PRESENTATION

FOR

CONCEPTUAL HYDROGEOLOGIC AND GROUNDWATER MODEL

JULY 11, 1995

MAGMA

MAGMA COPPER COMPANY
FLORENCE, ARIZONA

BROWN AND CALDWELL
PHOENIX, ARIZONA

MAGMA PRESENTATION FOR

CONCEPTUAL HYDROGEOLOGIC AND GROUNDWATER MODEL
PHOENIX, ARIZONA

AGENDA

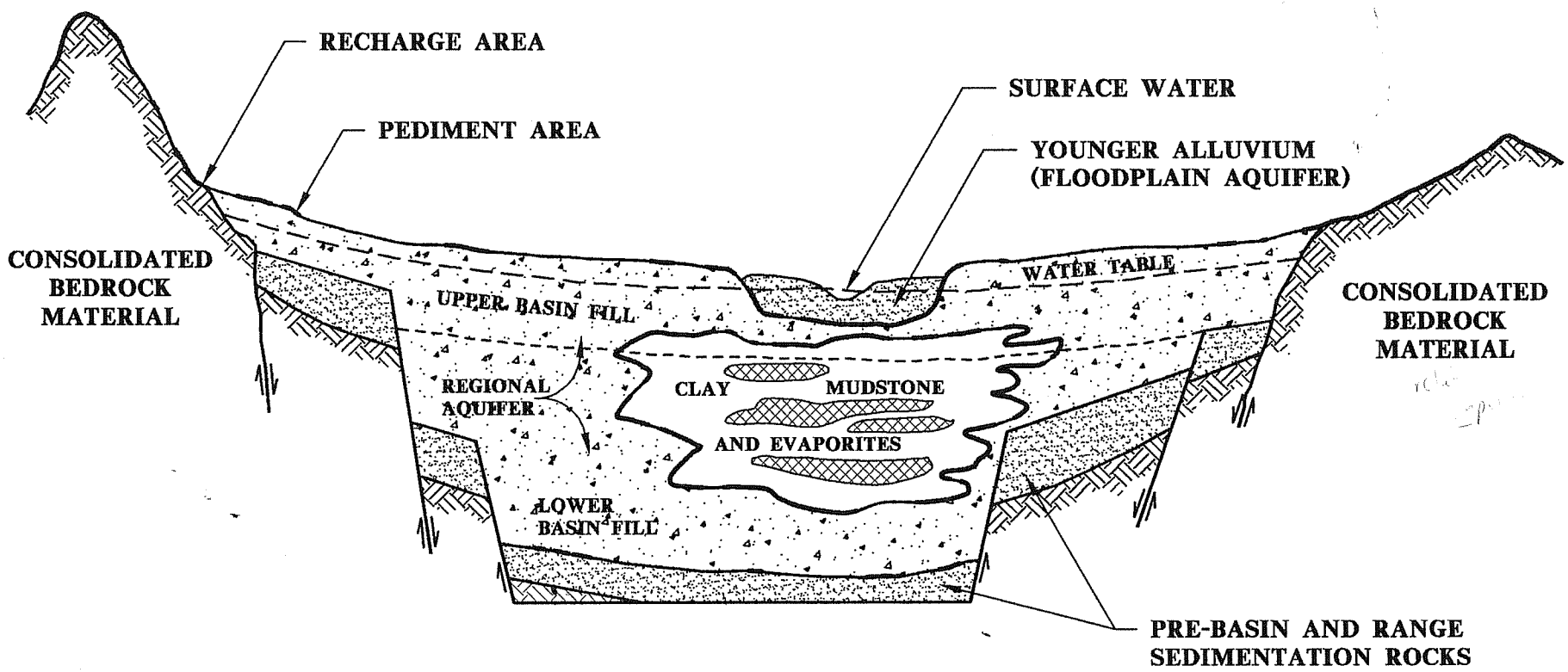
July 11, 1995, 10:00 a.m.

1. Introductions and Overview of the Presentation (John Kline)
2. Regional and Local Hydrogeological Setting (Mark Wallis)
3. Simulation of Groundwater Flow - Modeling (Fariba Sirjani)
4. Field Investigation Update and Conclusion (Steve Mellon)
5. Comments on the April 28, 1995 Submittals (Steve Mellon)
6. Review of Work Plans Submitted on June 27, 1995 (Steve Mellon)
7. Schedule for Next Meeting (Steve Mellon)
8. Open Discussion (Steve Mellon)

