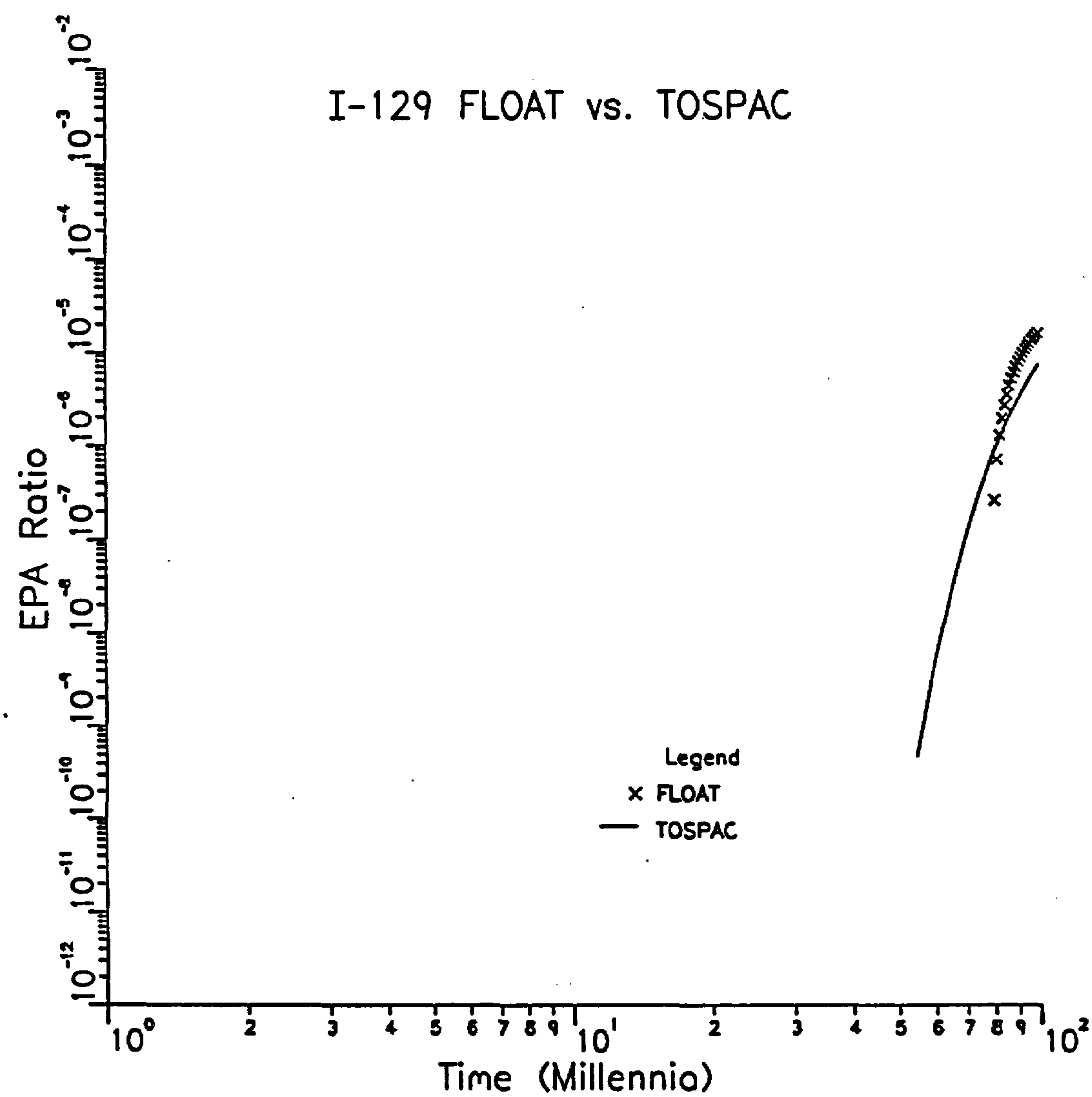
(a) Strong Coupling - Infiltration Rate 4 m/ma



