PARAMETER ESTIMATION FOR A LUMPED-PARAMETER GROUND-WATER MODEL OF THE MESILLA VALLEY, NEW MEXICO

by

C. David Updegraff

and

Lynn W. Gelhar

New Mexico Water Resources Institute

in cooperation with

Department of Geoscience

New Mexico Institute of Mining and Technology

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ABSTRACT

A lumped-parameter, linear-reservoir, ground-water model is developed for possible application to the Mesilla Valley, New Mexico. Using a discretized form of the model, specific-yield and response-time parameters are estimated by a least squares technique from water-level and drain-flow data for the Mesilla Valley. Net recharge is then estimated from water-level changes during months that recharge occurs. The estimated parameters are used in simulations which predict water levels and drain flows. The results show that the parameters are physically realizable and similar to values used by others. The simulations are in excellent agreement with the observed data over a five-year period.

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CHAPTER 1

INTRODUCTION

Mathematical models of ground-water flow and contaminant transport have developed rapidly in the last decade. However, proper application of these models requires various parameters (transmissivity, storage coefficients, dispersion coefficients, etc.), which are generally difficult to estimate. The models fall into two distinct categories: distributed-parameter models and lumped-parameter models. The parameter estimation procedure for one is much different than for the other.

The distributed-parameter models, whose parameters can vary in space and time, are quite complicated. These models are set up in some kind of grid network and are solved using finite difference or finite element techniques. They can take into account heterogeneous and anisotropic transmissivities, spatially varying storage coefficients and complicated boundary conditions.

Because of their complexity, distributed-parameter models require large amounts of input data that are generally hard to obtain or difficult to estimate. Initial conditions of the modeled area are obtained by measuring water levels in wells distributed over the area to be modeled, drawing a water table map and interpolating water levels for various node points. Estimation of transmissivities and storage coefficients is not as easy as the method used to determine initial conditions. Sometimes transmissivities and storage coefficients are determined from pump tests. However, analyses of pump tests assume that the aquifer is at least homogeneous -- an assumption which is generally not valid. At other times, the model is run repeatedly with different sets of parameters until the model produces water levels similar to those observed in wells within the area to be modeled. Hefez et al. (1975) used a finite difference scheme to estimate transmissivities and storage coefficients. This method requires an orderly location of wells throughout the modeled area and recharge estimates at every node. Frind and Pinder (1974) used a steady state Galerkin finite element approach to estimate transmissivities in a heterogeneous, isotropic aquifer. This method does not require the orderly positioning of wells as in Hefez et al., but it does require that some of the transmissivities be known beforehand. In short, methods of parameter estimation for distributed-parameter models have not obtained the degree of sophistication found in the models themselves.

Lumped-parameter models are essentially volume-averaged representations of the distributed systems. They are described by ordinary differential equations in which time is the only independent variable and are used when one wants a time trend of what is happening in an aquifer. Gelhar and Wilson (1974) used a lumped-parameter model to analyze salt build up in a Massachusetts aquifer because of highway de-icing. Flores and Gelhar (1976) applied a lumped-parameter model to a stochastic water management problem. In a current study, water quality of irrigation return flows is being analyzed by using a lumped-parameter model.

Lumped-parameter models can be described by linear ordinary differential equations and hence several methods have been developed to estimate their parameters (Dooge, 1973). Gelhar (1974) developed a stochastic method that can be used to estimate parameters for a linear-reservoir type aquifer.

Scope and Objectives

The purpose of this report is to estimate the parameters of two lumped-parameter models applied to an irrigated valley in New Mexico. This is done by considering the cyclical nature of irrigation water application. During non-growing months no water is applied to the land and so certain parameters are estimated while utilizing this knowledge. During the remaining months it is then possible to estimate net recharge to the aquifer.

CHAPTER 2

THE DEVELOPMENT OF THE LUMPED-PARAMETER GROUND-WATER MODEL

The lumped-parameter ground-water model (Gelhar and Wilson, 1974) is based on an aquifer water-balance equation and a discrete form of Darcy's law. The water-balance equation relates the flux of water into and out of an aquifer to the time change of storage of water within that aquifer. In simple terms it is written

$$\frac{dM_a}{dt} = m_i - m_o \quad , \tag{2.1}$$

where

M_a = mass of water within an aquifer,

m_i = mass flux of water into an aquifer,

m_o = mass flux of water out of an aquifer.

Darcy's law governs the transfer of water into and out of the aquifer. Both of these principles are used to develop two lumped-parameter ground-water models: one with a stream perched above the water table, and the other with a stream connected to the aquifer.

Perched-Stream Case

Figure 2.1 shows a schematic cross section for the perched-stream case and the expected types of aquifer inputs and outputs. For simplicity, assume that the surface area of the aquifer is rectangular with length, L, and width, W, and that the drain fully penetrates the aquifer. A cross section of this simplified aquifer is shown in Figure 2.2.

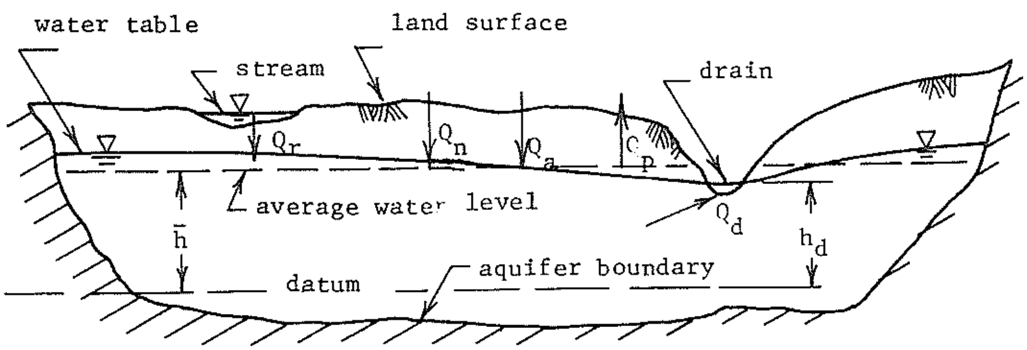

Figure 2.1: Schematic Vertical Section of an Aquifer with a Perched Stream

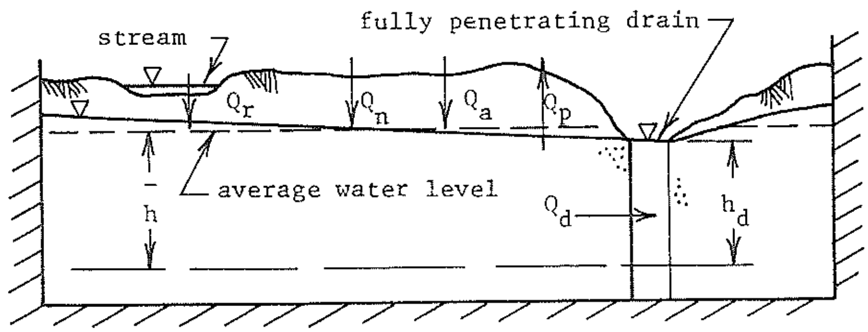

Figure 2.2: Idealized Aquifer with a Perched Stream

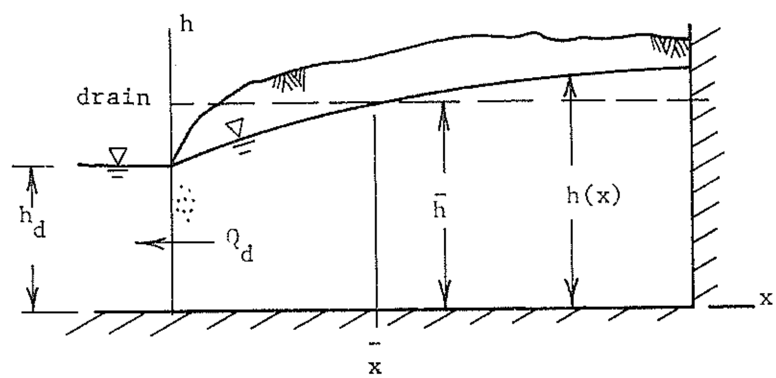

Figure 2.3: Idealized Aquifer with a Fully Penetrating Drain

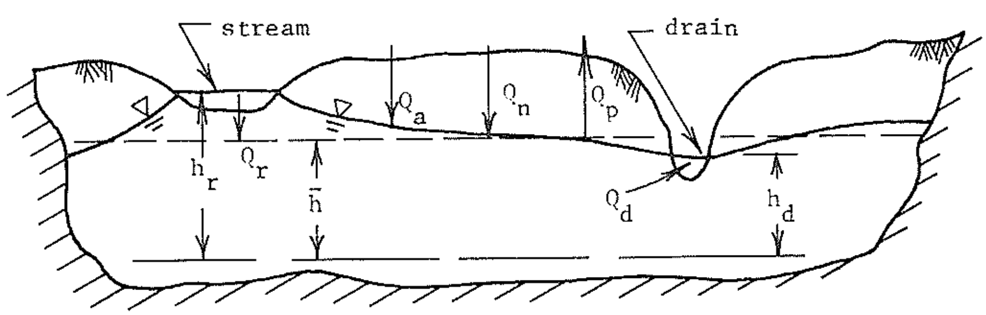

Figure 2.4: Schematic Illustration of an Aquifer with a Connected Stream

Referring to Figure 2.2 we can analyze each term of equation (2.1). The mass of water in the aquifer is simply

$$M_a = \rho S A \bar{h}(t) \quad , \tag{2.2}$$

where

ρ = density of water,

S = storage coefficient (specific yield),

A = area of the aquifer (L x W),

$\bar{h}(t)$ = average water level of aquifer.

The mass influx is

$$m_i = \rho \left[Q_n + Q_a + Q_r\right] \quad , \tag{2.3}$$

where

Q_n = volumetric rate of natural recharge,

Q_a = volumetric rate of artificial recharge,

Q_r = volumetric rate of river recharge,

and the mass efflux is

$$m_o = \rho \left[Q_p + Q_d\right] \tag{2.4}$$

where

Q_p = volumetric rate of pumpage,

Q_d = volumetric rate of drainflow.

Insertion of equations (2.2), (2.3) and (2.4) into the continuity equation (2.1) yields

$$\frac{d}{dt} \rho S A \bar{h}(t) = \rho \left[Q_n + Q_a + Q_r - Q_p - Q_d \right] . \tag{2.5}$$

Assuming that the density of water, ρ, the storage coefficient, S, and the area of the aquifer, A, are all independent of time and then manipulating equation (2.5), we obtain

$$S\frac{d\bar{h}}{dt} = q_n + q_a + q_r - q_p - q_d \quad , \tag{2.6}$$

where

$$q_n = \frac{Q_n}{A} \ , \quad q_a = \frac{Q_a}{A} \ , \quad q_r = \frac{Q_r}{A} \ ,$$

$$q_p = \frac{Q_p}{A} \ , \ \text{and} \quad q_d = \frac{Q_d}{A} \quad .$$

Let us now define net recharge as

$$E = q_n + q_a - q_p$$

and substitute this into equation (2.6) to obtain

$$S\frac{d\bar{h}}{dt} = q_r - q_d + E \quad , \tag{2.7}$$

which is the water-balance equation of the lumped-parameter model for the perched-stream case.

Looking through the inputs and outputs shown in Figure 2.2 we find that only the drain flow, Q_d, is dependent on the water level in the aquifer. This drain flow is estimated by applying Darcy's law, and using the notation of Figure 2.3 as follows:

$$Q_d = h_d L_d K \frac{\partial h}{\partial x}\bigg|_{x=0} \quad , \tag{2.8}$$

where

h_d = water elevation in drain above aquifer bottom,

L_d = length of drain,

K = hydraulic conductivity of aquifer.

Assume that

$$L_d = c_1 L \quad , \tag{2.9}$$

where

c_1 = a constant;

and

$$\frac{\partial h}{\partial x}\bigg|_{x=0} = c_2 \frac{\bar{h}(t) - h_d}{\bar{x}} \quad , \tag{2.10}$$

where

$\bar{h}(t)$ = average water level in aquifer,

$\bar{x}$ = point where average water level occurs,

c_2 = a constant;

and

$$\bar{x} = c_3 W \quad , \tag{2.11}$$

where

c_3 = a constant.

By keeping c_1, c_2 and c_3 constant, we make three implicit assumptions in the model: (1) the water table is always above the drain elevation throughout the aquifer, (2) the slope of water table at the drain is always proportional to the average slope of the water table in the aquifer and (3) the location of the average water table always stays at the same point. Inserting equations (2.9), (2.10), and (2.11) into (2.8) and recalling that A = LW, we obtain

$$q_d = \frac{c_1 c_2 h_d LK(\bar{h} - h_d)}{c_3 LW^2} \quad , \tag{2.12}$$

or more simply,

$$q_d = a_d(\bar{h} - h_d) \quad , \tag{2.13}$$

where

$$a_d = \frac{c_1 c_2 T}{c_3 W^2} = \text{drain discharge constant,}$$

$$T = Kh_d = \text{a transmissivity of the aquifer.}$$

Gelhar and Wilson (1974) have shown, using a simple steady flow solution for the distributed system, that $c_1 c_2 / c_3 = 3$. Equation (2.13) is now substituted into (2.7) yielding

$$S\frac{dh}{dt} = -a_d(h - h_d) + q_r + E \quad , \tag{2.14}$$

where the bars indicating average water levels are now dropped for convenience. Systems described by a linear first-order ordinary differential equation of the form of equation (2.14) are commonly called linear reservoirs.

Two solutions of equation (2.14), one general and the other for the special case where E = 0, are easily obtained. The general solution (recharge case) for constant q_r and h_d is

$$h = h_o e^{-t/t_h} + \left[h_d + \frac{q_r}{a_d}\right]\left[1 - e^{-t/t_h}\right]$$

$$+ \frac{1}{S}\int_0^t E(\tau) e^{-(t-\tau)/t_h} d\tau \quad , \tag{2.15}$$

where

h_o = water level at t = 0,

t_h = S/a_d = hydraulic response time of the aquifer,

τ = dummy integration variable.

The equation for the special case where E = 0 (recession case) for constant q_r and h_d is

$$h = h_R e^{-t/t_h} + \left[h_d + \frac{q_r}{a_d}\right]\left[1 - e^{-t/t_h}\right] \quad , \tag{2.16}$$

where

h_R = water level at start of recession,

and time, t, is measured from the beginning of the recession.

Stream-Connected Aquifer Case

Figure 2.4 shows an example of an aquifer connected to a stream. Its continuity equation is the same as that for the perched-stream case. Following the same analysis as for drain flow, the river discharge term is obtained:

$$q_r = -a_r(h - h_r) \quad , \tag{2.17}$$

where

a_r = river discharge constant,

h_r = average level of water in river.

Substituting equations (2.13) and (2.17) into equation (2.7), yields

$$S\frac{dh}{dt} = -a_d(h - h_d) - a_r(h - h_r) + E \quad . \tag{2.18}$$

The solution for the recharge case for constant h_d and h_r is

$$h = h_o e^{-t/t_h} + \left[\frac{a_r h_r + a_d h_d}{a_r + a_d}\right]\left[1 - e^{-t/t_h}\right]$$

$$+ \frac{1}{S}\int_0^t E(\tau) e^{-(t-\tau)/t_h} d\tau \quad , \qquad (2.19)$$

where

$$t_h = \frac{S}{a_r + a_d} = \text{hydraulic response time of the aquifer.}$$

For the recession case, the solution is

$$h = h_R e^{-t/t_h} + \left[\frac{a_r h_r + a_d h_d}{a_r + a_d}\right]\left[1 - e^{-t/t_h}\right] \quad . \qquad (2.20)$$

Special Cases

Due to heavy pumpage, it is possible that the average water level in the aquifer, h, may fall below the drain elevation h_d. Since the aquifer provides the only source of water to the drain, a situation such as this causes $q_d = 0$. This requires that equation (2.14) become

$$S\frac{dh}{dt} = q_r + E$$

and that equation (2.18) become

$$S\frac{dh}{dt} = -a_r(h - h_r) + E \quad .$$

Similarly, water levels in the aquifer may fall below the river elevation, h_r. Since rivers usually have an upstream source of water, equation (2.18) needs no modification. In essence, the equation

$$q_r = -a_r(h - h_r)$$

applies for both positive and negative $(h - h_r)$. Of course, if the river dries up, then $q_r = 0$, and the appropriate modifications are made to equation (2.18). Finally, it is also possible that h may fall so far below h_r that the river is essentially perched and equation (2.14) then applies.

CHAPTER 3

ESTIMATION OF PARAMETERS AND RECHARGE

In order to apply the models derived in Chapter 2, certain parameters (storage coefficient S, drain discharge constant a_d, river discharge constant a_r, drain elevation h_d, and river elevation h_r or river discharge q_r) must be obtained. These parameters are estimated by using the least squares method. Also the net recharge, E, is calculated by using an input-output analysis.

A Brief Description of the Least Squares Method

Define a residual, δ_i, as the difference between the observed value of a dependent variable and its "true" value. Then we can write

$$\delta_i = \hat{y}_i - y(\vec{x}_i \; ; \vec{\theta}) \quad , \tag{3.1}$$

where

δ_i = i^{th} residual,

$\hat{y}_i$ = observed value of a dependent variable,

y = "true" value of a dependent variable,

$\vec{x}_i$ = vector of observed independent variables,

$\vec{\theta}$ = vector of parameters,

i = index of i^{th} data point.

The "true" value of the dependent variable is described by some theoretical or empirical mathematical model. We now define the sums of squares of the residuals as

$$SSq = \sum_{i=1}^{N} \delta_i^2$$

$$= \sum_{i=1}^{N} \left(\hat{y}_i - y\left(\vec{x}_i \; ; \; \vec{\theta}\right) \right)^2 \quad , \tag{3.2}$$

where

SSq = sums of squares of the residuals,

N = number of data points.

