Sandia National Laboratories
Estimates of Precipitation

Presented to:
Nuclear Waste Technical Review Board

Presented by:
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Outline

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- Preliminary results
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Primary Contributors

- Joshua Stein (SNL) – Principal investigator and team lead
- Daniel Levitt (Los Alamos National Laboratory) – Conceptual models
- Robert Walsh (Apogen Technologies) – Precipitation and uncertainty analysis
- Cedric Sallaberry (SNL) – Precipitation and sensitivity analysis
- Sandra Dalvit-Dunn (Apogen) – Precipitation
- Steve Miller (SNL) – Precipitation
- Saxon Sharpe (Desert Research Institute) – Present and future climate consultant
Background

- Sandia National Laboratories (SNL) was tasked to review the U.S. Geological Survey net infiltration model, INFIL 2.0, and develop a replacement model (MASSIF) for use at Yucca Mountain (YM)
  - The representation of precipitation uncertainty was one of SNL’s focus areas
- *Future Climate Analysis (2004)* estimates features and timing of three climate states expected in the next 10,000 years at YM
  - Identifies analog meteorological stations to represent upper bounds (UBs) and lower bounds (LBs) for these climates
U.S. Nuclear Regulatory Commission provides guidance in the *Yucca Mountain Review Plan* (NUREG-1804, REV 02) to ensure that

- “The effects of...time-varying boundary conditions...are considered, such that net infiltration is not underestimated” (Section 2.2.1.3.5.3: Acceptance Criterion 2(3))
- “Models use parameter values...that are technically defensible, reasonably account for uncertainties and variabilities, and do not result in an under-representation of the risk estimate” (Section 2.2.1.3.5.3: Acceptance Criterion 3(1))
- “…the treatment of conceptual model uncertainty does not result in an under-representation of the risk estimate” (Section 2.2.1.3.5.3: Acceptance Criterion 4(3))
Motivation

• MASSIF model estimates long-term average net infiltration flux and uncertainty for each climate state

• MASSIF needs a set of weather years for each climate state that include daily values of
  – Precipitation
  – Minimum and maximum temperature
  – Mean daily wind speed

• Climate variability occurs over time-scales that are shorter than the climate durations expected at YM
  – Such variability may bias mean values calculated from historical weather records
Motivation (continued)

- Precipitation must be applied to grid cells covering the infiltration model domain (~125 km²) over an elevation range from 964 to 1,964 m above sea level; top of YM is at 1524 m
Climate States and Analog Records

- **Present Day**
  - Duration—400 to 600 years
  - Analog stations
    - "Yucca Mountain region"

- **Monsoon**
  - Duration—900 to 1,400 years
  - Analog stations
    - LB—Present day
    - UB—Hobbs, NM and Nogales, AZ

- **Glacial Transition**
  - Duration—Greater than 8,000 years
  - Analog stations
    - LB—Beowawe, NV and Delta, UT
    - UB—Spokane, Rosalia, and St. John, WA
Present-Day Climate Precipitation

- Precipitation is significantly influenced by elevation
- Published estimates of mean annual precipitation (MAP) for YM region vary significantly
  - Spaulding (1985) estimated 189 mm/yr (based on Nevada Test Site records 1963 to 1972)
  - Thompson et al. (1999) estimated MAP = 125 mm/yr at YM (based on climate division normals from NV region 3 and 4 (1951 to 1980))
    - NV-3 (1931 to 2000) — 195 mm
    - NV-4 (1931 to 2000) — 141 mm
    - Daly (2002) estimated that precipitation division normals in NV regions 3 and 4 are underestimated by as much as 25% due to elevation bias
- Analysis of meteorological data (up to 2004) from 10 regional stations suggest MAP at top of YM to be approximately 200 to 220 mm/yr
Present-Day Climate Precipitation

Yucca Mountain Region Meteorological Stations—
MAP vs. Elevation

\[ y = 0.1337x + 9.0365 \]

\[ R^2 = 0.9198 \]
Monsoon and Glacial-Transition Climates

- **Monsoon**
  - Climate during this period would vary between episodes of intense summer rain to present-day-like climates with relatively more winter and less summer precipitation
  - UB MAP—405 to 420 mm/yr (analog station MAP)

