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Delineation of Ground-Water Flow Systems in Nevada

by
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FOREWORD

This report may be considered the result of a pioneer effort to delineate ground-water flow systems in a large, relatively undeveloped region. This study was conducted by the Center with support provided by the Office of Water Resources Research, U. S. Department of the Interior under Matching Grant Agreement No. 14-01-0001-563, and Annual Allotment Nos. 14-01-0001-593, 798 and 923.

Results of this study should be of considerable interest to all who are students of ground-water in general, and in particular to those interested in ground-water flow systems in arid lands. The study has pointed out many problems associated with confident delineation of ground-water flow systems, most of which have not been fully resolved. It also points out techniques and lines of investigation that are not commonly practiced or pursued and that offer potential returns in knowledge of ground-water flow. Fluid potential of ground-water in three dimensions is pointed out as the optimum, but most neglected, technique of detailed flow system delineation known.

As well, this report provides a map of Nevada flow systems which should prove to be a useful tool for water resource management considerations and future ground water studies.

William S. Butcher
Acting Director
Center for Water Resources Research

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ABSTRACT

Available hydrologic and geologic information has been considered with flow system theory in an attempt to delineate ground-water flow systems in Nevada. Definition of sink areas, source areas and configuration of flow within the flow system has been the primary objective of the study. Source areas and configuration of flow have been approximated in most areas, whereas sink areas have been confidently located for nearly all of the flow systems. The one hundred and thirty-six recognized flow systems in Nevada have been separated into two groups based upon configuration of flow. Presence or absence of important interbasin flow has been used as a criterion.

Several types of fluid potential measurements are demonstrated to be the optimal methods of delineating ground-water flow systems. Changes in fluid potential in the vertical direction establish source areas, zones of lateral flow, sink areas and boundaries of circulation cells. These data are sparse in many areas of Nevada; hence, other approaches have been considered. Ground-water temperature has been used to establish apparent depth of circulation, and some evidence suggests utility for recognizing interbasin flow. Characteristics of large springs in the carbonate rock province of Nevada, including water chemistry, water temperature, variation in discharge, tritium concentrations and C^{14} determinations, have aided flow system delineation. Three general types of flow system have been recognized in carbonate terrane on the basis of these studies. These have been called "small local," "local" and "regional" flow systems.

A concept of flow capacity of terrane for ground-water flux has aided in the recognition and understanding of environmental influences on the configuration of ground-water flow systems. Interbasin flow is closely related to bedrock permeability and availability of moisture for recharge. In nearly every area where interbasin flow has been recognized, there is also relatively permeable bedrock. In most areas of interbasin flow, only limited moisture is available for recharge.

INTRODUCTION

Nevada, like most other western states, depends primarily upon the available water resources in the states. Under the existing economic development, most of the available surface water and part of the available ground water is utilized to some degree, generally in relatively low uses (*i.e.* small return income per unit of water used). However, as population increases and use of water gradually shifts from agriculture to industry and urbanization, demand for and development of local water resources throughout the state will greatly change, just as it has in the rapidly growing urbanized areas of western and southern Nevada. With increased competition for water, there will undoubtedly develop a need for more intensified management of water resources. Ideally, the management of water resources can only be applied if the resources are understood and delineated. Ground water in Nevada constitutes a prime water resource which will become more important as surface water supplies fall short of the demand throughout the state.

Purpose and Scope

This effort is believed to be the first statewide attempt to delineate ground-water flow systems in Nevada, and perhaps the first such effort in any large area. Investigations aimed at flow system delineation on a large scale are not common. Most ground-water studies are directed at local conditions of ground water, such as local occurrence, availability, character and movement. The present investigation is a marked departure from the more conventional ground-water study, in that the objectives are basically different. Of prime concern here is the regional occurrence and movement of ground water as established by sources and sinks of ground-water flow systems, and probable boundaries of the systems. Hydrologic and hydrogeologic data within each system are considered primarily to understand the particular system, rather than to illustrate local aspects of availability of ground water.

Many special problems in Nevada suggest the necessity of studying ground water within the context of flow system delineation, which gives better opportunity of recognizing the total area of response to a stress applied to the system. For example, interbasin flow, detonation of underground nuclear devices, underground mining in permeable rock and numerous hydrologically closed basins demand consideration of the entire ground-water flow system, if sound and intense utilization of the phenomenon of underground flow of water is to be accomplished with a minimum of undesirable responses.

One important product of this investigation is a map of the extent of ground-water flow systems in Nevada (Plate I). The utility of the map seems apparent if development, management and research aspects of ground water in an arid zone are considered. In the arid part of western United States, much economic development has been generated by surface water. Further economic development will necessarily be dependent upon ground-water development and a shift from low uses to higher uses of presently available water. In only a few parts of Nevada additional economic development must await realization of water importation schemes. Hence, detailed knowledge of ground water is critical in optimizing future growth in Nevada, the arid southwest and other arid lands of the world.

Knowledge of ground water should extend far beyond the technology of ground-water development. The full spectrum of management and utilization of ground water as a resource is dependent upon the character of the flow system involved. Even though ground water is considered a renewable resource, it is becoming increasingly apparent that a non-renewable part of the resource, *i.e.*, the ground water in storage, constitutes the major part of the resource in most arid lands (Domenico, 1967). Further, as technologic advances increase the amount of toxic wastes, ground-water flow system may be extremely valuable as widespread vehicles for long term waste disposal (Maxey and Farvolden, 1965).

The scope of this particular study is limited primarily to qualitative aspects of ground-water systems because of the large area covered, and the absence of the type of financial support which would be necessary to quantify most ground-water flow systems. This effort has searched for hydrologic and geologic relationships which may make the delineation relatively accurate as well as practical to perform. There are shortcomings in both theory and data used in the delineation presented; undoubtedly errors in delineation stemming from such problems will be found and demonstrated by subsequent investigations in Nevada. In many situations division of flow systems is a problem of scale, and determination of discrete boundaries between systems becomes both subjective and argumentative.

The entire state has been covered by flow system delineation even in areas where data are so sparse or ambiguous as to make any delineation open to justified question. Flow system boundaries in areas of greatest uncertainty are indicated by broken boundaries.

Definition of Terms

A number of terms are briefly defined at this point to aid the reader. Many are discussed in detail later in the text as various aspects of flow system delineation are described.

Regional Ground-water Flow System: A regional system is loosely defined as a large ground-water flow system which encompasses one or more topographic basins. A regional system may include within its boundaries several ground-water basins; interbasin flow is common and important with respect to total volume of water transferred within the system boundaries; lengths of flow paths are relatively great when compared to lengths of flow paths of "local" ground-water flow systems.

Local Ground-Water Flow System: A local system is generally confined to one topographic or ground-water basin; interbasin flow is not important with respect to total volume of water transferred within the system; the majority of flux of water within the system discharges within the associated ground-water basin; flow paths are relatively short when compared to regional systems.

Ground-Water Basin: A ground-water basin is usually only part of a ground-water system, and is used in a practical sense in that it is a region of a ground-water flow system where appreciable quantities of ground water can be encountered and developed by man. More than one ground-water flow system may be involved in a ground-water basin. Within the Great Basin Physiographic Province ground-water basins are commonly the alluvial basins, whereas the entire flow system may involve more than one alluvial basin and also extensive regions of adjacent indurated rocks. A less common relationship is when several flow systems head in a ground-water basin, as may be the case in a few basins in Nevada. It is important to note that there is a marked difference between a "ground-water basin" and a "ground-water flow system," and this distinction separates this study from most preceding ground-water studies in Nevada.

Ground-Water Flow System Cell: A flow system cell as used in this report refers to seemingly discrete circulation cells within large regional systems. A circulation cell may be comparable to a "local" flow system. However, by definition, the local system does not contribute to regional flow systems. The flow system cell, then, is a local system which contributes some flow to a regional flow system. This term is prompted by theoretical consideration of ground-water flow systems. Indirect evidence of cells of circulation within regional systems is present in some parts of the state. However, detailed knowledge of both configuration and flux of regional systems is such that rigid definitions are presented only to clarify thinking rather than to carefully define known physical relationships of flow systems.

Recharge Area: A recharge area is a region of the earth's surface where there is a ***net*** flux of water to the zone of regional saturation. This does not necessarily imply that no ground-water discharge occurs; rather it implies that more enters the zone of regional saturation than leaves. In many areas of Nevada believed to be recharge areas, there is local ground-water discharge from such features as springs, seeps, streams and phreatophytes. Such discharge has been referred to as ' rejected recharge."

Discharge Area: A discharge area is a region of the earth's surface where there is a *net* flux of ground water from the zone of regional saturation. In a manner similar to recharge areas, recharge to the saturated zone may occur, but on a long term basis, the net flux of water is from the ground water system. In arid lands it is very common for saturation to be as much as several tens of feet below land surface in discharge areas because of discharge by phreatophytes. Thus, when moisture is available at land surface in these areas, short term reversal of flux may occur.

Regional Saturation: Regional saturation implies continuous saturation in earth materials over broad areas where voids and permeability exist. Evidence for local saturation within earth materials with ground-water fluid potential unrelated to the fluid potential of extensive ground-water bodies in the same area prompts this term.

Local Saturation: This term is sometimes used for "perched water" or ground water where there is evidence for the absence of hydraulic continuity with nearby bodies of ground water.

Zone of Lateral Flow: Observed potential relationships and theoretical considerations of ground-water flow systems suggest regions within ground-water flow systems where flow is lateral or essentially horizontal. In arid Nevada, these regions of lateral flow in ground-water flow systems may be quite common and extensive. In the region of lateral flow net flux to or from the system is zero.

Sink and Source: These terms are used in a system sense, where the sink of a ground- or surface-water system is the position of termination of the system, and the source is the beginning of the system.

Surface-Water Features: Several terms are used to describe streams and lakes. A "live" stream is used in the sense that flow is prolonged, indicating effluent ground water which sustains the flow. However, the term "perennial" is purposely not used for these streams because the flow may not last throughout the year. Ephemeral streams or lakes are short-lived, with water mostly derived from the direct contribution of moisture occurring on the land surface as precipitation or snow melt.

Pluvial Period: This is a relative term referring to intervals of geologic time when, because of climatic variations, more moisture was available in the Great Basin. The geologic record in the Great Basin indicates several intervals of time when hydrologic conditions were markedly influenced by increased availability of water, probably related to greater precipitation and reduced rates of evaporation.

Playa and Playa Lake: Playas are flat areas essentially devoid of vegetation found in central parts of desert basins. Usually, but not always, they are closed depressions and surface runoff accumulates on the flat area in thin sheets, often only a few inches deep. Playa lakes are occupied by slightly deeper water, and are only entirely dry on occasion. Clastic sediments on playa surfaces are usually fine grained and light colored silt; however, some have various types of salt crusts.

Phreatophyte: This term was originally applied by O. E. Meinzer to a wide variety of plants that extend roots to the water table or associated capillary fringe. In this manner the plants depend on ground-water for moisture rather than precipitation or surface-water runoff. In general, the flora of arid areas which utilize ground water provide evidence of shallow saturation and also delineate where discharge of ground water is occurring by transpiration. The most common phreatophytes in northern Nevada include big greasewood (*Sarcobatus vermiculatus*), big rabbitbrush (*Chrysothamnus nauseosus*), and saltgrass (*Distichlis stricta*). Besides the above, pickleweed (*Allenrolfea occidentalis*) is common in much of central Nevada. The most common phreatophytes in southern Nevada besides some already mentioned include mesquite (*Prosopis veluntina* and *P. juliflora*) and another rabbitbrush (*C. graveolens*). A common but not indigenous phreatophyte, salt cedar (*Tamarix gallica*) is found in many areas of southern Nevada, and is locally present in other parts of Nevada. Common and widely distributed throughout Nevada are various species of willow (*Salix*) and cottonwood (*Populus*).

General Approach

A ground-water flow system is a region within saturated earth materials where there is dynamic movement of ground water from a source to a sink. At the source area water enters the system by virtue of passing from the vadose zone, or zone of incomplete saturation, to the zone of saturation. At the sink area of the flow system water passes from the saturated zone to positions outside the saturated zone of earth materials -- the atmosphere, surface-water drainage systems, lakes, capillary fringes in the vadose zone, plants and ice.

At every point within the flow system each molecule of water has the potential to move from the system; in other words, each water molecule within the flow system, however, slowly, is moving toward the sink of the system. From a practical point of view, water which does not move, or moves so slowly as to be undetectable by virtue of fluid potential differences with respect to surrounding water, can be considered exterior to the dynamic flow system, and such water is considered to be stagnant.

Hence, the ideal delineation of ground-water flow system includes locating the source of the system, the sink of the system, and reliably linking these parts of the system together by establishing a potential gradient from the source area to the sink area. Further, ideal delineation should establish the boundaries between adjacent flow systems, and other characterizing information such as depth of circulation, character of water at various positions in the system, and any other information about the flow system that may be useful. Ideal flow system delineation constitutes knowledge of flow paths of water in earth materials.

Unfortunately, reliable flow system delineation is made extremely difficult in many areas by the paucity of fluid-potential information, as well as the difficulties associated with attempts at locating and correlating source areas with sink areas. Further, most flow system boundaries in Nevada occur in mountainous terranes that are usually void of widespread subsurface information. Even in the basin and foothill areas subsurface information is extremely localized, and fluid potential data are generally unavailable below the upper few hundred feet of saturation.

Areas of recharge cannot be directly proven in many parts of Nevada. Furthermore, one of the most used hydrologic approaches, water budgets, must be made upon assumptions that are not readily defendable unless the flow system is first delineated -- in other words, using water budgets for flow system delineation employs varying amounts of circular reasoning. Thus, this study approaches the system delineation problem from several aspects, all believed to be at least conducive to valid delineation, but verification of delineations must await detailed study in many areas.

The basic approach has been to use fluid-potential information where available, either on the basis of water levels as indicated by wells or mines, or by considering surface features closely related to ground water, such as springs, seeps, base flow in perennial or live streams, phreatophytes and moist or salty areas associated with capillary fringes. Where this type of information is very sparse or ambiguous with respect to true saturation and associated fluid potential, more indirect evidence was called upon, such as hydrogeology, water budgets relationships and availability of moisture for recharge.

However, uncertainties remain in some areas even with these data; hence, in problem areas a search for supporting relationships was made. Studies of ground-water chemistry, ground-water temperature and detailed spring studies in carbonate rock terrance were made in an effort to supplement the more conventional data.

Data Sources

Data used in this study include most published work on ground water in Nevada, and in addition, data derived from the files of the Office of the State Engineer, as well as information collected in reconnaissance study throughout most of the state. No attempt is made to credit data sources in detail because of the bulk. Published data sources are included in the bibliography, and it can be seen that the principal work is by the U. S. Geological Survey. Appendix table 1 lists by number the references which offer ground water or related information within the 136 ground-water systems delineated in this study.

Sources of hydrologic data other than reports include topographic maps by the U. S. Geological Survey (scales 1:24,000; 1:62,500; 1:250,000); Nevada State Highway Department County maps; miscellaneous maps and reports of the Nevada Fish and Game Commission; U. S. Forest Service maps; and grazing district maps of the Bureau of Land Management. Use of these maps aided in the location of springs, wells and surface-water features.

Data obtained from the Office of the State Engineer included driller's logs and water right information. These data often aided in determination of water levels in wells, depth of wells and location of springs. Precipitation maps used in this study are the 1965 revised edition of Hardman, *et al.*, 1936, and Stidd, C. K., 1966.

Distribution and occurrence of ground-water discharge was derived from many sources, including Water Supply Papers, Ground-Water Reconnaissance Reports, well data from the State Engineer's records, and various publications of the Nevada Department of Conservation and Natural Resources. Aerial photography supplied by the Nevada Bureau of Mines proved to be of considerable value in location of discharge in many areas of the state. Further field reconnaissance and aerial reconnaissance were made of many areas of Nevada to field check distribution of phreatophytes and other features relating to water levels. Most of the large springs associated with carbonate rock terrane were located, inventoried and sampled.

GROUND-WATER POTENTIAL

Ground-water flow in natural environments of saturated media is recognized by observation of phenomena related to the movement of water through permeable earth materials. The actual movement of water is rarely, if ever, observed because of the subsurface position of flow, and the extremely low rates of movement. Hence, recognition and definition of ground-water flow systems must be established entirely by observation of phenomena related to movement of ground water. Fluid potential of ground water is believed to be the most reliable measure of ground-water flow.

Darcy's Equation

Even though the general concept of water moving through a porous medium apparently dates back to an early Roman engineer, Vitruvius Pollio, Darcy (1856) was the first to publish a rational description based on experiments. A form of Darcy's findings in the situation of steady flow in a porous medium is

$$Q = KA\frac{dh}{dl} \quad (1)$$

where Q is rate of flow, K is hydraulic conductivity of the medium (dependent also upon the viscosity and density of the fluid), A is area of cross section, h is hydraulic head, and l is distance along the flow path. The term $\frac{dh}{dl}$ is therefore the rate of change in hydraulic head along the flow path, or hydraulic gradient.

At a point in the flow system, head is defined as

$$h = z + \frac{p}{\gamma} \text{ and } \gamma = \rho g \quad (2)$$

where z is vertical distance from a horizontal datum to the point of interest, p is pressure at that point, γ is the unit weight of water, or density (ρ) times acceleration of gravity (g). Head is therefore the measure of energy per unit weight of fluid (water) and is a scalar quantity. This is the quantity commonly approximated in the field by measurement of static water levels in wells, or the measurement of elevation of discharge or recharge of ground water.

Most ground-water contour maps depict a hypsometric surface (head above sea level) frequently called a potentiometric surface in the United States at the present time. When head measurements are made in an environment of multiple aquifers, the often applied term of piezometric surface to the resulting map may or may not be strictly correct, depending upon whether the surface depicted is established by the head above a particular zone or aquifer (correct usage), or whether it is an equal head map constructed from head measured in more than one aquifer. Also, the term piezometric surface is applied incorrectly to the measure of head above some datum plane other than the aquifer.

Bernoulli's Equation and Fluid Potential

Hubbert (1940, p. 797-802) demonstrates that the property of the fluid which determines the dynamic flow system at any point in that system is the mechanical energy of fluid per unit of mass, and refers to it as the *potential* of the fluid. He approaches quantification of this property of the fluid by considering Bernoulli's equation for fluid flows without friction (as is approximately the case for liquids of very small viscosities and gases) where each element along the path of flow retains its initial mechanical energy and thus is characterized by the same potential:

$$\Phi = gz + \int_{p_0}^{p} \frac{dp}{\rho} + \frac{v^2}{2} = \text{constant} \quad (3)$$

where Φ is the fluid potential or mechanical energy per unit of mass, g is the acceleration of gravity at the position of consideration, z is the altitude of the position of consideration, p_0 and p are limiting values of pressure over the interval considered, ρ is density of fluid, and v is velocity of the fluid. In ground water and most fluids, however, viscosity is present and flow is accompanied by friction losses; therefore, along a flow line there is a continuous loss of mechanical energy, and thus the fluid potential continually decreases down the path of flow. The losses in mechanical energy down the flow line go to heat, or perhaps are in part converted to energy taken up by chemical reactions which occur in the flow system.

Further consideration permits the omission of the velocity potential term ($\frac{v^2}{2}$) of equation 3 as the rate of movement of ground water is so small as to make this term negligible. Thus, for liquids which are relatively incompressible, equation (3) can be simplified to

$$\Phi = gz + \frac{p - p_0}{\rho} \quad (4)$$

by integrating the second term between the limits of p and p_0. Figure 1 illustrates the relationships of the terms embodied in equation (4), and it can be seen that the equation further simplifies by recalling from equation (2) that pressure at the point of consideration, including atmospheric pressure (p_0) is

$$p = \rho g (h - z) + p_0 \ , \quad (5)$$

which is Bernoulli's equation for static fluids. Substituting the right hand term of equation (5) into equation (4) yields, upon simplifying

$$\Phi = gh \ , \quad (6)$$

a scalar quantity of potential (mechanical) energy per unit of mass. When gravity is considered essentially constant within the realm of consideration, *e.g.* within the part of the flow system that measurements are frequently obtained, dividing through by gravity yields potential energy per unit of weight

$$\frac{\Phi}{g} = h \quad (7)$$

or, very simply, head as measured from the datum.

Fluid or ground-water potential, as stated by Hubbert, and commonly used in the sciences relating to ground water, is therefore based on the following assumptions: (1) velocities of flow are so low as to permit omission of the velocity or kinetic energy component of fluid potential, (2) water is essentially incompressible in a steady state flow situation, or

$$\int p.dV = 0 \text{ and } V = V_0 \quad (8)$$

where V is volume, and V_0 is initial volume, and (3) viscosity is present.

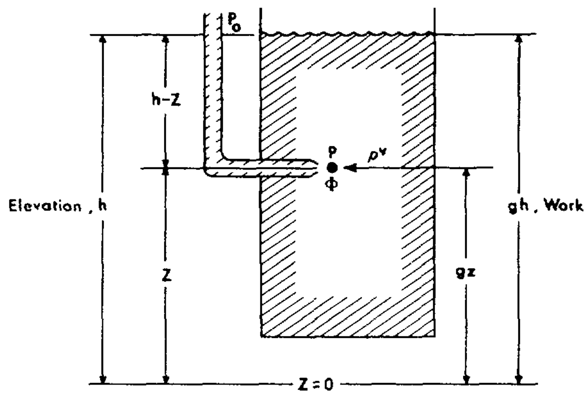


FIGURE 1 - Fluid potential at a point in a static fluid (modified after Hubert, 1940)

Thermochemical Energy

There is some evidence that fluid potential, as considered in Hubbert's development and in nearly all contemporary ground-water literature, may not truly embody all energy aspects of fluids that are necessary to correctly depict direction of flow in some environments of saturated media. Perhaps the best example of the deficiency of the theory is the phenomenon of osmatic pressures that may be experimentally shown to develop across a "semi-permeable membrane." Shales and clays, two very common lithologies in many environments of saturation, behave in experiments as semi-permeable membranes, or in other words, they apparently inhibit the movement of certain ions whereas water may pass through.

Briefly described, an experiment of placing two differing concentrations of water solution on either side of such a membrane (shale) at equal hydrostatic pressures results in water from the dilute solution passing to the more concentrated solution, which, on the basis of conservation of mass, raises the pressure of the more concentrated solution, while the net water chemistry effect is that of decreasing the concentration in the more concentrated solution. If allowed to proceed, the system will come to equilibrium with pressure increased in the more concentrated solution, and this then represents the mechanical energy that is just equal to the internal energy difference between the concentration of the two solutions.

Hence, we see evidence that thermochemical energy within the fluid may be transferred to mechanical energy in a natural medium. Further, the water has moved in a direction opposite to the fluid potential gradient. Therefore, the question of the relationship between fluid potential in natural environments and chemical energy seems pertinent in flow-system delineations, particularly when it is acknowledged that all ground water contains some ions, and some subsurface environments contain fluids that are brines, apparently atmospheric in origin. Thermodynamic description of the flow system in some environments may be desirable, in that all fluid potential losses are assumed to be the irreversible, yet there is firm evidence this is not always the case.

It has been suggested by experimental observation that thermochemical energy produces mechanical movement of water and hence may influence observed ground-water potential. This energy may be particularly important at depth in low permeability media where ground water is frequently charged with high concentrations of ions and is at high temperatures. In part, these manifestations of energy may be unrelated to initial mechanical energy at the position of recharge.

The phenomena that may give rise to such a situation are not carefully investigated in natural ground-water environments, but have been variously termed chemical osmosis, electroosmosis and thermoosmosis. The related phenomenon called the "semi-permeable membrane effect" has been postulated as operative (see, for example, De Sitter, 1947; Bredeheoft, *et al,* 1963; Graf *et al,* 1966) where low permeability rocks such as clays or shales may impede movement of various ions borne by water, thus generating the commonly observed concentrations of saline waters. Further, laboratory experiments indicate that the response of such unbalanced saline solutions on separate sides of clay aquitard give rise to mechanical transfer of water to a state of *higher* fluid potential in the more concenrrated solution (Wyllie, 1948, 1949, 11; McKelvey and Milne, 1962; Hanshaw, 1962, 1964).

The few field studies which attempt to investigate ground-water potential related to this "semi-permeable membrane effect" have been made (Berry and Hanshaw, 1960; Berry, 1959; Hanshaw, 1959; Jones, 1967). In general, these studies, while suggestive of a process which generates abnormal pore-water pressure, do not clearly indicate that the semi-permeable membrane effect has been responsible. Other sources of energy converted to increases in pore-water pressure, such as dynamic loading (Hubbert and Ruby, 1960, p. 151-153) could also be the cause, but in all the studies, the difficulties in collection of reliable three dimensional fluid potential data hinders establishment of cause and effect relationships. However, the closely related development of brines in low permeability subsurface environments is reasonably well documented as stemming from concentration of solutes in slowly circulating meteoric waters.

In summary, ground-water fluid potential is perhaps the most important parameter of ground water that aids in the delineation of a flow system; other parameters, such as chemistry and temperature, are less useful in that many uncertainties are usually involved when interpretations are applied to system delineation. It can be seen, however, that the relating factor of these parameters ultimately lies in the thermodynamics of the system.

The validity of fluid potential data indicating direction of flow seems reliable in shallow and relatively high permeability media. However, fluid potential measurements at depths, where rock permeability is low, may not be valid measures of ground-water flow systems in that thermochemical phenomenon may be an important factor in the actual movement of water.

Ground-water chemistry, as commonly practiced, may not, other than through comparative work, yield any precise knowledge of flow systems. Similarly, ground-water temperature seems perhaps most useful when considered a relic parameter of the environment through which the ground water has passed -- in this manner temperature depicts in an approximate manner the depth of circulation for that flow line sampled, rather than necessarily a measure of the amount of work done by the water.

Flow Systems as Depicted by Models

Previous investigations (Toth, 1962, 1963; Freeze and Witherspoon, 1966, 1967) have examined theoretical aspects of ground-water flow systems and modeled hypothetical systems in two dimensions. It has been found that, given certain boundary conditions, usually imposed by permeability, topography and available recharge, it is possible for what have been called local, intermediate and regional systems to exist (Toth, 1963).

The models provide important points of departure in attempts to delineate naturally occurring ground-water flow systems. The importance of models can be seen in Figure 2, because a commonly assumed criterion for a system boundary is a region of high ground-water potential. These regions of high potential are usually recognized in nature by the configuration of saturation, and fluid potentials at depth are rarely known. The models in Figure 2 clearly suggest that such regions of high fluid potentials are not necessarily perfect boundaries to the system as a whole, and that flow can occur at depth from one "cell" of the depicted system to another.

Most important to flow-system delineation are hydrogeologic conditions of relatively permeable lithologies at depth. In such situations models suggest that large quantities of water can move from one "cell" to another. Thus, it may be insufficient to map only the surficial or "shallow" fluid potential field of a ground-water system if full and reliable identification of the system is to be accomplished in terrane which may be underlain by rocks of high realtive permeability. Most hydrologic data of ground-water potential are limited to close to the top of the zone of saturation, and hence even a detailed knowledge of the configuration of saturation may be woefully inadequate to ascertain where some waters leave the system, or where they enter the system in areas underlain by permeable zones at depth. There is good evidence for extensive permeable zones at considerable depths in eastern and southern Nevada.

Vertical Boundaries of Flow System Recognized by Fluid Potential Measurements

By observing change in potential of ground water in a borehole or well considerable insight into the flow system configuration can be obtained. Recalling from equations (4), (5) and (6) that fluid potential of ground water is

$$\Phi = gz + \frac{p - p_o}{\rho} = gh \qquad (9)$$

and defining change in fluid potential in a single borehole as

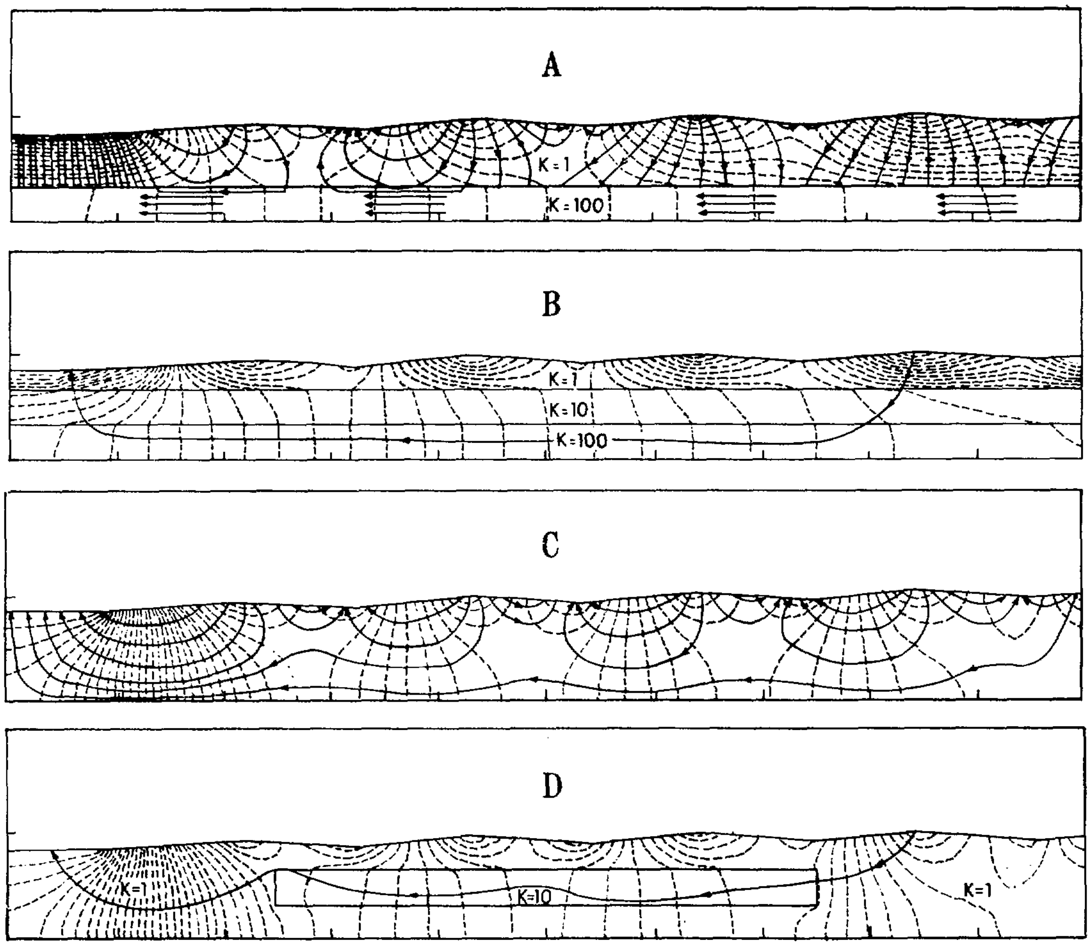
$$\Delta\Phi = \Phi_1 - \Phi_2 \text{ and } \Delta z = z_1 - z_2$$

where $z_1 > z_2$, the vertical rate of change in fluid potential is

$$\frac{d\Phi}{dz} = \lim_{z_1 \to z_2} \frac{\Delta\Phi}{\Delta z}$$

This is the rate of change in potential with respect to change in elevation. The measure provides a powerful tool for determining configurations of ground-water flow systems from borehole or well fluid potential measurements at a given geographic locality. The flow system is generally solenoidal in shape because both recharge and discharge (the source and sink of the system) occur near or at land surface. Hence, regions in the saturated zone displaying vertical components of flow are more or less indicative of the configuration of the system.

Figure 3 illustrates the generalized relationships of changing ground-water potential with respect to increase in depth. In areas where there is a component of downward flow $\frac{d\Phi}{dz}$ will be positive. Further, when deep borehole potential data is available, it is possible to recognize system boundaries when values of $\frac{d\Phi}{dz}$ are plotted with respect to the elevation of observation in Figure 4. When the value of $\frac{d\Phi}{dz}$ varies from positive or negative values to zero, penetration has proceeded from regions of either downward components of flow or upward components of flow to either regions of stagnation of flow or lateral flow. When $\frac{d\Phi}{dz}$ varies from a positive or negative value through zero to the opposite sign, one system or cell of a system has been penetrated and another system or cell has been encountered. When $\frac{d\Phi}{dz}$ is zero, either conditions of lateral flow or



A and B - Situation of interbasin flow produced by greater relative permeability at depth and relief.

C - Situation of interbasin flow produced by relief alone, in uniform permeability media.

D - Situation of interbasin flow created by lense of permeability material.

← - Flow line

---- - Equipotential line

K - Relative Hydraulic Conductivity

FIGURE 2 - Models of configuration of flow with varying boundary conditions (modified after Freeze and Witherspoon, 1967)

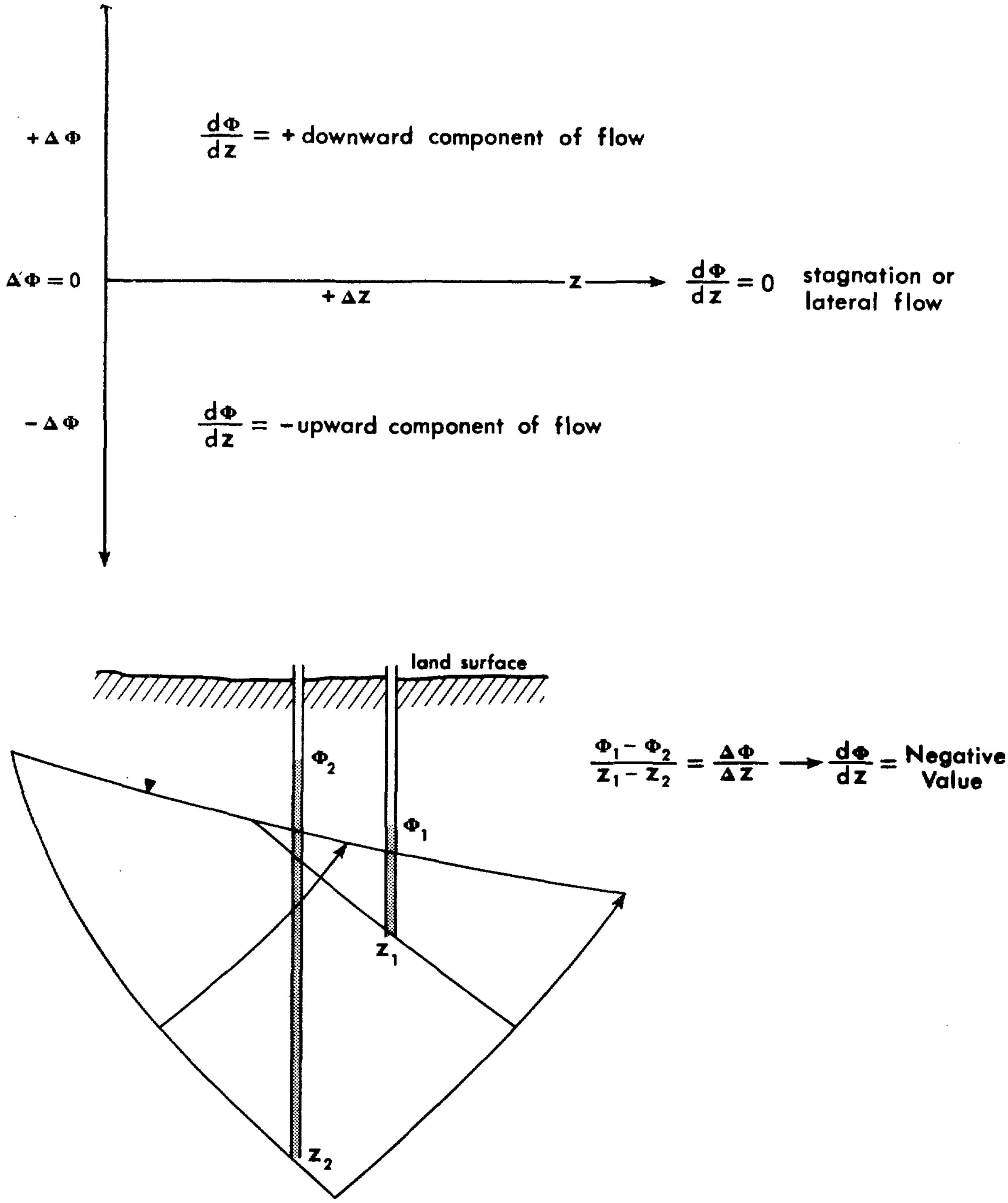


FIGURE 3 - The relationship of direction of flow and the sign of $\frac{d\Phi}{dz}$

stagnation are present. In the special situation where Φ_1 and Φ_2 are entirely constituted by elevation potential ($\frac{d\Phi}{dz} = g$), the observation suggests discontinuity of flow between the points of measurement, z_1 and z_2. In this latter situation water which stands only at the bottom of boreholes as the hole is deepened suggests local pockets of saturation, or perched water.

