University of Nevada

Reno

Relation Between Surficial Geology and Near-Surface Ground-Water Quality, Las Vegas Valley, Nevada

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by

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ABSTRACT

Chemical analyses of major dissolved constituents in near-surface ground water, defined as ground water within the upper 50 feet of alluvium, reflect general differences in surficial alluvial lithologies in Las Vegas Valley, Nevada.

Las Vegas Valley is an alluvium-filled valley in the Basin and Range physiographic province. Based on surficial geologic mapping, defined units, composed of intermixed clay, silt, sand, and gravel-sized alluvium, can be classified as either a carbonate or sulfate lithofacies.

Interpretation of correlation coefficients and R-mode, varimax factor analyses of log transformed water chemistry data for near-surface ground water suggest that (1) ground water temperature within the range of values measured in the study does not strongly control concentration of dissolved ions, (2) chloride, sulfate, sodium, calcium, and magnesium represent major contributions to TDS, and may have a common origin, and (3) nitrate and bicarbonate concentrations are controlled by factors not strongly linked with other major hydrochemical constituents.

Student's t-test indicates that all major ions exhibit significant concentration difference between sulfate and carbonate lithofacies at the 95 percent confidence level. Bicarbonate's mean log value is significantly higher in the carbonate lithofacies. Mean log values for other constituents are significantly greater in sulfate lithofacies.

Analysis of variance applied to ground water chemistry in three lithologic categories based on apparent abundance of gypsum in hand specimen indicates that the category containing the most abundant gypsum has, at the 95 percent level, significantly higher concentrations of chloride, sodium and potassium. Calcium and sulfate levels are significantly greater in the two gypsiferous categories when compared to the carbonate lithofacies.

Developed hydrochemical facies and trilinear diagram of dissolved ions indicate that near-surface ground water has a predominantly calcium-magnesium, sulfate-chloride hydrochemical facies with a slight bicarbonate anion facies shift exhibited by those data originating in carbonate lithofacies. A plot of sulfate versus theoretical carbonate thermochemical activity in ground water futher substantiates correspondence between carbonate and sulfate lithofacies and near-surface ground-water quality especially when a high magnesium to calcium ratio is considered.

Areal distribution of lithofacies, interpretation of analysis of variance testing, areal distribution of hydrochemical facies both in the vertical and horizontal planes, and thermochemical investigations indicate that surficial lithofacies exert partial quality control on ground water within 50 feet of land surface.

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INTRODUCTION

PURPOSE AND SCOPE

Even before formalization of the hydrochemical facies concept by Back (1966), studies were conducted to discover the role lithology played in controlling chemical composition of ground water. These studies and more recent investigations deal primarily with hydrogeochemistry of consolidated lithologies (primarily sedimentary but also igneous and metamorphic) or alluvial-fill aquifers that represent potential water supplies. Generally, these types of investigations in alluvium filled valleys in arid and semi-arid climates of the western United States merely acknowledge the existence of a zone of high-salinity ground water near land surface, attribute this salinity to evapotranspiraction effects, and then devote the majority of discussion to deeper, less saline aquifers (see as an example Hely, et al. 1971).

The purpose of this study is to determine some relationships between surficial alluvial lithology and chemical composition of this shallow, more saline ground water in Las Vegas Valley, Nevada.

Las Vegas Valley provides a useful site to study these relationships for several reasons: (1) the valley consist predominantly of alluvium, (2) the general hydrology and stratigraphy of the valley are reasonably well understood as a result of four major hydrogeologic studies completed since 1948, (3) shallow ground water is present and represents a potential water resource, (4) water quality data is available for this shallow ground water, and (5) the climate is arid.

The major emphasis of this study is restricted to ground water encountered in the upper 50 feet of alluvium, hereafter referred to as near-surface ground water. The relationship between surficial alluvial geology and near-surface water chemistry becomes obscure below this depth because geologic control is less definitive and the origin and movement of ground water are more uncertain. In addition, the salt concentrating effect of evapotranspiration diminishes rapidly in ground water greater than 50 feet deep in Las Vegas Valley.

There are five aspects to this study: (1) mapping of the surficial alluvial geology of the valley, (2) delineation of lithofacies which control near-surface ground-water quality, (3) characterization of near-surface ground-water quality, (4) investigation of areal differences in ground-water quality, and (5) development of the relationship between surficial alluvial lithology and near-surface ground-water quality.

GENERAL SETTING

Location

Las Vegas Valley is in the southern tip of Nevada (see Figure 1-1). The study site, an area of about 250 square miles, is located in the southeast portion of the valley and comprises the United States Geological Survey 15-minute Las Vegas Quadrangle (latitude 115° 00' - 115° 15' W, longitude 36° 00'-36° 14' N).

The cities of Las Vegas and North Las Vegas, and the "Las Vegas Strip," famous for its entertainment and gambling, are within the study area. The population of this area is approximately 300,000.

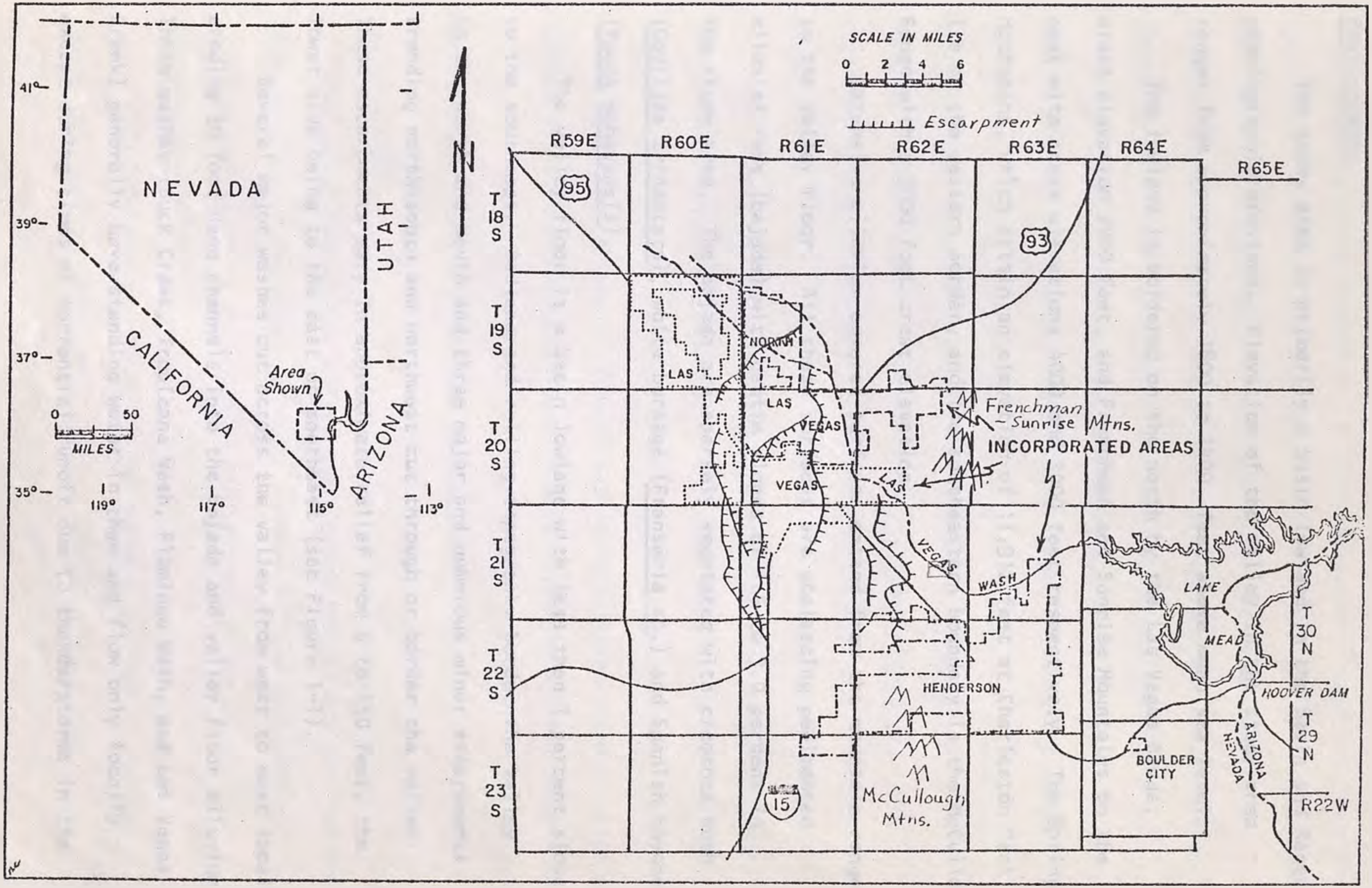


Figure 1-1. Location of Study Area.

Physiography

The study area is primarily a basin lowland in the Basin and Range physiographic province. Elevation of the valley in the study area ranges from approximately 1800 to 2400 feet above mean sea level.

The lowland is bordered on the north by the Las Vegas Range, crest elevation 7000 feet, and Frenchman and Sunrise Mountains on the east with crest elevations 4000 and 3000 feet respectively. The Spring Mountains, which attain an elevation of 11,912 feet at Charleston Peak, lie on the western border, and the southeastern boundary is the McCullough Range with a 5000 foot crest elevation.

Extensive alluvium covered surfaces extend from the mountain ranges to the valley floor. All these surfaces are coalescing pedimented alluvial fans (bajada) with gentle slopes of 1.5 to 3.0 percent in the study area. The bajada are sparsely vegetated with creosote bush (Covillea tridentata), white bursage (Franseria sp.) and Spanish bayonet (Yucca mohavensis).

The valley floor is a basin lowland with less than 1 percent slope to the southeast. Badlands and rolling topography border the valley in the north and south and three major and numerous minor escarpments trending north-south and northwest cut through or border the valley. These escarpments vary in approximate relief from 5 to 150 feet, the lower side being to the east or southeast (see Figure 1-1).

Several major washes cut across the valley from west to east locally eroding 30 foot deep channels into the bajada and valley floor alluvium. These washes (Duck Creek, Tropicana Wash, Flamingo Wash, and Las Vegas Creek) generally have standing water in them and flow only locally except during times of torrential runoff due to thunderstorms in the basin or surrounding mountains. A large wash, Las Vegas Wash, extends north-south near the eastern edge of the valley floor and drains surface waters, originating from the above described washes and return flows from cultural water use, to the southeast and out of the valley. Scattered sand dune fields are also found in the valley.

Vegetation in the basin lowland shows considerable range in composition and density due both to natural and urbanization effect. The dominant natural vegetation consists of iodine bush (*Alleurolfa occidentales*), mesquite (*Prosopis juliflora* and *P. pubescens*), white bursage (Franseria sp.), creosote bush (*Covillea tridentata*), and shadscale (*Atriplex canscens*) (Langan, *et al*. 1967).

