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NUCLEAR WASTE
DEPARTMENT

Nuclear Waste Technical Review Board
Full Board Meeting

The Unsaturated Zone (UZ) Site-Scale Flow Model and Results of the UZ Expert Elicitation

June 24 and 25, 1997

Las Vegas, Nevada

Bo Bodvarsson

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UZ Model Expert Elicitation:
Net Infiltration: Temporal Issues

Overall Summary

- Infiltration occurs primarily during severe storm events (every 1 to 20 years)
- Essentially no infiltration between these events

Gaylon Campbell

- Severe storm events with intervals of ~10 years
- Essentially no infiltration between these events

Glendon Gee

- Severe storm events with intervals of ~1 year
- Essentially no infiltration between these events

James Mercer

- Episodic storm events with average intervals of about 5 years give rise to most (~80% of infiltration)

Shlomo Neuman

- Extreme storm events lead to infiltration; recurrence interval tied to precipitation record

Karsten Pruess

- Infiltration occurs from few isolated storm events, 1-2 per year.
- Infiltration near zero or negative between these events

Daniel Stephens

- Infiltration occurs during short bursts of severe storm events that have recurrence intervals of 20 years
- Between these events, infiltration occurs, but in low amounts

Edwin Weeks

- Storm event or sequence every few years leads to infiltration event, intervening time essentially no net infiltration
- More severe events with longer recurrence intervals

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UZ Model Expert Elicitation: Net Infiltration: Spatial Issues

Overall Summary

- Map by Flint et al. (1996) generally reasonable in large scale spatial variability
- Expect more infiltration into washes and less at ridgetops
- Several processes neglected by Flint et al. may be important, including runoff lateral flow at alluvium/bedrock contact

Gaylon Campbell
- Agree with basic Flint map and relative importance of various factors
- Horse-tailing faults important

Glendon Gee
- Flint map generally OK, but expect more infiltration at upper reaches of washes
- Funneling of water into faults and fractures (<5% of surface area) is important process

James Mercer
- At lower net infiltration values, Flint map is OK
- At higher values, would expect higher values in washes and lower values on ridge-tops
- Lateral flow within alluvium into fractures is important

Shlomo Neuman
- Expected to be heterogeneous, but Flint map is counter-intuitive; highs expected in washes, lows on ridge tops
- Lateral flow at bedrock-alluvium contact into fractures/faults/ high-permeability paths

Karsten Pruess
- May be nonlinear relationship between amount of infiltration and spatial distribution

Daniel Stephens
- Flint infiltration map is generally OK, but would expect moderate infiltration amounts on ridgetops and high rates in washes
- Underflow at alluvium-bedrock surface is important process

Edwin Weeks
- Net infiltration map would be smoother than Flint's with lower highs on the ridges and higher rates in the washes
- Flow at alluvium bedrock contact into open fractures is important

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UZ Model Expert Elicitation: Lateral Diversion at Top of PTn or Other Interfaces?

Overall Summary

- Lateral flow exists but is limited to tens of meters up to 100m
- Likely places include the PTn, top of TSw and from Solitario Canyon

Gaylon Campbell
- Yes, but no more than few tens of meters at bottom of PTn and top of TSw

Glendon Gee
- Likely, but not on a regional-scale

James Mercer
- Yes, but not much lateral diversion because of faults and irregularities

Shlomo Neuman
- Expect some degree of lateral flow and redistribution at top of PTn and top of TSw; not major
- No evidence for or against lateral flow, so assume vertical

Karsten Pruess
- Yes, but will occur over scales of meters to 100 meters

Daniel Stephens
- Yes, some degree of diversion is likely, although faults and fractures will preclude regional-scale diversion
- Lateral flow from Solitario Canyon may be important contribution to perched water bodies

Edwin Weeks
- Yes, but significant diversion is unlikely

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UZ Model Expert Elicitation: Temporal Behavior of UZ Flow System

Overall Summary

- Episodic infiltration events
- PTn dampens most pulses
- Fast flow component is not dampened by PTn

Gaylon Campbell

- Episodic infiltration events; dampening of pulsed flow at PTn; essentially steady-state below PTn (except fast-flow component)

Glendon Gee

- Episodic infiltration events lead to pulse of water that can reach depth quickly, as evidenced by Cl