For different values of $\vec{\theta}$, SSq attains different values; we want to find the $\vec{\theta}$ that minimizes SSq. This is done by setting the derivative of SSq, with respect to each of its parameters, to zero. Mathematically, this yields

$$\frac{\partial SSq}{\partial \theta_j} = 2 \sum_{i=1}^{N} \left(\hat{y}_i - y\left(\vec{x}_i \; ; \; \vec{\theta}\right) \right) \left(- \frac{\partial y}{\partial \theta_j} \right) = 0 \quad , \tag{3.3}$$

where

θ_j = j^{th} parameter.

There is an equation of the form of equation (3.3) for each parameter. Depending on the degree of non-linearity of the function, the solution of equation (3.3) can be quite complicated. For more information concerning the least squares technique and methods of solution, see Draper and Smith (1966) and Bard (1974).

Estimation of a_d and h_d

Suppose we are given a set of observed drain flows, $\hat{q}_{d_{ji}}$, and water levels h_{ji}; then, using equation (3.2), we can set up the sum of squares of the residuals as

$$SSq = \sum_{j=1}^{NY} \sum_{i=1}^{NM_j} \left(\hat{q}_{d_{ji}} - q_d \left(h_{ji} ; a_d, h_d \right) \right)^2 , \qquad (3.4)$$

where

$\hat{q}_{d_{ji}}$ = observed drain flow for the i^{th} month of the j^{th} recharge-recession period,

q_d = mathematical equation describing drain flow,

h_{ji} = observed average water level in aquifer for the i^{th} month of the j^{th} recharge-recession period,

NM_j = number of months in the j^{th} recharge-recession period,

NY = number of recharge-recession periods.

In this report a recharge-recession period is defined as the period from the first month of recharge following a recession to the last month of the following recession. These are usually twelve months long, but sometimes they are shorter or longer. The double summation of equation (3.4) results from the use of the double subscripting system.

Substituting equation (2.13) into equation (3.4) yields

$$SSq = \sum_{j=1}^{NY} \sum_{i=1}^{NM_j} \left(\hat{q}_{d_{ji}} - a_d \left(h_{ji} - h_d \right) \right)^2 . \qquad (3.5)$$

Taking derivatives of equation (3.5) with respect to a_d and h_d and setting them to zero yields

$$\frac{\partial SSq}{\partial a_d} = 2\sum_{j=1}^{NY}\sum_{i=1}^{NM_j}\left[\hat{q}_{d_{ji}} - a_d\left(h_{ji} - h_d\right)\right]\left[-\left(h_{ji} - h_d\right)\right] = 0 \qquad (3.6a)$$

and

$$\frac{\partial SSq}{\partial h_d} = 2\sum_{j=1}^{NY}\sum_{i=1}^{NM_j}\left[\hat{q}_{d_{ji}} - a_d\left(h_{ji} - h_d\right)\right]\left(a_d\right) = 0 \quad . \qquad (3.6b)$$

The parameters a_d and h_d are then solved for:

$$a_d = \frac{\sum_{j=1}^{NY} NM_j \sum_{j=1}^{NY}\sum_{i=1}^{NM_j} \hat{q}_{d_{ji}} h_{ji} - \sum_{j=1}^{NY}\sum_{i=1}^{NM_j} \hat{q}_{d_{ji}} \sum_{j=1}^{NY}\sum_{i=1}^{NM_j} h_{ji}}{\sum_{j=1}^{NY} NM_j \sum_{j=1}^{NY}\sum_{i=1}^{NM_j} h_{ji}^2 - \left[\sum_{j=1}^{NY}\sum_{i=1}^{NM_j} h_{ji}\right]^2} \qquad (3.7a)$$

and

$$h_d = \frac{\sum_{j=1}^{NY}\sum_{i=1}^{NM_j} h_{ji} - \left[\sum_{j=1}^{NY}\sum_{i=1}^{NM_j} \hat{q}_{d_{ji}}\right] \Big/ a_d}{\sum_{j=1}^{NY} NM_j} \quad . \qquad (3.7b)$$

If equations (3.7a) and (3.7b) are to be programmed into a computer and if the values of h_{ji} are large, then the computer, because of its limited digital capacity, may produce erroneous results because of the loss of significant digits in the denominator of equation (3.7a). This is remedied by introducing a suitable datum; equations (3.7a) and (3.7b) then become

$$a_d = \frac{\sum_{j=1}^{NY} NM_j \sum_{j=1}^{NY} \sum_{i=1}^{NM_j} \hat{q}_{d_{ji}} h'_{ji} - \sum_{j=1}^{NY} \sum_{i=1}^{NM_j} \hat{q}_{d_{ji}} \sum_{j=1}^{NY} \sum_{i=1}^{NM_j} h'_{ji}}{\sum_{j=1}^{NY} NM_j \sum_{j=1}^{NY} \sum_{i=1}^{NM_j} h'^{2}_{ji} - \left[\sum_{j=1}^{NY} \sum_{i=1}^{NM_j} h'_{ji} \right]^2} \qquad (3.8a)$$

and

$$h_d = \frac{\sum_{j=1}^{NY} \sum_{i=1}^{NM_j} h'_{ji} - \left[\sum_{j=1}^{NY} \sum_{i=1}^{NM_j} \hat{q}_{d_{ji}} \right] \Big/ a_d}{\sum_{j=1}^{NY} NM_j} + h_b \quad , \qquad (3.8b)$$

where

$h'_{ji} = h_{ji} - h_b$,

h_b = base elevation.

Estimation of S, t_h and q_r for Perched-Stream Case

To estimate the parameters S, t_h and q_r for the perched-stream case, we make use of the recession curve of each recharge-recession period and the recession equation (2.16). We can discretize equation (2.16) as

$$h'_{ji+1} = h'_{ji} e^{-\Delta t/t_h} + \hat{h}_j \left(1 - e^{-\Delta t/t_h} \right) \quad ,$$

$$R_j \leq i \leq NM_j - 1 \qquad (3.9)$$

where

$$\hat{h}_j = h_d + \frac{q_r}{a_d} j - h_b$$

= steady-state water level for the j^{th} recharge-recession period,

Δt = a constant time interval between h'_{ji} and h'_{ji+1},

R_j = index of the first month of recession for the j^{th} recharge-recession period.

Note that we now assume that, while q_{r_j} is constant within a recharge-recession period, it changes from period to period. We set up the sum of squares as

$$SSq = \sum_{j=1}^{NY} \sum_{i=R_j}^{NM_j} \left[h'_{ji+1} - h'_{ji} e^{-\Delta t/t_h} - \hat{h}_j \left(1 - e^{-\Delta t/t_h} \right) \right]^2 . \quad (3.10)$$

Treating $e^{-\Delta t/t_h}$ and $\hat{h}_j$ as parameters, differentiating equations (3.10) with respect to these parameters, setting the resulting equations to zero and solving yields (see Appendix A)

$$e^{-\Delta t/t_h} = \frac{\sum_{j=1}^{NY} \sum_{i=R_j}^{NM_j-1} h'_{ji+1} h'_{ji} - \sum_{j=1}^{NY} \frac{1}{NM_j - R_j} \sum_{i=R_j}^{NM_j-1} h'_{ji+1} \sum_{i=R_j}^{NM_j-1} h'_{ji}}{\sum_{j=1}^{NY} \sum_{i=R_j}^{NM_j-1} {h'_{ji}}^2 - \sum_{j=1}^{NY} \frac{1}{NM_j - R_j} \left[\sum_{i=R_j}^{NM_j-1} h'_{ji} \right]^2} \quad (3.11a)$$

and

$$\hat{h}_j = \frac{e^{-\Delta t/t_h} \sum_{i=R_j}^{NM_j-1} h'_{ji} - \sum_{i=R_j}^{NM_j-1} h'_{ji+1}}{\left(NM_j - R_j \right) \left(e^{-\Delta t/t_h} - 1 \right)} , \quad (3.11b)$$

from which we calculate

$$t_h = - \frac{\Delta t}{\ln\left(e^{-\Delta t/t_h}\right)} \quad , \tag{3.12a}$$

$$q_{r_j} = a_d\left(\hat{h}_j + h_b - h_d\right) \quad , \qquad j = 1, NY \tag{3.12b}$$

and

$$S = a_d t_h \quad . \tag{3.12c}$$

<u>Estimation of S, a_r, h_r and t_h for Stream-Connected Aquifer Case</u>

The estimation of parameters for the stream-connected aquifer case involves a two-step process that utilizes the recession curve and characteristics for that case. From equation (2.20) the discretized recession equation is

$$h_{ji+1} = h_{ji} e^{-\Delta t/t_h} + \hat{h}\left(1 - e^{-\Delta t/t_h}\right) \quad , \tag{3.13}$$

where

$$\hat{h} = \frac{a_r h_r + a_d h_d}{a_r + a_d} \quad ,$$

from which the parameters $e^{-\Delta t/t_h}$ and $\hat{h}$ are solved using the least squares technique. We then have the equations

$$S = \left(a_r + a_d\right) t_h \tag{3.14a}$$

and

$$a_r h_r + a_d h_d = \left(a_r + a_d\right) \hat{h} \qquad (3.14b)$$

where a_d, h_d, t_h and $\hat{h}$ are known. Equation (2.17) is substituted into equation (2.7) with the E term deleted and integrated over the entire recession period to yield

$$SI_{j1} + a_r I_{j2} = a_r h_r I_{j3} - I_{j4} \quad , \qquad (3.15)$$

where

$$I_{j1} = h_{jNM_j} - h_{jR_j} \quad ,$$

$$I_{j2} = \int_{t_{R_j}}^{t_{NM_j}} h dt \quad ,$$

$$I_{j3} = t_{NM_j} - t_{R_j} \quad ,$$

$$I_{j4} = \int_{t_{R_j}}^{t_{NM_j}} q_d dt \quad .$$

The quantities I_{j2} and I_{j4} are obtained by numerical integration using the discrete values of h_{ji} and $\hat{q}_{d_{ji}}$. We now set up the sum of squares as

$$SSq = \sum_{j=1}^{NY} \left(SI_{j1} + a_r I_{j2} - a_r h_r I_{j3} + I_{j4}\right)^2$$

$$+ \lambda_1 \left[S - \left(a_r + a_d\right) t_h\right] + \lambda_2 \left[a_r h_r + a_d h_d - \left(a_r + a_d\right) \hat{h}\right] \qquad (3.16)$$

where λ_1 and λ_2 are Lagrange multipliers, and solve for S, a_r, h_r, λ_1 and λ_2. The use of Lagrange multipliers forces the estimates to satisfy equations (3.14a) and (3.14b), which are called constraints.

<u>Estimation of Net Recharge</u>

Given the parameters and equation (2.7), estimates of net recharge, E, can be obtained for the perched-stream case. Equation (2.7) is integrated over two time intervals using Simpson's Rule to yield

$$S\left(h_{ji+1} - h_{ji-1}\right) = 6q_{r_j}\frac{\Delta t}{3} - \frac{\Delta t}{3}\left(\hat{q}_{d_{ji+1}} + 4\hat{q}_{d_{ji}} + \hat{q}_{d_{ji-1}}\right) + \frac{\Delta t}{3}\left(E_{ji+1} + 4E_{ji} + E_{ji-1}\right) \quad , \quad i = 1, R_j-1 \qquad (3.17)$$

which we rearrange as

$$E_{ji-1} + 4E_{ji} + E_{ji+1} = \frac{3S}{\Delta t}\left(h_{ji+1} - h_{ji-1}\right) - 6q_{r_j} + \hat{q}_{d_{ji+1}} + 4\hat{q}_{d_{ji}} + \hat{q}_{d_{ji-1}} = A_{ji} \quad , \quad i = 1, R_j-1 \quad . \qquad (3.18)$$

This produces a set of R_j-1 equations in R_j+1 unknowns for each recharge-recession period j. For i = 1 we know that the preceding month is the last month of recession, implying $E_{j0} = 0$. Similarly, for i = R-1 we know that the following month is the first month of the next recession, implying $E_{jR} = 0$. We lose two of our unknowns; thence, equation (3.18) produces for each j a triadiagonal set of R-1 equations with R-1 unknowns of the form

$$
\begin{aligned}
4E_1 + E_2 \qquad\qquad\qquad\qquad &= A_1 \\
\vdots \qquad\qquad\qquad\qquad\qquad & \\
E_{i-1} + 4E_i + E_{i+1} \qquad\qquad &= A_i \\
\vdots \qquad \vdots \qquad \vdots \qquad\qquad\qquad & \\
E_{R-2} + 4E_{R-1} &= A_{R-1} \quad ,
\end{aligned}
\tag{3.19}
$$

which is easily solved using the algorithm given in Smith (1965, p. 20). Using a similar analysis we can estimate the net recharge for the stream-connected case.

CHAPTER 4

CASE STUDY - MESILLA VALLEY, NEW MEXICO

The Mesilla Valley, a rich agricultural area located along the Rio Grande in south-central New Mexico (Figure 4.1), was chosen for evaluation and estimation of the parameters of the two models. The valley covers 108,000 acres of which approximately 80,000 acres is irrigated farmland. An 80 to 100 foot-thick alluvial-fill aquifer underlies the valley and extends beyond its boundaries. Another aquifer, that of the Santa Fe formation, lies beneath the alluvial aquifer and extends thousands of feet below it. This study deals primarily with the shallow alluvial aquifer.

The data required for the study was obtained from two sources. Monthly water-level measurements from 1946 through 1971 at 39 United States Bureau of Reclamation (USBR) observation wells were obtained from Richardson (1971). The river bed of the Rio Grande at the Leasburg Dam at the northern-most point of the valley was used as an additional water-level observation because observation wells were lacking in that area. The valley was then divided into two parts: one east and the other west of the Rio Grande. Each part was subdivided into Thiessen polygons according to the location of the 39 observation wells and the river bed at the Leasburg Dam (see Figure 4.2). Each polygon was assigned a weighting factor calculated by dividing the area of the polygon by the area of the valley (Table 4.1). The water-level measurements and river-bed elevation were then referenced to sea level and the monthly average water levels were calculated as