Climate

The climate of the study area is arid, receiving an average of less than 5 inches of percipitation per year (usually in the form of thunderstorms in July and August) while potential evaporation rates exceed 80 inches per year. Winters are relatively short and mild whereas summers are long and very hot with wide variation in diurnal temperature and maximum daily temperatures above 90 degrees fahrenheit. Climatological data through 1974 are summarized in Table 1-1.

PREVIOUS WORK

Published work on the geology and hydrogeology of southern Nevada began with Gilbert's report in 1875. References from that time to 1948 are summarized in an annotated bibliography presented by Maxey and Jameson (1948).

A most comprehensive study of the regional geology of southern Nevada was reported by Longwell, *et al*. (1965) in which the

Table 1-1. Summary of Climatological Data, U.S. Weather Bureau Station, Las Vegas.

Precipitation; mean annual inches	3.9
Pan evaporation; mean annual inches	80.5
Temperature, max of record (°F)	117.0
Temperature, January mean (°F)	43.1
Clear days, mean annual	245
Partly cloudy, mean annual days	83
Percent of possible sunshine	86

stratigraphic and structural framework of Clark County is detailed. This publication documents that Clark County is composed of rocks dating from Precambrian to Holocene time and contains rocks of sedimentary, igneous, and metamorphic origin. Frenchman and Sunrise Mountains, bordering the eastern portion of the study area, have at their base Precambrian gneissic and granitic rocks on top of which lie formations of Cambrian, Devonian, Mississippian and Pennsylvanian Age. The Spring Mountains to the west contain sedimentary formations representing all Paleozoic Systems and the Triassic and Jurassic Systems, and cemented gravels of presumably late Cenozoic Age. The Las Vegas Range to the north is composed of sedimentary rocks of Devonian, Mississippian, Pennsylvanian, and Permian Age while the McCollough Range to the south is composed of Tertiary volcanics. Structural characteristics of these mountain systems along with interpretation of time, direction, and amount of displacement were described by Longwell, et al. (1965).

Longwell, et al. (1965) also examined alluvial-fill materials in the valleys and concluded that the sediments are diverse in both lithology and origin and that their ages extend from Pliocene to Holocene. The report includes a tentative separation of the Pleistocene Las Vegas Formation from Pliocene and Holocene sediments, but detail in Las Vegas Valley is not complete.

Several studies report more detailed examination of the alluvial-fill material found in Las Vegas Valley. Langan and Larsen completed a soil survey map of the Las Vegas area in 1957, and this map is reported in Langan, et al. (1967). Map units developed are based on soil lithology, chemistry, and structure according to the Comprehensive

System, 7th Approximation, 1964, with the result that over sixty map units are used to portray surficial soil conditions in Las Vegas Valley.

Price (1966) combined Langan and Larsen's soil units with previous work done by Longwell, et al. (1965) to produce a surficial geology map of the Las Vegas 15-minute Quadrangel. He subsequently related these units to economic geology problems, including sand and gravel supplies, ground-water development, and foundation problems such as expansive soils.

A detailed study of the geology of Tule Springs, Nevada, north of the present study area, was reported by Haynes (1967). Haynes used over 7,000 feet of bulldozer trench to examine the stratigraphy, geomorphology, and paleosols of the Las Vegas Formation between Tule Springs and North Las Vegas. His efforts resulted in the description of twenty-two facies changes in the Las Vegas Formation, many of which were radiocarbon dated. The geochronologic sequence obtained indicates that the oldest units are greater than 40,000 years old and the youngest about 1,000 years old.

With these abundant data Haynes constructed a detailed geologic history of Las Vegas Valley during the terminal Pleistocene (Haynes, 1967, p. 77) during the early part of which the valley floor consisted primarily of aggrading braided stream channels of silt, sand, and gravel with wide flood plains supplemented with numerous springs. About 30,000 years ago a pluvial period began and lasted for approximately 15,000 years during which lacustrine mudstones and carbonates were deposited in a shallow but extensive lake. Alluvial fans developed and interfingered with these basin sediments. Aggradation was followed by a period of degradating streams which cut canyons and washes in the alluvial fans and incised the basin lowlands. Springs were still abundant until 4000 years ago when the water table dropped and the predominant fluviatile sources dried up, thereby allowing eolian activity and minor alluvial processes to modify the stratigraphy and topography to that seen today. Haynes (1967) related facies changes to the shift between pluvial and fluvial periods and suggested that fault scarps may be related both to facies changes (ibid., p. 78) and tectonic activity as recent as 1000 years ago (ibid., p. 58).

Modern, interpretive hydrogeologic studies in the valley commenced with the work of Maxey and Jameson (1948) who defined a vertical sequence of four principal aquifer zones in the valley alluvium of the study area based on lithology, water quality, and hydrologic response (Maxey and Jameson, 1948, pp. 80-97). The aquifer zones are defined as (1) the zone of near-surface water in the upper 200 feet of sediment, in which water is found under both confined and unconfined conditions; (2) the shallow zone of aquifers which produces water from sand and gravel lenses to depths of approximately 450 feet where a blue clay is commonly encountered; (3) the middle zone of aquifers beneath the blue clay to approximately 700 feet; and (4) the deep zone of aquifers below 700 feet. The latter three zones are commonly called the artesian or deep aquifers. Maxey and Jameson (1948) indicated that the sand and gravel lenses producing water in these aquifers gradually grade into fine sands, silts and clays from west to east forming a discharge zone in the eastern and southeastern portion of the valley. They noted the effects of caliche distribution and structural features on ground-water flow along with the effects of early ground-water development by the first permanent settlers in the valley about 1900. Ground-water recharge to the valley from precipitation in the surrounding mountains was estimated to be between 25,000-35,000 acre-feet (AF) annually (Maxey and Jameson, 1948, pp. 107-108).

Malmberg (1965) extended the work of Maxey and Jameson through the use of additional wells drilled in the valley between 1948 and 1957. His estimation of 25,000 AF of recharge to the artesian system is in close agreement with that of Maxey and Jameson. Malmberg (1965) examined the effects of ground-water withdrawal from both the artesian and near-surface reservoirs and made suggestions as to where and in what amounts the artesian zones should be pumped to eliminate the loss of ground water via upward leakage to the near-surface reservoir and subsequent loss by evapotranspiration. Additionally, Malmberg discussed the ground-water hydrology of the near-surface reservoir (ibid., pp. 65-83) and indicated that the source of this water is from upward movement of water in underlying artesian aquifers. He also concluded that in 1955 approximately 24,000 AF of water was discharged from the near-surface reservoir via evapotranspiration while only 11000 AF was discharged from pumping of shallow wells.

Domenico, Stephenson, and Maxey (1964) examined the sediments and hydrology quantitatively and produced an electric analog model to be used for water management of the artesian aquifers (200-700 feet depth interval) in the valley. The value of this work to the present paper is that of reinforcing by quantitative approach the fact that the deeper aquifers undergo facies changes from west to east and thereby affect ground water flow in the study area.

effort to study interaction between natural ground water and return flows.

A map of the composite ground-water potentiometric surface for the near-surface aquifer zone was also developed for the Kaufmann (1976) report. This map is significant because shallow ground-water flow directions can be approximated from it and areas can be delineated where ground water is within 50 feet of land surface.

Although an attempt was made by Kaufmann (1976) to investigate the relationship between hydrochemistry and the distribution of soil types present in the valley, lack of a detailed surficial geology map prevented analysis of the hydrochemistry as related to the geologic framework of the most shallow ground waters encountered.

There are, in addition to the above references, many other reports dealing with the hydrology and hydrogeology of Las Vegas Valley done by consulting firms for state, county, municipal, and private concerns. These reports, however, generally use as their data base the references discussed above and, therefore, are not reviewed here.

Description of ground-water quality in terms of hydrochemical facies as used in the present paper was developed by Back (1960, 1961, and 1966) and Back and Hanshaw (1965). This technique of investigating the relation between ground-water quality and lithology has been primarily used in bedrock areas particularly in limestone terraines, (see Back and Hanshaw, 1970; Back, 1966, Drake and Harmon, 1973; Hess and White, in print; and Thrailkill, 1972) and in coastal plain sediments (see Back, 1960; Back, 1966; Seaber, 1965; and Schluger and Roberson, 1975). Kaufmann (1976) also used Back's method (1965) to depict hydrochemical facies in ground-water sampled between 101 and 300 feet in depth in the alluvial fill of Las Vegas Valley.

Chapter 2

SURFICIAL GEOLOGY

INTRODUCTION

The expressed intent of this study is to determine the relationships between alluvial lithology and near-surface ground-water quality. Therefore, the purpose of this chapter is to discuss the development of the surficial geologic map of the study area and the categorization of geologic map units into lithofacies that might affect near-surface ground-water quality. In this regard, a principal objective of this study was to map alluvial-fill stratigraphy with occupies more than 95 percent of the study area and provides the framework for near-surface ground water. Frenchman and Sunrise Mountains on the eastern border contain bedrock of Precambrian, Paleozoic, Mesozoic, and Cenozoic Age but their distribution is a minor portion of the study area and they have been described adequately by Longwell, et al. (1965) for the purpose of the present investigation.

Geologic studies previously reviewed are not adequate for meeting the goals expressed above. Haynes' work (1967) in and about Tule Springs is four miles northwest of the present study area, and Price's geologic map (Price, 1966) has major deficiencies due to soil classification errors incorporated in the soils map developed by Langan, et al. (1967) (personal communication, Lloyd Rooke, U.S. Soil Conservation Service, Las Vegas, Nevada). Therefore, the study area was remapped during the time period Spring 1974 to Spring 1976. The resulting surficial geology map is shown on Plate 1.

MAPPING METHODOLOGY

Geologic mapping followed a three-step process: (1) examination of aerial photographs to delineate obvious surficial patterns; (2) field checking of pattern boundaries established from aerial photographs; and (3) examination of core borings, well logs, and soil maps to check continuity of surficial lithologies with depth.

Four sets of black and white aerial photographs were used. They were (1) Millard-Spink series taken by Western Aerial Photos, Inc. (303 Convention Way, Redwood City, California) in February 1972 at two scales, 1:24000 and 1:48000; (2) U.S. Geological Survey series VBFN taken May 1965 at a scale of 1:22000; (3) U.S. Geological Survey series LJ taken in July 1950 at a scale of 1:47200; and (4) U.S. Geological Survey series LV taken in July 1943 at a scale of 1:20000. All four sets are extremely valuable for geologic mapping. Aerial photographs taken in 1943 and 1950 disclose large portions of unurbanized land from which natural surficial patterns can be identified whereas the 1965 and 1972 photographs contain present day ground control necessary for easy transformation of surficial patterns to maps.

