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

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: PERFORMANCE OF NATURAL BARRIERS

PRESENTER: DR. DWIGHT HOXIE

PRESENTER'S TITLE AND ORGANIZATION: HYDROLOGIST
YUCCA MOUNTAIN PROJECT
U.S. GEOLOGICAL SURVEY

PRESENTER'S TELEPHONE NUMBER: (303) 236-5019

MAY 16-17, 1989

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SCOPE OF PRESENTATION

- REGULATORY REQUIREMENTS FOR THE NATURAL BARRIERS: THE GROUND-WATER TRAVEL TIME (GWTT)
- INFORMATION NEEDS FOR GWTT CALCULATIONS
- GWTT CALCULATIONS FOR THE ENVIRONMENTAL ASSESSMENT
- UNSATURATED-ZONE HYDROGEOLOGIC SYSTEM: CONCEPTS AND UNCERTAINTIES
- ADDITIONAL INFORMATION NEEDS
- CURRENT AND FUTURE ACTIVITIES

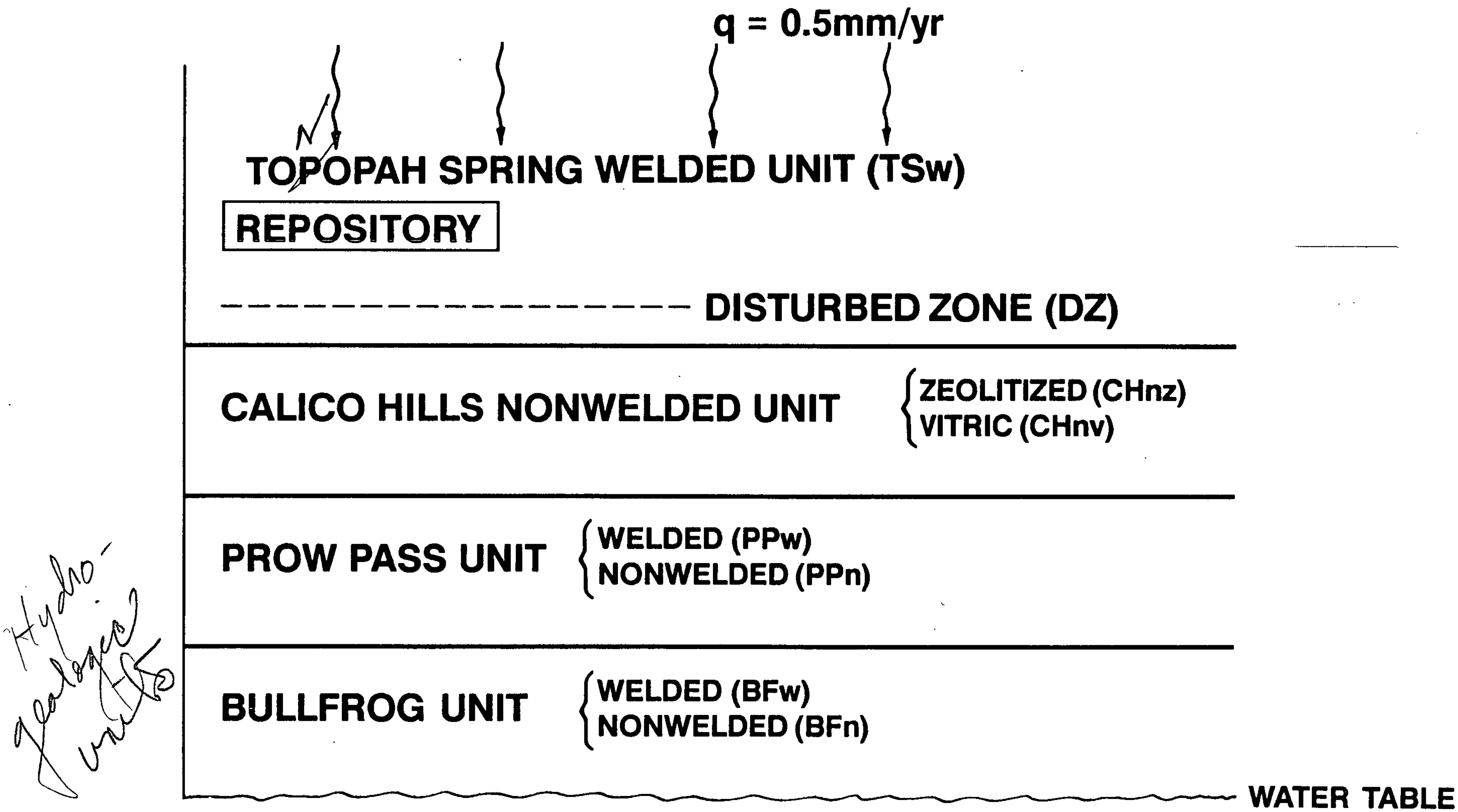
10 CFR PART 60.113(a)(2)