$$\bar{h} = \sum_{k=1}^{40} w_k h_k \quad ,$$

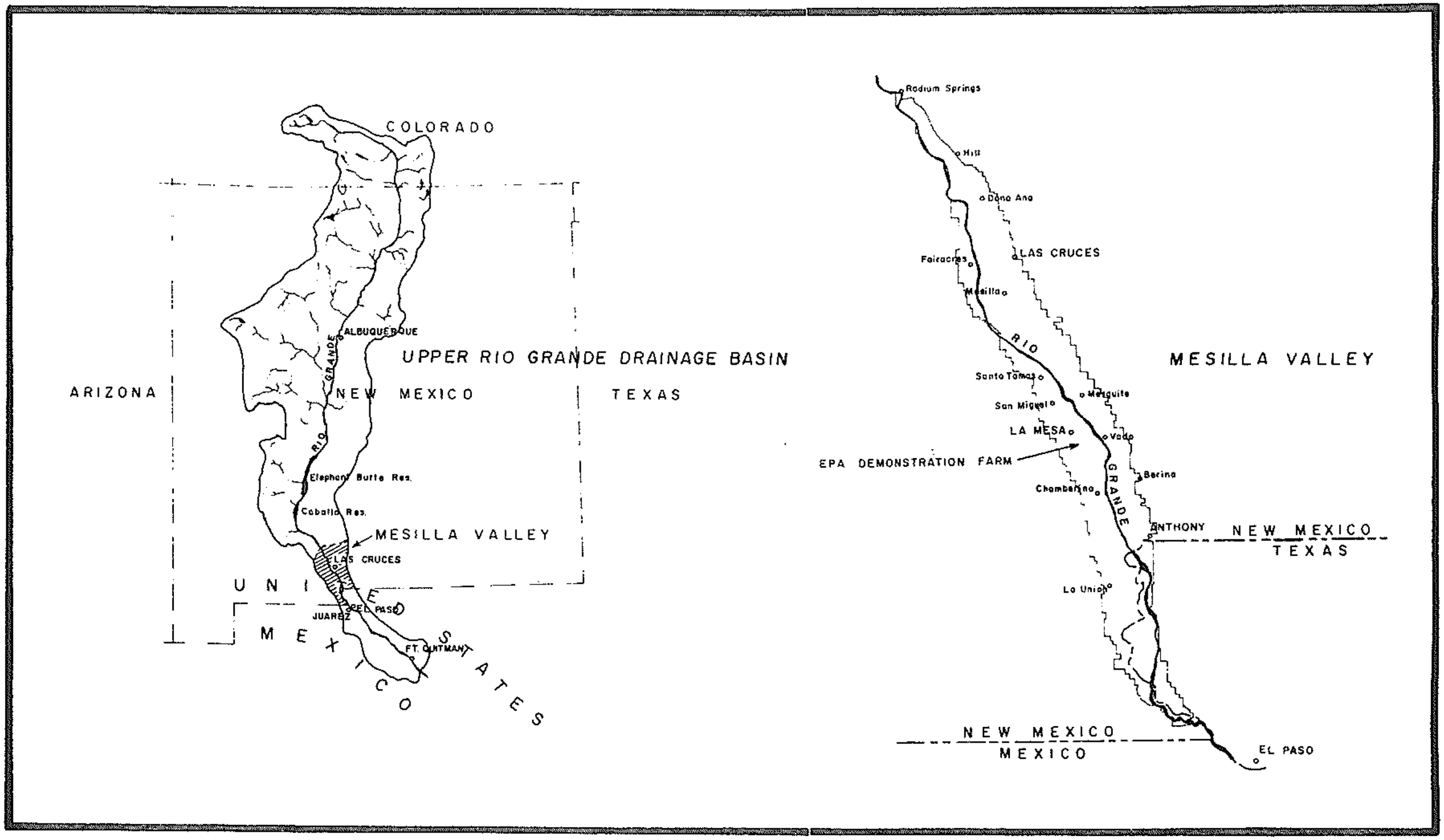

Figure 4.1: Location Map of the Mesilla Valley, New Mexico

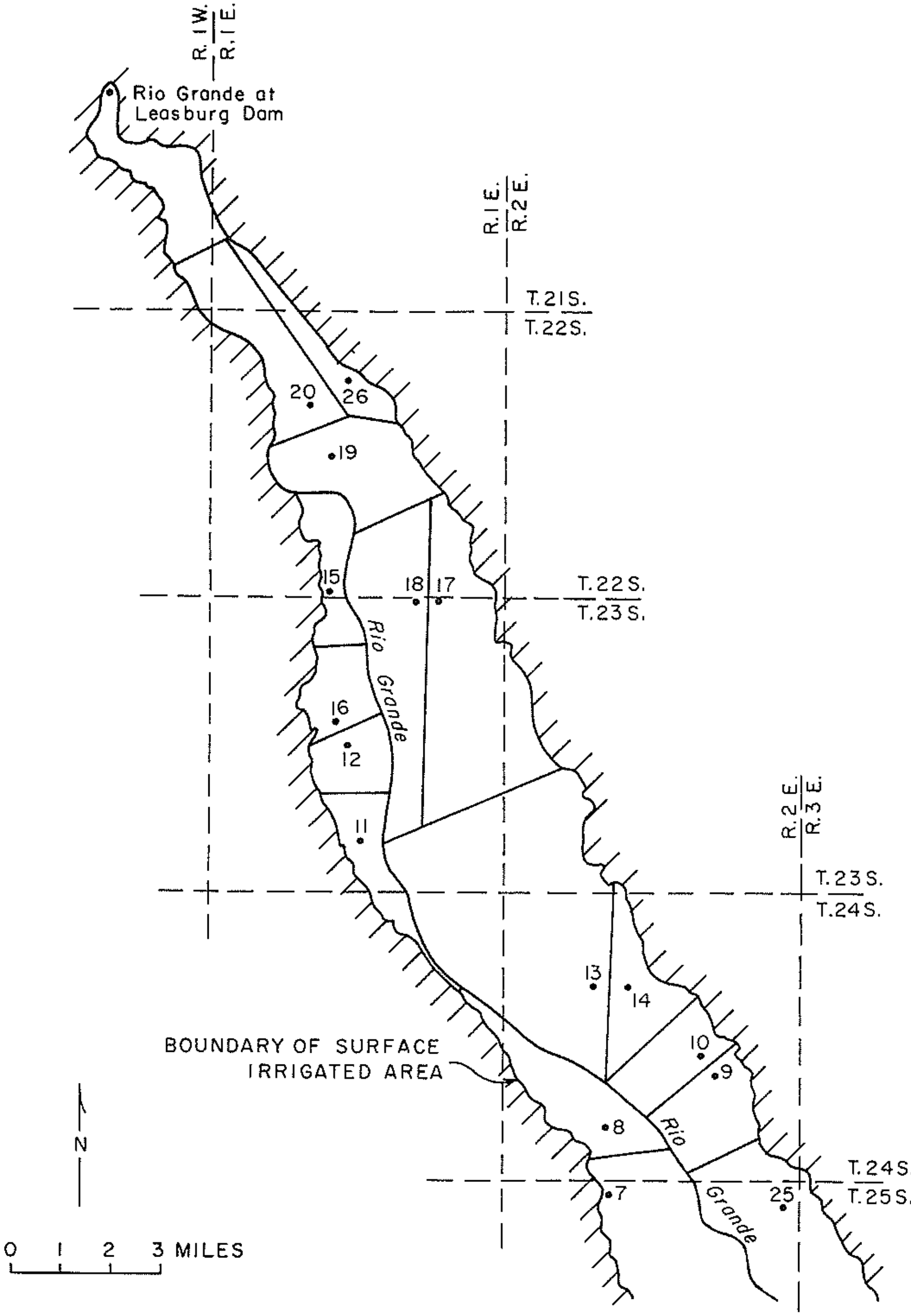

Figure 4.2: USBR Well Locations and Thiessen Polygons

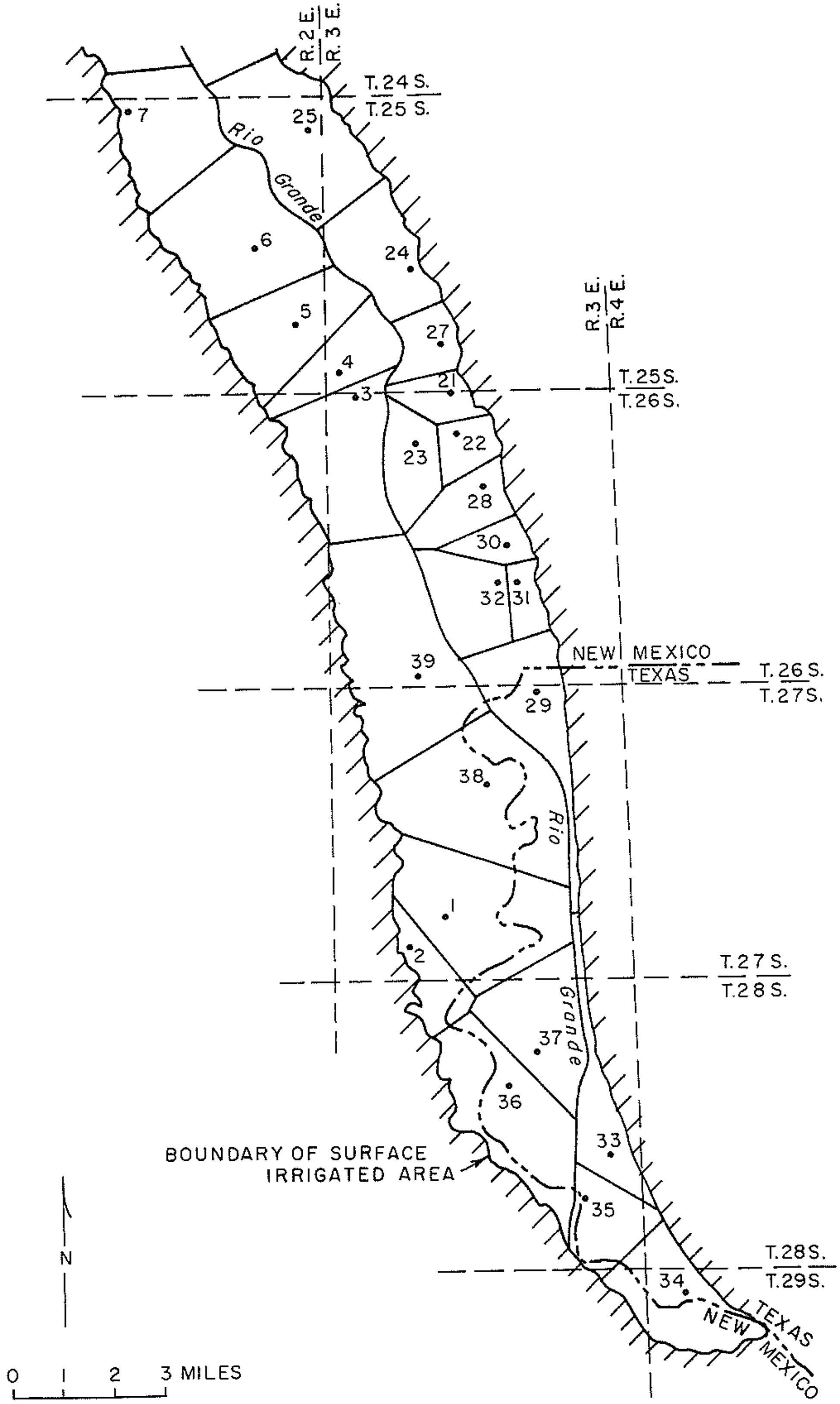

Figure 4.2: (Continued)

TABLE 4.1

THIESSEN POLYGON WEIGHT AND LAND SURFACE ELEVATION AT EACH OBSERVATION WELL

USBR WELL NO.	LAND ELEVATION	POLYGON WEIGHT	USBR WELL NO.	LAND ELEVATION	POLYGON WEIGHT
Rio Grande at Leasburg Dam	3960.00	0.01983	4	3812.76	0.01657
			27	3813.06	0.00845
26	3928.52	0.01190	21	3808.98	0.00789
20	3926.59	0.02833	23	3807.50	0.01223
19	3921.84	0.02838	22	3803.18	0.00756
15	3904.81	0.01421	3	3811.01	0.03282
18	3908.35	0.04524	28	3804.95	0.01237
17	3908.21	0.05813	32	3793.08	0.01672
16	3893.13	0.01162	31	3791.35	0.00614
12	3894.19	0.01483	30	3792.96	0.00661
11	3880.79	0.01417	39	3788.53	0.05288
13	3861.36	0.10548	29	3786.84	0.02248
14	3860.40	0.01757	38	3777.54	0.04900
10	3849.85	0.01761	1	3769.70	0.04056
9	3847.08	0.01851	2	3771.68	0.01105
8	3849.00	0.02507	37	3753.92	0.02725
25	3833.74	0.03626	36	3753.15	0.03376
7	3845.47	0.02710	35	3746.57	0.01516
6	3827.05	0.04042	33	3745.79	0.01577
5	3819.78	0.02521	34	3733.97	0.02399
24	3817.41	0.02087	Valley Mean	3834.07	1.00000

where

$\bar{h}$ = average water level,

h_k = water level of k^{th} well,

w_k = weighting factor for k^{th} well,

and plotted against time. Monthly total valley drain flows were available from the USBR in El Paso, Texas. These drain flows, divided by valley area, were used for this study. It has been assumed that the observed drain flow results entirely from outflow from the aquifer. Also obtained from the USBR in El Paso, Texas, were water distribution sheets. These sheets list the amounts and months of diverted irrigation water. They were used principally to determine the dates and length of recharge-recession periods and recession periods. Table 4.2 shows monthly average water levels, drain flows and diverted irrigation water.

An examination of a temporal plot of water levels showed that suitable recessions occurred from March, 1946, to February, 1951. After this period, heavy pumping resulting from a drought lowered the water table so much that recessions could not occur. Analysis of the water distribution sheets showed five recharge-recession periods: March, 1946, to February, 1947; March, 1947, to March, 1948; April, 1948, to February, 1949; March, 1949, to February, 1950; and March, 1950 to February, 1951. Respective recession periods began in October for each recharge-recession period. Having obtained the water levels and drain flows for this five-year period, the parameter estimation process was begun.

Using equation (3.8a) and (3.8b) the drain flow equation (2.13) was estimated as

TABLE 4.2

MONTHLY AVERAGE WATER LEVELS, DRAIN FLOWS, AND DIVERTED IRRIGATION WATER

DATE		AVERAGE WATER LEVEL (ft above MSL)	MONTHLY DRAIN FLOW (ft/mo)	DIVERTED IRRIGATION WATER (ft/mo)	TOTAL ANNUAL DIVERSION (ft)
JAN	1946	3826.22	0.1204	0.0	
FEB	1946	3826.12	0.0900	0.115	
MAR	1946	3826.38	0.1270	0.393	
APR	1946	3827.34	0.2034	0.725	
MAY	1946	3827.54	0.2312	0.487	
JUN	1946	3828.01	0.2489	0.704	
JUL	1946	3828.36	0.2858	0.856	
AUG	1946	3828.42	0.3016	0.811	
SEP	1946	3827.68	0.2446	0.309	
OCT	1946	3826.86	0.1616	0.103	
NOV	1946	3826.52	0.1256	0.082	
DEC	1946	3826.17	0.1152	0.060	4.63
JAN	1947	3825.95	0.0975	0.0	
FEB	1947	3825.89	0.0775	0.053	
MAR	1947	3826.18	0.1105	0.385	
APR	1947	3827.18	0.1831	0.718	
MAY	1947	3827.50	0.1995	0.502	
JUN	1947	3827.81	0.2101	0.607	
JUL	1947	3828.32	0.2503	0.851	
AUG	1947	3828.32	0.2640	0.697	
SEP	1947	3827.77	0.2182	0.452	
OCT	1947	3826.84	0.1356	0.042	
NOV	1947	3826.38	0.1061	0.023	
DEC	1947	3826.19	0.0915	0.018	4.35
JAN	1948	3825.86	0.0830	0.007	
FEB	1948	3825.79	0.0719	0.006	
MAR	1948	3825.74	0.0744	0.265	
APR	1948	3826.79	0.1485	0.683	
MAY	1948	3827.21	0.1875	0.406	
JUN	1948	3827.38	0.1943	0.540	

TABLE 4.2 (cont'd)

DATE		AVERAGE WATER LEVEL (ft above MSL)	MONTHLY DRAIN FLOW (ft/mo)	DIVERTED IRRIGATION WATER (ft/mo)	ANNUAL DIVERSION (ft)
JUL	1948	3828.06	0.2539	0.889	
AUG	1948	3828.24	0.2775	0.851	
SEP	1948	3827.69	0.2428	0.469	
OCT	1948	3826.95	0.1620	0.096	
NOV	1948	3826.58	0.1204	0.065	
DEC	1948	3826.25	0.1134	0.048	4.33
JAN	1949	3825.89	0.1045	0.0	
FEB	1949	3825.87	0.0823	0.0	
MAR	1949	3826.17	0.1182	0.481	
APR	1949	3827.01	0.1961	0.611	
MAY	1949	3827.28	0.2192	0.458	
JUN	1949	3827.43	0.2284	0.611	
JUL	1949	3828.06	0.2760	0.835	
AUG	1949	3828.11	0.2844	0.819	
SEP	1949	3827.62	0.2230	0.327	
OCT	1949	3826.87	0.1481	0.141	
NOV	1949	3826.52	0.1286	0.080	
DEC	1949	3826.24	0.1106	0.034	4.40
JAN	1950	3826.02	0.0947	0.0	
FEB	1950	3825.95	0.0776	0.042	
MAR	1950	3826.20	0.1384	0.655	
APR	1950	3826.98	0.1887	0.504	
MAY	1950	3827.40	0.2040	0.566	
JUN	1950	3827.59	0.2089	0.531	
JUL	1950	3827.80	0.2634	0.635	
AUG	1950	3828.00	0.2640	0.794	
SEP	1950	3827.38	0.2301	0.434	
OCT	1950	3826.68	0.1609	0.073	
NOV	1950	3826.33	0.1178	0.023	
DEC	1950	3826.11	0.1019	0.010	4.27
JAN	1951	3825.89	0.0924	0.0	
FEB	1951	3825.84	0.0659	0.0	

$$q_d = 0.0812(\bar{h} - 3824.85) \quad . \tag{4.1}$$

This equation along with the corresponding drain flows and water levels are plotted in Figure 4.3. As can be seen, the equation predicting drain flows fits the data very well, indicating that the linear outflow assumption is appropriate and that the estimates of a_d and h_d are suitable. Indeed, h_d compares reasonably with the average valley elevation of 3,834 feet. During the drought years in the early 1950's, the average water level dropped below the average drain elevation, but contrary to equation (4.1), drain flow still occurred. By referring to Figures 4.4a and 4.4b we can visualize a possible reason for this discrepancy. During the high water-table years of the late 1940's, drain flow occurred throughout the whole valley. This, as shown in Figure 4.4a, implied that the water table was higher than the drain elevation throughout the Mesilla Valley. During the drought, heavier pumpage in the northern part of the valley than in the southern part lowered and changed the slope of the water table to that shown in Figure 4.4b. The water table was higher than the drains in the southern part of the valley and lower in the northern part, violating one of the assumptions used to develop the drain flow equation (2.13). This implies that equation (4.1) is valid only for the condition illustrated in Figure 4.4a.

Using equations (3.11a), (3.11b), (3.12a), (3.12b) and (3.12c), the parameters for the perched-river case were estimated, for the five recharge-recession periods, as