Even with the aid of the above mentioned photographs field checking proved to be difficult. Urbanization, particularly in the central and east central portions of the study area, obscures contacts between surficial patterns delineated on aerial photographs. Also, similar patterns on the photographs are found to be different in lithologies. This is partially the result of ubiquitous fine eolian sand that lies on top of, and within, most alluvium in the study area. In places eolian deposits are so well developed and extensive that they are mapped as sand dune fields. Field mapping was also made difficult by the lack of subsurface erosional cuts, particularly in the basin lowland. In addition, washes generally tend to have a large amount of gravel deposits along and within their banks even when cutting through finer grained units. Heavy vegetation of saltcedar and mesquite also obscure the geology in both aerial photographs and field reconnaissance along reaches of Las Vegas Wash and Duck Creek in the southeast central portion of the study area.

Distinction between fine sands, silts and clays was difficult because they are generally intermixed in primary deposition and/or by secondary eolian processes mentioned above. Several attempts were made by the Nevada Bureau of Mines to quantitavely characterize this fine fraction by sieving analysis; however, the high pulverulent sulfate and calcareous content could not be dissolved thus precluding separation of the fine fraction (personal communications, E. Bingler, Nevada Bureau of Mines, Reno, Nevada). Therefore, size determinations used for description of map units were done in the field using a modified Wentworth scale as listed in Table 2-1. Subjectivity is, therefore, introduced into particle size descriptions, especially in the sand, silt, and clay fractions. Lithologic description of and relationships between various map units and topographic features are presented in Appendix I.

Contacts between units on Plate 1 should be considered approximate because of gradational facies changes generally associated with alluvial-fill stratigraphy and the difficulties discussed above. However, an

Table 2-1. Modified Wentworth Scale (modified from Krumbein and Sloss, 1963, p. 96).

Description	Diameter (inches)
Boulders	10.10
Cobbles	2.50-10.10
Pebbles	0.16-2.50
Coarse sand	0.02-0.16
Medium sand	0.01-0.02
Fine sand	0.002-0.01
Silt	0.0002-0.002
Clay	0.0002

effort was made to separate lithofacies considered to be part of more general units because this detail will probably be concealed by rapid urban sprawl in the next decade. A good example of this "splitting" is the separate designation of basin lowland units Qsc, Qs, Qsm, Qsw, and perhaps Qmg which could all be mapped as one unit by excluding small lithologic and topographic differences discussed in Appendix I.

Core boring logs provided by various engineering firms in Las Vegas were examined to establish lithologic continuity between surficial geology and lithology in the zone of near-surface ground-water saturation. Representative boring logs are presented in Appendix II and boring locations are shown on the geologic map (Plate 1). Agreement between the borings and surficial geology are satisfactory in most cases; however, major deviations sometimes occur in areas where surface water runoff has carried coarser sized materials off alluvial aprons into the basin lowland.

GENERAL STRATIGRAPHY

The alluvial fill can generally be classified as either basin lowland deposits or coalescing alluvial apron materials designated as bajadas. Minor portions of the bajadas may be classified as alluvial fans but the majority of the aprons are more correctly described as pediments on which a veneer of surficial gravels, cobbles, and boulders lie unconformably on erosional surfaces developed on layered sand, silt, and clay units that belong to older basin lowland-type deposits or consolidated alluvial apron gravels. These pedimented aprons are designated as geomorphic surfaces on Plate 1. Their lithologic composition reflects that of the mountains from which they developed (see Appendix I).

Basin lowland deposits consist primarily of intermixed sand, silt, and clay. Some pebble and small cobble horizons are present within the finer sized materials, and several units are distinguished because of their relatively greater abundance of gravels than other basin lowland map units (see units Qgg and Qmg on Plate 1 and in Appendix I).

Although no absolute dates were available, approximate relative age of units within each separate bajada and basin lowland is presented in the map explanation (see Plate 1). These tentative designations were established by topographic and stratigraphic relationships interpreted by this author. Temporal correlation was not attempted among units from the four physiographic subregions of the study area (three separate bajadas and basin lowland) due to lack of sufficient evidence.

Categorization of map units depicted on Plate 1 into lithofacies pertinent to the examination of ground-water quality is discussed next.

LITHOFACIES DESIGNATION

Map units on Plate 1 comprising both the basin lowland and bajadas can be differentiated by drainage and weathering patterns expressed on aerial photographs, size and lithologic composition of clasts, and degree of type of cementing materials and/or salts found in the matrix of the alluvium. To study the relationship between lithology and near-surface ground-water quality the latter criteria involving the mineralogic compositions of both the clasts and matrix material was examined.

Such analyses resulted in dividing the map units on Plate 1 into two general groups, the carbonate lithofacies and the sulfate lithofacies. This categorization of map units involves several subjective decisions discussed below. Most alluvial map units on Plate 1 contain at least some amount of sulfate and carbonate minerals in very local areas. This is the result of alluvial basin-fill and playa-type processes which have been active in Las Vegas Valley since the Pliocene (Longwell, et al. 1965). A source of sulfate in the form of gypsum and anhydrite beds is present in the Kaibab and Toroweap Formations and Permian red beds found in the mountain ranges bording the valley on both the east and west (Longwell, et al. 1965, pp. 152-156). In a similar manner these and other Paleozoic formations in the same mountains and the mountains to the north are comprised of limestone and dolomite which provide carbonate to valley-fill alluvium. Sulfate and carbonate particles may be transported from mountain sources by eolian and fluviatile processes, or sulfate and/or carbonate may be dissolved in surface and ground waters originating in the mountains, discharged to the valley, and evaporated, depositing sulfate and/or carbonate in the alluvium.

Separation of alluvial units into carbonate and sulfate lithofacies becomes difficult in light of the above processes which have intermixed these two components in the valley alluvium. The final decision as to which facies a particular map unit represents is based on the relative overall composition of that unit with respect to sulfate and carbonate and not on local mineralogic variations. Particular emphasis is placed on the relative amounts of sulfate versus carbonate in that portion of the study area where ground water occurs within 50 feet of land surface thereby presenting the opportunity for reacting with lithologies as surficially mapped.

The mineralogic composition of both the clasts and matrix material were examined primarily in hand specimen as they occurred in the field. Several x-ray analyses were performed to confirm hand identification of matrix material, particularly in the basin lowland where particle size is predominantly fine sand, silt, and clay. In addition to field work by this author, the soils map developed by Langan, et al. (1967) was consulted with the guidance of U.S. Soil Conservation Service personnel. Lithologic descriptions of over 100 core boring logs were also examined and discussed with soils engineering firms (principally Converse, Davis, Dixon, and Assoc., Las Vegas office) that have been involved with engineering properties of carbonate and sulfate enriched soils and subsurface material in Las Vegas Valley.

From the above investigations several criteria were developed for identifying carbonate and sulfate lithofacies in the study area. The carbonate facies is defined by the presence of ubiquitous calcium carbonate in the form of (1) extensive caliche strata, nodules, and fragments in basin lowland sediments; (2) calcium carbonate spheroids and hardpan developed in fine-grain sediments; and (3) calcium carbonate-cemented boulders and cobbles on bajada units. The sulfate facies is defined by the presence of predominantly calcium sulfates which occur as (1) layered gypsum strata in Muddy Creek Formation on the eastern bajada and (2) selinite crystals and sugary, powdery, and spheroidal gypsum in the sand-silt-clay fractions of both basin lowland deposits and lower portions of bajada units.

The above criteria were used to place the surficial geologic units mapped on Plate 1 into either sulfate or carbonate lithofacies based on overall relative occurrence of sulfate to carbonate in each map unit. The following discussion describes the manner by which the map units were categorized into these two lithofacies. The reader is referred to Plate 1 for locations of the map units and Appendix I for a more detailed lithologic description of each unit.

Map units W1, W2, and W3 on the western bajada were characterized as carbonate facies because they are composed of predominantly limestone - dolomite clasts with calcium carbonate matrix and/or cement.

In the proximal and central portion of the southern bajada, units S1, S3, S4, and S6 are composed of volcanic-rock clasts with calcium carbonate cement (caliche) and, therefore, were placed in the carbonate facies. However, units S2 and Qgcs in the distal portion of this bajada contain considerable quantities of highly gypsiferous silty-sandy matrix both on their surfaces and in subsurface exposures along railroad cuts and exploration pits. Although calcium carbonate is locally present in the form of caliche fragments lying on the surface, these two units are categorized as sulfate facies because of the large quantity of gypsiferous matrix material particularly in the subsurface where it might react with near-surface ground water.

All units on the eastern bajada except unit E3 in the northern portion were designated as sulfate facies. The southern half of this bajada is underlain by the Muddy Creek Formation (Tmc) which contains gypsum strata. This gypsum imparts a sulfate content to the surrounding sediments, especially in the lower portion of the bajada where it meets the basin lowland and where such sediments would be in contact with near-surface ground water. Therefore, these units were ascribed to the sulfate lithofacies.

In the extreme northern portion of the eastern bajada unit E3 is designated as a carbonate facies. Clasts composing this surface are predominantly limestone-dolomite and the matrix as observed on the surface and in gravel quarries apparently has no gypsum.