The utility of fluid potential data in very deep boreholes is compromised by the uncertainty of thermochemical energy relationships discussed in the preceding section. Further, there has been very little systematic collection rates of change in fluid potential with respect to depth, and even less recognition of the utility of such measurements for depiction of flow system boundaries.

Deep Well Fluid Potential Data

Some areas of Nevada that have deep wells or boreholes offer very gross data of fluid potential change with depth. Eagle Springs Oil Field underlies the discharge area of Railroad Valley flow system (No. 95 in Plate I). Flowing shallow wells in the unconsolidated sediments in the area indicate a negative $\frac{d\Phi}{dz}$, or upward flow of ground water. However, petroleum in underlying Tertiary and Paleozoic rocks (at intervals between about 7,000 and 12,000 feet of depth) does not stand at land surface (Robert Horton, 1968 personal communication). This suggests that the vertical rate of change in fluid potential is negative in shallow sediments, increases at some point above 7,000 feet to zero, and then becomes

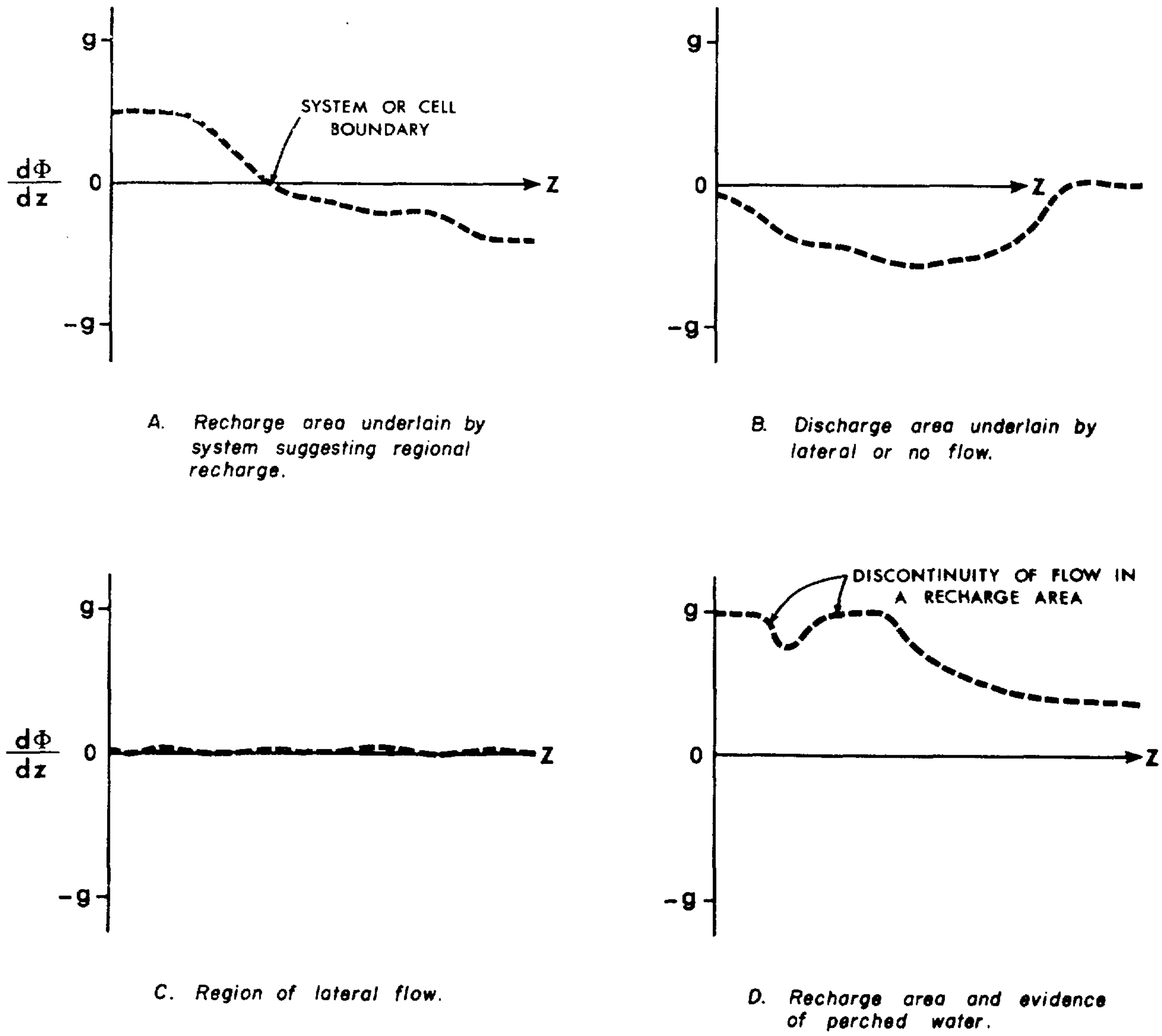


FIGURE 4 - Example of flow system information determined from single borehold plots of rates of potential change with respect to depth

positive by the time the petroleum production zones have been reached (below about 7,000 feet).

The apparent fluid potential change with depth suggests that one flow system has been totally penetrated and conditions of either stagnation, lateral flow, or perhaps even a separate flow system have been encountered in the hydrocarbon production zones. The reported potential relationships are too approximate to determine which is the case.

The geographic position of Eagle Springs Oil Field is of considerable interest when considered in the context of the geometry of ground-water flow system delineated in that area. The area is believed to constitute a ground-water discharge area where interbasin flow is discharged. The petroleum deposits therefore underlie an area where the deepest circulation of the active ground-water flow in the region is leaving the flow system.

In Hot Creek Valley (No. 96 in Plate I) recent deep drilling and testing by the Atomic Energy Commission suggests reversal of $\frac{d\Phi}{dz}$ from negative to positive; however, the data collected is not without ambiguities. In the Nevada Test Site area (No. 122 in Plate I) in alluvial basins underlain by tuffs and carbonate rock strata, reported decreasing fluid potential with depth suggests the basins behave as recharge areas for the Nevada Test Site flow system in the deep carbonate rock aquifers. These data suggest that some of the southern Nevada alluvial basins may constitute recharge areas where there is a net downward movement of ground water into permeable zones in the underlying bedrock. The importance, or relative contribution, of recharge to interbasin systems in such situations is not known; however, the boundaries of the Las Vegas and Amargosa-NTS Flow systems (Nos. 124 and 122, respectively, in Plate I) were drawn purposely through one of the alluvial basins to demonstrate the possibility of such an area constituting the ground-water divide between two interbasin flow systems in relatively deep seated carbonate rocks. The boundaries of these systems are as yet relatively uncertain because of the paucity of deep fluid potential measurements.

A recent test well in Las Vegas Valley yielded some fluid potential data of interest, though again of uncertain value because of construction problems. The reported observed static levels, with openings in the casing between about 5,000 feet and 8,000 below land surface, were always greater than 250 feet below land surface. Static water levels in shallow wells in this area are within 30 feet of land surface with an upward component of movement of water. This relationship suggests either stagnant conditions, or that a separate flow system or cell was penetrated.

In most of the wildcat wells drilled in eastern and southern Nevada, as well as those in western Utah, reports of cavernous carbonate rocks are common. Serious circulation problems are also reported, indicating zones of high permeability. Unfortunately, fluid potential data from most of these deep test holes were not carefully collected, or if collected, they were generally unreported. These test wells, representing many millions of dollars in total expenditures, have not been retained as monitoring points for ground-water systems, and for the most part fluid potential data which might have been developed from such test holes are not available.

Shallow Well Measurements of Fluid Potential

Figure 5 is a cross section illustration of a hypothetical ground-water flow system drawn so that observed relationships of typical Great Basin ground-water systems are included. It is important to note that depicted relationships of ground-water potential have been documented by careful observations in natural flow systems in Nevada, but not all in the same system. Illustrated is the type of detailed fluid potential information which can be derived during construction of cable-tool wells in which blank casing (unperforated casing or casing perforated only in a short interval near the bottom of casing) is driven as the well is deepened. Less detailed, but essentially as informative, fluid potential information can be derived from several closely spaced wells perforated at different depths.

Indicated by symbols are static water levels of first encountered saturation. In most earth materials the static level first recorded will often be slightly higher than the position of first noted saturation because of local confinement. For example, in mountain areas, where fracture premeability prevails in indurated rocks, chances are that the first-encountered saturated fracture will not be exactly at the air-water interface, but somewhere below, hence, the immediate rise in water. The same is true for other parts of flow systems, where penetrated earth materials are likely to be unconsolidated clastic sediments. Low permeability material may be saturated, but yield of water is so restricted that recognition of saturation may not occur until more permeable lenses of material are encountered, and hence, an apparent initial rise of water will occur.

Zones of Flow Systems as Indicated by Fluid Potential: Upon deepening wells in various parts of the flow system, static water levels measured in fully cased wells will respond according to the components of vertical movement of water. In the zone of recharge, heads or static water levels will fall as wells are deepened because the water has a downward component of movement, and head losses, as compared to initial heads measured near, or at, the air-water interface, are a function of energy lost by the water as it percolates from the top of the saturated zone to point of measurement. Decreasing fluid potential near the top of saturated zones is generally good evidence of recharge in the area.

In the so-called "zone of lateral flow", which may be commonly extensive only in flow systems of arid or semi-arid terrane, change in fluid potential with depth is very small, and often not detectable. It is common to experience an initial water level rise when the first saturated aquifer material is penetrated, which, unless the hole is considerably deepened and fluid potential monitored, can lead to erroneous interpretations of where in the flow system the well is situated. The reason for uniform ground-water potential with depth is that direction of flow is essentially all lateral, and hence, the vertical well flows an equipotential line. If the penetrated sequences of earth materials are relatively permeable near the air-water interface, the absence of vertical potential differences creates what has been called an "unconfined" or "water table" situation.

Another zone, closely related to the zone of lateral flow, is observed in some flow systems in Nevada. This is a region in the flow system where head or ground-water potential increases with depth, yet there is no ground-water discharge in the immediate area. This relationship seems anomalous at first glance because it suggests that matter is being destroyed, *i.e.* if water is moving upward, yet it does not leave the system, where does it go? Figure 5 illustrates how this phenomenon occurs, and that it is essentially related to an upward swing in direction of flow toward an adjacent discharge area. It occurs noticeably when significant flow is coming to the zone of discharge from depth in relatively permeable material, such as along the west side of Las Vegas Valley.

In the ground-water discharge zone, it is unusual not to observe rises in static water levels as wells are deepened. Because the zone of saturation is very near land surface, flowing or artesian wells often result if penetrated aquifers have not been extensively pumped by surrounding wells. In fully cased wells, this encounter of increased potential with depth will produce a flowing

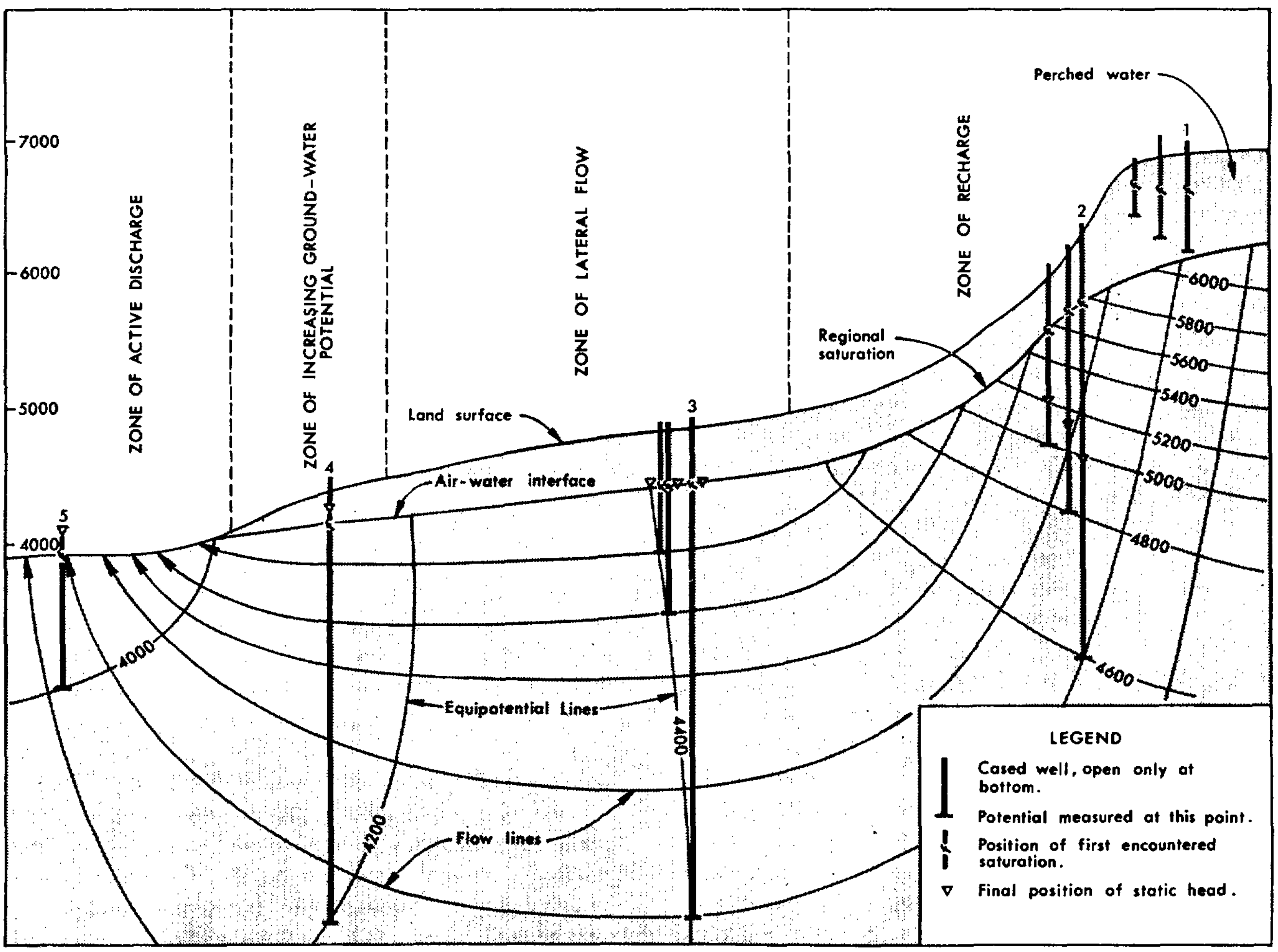


FIGURE 5 - Sketch of observed relationship in a typical Great Basin flow system

well nearly every time if the well encounters and terminates in a relatively permeable aquifer at depth. In alluvial valleys of Nevada, however, yield of such a well is often small because of the lenticular and discontinuous nature of most permeable horizons in discharge areas of basin lowlands.

In most areas closely adjacent to or in areas of ground-water discharge in alluvial basins of Nevada, experienced well drillers using cable-tool drilling methods commonly take advantage of the phenomena of increasing ground-water potential with depth. Typically, alluvial sediments of the basins are composed of alternating sequences of coarse- and fine-grained sediments with markedly varying permeabilities. Hence, as the better aquifer materials are initially penetrated, noticeable and measureable increases in static water level occur. The drillers thus have a direct measure of permeability as indicated by rapid, slow or unnoticable water level changes as various beds are encountered. In some valleys, such as Las Vegas Valley, lithologies as indicated by well cuttings are not always sufficient to establish the permeability of horizons because of ambiguous relationships (caliche horizons can be either confining beds or aquifers), and thus this approach is valuable in establishing proper placement of perforations. In some areas of Las Vegas Valley at the present time, withdrawal of ground water has greatly reduced, and in some zones reversed, the original upward gradients.

As described in the preceding discussion, variations of ground-water potential usually exist in vertical and lateral directions regardless of hydraulic properties of earth materials. The magnitude of variations in potential measured in the vertical direction is a function of both permeability and flux, as well as direction of movement. Hence, with an environment of low permeability, a moderate flux of water will produce marked changes in potential from one region to another. With little or no flux of water, only minor or no potential differences will exist in any direction, and thus a "hydrostatic" condition prevails. In such a situation, water potential is equal within all parts of the saturated evnironment and all static water levels measured in wells should be equal. Flow system analysis suggests the frequently expressed terms "confined", "unconfined" and "semiconfined" are misleading in that there is actually confinement in every part of a hydrodynamic flow system in porous media, and the degree of apparent "confinement" may be as much dependent upon direction of movement and flux as it is on variations of permeability.

Recognition of Perched Water: In Figure 5 there is also illustrated the effect of so-called "perched" water or local saturation, very common in indurated rocks with fracture permeability in areas where sufficient moisture is available for recharge. Where perched ground water exists, there is discontinuity of ground-water potential between zones permeable enough to yield water to a bore hole or well. Thus, if the entire zone of perched water is penetrated, and regional saturation is encountered, it will be found that at some point in penetration total head change with respect to vertical penetration is equal to unity; that is, for every foot the bore hole has been deepened, there has been a loss of head equal to increase in the depth of the hole. This relationship is difficult to observe in most field situations, but does provide the best criterion for recognizing perched water or local saturation versus ground water associated with regional saturation.

Head Versus Depth of Well: Figure 6 is a plot illustrating how carefully obtained head measurements made during construction of cable-tool holes with blank casing can depict positions in a flow system with respect to fluid potential environment. More than one hole in each zone of the system permits determination of lateral changes in potential as well, and thus provides a three dimensional potential field, which, if either flux or average permeability is known, permits quantitative treatment of the system. In the absence of these latter data, head data still more or less define direction of flow.

Plotted on the graph of Figure 6 are five wells shown in Figure 5, each within a different zone of the flow system, and one in the zone of perched water. The behavior of head change with depth clearly illustrates which part of the system each well is in when considered with other available data such as land surface evidence of ground-water discharge or recharge, and encountered rocks or sediments. In actual practice, trends in head variation must be considered more important than any particular measurement because of the influence of heterogeneous geologic environments, and the imperfect nature of the well as a sampling mechanism for tapping ground water with undistrubed fluid potential.

Apparent Gradients as Established by Water Levels in Wells: It is important to note in Figure 5 the apparent gradients as indicated by the final static water levels in the three wells in the recharge zone, and likewise the three wells in the "perched" water zone. These static levels would give the impression of ground water flowing in the opposite direction of the actual lateral component of flow. The relative depths of the wells and associated position of measurement of fluid potential are important considerations. Erroneous concepts of direction of flow may be developed in areas where marked vertical movement of water takes place, such as recharge and discharge areas of many flow systems. In these areas, many boreholes in indurated rock and extensively perforated wells in semi-consolidated or unconsolidated sediments are often of uncertain value as

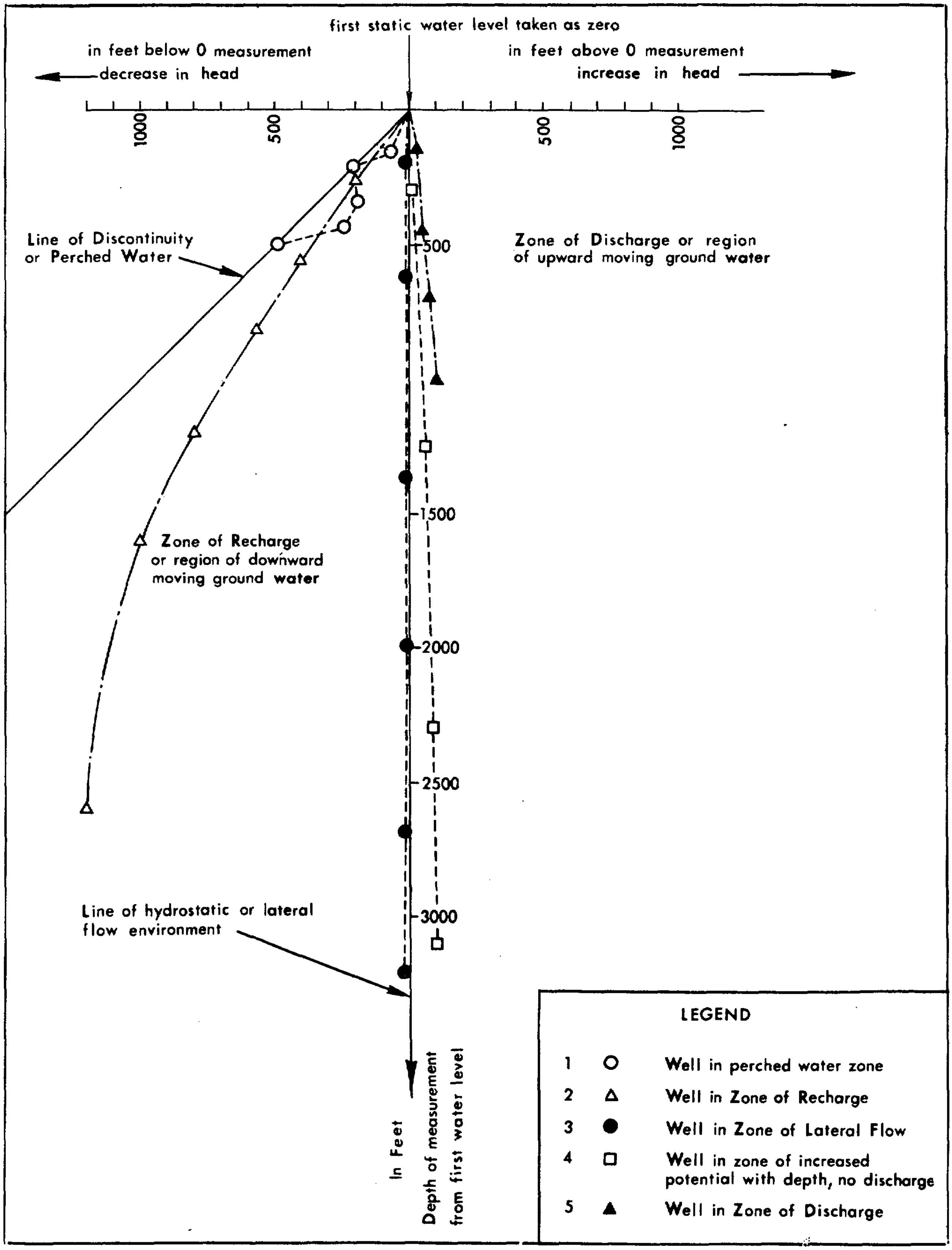


FIGURE 6 - Plot of head variation as observed in wells

control points for determining direction of ground-water flow.

Static water levels in such wells and boreholes are composite responses of the tapped permeable horizons, *i.e.* functions of several different fluid potentials. Some zones may be more permeable than others, and if all zones contain water at different potentials, there will occur, with enough time, adjustments of fluid potential from one zone to another. In other words, the observed level of water is a composite fluid potential, but not necessarily an average, until considerable time has lapsed after construction of the well, because of differences in transmissibility of contributing zones. Hence, after construction, a period of transient fluid potential may be observed. An example where this phenomenon, sometimes called "short circuiting", may have been observed was in deep boreholes in fractured granite (Mifflin, *et al.*, p. 294). However, in the cited case other influences may also have been operative.

HYDROGEOLOGY

In a flow system study a number of geologic considerations yield insight into the characteristics and configurations of ground-water flow. Included are lithologic considerations, such as expectable transmissivity of different rock types, expectable response of earth materials to various hydrologic phenomena, recorded history of hydrologic phenomena as indicated by geologic features, and in general, many aspects of interactions between earth materials and water.

Geologic Compilations and Uses

The geology of Nevada provides the physical framework which essentially controls the configuration and character of ground-water flow systems. This influence is comprised of distribution of permeability, landforms and what might be termed historical relationships. Within each of these categories lie many important relationships which influence character and configuration of ground-water flow systems. In most situations, however, great voids of knowledge permit recognition of hydrogeologic relationships in only a general sense.

Permeability: This basic parameter of rock determines the rapidity and location of possible flow in the lithosphere. In general, permeability is either of primary of secondary origin, the former dependent upon interconnected voids developed during formation of the earth material, and the latter dependent upon subsequent modifications of earth materials.

The complex tectonic history and related structure of the Great Basin essentially precludes any rational, detailed depiction of rocks in the subsurface without considerable subsurface information. Hence, three generalized approaches have been made to account for the gross influence of permeability on ground-water systems: 1) consideration of sedimentation and structural history of Nevada and surroundings to define the broad lithologic provinces of bedrock lithologies, and associated expectable permeability; 2) examination of the relative abundance of various rock types within these provinces to ascertain which may be permeable enough to transmit appreciable quantities of water; and 3) establishment of the areal distribution of hydrogeologic units at land surface to approximate the distribution of expectable relative permeability.

The first item is reported in Maxey and Mifflin (1966) and essentially defines, on the basis of geographical distribution of sedimentation and subsequent structural evolution, the regions of Nevada with extensive sequences of carbonate rock. In many areas there is ample evidence of limestone and dolomite, transmitting significant volumes of flow of ground water by virtue of secondary permeability.

The second consideration is in a sense an elaboration of the establishment of relative permeability provinces. In this compilation all reported measured sections in the state were plotted as to location, aggregate thickness of carbonate rocks, aggregate thickness of volcanic rocks and total thickness of measured section. Figure 7 illustrates the part of the state where about 80 percent of reported measured stratigraphic sections (in over 265 references) were constituted of 50-100 percent carbonate rock types. Unfortunately, this relationship is undoubtedly biased by the interest of most geologists in carbonate rock sequences -- other rock types in the area may be ignored or unmeasured. The approach leaves much to be desired even though it gives some idea of relative abundance of hydrologically important rock types in geographic areas. Further, though the state is about 30 percent volcanic rock at land surface, the amount of detailed stratigraphic information is extremely sparse if measured by the number of described stratigraphic sections.

The third approach toward establishing probable permeability distribution was the development of a map of relative permeabilities at land surface. This was accomplished by establishing probable ranges of relative maximum permeabilities for those lithologies shown in the geologic map of Nevada (Tagg, *et al.*, 1964, p. 12a). These data (Table 1) provided a base map of gross relative permeability to influence flow system boundary decisions in areas of Nevada where hydrologic data are sparse or absent.

Flow Capacity of Terrane

A relative condition observed in Nevada which is not

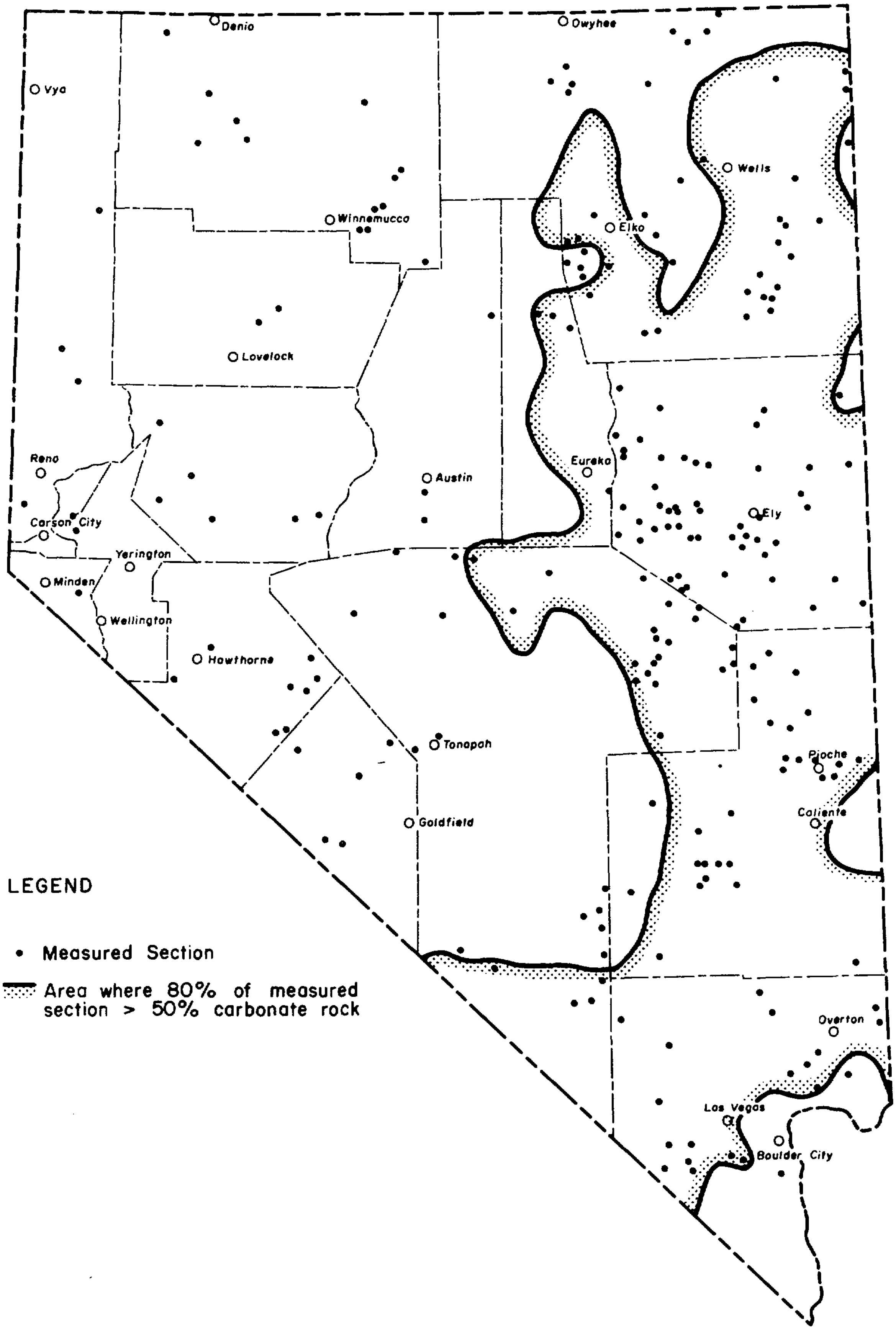


FIGURE 7 - Carbonate rock province in Nevada based on reported measured sections

clearly evident in ground-water literature is the flow capacity of terrane. This concept is here defined as the maximum amount of water any particular hydrogelogic environment can accept and transmit. Capacity of terrane is directly related to Darcy's law (equation 1) where Q is capacity of the terrane, K is a measure of permeability in the direction of flow, $\frac{dh}{dl}$ is hydraulic gradient, and A is the cross section area normal to direction of flow, which locally may be normal to the slope of terrane. The regional parameters of terrane which grossly determine flow capacity are average slope of terrane and average permeability. On a local basis, local permeability and slope become important limiting conditions. These measures essentially determine the amount of ground water that may be transmitted without being rejected by discharge from the terrane should moisture for maximum recharge be available. Figure 8 sketches the concept of flow capacity.

An example of an area at flow capacity (maximum possible flux of ground water) is the northern Ruby Mountains, where available moisture for recharge exceeds the capacity of the terrace, hence, each important drainage channel generally contains flow throughout the year. The permeability and slope of this area, underlain by fractured and jointed crystalline rocks for the most part, permits only so much flux of ground water before there is intersection of local low areas by the zone of saturation, and resulting discharge of ground water.

An example of mountainous terrane not a flow capacity is the east slope of the southern Ruby Mountains. Here, runoff in important drainage channels is more or less restricted to periods of snow melt, and regional saturation of rock does not intersect land surface even at the incised drainage channels. Hence, this terrane, with the present regimen of available moisture for recharge, is not a flow capacity. The difference between the two areas is produced by the occurrence of carbonate rock with higher average permeability than crystalline rocks of northern Ruby Mountains, and in the southern area a steep range front with few erosional reentrants, all of which permit high ground-water gradients. Should available moisture for recharge increase, the southern Ruby Mountain flow system would be influenced by an increase in flux in the system. Maximum flux would be reached when any further increase in flux results in an equal increase in local discharge, hence, the area would be at flow capacity. In the northern Ruby Mountains, additional availability of moisture for recharge would result in an increase in rejected recharge, and also an increase in direct runoff. The flux of the flow system would not be greatly influenced.

A similar relationship of flow capacity exists for valleys in the Great Basin. Most valleys are below flow capacity in arid Nevada. The results from limited availability of recharge and an average permeability of basin sediments that is at least several orders of magnitude higher than most bedrock lithologies in adjacent mountains. The amount of moisture available for recharge to these sedimentary basins consists of mountain terrane net flux (recharge minus local discharge), water which runs directly off the range from snow melt and heavy precipitation, baseflow in live or perennial streams which issues onto flanking alluvial deposits (actually an important part of local discharge), and minor recharge from direct precipitation on the alluvial plain of the basins.

The percent of recharge which occurs in the mountains, and that percentage which occurs at the margin or within the basin is not generally known.