$$S = 0.210, \quad t_h = 2.59 \text{ months},$$

$$q_{r_1} = 0.0622 \text{ ft./mo.},$$

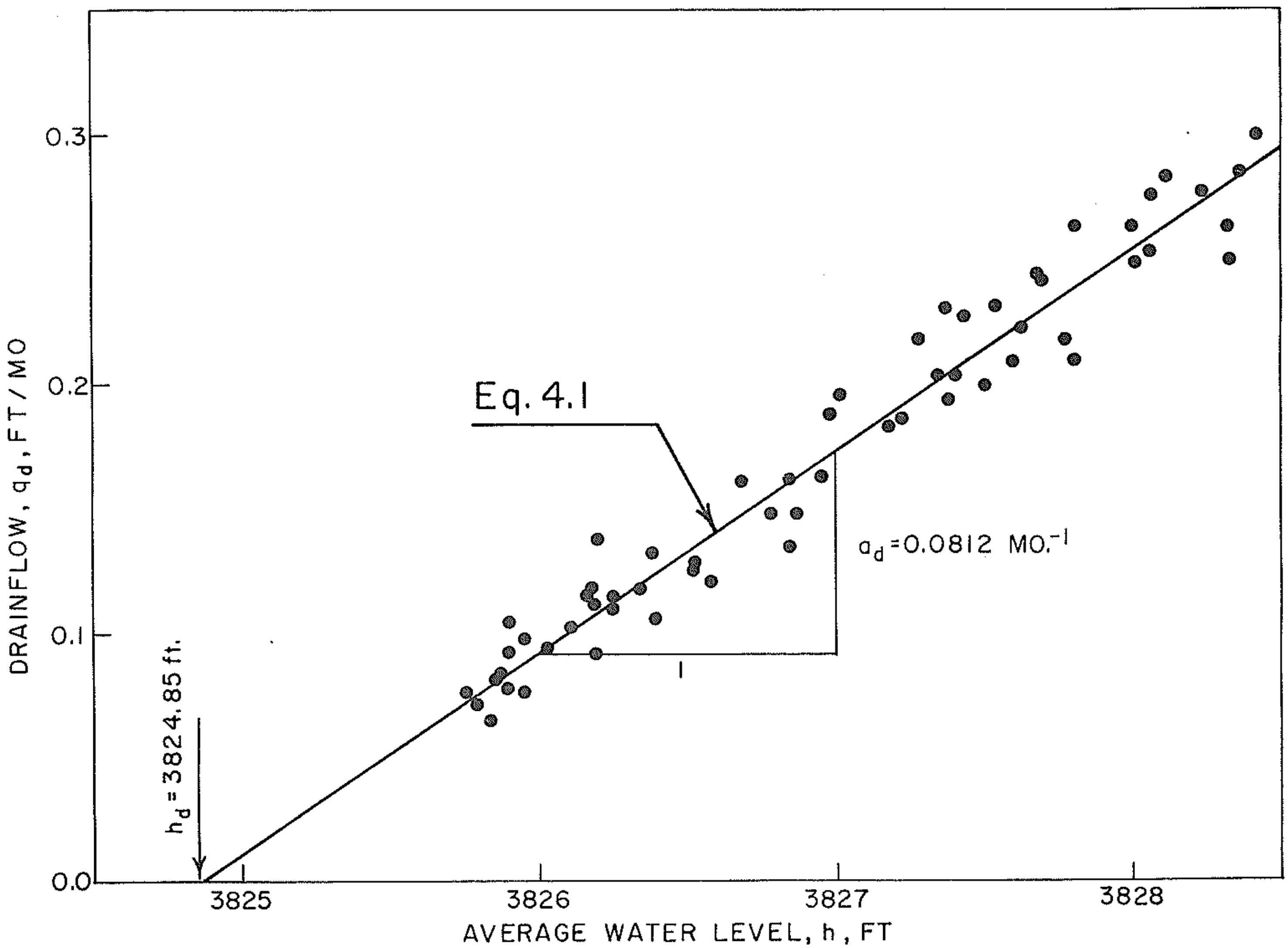

Figure 4.3: Average Water Level versus Drain Flow

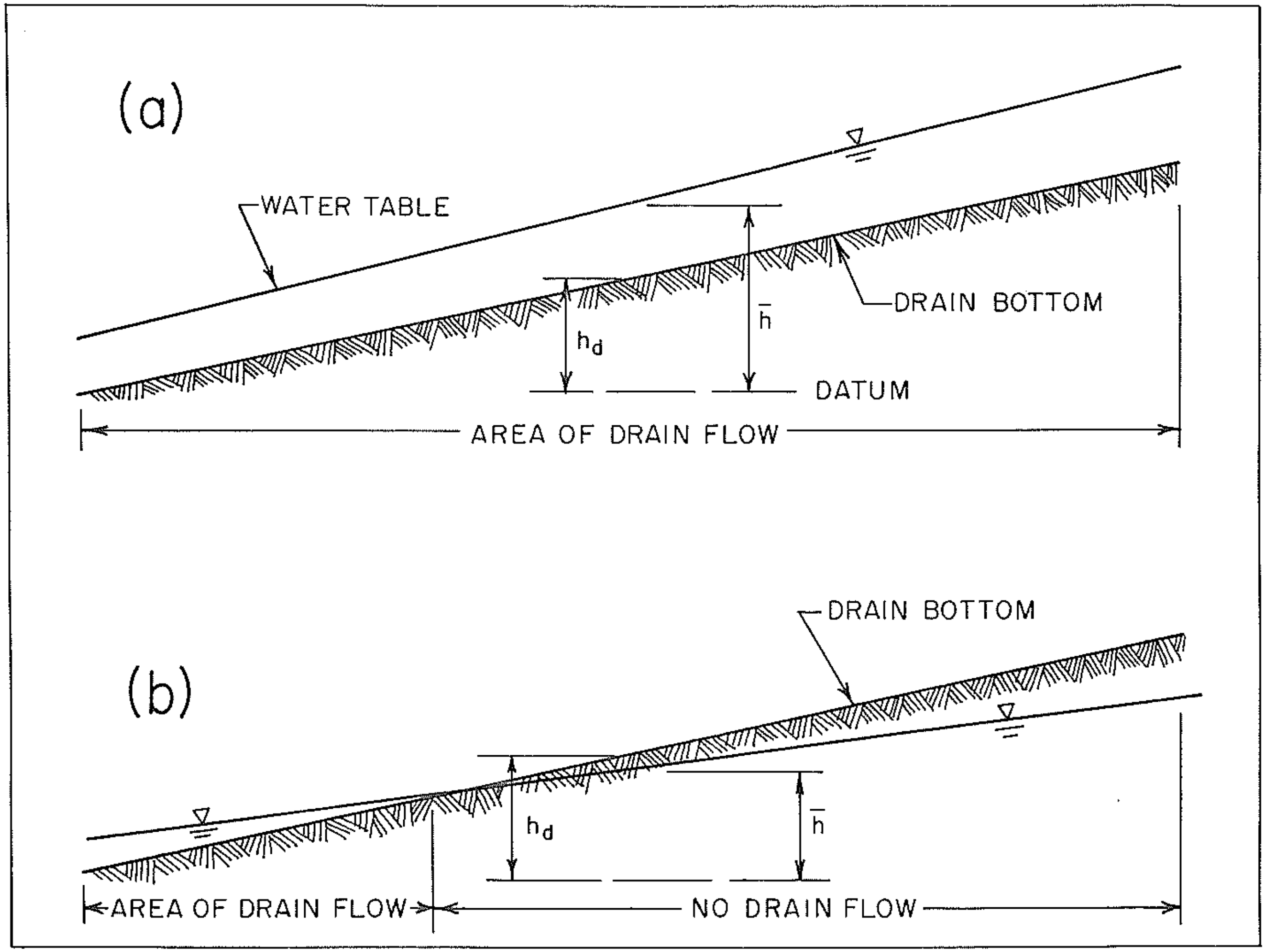

Figure 4.4: Water-Table Slope. (a): before Heavy Pumping. (b): after Heavy Pumping

$$q_{r_2} = 0.0546 \text{ ft./mo.,}$$

$$q_{r_3} = 0.0585 \text{ ft./mo.,}$$

$$q_{r_4} = 0.0682 \text{ ft./mo.,}$$

$$q_{r_5} = 0.0601 \text{ ft./mo.}$$

The values of h_{ji} and h_{ji+1} for each j along with the best fit lines are plotted on Figures 4.5a-e. The real data deviates systematically from the best fit line for each recession, indicating either that the river discharge, q_{r_j}, is not constant from month to month as assumed, or recession is not precisely exponential. The value of storage coefficient compares favorably with the value of 0.20 that Richardson (1971) used in his study of the Mesilla Valley and the value of 0.25 suggested by Conover (1954). Based on a monthly input-output analysis of the Rio Grande within the valley boundaries, the values of q_{r_j} are usually about three to four times too large and definitely vary from month to month. It is quite possible that the estimated values of q_{r_j} contain, in addition to river discharge, leakage from the Santa Fe aquifer and irrigation canals.

Net recharge for the perched-river case was estimated using equation (3.19), and the results, along with irrigation diversion, are presented in Table 4.3 and plotted in Figure 4.6. The irrigation diversion is always larger than the estimated recharge, reflecting consumptive use through evapo-transpiration of vegetation. The temporal pattern of variation of recharge is very similar to that of the irrigation diversion; the lower diversions in May are reflected in the smaller recharge amount for that month. The difference between the annual amounts of diversion and recharge (Table 4.2 and Table 4.3) ranges from 2.98 to 3.21 feet, indicating the annual water consumption based on the total valley

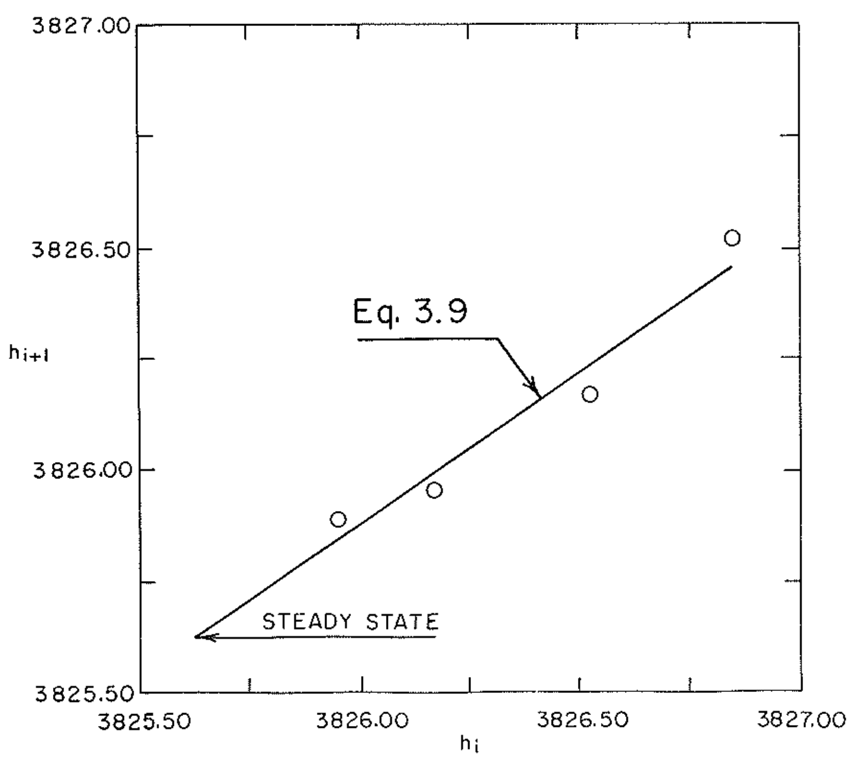

Figure 4.5a: h_i versus h_{i+1} for First Recession

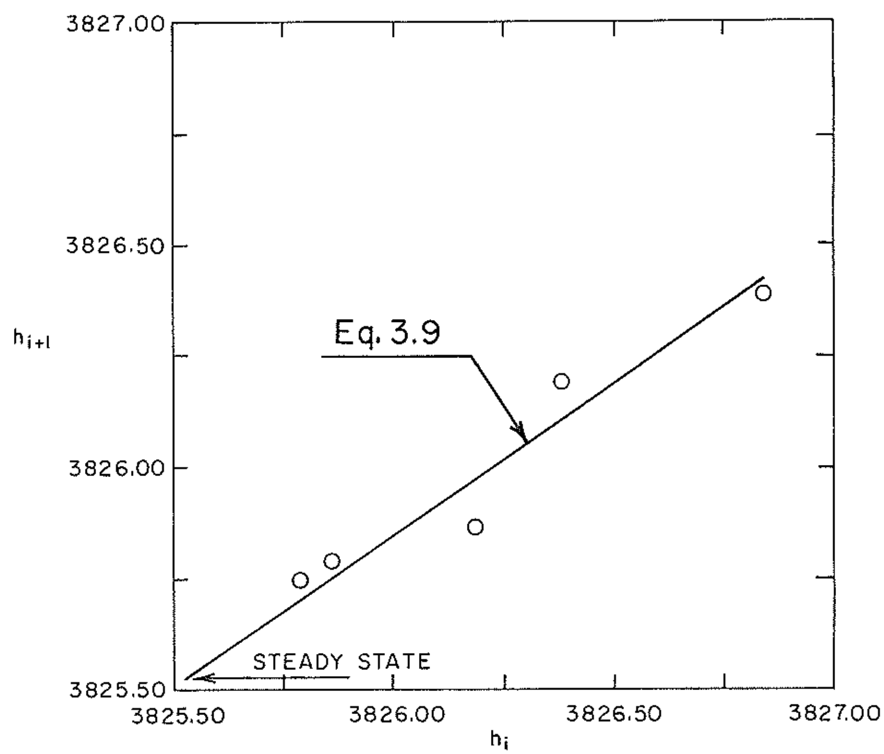

Figure 4.5b: h_i versus h_{i+1} for Second Recession

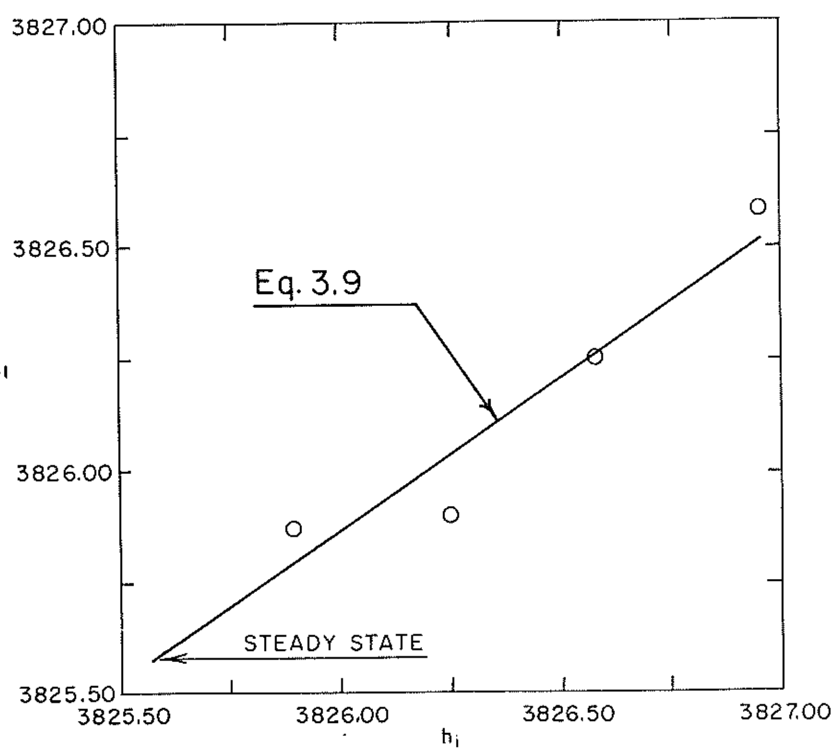

Figure 4.5c: h_i versus h_{i+1} for Third Recession

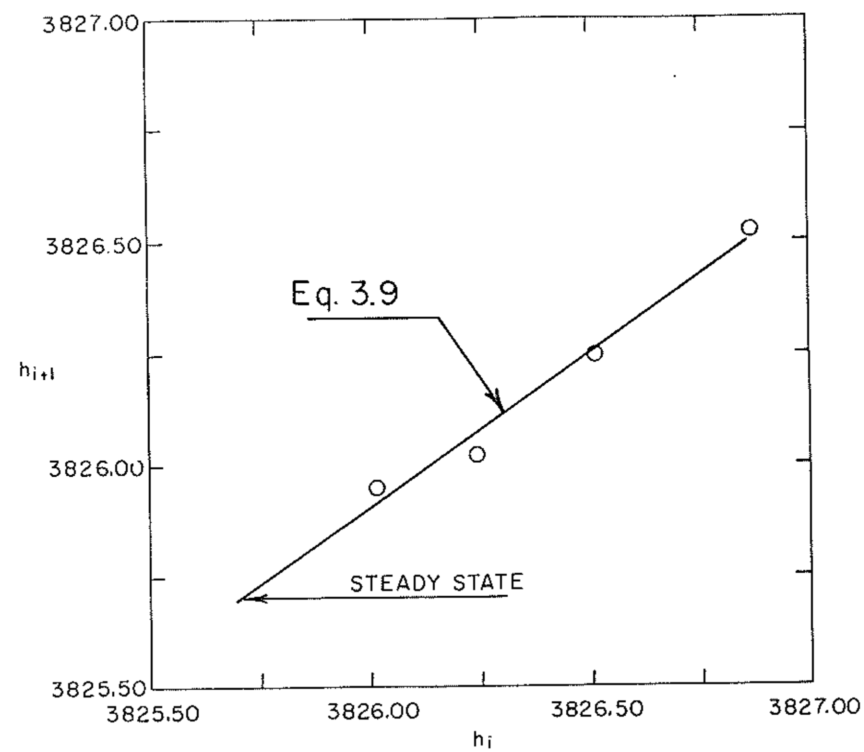

Figure 4.5d: h_i versus h_{i+1} for Fourth Recession

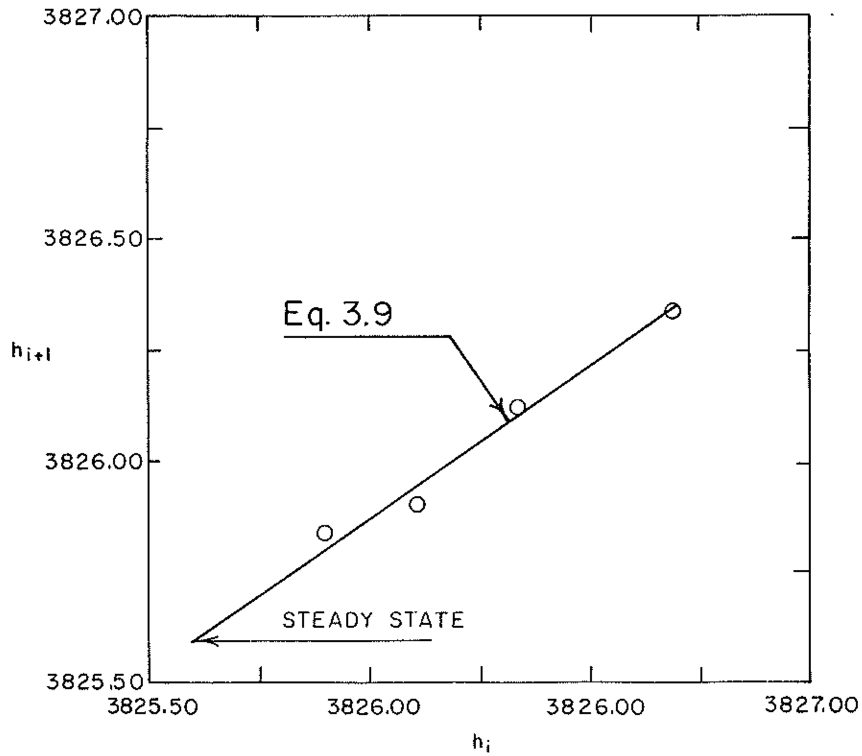

Figure 4.5e: h_i versus h_{i+1} for Fifth Recession

TABLE 4.3

RECHARGE ESTIMATES AND ANNUAL RECHARGE

DATE	RECHARGE ESTIMATES (ft/mo)	ANNUAL RECHARGE (ft)	DATE	RECHARGE ESTIMATES (ft/mo)	ANNUAL RECHARGE (ft/mo)
MAR 1946	0.2313		SEP 1948	0.0188	
APR 1946	0.2697		OCT 1948	0.0	
MAY 1946	0.2145		NOV 1948	0.0	
JUN 1946	0.2910		DEC 1948	0.0	1.21
JUL 1946	0.2791		JAN 1949	0.0	
AUG 1946	0.1680		FEB 1949	0.0	
SEP 1946	-0.0238		MAR 1949	0.2003	
OCT 1946	0.0		APR 1949	0.2623	
NOV 1946	0.0		MAY 1949	0.1591	
DEC 1946	0.0	1.43	JUN 1949	0.2581	
JAN 1947	0.0		JUL 1949	0.3036	
FEB 1947	0.0		AUG 1949	0.1636	
MAR 1947	0.2255		SEP 1949	-0.0077	
APR 1947	0.2862		OCT 1949	0.0	
MAY 1947	0.1778		NOV 1949	0.0	
JUN 1947	0.2596		DEC 1949	0.0	1.34
JUL 1947	0.2644		JAN 1950	0.0	
AUG 1957	0.1541		FEB 1950	0.0	
SEP 1947	-0.0347		MAR 1950	0.2105	
OCT 1948	0.0		APR 1950	0.2720	
NOV 1948	0.0		MAY 1950	0.1956	
DEC 1948	0.0	1.33	JUN 1950	0.1826	
JAN 1948	0.0		JUL 1950	0.2685	
FEB 1948	0.0		AUG 1950	0.1633	
MAR 1948	0.0		SEP 1950	-0.0014	
APR 1948	0.3223		OCT 1950	0.0	
MAY 1948	0.1400		NOV 1950	0.0	
JUN 1948	0.2358		DEC 1950	0.0	1.29
JUL 1948	0.3164		JAN 1951	0.0	
AUG 1948	0.1729		FEB 1951	0.0	

