U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: PRESENT DAY CLIMATE AND INFILTRATION

PRESENTER: ALAN L. FLINT

PRESENTER'S TITLE AND ORGANIZATION: HYDROLOGIST
U.S. GEOLOGICAL SURVEY
LAS VEGAS, NEVADA

TELEPHONE NUMBER: (702) 794-7811

JULY 9-10, 1996
DENVER, COLORADO

CLIMATE AND INFILTRATION AT YUCCA MOUNTAIN

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

II. *Historical perspective*: regional and site recharge estimates

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

IV. *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

V. *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

VI. *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, 4^{th} order Markov chains)

VII. *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

Historical Recharge Estimates

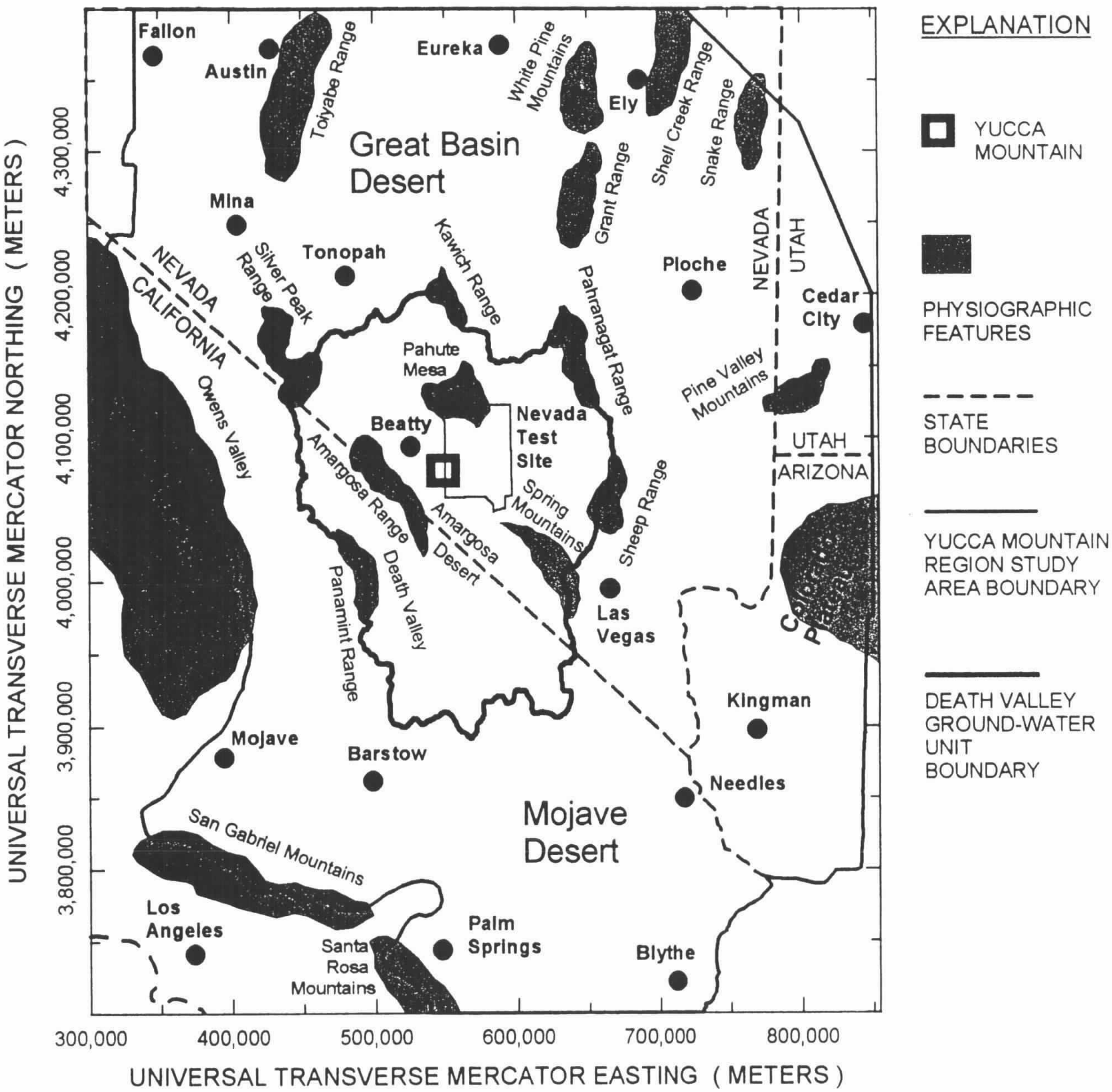
Author	*Method*	*Recharge*
Rush (1970)	Transfer eq. (Maxey-Eakin), Jackass Flats	1.5 mm/yr
Winograd & Thordarson (1975)	Discharge estimates, Ash Meadows	3% of precip.
Winograd (1981)	Water balance, Sedan Crater	2 mm/yr
Scott et al.(1983)	Transfer eq. (3% of 200 mm/yr), YM	6 mm/yr
Montazer & Wilson (1984)	Transfer eq. (3% of 160 mm/yr), YM	4.5 mm/yr
Czarnecki (1984)	Transfer eq. (Maxey-Eakin), YM	0 - 2 mm/yr
Nichols (1987)	Water balance, Beatty	0.04 mm/yr
Dettinger (1989)	Geochemistry, Nevada basins	(Maxey-Eakin)
Flint & Flint (1994)	Soil physics calculations, YM	0.02 - 13.4mm\yr
Fabryka-Martin (1995)	Chloride mass balance, YM	0 - 5.4 mm/yr
Lichty & McKinley (1995)	Water balance, No. Nevada	10-20 mm/yr
	Chloride mass balance, No. Nevada	300-320 mm/yr

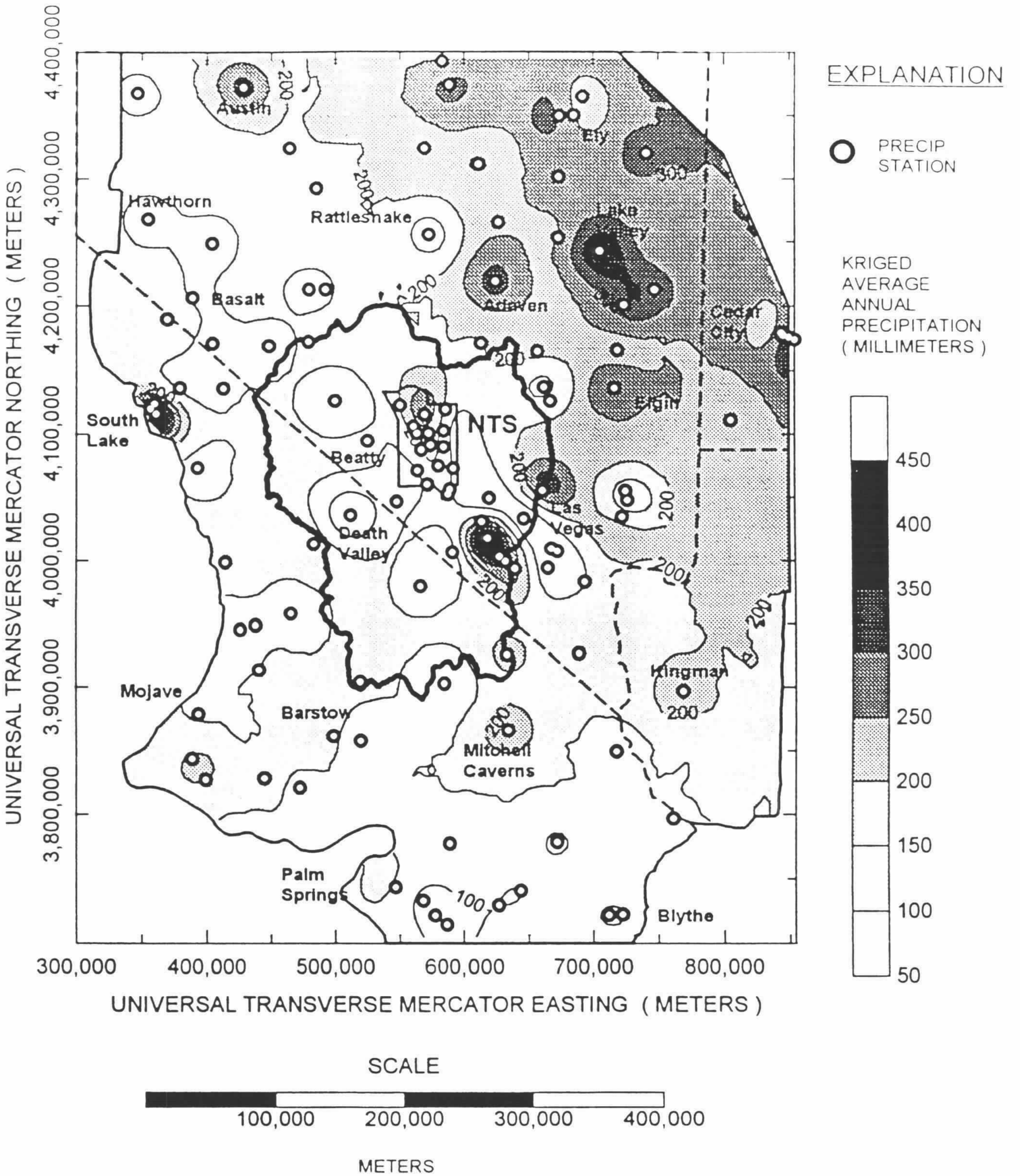
Climatic Variability

Spatial and temporal

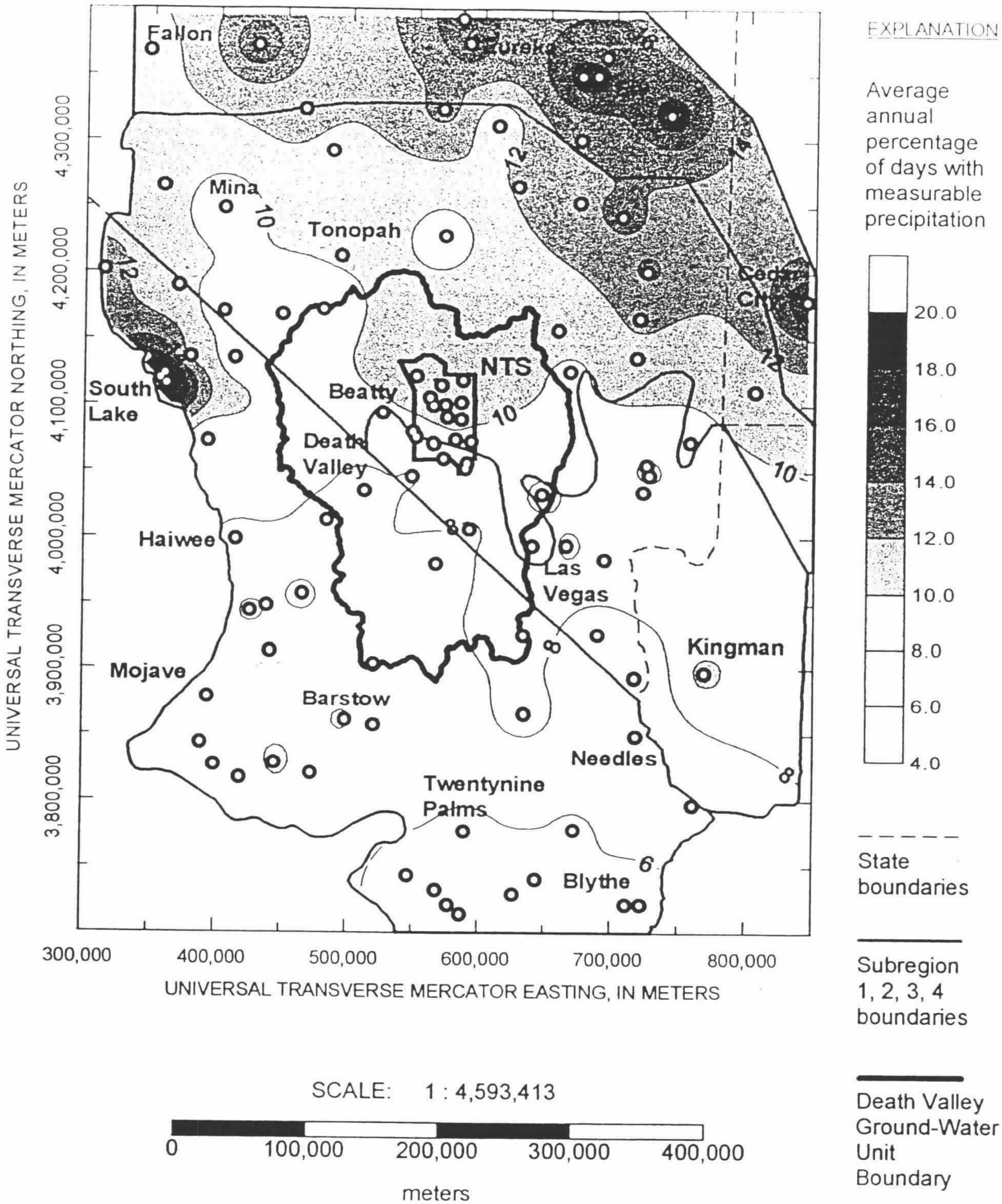
- Climate: regional and site
- *El Niño*: Anomalous or typical?

Location of study area for the Yucca Mountain region and the Death Valley Ground-Water Unit boundary.