Examples of entire valleys in Nevada at flow capacity are difficult to cite; however, a few approach this condition, usually by virtue of irrigation practices. Parts of Washoe Valley, Carson Valley, Mason Valley, Truckee Meadows, Ruby Valley, Independence Valley (N. Elko Co.) and several others are at or near flow capacity. These alluvial basins retain this condition by virtue of ample runoff from adjacent mountains and irrigation by diversion of water from large perennial streams.

Most basins in Nevada are not at ground-water capacity. This has been demonstrated even in the relatively well watered alluvial basins flanking the Sierra Nevada by irrigation projects noticeably altering conditions of saturation and ground-water discharge in some areas, such as Smith Valley, the area around Soda Lake west of Fallon, and the Fernley area.

The absence of flow capacity in many areas of Nevada is conducive to interbasin flow of ground water. Minor interbasin flow is produced by situations of small lateral displacement of ground-water divides with respect to surface-water divides; significant interbasin flow is produced by situations of low mountain ranges with so little recharge that ground-water divides do not develop.

Paleohydrologic Evidence: An interesting line of evidence as to flow capacity is provided by geologic manifestations of ground-water discharge that apparently relate to pluvial periods in the Pleistocene. In several valleys with exterior drainage in southern and central Nevada deposits of calcareous fine-grained sediments extend well beyond the modern limits of ground-water discharge. These deposits are believed to have been formed by ground-water discharging onto land surface, generating deposits of highly calcareous sediments (Mifflin, 1966, p. 15-16) very similar to those forming in modern ground-water discharge areas. In some areas the distribution of these deposits place them many feet above the modern elevation of ground-water discharge; such deposits give indirect evidence of greater flux in ancestral flow systems. These deposits are present in Pahrump Valley, Las Vegas Valley, Amargosa Desert

TABLE 1

Approximation of expectable relative permeability of geologic units of map compiled by Tagg, *et al.*, 1964

Mapped Units	Expectable Relative Permeability	Range of Most Permeable Zones gal/day/ft^2
Quaternary Alluvium	High	$10\text{-}10^6$
Quat. and Tertiary Volcanic and Sedimentary Rock	Low to Moderate	$10^{-4}\text{-}10$
Tertiary Sedimentary Rocks	Moderate to High	$10\text{-}10^4$
Mesozoic Sedimentary and Volcanic Rock	Low to Moderate	$10^{-4}\text{-}10$
WESTERN ASSEMBLAGE		
Mississippian through Permian Sedimentary and Volcanic Rocks	Low to Moderate	$10^{-4}\text{-}10$
Middle Cambrian through Devonian Siliceous Sedimentary and Volcanic Rocks	Low to Moderate	$10^{-4}\text{-}10$
EASTERN ASSEMBLAGE		
Mississippian through Permian Sedimentary Rocks	Moderate to High	$10\text{-}10^4$
Middle Cambrian through Devonian Sedimentary Rocks	Moderate to High	$10\text{-}10^4$
Undifferential Rocks, mainly Paleozoic	Western 1/2, Low to Moderate	$10^{-4}\text{-}10$
	Eastern 1/2, Moderate to High	$10\text{-}10^4$
Upper Precambrian through Lower Cambrian Sedimentary Rocks	Low	$10^{-2}\text{-}10$
Precambrian Metamorphic Rocks	Low	$10^{-4}\text{-}10$
Intrusive Igneous Rocks	Low	$10^{-4}\text{-}10$

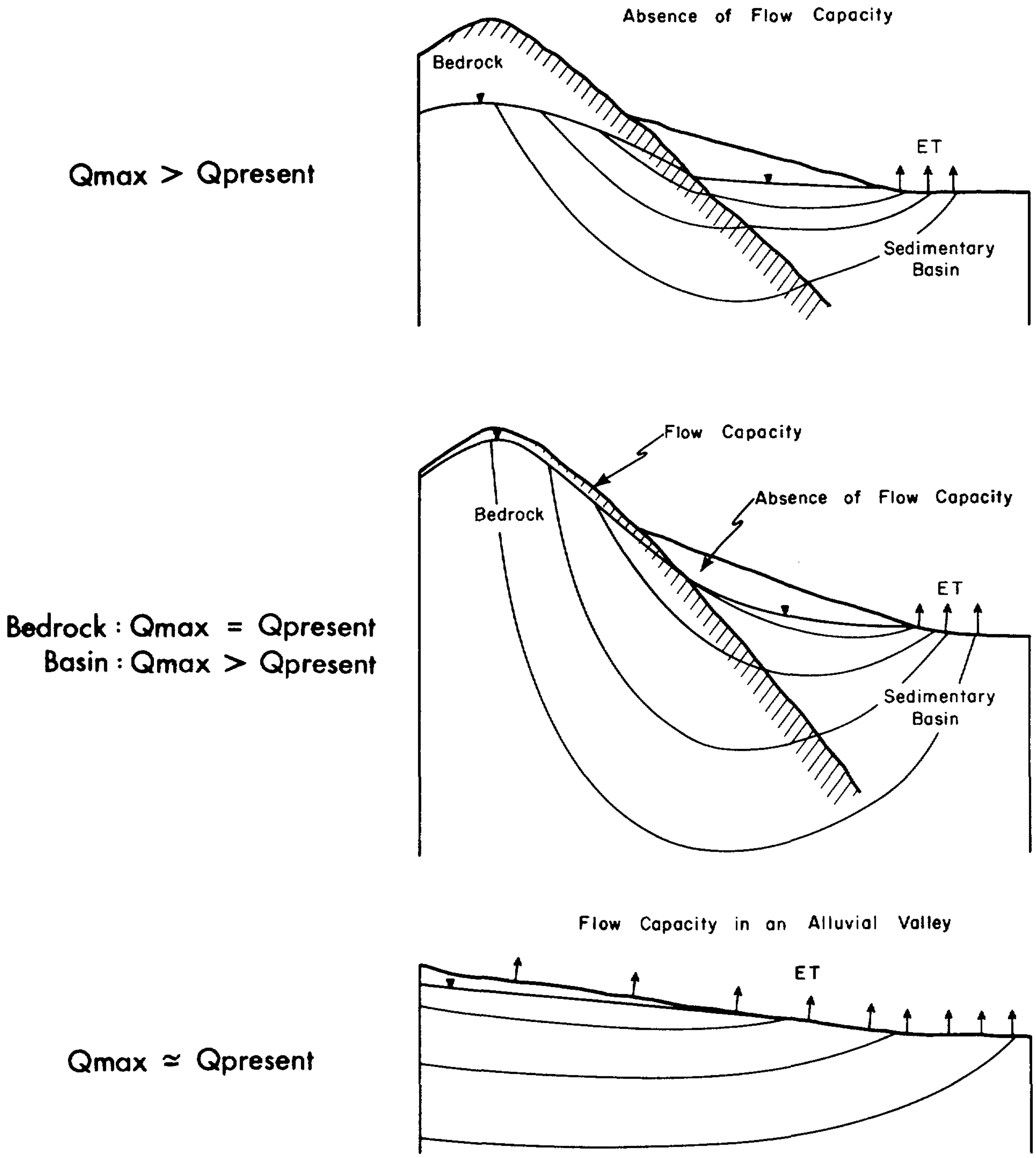


FIGURE 8 - Concept of terrane capacity for ground-water flow, diagrammatic sketches

and White River Valley -- all adjacent to modern discharge areas for flow systems in carbonate rock. This evidence of greater flux in ancestral flow systems could be directly related to the absence of present day flow capacity in most of the mountainous areas of carbonate rock terrane. Increased availability of moisture for recharge, as was undoubtedly the case during pluvial periods of the Pleistocene, may have significantly increased the flux of at least some flow systems in carbonate rock terrane because of a capacity for higher gradients in important recharge areas.

Unfortunately, little work has been done on the paleohydrology of the Great Basin, and the suggested relationship is little more than speculation with limited evidence at hand. Major differences are known to have existed in surface-water hydrology of the Great Basin, such as inundation of the lower parts of topographically closed basins in northern and central Nevada, and associated shift in location of ground-water discharge (Mifflin and Wheat, in preparation).

In summary, the concept of ground-water flow capacity of terrane seems particularly valuable in conjunction with changes in available moisture for recharge induced by man, such as spreading water by irrigation, urban development, large scale interbasin transfer of water and weather modification. Paleohydrologic studies offer an approach to establishing response to increased availability of moisture for recharge. Further, it can be demonstrated that some areas are at flow capacity, whereas others are not, hence, a predictable response to local changes in moisture availability is possible, qualitative in some situations, quantitative in others.

Lithologic Control on Ground-Water Systems: Lithology plays a very important role in the distribution and configuration of flow system boundaries. In saturated media of low permeability, considerable energy must be expended in order for appreciable quantities of water to be transmitted. In areas where there is an ample source of water, a very high hydraulic gradient may be established in low permeability rocks. Such is the case in many mountain ranges in Nevada where sufficient moisture is available for recharge. In such terrane, if viewed in a gross manner, high hydraulic gradients result in an intersection of the zone of saturation with the land surface, and *local* discharge forms such hydrologic features as live or perennial stream flow, seeps and springs. In such areas ground-water-system divides are easily recognized for at least near-surface ground-water flow by virtue of low permeability, and the resulting region of high ground-water potential. Similarly, deeply circulated waters which theoretically could be involved in interbasin flow become negligible in volume because of low permeability lithologies at depth.

Within Nevada, examples of such hydrogeologic environments are the Sierra Nevada, northern Ruby Range, Jarbidge Mountains, Independence Range, Desatoya Range, Toiyabe Range and many other high mountain ranges in northern, central and western Nevada. These ranges are comprised of low permeability indurated rocks and are of sufficient elevation to receive significant recharge. Spotty evidence suggests that north of the 38° parallel lower ranges composed of low permeability lithologies also contain ground-water potential barriers. However, obvious evidence of saturation (live streams and numerous springs) in lower ranges is usually absent. At these elevations recharge is not sufficient to establish hydraulic gradients which permit the zone of saturation to intersect land surface.

In contrast to low permeability terrane, moderate or variable permeability terrane, such as some volcanic rock assemblages, semi-consolidated sediments, and carbonate rocks, yields fewer hydrologic features. In these rocks hydraulic gradients are in general somewhat lower, hence, a greater amount of recharge is necessary for the intersection of the zone of saturation with land surface. For example, most ranges composed of carbonate rock have fewer springs in the higher parts of ranges, and most hydrologic features occur in the foothill areas or in deeply incised canyons. In the low ranges, often there is a total absence of springs or live steams. In volcanic terrane composed of flow rock, such as occurs in parts of Elko, Humboldt and northern Washoe counties, hydrølogic features such as ponded ephemeral water, ephemeral springs, small springs, and base-flow streams do occur, but there is less evidence of sustained "rejected recharge". Many of the small springs have been known to cease flowing during prolonged dry spells and are probably the result of perched water, as are the numerous ephemeral ponds.

Rocks of moderate or variable permeability may be the most efficient terrane for recharge in arid Nevada, as most of the water which enters the ground eventually reaches the lower parts of the ground-water system in the lowlands. In mountains composed of low permeability indurated rocks, so-called "rejected recharge" forms numerous seeps, springs and live streams; hence, a larger percentage of moisture which enters the ground is lost to evapotranspiration before it reaches the lower reaches of valleys or lowlands, *i.e.*, ground-water basins suitable for development of ground water. Terrane of varying rock types may be an important variable when recharge estimates are made on the basis of precipitation.

Mountain Springs: The occurrence of springs in mountainous terrane has often been used to determine the approximate configuration of saturation. Interpretation of spring data, even after field reconnaissance studies, is difficult and contains much uncertainty as to differentiation between so-called "perched" ground water, and regional saturation. In some mountains, particularly south of the 38° parallel, small springs in mountainous terrane may not necessarily be indicative of regional saturation. Live or perennial streams are a much more reassuring guide to saturation, but throughout large regions few of these features exist.

Wells, boreholes and mine shafts and tunnels aid in the determination of saturation on a local basis, yet the density of these control points is far too sparse to permit widespread mapping of configuration of saturation. Rather, these control points provide checks on actual conditions of saturation; thus they have provided basis for judgment on the meaning of springs in various lithologic terranes. Mining operations commonly illustrate that fracture permeability in igneous, metamorphic and indurated clastic rocks generates localized saturation and localized yield of water. Where detailed records are available, evidence of so-called perching is common.

Numerous springs in a given area have been considered to be indicative of regional saturation. It is recognized that numerous small springs are not necessarily a direct measure of regional saturation. However, the occurrence of numerous springs is a measure of both active recharge and at least local saturation, and in most areas probably represents hydrogeologic situations of active recharge to systems. The exception to this generalization is the hydrogeologic situation of relatively low permeability rocks underlain by relatively high permeability rocks. With such conditions it is possible for underflow from one basin to another to occur within high permeability medium, with or without hydraulic continuity between shallow and deep ground water.

Postulated Conditions of Ground-Water Recharge

A pertinent hydrogeologic problem of arid lands is the mechanics of ground-water recharge. Very little detailed study of this natural phenomena has been done in Nevada, yet knowledge of position and conditions necessary for ground-water recharge would greatly aid water budget studies which are commonly used in arid zones.

A brief review of theoretical conditions of recharge is justified to illustrate the author's thinking on the subject and the interpretations that arise.

When moisture is applied to most soils, a zone of capillary moisture advances downward from the wetted surface. This will usually occur even when standing or ponded water is at land surface. Not until field capacity of the soil is reached, or ponded water finds open conduits, will moisture become available to move below the soil horizon. Presumably, while infiltrating the zone of aeration between land surface and the water table, sufficient water must also be available to satisfy advancing fringes of capillarity that develop outward from the localized avenues of percolation (Smith, 1967).

In poorly sorted alluvium common to most alluvial fans in Nevada, the amount of water bound by capillary forces in the vadose zone may be large, whereas in fractured indurated rock it may be not as large. Two factors favor a terrane of indurated fractured rock for effective recharge: 1) thin or absent soil cover and 2) much less surface area per unit volume of material represented by fracture planes.

In either an alluvial or bedrock environment, it would seem necessary that a rather constant or prolonged supply of moisture at or near land surface would be necessary for infiltrating and percolating water to reach the water table. In Nevada depth to saturation commonly ranges from several tens of feet to several hundred feet, except in the areas of ground-water discharge. Therefore, it seems unlikely that significant recharge occurs directly from precipitation over broad areas in the state when the amount and distribution of rainfall is considered. High evaporation potential and low intensity precipitation result in a general absence of sustained moisture at land surface in nearly all intermontane basins and most foothill terranes.

Recharge in Nevada: In view of the above argument, where is recharge likely to occur, and under what moisture conditions? Much terrane above 6,500 feet elevation north of the 38° parallel in Nevada, and most of the highest mountain ranges south of the parallel receive enough snow during winter months to develop and maintain a snow pack for at least short intervals of time. In average winters enough moisture is stored in the snow pack to provide sustained water at the land surface, and hence, satisfy the previously discussed requirements for recharge both on mountain slopes and in the upper reaches of channels. Further, many live streams are at the heads of alluvial fans north of the 38° latitude even during summer months, and runoff which is not lost by evapotranspiration is also available for infiltration.

Thus, winter and spring moisture which is accumulated and stored in snow packs probably constitutes the most effective form of precipitation for recharge to ground-water systems in Nevada. During the rest of the year, precipitation which occurs may not be as effective. In most of Nevada, this moisture constitutes approximately one-half of the annual precipitation. Most rainfall in summer months is not of high enough intensity or long enough duration to generate significant runoff in dry washes throughout the state, *i.e.*, it does not exceed the field capacity of earth materials in the unsaturated zone. It seems doubtful that such moisture ever reaches the water table; rather, it is held as capillary moisture until transpired by plants or evaporated.

Occasionally (perhaps on an average of no more than every four or five years for most of the state), very intense and localized rain storms occur during warmer months and generate flash floods in dry washes, sometimes so intense that part of the runoff reaches playas and other surface-water sinks. At phreatic playas infiltration is probably very minor because of the fine-grained nature of sediments at these features. However, in transit from highlands to surface-water sinks, considerable flow is lost. Characteristically, flow durations rarely exceed more than 48 hours, and the ultimate contribution to ground water is not known. Some local evidence, including water level fluctuations, ground-water chemistry and tritium concentrations, suggests that part of this runoff may find its way to ground-water systems.

Moisture available for recharge is not necessarily directly proportional to measured precipitation in the state, but may be more closely related to 1) winter precipitation which is stored in snow packs, 2) live stream runoff which issued onto relatively permeable alluvial fans for extended periods of time, 3) infrequent high intensity summer storms which localize runoff in very permeable environments (wash channels) for short periods of time and 4) rock type in areas of important winter moisture. Information regarding the postulated moisture available for recharge is essentially undeveloped in Nevada.

Natural recharge from major through-flowing streams (such as the Virgin, Walker, Carson, Truckee and Humboldt Rivers) is probably not great under natural conditions. Nearly all major stream flow is through discharge areas where depth to saturation is very shallow, and hydraulic gradients of ground water are in an upward direction. Phreatophytes which are concentrated in dense growths along all major streams may discharge nearly as much water as is recharged along these streams during periods of peak flow. However, in valleys that have extensive networks of irrigation canals and ditches, water is often diverted to environments where depth to saturation is initially several tens of feet below land surface and sustained wetting of land surface is common in relatively permeable soils that characterize cultivated areas. Water tables are extensively modified by additional recharge (a case is pointed out in Smith Valley by Loeltz and Eakin, 1953) and hence, greater discharge in the form of increased evapotranspiration.

Areas where significant moisture available for recharge occurs are indicated in Plate I. This is not to imply that areas necessarily indicate the amount, or occurrence of recharge. The mapped areas are included because they suggest the relative extents of prime source areas for delineated ground-water systems. The distribution was developed on the basis of elevation and is therefore somewhat subjective. It is an attempt to illustrate mountainous areas which consistently display snow packs during most winters. In parts of northern Nevada, this constitutes areas above 6,000 feet, 6,500 feet and 7,000 feet of elevation, depending on the particular area. In much of central and eastern Nevada, lower limits of prolonged snow packs are usually above 6,500 feet above mean sea level. In much of southern Nevada, between 7,000 and 8,000 feet of elevation represents the lower range of common occurrence of snow packs in mountainous terrane. In these areas, or flanking these areas, recharge occurs each year in important amounts.

It will be noted in southern Nevada that large regions exist where only minor amounts of moisture are available for recharge. In this part of Nevada, nearly all terrane is below terrane capacity, and below 7,000 feet recharge is probably very sporadic, perhaps primarily a function of localized intense storms and short term cyclic variations in climate.

Ground-Water Discharge

In the basins of Nevada ground-water discharge occurs by transpiration from phreatophytes, base flow in streams, flow from springs and evaporation from bare soil, listed in order of probable importance. In the mountainous terrane, ground-water discharge (local discharge) occurs primarily by base flow in streams, small springs and plant growth associated with these features. Areas of ground-water discharge in the basins are shown in Plate I. Areas of local ground-water discharge in the mountains correspond reasonably well to areas of significant moisture available for recharge and runoff shown in Plate I. However, variations in rock type and relief generate important differences in terrane capacity in the mountainous areas, hence, some areas of significant moisture available for recharge display very little local discharge. No attempt has been made to portray local discharge in mountainous terrane.

Ground-water discharge by phreatophytes occurs in large areas in the basin lowlands where depth to saturation is less than 50 feet. Generally, where saturation is less than 30 feet, phreatophytic growth is relatively dense and ground-water discharge by transpiration is important. The discharge areas have been mapped by considering both distribution of phreatophytes and water-level data in wells. Areas where static water levels (in wells of 200 feet or less in depth) stand at 30 feet or less below land surface correspond quite well to areas of healthy phreatophytes. This relationship has been used as a guide to mapping the discharge areas in Plate I.

In Plate I two general patterns of configuration of discharge areas are apparent - those that are narrow and extensive, and those that are broad, often somewhat round or oval. The narrow and frequently dendritic discharge areas are formed by zones of phreatophytes along drainage ways in large basins without topographic closure. Live or perennial steam flow is usually associated with these discharge areas, and often an important part of the ground-water discharge that occurs is related to stream flow or spring discharge.

The broad, more or less round or oval areas of discharge are common in topographically closed basins with broad, low relief bolsons. Discharge in these areas is by transpiration from phreatophytes, spring discharge, and evaporation from phreatic playas that usually occupy the lowest parts of the basins.

Playas: The hydrologic role of playas (dry lakes) is important in Nevada as in most arid regions. Two broad relationships exist, with many variations in each. Some playas act as features of net ground-water discharge, and as such are here called phreatic playas. Others have surfaces that are many tens to hundreds of feet above regional saturation, and from a hydrologic viewpoint are thus dry of vadose playas. In phreatic playas, ground water discharges by a process of capillary rise of moisture from saturated sediments and subsequent evaporation in fine-grained deposits near the surface of the playa. However, discharge via seeps and springs, usually at or near the margins of the playa, is also common and may be the mechanism for a large part of the discharge that occurs. Also, discharge via phreatophytes such as greasewood, saltgrass, rabbitbrush, saltbush, and other plants is common in areas surrounding the playa. On a quantitative basis it is not known how much water is lost from capillary processes in phreatic playas, however, a wide variation in rates of discharge probably exists among phreatic playas in Nevada.

Some phreatic playas are essentially dry in the upper five or so feet of material throughout much of their extent, whereas others are damp or even saturated to land surface. In the large phreatic playas of the state, such as Carson Sink, Humboldt Sink, Smoke Creek Desert, Black Rock Desert and in many smaller playas found in topographically closed basins of central Nevada, the apparent rate of ground-water discharge is much higher along marginal areas. This relationship is indicated by salt accumulations, marshy areas, unstable ground, and in general, year-round moist conditions in the very shallow subsurface.

Low rates of ground-water discharge in the more central areas of playas appear to be in part related to the permeability of underlying sediments. Typical vertical profiles of playa sediments show silty sediments near land surface, and underlying this surface zone at various depths occur layers and lenses of salts intercalated with clayey silt horizons. This stratigraphy appears to be related to the latest pluvial period and more recent sedimentation history of playas.

During the desiccation of lakes of the latest pluvial period, salts became important consitiuents in sedimentation as lakes continued to shrink in volume. Also, the clastic lacustrine sediments associated with salt deposition are usually clayey, as the deepest parts of lake basins had the lowest sedimentation energy environments, hence, the finest grained sediments. As desiccation became complete, salt precipitation from ephemeral surface water greatly decreased, and at the same time energy levels increased. There is also evidence that sedimentation rates have increased during at least the last interpluvial in some parts of Nevada, hence, the upper silty deposits are sometimes quite thick when compared to the time interval they represent.

The net influence of normal playa stratigraphy on ground-water discharge is to reduce the flux of ground water in the central parts of the playa where subsurface salt precipitates are probably the thickest and most continuous. Exceptions of active localized ground-water discharge within playa margins often appear to be related to small structural displacements, usually lineations related to minor faults or cracks of tectonic, compaction, and desiccation origin.

Distribution and areal extent of ground-water discharge areas as indicated in Plate I is not indicative of volume of discharge in playa areas, nor in areas of various types and densities of phreatophytes or springs. For example, the broad expanse of some of the "deserts" of northwestern Nevada are mapped as discharge areas, yet they do not necessarily indicate large volumes of water lost from ground-water systems as the extents might indicate. The areas are, where subsurface data exist, places where fluid potential of ground water increases with depth and saturation is usually 30 feet or less in depth.

In Plate I, criteria used to establish phreatic playas are surrounding phreatophytes, saturation as indicated by water levels of 30 feet or less in wells equal to or less than 200 feet in depth, moist or marshy ground, salt accumulations and seeps and springs.

Ground-Water Chemistry

Within Nevada several important physical relationships interact to result in the chemical character of ground water found in various hydrogeologic environments. On an annual basis, climatic conditions throughout most of the state create an evaporation potential that exceeds rainfall. However, runoff and ground-water recharge does occur on a local basis throughout the state, primarily because of distribution of moisture with time. Within that portion of Nevada which is part of the Great Basin, all waters yielded by surface- or ground-water systems reach positions where they are discharged to the atmosphere by evapotranspiration. Left behind during evapotranspiration is the majority of dissolved constituents taken into solution along the paths of flow.

In sink areas of both surface- and ground-water systems, significant concentrations of the more soluble salts have developed.

In Nevada, numerous ground-water investigations (Water Supply Papers, Water Resources Bulletins and Ground-Water Reconnaissance Reports in the bibliography) have to various degrees considered ground-water chemistry, and have more or less demonstrated saline residues and poor quality ground water in discharge areas. Langbein (1961) has stated that saline residues are so common in discharge areas of closed basins that absence of such residues may be taken to indicate that the basin is not closed hydrologically, or that deflation must be called upon to remove the residue. The limited ground-water chemistry data suggests that this relationship is valid in general, but in detail many unknown relationships probably exist.

Pluvial Influence in Closed Basins: Many interacting and complicating phenomena that are or have been operative give rise to the modern distribution and concentration of soluble salts in basins and related ground-water quality in these areas. Among the most significant are the effects that pluvial periods of the Pleistocene have had on the distribution of solutes. Most topographically closed basins in Nevada have been periodically occupied by hydrographic features such as lakes or marshes. Lacustrine and paludal deposits provide evidence of marked change of hydrology in closed basins in response to climatic variations. The apparent effect of Pleistocene pluvial periods was to redistribute much of the available solutes to the lower parts of the closed basins (into lakes or marshes) because of more effective runoff in extra-lacustrine parts of the basins. Most lake waters were charged with loads of dissolved constituents which were either fixed within lacustrine deposits or precipitated in the lowest parts of basins as final desiccation occurred.

In compound lake basins (more than one topographically closed basin which became integrated with adjacent basins when inundated by water) such as the Lahontan Basin, concentration of disolved constituents in some areas has been intensified by several circulation thresholds into subbasins that did not have significant surface-water runoff. As lake levels dropped or fluctuated, some subbasins became more or less classical evaporite basins, *i.e.*, lake waters periodically spilled into subbasins and then evaporated. Hence, concentration of the most water-soluble constituents (primarily sulfates and chlorides) proceeded in the lowest subbasins as a function of subbasin threshold elevations.

In basins periodically occupied by lakes, post pluvial concentration of the more soluble salts into areas of ground-water discharge has occurred by ground water passing through lacustrine sediments. In ground-water discharge areas (usually more or less restricted to phreatic playas which have developed upon lacustrine deposits in the lowest part of each basin) ground-water flow has, subsequent to the last pluvial period, flushed salts from sediments to areas of ground-water discharge. Therefore, concentrations of poor quality ground water are common in the immediate vicinity of phreatic playas. In these areas water discharges by evapotranspiration, but the majority of salts are left behind and never leave the discharge area except by eolian processes. The importance of this latter process is uncertain in that rapid and active interbasin transport of silt and sand is observed at the present time, but areas with a salt crust seem to yield little airborne material.

Influence of Drainage: An important relationship between surface-water drainage and ground-water discharge is indicated by study of Nevada. Where ground-water discharge areas occur along active surface-water drainage, high concentrations of salts generally do not build up because of periodic flushing by infrequent but intense precipitation and surface-water runoff from the areas. Throughout much of northern Nevada where active surface water drainage occurs, if only infrequently, high concentrations of salines have little opportunity to develop from concentration by ground-water discharge. Modifying this generality are some areas where extensive irrigation is practiced in natural ground-water discharge areas within lower valleys of the Lahontan Basin, *i.e.*, Lovelock Valley, Fallon area, and Schurz area. In these areas drainage is poor; surface waters used for irrigation are already charged with considerable salt loads; discharging ground water passing through lacustrine sediments is also high in dissolved constituents; and resulting water supply from both sources of water permits evapotranspiration to essentially equal annual evaporation potential of 3 or 4 acre-ft. per acre. The local net effect is poor quality water in at least near-surface aquifers and drainage channels. The net effect of intensive irrigation along the four river systems in northern Nevada has been to intercept and spread surface waters above natural sinks. Irrigated areas of lowest elevation on surface-water systems receive far more solutes than was the case prior to irrigation.

Figure 9 is a sketch of Lahontan Basin illustrating general ground-water quality in discharge areas which are present in each subbasin (see Plate I for discharge area relationships). Three processes are recognized as being important to occurrence of saline or brackish ground water in local areas of the basin. These include: (1) discharge of ground water which has passed through lacustrine sediments relatively rich in soluble salts, (2) subbasin thresholds which, depending upon their elevations, permitted Lake Lahontan waters of various salt concentrations to periodically spill into subbasins

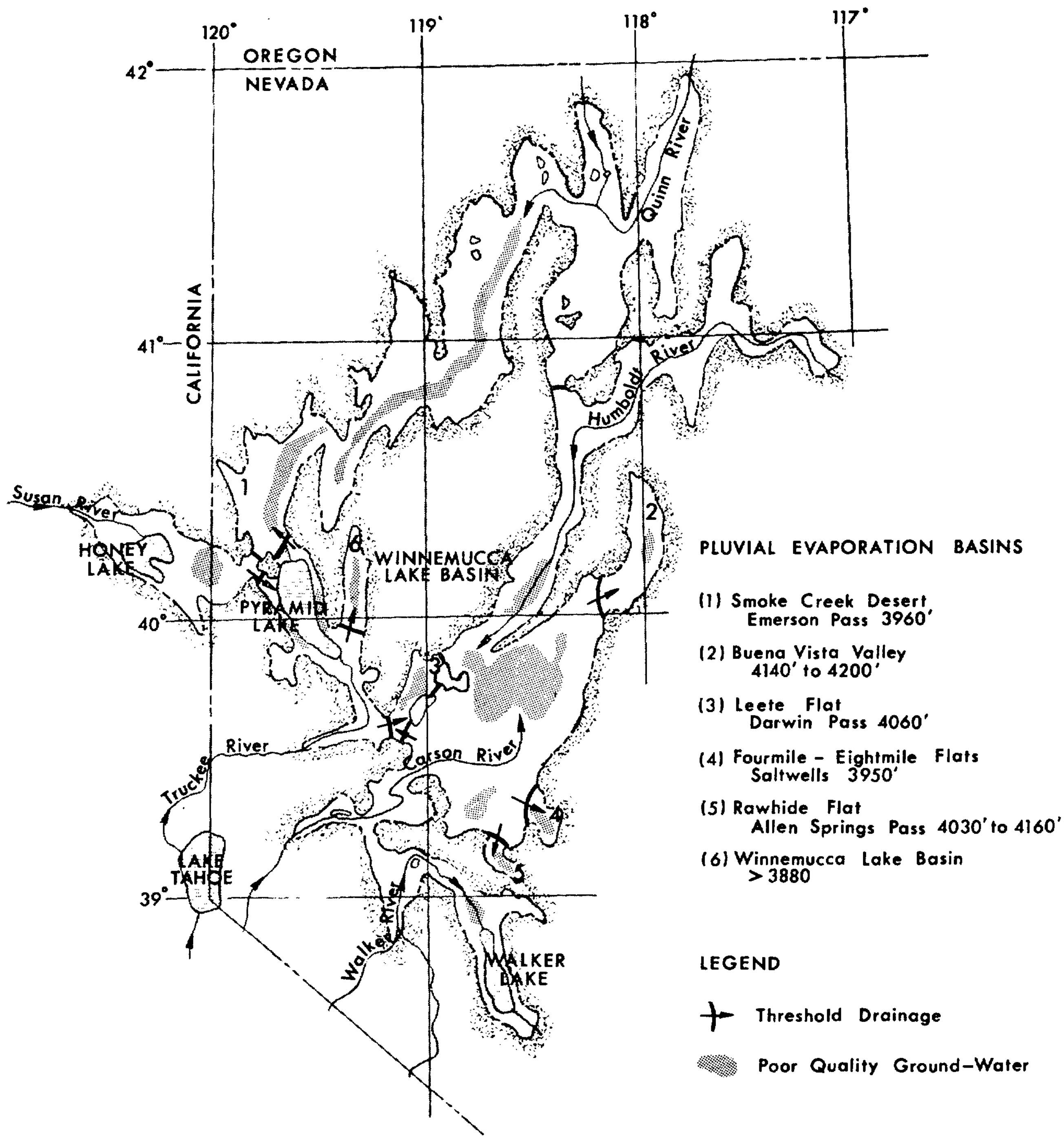


FIGURE 9 - Influence of pluvial history and modern drainage on ground-water quality in Lahontan Basin

and evaporate, which concentrate salts brought to the surface by ground water into the lowest depressions and (3) irrigation.

In southern Nevada, the vigor and frequency of surface-water flow is reduced by an even higher evaporation potential than in northern areas. Hence, in some ground-water discharge areas in drained valleys flushing of saline concentrations produced by ground-water discharge is not as effective as that in northern Nevada. For example, in Las Vegas Valley poor quality ground water in shallow zones is locally present even though the valley is drained by Las Vegas Wash. Prior to marked withdrawals of ground water in excess of natural discharge, only a few hundred acre-ft. per year of surface water drained from Las Vegas Valley to the Colorado River system, yet 25,000 to 30,000 acre-feet per year was discharged from the ground-water system in the valley. Under present conditions of water use in the valley, about 70,000 acre-ft. of ground water is withdrawn each year, and about 4,500 acre-ft. is imported to Las Vegas from Lake Mead. However, discharge to Lake Mead by surface water in Las Vegas Wash is still only in the neighborhood of 17,000 acre-ft./yr. Hence, because of high evapotranspiration losses in the valley and relatively inefficient surface drainage, there is build up of salts in the valley in both ground-water discharge areas and other areas where water is used. Some water which is not evaporated or transpired infiltrates back into shallow aquifers, often carrying a heavy salt load. Evidence of ground-water quality deterioration has been suggested to have already occurred on a local basis (G.B. Maxey, 1966, personal communication).

General Chemical Characteristics: The general relationship of ground-water quality and position in the ground-water flow system is important; however, detailed knowledge of influencing parameters is not well established throughout entire flow systems. Interaction between ground water and geologic environments under a multitude of possible influencing conditions in flow systems such as rate of movement, positions or recharge, mechanics of recharge, residence time, and length of flow paths, as well as rock types encountered along flow paths and biochemical reactions, do not permit many justified generalizations at the present time. The preceding discussion suggests the complications that paleohydrology of particular areas may impart to chemical character of ground water in discharge areas, as well as effects of irrigation and ground-water development. In other zones of flow systems, *i.e.*, zones of recharge and lateral flow, chemical data is relatively sparse and hydrogeologic environments are often quite diverse. Thus generalizations are difficult to establish.

Usually active recharge areas are characterized by ground water with relatively low concentrations of dissolved solids (predominantly calcium, magnesium, and bicarbonate ions). During transmission in the zone of lateral flow (at least in alluvial basins), there is frequently a decrease in calcium and magnesium ions, and increases in sodium and potassium ions by base exchange, and at the same time sulfate and chloride ions become important constituents. In carbonate rocks of Nevada, some detailed information and general relationships have become apparent, and may be of considerable utility in flow system delineations within this type of rock. These are discussed in detail in the following chapter on carbonate rock terrane.

