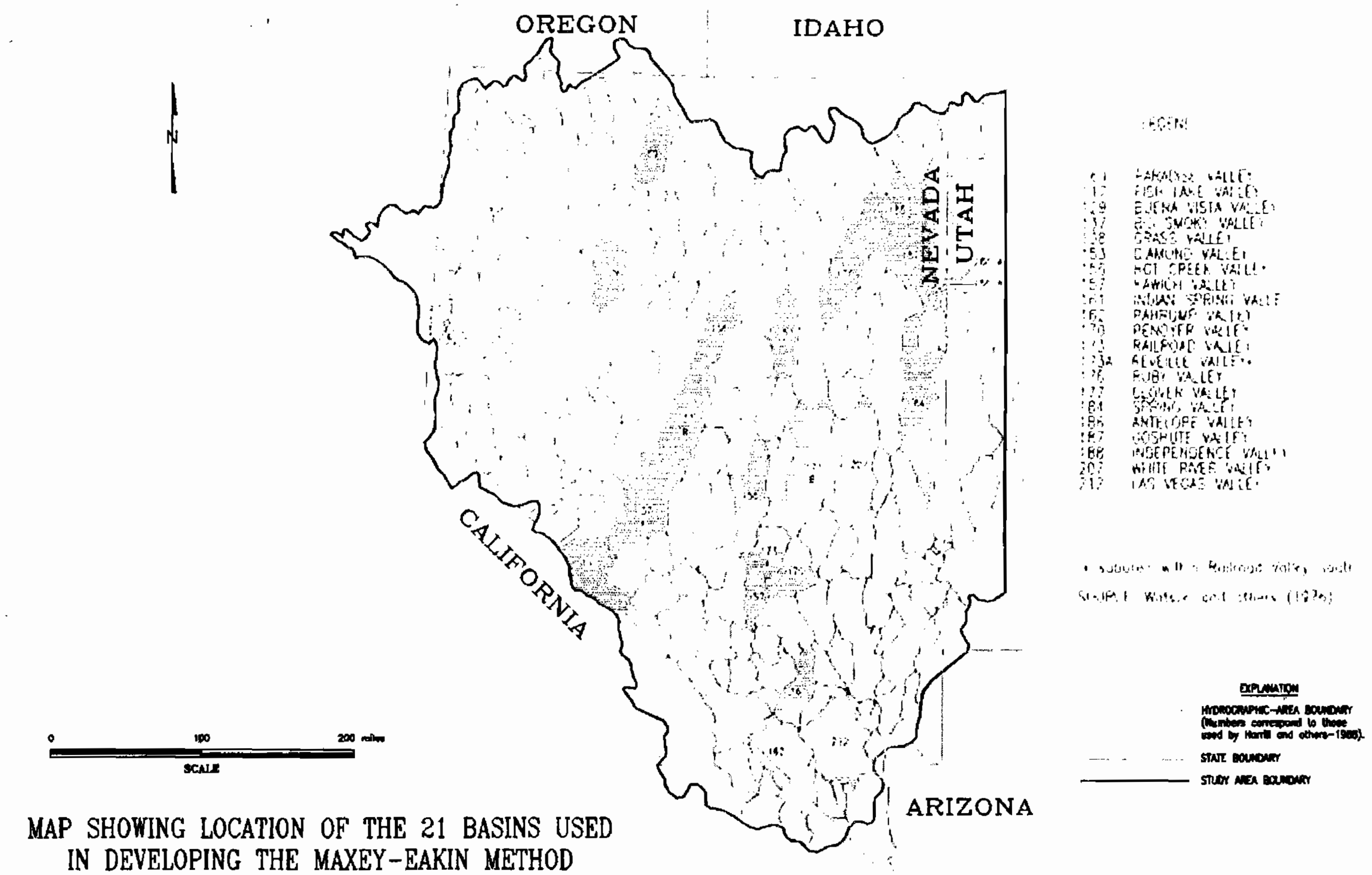

MAP SHOWING LOCATION OF THE 21 BASINS USED
IN DEVELOPING THE MAXEY-EAKIN METHOD

# EVALUATION OF THE MAXEY-EAKIN METHOD FOR CALCULATING RECHARGE TO GROUND-WATER BASINS IN NEVADA
1992

Las Vegas Valley Water District

COOPERATIVE WATER PROJECT
Water for Nevada's Future
Report No. 7

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# EXECUTIVE SUMMARY

In this study, an evaluation of the Maxey-Eakin method for calculating recharge to ground-water basins in Nevada was performed. The evaluation consisted of comparing Maxey-Eakin estimates with independent estimates of recharge, and analyzing the nature of the differences between the groups of estimates. In the comparison with the Maxey-Eakin estimates, two different groups of independent estimates were used: (1) 40 recharge estimates that were identified from water budgets contained in reports by the State of Nevada, and (2) 27 recharge estimates that were identified from previous studies that used models.

The results of the comparisons indicate generally good agreement between the Maxey-Eakin estimates and both groups of independent estimates. To quantify this agreement, an analysis was conducted to estimate the uncertainty in the Maxey-Eakin method. The analysis produced an upper bound on the standard deviation of the Maxey-Eakin estimate for a given basin. For the group of 40 water-budget estimates, the upper bound on the standard deviation for an individual basin is 4,800 acre-ft/yr, and the corresponding coefficient of variation of the Maxey-Eakin estimate is no greater than 44 percent. For the group of 27 model estimates, the upper bound on the standard deviation is 4,300 acre-ft/yr, and the corresponding coefficient of variation is no greater than 25 percent.

A similar analysis of uncertainty was performed for 20 basins in which the District is applying for the appropriation of ground water. This analysis showed that, for a total Maxey-Eakin recharge estimate of 224,000 acre-ft/yr, an upper bound on the standard deviation of this estimate is 21,500 acre-ft/yr. The corresponding coefficient of variation of the total Maxey-Eakin estimate is no greater than 10 percent, which as expected illustrates that the uncertainty in the Maxey-Eakin method decreases as more basins are included in the computation.

The conclusion from this study, that the Maxey-Eakin method is a fairly reliable predictor, is in contrast to previous work by Watson and others (1976). Watson and others (1976) performed multiple-linear regressions to determine the individual Maxey-Eakin coefficients based on using water-budget discharges as the dependent variables. The Maxey-Eakin method was then judged based on the confidence interval associated with each individual Maxey-Eakin coefficient computed by regression. It is argued here that this statistical approach is not appropriate for evaluating the predictive reliability of the Maxey-Eakin method.

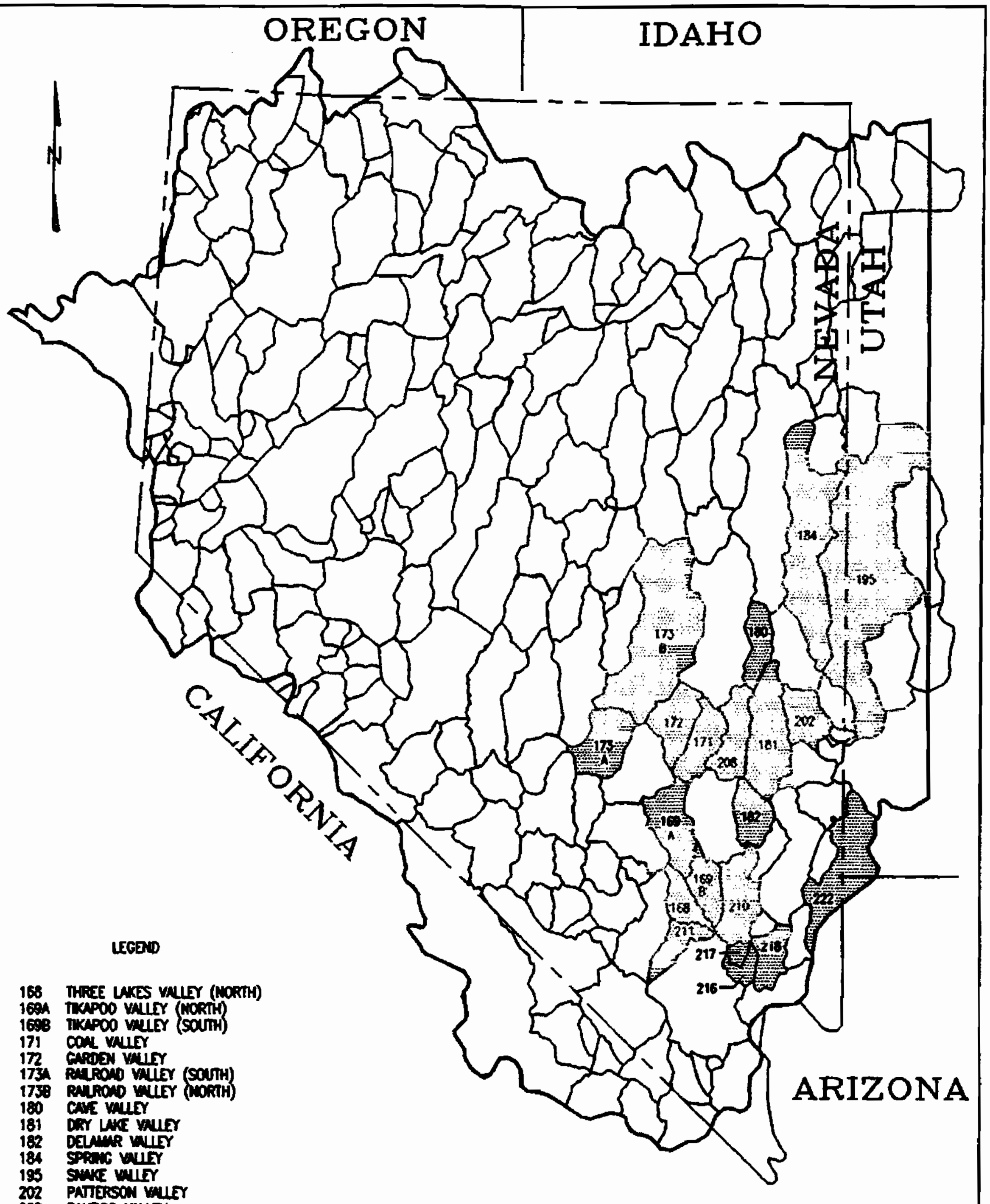
## 1.0 INTRODUCTION

This report presents an evaluation of the Maxey-Eakin method for calculating recharge to ground-water basins in Nevada. The Maxey-Eakin method, developed between 1947 and 1951, has been the primary method of recharge estimation used by the State of Nevada in its reconnaissance studies of ground-water resources. The method consists of an empirically-derived relationship between precipitation and recharge to a ground-water basin.

The primary objective of this study was to evaluate the Maxey-Eakin method by comparing Maxey-Eakin recharge estimates to ground-water discharge estimates that were independently derived using other methods. Several steps were necessary to accomplish this. First, Maxey-Eakin estimates for ground-water basins in Nevada were identified from two series of reports by the State of Nevada, Department of Conservation and Natural Resources: the Ground-Water Resources Reconnaissance Series and the Water-Resources Bulletins. Second, independent estimates of discharge or recharge for the same basins were identified wherever possible. Sources for these estimates included the state reports, publications of the U.S. Geological Survey, university publications, and journal articles. Criteria were developed in order to screen the data set for rejection of unsuitable estimates. Finally, the pairs of estimates were statistically evaluated to characterize the nature of the differences between the Maxey-Eakin recharge estimates and the independent estimates.

A second objective of the work was to evaluate the uncertainty in the Maxey-Eakin recharge estimates reported for 20 basins in eastern and southern Nevada. This set of valleys is of interest because the Las Vegas Valley Water District (District) filed for the appropriation of ground water and, in one case, surface water in these basins. The locations of these basins are shown in Figure 1.

The approach taken in this study has some similarities with an evaluation of the Maxey-Eakin method performed by Watson and others (1976). A similar screening procedure was used to identify suitable estimates of recharge. However, there are some significant differences in the



LEGEND

|  |  |
|---|---|
| 168 | THREE LAKES VALLEY (NORTH) |
| 169A | TIKAPOO VALLEY (NORTH) |
| 169B | TIKAPOO VALLEY (SOUTH) |
| 171 | COAL VALLEY |
| 172 | GARDEN VALLEY |
| 173A | RAILROAD VALLEY (SOUTH) |
| 173B | RAILROAD VALLEY (NORTH) |
| 180 | CAVE VALLEY |
| 181 | DRY LAKE VALLEY |
| 182 | DELAMAR VALLEY |
| 184 | SPRING VALLEY |
| 195 | SNAKE VALLEY |
| 202 | PATTERSON VALLEY |
| 208 | PAHROC VALLEY |
| 210 | COYOTE SPRING VALLEY |
| 211 | THREE LAKES VALLEY (SOUTH) |
| 216 | GARNET VALLEY |
| 217 | HIDDEN VALLEY (NORTH) |
| 218 | CALIFORNIA WASH |
| 222 | VIRGIN RIVER VALLEY |

EXPLANATION

—— HYDROGRAPHIC-AREA BOUNDARY (Numbers correspond to those used by Harrill and others-1988).

— — — STATE BOUNDARY

—— STUDY AREA BOUNDARY

0 100 200 miles

SCALE

|  |  |
|---|---|
| JOB NO. HCI-573 | DATE: 9-04-92 |
| BY: LA | DRAWN: DDG |
| CHKD: | REV: |

HCI HYDROLOGIC CONSULTANTS, INC.

MAP SHOWING LOCATION OF THE 20 BASINS IN WHICH THE DISTRICT HAS APPLIED FOR WATER RIGHTS

FIGURE 1

two analyses. In this study nearly 20 years later, a broader literature survey was conducted and more recent recharge estimates were included, resulting in a different and more comprehensive data base. In addition, different techniques of statistical analysis were used, resulting in conclusions that are different from those in the earlier evaluation.

## 2.0 GENERAL METHODS FOR ESTIMATING RECHARGE

Several authors have provided comprehensive reviews of the various methods for estimating ground-water recharge (Lerner and others, 1990; Simmers, 1988; Wilson and others, 1980). A brief review is given in Watson and others (1976). Following is a summary of the principal methods for estimating recharge.

### 2.1 DIRECT MEASUREMENT

The only direct way to measure recharge flux is by using lysimeters installed into the vadose zone. The lysimeters actually measure the change in water content at various depths within the soil zone. These data, along with an estimate of vertical permeability, are used to calculate the recharge to the soil block. Lerner and others (1990) note that lysimeters are better suited to humid rather than semi-arid climates. In arid and semi-arid regions, precipitation tends to be highly variable, and thus a long period of measurement is necessary to estimate average recharge. Furthermore, uncertainty in the recharge estimate occurs due to uncertainty in the assumed permeability value.

### 2.2 GROUND-WATER BUDGET METHODS

A general water budget for any ground-water basin can be defined as follows:

$$R = Q_{OUT} - Q_{IN} + ET + \Delta S \tag{1}$$

where

$R$ = ground-water recharge,

$ET$ = evapotranspiration from ground water,

$Q_{IN}$ = ground-water inflow into basin,

$Q_{OUT}$ = ground-water outflow from basin, and

$\Delta S$ = change in ground-water storage within the basin.