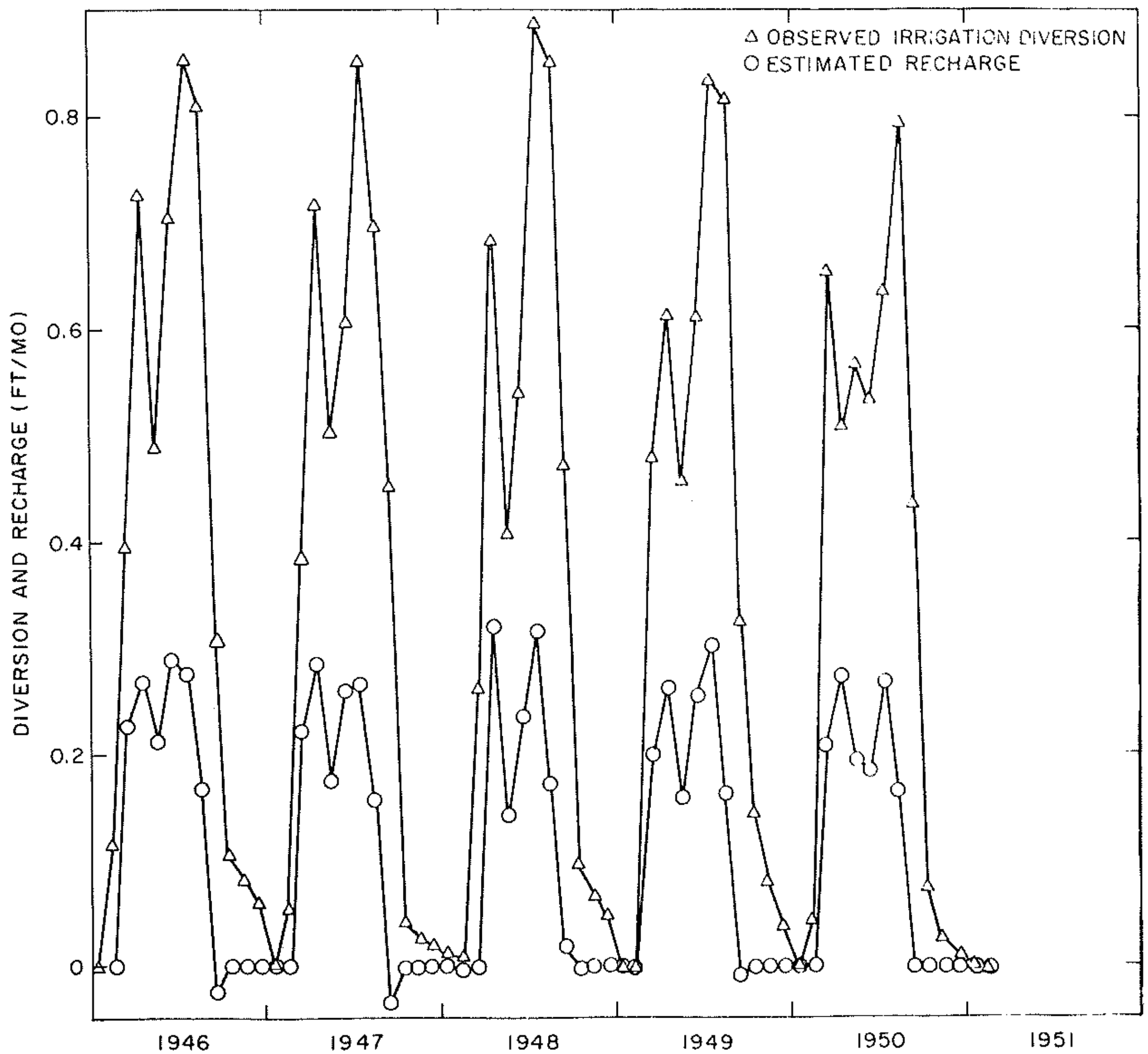

Figure 4.6: Recharge Estimates and Applied Irrigation Water

area. These consumption figures incorporate water use by agriculture as well as that of phreatophytes and other natural vegetation, and that associated with municipal water supply. It should also be recognized that some of the recharge resulting from the irrigation diversion (e.g., canal seepage) may be included in the q_{r_j} terms. If the entire q_{r_j} term, which averages about 0.06 ft./mo., were recharge from this source, then this water applied over a seven month irrigation season would increase the annual recharge by about 0.4 feet with a corresponding reduction in the estimated consumption. Thus, the over-all range for the annual consumptive use for the valley could be from 2.6 to 3.2 feet; we consider this range to be reasonable in relation to data on crop consumptive use (Henderson and Sorensen, 1968; Gregory and Hanson, 1976).

A simulation based on the parameter and net recharge estimates for the perched-stream case was run. This simulation was based on a discretized version of the general solution to the perched-stream case (equation (2.15)). This discretization yields

$$h_{i+1} = h_i e^{-\Delta t/t_h} + \left[h_d + \frac{q_r}{a_d}\right]\left[1 - e^{-\Delta t/t_h}\right] + \frac{1}{S}\int_0^{\Delta t} E(\tau) e^{-(t-\tau)/t_h}\, d\tau \quad . \tag{4.2}$$

Water levels, h_i and h_{i+1}, were assumed to be measured in the middle of the i^{th} and $i{+}1^{th}$ months and net recharge, E, was treated as a pulse recharge, E_i, during the i^{th} month. The last term of equation (4.2) was then rewritten as

$$\frac{1}{S}\int_0^{\Delta t} E(\tau)e^{-(t-\tau)/t_h}\,d\tau = \frac{1}{S}\int_0^{\Delta t/2} E_i e^{-(t-\tau)/t_h}\,d\tau$$

$$+ \frac{1}{S}\int_{\Delta t/2}^{\Delta t} E_{i+1} e^{-(t-\tau)/t_h}\,d\tau$$

$$= \frac{E_i e^{-t/t_h}}{a_d}\left(e^{\Delta t/2t_h} - 1\right)$$

$$+ \frac{E_{i+1} e^{-t/t_h}}{a_d}\left(e^{\Delta t/t_h} - e^{\Delta t/2t_h}\right) \quad . \qquad (4.3)$$

When discretized, the right-hand side of equation (4.3) becomes

$$\frac{E_i}{a_d}\left(e^{-\Delta t/2t_h} - e^{-\Delta t/t_h}\right) + \frac{E_{i+1}}{a_d}\left(1 - e^{-\Delta t/2t_h}\right) \quad . \qquad (4.4)$$

Substitution of equation (4.4) into the last term on the right hand side of equation (4.2) yields the simulation equation

$$h_{i+1} = h_i e^{-\Delta t/t_h} + \left(h_d + \frac{q_r}{a_d}\right)\left(1 - e^{-\Delta t/t_h}\right)$$

$$+ \frac{E_i}{a_d}\left(e^{-\Delta t/2t_h} - e^{-\Delta t/t_h}\right) + \frac{E_{i+1}}{a_d}\left(1 - e^{-\Delta t/t_h}\right) \quad . \qquad (4.5)$$

Drain flow is then simulated from equation (2.13).

Simulated water levels and drain flows are shown in Figure 4.7a and 4.7b, respectively. As can be seen, the simulation matches (except for a couple of peaks) the observed data very well. The root-mean-squared error (RMSE) for water levels and drain flows is 0.13 feet and 0.012 ft./mo., respectively. It seems that the perched-stream linear-reservoir model can simulate water levels and drainflows very well for the Mesilla Valley.

The parameter estimation and simulation computations for the Mesilla Valley were carried out using the IBM 360-44 at the New Mexico Tech Computer Center; Appendix B gives a brief description of the computer program, plus listing of the code and the results.

An attempt was made to estimate the parameters for the stream-connected aquifer case. However, the value of the storage coefficient was less than zero which is physically impossible. This result implies that the assumption of the stream-connected aquifer as developed herein is not appropriate for the field conditions in the Mesilla Valley.

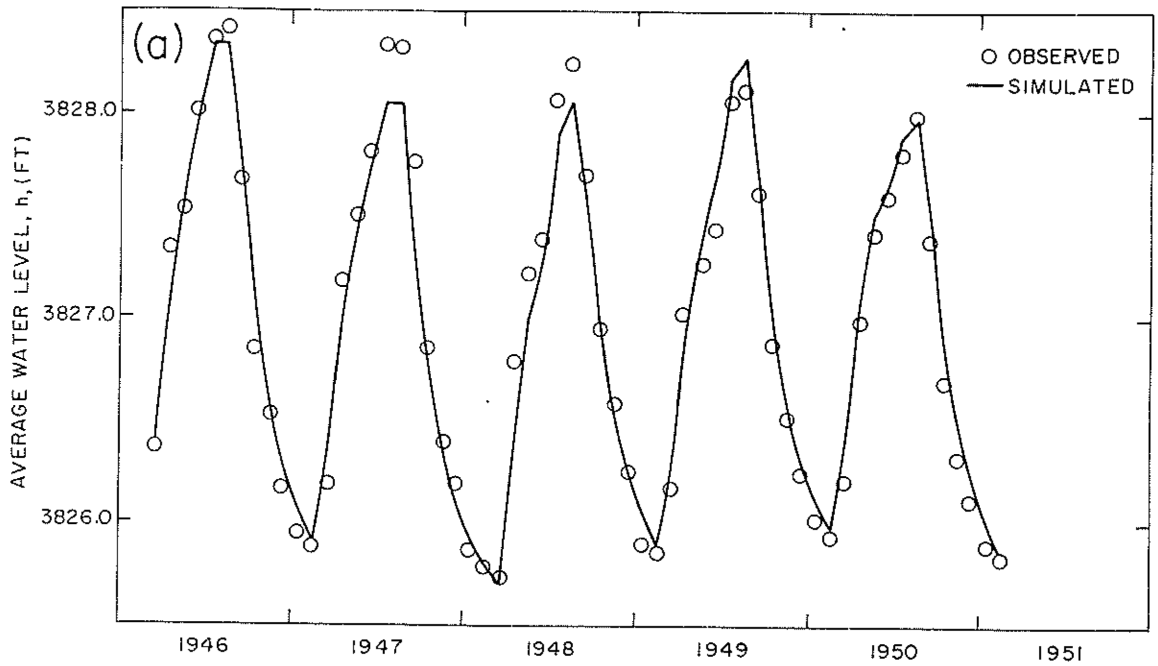

Figure 4.7a: Observed and Simulated Average Water Levels

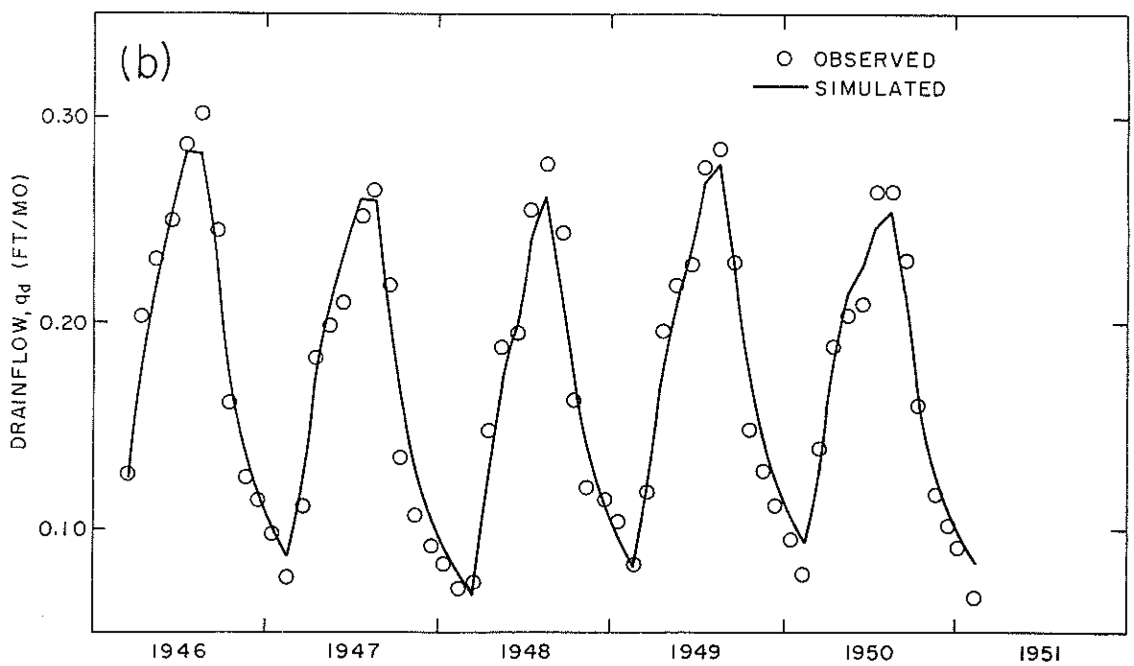

Figure 4.7b: Observed and Simulated Drain Flows

CHAPTER 5

SUMMARY, RECOMMENDATIONS, AND CONCLUSIONS

In the previous chapters, two lumped-parameter ground-water models were developed and their respective parameters were estimated by using the least squares technique. This method was applied to the Mesilla Valley, an irrigation area in south-central New Mexico. The data required for parameter estimation consisted of average monthly water levels, monthly drain flows and dates of recession. For the model aquifer with the perched stream, the parameter estimates were quite reasonable; however, when the stream-connected aquifer model was chosen, some of the parameter estimates were physically unreasonable ($S < 0$). Estimates of leakage from the river appeared to be high. It is likely that there were additional inputs into the aquifer not accounted for in the models but which were computationally included in the river discharge and net recharge estimates by the recharge estimation routine. A simulation using the parameters and net recharge estimates for the Mesilla Valley produced good agreement with the observed water levels and drain flows.

Conclusions drawn from this study include:

(1) if the water levels follow a yearly pattern of recharge and recession, reasonable parameter and net recharge estimates can easily be obtained for the lumped-parameter ground-water model by using the least squares method, and

(2) the results of the application to the Mesilla Valley show that a lumped-parameter, linear-reservoir ground-water model with appropriate stream-aquifer interaction can provide accurate predictions of average water levels and drain flows.

Recommendations for further research include:

(1) a study to determine the extent to which lumped-parameter ground-water

models are suitable for both flow and water quality simulations,

(2) the development of methods to decompose net recharge into its various components,

(3) an evaluation of the possible nonlinearity of the drain flow-water level relationship (equation (2.13)), and

(4) the application of the parameter estimation technique to other irrigated areas similar to the Mesilla Valley.