James Mercer

- Transient pulse related to infiltration is significantly dampened as it moves through system; fast-flow component is unaffected

Shlomo Neuman

- Transient pulse dampened in PTn

Karsten Pruess

- Episodic pulses can flow through system
- Pulses dampened as they pass through PTn and other layers with different hydraulic properties
- System may not be steady state

Daniel Stephens

- Fast-flow component is years to tens of years; fracture component travel times are ~thousands of years; matrix component ~hundreds of thousands of years

Edwin Weeks

- Transient pulse moves through system with little matrix interaction
- At high percolation fluxes, a significant fraction may occur in fractures as pulses following extreme precipitation events

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UZ Model Expert Elicitation:
Method(s) Used to Estimate Percolation Flux at Repository Horizon

Overall Summary

- Net infiltration mostly
- Saturation and water potentials within PTn
- Temperature gradients
- Chemicals such as total chloride and ^{14}C
- Perched water

Gaylon Campbell
Relative weights:
Net Infiltration/sfc water balance (0.3); Cl (0.3); Flux through PTn (0.2); Convection heat flux (0.05); Radiocarbon decay (0.05); Mineral coatings (0.05); Perched water (0.05)

Glendon Gee
- Net infiltration, checked with water potentials and isotopic evidence

James Mercer
- Net infiltration, checked with chloride mass balance, temperature gradients, and perched water

Shlomo Neuman
- Saturations and water potentials within PTn, supplemented by isotopic evidence and ESF moisture balance

Karsten Pruess
- Net infiltration

Daniel Stephens
- Net infiltration

Edwin Weeks
- Temperature gradients
- Radiocarbon gas
- Perched water

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UZ Model Expert Elicitation: Percolation Flux Estimate: Temporal and Spatial Average

Overall Summary

- Mean: 10.3 mm/yr
- Median: 7.2 mm/yr
- 5th percentile: 1.0 mm/yr
- 95th percentile: 30.0 mm/yr

Gaylon Campbell

Mean:	5.3 mm/yr
Median:	4 mm/yr
5th:	1 mm/yr
95th:	14 mm/yr

Based on net infiltration, Cl, and flux through PTn

Glendon Gee

- Same spatial and temporal average as net infiltration

James Mercer

- Same spatial and temporal average as net infiltration

Shlomo Neuman

Mean:	21.1 mm/yr
Median:	17 mm/yr
5th:	6 mm/yr
95th:	50 mm/yr

Karsten Pruess

- Same spatial and temporal average as net infiltration

Daniel Stephens

- Same spatial and temporal average as net infiltration
- Lateral input from Solitario Canyon to TSw is probably minor