GEOLOGY and HYDROGEOLOGY CHARACTERIZATION OBJECTIVES

- FORMULATE CONCEPTUAL GROUNDWATER FLOW MODEL

- PROVIDE BASIS FOR MODEL PARAMETER DEFINITION



ADAPTED FROM: ADWR Hydrographic Survey Report for the San Pedro River Watershed

GENERALIZED CROSS-SECTION OF THE BASIN AND RANGE

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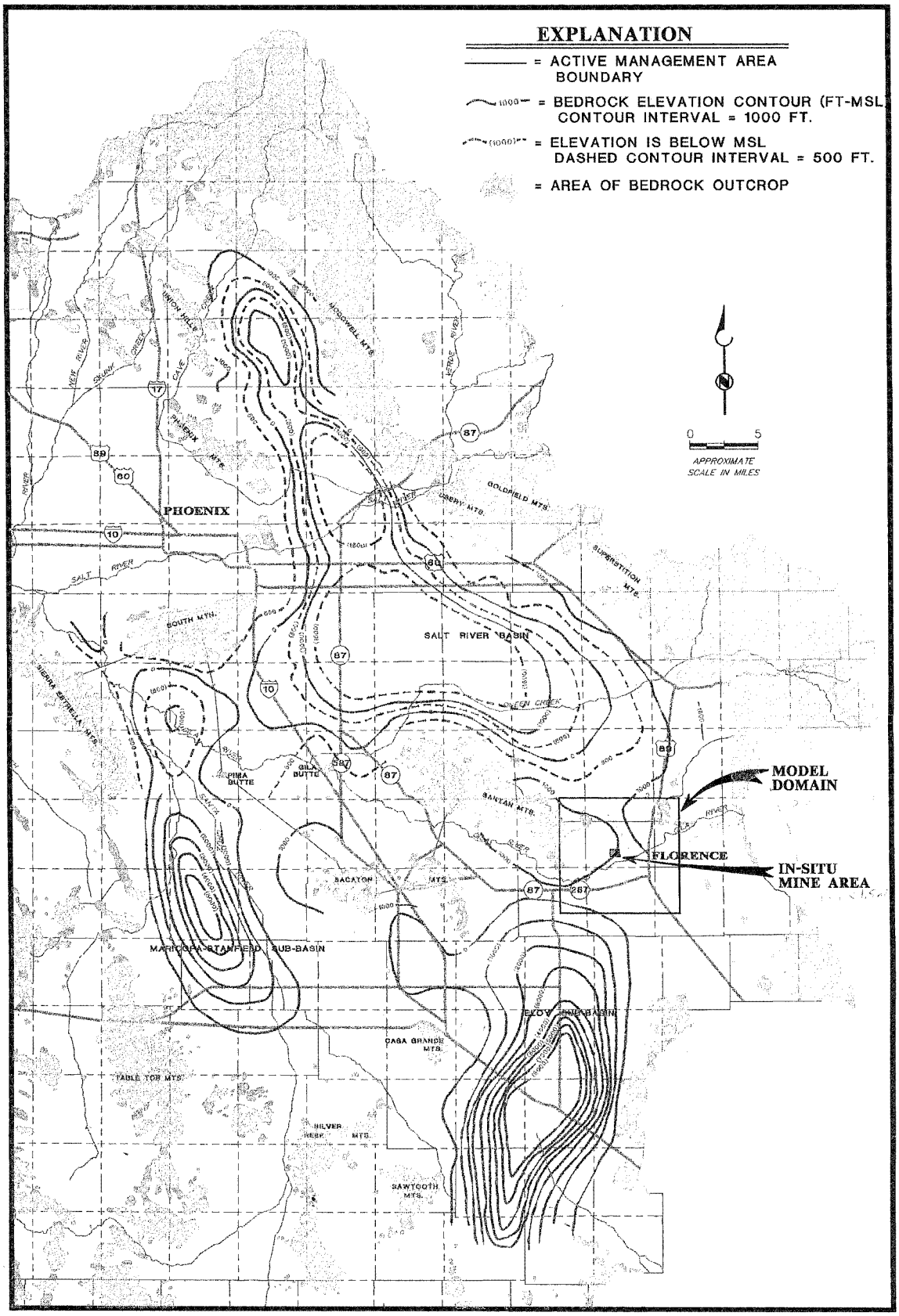

TOP OF BEDROCK ELEVATION CONTOURS

Modified From Wickham and Corkhill (1989) and Corkhill and Others (1993)

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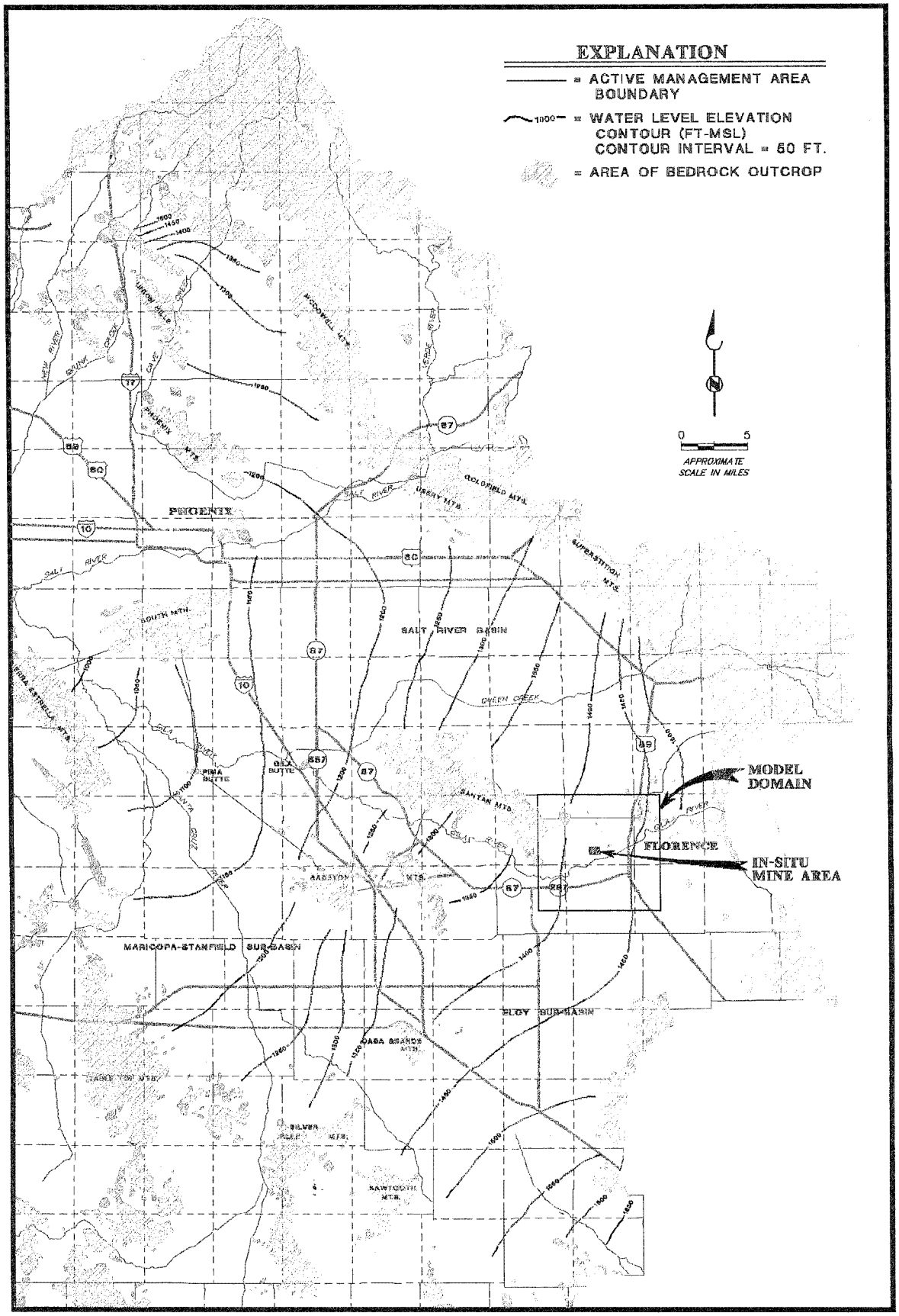

PRE-DEVELOPMENT GROUNDWATER ELEVATIONS (Circa 1900)

Modified From Corkhill and Hill (1990) and Corkhill and Others (1993)

