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Application of a Lumped-Parameter Model Toward Understanding the Behavior of the Mortandad Canyon Perched Alluvial Aquifer System, Los Alamos, New Mexico

by

Eric D. Koenig

Stephan G. McLin

Los Alamos National Laboratory

Dear [illegible],

[illegible]

[illegible]

Good luck in your modeling effort.

Eric Koenig

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0.0 Abstract

The Mortandad Canyon perched aquifer in Los Alamos County, New Mexico receives treated effluents from Los Alamos National Laboratory that contain some radionuclides, including ^{238}Pu, ^{239}Pu, ^{241}Am, uranium and tritium.

The main purpose of this study is to characterize the perched aquifer in Mortandad Canyon so that its contaminant mass balance may be modeled, and future behavior predicted. A secondary purpose is to make recommendations for field studies that would help refine such a model. To meet the first objective, a two-cell lumped-parameter model has been constructed. Observational data and inputs for this model are from monthly observations and calculations made by William Purtymun from June 1963 through June 1965 (8).

Parameter estimation for the lumped-parameter water balance model and water level observations indicate that the response time of the perched alluvial aquifer is on the order of 2-4 months. Implementation of the water balance model using Purtymun's data suggests that most of the storm runoff and effluent that enters the perched aquifer leaves via downward seepage.

Recommendations for further field studies include: the installation of a continuous water level monitoring system in current Mortandad observation wells; refurbishing and monitoring of Mortandad Canyon gaging stations; and drilling deep observation wells to improve estimates of downward seepage.

1.0 Introduction

1.1 Los Alamos National Laboratory

Los Alamos National Laboratory (LANL) is located in Los Alamos County, New Mexico, approximately 40 km northwest of Santa Fe (see fig. 1). The laboratory comprises numerous installations, or "TA's" (Technical Areas), spread over 111 km^2 of the Pajarito Plateau. Constructed for development of the first nuclear fission bomb during World War II, the laboratory continues with its original mission of weapons/defense R&D, but additionally supports basic

research in such fields as astro-, nuclear- and particle physics, chemistry, geology and bio/medical sciences (11). Many resources have also been committed over the years under the auspices of environmental monitoring, -remediation and -protection. This study is part of that effort.

1.2 Geology of the Pajarito Plateau

The Pajarito Plateau is an apron of tuff, volcanic sediments and interfingering basalt flows that surrounds the Valles (aka Jemez) Caldera in north-central New Mexico on the northern edge of the Basin and Range province (see fig. 2).

The Valles Caldera is a classic example of a resurgent caldera —one of the largest in the world. Approximately 1- to 1.4 million years ago, volcanic activity at the caldera climaxed with two extremely large explosions, depositing approximately 400 km^3 (100 mi^3) of rhyolite tuff and other pyroclastics (11). These strata, a formation known as the Bandelier Tuff, constitute most of the Pajarito Plateau.

Bandelier Tuff laps onto the older, exposed volcanics of the Tschicoma formation that form the Jemez Mountains, the rim of the Valles Caldera. The tuff shallowly dips and gradually thins to the Southeast, toward the Rio Grande, from a thickness of approximately 300 m (984 ft) down to 80 m (262 ft; see figures 3 & 4 [11]). Ephemeral streams flow southeast to the Rio in a parallel/dendritic pattern that dissects the plateau into alternating canyons and finger-like mesas. Most of the laboratory's T.A's are situated atop the mesas.

The following passage on local stratigraphy is excerpted from the 1991 LANL report, *Extent of Saturation in Mortandad Canyon*, pages 13-14 (10).

[Stratigraphy]

(In descending order)

"Bandelier Tuff

"Tshirege Member

"Unit 1A Tuff, nonwelded, light-grey, consisting of quartz and sanidine crystal and crystal fragments, rock fragments of pumice, latite, and rhyolite in a matrix of gray ash; weathered grey, buff, light- to dark brown in color, pumice- and ash matrix weathered to clay.

"Tsankawi Member

"Thin lenses of silt, sand, and gravels consisting of pumice, quartz and sanidine crystals and rock fragments of latite and rhyolite ranging in color from grey to dark brown, ash and some pumice weathered to clay; member represents erosion and deposition at the top of a massive ash flow.

"Otowi Member

"Tuff, nonwelded to moderately welded, grey to dark brown when weathered, consisting of quartz and sanidine crystals and crystal fragments, numerous pumice fragments up to 2-inches [5 cm] in length, rock fragments of latite and rhyolite in an ash matrix; ash matrix and some of the pumice weather to silt and clays..."

1.3 Hydrogeology

Some of the ephemeral streams provide enough recharge to their canyons to maintain small shallow aquifers, perched in the canyon alluvia far above the main aquifer's water table. The bottom of the perched aquifers may extend from 0- to about 30 m (0-100 ft), while the ground water table ranges in depth from 180- to 335 m (about 600-1100 ft) below the canyon floors (see fig. 5 [10]).

Groundwater from the main aquifer is the only viable municipal water supply/source (11). However, the canyon perched systems are important, because some receive treated municipal or laboratory effluents. Mortandad Canyon receives treated discharges from LANL facilities. TA-50, located on the south rim of the canyon (see map), treats radioactive liquid wastes from LANL operations, and has been a major industrial outfall in the canyon since the summer of 1963. Mortandad Canyon receives some heavy radionuclides such as ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Am, and uranium from the discharge. These tend to become bound to sediment particles. In the mid-1970's, the laboratory constructed three sediment traps in Mortandad Canyon (see map) to prevent radionuclide transport off LANL property onto Native American sacred lands through overland flow. These consist of a chain of three large, interconnected pits, each approximately 40m (130 ft) across and surrounded by a high berm to prevent overflow. Together, they hold an approximate total of 4.5 million liters (1.2 million gallons) (10). The stream channel terminates at the sediment traps.

Another component of the treatment plant's discharge is tritium-bearing water molecules (see table 1). Obviously, the sediment traps will not prevent tritiated water from entering the system. The water infiltrates and moves via the perched aquifer down the canyon gradient. Losses from the perched aquifer occur due to evapotranspiration (the sum evaporation plus plant transpiration) and seepage into the tuff below the alluvium. Seepage is retarded by the hydraulic properties of the strata below, that include residual silts and clays weathered from the tuff (10). Most of the recharge to the main aquifer probably originates from the Jemez Mountains and the Valles Caldera, not from the canyons on the plateau (10).

In the early 1960's, it was apparent that regular groundwater monitoring would be necessary because of the advent of the TA-50 outfall. William Purtymun monitored stream flow and infiltration using gaging stations, and calculated perched aquifer storage and flow by monitoring water levels and computing gradients between observation wells (8). He eventually assembled a water balance for

Mortandad Canyon by a summation process. He calculated evapotranspiration using a modified Thornthwaite method (5) and closed the balance calculation with vertical seepage into the tuff (see tables 3, 4 & 5 for his observational data), conceptually dividing the canyon and aquifer into three segments: the upper, middle and lower (see map). For the purpose of model simplification, the middle- and upper segments have been combined in the simulations presented in this report (see fig. 6).

The next section, the descriptions of the canyon segments, has been excerpted from the 1991 LANL report, *Extent of Saturation in Mortandad Canyon*, pages 14-15 (10).

> "...The upper canyon is narrow and filled with underbrush, shrubs, pine, fir, box elder and oak trees. The alluvium thickens eastward from less than 1 ft at plant outfall to about 18 ft [5.5 m] thick at MCO-4 [N.B.: the wells in Mortandad Canyon are designated MCO for observation/sampling wells and MCM for neutron moisture access tubes; some additional wells, used only for observing water levels, are designated MT; numbers increase downstream]. The stream flow in this section is perennial from waste water and periodic releases of industrial effluents. The stream channel is entrenched. Major recharge to the shallow aquifer occurs in the upper canyon. Large losses by evapotranspiration occur in this section of the canyon due to the large amount of vegetation and to the surface of the [perched] aquifer being near the ground surface.
>
> "The middle canyon widens and alluvium thickens from 18 ft [5.5 m] to 36 ft [11 m] at MCO-6. The stream channel is well-defined, but surface flow is intermittent. The underbrush thins and the canyon floor is covered with pines.
>
> "The lower canyon becomes progressively wider and the alluvium continues to thicken to about 60 ft [18.3 m]. near MCO-8. The stream channel is discontinuous, braiding out on the canyon floor. The number of pines decrease eastward of the middle canyon with a

transition to a scattered piñon-juniper community. ...three sediment traps have been constructed between MCO-7 and MCO-7.5..."

1.4 Purpose and Scope

This study comprises a number of objectives. In order to estimate the amount of downward seepage from the perched aquifer into the tuff, a lumped parameter water balance expression has been constructed. Another task was to estimate parameters incorporated in the model, such as the hydraulic response time of the system, t_h. This parameter is of special importance, because it may be used to determine the frequency of field measurements needed to discern aquifer responses.

In addition, this report will be used to indicate shortcomings in the background knowledge essential to the characterization of the Mortandad perched aquifer system, and to initiate further field investigations to that end.

2.0 The Lumped-Parameter Model

With the advent of powerful personal computers, physical models of aquifer systems, except for the purpose of educational demonstration, have fallen by the wayside, replaced entirely by mathematical models. Mathematical computer models of groundwater flow generally exist in two forms: lumped-parameter and distributed-parameter models (12). Each has different data requirements, procedures for parameter estimation, and underlying assumptions governing their use and execution.

Distributed-parameter models can account for spatial heterogeneity as well as variations through time. They employ a finite-difference or finite-element array of data points or areas that may represent a surface- or cross-sectional area of an aquifer. Properties such as transmissivity, storage coefficients, and degrees of anisotropy with respect to hydraulic conductivity, can vary spatially in these models. The output is commonly a water level or potentiometric surface map or cross section that displays transient effects with each computational

iteration. Naturally, distributed-parameter models often require a vast amount of data that is hard to acquire. For example, if one needs transmissivities or hydraulic conductivities or storage coefficients for multiple data points, one would have to conduct an aquifer pumping test at several of those points. Values for some of those points may be interpolated or estimated, but this results in less credible models.

Lumped-parameter models are volume-averaged models that are good for simulating average- or system-wide changes (12). They do not require the same exhaustive data on spatial variation of parameters, but they do often require long term gathering of information in order to estimate parameters by statistical means. Instead of using an array of data that represents the aquifer system, the lumped model uses a single linear differential equation to model average conditions. The system becomes a single cell or a few discrete cells. The only major assumption inherent in this approach is that the system is supposedly well-mixed (6), that is, that an average condition is representative of the whole cell. This is a reasonable argument for a relatively small system like the perched aquifer in Mortandad Canyon. Figures 7 through 10 show variations in chloride concentration for observation wells distributed along the entire the length of the perched aquifer. Similar behavior with respect to chloride concentration over time is visible in each of the wells. Note that for the sampling months indicated, all of the wells were sampled within a week of each other.

2.1 Water Balance General Solution

For the full derivation of the water balance general solution, see Appendix A.

A general water balance expression for the perched aquifer system in Mortandad Canyon can be written as:

$$n\, dV/dt = Q_N + Q_A - Q_{RT} - Q_T - Q_{GW},$$

where: n = effective porosity
V = the volume occupied by that segment of the perched aquifer
t = time
Q_N = natural recharge (volume/time)
Q_A = artificial recharge, e.g. the effluent from TA 50
Q_{ET} = evapotranspiration losses (aka ET)
Q_T = downward flow into the tuff
Q_{GW} = lateral groundwater transfers to the downstream alluvial aquifer.

After summing all the recharge terms and ET together into a net recharge term, E, integrating the equation from zero to some time, t, and converting the result to a forward difference approximation, the final water balance expression for the upper/middle aquifer is:

$$V_{i+1} = V_i \exp(-\Delta t/t_h)$$

$$+ [(aV_{GW} + bV_T)/(a + b)] [1 - \exp(\Delta t/t_h)]$$

$$+ [E_i/(a+b)] [\exp(-\Delta t/2/t_h) - \exp(-\Delta t/t_h)]$$

$$+ [E_{i+1}/(a+b)] [1 - \exp(-\Delta t/2/t_h)]$$

where: V_i = the volume of water in that aquifer segment at the end of the month of i
E_i = the net recharge for the month of i
Δt = one month
a = the slope of a best-fit line on a plot of Q_{GW} versus V
b = the slope of a best-fit line on a plot of Q_T versus V
V_{GW} = the V intercept on the Q_{GW} versus V plot
V_T = the V intercept on the Q_T versus V plot
t_h = the aquifer response time, equivalent to $(a+b)/n$, where n is effective porosity

The above version applies in its entirety to the upper/middle aquifer. However, the solution for the lower aquifer segment is somewhat different. Lateral groundwater flow from the upper/middle aquifer is part of the recharge

term. Stream flow is generally depleted by infiltration before it reaches the lower aquifer, except during runoff events associated with rainfall of high intensity or long duration. In addition, the lower aquifer segment, for all practical purposes, is truly the farthest downgradient. So the entire output from this segment presumably seeps into the tuff. Therefore, Q_{OW} is zero in the lower aquifer. *Note that the values of the constants change from aquifer segment to aquifer segment.*

$$n\, dV/dt = Q_{OW(upper/middle)} - Q_{NT} - Q_T$$

$$V_{i+1} = V_i \exp(-b\Delta t/2) + V_T[1 - \exp(-b\Delta t/n)] + E_i/b\, \{\exp(\Delta t/[2t_h]) - \exp(-\Delta t/t_h)\} + E_{i+1}/b\, (1 - \exp(-\Delta t/[2t_h]))$$

where n/b equals t_h, the hydraulic response time (aka aquifer time constant).