Water-budget methods for estimating ground-water recharge can be broadly defined as all methods that estimate the components of the water budget on the right side of Equation 1. Determination of all the components of the water budget requires the collection of a large amount of data. In practice, various terms of the budget are estimated, and the uncertainty in these terms produces uncertainty in the recharge estimate. The various terms of the water budget are commonly estimated as follows:

- Evapotranspiration (ET) is estimated by mapping areas of phreatophytes and playas from which ground water evaporates, applying an accepted use rate, and calculating consumption of ground water. In the Great Basin region, ET is usually a large component of the total discharge. Accordingly, this technique for estimating ET has been widely used in developing water budgets for basins within Nevada.

- Ground-water inflow or outflow is often estimated using Darcy's Law in a form commonly known as the TIW method, where the ground-water flux is calculated from the product of the transmissivity (T), the horizontal hydraulic gradient (I), and the cross-sectional width (W) through which flow occurs. Values for T and I are often assumed where no data are available.

- Changes in ground-water storage can be estimated from water-level fluctuations measured in wells. Water-level data are used with an estimate of the storage coefficient to calculate the change in the volume of storage. However, in developing a water budget, it is frequently assumed that the basin is in hydrologic equilibrium so that total recharge is equal to total discharge, and there is no change in storage.

Numerical ground-water flow models have been used to estimate ground-water recharge or to refine earlier estimates of recharge. This type of analysis can be considered a water-budget method, since the models produce a balance of ground-water inflows with outflows and change in ground-water storage.

Mathematical models of soil-moisture infiltration may also be used to estimate ground-water recharge. This type of analysis can also be considered a water-budget method, since the models produce a soil-moisture balance. Such models may vary in the degree to which they simulate physical infiltration processes in the unsaturated zone. Water-budget type models partition precipitation at the land surface into evapotranspiration, runoff, recharge, and change in storage using simplified representations of physical processes. More sophisticated models simulate the infiltration of soil moisture using Richard's equation for unsaturated flow (Freeze and Cherry, 1979).

## 2.3 GEOCHEMICAL MASS BALANCE METHODS

Estimates of recharge to ground water can be obtained using environmental tracers such as chloride, deuterium, tritium, or oxygen-18. A mass balance principal is used to compare the total quantity of tracer input from precipitation in recharge areas to tracer concentrations in the ground water. Application of this basic technique to basins in Nevada has been performed by Dettinger (1989) using chloride, and by Kirk and Campana (1990) using deuterium.

Chemical mass balance methods have been widely used for recharge estimation in arid and semi-arid areas (Lerner and others, 1990). Dettinger (1989) provides a discussion of the assumptions underlying the chemical-balance method and describes some potential sources of error.

## 2.4 EMPIRICAL METHODS

Empirical methods involve developing a correlation between recharge and other variables such as precipitation, elevation, or temperature. Such relationships are derived from the study of a basin or group of basins, and then applied to estimate recharge in other basins that are assumed to have similar characteristics. The simplest form of an empirical relationship assumes recharge $R$ is a proportion of precipitation $P$ (Lerner and others, 1990):

$$R = f(P) \tag{2}$$

where the function $f$ will depend on terrain and climate. More complex relationships may include a threshold value for precipitation, below which there is no recharge, may be non-linear, or may include dependence on other factors. An advantage of such empirical relationships is that once developed, they are easy to use. However, Lerner and others (1990) stress the importance of verifying the accuracy of the method by checking against independent estimates.

The remainder of this report will focus on one type of empirical method, the Maxey-Eakin method. This method consists of an empirical relationship between precipitation and recharge, which has been applied throughout Nevada. In accordance with conclusions reached by Lerner and others (1990), this report compares Maxey-Eakin estimates to independent estimates of recharge.

## 3.0 MAXEY-EAKIN METHOD

### 3.1 DEFINITION

The Maxey-Eakin method for estimating recharge to a ground-water basin was developed by G. B. Maxey and T. E. Eakin between 1947 and 1951 and has been applied to over 200 basins in Nevada and also in other western states. In brief, the Maxey-Eakin method consists of (1) estimating the mean annual volumes of precipitation within several precipitation zones for the drainage basin, (2) scaling these volumes by a factor representing losses from evapotranspiration and surface-water runoff that does not become ground-water recharge, and (3) summing the resulting recharge volumes to obtain an estimate of total recharge to the ground-water basin.

Watson and others (1976) review the development of the Maxey-Eakin method. In Water-Resources Bulletin 8 (1949), Maxey and Eakin delineate the precipitation zones used in the method, based on a map of precipitation in Nevada by Hardman (1936). According to Water-

Resources Bulletin 8, discharge data for 13 valleys in east-central Nevada were used to determine the recharge percentages by trial-and-error balancing of recharge with estimated ground-water discharges. Watson and others (1976) report that a total of 21 valleys (see Figure 2) was ultimately used in the development of the method, based on Water-Resources Bulletins 8 and 12, and on personal communication with Maxey. Table 1 shows the precipitation zones, referred to by Watson and others (1976) as Hardman zones, and the corresponding recharge coefficients that were developed by Maxey and Eakin. Accordingly, calculation of the Maxey-Eakin recharge for a given basin can be expressed mathematically as:

$$ME = \sum_{i=1}^{5} a_i P_i \tag{3}$$

where

$ME$ = Maxey-Eakin recharge for a basin,

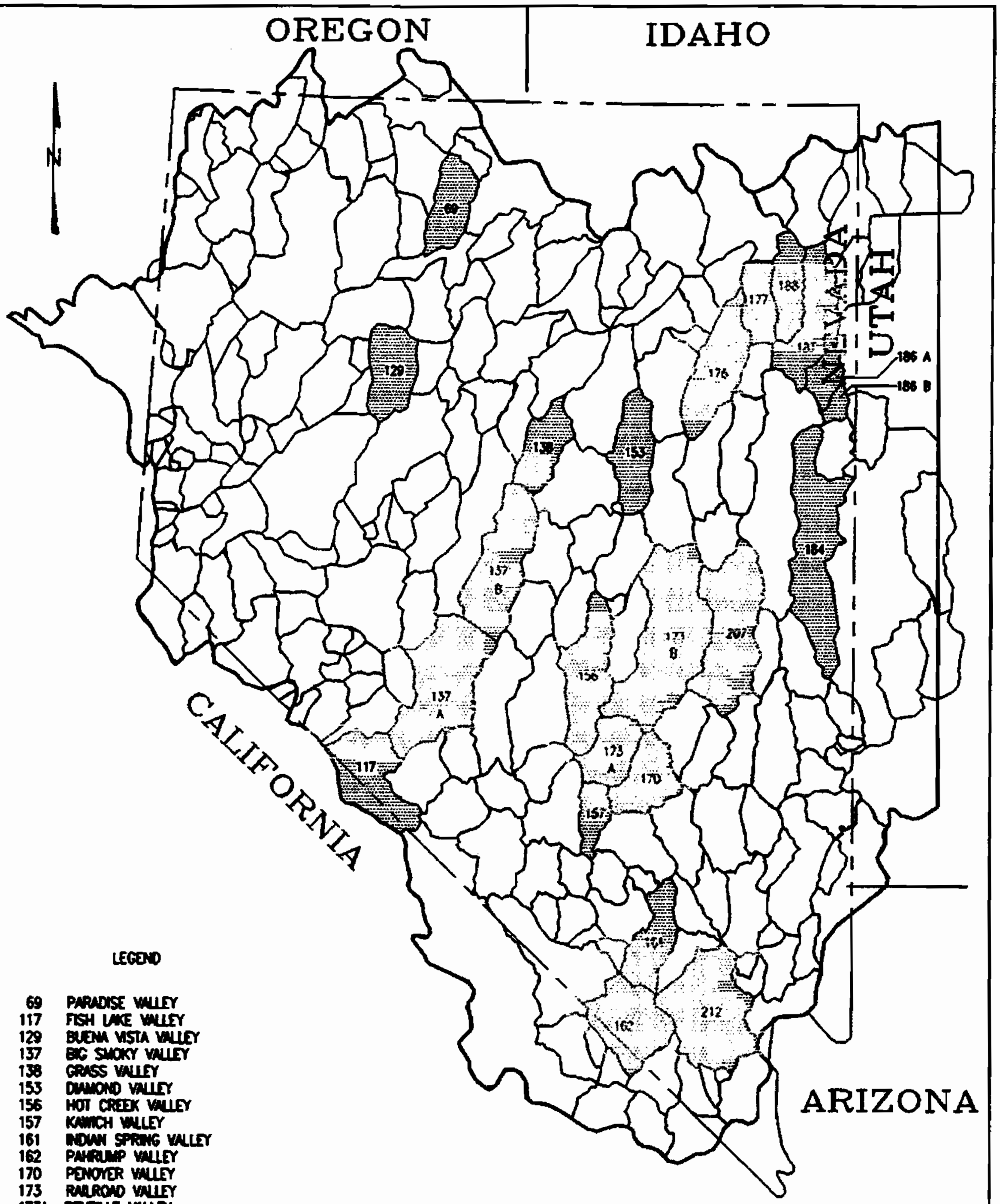
$P_i$ = volume of precipitation within each of the five Hardman zones, and

$a_i$ = recharge coefficient for each of the five Hardman zones.

### TABLE 1
### PRECIPITATION ZONES AND CORRESPONDING COEFFICIENTS FOR THE MAXEY-EAKIN METHOD

| Precipitation Zone | Maxey-Eakin Coefficient (%) |
|---|---|
| >20 in. | 25 |
| 15-20 in | 15 |
| 12-15 in. | 7 |
| 8-12 in. | 3 |
| <8 in. | 0 |

References: Water Resources Bulletin No. 8 (Maxey and Eakin, 1949), p.40.
Water Resources Bulletin No. 12 (Eakin and others, 1951), p. 80-81.



LEGEND

| | |
|---|---|
| 69 | PARADISE VALLEY |
| 117 | FISH LAKE VALLEY |
| 129 | BUENA VISTA VALLEY |
| 137 | BIG SMOKY VALLEY |
| 138 | GRASS VALLEY |
| 153 | DIAMOND VALLEY |
| 156 | HOT CREEK VALLEY |
| 157 | KAWICH VALLEY |
| 161 | INDIAN SPRING VALLEY |
| 162 | PAHRUMP VALLEY |
| 170 | PENOYER VALLEY |
| 173 | RAILROAD VALLEY |
| 173A | REVEILLE VALLEY* |
| 176 | RUBY VALLEY |
| 177 | CLOVER VALLEY |
| 184 | SPRING VALLEY |
| 186 | ANTELOPE VALLEY |
| 187 | GOSHUTE VALLEY |
| 188 | INDEPENDENCE VALLEY |
| 207 | WHITE RIVER VALLEY |
| 212 | LAS VEGAS VALLEY |

* subarea within Railroad Valley South

SOURCE: Watson and others (1976)

EXPLANATION

| | |
|---|---|
| ——— | HYDROGRAPHIC-AREA BOUNDARY (Numbers correspond to those used by Harrill and others-1988). |
| — — — | STATE BOUNDARY |
| ━━━ | STUDY AREA BOUNDARY |

0 100 200 miles

SCALE

| | |
|---|---|
| JOB NO. HCI-573 | DATE: 9-04-92 |
| BY: LA | DRAWN: DDG |
| CHKD: | REV: |

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MAP SHOWING LOCATION OF THE 21 BASINS USED IN DEVELOPING THE MAXEY-EAKIN METHOD

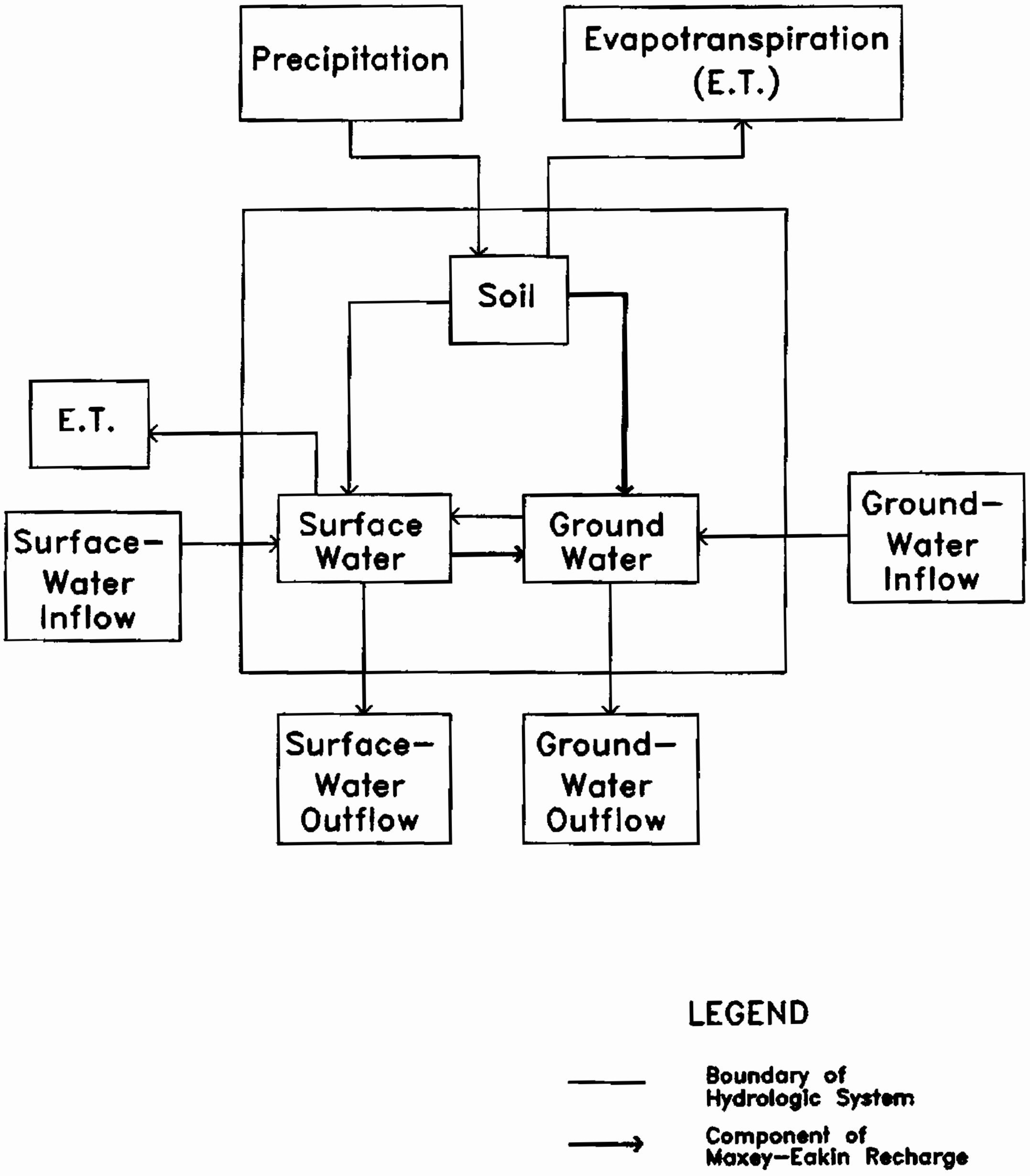
FIGURE 2

A schematic depiction of the Maxey-Eakin recharge is given in the water budget shown in Figure 3. Virtually all of the ground-water recharge to a basin originates as precipitation in the mountains. Some of that precipitation is lost to evapotranspiration, some infiltrates directly into the ground water, and some becomes surface-water runoff. Runoff from the mountains onto the alluvial fans provides an additional source of recharge to the ground-water basin. The bold arrows in Figure 3 indicate these two components of the Maxey-Eakin ground-water recharge.