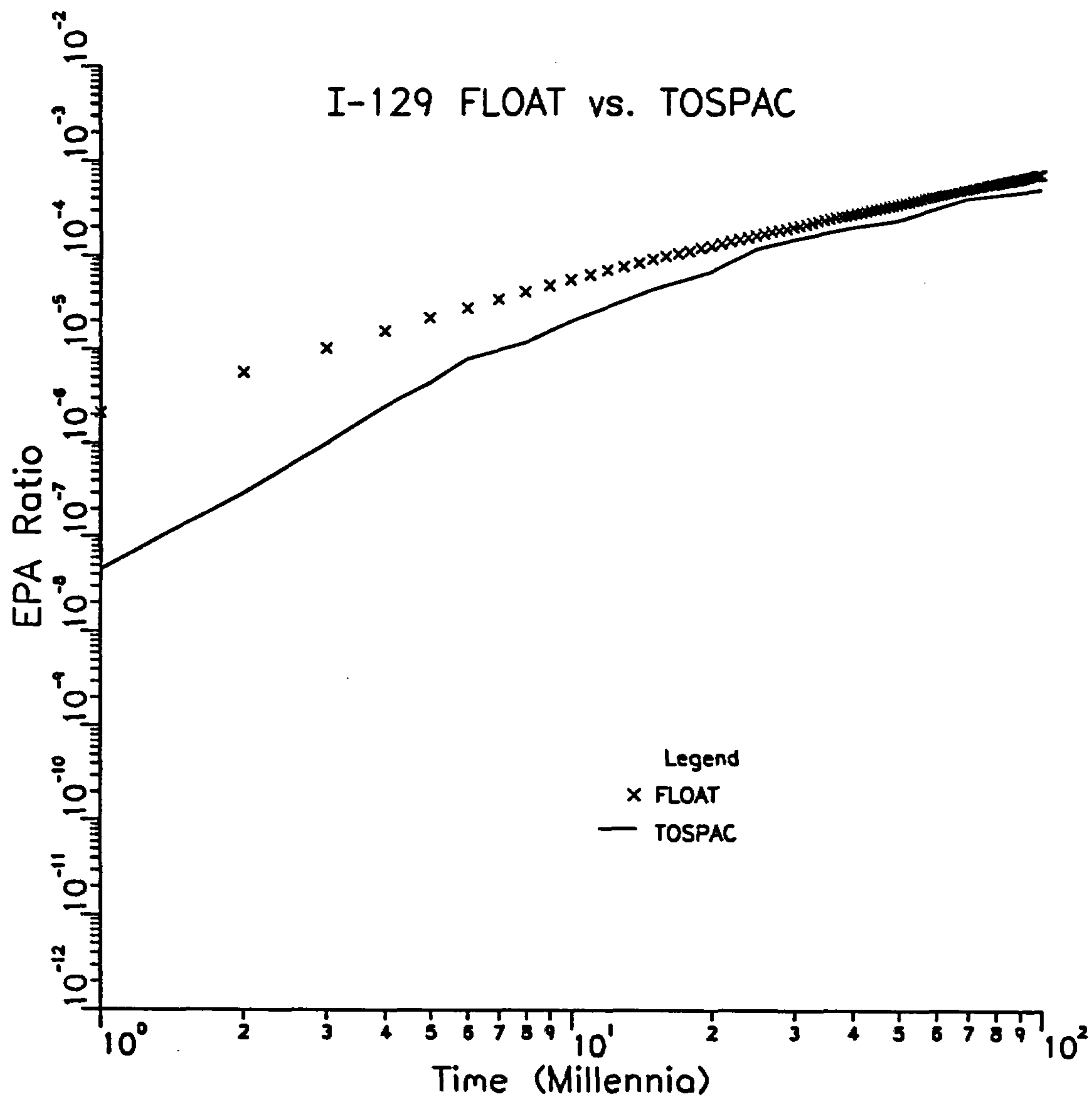
(b) Strong Coupling - Infiltration Rate 4 m/ma



(c) Strong Coupling - Infiltration Rate 0.5 m/ma



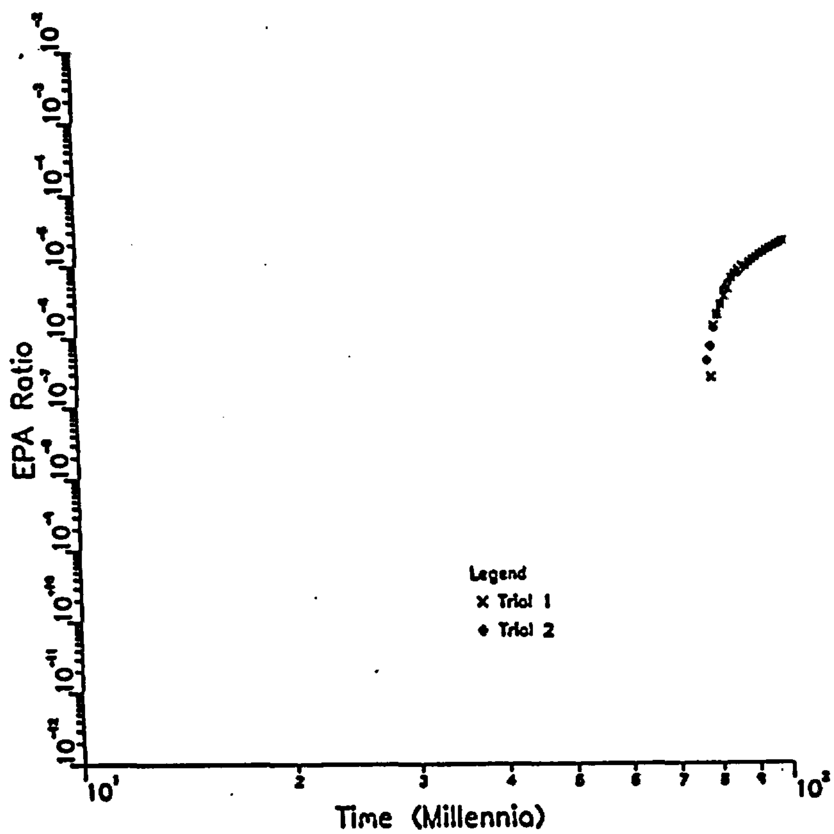
(d) Weak Coupling - Infiltration Rate 4.0 m/ma