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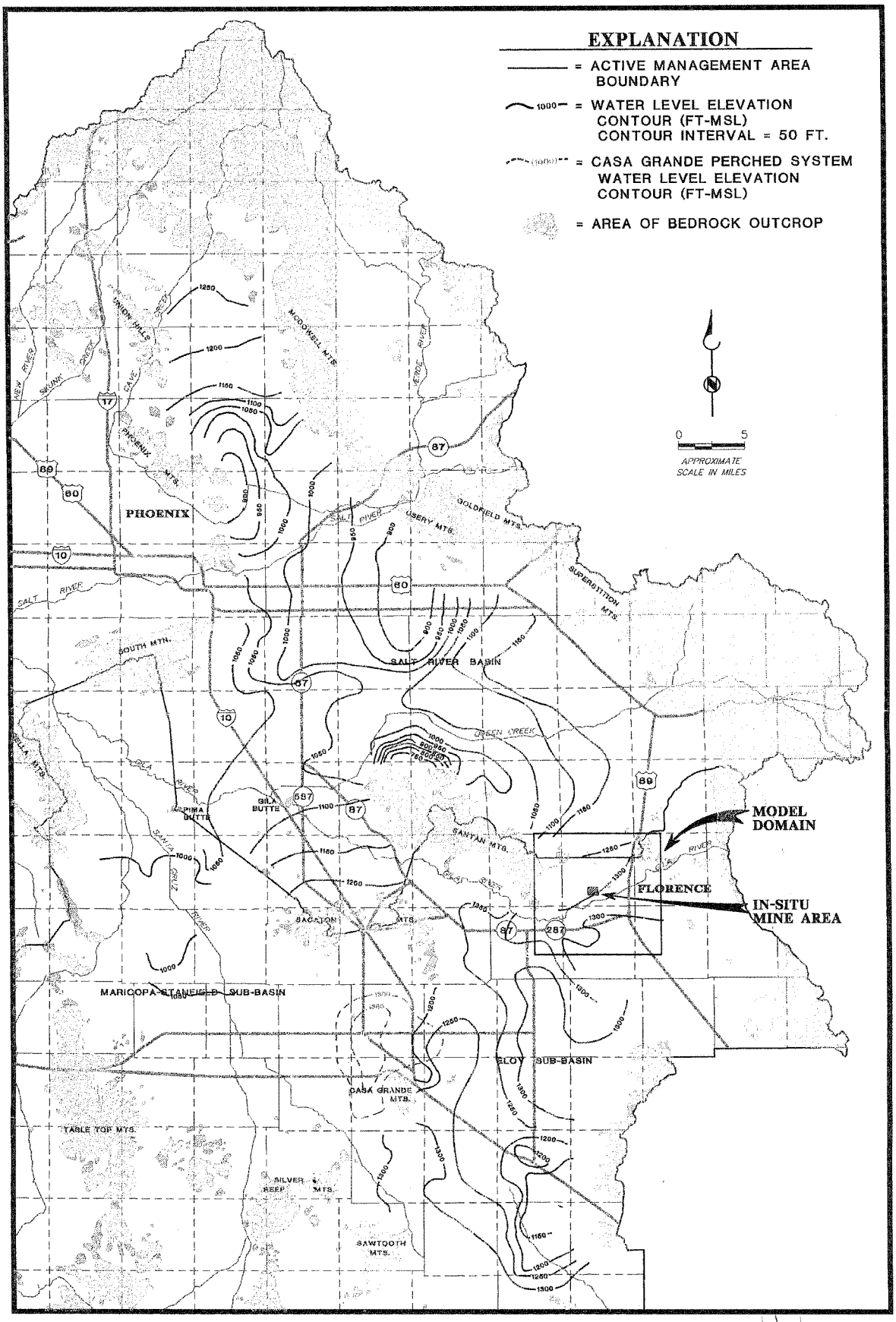

GROUNDWATER ELEVATION CONTOURS (1982-1985)

Modified From Reeter and Remick (1986) and Wickham and Corkhill (1989)

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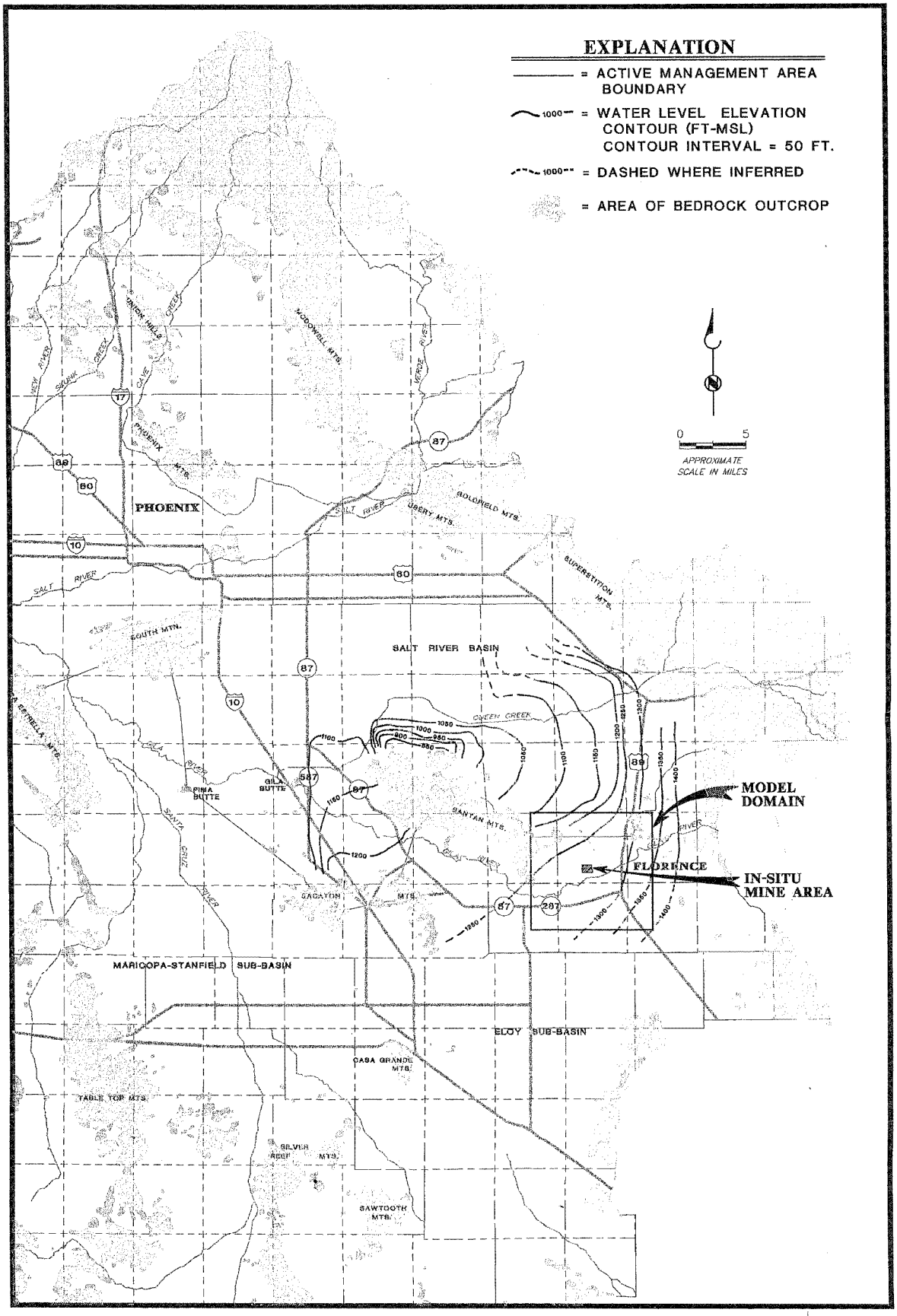