- **Glacial transition**
  - The climate during the glacial-transition period would consist of a typically cool, usually wet winter season with warm (but not too hot) to cool summers that are usually dry relative to present-day summers
  - LB MAP—207 to 241 mm/yr (analog station MAP)
  - UB MAP—419 to 455 mm/yr (analog station MAP)

- **MAP from analog stations assumed to be representative at the top of YM (1,524 m above sea level)**
Long-Term Precipitation Simulation

- To include the effects of low probability, high precipitation years on long-term average net infiltration, we chose to generate a long simulation of precipitation (1,000 years)

- Well-established approach for stochastic simulations of precipitation that includes seasonal variations (Woolhiser and Pegram, 1978)
  - Markov chain model of precipitation frequency
  - Probability distribution for daily precipitation amount

- Meteorological records used to parameterize the simulation
Simulation of Daily Precipitation

- Seasonal representation of daily precipitation
  - Stochastic parameters, $p(d)$ include
    - $p_{00}(d)$—The probability that day $d$ is dry, given that day $d-1$ is dry
    - $p_{10}(d)$—The probability that day $d$ is dry, given that day $d-1$ is wet
    - $\lambda(d)$—Mean of the lognormal precipitation distribution, given that day $d$ is wet
    - $m(d)$—Mean of the natural logarithm of the amount of precipitation, given that day $d$ is wet
  - Parameters are each represented by an annual 1st order Fourier series constrained by parameters $a$, $b$ and $\theta$:

$$p_X(d) = a_X + b_X \sin(\theta_X + 2\pi d / 365)$$
Implementation

- **For each climate state**
  - 12 stochastic parameters calculated for each meteorological station using least-squares approach
  - Parameter distributions are defined for each stochastic parameter
  - Stochastic parameters are screened for inclusion in Latin Hypercube Sampling (LHS) by a relative uncertainty threshold (15%)
  - Two LHS replicates (2 x 20 = 40 realizations total) generated

- **For each LHS realization**
  - A large set of random numbers are generated and saved
  - 1,000 years are simulated (using random numbers, day of year, and Fourier model with sampled fitting parameter values)
Definition of Representative Years

For each LHS realization (1,000-year simulated record)

- Years are sorted by annual precipitation and split into 10 bins of unequal weight
- A year is randomly selected and weights assigned according to each bin size

<table>
<thead>
<tr>
<th>Representative Year</th>
<th>Weight</th>
<th>Recurrence (years)</th>
<th>Present-Day Mean Precipitation (mm/yr)</th>
</tr>
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<tr>
<td>Y1</td>
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<td>1000</td>
<td>708</td>
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<tr>
<td>Y2</td>
<td>0.002</td>
<td>333</td>
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<tr>
<td>Y10</td>
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</table>
Preliminary Results
Present-Day Climate

MAP—Data vs. 1,000-year Simulation

- Station range ≈ 165 to 244 mm/yr (YM Site 9 – Cane Springs)
- Simulation range = 153 to 246 mm/yr
- Station MAP ≈ 201 mm/yr; standard deviation ≈ 25 mm/yr
- Simulation MAP = 199 mm/yr; standard deviation = 29 mm/yr
Preliminary Results
Monsoon Climate

MAP—Data vs. 1,000-year Simulation

- Station range ≈ 165 to 420 mm/yr (YM Site 9 – Hobbs)
- Simulation range = 143 to 528 mm/yr
- Station LB MAP ≈ 201 mm/yr; UB MAP ≈ 413 mm/yr (mean of Hobbs and Nogales)
- Simulation MAP = 313 mm/yr
Preliminary Results
Glacial-Transition Climate

MAP—Data vs. 1,000-year Simulation

- Station range
  ≈ 207 to 455 mm/yr
  (Delta – Rosalia)

- Simulation range
  = 195 to 437 mm/yr

- Station LB mean
  MAP ≈ 224 mm/yr;
  UB mean MAP
  ≈ 435 mm/yr

- Simulation MAP
  = 326 mm/yr
Summary and Preliminary Conclusions

- Future precipitation is represented as a stochastic process conditioned on historical data from analog meteorological stations.
- Seasonality is represented by a 1\textsuperscript{st} order Fourier series (e.g., one wet and one dry season).
- Stochastic simulations generate 1,000 years for each LHS of parameters.
- Ten representative years are selected as input to the MASSIF net infiltration model.
- Simulated precipitation matches climate uncertainty based on observations from the historical record.