In understanding the Maxey-Eakin method, it is important to note that it is a direct relationship between precipitation and recharge, and not a direct relationship between elevation and recharge. Elevation is important only insofar as it is used to estimate the precipitation within each of the five precipitation zones delineated by Maxey and Eakin. The relationship between precipitation and elevation varies across the state of Nevada, depending on geography and climatic conditions. For example, the 12- to 15-inch zone of precipitation falls between 6,000 and 7,000 ft elevation in the San Emidio Desert area (Reconnaissance Report 44), 7,000 and 8,000 ft elevation in Edwards Creek Valley (Reconnaissance Report 26), and 8,000 and 9,000 ft elevation in the Sarcobatus Flat area (Reconnaissance Report 54). All that is required to apply the Maxey-Eakin method is an estimate of the total volume of precipitation within each of precipitation zones shown in Table 1. Determination of the appropriate precipitation-elevation relationship does have an impact on the accuracy of the estimate of the volume of precipitation within each Hardman zone, but an evaluation of the precipitation-elevation relationships used is not within the scope of this report.

## 3.2 APPLICATION

As defined by Maxey and Eakin (Water-Resources Bulletins 8 and 12), the empirical method for calculating recharge is straightforward. However, variations in the method are apparent in its application to basins across Nevada. In the Reconnaissance Reports and Water-Resources Bulletins, both the percentages of recharge applied to each precipitation zone and the estimates of precipitation within each zone have sometimes been adjusted. The adjustments were



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Generalized Water Budget for a Ground-Water Basin.

FIGURE 3

presumably made to achieve a better balance between estimates of recharge and estimates of ground-water discharge when it was judged that the discharge estimates were more accurate.

This unevenness in the application of the Maxey-Eakin method introduces complexity into the evaluation process. In this report, as in Watson and others (1976), the "standard" Maxey-Eakin method is defined as in Table 1. Accordingly, arbitrary variations of the method were identified in this analysis. The following section describes in detail the criteria used for screening such "non-standard" Maxey-Eakin estimates.

## 4.0 APPROACH USED TO EVALUATE MAXEY-EAKIN METHOD

The general approach used to evaluate the Maxey-Eakin method involved identifying independent estimates of ground-water recharge to compare with the Maxey-Eakin estimates. In order to compile the data base of estimates, three distinct stages of screening were performed. First, reports by the State of Nevada were reviewed to identify usable Maxey-Eakin recharge estimates. Second, independent estimates of ground-water discharge were identified from these reports, where these discharges were compared to the Maxey-Eakin recharge estimates within a ground-water budget. Third, independent estimates of recharge derived from modeling studies were compiled. The following sections describe each of these procedures.

### 4.1 SCREENING OF MAXEY-EAKIN ESTIMATES

Maxey-Eakin estimates of recharge within ground-water basins in Nevada are contained within two series of reports published by the State of Nevada, Department of Conservation and Natural Resources: the Ground-Water Reconnaissance Series, a series of 60 reports written between 1960 and 1974, and the Water-Resources Bulletins, which include 44 reports produced between 1946 and 1976. A total of 233 Maxey-Eakin estimates were collected from these reports. However, because of various reasons, some of the recharge estimates were considered potentially unusable in the analysis. The estimates were organized into a computer worksheet, and the following criteria were used to classify the estimates. The categories are similar, but not entirely coincident, with those developed by Watson and others (1976). The number in brackets after each category corresponds to the total number of estimates in that group.

0. A "standard" Maxey-Eakin estimate, as defined in Table 1, was identified and calculations were given in the report. [146]

1. The Hardman zones for precipitation were not developed (and recharge was not computed) or the zones were inconsistent with those normally used (see Table 1). [26]

2. The water table or capillary fringe was thought to be too close to the ground surface to allow for significant infiltration. Therefore, the Maxey-Eakin method was not applied. [3]

3. The Maxey-Eakin coefficients were changed from the standard values of 25, 15, 7, 3, and 0 percent. Common cases in which this occurred include (1) when precipitation was judged to be less than the Hardman zones indicated, and the Maxey-Eakin coefficients were reduced, and (2) when ground-water recharge was judged to be small because of great depth to the water table. [13]

4. Earlier or duplicate estimate for a valley was discovered. When two differing estimates for a valley were found, the most recent estimate was used. [14]

5. In computing the Maxey-Eakin recharge, values were rounded significantly or an error was made in the calculation, resulting in a greater than 10 percent difference between the computed and the reported values. [16]

6. An estimate reportedly based on the Maxey-Eakin method is given, but no calculations were supplied. [15]

The results show a total of 146 estimates that can be considered as "standard" applications of the Maxey-Eakin method, and 87 estimates that represent deviations from standard application of the method. A listing of the basins that were screened and their corresponding classification numbers from the above list is contained within Appendix A.

## 4.2 SCREENING OF WATER-BUDGET ESTIMATES

The second level of screening that was performed was to review the Reconnaissance Reports and Water-Resources Bulletins to identify independent estimates of recharge from the ground-water budgets contained within these reports. In basins in which no change in storage could be assumed, estimates of ground-water discharge were identified from the water budgets, and these estimates were taken as independent estimates of recharge. In a few cases, revisions of the ground-water budgets contained within the State publications were reported elsewhere, e.g. in publications by the U.S. Geological Survey, or in journal articles. In these cases, the revised discharge estimates were used for comparison with the Maxey-Eakin recharge estimates.

As with the screening of the Maxey-Eakin recharge estimates, a classification system was developed in order to screen the discharge estimates. Following are the categories that were used, where the number in brackets after each category refers to the total number of estimates within that group.

0. Water-budget estimate of discharge is usable as an independent estimate of recharge. [56]
1. Estimate is for a subarea within a major basin that could not be used individually because only the total discharge for the major basin was given. [31]
2. Component(s) of the ground-water budget were determined by difference. Thus, the estimate of discharge is not independent of the Maxey-Eakin recharge. [64]
3. Ground-water inflow or outflow exists but was not estimated. [23]
4. Ground-water inflow was estimated by an analog model, and the results are considered as provisional. [1]
5. Ground-water discharge from within the basin cannot be separated out from the total discharge, i.e., both surface water and ground water. [6]
6. A major river flows through the valley, and surface-water inflow and outflow dominate the water budget in comparison to ground-water recharge and discharge within the basin. Therefore, mainstem areas were rejected. [26]

7. Evapotranspiration by phreatophytes occurs but was not estimated and included in the discharge estimate. [1]

8. Evaporation from playas, which is either unreliably estimated or not estimated, is a significant portion of the total discharge. [2]

9. Uncertainty in the water budget results from transient interactions between a lake and ground water. Examples are: (1) lake desiccation that results from depletion of ground-water storage, and (2) lowering of lake water levels, which affects ground-water storage. [4]

10. Either an earlier estimate that was later revised, or a duplicate of an estimate reported elsewhere. [9]

11. Discharge estimate was reported, but no Maxey-Eakin recharge was computed, or Maxey-Eakin calculation found to be erroneous. [6]

12. No water budget was reported. [2]

The results of this screening process indicated that, of the 229 water budgets reviewed, 56 estimates of discharge were usable as independent estimates of recharge. Appendix A gives a complete listing of each basin and the corresponding classification of the discharge estimate for that basin.

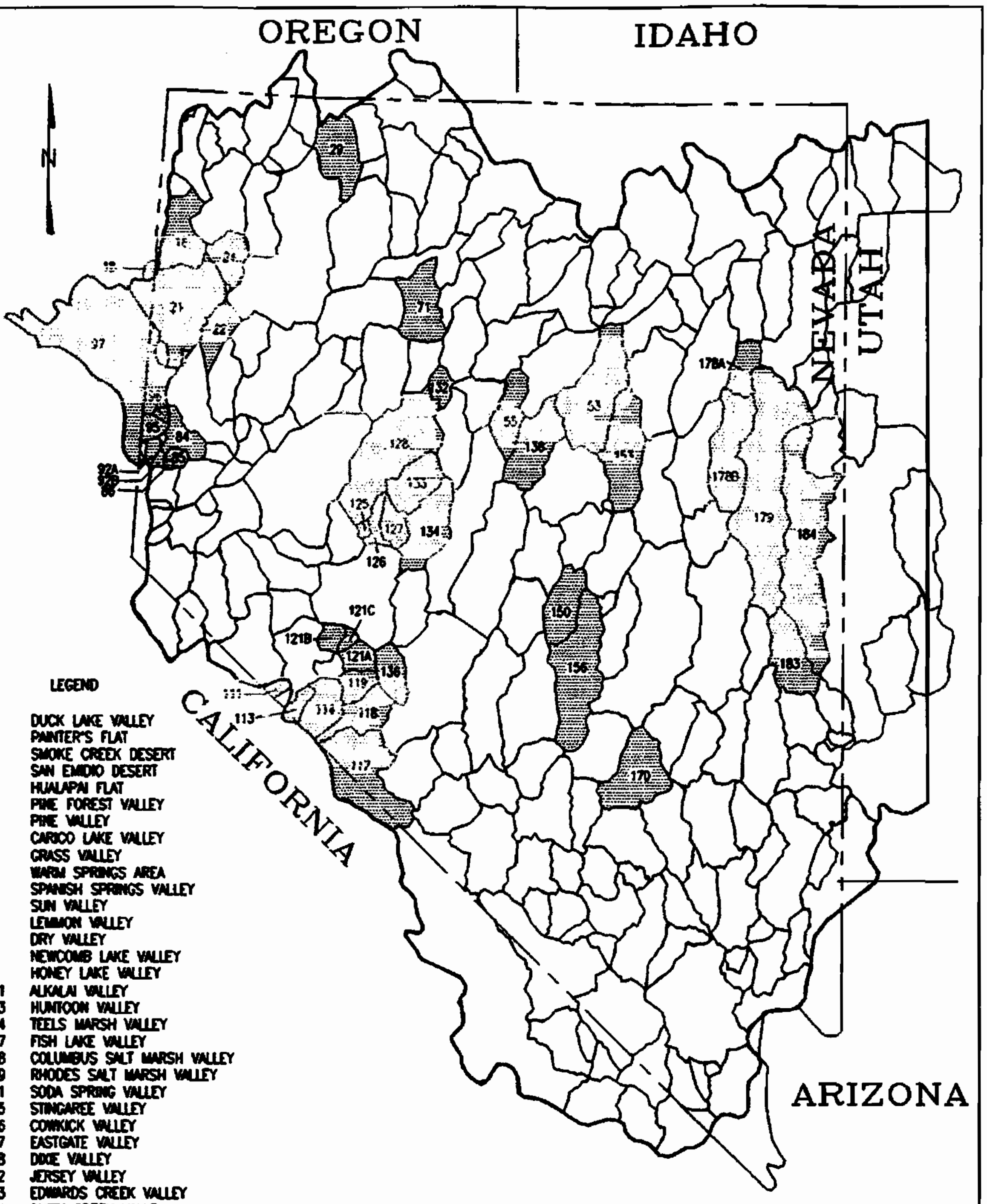
Potential bias may exist within this group of estimates, however, because the methods historically used to develop the water budgets may have a subjective component that is not easily identified from the State reports. In certain cases, knowledge about the discharge may have been considered in developing a Maxey-Eakin recharge estimate. This is what probably resulted in the various "non-standard" applications of the Maxey-Eakin method. Arguably, the set of 56 estimates should be reduced by the number that have "non-standard" Maxey-Eakin recharge estimates, since adjustment of the Maxey-Eakin method may have reduced the difference between the Maxey-Eakin estimates and the discharge estimates. Of the 56 discharge estimates, 16 have corresponding Maxey-Eakin recharge values that were computed in a non-standard way. Removing these 16 estimates leaves the 40 estimates listed in Table 2. These 40 independent estimates of discharge that are derived from water budgets will be referred to as the "budget estimates" throughout the remainder of the report. The locations of the basins for the 40 budget estimates are shown in Figure 4. A comparison with Figure 2 shows that six of these basins are in the set that was reportedly used to develop the Maxey-Eakin method.

## TABLE 2
## LIST OF THE 40 WATER-BUDGET ESTIMATES OF RECHARGE

| Hydrographic Area | BASIN | MAXEY-EAKIN RECHARGE (AC-FT/YR) | WATER-BUDGET DISCHARGE (AC-FT/YR)[1] | SOURCE[2] |
|---|---|---|---|---|
| 16 | DUCK LAKE | 9000 | 7000 | R17 |
| 18 | PAINTERS FLAT | 1300 | 1200 | R44 |
| 21 | SMOKE CREEK DESERT | 13000 | 18620 | R44 |
| 22 | SAN EMIDIO DESERT | 2100 | 3200 | R44 |
| 24 | HUALAPAI FLAT | 7000 | 6700 | R11,B37 |
| 29 | PINE FOREST | 10000 | 14100 | R4 |
| 53 | PINE | 45500 | 24000 | R2,B32 |
| 55 | CARICO LAKE | 4300 | 4500 | R37 |
| 71 | GRASS (HUMBOLDT) | 12000 | 16800 | R29,B32 |
| 84 | WARM SPRINGS | 6000 | 2000 | R43 |
| 85 | SPANISH SPRINGS | 600 | 1000 | R43 |
| 86 | SUN | 50 | 25 | R43 |
| 92 | LEMMON | 1800 | 900 | R43 |
| 95 | DRY | 2400 | 2300 | R43 |
| 96 | NEWCOMB LAKE | 300 | 130 | R43 |
| 97 | HONEY LAKE (E ONLY) | 1500 | 10500 | R43 |
| 111 | ALKALI N | 400 | 300 | R52 |
| 113 | HUNTOON | 800 | 300 | R52 |
| 114 | TEELS MARSH | 1300 | 1400 | R52 |
| 117 | FISH LAKE | 33000 | 27000 | R58 |
| 118 | COLUMBUS SALT MARSH | 700 | 3800 | R52 |
| 119 | RHODES SALT MARSH | 500 | 600 | R52 |
| 121 | SODA SPRING E | 600 | 700 | R52 |
| 121 | SODA SPRING W | 100 | -270 | R52 |
| 125-127 | EASTGATE, COWKICK, STINGAREE | 6000 | 6000 | R23 |
| 128 | DIXIE | 6000 | 9200 | R23 |
| 132 | JERSEY | 800 | 800 | R23 |
| 133 | EDWARDS CREEK | 8000 | 7600 | R26 |
| 134 | SMITH CREEK | 9600 | 7000 | R28,P1409E |
| 136 | MONTE CRISTO | 500 | 400 | R52 |
| 138 | GRASS (LANDER) | 13000 | 13000 | R37 |
| 150 | LITTLE FISH LAKE | 11000 | 10000 | R38 |
| 153 | DIAMOND total | 21000 | 21000 | R6, B35 |
| 156 | HOT CREEK | 7000 | 6100 | R38 |
| 170 | PENOYER | 4300 | 3800 | R60 |
| 178 | BUTTE S | 15000 | 12000 | R49 |
| 178 | BUTTE N | 3900 | 8700 | R49 |
| 179 | STEPTOE | 85000 | 70000 | R42 |
| 183 | LAKE | 13000 | 11500 | R24 |
| 184 | SPRING | 75000 | 74000 | R33 |

[1] Ground-water discharges are adjusted by removing any additional ground-water inflows reported in the water budget, allowing comparison with Maxey-Eakin recharge.

