SUBJECT: PRESENT DAY CLIMATE AND INFILTRATION

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Objective: Convert the climatic variables of precipitation and air temperature to infiltration.

Historical perspective: regional and site recharge estimates

Climatic Variability: Spatial and temporal
- Climate: regional and site
- El Nino: Anomalous or typical?

Mechanisms of infiltration: Conceptual model based on site specific measurements
- Precipitation
- Runoff
  - Hydrographs
  - Infiltration
    - neutron holes (change with time)
- Evapotranspiration
- Redistribution
  - initiation of fracture flow to obtain net infiltration

Distribute infiltration spatially: point measurements to expanded 3-D site scale model
- Spatial distribution of controlling properties
  - Precipitation
  - Radiation Loads
  - Soils
  - Geology
  - Maxey-Eaken distribution based on regional precipitation (Dynamic-Static)
  - Flux Map Approach (Static)
    - based on properties, in situ conditions and soil physics calculations
    - based on statistical distribution calibrated to neutron hole measurements
  - Numerical model: Water balance approach (Dynamic)
    - Simplified Bucket Model
    - Complex Richards Equation Model

Distribute infiltration in time: Measured and Modeled
- Use 10 years of site data from neutron probes and precipitation
- Use 50 years of regional precipitation data
- Stochastic rainfall model
  - Used to match regional climate (precipitation and air temperature)
  - Individual simulation is based on seasonality (monthly, 4th order Markov chains)

Model infiltration for future climate scenarios
- Evaluate infiltration response to determine influence of
  - Precipitation event frequency, duration, intensity and seasonality
  - Air Temperature
  - Cloudiness
- Use past climate record (SPECMAP, DEVILS HOLE, GRID)
- Use NCAR GCM (MM4 submodel)
OBJECTIVE

Convert the climatic variables of precipitation and air temperature to infiltration
HISTORICAL PERSPECTIVE

There are several ways recharge can be estimated in arid environments:

- Transfer equations based on other variables (i.e. precipitation)
- Geochemistry
- Estimating discharge
- Water balance and soil physics techniques
<table>
<thead>
<tr>
<th>Author</th>
<th>Method</th>
<th>Recharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rush (1970)</td>
<td>Transfer eq. (Maxey-Eakin), Jackass Flats</td>
<td>1.5 mm/yr</td>
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<tr>
<td>Winograd &amp; Thordarson (1975)</td>
<td>Discharge estimates, Ash Meadows</td>
<td>3% of precip.</td>
</tr>
<tr>
<td>Winograd (1981)</td>
<td>Water balance, Sedan Crater</td>
<td>2 mm/yr</td>
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<tr>
<td>Scott et al. (1983)</td>
<td>Transfer eq. (3% of 200 mm/yr), YM</td>
<td>6 mm/yr</td>
</tr>
<tr>
<td>Montazer &amp; Wilson (1984)</td>
<td>Transfer eq. (3% of 160 mm/yr), YM</td>
<td>4.5 mm/yr</td>
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<tr>
<td>Czarnecki (1984)</td>
<td>Transfer eq. (Maxey-Eakin), YM</td>
<td>0 - 2 mm/yr</td>
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<tr>
<td>Nichols (1987)</td>
<td>Water balance, Beatty</td>
<td>0.04 mm/yr</td>
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<tr>
<td>Dettinger (1989)</td>
<td>Geochemistry, Nevada basins</td>
<td>(Maxey-Eakin)</td>
</tr>
<tr>
<td>Flint &amp; Flint (1994)</td>
<td>Soil physics calculations, YM</td>
<td>0.02 - 13.4 mm/yr</td>
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<tr>
<td>Fabryka-Martin (1995)</td>
<td>Chloride mass balance, YM</td>
<td>0 - 5.4 mm/yr</td>
</tr>
<tr>
<td></td>
<td>Chloride mass balance, No. Nevada</td>
<td>300-320 mm/yr</td>
</tr>
</tbody>
</table>
Climatic Variability

Spatial and temporal

- Climate: regional and site
- *El Niño*: Anomalous or typical?
Location of study area for the Yucca Mountain region and the Death Valley Ground-Water Unit boundary.
Average annual percentage of days with measurable precipitation
Explanation
- Average for 37 stations
- Average for 12 stations
- Average for 13 NTS stations
Mechanisms of infiltration:

Conceptual model based on site specific measurements

- Precipitation
- Runoff
  - hydrographs
- Infiltration
  - neutron holes (change with time)
- Evapotranspiration
- Redistribution
  - initiation of fracture flow to obtain *net* infiltration
Infiltration at Borehole N01

Depth (m)

31000 31500 32000 32500 33000 33500 34000 34500

Time (days since 1/1/1900)

Depth (m)

0.05 0.10 0.15 0.20 0.25 0.30

Water Content (m/m)
Infiltration at Borehole N66

Time (days since 1/1/1900)

Depth (m)

31000 31500 32000 32500 33000 33500 34000 34500

0.06 0.11 0.16

N66_spy
Infiltration at Borehole N15

Depth (m)

Time (days since 1/1/1900)

Water Content (m/m)
Volumetric water content of bedrock  

- Flux with 0.006 filter  
- Flux with 0.009 filter
Water Potential in upper Pagany Wash
Calendar Year 1995

Probe depth is from ground surface. Depth to bedrock is 75 cm.

- 7.0 cm
- 15.0 cm
- 35.6 cm
- 73.7 cm
Water Content in upper Pagany Wash
Calendar Year 1995

Profile Water Content (m/m)

Time, day of year

Change in Profile Water Content (mm/day)

- HDP Data
- Selected Data
△ Change in Profile Water Content
Distribute infiltration spatially
(point measurements expanded to 3-D site scale model)

- Maxey-Eakin distribution based on regional precipitation (Dynamic-Static)
Isohyetal map of cokriged AAP using 114 stations with at least 8 complete years of record and the DEM for the DVGWU and the Yucca Mountain Region.
AVERAGE ANNUAL PRECIPITATION (MILLIMETERS)

ESTIMATED AVERAGE ANNUAL RECHARGE (MILLIMETERS)

- Maxey Eakin Model (1949)
- Lichty-McKinley estimates (1995)
- Modified Maxey-Eakin model 1
- Modified Maxey-Eakin model 2
Modified Maxey-Eakin model #1
- Modified Maxey-Eakin model #2
- Long & Childs 1993 (current)
- Long & Childs 1993 (Greenhouse)
- Long & Childs 1993 (FGM)
- Flint & Flint 1994 (current)
- Nichols 1987 (Beatty site)
- Maxey-Eakin Model 1949

AVERAGE ANNUAL PRECIPITATION (MILLIMETERS)

ESTIMATED AVERAGE ANNUAL RECHARGE (MILLIMETERS)

100 150 200 250

0 1 2 3 4 5 6 7 8
Estimated average annual recharge for the Yucca Mountain region using cokriged average annual precipitation and the modified Maxey-Eakin model 2.
Distribute infiltration spatially

- Flux map approach (Static)
  - based on properties, *in situ* conditions and soil physics calculations
  - based on statistical distribution calibrated to neutron hole measurements
Matrix flux in mm/year

<table>
<thead>
<tr>
<th>Material</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTn</td>
<td>13.40</td>
</tr>
<tr>
<td>Rainier Mesa</td>
<td>0.60</td>
</tr>
<tr>
<td>Tiva Mod. Welded</td>
<td>0.22</td>
</tr>
<tr>
<td>Topopah Welded</td>
<td>0.08</td>
</tr>
<tr>
<td>Tiva Welded</td>
<td>0.02</td>
</tr>
</tbody>
</table>
Potential Repository

Shallow Infiltration

- 0.0 mm/yr
- >0.0 to <10.0 mm/yr
- 10.0 to <20.0 mm/yr
- 20.0 to <30.0 mm/yr
- 30.0 mm/yr or more
Faults

< 10.0 mm/yr

10.0 to < 20.0 mm/yr

> 20.0 mm/yr

Potential Repository
Distribute infiltration spatially

- Numerical model: Water balance approach
  (Dynamic)
    - Simplified bucket model
    - Complex Richards equation model
The BUCKET model solves this equation in a simplified way in space and time on a daily basis.