" THE GEOLOGIC REPOSITORY SHALL BE LOCATED SO THAT PRE-WASTE-EMPLACEMENT GROUNDWATER TRAVEL TIME ALONG THE FASTEST PATH OF LIKELY RADIONUCLIDE TRAVEL FROM DISTURBED ZONE TO THE ACCESSIBLE ENVIRONMENT SHALL BE AT LEAST 1,000 YEARS OR SUCH OTHER TRAVEL TIME AS MAY BE APPROVED OR SPECIFIED BY THE COMMISSION"

INFORMATION NEEDED TO EVALUATE GROUND-WATER TRAVEL TIME

- CHARACTERISTICS OF THE GROUND-WATER FLOW SYSTEM
  - GEOLOGIC FRAMEWORK
  - INITIAL AND BOUNDARY CONDITIONS
  - HYDROLOGIC AND OTHER PHYSICAL PROCESSES
- CALCULATIONAL MODELS
- EXTENT OF DISTURBED ZONE
- PATHS OF LIKELY RADIONUCLIDE TRAVEL
- EVALUATION OF GROUND-WATER TRAVEL TIME

CONCEPTUAL MODEL USED FOR THE ENVIRONMENTAL ASSESSMENT (EA) GWTT CALCULATIONS

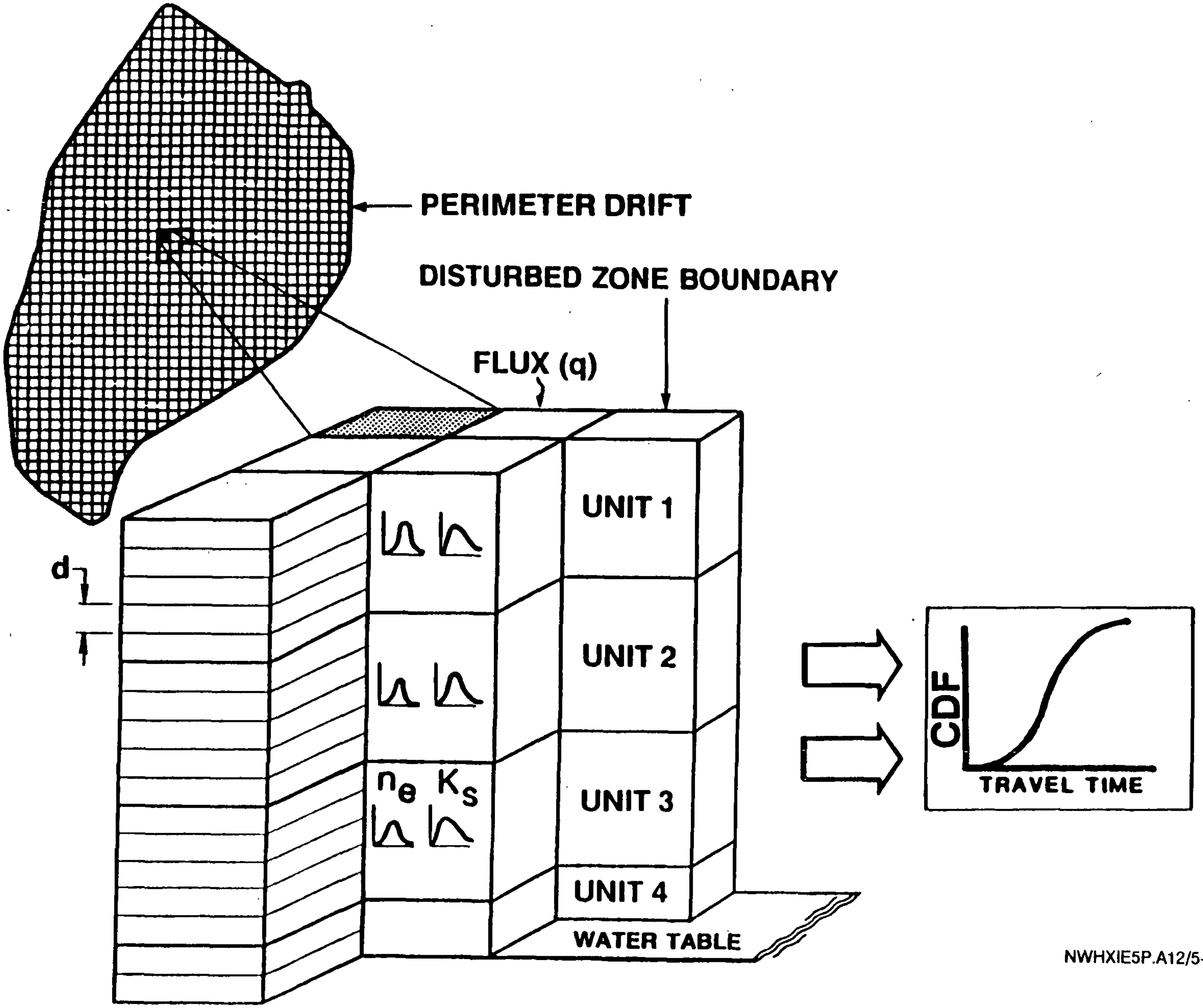


GWTT CALCULATIONS FOR THE EA

THE PRINCIPAL ASSUMPTIONS:

- UNIT VERTICAL HYDRAULIC GRADIENT
- LIQUID-WATER FLUX q IS VERTICAL AND IS CONSTANT IN SPACE AND TIME
- EFFECTIVE MATRIX HYDRAULIC CONDUCTIVITY $K = q$
- SATURATED HYDRAULIC CONDUCTIVITY (K_{sat}) AND EFFECTIVE POROSITY (n_e) ARE RANDOM VARIABLES
- WATER FLOW IN FRACTURES DOMINATES IF $q \geq 0.95 \cdot K_{sat}$
- BASE OF DISTURBED ZONE (DZ) IS 50m BELOW RE-POSITORY MIDPLANE