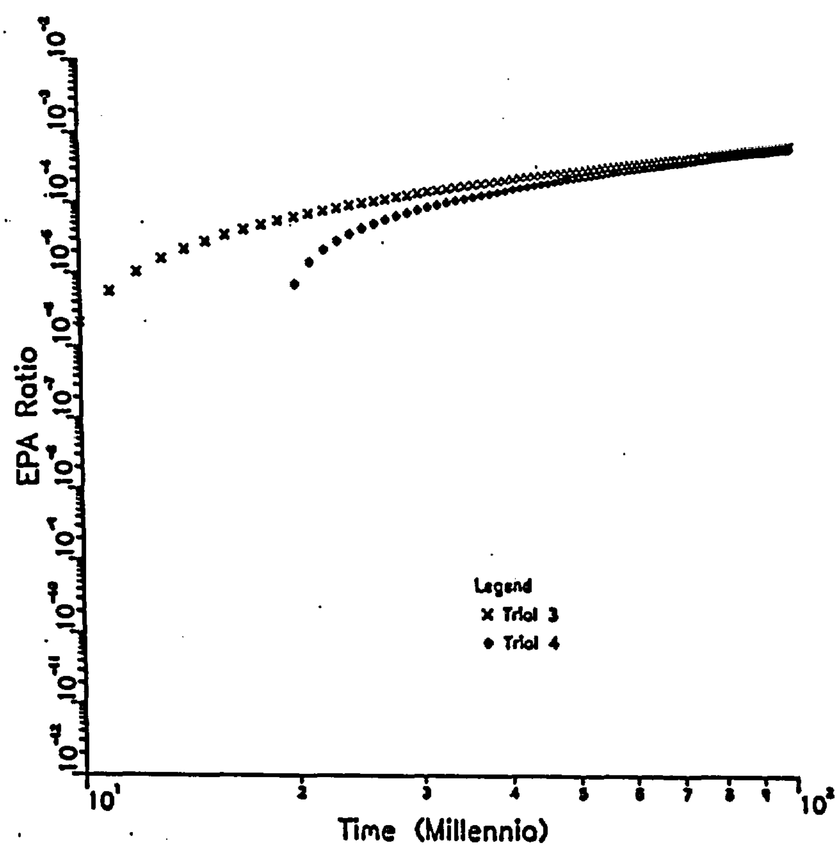
Illustrative Results

- Trials 1 and 2 compare the effects of shallow, fast fracture flow - I_{s1} = 0.1 mm/yr; I_{s2} = 0.55 mm/yr (t >1 ma)

- adjustment time lag (t_{adj}) is 2 ma



- Trials 3 and 4 illustrate how heating - APD of 114 kW/acre with 60 year old fuel may influence performance
- assumes a flux of 4.0 mm/yr and δ heating curve
- with this large flux
  - dyt_2 = 0.0 ma; and dyt_m = max{10 ma, 0 ma}



Alternative Infiltration Scenarios for Yucca Mountain

State of Nevada Sponsored Research

Presented by:
Linda L. Lehman
L. Lehman & Associates, Inc.

To the DOE/NRC Technical Exchange Meeting on Groundwater Flow and Travel Time, Denver CO, Nov. 29 - Dec. 1, 1994

Frequency Analysis

- Linearity - structure controlled
- Frequency and phase shift different on each side of the block
- 2.5 year Deviation from mean average annual rainfall

TABLE I

WATER-LEVEL DATA SET RESULTS

Well #	Period	Phase Shift	Amplitude	r^2	Slope	Cycles
WT-7	1012.2	177.7	0.09	0.47	0.000107	1½ cycle
WT-10	925.4	182.4	0.7	0.22	0.000074	~ 2 cycles
WT-12	1240.0	169.8	0.7	0.35	0.000101	~ 1¼ cycles
WT-1	889.2	249.5	0.1	0.44	.000191	almost 2 cycles
WT-11	887.7	253.4	0.115	0.58	0.000100	~ 1¼ cycles
WT-16	860.6	266.9	0.11	0.68	0.000240	~ 1¼ cycles
WT-6	2975.2	738.1	1.3	0.75	.00323	~ ½ cycle
H-5	1936.8	416.6	0.54	0.45	-0.000044	< ½ cycle
H-5	1888.4	417.9	0.31	0.28	-0.00033	~ ½ cycle