[2] R = Reconnaissance Report, Nevada Department of Conservation and Natural Resources
B = Water-Resources Bulletin, Nevada Department of Conservation and Natural Resources
P = U.S. Geological Survey Professional Paper



LEGEND

| | |
|---|---|
| 16 | DUCK LAKE VALLEY |
| 18 | PAINTER'S FLAT |
| 21 | SMOKE CREEK DESERT |
| 22 | SAN EMIDIO DESERT |
| 24 | HUALAPAI FLAT |
| 29 | PINE FOREST VALLEY |
| 53 | PINE VALLEY |
| 55 | CARICO LAKE VALLEY |
| 71 | GRASS VALLEY |
| 84 | WARM SPRINGS AREA |
| 85 | SPANISH SPRINGS VALLEY |
| 86 | SUN VALLEY |
| 92 | LEMMON VALLEY |
| 95 | DRY VALLEY |
| 96 | NEWCOMB LAKE VALLEY |
| 97 | HONEY LAKE VALLEY |
| 111 | ALKALAI VALLEY |
| 113 | HUNTOON VALLEY |
| 114 | TEELS MARSH VALLEY |
| 117 | FISH LAKE VALLEY |
| 118 | COLUMBUS SALT MARSH VALLEY |
| 119 | RHODES SALT MARSH VALLEY |
| 121 | SODA SPRING VALLEY |
| 125 | STINGAREE VALLEY |
| 126 | COWKICK VALLEY |
| 127 | EASTGATE VALLEY |
| 128 | DIXIE VALLEY |
| 132 | JERSEY VALLEY |
| 133 | EDWARDS CREEK VALLEY |
| 134 | SMITH CREEK VALLEY |
| 136 | MONTE CRISTO VALLEY |
| 138 | GRASS VALLEY |
| 150 | LITTLE FISH LAKE VALLEY |
| 153 | DIAMOND VALLEY |
| 156 | HOT CREEK VALLEY |
| 170 | PENOYER VALLEY |
| 178A | BUTTE VALLEY (NORTH) |
| 178B | BUTTE VALLEY (SOUTH) |
| 179 | STEPTOE VALLEY |
| 183 | LAKE VALLEY |
| 184 | SPRING VALLEY |

EXPLANATION

——— HYDROGRAPHIC-AREA BOUNDARY (Numbers correspond to those used by Harrill and others–1988).

— — — STATE BOUNDARY

——— STUDY AREA BOUNDARY

0 100 200 miles

SCALE

| | |
|---|---|
| JOB NO. HCI-573 | DATE: 9-04-92 |
| BY: LA | DRAWN: DDG |
| CHKD: | REV: |

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MAP SHOWING LOCATION OF BASINS
FOR THE 40 BUDGET ESTIMATES

FIGURE
4

## 4.3 SCREENING OF MODEL ESTIMATES

The third stage in gathering the data base used in the analysis was to conduct a general literature review to identify other independent estimates of ground-water recharge for basins within Nevada. Sources for the estimates collected included U.S. Geological Survey reports, publications of the Desert Research Institute of the University of Nevada, and scholarly articles. A total of 27 independent estimates of recharge that were derived from techniques other than water budgeting were identified during this process. The methods used to derive these recharge estimates include the following, where the numbers in brackets refer to the total number of estimates:

- Chloride mass balance [12],
- Deuterium-calibrated mixing-cell flow model [11],
- Numerical ground-water flow models [3], and
- Infiltration model [1].

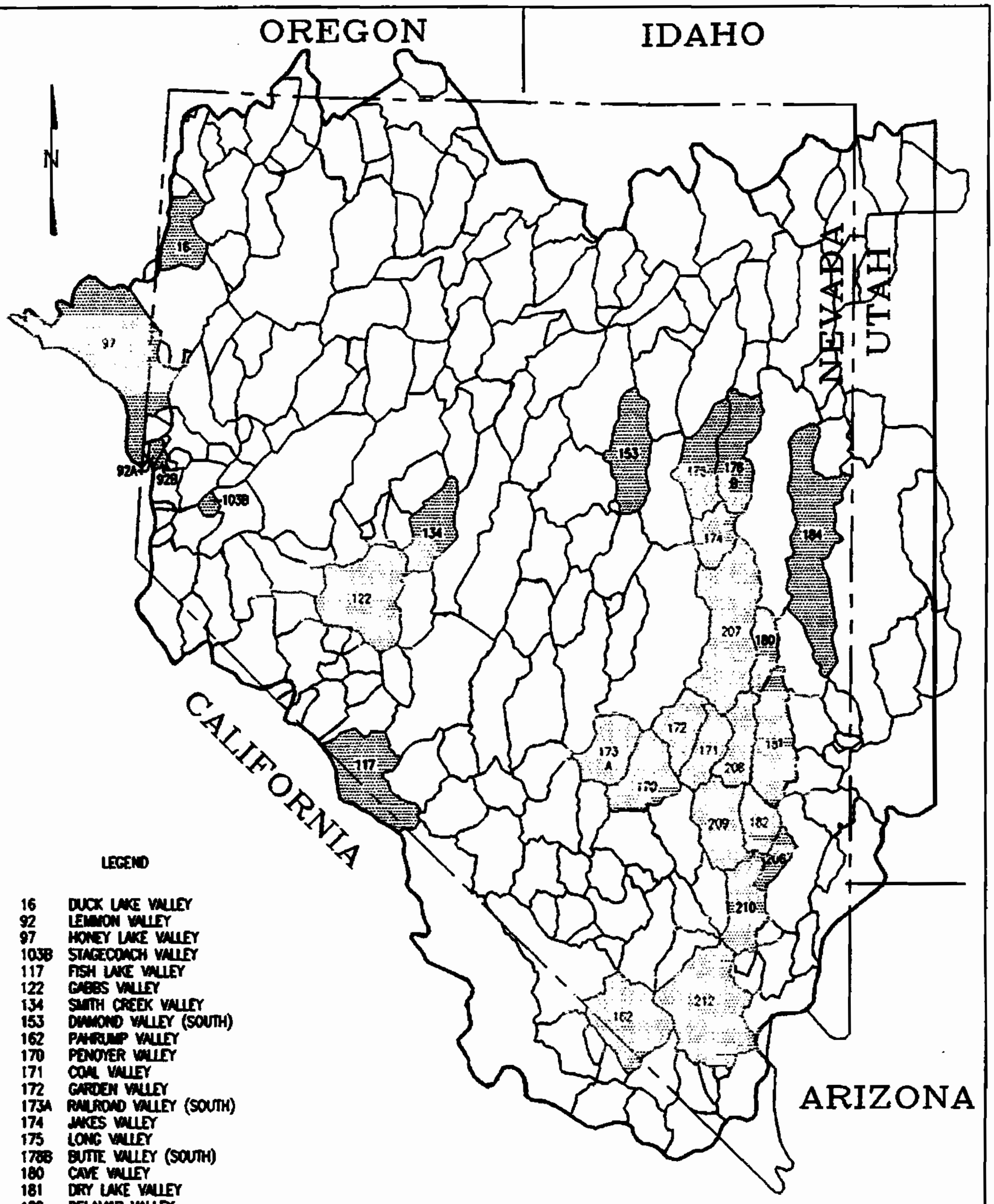
Because most of these estimates were obtained using models, this group of 27 estimates will be referred to as the "model estimates." The 27 model estimates are listed in Table 3, and Figure 5 shows the locations of the basins for the group. Each of the types of model estimates is discussed briefly below.

The 12 chloride mass balance estimates of recharge were reported in two publications (Dettinger, 1989; Thomas and others, 1989). In Dettinger's study, a total of 16 estimates were derived. However, only 11 of the estimates were used in this analysis. The estimates in three basins (N. Butte, Mesquite, and N. Railroad) were excluded based on a discussion of their recharge estimates by Dettinger (1989). Dettinger noted that the chloride balance estimates in these basins may be inaccurate because subsurface inflows that were not considered may have resulted in an underestimate of recharge. Therefore, these three estimates were rejected. An additional estimate (for Independence Valley) was rejected because there was no documented Maxey-Eakin recharge estimate with which to compare it. Finally, one of the estimates (for Upper Reese

# TABLE 3. LIST OF THE 27 MODEL ESTIMATES OF RECHARGE

| HYDROGRAPHIC AREA | BASIN | MAXEY-EAKIN RECHARGE (AC-FT/YR) | MODEL ESTIMATED RECHARGE (AC-FT/YR) | TYPE OF ESTIMATE | SOURCE[1] |
|---|---|---|---|---|---|
| 16 | DUCK LAKE | 9000 | 9000 | chloride balance | Dettinger, JH 106 |
| 92 | LEMMON | 1800 | 1800 | chloride balance | Dettinger, JH 106 |
| 97 | HONEY LAKE total | 95000 | 99000 | infiltration model | Handman & others, WRIR 90-4050 |
| 97 | HONEY LAKE subarea | 17000 | 22200 | gw flow model | Handman & others, WRIR 90-4050 |
| 103B | STAGECOACH | 400 | 400 | chloride balance | Dettinger, JH 106 |
| 117 | FISH LAKE | 33000 | 27000 | chloride balance | Dettinger, JH 106 |
| 122 | GABBS | 5200 | 5200 | chloride balance | Dettinger, JH 106 |
| 134 | SMITH CREEK | 9600 | 8300 | chloride balance | Thomas & others, P1409E |
| 153 | DIAMOND S SUBAREA | 12000 | 10500 | chloride balance | Dettinger, JH 106 |
| 162 | PAHRUMP | 26000 | 37000 | gw flow model | Harrill, WSP-2279 |
| 170 | PENOYER | 4300 | 3200 | chloride balance | Dettinger, JH 106 |
| 171-172 | COAL/GARDEN | 12000 | 11000 | deuterium model | Kirk & Campana, JH 119 |
| 173 | RAILROAD S | 5500 | 5000 | chloride balance | Dettinger, JH 106 |
| 174 | JAKES | 17000 | 20700 | deuterium model | Kirk & Campana, JH 119 |
| 175 | LONG (WRFS) | 10000 | 1700 | deuterium model | Kirk & Campana, JH 119 |
| 178 | BUTTE (S) | 15000 | 12000 | chloride balance | Dettinger, JH 106 |
| 180 | CAVE | 14000 | 12000 | deuterium model | Kirk & Campana, JH 119 |
| 181 | DRY LAKE | 5000 | 6700 | deuterium model | Kirk & Campana, JH 119 |
| 182 | DELAMAR | 1000 | 1800 | deuterium model | Kirk & Campana, JH 119 |
| 184 | SPRING | 75000 | 62000 | chloride balance | Dettinger, JH 106 |
| 206 | KANE SPRINGS | 500 | 1000 | deuterium model | Kirk & Campana, JH 119 |
| 207 | WHITE RIVER | 38000 | 35000 | deuterium model | Kirk & Campana, JH 119 |
| 208 | PAHROC | 2200 | 2000 | deuterium model | Kirk & Campana, JH 119 |
| 209 | PAHRANAGAT | 1800 | 1500 | deuterium model | Kirk & Campana, JH 119 |
| 210 | COYOTE SPRINGS | 2100 | 5300 | deuterium model | Kirk & Campana, JH 119 |
| 212 | LAS VEGAS N ONLY | 28000 | 27600 | chloride balance | Dettinger, JH 106 |
| 212 | LAS VEGAS | 30000 | 30000 | gw flow model | B44 |

[1] Abbreviations:
JH = Journal of Hydrology
WRIR = U.S. Geological Survey Water-Resources Investigations Report
P = U.S. Geological Survey Professional Paper
WSP = U.S. Geological Survey Water-Supply Paper
B = Water-Resources Bulletin, Nevada Department of Conservation and Natural Resources



LEGEND

| | |
|---|---|
| 16 | DUCK LAKE VALLEY |
| 92 | LEMMON VALLEY |
| 97 | HONEY LAKE VALLEY |
| 103B | STAGECOACH VALLEY |
| 117 | FISH LAKE VALLEY |
| 122 | GABBS VALLEY |
| 134 | SMITH CREEK VALLEY |
| 153 | DIAMOND VALLEY (SOUTH) |
| 162 | PAHRUMP VALLEY |
| 170 | PENOYER VALLEY |
| 171 | COAL VALLEY |
| 172 | GARDEN VALLEY |
| 173A | RAILROAD VALLEY (SOUTH) |
| 174 | JAKES VALLEY |
| 175 | LONG VALLEY |
| 178B | BUTTE VALLEY (SOUTH) |
| 180 | CAVE VALLEY |
| 181 | DRY LAKE VALLEY |
| 182 | DELAMAR VALLEY |
| 184 | SPRING VALLEY |
| 206 | KANE SPRINGS VALLEY |
| 207 | WHITE RIVER VALLEY |
| 208 | PAHROC VALLEY |
| 209 | PAHRANAGAT VALLEY |
| 210 | COYOTE SPRING VALLEY |
| 212 | LAS VEGAS VALLEY |

EXPLANATION

| | |
|---|---|
| ——— | HYDROGRAPHIC-AREA BOUNDARY (Numbers correspond to those used by Harrill and others–1988). |
| — — — — | STATE BOUNDARY |
| ——— | STUDY AREA BOUNDARY |

0 100 200 miles

SCALE

| | |
|---|---|
| JOB NO. HCI-573 | DATE: 9-04-92 |
| BY: LA | DRAWN: DDG |
| CHKD: | REV: |

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**MAP SHOWING LOCATION OF BASINS FOR THE 27 MODEL ESTIMATES**

FIGURE 5

River Valley) was rejected because the corresponding Maxey-Eakin recharge estimate was computed in a non-standard way. In addition to the 11 estimates by Dettinger (1989), one chloride mass balance estimate was obtained for Smith Creek Valley from Thomas and others (1989).

Eleven independent estimates of recharge were derived using a deuterium-calibrated mixing-cell flow model of the White River Flow System in southeastern Nevada (Kirk and Campana, 1990). The model consists of an interconnected network of cells through which water and deuterium are routed. A two-layer hydrologic system was modeled, assuming a carbonate layer underlying an alluvial layer. Assumptions regarding the flow paths were made, and the model was calibrated using the spatial distribution of the deuterium isotope. Three slightly different flow scenarios were calibrated; however, a consistent set of recharge values was obtained. For this analysis, where a range of recharge values was reported by Kirk and Campana (1990), the mean recharge from the three scenarios was selected.

Three independent estimates of recharge were obtained from numerical ground-water flow models. The first estimate (Water-Resources Bulletin 44) was developed by simulating steady-state ground-water flow conditions in Las Vegas Valley. Recharge was one of the parameters calibrated in the model, along with transmissivity values, to match measured hydraulic heads. The second estimate (Harrill, 1986), for Pahrump Valley, was developed in a similar way. The third estimate (Handman and others, 1990) was obtained from a numerical ground-water flow model for a subarea within Honey Lake Valley. The recharge values initially selected for use in this model were derived from an infiltration model, but were adjusted during model calibration.

The study of Honey Lake Valley (Handman and others, 1990) provided a second independent estimate of recharge that was based on the results of an infiltration model. Direct infiltration of precipitation was estimated using a numerical model that determines the soil-moisture budget (evapotranspiration, runoff, and recharge) based on long-term data for precipitation, temperature, soil characteristics, and vegetative cover. Surface-water infiltration was separately estimated from streamflow data and added to the direct infiltration computed by the model to obtain an estimate of 99,000 acre-ft/yr for the total ground-water recharge to Honey Lake Valley.