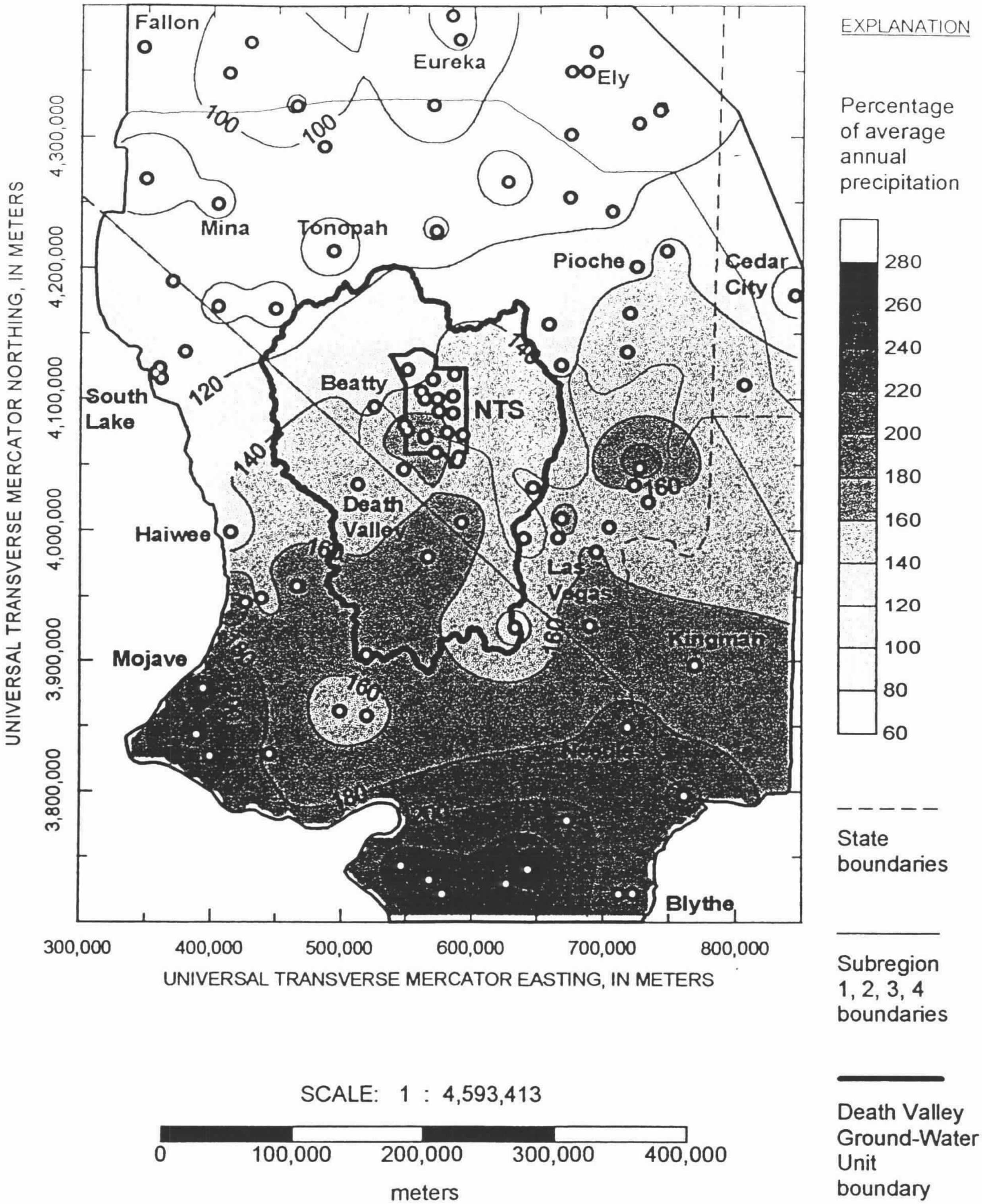


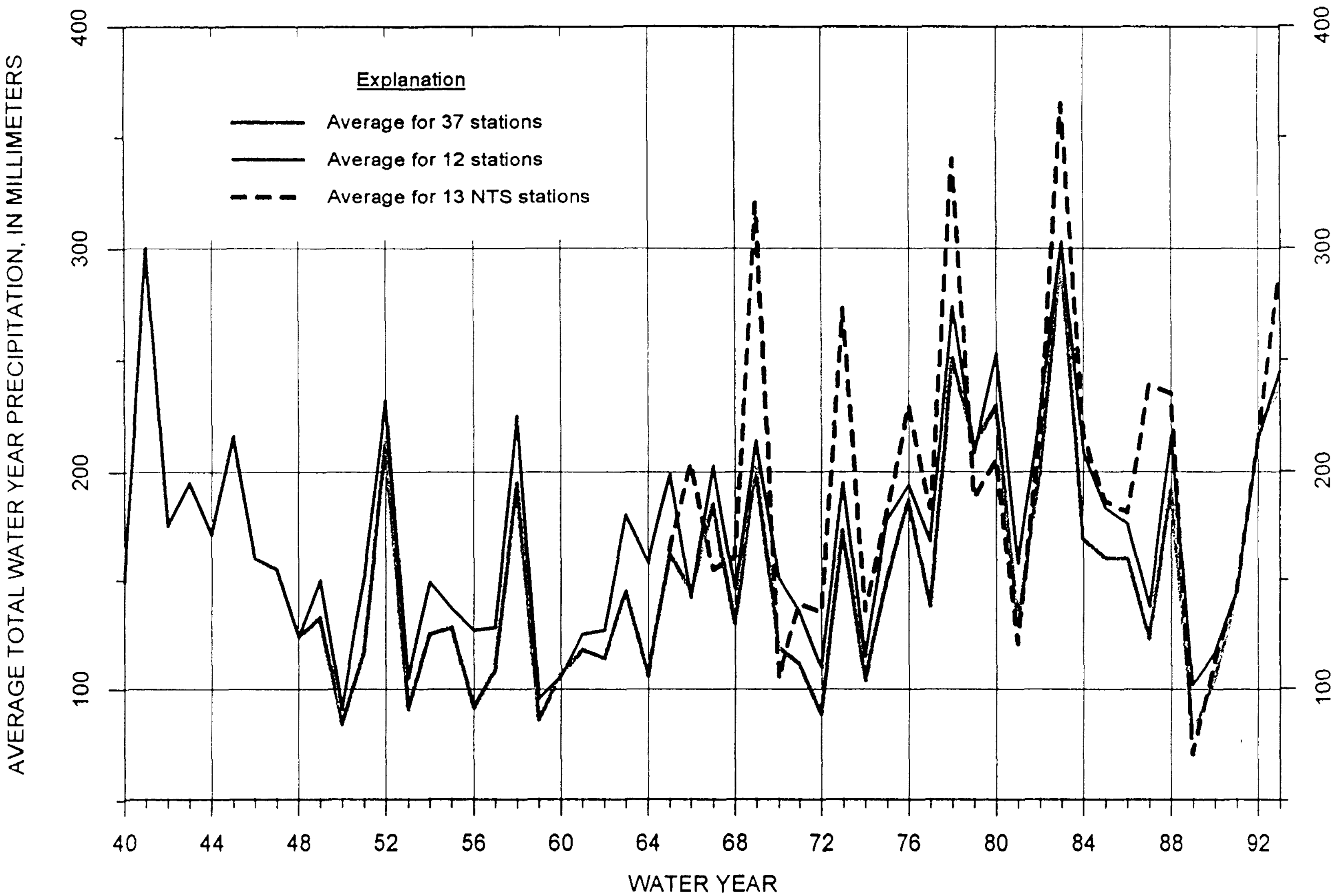


EXPLANATION
PRECIP STATION
KRIGED AVERAGE ANNUAL PRECIPITATION (MILLIMETERS)
450
400
350
300
250
200
150
100
50
UNIVERSAL TRANSVERSE MERCATOR NORTHING (METERS)
UNIVERSAL TRANSVERSE MERCATOR EASTING (METERS)
4,400,000
4,300,000
4,200,000
4,100,000
4,000,000
3,900,000
3,800,000
300,000
400,000
500,000
600,000
700,000
800,000
Austin
Ely
Hawthorn
Rattlesnake
Basalt
Adaven
Cedar City
South Lake
NTS
Beatty
Elgin
Las Vegas
Death Valley
Mojave
Barstow
Kingman
Mitchell Caverns
Palm Springs
Blythe
200
300
100
SCALE
100,000
200,000
300,000
400,000
METERS



Fallon
Eureka
Mina
Tonopah
South Lake
Beatty
NTS
Death Valley
Haiwee
Las Vegas
Kingman
Mojave
Barstow
Needles
Twentynine Palms
Blythe
UNIVERSAL TRANSVERSE MERCATOR NORTHING, IN METERS
UNIVERSAL TRANSVERSE MERCATOR EASTING, IN METERS
4,300,000
4,200,000
4,100,000
4,000,000
3,900,000
3,800,000
300,000
400,000
500,000
600,000
700,000
800,000
EXPLANATION
Average annual percentage of days with measurable precipitation
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
State boundaries
Subregion 1, 2, 3, 4 boundaries
Death Valley Ground-Water Unit Boundary
SCALE: 1 : 4,593,413
0
100,000
200,000
300,000
400,000
meters


Fallon
Eureka
Ely
Mina
Tonopah
Pioche
Cedar City
South Lake
Beatty
NTS
Death Valley
Haiwee
Las Vegas
Mojave
Kingman
Blythe
100
120
140
160
180
4,300,000
4,200,000
4,100,000
4,000,000
3,900,000
3,800,000
UNIVERSAL TRANSVERSE MERCATOR NORTHING, IN METERS
300,000
400,000
500,000
600,000
700,000
800,000
UNIVERSAL TRANSVERSE MERCATOR EASTING, IN METERS
SCALE: 1 : 4,593,413
0
100,000
200,000
300,000
400,000
meters
EXPLANATION
Percentage of average annual precipitation
280
260
240
220
200
180
160
140
120
100
80
60
State boundaries
Subregion 1, 2, 3, 4 boundaries
Death Valley Ground-Water Unit boundary



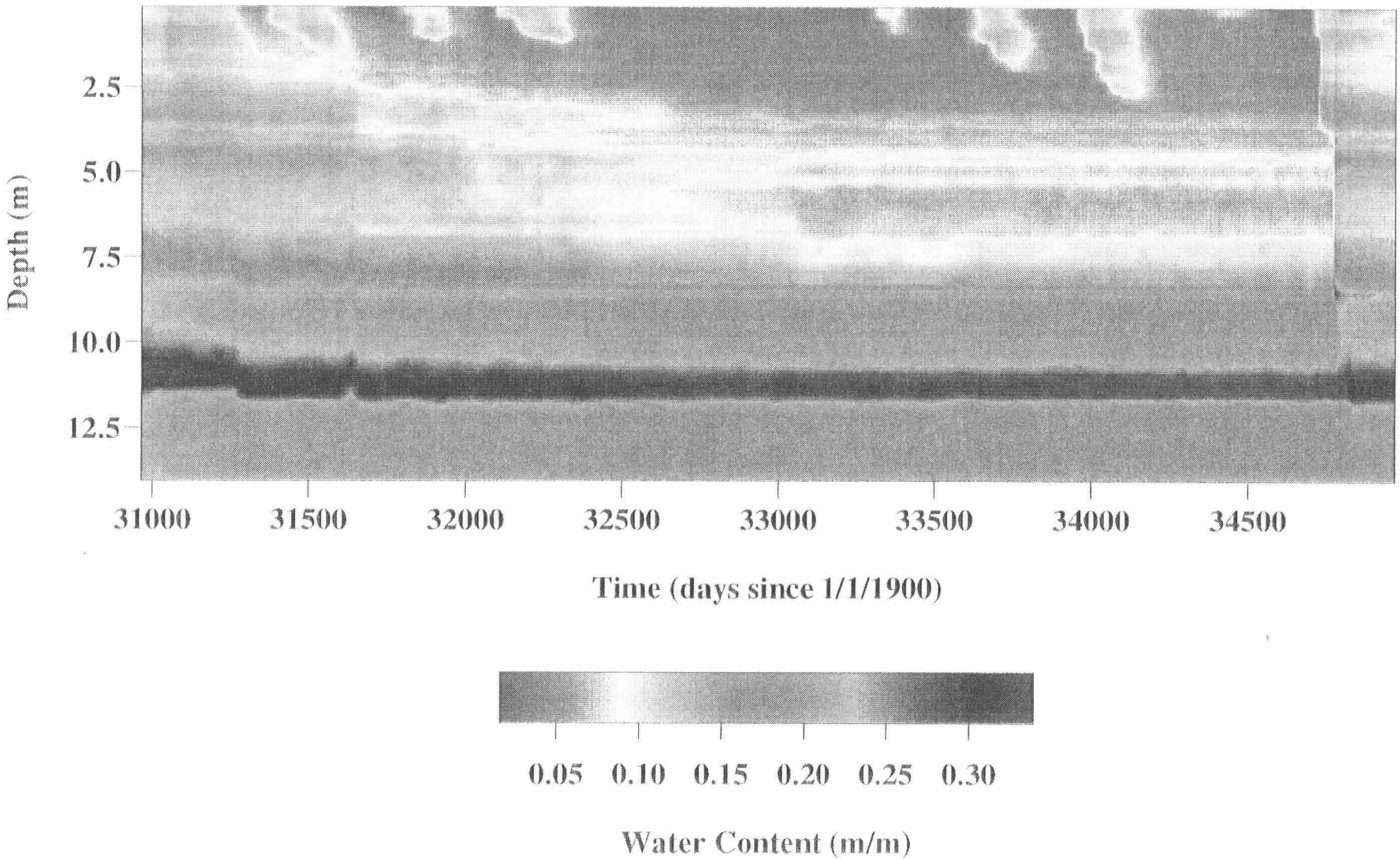
Explanation
Average for 37 stations
Average for 12 stations
Average for 13 NTS stations
AVERAGE TOTAL WATER YEAR PRECIPITATION, IN MILLIMETERS
400
300
200
100
40
44
48
52
56
60
64
68
72
76
80
84
88
92
WATER YEAR

Mechanisms of infiltration:

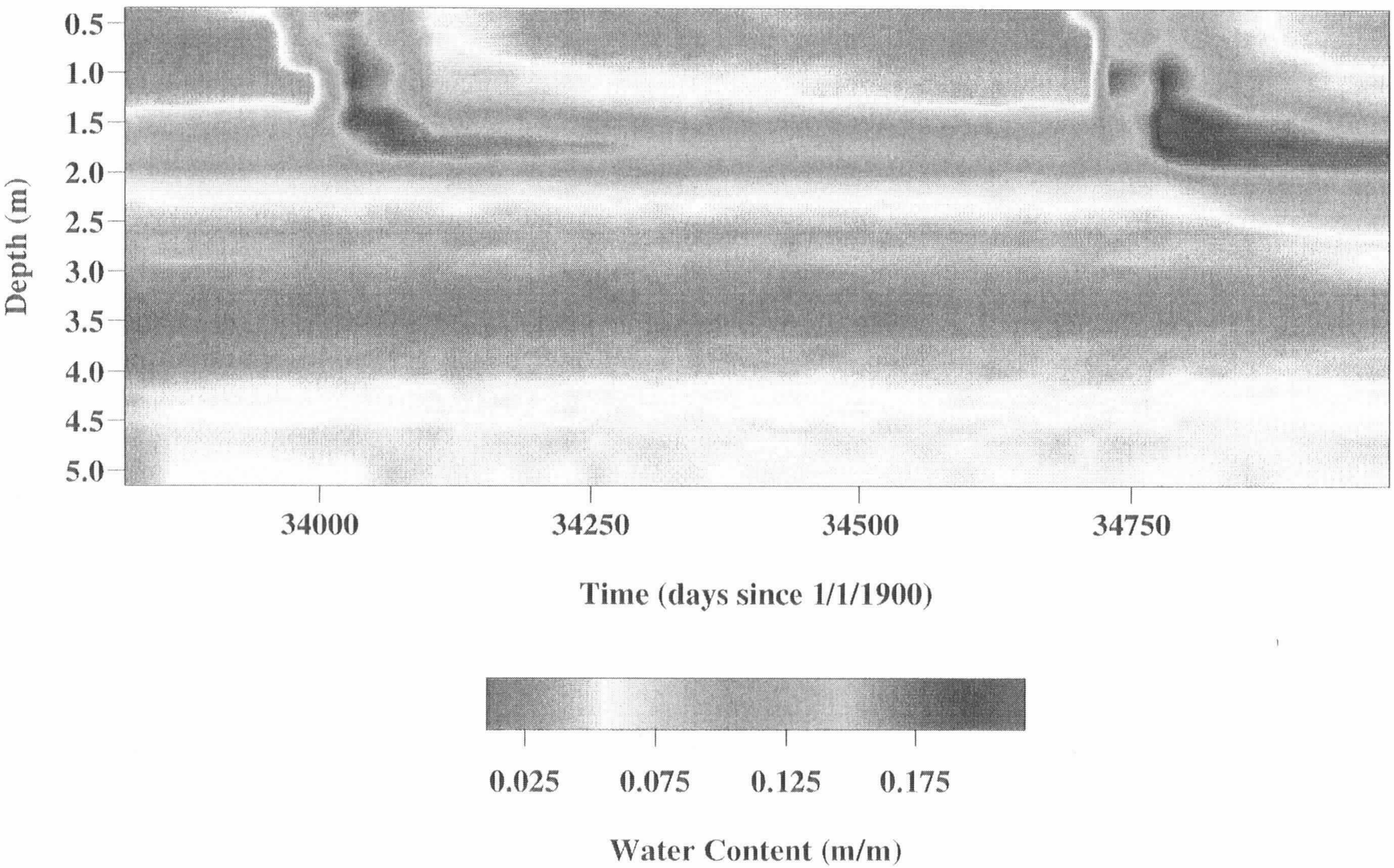
Conceptual model based on site specific measurements