In other rock types, such as alluvium and various volcanic rocks, considerable insight, and sometimes supporting evidence, has been gained from study of ground-water chemistry. In the Winnemucca segment of the Humboldt River Valley and in Truckee Meadows, water chemistry studies by Cohen, 1962c, and Cohen and Loeltz, 1964, significantly aid understanding of ground-water flow system relationships.

In a study which included Fourmile Flat, Eightmile Flat, Sand Springs Range, Fairview Valley and Dixie Valley, knowledge of ground-water chemistry played an important role in verifying flow system relationships in both indurated rocks and alluvial sediments (Mifflin, *et al.*, 1965). In efforts at the Nevada Test Site and adjacent areas, ground-water chemistry has been used to recognize ground water from carbonate rock terrane and that from volcanic rock terrane (Eakin, *et al.*, 1963).

Ground-Water Temperature

Ground-water temperatures in Nevada are generally higher, by at least 5 to 10°F, then the mean annual air temperature at the point of sample. On the basis of ground-water studies in more humid areas, it has been more or less established that shallow ground-water temperatures are usually within a few degrees of mean annual air temperature. The higher temperatures noted in Nevada are not particularly anomalous when the configurations of many ground-water flow systems are considered. Some areas of Nevada may have considerable circulation of ground water several thousands of feet below land surface. Within Nevada, ground-water temperatures observed in the 40's or 50's° F (temperatures which closely approximate mean annual air temperature) are most frequently found in areas where saturation is relatively shallow, and active recharge to the system is often nearby or in the immediate vicinity of observation points. These ground-water temperatures are usually observed in mountainous areas, or in valleys where there is local recharge such as very local areas along valley margins or irrigated areas, and along major drainage systems in shallow wells.

A far more commonly observed temperature range extends from the mid 50's to the mid 60's (°F). These temperatures average about 10° F above local average air temperature, and they prevail in many shallow or moderate depth wells constructed within most alluvial basins in the northern half of the state. These temperatures appear to be associated with ground water that has circulated to moderate depths in "local" ground-water systems.

A third temperature range frequently noted in ground water in Nevada is between the mid 60's to about 80° F. Temperatures within this range are often observed in relatively deep wells constructed in foothills or valley margin areas in the northern part of Nevada, in vicinities of thermal springs throughout most of the state and within alluvial basins in several areas of southern Nevada. These temperatures seem to be either associated with 1) lateral flów in moderate to low permeability rock environments where depth to saturation is commonly several hundred feet, 2) ground water which has circulated to moderate depths through indurated rocks which permit interbasin or regional flow systems and 3) ground water associated with localized concentrations of thermal ground water, usually near major structural features.

Locally, many areas within the state have even higher ground-water temperatures. In general, occurrence of hot wells and springs is more localized areally than lower temperature ground water. In areas of thermal ground water there is not necessarily a direct correlation between depth and encountered temperature of ground water (for example in the southwestern part of Truckee Meadows and in Pahrump Valley), yet there seems little doubt that the frequent occurrence of abnormally high temperatures observed in ground water is related to deep circulation.

Many geothermal gradients (change in temperature with respect to depth) could be illustrated in Nevada by picking the area. However, it seems likely that the gradients of 1° F to 2° F per 100 feet of depth are more common than 3° F per 100 feet or more. If so, an approximate idea of depth of circulation of waters commonly encountered can be made, *i.e.*, waters in the 55° F to 65° F range may not have circulated much deeper than 2,500 feet, and perhaps much less. Similarly, waters of 65° F to 80° F may have circulated to about 4,000 feet of less. On the other hand, waters with temperatures much over 80° F are likely to have circulated quite deep, perhaps greater than 4,000 feet. Deep drilling in eastern Nevada has indicated "vuggy" porosity in dolomite to depths greater than 10,000 feet (Lintz, 1957, p. 61) and caverns to greater than 4,000 feet (Lintz, 1957, p. 47). Also several reports of "fresh" water at depths greater than 4,000 feet (Nevada Oil and Gas Commission files) from drill stem tests would suggest deep circulation of considerable flux, and Nevada Test Site deep well samples and fluid potential measurements fully confirm similar deep circulation of ground water (Winograd, 1963).

In Nevada, it appears that average heat flow may be in the neighborhood of 2.1 to 2.36 μcal/cm^2 sec. (Lee and Uyeda, 1965), however, local areas are known to have much higher rates (White, 1957a). the "normal' geothermal gradient of Nevada may be higher than many other continental areas where heat flow measurements cluster around 1 μcal/cm^2 sec. However, a multitude of complicating conditions makes it difficult to recognize truly representative measurements. For example, in hydrothermal areas most authorities agree that abnormal heat flow and temperature gradients are a result of heat being transferred to near land surface by upward circulating high temperature water. Thus, on a local basis and perhaps even in some entire ground-water basins, upward movement of ground water may be a more efficient mechanism of heat transfer than normal conductivity, and in some situations may be sufficient to greatly modify the "normal" gradient of an area.

Significant to flow system analysis is the apparent meteoric source of the majority of high temperature ground water. Several studies (Craig, *et al.*, 1954, 1956; White, 1957a, 1957b, 1961, White *et al.*, 1963; DeGrys, 1965) have demonstrated that most, if not nearly all, thermal ground water that has been studied in detail is in some manner related to the normal hydrologic cycle. Water chemistry and stable isotope studies as well as other considerations indicate that in any given sample the majority of water is meteoric water (from precipitation) not greatly different from other ground water in the region with respect to certain isotope ratios. Thus, ground-water temperature may be used to study configuration of circulation. The heat displayed by ground water is somewhat a relic parameter, just as is water chemistry, and as such may indicate environments through which it has passed. It is suggested that temperature gives rough indication of depth of circulation in ground-water flow systems, but unfortunately its value is weakened by the usual absence of knowledge of the source of heat in any particular area.

The actual source of heat is problematical. Usually the immediate heat source cannot be clearly delineated in a tectonically active environment such as Nevada. Localized Quaternary volcanism is known throughout much of the Basin and Range Structural Province, as well as is the existence of deep-seated and relatively active faults. Where some sub-surface temperature data is available in Nevada, such as from wildcat test holes and AEC test holes in central and southern Nevada, temperatures at depth are relatively uniform over large areas. Unfortunately, most temperature data has been obtained in freshly constructed wells where temperature equilibrium has not been reestablished at the time of measurements.

Ground-water temperature data in Nevada indicate marked differences in distribution and source of thermal water in ground-water flow systems. For example, many warm or hot springs in the northern two-thirds of the state are closely associated with major structural features, such as basin margin faults or junction of several such fault zones or major topographic lineations. Where detailed geology is available, location of thermal springs on or closely adjacent to faults is quite common. In several instances within Nevada, thermal springs occur closely adjacent to springs with considerably lower water temperatures; sometimes the distance between thermal and low temperature springs is only a few hundred feet. This phenomenon strongly suggests there are localized and relatively sealed conduits of deep-seated sources of thermal water rising up through the low temperature water in local ground-water systems in the immediate environments of hot springs. Another interesting and not uncommon relationship lending support to separate and hydraulically discrete sources of hot water is concentration of thermal water discharge at comparable, but not necessarily the same, fluid potential as low temperature ground water in many areas of the state. Often hot water discharges at slightly higher elevations than lower temperature springs in the same area.

In most of Nevada dense ground-water temperature data are sparse, but in a few ground-water basins (*e.g.*, Las Vegas Valley, Truckee Meadows, and Quinn River Valley) enough data are available to illustrate gross differences in configuration of ground-water flow from observed temperatures of ground water. Even in these areas, areal distribution of data leaves something to be desired for truly significant statistical analysis; nevertheless, trends represented by available data can be seen in these examples.

In Las Vegas Valley, most ground water displays temperatures in the 70°-75° F range (Figure 10 A). The range of data extends from one sample in the 60-65° F range to two samples in the 90-95° F temperature range. However, about 98 percent of the data fall within the 65-85°F temperature range, and about 61 percent of the data into the 70-75° F range. Available data indicate a marked uniformity of ground-water temperature when compared to many other ground-water basins in Nevada. Also shown in Figure 10A is the mean air temperature at Las Vegas of approximately 66°F and mean air temperature at 7,165 feet altitude on the east slope of Spring Mountains. The question of position of recharge is quite significant – if it occurs mostly in Las Vegas Valley it would suggest less than 10° F rise in ground water temperature. However, if the bulk of recharge to the system which discharges in the valley occurs in surrounding mountain areas above 6,500 feet altitude, as several investigators suggest and is favored by this study, rise in ground-water temperature is in the neighborhood of 25° F. Further, uniformity of temperature clearly indicates a more or less common temperature environment before ground water reaches ground-water discharge area in the valley.

In Truckee Meadows (Figure 10B) ground-water temperatues strongly reflect at least two sources. These are interpreted as 1) a deeply circulated source that rises for the most part from a northerly trending fault zone along the western edge of the meadows, and 2) ground water of shallow circulation resulting from recharge within the basin related to irrigation and surface runoff from adjacent Carson Range. Temperature range in Figure 10B is likely a result of the degree of mixing of two types of water at various sample points. The contrast between Las Vegas and Truckee Meadow ground-water temperatures illustrates a marked difference in the source of thermal ground water.

An example of uniform low ground-water temperature is provided by Quinn River Valley in northern Nevada (flow system No. 17 in Plate I). Here 86 percent of the reported temperature measurements are between 50 F and 60 F, with 8 percent higher and 6 percent lower (Figure 10C). This relationship indicates shallow circulation and nearby recharge from surface runoff.

Thermal Ground Water and Interbasin Flow: There is little doubt that thermal ground water is in some manner closely related to either recent volcanism (shallow, high temperature rock) or mountainous terrane (see the distribution of thermal springs in the world, Waring, *et al.*, 1964), but in the latter case it is unclear as to the connection. The genetic relation may be deep-seated structural zones in mountainous areas, providing local permeability to great depths, or perhaps high relief of terrane permits sufficient initial fluid potential for deep penetration and associated heating.

If it is assumed that most thermal ground water in Nevada is not generated by shallow, high temperature bodies of rock, the fluid potential of thermal water in the state may be indicative of the general direction of flow of deeply circulated ground water. When the approximate fluid potential of known occurrences of ground water equal to or greater than 80° F is contoured to produce a potentiometric map, an interesting surface is developed (Figure 11). These data points include verified temperature data from springs and wells from Horton, 1964 and Waring, *et al.*, 1965, and a number of ground-water reports in Nevada and bordering states. The pattern developed was drawn strictly on the basis of generalized fluid potential, and not biased by topography; in other words, contour lines did not have to be at or below land surface.

There is an interesting correlation between direction of movement of ground water in interbasin flow systems and the apparent gradients of flow formed by the

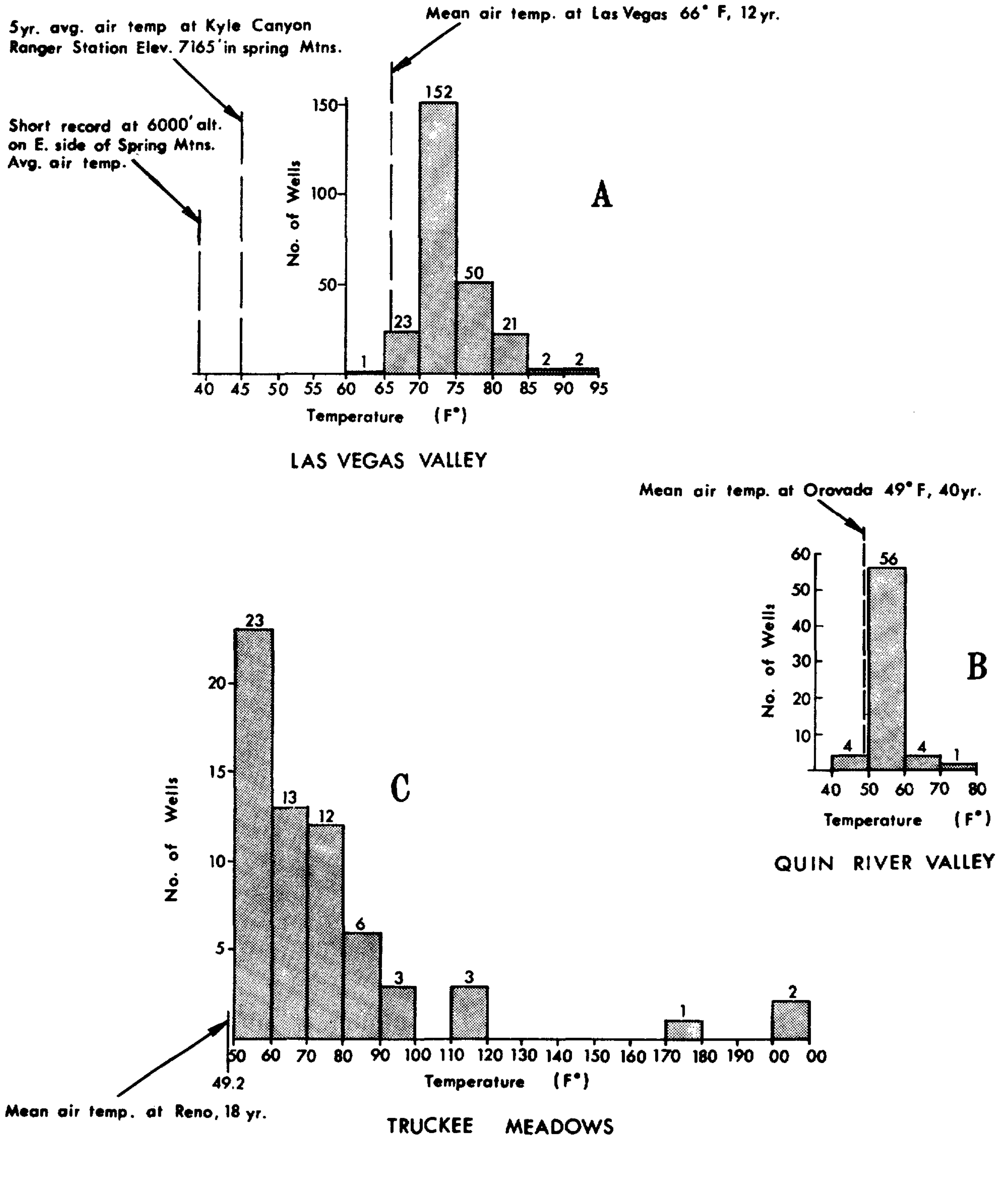


FIGURE 10 - Histograms of ground-water temperature in three ground-water basins of Nevada

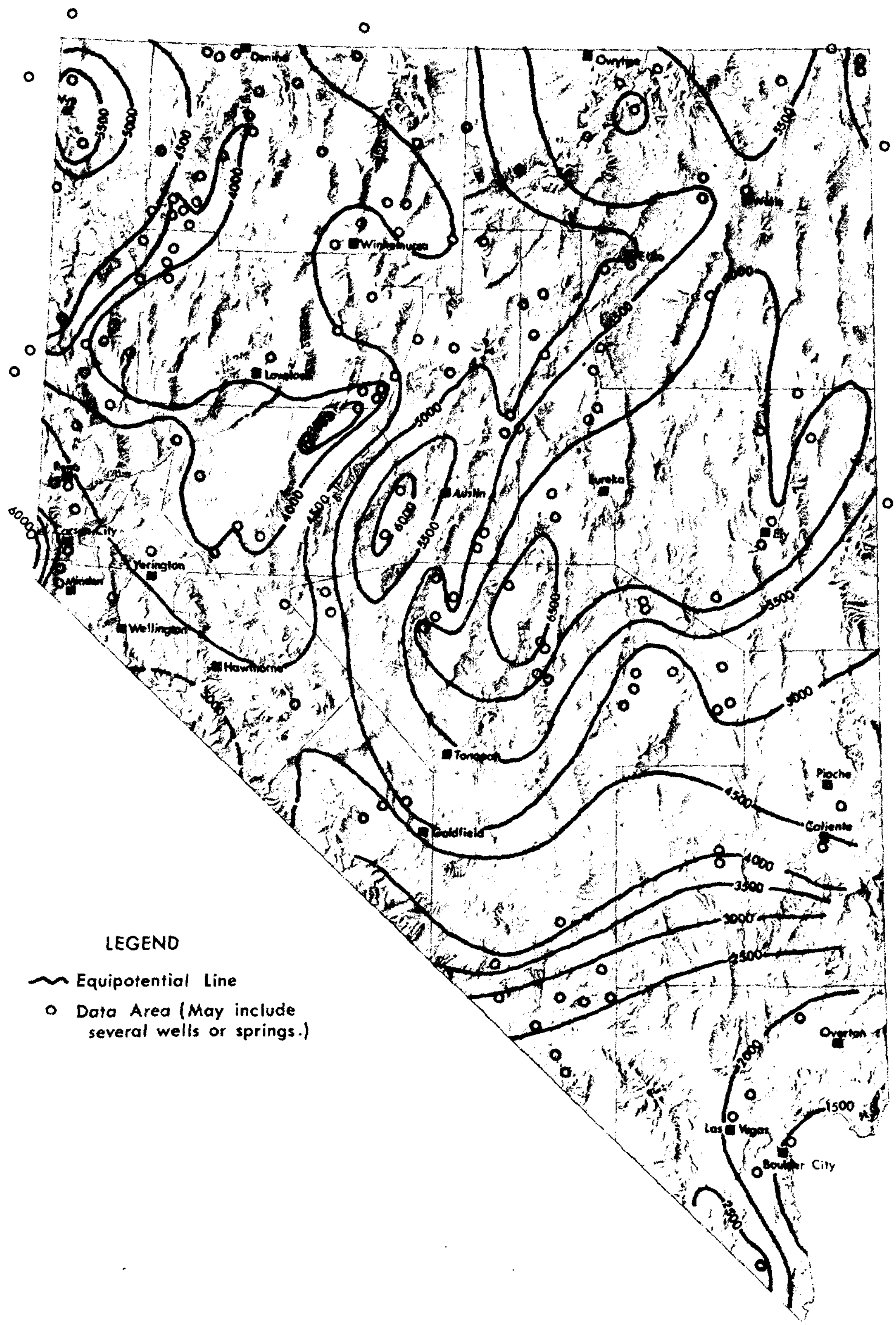


FIGURE 11 - Equipotential map of ground-water equal to or greater than 80°F

thermal ground-water potentiometric surface of Figure 11.

Interbasin flow systems which correspond to the direction of flow suggested by the gradients of the thermal ground water include Lake Valley-Spring Valley (No. 93 in Plate I), White River (No. 94 in Plate I), Railroad Valley (No. 95 in Plate I), Las Vegas (No. 124 in Plate I), Amargosa Desert-NTS (No. 122 in Plate I), Oasis Valley (No. 120 in Plate I), Sarcobatus Flat (No. 119 in Plate I), Clayton Valley-Monitor Range (No. 100 in Plate I), Columbus Salt Marsh-Toiyabe (No. 101 in Plate I), and Highrock (No. 11 in Plate I). It is important to note that the listed interbasin flow systems and the thermal ground-water potentiometric surface were established by considerably different criteria and considerations. The only areas where interbasin flow is believed present, where thermal ground-water potential gradients are not definitive is the Diamond Valley, Newark Valley, Long Valley, Jakes Valley, S. Butte Valley area. Here the thermal data is sparse, but apparently the area is a fluid potential high of thermal ground water (greater than 6,000 feet) and apparent gradients are to the northwest, the east and the south.

The coincidence of interbasin flow with apparent regional gradients of thermal ground water raises two important questions: 1) Are apparent gradients established by fluid potential of thermal ground water a reliable approach to delineation of interbasin flow? 2) Is interbasin flow important in other parts of Nevada and not recognized?

The answer to the first question can only be based upon the areas of known interbasin flow; there such an approach seems of value. However, the answer to the second question qualifies the utility of this thermal ground-water approach to interbasin flow. Flow system theory indicates a certain amount of interbasin flow is possible in most terrane, but the thermal water potential surface does not necessarily demonstrate amount or importance of such flow. The majority of data points in the northern part of the state represent a very small fraction of the total flux of the involved flow systems, hence, even if interbasin flow is present its importance might be measured by the relative amount of thermal ground water. Further, not all thermal ground water necessarily is involved in interbasin flow. Therefore, strong independent evidence seems necessary to prove interbasin flow in most areas.

In summary, ground-water temperature has been considered in this study as an aid to characterize the configuration of flow in a vertical sense. Where temperature data appear to be uniform and near mean annual air temperature, the depth of circulation is not believed to be great. Where temperature data display a wide range of values, both shallow and deep circulation is believed present. Where temperature data are uniformly high, deep circulation of flow is believed present. The use of temperature data for establishing interbasin flow may be possible, however the evidence is not strong enough for confident utility at the present time. Areas with large amounts of thermal ground-water discharge may constitute discharge areas for interbasin flow of water. This hypothesis has not been tested on a local basis in Nevada by study of amount of thermal water discharge as compared to the amount of estimated recharge in a particular ground-water basin. Problems of accurate recharge estimates, discharge estimates, and paucity of temperature data made such studies beyond the scope of this investigation.

FLOW SYSTEM DELINEATION IN CARBONATE ROCK TERRANE

At the onset of this study it was recognized that the most difficult area for reliable flow system delineation is eastern and southern Nevada where thick sequences of predominantly carbonate rock are exposed in most mountain ranges. Similar sequences are extensive in the subsurface where spotty subsurface information exists (wildcat oil test holes and Nevada Test Site test holes). The limited evidence available suggests that thick sequences of carbonate rocks underlie most of the alluvial basins, and much of the volcanic rock sequences in this area. Further, deep drilling indicates that intervals of cavernous carbonate rock exist to depths perhaps greater than 5,000 feet, as some test holes experienced extreme circulation difficulties, and a few have experienced dropping bits upon encountering caverns.

The prime hydrologic evidence of extensive zones of permeability in bedrock is provided by a number of large topographically closed basins which display no important ground-water discharge. Impressive examples of valleys which must lose water by interbasin flow through the surrounding mountain ranges include Jakes Valley, Cave Valley, Coal Valley, Dry Lake and Delmar Valleys, Sand Springs Valley (just west of Railroad Valley and also called Little Smoky Valley) and Long Valley. Many other basins in the eastern and southern part of Nevada also are believed to lose ground water by interbasin flow, but their smaller size or the limited availability of moisture for recharge makes the phenomenon of interbasin flow less impressive, and in some cases, less certain. The recharge and discharge estimates of Appendix Table 2, and the distribution of ground-water discharge areas in Plate I further illustrate this phenomenon of interbasin flow.

In eastern and southern Nevada previous efforts of flow system delineation met the problem with several approaches. In the Nevada Test Site large expenditures in drilling and testing have given fluid potential data to characterize in detail that part of the Nevada Test Site flow system within the central and west part of the test site (Winograd, 1962, 1963; Winograd and Eakin, 1965).

Further, gross water chemistry differences in ground water associated with volcanic rock terrane and ground water in carbonate rocks has been noted in that area. These direct measurement methods are undoubtedly the most reliable approaches to interbasin flow delineation, but are totally impractical for most of the carbonate rock province because of tremendous expense associated with deep drilling and testing.

In the White River flow system, Eakin (1966) has approached the problem of delineation on the basis of water budgets and sparse subsurface control on fluid potential. His interpretations of interbasin flow are believed valid, but the support lent to details of delineation by water budgets is not without considerable question because of the necessary assumption of first deciding where recharge is occurring and what amount is occurring.

In the early stages of this work Maxey and Mifflin (1966) demonstrated the apparent utility of water chemistry from large discharged springs associated with flow systems in this part of Nevada. It was demonstrated that water chemistry of springs believed to be associated with regional flow systems (as determined by previously discussed methods of delineation) characteristically illustrated increased concentrations of certain dissolved constituents with increased lengths of flow paths. Cations which behave consistently in this manner include sodium and potassium; anions which displayed corresponding increase with length of flow path are chloride and sulfate. Thus, a more intensive study of this phenomena was pursued.

Ground-Water Chemistry of Large Springs

The approach of characterizing a flow system on the basis of water chemistry in large springs differs from most such studies in that the utility of water chemistry must be evaluated on the basis of only a very few analyses in any given flow system. This approach would be unreliable in most hydrogeologic environments of flow in that variations in water chemistry from one position to another may be greatly dependent upon minerals that the water is in contact with, temperature, and perhaps rate of flow.

This relationship is perhaps best illustrated by the classic study made by Back (1966) in the Atlantic Coastal Plain of North America. Any few analyses taken randomly from hundreds of analyses in the Atlantic Coastal Plain flow system would have very little meaning as to relative stratigraphic position and relative flow system position. Local hydrogeologic environments of the Atlantic Coastal Plain are too diverse to establish hydrochemical facies and associated flow system positions on such limited data.

However, ground water which flows through carbonate rock terrane is not as subject to an infinite number of combinations of local environments which might significantly change water chemistry. Hydrogeologic environments in regions of most active movement (cavernous zones of higher relative permeability) are relatively constant, with minerals of calcite, aragonite, and dolomite dominating. Further, by sampling only waters issuing from springs characterized by carbonate rocks nearby, and further limiting samples to springs with large discharge so that there is even greater assurance that the sample is truly from an active zone of flow in carbonate rock environment, influencing variables on water chemistry approach the objective of the study--variations in water chemistry that reflect history of flow path.

Constituents which remain relatively constant or vary only over a limited range of concentration, such as calcium, magnesium and bicarbonate ions, are usually related to their equilibrium concentrations with respect to carbonate minerals under the particular temperature and pressure conditions. At the point of sample, the spring orifice, pressure is atmospheric and therefore relatively uniform, hence, only variations in water temperature become an important physical variable in equilibrium concentration of these ions. With a few exceptions, this influence is not great enough to significantly influence the limited range in concentrations observed in these ions (Maxey and Mifflin, 1966, p. 152; Appendix Table 5).

Gypsum, anhydrite and halite have greater solubility than carbonate minerals, hence, there is an increase in concentrations of Na, K, Cl and SO_4 ions as the ground water circulates through the rocks. Within physical environments under consideration, solution equilibrium is not reached with these minerals. The observed concentrations of these ions are believed to be a function of amount of contact with these minerals. The minute quantities incorporated in most limestones and dolomites permit only gradual release to solution, perhaps as the calcite and dolomite is dissolved, allowing active contact and solution of these materials. Regardless of the exact source of these ions in ground water of carbonate terrane, recent work clearly indicates that these particular ions continue to increase along the flow path, not only in arid Nevada, but also in humid environments such as the Floridian Aquifer, (Hanshaw, *et al.*, 1965, p. 603), and in the Yucatan Peninsula (Back and Hanshaw, 1967, p. 71).

Hence, at each large spring associated with carbonate terrane, an indication of distance water has traveled as well as the potential, temperature and character of discharge can be obtained. This provides a powerful tool in the absence of widespread fluid potential data. Further, the temperature of water gives indication of probable depth of circulation immediately up gradient from the spring. The elevation of the spring gives indication of fluid potential at that point in the system.

Character of discharge (*i.e.*, either variable or constant) gives indication of proximity of significant recharge areas. All these attributes, if considered together, offer qualitative characterization of the involved flow system at that geographic point.

An effort was made in this study to locate and sample all of the large springs associated with carbonate rock terrane. Appendix Table 4 lists representative springs (often more than one large spring is present in localized areas of discharge) and data of location, local environment of occurrence, discharge, elevation, temperature and classification with respect to represented flow system.

Tritium in Carbonate Rock Springs

Tritium, the hydrogen isotope of mass 3 with a half-life of approximately 12.27 years, is a useful hydrologic tool. Before March 1954, limited data suggests that the normal level of tritium in the atmosphere and in precipitation was in the neighborhood of 8 to 10 Tritium Units (T.U., number H_3 isotopes per 10^{18} hydrogen atoms). This level of tritium was generated by extra-terrestrial sources and cosmic rays; however, since the early 1950's, thermonuclear devices have released large concentrations of tritium to the atmosphere. Since that time atmospheric moisture in the northern hemisphere has been well above 10 T.U., and usually above 100 T.U. over the continents. Thus, ground water which assays greater than 8 or 10 T.U. has some component of water that has recharged since 1954, or at least some source of contamination. For this reason tritium is useful for ascertaining if recently recharged ground water is present at the point of sampling. Generally, control on mixing with older, tritium-poor water, and uncertain tritium concentration and timing of recharging waters does not permit confident dating of ground water.

Reconnaissance sampling for tritium in large springs associated with carbonate rock terrane has been used to further investigate the character of carbonate rock flow systems and the monitoring utility of springs which are frequently associated. Determination of water chemistry of springs is far more economical than determinations of tritium concentrations; thus another useful aspect is demonstrated. Figure 12 illustrates that concentration of Na + K forms a fairly reliable criteria for predicting absence or presence of significant amounts of tritium in a spring which issues from carbonate rock terrane. Significant amounts of tritium were found in all sampled springs that contained less than 3.8 ppm Na + K. No significant amount of tritium was found in any sampled spring that contained more than 8 ppm Na + K.

Another aspect demonstrated by the assays is a better understanding of the so-called "local" and "regional" carbonate rock flow systems which have been suggested (Maxey and Mifflin, 1966). On the basis of water chemistry and independent hydrologic data, relative paths of flow or lengths of flow systems in carbonate rock terrane were divided into two broad categories, local and regional systems. Occurrence of tritium in significant concentrations in waters with low concentrations of Na+K, Cl and SO_4, and consistent absence of significant tritium in waters with higher concentrations of these ions lends strong support to characterization of flow systems into local and regional systems, and indicates further that very little or no recharge occurs near points of discharge of large springs associated with regional systems. Springs which contain significant concentrations of tritium may be further separated on that basis as being related to "small local" flow systems. At least part of the water that discharges in these springs circulates from positions of recharge to point of discharge in no more than 12 years. Those springs which assay 300-600 T.U. are likely to be discharging a high percentage of ground water with a very short resident time in rocks, perhaps as short as a few months. This is based on probable levels of 200-1500 T.U. in precipitation in Nevada since bomb testing began.

Flow System Classification by Chemistry and Tritium

Variations in water chemistry and tritium in large springs associated with flow systems in carbonate terrane aid in flow system delineation. A classification is applied that is broken into three general groups of springs associated with 1) small local flow systems, 2) local flow systems and 3) regional flow systems. The approach has been to consider water chemistry in springs known to be associated with systems that are interbasin in configuration (regional with long flow paths) and water chemistry in large springs which are intrabasin in configuration (local with short flow paths). Further, the occurrence of tritium in significant quantities in some springs permits a third classification with limits based on tritium.

The water chemistry chosen to establish the division between regional flow systems and local flow systems is based on that observed in the large springs in Pahranagat Valley. There seems little doubt that the 25,000 acre-ft. per year discharge of these springs is greater than any rational estimate of recharge in the surrounding basin (Eakin, 1966, p. 266, estimates 2,000 acre-ft. per year of recharge) and the nearest positions of ground-water discharge up gradient is at least 40 miles. Hence, interbasin flow and long flow paths are certain for these springs. The water chemistry of interest is as follows:

Spring	Na+K	C1+SO_4
Hiko Spring	1.44 epm	1.06 epm
Crystal Spring	1.13 epm	.79 epm
Brownie Spring	2.10 epm	1.02 epm
Ash Spring	1.51 epm	1.05 epm

Of this group of springs Ash assayed < 5 T.U., and gave an apparent C^{14} age of 22,200 ± years. For convenience, the cutoff for regional classification is 1 epm of Na+K, and 1 epm of C1+SO_4. To further check this criteria, the other best documented springs relating to interbasin flow are the Muddy River Springs and the Ash Meadow Springs. The former group contains over 4 epm of Na+K, and over 2 epm of C1+SO_4. There is little question that 1 epm includes the water chemistry of springs associated with documented regional carbonate rock flow systems. In view of the total sample available in this study, the Pahranagat Valley springs are considered the type springs for the division between spring-water chemistry in regional flow systems and local flow systems in carbonate rock terrane.

The local flow system classification includes large springs with Na+K and C1+SO_4 concentrations ranging between 1.0 epm and .3 epm. The upper limit is provided by the Pahranagat Valley Springs; the lower limit is chosen on the basis of the results of reconnaissance tritium samples. Only one large spring, Spring Creek Spring, with concentrations greater than 0.3 epm Na+K and C1+SO_4, contained significant quantities of tritium. This spring contains .31 epm of Na+K and .49 epm of C1+SO_4. Many sampled springs had no significant tritium below .3 epm cut-off.