Edwin Weeks

Mean:	7.4 mm/yr
Median:	6 mm/yr
5th:	1 mm/yr
95th:	22 mm/yr

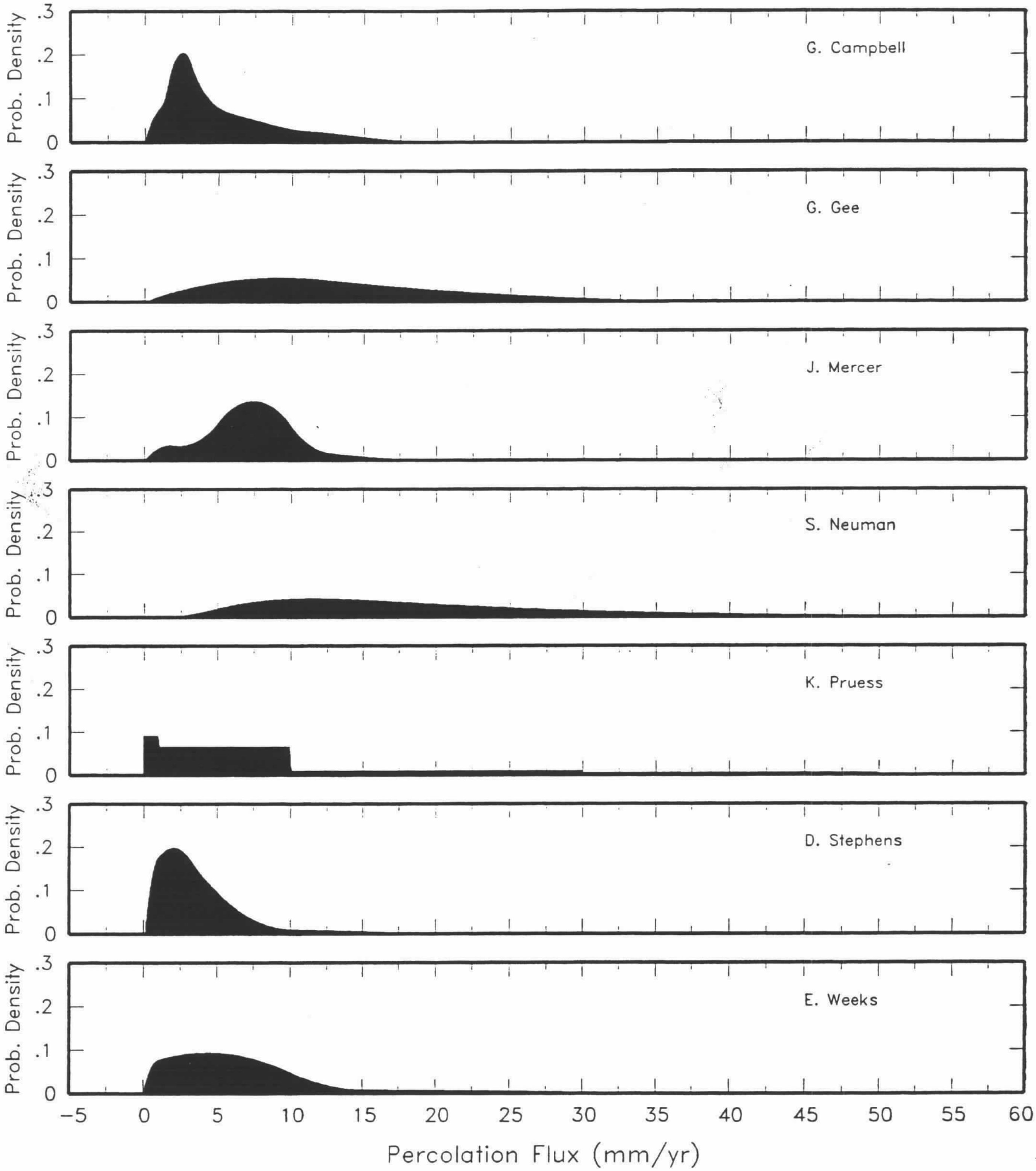

Figure 3-2a Probability density distributions for percolation flux at the repository level defined by the seven experts.