2.2 Estimation of Parameters

As discussed in Gelhar and Wilson (4), "...the outflow from the aquifer can be approximated by the linear term

$$q = a(h - h_0)\ldots"$$

where q is specific discharge and h is the water level above some reference datum, h_0. This expression is intuitively related to Darcy's Law. In our derivation, we have:

$$Q_{OW} = a(V - V_{OW})$$

Through this relationship, one can estimate a and V_{OW} by plotting Q_{OW} versus V from Purtymun's data, and doing a least squares analysis (12). V_T, b, and t_h can be estimated by approximating the integral of the water balance,

$$n\, dV/dt = E - Q_T - Q_{OW},$$

by Simpson's rule and then solving for the constants (6).

Simpson's rule approximates an integral by fitting an arc of a parabola over the function. The generalized form of the approximation is:

$$\int_a^b f(x)\,dx = h/3\ (y_0 + 4y_1 + 2y_2 + 4y_4 + \ldots$$

$$\ldots + 2y_{n-2} + 4y_{n-1} + y_n)$$

where n is an even number, $h = (b - a)/n$, $y_0 = f(a)$ and $y_n = f(b)$ (7). Substituting Q_T with

$$b(V - V_T)$$

and Q_{GW} with

$$a(V - V_{GW}),$$

Simpson's rule applied to the water balance for the upper/middle aquifer is:

$$n\ (V_{i+1} - V_{i-1})/\Delta t = 1/3\ (E_{i+1} + 4E_i + E_{i-1}) -$$

$$b/3\ (V_{i+1} + 4V_i + V_{i-1}) + 6bV_T/3 -$$

$$a/3\ (V_{i+1} + 4V_i + V_{i-1}) + 6aV_{GW}/3$$

or

$$E_{i+1} + 4E_i + E_{i-1} = 3n/\Delta t\ (V_{i+1} - V_{i-1}) +$$

$$(a + b)\ (V_{i+1} + 4V_i + V_{i-1}) - 6(aV_{GW} + bV_T).$$

The latter equation is now in the form:

$$y = Ax_1 + Bx_2 + C$$

where $A = 3n/\Delta t$
$B = a + b$

Δt equals one, a and V_{GW} are known beforehand, and the rest can be solved for using linear regression. Deriving b and V_T by this method is better than plotting Q_T versus V and doing a least squares analysis, because the values for Q_T in Purtymun's water balance summation are not empirically calculated like the values for Q_{GW}.

Once again, the approach to estimating parameters for the lower aquifer is the same as that of the upper/middle

aquifers; but the water balance expression changes slightly, so the rest of the equations change slightly as well.

$$n\ dV/dt = Q_{GW(upper/middle)} - Q_{RT} - Q_T = E - Q_T$$

Again,

$$Q_T = b(V - V_T).$$

Applying Simpson's rule,

$$n(V_{i+1} - V_{i-1}) = 1/3\ (E_{i+1} + 4E_i + E_{i-1}) -$$

$$b(V_{i+1} + 4V_i + V_{i-1}) + 6bV_T$$

or

$$E_{i+1} + 4E_i + E_{i-1} = 3n/\Delta t\ (V_{i+1} - V_{i-1}) +$$

$$b(V_{i+1} + 4V_i + V_{i-1}) - 6bV_T$$

2.3 Model Conceptualization and Application to Mortandad

2.3.1 Conceptual Model

Instead of using William Purtymun's conceptual model of an upper, middle, and lower aquifer, we combined the upper- and middle segments for reasons discussed later (see fig. 6).

2.3.2 William Purtymun's Data (8)

The parameters gleaned from Purtymun's water balance summation calculations for use in this model included: monthly aquifer volumes, lateral groundwater flow, and surface water inputs. ET was recalculated in order to be maximized (see tables 2 & 3). A first approximation was made using the Blaney-Criddle method (3). Rainfall was then subtracted off for a net ET. This net ET was then multiplied by an "ET factor" to account for the change in vegetation and depth to the perched water table (see fig. 11 for graphical representation of ET). The only other forced parameter was porosity. A porosity of 0.2 was used for the upper/middle canyon and a porosity of 0.25 for the lower canyon. These are reasonable values, since the alluvium is

mostly coarse sand and gravel in the upper canyon, grading down to fine sand, silt, and clays in the lower canyon (10).

2.3.3 Water Level Phenomena During 1991

In July of 1991, several large storms in close succession, combined with TA-50 discharges, produced enough runoff to fill the sediment traps to capacity. The wetting front from the resulting high amounts of infiltration eventually connected with the perched water table and created a groundwater "mound" that gradually propagated down the canyon. This rise in water levels, about 2-4 m (7-13 ft), took approximately one month to travel from well MT-1 to well MT-4 (see map). This is about 50 percent of the length of the lower aquifer segment (see fig. 12 for 1991 lower aquifer segment water level changes).

3.0 Results

Tables 4 and 5 contain the numerical results for the lumped-parameter water balance simulations. Alluvial aquifer water volumes are presented as average saturated thicknesses (water levels) instead. Constants estimated in the model are also displayed in tables 4 and 5. The actual response time for the lower aquifer, as calculated from the observed water level changes mentioned in section 2.3.3, appears to be about 1.75 times longer than the value estimated in the model.

Figures 13 and 14 graphically compare observed with modeled parameters for the upper/middle aquifer. Note the similar shape of the simulated Q_{aw} data to the variation in aquifer storage, due to the aforementioned proportional relationship (see section 2.2).

Figures 15 and 16 both compare modeled- to observed storage in the lower aquifer. The simulated response in figure 15 was calculated using observed data, while the predicted response in figure 16 was calculated using simulated inputs from the upper/middle aquifer.

Figures 17 and 18 both show predicted downward seepage into the tuff; but the seepage numbers used in figure 17's plot were generated from Purtymun's observed storage, while the ones in figure 18 were calculated from the simulated storage response. Once again, note the similar shape between the upper/middle aquifer seepage in figure 18 and the modeled storage response in figure 13.

4.0 Discussion and Conclusions

4.1 Sources of Error

There are a number of possible error sources inherent in the approach taken in this model. They range from uncertainties in various forced parameters to differences between calculations made here and in William Purtymun's work. Clearly the potential innaccuracies enumerated below are a caveat against taking this paper as the last word on Mortandad Canyon, but the objective was to obtain *approximate* figures in order to make reasonable recommendations for the next phase of study.

One reason the calculated aquifer volumes presented here do not exactly match Purtymun's is that we lack his original data and computations. This includes water levels, the surface areas he used for the middle- and lower aquifers and the exact cross-sectional shape he used for the perched aquifer. The surface area Purtymun used for the upper aquifer segment is stated in his paper (8). The canyon floor area, as planimetered from a large scale topographic map generated from LANL's MOSS mapping system, was larger for the upper canyon. Thus all the planimetered canyon areas were multiplied by a coefficient so that they would be proportionally smaller. The coefficient was the ratio of Purtymun's original upper canyon area approximation to the planimetered upper canyon area (see table 2 for canyon areas used). Purtymun used a trapezoidal or V-notch shape for the aquifer cross section (9), because the perched aquifer is in a sediment-filled stream valley. However, the exact shape and dimensions of the cross sections Purtymun used are unknown. To keep the model simple, the cross sectional shape used in this simulation was rectangular. Note the

differences between the saturated thickness in figure 12 and those in figures 15 and 16. Water levels have not changed very much since the 1960's. Thus, the perched aquifer must be narrower than was assumed in the model or must bulge upward in the middle of the canyon and taper toward the canyon walls, away from the stream channel.

Another potential source of error is in estimating forced parameters. Evapotranspiration is an especially elusive quantity. Although numerous formulas have been suggested since the middle of the century, there is no way to *accurately* estimate ET via some formula method alone, due to the variation in soil and vegetation. Purtymun used a method proposed by Hantush that is a modification on Thornthwaite's evapotranspiration calculation (5). This technique involves multiplying the potential ET values obtained from the Thornthwaite calculation by the ratio of actual- to "field capacity" soil moisture (5). The concept of multiplying potential ET by some coefficient to derive an actual ET in drier soils is intuitively reasonable, although "field capacity" is a term that, over the years, has proven to be quite nebulous. Additionally, while Thornthwaite's method has been successfully used in the eastern and midwestern United States, some of its fundamental assumptions, such as the non-influence of moist or dry winds on the rate of ET, do not apply to the semi-arid and arid climates of the Southwest. The procedure chronically underestimates evapotranspiration under those climatic conditions (1).

As aforementioned, one objective was to get estimates on vertical seepage into the tuff. In order to produce conservative figures for seepage, Steve McLin recommended that vertical seepage estimates be minimized by minimizing the net recharge, that is, to maximize ET (6). This was accomplished by multiplying ET by an arbitrary constant for each aquifer segment. There is a gradational change from abundant trees and vegetation, in the upper canyon to sparse trees and mostly scrub growth in the lower canyon. Thus, ET in the upper canyon is multiplied by the largest "ET factor", and ET in the lower canyon by the smallest (see the header of table 3 for these coefficients, labeled "ET Factor"). Hence, the result is actually an estimate of

minimum seepage. Indeed, the fact that vegetation was not nearly as lush in Mortandad Canyon in the early 1960's as it is today supports the notion that ET may be overestimated here, albeit deliberately.

There are additional factors that may affect the accuracy of the seepage figures derived from the model. Seepage may not be linear with respect to the changes in aquifer volumes, as previously assumed. Also, the areal extent of the perched aquifer may change seasonally, expanding in the late summer during the rainy season and contracting in the late fall and winter.

Other problems are inherent in the data. Twenty-four data points is a rather scanty amount on which to base the statistical outflow fits. Also, it is difficult to see whether the simulations diverge with the observed data over such a short range.

4.2 Future Work

The contaminant mass balance version of this model has not been projected out into the future. Yet, such an exercise should be an important part of the decision making process for the fate of Mortandad Canyon, but there is simply not enough data to run an accurate simulation of future conditions at this point. The problem is principally in the surface water data. There is abundant data on TA-50 plant discharge volumes, contaminant concentration levels and rainfall covering the last thirty years. What is lacking is surface water runoff/streamflow information. That is an important component in the water balance and critical dilution factor in the contaminant mass balance. What is missing is the characteristic flood wave curves from combined rainfall runoff and plant discharges. William Purtymun calculated his monthly surface flow volumes from such curves obtained from gaging stations in Mortandad Canyon, but this raw data is lost. In addition, using the original hydrographs to generate simulations of future discharges/runoff events may not be a sound method, because the basin characteristics for Mortandad Canyon have changed significantly over the last twenty-nine years. Numerous buildings and parking lots have been constructed in the

Mortandad drainage basin since the early sixties, which is a factor that greatly increases storm runoff.

4.3 Important Results of Study

The aquifer response times, t_u, are of key importance in estimating frequency of data collection. Field observations and parameter estimation for the lumped-parameter model indicate the aquifer response time is fairly short -on the order of a few months. However, water level observations from the summer and fall of 1991 suggest that the aquifer response time for the lower aquifer is almost twice as long as estimated in the model.

The other major finding concerns water losses from the perched aquifer. It appears, even after maximizing evapotranspiration, that most of the water that flows into the perched aquifer leaves via downward seepage into the tuff -on the order of 75 percent, conservatively speaking. The high seepage rate combined with the fast response time of the system means that the perched aquifer is regularly flushed out.

4.4 Conclusions

1) Most of the storm runoff and treated effluent that enters the Mortandad Canyon perched aquifer leaves via downward seepage

2) The perched aquifer's response time is on the order of a few months.

4.5 Recommendations for Model Refinement

Statistically better correlation between storage and outflow terms will result in a closer match between observed and simulated aquifer responses. This can be accomplished by collecting water level data for extended periods through a monitoring system consisting of well transducers connected to a computer data logger.

Synthetic hydrographs need to be generated from actual flood wave curves so that extended simulations of perched aquifer behavior can be run . Refurbishing and monitoring the gaging stations in Mortandad Canyon will yield the necessary data.

Seepage from the perched aquifer and evapotranspiration are unknown quantities. Better estimates of seepage can be obtained from drilling additional observation wells. Elimination of seepage as an unknown will help to quantify ET.