**Inputs:**

- **Precipitation (Daily)**
  - Real data
  - Stochastic simulation
  - Implied climate scenario

- **Evaporation and Transpiration (Hourly)**
  - Solar radiation model
    - Slope, aspect, elevation, latitude, longitude, blocking ridges
  - Priestley-Taylor Equation
    - Plant root function
    - Soil water limiting function
- Soil Water Storage (Daily)
  - Field capacity
  - Residual water content
  - Soil thickness
  - Bucket overflow term

- Drainage (Daily)
  - Permeability of underlying matrix
  - Permeability of underlying fractures
    Fracture density
    Fracture properties
      Open fractures
      Filled fractures
Net Infiltration vs. Precipitation (96 Neutron holes)

100 Year Stochastic Rainfall Simulation

Net Infiltration, mm

Precipitation, mm

Yearly (Modeled)  Maxey-Eakin  Neutron Holes
Field Capacity

UTM Easting (m)

UTM Northing (m)

Field Capacity (m/m)
Water Storage Capacity (m)

Storage Capacity (Field Capacity X Soil Depth, m)
Bedrock Permeability (with Fractures) (or deep soil permeability)

![Map of Bedrock Permeability](image)

- **UTM Easting (m)**
  - 545000 548000 551000 554000

- **UTM Northing (m)**
  - 4069500 4072500 4075500 4078500 4081500 4084500 4087500

- **Permeability (mm/day)**
  - 50 150 250 350 450
Bedrock Permeability (with fractures)

UTM Easting (m)

UTM Northing (m)

Permeability (mm/day)
Infiltration (Precipitation simulation of 205 mm/yr)
Infiltration (Precipitation simulation of 205 mm/yr)
Infiltration (Precipitation simulation of 162 mm/yr)
Distribute infiltration in time
Measured and Modeled

- Use 10 years of site data from neutron probes and precipitation
- Use 50 years of regional precipitation data
- Stochastic rainfall model
  - Used to match regional climate (precipitation and air temperature)
  - Individual simulation is based on seasonality (monthly, 4th order Markov chains)
4JA Probability of Daily Precip.

3rd order Markov chain

4-day window
1 = precip

probability

month

0.6
0.5
0.4
0.3
0.2
0.1
0
1 2 3 4 5 6 7 8 9 10 11 12

0001
0011
0111
0101
1001
1111
Probability Distribution Function for Station 4JA
DAILY PRECIP MAGNITUDE FOR DAYS WITH PRECIP.

\[ \text{PROB} = \text{EXP}(-A \cdot (\text{PPT(hin)})^B + A) \]
\[ \text{PPT(hin)} = ((\ln(\text{PROB}) - A)/-A)^{(1/B)} \]

- JAN, FEB, MAR (A = 0.10, B = 0.82)
- APR, MAY, JUN (A = 0.77, B = 0.43)
- JUL, AUG, SEP (A = 1.03, B = 0.32)
- OCT, NOV, DEC (A = 0.29, B = 0.58)

DAILY PRECIP AMOUNT (MILLIMETERS)
100 Year Stochastic Rainfall Simulation

Precipitation (mm/year)

Time (years)

- Yearly (modeled)
- Mean (modeled)
Net Infiltration for 96 Neutron Holes

100 Year Stochastic Rainfall Simulation

Net Infiltration (mm) vs. Time (years)

- Yearly (modeled)
- Mean (modeled)
Model infiltration for future climate scenarios

- Evaluate infiltration response to determine influence of:
  - Precipitation event frequency, duration, intensity and seasonality
  - Air Temperature
  - Cloudiness
- Use past climate record (SPECMAP, DEVIL’S HOLE, GRID)
- Use NCAR GCM (MM4 submodel)
Recharge for the Yucca Mountain Region

- Maxey-Eakin Model 2
- Average (model 2)
SUMMARY

- Infiltration is temporally and spatially variable
- Infiltration is controlled by
  - the daily variation in precipitation (timing)
  - depth of alluvium
  - hydrologic properties of the underlying bedrock
  - topographic position
- In development of climate scenarios it is necessary to account for the frequency, timing and spatial distribution of precipitation
- Infiltration modeling can convert any climate scenario that provides precipitation and air temperature into infiltration