APPROACH TO GROUNDWATER TRAVEL TIME CALCULATION FOR THE ENVIRONMENTAL ASSESSMENT



GWTT T_i FOR COLUMN i CONSISTING OF N_i ELEMENTS OF THICKNESS d

$$Ti = \sum_{i=1}^{N_i} \frac{d}{V_i}$$

WHERE THE SEEPAGE VELOCITY V_i IS GIVEN BY

- **FOR THE ROCK MATRIX**

$$V_i = \frac{q}{n_e}\left(\frac{K_{sat}}{q}\right)^{\frac{1}{E}}$$

$$n_e = n(1 - S_r)$$

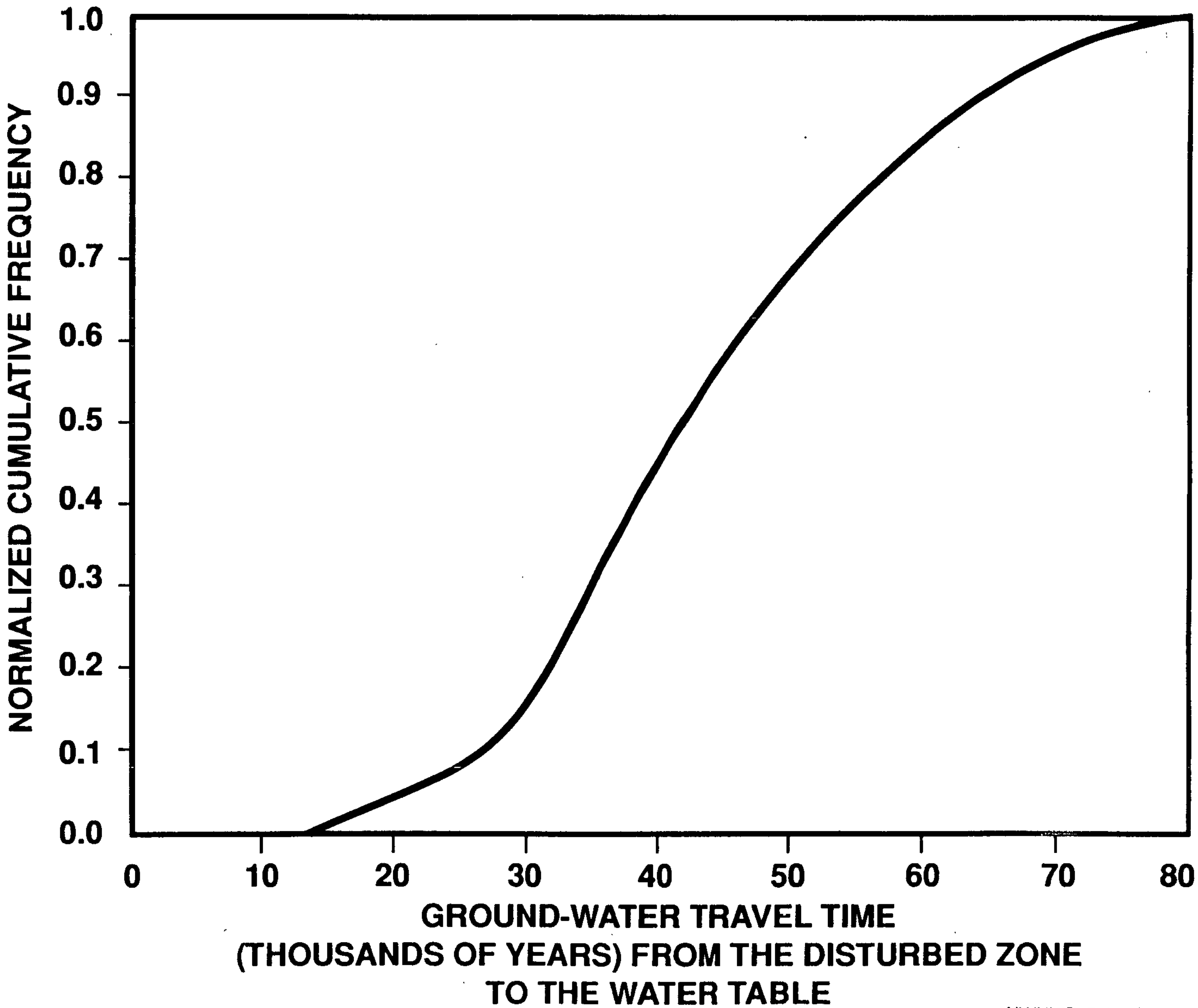
- **FOR THE FRACTURES**

$$V_i = (q - K_{sat}) \times 10^4 \quad \text{IF } q \geq 0.95 \cdot K_{sat}$$

HYDROLOGIC-PROPERTY DATA FOR THE EA GWTT CALCULATIONS

PROPERTY / HYDROGEOLOGIC UNIT	TSw	CHnv	CRATER FLAT TUFF				
			CHnz	PPw	PPn	BFw	BFn
MAXIMUM THICKNESS OF UNIT BETWEEN DZ AND THE WATER TABLE (m)	72	135	133	44	122	91	55
K_{sat} (mm/yr)	0.7	107	0.5	88	22	118	22
N_e	0.11	0.32	0.27	0.24	0.25	0.22	0.25
ε	5.9	4.2	7.0	4.0	5.2	4.6	5.2