The proof of small local and local flow systems as characterized by the water chemistry and tritium is not difficult to establish. Other relationships, particularly adjacent ground-water divides and elevations of discharge, variation in discharge on an annual basis and

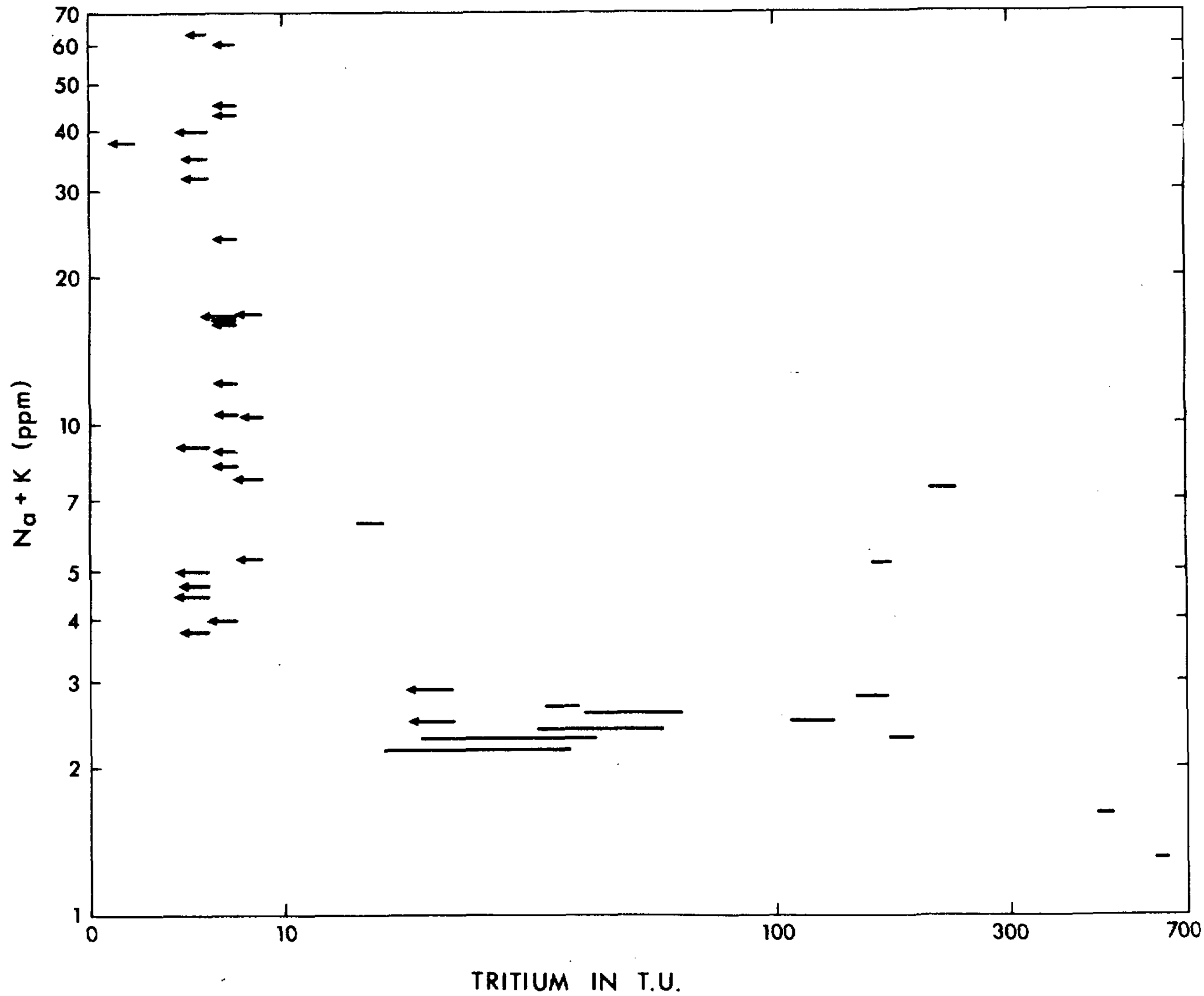


FIGURE 12 - Relation of Na + K concentration to tritium concentration

water temperatures usually preclude great distances of movement from recharge area to the position of the spring. For example, the springs in mountainous terrane usually have no other plausible source other than nearby recharge because of 1) elevation of occurrence, 2) absence or distant separation from higher recharge areas other than those immediately adjacent, 3) discharge pulses that follow spring runoff and 4) low temperature water which suggests shallow circulation. However, the springs that fall into the higher water chemistry range of the local flow system classification are the least well documented as to their true system relationships. Many of these occur in or along the flanks of alluvial basins, and in such environments could be positions of discharge for short interbasin flow systems.

Figure 13 is a log-log plot of concentrations of Na+K ions versus $Cl+SO_4$ ions found in the large springs associated with the carbonated rock terrane. Also shown are the discussed boundaries of flow system classification, the springs assayed for tritium, and the springs that displayed significant tritium. Although the scatter of data is not extreme, it is believed that part of the scatter relates to analytical problems produced by using several sources of analysis, and part relates to local hydrogeological environments. For example, many springs in the sample issue through at least a limited thickness of alluvium and many different temperatures of water are involved. It is also possible that various carbonate rock sequences contain different concentrations of the considered ions, and this

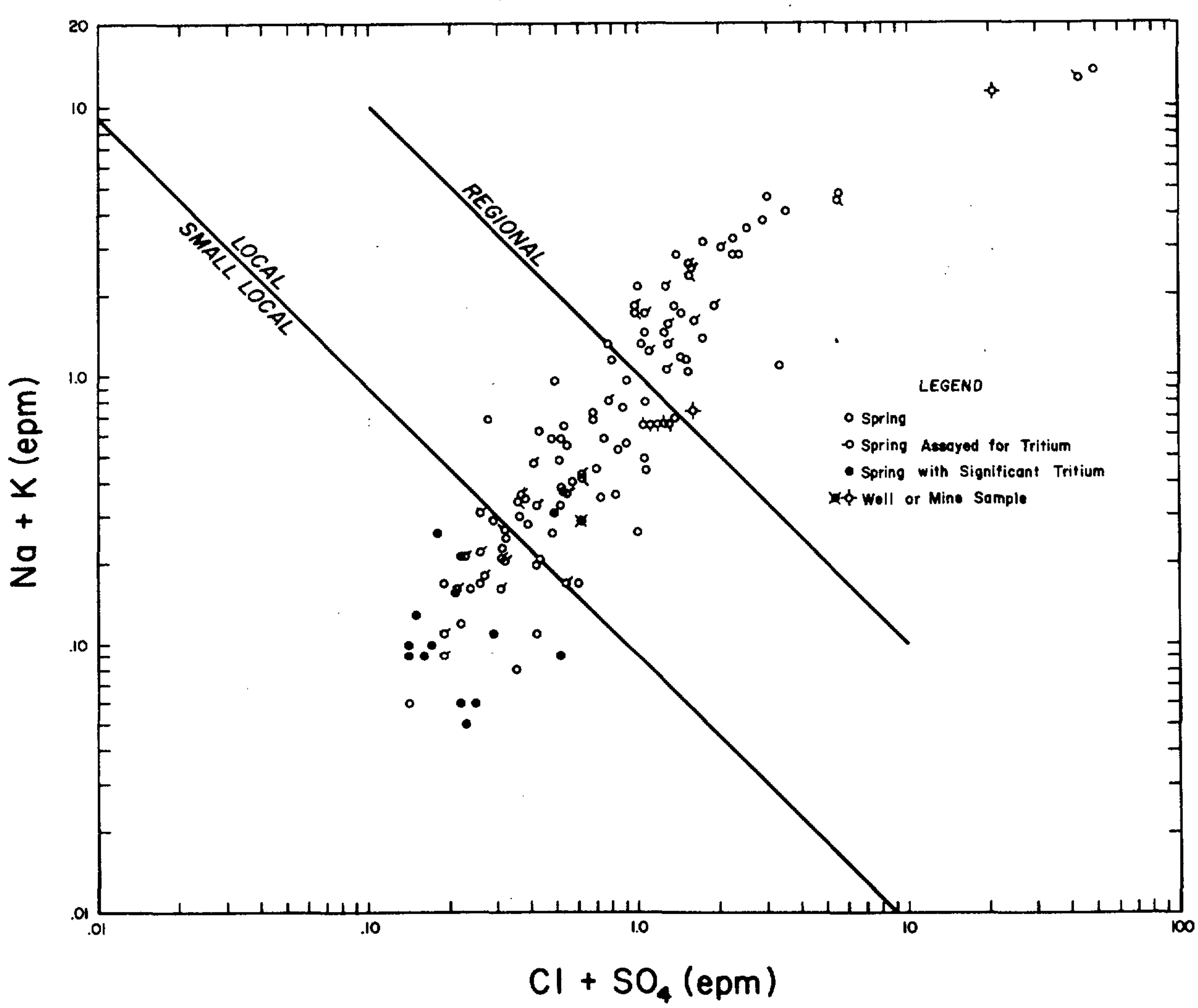


FIGURE 13 - Plot of the relation between water chemistry, tritium, and spring classification

possibility constitutes the greatest weakness of the approach. This aspect seems negligible within the broad ranges considered in each classification; however, the tritium data are the only good test of important differences in rates of increase of soluble salts along flow paths.

Appendix Table 5 lists tritium determinations and concentrations of Na+K, Ca+Mg and Cl+SO_4 in large springs. Further, the classification as discussed is indicated, and the water temperature is listed for ease in comparison. Concentrations of Ca+Mg are given to demonstrate the limited range of variation associated with ground water from carbonate rock terrane. A few C^{14} determinations are also listed in the table.

The use of water chemistry for system classification in samples from wells or mines is not clearly reliable. Several such points are included for comparative purposes, and reasonable results are found. However, the tritium found in the Eberhardt Tunnel gouge seepage seems too high for the water chemistry, possibly because of direct communication of air and opportunity for evaporation. The Fad Shaft sample (No. 31) borders on the local-regional classification boundary, and this seems valid when compared to the lack of success of mine dewatering in this area and spring to the north (Nos. 25, 27, 28, 29 and 30) which fall into the regional classification. However, the known sulfide deposits of the area should impart high concentrations of SO_4, and this is the case.

A number of water analyses from deep carbonate rock aquifers in the Nevada Test Site area (flow system No. 122 in Plate I) display greater salt concentrations than those present in the springs at Ash Meadows. These springs constitute the majority of discharge for that flow system. Thus, it appears that the most reliable water-chemistry samples from carbonate terrane flow systems are those taken at positions of natural discharge. At positions of natural discharge the water chemistry relates directly to the entire flux reaching that point; hence, water from stagnant zones blends with water from permeable zones to give an integrated sample of the flow system. Artificial sample points may yield water chemistry relationships which grossly differ from the average character of flux in the entire flow system. For this reason samples from points other than large springs have not been used to characterize the carbonate rock flow systems.

Flow System Boundaries in Southern and Eastern Nevada

The flow system boundaries in southern and eastern Nevada have been developed on the basis of both conventional hydrologic data and system classification studies of the large springs. Even with the combined approach, delineation of flow systems in this region is believed subject to major error, and truly confident delineation awaits the proof provided by carefully collected fluid potential data from deep boreholes in key areas.

Plate II illustrates the distribution of flow system boundaries and location of the large springs associated with the carbonate rock terrane of eastern and southern Nevada. Illustrated by symbol are system classifications of each spring, and each is identified by the spring number in Appendix Tables 4 and 5. Several springs classified as regional occur in flow systems delineated as essentially confined to topographic basins. These springs are suggestive of localized interbasin flow in areas where shallow configuration of saturation indicates local flow systems.

Areas of Possible Interbasin Flow: Diamond Valley flow system No. (85 in Plate I) is a situation where considerable interbasin flow may occur but the source area for flow into the basin is uncertain. Shipley Hot Springs, with a discharge of 6,750 gpm, Siri Ranch Spring, Bailey Spring, Romano Artesian Spring, all less than 200 gpm, and Thompson Ranch Spring with 900 gpm classify as to related to regional flow systems. Further support is provided by water chemistry of Emerald Lake Cave Pool and the Fad Shaft of the Eureka Mining District. Northward, or northwesterly gradients of flow seem probable on the basis of water levels along the southern and eastern margins of the basin. Eakin, 1962, p. 21-23, has estimated 16,000 acre-ft/yr of recharge in the topographic basin, and 23,000 + acre-ft/yr discharge. Omitted from the discharge estimate is 49,000 acres of phreatic playa. This area of discharge would yield about 15,000 acre-ft/yr additional discharge if the rate of evaporation is assumed one-tenth of potential evaporation. However, it is the opinion of most hydrologists that such a rate is higher than most phreatic playas, but there is little quantitative data to support this belief. Thus, if the recharge-discharge estimates are applied, there is a minimum imbalance of discharge over recharge by 7,000 acre-ft/yr, and perhaps two or three times this value.

The water chemistry and water budget approach to delineation supports interbasin flow into Diamond Valley, yet fluid potential relationships suggest shallow ground-water divides surround the valley. Further, a source for the interbasin flow is not established.

Newark Valley flow system (No. 86 in Plate I) is also of questionable delineation. Its relationship to Long Valley flow system (No. 87 in Plate I) is uncertain, but it seems a possible position of discharge for ground water that has recharged in the Long Valley basin. The evidence for this relationship is given in the following paragraphs.

A large warm spring, Giocoechea Warm or Simonson Spring, occurs adjacent to the northeast margin of

Newark Valley phreatic playa. Its discharge is over 1,000 gpm, and the elevation of discharge is approximately 5,880 feet, at least one hundred feet lower than the lowest known fluid potential in Long Valley. The water chemistry of the spring is slightly below the regional classification, with Na+K .96 epm, and $Cl+SO_4$ .91 epm (1 epm is the arbitrary boundary between regional and local).

Eakin (1961, p. 23) estimated about 2,200 acre-ft/yr of ground-water discharge in Long Valley, and about 10,000 acre-ft/yr recharge. In Newark Valley, Eakin (1960, p. 13 and p. 15) estimated about 18,000 acre-ft/yr recharge, and 16,000+acre-ft/yr discharge. However, he omitted 25,000 acres of phreatic playa because of the uncertain rate of evaporation.

At one tenth potential evapotranspiration, the playa would yield about 7,500 acre-ft/yr of additional discharge. This would unbalance the budget by approximately 5,000 acre-ft/yr of more discharge than recharge. The amount of underflow from Long Valley was estimated at 8,000 acre-ft/yr; the amount of discharge of Giocoechea Warm Spring in Newark Valley is in the neighborhood of 2,000 acre-ft/yr; and there may be an imbalance of the water budget in Newark Valley by at least several thousand acres-ft/yr. Thus, on the basis of water chemistry and water budgets a case can be made for flow from Long Valley to Newark Valley. Although the budget approach is believed very weak in any delineation, the evidence seems more acceptable for flow to Newark Valley than southward into the White River flow system as Eakin (1966) suggests.

Southern Butte Valley (flow system No. 88 in Plate I) is an area where interbasin flow is suspected, but firm evidence is not presently available. In the southern and lowest part of the valley ground-water discharge is relatively minor in an environment where discharge should be extensive. This area is just east of the lowest area in Long Valley where discharge is entirely absent. This relationship raises the question of interbasin flow from both basins, perhaps to the same area of discharge. As mentioned previously, Newark Valley may be the discharge area of Long Valley flow. Steptoe Valley (No. 89 in Plate I) is another candidate for discharge to the east. However, budget studies in Steptoe Valley indicate less discharge than estimated recharge, and most of the springs in Steptoe Valley classify as related to local flow systems. There are no published budgets for Butte Valley.

Interbasin Flow in Southern and Eastern Nevada: Most flow systems in southern and eastern Nevada are interbasin in configuration of flow. Confident delineation of flow system boundaries in this region cannot be accomplished in detail with available data; however, the general aspects of delineation shown in Plate I are more or less valid. The greatest problem of delineation in this region is location of flow system boundaries in areas where important flow occurs at depth in carbonate rock. Shallow fluid potential data may be misleading as to the location of important boundaries.

The four largest interbasin flow systems in this area of Nevada are White River (No. 94 in Plate I), Railroad Valley (No. 95 in Plate I), Las Vegas (No. 124 in Plate I), and Amargosa Desert-NTS (No. 122 in Plate I). Pahrump Valley-Mesquite Valley flow system (No. 123 in Plate I) has been classified as a local flow system in the Nevada portion even though characteristics are very similar to the Las Vegas flow system. The boundaries of all these flow systems are uncertain in at least some areas. The chosen boundaries of these four systems in Plate I have been based on all available data, which includes shallow fluid potential data, lithology, budget estimates and water chemistry in springs, but none of the evidence is believed powerful enough to delineate boundaries with confidence.

White River flow system, Las Vegas flow system, and Amargosa Desert-NTS flow system all involve flow in carbonate rock with regional gradients to the south. The head or source of the White River flow system has been suggested as far north as Long Valley (Eakin, 1966); however, firm evidence for southward flow in the White River flow system does not extend beyond the north end of White River Valley. Jakes Valley, a closed basin without important ground-water discharge that is just north of White River Valley, is favored to discharge its ground-water flow into the White River flow system both in this study and two previous studies (Maxey and Eakin, 1949; Eakin, 1966). Even in this case, however, there are other possible directions of interbasin flow for at least part of the recharge that occurs in the Jakes Valley drainage basin. For example, some of the springs in the northern part of Railroad Valley which classify as related to regional flow systems may be manifestations of interbasin flow from the Jakes Valley drainage basin.

Railroad Valley flow system (No. 95 in Plate I) is an area where a number of springs in the northern part of the valley are believed to be related to regional flow, yet source for this interbasin flow is not clearly evident. Here again absence of fluid potential information in the deep carbonate aquifers may limit the accuracy of the delineation in this area. The flow system boundaries in this part of the flow system have been established on the basis of shallow fluid potential.

In Plate I, the common boundary between White River flow system (No. 94) and Las Vegas flow system (No. 124), and the common boundary between Las Vegas flow system and Amargosa Desert-NTS (No. 122) are generally unsupported by data indicative of boundary conditions. The boundaries are presented on the basis of theory and the adjacent relationships in the three flow systems. Hence, the positions and configuration are only speculative. Adjacent data indicates that flow is in the carbonate rock aquifers in this area, and that there is separation of flow to at least two positions of important discharge (Ash Meadows in No. 122 and Muddy River Springs in No. 94) and perhaps two more (Pahranagat Valley Springs in No. 94 and Las Vegas area in No. 124). Flow system theory necessitates flow system boundaries because of the widely separated discharge areas at about the same fluid potential. Thus, there must be flow system divides in the area under discussion, but total absence of fluid potential data in the carbonate rocks of this area does not permit any reliable determination of configuration or positions. Hence, Eakins (1966) boundary of the White River flow system has been shown in Plate I, and flow to Las Vegas flow system has been assumed. These boundaries are grossly supported by budget considerations (discharge in the three flow systems) and areas of prime recharge (Spring Mountains and the Sheep Range).

Characterization of Carbonate-Rock Flow Systems

Indirect evidence provided by water chemistry, tritium and fluid potential relationships, as well as hydrogeologic environments and gross water budgets, indicate rater diverse character of flow systems in carbonate terrane.

Regional Flow Systems: Regional carbonate rock flow systems are generally characterized by (1) interbasin flow, (2) long flow paths, (3) one or more local systems feeding the regional system, (4) thermal water at positions of discharge, (5) discharge waters light in C^{14} and tritium, (6) discharge waters relatively high in disolved constituents, particularly Na, K, Cl, and SO_4 and (7) springs with relatively large discharges and small ranges in discharge fluctuation. Though not demonstrable on the basis of firm evidence, reasoning suggests that transfer of water in regional carbonate rock flow systems over long distances (perhaps more than 100 miles) is restricted to fairly narrow or localized zones of secondary permeability created by contiguous masses of highly permeable carbonate rock. Intense deformation related to tectonic history of the Basin and Range structure has probably permitted development of such hydrogeologic environments by repeatedly stressing and deforming zones in these rocks. Over the same interval of geologic time, flow system configurations have been altered many times with an apparent net result of maintaining or developing secondary permeability.

These so-called "carbonate rock flow systems" in Nevada are not entirely confined to carbonate rocks. Rather, evidence suggests only that physical transfer of water seems dominant in zones within limestones and dolomites, as well as contiguous alluvium, and because of this relationship the chemical character of associated water, and localization of discharge, are rational characteristics of these flow systems. Local fluid potential observed within low permeability zones of these regional systems probably grades to the potential of prime transmitting zones; thus, hydrologic information such as water chemistry and permeability from sparse bore hole data may be misleading when prime transmitting zones are not sampled. Possible evidence of this is the water chemistry observed in deep bore holes into carbonate rocks of the Nevada Test Site. Some samples suggest conformance with known water chemistry at prime points of discharge (the Ash Meadows Springs) however, other samples are higher in dissolved constituents, perhaps because of more stagnant conditions in local environments of collection. Such sample points may represent water external to the main flux of the system.

The presently available tritium and radiocarbon determinations at points of prime discharge of regional systems indicate two important relationships--the water is old, and local recharge near the position of discharge must be very minor or nonexistent.

The amount of water bound up in storage in these regional systems is very large, and should effective and economic means be developed to tap these resources, long-term water supplies far exceeding current rates of replenishment could be realized. In southeastern Nevada such water supplies should be considered to the extent of determining feasibility of intensive development. In other arid parts of the world, such as Israel, and in many humid areas of the United States, large carbonate rock flow systems are being mined for water supplies.

Local Flow Systems: Local carbonate rock flow systems are characterized by (1) predominantly intrabasin flow, (2) flow paths wholly of essentially confined to one topographic basin, therefore usually less than twenty or thirty miles in length, (3) prime recharge and discharge areas immediately adjacent to much of the system, hence, short regions of lateral flow, (4) discharge with water temperatures typically in the 50 to 60°F range, (5) discharge waters of probable intermediate apparent age and absence of significant amounts of tritium, (6) some dissolved constituents ranging between certain concentrations, such as Na+K ranging between 0.3 and 1.0 epm, and $Cl+SO_4$ between 0.3 and 1.0 epm and (7) large springs displaying moderate fluctuations in discharge.

Generally these systems discharge significant flow both to large springs and alluvial basins, and in several areas of eastern Nevada interbasin flow occurs on a small scale (*e.g.*, Spring and Lake Valleys in Plate II). Further, local carbonate rock flow systems often constitute cells or headwater areas of regional carbonate rock systems, such as indicated by several large discharge springs along the east side of White River Valley.

Small Local Flow Systems: Small local carbonate rock flow systems are generally characterized by (1) intrabasin flow, (2) very short flow paths, usually no more than several miles, (3) proximity to areas with moisture available for significant recharge, (4) low water temperatures that commonly approach mean air temperatures, (5) discharge water rich in C^{14} and frequently rich in tritium, (6) discharge water relatively low in dissolved constituents, particularly Na, K, Cl and SO_4, and (7) large springs with a notable annual range in discharge. Separation of "small local" systems from "local" systems is essentially based on four directly observable relationships, items 4-7. These criteria establish what headwater characteristics of local systems apparently are near the recharge areas in carbonate rock. Hence, true physical separation of the three categorized systems is based for the most part on positions in systems; in some cases large springs from which these divisions are based may constitute the sink of the entire flow system, but in the majority of situations springs probably constitute only points of prime discharge for part of the flux in more extensive systems.

Small local systems, as characterized by large springs, may offer the most favorable hydrologic environment for understanding recharge relationships through careful study of flow regimen and adjacent recharge area moisture conditions. For the most part, small local systems do not offer significant opportunity for developing prolonged water supplies in excess of annual flux because of an apparent lack of storage within the systems.

In summary, the carbonate rock province of Nevada is an area where the characteristics of flow systems are quite diverse, and interbasin flow is common. Presently available data and techniques are adequate to roughly outline the flow systems in this region; however, these data and methods are not adequate to accurately delineate interbasin flow in many areas. Water chemistry in some large springs in the province suggests long flow paths and deep circulation in the carbonate rocks that is unrelated to configuration of shallow circulation. In these areas accurate delineation of interbasin flow will require fluid potential information from deep boreholes.

SUMMARY

General Description of Flow Systems

One hundred and thirty-six ground-water flow systems are recognized within the boundaries of Nevada. These are generally described in Appendix Table 2 by listing for each flow system (1) prime source areas, (2) prime sink areas, (3) hydrographic basins that are involved, (4) budget estimates for the hydrographic basins that have been made by the U.S. Geological Survey and (5) remarks about aspects of the delineated flow system.

Prime source areas are listed by the geographic features which provide the most important sources of water for recharge to the flow system. In each flow system the source areas are listed by probable importance with respect to amount of moisture available for recharge. In some flow systems of southern Nevada, localized recharge areas are unknown, and most recharge is believed to be related to infrequent and localized precipitation which occurs sporadically throughout the area of the ground-water flow systems.

Prime sinks of the ground-water flow systems are listed by geographic features or areas. For example, if most discharge is restricted to base-flow in a stream, the stream is named. However, when ground-water discharge is a combination of spring flow or stream flow and widespread transpiration by phreatophytes, the basin or valley in which the discharge occurs is named as the prime sink of the system. When several areas of important discharge are present, they are named in order of probable importance.

Hydrographic basins which are partly or entirely within the boundaries of each flow system are listed. These areas are more or less based on surface water drainage basins as named and defined in the January 1968 map "Hydrographic Areas" produced by the Division of Water Resources in the Nevada State Engineers Office. The hydrographic divisions essentially correspond to the areas where recharge-discharge estimates have been made in the state. However, in many areas, hydrographic divisions do not correspond to the boundaries of ground-water flow systems as defined in this study.

Available recharge and discharge estimates are listed by hydrographic divisions. Hence, the direct application of the estimates for water budget balancing is not possible in many ground-water flow systems. However, the discharge estimates are of value because they give an idea of the flux from some flow systems.

Confidence of System Boundaries

A study such as this would be incomplete unless the degree of confidence in delineation is in some manner presented. Problems and assumptions of flow-system delineation have been discussed at length, but it has not been possible to present in detail the density and quality of available data from which each flow system has been delineated. Thus, Appendix Table 1 indicates uncertain delineation and confident delineation. Most uncertainties are related to the location of boundaries between flow systems in areas of sparse hydrologic data, or areas where interbasin flow is suspected.

Most of the regional flow systems are subject to a low degree of confidence, and many local systems are subject to a high degree of confidence.

Classification by Configuration of Flow

Toth (1963, p. 4806-4807) separated ground-water flow systems into local, intermediate and regional flow systems on the basis of theory and associated models. His models simulated prairie terrane of undulatory relief superimposed upon large drainage basins in Alberta, Canada. Circulation cells that discharge only recharge derived within the area bounded by shallow fluid potential divides were termed "local" systems. "Intermediate" flow systems discharge water which in part is derived beyond shallow fluid potential divides. The "regional' classification was applied to the group of flow lines which discharge at the lowest part of the large drainage basins, and the discharge includes water derived from a number of intermediate or local flow system cells of circulation.

When an attempt is made to apply Toth's classification to flow systems observed in Nevada, the general idea of long or short flow lines and the distinction of discharge derived entirely or only partly within the same basin is applicable. However, differentiation between intermediate and regional flow systems seems impossible on the basis of available information. Therefore, in this study the two broad system classes applied are local and regional flow systems.

In Nevada local flow systems are best defined as systems where the majority of flux recharges and discharges in the same basin. Regional flow systems involve significant interbasin flow. In other words, there are flow systems which discharge water that was recharged in different basins. Significant interbasin flow implies that the process is recognized with the available data and methodology.

The application of the chosen system classification is misleading in some instances with respect to size of systems or length of flow paths. The fundamental attempt to separate short flow paths from long flow paths by virtue of the interbasin flow criteria occasionally leads to situations where general physical attributes, such as water chemistry, temperature and length of flow, are typical of local flow systems, when in fact the criteria forces a regional classification. Also encountered in some cases is the opposite situation of local classed systems with physical attributes that correspond better to regional flow systems. However, on the basis of ground-water use and associated management considerations, the criterion of interbasin flow is practical. Appendix Table 3 lists the classification (regional or local) for each flow system shown in Plate I. In a few areas where minor interbasin flow is present a local classification has been applied.

Further characterization of configuration of flow within the two classifications partly rectifies inherent problems of "local" and "regional" classification. In Nevada these two broad categories may eventually be subdivided, or perhaps reclassified, on the basis of detailed configuration of flow. However, with presently available data such elaboration would necessarily be on the basis of temperature relationships assumed to indicate depth of circulation, water chemistry relationships as discussed in the section on flow systems in carbonate rock terrane, and fluid potential relationships indicating configuration of interbasin transfer. In the present study, only the criterion of the occurrence or absence of interbasin flow is applied to each delineated flow system; however, further differences of several flow systems are well enough known to discuss with respect to apparent configurations of flow and possible classification.

Thermal Relationships: Local flow systems are by definition confined to topographic basins. However, within this generalization, the thermal relationships of ground water imply that some local flow systems are "shallow" in circulation; some are both shallow and deep in circulation, or are "composite" in that both normal and thermal ground water occur in the lower reaches of the systems; and in some there is observed almost entirely thermal ground water in the lower reaches of "deep" circulation. Therefore, if the temperature of ground water is a good indicator of circulation depth, this variation provides a criterion for further classification of configuration of flow. Examples of two configurations of local flow systems are illustrated by water temperature histograms in Figure 10. Quinn River Valley-Silver State Valley (No. 17 in Plate I), Truckee Meadows (No. 66 in Plate I) flow systems illustrate the shallow circulation type and the composite type, respectively.

The other histogram in Figure 10 involves Las Vegas flow system (No. 124 in Plate I). This histogram provides an example of a deeply circulating regional flow system. Pahrump Valley-Mesquite Valley (No. 123 in Plate I) is classified as a local flow system in the Nevada portion. Here, ground-water temperatures reported by Malmbert (1967, p. 45) indicate marked similarity in ground-water temperatures of Las Vegas Valley and Pahrump Valley. Below a depth of about 400 feet in Pahrump Valley, Malmberg reports ground-water temperatures ranging between 67° and 80°F, and averaging about 75°F. This water appears to be related to deeply circulated flow in the carbonate rock aquifers.

Evaluated on the basis of extremely sparse ground-water temperature data, many local flow systems in Nevada are believed to be "composite". This seems a particularly valid generalization for most of the large flow systems in northern and central Nevada that discharge in the major topographic basins. It is suggested that high relief provided by adjacent mountains, thick and relatively permeable basin sediments, and recharge occurring within the mountain ranges generates considerable deep circulation of ground water. However, in these basins moisture availability is such that important recharge occurs directly into the basin sediments, and this ground water does not circulate to great depths. Therefore, both high and low temperature ground water is noted in these basins. The relationship of this thermal ground water to interbasin flow is not clearly established (see the discussion under Thermal Ground Water and Interbasin Flow).

Most "shallow" local flow systems (ground water near mean air temperature) relate to basins near or within areas of abundant moisture available for recharge. The general impression is one of major amounts of recharge occurring near discharge areas, and only a very small percentage of flux is deeply circulated ground water. If this interpretation is valid, it suggests that sparse ground-water temperature data presently available in many basins may be misleading in attempts to characterize the circulation configuration of flow systems. Areas of thermal ground water usually are accompanied by thermal springs. Frequently, in undeveloped ground-water basins thermal springs constitute the bulk of available temperature data, yet these springs may also constitute the bulk of thermal ground-water flux present in the flow systems. Appendix Table 3 lists the apparent circulation configuration based on temperature data. The utility and accuracy of this aspect of the flow systems shown in Plate I is compromised by sparse data in many areas.

Fluid Potential Relationships: Regional flow systems in Nevada, besides being characterized by ground-water temperature assumed indicative of depth of circulation or water-chemistry relationships in carbonate terrane, may be characterized by two general configurations of interbasin transfer of ground water. The most commonly recognized type of interbasin transfer occurs by the development of a shallow fluid potential gradient through a topographic divide, so that there is a regionally sloping air-water interface between two or more basins. This configuration of transfer is referred to as the "regional gradient" type.

The second type of interbasin flow is suggested in a few areas, yet it may be the most common form of interbasin transfer of ground water in natural flow systems. For lack of a better term, it is referred to as "deep circulation" interbasin transfer. The "deep circulation" configuration of flow is that illustrated in the models of Figure 2. Shallow fluid potential divides are not necessarily barriers to interbasin flow if relatively high permeability zones of earth materials underlie topographic divides. Model studies suggest that the amount of interbasin flow that may occur is closely related to relative permeability of zones at depth, as well as general configuration of the flow system as determined by the distribution of recharge and relief.

Most regional flow systems with "regional gradient" configuration of flow between the involved basins are established by sparse water-level data in wells near topographic barriers formed by low mountain ranges or minor topographic barriers formed by low mountain ranges or minor topographic divides. Flow systems which locally display this configuration of interbasin flow are: Columbus Salt Marsh-Toiyabe (No. 100 in Plate I), Sarcobatus Flat (No. 119 in Plate I), Amargosa Desert-NTS (No. 122 in Plate I), Railroad Valley (No. 95 in Plate I), White River (No. 94 in Plate I), Lake Valley-Spring Valley (No. 93 in Plate I), Snake Valley (No. 92 in Plate I) and Ivanpah Valley (No. 132 in Plate I).

Sparse data indicates Oasis Valley flow system (No. 120 in Plate I) heads in the Gold Flat area and flows southward through Pahute Mesa, where water levels in deep boreholes suggest a regional gradient to the south toward the Oasis Valley discharge areas. However, the reported water-level data does not clearly document shallow fluid potential relationships in this area, and "deep circulation" configuration of transfer may exist.

In Eldorado Valley (No. 130 in Plate I) a few wells indicate northerly flow of ground water, and absence of discharge within the valley and elevations of ground-water discharge in this part of the state indicates probable flow to the east or northeast into Colorado River drainage. However, position of interbasin transfer and absence of a region of high fluid potential in the Eldorado Mountains are not demonstrated by currently available subsurface information.

In the northern part of Spring Valley flow system (No. 90 in Plate I) flow is believed to be southward from Antelope Valley, but water level data is too sparse to confirm a "regional gradient" configuration of flow.

In Nevada, the available evidence of interbasin transfer of "deep circulation" configuration is provided by imbalance of water budgets, water chemistry in large springs associated with carbonate rock terrane, and apparent shallow saturation in basin bounding ranges indicated by numerous springs and occasional live streams. "Abnormal' ground-water temperatures may also add to the evidence. Such evidence culminates to suggest "deep circulation" configuration of interbasin transfer of ground water in the region constituted by Jakes Valley, Long Valley, Newark Valley, Diamond Valley and perhaps southern Butte Valley. The majority of the topographic divides between these valleys are at elevations which provide significant moisture available for recharge, and some evidence of shallow saturation more or less conforming to mountain topography is present in the form of surface-water features. Budget estimates made by the U.S. Geological Survey (see Appendix Table 2), large discharged springs which display water chemistry comparable to known regional carbonate rock flow systems, and occurrence of thick sequences of carbonate rock of possible high relative permeability underlying many of the basin divides points to interbasin transfer of ground water. Thus, "deep circulation" configuration is probable, but accurate delineation of such movement is not firmly established.

The most reliable proof of "deep circulation" interbasin flow would be established by collecting $d\phi/dz$ data in deep boreholes in the areas of shallow fluid potential divides (see Figure 4 and the related discussion). Unfortunately, such data is not available in the area, even though several deep petroleum test wells have been drilled in this area. The few drill-stem tests conducted in the test holes of this area are not adequate to establish absence or presence of circulation cell boundaries. Limited experience in drilling and testing procedures in deep boreholes indicates practiced procedures are not conducive to fluid potential measurement useful for flow system definition.

Flow systems in Nevada which may have areas of "deep circulation" interbasin transfer configuration are: White River (No. 94 in Plate I), Long Valley (No. 87 in Plate I), Diamond Valley (No. 85 in Plate I), Steptoe Valley (No. 89 in Plate I) and possibly Butte Valley (No. 88 in Plate I).

In the White River flow system "deep circulation" configuration of flow southward from Jakes Valley area into White River Valley is suggested. In his White River flow system study Eakin (1966) indirectly implies "deep circulation" configuration of flow southward from Long Valley into Jakes Valley and White River Valley, but he does not discuss the configuration. Numerous springs in the mountainous terrane between Long Valley and Jakes Valley indicate a shallow fluid potential boundary between the two basins. However, another plausible direction of "deep circulation" configuration of flow from Long Valley is west or northwest into Newark Valley. This is favored because: 1) the distance is shorter (10-20 miles into Newark Valley as compared to a minumum of 45 miles to White River Valley discharge areas); 2) the budget of Newark Valley is open to question as to balance; 3) one large spring area displays water chemistry that is near the regional-local boundary of classification; and 4) the elevation of discharge in Newark Valley is lower than the lowest known water levels in Long Valley.