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Appendix C

Theissen Weights

WELL NO	AREA(ft^3)	WEIGHT
MCO-3	112565	0.08
MCO-4	106769	0.07
MCO-5	89940	0.06
MCO-6	354338	0.25
MCO-7	365557	0.26
MCO-7.5	400150	0.28
TOTAL	1429319	1.00

WELL NO	AREA(ft^3)	WEIGHT
MCO-3	112565	0.59
MCO-4	77973	0.41
UPPER CANYON		
MCO-4	28796	0.14
MCO-5	89940	0.43
MCO-6	89566	0.43
MIDDLE CANYON		
MCO-6	264772	0.26
MCO-7	365557	0.35
MCO-7.5	400150	0.39
LOWER CANYON		
TOTAL	1429319	

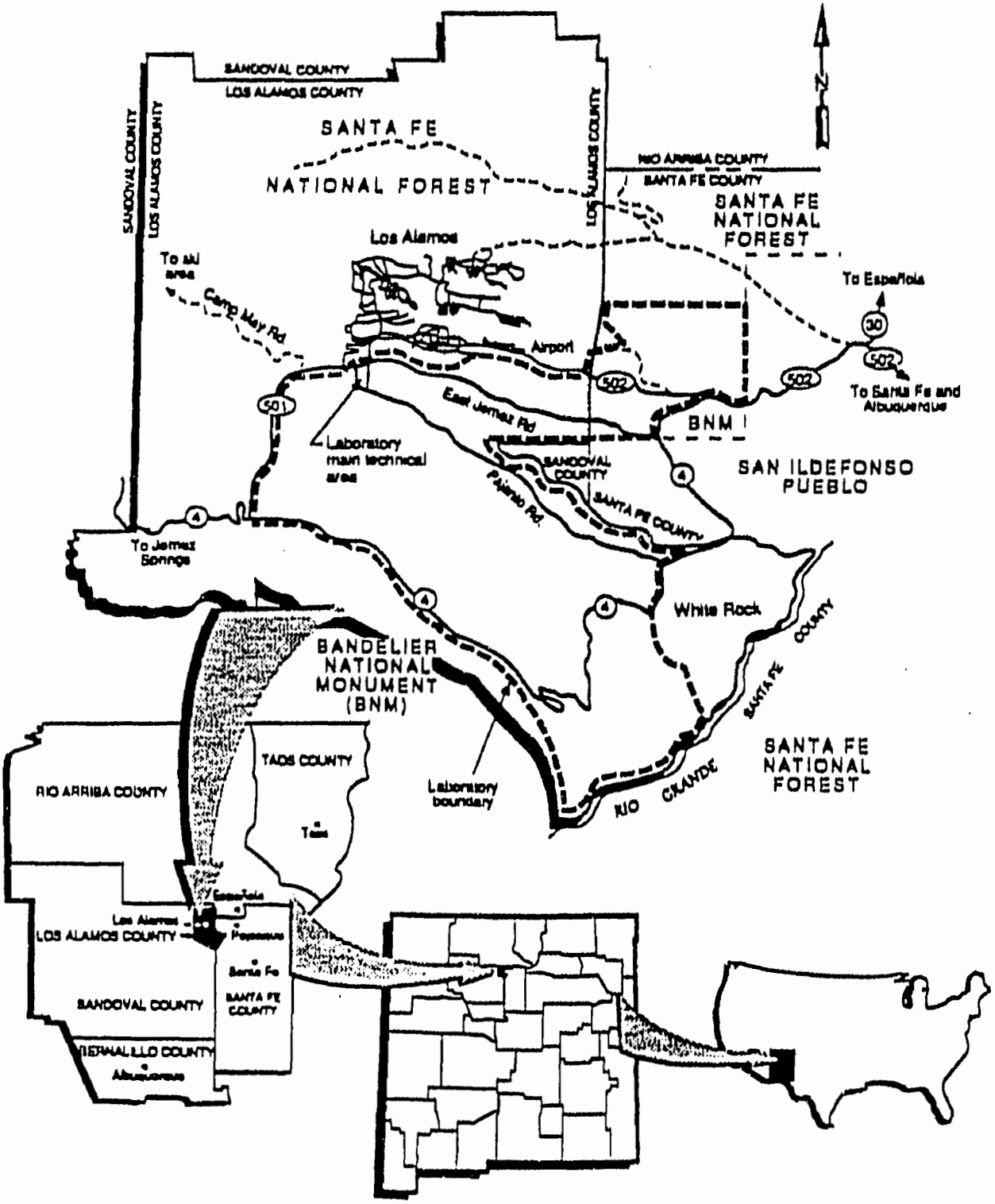


Fig 1. Regional location of Los Alamos.

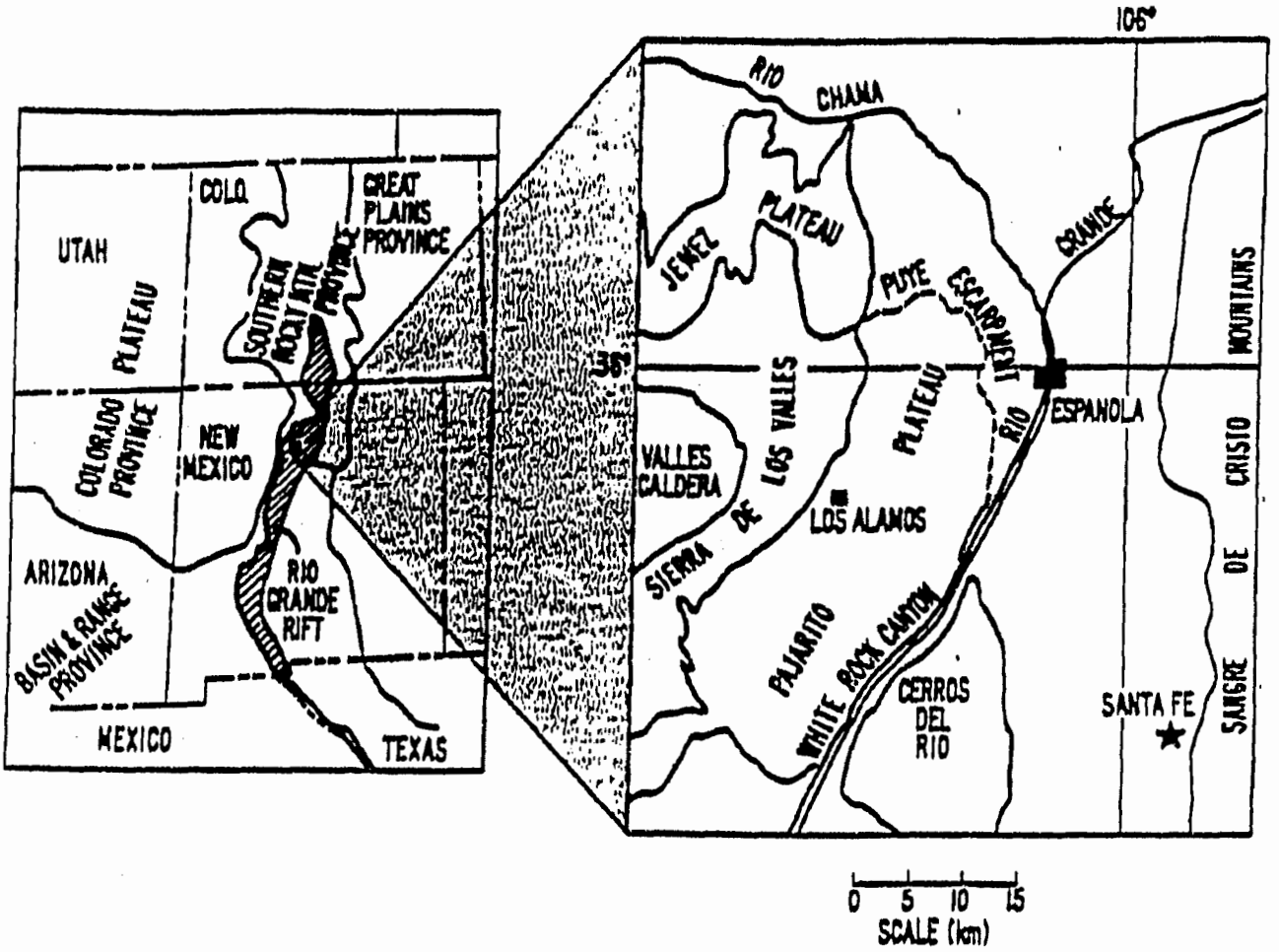
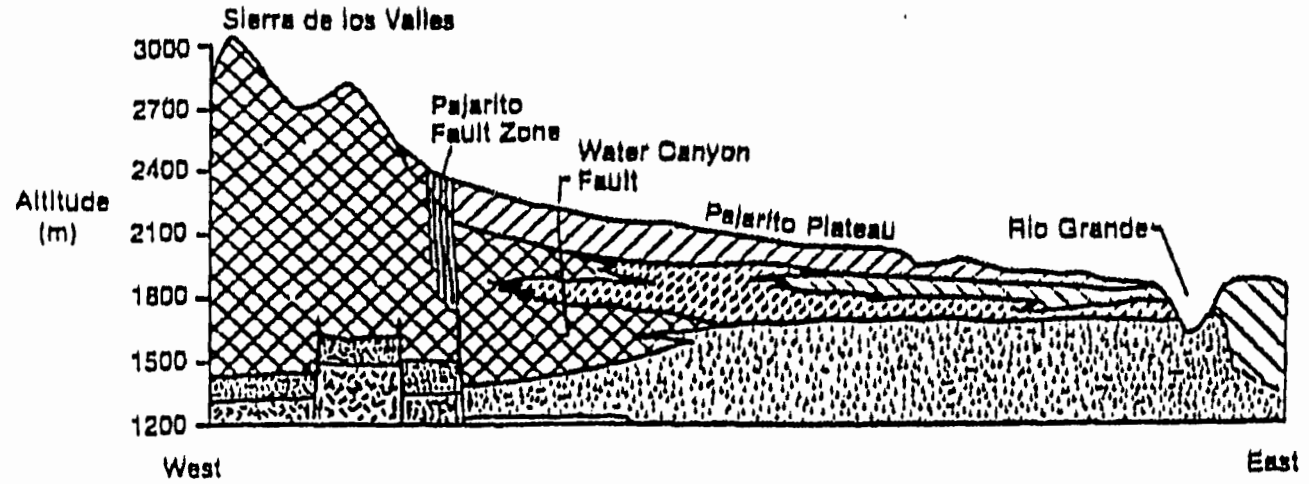
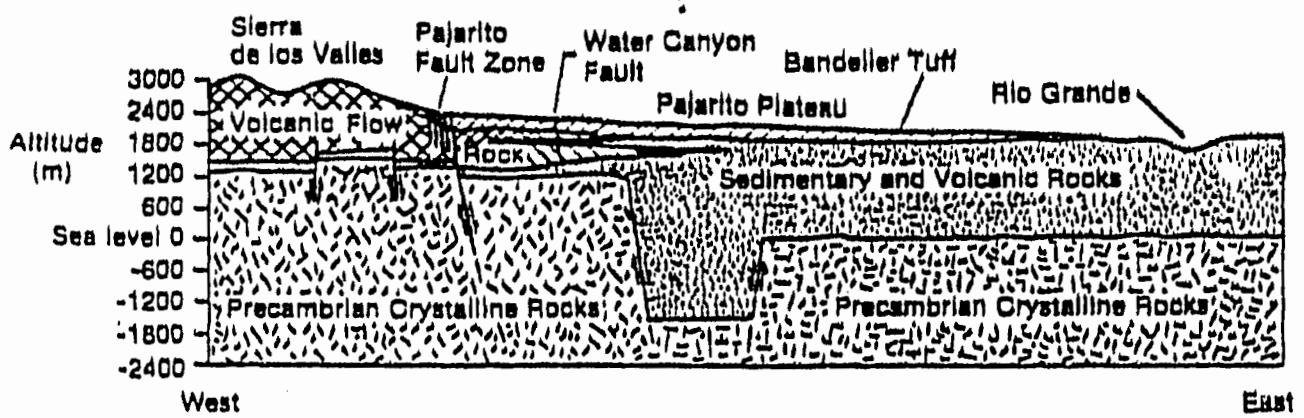


Figure [redacted]-2 Physiographic Features of the Los Alamos Area





LEGEND:

- Bandelier tuff
- Basaltic rocks of Chino Mesa
- Tschicoma formation
- Puye conglomerate
- Tesuque formation
- Precambrian crystalline rocks