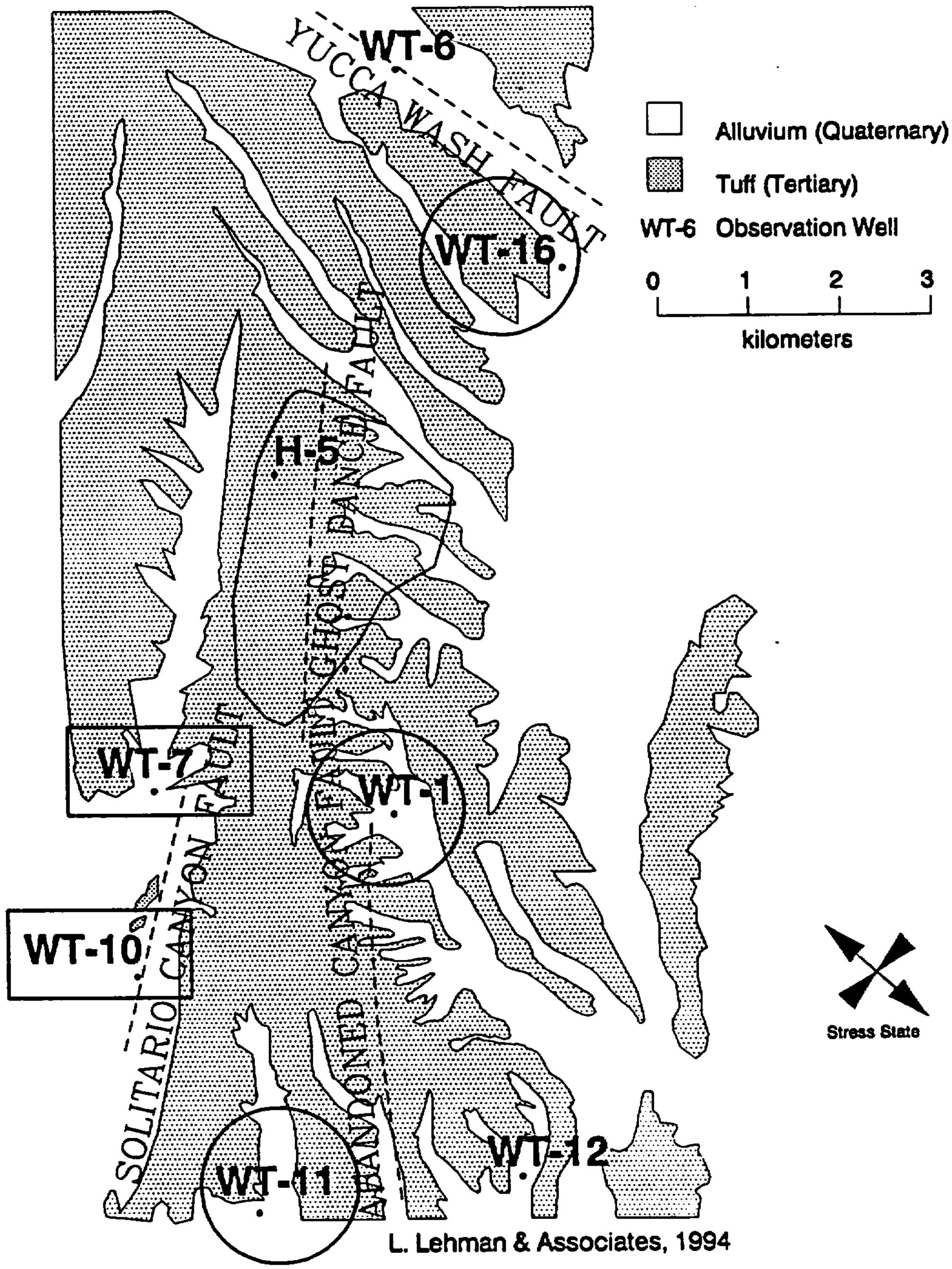
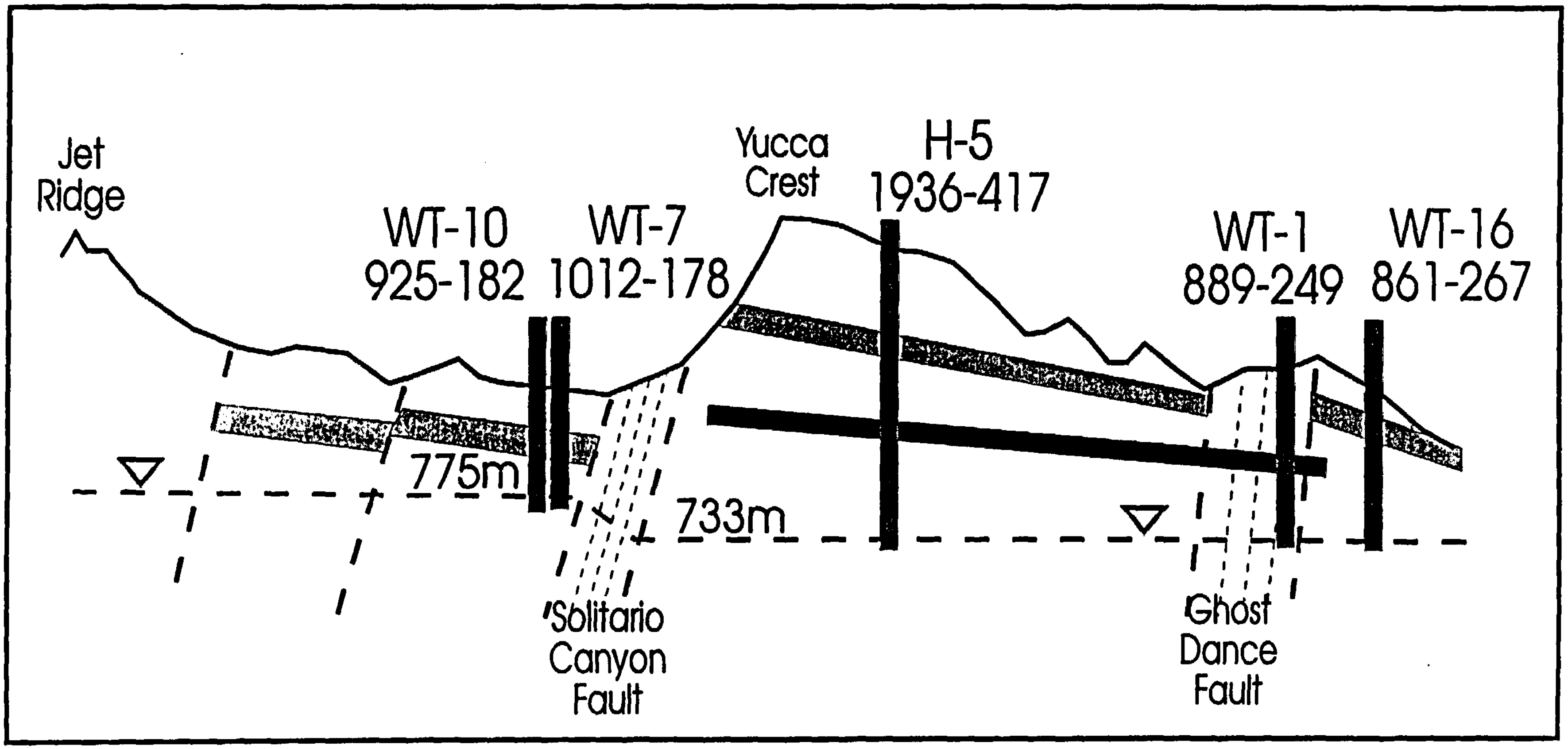


Figure 1. Location of wells that exhibited different fitted periodicity at Yucca Mountain with circles indicating periods of 870 days and squares indicating periods near 1000 days.

Water Level Frequency Analysis



XXX-000

period phase shift
(days)