## 5.0 DISCUSSION OF RESULTS

The screening processes described previously resulted in 40 water-budget estimates and 27 model estimates of recharge for comparison to their corresponding Maxey-Eakin recharge estimates. Table 4 summarizes the characteristics of the two groups of estimates. Together, the 67 independent estimates cover a total of 57 basins in Nevada. The number of basins covered is fewer than 67 because there is some overlap between the two groups of estimates, and also because within one group, there may be more than one estimate for a particular basin. For the purposes of the analysis, the two groups of estimates were separately compared to the Maxey-Eakin estimates to see if any differences in the groups were apparent.

### TABLE 4

### GROUPING OF RECHARGE ESTIMATES IDENTIFIED BY SCREENING PROCESS

| Group | Budget Estimates | Model Estimates |
|---|---|---|
| Number | 40 | 27 |
| Description | Recharge estimates determined from independent estimates of discharge reported in ground-water budgets. | Recharge estimates determined from geochemical models (23), numerical flow models (3), and infiltration model (1). |
| Source | Nevada Department of Conservation and Natural Resources:<br>● Reconnaissance Reports<br>● Water-Resources Bulletins | ● U.S. Geological Survey reports<br>● Desert Research Institute, University of Nevada reports<br>● Journal articles |

As a qualitative evaluation of the degree of agreement between the Maxey-Eakin recharge estimates and the two groups of independent estimates, scatter diagrams were prepared. Figure 6 shows the scatter for the group of 40 water-budget estimates of recharge. Figure 7 shows the scatter for the group of 27 model estimates of recharge. A line having a one-to-one slope is shown on both plots for comparison. If the pairs of estimates were in perfect agreement, all of the points would fall on this line. The scatter of the points about this line is a measure of the degree of agreement between the Maxey-Eakin estimates and the independent estimates. From the scatter diagrams, one may conclude that the general agreement between the Maxey-Eakin estimates and the independent estimates indicates that the Maxey-Eakin method is fairly good.

## 5.1 ANALYSIS OF UNCERTAINTY

An analysis can be performed to evaluate the uncertainty in both groups of Maxey-Eakin estimates, i.e., the 40 budget estimates and the 27 model estimates. If either group of basins is taken as representative of any ground-water basin in Nevada, then the uncertainty determined from this analysis provides a measure of the uncertainty in the Maxey-Eakin method in general.

Several definitions are necessary for the analysis. For each pairs of estimates within a group, the difference in the estimates is the residual $R$, where

$$R = ME - D \tag{4}$$

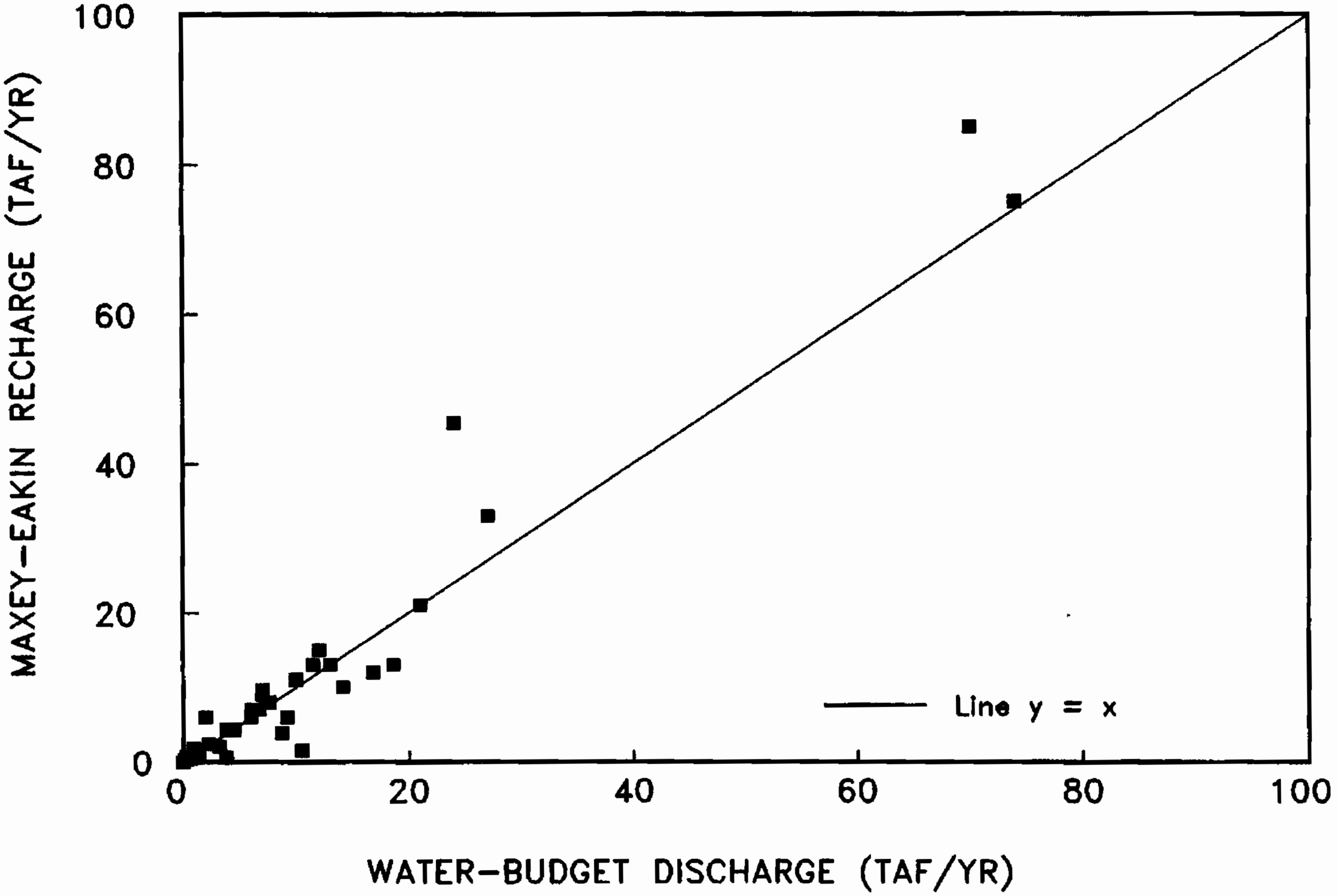
where

$ME$ = the Maxey-Eakin recharge estimate (acre-ft/yr), and
$D$ = the independent estimate of discharge (acre-ft/yr).

Each value of $ME$ and $D$ can be considered as a random variable with a probability distribution having an expected value and associated uncertainty, i.e., a mean and a variance or standard deviation. Accordingly, the values $ME$ and $D$ can each be broken down into random-variable components

$$ME = ME' + e_{ME} \tag{5}$$

$$D = D' + e_D \tag{6}$$



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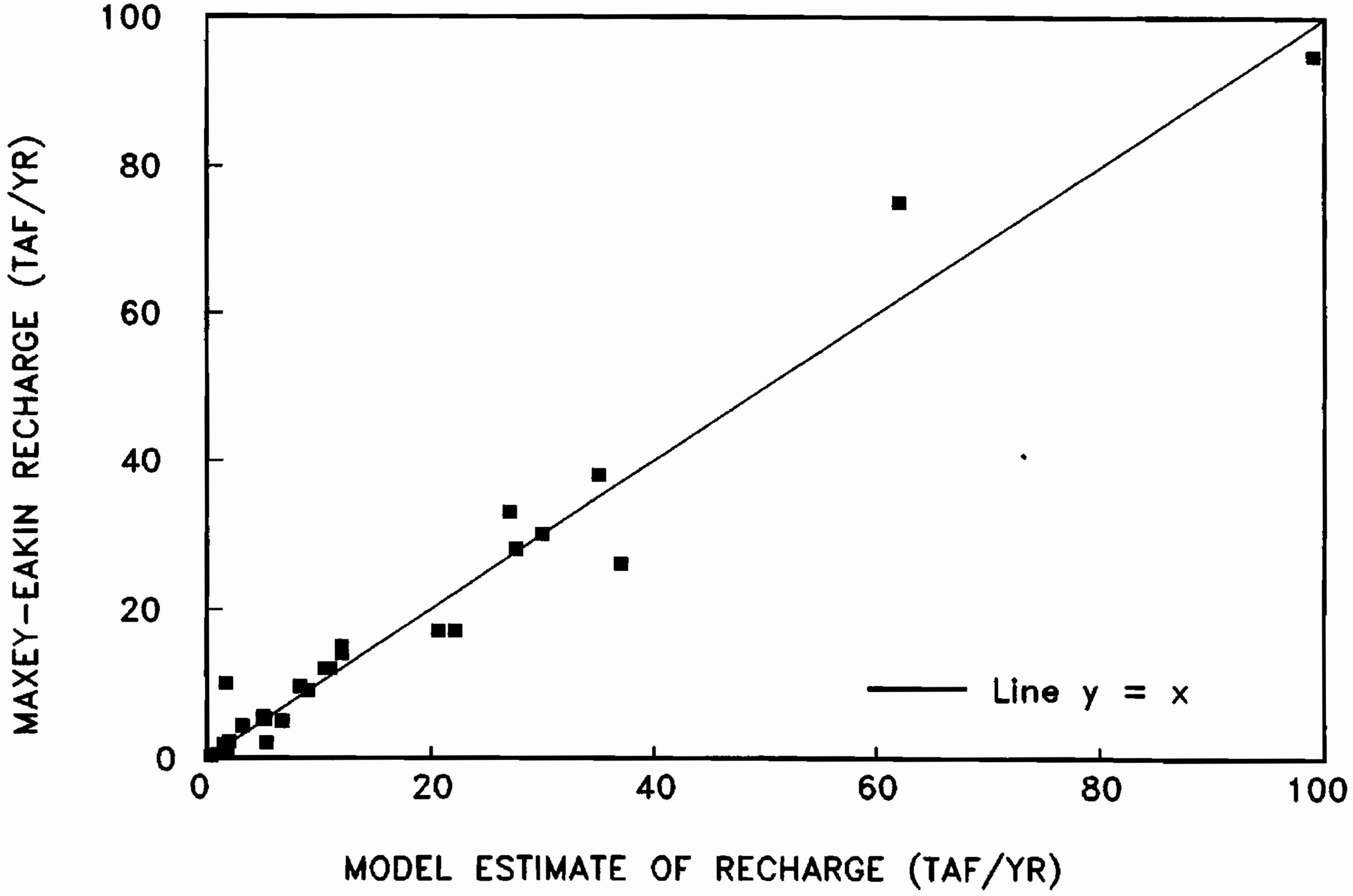
Scatter Diagram of Maxey–Eakin Estimates vs. Budget Estimates, 40 Points.

FIGURE 6



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Scatter Diagram of Maxey–Eakin Estimates vs. Model Estimates, 27 Points.

FIGURE 7

where

$ME'$ = the true value for the Maxey-Eakin recharge,
$D'$ = the true value for the discharge,
$e_{ME}$ = the error in the Maxey-Eakin recharge estimate, and
$e_D$ = the error in the estimate of discharge.

However, by definition,

$$ME' = D' \tag{7}$$

Therefore, substituting Equations 5, 6, and 7 into Equation 4 above gives an expression for the residual as follows:

$$R = e_{ME} - e_D \tag{8}$$

The degree of uncertainty in the Maxey-Eakin method can be evaluated by determining the structure of the random variable $e_{ME}$, i.e, the variance or the standard deviation of the distribution. The appropriate formula for the variance of a function of the form $y = g(x_n)$ is as follows (Benjamin and Cornell, 1970):

$$Var[y] = \sum_{i=1}^{n} \left[ \frac{\partial g}{\partial x_i} \right]^2 Var[x_i] \tag{9}$$

where it is assumed that the $x_i$ are not correlated. Applying this relation to Equation 8 produces

$$Var[R] = Var[e_{ME}] + Var[e_D] \tag{10}$$

Finally, rearranging gives

$$Var[e_{ME}] = Var[R] - Var[e_D] \tag{11}$$

This relationship gives the variance in the Maxey-Eakin errors as a function of the variance in the residuals and the variance in the discharge errors. The term $Var[R]$ can be computed directly from the 40 residuals. However, the term $Var[e_D]$ is not known. Therefore, the known value of $Var[R]$ will provide an upper bound on the value of $Var[e_{ME}]$, since Equation 11 dictates that

$$Var[e_{ME}] \leq Var[R] \tag{12}$$

Because it has the same units as the estimate, the standard deviation is a more convenient measure of uncertainty than the variance. The above relation can be expressed in terms of standard deviations by taking the square root of both sides, giving

$$\sigma[e_{ME}] \leq \sigma[R] \tag{13}$$

The relation expressed by Equation 13 can now be applied to both groups of estimates-- the 40 water-budget estimates and the 27 model estimates. As calculated from the 40 water-budget residuals, $\sigma[R]$ is 4,800 acre-ft/yr. Therefore, as an upper bound on $\sigma[e_{ME}]$, the standard deviation of the Maxey-Eakin estimate for a particular ground-water basin in this group is 4,800 acre-ft/yr. For the group of 27 estimates, the upper bound on the standard deviation of the Maxey-Eakin estimate is 4,300 acre-ft/yr.

The coefficient of variation $c_v$, which gives a measure of the relative dispersion or closeness of the set of values, can be computed from the relation

$$c_v = \frac{\sigma}{\mu} \tag{14}$$

where

$\sigma$ = the standard deviation of the distribution, and

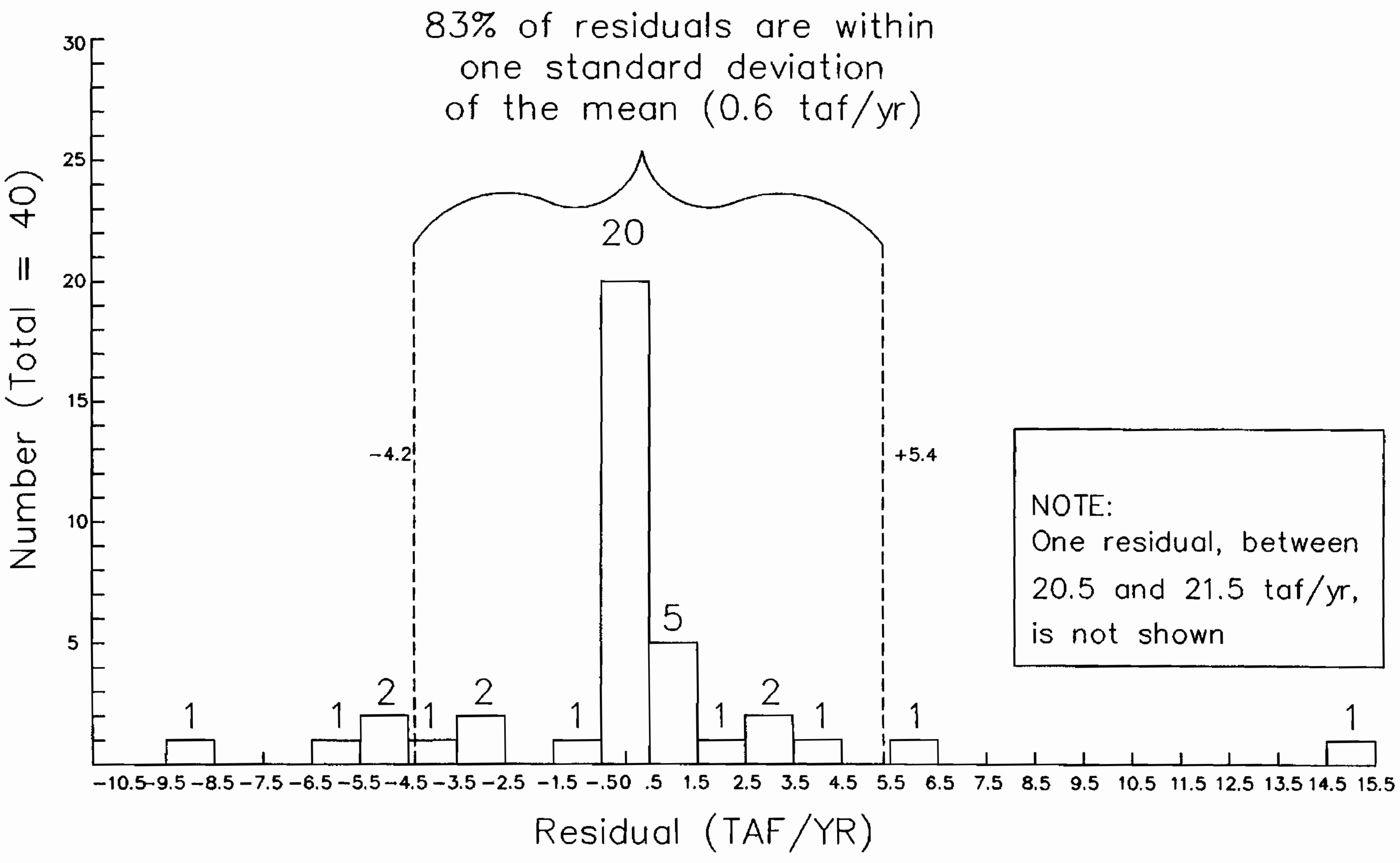
$\mu$ = the mean of the distribution.