GWTT CALCULATIONS FOR THE EA



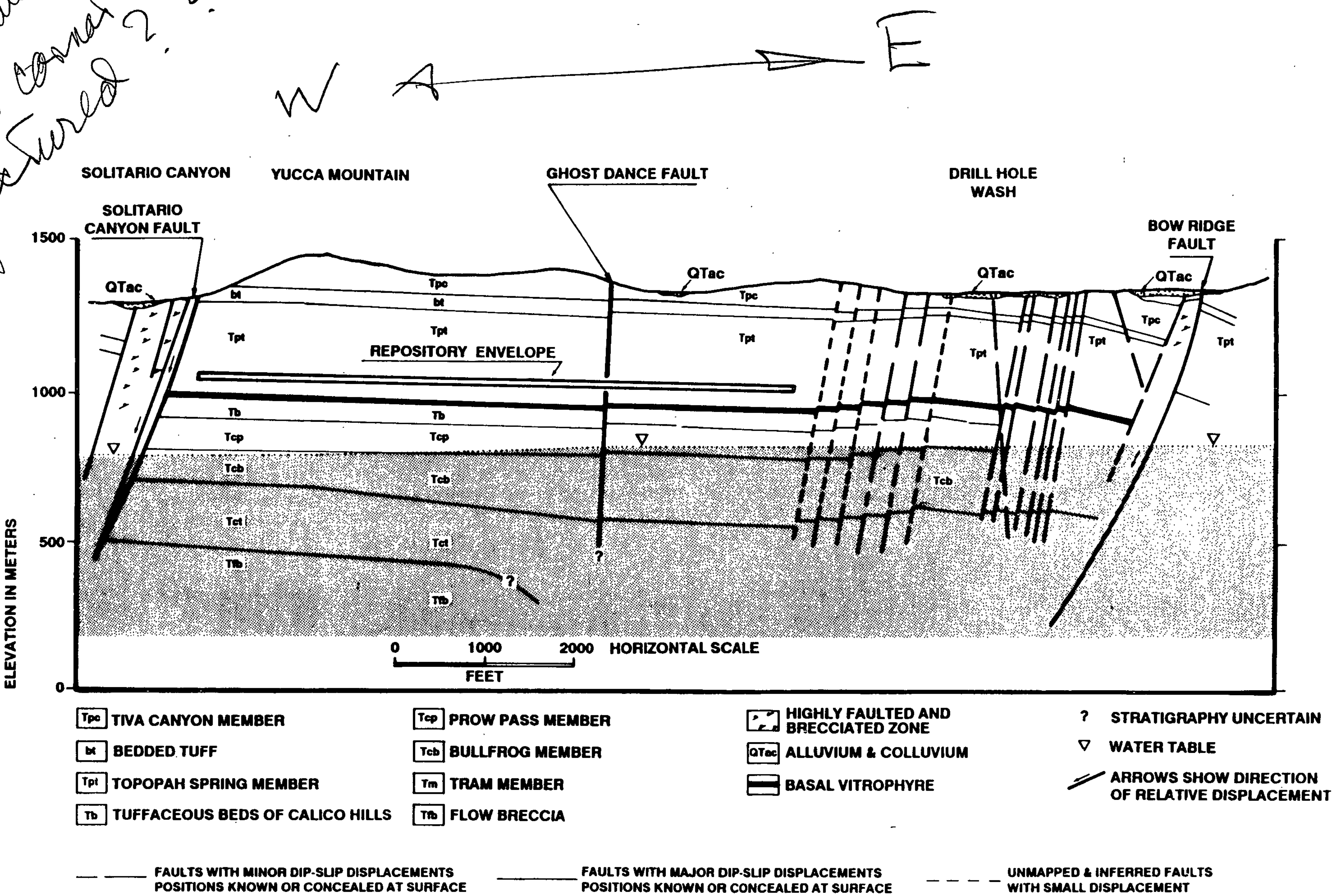
COMPONENTS OF A CONCEPTUAL MODEL FOR A HYDROLOGIC SYSTEM

- GEOLOGIC FRAMEWORK
- INITIAL AND BOUNDARY CONDITIONS
- HYDROLOGIC AND OTHER PHYSICAL PROCESSES

GEOLOGIC FRAMEWORK

- **STRUCTURAL FEATURES**
  - FAULTS
  - FOLDS
  - FRACTURES
- **HYDROGEOLOGIC UNITS**
  - HIGHLY FRACTURED WELDED TUFFS
  - SPARSELY FRACTURED NONWELDED TUFFS

no welded units cannot be fractured?