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

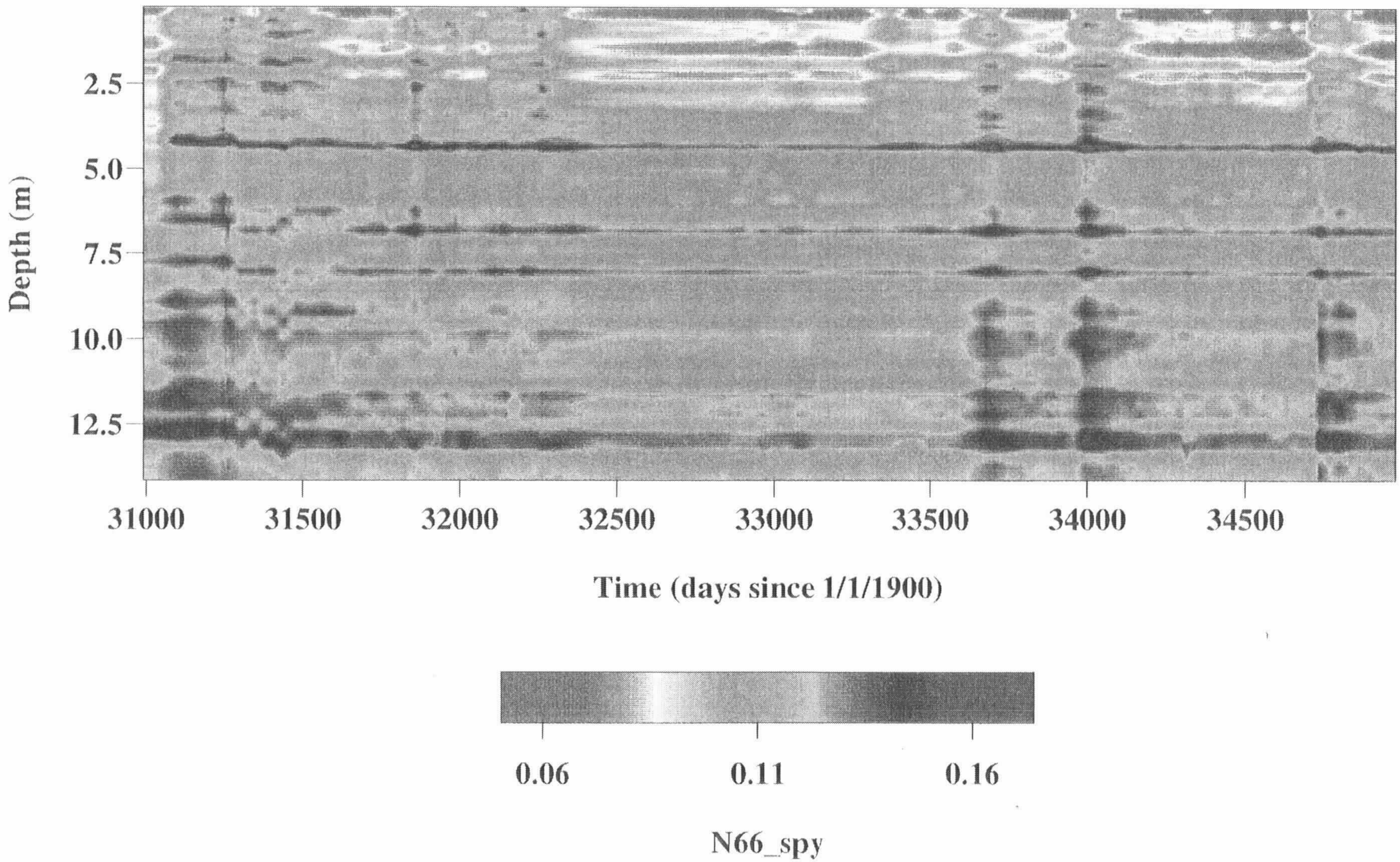
Infiltration at Borehole N01



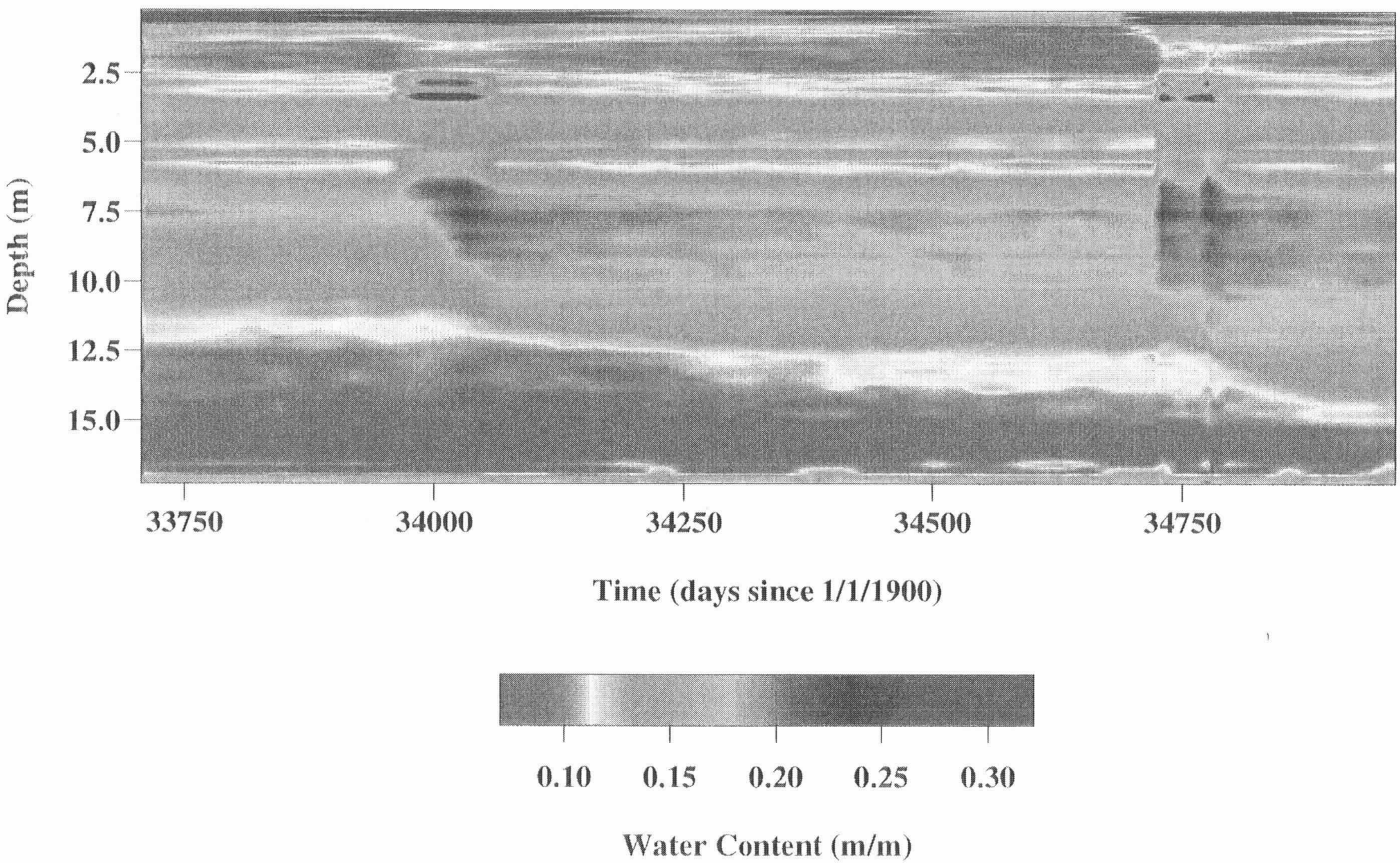
Infiltration at Borehole N63

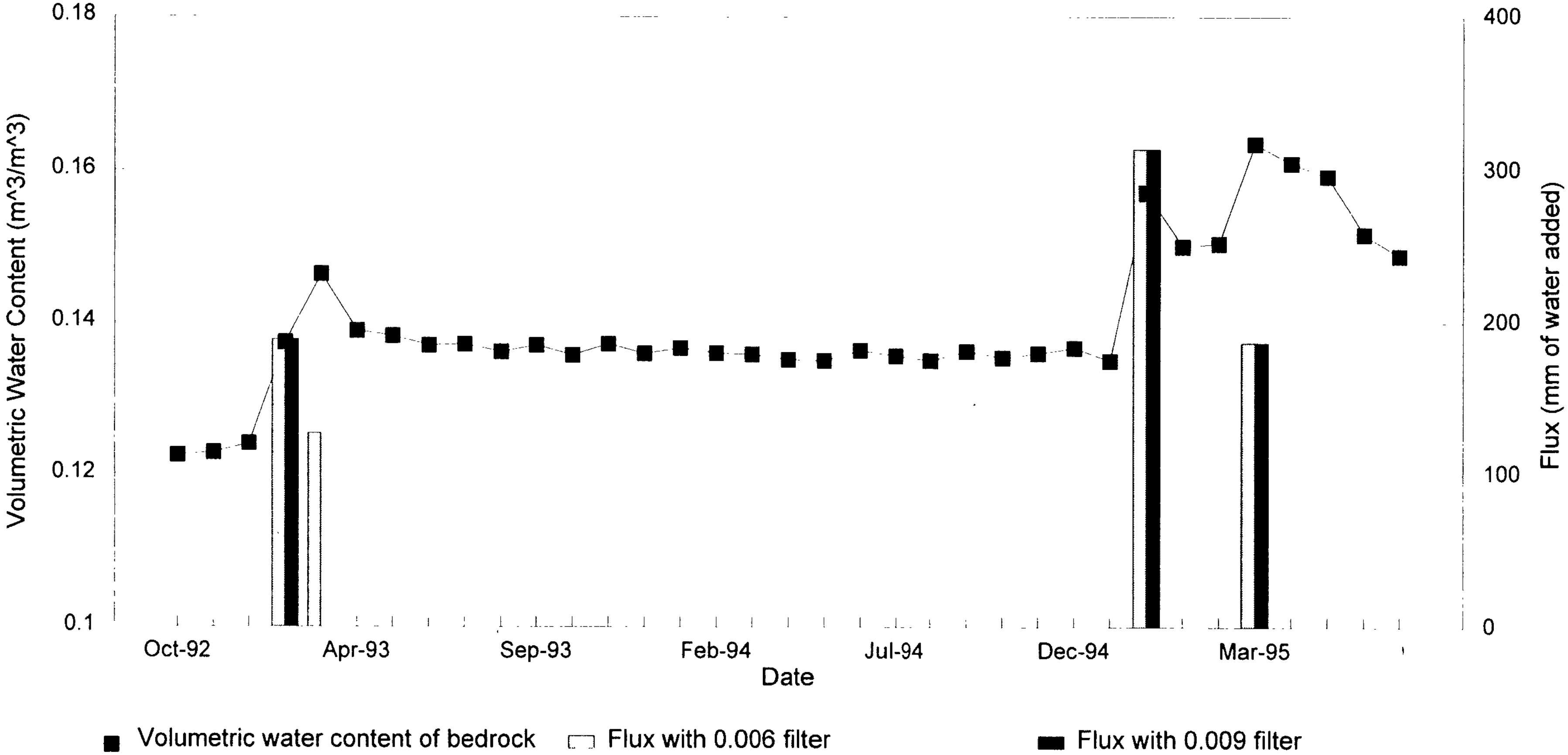


Infiltration at Borehole N66

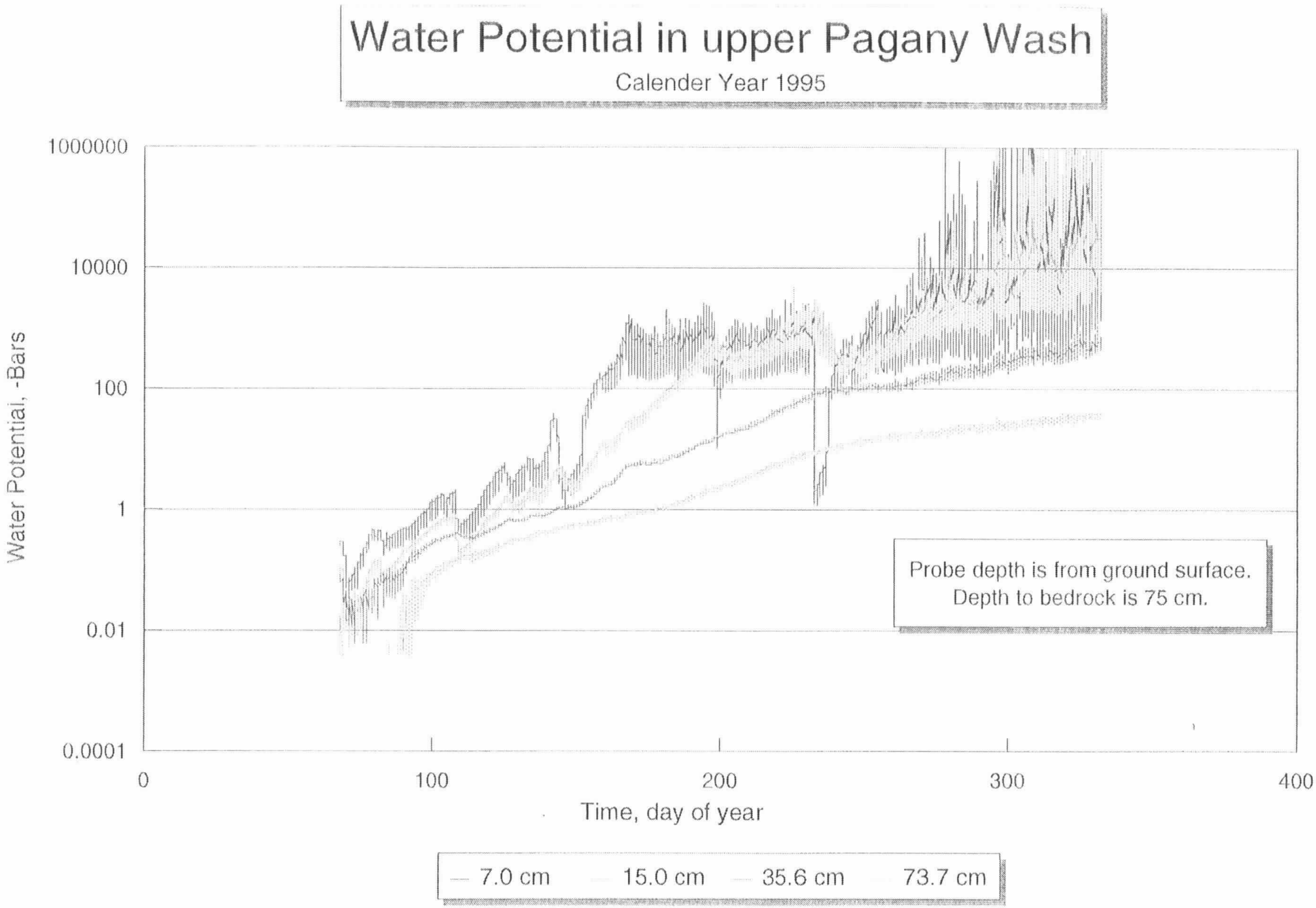


Infiltration at Borehole N15

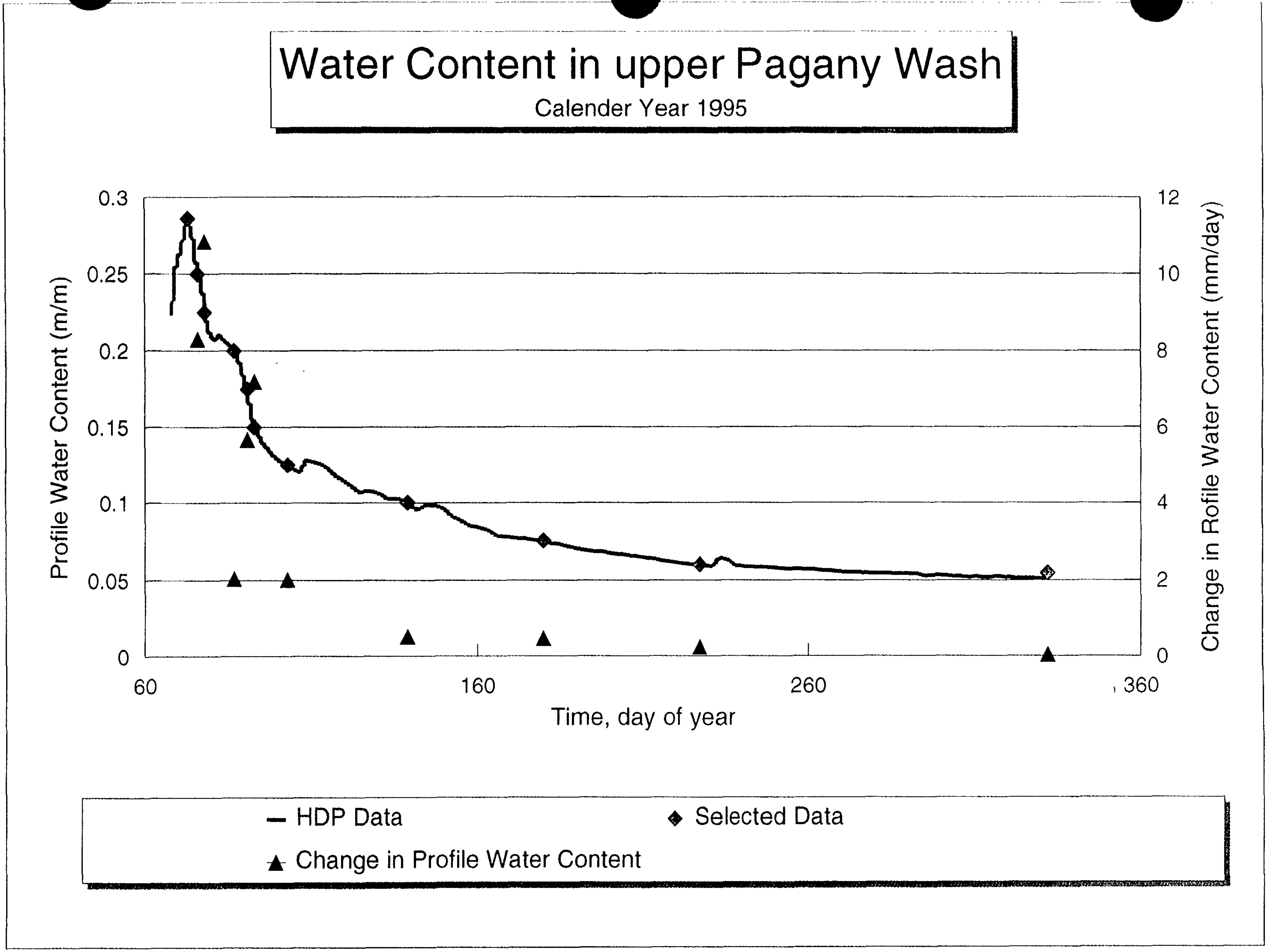




0.18
0.16
0.14
0.12
0.1
Volumetric Water Content (m^3/m^3)
400
300
200
100
0
Flux (mm of water added)
Oct-92
Apr-93
Sep-93
Feb-94
Jul-94
Dec-94
Mar-95
Date
Volumetric water content of bedrock
Flux with 0.006 filter
Flux with 0.009 filter



Water Potential in upper Pagany Wash
Calender Year 1995
1000000
10000
100
1
0.01
0.0001
Water Potential, -Bars
0
100
200
300
400
Time, day of year
Probe depth is from ground surface.
Depth to bedrock is 75 cm.
7.0 cm
15.0 cm
35.6 cm
73.7 cm