For the group of 40 estimates, the maximum standard deviation of 4,800 acre-ft/yr is divided by the mean Maxey-Eakin estimate, which is 10,800 acre-ft/yr, to obtain a coefficient of variation no greater than 0.44, or 44 percent. For the group of 27 estimates, the maximum standard deviation of 4,300 acre-ft/yr is divided by the mean Maxey-Eakin estimate, which is 17,400 acre-ft/yr, to produce a coefficient of variation no greater than 0.25, or 25 percent.

The results of this uncertainty analysis indicate that the degree of uncertainty in a Maxey-Eakin estimate is somewhat less for the group of model estimates than for the group of water-budget estimates. As the model estimates were generally derived later in time than the water-budget estimates and presumably utilized previous knowledge about a basin, this result is not surprising.

If the errors in each group of Maxey-Eakin estimates were normally distributed, 68 percent of these values would fall within plus or minus one standard deviation of the mean. As a qualitative assessment of the shape of the distribution of $e_{ME}$, the distribution of the residuals R can be examined for each group of estimates. Figures 8 and 9 show histograms of the 40 and 27 residuals, respectively. The mean residuals are 600 and 400 ac-ft/yr for the two groups, respectively. It can be demonstrated statistically that these sample means are not significantly different from a mean of zero. Therefore, although both mean residuals are greater than zero, there is no indication of statistical bias in the Maxey-Eakin method.

Figures 8 and 9 indicate one standard deviation in either direction from the mean of the distribution and show the number of residuals within this range. For the group of 40 residuals, this range contains 83 percent of the residuals. For the group of 27 residuals, this range contains 78 percent of the residuals. Thus, for both groups of estimates, the residuals are clustered more closely about the mean than they would be in a normal distribution.



83% of residuals are within one standard deviation of the mean (0.6 taf/yr)

NOTE:
One residual, between 20.5 and 21.5 taf/yr, is not shown

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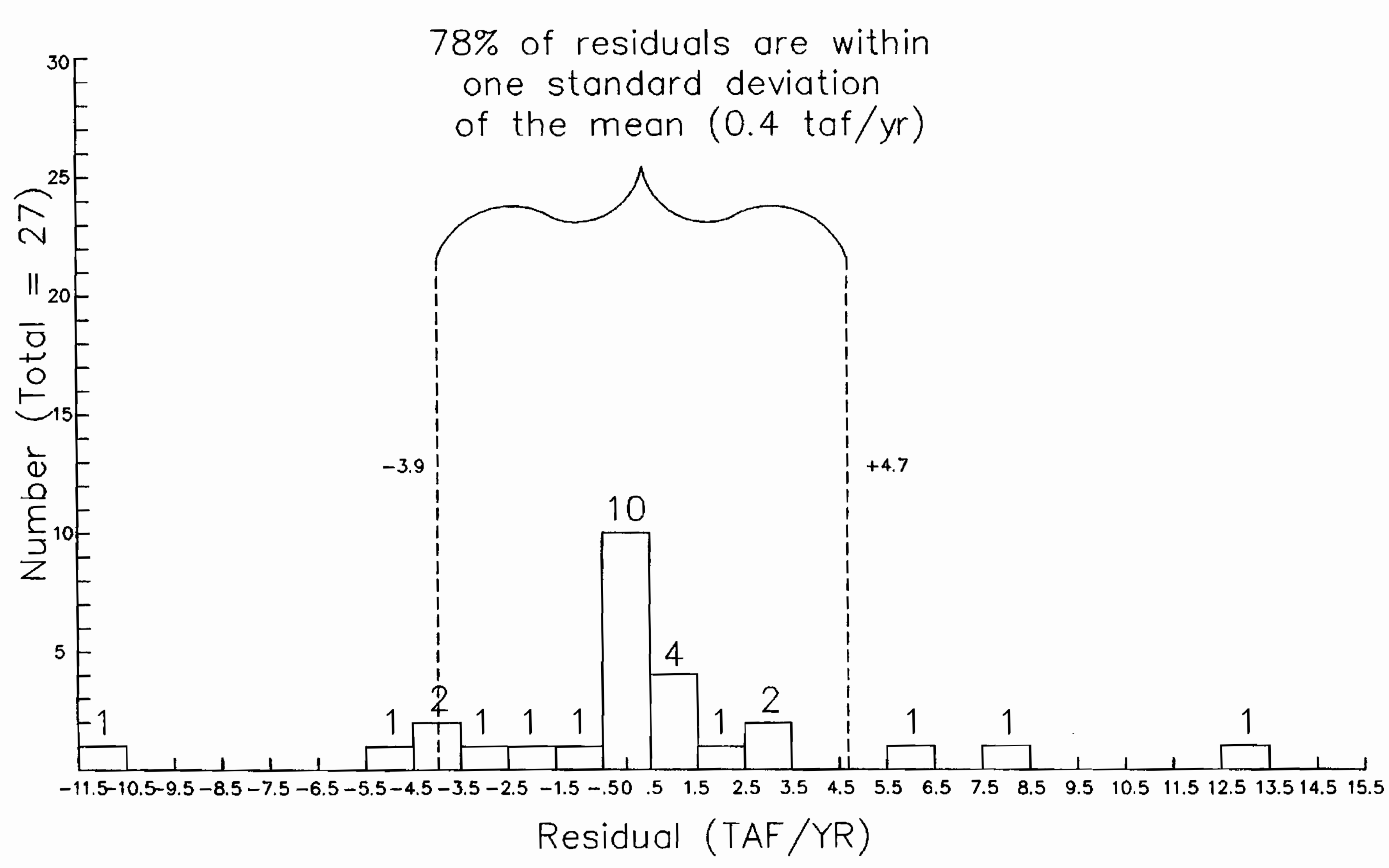
Histogram of Residuals (Residual = Maxey–Eakin Estimate Minus Water–Budget Estimate), 40 Points.

FIGURE 8



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Histogram of Residuals (Residual = Maxey–Eakin Estimate Minus Model Estimate), 27 Points.

FIGURE 9

## 5.2 COMPARISON TO PREVIOUS WORK

### 5.2.1 Study by Watson and Others (1976)

A previous evaluation of the Maxey-Eakin method was performed by Watson and others (1976), with the objective of examining the statistical validity of the method. In that analysis, a multiple-linear regression was performed to compute the five Maxey-Eakin coefficients based on data from the Reconnaissance Reports. The regression was of the form

$$Y = \sum_{i=1}^{5} a_i P_i \qquad (15)$$

where

$Y$ = water-budget discharge (dependent variable),
$P_i$ = volume of precipitation within each Hardman zone (independent variable), and
$a_i$ = the Maxey-Eakin coefficient for each Hardman zone (regression coefficient).

The regression was computed using 63 observations that were collected by screening the Reconnaissance Reports according to a set of criteria similar to that used in this report.

The results of the analysis were reported as the computed Maxey-Eakin coefficients and their corresponding 95-percent confidence intervals. Because the 95-percent confidence intervals for the five coefficients were relatively large, Watson and others (1976) concluded that the predictive capability of the Maxey-Eakin method is suspect.

Based on these conclusions, other authors have dismissed the reliability of the Maxey-Eakin method. For example, Lerner and others (1990) cite Watson's study as an illustration of the low accuracy of simple precipitation-recharge relations. Lerner and others (1990) conclude that "the wide confidence intervals make the coefficients unusable for prediction, despite being derived from a large, carefully assembled database." Burbey and Prudic (1991) also reference the Watson study, noting the conclusion that "the method could not reliably predict recharge other than provide an approximation."

However, it may not be appropriate to draw conclusions about the overall reliability of the Maxey-Eakin method based on the individual confidence intervals for each coefficient. What is most important is the overall predictive reliability of the Maxey-Eakin method as compared against independent estimates of recharge. This predictive reliability is only indirectly related to the standard error of the individual Maxey-Eakin coefficients. Rather, the predictive reliability is measured by the standard error of prediction of the regression, which is nearly equivalent to the standard deviation of the residuals that was discussed in the analysis of uncertainty in Section 5.1. Therefore, this report argues that the overall predictive reliability of the Maxey-Eakin method can best be evaluated by the type of uncertainty analysis presented here.

In addition to the difference in analytical approach, the current study is distinguished from Watson and others (1976) by an expanded and improved data base. In order to separate the effects of the two differences, the technique used by Watson and others (1976) was applied to the current data set. A multiple-linear regression of the form used by Watson and others (1976) was performed using the group of 40 water-budget estimates identified in this study. The results of this regression are compared to the results obtained by Watson and others (1976) in Table 5.

Table 5 shows that, for three of the five precipitation zones, the approximate 95-percent confidence intervals computed in this analysis are smaller than those by Watson. This indicates less variability in those Maxey-Eakin coefficients, which suggests that the data base of 40 observations used in this analysis is somewhat better than the data base used by Watson and others (1976). Despite these improvements, however, it appears that the final conclusion reached by Watson and others (1976) would not have changed if the current data base had been available. This is because both analyses generally indicate high variability of the Maxey-Eakin coefficients as computed by regression.

## TABLE 5

## RESULTS OF MULTIPLE-LINEAR REGRESSIONS

| Precipitation Zone (in.) | Maxey-Eakin Coefficients (%) | | 95% Confidence Intervals (%) | |
|---|---|---|---|---|
| | Watson (1976)[1] | This Analysis[2] | Watson (1976) | This Analysis[3] |
| >20 | 24 | 20.3 | ±15 | ±10.4 |
| 15-20 | 19 | 20.4 | ±16 | ±10.0 |
| 12-15 | -1 | -3.5 | ± 6 | ± 5.5 |
| 8-12 | 4 | 6.7 | ± 2 | ± 2.5 |
| <8 | 0 | 1.1 | ± 1 | ± 1.4 |

[1] 63 observations.

[2] 40 observations.

[3] 95% confidence intervals were estimated as equal to two standard deviations.

The approach used in the current analysis suggests that the Maxey-Eakin method provides estimates of recharge that are generally in good agreement with independent estimates. This conclusion contradicts that of Watson and others (1976) because the two analyses have used different statistical indicators as a measure of predictive reliability. The methods used in this report are more appropriate to evaluate the total uncertainty in the Maxey-Eakin method. The predictive reliability of the Maxey-Eakin method should not be judged by the standard error of the individual coefficients as computed by regression.

### 5.2.2 Study by Bredenkamp (1990)

Another evaluation of an empirical relationship for determining recharge from precipitation was conducted by Bredenkamp (1990). The results of Bredenkamp's investigation parallel the conclusion of this study that an empirical relationship for calculating recharge provides reasonably good estimates of recharge.

The study by Bredenkamp (1990) focussed on the dolomite region in South Africa. Bredenkamp identified independent estimates of recharge for 14 basins to compare with recharge estimates determined from this empirical relationship:

$$R = 0.35\ (P - 360) \qquad (16)$$

where

$R$ = annual recharge (in mm), and

$P$ = annual precipitation (in mm).

The independent estimates used by Bredenkamp, referred to as "reconstructed estimates," were derived primarily from water balances, ground-water flow models, and chemical mass balances. The results of the analysis showed good general agreement between the two groups of estimates. However, the relation that best fit the data was provided by:

$$R = 0.30\ (R - 313) \qquad (17)$$

This relationship was determined by regression using the rainfall estimates as the independent variables and the "reconstructed" recharge estimates as the dependent variables. As Bredenkamp notes, "The high correlation coefficient ($r = 0.989$) reflects excellent agreement between the reconstructed and reference recharge values."

## 6.0 EVALUATION OF UNCERTAINTY IN ESTIMATES FOR 20 BASINS

The results of the previous analysis of uncertainty can be used to evaluate the uncertainty in the Maxey-Eakin estimates for the 20 basins in which the District has applied for the appropriation of ground water (Figure 1). In order to produce results that are conservative, the group of 40 budget estimates is selected as a basis for the analysis because this group displays somewhat greater uncertainty than the group of 27 model estimates. Consequently, the analysis in this section assumes that the residuals for the 20 basins have the same distribution as the residuals for the 40 basins.

Maxey-Eakin recharge estimates have been computed for all of the 20 basins of interest and are given in the Reconnaissance Reports. The cumulative Maxey-Eakin recharge can be designated as $ME_{20}$, and is equal to the sum of these 20 estimates. Proceeding as in the earlier analysis, this quantity can be separated into two components:

$$ME_{20} = ME'_{20} + e_{ME20} \tag{18}$$

where

$ME'_{20}$ = the true value for the total Maxey-Eakin recharge to the 20 basins, and

$e_{ME20}$ = the error in the total Maxey-Eakin estimate of recharge for the 20 basins.

In turn, the total error $e_{ME20}$ can be expressed as the sum of the individual errors in each of the 20 basins as follows:

$$e_{ME20} = \sum_{i=1}^{20} e_i \tag{19}$$

Taking the variance of the above relation produces

$$Var[e_{ME20}] = Var\left[\sum_{i=i}^{20} e_i\right] \tag{20}$$

But, if it assumed that the errors for each of the 20 basins are distributed the same as for the group of 40, then

$$Var[e_{ME20}] = 20\ Var[e_{ME}] \tag{21}$$

Square-rooting both sides of Equation 21 to obtain an expression in terms of standard deviations gives

$$\sigma[e_{ME20}] = \sqrt{20}\ \sigma[e_{ME}] \tag{22}$$

The previous analysis established an upper bound for the standard deviation of the Maxey-Eakin estimate for an individual basin, $\sigma[e_{ME}]$, equal to 4,800 acre-ft/yr. Using this value in Equation 22 produces $\sigma[e_{ME20}] \leq$ 21,500 acre-ft/yr. This means that the standard deviation of the total Maxey-Eakin recharge estimate for the 20 valleys is no greater than 21,500 acre-ft/yr.