Diamond Valley and Steptoe Valley flow systems are suggested to involve "deep circulation" transfer configuration primarily because of spring water chemistry and evidence of saturated basin divides. However, interbasin transfer is not clearly proven, and if present, the source of recharge is not recognized on the basis of currently available water budgets. Southern Butte Valley is an area where sparse discharge in the lowest part of the valley suggests possibility of "deep circulation" configuration of interbasin transfer to another basin. Steptoe Valley flow system is a possible position of discharge by virtue of adjacent position, elevation of ground-water discharge and water chemistry in a few large springs. Budget studies in Steptoe Valley (see Appendix Table 2) indicate slightly more recharge than discharge in Steptoe. However, the character of discharge in Steptoe Valley is diverse, and in this case both recharge and discharge estimates may be subject to considerable error.

Water chemistry in several large springs associated with carbonate rock terrane provides evidence of possible small scale interbasin transfer of water by "deep circulation" configuration in a number of other flow systems. Figure 14 shows the location of several of these "regional" springs near flow system boundaries established by evidence of shallow saturation in basin divides. If water-chemistry relationships are as reliable as the available evidence indicates, "deep circulation" configuration of interbasin transfer may be quite common in areas of extensive carbonate rock terrane, and conventional depiction of flow systems on the basis of configuration of shallow saturation may lead to substantial error in the definition of flow system boundaries. Thus, confidence in the flow system delineations in these areas is greatly decreased by the water-chemistry evidence developed in the spring study.

Characterization by Environmental Variables

There are marked differences in flow system environments in Nevada generated by differences in geology and the availability of water for recharge. Relative differences aid in the general description of the involved flow systems and at the same time indicate the importance of some variables of environment to the configuration of flow. These aspects are treated in general terms and are included in Appendix Table 3.

Permeability: Basin and range physiography throughout most of Nevada creates the basic unifying geological framework for the ground-water flow systems. The intermontane basins are underlain by various thicknesses of relatively permeable unconsolidated and semiconsolidated clastic sediments. In some areas these deposits contain interbedded volcanic flow rock or tuffaceous rock, and some basins are underlain at depth by thick sequences of less permeable consolidated or semiconsolidated clastic and pyroclastic rocks. The basin sediments are bounded by generally less permeable "bedrock" lithologies of the adjacent mountain ranges. Similar rocks underlie the basin sediments at depth.

An important variation in this geologic setting is the amount and relative differences in permeability of the bounding bedrock. Several types of volcanic rock are far more permeable than most indurated rock, and the same generalization is true of carbonate rock. On a statewide basis, the absolute differences in permeability and precise location in the subsurface is not generally known. However, relative differences based upon the widespread presence or absence of such bedrock lithologies can be established for most areas. Flow systems in areas of 1) low permeability bedrock, 2) relatively permeable bedrock and 3) localized occurrences of relatively permeable rock are listed in Appendix Table 3. In many situations a given flow system may embrace terrane which involves more than one of the three categories, and in such situations an attempt has been made to be liberal in suggesting the importance of relatively permeable bedrock.

Moisture Availability: A second environmental variable important to the character of the flow system in Nevada is the relative availability of water for recharge, and its distribution. This aspect of environment gives rise to marked differences in configuration of flow. The concept of ground-water flow capacity of terrane is the direct result of moisture availability for recharge.

In this study, the relative availability of moisture for recharge is divided into four categories: 1) abundant moisture available for recharge by direct precipitation and associated runoff, 2) intermediate moisture availability for recharge, which implies presence of limited areas where significant moisture is available for recharge, 3) abundant moisture available for recharge only within the basins because of important surface water transfer to the basin, and 4) sparse availability of moisture for recharge.

The abundant moisture category (1) commonly generates at least local conditions of terrane at ground-water flow capacity; hence, live streams or marshes are often found in the associated basins. Category 2 of the intermediate moisture availability is not generally conducive to terrane at flow capacity except in the high mountains. Here, low permeability terrane is commonly at flow capacity; hence, numerous small springs and small live stream are found only in the mountains. Category 3 of abundant surface water in the basins creates widespread shallow saturation and large discharge areas in the basin lowlands, but in such areas probably only a small part of the flow system flux is derived from precipitation in the bounding mountain ranges. Category 4 of sparse moisture available for recharge generates widespread absence of terrane at flow capacity. Hence, there is often little evidence of saturation near land surface throughout most of the flow system. Zones of rock which would ordinarily be considered essentially impermeable boundaries may transmit relatively important amounts of flux in the involved flow systems. In a few areas local evidence suggests that the hydrologic role of some basins may be reversed in that they behave as recharge areas, and adjacent or underlying bedrock behaves as the prime transmitting zone of the flow system.

The distribution of moisture availability and bedrock permeability is more or less related to geographic areas in Nevada. For example, many of the topographically closed basins of central Nevada are founded by rock types of low permeability, and moisture for recharge is restricted to high areas in bounding ranges. Much of the bedrock in the eastern and southern part of the state is thick sequences of carbonate rock of high relative permeability. However, within this geologic province, moisture availability for recharge varies from category (1) of abundant moisture in a few areas in the north to category (4) of sparse moisture availability in the south. Further sparse moisture availability extends into the northern half of Nevada in several areas because of a combination of terrane elevation and a rain shadow effect immediately east of the Sierra Nevada.

Correlation of System Classification with Environmental Variables

Some relative environmental variables of geology and moisture availability are conducive to interbasin flow. If these environmental considerations were listed on the basis of major topographic basins rather than geographic areas representing individual flow systems, marked correlation between interbasin flow and certain aspects of the environments would stand out. However, when listed by flow system in Appendix Table 3, relationships between environmental variables and system class are not as apparent. Table 2 lists number and percentages of regional and local flow systems that display the discussed environmental variables.

Regional or interbasin flow systems are closely related to bedrock permeability, and also are related to conditions of limited availability of moisture for recharge. This latter correlation is not seen in percentages of Table 2 because many of the regional flow systems include several topographic basins in the sparse moisture categories. If environmental variables were broken down by large topographic basins rather than by flow systems, about 30 additional areas would be added to the sparse moisture category where regional flow occurs. Regional flow would then outweigh local flow in basins of the sparse moisture category.

The close correlation of interbasin flow in flow systems in areas of relatively permeable bedrock is expectable. However, the correlation of limited recharge with areas of interbasin flow has not been generally recognized. This study indicates that the combination of limited recharge and relatively permeable bedrock is most likely to produce conditions of recognizable interbasin flow. It is suggested that absence of flow capacity and important recharge in the alluvial basins enhances the opportunity for interbasin flow systems to develop. Small system flux and only minor recharge in the basin bounding bedrock areas permit "regional gradient" configuration of interbasin flow through zones of relatively permeable bedrock.

Table 2 - Comparison of Environmental Variables with Flow System Class

	No. of Local Systems	% of 114 Local Systems	No. of Regional Systems	% of 22* Regional Systems
MOISTURE				
Abundant (Cate. 1)	25	22%	0	0%
Intermediate (Cate. 2)	65	57%	16 [a]	73%
Abundant Surf. Water (Cate. 3)	9	8%	0	0%
Sparse (Cate. 4)	15	13%	11 [a]	50%
BEDROCK PERMEABILITY				
High	63	55%	20	91%
Low	25	22%	0	0%
Local	26	23%	2	9%

* - Four systems of local classification are included in regional tabulation because they are believed to constitute headwater portions of regional flow systems.

a - Several regional systems extend from category two to category four moisture conditions, hence, an apparent double count.

CONCLUSIONS

An attempt has been made to delineate ground-water flow systems that occur in Nevada. Available hydrologic and geologic data has been considered on the basis of flow system theory. As a result, one hundred and thirty-six flow systems have been recognized; some have relatively accurate boundaries and others have only approximate boundaries. Fluid potential data are believed to be the most accurate physical measures of ground-water flow systems, but these data are only abundant in the shallow subsurface in lower reaches of the flow systems. Though important in determining flow system configuration, data of vertical change in fluid potential is not common. Fluid potential information in the deep subsurface is extremely sparse in Nevada, yet there is abundant indirect evidence of important deep circulation in many ground-water flow systems in Nevada.

Many techniques which have been used to delineate flow systems are weakened by questionable assumptions. This study has attempted to avoid placing too much confidence upon the results of these techniques. These techniques usually involve indirect measures of flow systems. Some are predicated upon parameters which are unrelated to ground-water flow. Ground-water budgets are a good example of such a technique. The recharge half of the budget calls upon annual precipitation, a phenomenon which in some areas may have no relationship to recharge. Other techniques of delineation, such as interpretations of water chemistry and temperature are also based on uncertain assumptions, yet at least they involve measureable parameters of ground water. If used with care within the context of flow system theory, these relic parameters of flow path aid in understanding flow systems.

Optimal flow system delineation consists of knowledge of the source and sinks of the flow system, as well as the configuration between these two boundaries of the system. This study has attempted to approach each of these requirements of delineation and has met with varying degrees of success. Adequate delineation of flow system sinks has been attained. Source areas have been established only in an approximate manner by using indirect measures. Configuration of flow has been approached by direct measures (fluid potential) and indirect measures (ground-water temperature and chemistry). In most areas this delineation requirement has been met only in gross terms because of paucity of data.

Very detailed flow system delineation is believed possible with the present understanding of fluid flow in porous media. However, this type of flow system delineation requires careful collection of fluid potential data in three dimensions. In Nevada there is no large ground-water flow system that is delineated in detail and there may not be any large flow system so delineated in the world. This follows from the fact that the wrong type of fluid potential data is commonly sought and collected. Further, other measurable physical parameters of ground water are not often carefully considered within the context of flow system theory, hence, the potential utility of these data has not been carefully investigated.

This study, besides providing a delineation of flow systems that may be tested and perhaps improved by future studies, has pointed out some potentially valuable approaches and relationships for ground-water studies. These include the recognition of vertical distribution of flow system cell boundaries by fluid potential measurements in wells, the concept ground-water flow capacity of terrane, the gross environmental variables which permit interbasin flow, the potential value of ground-water temperature as an indication of flow-system configuration, and the utility of large springs for ground-water studies in carbonate rock terrane. All of these aspects are promising approaches that could not be fully explored in this study.

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APPENDIX TABLE 1

Ground-Water Flow Systems in Nevada

This table names, locates and lists ground-water references for each delineated flow system in Nevada. Further, each flow system is evaluated as to whether the delineation is believed reliable, or whether there are enough uncertainties to render the delineation questionable.

The table also includes generalized information not specifically dealt with in the text. This information includes various physical aspects of the involved ground-water basins, and the apparent resource value of the flow systems. The physical attributes of the ground-water basin which influence the economics of ground-water development are the extent of shallow saturation, the extent of favorable aquifers, and the extent of ground-water quality problems. The apparent resource values of the flow systems are described by three aspects, listed in order of importance for each flow system. These are 1) storage, 2) flux, and 3) other. "Storage" refers to water in storage, or ground water which must be mined (it is available only once). "Flux" refers to the ground water passing through the flow system at some rate, or in other words, some part of the ground water that is discharging annually. "Other" refers to some use not directly associated with the development of a water supply, such as long term waste disposal or storage of fluids.

APPENDIX TABLE 1 LEGEND

C = confident; ? = questionable; F = flux; S = storage; O = other; E = extensive; L = local; A = absent, U = unknown; P = probable.

APPENDIX TABLE 1
Ground-Water Flow System Data

C = confident
? = questionable
F = flux
S = storage
O = other

E = extensive
L = local
A = absent
U = unknown
P = probable

Plate I System No.	Flow System Name	Location County, State	Ground-Water References	Delineation	Resource Value	Shallow Sat.	Aquifers	Chem. Problems
1	Suprise Valley	Wa, Nev.; Calif., Ore.	167, 175	?	S,F	L	E	L
2	Long Valley	Wa, Nev.	120, 167, 175	C	S,F	E	E	U
3	Massacre Valley	Wa, Nev.	120, 167	C	S,F	E	E	L
4	Warner Valley	Wa, Nev; Ore.	167	C	F	L	L	A
5	Badger Ck.-Catlow V.	Wa, Nev; Ore.	167	?	F	L	L	U
6	Big Springs Res.	Hu, Wa, Nev; Ore.	170	C	F	L	L	A
7	Virgin Valley	Hu, Nev.	170	?	F	L	L	P
8	Thousand Springs V.	Hu, Nev; Ore.	107, 120, 170, 175	C	F,S	E	E	L
9	Alvord Valley	Hu, Nev; Ore.	120, 170, 175	C	F,S	L	E	U
10	Summit Lake	Hu, Nev.	120, 169, 170	C	F,S	E	E	U
11	Highrock	Wa, Hu; Nev.	169	C	F	L	L	U
12	Duck Flat	Wa, Nev; Calif.	168	C	F,S	E	E	U
13	Smoke Creek	Wa, Nev; Calif.		C	F	L	L	U

Appendix Table 1 Continued

Plate I System No.	Flow System Name	Location County, State	Ground-Water References	Delineation	Resource Value	Shallow Sat.	Aquifers	Chem. Problems
14	Smoke Creek Desert	Wa, Nev.	120, 175	?	S,F.O	E	E	E
15	Black Rock Desert	Hu, Wa, Nev.	107, 120, 164, 165, 166, 169, 175	C	S,F,O	E	E	E
16	Desert V.-King River	Hu, Pe, Nev.; Calif.	9, 71, 120, 127, 165, 175	C	S,F	E	E	P
17	Quinn V.-Silver State V.	Hu, Nev.; Ore; Calif.	71, 101, 107, 113, 120, 184	C	S,F	E	E	A
18	Paradise V.-Grass Valley	Hu, Pe, Nev.	7, 9, 13, 15, 18, 19, 21, 22, 23, 24, 25,39, 57, 82, 89, 98, 107, 119, 120, 153, 175	C	S,F	E	E	L
19	Little Humboldt River	Hu, El, Nev.	57, 71, 89	?	F	L	L	L
20	Owyhee Desert	El, Hu, Nev.; Ore; Ida.	120	?	F	L	U	U
21	Duck Valley	El, Nev.; Ida.	120, 175	?	F,S	E	E	L
22	Wildhorse Res.	El, Nev.		C	F	L	U	U
23	Independence V.	El, Nev.		C	F,S	E	E	U

Appendix Table 1 Continued

Plate I System No.	Flow System Name	Location County, State	Ground-Water References	Delineation	Resource Value	Shallow Sat.	Aquifers	Chem. Problems
24	Squaw V.	El, Nev.	57, 97	C	F	L	U	U
25	Rock Creek	El, La, Eu, Nev.	57, 97	C	F	L	U	U
26	L. Reese R.-Humboldt R.	Pe, La, El, Hu, Eu, Nev.	7, 9, 15, 19, 21, 22, 23, 24, 31, 39, 57, 71, 82, 96, 97, 98, 107, 114, 120, 148, 153, 175, 186,	C	S,F	E	E	L
27	Maggie Cr.-Suzie Cr.	El, Nev.	57, 94, 95, 120, 153, 175	C	S,F	L	E	U
28	Tule Valley	El, Nev.	57, 93, 120	C	S,F	L	E	U
29	Upper Humboldt River	El, Nev.	57, 91, 92, 93, 95, 107, 120, 153, 175	C	S,F	L	E	L
30	Jarbidge River	El, Nev.; Ida.	120, 175	C	F	L	L	U
31	Evans Flat	El, Nev.		C	F	E	L	U
32	O'Neil Basin-Buckhorn Pasture	El, Nev.; Ida.	120	C	F	E	U	U
33	N. Salmon Falls Creek	El, Nev.; Ida.	120	C	F	L	L	U

Appendix Table 1 Continued

Plate I System No.	Flow System Name	Location County, State	Ground-Water References	Delineation	Resource Value	Shallow Sat.	Aquifers	Chem. Problems
34	Salmon Falls Creek	El, Nev.; Ida.	120	C	F	L	E	U
35	Thousand Creek	El, Nev.	120	C	F	L	E	
36	Rock Spring	El, Nev.	120	C	F	L	U	U
37	Goose Creek	El, Nev.; Ida., Utah	107, 120, 149a, 175	C	F	L	L	L
38	18-21 Mile Ranch	El, Nev.		C	F	L	L	P
39	Gamble Ranch	El, Nev., Utah	107, 120, 175	C	S,F	L	E	L
40	West Bonneville	El, Nev.; Utah	120	C	S,F	E	E	E
41	Goshute Valley	El, Nev.	56, 58, 107, 120	C	S,F	E	E	P
42	Clover-Independence V.	El, Nev.	46, 58, 107, 120, 175	C	S,F	E	E	L
43	N. Butte Valley	El, Nev.		?	S,F	E	E	U
44	Ruby Valley	El, Wp, Nev.	38, 58, 120, 174, 175	C	S,F	E	E	P
45	Huntington Valley	Wp, El, Nev.	38, 57, 91, 107, 120, 159, 174	C	F	L	E	L
46	Pine Valley	Eu, El, Nev.	42, 57, 90, 107, 120, 175	C	F,S	L	E	U

Appendix Table 1 Continued

Plate I System No.	Flow System Name	Location County, State	Ground-Water References	Delineation	Resource Value	Shallow Sat.	Aquifers	Chem. Problems
47	Whirlwind Valley	La, Eu, Nev.	7, 9, 57, 97, 175 194	C	S,F	E	E	L
48	Crescent Valley	La, Eu, Nev.	9, 57, 96, 120, 175, 205	C	S,F	E	E	L
49	Carico Lake Valley	Ny, La, Nev.	57, 69, 96, 205	C	S,F	E	E	U
50	Buffalo Valley	Hu, La, Pe, Nev.	57, 71, 175, 186	C	S,F	E	E	P
51	Pleasant Valley	Pe, Nev.	71, 107	C	S,F	L	E	U
52	Buena Vista Valley	Ch, Pe, Nev.	71, 107, 118, 120, 175	C	S,F	E	E	E
53	Lower Humboldt V.	Ch, Pe, Hu, Nev.	15, 18, 19, 21, 22, 23, 24, 39, 44, 57, 68, 71, 82, 98, 99, 120, 151, 153, 194	C	S,F	E	E	E
54	Granite Springs V.	Pe, Ch, Nev.		C	S,F	E	E	P
55	Kumiva	Pe, Nev.		?	S,F	L	E	U
56	San Emido Desert	Wa, Pe, Nev.		C	S,F	E	E	P
57	Winnemucca Lake	Wa, Pe, Nev.	175, 204	C	F,S	E	E	E

Appendix Table 1 Continued

Plate I System No.	Flow System Name	Location County, State	Ground-Water References	Delineation	Resource Value	Shallow Sat.	Aquifers	Chem. Problems
58	Lower Truckee R.-Pyramid Lk.	Wa, St, Ch, Nev.	171, 175	C	F,S	E	E	E
59	Henry Lake	Wa, Nev.; Calif.	175	C	S,F	E	E	P
60	Long Valley	Wa, Nev,;Calif.		C	S,F	E	E	U
61	Red Rock Ranch	Wa, Nev.		C	S,F	L	E	U
62	Warm Springs V.	Wa, Nev.	175	C	S,F	L	E	U
63	Cold Spring Valley	Wa, Nev.; Calif.		?	S,F	E	E	L
64	Lemmon Valley	Wa, Nev.		?	S,F	E	E	L
65	Spanish Springs Valley	Wa, Nev.	154	C	S,F	E	E	L
66	Truckee Meadows	Wa, Nev.	14, 20, 27, 107, 120, 153, 175, 189, 190, 194	C	S,F	E	E	E
67	Upper Truckee River	Wa, Nev.; Calif.	107, 152, 175	C	F	L	L	L
68	Washoe Valley	Wa, Nev.	153, 156, 175, 194	C	S,F	E	E	L
69	Lake Tahoe	Dg, Or, Wa, Nev.; Calif.		C	F	L	L	L
70	Eagle Valley	Or, Nev.	175, 200	C	S,F	E	E	L

Appendix Table 1 Continued

Plate I System No.	Flow System Name	Location County, State	Ground-Water References	Delineation	Resource Value	Shallow Sat.	Aquifers	Chem. Problems
71	Dayton	Dg, St, Ly, Or, Nev.	194	C	S,F	E	E	L
72	Corral Springs	St, Ly, Nev.		C	S,F	E	E	U
73	Churchill Valley	St, Ly, Ch, Nev.		C	S,F	E	E	L
74	Leets Flat	Wa, Ch, St, Nev.	171, 175	C	S,F,O	E	E	E
75	Carson Desert	Ly, Ch, Pe, Nev.	144, 175	C	S,F,O	E	E	E
76	Dixie Valley	Mn, Ch, La, Pe, Nev.	26, 107, 120, 144, 175, 203	C	S,F,O	E	E	E
77	East Gate Basin	Ch, La, Nev.	26, 144	C	S,F	L	E	U
78	Edwards Creek Valley	Ch, La, Nev.	66	C	S,F	E	E	P
79	Smith Creek Valley	Ny, La, Ch, Nev.	67,107, 120, 175	C	S,F	E	E	P
80	Antelope Valley	La, Ch, Pe, Nev.	31, 72, 96, 175	C	S,F	L	E	U
81	Reese River Valley	Ny, La, Nev.	60, 72, 96, 120, 149, 186	C	S,F	E	E	P
82	Grass Valley	La, Eu, Nev.	69, 72, 120	C	S,F	E	E	P
83	N. Big Smoky Valley	Ny, La, Nev.	72, 107, 120, 137, 138, 153, 175	C	S,F	E	E	P

Appendix Table I Continued

Plate I System No.	Flow System Name	Location County, State	Ground-Water References	Delineation	Resource Value	Shallow Sat.	Aquifers	Chem. Problems
84	Monitor V.-Antelope V.	Eu, La, Nev.	72, 107, 158, 175	C	S,F	E	E	L
85	Diamond Valley	Eu, El, Nev.	9, 72, 107, 175	?	S,F	E	E	L
86	Newark Valley	Wp, Nev.	41, 72, 107, 120, 174, 175	?	S,F	E	E	L
87	Long Valley	Wp, El, Nev.	43, 55, 120, 174	?	S,F	L	E	A
88	Butte Valley	Wp, El, Nev.	120, 174	?	S,F	E	E	P
89	Steptoe Valley	Wp, El, Nev.	12, 56, 107, 120, 153, 174, 175, 181	?	S,F	E	E	L
90	Spring Valley	Wp, El, Ln, Nev.	12, 120, 162, 174, 175	?	S,F	E	E	U
91	Spring Creek	Wp, El, Nev.; Utah		C	S,F	L	E	U
92	Snake Valley	Wp, Ln, Nev.; Utah	83, 107, 120, 136, 139, 153, 162, 174, 175	?	S,F	E	E	U
93	Lake Valley-Spring V.	Ln, Wp, Nev.; Utah	11, 107, 120, 146, 153, 155, 157, 174, 175	?	S,F	E	E	L

Appendix Table I Continued

Plate I System No.	Flow System Name	Location County, State	Ground-Water References	Delineation	Resource Value	Shallow Sat.	Aquifers	Chem. Problems
94	White River	Ln, Wp, Cl, Nev.	11, 49, 50, 51, 52, 53, 55, 59, 107, 120, 128, 132, 139, 142, 153, 155, 174, 175	?	S,F	L	L	L
95	Railroad Valley	Ny, Ln, Wp, Nev.	3, 11, 72, 107, 120, 132, 142, 160, 174, 175	?	S,F	E	E	L
96	Hot Creek Valley	Ny, Nev.	3, 72, 107, 120, 160, 175	?	S,F,O	L	E	L
97	Little Smoky Valley	Ny, Eu, Wp, Nev.	72, 160, 174, 175	?	S,F	L	E	U
98	Little Fish Lake V.	Ny, Nev.	72, 160	C	S,F	E	E	U
99	Monitor Valley	Ny, Nev.	72, 120, 158	C	S,F	E	E	L
100	Clayton V.-Monitor Range	Es, Ny, Nev.	3, 48, 62, 63, 72, 107, 120, 142, 147, 175, 194	?	S,F,O	L	E	E
101	Columbus Salt Marsh-Toiyabe	Ny, Mn, Es, Nev.	72, 120, 147, 175, 194	?	S,F,O	E	E	E
102	Ione Valley	Ny, Mn, Nev.	67	C	F,S	L	E	U
103	Monte Cristo Valley	Mn, Es, Nev.		?	S,F	L	E	U

Appendix Table I Continued

Plate I System No.	Flow System Name	Location County, State	Ground-Water References	Delineation	Resource Value	Shallow Sat.	Aquifers	Chem. Problems
118	Death Valley	Es, Nev.; Calif.	3, 100, 122	C	O	A	E	U
119	Sarcobatus Flat	Es, Ny, Nev.; Calif.	3, 62, 63, 120, 122, 142	?	S,F	E	E	E
120	Oasis Valley	Ny, Nev.	3, 62, 63, 122, 126, 142, 194	?	S,F,O	L	E	L
121	Penoyer Valley	Ny, Ln, Nev.	62, 63, 120	?	S,F	E	E	P
122	Amorgosa D.-NTS	Ny, Cl, Ln, Nev.; Calif.	3, 62, 63, 87, 100, 107, 115, 120, 131, 132, 133, 142, 153, 175, 185, 195, 196, 197, 199	?	S,F,O	E	E	L
123	Pahrump V.-Mesquite V.	Ny, Cl, Nev.; Calif.	11, 87, 107, 120, 124, 131, 132, 133, 142, 153, 175, 187, 196	C	S,F	E	E	L
124	Las Vegas	Ly, Cl, Nev.	11, 37, 62, 63, 107, 112, 116, 120, 121, 122, 123, 131, 132, 133, 142, 153, 175, 187, 196	?	S,F	E	E	L

Appendix Table I Continued

Plate I System No.	Flow System Name	Location County, State	Ground-Water References	Delineation	Resource Value	Shallow Sat.	Aquifers	Chem. Problems
104	Gabbs Valley	Mn, Ny, Ch, Nev.	47, 175	C	S,F,O	E	E	E
105	Rawhide Flats	Mn, Ly, Ch, Nev.	175	C	S,F,O	L	E	E
106	Walker Lake	Mn, Ly, Nev.	70, 150	C	S,F,O	E	E	E
107	Acme Flat	Mn, Nev.		?	S,F	L	E	U
108	East Walker River	Ly, Dg, Mn, Nev.	120, 153, 175	C	S,F	E	E	L
109	Smith Valley	Dg, Or, Nev.; Calif.	107, 117, 120, 175	C	S,F	E	E	L
110	Carson Valley	Dg, Or, Nev.; Calif.	107, 120, 175	C	S,F	E	E	L
111	Upper West Walker Riv.	Dg, Nev.; Calif.	107, 120, 175	C	S,F	E	E	U
112	Masonic	Ly, Mn, Nev.; Calif.		C	F	L	L	U
113	Rough Cr.-Bodie Cr.	Ly, Mn, Nev.; Calif.		C	F	L	L	U
114	Whiskey Flat	Mn, Nev.	61	C	S,F	L	E	U
115	Huntoon Valley	Mn, Nev.; Calif.		?	S,F	L	E	U
116	Teels Marsh	Mn, Es, Nev.; Calif.		?	S,F	E	E	E
117	Fish Lake Valley	Es, Nev.; Calif.	40, 107, 120, 142	C	S,F	E	E	U

Appendix Table I Continued

Plate I System No.	Flow System Name	Location County, State	Ground-Water References	Delineation	Resource Value	Shallow Sat.	Aquifers	Chem. Problems
125	Gypsum Wash	Cl, Nev.	11, 116	?	O	L	E	E
126	Virgin River	Ln, Cl, Nev.; Utah, Ariz.	11, 120	?	S,F,O	L	E	E
127	Greasewood Basin - Hell's Kitchen	Cl, Nev.; Ariz.	11, 120	C	F	L	L	P
128	Lake Mead	Cl, Nev.; Ariz.	11	?	S,F	L	L	P
129	Black Canyon	Cl, Nev.; Ariz,; Calif.	161, 198	?	F	L	L	P
130	Eldorado Valley	Cl, Nev.	161	C	O	A	E	E
131	Piute Valley	Cl, Nev.; Calif.	142, 161	C	S,F	L	E	P
132	Ivanpah Valley	Cl, Nev.; Calif.	142, 187	C	S,F	A	E	U
133	Queen V.-Benton V.	Es, Mn, Nev.; Calif.		C	F,S	U	P	U
134	Mono Valley	Mn, Nev.; Calif.		?	F,S	U	P	U
135	Escalante Desert	Ln, Nev.; Utah		C	F	L	U	U
136	Rhodes Salt Marsh	Mn, Nev.	175,194	?	F,S,O	L	P	E

APPENDIX TABLE 2

Aspects of Ground-Water Flow Systems in Nevada

Flow systems shown in Plate I and listed in Appendix Table I are described more fully in this table. Geographic areas that constitute source and sink areas are listed for each flow system. Also listed are hydrographic areas (as published by the Office of the State Engineer) that are partly or entirely involved in each flow system, and the recharge and discharge estimates that have been made for these areas by the U.S. Geological Survey. The discharge estimates, though probably quite variable in accuracy, are believed to be more accurate than the recharge estimates. Discharge estimates, where available, offer indications of the amounts of flux that leave the flow systems in the associated ground-water basins.

APPENDIX TABLE 2 LEGEND

1 - The hydrographic areas (1968 edition) are not always related to surface-water or ground-water divides. An attempt has been made to include hydrographic areas partly or entirely involved in the ground-water flow system, and also to use the listed hydrographic name. The subdivisions are designated by letter rather than name in this compilation.

2 - An attempt has been made to use the fundamental recharge and discharge estimates in acre-ft/year. In some cases this yields values different than the values favored in the source report. Careful comparison of the methodologies employed indicates judgement has played an important role in many of the estimates, and several different approaches have been used.

a - In the Nevada portion only.

b - Discharge from the phreatic playa not included.

c - Area of recharge estimate and flow system do not approximately coincide.

d - Includes ground-water pumpage.

e - Includes stream flow from system or basin.

f - Includes irrigation seepage to ground-water system.

g - Early estimate of recharge or discharge.

APPENDIX TABLE 2
Aspects of Ground-Water Flow Systems in Nevada.

Flow System No.	Prime Source Area(s)	Prime Sink Area(s)	[1]Involved Hydrographic Divisions	[2]U.S. Geol. Survey Estimates Recharge	Discharge	Remarks
1	Hays Canyon, New Year Lake Range	Surprise Valley	Surprise Valley Warner Valley	[a]2,000		Uncertain hydrologic role of New Year Lake. Ground-water basin mostly in California.
2	Bald Mountain, Hay Canyon, New Year Lake Range	Long Valley	Long Valley, Mosquito Valley, Boulder Valley, Macy Flat	5,900 700 2,100	[b]7,000 [b]800 ?	Flow in volcanic bedrock probably important.
3	Bald Mountain, Bitner Butte	Massacre Lake Valley	Massacre Lake Valley	3,500	[b]500	Flow in volcanic bedrock probably important.
4	surrounding hills	Coleman Valley	Coleman Valley	[a]1,000		Flow in volcanic bedrock probably important.
5	Bald Mountain, Catnip Mountain, Bitner Butte	Swan Lake, Catnip Res. Guano Valley, Stream flow	Guano Valley Swan Lake Valley	[a]7,500		Flow in volcanic bedrock probably important.
6	Sage Hen Hills, Catnip Mountain, Gooch Table	Big Springs Res., stream flow	Virgin Valley Sage Hen Valley	7,000	6,000	Flow in volcanic bedrock probably important.
7	Gooch Table, Blow Out Mountain, Rock Springs Table	Virgin Valley	Virgin Valley			Flow in volcanic bedrock probably important.
8	Pine Forest Range, Rock Spring Table, Pueblo Mtns.	Thousand Creek Valley	Continental Lake V. Gridley Lake V.	10,900 4,400	10,500 2,000	
9	Pine Forest Range, Pueblo Mtns., Trout Creek Mtns.	Pueblo Valley	Pueblo Valley	[a]2,000	[a]1,200	Majority of ground-water basin in Oregon.
10	Black Rock Range	Summit Lake	Summit Lake Valley	[c]4,200		Some interbasin flow to NE?
11	Calico Mountains	High Rock lake drainage bottom land	High Rock Lake V.	13,000	2,000ave	Discharge based on 500 acre area for High Rock Lake. Probable important interbasin flow to Soldiers Meadow.
12	Hays Canyon Peak, Granite range	Duck Flat	Duck Lake Valley	9,000	7,000	

Appendix Table 2 (cont'd)

Flow System No.	Prime Source Area(s)	Prime Sink Area(s)	[1]Involved Hydrographic Divisions	[2]U.S. Geol. Survey Estimates Recharge	[2]U.S. Geol. Survey Estimates Discharges	Remarks
13	Buffalo Hills	Smoke Creek Valley	Smoke Creek Desert			
14	Granite Range, Buffalo Hills, Pah Rum Range	Smoke Creek Desert	Smoke Creek Desert			May received some interbasin flow.
15	Pine Forest Range, Black Rock Range, Jackson Mountains, Calico Mountains, Granite Range, Selenite Range	Black Rock Desert	Pine Forest Valley Black Rock Desert } Mud Meadow } Hualapai Flat	9,700 23,900 4,000	14,000 ? 5,000	May receive interbasin flow; large discharge area probably averages an extremely low rate evapotranspiration.
16	Trout Creek Mountains, Jackson Mountains, Slumbering Hills, Eugene Mountains	Kings River Valley Desert Valley	Kings River V. (A+B) Desert Valley	15,000 5,000	[g]15,000 16,000	Part of southern boundary uncertain.
17	Trout Creek Mountains, Santa Rosa Range, Slumbering Hills	Quinn River Valley	Quinn River V. (A+B) Silver State V.	74,000 [g]24,000	*68,000 [g]25,000	*Assumes 5000 acre-ft/yr. surface water outlfow ground-water discharge. Note major difference in estimates resulting from two different approaches.
18	Humboldt River, Little Humboldt River, Santa Rosa Range, Sonoma Range, East Range	Paradise Valley Grass Valley Humboldt River	Hardscrabble Area Paradise Valley Winnemucca segment Grass Valley	 23,000 * 18,000	 26,000 * 6,800	*See Cohen, 1964a, b for budget estimates.
19	Sugar Loaf Hill, Hot Springs Range, Osgood Mountains	Little Humboldt R.	Little Humboldt Valley			NE boundary based on small springs; flow in volcanic bedrock may be important in this area.
20	Capitol Peak, Owyhee Plateau, Tuscarora Mountains, Bull Mountains	South Fork Owyhee River	Little Owyhee River Area, South Fork Owyhee River Area			Large flow system with majority of flux in volcanic bedrock, discharge almost entirely to stream flow.
21	Bull Run Mountains, Jarbridge Mountains	Duck Valley Owyhee River	Owyhee River area			
22	Independence Mountains, Jarbridge Mountains	Wild Horse basin	Owyhee River area			
23	Independence Mountains, Tuscarora Mountains	Independence Valley South Fork Owyhee R.	Independence Valley	10,000	[e]10,000	Terrane at or near ground-water capacity.