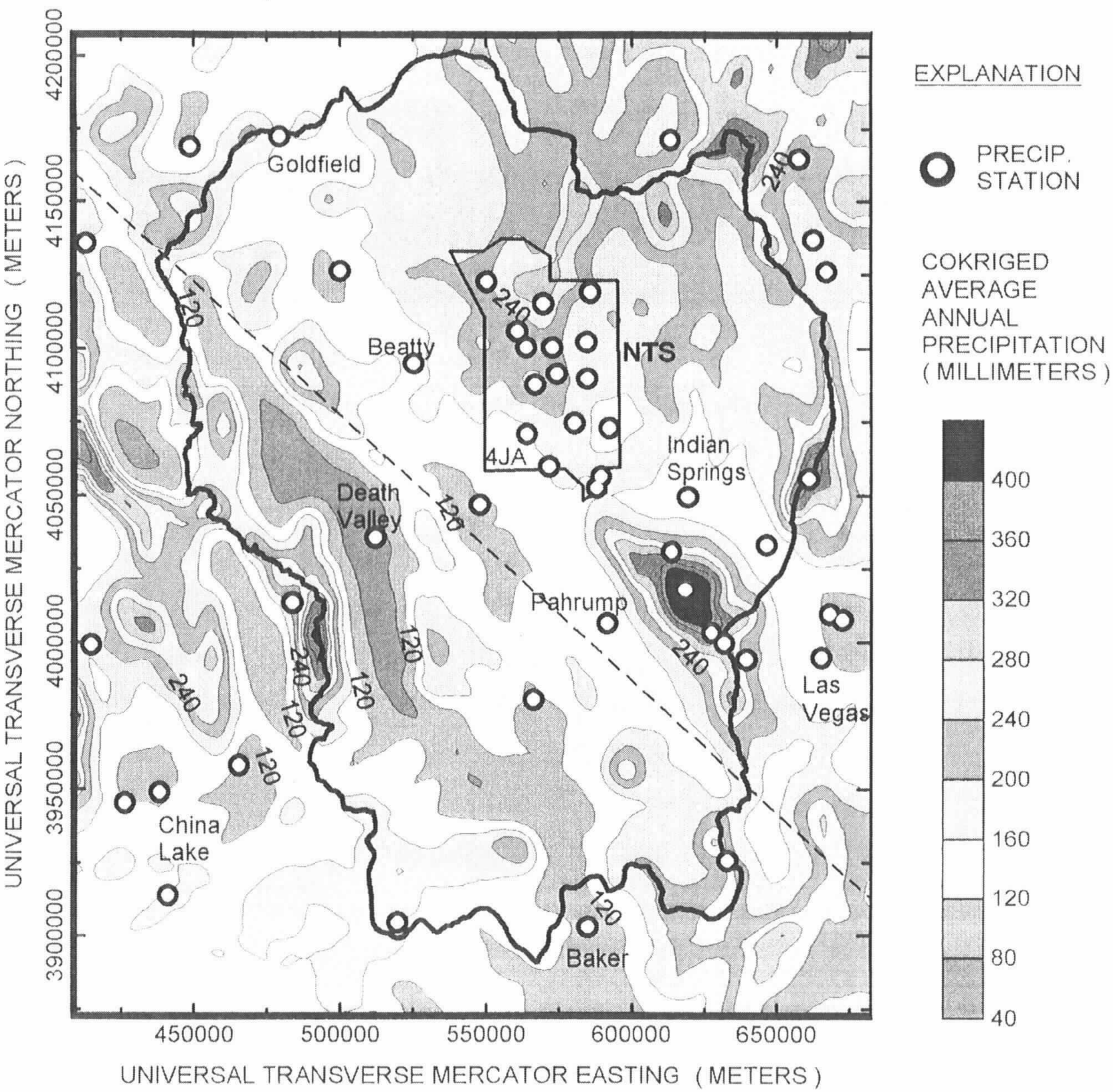
Water Content in upper Pagany Wash
Calender Year 1995
Profile Water Content (m/m)
0.3
0.25
0.2
0.15
0.1
0.05
0
Change in Rofile Water Content (mm/day)
12
10
8
6
4
2
0
60
160
260
360
Time, day of year
HDP Data
Selected Data
Change in Profile Water Content

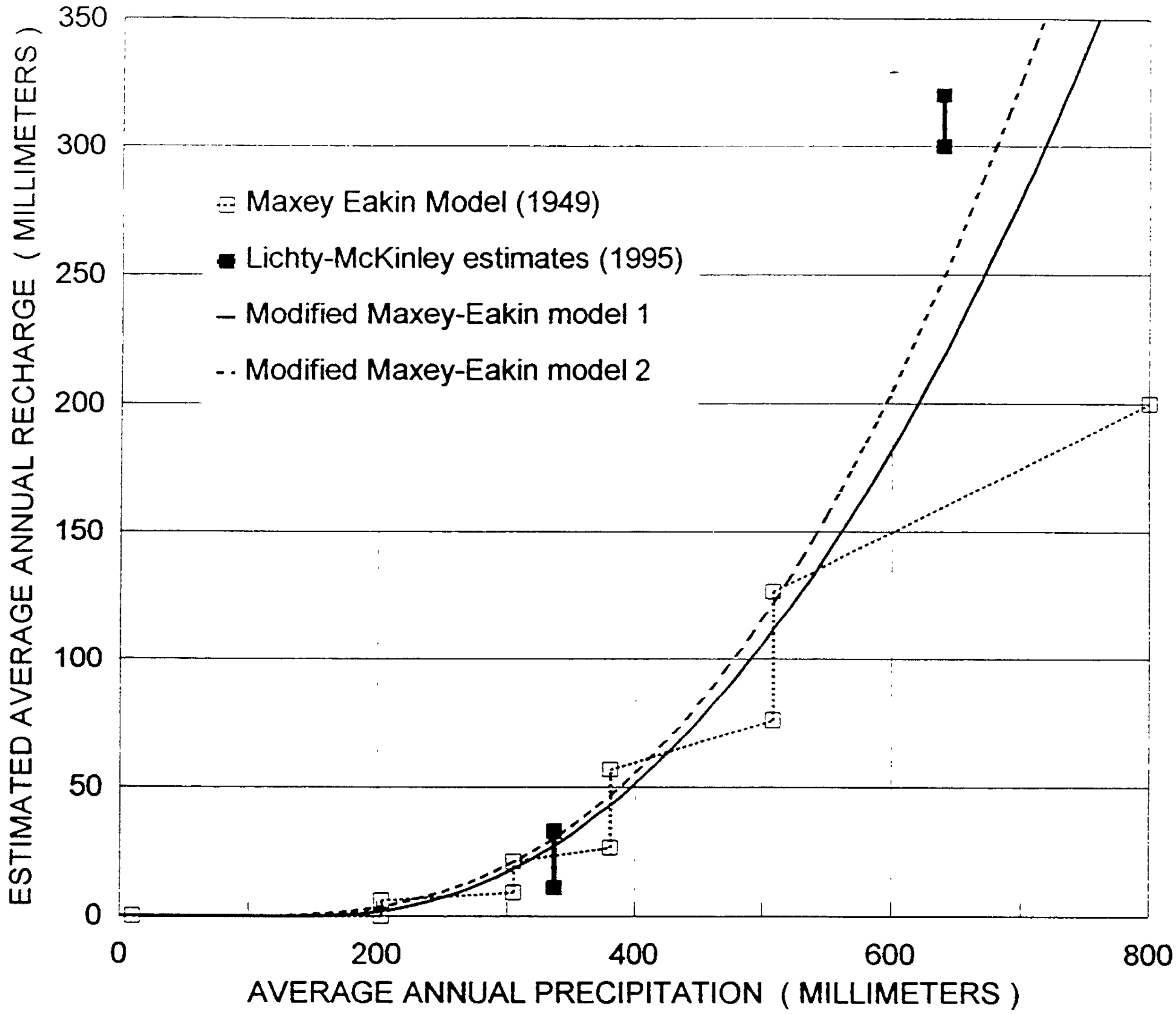
Distribute infiltration spatially

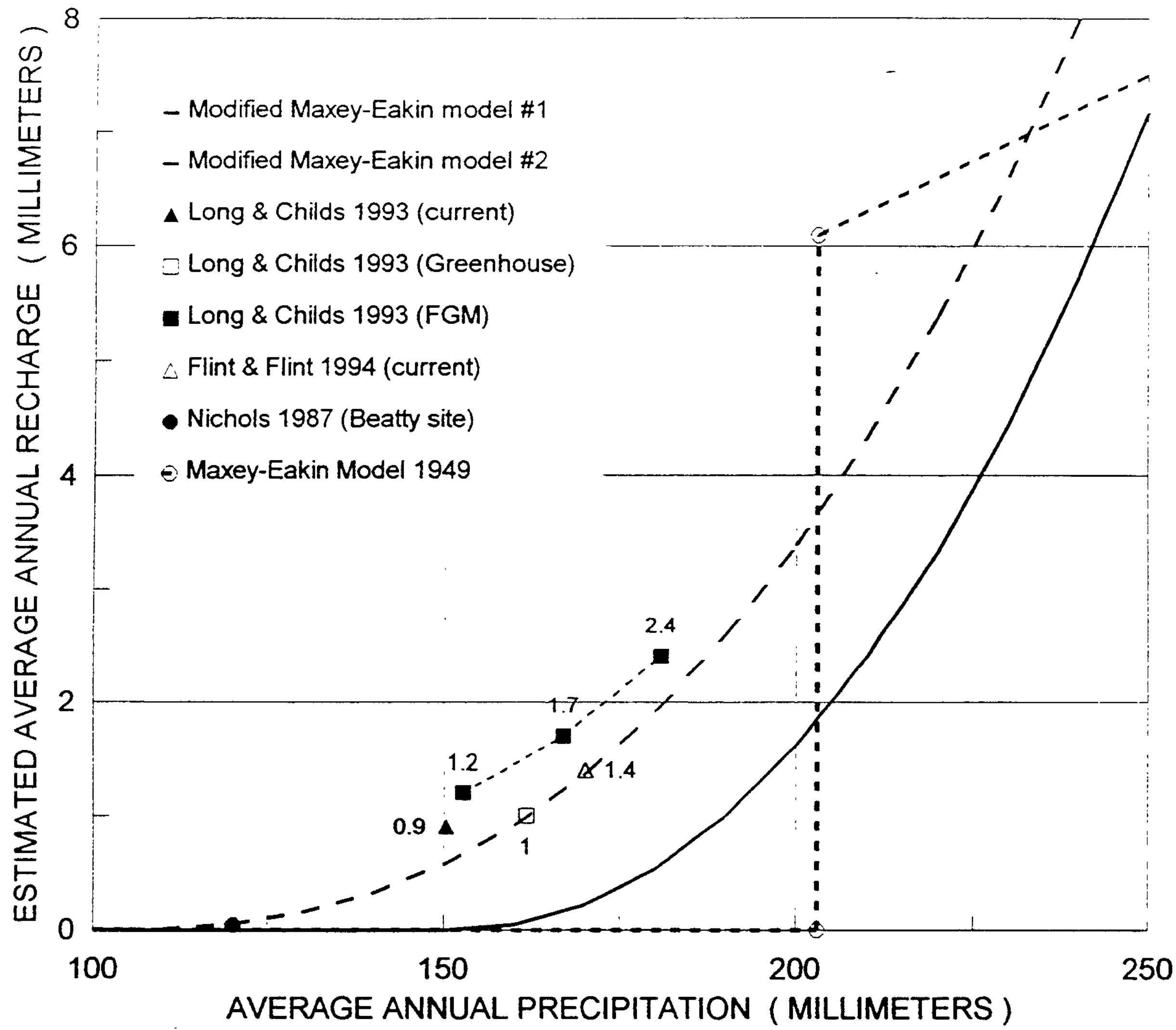
(point measurements expanded to 3-D site scale model)

- **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.

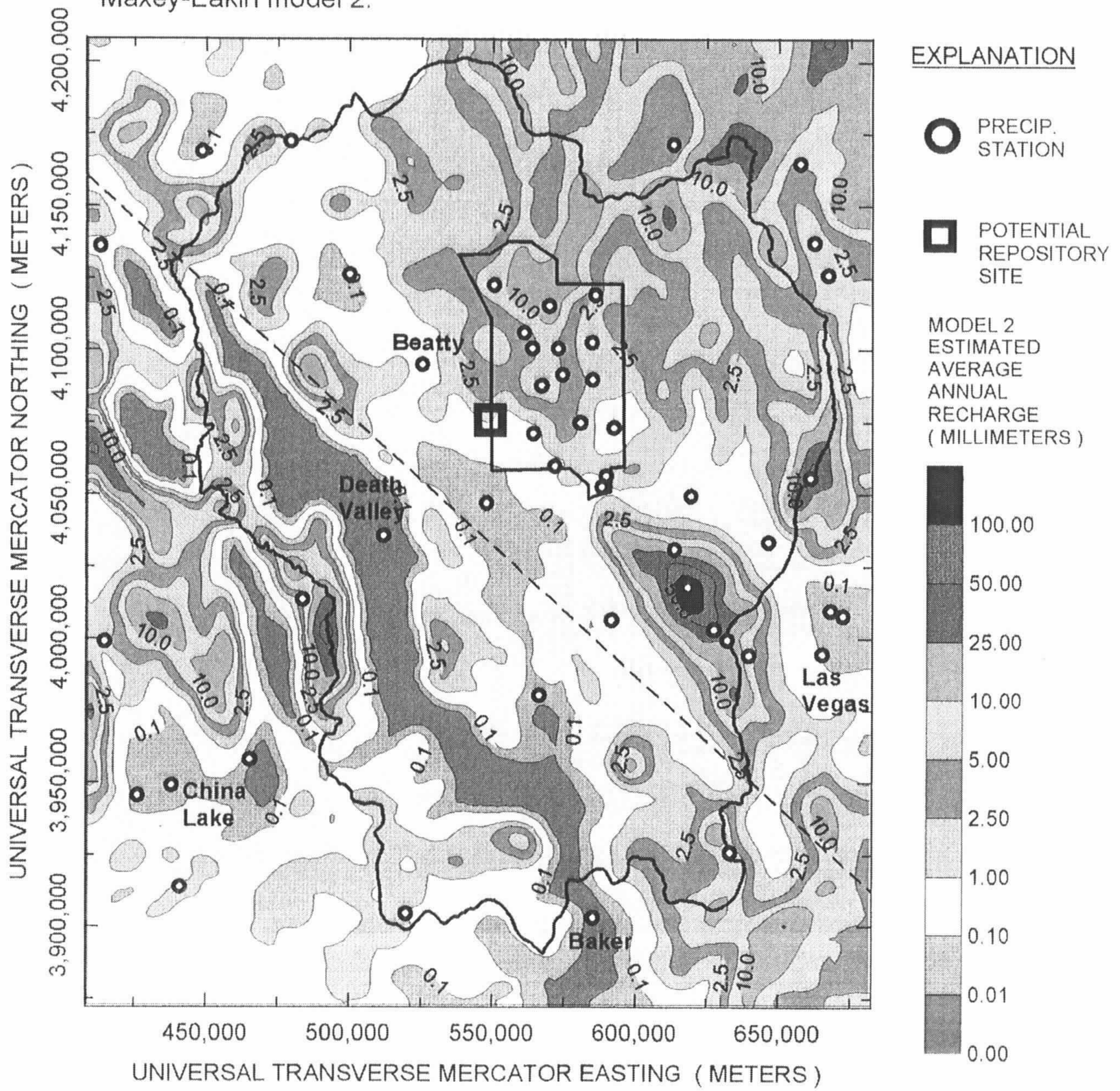



350
300
250
200
150
100
50
0
ESTIMATED AVERAGE ANNUAL RECHARGE (MILLIMETERS)
Maxey Eakin Model (1949)
Lichty-McKinley estimates (1995)
Modified Maxey-Eakin model 1
Modified Maxey-Eakin model 2
0
200
400
600
800
AVERAGE ANNUAL PRECIPITATION (MILLIMETERS)



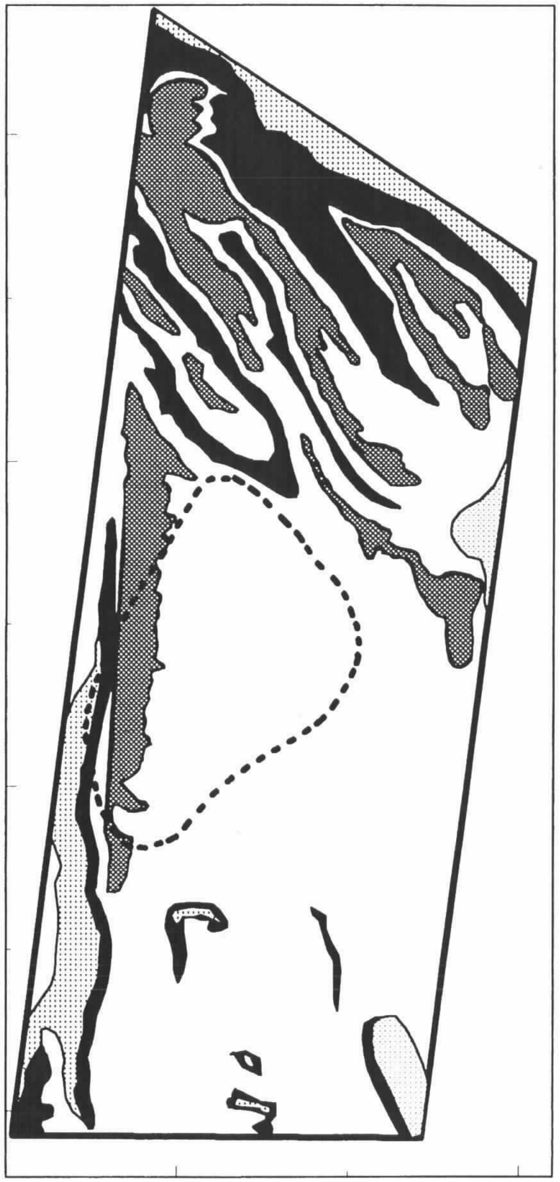
ESTIMATED AVERAGE ANNUAL RECHARGE (MILLIMETERS)
AVERAGE ANNUAL PRECIPITATION (MILLIMETERS)
0
2
4
6
8
100
150
200
250
Modified Maxey-Eakin model #1
Modified Maxey-Eakin model #2
Long & Childs 1993 (current)
Long & Childs 1993 (Greenhouse)
Long & Childs 1993 (FGM)
Flint & Flint 1994 (current)
Nichols 1987 (Beatty site)
Maxey-Eakin Model 1949
2.4
1.7
1.2
1.4
0.9
1

Estimated average annual recharge for the Yucca Mountain region using cokriged average annual precipitation and the modified Maxey-Eakin model 2.