Note: See Figure 3.1.1-6 for approximate alignment of cross-section

Figure 3[redacted] Geologic Stratigraphic Relationships

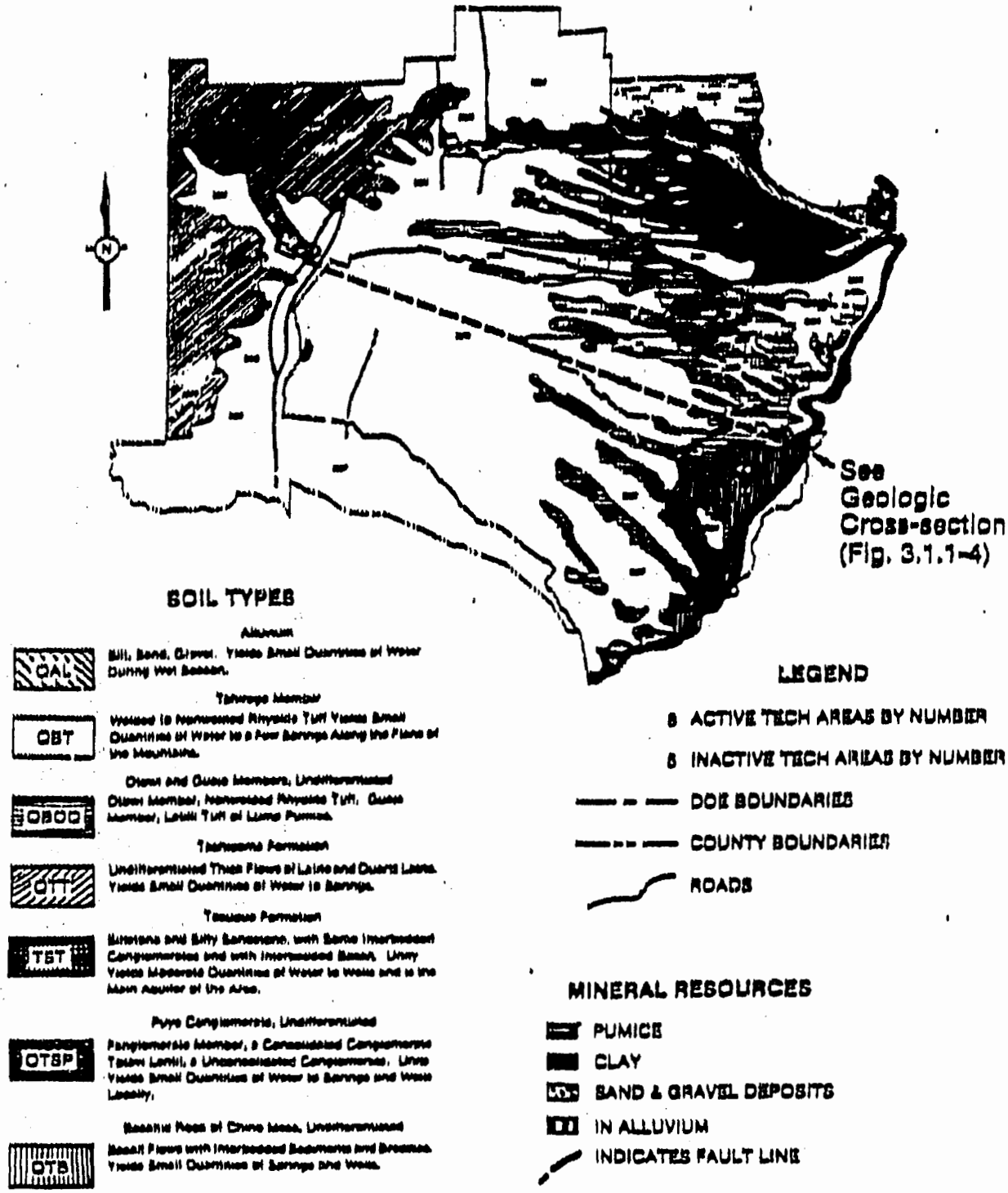
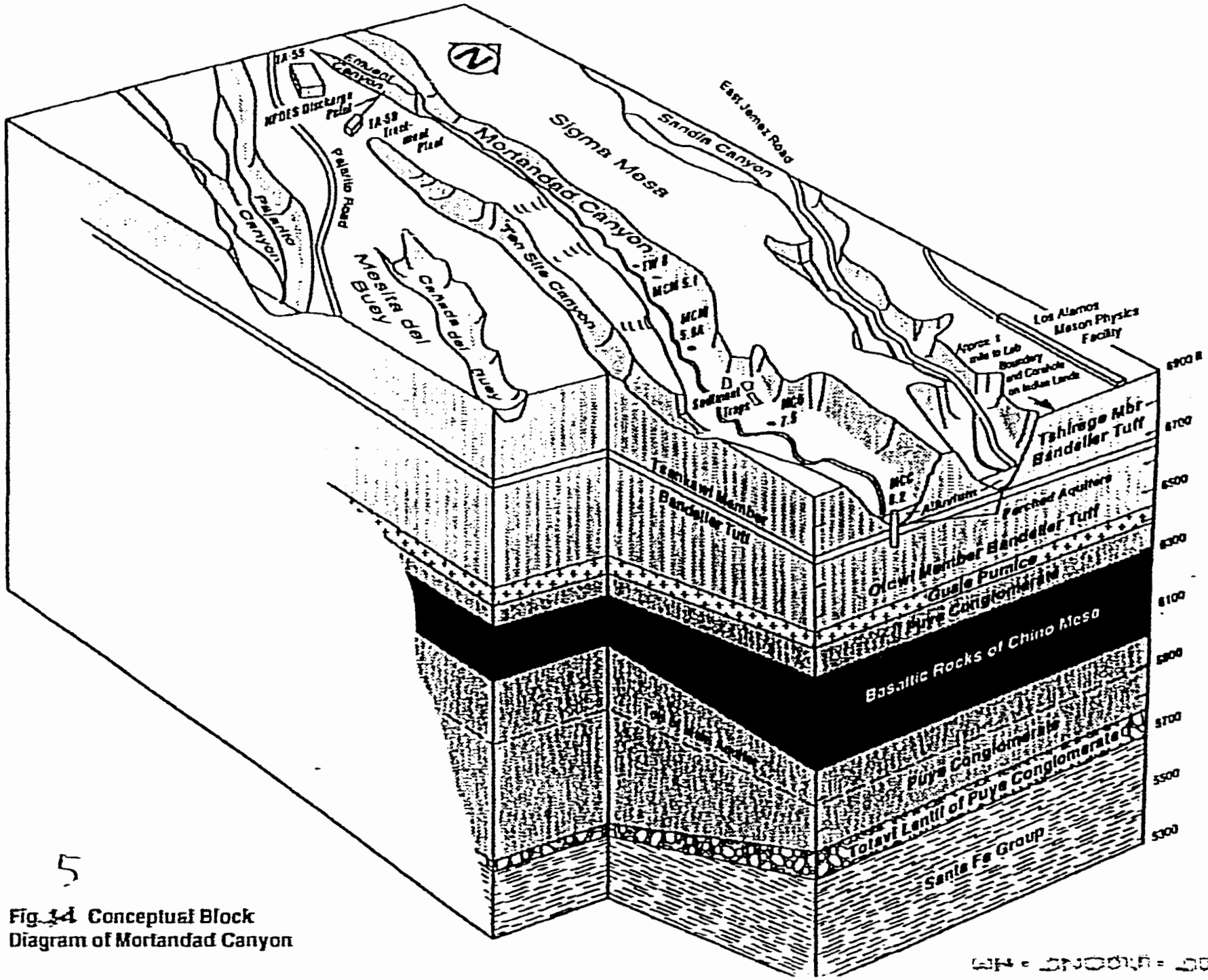
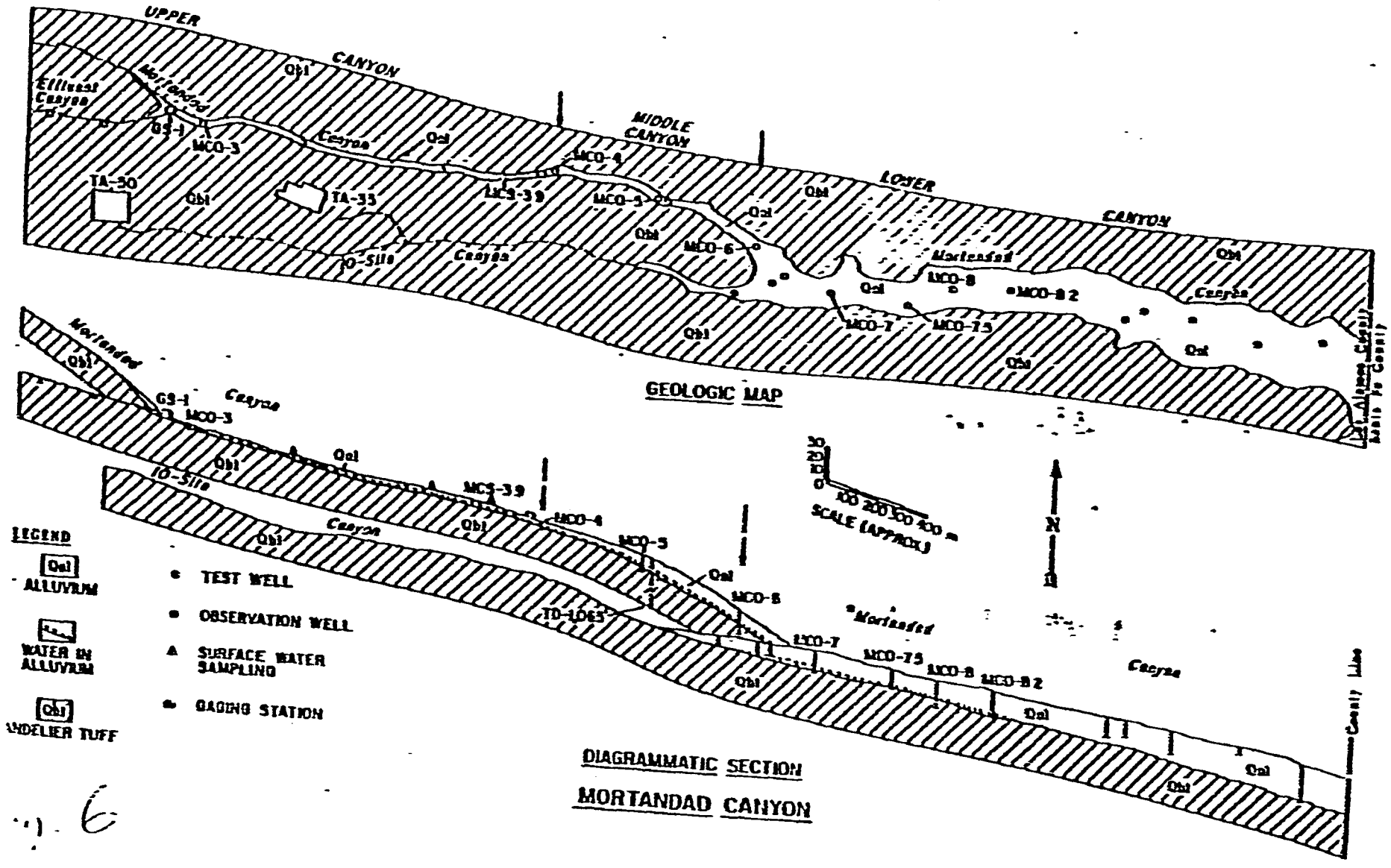