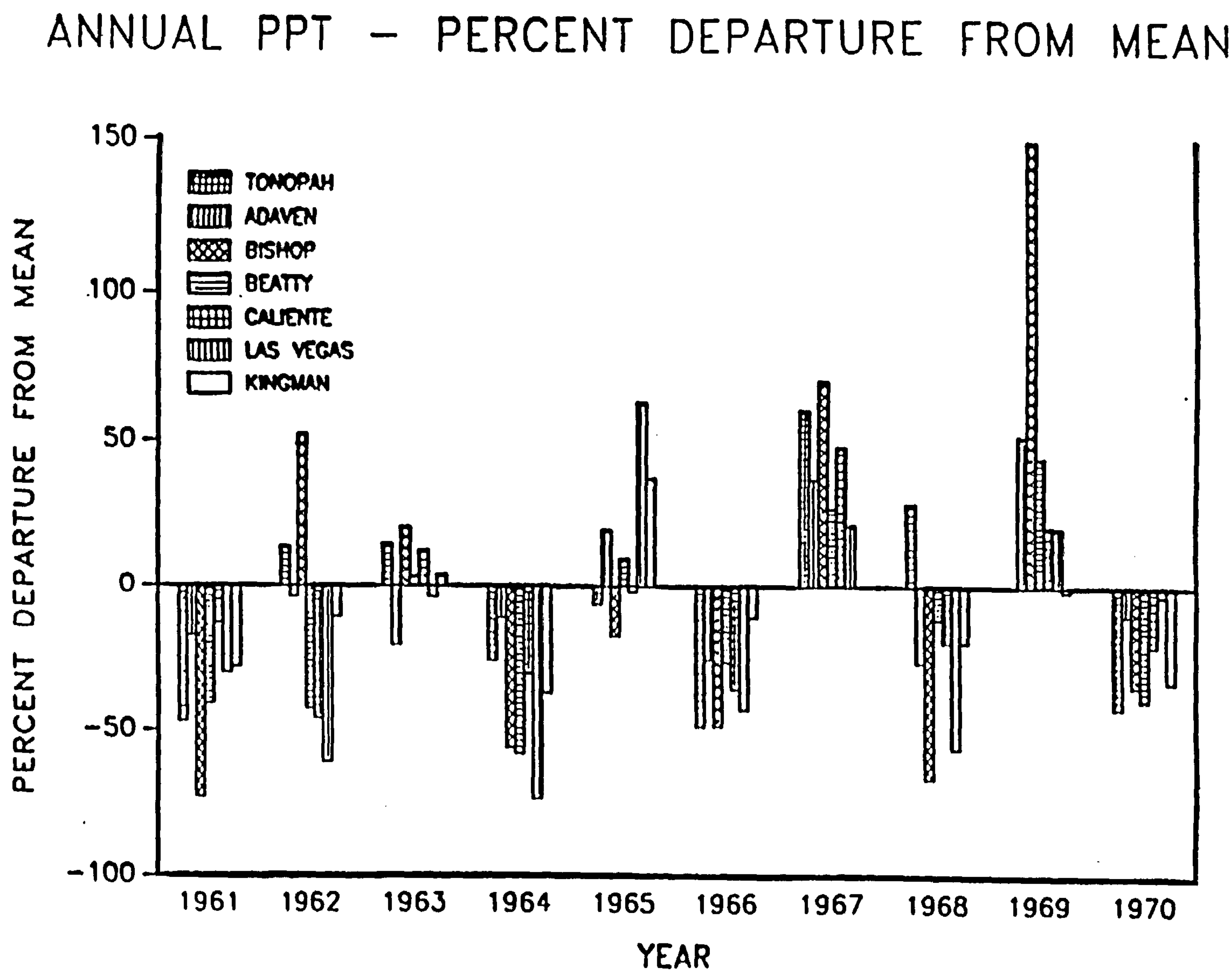
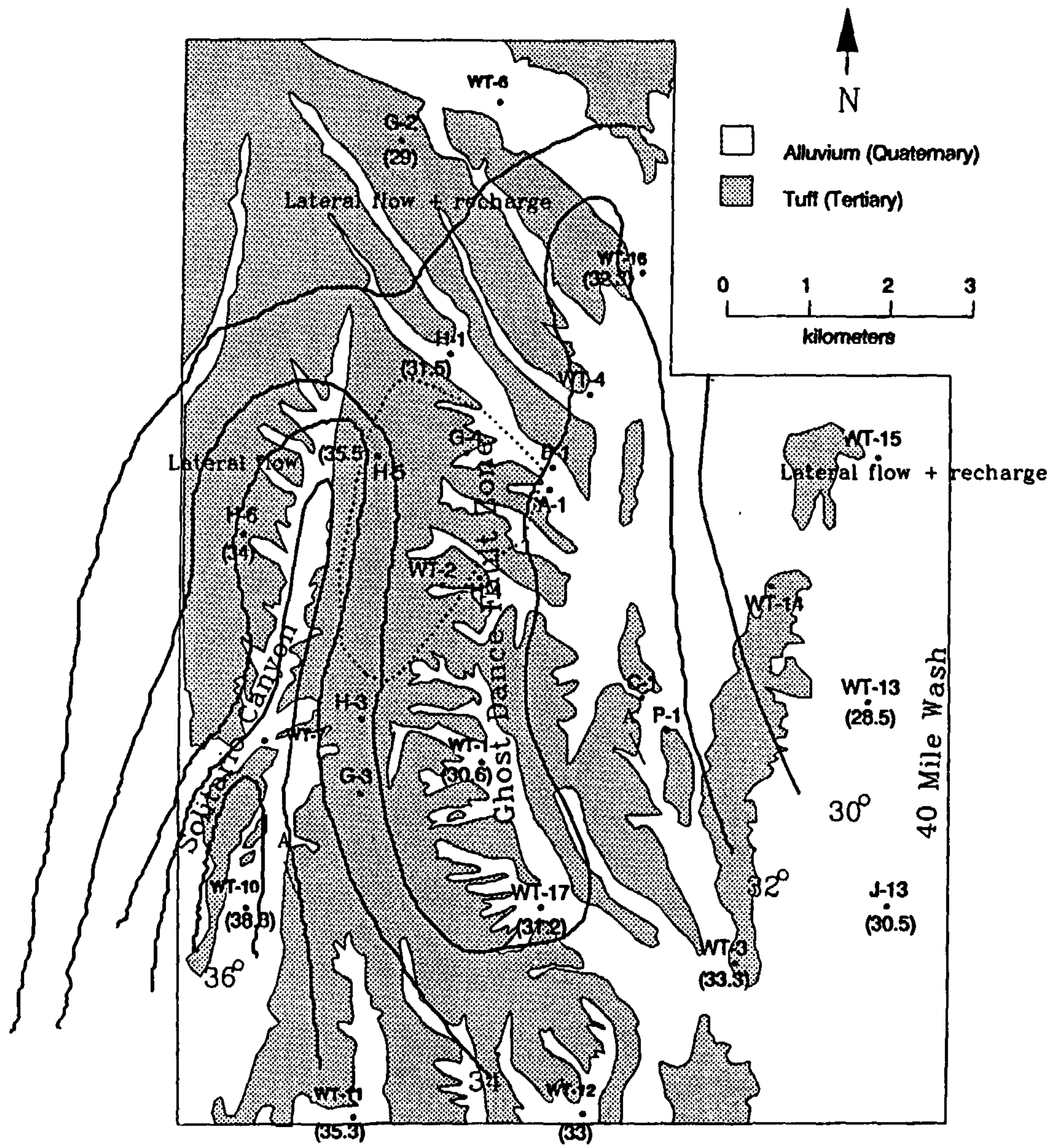