Appendix Table 2 (cont'd)

Flow System No.	Prime Source Area(s)	Prime Sink Area(s)	[1]Involved Hydrographic Divisions	[2]U.S. Geol. Survey Estimates Recharge	Discharge	Remarks
24	Tuscarora Mountains	Squaw Valley Rock Creek	Willow Creek Valley			Flow in volcanic rock probably important.
25	Tuscarora Mountains, Sheep Creek Range	Rock Creek Valley Rock Creek	Rock Creek Valley			
26	Humboldt River, Owyhee Plateau Tuscarora Mountains, Osgood Mountains, Battle Mountain, Shoshone Range	Humboldt River Valley Kelley Creek Valley, Pumpernickel Valley, N. Reese River Valley, Boulder Valley, Humboldt River	Lower Reese River V. M. Reese River V. Boulder Flat Clovers Area Pumpernickel Valley Kelley Creek Area	6,600	3,000	Large amounts of discharge by evapotranspiration present in several areas along the Humboldt.
27	Tuscarora Mountains, Independence Mountains, Adobe Range, Buckskin Mountains	Maggie Creek, Susie Creek, Humboldt River Valley	Elko Segment Susie Creek area Maggie Creek area Mary's Creek area			Important part of discharge may be stream flow.
28	Independence Range, Adobe Range, Jarbidge Mountains	North Fork Humboldt River and tributary valleys	North Fork area			Majority of terrane at ground-water capacity; important part of discharge is stream flow.
29	Jarbidge Mountains, East Humboldt Range, Adobe Range	Humboldt River Valley and tributary valleys	Elko Segment N. Fork Area Marys River area Starr Valley area Lamoille Valley			Important part of ground-water discharge is stream flow.
30	Jarbidge Mountains	[a]north flow streams	Bruneau River area Jarbidge River area			Discharge mostly stream flow in Nevada.
31	Jarbidge Mountains	Evans Flat, Bruneau River	Bruneau River area			Terrane at ground-water capacity.
32	Jarbidge Mountains	Salmon Falls Creek and tributaries	Salmon Falls Creek area			Terrane at ground-water capacity.
33	Bear Mountain, L&D Mountain, Grassy Mountain	[a]Cottonwood Creek, Salmon Falls Creek	Salmon Falls Creek area			Discharge by stream flow in Nevada.
34	Granite Range, Antelope Peak Range	Salmon Falls Creek	Salmon Falls Creek area			S and E boundaries approximate.

Appendix Table 2 (cont'd)

Flow System No.	Prime Source Area(s)	Prime Sink Area(s)	[1]Involved Hydrographic Divisions	[2]U.S. Geol. Survey Estimates Recharge	Discharge	Remarks
35	Granite Range, Pequop Mountains	Thousand Springs Creek Valley	Thousand Springs Valley (A+B)			
36	Granite Range, Round Top	Rock Springs Creek Valley, Thousand Springs Creek Valley	Thousand Springs Valley (B)			
37	Gollyer Mountain, Monument Peak Mountains, Bald Mountain	Goose Creek	Goose Creek area			
38	Delano Mountains	Thousand Springs Creek Valley	Thousand Springs Valley (C)			
39	mountains to the north	[a]Gamble Ranch and Montello area	Thousand Springs Valley (D) Grouse Creek			
40	Toana Range, Pilot Range, Goshute Mountains	Great Salt Lake Valley	Great Salt Lake Desert Pilot Creek Valley			
41	Pequop Mountains, Toana Range, Goshute Mountains, Dolly Varden Mountains	Goshute Valley	Goshute Valley Antelope Valley (B)	} 10,400	[d]10,075	Discharge seems too small in this system, may have incorrect system boundaries.
42	Pequop Mountains, Wood Hills, East Humboldt Range	Clover Valley, Independence Valley	Clover Valley Independence Valley	20,700 9,300	19,000 9,500	Discharge present derived within Goshute flow system boundaries?
43	Spruce Mountain, Cherry Creek Mountains, Medicine Range	northern Butte Valley	Butte Valley (A)			
44	East Humboldt Range, Ruby Mountains, Maverick Springs Range	Ruby Valley	Ruby Valley	68,000	>68,000*	*Just Ruby Marsh of about 22,000 acres would yield at least 66,000 acre-ft. of discharge if essentially supplied by ground water. Estimates may be low.
45	Ruby Mountains, Sulphur Spring Range, Diamond Mountains	Huntington Creek and tributaries, Huntington Creek Valley and tributaries	Huntington Valley Dixie Creek-Tenmile Creek area		} 30,000	Has been suggested to be low in ground-water discharge.

Appendix Table 2 (cont'd)

Flow System No.	Prime Source Area(s)	Prime Sink Area(s)	[1]Involved Hydrographic Divisions	[2]U.S. Geol. Survey Estimates Recharge	Discharge	Remarks
46	Sulphur Spring Range, Cortez Mountains, Roberts Mountain	Pine Valley, Pine Creek	Pine Valley	46,100	[e]24,100	27,700 acre-ft. of recharge estimated to occur from precipitation below 7,000 ft. of elevation; may show a basic problem in estimation methods rather than interbasin flow.
47	Tuscarora Mountains	Whirlwind Valley Humboldt River Valley	Whirlwind Valley Cresent Valley Boulder Flat			
48	Cortez Mountains, Shoshone Range	Cresent Valley	Cresent Valley	14,000	12,000+	
49	Shoshone Range, Toiyabe Range	Carico Lake Valley	Carico Lake Valley	4,300	3,800	
50	Tobin Range, Fish Creek Mountain, Battle Mountain, Buffalo Mountain	Buffalo Valley	Buffalo Valley			
51	East Range, Tobin Range	Pleasant Valley	Pleasant Valley	3,000	2,200	
52	Humboldt Range, East Range, Stillwater Range	Buena Vista Valley	Buena Vista Valley	10,000	12,500	
53	Humboldt Range, Humboldt River irrigation, East Range, Eugene Mountains	Humboldt River, Humboldt River Valley, Lovelock Valley	Winnemucca segment White Plains Lovelock Valley Imlay area	} [f]24,200 3,800	} 23,900 4,400	
54	Seven Troughs Range, Shawaue Mountains	Adobe Flat	Granite Springs Valley			
55	Selenite Range, Shawaue Mountains	Kumiva Flat	Kumiva Valley			Sparse data in this area
56	Pah Rum Peak, Lake Range	San Emidio Desert Granite Creek Desert	San Emidio Desert			
57	Lake Range, Selenite Range, Nightingale Mountains	Winnemucca Lake basin	Winnemucca Lake Valley	8,000	8,000	Flow system may not be in equilibrium because of lake desiccation.

Appendix Table 2 (cont'd)

Flow System No.	Prime Source Area(s)	Prime Sink Area(s)	[1]Involved Hydrographic Divisions	[2]U.S. Geol. Survey Estimates Recharge	Discharge	Remarks
58	Lake Range, Virginia Mountains, Pah Rah Range, Truckee River, Virginia Range	Truckee River, Pyramid Lake area	Pyramid Lake Valley Dodge Flat Tracy segment			Evidence of nonequilibrium of flow system near north end of Pyramid Lake because of lake drop.
59	[a]Virginia Mountains, Fort Sage Mountain	Honey Lake Valley	Honey Lake Valley Dry Valley Skedaddle Creek Valley			May recieved some interbasin flow.
60	[a]Virginia Mountains, Dogskin Mountain, Seven Lakes Mountain	Dry Valley	Dry Valley Newcomb Lake Valley			
61	Petersen Mountain, Dogskin Mountain	Red Rock Valley Bedell Flat	Red Rock Valley Bedell Flat Antelope Valley			Minor interbasin flow from Antelope Valley, probably to Bedell Flat.
62	Virginia Mountains, Pah Rah Range, Dogskin Mountain	Warm Springs Valley	Warm Springs Valley			
63	Peavine Peak, Petersen Mountain	Cold Spring Valley	Cold Spring Valley			
64	Peavine Peak	Lemmon Valley	Lemmon Valley (A+B)			
65	Pah Rah Range, irrigation ditches	Spanish Springs Valley	Spanish Springs Valley			
66	Carson Range, Truckee River irrigation, Virginia Range	Truckee Meadows	Truckee Meadows Pleasant Valley Sun Valley	>36,000	33,000+	
67	[a]Carson Range	Truckee River	Truckee Canyon Segment			
68	Carson Range, Virginia Range	Washoe Valley	Washoe Valley	15,000[1] 33,000[2]	8,500[1] 31,000[2]	1)Estimates do not include surface water relationships. 2)Total water budget of valley.
69	[a]Carson Range	Tahoe Basin	Lake Tahoe Basin			
70	Carson Range, Virginia Range	Eagle Valley	Eagle Valley Dayton Valley	[f]14,400	[e]12,800	

Appendix Table 2 (cont'd)

Flow System No.	Prime Source Area(s)	Prime Sink Area(s)	[1]Involved Hydrographic Divisions	[2]U.S. Geol. Survey Estimates Recharge	Discharge	Remarks
71	Virginia Range, Pine Nut Mountains	Dayton Valley	Dayton Valley			
72	Virginia Range, Pine Nut Mountains		Dayton Valley			
73	Pine Nut Mountains, Virginia Range	Churchill Valley	Churchill Valley			
74	Truckee Canal irrigation water, Truckee Range	Leete's Flat	Bradys Hot Springs Area Fernley area Fireball Valley			Majority of discharge from surface water infiltration in Fernley area.
75	Irrigation from Truckee and Carson Rivers, Stillwater Range	Carson Desert, Carson Sink, Fourmile-Eightmile Flats	Carson Desert			Local thermal ground-water may relate to late Quaternary volcanism.
76	Stillwater Range, Clan Alpine Mountains	Dixie Valley	Dixie Valley	6,000		Discharge estimate in Dixie Valley seems low to this investigator.
			Fairview Valley	500	16,500	
			Jersey Valley	800		
			Stingaree Valley			
			Cowkick Valley	6,000	400	
77	Desatoya Mountains, Clan Alpine Mountains	East Gate Area Dixie Wash	Eastgate Valley area			
78	Clan Alpine Mountains, Desatoya Range	Edwards Creek Valley	Edwards Creek Valley	7,900	7,300	
79	Shoshone Mountains, Desatoya Mountains	Smith Creek Valley	Smith Creek Valley	12,100	6,650	No known evidence for interbasin flow.
80	New Pass Range, Shoshone Mountains, Augusta Mountains, Fish Creek Mountains	Antelope Valley	Antelope Valley	11,300	500	
81	Toiyabe Range, Shoshone Mountains	Reese River Valley	Upper Reese River Valley	36,700	37,000	Discharge estimate seems low to this investigator.
82	Toiyabe Range, Simpson Park Range	Grass Valley	Grass Valley	12,600	12,000	May receive minor interbasin from east.

Appendix Table 2 (cont'd)

Flow System No.	Prime Source Area(s)	Prime Sink Area(s)	[1]Involved Hydrographic Divisions	[2]U.S. Geol. Survey Estimates Recharge	Discharge	Remarks
83	Toiyabe Range, Toquima Range	Big Smoky Valley	Big Smoky Valley (B)			
84	Simpson Park Range, Roberts Mountains, Fish Creek Range, Antelope Range, Monitor Range, Toquima Range	Bean Flat, Antelope Valley	Kobeh Valley Monitor Valley (A) Antelope Valley Steven Basin	10,900 6,300 4,100 200	14,900 2,000 4,200 0	
85	Fish Creek Range, Diamond Mountains, Sulphur Spring Range, Roberts Mountains	Diamond Valley	Diamond Valley	16,300	[b]23,000+	May receive significant interbasin flow from E or SE.
86	Diamond Mountains, White Pine Range, Fish Creek Range, S. Ruby Mountains	Newark Valley	Newark Valley	17,500	[b]16,000+	May receive significant interbasin flow from Long Valley area to E.
87	S. Ruby Mountains, Butte Mountains, White Pine Range	Newark Valley? Long Valley	Long Valley	10,300	2,200	Significant interbasin flow may leave to W or S.
88	Cherry Creek Mountains, Egan Range, Butte Mountains	Butte Valley	Butte Valley (B)			Interbasin flow may leave to E.
89	Egan Range, Schell Creek Range	Steptoe Valley	Steptoe Valley	85,400	70,000	Discharge estimate seems low to this investigator.
90	Schell Creek Range, Snake Range, Antelope Range, Kern Mountains	Spring Valley	Spring Valley Tippett Valley	73,000	57,000	Interbasin flow from Antelope Valley, and some flow to Snake Valley in S.
91	Goshute Mountains, Kern Mountains	[a]Spring Creek Valley Deep Creek Valley	Deep Creek Valley			
92	[a]Snake Range, Wilson Creek Range	[a]Snake Valley, Pleasant Valley	Snake Valley Hamlin Valley Pleasant Valley	103,000	79,000	
93	Schell Creek Range, Wilson Creek Range, Fortification Range, White Rock Mountains	Lake Valley, Panaca Valley	Lake Valley Patterson Valley Panaca Valley Spring Valley Dry Valley Rose Valley Eagle Valley Clover Valley	13,200 } [c]24,000	[d]8,500 [d]165 [d]8,030 [d]1,030 [d]3,610 [d]1,210 [d]510 210	[c]Lower Meadow Valley drainage, below Caliente is included in the recharge estimate

Appendix Table 2 (cont'd)

Flow System No.	Prime Source Area(s)	Prime Sink Area(s)	[1]Involved Hydrographic Divisions	[2]U.S. Geol. Survey Estimates Recharge	Discharge	Remarks
94	White Pine Range, Egan Range, Horse Range, Grant Range, S. Egan Range, S. Schell Creek Range, Quinn Canyon Range, Highland Range, Sheep Range?	White River Valley, Pahranagat Valley, Moapa Valley, Meadow Valley Wash, Overton area	Jakes Valley	13,000	minor......	A later estimate of recharge is 17,000 ac-ft/yr.
			White River Valley	40,000	[e]35,500	This interbasin system in carbonate rock terrane is the largest in Nevada. The interbasin flow from White River Valley is present, but its importance is open to question. Jakes Valley and Long Valley participation have been suggested, this study includes only Jakes Valley. Firm fluid potential data is not present to support important southward interbasin flow.
			Garden Valley	10,200	2,000 max.	
			Coal Valley	2,200	minor	
			Pahroc Valley	2,200	minor	
			Cave Valley	14,000	minor	
			Dry Lake Valley	4,800	minor	
			Delamar Valley	1,200	minor	
			Pahranagat Valley	1,800	25,000	
			Kane Springs Valley, Coyote Spring Valley, Muddy River Springs area	2,600	36,000	
			Hidden Valley			
			California Wash			
			L. Moapa Valley			
			L. Meadow Valley wash		[d]8,000	
			Garnet Valley			
95	White Pine Range, Horse Range, Grant Range, Pancake Range, Quinn Canyon Range, Reveille Range, Belted Range	Railroad Valley, Duckwater area	Railroad Valley (A+B)	50,400	50,000	Interbasin flow is present, and flow system boundaries are not well established.
			Kawich Valley	3,500	0	
			Little Smoky Valley (B+C)	1,400	0	
96	Hot Creek Range	Hot Creek Valley	Hot Creek Valley	[g]10,000 7,000	[g]9,000 4,600	
97	Antelope Range, Fish Creek Range, Pancake Range	Fish Creek Valley, Newark Valley	Little Smoky Valley (A)	4,000	1,900	Interbasin flow in carbonate terrane may be important.
98	Hot Creek Range, Monitor Range	Little Fish Lake Valley	Little Fish Lake Valley	11,000	9,980	
99	Toquima Range, Monitor Range	Monitor Valley	Monitor Valley (B)	15,000	9,250	No important interbasin flow believed present.
100	Monitor Range, Toquima Range, Hot Creek Range, Kawich Range	Clayton Valley	Stone Cabin Valley	16,000	[d]2,025	Pumpage est. at 175 ac-ft/yr in Stonecabin and Ralston Valleys. Good evidence of interbasin flow.
			Ralston Valley	16,400	[d]2,650	
			Cactus Flat			
			Alkali Spring Valley			
			Clayton Valley			

Appendix Table 2 (cont'd)

Flow System No.	Prime Source Area(s)	Prime Sink Area(s)	[1]Involved Hydrographic Divisions	[2]U.S. Geol. Survey Estimates Recharge	Discharge	Remarks
101	Toquima Range, Toiyabe Range, Pilot Mountains	S. Big Smoky Valley	Big Smoky Valley (A) Columbus Salt Marsh Valley			Flow is believed to terminate at Columbus Salt Marsh on the basis of very low fluid potential gradients from lower Big Smoky Valley.
102	Shoshone Mountains, Paradise Range, Cedar Mountains	Ione Valley	Ione Valley	8,100	1,300	Under flow to Big Smoky Valley apparent.
103	Pilot Mountains	Monte Cristo Valley	Monte Cristo Valley			
104	Paradise Range, Gabbs Valley Range	Gabbs Valley	Gabbs Valley	5,200	[d]4,300	
105	none	Rawhide Flats	Rawhide Flats	150	780	Volume of discharge suggests possible interbasin flow from north.
106	Wassuk Range, Walker River irrigation	Schurz Area Walker Lake area	Walker Lake Valley (A+B+C)	6,500	21,000	Whisky Flat system (No. 114) included in estimates. Recharge estimate does not include Walker River irrigation seepage.
107	Gillus Range, Garfield Hills	Acme Flat	Soda Spring Valley (B)			
108	Wassuk Range, Pine Grove Hills, East and West Walker River irrigation	Mason Valley East Walker River	Mason Valley Churchill Valley East Walker area			Majority of flux in Mason valley from irrigation seepage.
109	Pine Nut Mountains, Wellington Hills, W. Walker River irrigation	Smith Valley	Smith Valley			Majority of flux probably related to irrigation seepage.
110	Carson Range, Pine Nut Mountains, Carson River irrigation	Carson Valley	Carson Valley			
111	[a]Pine Nut Mountains, Wellington Hills	Antelope Valley	Antelope Valley			
112	Sweetwater Mountains, Pine Grove Hills	Sweetwater Flat	East Walker Area			
113	Wassuk Range	Rough Creek Valley	East Walker Area			

Appendix Table 2 (cont'd)

Flow System No.	Prime Source Area(s)	Prime Sink Area(s)	[1]Involved Hydrographic Divisions	[2]U.S. Geol. Survey Estimates Recharge	Discharge	Remarks
114	Wassuk Range, Excelsior Mountains	Whisky Flat	Walker Lake Valley (C)			
115	Excelsior Mountains	Huntoon Valley	Huntoon Valley			Interbasin flow may be present in volcanic rock terrane in this area.
116	Excelsior Mountains, Adobe Hills	Teels Marsh	Teels Marsh Valley			
117	White Mountains, Silver Peak Range	Fish Lake Valley	Fish Lake Valley	53,700	50,000	
118	[a]Palmetto Mountains, Grapevine Mountains	Death Valley	Oriental Wash Grapevine Canyon			No discharge in Nevada.
119	Palmetto Mts., Stonewall Mt. Pahute Mesa	Sarcobatus Flat	Lida Valley Stonewall Flat Sarcobatus Flat Grapevine Canyon	 3,000 1,200 	 3,000 	NE boundary uncertain.
120	Gold Flat?, Pahute Mesa	Oasis Valley	Gold Flat Oasis Valley	1,600 250	none 2,000	Boundaries uncertain.
121	Belted Range, Worthington Mountains, Groom Range	Penoyer Valley	Penoyer Valley	[g]13,500 3,600	[g]6,400 3,500	Available evidence indicates a local flow system surrounded by regional flow systems.
122	Belted Range, Spring Mountains, closed basins?	[a]Ash Meadows	Emigrant Valley (A+B) Fortymile Canyon (A+B) Crater Flat Amargosa Desert Rock Valley Mercury Valley Yucca Flat Frenchman Flat Indian Springs Valley Three Lakes Valley (N+S)	2,500 1,300 <100 1,500 <100 400 <100 <100 [c]1,900	none none none 23,000 none none none none none	Important regional flow in both carbonate and volcanic rocks well documented. Some boundaries uncertain.
123	Spring Mountains	[a]Pahrump Valley	Pahrump Valley Mesquite Valley	[g]23,000 22,100	[g]10,000 10,000	Important interbasin flow in Calif.

Appendix Table 2 (cont'd)

Flow System No.	Prime Source Area(s)	Prime Sink Area(s)	[1]Involved Hydrographic Divisions	[2]U.S. Geol. Survey Estimates Recharge	Discharge	Remarks
124	Spring Mountains, Sheep Mountains	Las Vegas Valley	Las Vegas Valley	[g]30,000 25,000	[g]30,000 25,000	Northern boundaries speculative.
			Tikapoo Valley	2,800	?	
			Three Lakes Valley	[c]1,900	none	
125	none	Lake Mead area	Black Mountains area			Sparse information.
126	Morman Mountains	Virgin River Valley	Virgin River Valley Tule Desert			Sparse information.
127	Virgin Mountains, Hells Kitchen area	Lake Mead area	Gold Butte area Greasewood Basin			Sparse information.
128	Virgin Mountains, Jumbo Peak area	Lake Mead area	Black Mountains area Gold Butte area			Sparse information.
129	none	Black Canyon area	Colorado River Valley	200	minor	
130	McCullough Range	Black Canyon area?	Eldorado Valley	1,100	none	Position of discharge unknown.
131	McCullough Range	[a]none	Paiute Valley	1,700	[a]minor	
132	Spring Mountains, McCullough Range	[a]none	Hidden Valley Jean Lake Valley Ivanpah Valley (A+B)			
133	White Mountains, Adobe Hills	[a]none	Adobe Valley Queen Valley			
134	Wassuk Range	[a]none	Alkali Valley Mono Valley			[a]Sparse information.
135	Cedar Range	[a]none	Escalante Desert			
136	Pilot Mountains, Excelsior Mountains	Rhodes Salt Marsh	Rhodes Salt Marsh Valley Soda Spring Valley (A) Garfield Flat			

APPENDIX TABLE 3

Flow System Classification

Each delineated ground-water flow system has been classified in several ways. The prime classification separates flow systems which involve important interbasin flow from flow systems essentially confined to major topographic basins. Those that involve interbasin flow have been called regional flow systems, and those that are essentially confined to major topographic basins are called local flow systems.

Configuration of flow is also classified on the basis of ground-water temperature where data permit. Depth of circulation is divided into three categories: 1) shallow circulation, 2) both shallow and deep circulation (composite circulation) and 3) deep circulation.

Relative bedrock permeability has been classified for each flow system. This aspect has been generalized into three categories: 1) widespread presence of relatively permeable bedrock, 2) general absence of relatively permeable bedrock and 3) limit presence of relatively permeable bedrock of unknown importance.

Moisture availability for recharge has been generalized into four categories. These include: 1) abundant moisture for recharge, 2) intermediate moisture for recharge, which implies localized areas within the flow system boundaries where there is abundant moisture for recharge, 3) abundant surface water for recharge in the basins, and 4) sparse moisture available for recharge.

APPENDIX TABLE 3 LEGEND

Classification Symbols

L = Local flow system
R = Regional flow system
C = Composite circulation
S = Shallow circulation
D = Deep circulation
P = Presence of relatively permeable bedrock
A = General absence of relatively permeable bedrock
U = Local presence of relatively permeable bedrock

1 = Abundant moisture for recharge
2 = Intermediate moisture for recharge
3 = Abundant surface water for recharge in basin
4 = Sparse moisture for recharge

b = Local as delineated, headwater part of regional system
c = Minor interbasin flux known
d = Water chemistry of spring suggests regional contribution to discharge
e = In Nevada portion only
f = Formerly category 3

APPENDIX TABLE 3

Flow System Classification

Flow System No. (Plate I)	Class	Circulation	Permeability Bedrock	Moisture Availability
1	L	C	P	2
2	L	-	P	2
3	L	-	P	2
4	L	-	P	2
5	L	S	P	2
6	L	S	P	1
7	L	C	P	2
8	L	C	P	2
9	L	-	P	2
10	L	S	P	1
11	L[b]?	-	P	2
12	L	-	P	2
13	L	-	P	2
14	L	C	P	2
15	R	C	P	2

Flow System No. (Plate I)	Class	Circulation	Permeability Bedrock	Moisture Availability
16	L	-	A	2
17	L	S	A	2
18	L	S	P	2
19	L	-	P	1
20	L	-	P	2
21	L	-	P	1
22	L	S	A	1
23	L	S	P	1
24	L	-	P	1
25	L	-	P	2
26	L	S	P	2
27	L	-	P	1
28	L	S	P	1
29	L	-	P	1
30	L	-	P	1
31	L	-	A	1
32	L	-	P	1

Flow System No. (Plate I)	Class	Circulation	Permeability Bedrock	Moisture Availability
33	L	-	P	2
34	L	C	P	1
35	L	-	P	2
36	L	-	P	2
37	L	C	P	2
38	L	-	P	2
39	L	C	P	2
40	L	C	P	2
41	L	-	P	2
42	L[d]	C	P	2
43	L	-	P	2
44	L	C?	P	1
45	L	C?	P	1
46	L	-	U	2
47	L	C	U	2
48	L	C	A	2
49	L	C	A	2

Flow System No. (Plate I)	Class	Circulation	Permeability Bedrock	Moisture Availability
50	L	C?	A	2
51	L	-	A	2
52	L	C?	A	2
53	L	C?	A	3
54	L	-	U	4
55	L	-	U	4
56	L	C?	A	4
57	L	C?	P	4[f]
58	L	C	P	3
59	L	C	P	2
60	L	-	P	2
61	L[c]	C	U	2
62	L	-	P	4
63	L	-	A	2
64	L	-	P	2
65	L	C?	P	3
66	L	C	U	1

Flow System No. (Plate I)	Class	Circulation	Permeability Bedrock	Moisture Availability
67	L	S	A	1
68	L	C?	U	1
69	L	-	A	1
70	L	C	U	1
71	L	-	U	3
72	L	-	U	3
73	L	-	P	3
74	L	C	P	3
75	L	C	U	3
76	L	C	A	2
77	L	-	P	2
78	L	-	A	2
79	L	-	A	2
80	L	-	A	2
81	L	-	A	2
82	L[d]	-	A	2
83	L	C	A	2
84	L	C	U	2

Flow System No. (Plate I)	Class	Circulation	Permeability Bedrock	Moisture Availability
85	R?[d]	C	P	2
86	R?	C	P	2
87	L[b]	S	P	2
88	L[b]?	S?	P	2
89	R?[d]	C	P	2
90	R	-	P	2
91	L	-	P	2
92	R[c]	-	P	2
93	R	C	P	2
94	R	C-D	P	2-4
95	R	D-C	P	2-4
96	L	C	P	2
97	L[d]	C	P	2
98	L	-	U	2
99	L	C	A	2
100	R	C-D	P	2-4
101	R	C	P	2-4
102	L	-	P	2

Flow System No. (Plate I)	Class	Circulation	Permeability Bedrock	Moisture Availability
103	L	-	P	2
104	L	C	U	4
105	L	-	U	4
106	L	C	U	3
107	L	-	U	4
108	L	S	U	2
109	L	C	U	2
110	L	C	U	1
111	L	-	U	1
112	L	S	U	1
113	L	S	U	1
114	L	-	U	2
115	L	-	P	2
116	L	C	P	4
117	L	-	A	2
118	L[e]	-	P	4
119	R	C	P	4

Flow System No. (Plate I)	Class	Circulation	Permeability Bedrock	Moisture Availability
120	R	D	P	4
121	L	C?	P	4
122	R	C-D	P	4
123	R	D	P	2
124	R	D-C	P	2
125	L	-	P	4
126	L	-	P	4?
127	L	-	A	4
128	L	-	U	4
129	L	-	P	4
130	L[b]	D	P	4
131	L[e]	D?	U	4
132	R	D?	U	4
133	L[e]	-	P	2
134	L[e]	-	P	2
135	L[e]	-	A	2
136	R	-	U	4

APPENDIX TABLE 4

Large Springs Associated with Carbonate Rock Terrane

This table lists, locates, and briefly describes local environments of occurrence and spring characteristics of selected large springs believed to be points of discharge for carbonate rock flow systems. Also included are a few other types of water-sample points in carbonate rock terrane. Many of the springs issue from local environments of alluvium. Several lines of evidence tie these hydrologic features to carbonate rock terrane, and the influence of the alluvial environments of discharge on the parameters considered in this study does not seem appreciable in the type of analysis made in this study.

The tabulated springs are not all of the large springs in the carbonate rock province of Nevada. This table has been arrived at by selecting the larger springs most clearly associated with carbonate rock terrane, and then in some areas selecting only one representative spring from a group of springs. In other areas, as a test of the variability in localized groups of springs, more than one spring has been considered. In most cases closely grouped springs are similar in most characteristics, but on a slightly larger scale (for example, those in Ruby Valley), and certainly on a basin-wide scale, there may be marked variation in characteristics of large springs.

APPENDIX TABLE 4 LEGEND

1 - Pine Valley
2 - Central Schell Creek Range
3 - White River Valley
4 - Railroad Valley
5 - Near Ash Meadows
6 - North end of Cave Valley
7 - East end of Muddy Mountains
8 - Elevation of colar, water level approx. 5,900
* - Applied name if unknown
a - About 4,000 gpm is the apparent discharge, but 25 cfs has been reported
b - A discharge of 600 gpm has been reported
c - A discharge of 900 gpm has been reported
d - Spring destroyed by drilling of nearby flowing well, originally discharged 2,520 gpm and temp. was 75°F.
e - Spring originally flowed 1,500 gpm, but has diminished because of drilling of nearby flowing well
f - An ebb and flow spring with diurnal variations
g - Average for several springs in Moapa Valley
h - Ebb and flow spring
i - Springs essentially dry due to intense ground-water development - originally flowed 2,576 gpm
SL - Small local flow system
L - Local flow system
R - Regional flow system
900E - Estimated discharge
900V - Variable Discharge

APPENDIX TABLE 4

Large Springs Associated with Carbonate Rock Terrane

Sprg. No.	Name and Location	Hydrogeologic Environment	Elevation (Feet)	Disch. (gpm)	Temp. (F)	System Class
1	Crittenden Springs NW/SE/8/42N/69E	Faulted Paleozoic ls. at foot of mountain range	5,280	1,000E	61	L
2	Thousand Sprgs. (Gamble Rch. Sprg.) SW/NW/8/40N/69E	Alluvium approx. 4 mi. E. Paleozoic carbonate rocks	4,950	1,350	69	L
3	*Foothill Sprg. SW/SE/18/36N/62E	Contact at alluvium and ls. bedrock	5,800	200E	60	L
4	*Wright Ranch Sprg. NE/NE/30/36N/62E	Ls. Cobbles adjacent to ls. bedrock	5,800	450E	55	L
5	Ralphs Warm Sprg. 33/36N/64E	Alluvium from several pool sprgs. Approx. 1.5 mi. E. Paleozoic carbonate rocks	5,700	1,193	70	L
6	Johnson Ranch Sprg. NW/NW/33/36N/66E	Ls. cobbles few hundred feet E. Paleozoic carbonate rocks	5,700	2,588	67	SL-L
7	Warm Springs SW/SE/12/33N/61E	Alluvium adjacent to Paleozoic carbonate rocks	5,700	2,250	63	R
8	*Odger Ranch Sprg. SW/SE/23/29N/63E	Alluvium approx, 2 mi. from Paleozoic carbonate rocks	6,000	200E	65	L-R
9	Twin Springs NE/NE/35/29N/63E	Two springs from ls. cobbles near fault few hundred feet S. Paleozoic carbonate rocks	6,200	200E	69	L
10	Hot Creek Sprgs, (P.V.)[1] SW/NW/12/28N/52E	Several sprgs adjacent to ls. bedrock-main sprg from orifice in bedrock	5,680	5,900R	84	L

Appendix Table 4 (cont'd)

Sprg. No.	Name and Location	Hydrogeologic Environment	Elevation (Feet)	Disch. (gpm)	Temp. (F)	System Class
11	*Brown Ranch Sprg. NW/SW/28/28N/56E	Toe of alluvial apron approx, 3 mi. E. Paleozoic carbonate rocks	5,880	90R		L
12	Taylor Spring SE/SE/11/28N/61E	Several springs flow into large pond near toe of alluvial fan, approx. 3 mi. E. Paleozoic carbonate rocks	6,100	550E	61	L
13	Currie Gardens 36/28N/63E	Several seeps from alluvial fan, approx, .5 mi. W. Paleozoic carbonate rocks	6,000	450E	57	L-SL
14	Cave Creek Cave SW/SE/24/27M/57E	Cave near range front fault-Devonian Devil's Gate Ls.	6,042	3,250V	42-44	SL
15	Fish Hatchery Sprg. NE/NE/36/27N/57E	Alluvium adjacent to mtn. front Devonian Devils Gate Ls.	5,900	800E	cool	SL
16	Bressman Sprg. SW/NW/18/27N/58E	Ls. alluvium, approx. 5 mi. E. Devonian Devils Gate Ls.	5,900	1,000E	cool	SL
17	Spring No. 29 NW/SW/18/27N/58E	Ls. alluvium adjacent to Devonian, Devils Gate Ls.	5,900	100E	cool	SL
18	X-1 Spring SE/SW/18/27N/58E	Alluvium, approx. .5 mi. E. Devonian, Devils Gate Ls.	5,900	450E	cool	SL
19	Nelson Spring NE/SW/4/27N/64E	From large vegetated pool, alluvium adjacent to Tertiary volcanics, underlain by carbonate rocks?	5,800	600E	57	R
20	Flyn Spring SW/NW/1/26N/57E	Ephemeral, from a cobble filled orifice in Devonian, Devils Gate Ls.	6,160	0-9,425R	45	SL

Appendix Table 4 (cont'd)