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APPENDIX A

ALGEBRAIC MANIPULATION TO OBTAIN t_h AND S ESTIMATES FOR THE CASE OF AN AQUIFER WITH A PERCHED STREAM

The objective function which is used to estimate t_h and S for the aquifer with a perched stream is equation (3.10); for ease of calculation let $\alpha = e^{-\Delta t/t_h}$. Differentiating equation (3.10) with respect to α and $\hat{h}_j$, setting to zero and dividing off constants yield

$$\frac{\partial SSq}{\partial \alpha} = \sum_{j=1}^{NY} \sum_{i=R_j}^{NM_j-1} \left(h'_{ji+1} - h'_{ji}\alpha - \hat{h}_j + \hat{h}_j\alpha\right)\left(-h'_{ji} + \hat{h}_j\right) = 0, \qquad \text{(A1)}$$

$$\frac{\partial SSq}{\partial \hat{h}_j} = \sum_{i=R_j}^{NM_j-1} \left(h'_{ji+1} - h'_{ji}\alpha - \hat{h}_j + \hat{h}_j\alpha\right) = 0 \quad . \qquad \text{(A2)}$$

There are NY equations (A2), one for each recharge-recession period. Equation (A1) can be rewritten as

$$\sum_j \sum_i \left(-h'_{ji+1}h'_{ji} + h'^{2}_{ji}\alpha + \hat{h}_j h'_{ji} - \hat{h}_j h'_{ji}\alpha\right)$$

$$+ \sum_j \hat{h}_j \sum_i \left(h'_{ji+1} - h'_{ji}\alpha - \hat{h}_j + \hat{h}_j\alpha\right) = 0 \quad . \qquad \text{(A3)}$$

where i always runs from R_j to NM_j-1 and j runs from one to NY. Multiply each equation (A2) by $\hat{h}_j$ and sum over all j to obtain

$$\sum_j \hat{h}_j \sum_i h'_{j+1} - h'_{ji}\alpha - \hat{h}_j + \hat{h}_j\alpha = 0 \qquad \text{(A4)}$$

which can be subtracted from equation (A3) to yield

$$\sum_j \sum_i \left(-h'_{ji+1}h'_{ji} + h'^{2}_{ji}\alpha + \hat{h}_j h'_{ji} - \hat{h}_j h'_{ji}\alpha\right) = 0 \qquad \text{(A5)}$$

and can be rewritten

$$\sum_j \sum_i -h'_{ji+1}h'_{ji} + \alpha \sum_j \sum_i h'^{\,2}_{ji} + \sum_j \hat{h}_j \sum_i h'_{ji} - \alpha \sum_j \hat{h}_j \sum_i h'_{ji} = 0. \quad \text{(A6)}$$

Multiply equation (A2) by $\sum_i h'_{ji}/\left(NM_j - R_j\right)$ and sum over all j to yield

$$\sum_j \left\{ \frac{\sum_i h'_{ji+1} \sum_i h'_{ji}}{\left(NM_j - R_j\right)} - \alpha \frac{\left[\sum_i h'_{ji}\right]^2}{\left(NM_j - R_j\right)} - \frac{\sum_i \hat{h}_j \sum_i h'_{ji}}{\left(NM_j - R_j\right)} + \alpha \frac{\sum_i \hat{h}_j \sum_i h'_{ji}}{\left(NM_j - R_j\right)} \right\} = 0. \quad \text{(A7)}$$

Note now that $\hat{h}_j = \dfrac{\sum_i \hat{h}_j}{\left(NM_j - R_j\right)}$ which can be substituted into equation (A7) to yield

$$\sum_j \frac{\sum_i h'_{ji+1} \sum_i h'_{ji}}{\left(NM_j - R_j\right)} - \alpha \sum_j \frac{\left[\sum_i h'_{ji}\right]^2}{\left(NM_j - R_j\right)} - \sum_j \hat{h}_j \sum_i h'_{ji} + \alpha \sum_j \hat{h}_j \sum_i h'_{ji} = 0 \quad \text{(A8)}$$

which can be added to equation (A6) to yield

$$\sum_j \sum_i -h'_{ji+1}h'_{ji} + \alpha \sum_j \sum_i h'^{\,2}_{ji} + \sum_j \frac{\sum_i h'_{ji+1} \sum_i h'_{ji}}{\left(NM_j - R_j\right)} - \alpha \sum_j \frac{\left[\sum_i h'_{ji}\right]^2}{\left(NM_j - R_j\right)} = 0 \quad \text{(A9)}$$

Equation (A9) can be solved for α to yield

$$\alpha = \frac{\sum_j \sum_i h'_{ji+1} h'_{ji} - \sum_j \frac{\sum_i h'_{ji+1} \sum_i h'_{ji}}{\left(NM_j - R_j\right)}}{\sum_j \sum_i {h'_{ji}}^2 - \sum_j \frac{\left(\sum_i h'_{ji}\right)^2}{\left(NM_j - R_j\right)}} = e^{-\Delta t/t_h} \qquad \text{(A10)}$$

where

$i = R_j, NM_j-1,$

$j = 1, NY.$

The set of equations (A2) can be rewritten as

$$\sum_i h'_{ji+1} - \alpha \sum_i h'_{ji} - \left(NM_j - R_j\right)\hat{h}_j + \alpha\left(NM_j - R_j\right)\hat{h}_j = 0 \qquad \text{(A11)}$$

which can be solved for $\hat{h}_j$ to yield

$$\hat{h}_j = \frac{\alpha \sum_i h'_{ji} - \sum_i h'_{ji+1}}{\left(NM_j - R_j\right)\left(\alpha - 1\right)} \qquad \text{(A12)}$$

where

$\alpha = e^{-\Delta t/t_h},$

$i = R_j, NM_j-1.$

APPENDIX B

COMPUTER PROGRAM FOR THE CASE OF THE AQUIFER WITH A PERCHED STREAM

The following program estimates h_d and a_d from water-level and drain flow data, then estimates S, t_h and q_r from water-level data from months that recession occurs, then estimates E (net recharge) for each month that recharge occurs. Finally the program runs a simulation using the estimated parameters and results. The program is set up to run on a monthly basis.

Running the program requires four different types of data cards. The first data card is the TITLE CARD and it contains the name of the project. After the TITLE CARD comes the BASIC DATA CARD which contains data required to run the program that cannot fit on other cards. Next come the RECHARGE-RECESSION CARDS. There is one of these cards for each recharge-recession period. Following these cards come the WATER LEVEL-DRAIN FLOW CARDS. There is one card for each month. The following tables give a list of the more important symbols used in the program and a list of what is contained on the data cards.

DATA CARDS

CARD NAME	NO. OF CARDS	DATA NAME	COLUMNS	FIELD
TITLE CARD	1	TITLE	1-80	20A4
BASIC DATA CARD	1	NY	1-10	I10
		HBASE	11-20	F10.0
		HS	21-30	F10.0
		DRS	31-40	F10.0
RECHARGE - RECESSION CARDS	NY (1 FOR EACH RECHARGE - RECESSION PERIOD)	NM	1-10	I10
		IBEG	11-20	I10
WATER LEVEL - DRAINFLOW CARDS	$\sum_{J=1}^{NY} NM(J)$ (1 FOR EACH MONTH)	DATE	3-10	2A4
		H	11-20	F10.0
		DR	21-30	F10.0

LIST OF IMPORTANT SYMBOLS

SYMBOLS READ ON INPUT

SYMBOL	MEANING
DR(J,I)	Observed drainflow for the i^{th} month of the j^{th} recharge-recession period
DRS	Observed drain flow for month before the first month of the first recharge-recession period
DATE(K,J,I)	Month (K=1) and year (K=2) for the i^{th} month of the j^{th} recharge-recession period
HBASE	Base average water level or datum of aquifer
HS	Observed average water level of aquifer for month before the first month of the first recharge-recession period
IBEG(J)	Index of month that recession starts for j^{th} recharge-recession period. (First month of a recharge-recession period is indexed 1).
M(J)	Total number of months in j^{th} recharge-recession period
NY	Total number of recharge-recession periods
TITLE	Title of problem

SYMBOLS WRITTEN ON OUTPUT

AD	Drain discharge constant
DR(J,I)	Observed drain flow for i^{th} month of the j^{th} recharge-recession period
DRPRED(J,I)	Predicted drain flow from regression equation or simulated drain flow for the i^{th} month of the j^{th} recharge-recession period
E(J,I)	Estimated net recharge for the i^{th} month of the j^{th} recharge-recession period

H(J,I)	Observed average water level of aquifer for the i^{th} month of the j^{th} recharge-recession period
HDP	Average drain elevation minus HBASE
HPPRED(J,I)	Simulated average water level of aquifer for the i^{th} month of the j^{th} recharge-recession period
J	Index of recharge-recession period
N	Storage coefficient (specific yield, S)
NEND	Index of last month of a recharge-recession period
NR	Number of months of recession in a recharge-recession period
QR(J)	Discharge per month from river to aquifer for j^{th} recharge-recession period
RES(J,I)	DR(J,I) - DRPRED(J,I)
RHOSQU	Correlation coefficient between observed drain flows and observed average water levels
RMSD	Mean squared error between observed and simulated drain flows
RMSH	Mean squared error between observed and simulated water levels
SERES	Standard error of the residuals from the drain flow-average water level regression
TH	Hydraulic response time of the aquifer
VARRES	Variance of the residuals from the drain flow-average water level regression

```
      DIMENSION TITLE(20),M(25),IBEG(25),DATE(2,25,15),H(25,15),
     &HP(25,15),DR(25,15),QR(25),E(25,15),HR(25),HI(25),HIP1(25),
     &HI2(25),HIP12(25),HIHIP1(25),ALPHA(15),RES(25,15),DRPRED(25,15),
     &HPPRED(25,15)
      REAL N
      READ(5,100) TITLE
  100 FORMAT(20A4)
      READ(5,101) NY,HBASE,HS,DRS
  101 FORMAT(I10,3F10.0)
      READ(5,102) (M(J),IBEG(J),J=1,NY)
  102 FORMAT(2I10)
      DO 1 J=1,NY
      NM=M(J)
      READ(5,103) (DATE(1,J,I),DATE(2,J,I),H(J,I),DR(J,I),I=1,NM)
    1 CONTINUE
  103 FORMAT(2X,2A4,2F10.0)
      WRITE(6,104) TITLE,NY,HBASE
  104 FORMAT(1H1,10X,'ESTIMATION OF PARAMETERS AND RECHARGE FOR LUMPED P
     &ARAMETER GROUNDWATER MODEL'//
     &11X,20A4,////11X,'BASIC INPUT DATA :'//
     &15X,'NUMBER OF YEARS IS ',I2/
     &15X,'THE BASE ELEVATION IS ',F8.3////
     &11X,'WATER YEAR DATA :'//
     &15X,'WATER YEAR      BEGINNING      START OF      ENDING      TOTAL MO
     &NTHS IN      TOTAL MONTHS IN'/17X,'NUMBER              DATE        RECES
     &SION       DATE              WATER YEAR           RECESSION'/)
      DO 20 J=1,NY
      NR=M(J)-IBEG(J)+1
      IREC=IBEG(J)
      NEND=M(J)
      WRITE(6,105) J,DATE(1,J,1),DATE(2,J,1),DATE(1,J,IREC),
     &DATE(2,J,IREC),DATE(1,J,NEND),DATE(2,J,NEND),NEND,NR
   20 CONTINUE
  105 FORMAT(1H0,18X,I2,10X,2A4,6X,2A4,4X,2A4,11X,I2,18X,I2/)
      DO 2 J=1,NY
      NM=M(J)
      DO 2 I=1,NM
      HP(J,I)=H(J,I)-HBASE
    2 CONTINUE
      DRSUM=0.0
      DR2SUM=0.0
      HPSUM=0.0
      HP2SUM=0.0
      HPDRSU=0.0
      RESSQ=0.0
      DRP2SU=0.0
      NMT=0
      DO 3 J=1,NY
      NM=M(J)
      NMT=NMT+NM
      DO 3 I=1,NM
      DRSUM=DRSUM+DR(J,I)
      DR2SUM=DR2SUM+DR(J,I)*DR(J,I)
      HPSUM=HPSUM+HP(J,I)
      HP2SUM=HP2SUM+HP(J,I)*HP(J,I)
      HPDRSU=HPDRSU+HP(J,I)*DR(J,I)
    3 CONTINUE
      RNMT=NMT
      AD=(RNMT*HPDRSU-DRSUM*HPSUM)/(RNMT*HP2SUM-HPSUM*HPSUM)
      HDP=(HPSUM-DRSUM/AD)/RNMT
      RHOSQU=(RNMT*HPDRSU-HPSUM*DRSUM)**2.0/
     &(RNMT*DR2SUM-DRSUM*DRSUM)/(RNMT*HP2SUM-HPSUM*HPSUM)
      DO 4 J=1,NY
      NM=M(J)
      DO 4 I=1,NM
      DRPRED(J,I)=AD*(HP(J,I)-HDP)
      RES(J,I)=DR(J,I)-DRPRED(J,I)
      RESSQ=RESSQ+RES(J,I)*RES(J,I)
    4 CONTINUE
      VARRES=RESSQ/(RNMT-2.0)
      SERES=SQRT(VARRES)
      WRITE(6,106) AD,HDP
  106 FORMAT(1H1,10X,'WATER LEVEL - DRAINFLOW PARAMETERS'//
     &16X,'AD = ',F8.5//
     &16X,'HD = ',F8.5,' + BASE ELEVATION'//////22X,'H              DR
     &        DR                RESIDUAL'/31X,'(OBSERVED)     (PREDICTED)'///)
      DO 21 J=1,NY
      NM=M(J)
      DO 21 I=1,NM
      WRITE(6,107) H(J,I),DR(J,I),DRPRED(J,I),RES(J,I)
   21 CONTINUE
  107 FORMAT(1H0,17X,F8.3,6X,F8.6,6X,F8.6,7X,F8.6)
      WRITE(6,108) RHOSQU,VARRES,SERES
  108 FORMAT(/////25X,'CORRELATION BETWEEN DR AND H IS ',F7.6/
     &25X,'VARIANCE OF THE RESIDUALS IS ',F8.6/
     &25X,'STANDARD ERROR OF THE RESIDUALS IS ',F8.6)
      DO 5 J=1,NY
      NM=M(J)-1
      ISTART=IBEG(J)
      HI(J)=0.0
      HIP1(J)=0.0
      HI2(J)=0.0
      HIP12(J)=0.0
      HIHIP1(J)=0.0
      DO 5 I=ISTART,NM
      HI(J)=HI(J)+HP(J,I)
      HIP1(J)=HIP1(J)+HP(J,I+1)
      HI2(J)=HI2(J)+HP(J,I)*HP(J,I)
      HIP12(J)=HIP12(J)+HP(J,I+1)*HP(J,I+1)
      HIHIP1(J)=HIHIP1(J)+HP(J,I+1)*HP(J,I)
    5 CONTINUE
      SUM1=0.0
      SUM2=0.0
      SUM3=0.0
      SUM4=0.0
      DO 6 J=1,NY
      SUM1=SUM1+HIHIP1(J)
      SUM2=SUM2+HIP1(J)*HI(J)/FLOAT(M(J)-IBEG(J))
      SUM3=SUM3+HI2(J)
      SUM4=SUM4+HI(J)*HI(J)/FLOAT(M(J)-IBEG(J))
    6 CONTINUE
      EXPNT=(SUM1-SUM2)/(SUM3-SUM4)
```

```
      DO 7 J=1,NY
      HB(J)=(EXPNNT*HI(J)-HIPI(J))/(EXPNNT-1.0)/FLOAT(M(J)-IBEG(J))
      QR(J)=AD*(HB(J)-HDP)
    7 CONTINUE
      TH=-1.0/ALOG(EXPNNT)
      N=AD*TH
      WRITE(6,109) TH,N,(J,QR(J),J=1,NY)
  109 FORMAT(1H1,10X,'RIVER LOSS , RESPONSE TIME AND POROSITY'//
     &21X,'TH = ',F9.5,//21X,'N  = ',F8.5////
     &16X,'YEAR             RIVER LOSS'//(17X,I2,12X,F8.6/))
      ALPHA(1)=4.0
      DO 8 I=2,15
      ALPHA(I)=4.0-1.0/ALPHA(I-1)
    8 CONTINUE
      HS=HS-HBASE
      DO 9 J=1,NY
      IBEGJ=IBEG(J)
      IBEGM1=IBEGJ-1
      E(J,1)=DRS+4.0*DR(J,1)+DR(J,2)-6.0*QR(J)+3.0*N*(HP(J,2)-HS)
      DO 10 I=2,IBEGM1
      E(J,I)=DR(J,I-1)+4.0*DR(J,I)+DR(J,I+1)-6.0*QR(J)+
     &3.0*N*(HP(J,I+1)-HP(J,I-1))
      E(J,I)=E(J,I)-E(J,I-1)/ALPHA(I-1)
   10 CONTINUE
      E(J,IBEGM1)=E(J,IBEGM1)/ALPHA(IBEGM1)
      DO 11 I=2,IBEGM1
      II=IBEGJ-I
      E(J,II)=(E(J,II)-E(J,II+1))/ALPHA(II)
   11 CONTINUE
      NM=M(J)
      HS=HP(J,NM)
      DRS=DR(J,NM)
      DO 12 I=IBEGJ,NM
      E(J,I)=0.0
   12 CONTINUE
    9 CONTINUE
      WRITE(6,110)
  110 FORMAT(1H1,10X,'RECHARGE ESTIMATES'///
     &21X,'DATE              RECHARGE')
      DO 22 J=1,NY
      NM=M(J)
      DO 22 I=1,NM
      WRITE(6,111) DATE(1,J,I),DATE(2,J,I),E(J,I)
   22 CONTINUE
  111 FORMAT(1H0,18X,2A4,8X,F8.6)
      RMSH=0.0
      DE=AD*(HPPRED(1,1)-HDP)-DR(1,1)
      RMSD=DE*DE
      TM=0.0
      C1=EXPNNT
      C2=(SQRT(EXPNNT)-EXPNNT)/AD
      C3=(1.0-SQRT(EXPNNT))/AD
      HS=HP(1,1)
      ES=E(1,1)
      HPPRED(1,1)=HP(1,1)
      ISTART=2
```

```
      DO 30 J=1,NY
      C4=HB(J)*(1.0-EXPNNT)
      NM=M(J)
      DO 31 I=ISTART,NM
      HPPRED(J,I)=HS*C1+ES*C2+E(J,I)*C3+C4
      DRPRED(J,I)=AD*(HPPRED(J,I)-HDP)
      HS=HPPRED(J,I)
      ES=E(J,I)
      TM=TM+1.0
      HE=HPPRED(J,I)-HP(J,I)
      DE=AD*(HPPRED(J,I)-HDP)-DR(J,I)
      RMSH=RMSH+HE*HE
      RMSD=RMSD+DE*DE
   31 CONTINUE
      ISTART=1
   30 CONTINUE
      RMSH=RMSH/TM
      RMSD=RMSD/(TM+1.0)
      DO 40 J=1,NY
      NM=M(J)
      DO 40 I=1,NM
      HPPRED(J,I)=HPPRED(J,I)+HBASE
   40 CONTINUE
      WRITE(6,114)
  114 FORMAT(1H1,10X,'PREDICTION OF WATER LEVELS AND DRAINFLOWS'////
     &24X,'DATE',17X,'H',14X,'H',18X,'DR',14X,'DR'/
     &41X,'(OBSERVED)',4X,'(PREDICTED)',9X,'(OBSERVED)',5X,'(PREDICTED)'
     &///)
      DO 41 J=1,NY
      NM=M(J)
      WRITE(6,112) (DATE(1,J,I),DATE(2,J,I),H(J,I),HPPRED(J,I),
     &DR(J,I),DRPRED(J,I),I=1,NM)
   41 CONTINUE
      WRITE(6,113) RMSH,RMSD
  112 FORMAT(1H0,21X,2A4,12X,F8.3,7X,F8.3,11X,F8.6,8X,F8.6)
  113 FORMAT(1H0,////,25X,'MEAN SQUARED ERROR OF WATER LEVELS IS ',F8.5//0000800
     &25X,'MEAN SQUARED ERROR OF DRAINFLOWS IS ',F8.5)
      END
```