Fig. 5.
Annual Precipitation Totals During Years 1961-1970
From Cochran et al.

Saturated Zone Model

- Highly Structure Controlled and Compartmentalized
- Self Similar
- Interbasin Transfer
- Temperature is a good indicator of pathways
- Accurate potentiometric surface is also an indicator of pathways

Saturated Zone Isotherms



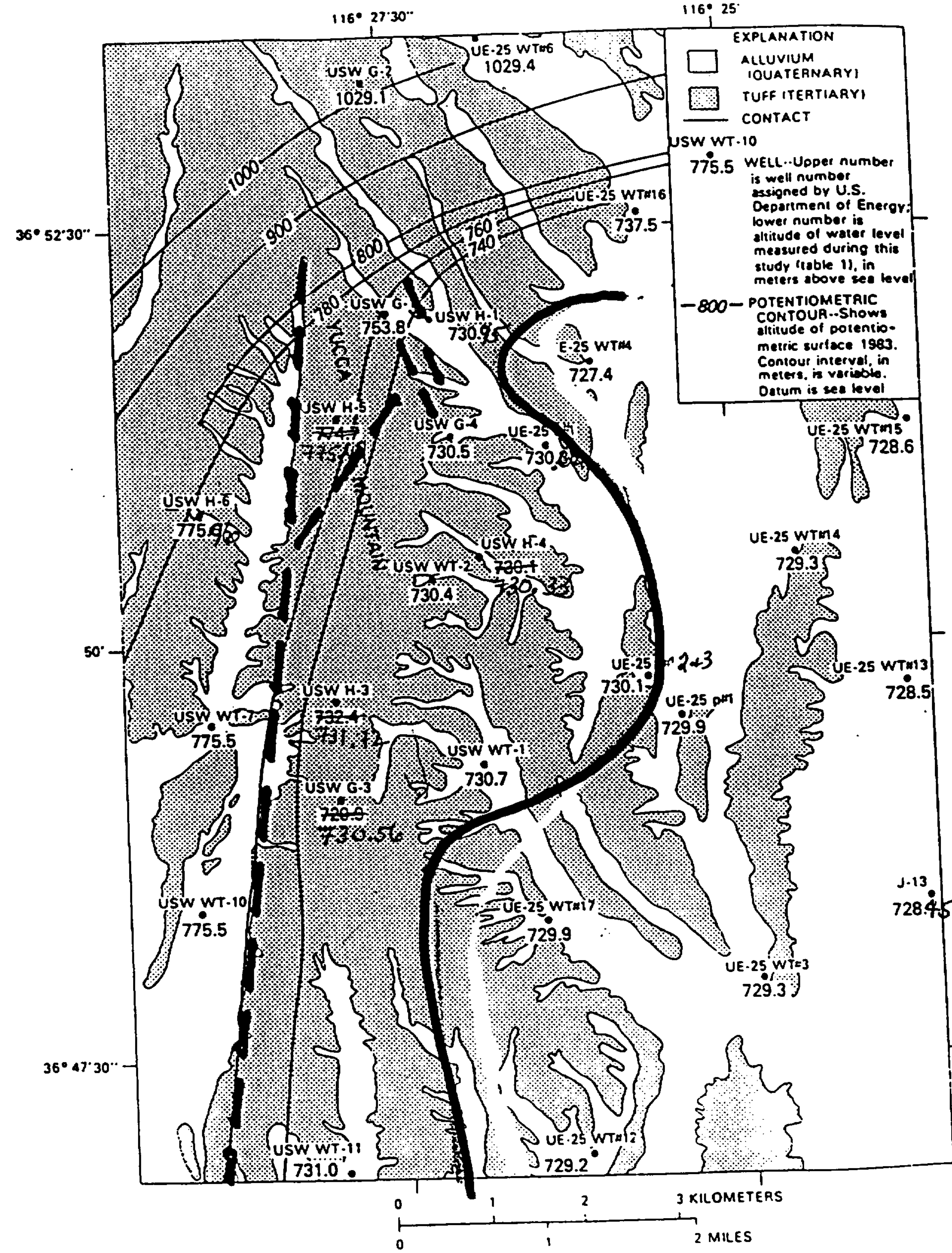


Figure 2.--Preliminary potentiometric-surface map, Yucca Mountain.