→ GW level was stabilized (data gap)

GROUNDWATER ELEVATION CONTOURS (1991-1992)

→ GW flow direction north-northwest

Modified From Preliminary ADWR Water Level Elevation Map - SRV Flow Model

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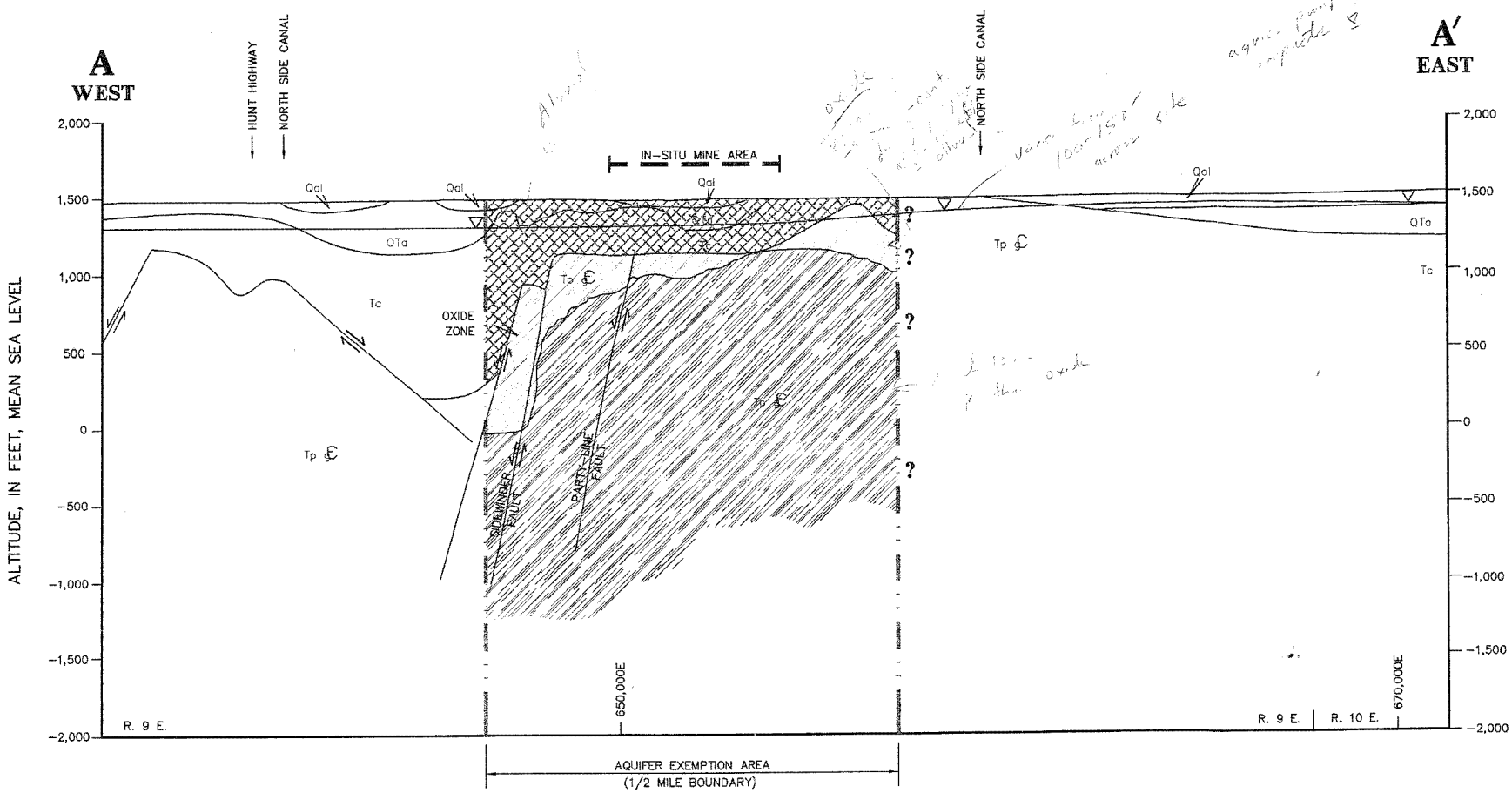

EXPLANATION

ALLUVIUM | OXIDE | SULFIDE | AQUIFER EXEMPTION AREA

CROSS-SECTION

Modified from Montgomery (1993)