Sprg. No.	Name and Location	Hydrogeologic Environment	Elevation (Feet)	Disch. (gpm)	Temp. (F)	System Class
21	*South Stratton Sprg. 15/26N/62E	Alluvium, near contact with ls. bedrock	6,350	450E	58.5	SL
22	*South Stratton Pond Sprg. 15/26N/62E	Alluvium near contact with Paleozoic carbonate rocks	6,350	450E	58.5	SL
23	Aspen Spring SE/SW/10/26N/63E	Thin alluvial mantle, adjacent to approx. 20 Deg. westward dipping faulted ls. on contact with volcanic conglomerate	7,000	300E	50	SL
24	Walti Hot Spring SW/33/24N/48E	Mtn. Front Fault, adjacent to Devonian, Nevada Fm.	5,640	897E	160	R
25	Shipley (Sadler) Hot Sprg. NE/SE/23/24N/52E	Alluvium adjacent to Devonian, Nevada Fm.	5,800	6,750	106	R
26	Siri Ranch Spring NW/SW/6/24N/53E	From small pool in alluvium approx. 1 mi. E. Devonian, Nevada Fm.	5,800	175E	81	L
27	Bailey Spring SW/SW/36/24N/53E	From 45-ft. diameter pool in alluvium, approx, 1 mi. E. Silurian, Lone Mtn. Dol.	5,800	200E	60	R
28	Emerald Lake Cave SE/SE/34/24N/54E	A cave lake 50 ft. long, 7 ft. wide, 16 ft. deep - 90 ft. below surface in Permian, Leonardian rocks (here Ls.)	5,960	0	66	R
29	*Romano Artesian Spring NE/24/23N/53E	6 in. pipe in alluvium approx. 1.5 mi. E. Silurian, Lone Mtn. Dol.	5,800	100E	61	R

Appendix Table 4 (cont'd)

Sprg. No.	Name and Location	Hydrogeologic Environment	Elevation (Feet)	Disch. (gpm)	Temp. (F)	System Class
30	Thompson Ranch Spring NW/SE/3/23N/54E	Alluvium adjacent to Permian, Leonardian rocks (here ls.)	5,840	900	71-75	R
31	Fad Shaft SE/NE/22/19N/53E	From Shaft at 2,200-ft. level	6,904[8]			R-L
32	Fish Creek Sprgs. (Sara Ranch Sprgs. NW/8/16N/53E	Several Spring,.25 mi. area in valley alluvium approx. 1.5 mi. E.Devonian, Nevada Fm.	6,030	4,000	66	L-R
33	Willow Spring NE/SE/22/26N/57E	Alluvial fan,.5 mi. E. Down-faulted Mississippian (?) ls.	6,000	300E	51	SL
34.	Ramires Sprgs, No. 2 NW/SW/27/26N/57E	Three springs, alluvial fan, .75 mi. E. down-faulted Mississippian (?) ls.	6,000	500E	52	SL
35	Ramires Springs SW/NE/34/26N/57E	Alluvium,.75 mi. E. down-faulted Mississippian (?) ls.	6,000		cool	SL
36	Spring No. 101 SE/SE/34/26N/57E	Alluvil fan,.5 mi. E. Devonian, Devils Gate Fm.	6,000	225E	52	SL
37	Indian Creek Spring SE/NW/20/26N/64E	Orifice in cobbles adjacent to Pogonip Group (?) ls., Lower & Middle Ordovician	6,800	150E	61.5	L
38	Headwaters Spring SW/SE/34/25N/55E	Cobbles few hundred feet from approx. 35 deg. westward dipping Pennsylvanian, Ely ls.	6,040	670R	63	L
39	Pony Express Spring SW/13/25N/57E	Large marsh area in valley bottom alluvium	6,000	200E	52	L
40	Goshute Creek 12/25N/63E	Creek at mouth of canyon amidst ls. bedrock rept. to rise as spring in canyon	6,400	400V	66	SL-L

Appendix Table 4 (cont'd)

Sprg. No.	Name and Location	Hydrogeologic Environment	Elevation (Feet)	Disch. (gpm)	Temp. (F)	System Class
41	Chin Spring NE/SW/27/25N/67E	Alluvium in narrow canyon adjacent to fault contact with volcanics (andesite (?)) and ls.	7,000	100E	cool	L
42	Cold Spring SW/SW/26/23N/67E	Cobbles, adjacent to Permian ls.	6,120	200E	56	L
43	Tippet Warm Spring NE/NW/14/23N/67E	Steep talus slope near ls. bedrock	6,000	150E	65-70E	L
44	Goicoechea Ranch Spring NW/SW/11/22N/55E	Alluvium, .33 mi. E. Permian ls.	5,860	400E	62	SL
45	Minoletti Spring NE/NW/11/22N/55E	Toe of Alluvial Fan, .75 mi. E. Permian ls.	5,860	425E	60	L
46	Giocoechea (Simonson) Warm Spring NE/NE/1/22N/56E	Pond in alluvium and dune area 1 mi. W. Devonian, Guilmetti Fm.	5,880	1,120R	74-76	L
47	John Borchert Spring NE/16/22N/63E	Alluvial for near Cambrian ls.	6,200	447	64	L
48	Lower Schellbourne Cold Spring 1/22N/64E	Head of fan, localized seep in ls. alluvium	7,000	100E	54	L
49	Lower Schellbourne Warm Spring 12/22N/64E	Colluvial fan head near Permian, Arturus Fm.	7,000	450E	77	L

Appendix Table 4 (cont'd)

Sprg. No.	Name and Location	Hydrogeologic Environment	Elevation (Feet)	Disch. (gpm)	Temp. (F)	System Class
50	Upper Schellbourne Warm Spring SE/NW/8/22N/65#	In canyon adjacent to gently SE dipping ls. near fault contact with Cambrian, Hamburg Fm, and Permian, Arcturus Fm	7,200	450E	73.5	L-SL
51	Deadman Spring SW/NW/25/21N/63E	Alluvium, adjacent to Pennsylvanian, Moleen Fm.	6,480	175E	52	L
52	Monte Neva Hot Spring NE/NW/25/21N/63E	Alluvium, 2 mi. E. Ordovician-Silurian-Devonian carbonate rocks	6,030	630	174	L
53	Indian Spring SE/SW/10/21N/70E	Large seep, ravine along complex faulting on mtn. front adjacent to Cambrian ls.	7,000	100E	cool	L
54	*Pleasant Valley Spring SE/NE/21/21N/70E	Narrow valley, alluvium - 1 mi. SSW. Cambrian ls.	6,000	100E	cool	R
55	Robinson Springs 5-8/20N/553	Several springs flowing from Carboniferous carbonate rocks	6,960	175E	60	SL
56	North Group Springs 5/19N/63E	Several Springs, Valley alluvium approx. 1.33 mi. E. Cambrian, Hamburg ls.	6,100	450(?)	77	L
57	Gallagher Gap Spring SW/NE/3/18N/64E	Alluvium adjacent to faulted Devonian ls.	6,480	337E	cool	L
58	Schoolhouse Spring NW/SE/3/18N/64E	Alluvium, concealed McGill fault approx. 1 mi. W. Middle Cambrian, Raiff ls.	6,280	450(?)	76	L
59	McGill (Warm) Spring SE/NE/3/18N/65E	Alluvium, concealed McGill fault approx, 1 mi. W. Middle Cambrian, Raiff ls.	6,640	4,578	76-84	R

Appendix Table 4 (cont'd)

Sprg. No.	Name and Location	Hydrogeologic Environment	Elevation (Feet)	Disch. (gpm)	Temp. (F)	System Class
60	Bird Creek Spring SE/NE/3/18N/65E	In canyon near folded and faulted ls. on contact with Upper Cambrian, Dunderberg (?) and Windfall Fms.	7,760	718R		SL
61	South Mulick Spring NE/SW/25/17N/67E	Seeps at edge of 45-ft. dia. pool 2.5 mi. from carbonate rocks	5,600	200E	55	L
62	Illipah Spring SE/SW/10/16N/58E	500-ft. long base flow spring in canyon in Pennsylvanian, Ely ls.	7,560	900E	cool	SL
63	Eberhardt Tunnel NW/SE/31/16N/58E	3,600 feet in mine and approx. 900 feet below surface, seepage from a 1-ft. gouge in Devonian, Nevada ls.	7,680	0	47.5	SL
64	Murry Springs SE/SE/20/16N/63E	Along fault in canyon in Lower and Middle Pennsylvanian, Ely ls.	6,640	3,300	55	SL
65	Green Springs SE/SW/33/15N/57E	Alluvium, adjacent to Devonian, Nevada ls.	6,080	675	63	L
66	Cave Springs (S.C.R.)[2] SE/NW/10/15N/65E	Faulted area in canyon alluvium adjacent to C-member Guilmette Fm. (Devonian)	7,600	300E	cool	SL
67	Bastian Spring SW/NE/21/15N/66E	Fault contact between Lincoln Peak Fm. (Cambrian) and Windfall Fm. (Cambrian) at base 400-ft. cliff	6,640	150E[b]	53	SL
68	Big Bull Spring SE/SE/14/14N/56E	Pool at base of ls. knoll, Lower and Middle Pennsylvanian, Ely ls.	5,800	400	54	L
69	Bull Creek Spring SE/NW/25/14N/56E	Faulted Lower and Middle Pennsylvanian Ely ls.	5,800	225	54	L

Appendix Table 4 (cont'd)

Sprg. No.	Name and Location	Hydrogeologic Environment	Elevation (Feet)	Disch. (gpm)	Temp. (F)	System Class
70	Willow Creek Basin Sprgs. NE/NW/35/14N/63E	Springs and seeps from thin alluvium adjacent to Lower Permian, Arcturus Fm.	7,200-7,640	685	55.5	SL
71	Water Canyon Springs NW8/13N/63E	Canyon .12 mi. base flow, in Lower and Middle Pennsylvanian, Ely ls.	7,600-7,680	325V	48	SL
72	Rowland (Lemay or Lahnan) Spring SE/SE/10/13N/69E	Head alluvial fan near Middle Cambrian Pole Canyon ls.	6,300	1,900	48	L-SL
73	Preston Big Spring SW/NE/2/12N/61E	Alluvium in valley, adjacent to mts. carbonate rock	5,700	3,900	70	L
74	Cold Spring SW/NW/12/12N/61E	Alluvium in valley, adjacent to mts. carbonate rock	5,700	780	70	L
75	Nicholas Spring SE/12/12N/61E	Alluvium in valley, adjacent to mts, carbonate rock	5,70	1,125	71	L
76	Arnoldson Spring SW/SE/12/12N/61E	Alluvium in valley, adjacent to mts. carbonate rock	5,700	1,380	72	L
77	Mount Wheeler Mine NW/SW/15/12N/68E	Flow from 1,500 feet inside, probably from 5 to 50-ft. Wheeler ls. near basal part of lower Cambrian, Pioche Shale	7,960	36	45	SL
78	Spring Creek Spring NW/SW/15/12N/70E	Faulted Ordovician-Silurian-Devonian carbonate rocks	6,120	713-1683V	54-56	SL
79	Lund Spring NE/NE/1/11N/62E	Alluvium, 40 ft. W. of westward dipping Pennsylvanian, Ely ls.	5,600	2.800	66	SL
80	Shoshone Springs SE/SW/1/11N/67E	Springs and seeps in valley alluvium 2.5 mi. W. Middle Cambrian, Pole Canyon ls.	5,800	300E	53	SL

Appendix Table 4 (cont'd)

Sprg. No.	Name and Location	Hydrogeologic Environment	Elevation (Feet)	Disch. (gpm)	Temp. (F)	System Class
81	Minerva Spring NE/SE/12/11N/67E	Large pond in alluvium, 2 mi. W. Middle Cambrian, Pole Canyon ls.	6,400	300E	53	SL
82	Swallow Canyon Spring SW/4/11N/68E	In stream bed at Middle Cambrian, B-Member, Pole Canyon ls.	6,400	0-1800R	49	SL
83	Spring NE/SW/5/11N/68E	2 springs in alluvium near Middle Cambrian, Pole Canyon ls.	6,080	275E	49.5	SL
84	Six Mile Springs NE/NE/4/10N/62E	2 springs on alluvial fan .75 mi. W Ordovician-Silurian-Devonian carbonate rocks	5,650	175	61	SL-L
85	Big Spring 33/10N/70E	2-3 springs in alluvial fan near outcrop of Ordovician and Silurian carbonate rocks	5,550	4,000[a]	61	SL-L
86	Big Warm Spring SE/NW/32/13N/56E	Alluvium,.7 mi. W. Fault zone, volcanics and Devonian, Devils Gate ls.	5,600	6,300	90	R
87	Little Warm Spring NW/NE/5/12N/56E	Alluvium, .5 mi. W. fault zone, volcanics and Devonian, Devils Gate ls.	5,600	300E	90	R
88	Current Spring SE/SW/18/12N/59E	In stream bed between volcanic rock hills,.75 mi. E. of eastward dipping Devonian ls.	7,700	150	47	SL
89	West Immigrant (Hardy) Spring SW/13/9N/61E	3 small springs in alluvium Ordovician carbonate rock exposed 3 mi. E.	5,350	200E	66.5	L
90	Mormon Spring (W.R.V.)[3] SE/32/9N/61E	Alluvium, ls. bedrock 3 mi. W.	5,300	225E	98-100	R

Appendix Table 4 (cont'd)

Sprg. No.	Name and Location	Hydrogeologic Environment	Elevation (Feet)	Disch. (gpm)	Temp. (F)	System Class
91	Immigrant Spring SW/NE/19/9N/62E	Alluvium with calcareous deposits Ordovician-Silurian-Devonian carbonate rocks exposed 1 mi. NE.	5,450	1,350	67	SL-L
92	Lockes Stockyard Sprg. (Hay Corral) NE/NE/15/8N/55E	Near tufa bluff, Devonian, Nevada Fm. exposed 3.5 mi. W.	4,860	425E[b]	89-93	R
93	Lockes Big Spring SW/NE/15/8N/55E	Atop tufa bluff, Devonian, Nevada Fm. exposed 3.5 mi. W.	4,860	520[e]	99-101	R
94	Reynolds Spring SE-NE/15/8N/55E	Two pools approx. 40 feet apart at base tufa bluff, Devonian, Nevada Fm exposed 3.5 mi. W.	4,860	323	97-99	R
95	Blue Eagle & Jacks Sprgs. SE/SE/11/8N/57E	Toe of alluvial fan, Devonian carbonate rock exposed 1 mi. E.	4,760	2,270V	82.5	R
96	Tom Spring NW/NW/12/8N/57E	Alluvium Devonian carbonate rocks exposed 1.5 mi. E.	4,760	250E	71	R
97	Butterfield Spring (R.V.)[4] NE/SE/27/8N/57E	Alluvium, Devonian carbonate rocks exposed 1.5 mi. E.	4,750	200E	61.5	R
98	Butterfield Springs (W.R.V.)[3] NW/NE/28/7N/62E	Two springs in alluvium, Ordovician-Silurian carbonate rocks exposed .75 mi. SE	5,250	1,125		L
99	Flag Springs SW/NW/33/7N/62E	Three springs at toe of alluvial fan, Fish Haven Dol. (Upper Ordovician) exposed 1 mi. E.	5,250	1,125		L
100	Forest Home Spring NE/SE/18/6N/59E	On fault in Paleozoic carbonate rocks	6,210	425E	57	L

Appendix Table 4 (cont'd)

Sprg. No.	Name and Location	Hydrogeologic Environment	Elevation (Feet)	Disch. (gpm)	Temp. (F)	System Class
101	Moon River Spring NW/25/6N/60E	Alluvium near small hill, Lehman Fm. of Pogonip Group (Middle Ordovician) few hundred feet NE	5,200	900	92	R
102	Hot Creek Springs (W.R.V.)[3] SE/NE/18/6N/61E	In alluvium, Silurian, Laketwon Dol. exposed few hundred feet SE	5,200	6,885	92	R
103	Fairbanks Spring SE/NE/9/17S/50E	In alluvium, Cambrian ls. exposed 1.33 mi. SE	2,280	1,715	80	R
104	Rogers Spring (A.M.)[5] NW/NE/15/17S/50E	In alluvium, Cambrian ls. exposed 1.25 mi. SE	2,260	717-736	82-84	R
105	Longstreet Spring NW/NE/22/17S/50E	In alluvium, Cambrian, Nopah Fm. exposed .75 mi. E.	2,300	1042-1239	80-82	R
106	Devil's Hole SW/SE/36/17S/50E	Standing water in solution sink, upper Bonanza King Fm. (Middle & Upper Cambrian)	2,400	0	92	R
107	Crystal Pool SE/NE/3/18S/50E	In alluvium, upper Bonanza King Fm. (Middle & Upper Cambrian) exposed 2 mi. E.	2,180	2,824	89-91	R
108	Point-of-Rock (King) Sprg. SE/NW/7/18S/51E	In alluvium near upper Bonanza King Fm. (Middle & Upper Cambrian)	2,250	1,162	89-90	R
109	Big Aprg. (Deep or Ash Meadows) SW/NE/19/18S/51E	In alluvium, upper Bonanza King Fm. (Middle & Upper Cambrian) exposed 2 mi. E.	2,240	1078-1247	83	R
110	Bennetts Springs SW/SE/14/20S/53E	In alluvium 5 mi. W. Mississippian-Pennsylvanian-Permian, Bird Sprg. Fm.	2,680	0[d]	76	L

Appendix Table 4 (cont'd)

Sprg. No.	Name and Location	Hydrogeologic Environment	Elevation (Feet)	Disch. (gpm)	Temp. (F)	System Class
111	Manse Springs 3/21S/54E	In alluvium approx. 3 mi. S. Mississippian-Pennsylvanian-Permian, Bird Spring Fm.	2,800	605[e]	75	R
112	Cave Spring (C.V.)[6] 16/9N/64E	Base of 40-ft. bluff, Middle Cambrian, Pole Canyon ls., from orfice 3 ft. high & 5 ft. wide	6,500	400V	cool	Sl
113	Geyser Spring SW4/9N/65E	Alluvial apron near Middle Cambrian, Pole Canyon ls.	6,800	58-1153[f]	68	SL
114	Panaca Warm Sprg. (Owl) NW/NE/4/2S/68E	On alluvium and bedrock fault contact, Middle Cambrian, Highland Peak ls.	4,760	3600-4883	85-88	R
115	Hiko Spring 14/4S/60E	Alluvium and Bedrock contact, Middle Devonian, Simonsen Dol.	3,890	2,400	80	R
116	Crystal Spring NE/10/5S/60E	Area mostly covered by alluvium, orfice in bedrock, probably Devonian ls.	3,840	5,300	82	L-R
117	Brownie Spring NE/26/5S/60E	Alluvium, Devonian carbonate rocks outcrop 1.5 mi. E.	3,700	50E	warm	R
118	Ash Spring SE/SE/36/5S/60	Alluvium and bedrock contact, Devonian, Sevy Dol	3,610	7,630	90	R
119	Warm (Muddy) Spring 16/14S/65E	Alluvium, approx. 1.25 mi. E. Pennsylvanian & Permian, Bird Spring Fm.	1,760	3,236	90	R
120	Iverson (Warm) Spring NE/NE/21/14S/65E	Alluvium near Mississippian, Pennsylvanian & Permian, Bird Spring Fm.	1,760	1,696	89	R

Appendix Table 4 (cont'd)

Sprg. No.	Name and Location	Hydrogeologic Environment	Elevation (Feet)	Disch. (gpm)	Temp. (F)	System Class
121	Indian Springs NW/NW/16/16S/55E	Alluvium near Mississippian, Pennsylvanian & Permian, Bird Spring Fm.	3,200	408	78	R
122	Willow Spring SW/NE/2/18S/55E	Near Paleozoic carbonate rocks	6,000	225	54	L-SL
123	Rogers Spring (M.M.)[7] SE/SE/12/18S/67E	Fault contact of conglomerate and Mississippian ls.	1,600	880	80	R
124	Blue Point Spring SW/SE/6/18S/68E	Junction of 2 faults near Mississippian ls.	1,520	400E	80	R
125	Deer Creek Springs 18/19S/57E	Fractures and solution cavities and fault contact with Upper & Middle Cambrian ls. & Dol. and Ordovician carbonate rocks	8,600	140	42.5-44	SL
126	Intermittant Spring SE/31/20S/56E	In Middle & Upper Cambrian ls and Dol.	4,640	450-15,000[h]	57	L
127	Las Vegas Springs 30/20S/61E	Several springs along fault displacing basin sediments approx. 9 mi. E. of Paleozoic carbonate rocks		0[i]	73	L
128	Well NW/NW/22/155/67E	16" well penetrating unconsolidated sediments finished in cavernous carbonate rock, 154' deep, lower 70' uncased	1,400	yield: 2700 gpm 25' dd	68	R

Appendix Table 5 Cont.

Append. Tab. 4 Spr. No.	Sample Date	Source of Anal.	Selected Constituents in epm			Water Temp. °F	Tritium Assay T.U.	System Class.	Remarks
			Na+K	Ca+Mg	Cl+SO_4				
127	11/2/51	USGS	.34	4.58	1.07	73		L	Las Vegas Spgs., for comparison
128	July,'67	CWRR	11.12	15.77	20.90	68		R	Well, for comparison

APPENDIX TABLE 5

Chemistry and Tritium of Springs Associated with Carbonate Rock Terrane

Concentrations of certain combined ions are listed in this table, and available tritium and C^{14} determinations are presented for comparision. Figures 12 and 13 have been developed from these data.

Concentrations of Na + K and C1 + SO_4 are believed to be primarily dependent upon lengths of flow paths, whereas some of the other common constituents, such as Ca + Mg, are believed dependent upon other factors, such as solution equilibrium with calcite and dolomite. Tritium concentrations are more or less related to recharge that has entered the flow systems since 1954. C^{14} concentrations and associated apparent age more or less indicate the relative ages of the water sampled. However, where careful studies have been made of C^{14} in ground water in carbonate rocks, apparent ages corrected by $C^{13/12}$determinations generally give younger ages. These corrections may be as great as several thousand years.

APPENDIX TABLE 5 LEGEND

Analyses:

- DRI - Cation determinations by the Nevada Bureau of Mine Analytical Laboratories, anion determinations by the Center for Water Resources Research and the College of Agriculture, Univ. of Nevada, Reno (the latter chloride determinations).
- CWRR - Total analyses by the Center for Water Resources Research laboratory, Univ. of Nevada, Reno.
- HNSC - Total analyses by Hazleton-Nuclear Science Corp., Palo Alto, California.
- USGS - Published analyses by the U.S. Geological Survey, includes "field analyses" conducted in Carson City, and out of state analyses in USGS laboratories.
- AES - Published analyses of the Agricultural Experiment Station, Univ. of Nevada.
- NSDH - Nevada State Department of Health and Welfare, generally from the Reno facilities.
- a - Only Sodium reported.

Other Symbols: Under system classification R = Regional, L = Local, SL = Small Local. Compounded symbols indicate water chemistry near chosen boundaries.

E = Estimated value

Appendix Table 5
Chemistry and Tritium of Springs associated with Carbonate Rock Terrane

Append. Tab. 4 Spr. No.	Sample Date	Source of Anal.	Selected Constituents in epm Na+K	Ca+Mg	$Cl+SO_4$	Water Temp. °F	Tritium Assay T.U.	System Class.	Remarks
1	6/28/66	DRI	.65	3.43	1.11	55-65E	≤8	L	
2	9/25/65	HNSC	.48	3.82	1.06	69		L	
3	9/26/65	HNSC	.62	3.24	.43	60		L	
4	9/26/65	HNSC	.58	3.19	.38	55		L	
5	9/26/65	HNSC	.69	3.06	.68	70		L	
6	9/26/65	HNSC	.25	2.85	.31	67		SL-L	
7	9/26/65	HNSC	2.89	3.26	1.39	63		R	
8	6/15/66	DRI	.69	4.38	1.39	65		L-R	
9	6/15/66	DRI	.26	3.36	.48	69		L	
10	9/27/65	HNSC	.53	3.77	.74	84		L	
11	10/20/64	USGS	.96	3.32	.49	-		L	
12	6/15/66	DRI	.37	3.10	.53	61		L	
13	9/10/66	DRI	.28	3.64	.39	57		L-SL	
14	9/27/65	HNSC	.08	2.57	.35	42-46		SL	
15	10/26/66	DRI	.11	3.19	.29	54	37±3	SL	
16	10/26/66	DRI	.11	3.25	.19	53	≤22	SL	
17	10/26/66	DRI	.09	3.05	.19	52	≤22	SL	
18	10/26/66	DRI	.09	2.94	.16	51	27±11	SL	

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Appendix Table 5 Cont.

Append. Tab. 4 Spr. No.	Sample Date	Source of Anal.	Selected Constituents in epm Na+K	Ca+Mg	$Cl+SO_4$	Water Temp. °F	Tritium Assay T.U.	System Class.	Remarks
19	9/10/66	DRI	1.67	3.69	1.42	57		R	Chem. suggests carbonate terrane spg.
20	9/27/65 6/14/66	HNSC	.13	3.34	.15	45	119 ± 12 500 ± 12	SL	$-\delta C^{14} < 90$ or <750 yrs.
21	9/12/66	DRI	.18	3.61	.27	58	≤ 7	SL	
22	9/12/66	DRI	.21	3.50	.31	58.5	≤ 9	SL	
23	9/10/66	DRI	.10	3.43	.14	50	52 ± 12	SL	
24	6/17/65	USGS	3.04	3.82	1.75	160		R	
25	9/18/52	USGS	1.52	4.57	1.29	106		R	
26	7/11/66	DRI	.76	4.00	.89	81		L	
27	7/11/66	DRI	1.60	4.57	1.61	60	≤ 7	R	
28	7/11/66	DRI	1.13	4.47	1.50	66		R	Pool in limestone cave
29	7/11/66	DRI	1.79	3.95	1.32	61		R	
30	7/11/66	DRI	1.14	5.03	1.47	71-75		R	
31	8/20/65	HNSC	.73	2.98	1.60	-		R-L	From flooded mine shaft
32	9/29/65	HNSC	1.31	4.37	.77	54		L-R	
33	10/26/66	DRI	.16	3.54	.21	51	≤ 7	SL	
34	10/26/66	DRI	.21	3.98	.23	52	≤ 7	SL	
35								SL	Assumed similar to 34
36	10/26/66	DRI	.22	3.42	.26	52	≤ 8	SL	

Appendix Table 5 Cont.

Append. Tab. 4 Spr. No.	Sample Date	Source of Anal.	Selected Constituents in epm			Water Temp. °F	Tritium Assay T.U.	System Class.	Remarks
			Na+K	Ca+Mg	$Cl+SO_4$				
37	7/14/66	DRI	.26	4.50	1.00	61.5		L	
38	10/24/64	USGS	.40[a]	3.39	.57	63		L	
39	10/26/66	DRI	.33	4.02	.41	52		L	
40	7/14/66	DRI	.20	3.86	.42	66		SL-L	
41	9/10/66	DRI	.56	4.49	.90	cold		L	
42	7/12/66	DRI	.58	2.95	.52	56		L	
43	9/9/66	DRI	.36	5.28	.81	65-70E		L	
44	7/12/66	DRI	.23	2.41	.31	62		SL	
45	7/12/66	DRI	.37	3.01	.54	60	≤ 7	L	
46	10/25/66	DRI	.96	4.60	.91	74-75		L	
47	9/29/65	HNSC	.26	3.51	.48	64		L	
48	9/11/66	DRI	.45	4.42	.70	54		L	
49	9/11/66	DRI	.36	4.22	.37	77	≤ 8	L	Note temp. and elev.
50	9/11/66	DRI	.17	4.43	.54	73	≤ 8	L-SL	Note temp. and elev.
51	7/12/66	DRI	.38	2.60	.52	52		L	
52	10/27/66	DRI	.72	4.76	.68	174		L	
53	9/9/66	DRI	.79	1.61	1.04	cool		L	
54	9/9/66	DRI	1.02	5.36	1.53	cold		R	

Appendix Table 5 Cont.

Append. Tab. 4 Spr. No.	Sample Date	Source of Anal.	Selected Constituents in epm Na+K	Ca+Mg	$Cl+SO_4$	Water Temp. °F	Tritium Assay T.U.	System Class.	Remarks
55	7/12/66	DRI	.11	2.20	.36	60		SL	
56	<1920	USGS	.65	4.33	.53	77		L	
57	5/21/66	DRI	.69	3.86	.28	cool		L	
58	5/21/66	DRI	.58	3.51	.74	76		L	
59	9/29/65	HNSC	1.01	5.11	3.34	76-84		R	
60	5/7/66	DRI	.16	3.10	.24	-		SL	
61	7/12/66	DRI	.48	4.32	.51	55		L	
62	8/18/65	HNSC	.26	2.61	.18	55-60E	15±1	SL	
63	8/18/65 11/11/66	HNSC	.29	3.25	.62	47.5	145±12 150±11	SL	Gouge Seepage, local sat. in limestone
64	12/11/51	USGS	.16	3.94	.31	55	≤7	SL	
65	8/19/65	DRI	.43	4.06	.62	63	≤9	L	
66	5/21/66	DRI	.06	3.32	.14	cool		SL	
67	7/13/66	DRI	.10	2.78	.17	53	178±14	SL	
68	11/12/66	CWRR	.55	2.91	.61	54		L	
69	11/12/66	CWRR	.80	2.30	.78	54	≤7	L	
70	10/28/66	DRI	.09	3.74	.51	55	31±12	SL	
71	10/28/66	DRI	.09	3.59	.14	48	46±13	SL	
72	9/30/66	HNSC	.30	1.46	.36	48		L-SL	

Appendix Table 5 Cont.

Append. Tab. 4 Spr. No.	Sample Date	Source of Anal.	Selected Constituents in epm			Water Temp. °F	Tritium Assay T.U.	System Class.	Remarks
			Na+K	Ca+Mg	$Cl+SO_4$				
73	11/13/66	CWRR	.64	3.17	1.18	70	≤ 8	L	
74	11/13/66	CWRR	.65	3.47	1.15	70	≤ 8	L	
75	11/13/66	CWRR	.66	3.00	1.31	71	≤ 8	L	
76	11/13/66	CWRR	.66	2.98	1.28	72	≤ 9	L	
77	10/28/66	DRI	.05	2.96	.23	45	321 ± 14	SL	Mine flow, local sat.
78	7/13/66	CWRR	.31	3.84	.49	56	220 ± 16	SL	Chem. and tritium presently monitored, variable
79	11/13/66 6/15/66	CWRR	.21	4.35	.32	66	≤ 7 ≤ 8	SL	 $-\delta C^{14} = 584 \pm 14$; $7050 \pm$ yrs.
80	10/29/66	DRI	.22	3.44	.43	54		L-SL	
81	10/29/66	DRI	.16	3.30	.22	53	158 ± 12	SL	
82	7/12/66	DRI	.06	3.41	.25	49	611 ± 20	SL	
83	7/12/66	DRI	.06	3.14	.22	49.5	475 ± 18	SL	
84	11/14/66	CWRR	.31	4.87	.26	61	≤ 9	SL-L	
85	9/30/65	HNSC	.29	3.33	.29	61		SL-L	
86	10/19/12	AES	2.96[a]	3.54	2.02	90	≤ 7	R	
87	11/12/66	CWRR	1.42	4.80	1.26	90	≤ 7	R	
88	11/13/66	CWRR	.21	3.61	.22	47	164 ± 8	SL	
89	11/14/66	CWRR	.33	4.62	.42	66.5	≤ 8	L	
90	11/15/66	CWRR	1.27	4.30	1.28	98	≤ 7	R	

Appendix Table 5 Cont.

Append. Tab. 4 Spr. No.	Sample Date	Source of Anal.	Selected Constituents in epm Na+K	Ca+Mg	$Cl+SO_4$	Water Temp. °F	Tritium Assay T.U.	System Class.	Remarks
91	11/14/66	CWRR	.27	4.77	.32	67	≤ 8	SL-L	
92	11/12/66	CWRR	2.55	4.74	1.57	89-93	≤ 7	R	
93	11/12/66	CWRR	2.43	4.70	1.56	99-101	≤ 8	R	
94	11/12/66	CWRR	2.45	4.65	1.58	97-99	≤ 8	R	
95	11/12/66	CWRR	1.71	5.07	1.05	83	≤ 8	R	Near oil field
96	11/13/66	CWRR	1.77	5.20	.99	71	≤ 8	R	Near oil field
97	11/13/66	CWRR	1.70	4.81	.99	62	≤ 8	R	Near oil field
98	11/14/66	CWRR	.34	3.98	.36	-	≤ 8	L	
99	11/14/66	CWRR	.47	3.91	.41	-	≤ 8	L	
100	11/14/66	CWRR	.42	4.81	.61	57	≤ 8	L	
101	11/14/66	CWRR	1.23	4.26	1.10	92	≤ 8	R	
102	11/14/66	CWRR	1.05	4.26	1.28	92	≤ 10	R	
103	4/3/53	AES	2.82[a]	4.23	2.28	80		R	
104	1/14/65	NSDH	4.00[a]	4.14	3.52	82-84		R	
105	1/14/65	NSDH	3.74	4.10	2.91	80-82		R	
106	1/23/53	USGS	2.79	4.27	2.28	92		R	Limestone cave pool
107	2/24/29	USGS	3.53	4.07	2.51	89-91		R	
108	2/28/49	USGS	3.20	4.17	2.26	89		R	

Appendix Table 5 Cont.

Append. Tab. 4 Spr. No.	Sample Date	Source of Anal.	Selected Constituents in epm Na+K	Ca+Mg	$Cl+SO_4$	Water Temp. °F	Tritium Assay T.U.	System Class.	Remarks
109	1/27/59	USGS	4.55	4.72	3.00	83		R	
110	8/5/27	AES	.35[a]	4.30	.72	77		L	Now dry
111	8/27/16 8/5/27	AES	1.30	3.50	1.02	75		R	Now dry
112	5/24/66	DRI	.12	.77	.22	cool		SL	Chem. and flow suggest local sat.
113	8/7/63	USGS	.17	1.78	.19	68		SL	
114	5/22/66	DRI	1.83	2.03	1.91	85-88	≤8	R	
115	3/10/62	USGS	1.44	3.12	1.06	80		R	
116	4/15/63	USGS	1.13	4.18	.79	82		L-R	
117	5/23/66	DRI	2.10	3.72	1.02	warm		R	
118	5/23/66	DRI	1.51	3.08	1.05	90	≤5	R	$-\delta C^{14}$=937±12; 22,200±yrs. B.P.
119	4/15/63	USGS	4.55	5.54	5.48	90	≤4	R	$-\delta C^{14}$=912±13; 19,500±yrs. B.P.
120	9/12/63	USGS	4.68	5.64	5.53	89		R	
121	8/5/27	AES	1.37	5.94	1.73	78		R	
122	8/2/65	NSDH	.35[a]	3.60	.38	54		L-SL	
123	10/9/50	NSDH	12.75[a]	34.73	43.37	81	≤5	R	$-\delta C^{14}$>927,>21,000 yrs. B.P.
124	11/27/45	NSDH	13.78[a]	37.98	49.68	82		R	
125	8/28/65	NSDH	.17[a]	4.16	.26	43-44		SL	
126	8/24/16	USGS	.17[a]	4.92	.60	57		L	