ESTIMATION OF PARAMETERS AND RECHARGE FOR LUMPED PARAMETER GROUNDWATER MODEL

MESILLA VALLEY , NEW MEXICO AND TEXAS - MARCH , 1946 , TO FEBRUARY , 1951

BASIC INPUT DATA :

NUMBER OF YEARS IS 5
THE BASE ELEVATION IS 3820.000

WATER YEAR DATA :

WATER YEAR NUMBER	BEGINNING DATE	START OF RECESSION	ENDING DATE	TOTAL MONTHS IN WATER YEAR	TOTAL MONTHS IN RECESSION
1	MAR 1946	OCT 1946	FEB 1947	12	5
2	MAR 1947	OCT 1947	MAR 1948	13	6
3	APR 1948	OCT 1948	FEB 1949	11	5
4	MAR 1949	OCT 1949	FEB 1950	12	5
5	MAR 1950	OCT 1950	FEB 1951	12	5

RIVER LOSS , RESPONSE TIME AND POROSITY

TH = 2.58663

N = 0.20999

YEAR	RIVER LOSS
1	0.062816
2	0.054633
3	0.058538
4	0.068208
5	0.060073

WATER LEVEL - DRAINFLOW PARAMETERS

AD = 0.08119

HD = 4.95229 + BASE ELEVATION

CORRELATION BETWEEN DR AND H IS .957931
VARIANCE OF THE RESIDUALS IS 0.000202
STANDARD ERROR OF THE RESIDUALS IS 0.014224

H	DR (OBSERVED)	DR (PREDICTED)	RESIDUAL
3826.377	0.126993	0.123779	0.003214
3827.344	0.203447	0.202287	0.001160
3827.535	0.231206	0.217787	0.013419
3828.008	0.248913	0.256199	-.007286
3828.363	0.285803	0.285018	0.000785
3828.419	0.301573	0.289556	0.012017
3827.677	0.244579	0.229322	0.015257
3826.845	0.161577	0.161774	-.000197
3826.522	0.125609	0.135552	-.009943
3826.168	0.115188	0.106812	0.008376
3825.951	0.097481	0.089192	0.008289
3825.889	0.077468	0.084158	-.006690
3826.177	0.110485	0.107546	0.002939
3827.180	0.183065	0.188968	-.005903
3827.500	0.199481	0.214953	-.015472
3827.805	0.210087	0.239708	-.029621
3828.323	0.250297	0.281767	-.031470
3828.319	0.264038	0.281450	-.017412
3827.766	0.218202	0.236557	-.018355
3826.844	0.135570	0.161695	-.026125
3826.384	0.106058	0.124354	-.018296
3826.185	0.091486	0.108200	-.016714
3825.863	0.083002	0.082057	0.000945
3825.787	0.071935	0.075893	-.003958
3825.742	0.074425	0.072226	0.002199
3826.785	0.148481	0.156899	-.008418
3827.210	0.187492	0.191406	-.003914
3827.383	0.194316	0.205459	-.011142
3828.055	0.253893	0.260004	-.006111
3828.237	0.277503	0.274790	0.002713
3827.692	0.242826	0.230531	0.012295
3826.949	0.162038	0.170218	-.008180
3826.579	0.120353	0.140190	-.019837
3826.252	0.113436	0.113631	-.000195
3825.894	0.104490	0.084574	0.019916
3825.865	0.082264	0.082215	0.000049
3826.170	0.118231	0.106971	0.011260
3827.010	0.196069	0.175173	0.020896
3827.275	0.219217	0.196678	0.022539
3827.430	0.228439	0.209264	0.019175
3828.061	0.276027	0.260500	0.015527
3828.110	0.284419	0.264484	0.019935
3827.621	0.222998	0.224783	-.001785
3826.868	0.148112	0.163638	-.015526
3826.519	0.128561	0.135314	-.006753
3826.243	0.110577	0.112897	-.002320
3826.018	0.094714	0.094643	0.000071
3825.945	0.077644	0.088716	-.011072
3825.201	0.138392	0.109488	0.028904
3826.984	0.188691	0.173052	0.015639
3827.403	0.204000	0.207084	-.003084
3827.593	0.208888	0.222504	-.013616
3827.803	0.263392	0.239550	0.023842
3827.996	0.264038	0.255228	0.008810
3827.376	0.230053	0.204884	0.025169
3826.683	0.160904	0.148633	0.012271
3826.330	0.117761	0.119973	-.002212
3826.107	0.101871	0.101857	0.000014
3825.894	0.092409	0.084574	0.007835
3825.835	0.065940	0.079777	-.013837

RECHARGE ESTIMATES

DATE	RECHARGE
MAR 1946	0.231311
APR 1946	0.269693
MAY 1946	0.214497
JUN 1946	0.290951
JUL 1946	0.279163
AUG 1946	0.168046
SEP 1946	-.023764
OCT 1946	0.0
NOV 1946	0.0
DEC 1946	0.0
JAN 1947	0.0
FEB 1947	0.0
MAR 1947	0.225459
APR 1947	0.286157
MAY 1947	0.177804
JUN 1947	0.259642
JUL 1947	0.264428
AUG 1947	0.154070
SEP 1947	-.034685
OCT 1947	0.0
NOV 1947	0.0
DEC 1947	0.0
JAN 1948	0.0
FEB 1948	0.0
MAR 1948	0.0
APR 1948	0.322348
MAY 1948	0.140043
JUN 1948	0.235834
JUL 1948	0.316356
AUG 1948	0.172907
SEP 1948	0.019809
OCT 1948	0.0
NOV 1948	0.0
DEC 1948	0.0
JAN 1949	0.0
FEB 1949	0.0
MAR 1949	0.200259
APR 1949	0.262316
MAY 1949	0.159071
JUN 1949	0.258074
JUL 1949	0.303637
AUG 1949	0.163595
SEP 1949	-.007719
OCT 1949	0.0
NOV 1949	0.0
DEC 1949	0.0
JAN 1950	0.0
FEB 1950	0.0
MAR 1950	0.210476
APR 1950	0.272000
MAY 1950	0.195575
JUN 1950	0.182582
JUL 1950	0.268535
AUG 1950	0.163261
SEP 1950	-.001426
OCT 1950	0.0
NOV 1950	0.0
DEC 1950	0.0
JAN 1951	0.0
FEB 1951	0.0

PREDICTION OF WATER LEVELS AND DRAINFLOWS

DATE	H (OBSERVED)	H (PREDICTED)	DR (OBSERVED)	DR (PREDICTED)
MAR 1946	3826.377	3826.377	0.126993	0.123779
APR 1946	3827.344	3827.133	0.203447	0.185145
MAY 1946	3827.535	3827.595	0.231206	0.222694
JUN 1946	3828.009	3827.977	0.248913	0.253645
JUL 1946	3828.363	3828.346	0.285803	0.283676
AUG 1946	*3828.419	3828.336	0.301573	0.282840
SEP 1946	3827.677	3827.716	0.244579	0.237460
OCT 1946	3826.845	3827.003	0.161577	0.174622
NOV 1946	3826.522	3826.562	0.125609	0.138773
DEC 1946	3826.169	3826.261	0.115188	0.114418
JAN 1947	3825.951	3826.058	0.097481	0.097872
FEB 1947	3825.889	3825.919	0.077468	0.086632
MAR 1947	3826.177	3826.281	0.110485	0.116000
APR 1947	3827.180	3827.061	0.183065	0.179283
MAY 1947	3827.500	3827.464	0.199481	0.212023
JUN 1947	3827.805	3827.722	0.210087	0.232953
JUL 1947	3828.323	3828.053	0.250297	0.259869
AUG 1947	3828.319	3828.048	0.264038	0.259451
SEP 1947	3827.766	3827.439	0.218202	0.210002
OCT 1947	3826.844	3826.763	0.135570	0.155160
NOV 1947	3826.384	3826.366	0.106058	0.122927
DEC 1947	3826.185	3826.097	0.091486	0.101029
JAN 1948	3825.863	3825.913	0.083002	0.086153
FEB 1948	3825.787	3825.789	0.071935	0.076046
MAR 1948	3825.742	3825.704	0.074425	0.069180
APR 1948	3826.785	3826.360	0.148481	0.122426
MAY 1948	3827.210	3826.986	0.187492	0.173255
JUN 1948	3827.383	3827.294	0.194316	0.198212
JUL 1948	3828.055	3827.848	0.253893	0.243198
AUG 1948	3828.237	3828.057	0.277503	0.260211
SEP 1948	3827.692	3827.610	0.242826	0.223902
OCT 1948	3826.949	3826.990	0.162038	0.173605
NOV 1948	3826.579	3826.536	0.120353	0.136710
DEC 1948	3826.252	3826.227	0.113436	0.111645
JAN 1949	3825.894	3826.018	0.104490	0.094617
FEB 1949	3825.865	3825.875	0.082264	0.083049
MAR 1949	3826.170	3826.250	0.118231	0.113489
APR 1949	3827.010	3826.997	0.196069	0.174088
MAY 1949	3827.275	3827.391	0.219217	0.206100
JUN 1949	3827.430	3827.699	0.228439	0.230292
JUL 1949	3828.061	3828.167	0.276027	0.269078
AUG 1949	3828.110	3828.269	0.284419	0.277414
SEP 1949	3827.621	3827.718	0.222998	0.232678
OCT 1949	3826.868	3827.055	0.148112	0.178824
NOV 1949	3826.519	3826.618	0.128561	0.143356
DEC 1949	3826.243	3826.321	0.110577	0.119260
JAN 1950	3826.019	3826.120	0.094714	0.102891
FEB 1950	3825.945	3825.983	0.077644	0.091770
MAR 1950	3826.201	3826.313	0.138392	0.118601
APR 1950	3826.994	3827.046	0.188691	0.178135
MAY 1950	3827.403	3827.489	0.204000	0.214060
JUN 1950	3827.593	3827.625	0.208889	0.225111
JUL 1950	3827.803	3827.880	0.263392	0.245844
AUG 1950	3827.996	3827.979	0.264038	0.253877
SEP 1950	3827.376	3827.502	0.230053	0.215137
OCT 1950	3826.683	3826.887	0.160904	0.165211
NOV 1950	3826.330	3826.472	0.117761	0.131499
DEC 1950	3826.107	3826.190	0.101871	0.108597
JAN 1951	3825.894	3825.998	0.092409	0.093038
FEB 1951	3825.835	3825.868	0.065940	0.082468

APPENDIX C

WATER LEVELS FOR USBR WELLS (1946 - 1951)

1946

WELL NO.	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
26	3919.82	3919.32	3919.12	3920.02	3920.42	3921.32	3922.12	3922.92	3922.12	3921.32	3920.62	3919.92
20	3919.69	3919.79	3919.59	3921.19	3921.39	3921.39	3922.19	3922.19	3921.69	3920.49	3919.99	3919.49
19	3914.74	3914.34	3915.54	3916.24	3916.34	3917.04	3916.94	3916.24	3915.54	3914.94	3914.44	3914.04
15	3897.81	3897.81	3897.91	3898.91	3898.91	3898.91	3899.41	3899.31	3898.51	3898.51	3898.01	3897.71
18	3898.35	3897.95	3898.05	3898.35	3898.55	3899.25	3899.75	3900.05	3899.95	3898.35	3898.35	3898.15
17	3897.51	3897.01	3897.11	3898.61	3898.91	3899.41	3900.11	3900.21	3899.71	3898.41	3897.71	3897.11
16	3885.73	3885.63	3885.53	3885.53	3885.53	3885.43	3885.53	3885.53	3885.63	3885.63	3885.63	3885.53
12	3881.89	3881.69	3881.79	3882.49	3882.39	3882.99	3882.79	3882.89	3882.49	3882.09	3881.89	3881.67
11	3874.49	3874.89	3875.39	3875.99	3875.79	3876.59	3876.49	3876.19	3875.09	3874.79	3874.79	3874.69
13	3852.96	3852.56	3852.76	3853.66	3854.36	3855.36	3856.26	3856.36	3855.56	3854.56	3853.86	3853.46
14	3852.00	3851.90	3851.90	3852.80	3853.20	3853.40	3853.40	3854.20	3853.30	3852.60	3852.20	3851.90
10	3842.15	3841.85	3841.55	3842.45	3842.65	3842.95	3843.65	3843.95	3843.35	3842.75	3842.45	3841.95
9	3839.58	3839.48	3839.48	3839.38	3839.38	3839.38	3839.38	3839.48	3839.48	3839.48	3839.48	3839.38
8	3838.60	3838.70	3839.30	3840.30	3840.50	3841.00	3841.60	3841.40	3841.20	3839.90	3839.80	3838.90
25	3825.84	3825.64	3826.04	3827.54	3828.64	3828.84	3829.84	3829.74	3828.34	3826.94	3826.44	3825.94
7	3834.27	3834.17	3834.47	3834.97	3835.37	3835.87	3836.17	3836.17	3836.07	3835.17	3834.87	3834.37
6	3818.25	3818.15	3818.15	3818.95	3819.65	3820.05	3820.25	3820.55	3819.85	3819.25	3818.85	3818.25
5	3809.88	3809.88	3811.08	3811.28	3811.58	3811.48	3812.18	3811.98	3810.98	3810.48	3810.18	3809.98
24	3811.01	3811.21	3811.71	3812.51	3812.91	3812.91	3813.11	3813.21	3812.81	3811.71	3811.51	3811.71
4	3805.26	3805.16	3805.66	3806.16	3806.46	3805.76	3807.26	3807.36	3806.66	3806.16	3805.96	3805.46
27	3804.75	3804.76	3805.66	3807.16	3807.76	3808.06	3808.46	3808.66	3808.26	3805.56	3805.16	3804.96
21	3801.08	3800.98	3801.38	3801.88	3802.28	3802.38	3802.88	3803.18	3802.78	3801.78	3801.49	3801.08
23	3799.40	3799.00	3801.80	3802.10	3801.60	3803.40	3802.90	3802.80	3801.70	3800.50	3800.30	3799.30
22	3795.68	3795.68	3795.98	3797.38	3798.08	3798.38	3798.48	3798.78	3797.38	3796.58	3795.18	3795.78
3	3803.21	3803.11	3803.21	3803.71	3803.81	3804.11	3804.21	3804.31	3803.81	3803.41	3803.21	3803.21
28	3796.75	3796.75	3797.05	3798.25	3798.75	3798.95	3798.95	3799.85	3799.25	3797.35	3797.15	3796.95
32	3786.68	3786.98	3787.38	3789.08	3788.78	3789.38	3789.38	3789.88	3788.48	3787.38	3786.98	3786.58
31	3785.85	3786.25	3786.45	3787.75	3787.85	3787.95	3788.15	3788.55	3788.05	3786.35	3786.05	3785.75
30	3786.56	3786.26	3788.46	3789.26	3788.56	3787.56	3787.66	3787.56	3787.36	3787.46	3787.26	3787.16
39	3781.33	3781.33	3781.73	3783.13	3782.93	3783.73	3784.03	3783.93	3783.03	3781.93	3781.73	3781.43
29	3781.24	3781.24	3782.14	3783.24	3782.34	3782.84	3782.64	3782.74	3782.54	3781.34	3781.14	3781.04
38	3773.74	3773.84	3772.24	3774.54	3774.14	3775.44	3775.24	3775.54	3774.54	3773.24	3772.64	3772.14
1	3759.40	3759.60	3760.20	3760.60	3760.70	3761.20	3761.50	3761.20	3760.10	3759.80	3759.80	3759.50
2	3763.48	3763.28	3763.28	3764.28	3764.18	3764.78	3765.38	3765.48	3764.78	3764.18	3763.78	3763.38
37	3747.62	3747.62	3748.02	3748.72	3748.62	3748.62	3748.92	3749.02	3748.52	3749.02	3747.92	3747.92
36	3746.45	3746.35	3746.65	3748.55	3748.45	3748.85	3749.25	3749.15	3747.75	3746.95	3746.75	3746.35
35	3740.27	3740.57	3741.47	3741.67	3741.77	3741.87	3741.97	3741.87	3740.77	3740.27	3740.57	3740.37
33	3737.49	3737.79	3738.09	3739.19	3739.59	3739.69	3739.39	3738.89	3738.09	3737.59	3737.59	3737.49
34	3728.47	3728.77	3728.97	3730.27	3730.47	3730.77	3730.37	3730.27	3729.47	3728.87	3728.67	3728.57
VALLEY MEAN	3826.222	3826.121	3826.377	3827.344	3827.535	3828.008	3828.363	3828.419	3827.677	3826.845	3826.522	3826.168
NODE 1 MEAN	3886.433	3886.158	3886.319	3887.161	3887.449	3888.011	3888.514	3888.597	3887.932	3887.176	3886.745	3886.38[illegible]
NODE 2 MEAN	3789.503	3789.510	3789.825	3790.869	3790.999	3791.419	3791.683	3791.722	3790.933	3790.055	3789.797	3789.448