LOWER BOUNDARY CONDITION: THE WATER-TABLE CONFIGURATION

- DEFINITION: SURFACE IN SPACE ON WHICH LIQUID-WATER PRESSURE IS ZERO (ATMOSPHERE)
- VARIABLE IN SPACE
- VARIABLE IN TIME

UPPER BOUNDARY CONDITION: LAND-SURFACE NET INFILTRATION

- PAST → PALEOCLIMATOLOGY
- PRESENT

→ MEAN PRECIPITATION ~ 150 mm/yr

→ POTENTIAL EVAPOTRANSPIRATION
~1600 mm/yr

→ NET INFILTRATION 1 mm/yr

- FUTURE → CLIMATE CHANGE

LATERAL BOUNDARY CONDITIONS

- MUST ENCLOSE ALL POINTS IN SPACE FROM WHICH HYDROLOGIC-RELATED EFFECTS CAN PROPAGATE TO REPOSITORY SITE

- VARIABLE IN SPACE AND TIME

- WORKING HYPOTHESIS: DEFINED BY THE FAULT SYSTEMS SURROUNDING THE REPOSITORY BLOCK

HYDROLOGIC PROCESSES: AIR AND WATER-VAPOR FLOW

- TOTAL MOISTURE BALANCE = LIQUID WATER
  + WATER VAPOR
- WATER-VAPOR DIFFUSION
- WATER-VAPOR ADVECTION DUE TO BULK FLOW OF AIR

NOTATION

$\vec{r}$ **POSITION VECTOR IN SPACE** $\vec{r} = x\hat{i} + y\hat{j} + z\hat{k}$ (L)

S_f **SATURATION OF FLUID** f

$K(\vec{r})$ **INTRINSIC PERMEABILITY OF POROUS MEDIUM** (L^2)

$k_R(S_f)$ **RELATIVE PERMEABILITY OF FLUID** f

ρ_f **MASS DENSITY OF FLUID** f (M/L^3)

μ_f **VISCOSITY OF FLUID** f (M/LT)

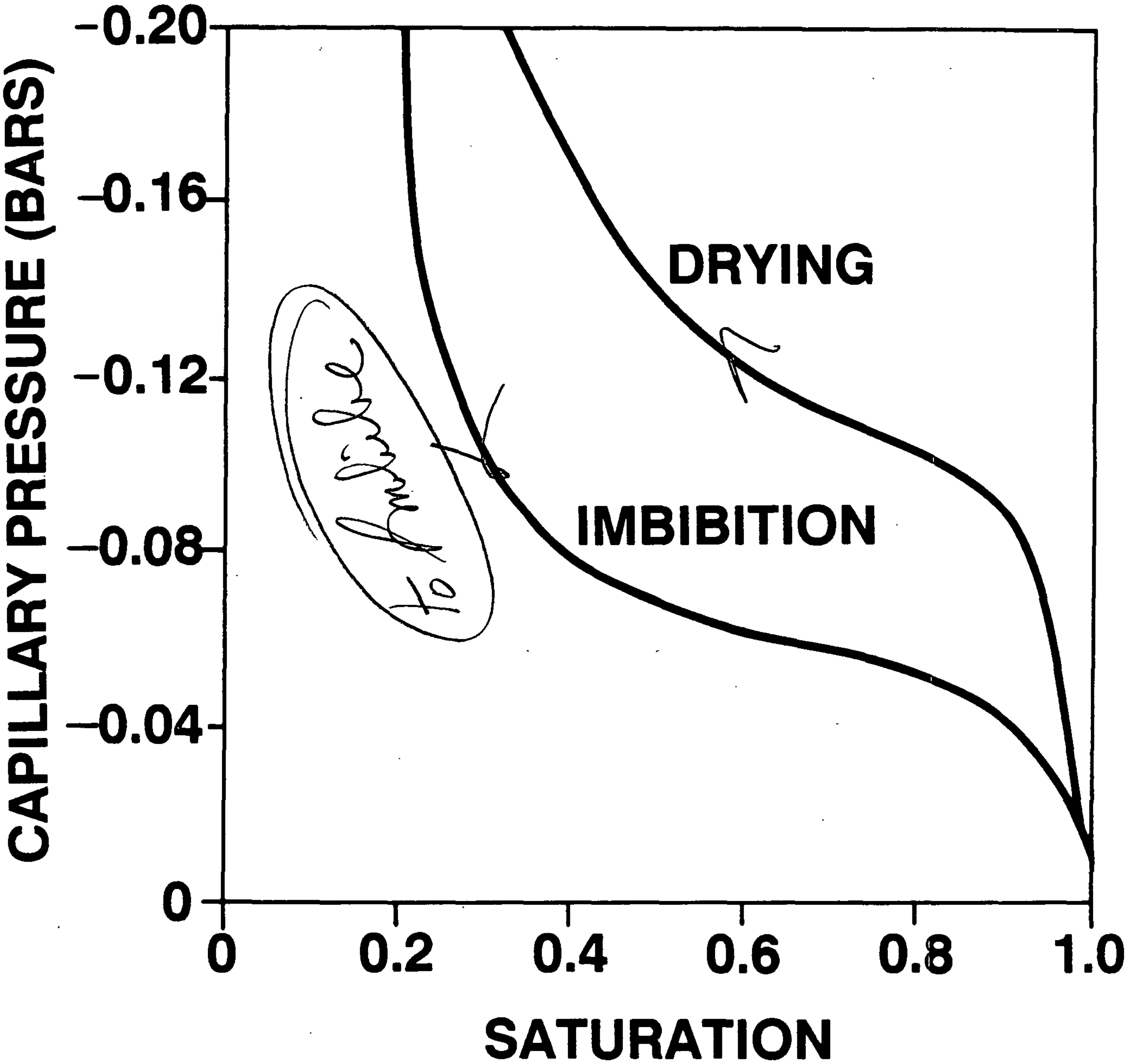
P_f **PORE PRESSURE OF FLUID** f (M/LT^2)