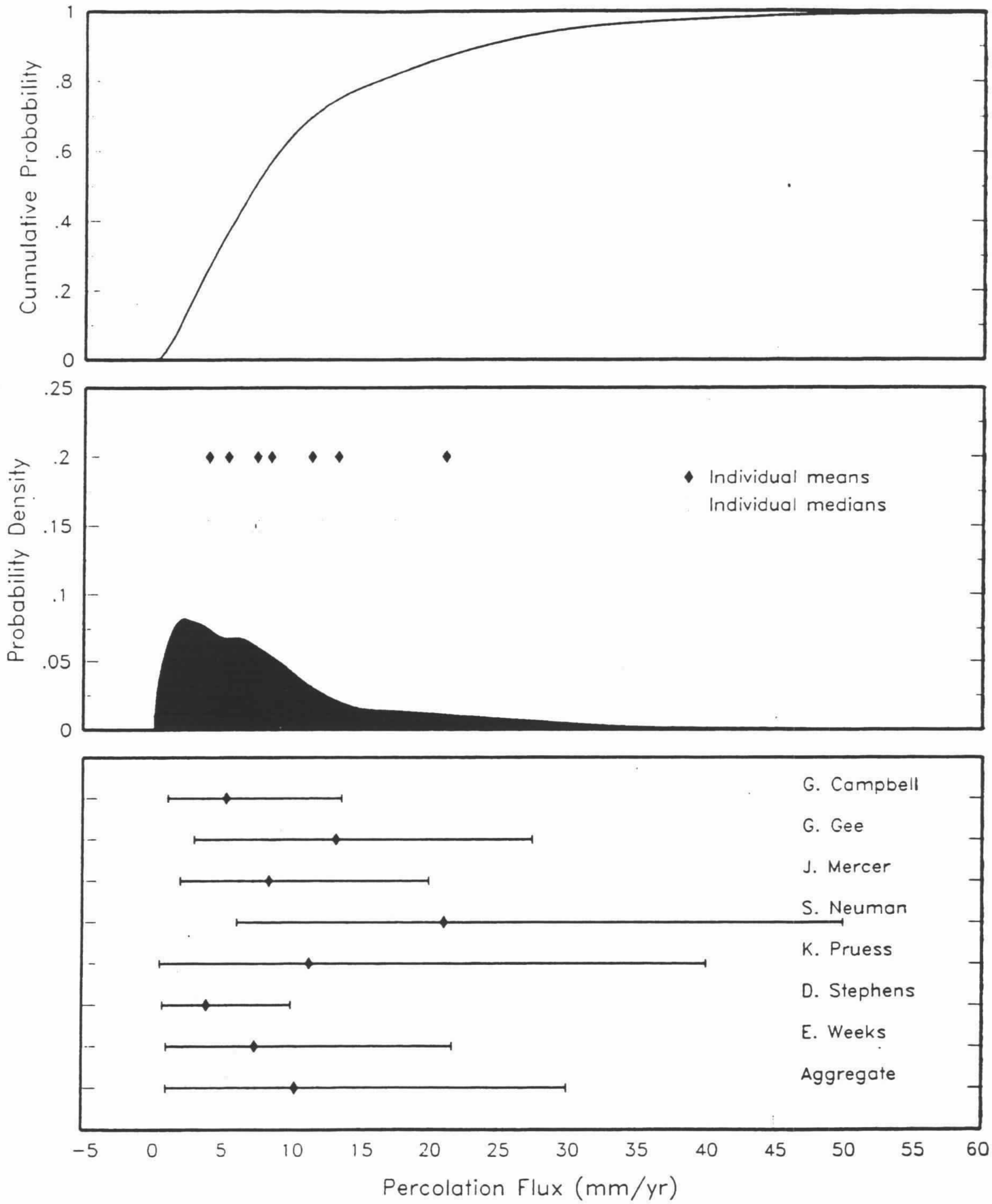

Figure 3-2b Summary of the UZFM elicitation results. Top plot: aggregate cumulative probability distribution for percolation flux across the seven expert panel members. Middle plot: corresponding probability density function for the aggregate probability distribution. Also shown are the mean and median values for the individual expert's distributions. Bottom plot: median, mean, and 5^{th} to 95^{th} percentile range for the seven individual expert's distributions and the aggregate distribution.

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UZ Model Expert Elicitation:

Percolation Flux: Spatial Issues

Overall Summary

- Generally the same as the infiltration map, but smoother
- As predicted by LBNL model results
- Some heterogeneities in flow may develop with depth

Gaylon Campbell

- Generally same as net infiltration map, but smoother
- As predicted by LBNL model results

Glendon Gee

- Generally same as net infiltration map

James Mercer

- More uniform distribution than infiltration, because of diffusion into TSw fracture network (which contains ubiquitous fractures)

Shlomo Neuman

- Should generally correlate with infiltration map, but local lateral flow, medium heterogeneities and fast-flow channels will modify

Karsten Pruess

- Not known; may be similar to net infiltration map; or heterogeneities may develop new variability

Daniel Stephens

- Generally same as infiltration map (highs and lows generally the same locations)
- Superimposed are local highs as faults and fractures

Edwin Weeks

- Map expected to be subdued replica of net infiltration map

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UZ Model Expert Elicitation:
Components of Flux in TSw: Fractures versus Matrix

Overall Summary

- Fractures carry bulk of flow, or about 90%
- Matrix carries about 10% of the flux

Gaylon Campbell
- Fractures (95% of flux) Matrix (5%)

Glendon Gee
- 90% of flux in faults/fracture
- 2-3 mm/yr occurs in matrix

James Mercer
- Most (~90%) of flux is in fracture network of TSw

Shlomo Neuman
- Maximum flux in matrix is 1.5 mm/yr; therefore, at 17 mm/yr total flux, ratio of matrix to fracture is 10% to 90%

Karsten Pruess
- Matrix conductivity is about 0.3 mm/yr; rest is in fractures
- Slow component in both fractures and matrix

Daniel Stephens
- Partitioning is uncertain (10% to 70% in fractures based on UZ model, depending on total flux); possibly most of total flux is in matrix