1947

WELL NO.	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
26	3919.42	3919.02	3918.82	3920.02	3920.22	3920.82	3921.92	3921.92	3921.02	3921.32	3919.62	3919.12
20	3919.29	3919.09	3919.29	3921.09	3921.29	3921.79	3921.79	3921.79	3920.09	3919.29	3918.89	3918.79
19	3913.74	3913.54	3914.14	3915.04	3915.54	3916.04	3916.74	3916.64	3914.84	3914.24	3913.64	3913.34
15	3897.71	3897.61	3897.81	3898.71	3898.91	3898.71	3899.01	3898.91	3898.31	3897.91	3897.81	3897.71
18	3898.05	3897.75	3897.95	3898.15	3898.45	3898.85	3900.05	3899.75	3899.05	3898.45	3898.35	3898.35
17	3897.01	3896.81	3896.91	3897.81	3898.31	3898.81	3899.51	3899.51	3898.91	3898.21	3897.71	3898.01
16	3885.43	3885.43	3885.33	3885.33	3885.33	3885.33	3885.43	3885.43	3885.53	3885.53	3885.23	3885.23
12	3881.59	3881.39	3881.69	3882.29	3882.39	3881.99	3881.89	3881.49	3881.19	3880.99	3880.69	3880.39
11	3874.49	3874.59	3875.39	3875.69	3875.19	3876.09	3876.09	3875.49	3874.49	3874.49	3874.39	3874.39
13	3852.86	3852.66	3852.46	3853.76	3854.66	3855.26	3855.56	3856.06	3855.76	3855.16	3854.46	3853.76
14	3851.70	3851.60	3851.30	3852.60	3853.10	3853.40	3853.80	3854.20	3853.30	3852.70	3852.50	3852.20
10	3841.85	3841.65	3841.55	3842.55	3842.55	3842.65	3843.35	3843.45	3843.15	3842.75	3842.35	3842.15
9	3839.38	3839.38	3839.38	3839.28	3839.28	3839.28	3840.28	3840.28	3840.38	3840.28	3840.38	3840.18
8	3838.60	3838.60	3839.90	3840.90	3841.30	3841.80	3841.80	3841.50	3841.00	3840.80	3839.50	3838.90
25	3825.34	3825.44	3825.84	3827.34	3828.14	3828.84	3830.14	3829.64	3829.44	3826.44	3825.54	3825.44
7	3834.27	3834.37	3834.47	3835.37	3836.07	3836.17	3836.57	3836.37	3836.17	3835.27	3834.67	3834.37
6	3818.15	3818.15	3818.25	3819.05	3819.25	3820.05	3820.45	3820.65	3820.55	3819.65	3818.95	3818.55
5	3810.08	3810.08	3810.28	3811.38	3811.48	3811.48	3812.18	3811.98	3811.78	3810.78	3810.38	3810.18
24	3811.01	3811.01	3811.51	3812.41	3812.61	3812.71	3812.91	3813.31	3812.81	3811.41	3811.11	3811.01
4	3805.26	3805.36	3805.36	3806.26	3806.86	3806.76	3807.36	3807.46	3807.06	3806.26	3805.86	3805.76
27	3804.76	3804.86	3805.86	3806.96	3807.66	3808.66	3808.36	3808.16	3807.96	3805.56	3804.96	3804.76
21	3801.08	3801.08	3801.38	3802.18	3801.88	3802.08	3802.78	3802.78	3802.58	3801.68	3801.38	3801.18
23	3798.80	3799.00	3800.00	3801.50	3803.30	3801.50	3803.30	3801.60	3801.60	3799.40	3798.90	3798.80
22	3795.48	3795.48	3795.58	3797.08	3797.48	3796.98	3798.48	3798.08	3797.58	3796.38	3795.88	3795.78
3	3803.11	3803.11	3803.11	3803.91	3804.01	3804.21	3804.41	3804.41	3804.21	3803.51	3803.31	3803.21
28	3796.85	3796.85	3797.35	3798.45	3798.55	3798.35	3798.55	3798.55	3798.45	3797.05	3796.95	3796.85
32	3786.38	3786.38	3786.88	3788.48	3788.58	3788.38	3789.28	3789.08	3788.58	3787.18	3786.78	3786.58
31	3785.75	3785.65	3786.35	3787.05	3787.05	3786.95	3788.15	3787.75	3787.55	3786.15	3785.85	3785.75
30	3786.96	3786.96	3786.66	3786.96	3787.36	3786.96	3789.36	3789.76	3788.36	3786.76	3786.16	3785.86
39	3781.23	3781.03	3781.63	3782.93	3783.23	3783.63	3784.03	3784.13	3783.03	3781.93	3781.53	3781.33
29	3781.04	3781.14	3781.94	3782.44	3782.64	3782.64	3782.94	3782.34	3782.24	3781.04	3780.94	3780.94
38	3771.84	3771.84	3772.24	3774.14	3774.44	3775.14	3775.44	3775.74	3775.24	3773.54	3772.34	3772.14
1	3759.10	3759.40	3760.20	3760.90	3760.90	3761.00	3761.50	3761.10	3760.60	3759.80	3759.60	3759.50
2	3763.18	3762.98	3763.08	3763.78	3764.08	3764.28	3764.78	3765.48	3764.98	3764.08	3763.58	3763.28
37	3747.82	3747.82	3747.92	3748.82	3748.62	3748.82	3749.22	3750.42	3748.92	3748.22	3748.12	3748.02
36	3746.35	3746.25	3746.45	3747.85	3748.15	3748.75	3749.65	3749.75	3748.65	3746.95	3746.65	3746.45
35	3740.27	3740.47	3741.27	3741.57	3741.37	3741.87	3741.87	3741.87	3740.77	3740.07	3740.07	3740.07
33	3737.39	3737.29	3738.39	3738.69	3738.89	3738.99	3739.19	3738.69	3738.19	3737.49	3737.39	3737.39
34	3728.47	3728.37	3728.87	3730.67	3730.27	3730.17	3730.77	3730.17	3730.17	3728.97	3728.77	3728.67
VALLEY MEAN	3825.951	3825.889	3826.177	3827.180	3827.500	3827.805	3828.323	3828.319	3827.766	3826.844	3825.384	3826.185
NODE 1 MEAN	3886.126	3885.949	3886.023	3886.901	3887.310	3887.706	3888.194	3888.253	3887.597	3887.110	3886.671	3886.458
NODE 2 MEAN	3789.256	3789.263	3789.683	3790.761	3791.027	3791.279	3791.816	3791.771	3791.282	3790.096	3789.621	3789.431

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WELL NO.	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
26	3918.62	3918.32	3918.22	3918.72	3919.22	3919.62	3920.22	3921.02	3920.92	3920.22	3919.62	3919.22
20	3918.59	3918.49	3918.49	3919.59	3920.29	3920.49	3921.69	3921.89	3921.59	3920.49	3919.79	3919.29
19	3913.04	3912.64	3912.74	3913.74	3914.04	3914.74	3915.24	3915.74	3915.34	3914.64	3915.14	3913.84
15	3897.31	3897.41	3897.41	3898.61	3898.51	3898.41	3898.81	3899.01	3898.61	3897.91	3897.71	3897.71
18	3898.35	3898.35	3898.35	3898.35	3898.35	3898.35	3899.35	3899.95	3899.25	3898.45	3898.35	3898.35
17	3897.01	3897.01	3897.01	3897.51	3897.91	3898.01	3899.01	3899.61	3899.21	3898.21	3897.91	3897.51
16	3885.13	3885.13	3885.03	3885.03	3885.03	3885.03	3885.03	3885.03	3885.03	3885.13	3885.13	3885.03
12	3880.39	3880.19	3880.19	3880.79	3881.09	3881.29	3881.59	3881.99	3881.89	3881.19	3880.89	3880.69
11	3874.19	3874.19	3874.19	3875.29	3875.19	3875.69	3876.19	3875.39	3875.09	3874.29	3874.29	3874.29
13	3852.96	3852.46	3852.16	3852.86	3853.86	3854.36	3855.96	3856.66	3856.36	3854.86	3854.26	3853.66
14	3851.70	3851.50	3851.40	3851.70	3852.40	3852.70	3853.30	3854.40	3853.80	3852.70	3852.30	3852.00
10	3841.85	3841.65	3841.65	3841.95	3842.35	3842.25	3842.85	3843.45	3843.65	3842.85	3842.65	3842.35
9	3840.18	3840.18	3840.18	3840.18	3940.18	3840.18	3840.18	3840.18	3840.18	3840.28	3840.28	3840.18
8	3838.70	3838.60	3838.50	3839.00	3839.30	3839.70	3840.30	3840.30	3840.30	3840.20	3838.50	3838.30
25	3825.34	3825.74	3826.14	3827.14	3828.44	3828.94	3829.94	3829.84	3828.44	3827.14	3826.54	3826.04
7	3834.27	3834.27	3834.27	3834.47	3834.87	3835.17	3835.47	3835.67	3834.97	3834.77	3834.27	3834.27
6	3818.15	3818.15	3818.15	3818.65	3818.95	3819.25	3819.65	3819.65	3819.65	3819.35	3818.35	3818.25
5	3809.98	3809.88	3809.78	3811.48	3811.28	3810.98	3811.58	3811.78	3811.18	3810.68	3810.08	3809.88
24	3810.91	3810.81	3810.71	3812.91	3813.11	3813.21	3813.11	3813.11	3812.61	3812.01	3811.71	3811.61
4	3805.56	3805.56	3805.46	3806.26	3806.96	3806.36	3806.56	3806.66	3806.56	3806.06	3806.06	3804.76
27	3804.66	3804.66	3804.56	3807.46	3807.86	3808.16	3808.26	3808.36	3807.26	3806.06	3805.46	3805.16
21	3801.08	3801.08	3801.08	3801.98	3802.08	3802.18	3802.68	3802.88	3802.48	3801.88	3801.58	3801.38
23	3798.50	3798.50	3798.60	3801.90	3802.30	3802.70	3803.20	3803.00	3801.30	3800.90	3799.60	3800.00
22	3795.48	3795.38	3795.28	3796.68	3797.18	3797.68	3797.88	3798.08	3797.38	3796.58	3795.98	3795.58
3	3803.11	3803.11	3803.11	3803.91	3804.11	3803.31	3803.41	3803.51	3803.21	3803.21	3803.11	3803.11
28	3796.65	3796.65	3796.65	3798.05	3798.55	3798.95	3798.75	3799.05	3798.55	3798.55	3798.45	3798.45
32	3786.28	3786.18	3786.08	3787.98	3788.08	3788.08	3789.28	3789.18	3788.48	3787.48	3787.18	3786.88
31	3785.75	3785.75	3785.75	3787.05	3787.05	3787.15	3788.05	3788.15	3787.35	3786.55	3786.25	3786.05
30	3785.76	3785.76	3785.76	3786.86	3786.86	3786.76	3787.76	3787.86	3787.36	3786.56	3786.16	3786.06
39	3780.63	3780.73	3780.83	3783.03	3783.13	3783.23	3782.93	3782.93	3781.83	3781.03	3781.03	3780.73
29	3780.84	3780.84	3780.84	3782.54	3782.44	3782.14	3783.54	3783.44	3782.04	3781.24	3781.04	3780.84
38	3771.84	3771.84	3771.74	3772.74	3774.34	3774.74	3775.94	3775.74	3775.34	3774.74	3774.04	3772.94
1	3759.30	3759.30	3759.20	3760.50	3760.80	3761.10	3761.50	3761.30	3760.90	3760.20	3760.10	3760.00
2	3763.08	3762.48	3761.88	3763.58	3763.68	3763.88	3764.98	3765.38	3764.88	3764.18	3763.78	3763.48
37	3747.92	3747.92	3747.82	3749.02	3749.22	3749.42	3750.32	3750.02	3749.22	3748.72	3748.52	3748.42
36	3746.25	3746.25	3746.25	3747.95	3748.75	3749.15	3750.05	3749.95	3748.65	3747.35	3746.95	3746.75
35	3740.07	3740.07	3739.97	3741.67	3741.97	3742.17	3742.37	3741.97	3740.97	3740.47	3740.37	3740.37
33	3737.39	3737.39	3737.29	3739.59	3739.49	3739.39	3739.89	3739.99	3738.69	3737.99	3737.99	3737.39
34	3728.47	3728.47	3728.47	3730.37	3730.17	3729.97	3729.97	3730.17	3729.57	3728.97	3728.77	3728.67
VALLEY MEAN	3825.863	3825.787	3825.742	3826.785	3827.210	3827.383	3828.055	3828.237	3827.692	3826.949	3826.579	3826.252
NODE 1 MEAN	3885.995	3885.805	3885.728	3886.285	3886.732	3886.984	3887.893	3888.365	3888.041	3887.110	3886.828	3886.434
NODE 2 MEAN	3789.194	3789.188	3789.164	3790.503	3790.914	3791.039	3791.566	3791.570	3790.891	3790.262	3789.839	3789.553

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WELL NO.	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
26	3918.22	3918.22	3918.12	3919.12	3919.42	3919.92	3920.62	3921.82	3921.32	3920.32	3919.72	3919.22
20	3918.59	3918.59	3918.69	3920.09	3921.09	3921.19	3921.49	3921.19	3920.89	3920.09	3919.59	3919.19
19	3913.14	3913.14	3913.94	3914.54	3914.94	3915.04	3916.14	3916.04	3915.74	3914.94	3914.44	3914.04
15	3897.41	3897.41	3897.71	3898.61	3898.71	3899.11	3899.31	3899.61	3900.31	3898.51	3898.41	3898.11
18	3898.35	3898.35	3898.35	3898.35	3898.35	3898.65	3900.25	3900.65	3899.35	3898.35	3898.35	3898.35
17	3897.01	3897.01	3897.01	3898.41	3898.81	3898.81	3899.61	3899.91	3899.31	3898.51	3897.91	3897.51
16	3884.93	3884.93	3884.93	3884.93	3884.93	3884.93	3884.83	3885.33	3885.53	3885.33	3885.43	3885.23
12	3880.29	3880.29	3880.59	3881.09	3881.19	3881.39	3881.99	3882.09	3881.89	3881.29	3880.99	3880.69
11	3874.19	3874.19	3874.49	3875.09	3876.19	3875.99	3875.49	3875.79	3874.89	3874.29	3874.29	3874.19
13	3852.56	3852.56	3852.56	3854.06	3854.56	3854.96	3856.66	3856.66	3855.66	3855.06	3854.26	3853.66
14	3851.60	3851.60	3851.90	3852.60	3852.90	3853.30	3854.00	3854.60	3854.90	3852.90	3852.50	3852.20
10	3841.85	3841.85	3841.85	3842.75	3842.85	3842.95	3843.55	3844.05	3843.65	3843.25	3843.05	3842.75
9	3840.08	3840.08	3840.08	3840.08	3839.98	3839.98	3840.08	3840.08	3840.18	3840.08	3840.18	3840.08
8	3838.20	3837.50	3837.80	3838.90	3839.50	3839.50	3839.40	3839.40	3839.00	3838.10	3838.00	3837.50
25	3825.34	3825.34	3825.64	3827.64	3828.54	3828.64	3828.74	3829.14	3828.54	3826.94	3826.64	3826.04
7	3834.27	3834.27	3834.37	3834.87	3835.57	3835.37	3835.67	3835.37	3835.27	3835.07	3834.67	3834.37
6	3818.25	3818.25	3818.25	3818.45	3818.95	3819.35	3819.85	3820.05	3819.65	3819.05	3818.55	3818.25
5	3809.78	3809.78	3809.88	3810.88	3811.08	3811.18	3811.68	3811.68	3811.38	3810.48	3810.18	3809.88
24	3811.41	3811.31	3811.01	3813.11	3813.41	3813.41	3813.51	3813.41	3813.21	3812.01	3811.71	3811.41
4	3804.76	3804.76	3804.86	3805.66	3805.86	3805.86	3806.16	3806.36	3806.26	3805.86	3805.56	3805.46
27	3804.96	3804.86	3805.16	3807.16	3807.66	3807.96	3808.66	3808.66	3807.86	3806.16	3805.66	3805.36
21	3801.19	3801.18	3801.48	3801.98	3801.98	3802.28	3802.58	3803.38	3803.08	3801.78	3801.28	3801.28
23	3798.60	3798.60	3798.80	3800.20	3801.40	3802.30	3802.80	3803.40	3802.00	3800.30	3799.70	3799.00
22	3795.38	3795.18	3795.28	3797.08	3796.68	3797.18	3797.78	3797.58	3797.18	3796.28	3795.88	3795.58
3	3803.11	3803.11	3803.11	3803.11	3803.21	3803.21	3803.41	3803.41	3803.31	3803.21	3803.21	3803.21
28	3799.35	3798.15	3798.05	3798.05	3798.15	3798.55	3798.95	3798.55	3798.25	3797.45	3797.05	3796.95
32	3786.68	3786.58	3786.78	3789.08	3788.68	3789.08	3789.88	3789.58	3788.88	3787.98	3787.48	3787.08
31	3785.95	3785.75	3785.85	3787.75	3787.45	3787.75	3788.55	3788.25	3787.65	3786.75	3786.25	3786.05
30	3785.86	3785.86	3786.06	3786.86	3786.96	3787.16	3787.66	3787.56	3786.96	3786.36	3786.06	3785.86
39	3780.53	3780.83	3781.13	3781.93	3782.03	3782.33	3782.63	3782.63	3782.13	3780.93	3780.73	3780.73
29	3780.84	3780.74	3780.94	3782.54	3781.94	3782.44	3783.14	3783.54	3783.04	3782.14	3781.34	3781.34
38	3772.14	3771.94	3772.64	3773.04	3773.84	3773.34	3774.34	3774.44	3774.34	3774.24	3774.04	3773.44
1	3760.00	3759.80	3760.10	3760.70	3760.30	3760.80	3760.90	3760.90	3760.80	3760.70	3760.60	3760.50
2	3763.28	3763.28	3763.38	3763.78	3763.78	3764.08	3764.98	3764.78	3764.38	3763.98	3763.58	3763.08
37	3748.32	3748.32	3749.12	3749.52	3748.92	3748.62	3749.52	3748.72	3748.32	3747.82	3747.52	3747.62
36	3746.45	3746.45	3748.75	3748.55	3748.85	3748.65	3749.55	3749.15	3747.75	3746.75	3746.45	3746.45
35	3740.37	3740.27	3741.67	3741.87	3741.87	3742.47	3742.47	3741.77	3741.27	3740.37	3739.87	3739.77
33	3737.39	3737.79	3739.99	3739.79	3739.79	3739.99	3739.99	3739.99	3738.79	3737.49	3737.29	3737.29
34	3728.57	3728.47	3729.47	3730.17	3730.27	3730.07	3730.37	3730.07	3729.77	3728.97	3728.77	3728.57
VALLEY MEAN	3825.894	3825.965	3826.170	3827.010	3827.275	3827.430	3828.061	3828.110	3827.621	3826.868	3826.519	3826.243
NODE 1 MEAN	3885.878	3885.878	3885.989	3886.894	3887.258	3887.459	3888.382	3888.567	3888.002	3887.239	3886.822	3886.478
NODE 2 MEAN	3789.316	3789.270	3789.693	3790.493	3790.700	3790.825	3791.276	3791.243	3790.801	3790.052	3789.745	3789.511