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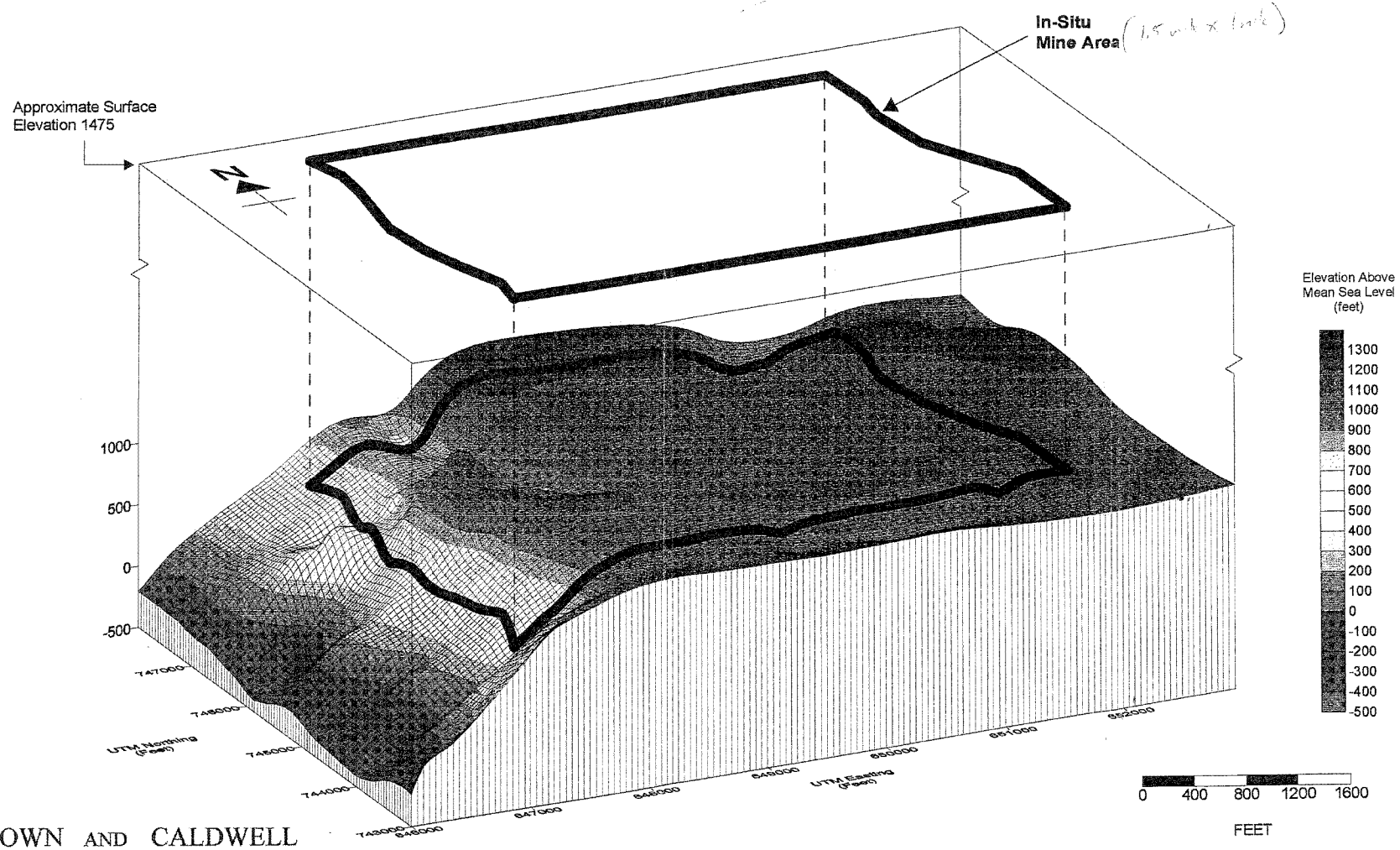
Surface Map
Top of Oxide Zone
(View Looking Northeast)



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OUTLINE

- PRIMARY OBJECTIVE
- MODEL DEVELOPMENT
  - CONCEPTUAL MODEL
  - MODEL PARAMETERS
  - MODEL CALIBRATION
- PARTICLE TRACKING AND TRANSPORT MODELING
- SIMULATION SCENARIOS

PRIMARY MODELING OBJECTIVE

ASSESS POTENTIAL IMPACTS OF PROPOSED OPERATIONS ON GROUNDWATER FLOW AND QUALITY

■ SECONDARY OBJECTIVES

- VERIFY THE CONCEPTUAL GROUNDWATER FLOW MODEL
- IDENTIFY DATA GAPS TO BE ADDRESSED IN ONGOING DATA COLLECTION ACTIVITIES
- EXAMINE THE INTERACTIONS BETWEEN OPERATIONS AND GROUNDWATER FLOW AND QUALITY
- ESTABLISH DISCHARGE IMPACT AREA (DIA) AND POINTS OF COMPLIANCE (POC)
- EVALUATE AND OPTIMIZE CONTROL AND MONITORING MEASURES

CONCEPTUAL MODEL

- PREVIOUS MODELS
- ADWR MODELS
  - PINAL AMA FLOW MODEL (MODFLOW)
  - PHOENIX AMA FLOW MODEL (MODFLOW)
- MONTGOMERY AND ASSOCIATES MODEL (MODFLOW)
- MODEL DOMAIN
  - 10 BY 10 MILES
  - MINE AREA 1 MILE BY 1/2 MILE
  - RATIO 200:1

MODEL GRID

- 1,000-FEET BY 1,000-FEET
- MINE AREA: 50-FEET BY 50-FEET
- GRADUAL TRANSITION BETWEEN GRIDS

MODEL LAYERS

- LOCAL AND REGIONAL STRATIGRAPHY
- REPRESENTATION OF STRATIGRAPHIC UNITS IN THE MODEL
- SECONDARY LAYERS

■ MODEL BOUNDARIES

- **TOP:** WATER TABLE
- **BASE:** UNALTERED BEDROCK (MONTGOMERY, HARSHBARGER, 1989)

NO FLOW BOUNDARIES

- **NORTHERN:** FLOW LINE (1900 WATER LEVELS)
- **SOUTHERN:** FLOW LINE (1900 WATER LEVELS)
- **WESTERN:** CONSTANT FLUX/GENERAL HEAD (1900 WATER LEVELS)
- **EASTERN:** CONSTANT FLUX/GENERAL HEAD (1900 WATER LEVELS)

■ HYDRAULIC AND HYDROLOGIC STRESSES

■ GILA RIVER

■ GROUNDWATER WITHDRAWALS

■ RECHARGE

- AGRICULTURAL FIELDS
- CANALS
- PRECIPITATION – negligible but not zero

MODEL PARAMETERS

AQUIFER THICKNESS

- ALLUVIUM: 0 TO 300 FEET (REGIONAL STUDIES)
- OXIDE: 100 TO 950 FEET (MINE INVESTIGATIONS)