Edwin Weeks
- Matrix can carry 1 mm/yr, rest is in fractures
- Small percentage (1%-10%) of total fractures are accommodating flux

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UZ Model Expert Elicitation:

Components of Flux in TSw: Fast Flow versus Total Fux

- Fast flow is only 1% or so
- Fast Flow May Occur in many fractures

Gaylon Campbell

- Fast flow component is <1% of total flux

Glendon Gee

- ~5% of area is faults and fractures
- Some fractures accommodate fast flow (~150-200 mm/yr)

James Mercer

- Not sure of volume that fast-flow component represents; would trust results of LBNL model

Shlomo Neuman

- Fast flow component is small part of total flux
- Area of ESF with fast paths is 0.03-2% of total area (19-1200 m^2 out of 64,000 m^2 of tunnel)

Karsten Pruess

- ^{36}Cl is localized, thus only a small number of fractures could be carrying fast-flow component

Daniel Stephens

- Fast-flow component is small % of total flux

Edwin Weeks

- Fractures and ^{36}Cl are ubiquitous, suggesting fast-flow occurs over many fractures
- Not sure of flux represented by fast flow component

UZ Model Expert Elicitation:
Seepage into the Drifts

Overall Summary

- Mixed opinion
- Water flow in fractures will enter drifts
- Matrix component will go around drifts
- Some believe no water will enter drifts
- Area with seeps is small or 1 to 10%

Gaylon Campbell

- Not sure under ambient conditions
- Avoid by providing a small amount of ventilation

Glendon Gee

- Very unlikely based on available data, consistent with absence of seeps in ESF, even in Faults

James Mercer

- Expect seepage into drift due to film flow along wall of drift; weeps are believed to be ubiquitous, as evidenced by Cl found everywhere

Shlomo Neuman

- Full saturation not needed for seeps, therefore percent of area with seeps will be less than area with fast paths (see above)

Karsten Pruess

- Slight negative matric potential should stop matrix component; fracture component will enter drift

Daniel Stephens

- Will occur only at fractures, not matrix
- A very small part of total area (<1%) will occupy seeps

Edwin Weeks

- Matrix component will go around drifts
- Most of fracture component will enter drift
- Small percentage of fractures carry flux, location unpredictable

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UZ Model Expert Elicitation:
Modeling Issues: Infiltration

Overall Summary

- 1-d modeling is limited as it neglects runoff and lateral flow
- Bucket model may not be adequate
- Need mass balance model for infiltration

Gaylon Campbell
- 1-d finite difference model for net infiltration is OK

Glendon Gee
- 1-d infiltration modeling doesn't adequately address runoff
- Need mass balance model for infiltration
- Neutron probe data do not capture episodic nature of storm events

James Mercer
- Transient component of flow should be included

Shlomo Neuman
- One-dimensional modeling is not capable of incorporating lateral flow at bedrock-alluvium contact

Karsten Pruess

Daniel Stephens
- No confidence in Bucket model for infiltration; Maxey-Eakin not satisfactory for points within a watershed

Edwin Weeks

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UZ Model Expert Elicitation:
UZ Modeling Issues

Overall Summary

- Dual-K model needed above PTn, ECM model adequate below that
- Fast-paths need to be modeled, and more faults added and the sensitivity evaluated
- Transient component of flow needs to be modeled
- Investigate alternative models to the continuum models, e.g. Weeps model
- Model mass balance of perched water and water table fluctuation
- Predictability of which fracture flow should be modeled as random
- Perform uncertainty and error analysis of heat flux and temperature data

Gaylon Campbell
- Dual-K needed through PTn; ECM probably OK below PTn
- Fast paths need to be represented
- Add faults and test sensitivity
- Upscaling should reasonably match measured matrix properties

Glendon Gee

James Mercer
- Dual-K above PTn, ECM probably OK below, as long as fast-flow component included
- Fast-flow component in PTn probably requires faults modeled in this unit
- Expect little fracture matrix interaction in TSw

Shlomo Neuman
- Uncertainty and error analyses of heat flux estimates and measured temperature profiles should be conducted

Karsten Pruess
- A WEEPs-type model embedded in a more complex model may be way to portray fast-flow component
- Continuum description of flow assumes volume-averaging and may miss much of localized flow volume
- Role of faults is not understood; may not be need in PTn