g **ACCELERATION OF GRAVITY** (L/T^2)

F_f **VECTOR VOLUMETRIC FLUX OF FLUID** f (L/T)

DARCY'S LAW II

$$F_f(r) = -\frac{k(r)k_R[S_f(r)]\rho_f}{\mu_f}\mathrm{Grad}(\frac{P_f(S_f)}{\rho_f} + gz)$$



CAPILLARY PRESSURE AS A FUNCTION OF
LIQUID-WATER VOLUMETRIC SATURATION
(DEL MONTE SAND)

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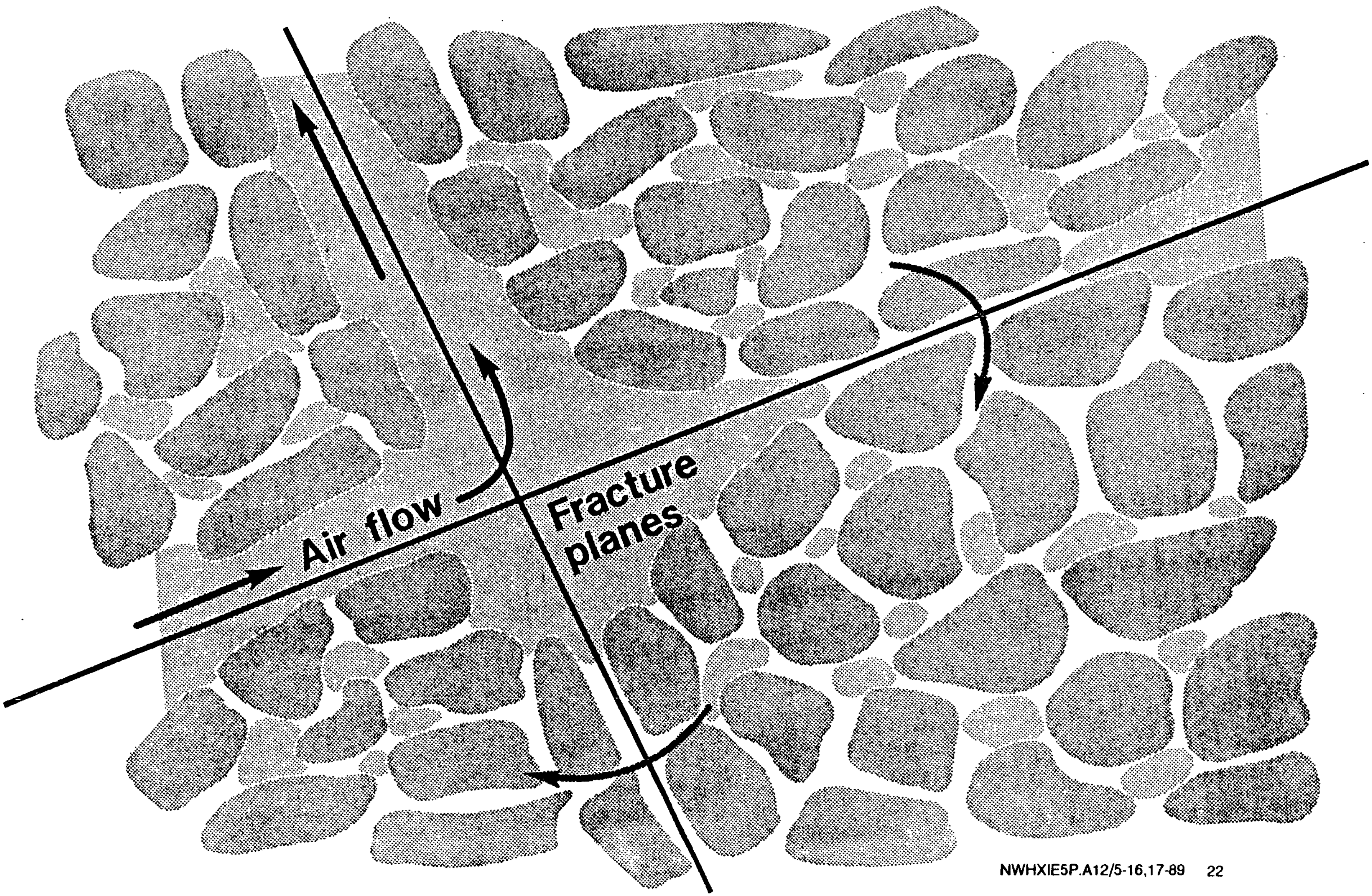
HYDRAULICS OF UNSATURATED FRACTURES

FLOW BARRIERS OR CONDUITS ?

- LATERAL FLOW ACROSS FRACTURES
- LONGITUDINAL FLOW WITHIN FRACTURES

Flow in Unsaturated Fractures



THE SITE-CHARACTERIZATION PROGRAM (PRE-WASTE EMPLACEMENT)

- DATA ACQUISITION
  - EXPLORATORY-SHAFT FACILITY
  - SURFACE-BASED BOREHOLES
- HYDROLOGIC-PROPERTY DATA
  - ROCK MATRIX: n, Ksat, CHARACTERISTIC RELATIONS