Figure 4. Natural Resources of Los Alamos County



5

Fig. 14 Conceptual Block Diagram of Mortandad Canyon



6

12 Planview and geologic section showing most

Fig. 9 Mortandad Canyon Lower Aquifer Chloride Concentrations

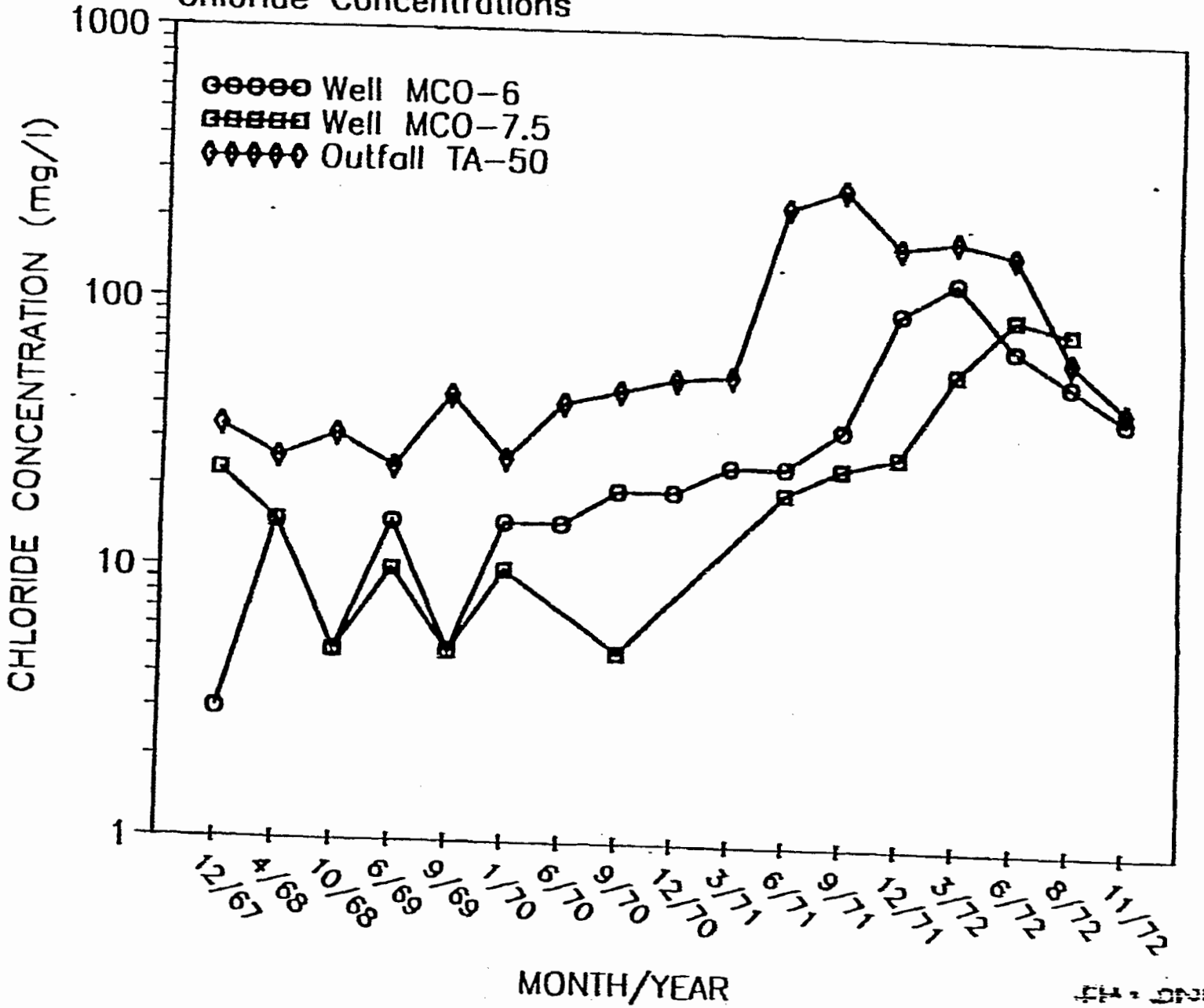


Fig. 10 Mortandad Canyon Perched Aquifer
Average Chloride Concentrations

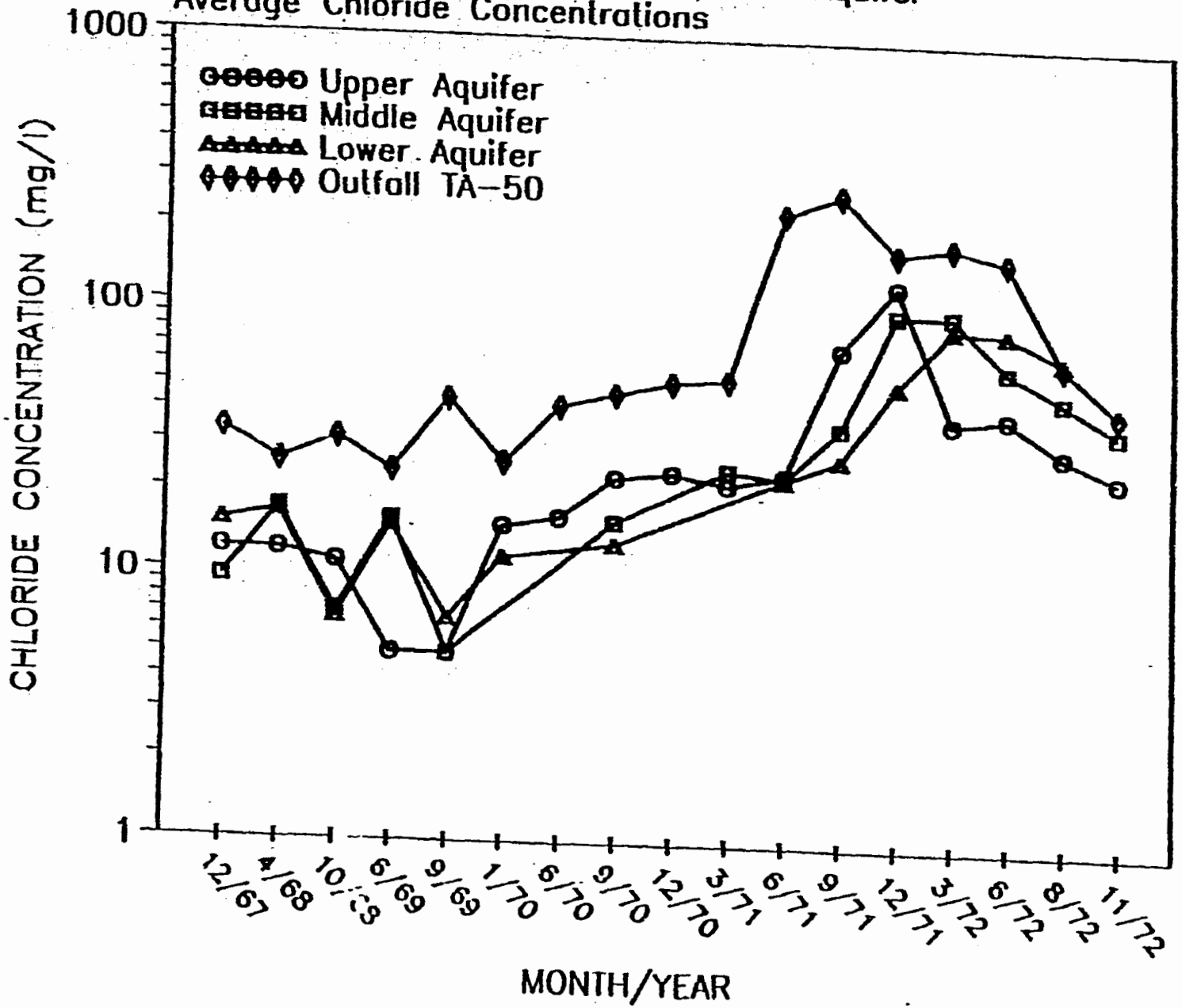
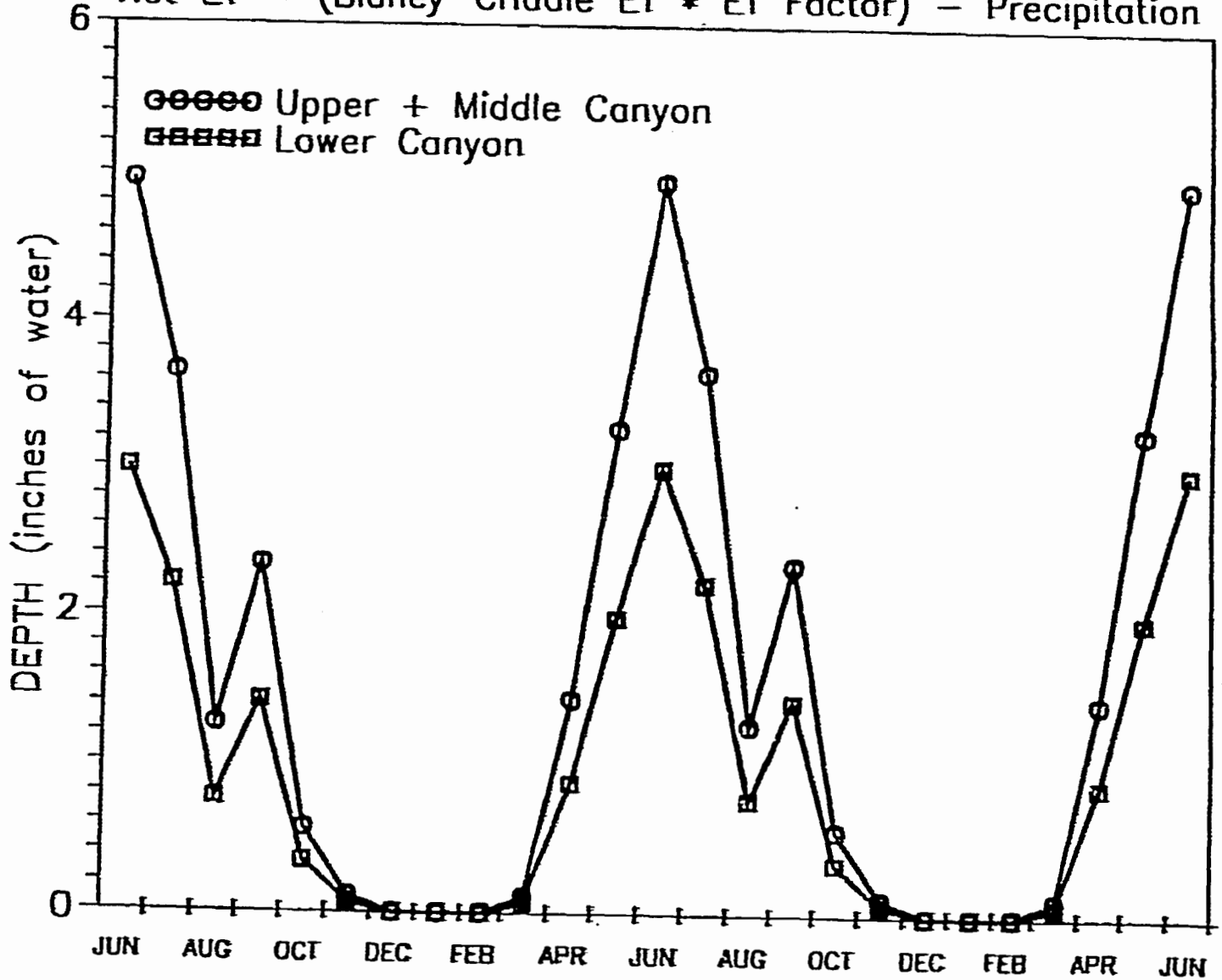


Fig. 11 Mortandad Canyon Net ET
Net ET = (Blaney–Criddle ET * ET Factor) – Precipitation



JUNE 1963 – JUNE 1965

Fig. 12 Approximate Saturated Aquifer Thicknesses
Mortandad Canyon, Summer and Fall 1991

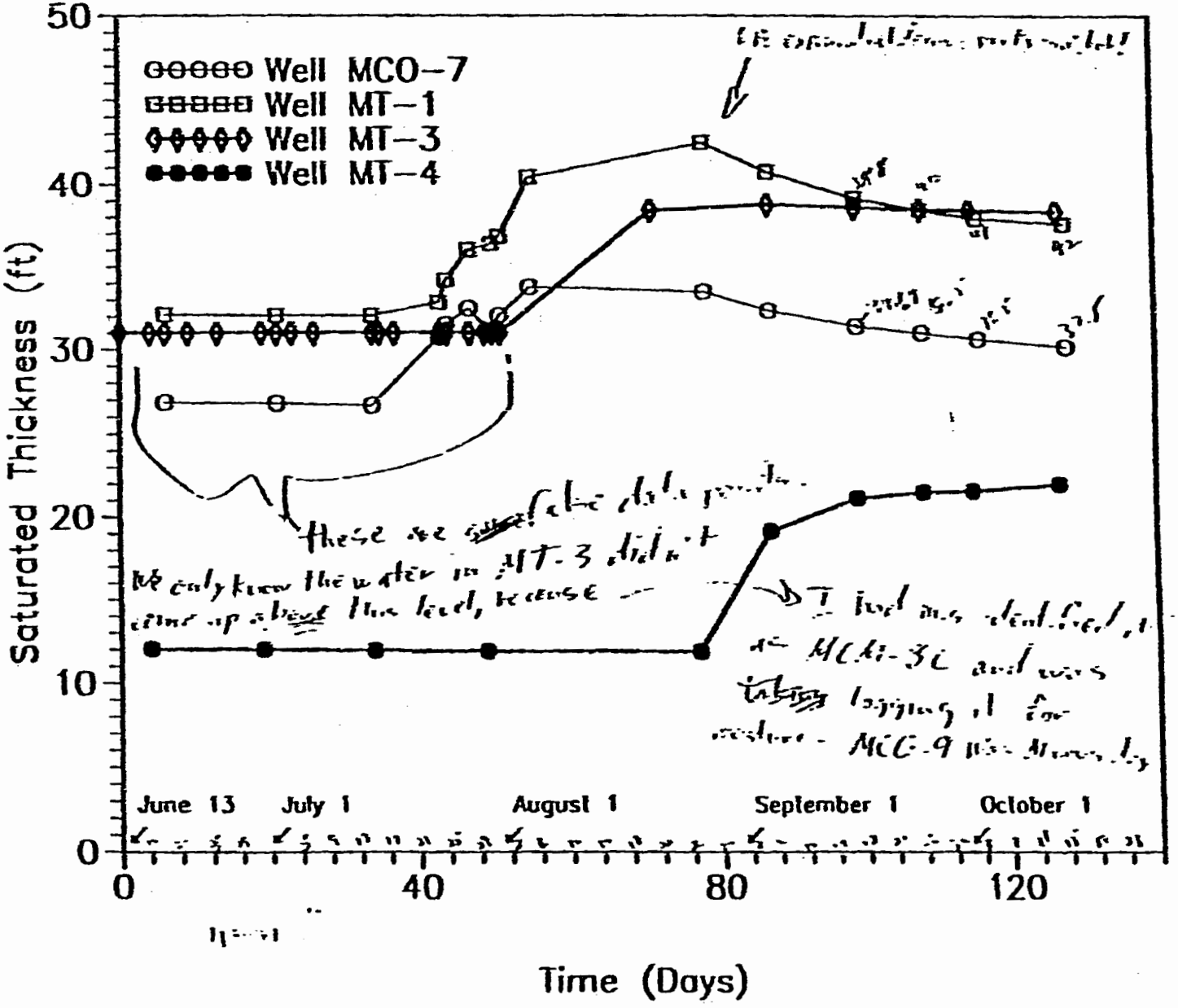


Fig. 13 Mortandad Canyon Upper/Middle Alluvial Aquifer: Observed and Modeled Storage