Daniel Stephens
- Perched water balance and overall water balance including water table fluctuations should be modeled
- TOUGH2 modeling should predict key observations such as the wet spot in ESF at station 75+00

Edwin Weeks
- Transient pulse through PTn and deeper in section with little matrix interaction
- Episodic pulse, not steady state
- Predictability of which fractures in TSw will carry flow should be modeled as random

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UZ Model Expert Elicitation: Additional Data Collection/Future Work

Overall Summary

- Collect water potential, water content and hydrologic property measurements in ESF
- Unsaturated conductivity measurement are a high priority
- Collect data on surface water balance
- Inject water above sealed room in the ESF to test for seepage
- Run UZ model to examine effects of higher infiltration patterns; do many "what-if" studies
- Analyze pump test data for perched water bodies to determine drainable porosity

Gaylon Campbell
- Water potential, water content, hydraulic properties measurements in situ in ESF
- Unsaturated conductivity measurements should be high priority
- Sfc water balance info, plant uptake, rock cover on slopes, snow, washes, rock-alluvium contact

Glendon Gee
- Mass balance using drip line source above ESF and pan
- Inject water above sealed-off room of ESF to test for seepage
- Perform non-linear fit to temperature data to see if profiles show curvature

James Mercer
- Run UZ model to examine the effect of higher infiltrations
- Evaluate effect of more infiltration in washes

Shlomo Neuman
- Extract from pumping test data in perched water bodies, information about the drainable porosity of the fracture system

Karsten Pruess
- Monitoring and data collection related to net infiltration should continue

Daniel Stephens
- Thoroughly study and instrument small drainage basin above repository
- More unsaturated hydraulic conductivity measurements
- More accurate measurements of water potentials in PTn
- Infiltration study of Solitario Canyon

Edwin Weeks
- Large-scale experiments in the ESF; install plastic sheets on roof and walls and monitor water inflow
- Obtain temperature logs with measurements at close intervals

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UZ Model Expert Elicitation: Additional Data Collection/Future Work

Overall Summary cont.

- Continue infiltration studies
- Thorough study of small drainage basin above the repository
- More accurate measurements of water potential in the PTn
- Infiltration study of the Solitario Canyon area
- Develop hydrographs of perched water
- Perform large-scale experiments in ESF with plastic sheets to investigate inflow
- Obtain more detailed temperature logs

Gaylon Campbell

- Water potential, water content, hydraulic properties measurements in situ in ESF
- Unsaturated conductivity measurements should be high priority
- Sfc water balance info, plant uptake, rock cover on slopes, snow, washes, rock-alluvium contact

Glendon Gee

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- Large-scale experiments in the ESF; install plastic sheets on roof and walls and monitor water inflow
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UZ Model Expert Elicitation

Recommendation	Action
LBNL develop a surface hydrology module for TOUGH2	Preliminary module developed during Elicitation; tested on a 2.0 cross section in Wren Wash; full evaluation in FY98 planning
Dual-K model needed above Ptn, ECM model adequate below that	UZ model has dual-K model throughout entire unsaturated zone
Fast-paths need to be modeled, and more faults added and the sensitivity evaluated	UZ model matches bomb-pulse Cl-36 data; we have added more faults
Transient component of flow needs to be modeled	We have performed sensitivity studies of transient flow
Investigate alternative models to the continuum models, e.g. Weeps model	A new activity of alternative models has been incorporated into FY98 planning
Model mass balance of perched water and water table fluctuation	Perched water mass balance is included in FY97 report
Predictability of which fracture flow should be modeled as random	Currently fracture flow is modeled using dual K continuum with all or some random fractures flowing
Perform uncertainty and error analysis of heat flux and temperature data	We have developed an analytical model for the evaluation of temperature data, that allows for uncertainty and error analysis
Run UZ model to examine effects of higher infiltration; do many "what-if" studies	We have performed some studies and the results suggest that UZ model becomes inconsistent with observed data for average percolation flux rates exceeding 20mm/yr

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UZ Model Expert Elicitation:
Components of Flux in TSw: Fast Flow versus Total Flux

- Fast flow is only 1% or so
- Fast Flow May Occur in many fractures

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- ~5% of area is faults and fractures
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Edwin Weeks
- Fractures and ^{36}Cl are ubiquitous, suggesting fast-flow occurs over many fractures
- Not sure of flux represented by fast flow component

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UZ Model Expert Elicitation: Lateral Diversion at Top of PTn or Other Interfaces?