HYDRAULIC CONDUCTIVITY

- ALLUVIUM: 30 TO 90 FEET/DAY (HALPENNY, 1976)
- OXIDE: 0.1 TO 6 FEET/DAY (MINE INVESTIGATIONS)

SPECIFIC YIELD/SPECIFIC STORAGE

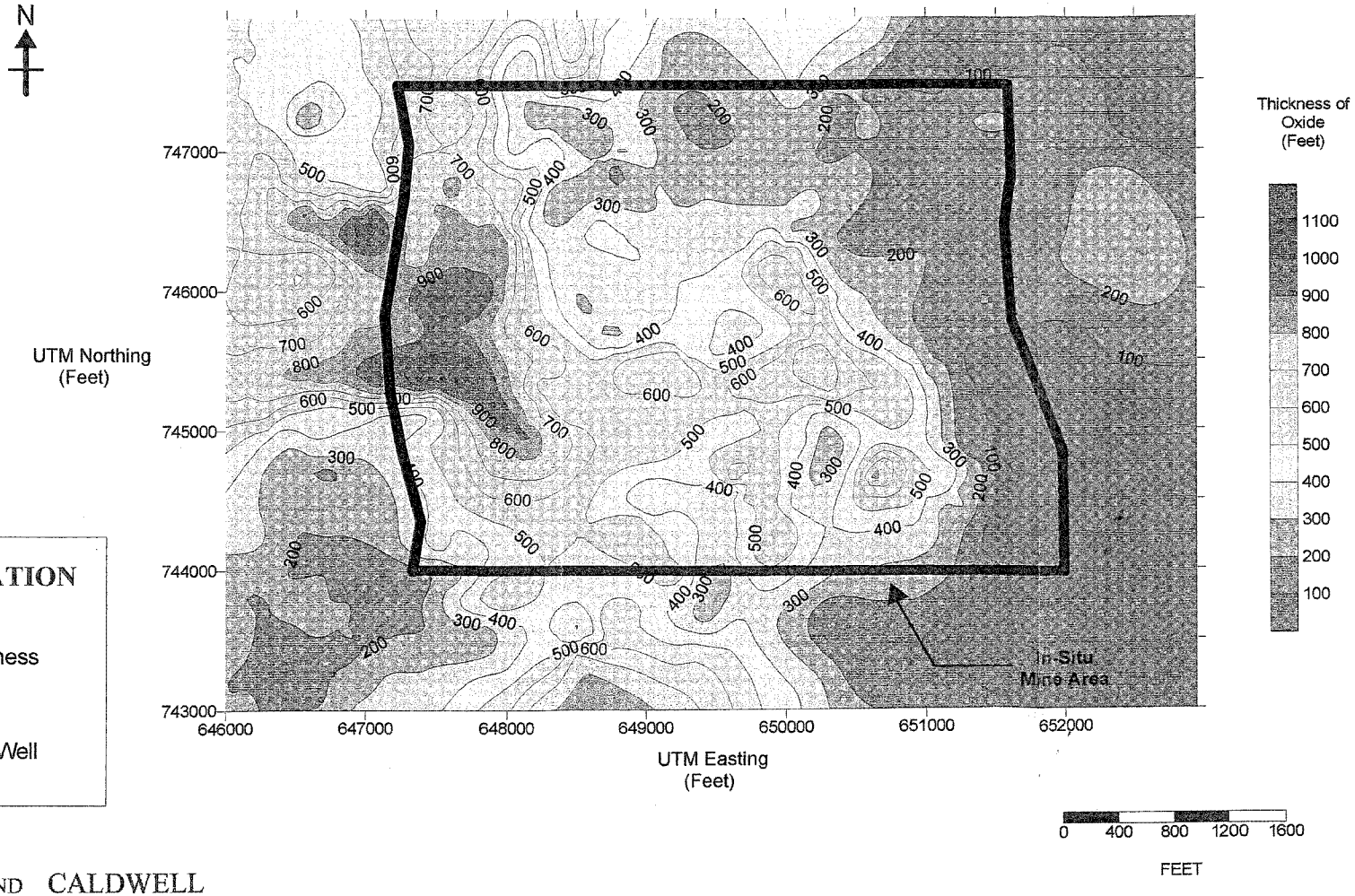
- ALLUVIUM: 0.17/NA (HALPENNY, 1976)
- OXIDE: NA/NA (MINE INVESTIGATIONS)

POROSITY

- ALLUVIUM: 0.25-0.35 (MONTGOMERY, 1989)
- OXIDE: NA (MINE INVESTIGATIONS)

NA: NOT AVAILABLE AND TO BE DETERMINED

Isopach of Oxide Zone



EXPLANATION

—300— Oxide Thickness

⊗ Monitor Well

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MODEL CALIBRATION

- ASTM STANDARDS
- CALIBRATION AND VERIFICATION DATA
  - STEADY STATE WITH 1900 PREDEVELOPMENT GROUNDWATER ELEVATIONS
  - TRANSIENT WITH 1993 GROUNDWATER ELEVATIONS
  - TRANSIENT WITH 1994 GROUNDWATER ELEVATIONS
  - TRANSIENT WITH 1994 GROUNDWATER ELEVATIONS