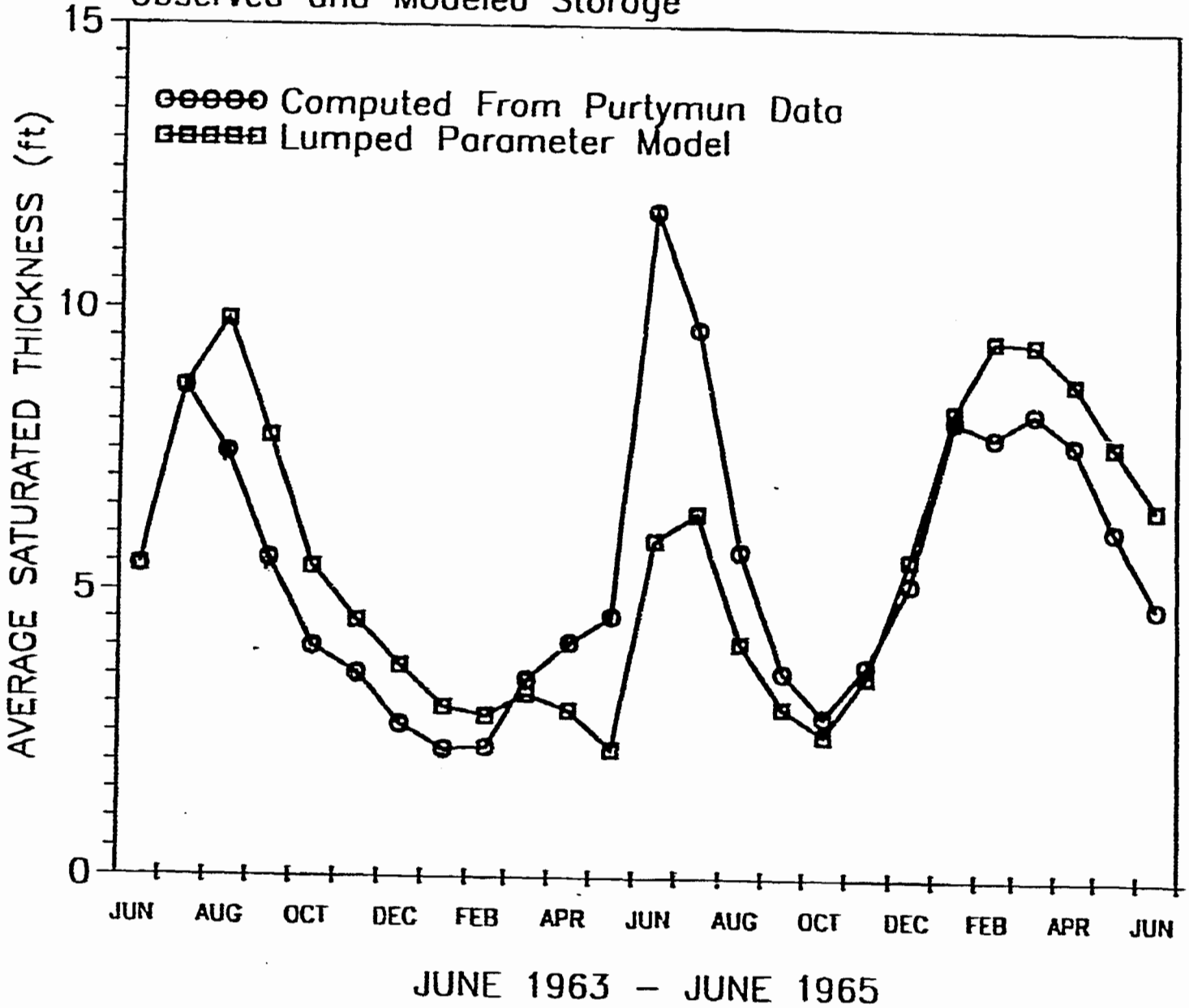
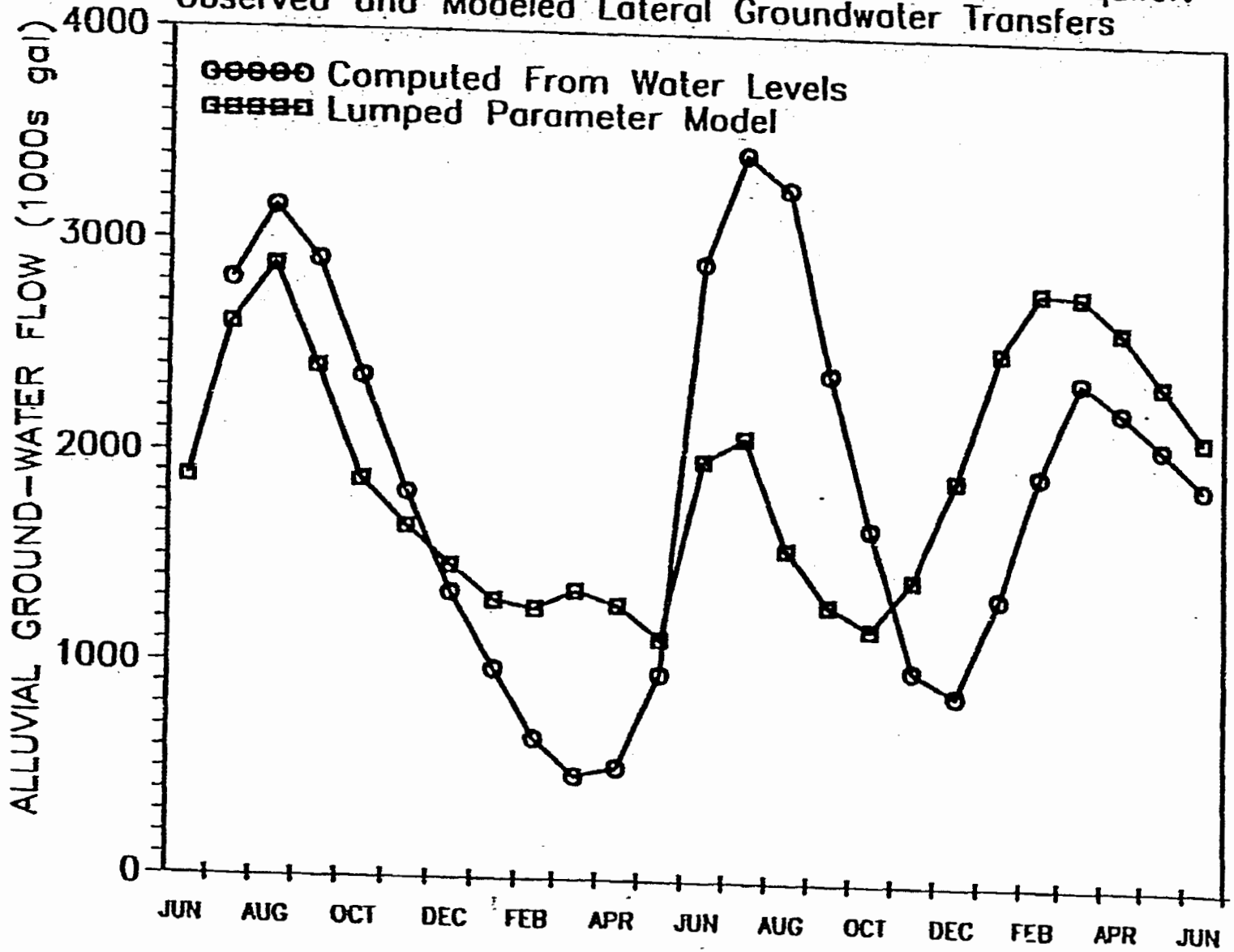
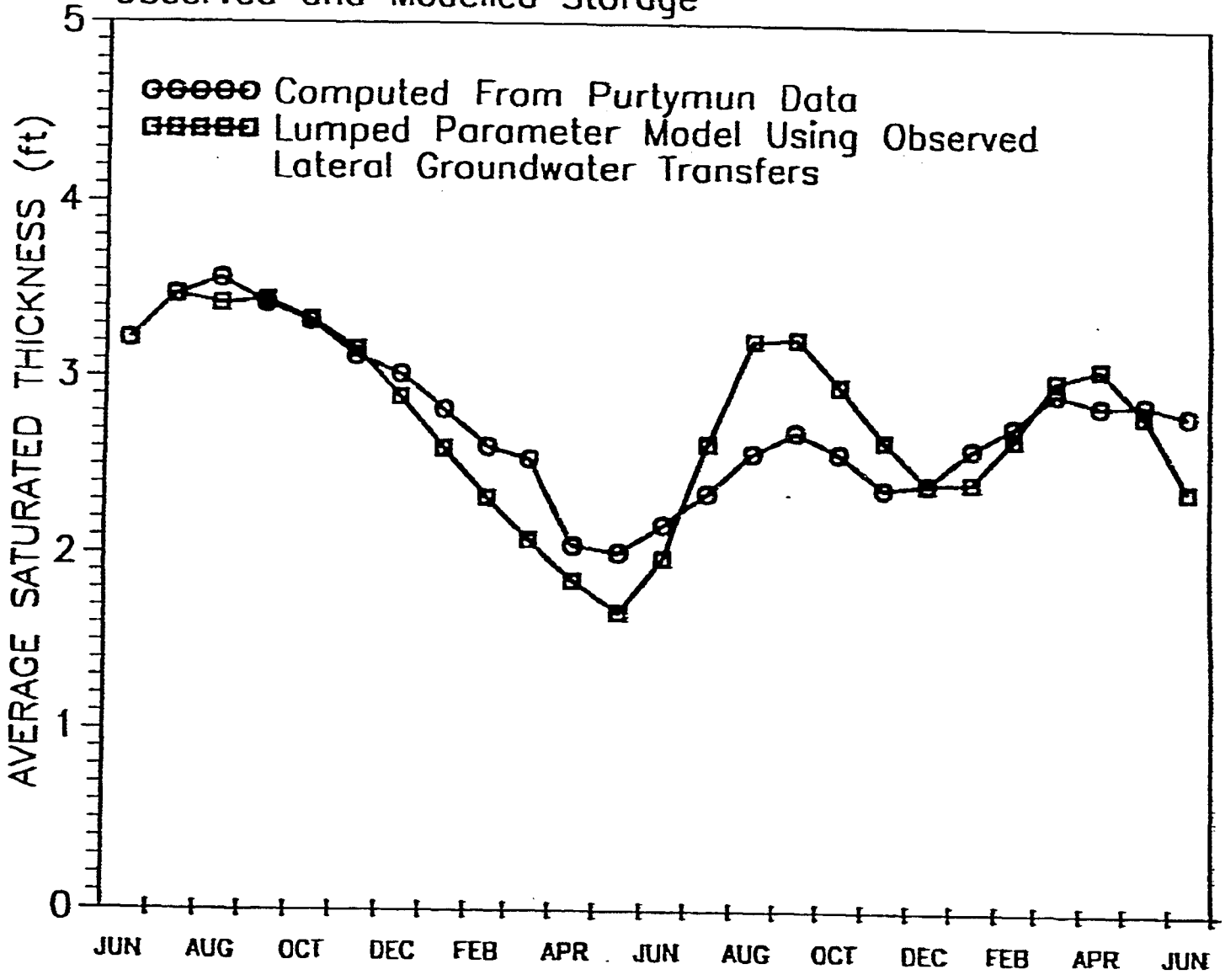


Fig. 14 Mortandad Canyon Upper/Middle Alluvial Aquifer: Observed and Modeled Lateral Groundwater Transfers



JUNE 1963 – JUNE 1965

Fig. 15 Mortandad Canyon Lower Alluvial Aquifer: Observed and Modelled Storage



JUNE 1963 – JUNE 1965

Fig. 16 Mortandad Canyon Lower Alluvial Aquifer: Observed and Modeled Storage

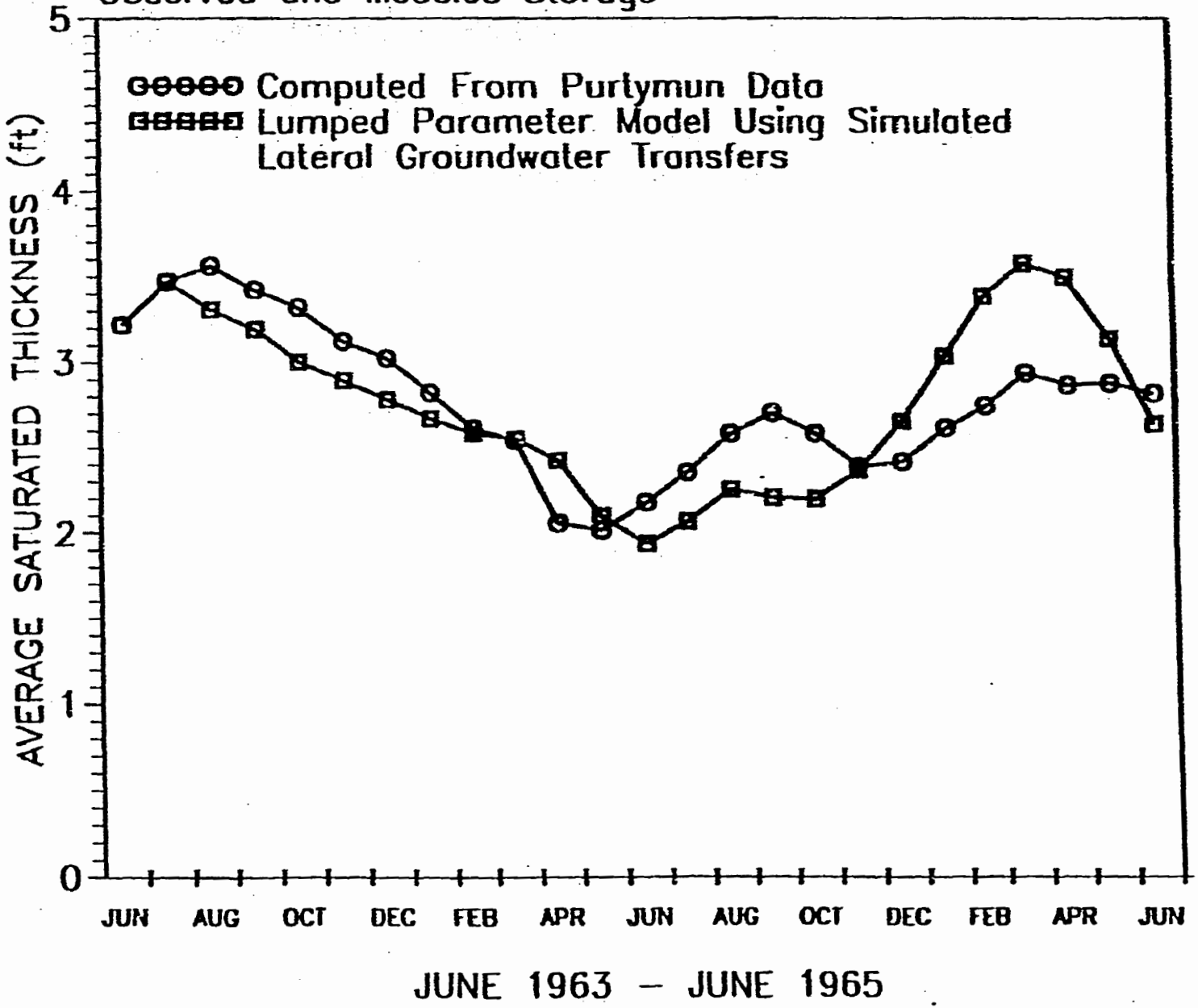


Fig. 17 Mortandad Canyon: Predicted Seepage Into Tuff Calculated Using Observed Input Data