unadjusted

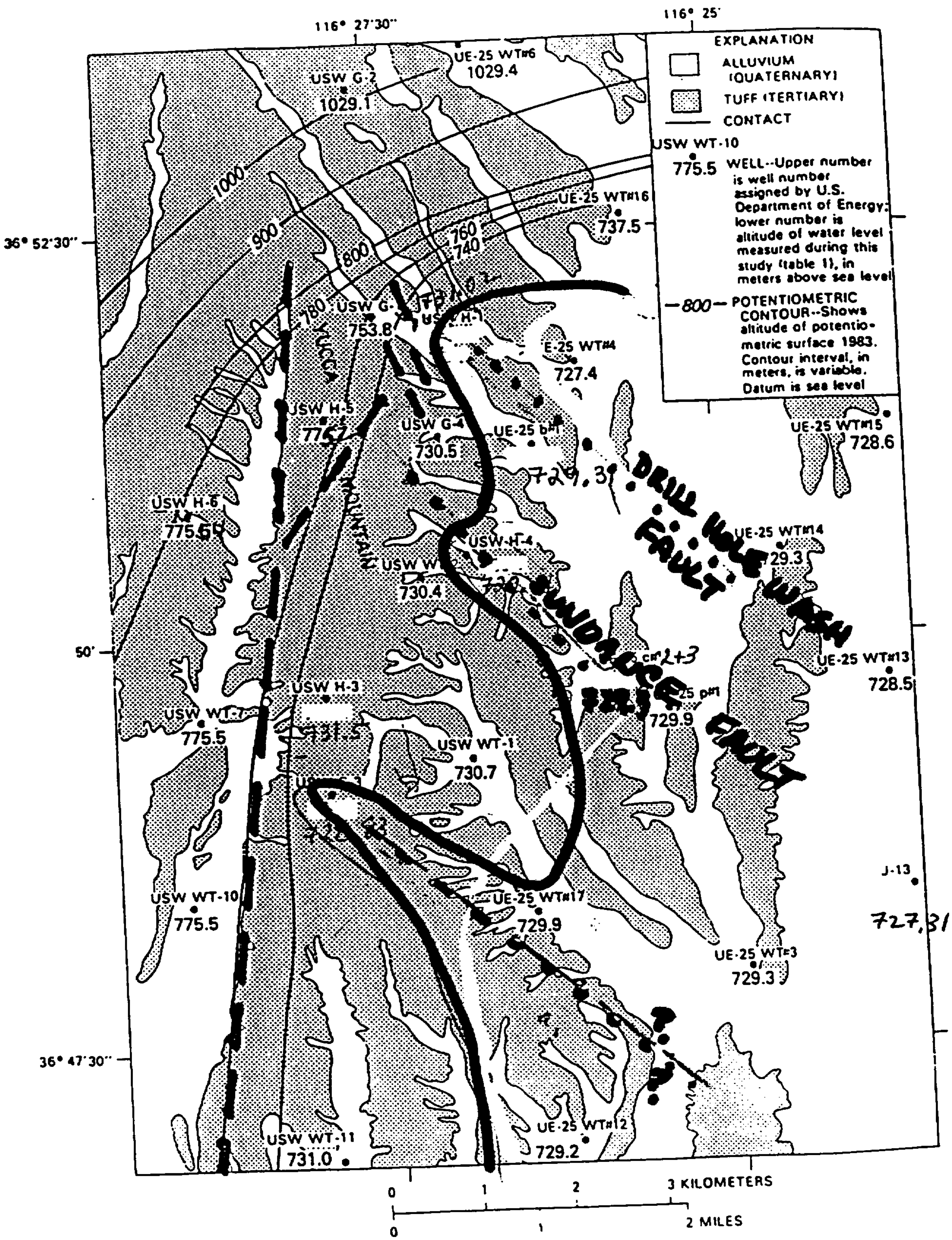
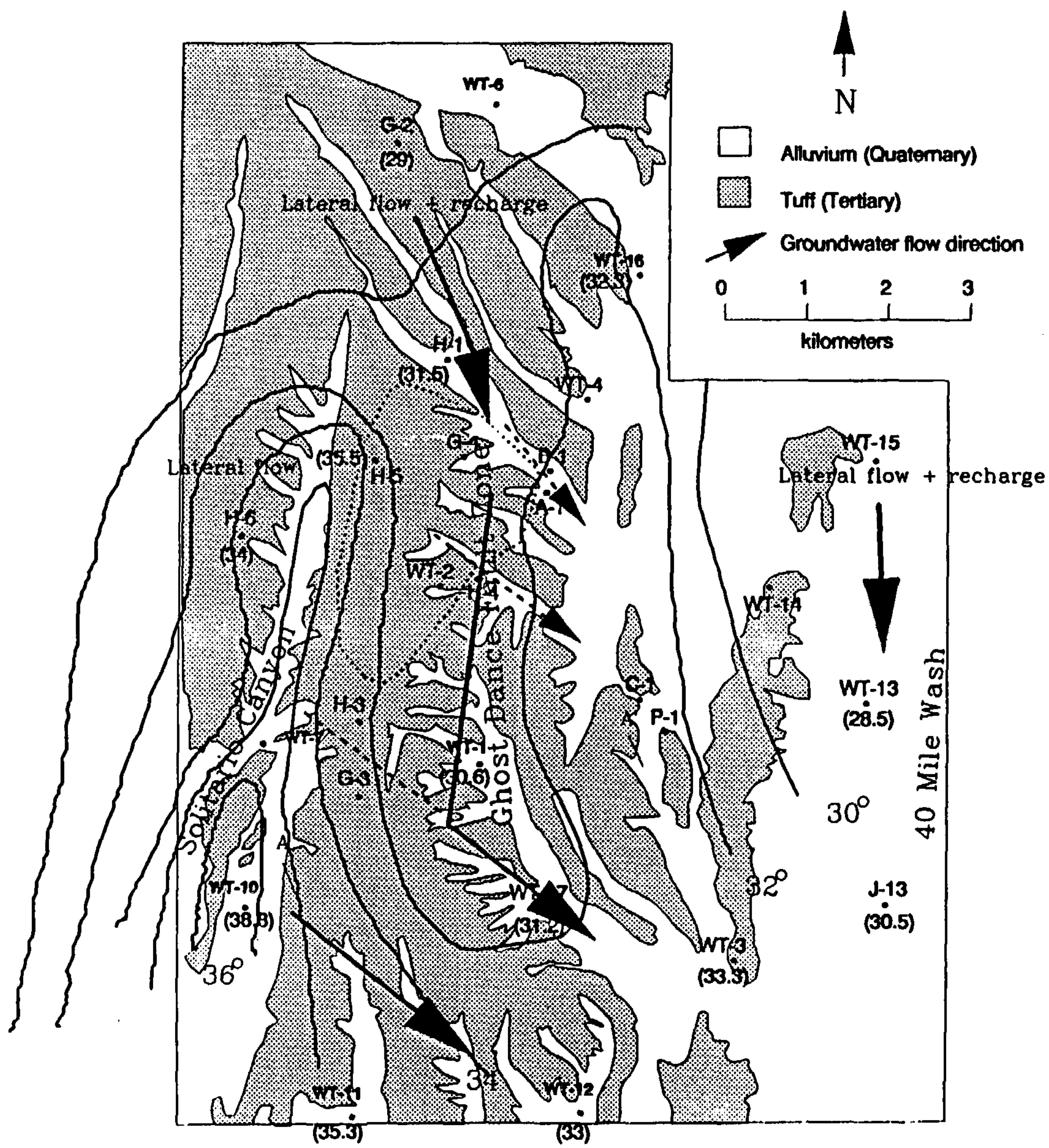