Overall Summary

- Lateral flow exists but is limited to tens of meters up to 100m
- Likely places include the PTn, top of TSw and from Solitario Canyon

Gaylon Campbell
- Yes, but no more than few tens of meters at bottom of PTn and top of TSw

Glendon Gee
- Likely, but not on a regional-scale

James Mercer
- Yes, but not much lateral diversion because of faults and irregularities

Shlomo Neuman
- Expect some degree of lateral flow and redistribution at top of PTn and top of TSw; not major
- No evidence for or against lateral flow, so assume vertical

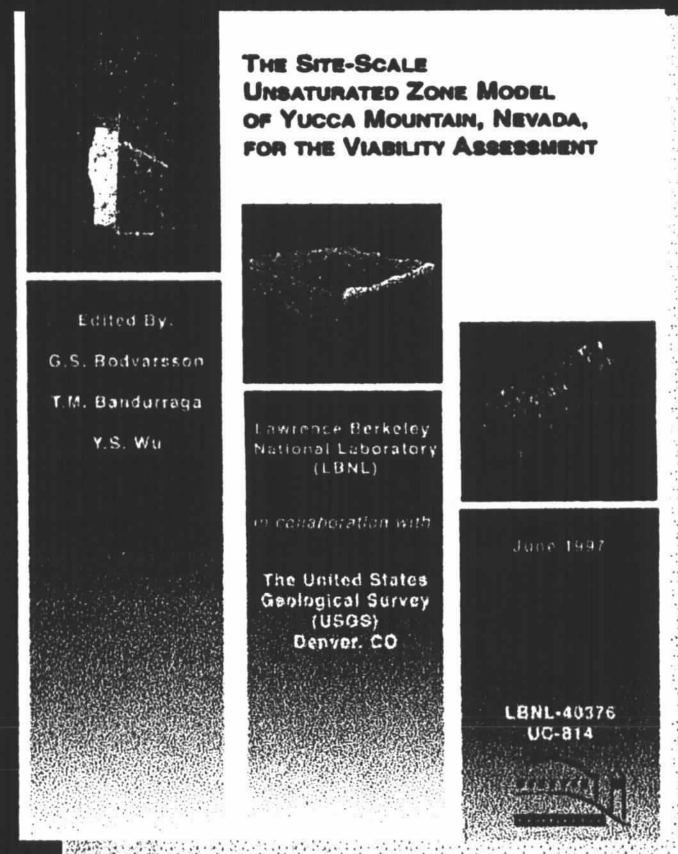
Karsten Pruess
- Yes, but will occur over scales of meters to 100 meters

Daniel Stephens
- Yes, some degree of diversion is likely, although faults and fractures will preclude regional-scale diversion
- Lateral flow from Solitario Canyon may be important contribution to perched water bodies

Edwin Weeks
- Yes, but significant diversion is unlikely

Major Results of UZ Site-Scale Flow Model for VA *(cont.)*

- Little, if any, water will seep into drifts
- Different fracture/matrix interaction conceptual models lead to different calibrated hydrological properties
- Flow patterns below the repository horizon are uncertain; it is estimated that about 25% of the total flow passes through sorptive zeolitic rock
- Future climate change analysis is estimated to incrase percolation flux multi-fold, and will elevate perched water levels by less than 10 meters