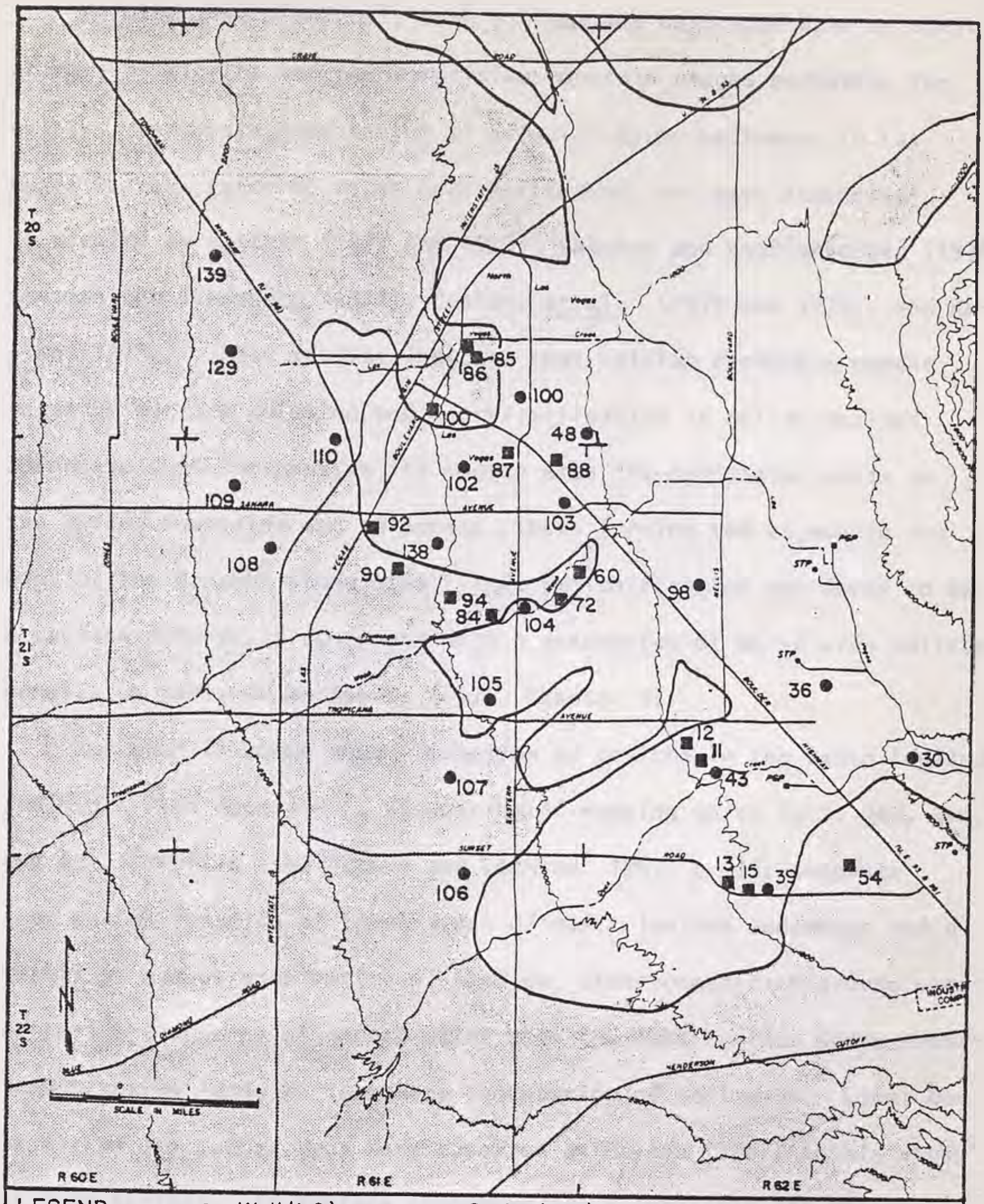
Lithology of map units Qsc, Qs, Qsm, and Qsw in the basin lowland indicates that these units contain abundant calcium carbonate. There are local areas where gypsum is present in unit Qsm particularly in the southwest quarter of the study area. This might be expected due to the source of calcium sulfate in the mountains to the southwest as discussed previously. Also, unit Qsm interfingers with units Qmg and Qals in this portion of the project area and these latter units are characterized by high gypsum composition. However, in general units Qsm, Qsc, Qs, and Qsw are characterized by calcium carbonate more so than sulfate and for this reason these units were placed in the carbonate lithofacies category.

The sulfate lithofacies in the basin lowland is represented by unit Qgcs, discussed previously in conjunction with the southern bajada units, and units Qgg, Qmg, and Qals. Of these units only the sulfate classification of units Qals is tenuous, the others having abundant gypsum relative to carbonate both on the surface and at depth. Unit Qals occupies approximately one-third the map area and consequently varies in lithology. It has associated with it thin discontinuous limestone-dolomite gravel strata and occasional caliche horizons.

However, the surface of this unit commonly contains sulfate salts and core boring logs in the central and east central portions of the map area -- where the ground water is within 50 feet of land surface -- also indicate the presence of sulfate at shallow depths in unit Qals (see Appendix II, core boring numbers 6, 9, and 17). For these reasons unit Qals was placed with units Qgcs, Qgg, and Qmg in the sulfate lithofacies category.

The map units discussed above were combined into the appropriate facies to construct a lithofacies map of the study area as shown in Figure 2-1. The facies boundary line was drawn on contact lines where carbonate lithofacies units abut sulfate lithofacies units. In reality these lithofacies boundaries should not necessarily reflect unit contacts due to the gradational nature of alluvial sediments and the subjectivity of lithofacies designation discussed previously. If examined in close detail these boundaries as presented in Figure 2-1 might be in error; however, they are believed adequate for this broad areal study of the valley.

Carbonate and sulfate minerals used to differentiate the two lithofacies are of secondary origin. This brings to question the processes responsible for the development of these lithofacies. Integral to the various processes that might be responsible for sulfate and carbonate enrichment of valley fill alluvium is the factor of time. In this regard, little detail is known about the erosional and depositional sedimentary environments of the study area during and since late Tertiary time. Similar ambiguity exists concerning the history of hydrogeologic parameters such as quantity and quality of both surface and ground water which play important roles in development of secondary minerals.



LEGEND: ● - Well(LG) ■ - Spring(LW)

Carbonate Facies - ▨

Qsw W1 S1 E2
Qsm W2 S3 E3
Qs W3 S4 E4
Qsc Qalg

Sulfate Facies - ☐

Qals Qgcs S2
Qmg Tmc E1
Qgg

See Appendix I for detailed descriptions of these map units.

Figure 2-1. Areal Distribution of Carbonate and Sulfate Lithofacies.

As discussed previously both sulfate and carbonate have as their primary origin the bedrock comprising mountain ranges bordering the valley. Carbonate cementation of alluvial apron sediments in Las Vegas Valley, referred to as calichification, has been extensively studied by Lattman (1971 and 1973), Lattman and Lauffenburger (1974), Lattman and Simenberg (1971), Cooley, et al. (1973 and 1974), and Kaplan (1973). These studies indicate that calcium carbonate cement forms by surface solution and recrystallization of eolian derived carbonate dust that has as its source area the carbonates units in the Spring Mountains and carbonate clasts forming the bajada to the west of the present study area. That calichification was found to be a surface process is consonant with a discussion of world wide caliche genesis as reviewed by Reeves (1976, Chapter 4).

Not much is known about formation of caliche in the basin lowland sediments (see Appendix I, discussion of mapping units Qgcs, Qsw, Qsm, and Qs). Mifflin (see Orcutt and Cochran, 1967, p. 15) suggests that calichification of these types of basin lowland sediments are a result of evapotranspiration of shallow, bicarbonate-rich ground water or spring discharge of ground water onto the land surface where evapotranspiration leads to carbonate cementation of sediments. Local deposits of the latter type were reported by Haynes (1967) in his study at Tule Springs. If surface phenomena are responsible for calichification of alluvium as reported by Reeves (1976) and by the studies in Las Vegas Valley, the carbonate indurated sediments encountered in core borings (see Appendix II) and reported in drillers' well logs at depth in the presently designated carbonate lithofacies must have originated at the surface and have been subsequently buried during periods of sediment aggradation.

The processes of sulfate enrichment in valley-fill alluvium of Las Vegas Valley are not known in detail. General information concerning sulfate enrichment as evaporite deposits in playa environments is discussed by Krauskopf (1967) and Lamey (1966). The sulfate lithofacies delineated in the study area (see Appendix I for a detailed description of map units and Plate 1 and Figure 2-1 for locations) are located in the eastern portion of the valley where a source of gypsum is readily available in the Kaibab and Toroweap Formations and Permian red beds which comprise parts of the bordering Sunrise and Frenchman Mountains (Longwell, et al. 1965). Eolian deposition, ponding of surface runoff, and ground-water discharge from this source area are probably responsible for secondary sulfate enrichment through evaporation processes similar to calichification.

Gypsum is reported at depths from three to seven feet below the basin lowland surface (see Appendix II core borings 5, 6, and 9), and this may indicate burial of gypsiferous surface sediments. That sulfate salt strata are infrequently reported in core boring logs and drillers' well logs at depth in the designated sulfate lithofacies may be due to several reasons: (1) sulfates offer no extraordinary resistence to drilling as does caliche and, therefore, go unnoticed; (2) sulfate crystals are easily broken up during the drilling process and not readily recognized when incorporated with drilling fluids; (3) ground water may dissolve buried strata; (4) only thin strata of sulfate salts were deposited in the basin lowland; or (5) any combination of the above. Well logs reported by Maxey and Jameson (1946) occasionally reference lithologic materials below 25 feet in depth in the southeastern part of the study area which may be strata of sulfate salts (for example see the Splane well log, page 116, where "talc" and "gypsite" are reported; and the Stadelman well log, page 118, where "gypsum" is reported).

Chapter 3

NEAR-SURFACE GROUND WATER

INTRODUCTION

To distinguish what effect the previously defined carbonate and sulfate lithofacies have on natural near surface ground water quality, the origin and chemical composition of this ground water must be defined. This chapter discusses (1) the origin of near-surface ground water, (2) selection of data points used to portray near-surface ground-water quality, (3) statistical distribution of water-quality data, (4) water-quality differences between wells and springs, and (5) variation between location of well and spring sampling points.

Development of these topics in this chapter permits the characterization of natural ground-water quality and clarification of the relationship between hydrochemical facies and lithofacies in Chapter 4.

HYDROLOGY

General Hydrology

Maxey and Jameson (1948) and Malmberg (1965) reported that ground water in the near-surface zone (zero to approximately 200 feet deep) is generally unconfined. However, they noted that confined/semiconfined conditions exist in local areas principally in the northwest central portion of the study area where alternating strata of caliche, gravels, and sand and silt occur. Evidence of confinement of near-surface ground water (ground water within 50 feet of land surface as defined here) was also reported by the Nevada Department of Highways when conducting core boring operations in this same area during 1972 along Las Vegas Expressway east of Valley View Road, section 30, T20S-R61E (personal communication, D. Cochran, Laboratory Testing Division, Nevada Department of Highways). However, well logs, core boring logs, and engineering reports examined by this author indicate that the major portion of near-surface ground water examined in the present study is primarily unconfined except in the area noted above.

Plate 2 is a hydraulic potential map of the near-surface aquifer developed by the present author and modified by others for the Kaufmann (1976) study. Due to the lack of concomitant near-surface ground-water data, this map actually represents a composite hydraulic potential surface for two reasons: (1) water-level data from a three year span (1971 to 1973) were used, and (2) water levels from wells and core borings of different depths were used to construct the potential surface. In addition, heavy pumping from deeper aquifers in the Las Vegas Valley Water District (LVVWD) well field (principally in sections 31 and 32, T205-R613) has produced a cone of depression in the near-surface ground water at this location.

The hydraulic potential map is pertinent to the present study because it indicates an approximate natural lateral flow direction, excluding the local area around LVVWD well field, for near-surface ground water, and it defines an approximate boundary for ground water within 50 feet of land surface -- that ground water of specific interest to this study.