  - FRACTURES: DISCRETE, NETWORKS, OVERLAPPING CONTINUA
  - FAULTS: DISCRETE BARRIERS OR CONDUITS
- HYPOTHESIS TESTING: ALTERNATIVE CONCEPTUAL MODELS
- UNCERTAINTY ANALYSES
  - SENSITIVITY STUDIES: IMPORTANCE OF PROPERTIES
  - CLASSICAL STATISTICS: PROBABILITY DISTRIBUTION FUNCTIONS
  - GEOSTATISTICS: SPATIAL CORRELATION AND HETEROGENEITY
- NUMERCIAL MODELING
  - LIQUID-WATER STORAGE AND FLOW
  - CONVECTIVE AIR FLOW IN FRACTURE SYSTEMS
  - ADVECTIVE WATER-VAPOR TRANSPORT
  - GEOTHERMAL HEAT FLOW

CURRENT ACTIVITIES (FY89)

- COMPILE BEST AVAILABLE DATA FOR THE SITE
- PERFORM CLASSICAL AND GEOSTATISTICAL ANALYSES OF THESE DATA
- ASSEMBLE A SET OF APPROPRIATE HYDRO-LOGIC NUMERICAL MODELS

FUTURE ACTIVITIES (FY90)

- REPEAT GWTT CALCULATIONS USING
  - BEST AVAILABLE DATA
  - BEST AVAILABLE MODELING TECHNIQUES