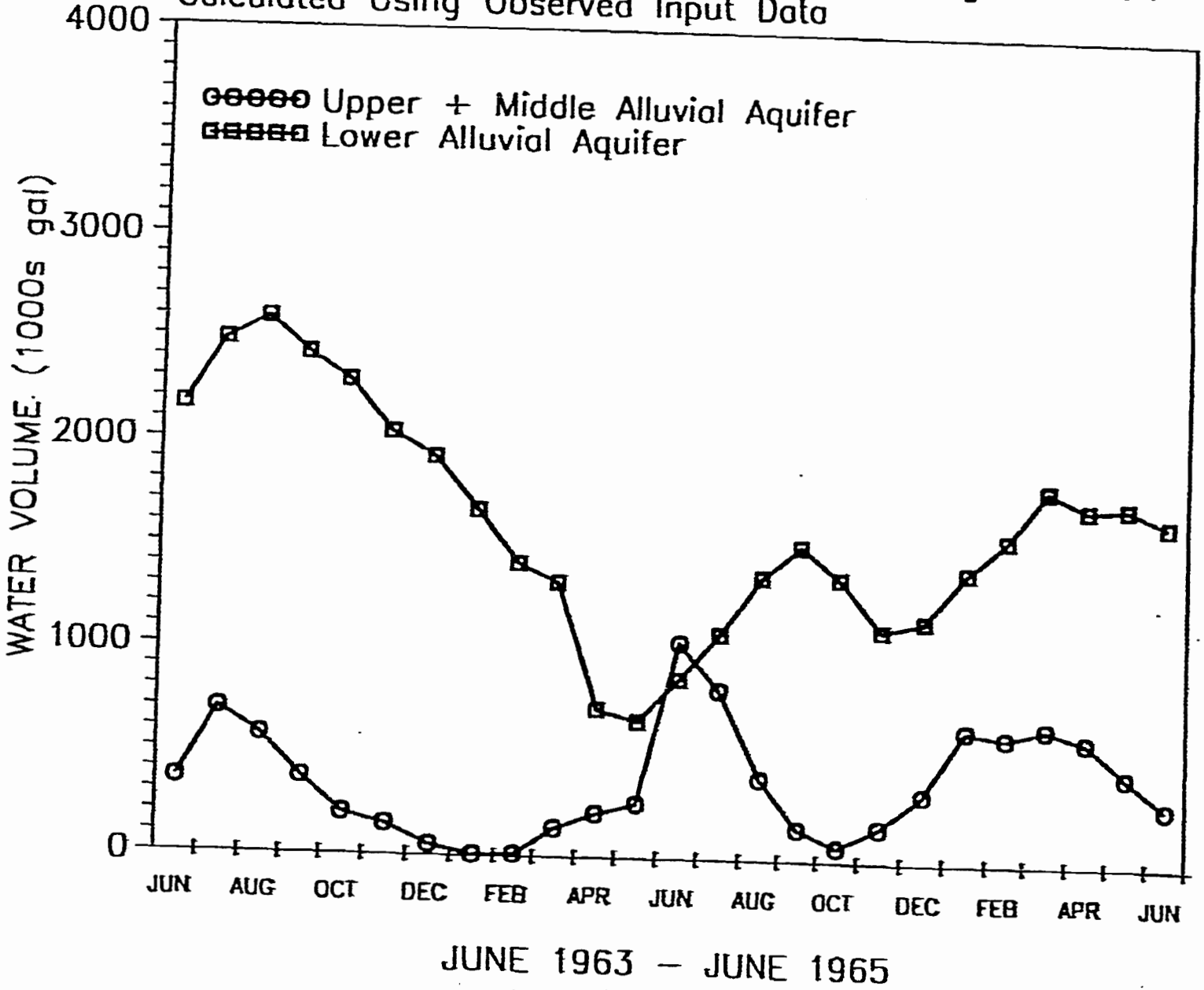
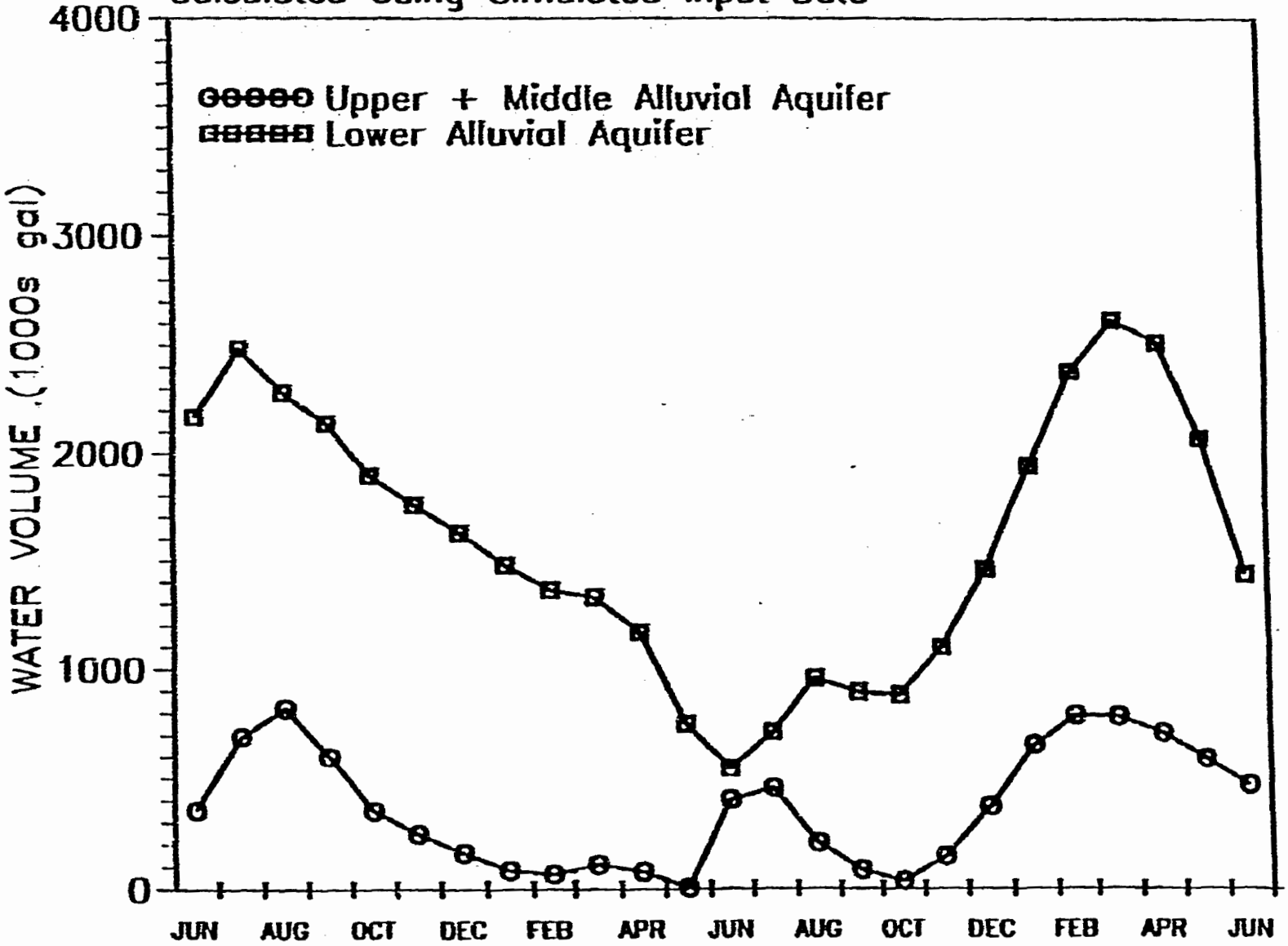


Fig. 18 Mortandad Canyon: Predicted Seepage Into Tuff Calculated Using Simulated Input Data



JUNE 1963 – JUNE 1965

Table 1

Mortandad Canyon Tritium Data (10)*

Units = 1000's of cubic meters and nCi/l unless noted

Year	TA-50 Effluent Volumes	Avg TA-50 Conc	Average Alluvial Aquifer Concentrations UPPER	MIDDLE	LOWER
1963	27.38				
1964	51.39				
1965	48.99				
1966	52.80				
1967	59.67		85.52	109.5	247.6
1968	60.28		31.51	81.5	136.1
1969	54.47	367.20	31.49	32.8	46.9
1970	53.17		648.64	706.6	483.8
1971	45.67		43.69	60.7	90.3
1972	57.07	104.60	54.07	68.5	58.8
1973	53.72	325.20	55.56	51.6	54.8
1974	40.60	99.80	58.88	46.5	38.2
1975	39.72	654.60	135.14	36.1	28.2
1976	39.89	4687.90	944.49	1478.0	626.2
1977	42.09	867.20	338.55	492.9	586.4
1978	40.54	303.40	180.52	276.7	185.5
1979	48.58	673.10	67.86	64.4	83.6
1980	52.83	849.90	53.90	28.6	52.6
1981	55.33	307.20	116.84	384.3	160.0
1982	39.76	357.10	35.00	70.3	76.2
1983	34.50	252.20	74.19	67.1	62.6
1984	35.05	370.90	18.13	50.7	37.0
1985	28.60	2426.60	21.61	28.4	27.3
1986	30.50	2377.00	291.18	805.9	646.1
1987	26.60	3759.40	3722.75	392.3	458.1
1988	29.30	716.70	75.13	138.6	150.0
1989	22.80	701.80	200.96	382.5	314.5
1990	21.10	568.70	53.98	173.3	95.3

*Blank spaces indicate "No data available"

THEISSEN WEIGHTS:

WELL NO	AREA(sf)	WEIGHT
3	112565	0.08
4	106769	0.07
5	89940	0.06
6	354338	0.25
7	365557	0.26
7.5	400150	0.28

Table 2

Net Evapotranspiration Calculations

Blaney-Criddle ET = kPt
P = % of Yearly Daylight Hours
t = Average Monthly Temperature (°F)
k = Crop Coefficient NET ET = Blaney-Criddle ET - Precipitation

MONTH	P	t	k	ET(in)	PREC(in)	ET-P	NET ET
63 JUN	0.09824	65.10	0.80	5.12	1.12	4.00	4.00
JUL	0.09980	68.20	0.90	6.13	3.18	2.95	2.95
AUG	0.09399	65.80	0.80	4.95	3.93	1.02	1.02
SEP	0.08352	60.20	0.70	3.52	1.63	1.89	1.89
OCT	0.07849	50.30	0.50	1.97	1.52	0.45	0.45
NOV	0.06927	37.90	0.40	1.05	0.96	0.09	0.09
DEC	0.06801	30.80	0.10	0.21	0.96	-0.75	0.00
64 JAN	0.07000	29.10	0.05	0.10	0.85	-0.75	0.00
FEB	0.06850	32.20	0.10	0.22	0.68	-0.46	0.00
MAR	0.08346	37.60	0.35	1.10	1.01	0.09	0.09
APR	0.08851	45.60	0.50	2.02	0.86	1.16	1.16
MAY	0.09805	54.90	0.70	3.77	1.13	2.64	2.64
JUN	0.09824	65.10	0.80	5.12	1.12	4.00	4.00
JUL	0.09980	68.20	0.90	6.13	3.18	2.95	2.95
AUG	0.09399	65.80	0.80	4.95	3.93	1.02	1.02
SEP	0.08352	60.20	0.70	3.52	1.63	1.89	1.89
OCT	0.07849	50.30	0.50	1.97	1.52	0.45	0.45
NOV	0.06927	37.90	0.40	1.05	0.96	0.09	0.09
DEC	0.06801	30.80	0.10	0.21	0.96	-0.75	0.00
65 JAN	0.07000	29.10	0.05	0.10	0.85	-0.75	0.00
FEB	0.06850	32.20	0.10	0.22	0.68	-0.46	0.00
MAR	0.08346	37.60	0.35	1.10	1.01	0.09	0.09
APR	0.08851	45.60	0.50	2.02	0.86	1.16	1.16
MAY	0.09805	54.90	0.70	3.77	1.13	2.64	2.64
JUN	0.09824	65.10	0.80	5.12	1.12	4.00	4.00
			ET(in/y)=	30.15	17.83		14.2.