The coefficient of variation $c_v$ (Equation 14) of the total recharge estimate can be computed by dividing the maximum standard deviation of 21,500 acre-ft/yr by the total Maxey-Eakin recharge from the 20 basins, which is 224,000 acre-ft/yr. The result is a coefficient of variation no greater than 0.10, or 10 percent. This value for $c_v$ can be compared to the value computed for the individual basins within the group of 40, which was 44 percent. Mathematically, it can be demonstrated that the coefficient of variation for the sum of a number of basins decreases as more basins are included in the computation. In the general case, the decrease in $c_v$ is inversely proportional to the square root of the number of basins included in the analysis. Therefore, the predictive reliability of a total Maxey-Eakin recharge estimate for a group of basins increases with the number of basins used.

## 7.0 CONCLUSIONS

Based on the findings from this current analysis of the Maxey-Eakin method, the conclusions of this report are:

- The Maxey-Eakin method provides fairly reliable estimates of recharge to ground-water basins in Nevada,

- Using a group of 40 independent estimates of recharge obtained from water budgets, an analysis of the uncertainty in the method indicates that the standard deviation of a Maxey-Eakin estimate for a given ground-water basin is not more than 4,800 acre-ft/yr, with a maximum coefficient of variation of 44 percent,

- Using a group of 27 independent estimates of recharge obtained from models, the uncertainty analysis indicates that the standard deviation of a Maxey-Eakin estimate for a given ground-water basin is not more than 4,300 acre-ft/yr, with a maximum coefficient of variation of 25 percent,

- Applying the results of the uncertainty analysis from the 40 water-budget estimates to the total Maxey-Eakin recharge estimate from 20 selected basins indicates that the standard deviation of this estimate is not more than 21,500 acre-ft/yr, with a maximum coefficient of variation of 10 percent, and

- In the general case, the predictive reliability of a Maxey-Eakin recharge estimate for a group of basins, as measured by the coefficient of variation, is expected to increase with the number of basins evaluated.

# 8.0 REFERENCES

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**(Report Series arranged alphabetically on**
**basis of series abbreviation)**

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R8 Independence Valley: T.E. Eakin, 1962.
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# APPENDIX A

APPENDIX A: WORKSHEET FOR SCREENING RECHARGE ESTIMATES
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NOTES:

(1) KEY TO REFERENCES:
R = RECONNAISSANCE REPORT, NEVADA DEPARTMENT OF CONSERVATION AND RESOURCES
B = WATER-RESOURCES BULLETIN, NEVADA DEPARTMENT OF CONSERVATION AND RESOURCES
P = U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER
W = U.S. GEOLOGICAL SURVEY WATER-SUPPLY PAPER
WR = U.S. GEOLOGICAL SURVEY WATER-RESOURCES INVESTIGATIONS REPORT
OF = U.S. GEOLOGICAL SURVEY OPEN-FILE REPORT
JH = JOURNAL OF HYDROLOGY

(2) HYDROGRAPHIC BASIN NUMBERS AFTER HARRILL AND OTHERS (1988)

(3) SEE REPORT TEXT FOR REASONS FOR REJECTING MAXEY-EAKIN RECHARGE ESTIMATE

(4) SEE REPORT TEXT FOR REASONS FOR REJECTING WATER-BUDGET ESTIMATE OF DISCHARGE

| | | | | | WATER-BUDGET ESTIMATE OF DISCHARGE | | | | |
|---|---|---|---|---|---|---|---|---|---|
| REF. (1) | HYDRO-GRAPHIC BASIN NO. (2) | VALLEY | RECHARGE REJECTION REASON (3) | REPORTED MAXEY-E RECHARGE (AF/YR) | TOTAL DISCHARGE (AF/YR) | OTHER INFLOW (AF/YR) | DISCH REJEC. REASON (4) | MODEL ESTIMATE OF RECHARGE (AF/YR) | SOURCE |
| B33 | | WHITE R FLOW SYSTEM | 6 | 104000 | 103000 | 0 | 0 | | |
| R17 | 16 | DUCK LAKE | 0 | 9000 | 7000 | 0 | 0 | 9000 | Dettinger (1989), JH 106 |
| R44 | 18 | PAINTERS FLAT | 0 | 1300 | 1200 | 0 | 0 | | |
| R44 | 20 | SANO | 1 | 10 | 30 | 0 | 0 | | |
| R44 | 21 | SMOKE CREEK DESERT | 0 | 13000 | 19000 | 380 | 0 | | |
| R44 | 22 | SAN EMIDIO DESERT | 0 | 2100 | 3200 | 0 | 0 | | |
| R11,B37 | 24 | HUALAPAI FLAT | 0 | 7000 | 6700 | 0 | 0 | | |
| R4 | 29 | PINE FOREST | 0 | 10000 | 14100 | 0 | 0 | | |
| R2,B32 | 53 | PINE | 0 | 45500 | 24000 | 0 | 0 | | |
| R37 | 55 | CARICO LAKE | 0 | 4300 | 4500 | 0 | 0 | | |
| R31,B32 | 56 | UPPER REESE RIVER | 3 | 37000 | 37000 | 0 | 0 | | |
| R29,B32 | 71 | GRASS (HUMBOLDT) | 0 | 12000 | 16800 | 0 | 0 | | |
| R43 | 84 | WARM SPRINGS | 0 | 6000 | 2000 | 0 | 0 | | |
| R43 | 85 | SPANISH SPRINGS | 0 | 600 | 1000 | 0 | 0 | | |
| R43 | 86 | SUN | 0 | 50 | 25 | 0 | 0 | | |
| B42 | 92 | E LEMMON SUBAREA | 3 | 500 | 620 | 0 | 0 | | |
| B42 | 92 | SILVER LAKE SUBAREA | 3 | 1000 | 760 | 0 | 0 | | |

WATER-BUDGET ESTIMATE
OF DISCHARGE

APPENDIX A: WORKSHEET FOR SCREENING RECHARGE ESTIMATES
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| REF. (1) | HYDRO-GRAPHIC BASIN NO. (2) | VALLEY | RECHARGE REJECTION REASON (3) | REPORTED MAXEY-E RECHARGE (AF/YR) | TOTAL DISCHARGE (AF/YR) | OTHER INFLOW (AF/YR) | DISCH REJEC. REASON (4) | MODEL ESTIMATE OF RECHARGE (AF/YR) | SOURCE |
|---|---|---|---|---|---|---|---|---|---|
| R43 | 92 | LEMMON | 0 | 1800 | 1200 | 300 | 0 | 1800 | Dettinger (1989), JH 106 |
| R43 | 95 | DRY | 0 | 2400 | 2300 | 0 | 0 | | |
| R43 | 96 | NEWCOMB LAKE | 0 | 300 | 130 | 0 | 0 | | |
| R43 | 97 | HONEY LAKE (EAST) | 0 | 1500 | 11000 | 500 | 0 | | |
| R39 | 104 | EAGLE (CAR&VIR) | 3 | 8700 | 14800 | 0 | 0 | | |
| R52 | 111 | ALKALI (N) | 0 | 400 | 300 | 0 | 0 | | |
| R52 | 113 | HUNTOON | 0 | 800 | 300 | 0 | 0 | | |
| R52 | 114 | TEELS | 0 | 1300 | 1400 | 0 | 0 | | |
| R58 | 117 | FISH LAKE | 0 | 33000 | 27000 | 0 | 0 | 27000 | Dettinger (1989), JH 106 |
| R52 | 118 | COLUMBUS | 0 | 700 | 4000 | 200 | 0 | | |
| R52 | 119 | RHODES | 0 | 500 | 1000 | 400 | 0 | | |
| R52 | 121 | SODA SPRING E | 0 | 600 | 900 | 200 | 0 | | |
| R52 | 121 | SODA SPRING W | 0 | 100 | 30 | 300 | 0 | | |
| R23 | 124 | FAIRVIEW | 5 | 500 | 500 | 0 | 0 | | |
| R23 | 128 | DIXIE | 0 | 6000 | 16200 | 7000 | 0 | | |
| R23 | 130 | PLEASANT | 5 | 3000 | 3000 | 0 | 0 | | |
| R23 | 132 | JERSEY | 0 | 800 | 800 | 0 | 0 | | |
| R26 | 133 | EDWARDS CREEK | 0 | 8000 | 7600 | 0 | 0 | | |
| R28,P1409E | 134 | SMITH CREEK | 0 | 9600 | 7000 | 0 | 0 | 8300 | P1409E |
| R28 | 135 | IONE | 3 | 8000 | 4000 | 0 | 0 | | |
| R52 | 136 | MONTE CRISTO | 0 | 500 | 400 | 0 | 0 | | |
| R37 | 138 | GRASS (LANDER) | 0 | 13000 | 13000 | 0 | 0 | | |
| R30 | 140 | MONITOR (S) | 1 | 15000 | 11200 | 0 | 0 | | |
| R30 | 140 | MONITOR (N) | 1 | 6300 | 8000 | 2000 | 0 | | |
| R45 | 145 | STONEWALL | 5 | 100 | 200 | 0 | 0 | | |
| R54 | 146 | SARCOBATUS FLAT | 3 | 1200 | 3500 | 1200 | 0 | | |
| R38 | 150 | LITTLE FISH LAKE | 0 | 11000 | 10000 | 0 | 0 | | |
| R30 | 151 | ANTELOPE | 1 | 4100 | 4200 | 0 | 0 | | |
| R6, B35 | 153 | DIAMOND total | 0 | 21000 | 30000 | 9000 | 0 | | |
| R38 | 156 | HOT CREEK | 0 | 7000 | 6300 | 200 | 0 | | |
| R60 | 170 | PENOYER | 0 | 4300 | 3800 | 0 | 0 | 3200 | Dettinger (1989), JH 106 |
| R49 | 178 | BUTTE (S) | 0 | 15000 | 12000 | 0 | 0 | 12000 | Dettinger (1989), JH 106 |
| R49 | 178 | BUTTE (N) | 0 | 3900 | 8700 | 0 | 0 | | |
| R42 | 179 | STEPTOE | 0 | 85000 | 70000 | 0 | 0 | | |

| | | | | | WATER-BUDGET ESTIMATE OF DISCHARGE | | | MODEL ESTIMATE OF | SOURCE |
|---|---|---|---|---|---|---|---|---|---|
| | HYDRO- | | RECHARGE | REPORTED | TOTAL | OTHER | DISCH | | |

APPENDIX A: WORKSHEET FOR SCREENING RECHARGE ESTIMATES

| REF. (1) | GRAPHIC BASIN NO. (2) | VALLEY | REJECTION REASON (3) | MAXEY-E RECHARGE (AF/YR) | DISCHARGE (AF/YR) | INFLOW (AF/YR) | REJEC. REASON (4) | RECHARGE (AF/YR) | |
|---|---|---|---|---|---|---|---|---|---|
| R24 | 183 | LAKE | 0 | 13000 | 11500 | 0 | 0 | | |
| R33 | 184 | SPRING | 0 | 75000 | 74000 | 0 | 0 | 62000 | Dettinger (1989), JH 106 |
| JH106 | 103B | STAGECOACH | 6 | 400 | 400 | 0 | 0 | 400 | Dettinger (1989), JH 106 |
| R23 | 125-127 | EASTGATE, COWKICK, | 0 | 6000 | 6000 | 0 | 0 | | |
| R19,B32 | 57,58 | ANTELOPE&MIDDLE REE | 3 | 18000 | 18100 | 3500 | 0 | | |
| R27 | 205? | REMAINDER MEADOW | 0 | 8000 | | | 1 | | |
| R20 | 23 | GRANITE BASIN | 0 | 400 | | | 1 | | |
| R20 | 25 | HIGH ROCK LAKE | 0 | 13000 | | | 1 | | |
| R20 | 27 | SUMMIT LAKE | 0 | 4200 | | | 1 | | |
| R54 | 144 | LIDA | 4 | 500 | | | 1 | | |
| R54 | 145 | STONEWALL FLAT | 4 | 100 | | | 1 | | |
| R54 | 147 | GOLD FLAT | 0 | 3800 | | | 1 | | |
| R54 | 148 | CACTUS FLAT | 0 | 600 | | | 1 | | |
| R6, B35 | 153 | DIAMOND N SUBAREA | 0 | 9000 | | | 1 | | |
| R6, B35 | 153 | DIAMOND S SUBAREA | 0 | 12000 | | | 1 | 10500 | Dettinger (1989), JH 106 |
| R54 | 157 | KAWICH | 0 | 3500 | | | 1 | | |
| R54 | 158 | GROOM LAKE | 0 | 3200 | | | 1 | | |
| R54 | 158 | PAPOOSE LAKE | 0 | 4 | | | 1 | | |
| R54 | 159 | YUCCA FLAT | 0 | 700 | | | 1 | | |
| R54 | 160 | FRENCHMAN FLAT | 0 | 100 | | | 1 | | |
| R54 | 161 | INDIAN SPRINGS | 0 | 10000 | | | 1 | | |
| R54 | 168 | THREE LAKES (N) | 0 | 2000 | | | 1 | | |
| R54 | 169 | TIKAPOO (N) | 0 | 2600 | | | 1 | | |
| R54 | 169 | TIKAPOO (S) | 0 | 3400 | | | 1 | | |
| R27 | 201 | SPRING | 0 | 10000 | | | 1 | | |
| R27 | 202 | PATTERSON | 0 | 6000 | | | 1 | | |
| R54 | 211 | THREE LAKES (S) | 0 | 6000 | | | 1 | | |
| R54 | 212 | LAS VEGAS W ONLY | 0 | 4700 | | | 1 | | |
| JH106 | 212 | LAS VEGAS N ONLY | 6 | 28000 | | | 1 | 27600 | Dettinger (1989), JH 106 |
| R54 | 225 | MERCURY | 0 | 250 | | | 1 | | |
| R54 | 226 | ROCK | 5 | 30 | | | 1 | | |
| R54 | 227 | JACKASS FLATS E | 0 | 300 | | | 1 | | |
| R54 | 227 | JACKASS FLATS W | 0 | 580 | | | 1 | | |
| R54 | 227 | BUCKBOARD MESA | 0 | 1400 | | | 1 | | |

| | | | | | WATER-BUDGET ESTIMATE OF DISCHARGE | | | | |
|---|---|---|---|---|---|---|---|---|---|
| REF. (1) | HYDRO-GRAPHIC BASIN NO. (2) | VALLEY | RECHARGE REJECTION REASON (3) | REPORTED MAXEY-E RECHARGE (AF/YR) | TOTAL DISCHARGE (AF/YR) | OTHER INFLOW (AF/YR) | DISCH REJEC. REASON (4) | MODEL ESTIMATE OF RECHARGE (AF/YR) | SOURCE |