Source of Near-Surface Ground Water

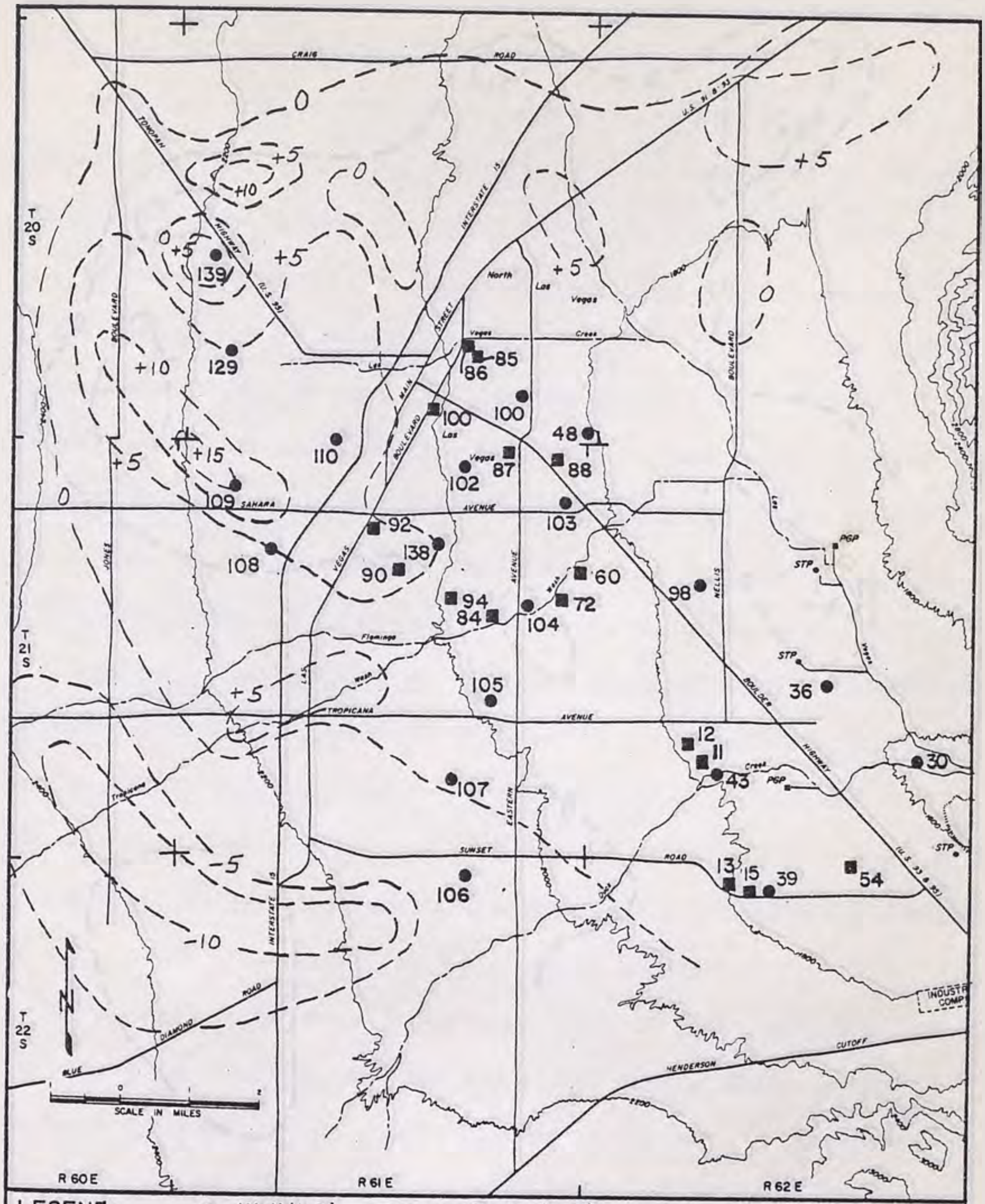
It is important to establish the origin of near-surface ground water if its chemical composition is to be related to surficial alluvial lithologies. There are several possible sources of recharge to the near-surface ground water: (1) precipitation occurring in the valley, (2) upward movement of ground water from deeper aquifers, and/or (3) surface return flows from municipal water supplies originating from both deep ground water and imported Colorado River water,

The arid climate of Las Vegas Valley generally yields less than five inches of annual precipitation and has approximately 80 inches of potential evaporation (see Chapter 1, Table 1-1). Major recharge to the near-surface ground water, then, must occur by means other than direct infiltration of precipitation in the valley although infiltration of water derived from thunder storms and transported in the washes may occur to some extent. In light of the valley's arid climate, upward movement of artesian ground water is most likely responsible for major natural recharge to near-surface ground water.

Recharge from deep aquifers. Maxey and Jameson (1948) and Malmberg (1965) indicated that approximately 20,000-30,000 AF of water recharge the ground-water reservoir in the valley. According to these investigators, principal recharge most likely originates as precipitation in the Spring and Sheep Mountains which border the valley on the west and north respectively. This precipitation recharges ground water which then is transmitted from aquifers within the mountain ranges to coarse alluvial fill materials forming the bajadas and subsequently into the basin lowland where it is discharged by pumping, natural discharge from springs, and evapotranspiration by vegetation,

Maxey and Jameson (1948) and Malmberg (1965) discuss several lines of evidence which indicate that the near-surface aquifier is hydraulically connected to deeper artesian aquifers. Evidence cited for upward movement of ground water in the valley includes the presence of many natural springs and flowing artesian wells at the turn of this century and the presence of large spring mounds in the northwest central portion of the study area (see Plate 1). The latter features suggest that this recharge process occurred during and since Pleistocene time (Haynes, 1967). Maxey and Jameson (1948, pp. 86-88) also noted that in 1945 and 1946 declines in water levels of shallow wells followed periods of heavy pumping from deeper artesian aquifers which indicated interconnection between the two zones. Malmberg (1965) concurred with Maxey and Jameson (1948) suggesting that springs and associated phreatophytes indicate upward leakage of ground water from deeper aquifers to the near-surface zone along fault scarps and between semiconfining strata (Malmberg, 1965, pp. 65, 68, and 78).

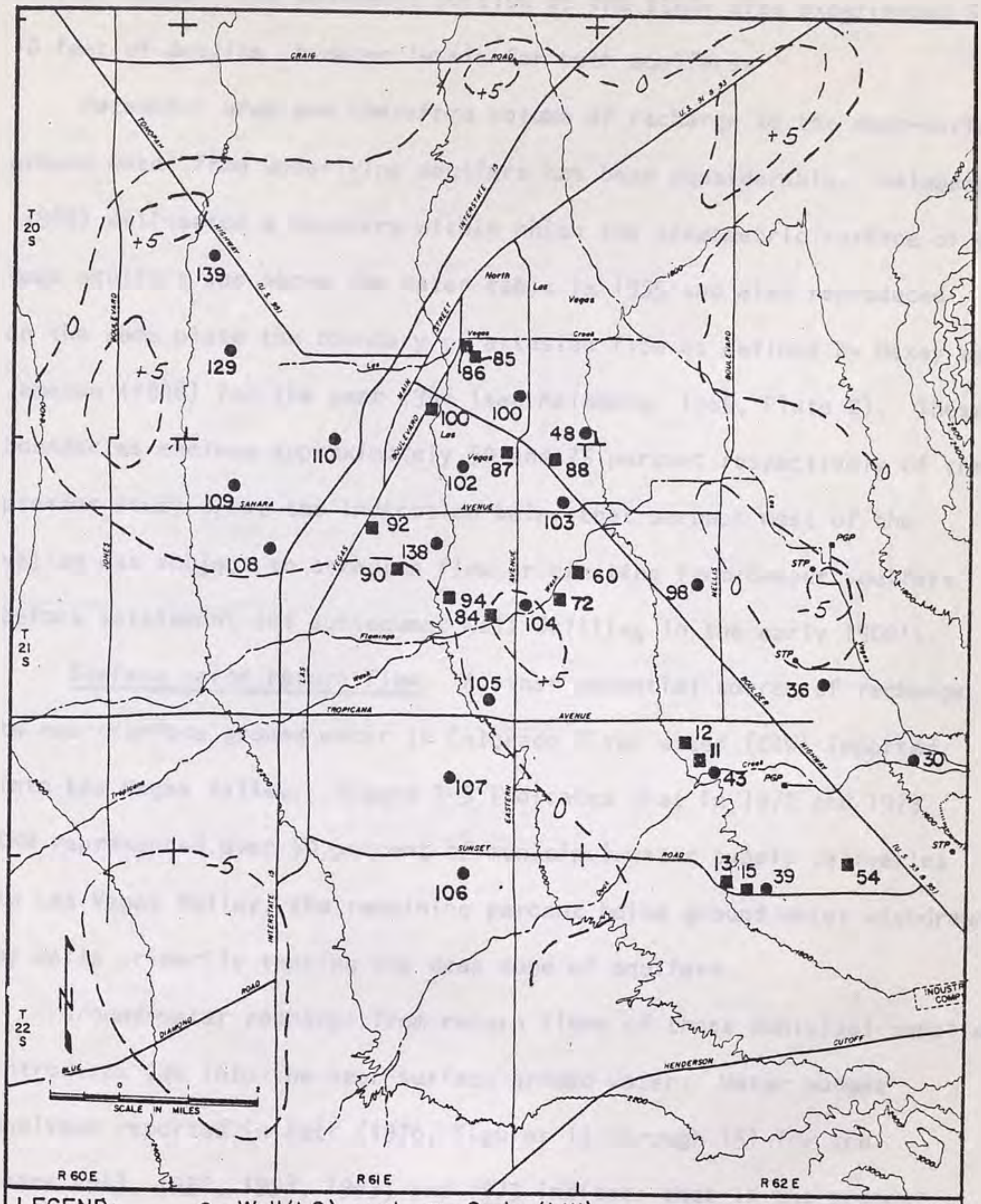
Additional evidence of this hydraulic interconnection was interpreted by the present author from Figures 3-1 and 3-2 (adapted from Harrill, 1973, Figures 6 and 10). Figure 3-1 indicates the net change in water levels between February 1972 and February 1973 in wells that penetrate the principal (deep) aquifers, Figure 3-2 shows, for the same period, the net change in water levels in wells that penetrate only the near-surface reservoir defined by Harrill as those wells which penetrate no deeper than 100 ft below the water table. These figures imply that in the west central portion of the valley both aquifers underwent a general rise in water levels that suggests hydraulic connection. In a



LEGEND: ● - Well(LG) and ■ - Spring(LW) used in present study.

\- - - = Net change in water levels (ft) between February 1972 and February 1973 (after Harrill, 1973).

Figure 3-1. Net Change in Water Levels for Wells Penetrating Deep Aquifers.