Figure 2.--Preliminary potentiometric-surface map, Yucca Mountain.

adjusted water levels

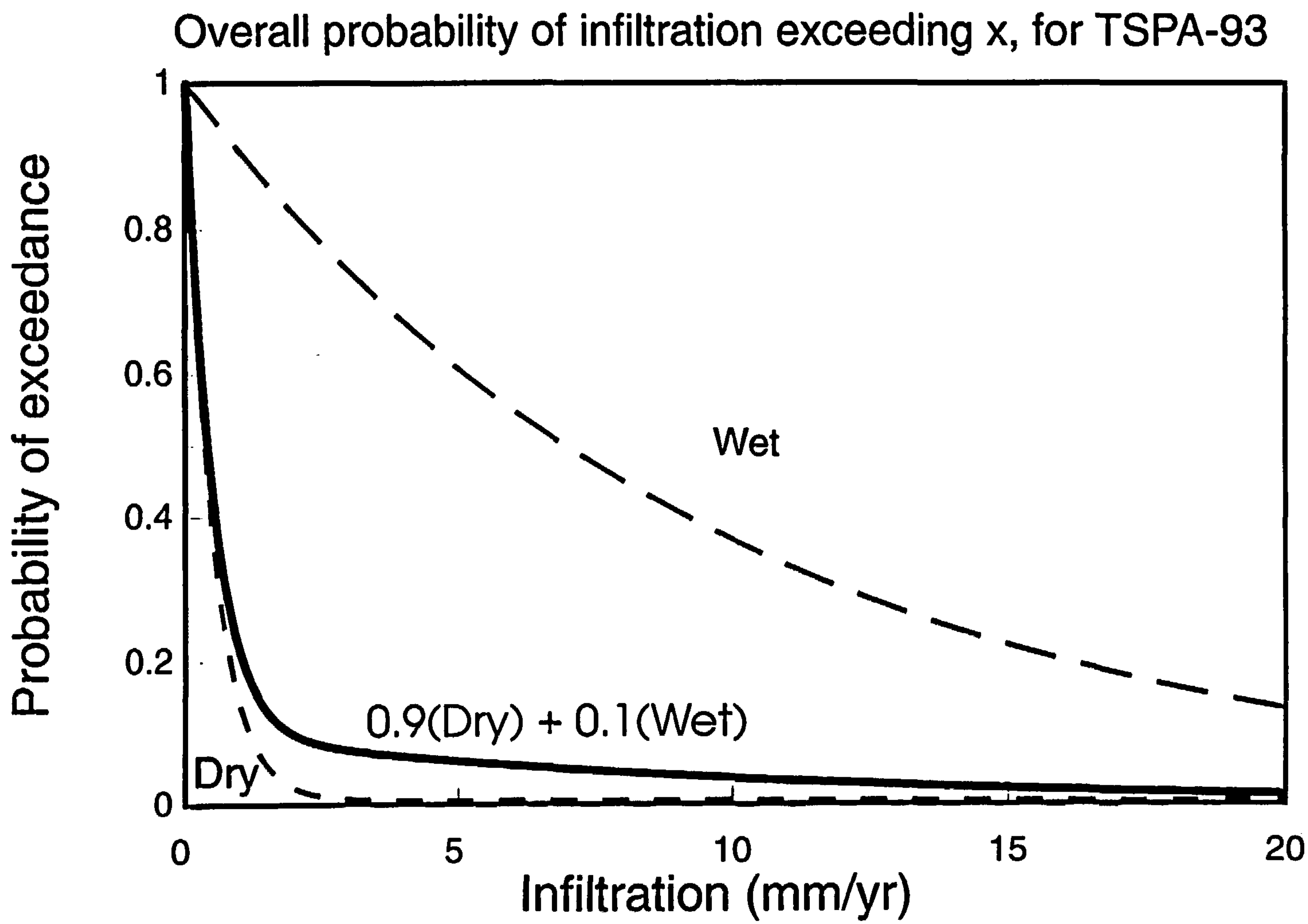
Saturated Zone Conceptual Flow Model



Earthquake Response

Observations

- Extensional Zones Water Table Decreased
- Shear Zones Water Table Increased



Overall probability of infiltration exceeding x, for TSPA-93
Probability of exceedance
1
0.8
0.6
0.4
0.2
0
Wet
0.9(Dry) + 0.1(Wet)
Dry
0
5
10
15
20
Infiltration (mm/yr)

Unsaturated Zone Model

- Rapid Focused Recharge
- Fault Controlled
- Wetter to the West
- Importance of PT_n with Respect to Deep Infiltration

3-D Focused Infiltration Scenario