PARTICLE TRACKING AND TRANSPORT MODELING PATH3D AND MT3D

■ PARTICLE TRACKING

- ESTABLISH FLOW LINES
- ESTIMATE TRAVEL TIMES

■ CHEMICAL TRANSPORT

diffusion, dispersion

- INCORPORATE CHEMICAL PROCESSES
- DEMONSTRATE ATTENUATION CAPACITIES

chemical / rock interaction

lab samples

2 tests
→ PCS
→ attenuation thru different core samples

lab data for input to model
however, iterative process
always update model

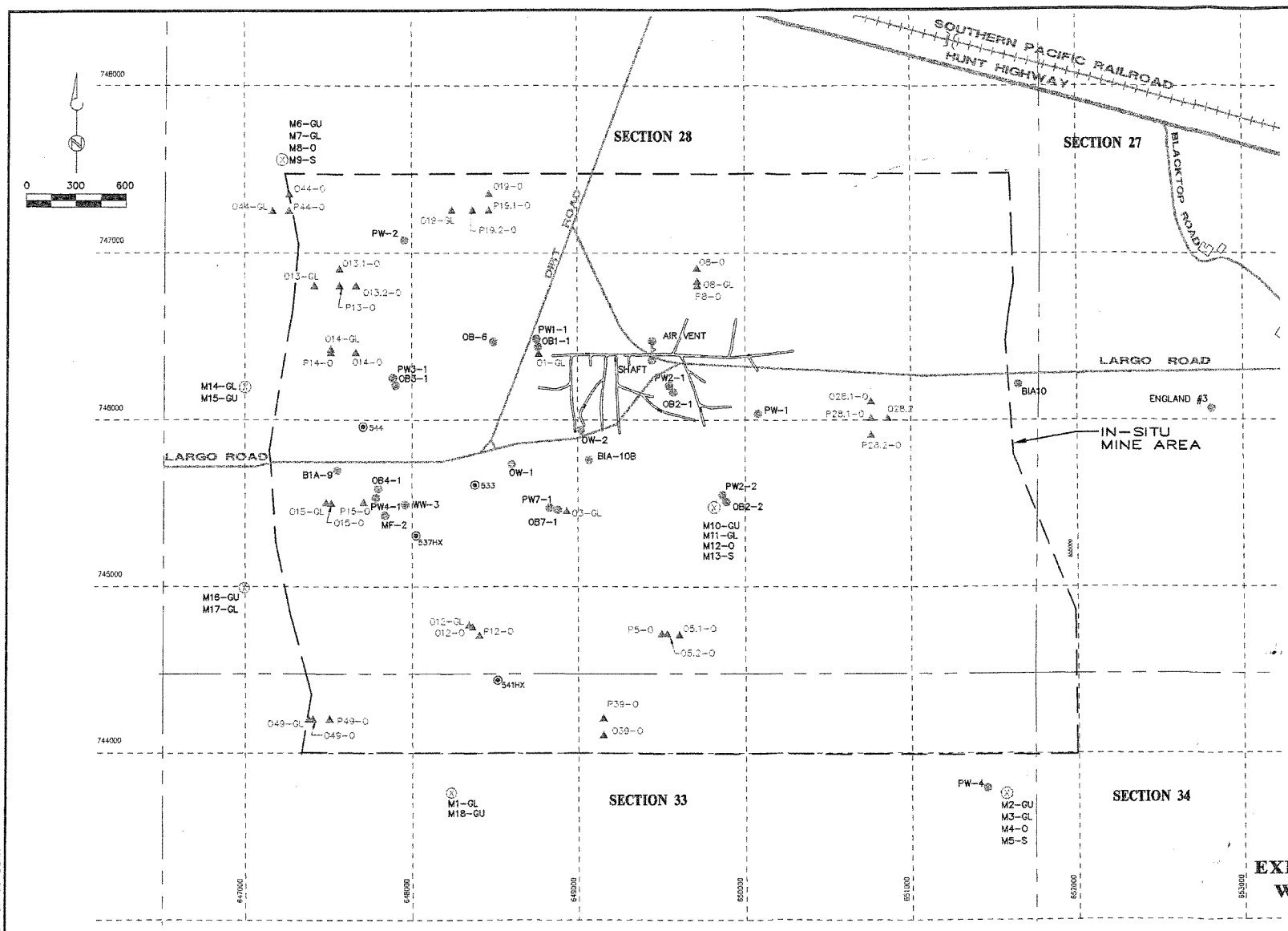
SIMULATION SCENARIOS

- MINING OPERATIONS
- EXTREME FLOOD EVENTS
- EXTREME IRRIGATION PUMPING → e.g. reverse gradient
- EVAPORATION PONDS LINER FAILURE

STATUS OF FIELD INVESTIGATIONS

- 18 MONITORING WELLS
  - MULTIPLE LEVELS
- 22 AQUIFER TEST WELLS
  - MULTIPLE LEVELS
  - MULTIPLE PUMPING WELLS
- 3 PRELIMINARY AQUIFER TESTS
- PACKER TESTS IN 4 COREHOLES

APPLICATION SUBMITTAL SCHEDULED FOR NOVEMBER 1995



LEGEND

- = EXISTING WELL LOCATION
- = PROPOSED AQUIFER TEST AND OBSERVATION WELL LOCATION
- = RECENT EXISTING & PROPOSED MONITORING WELL LOCATION
- = TESTING COREHOLES WITH PACKER
- = UNDERGROUND WORKINGS

WELL DESIGNATIONS

PW2-2 ← EXISTING PUMPING WELL
OB2-2 ← EXISTING OBSERVATION WELL

P28-0
- COMPLETION ZONE: OXIDE
- MINING BLOCK LOCATION: #28
- WELL TYPE: PUMPING

O28.2-0
- COMPLETION ZONE: OXIDE
- NUMBER OF TYPE IN THIS BLOCK: SECOND
- MINING BLOCK LOCATION: #28
- WELL TYPE: OBSERVATION

M10-GU
- COMPLETION ZONE: GILA (UPPER)
- WELL NUMBER: 10
- WELL TYPE: MONITORING

COMPLETION ZONES:

GU = GILA (UPPER) O = OXIDE
GL = GILA (LOWER) S = SULFIDE

EXISTING AND PROPOSED WELL AND COREHOLE LOCATIONS

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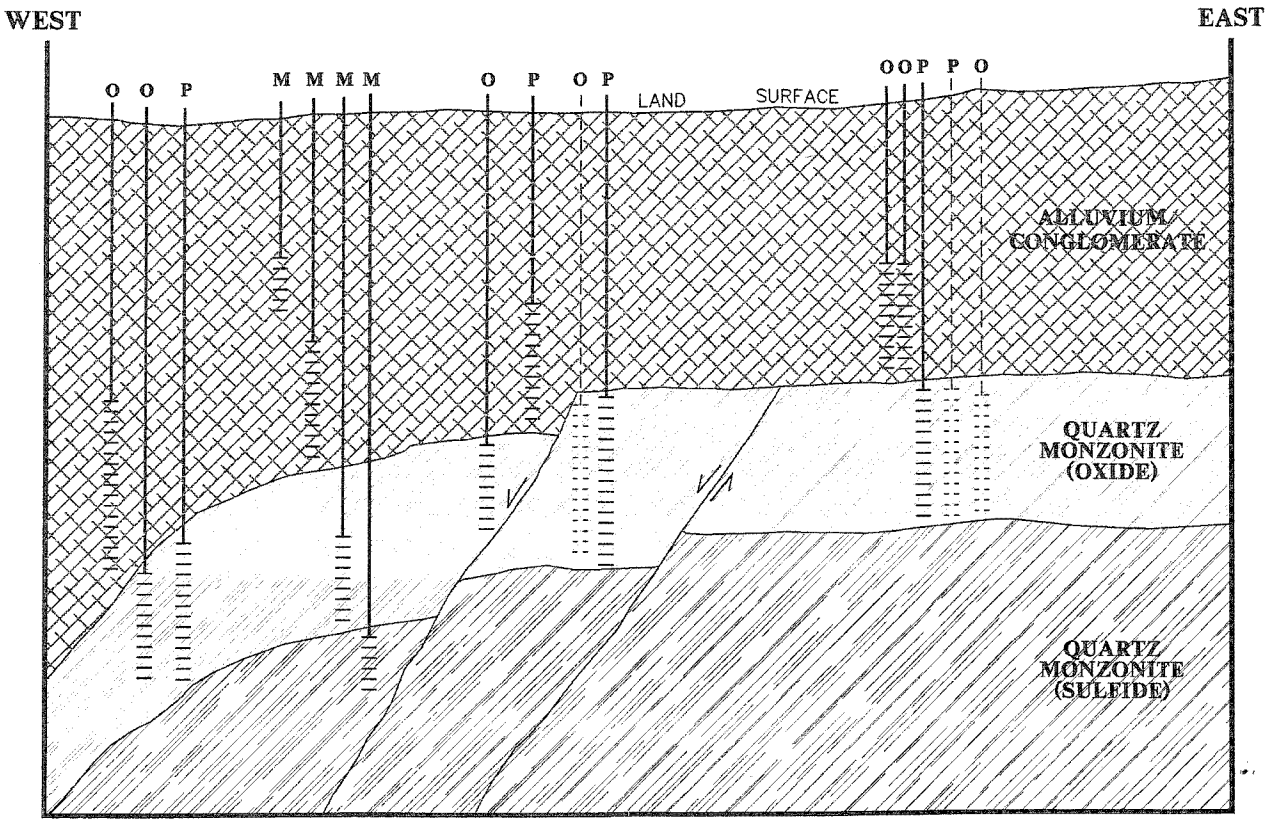

GENERALIZED CROSS SECTION
N.T.S.

LEGEND

WELL SCREEN INTERVAL

WELL DEPICTION OUT OF CROSS SECTION PLANE

P = PUMPING WELL **O** = OBSERVATION WELL **M** = MONITORING WELL

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SIMPLIFIED CROSS SECTION
TYPICAL AQUIFER TEST AND MONITORING WELL ARRANGEMENTS

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(75 million lbs/yr Cu^{2+}) Magma Goal (15 years)

CONCLUSION

- VERY COMPREHENSIVE INVESTIGATION PROGRAM
- REVIEW ALL ASPECTS OF MINING ACTIVITIES ON LOCAL WATER QUALITY
- USING EXISTING STANDARDS FOR MODELING
- USING MOST CURRENT METHODS FOR MODELING
- INCORPORATING ALL EXISTING DATA
- INCORPORATING EXISTING MODELS
- CONFIRM CHOSEN LITERATURE VALUES WITH ACTUAL FIELD WORK

APPLICATION VERIFICATION:

- Using the set of parameter values and boundary conditions from a calibrated model to verify a second set of field data measured under similar hydrologic conditions.

CALIBRATION:

- The process of refining the model representation of the hydrogeologic framework, hydraulic properties and boundary conditions to achieve a desired degree of correspondence between the model simulations and observations of the ground-water flow system.

CONCEPTUAL MODEL:

- An interpretation or working description of the characteristics and dynamics of the physical system. Conceptualizing the hydraulic system is one of the most important parts of the modeling process. Before a mathematical model can be developed, a conceptual understanding of the hydrologic system must be established. Designing the conceptual model involves identifying all of the inflows, outflows and hydraulic stresses on the aquifer system.

MODFLOW:

- The USGS Modular three-dimensional Finite Difference Ground-Water Flow Model. By McDonald and Harbaugh, 1988.

MT3D:

- The Modular Three-Dimensional Finite Difference Chemical Transport Model. By Chunmiao Zheng (Papadopulos and Associates) 1990.

PATH3D:

- A Ground-Water Path and Travel-Time Simulator. By Chunmiao Zheng (Papadopulos and Associates) 1992. A general particle tracking program for calculating ground-water paths and travel times in steady-state or transient two- or three-dimensional flow fields.

PARTICLE TRACKING:

- Particle tracking is used to trace out flow paths, or pathlines, by tracking the movement of infinitely small imaginary particles placed in the groundwater flow field. Particle tracking is primarily used to understand the transient movement of groundwater flow and calculate groundwater travel times.

CHEMICAL TRANSPORT:

- Chemical transport involves further refinement of the groundwater flow model to include simulation of chemical movement and distribution in a groundwater flow system. Chemical transport modeling includes diffusion, dispersion, chemical decay and reactions between the chemical and the porous media.

FLOW LINE:

- Is a representation of the direction of groundwater flow. Flow lines are always perpendicular to lines of equal groundwater elevation. Flow lines only converge in areas of groundwater discharge or recharge. A groundwater particle trace or pathline is the actual tortuous paths of the water molecules as they flow through pores, cracks and crevices of the soil or other aquifer material.

CONSTANT FLUX BOUNDARY:

- A numerical boundary condition in MODFLOW through which the inflow or outflow flux of groundwater remains constant, and does not vary due to changing groundwater flow gradients.

GENERAL HEAD BOUNDARY:

- The general head boundary is a numerical constraint in MODFLOW that simulates regional flow beyond the finite difference grid. The general head boundary will adjust the flux of water in or out of the model depending on simulated groundwater flow gradients.

HYDRAULIC CONDUCTIVITY:

- Hydraulic conductivity describes the ease with which water can pass through an aquifer. The hydraulic conductivity multiplied by the thickness of the aquifer is equal to the transmissivity. Typical units for permeability and hydraulic conductivity are feet per day or centimeters per second.

STORATIVITY/SPECIFIC YIELD:

- Storativity and specific yield are related parameters. Storativity is defined as the amount of water released or added to storage per change in pressure due to pumping or recharge in a confined aquifer. Specific yield is the percentage of water that would drain from a unit volume of aquifer material (i.e., one cubic-foot) in an unconfined aquifer. For coarse sands and gravel, the specific yield is roughly equal to the porosity. Storativity and specific yield control the time it will take for changes in pumping or recharge to propagate throughout the aquifer system.

POROSITY:

- Porosity is the amount of void space between soil or rock particles, and reflects the ability of the aquifer to store water.