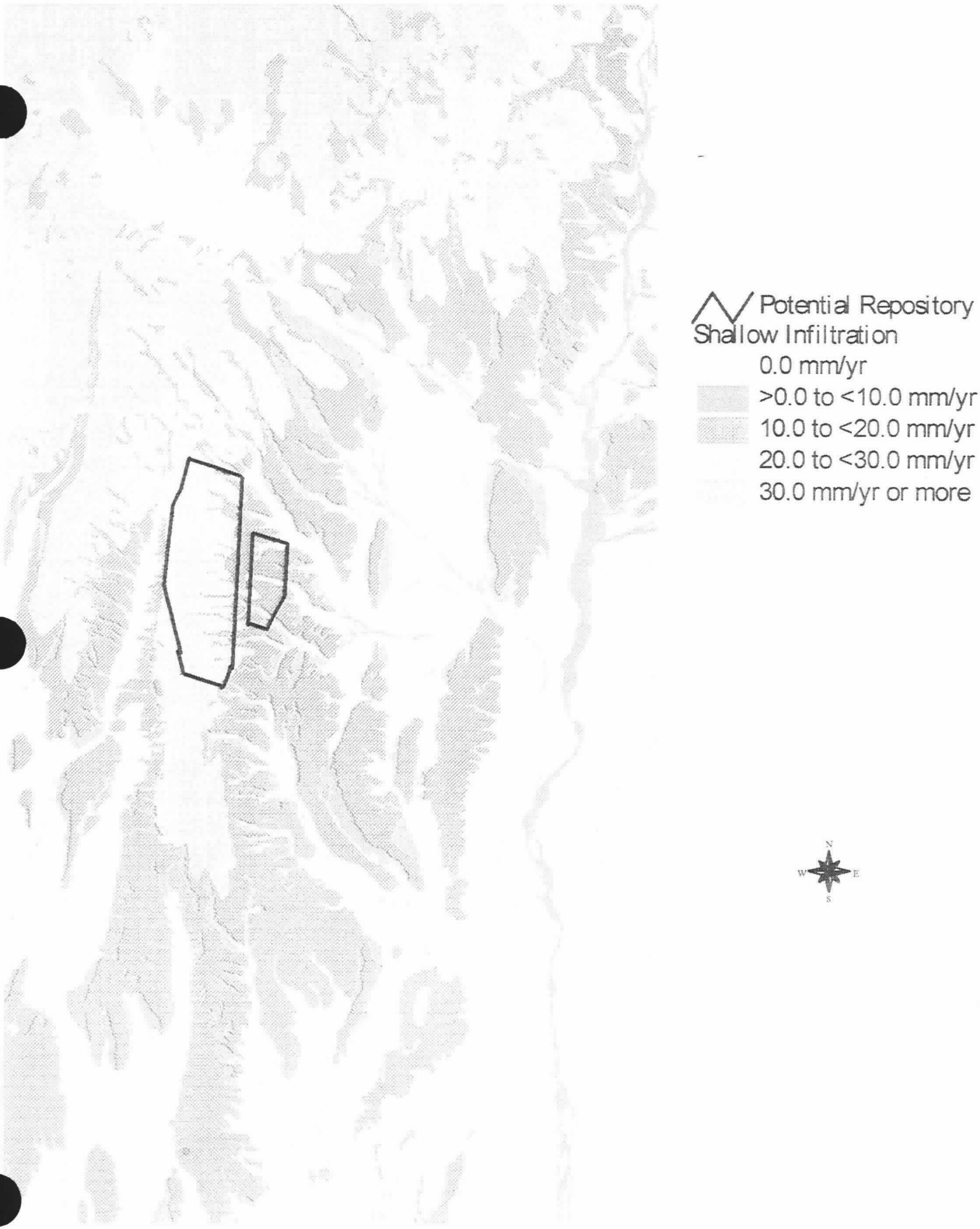
Distribute infiltration spatially

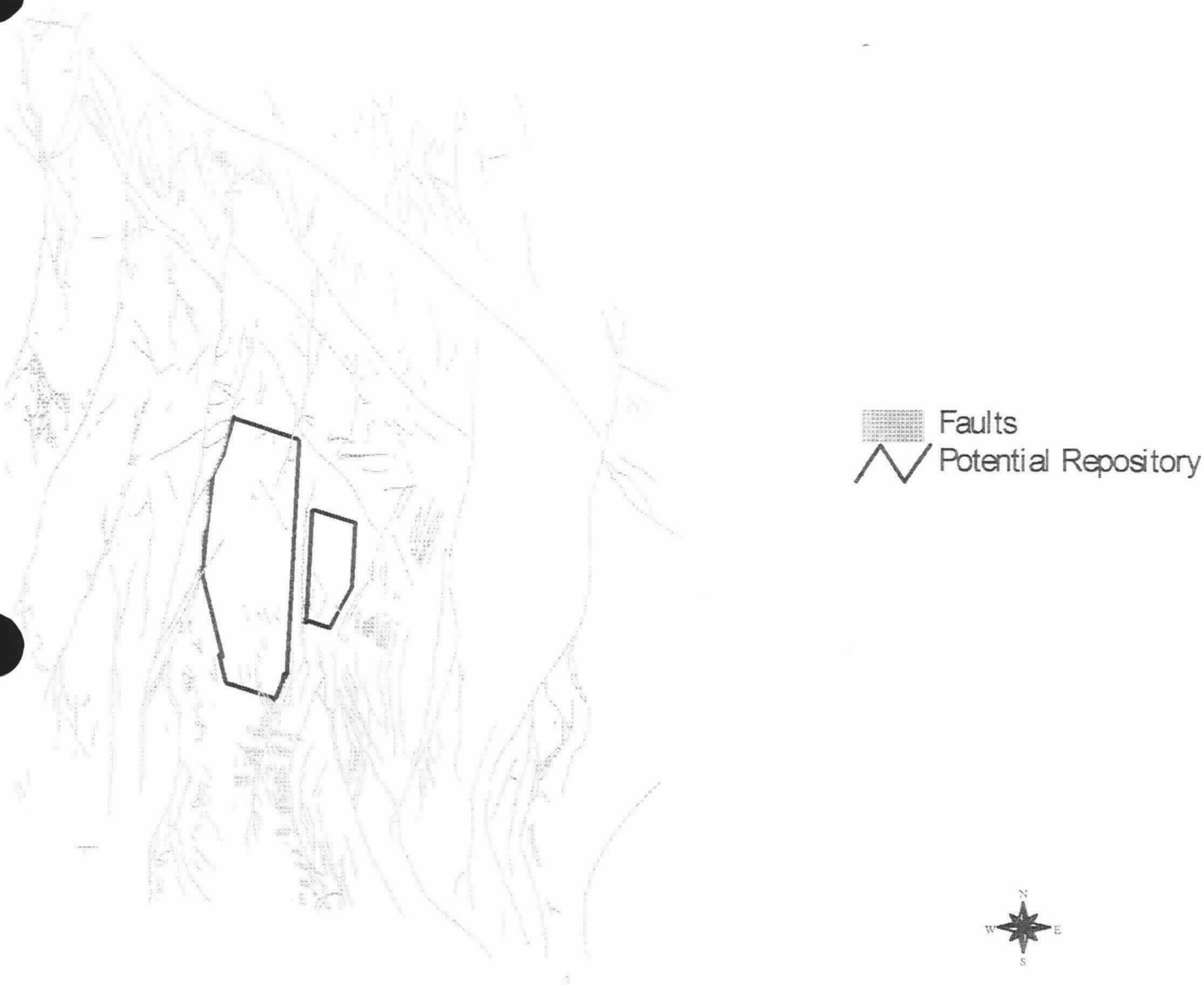
- Flux map approach (Static)
  - based on properties, *in situ* conditions and soil physics calculations
  - based on statistical distribution calibrated to neutron hole measurements

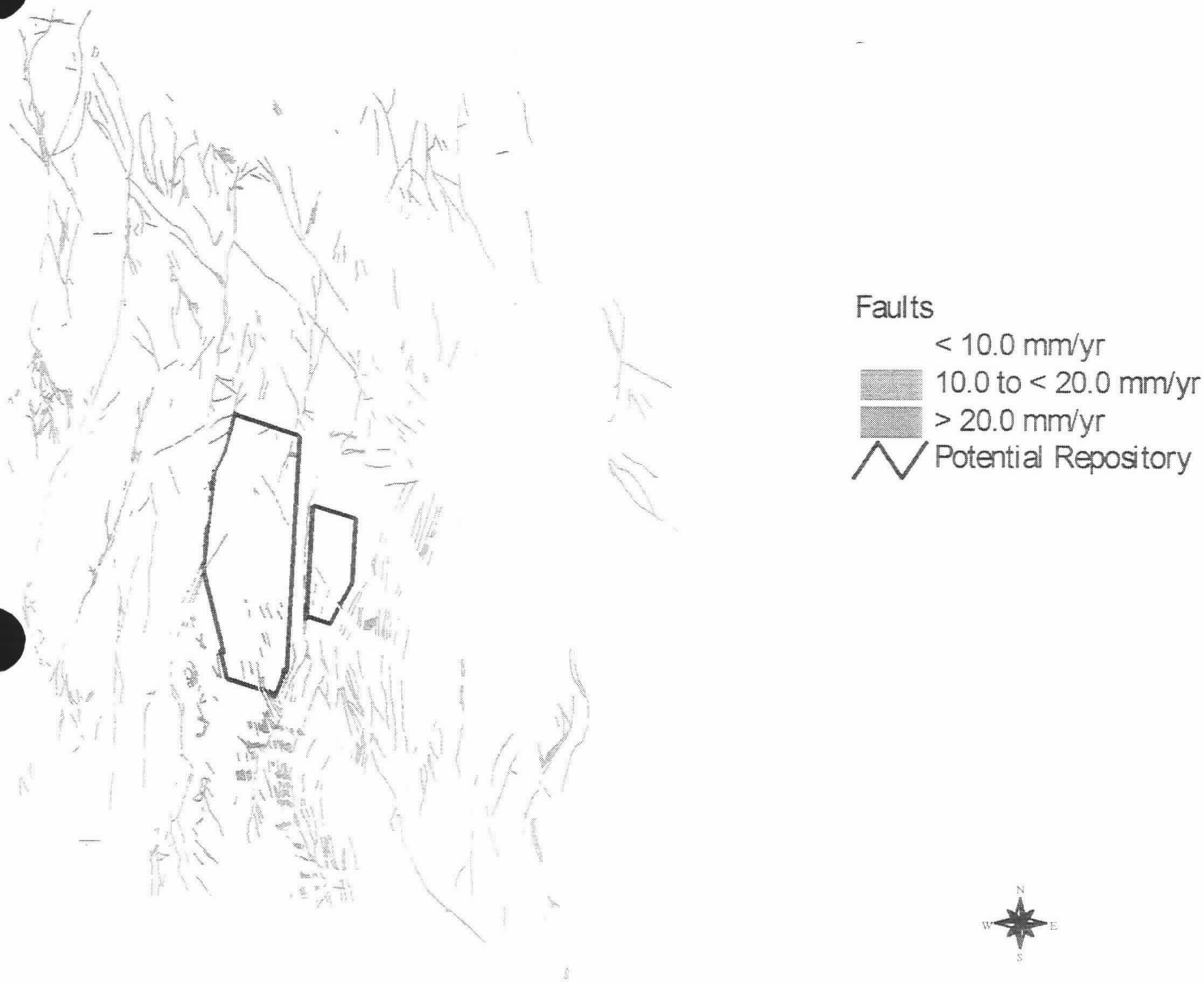


Matrix flux in mm/year

PTn	13.40
Rainier Mesa	0.60
Tiva Mod. Welded	0.22
Topopah Welded	0.08
Tiva Welded	0.02


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
Potential Repository
N
W
E
S


Faults
< 10.0 mm/yr
10.0 to < 20.0 mm/yr
> 20.0 mm/yr
Potential Repository
N
W
E
S

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

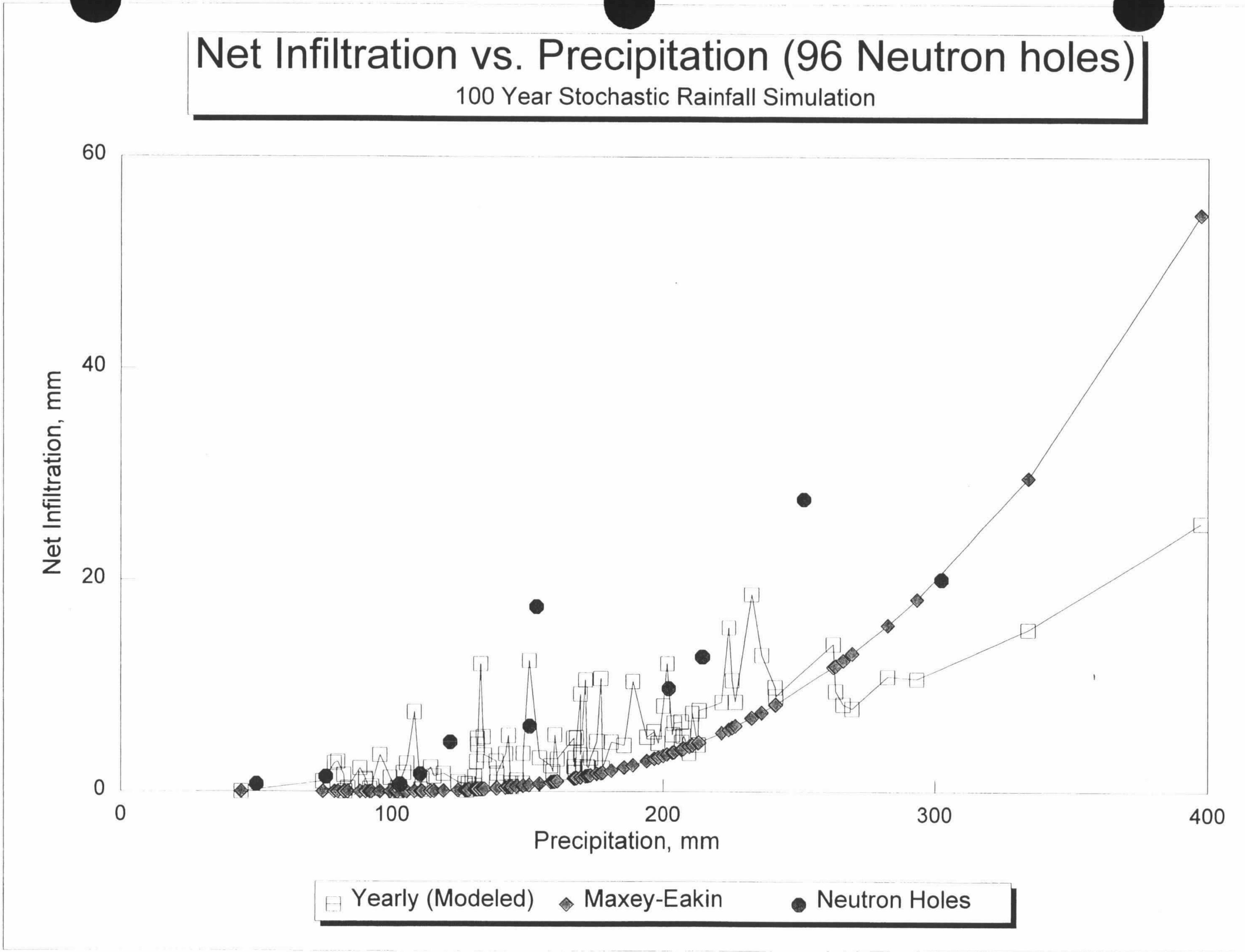
Inputs:

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

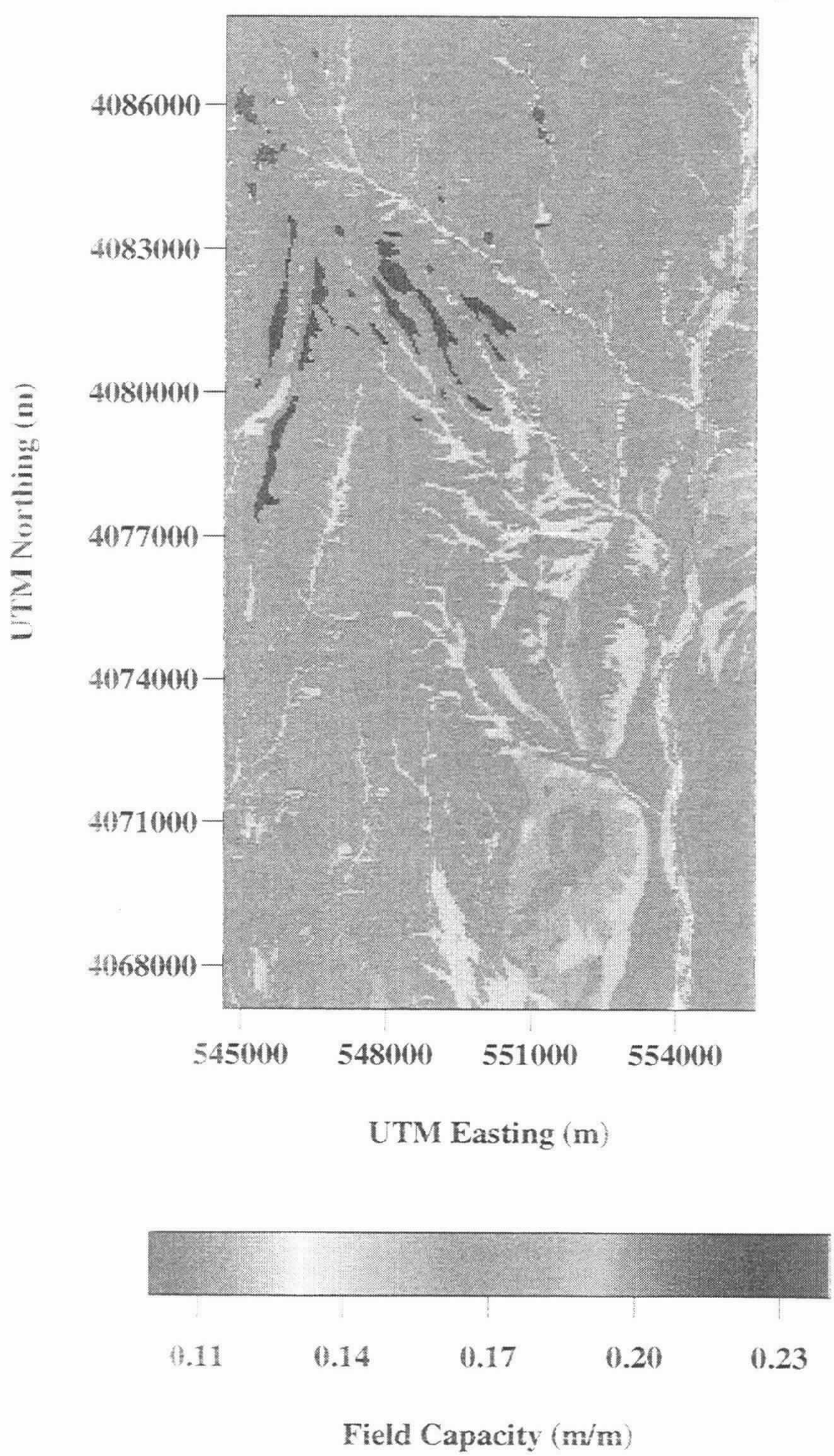
- Evaporation and Transpiration (Hourly)
  - -Solar radiation model
    - Slope, aspect, elevation, latitude, longitude, blocking ridges
  - -Priestley-Taylor Equation
    - Plant root function
    - Soil water limiting function

- Soil Water Storage (Daily)
  - Field capacity
  - Residual water content
  - Soil thickness
  - Bucket overflow term

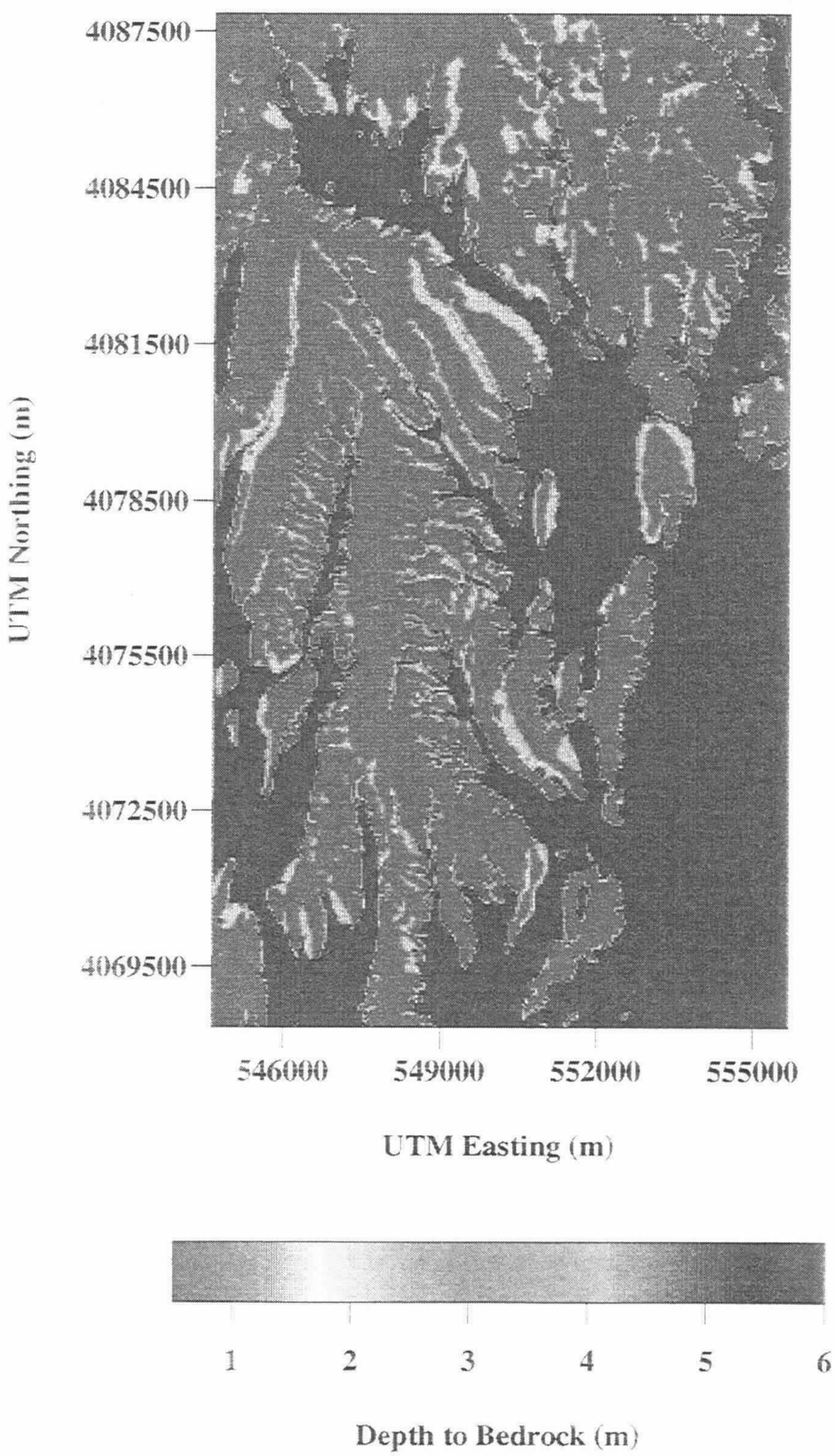
- Drainage (Daily)
  - Permeability of underlying matrix
  - Permeability of underlying fractures
    - Fracture density
    - Fracture properties
      - Open fractures
      - Filled fractures

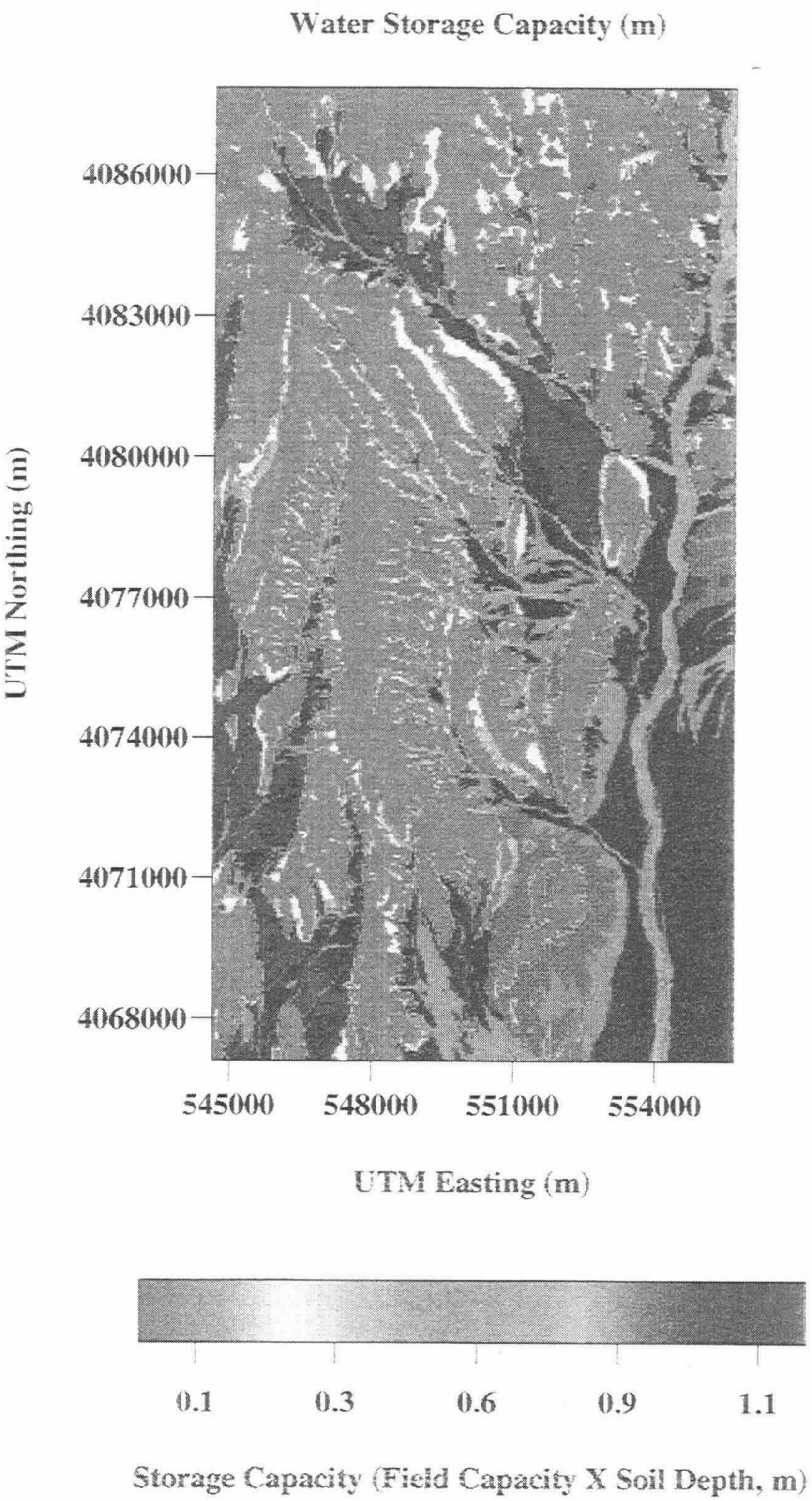

Net Infiltration vs. Precipitation (96 Neutron holes)
100 Year Stochastic Rainfall Simulation
Net Infiltration, mm
60
40
20
0
0
100
200
300
400
Precipitation, mm
Yearly (Modeled)
Maxey-Eakin
Neutron Holes

Field Capacity

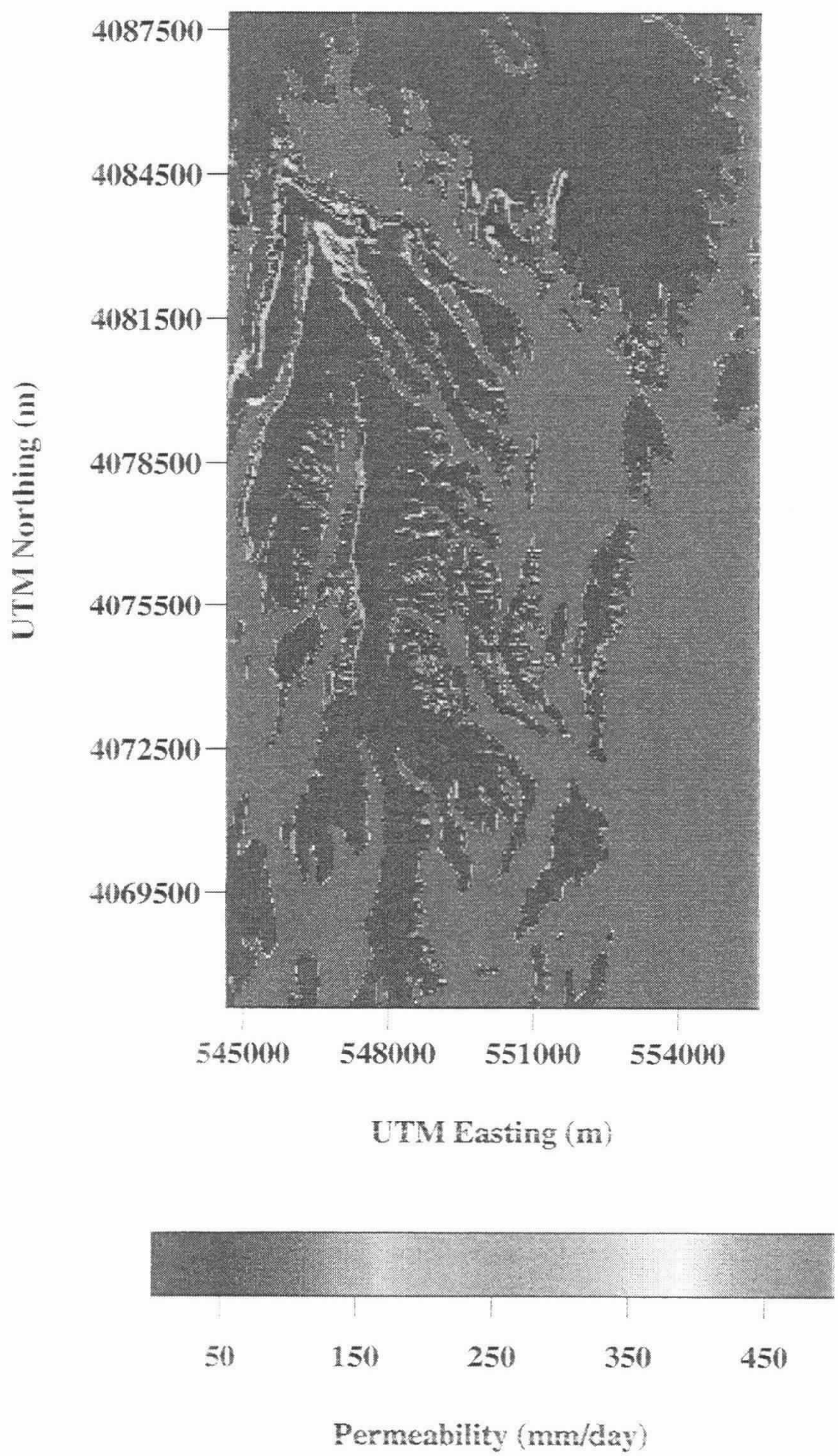


Depth to Bedrock Catagories

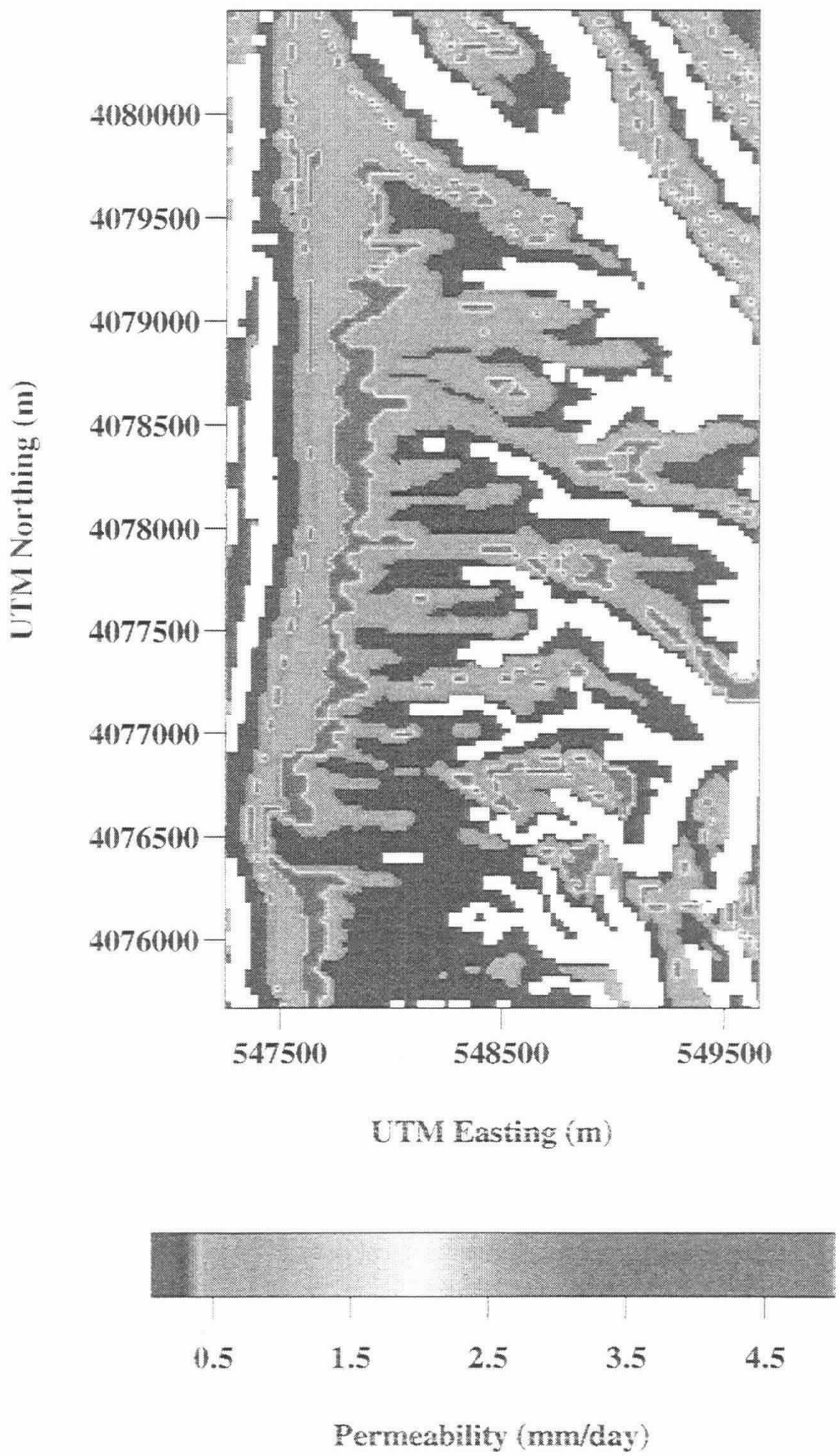



Water Storage Capacity (m)
4086000
4083000
4080000
4077000
4074000
4071000
4068000
UTM Northing (m)
545000
548000
551000
554000
UTM Easting (m)
0.1
0.3
0.6
0.9
1.1
Storage Capacity (Field Capacity X Soil Depth, m)