Table 3

Volumetric Evapotranspiration Calculations

		UPPER	MIDDLE	UPPER + MIDDLE	LOWER
	William Purtymun's Areas (8)	143000	Unknown	Unknown	Unknown
Areas in ft²	Planimetered Surface Areas	190538	208302	398840	1030479
Volumes in 1000's	Adjusted Surface Areas	143000	156332	1049838	773381
of gallons	ET Factor	1.50	1.00	1.24	0.75

MONTH	WP1	Net ET UPPER	MIDDLE	LOWER	Net ET * ET Factor UPPER	MIDDLE	UPPER + MIDDLE	LOWER
63 JUN		356	389	1927	534.3	389.4	924	1445
JUL	460	263	287	1420	393.9	287.1	681	1065
AUG	365	91	99	491	136.1	99.2	235	368
SEP	290	168	184	911	252.6	184.1	437	683
OCT	225	40	44	219	60.7	44.2	105	164
NOV	55	8	9	43	12.1	8.8	21	33
DEC	0	0	0	0	0.0	0.0	0	0
64 JAN	0	0	0	0	0.0	0.0	0	0
FEB	0	0	0	0	0.0	0.0	0	0
MAR	20	8	9	43	11.8	8.6	20	32
APR	100	103	113	558	154.8	112.8	268	419
MAY	260	235	257	1272	352.7	257.1	610	954
JUN	370	356	389	1927	534.3	389.4	924	1445
JUL	450	263	287	1420	393.9	287.1	681	1065
AUG	390	91	99	491	136.1	99.2	235	368
SEP	270	168	184	911	252.6	184.1	437	683
OCT	180	40	44	219	60.7	44.2	105	164
NOV	35	8	9	43	12.1	8.8	21	33
DEC	0	0	0	0	0.0	0.0	0	0
65 JAN	0	0	0	0	0.0	0.0	0	0
FEB	0	0	0	0	0.0	0.0	0	0
MAR	20	8	9	43	11.8	8.6	20	32
APR	100	103	113	558	154.8	112.8	268	419
MAY	250	235	257	1272	352.7	257.1	610	954
JUN	360	356	389	1927	534.3	389.4	924	1445
Net Adjusted ET: inches/year					21.42	14.28	17.69	10.71

Table 4

Observed (8) and Modeled Parameters for Upper/Middle Aquifer

$n = 0.2$ $a = 0.1$ $b = 0.05$
$t_h = 1.32$ months $V_{GW} = -161 * 10^3$gal $V_T = 129 * 10^3$gal
Volumes in 1000's of gallons, water levels [H(obs,calc)] in feet, Net ET in inches

MONTH	H(obs)	H(calc)	$Q_N + Q_A$	E	Q_{GW} (obs)	Q_{GW} (calc)	Q_T	ET
63 JUN	5.45	5.45				1880	355	4.95
JUL	8.61	8.61	5812	5131	2816	2608	694	3.65
AUG	7.46	9.81	3569	3334	3164	2884	822	1.26
SEP	5.57	7.74	2173	1736	2912	2406	600	2.34
OCT	4.01	5.43	1508	1403	2364	1876	353	0.56
NOV	3.54	4.47	1782	1761	1816	1654	249	0.11
DEC	2.64	3.67	1137	1137	1340	1469	163	0.00
64 JAN	2.21	2.95	1201	1201	980	1304	86	0.00
FEB	2.25	2.80	1351	1351	656	1268	69	0.00
MAR	3.43	3.18	1760	1740	484	1356	111	0.11
APR	4.08	2.89	1236	968	528	1289	79	1.43
MAY	4.55	2.21	1523	913	968	1133	6	3.27
JUN	11.76	5.90	6186	5262	2916	1984	403	4.95
JUL	9.66	6.39	1623	942	3440	2097	456	3.65
AUG	5.73	4.09	1420	1185	3280	1567	209	1.26
SEP	3.58	2.96	1394	957	2404	1304	86	2.34
OCT	2.80	2.48	1277	1172	1672	1194	35	0.56
NOV	3.69	3.51	2396	2375	1004	1431	146	0.11
DEC	5.16	5.60	3277	3277	892	1913	370	0.00
65 JAN	8.06	8.23	4438	4438	1352	2521	654	0.00
FEB	7.78	9.49	3664	3664	1944	2812	789	0.00
MAR	8.21	9.44	3524	3504	2392	2800	784	0.11
APR	7.66	8.74	3149	2881	2256	2638	708	1.43
MAY	6.14	7.64	3096	2486	2088	2385	590	3.27
JUN	4.77	6.53	3035	2111	1900	2128	470	4.95

Table 5

Observed and Modeled Parameters for Lower Aquifer

$n = 0.25$ $b = 0.22$
$t_h = 1.15$ months $V_T = 288 * 10^3$gal

MONTH	H(obs)	H(calc1)*	H(calc2)†	$Q_N + Q_A$	E†	E(sim)**	Q_{GW}	Q_T (calc1)*	Q_T (calc2)†	ET(in)
63 JUN	3.22	3.22	3.22					2170	2170	3.00
JUL	3.47	3.47	3.47	0	1751	1543	0	2485	2485	2.21
AUG	3.56	3.42	3.31	0	2796	2516	0	2594	2281	0.76
SEP	3.42	3.44	3.19	0	2229	1723	0	2421	2138	1.42
OCT	3.32	3.33	3.00	0	2200	1712	0	2292	1893	0.34
NOV	3.12	3.16	2.89	0	1783	1622	0	2041	1756	0.07
DEC	3.02	2.89	2.78	0	1340	1469	0	1920	1624	0.00
64 JAN	2.82	2.60	2.67	0	980	1304	0	1665	1476	0.00
FEB	2.61	2.32	2.58	0	656	1268	0	1410	1363	0.00
MAR	2.54	2.08	2.55	0	452	1324	0	1321	1328	0.07
APR	2.05	1.85	2.42	0	109	871	0	707	1166	0.87
MAY	2.01	1.67	2.09	0	14	179	0	650	751	1.98
JUN	2.17	1.98	1.93	0	1471	539	0	857	546	3.00
JUL	2.35	2.63	2.06	0	2375	1032	0	1079	715	2.21
AUG	2.58	3.22	2.25	0	2912	1199	0	1362	958	0.76
SEP	2.70	3.23	2.20	0	1721	621	0	1516	894	1.42
OCT	2.58	2.96	2.19	0	1508	1030	0	1362	880	0.34
NOV	2.38	2.65	2.36	0	971	1399	0	1111	1097	0.07
DEC	2.41	2.41	2.65	0	892	1913	0	1160	1453	0.00
65 JAN	2.61	2.42	3.03	0	1352	2521	0	1403	1934	0.00
FEB	2.74	2.67	3.38	0	1944	2812	0	1564	2377	0.00
MAR	2.93	3.00	3.57	0	2360	2768	0	1806	2614	0.07
APR	2.86	3.07	3.49	0	1837	2219	0	1718	2510	0.87
MAY	2.87	2.81	3.13	0	1134	1431	0	1732	2064	1.98
JUN	2.81	2.38	2.63	0	455	683	0	1651	1433	3.00

*Calculated using observed Q_{GW} (upper/middle aquifer lateral groundwater outflow) from Purtymun's data (8
†Calculated using simulated Q_{GW}
†Observed Q_{GW} (upper/middle) minus ET
**Simulated Q_{GW} minus ET

TO: AlanB
StevemM

CC:

DATE: 08-07-91
TIME: 08:16

FROM: Erick
SUBJECT: Water Levels, et c.
PRIORITY:
ATTACHMENTS:

Arright, Here's the water levels for the last month in review...

	7-16-91	7-17-91	7-25-91	7-26-91	7-29-91	8-1-91	8-2-91
MCO-4		14.81 ft					5.16 ft
MCO-4A		TOO LOW TO MEASURE					12.86
MCO-4B		19.98					13.49
MCO-4.9		22.08					16.84
MCO-5		20.08					15.25
MCO-6		36.74					33.35
MCO-6A			TOO LOW TO MEASURE				
MCO-6B		37.18					33.70
MCO-7	39.32 36.07		35.26 34.02	34.48 33.24	33.52 32.28	33.01 33.77	33.96 32.[illegible]
MCO-7A	38.78 36.08		35.18 33.78	34.38 32.38	33.33 31.33	34.07 32.69	33.72 31.[illegible]
MT-1	45.96 44.16		45.16 43.36	43.82 42.02	41.98 40.18	41.61 39.81	41.20 39.[illegible]
MCO-7.5	45.45 44.15		45.35 44.05	45.22 43.94	44.07 42.74	43.38 42.1	43.16 41.[illegible]

	8-6-91
MCO-7	32.24
MCO-7A	32.06
MT-1	37.60
MCO-7.5	41.33

I got a gallon sample from each sediment trap yesterday to be analyzed for Tritium, Pu 238 & 239, total U, Cs, gross-me-out alpha and beta, and gamma scan and I walked around the place and made a rough sketch of the extent of overflow around the sediment traps.

PRIORITY:
ATTACHMENTS:

	7-31-91	8-1-91	8-2-91	8-6-91	8-20-91	8-26-91	8-27-91
MCO-9.5	DRY (57 ft)	--	--	--	--	--	--
MCO-9	DRY (42 ft)						
MCO-8.2	DRY (62 ft)						
MT-4	66.11 ft	--				66.15	
MCO-8A(?)	DRY (49 ft)					44.44	
MCM-8C(?)					45.60!		
MCO-7.5		43.38	43.16	41.33 40.65			37.28 36.8
MT-1		41.61	41.20	37.60 35.8			35.52 33.72
MCO-7		35.01	33.96	32.24 31-			32.54 [illegible]3
MCO-7A		34.69	33.72	32.24 30.06 32.06			32.12 30.12
MCO-6A			DRY (34 ft)				29.88
MCO-6B			33.70				28.[illegible]
MCO-5			15.25				7.[illegible]
MCO-4.9							9.54
MCO-4B			13.49				8.08
MCO-4A			12.88				7.58
MCO-4			5.16				DEFUNCT

	8-26-91	9-5-91	9-17-91
MCO-9.5		DRY	DRY
MCO-9		DRY	DRY
MCO-8.2			60.39

8/28 915 9

MCU-8A	44.37	44.64
MCM-8C	45.24	45.44
MCO-7.5	38.46 37.18	39.79 38.51
MT-1	37.26 35.46	36.86 37.26
MCO-7	33.68 32.44	34.64 33.4
MCU-7A	33.23 31.23	34.17 32.14
MCO-6.5A		SOME WATER - LIKE 15 OR 16" IN BOTTOM
MCO-6A		30.78
MCO-6B		29.73
MCO-6		30.06
MCO-5		6.51
MCO-4.9		8.36
MCO-4B		7.29
MCO-4A		6.80
MCO-3	5.73	

++

All water level measurements NOT corrected for casing stickup (as per usual)

Huh... it'll be interressant to see how long that little recession pulse takes to get all the way down to MT-4 and MCO-8.2.

Be seeing you,

TO: AlanS CC: DATE: 07-26-91
TIME: 13:18

FROM: Erick
SUBJECT: Mortandad Measurements 7-26-91 (Friday)
PRIORITY:
ATTACHMENTS:

Dear Dr. Stoker,

Here are the results from Friday morning's foray:

Moisture Profile at MCM-6.31 essentially unchanged except for a higher moisture content in the first foot

Water levels closer to the ponds went up overnight:

	7-25-91	Rise	7-26-91
MCO-7	35.26 FT	1.24 34.02	34.48 FT 33.24
MCO-7A	35.18 FT	1.2	34.38 FT
MI-1	45.16 FT	1.79	43.62FT
MCO-7.5	45.80 FT	1.58	43.22 FT

My notes from a month ago indicate that MCM-7.5 is obstructed around 7 feet from the top of the casing.

The pond near MCO-7 looked like it had a fair amount of water in it still (the water was maybe 1-2 feet below the bank [not the berm]).

The pond farthest to the East looked rather drained (I could see bottom at its westernmost reaches).

Be seeing you,

Eric

TO: AlanB CC: DATE: 07-29-91
TIME: 15:48

FROM: Erick
SUBJECT: LATEST WATER LEVELS
PRIORITY:
ATTACHMENTS:

Dear Alan,

Huh... well I was #wondering# when this crummy network would be up again...

Okay, so here is the latest tally for those four wells near the sediment traps.

	7-18-91	7-20-91	7-26-91	7-29-91
MCU-7	36.58 39.32 ft	34.04 35.26 ft	33.24 34.48 ft	33.52 ft 32.27
MCU-7A	38.78	35.18	34.38	33.33
MT-1	45.76	45.16	43.82	41.98
MCU-7.5	48.43	45.35	45.22	44.07

speeter.

Eric

TO: AlanS CC: DATE: 08-01-91
TIME: 16:07

FROM: Erick
SUBJECT: Re: Latest Water Levels
PRIORITY:
ATTACHMENTS:

Ha! You think the last water levels were interressant?
Check out today's...

8-1-91
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MT-1	41.61 ft
MCO-7.5	43.38
MCO-7	35.01 33.77
MCO-7A	34.69

Spaeter,

Eric

==========

FROM : UNCONF - CDT

TO: Alan B CC: DATE: 06-02-91
TIME: [illegible]

FROM: Brick
SUBJECT: [illegible]
PRIORITY:
ATTACHMENTS:

Water levels from upper part of lower Mortandad

[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	16.54
[illegible]	LOW	12.88
[illegible]	17.98	13.49
[illegible]	14.81	3.16

Since the sediment traps had water in them again today, I got the other wells again...

	6-2-91
MCO-7	35.96 3217
MCO-7A	35.72
MCO-7.5	43.16
MT-1	41.20