LEGEND: ● - Well(LG) and ■ - Spring(LW) used in present study.

\- - - = Net change in water levels (ft) between February 1972 and February 1973 (after Harrill, 1973).

Figure 3-2. Net Change in Water Levels for Wells Penetrating the Near-Surface Reservoir.

similar manner, the southwest portion of the study area experienced 5 to 10 feet of decline in water levels for both aquifers.

Potential area and therefore volume of recharge to the near-surface ground water from underlying aquifers has been considerable. Malmberg (1965) delineated a boundary within which the piezometric surface of the deep aquifers was above the water table in 1955 and also reproduced on the same plate the boundary of artesian flow as defined by Maxey and Jameson (1948) for the year 1946 (see Malmberg, 1965, Plate 2). These boundaries enclose approximately 50 and 75 percent respectively of the present study area, the indication being that perhaps most of the valley was subject to artesian flow originating from deeper aquifers before settlement and subsequent well drilling in the early 1900's.

Surface water return flow. Another potential source of recharge to near-surface ground water is Colorado River water (CRW) imported into Las Vegas Valley. Figure 3-3 indicates that in 1972 and 1973 CRW represented over 50 percent of municipal water supply deliveries to Las Vegas Valley, the remaining percent being ground water withdrawn by wells primarily tapping the deep zone of aquifers.

Ground-water recharge from return flows of these municipal supplies introduces CRW into the near-surface ground water. Water budget analyses reported in Patt (1976, Figures 11 through 15) for the years 1943, 1950, 1958, 1965, and 1973 indicate that in the present study area this recharge, ranging from 21 to 32 percent of water delivered for the years above, took place in the form of lawn watering, golf course irrigation, agricultural irrigation, septic tank effluent, and liquid waste discharge from Basic Management Industries (BMI).

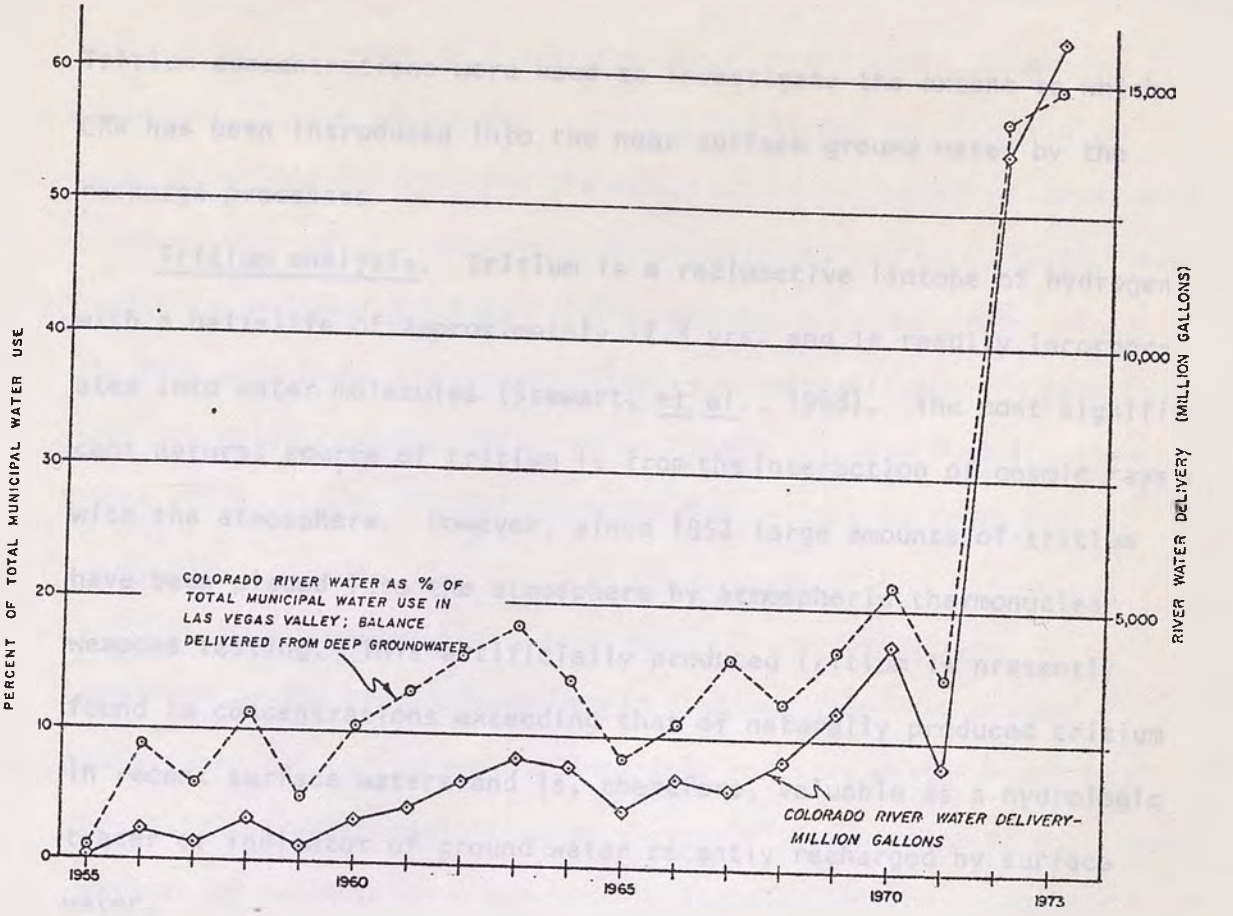


Figure 3-3. Colorado River Water Deliveries to Las Vegas Valley (after Kaufmann, 1976).

Tritium concentrations were used to investigate the extent to which CRW has been introduced into the near-surface ground water by the recharge processes.

Tritium analysis. Tritium is a radioactive isotope of hydrogen with a half-life of approximately 12.3 yrs. and is readily incorporated into water molecules (Stewart, et al., 1968). The most significant natural source of tritium is from the interaction of cosmic rays with the atmosphere. However, since 1952 large amounts of tritium have been placed into the atmosphere by atmospheric thermonuclear weapons testing. This artificially produced tritium is presently found in concentrations exceeding that of naturally produced tritium in recent surface waters and is, therefore, valuable as a hydrologic tracer or indicator of ground water recently recharged by surface water.

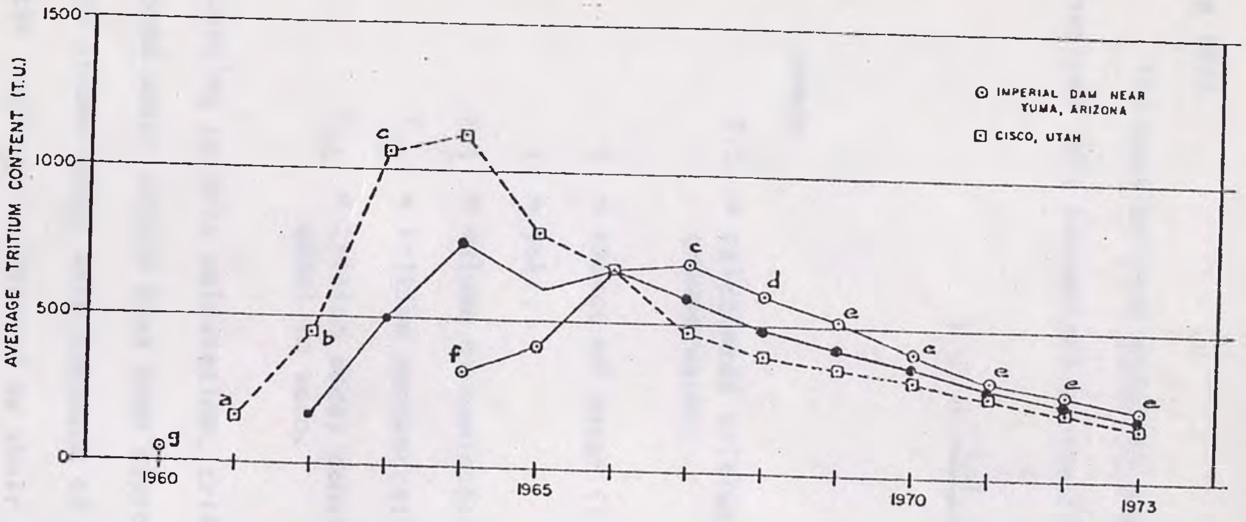
Tritium concentration is usually reported in tritium units where a tritium unit (T.U.) is defined as being equal to one tritium atom in 10^{18} protium atoms (protium is a hydrogen atom with an atomic mass of 1 while tritium is a hydrogen atom with an atomic mass of 3).

To examine the role that imported CRW might play in recharge to near-surface ground water a simple mass balance model of tritium concentration was calculated. Several basic assumptions were made for this model: (1) near-surface ground water is composed only of a mixture of deep ground water and CRW recharged to near-surface ground water by methods previously mentioned; (2) deep ground water has a fixed background tritium concentration of approximately 5 T.U. (Kaufmann, 1976, reports an average of 4.6 T.U. for deep ground water);

(3) annual recharge to the near-surface ground water is assumed constant for the eleven year period under study; and (4) tritium concentrations for imported CRW water can be estimated as the straight line average of tritium concentration measured in CRW at Cisco, Utah, and Yuma, Arizona (Kaufmann, 1976) upstream and downstream respectively from Lake Mead (tritium analyses were not available for Lake Mead, the source of imported CRW water). Figure 3-4, modified from Kaufmann (1976, Figure 51) indicates the T.U. values at these monitor stations.

It is recognized that the model is an approximation. In addition to the above assumptions it does not take into account water used for irrigation obtained from domestic wells (about 6,900 AF in 1973), which would tend to dilute tritium concentration, the effects of evaporation which tend to increase tritium due to its lower vapor pressure (Wahl and Urey, 1935), the effects of transpiration which have been reported to increase tritium levels (Hem, 1959), nor the effects of tritium adsorption to fine-grained particles which would decrease tritium concentrations in the waters. The quantitative effects of the above mechanisms are not known but are assumed to be self-compensating for the simple model presented.

Input to the model consisted of eleven years of municipal water delivery data (see Figure 3-3) and tritium concentration in this water (see Figure 3-4) from 1962 through 1972. This time period encompasses the highest measured tritium concentrations in CRW (the year 1964: see Figure 3-4). Calculations indicated that tritium input from recharge in the valley pre-1962 would be



a) Samples collected only in September and October
b) Samples collected only in August
c) Average of 9 monthly samples
d) Average of 10 monthly samples
e) Average of 11 monthly samples
f) Sample collected only in November
g) Concentration in water delivered to Southern California in February 1960 (Libby, 1961)

●——● = Estimated tritium content at Lake Mead

Figure 3-4. Average Annual Tritium Content in Colorado River Water (modified after Kaufmann, 1976).

negligible because of (1) tritium's relatively short half-life (approximately 12.3 years; Stewart, et al., 1968) and (2) the relatively small volume of water imported into the valley before this time (see Figure 3-3). The 1962 value represents only 0.7 T.U. when corrected to 1973.