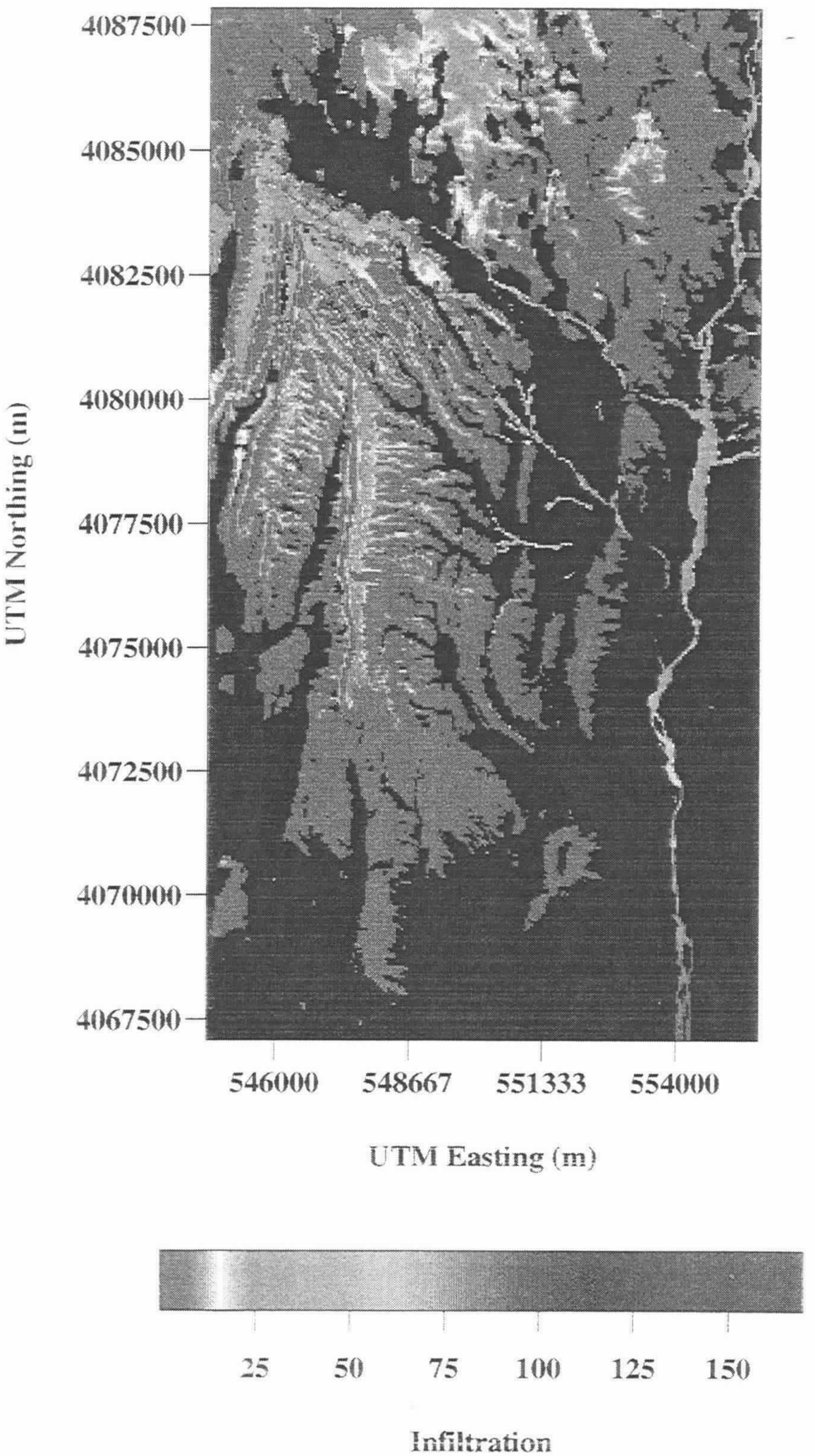
Bedrock Permeability (with Fractures) (or deep soil permeability)



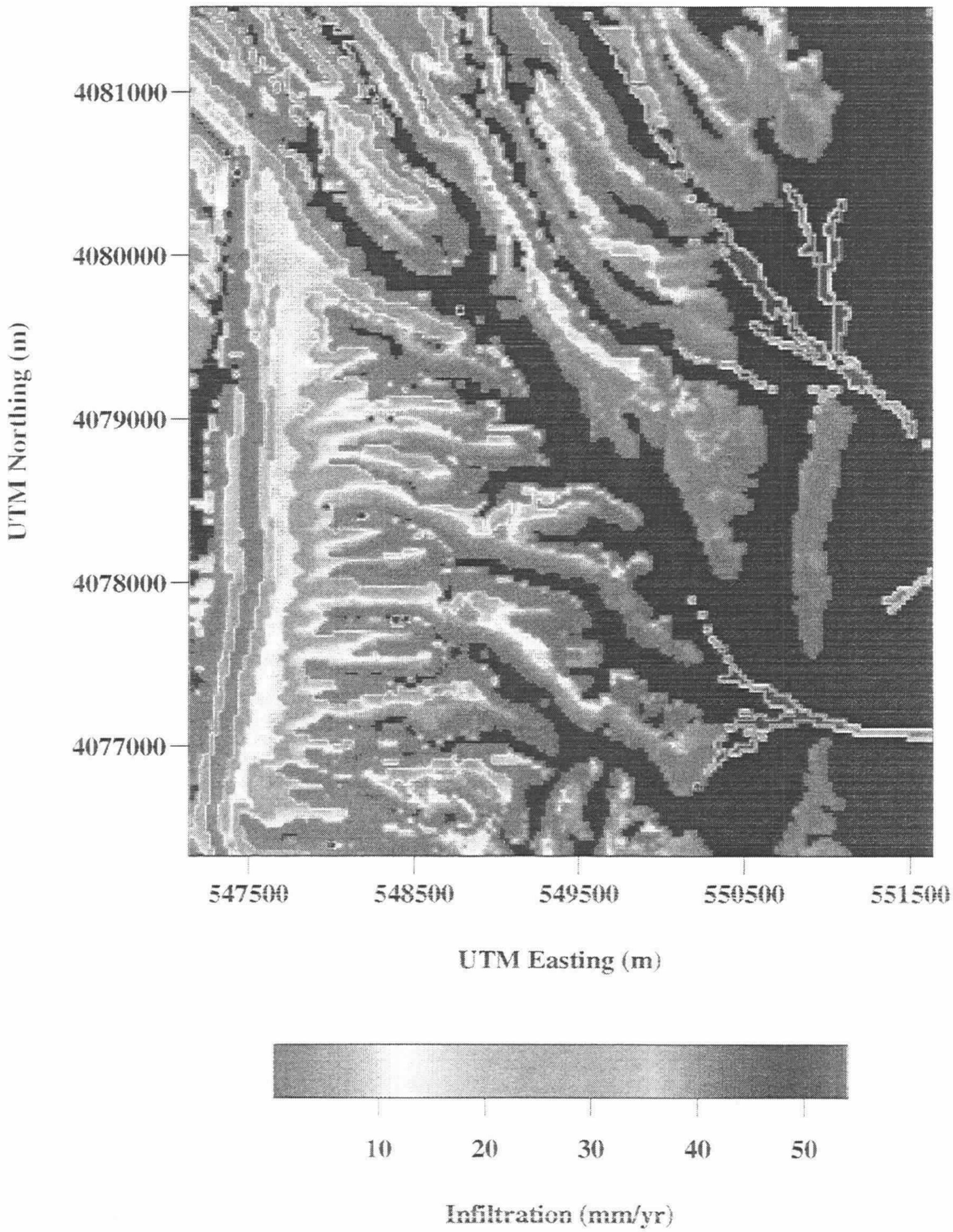
Bedrock Permeability (with fractures)



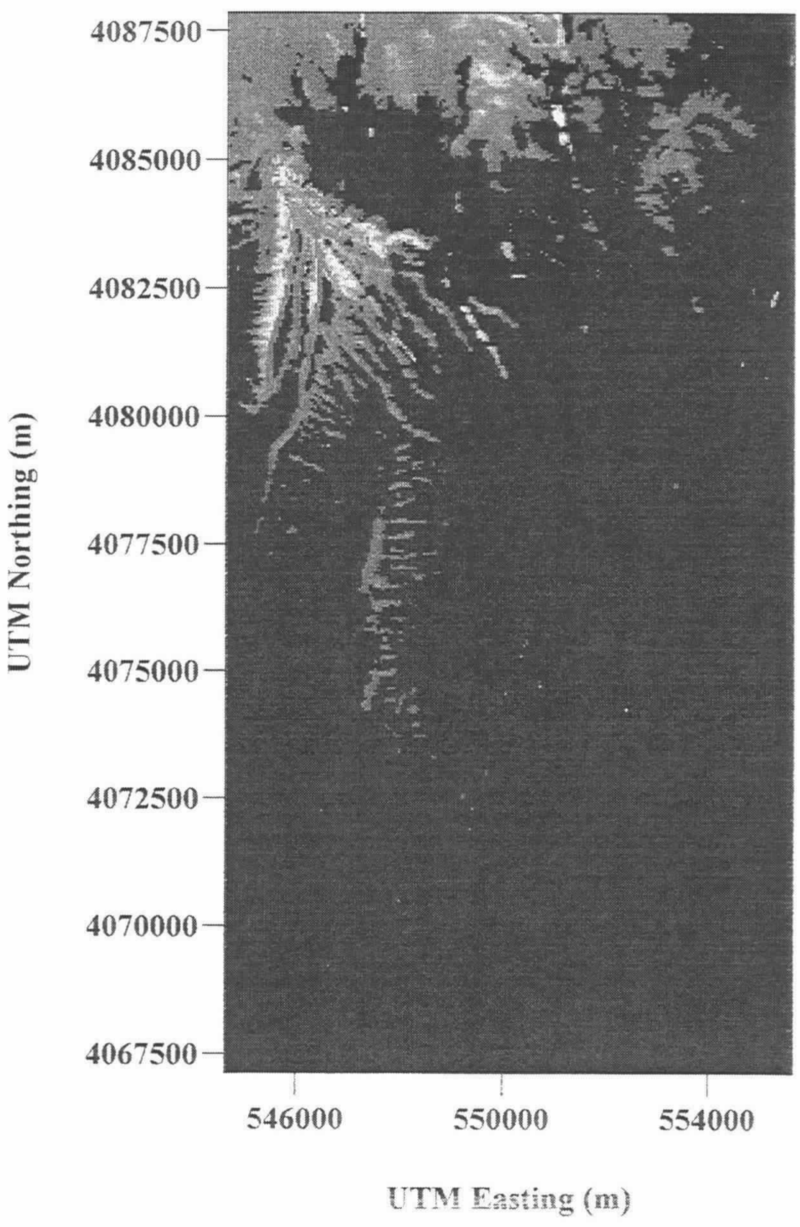
Infiltration (Precipitation simulation of 205 mm/yr)

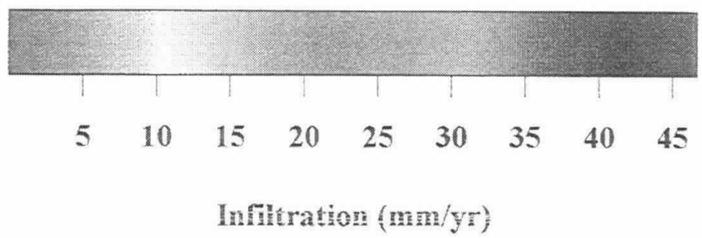


Infiltration (Precipitation simulation of 205 mm/yr)



Infiltration (Precipitation simulation of 162 mm/yr)