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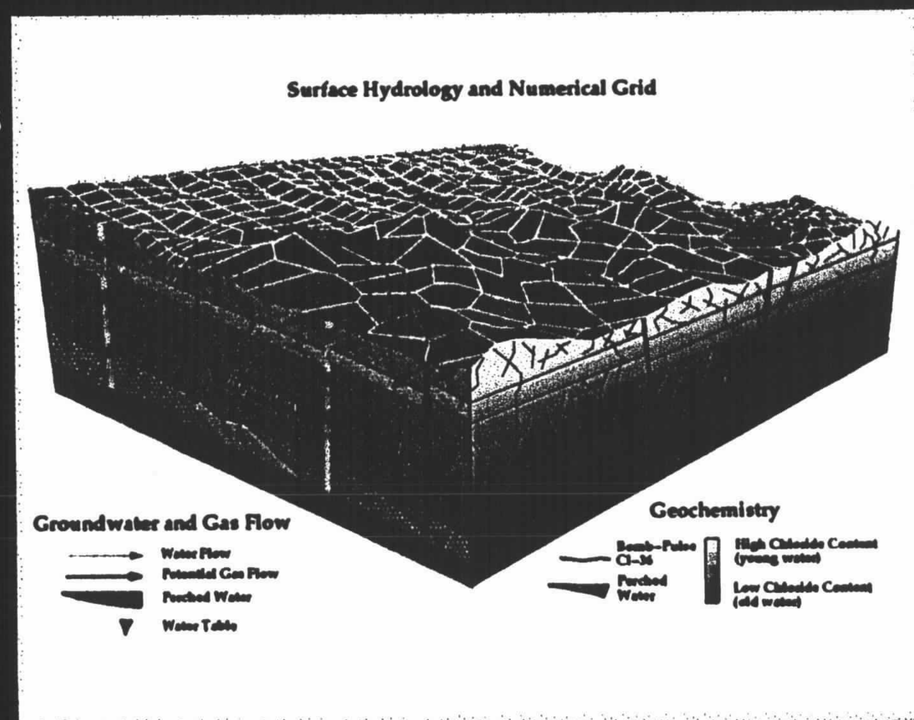
UZ FLOW MODEL

Major Results of UZ Site-Scale Flow Model for VA

- Current average percolation flux is estimated to be 1-10 mm/yr in the repository area
- Current average percolation flux cannot exceed 20 mm/yr
- Geochemical evidence including total CL, C-14 and Sr helps bound percolation flux, as does the temperature data
- Bomb-pulse CL-36 represents only a very small fraction of total flow, and may be over-emphasized
- Over 80% of flow in TSw occurs through fractures
- Flow occurs through thousands or millions of flow channels, each carrying small amounts of water



Berkeley Lab UZ Flow Model

Major Results of UZ Site-Scale Flow Model for VA

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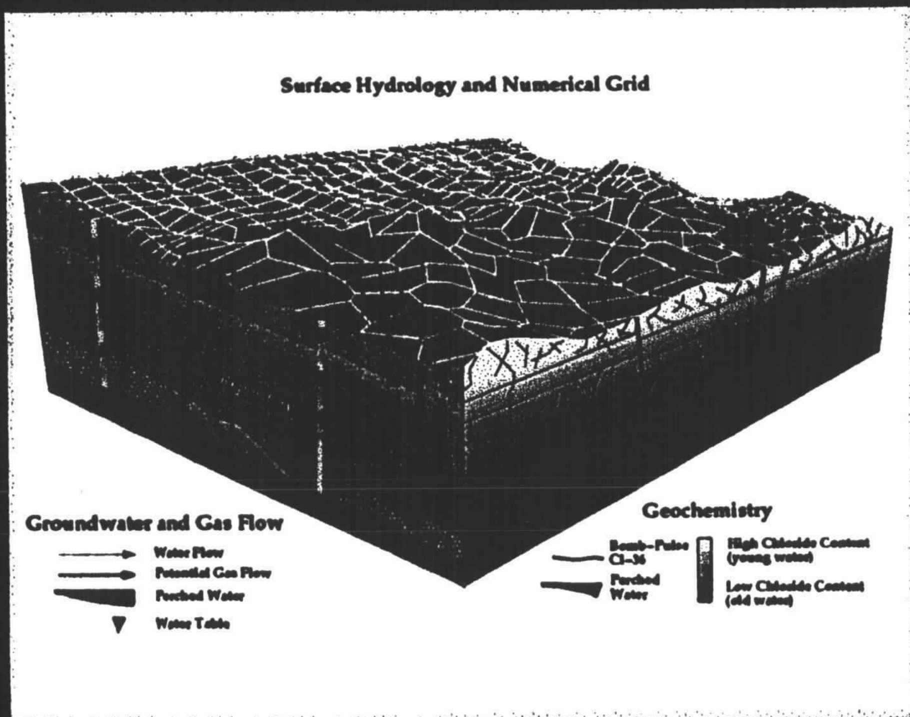

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Use of the UZ Expert Elicitation Results in the UZ Site Scale Model

June 24 and 25, 1997
Las Vegas, Nevada

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E.O. Lawrence Berkeley National Laboratory