The mass balance model is presented in Table 3-1, and calculations involved are summarized by the following equation:

$$T.U. = \frac{\sum_{i=1}^{2} \sum_{j=1962}^{1972} V_{ij} T_{ij} e^{-\lambda_{ij}(1973-j)}}{\sum_{i=1}^{2} \sum_{j=1962}^{1972} V_{ij}},$$

where

T.U. = calculated tritium concentration in near-surface ground water.

i = source of water (1 = CRW, 2 = deep ground water),

j = year,

V_{ij} = volume of municipal water delivered, AF,

T_{ij} = tritium concentration, T.U., and

λ_{ij} = tritium decay constant; $\lambda_{1j} = 0.0564$, λ_{2j} assumed equal to zero.

According to this calculation, tritium concentration in near-surface ground water should have been approximately 64 T.U. in early 1973 if this ground water were composed of a mixture of CRW and deep ground-water recharge as defined by their relative delivery volumes from 1962 to 1972.

To examine whether or not CRW contributed to ground-water recharge is as prescribed above, the mass balance T.U. value was compared to

Table 3-1. Mass Balance Model for Tritium Units (T.U.) in Near-Surface Ground Water.

Year	1[a]	2[b]	3	4	5	6	7[c]	8	9[d]	10	11
1962	.065	175	11.4	6.1	.935	5	4.7	10.8	31179.6	0.061	0.7
1963	.085	500	42.5	24.2	.915	5	4.6	28.8	35263.5	0.070	2.0
1964	.080	750	60.0	36.1	.920	5	4.6	40.7	42344.8	0.084	3.4
1965	.090	625	56.3	35.8	.910	5	4.6	40.4	40632.3	0.080	3.2
1966	.110	650	71.5	48.2	.890	5	4.5	52.7	48840.9	0.096	5.1
1967	.165	625	103.1	73.5	.835	5	4.2	77.7	28781.3	0.057	4.4
1968	.130	500	65.0	49.0	.870	5	4.4	53.4	52190.0	0.103	5.5
1969	.170	450	76.5	61.0	.830	5	4.2	65.2	54176.4	0.107	7.0
1970	.225	375	84.4	71.3	.775	5	3.9	75.2	59306.8	0.117	8.8
1971	.155	300	46.5	41.5	.845	5	4.2	45.7	40933.0	0.080	3.7
1972	.575	250	143.8	135.9	.425	5	2.1	138	73383.7	0.145	20.0

Calculated tritium concentration in near-surface ground water at the beginning of 1973 = 63.8 T.U.

1[a] = Percentage of Colorado River Water delivered to Las Vegas Valley by municipalities.

2[b] = Estimated Colorado River Water T.U.
(continued)

Table 3-1., continued

3 = Weighted T.U. input to Valley from Colorado River water: col 1 x col 2.

4 = Corrected T.U. to 1973 using $N = N_o e^{-\lambda t}$.

5 = Fraction of well water used: 1.000 - col 1.

6 = Well water T.U.

7[c] = Weighted T.U. input to Valley from deep well water: col 5 x col 6.

8 = Weighted sum of T.U.: col 5 x col 7.

9[d] = Total water delivered (AF).

10 = Total composition weight factor: col 9/Total water delivered from 1962 through 1972.

11 = T.U. concentration for a particular year adjusted by percent of total water delivered for the eleven year period: col 8 x col 10.

a. Kaufmann, Figure 54 (1976).

b. Kaufmann, Figure 51 (1976).

c. No correction for year made on well waters as they were assumed to be in natural equilibrium at 5.0 T.U.

d. This excludes Henderson, BMI surface deliveries, domestic wells in Las Vegas Valley and Nellis Air Force Base wells. The Henderson and BMI areas are outside the present study area and domestic wells in Las Vegas Valley combined with Nellis Air Force Base wells pump a small percentage of total water delivered (7% in 1973, 6% in 1965, 7% in 1958 as examples).

average T.U. concentration measured in near-surface ground water in 1973. Table 3-2 lists tritium concentrations collected from near-surface ground water for the Kaufmann study (1976, see Appendix 1). In order to calculate a meaningful average, all T.U. values measured (see Plate 3 for location of samples) prior to 1973 and above natural background levels (assumed to be 10 T.U. or less according to Stewart, et al. 1968) were adjusted to 1973 levels by the following equation:

$$N = N_o e^{-\lambda t} ,$$

where

N = T.U. value corrected to 1973,

N_o = original T.U. value at year measured,

λ = decay constant $\simeq 0.0564$, and

t = number of years between time of measurement and 1973 taken as nearest whole year.

In addition, data points containing low T.U. values (T.U.< 5.0) were not considered in the average. Such low values indicate very direct and recent recharge to the near-surface ground water from deeper aquifer. In a similar manner, data points indicative of very recent recharge by CRW (T.U.> 90) were eliminated for averaging purpose. Such T.U. levels were thought by this author to be isolated concentrations which could not be laterally extended and, therefore, did not represent extensive areal recharge conditions to near-surface ground water. Applying these criteria to the data listed in Table 3-2, the average tritium concentration for near-surface ground water in 1973 was approximately 25 T.U.

Table 3-2. Tritium Values for Near - Surface Ground Water from Wells (LG) and Springs (LW). Modified from Kaufmann, 1976. See Plate 3 for location.

Station	T.U. Value	Analysis Date	Remarks
LG041	4.2 ± 0.3	9-30-71	67' piezometer in flood plain.
LG043	2.9 ± 0.3	9-30-71	Whitney Mesa. Dead water.
LG048	4.2 ± 0.3	6-09-71	West side of scarp, crossing E. Charleston Blvd. Dead water.
LG050	212 ± 9 *189	May-June 71 May-June 73	Shallow ground water north of B.M.I. Discussed in "Lower Wash" section.
LG098	17.0 ± 0.8	6-14-73	Shallow ground water next to development using Colorado River water.
LG099	24.7 ± 1.1	6-14-73	Shallow ground water beneath Winterwood Golf Course.
LG100	30.9 ± 1.3	6-14-73	Shallow ground water adjacent to an older development (residential).
LG101	166 ± 7	6-14-73	Shallow ground water adjacent to residential area served by Colorado River water.
LG102	53.0 ± 2.1	6-14-73	Shallow ground water seeping from scarp face.
LG103	45.0 ± 1.8	6-14-73	Shallow ground water occurring in zone of high permeability - a buried wash?
LG105	79.1 ± 3.2	6-14-73	Shallow ground water adjacent to residential area using Colorado River water.
LG107	36.0 ± 1.4	6-14-73	Shallow ground water adjacent to residential area using Colorado River water.
LG108	16.4 ± 0.8	6-14-73	Shallow ground water adjacent to residential area using Colorado River water.

(continued)

Table 3-2., continued

Station	T.U. Value	Analysis Date	Remarks
LG110	16.3 ± 0.7	10-21-71	Shallow ground water beneath old residential area served by local ground water.
LG128	100.9 ± 4.1	6-14-73	Shallow dewatering well, LDS farm.
LG129	38.8 ± 1.6	6-14-73	Shallow ground water adjacent to residential area served by deep ground water.
LW011	5.5 ± 0.4	9-30-71	Seepage north of Whitney Mesa.
LW012	2.9 ± 0.3	9-30-71	Grapevine Springs.
LW015	28.7 ± 3.3 *25.6	9-30-71 9-30-71	Seepage beneath Sunset Road, Whitney Mesa.
LW033	11.7 ± 0.5	4-23-73	Shallow ground water extreme east end of Tropicana Avenue.
LW060	23.7 ± 1.7 21.2	9-30-71 9-30-73	Spring discharge into Flamingo Wash.
LW084	35.6 ± 1.6	4-23-73	Tile field beneath Stardust Country Club.
LW085	22.6 ± 0.9	4-23-73	Underdrain beneath 15th Street.
LW086	13.3 ± 0.6	4-23-73	Underdrain Maryland Parkway & Harris.
LW087	98.9 ± 4.0	4-23-73	Underdrain Eastern & Ballard.
LW088	41.1 ± 1.6	4-23-73	Underdrain Montgomery Wards.
LW089	125 ± 5	4-23-73	Underdrain El Cortez parking lot.
LW090	25.4 ± 1.0	4-23-73	Underdrain Convention Center.
LW091	188 ± 7	4-23-73	Elevator shaft Dunes Hotel.

(continued)

Table 3-2, continued

Station	T.U. Value	Analysis Date	Remarks
LW092	21.1 ± 1.0	4-23-73	Beneath Sahara Hotel.
LW094	91.8 ± 3.6	4-23-73	Basement of Sears Roebuck Department Store.
LW096	38.3 ± 1.7	4-23-73	Seepage UPRR at Bonanza Road.

Average T.U. values disregarding data points with suggested recent recharge by CWR (T.U. > 90), and deep well water (T.U. < 5) is 25.3 with a standard error of 12.9.

* All values corrected to 1973 by using the equation $N = N_o e^{-\lambda t}$ where,

N = T.U. value corrected to 1973.

N_o = original T.U. value at year measured.

λ = decay constant ≃ 0.0564.

t = number of years between time of measurement and 1973 taken as nearest whole year for this study.

Two interpretations of this average value can be made, both of which suggest that near-surface ground water did not contain large volumes of imported CRW as of 1973. Comparison of the average tritium concentration with the mass balance calculation of 64 T.U. indicates that CRW represents a smaller component of near-surface ground water than predicted by the mass balance model. On the other hand, the average value of 25 T.U. may represent natural equilibrium between near-surface ground water and atmospheric tritium present in precipitation. Kaufmann (1976) presented evidence supporting the contention that infrequent precipitation and subsequent infiltration in Las Vegas Valley may produce tritium levels of approximately 22 to 36 T.U. with concentrations reaching as high as 55 T.U. The average value of 25 T.U. for near-surface ground water calculated here is within the range suggested by Kaufmann (1976). With either of the above interpretations the fact remains that the average tritium concentration is less than half that calculated by the mass balance model and, therefore, CRW did not represent a major portion of the near-surface ground water as of 1973.

Water quality ratios. Table 3-3 was prepared to examine the relation among average water quality of potential sources of recharge and near-surface ground water. Ratios of sulfate to chloride (SO_4:Cl) and calcium to magnesium (Ca:Mg) were computed in an effort to quantitively assess similarities between waters. The Ca:Mg ratio was used because sodium and potassium values were reported as summed values for shallow ground water (source 2) and CRW (source 5) and, therefore, should not be used for quantitative comparison (Hem, 1970,

Table 3-3. Average Chemical Composition of Near-Surface Ground Water and Potential Sources of Recharge. Quantities reported in mg/l.