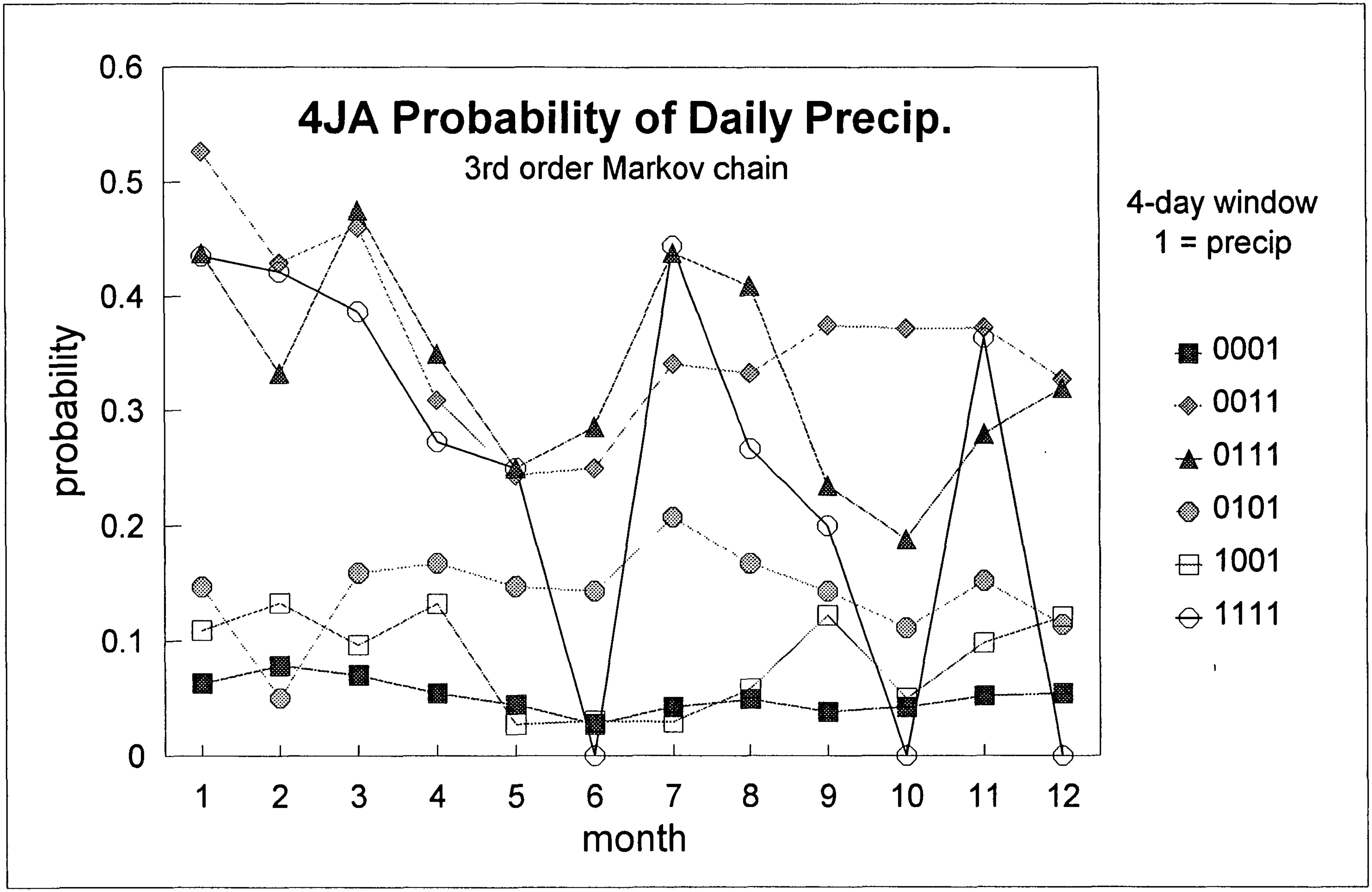




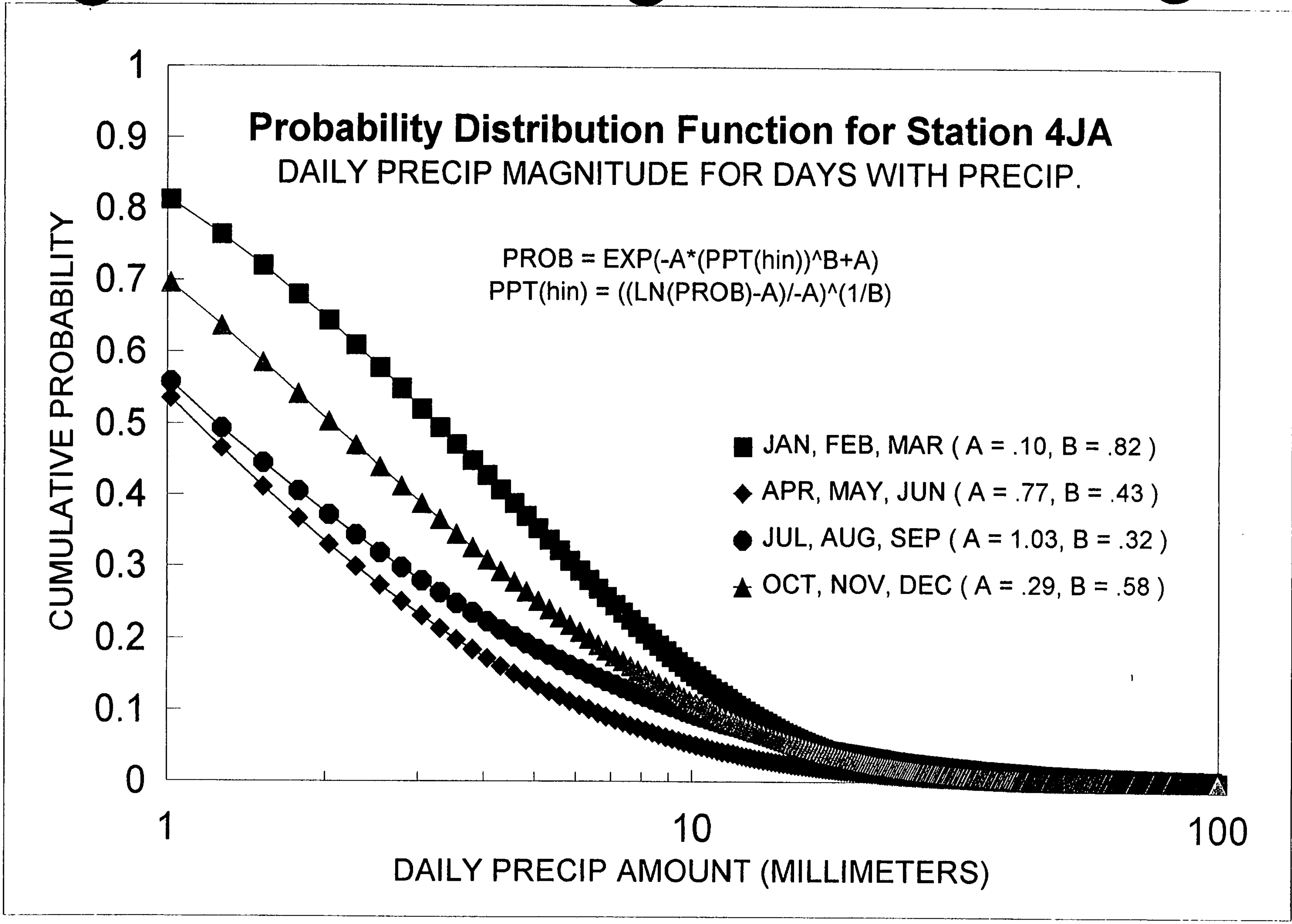
Distribute infiltration in time

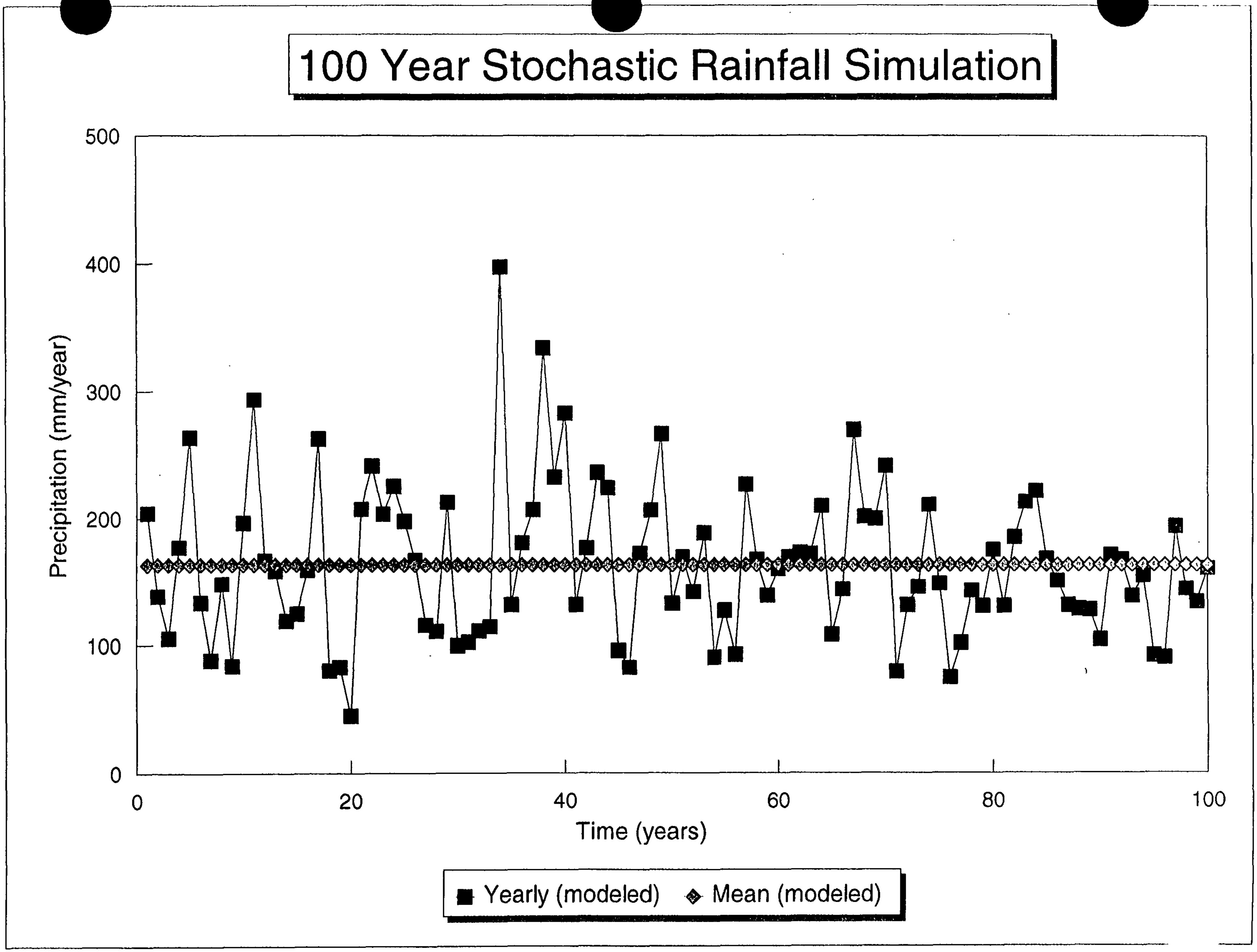
Measured and Modeled

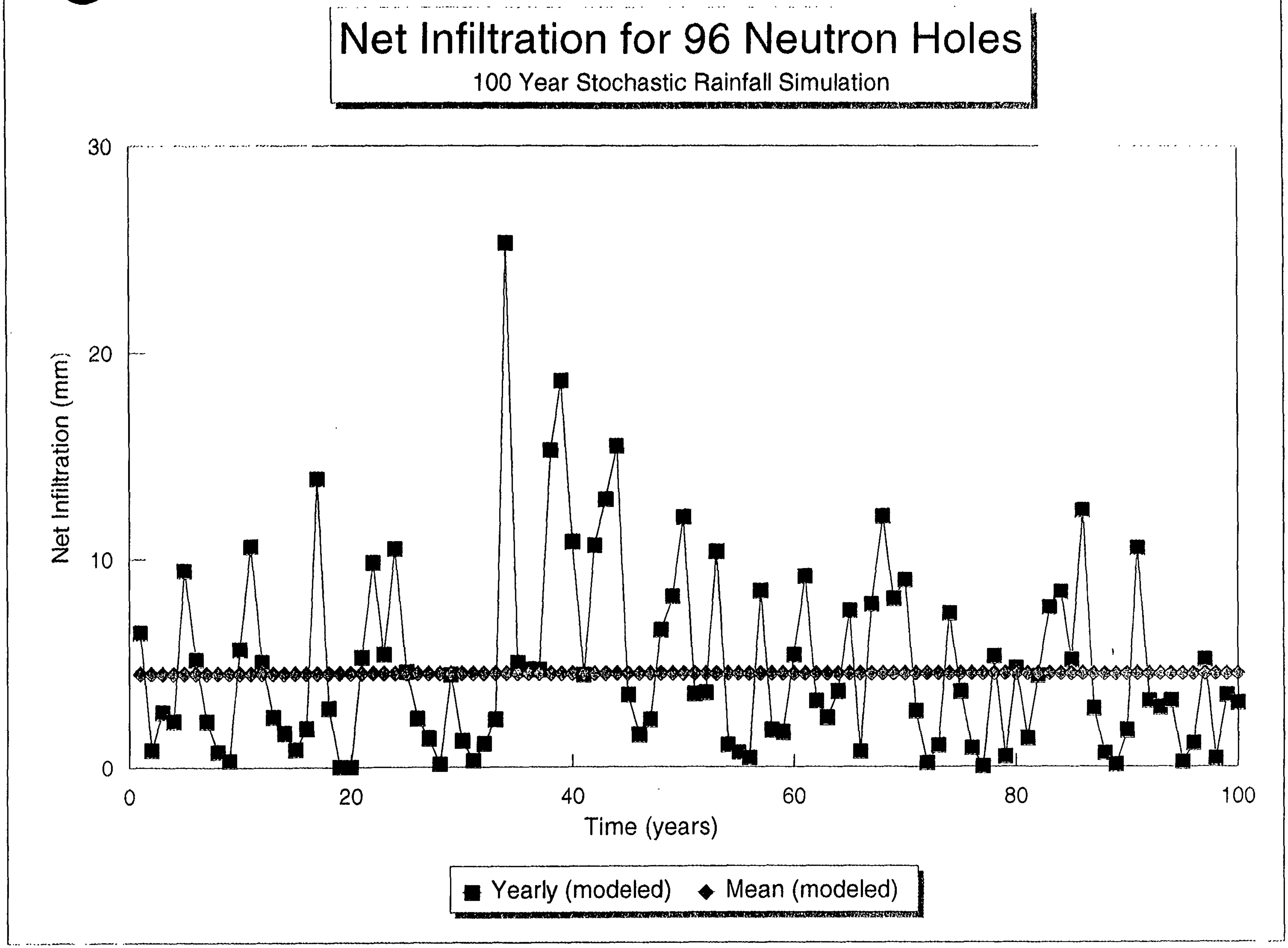
- Use 10 years of site data from neutron probes and precipitation
- Use 50 years of regional precipitation data
- Stochastic rainfall model
  - Used to match regional climate (precipitation and air temperature)
  - Individual simulation is based on seasonality (monthly, 4th order Markov chains)



4JA Probability of Daily Precip.
3rd order Markov chain
4-day window
1 = precip
0001
0011
0111
0101
1001
1111
probability
0.6
0.5
0.4
0.3
0.2
0.1
0
month
1
2
3
4
5
6
7
8
9
10
11
12


Probability Distribution Function for Station 4JA
DAILY PRECIP MAGNITUDE FOR DAYS WITH PRECIP.
PROB = EXP(-A*(PPT(hin))^B+A)
PPT(hin) = ((LN(PROB)-A)/-A)^(1/B)
JAN, FEB, MAR (A = .10, B = .82)
APR, MAY, JUN (A = .77, B = .43)
JUL, AUG, SEP (A = 1.03, B = .32)
OCT, NOV, DEC (A = .29, B = .58)
CUMULATIVE PROBABILITY
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
10
100
DAILY PRECIP AMOUNT (MILLIMETERS)

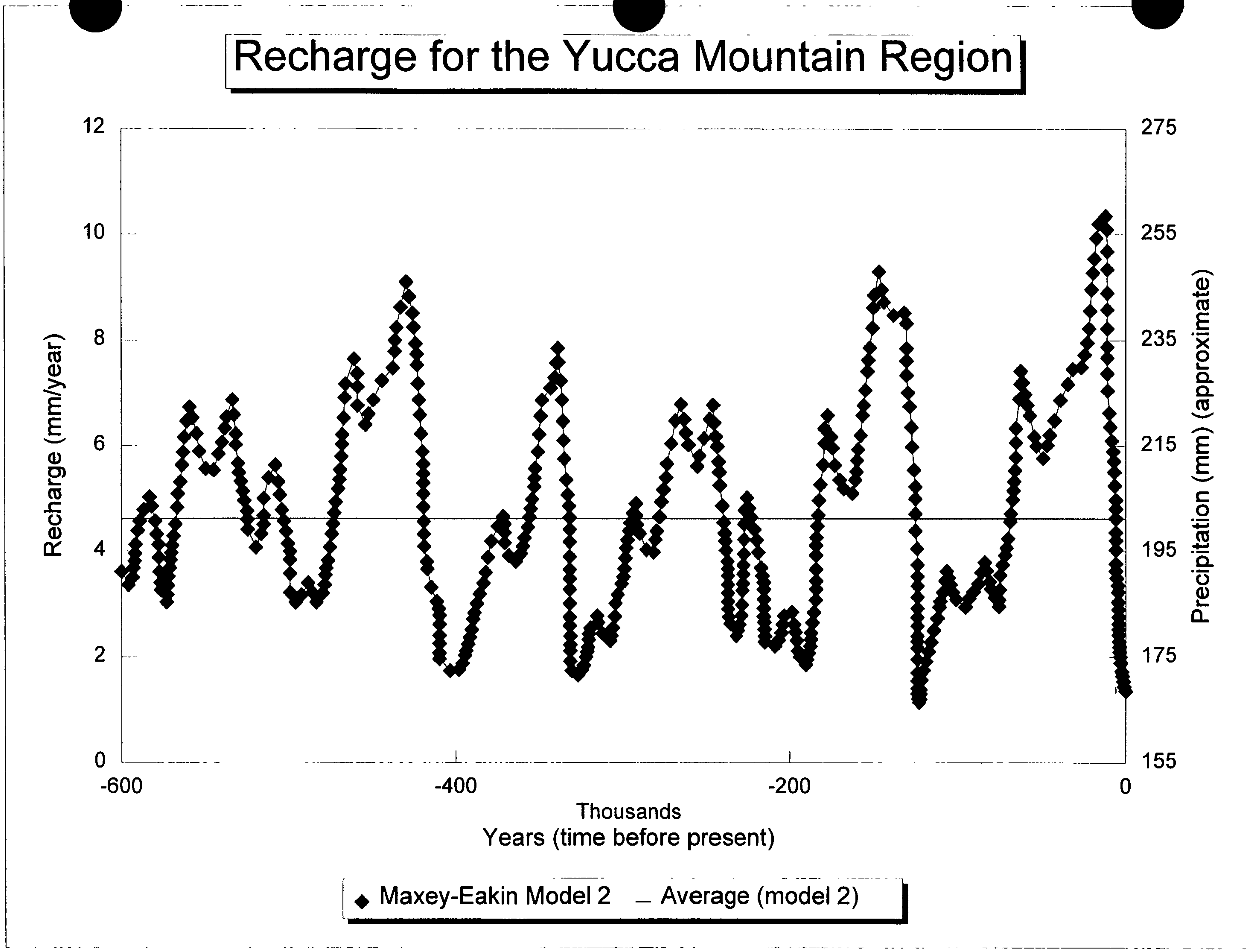

100 Year Stochastic Rainfall Simulation
Precipitation (mm/year)
500
400
300
200
100
0
0
20
40
60
80
100
Time (years)
Yearly (modeled)
Mean (modeled)



Net Infiltration for 96 Neutron Holes
100 Year Stochastic Rainfall Simulation
30
20
10
0
Net Infiltration (mm)
0
20
40
60
80
100
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
Recharge (mm/year)
Precipitation (mm) (approximate)
0
2
4
6
8
10
12
155
175
195
215
235
255
275
-600
-400
-200
0
Thousands
Years (time before present)
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