| | | | | | WATER-BUDGET ESTIMATE OF DISCHARGE | | | | |
|---|---|---|---|---|---|---|---|---|---|
| REF. (1) | HYDRO-GRAPHIC BASIN NO. (2) | VALLEY | RECHARGE REJECTION REASON (3) | REPORTED MAXEY-E RECHARGE (AF/YR) | TOTAL DISCHARGE (AF/YR) | OTHER INFLOW (AF/YR) | DISCH REJEC. REASON (4) | MODEL ESTIMATE OF RECHARGE (AF/YR) | SOURCE |
| R54 | 228 | OASIS | 0 | 1000 | | | 1 | | |
| R54 | 229 | CRATER FLAT | 0 | 220 | | | 1 | | |
| R18,B33 | 171-172 | COAL/GARDEN | 5 | 12000 | | | 2 | 11000 | Kirk & Campana (1990), JH 119 |
| R52 | ? | MONO | 0 | 700 | | | 2 | | |
| R45 | ? | GRAPEVINE CYN | 5 | 50 | | | 2 | | |
| R52 | ? | ADOBE | 5 | 300 | | | 2 | | |
| R59 | ? | PACKARD | 0 | 710 | | | 2 | | |
| R52 | ? | QUEEN | 0 | 2000 | | | 2 | | |
| R45 | ? | ORIENTAL WASH | 5 | 300 | | | 2 | | |
| R22 | 1 | PUEBLO | 0 | 2000 | | | 2 | | |
| R15 | 6 | GUANO (NV) | 0 | 7500 | | | 2 | | |
| R15 | 11 | COLEMAN (NV) | 0 | 1000 | | | 2 | | |
| R15 | 14 | SURPRISE (NV) | 0 | 1500 | | | 2 | | |
| R15 | 15 | BOULDER | 0 | 2000 | | | 2 | | |
| R44 | 17 | PILGRIM FLAT | 1 | 500 | | | 2 | | |
| R44 | 19 | DRY | 0 | 200 | | | 2 | | |
| R55 | 75 | BRADYS HOT SPRING | 0 | 160 | | | 2 | | |
| R57 | 76 | FERNLEY AREA | 0 | 600 | | | 2 | | |
| R55 | 77 | FIREBALL | 0 | 200 | | | 2 | | |
| R55 | 78 | GRANITE SPRINGS | 0 | 3500 | | | 2 | | |
| R55 | 79 | KUMIVA | 0 | 1000 | | | 2 | | |
| R57 | 88 | PLEASANT | 1 | 10000 | | | 2 | | |
| R41 | 89 | WASHOE (CARSON&VIRGINIA) | 4 | 14000 | | | 2 | | |
| R52 | 111 | ALKALI (S) | 0 | 1400 | | | 2 | | |
| R52 | 120 | GARFIELD | 0 | 300 | | | 2 | | |
| R45 | 141 | RALSTON | 0 | 5000 | | | 2 | | |
| R45 | 142 | ALKALI SPRING | 1 | 100 | | | 2 | | |
| R45 | 143 | CLAYTON | 0 | 1500 | | | 2 | | |
| R45 | 144 | LIDA | 0 | 500 | | | 2 | | |
| R45 | 149 | STONECABIN | 0 | 5000 | | | 2 | | |
| R30 | 152 | STEVENS BASIN | 1 | 200 | | | 2 | | |
| R38 | 155 | LIT. SMOKY (N) | 0 | 4000 | | | 2 | | |
| W2279 | 162 | PAHRUMP | 0 | 26000 | | | 2 | 37000 | Harrill (1986), W2279 |
| R46 | 163 | MESQUITE NV+CA | 5 | 1500 | | | 2 | | |
| R46 | 164 | IVANPAH (NV) | 0 | 700 | | | 2 | | |
| R46 | 164 | IVANPAH (CA) | 0 | 800 | | | 2 | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| R46 | 165 | JEAN LAKE | 5 | 100 | | 2 | |
| R46 | 166 | HIDDEN | 0 | 0 | | 2 | |
| R36 | 167 | ELDORADO | 0 | 1100 | | 2 | |
| R60 | 173 | RAILROAD S | 0 | 5500 | | 2 | 5000 Dettinger (1989), JH 106 |
| B33 | 174 | JAKES | 6 | 17000 | | 2 | 20700 Kirk & Campana (1990), JH 119 |
| R3, B33 | 175 | LONG (WHITE RIV) | 3 | 10000 | | 2 | 1700 Kirk & Campana (1990), JH 119 |
| R13, B33 | 180 | CAVE | 0 | 14000 | | 2 | 12000 Kirk & Campana (1990), JH 119 |
| R16 | 181 | DRY LAKE | 0 | 5000 | | 2 | 6700 Kirk & Campana (1990), JH 119 |
| R16 | 182 | DELAMAR | 5 | 1000 | | 2 | 1800 Kirk & Campana (1990), JH 119 |
| R56 | 185 | TIPPETT | 0 | 6900 | | 2 | |
| R56 | 186 | ANTELOPE (N) | 0 | 3200 | | 2 | |
| R56 | 186 | ANTELOPE (S) | 0 | 1500 | | 2 | |
| R51 | 197 | ESCALANTE DESERT | 3 | 2300 | | 2 | |
| R25 | 206 | KANE SPRINGS | 0 | 500 | | 2 | 1000 Kirk & Campana (1990), JH 119 |
| B33 | 207 | WHITE RIVER | 6 | 38000 | | 2 | 35000 Kirk & Campana (1990), JH 119 |
| R21 | 208 | PAHROC | 0 | 2200 | | 2 | 2000 Kirk & Campana (1990), JH 119 |
| R21 | 209 | PAHRANAGAT | 0 | 1800 | | 2 | 1500 Kirk & Campana (1990), JH 119 |
| R25 | 210 | COYOTE SPRINGS | 0 | 2100 | | 2 | 5300 Kirk & Campana (1990), JH 119 |
| R36 | 213 | COLORADO RIVER | 5 | 200 | | 2 | |
| R36 | 214 | PIUTE (NV & CA) | 0 | 1700 | | 2 | |
| R50 | 216 | GARNET | 0 | 400 | | 2 | |
| R50 | 217 | HIDDEN (N) | 0 | 400 | | 2 | |
| R25, B33 | 219 | MUDDY SPRINGS | 1 | 100 | | 2 | |
| R51 | 221 | TULE DESERT | 0 | 2100 | | 2 | |
| R51 | 222 | LOWER VIRGIN RV (NV | 0 | 3600 | | 2 | |
| R50 | 223 | GOLD BUTTE | 0 | 1000 | | 2 | |
| R50 | 224 | GREASEWOOD | 0 | 600 | | 2 | |
| R56 | 253 | DEEP CREEK | 0 | 2200 | | 2 | |
| R34 | 254 | SNAKE (NV&CA) | 1 | 103000 | | 2 | |
| R56 | 261 | GREAT SALT LAKE DES | 0 | 4800 | | 2 | |
| R54 | | ASH MEADOWS | 4 | 33000 | | 3 | |

| | | | | | WATER-BUDGET ESTIMATE OF DISCHARGE | | | | |
|---|---|---|---|---|---|---|---|---|---|
| REF. (1) | HYDRO-GRAPHIC BASIN NO. (2) | VALLEY | RECHARGE REJECTION REASON (3) | REPORTED MAXEY-E RECHARGE (AF/YR) | TOTAL DISCHARGE (AF/YR) | OTHER INFLOW (AF/YR) | DISCH REJEC. REASON (4) | MODEL ESTIMATE OF RECHARGE (AF/YR) | SOURCE |
| R54 | | PAHUTE MESA | 4 | 12000 | | | 3 | | |
| R22 | 2 | CONTINENTAL LAKE | 0 | 11000 | | | 3 | | |
| R22 | 3 | GRIDLEY LAKE | 0 | 4500 | | | 3 | | |
| R22 | 4 | VIRGIN | 0 | 7000 | | | 3 | | |
| R15 | 8 | MASSACRE LAKE | 0 | 3500 | | | 3 | | |
| R15 | 9 | LONG (NW NEV) | 0 | 6000 | | | 3 | | |
| R15 | 12 | MOSQUITO | 5 | 700 | | | 3 | | |
| R43 | 93 | ANTELOPE | 1 | 300 | | | 3 | | |
| R43 | 94 | BEDELL FLAT | 0 | 1100 | | | 3 | | |
| WR90-4050 | 97 | HONEY LAKE model | 6 | 17000 | | | 3 | 22200 | Handman & others (1990), WR90-4050 |
| WR90-4050 | 97 | HONEY LAKE total | 6 | 95000 | | | 3 | 99000 | Handman & others (1990), WR90-4050 |
| R44 | 98 | SKEDADDLE CR | 0 | 600 | | | 3 | | |
| R43 | 99 | RED ROCK | 5 | 900 | | | 3 | | |
| R43 | 100 | COLD SPRINGS | 1 | 900 | | | 3 | | |
| R40 | 123 | RAWHIDE FLATS | 0 | 150 | | | 3 | | |
| R30 | 139 | KOBEH | 1 | 11000 | | | 3 | | |
| R38 | 155 | LIT. SMOKY (S) | 0 | 1400 | | | 3 | | |
| R60 | 173 | RAILROAD N | 0 | 46000 | | | 3 | | |
| R47 | 189 | TOANO-ROCK SPRING | 0 | 5000 | | | 3 | | |
| R47 | 189 | MONTELLO-CRITTENDEN | 5 | 4000 | | | 3 | | |
| B44,W1780 | 212 | LAS VEGAS | 6 | 30000 | | | 3 | 30000 | B44 |
| R14 | 230 | AMARGOSA DESERT | 3 | 1500 | | | 3 | | |
| R56 | 191 | PILOT CREEK | 0 | 2400 | | | 4 | | |
| R47 | 189 | ROCKY BUTTE | 0 | 1300 | | | 5 | | |
| R47 | 189 | HERRELL SIDING-BRUS | 0 | 2000 | | | 5 | | |
| R50 | 215 | BLACK MTN. | 0 | 70 | | | 5 | | |
| R50 | 218 | CALIF. WASH | 0 | 60 | | | 5 | | |
| R50 | 220 | LOWER MOAPA | 0 | 40 | | | 5 | | |
| R59 | ? | WHITE PLAINS | 1 | 100 | | | 5 | | |
| R48 | 28 | BRUNEAU RIVER | 6 | 26000 | | | 6 | | |
| R48 | 34 | E LITTLE OWYHEE | 6 | 2700 | | | 6 | | |
| R48 | 35 | S FORK OWYHEE | 6 | 28000 | | | 6 | | |
| R48 | 37 | OWYHEE RIVER | 6 | 17000 | | | 6 | | |
| R48 | 39 | JARBRIDGE RIVER | 6 | 32000 | | | 6 | | |

WATER-BUDGET ESTIMATE
OF DISCHARGE

| REF. (1) | HYDRO-GRAPHIC BASIN NO. (2) | VALLEY | RECHARGE REJECTION REASON (3) | REPORTED MAXEY-E RECHARGE (AF/YR) | TOTAL DISCHARGE (AF/YR) | OTHER INFLOW (AF/YR) | DISCH REJEC. REASON (4) | MODEL ESTIMATE OF RECHARGE (AF/YR) | SOURCE |
|---|---|---|---|---|---|---|---|---|---|
| R48 | 40 | SALMON FALLS CR | 6 | 44000 | | | 6 | | |
| R48 | 41 | GOOSE CREEK | 6 | 6700 | | | 6 | | |
| R5 | 72 | IMLAY | 0 | 4000 | | | 6 | | |
| R32 | 73 | UPP/LOW LOVELOCK | 0 | 1200 | | | 6 | | |
| R32 | 73 | OREANA SUBAREA | 0 | 2000 | | | 6 | | |
| R57 | 81 | PYRAMID LAKE | 0 | 6600 | | | 6 | | |
| R57 | 82 | DODGE FLAT | 0 | 1400 | | | 6 | | |
| R57 | 83 | TRACY SEGMENT | 0 | 6000 | | | 6 | | |
| R57 | 87 | TRUCKEE MEADOWS | 1 | 27000 | | | 6 | | |
| R57 | 91 | TRUCKEE CYN NV&CA | 1 | 24000 | | | 6 | | |
| R57 | 91 | TRUCKEE CYN NV | 1 | 27000 | | | 6 | | |
| R59 | 101 | CARSON DESERT | 0 | 1300 | | | 6 | | |
| R59 | 103 | DAYTON | 3 | 7900 | | | 6 | | |
| R59 | 104 | CHURCHILL | 0 | 1300 | | | 6 | | |
| R59 | 105 | CARSON NV W OF CARS | 1 | 11000 | | | 6 | | |
| R59 | 105 | CARSON NV E OF CARS | 1 | 14000 | | | 6 | | |
| R59 | 105 | CARSON CA W FORK CA | 1 | 10600 | | | 6 | | |
| R59 | 105 | CARSON CA E FORK CA | 1 | 5400 | | | 6 | | |
| R53 | 106 | ANTELOPE | 1 | 18000 | | | 6 | | |
| B38 | 107 | MASON | 0 | 2000 | | | 6 | | |
| R53 | 109 | EAST WALKER AREA | 1 | 31000 | | | 6 | | |
| R7 | 31 | DESERT | 0 | 5000 | | | 7 | | |
| R9 | 122 | GABBS | 3 | 5200 | | | 8 | 5200 | Dettinger (1989), JH 106 |
| R1 | 154 | NEWARK | 0 | 17500 | | | 8 | | |
| R57 | 80 | WINNEMUCCA LAKE | 0 | 2900 | | | 9 | | |
| R40 | 110 | SCHURZ SUBAREA | 0 | 500 | | | 9 | | |
| R40 | 110 | LAKE SUBAREA | 5 | 600 | | | 9 | | |
| R40 | 110 | WHISKY FLAT | 0 | 5400 | | | 9 | | |
| R17 | 14 | SURPRISE (NV) | 4 | 500 | | | 10 | | |
| R57 | 84 | WARM SPRINGS | 4 | 6000 | | | 10 | | |
| R57 | 85 | SPANISH SPRINGS | 4 | 600 | | | 10 | | |
| R57 | 86 | SUN | 4 | 50 | | | 10 | | |
| R57 | 89 | WASHOE (TOTAL) | 4 | 15000 | | | 10 | | |

| | | | | WATER-BUDGET ESTIMATE OF DISCHARGE | | | | |
|---|---|---|---|---|---|---|---|---|
| HYDRO-GRAPHIC | VALLEY | RECHARGE REJECTION | REPORTED MAXEY-E | TOTAL DISCHARGE | OTHER INFLOW | DISCH REJEC. | MODEL ESTIMATE OF RECHARGE | SOURCE |

| REF. (1) | BASIN NO. (2) | | REASON (3) | RECHARGE (AF/YR) | (AF/YR) | (AF/YR) | REASON (4) | (AF/YR) |
|---|---|---|---|---|---|---|---|---|
| R12 | 141 | RALSTON | 4 | 16000 | | | 10 | |
| R10 | 146 | SARCOBATUS FLAT | 4 | 1200 | | | 10 | |
| R12 | 149 | STONECABIN | 4 | 16000 | | | 10 | |
| R10 | 228 | OASIS | 4 | 250 | | | 10 | |
| R20 | 28 | BLACK ROCK DESERT | 1 | NC | | | 11 | |
| R8 | 36 | INDEPENDENCE | 1 | NC | | | 11 | |
| R35 | 46 | SOUTH FORK | 2 | NC | | | 11 | |
| R35 | 47 | HUNTINGTON CR | 2 | NC | | | 11 | |
| R35 | 48 | DIXIE CR | 2 | NC | | | 11 | |
| B15, R32 | 54 | CRESCENT | 1 | NC | | | 11 | |
| R43 | NA | LONG (WASHOE, NV) | 0 | 700 | | | 12 | |
| R47 | 190 | GROUSE CR (NV) | 0 | 700 | | | 12 | |