Source	pH	HCO_3^-	Cl	SO_4^{2-} ($SO4:Cl$)	NO_3^-	Na^+	K^+	Ca^{2+}	Mg^{2+} ($Ca:Mg$)	NH_4^+	TDS	Ave. depth of screened interval
1.	7.58	242	311	1569 (5.00)	13.5	262	34	303	212 (1.42)	0.43	2824	--------- 0-50
2.	----	120	45	267 (5.88)	3.18	35 *		89	55 (1.62)	----	640	--------- 101-300
3.	----	237	9	47 (5.26)	2.3	12	2	40	35 (1.14)	----	295	457
4.	----	219	6	36 (6.25)	1.8	12	2	46	26 (1.77)	----	265	942
5.	8.1	128	88	310 (3.57)	1.59	105*		85	28 (3.03)	0.00	737	--------

1. Near-surface ground water (0-50 feet deep): average of 35 samples representing natural ground water listed in Appendix III.

2. Shallow ground water (101-300 feet deep): average of 250 samples reported by Kaufmann (1976, Appendix 3).

3. Deep ground water: average of 3 samples taken from screened interval average depth of 457 feet.

4. Deep ground water: average of 6 samples taken from screened interval with average depth of 942 feet reported by the city of North Las Vegas, 1973.

5. Colorado River Water: average of 4 samples taken by Las Vegas Valley Water District, 1973.

* Reported as $Na^+ + K^+$.

p. 234). The SO_4:Cl ratio was selected because sulfate is the most abundant ion in near-surface ground water and chloride generally exhibits rather subdued behavior with respect to its chemical interaction with other major ions (Hem, 1970, p. 172).

Examination of these ratios reported in Table 3-3 emphasizes the chemical similarity between near-surface ground water and underlying ground water in deeper aquifer zones although individual ion concentrations and TDS are slightly different. In addition, it is to be noted that CRW appears to be the most dissimilar of the possible sources of recharge.

Summary. In general, near-surface ground water is primarily composed of recharge from deeper aquifers. Maxey and Jameson (1948) and Malmberg (1965) cited evidence of hydraulic connection between the near-surface ground-water zone and these deeper aquifers, and Malmberg (1965) indicated that the area and, therefore, potential volume of recharge is extensive in the valley. Interpretation by the present author of reflected fluctuations in ground-water potentials of deep and shallow aquifers from data presented by Harrill (1973) support the above investigations. Comparison of average tritium concentrations with a simple mass balance calculation indicates that CRW did not comprise a large portion of recharge to near-surface ground water as of 1973. This might be expected in light of the small percentage CRW represents of total water delivered to the valley prior to 1972. Comparison of SO_4:Cl and Ca:Mg ratios also indicate that upward movement of ground water from deeper aquifer zones is the major source of recharge to near-surface ground water.

HYDROCHEMISTRY

Introduction

To study the natural relationship between lithofacies and hydrochemical facies, sampling points for water chemistry must represent natural near-surface ground water. As discussed in the previous section, near-surface ground water has as its principal source recharge from deeper ground water, but several local areas in Las Vegas Valley have experienced recent return flows of CRW as indicated by high tritium concentrations (see Table 3-2), and several areas of the valley have been irrigated with secondarily treated sewage effluent. Near-surface ground-water chemistry data were primarily examined with respect to dissolved concentrations of (1) nutrients (nitrate, phosphate, and ammonium), (2) total dissolved solids, and (3) tritium to eliminate from the data base sampling points thought to be monitoring return flows.

Ground water quality data used for this investigation were collected by Desert Research Institute personnel, including this author, and chemically analysed by the Desert Research Institute laboratory in Boulder City, Nevada, for the Kaufmann (1976) study. Appendix III contains chemical analyses from springs (denoted by the symbol LW) and wells (denoted by the symbol LG) up to and including 50 feet in depth. Ground-water data reported in Appendix III are type of sample, date of collection, laboratory number, field temperature (^{o}C), and laboratory analyses of the following: specific electrical conductance (μ); pH; total alkalinity reported as bicarbonate (HCO_3^-); chloride (Cl^-); sulfate (SO_4^{2-});

total phosphate reported as orthophosphate (PO_4^{3-}); nitrate (NO_3^-); sodium (Na^+); potassium (K^+); calcium (Ca^{2+}); magnesium (Mg^{2+}); ammonium (NH_4^+); fluoride (F^-); and total dissolved solids (TDS) by summation. All constituents are reported in milligrams per liter (mg/l). Each analysis used in this study has a cation:anion ratio of between 0.9 and 1.1 suggesting only small analytical errors are incorporated into the data base.

Springs include both natural ground-water discharge at land surface and ground water intercepted by building foundations such as sample point LW092 collected from a basement drain in the Sahara Hotel. For such "drain samples" care was taken to collect ground water thought to represent recent seepage and had, therefore, not been ponded in the foundation for appreciable time (personal communication, R. Kaufmann, E.P.A., Las Vegas office).

To minimize the possibility that near surface ground water quality might change with time, most water-chemistry data used in the following analyses were collected between January and early May 1973. However, several 1971-1972 samples were also incorporated into the data base because 1973 data were sparse in particular geographic areas. When these earlier data were used an effort was made to establish the chemical behavior of the sample point with time, and a springtime sample was generally selected to correspond to the season during which the 1973 samples were taken. Sample dates marked with an asterisk in Appendix III are those used in Chapter 4 to study the relationship between ground-water quality and lithofacies.

Locations of all sample points considered in this study are indicated on Plate 2.

Delineation of Return Flows

As previously mentioned, recharge to near-surface ground water by return flows has occurred in Las Vegas Valley since 1906 when the first artesian wells were drilled and left uncapped. Ground water was allowed to flow continuously onto the surface from whence it infiltrated into the near-surface ground water (Maxey and Jameson, 1948). For approximately thirty years treated sewage effluent has been spread on the land surface in the eastern portion of the valley to facilitate volume reduction by evaporation and as irrigation to farmlands. In addition, liquid industrial waste from evaporation ponds has infiltrated into the alluvium in the extreme southeast portion of the study area.

To evaluate which sample points and subsequent portions of the near-surface ground water have been substantially modified by return flows, the author examined each point with respect to all reported chemical constituents. Particular emphasis was placed on high tritium concentrations, indicative of the presence of imported CRW, and high concentrations of nitrate, phosphate, and ammonium. These latter three constituents are plant nutrients contained in treated sewage effluent and fertilizer and, therefore, may indicate return flows to near-surface ground water from irrigation practices associated with farmlands and golf courses in Las Vegas Valley. Plate 3 shows the location of the 53 sampling points listed in Appendix III with appropriate nutrient and tritium concentrations.

Although the three nutrients above are associated with sewage effluent and fertilizer applied to crops and grasses in the valley, interpretation of the data presented on Plate 3 is difficult due to the lack of understanding of nutrient behavior in nature. George and Hastings (1951) reported that nitrate levels up to 10 milligrams per liter (mg/l) indicate natural ground water whereas values above 20 mg/l are considered abnormal. They point out that nitrate values exhibit a seasonal fluctuation but, whereas most investigations report high values in winter months and lower values in the summer, other studies indicate the reverse is true. Additionally, Rainwater and Thatcher (1960) suggest that if rising nitrate levels indicate contamination of waters by sewage effluent there should be a concomitant increase in chloride, and such relations are not always found. Hem (1970) and Feth (1966) reviewed the sources of nitrate in ground water and elucidated the complex relation among nitrates, vegetation nutrition, soil bacteria, and other microbiota. Hem (1970) suggested that because these chemical constituents are plant nutrients, they can be removed by plants and other microorganisms from water and fixed in both soil and the plants themselves. Thus, their concentrations in most ground water are only a few tenths or hundredths of a mg/l. Concentrations of these nutrients in ground water may also fluctuate due to fixation based on seasonal metabolic activity of plants.

Interpretation of nitrate data with regard to return flows in Las Vegas Valley becomes even more difficult when examined in light of evidence that perhaps natural decomposition of organic material in the alluvial sediments of the valley may produce high concentrations of nitrate available to ground water (Mansfield and Boardman, 1932; Patt and Hess, 1976; Hess and Patt, 1977). Because of these complexities, nutrient data were examined along with other chemical constituents, tritium, and sample-point locations to provide more reliable criteria as to whether or not a particular sample point was influenced by return flows.

Out of the 54 data points tabulated in Appendix III, 19 are thought to be monitoring return flows in near-surface ground water, and were eliminated from the data base for further chemical characterization of ground water. These sample points together with their pertinent chemical characteristics are listed in Table 3-4. The following discussion elaborates on the characteristics of several of the data points listed in this table and on the behavior of nutrient concentrations monitored at several sample points. The reader is referred to Appendix III and Plate 3 for appropriate chemical data and location of sample points in the study area.

High nitrate values are recorded in near-surface ground water in the eastern portion of the valley and the probable sources are apparent. Well LG099 is located on the Winterwood Golf Course which has been using sewage effluent since 1948 to water fairways and greens. Phosphate concentration is less than 0.4 mg/l and ammonia nitrogen is 0.3 mg/l. Well LG128 is downgradient from the probable ground-water flow path underlying the Latter Day Saints farm (LDS) which has used sewage effluent for irrigation purposes since 1959. Phosphate in this well is 8.83 mg/l which also indicates that contamination has occurred although no ammonium is reported. In addition, this well also contained a high tritium concentration

Table 3-4. Sample Points Eliminated as Monitoring Return Flows in Near-Surface Ground Water.

Designation	Location[1]	Depth (ft)	Ground-Water Character
LG031	22-62,11,322	62	High Cl, NO_3, and low SO_4. Possible return flow from chemical plant.
LG034	21-62,11,322	35	High TDS, NO_3. Return flow of sewage effluent irrigation from farms in the area.
LG037	21-62,22,241	31	Clark County Sewage Treatment Plant. Inconsistent fluctuations in all chemical constituents.
LG046	21-62,19,111	40	Low chemical concentration. Leakage from Campbell Reservoir.
LG050	21-62,35,441	shallow (?)	High TDS, H^3, Cl. Return flow from BMI effluent.
LG060	21-62,22,224	shallow (?)	High TDS, NO_3, PO_4. Clark County Sewage Treatment Plant monitor well, return flow from sewage effluent irrigation.
LG099	21-62,09,122	26	High TDS, NO_3. Winterwood Country Club, return flow from sewage effluent irrigation.
LG101	21-62,21,314	31	High TDS, NO_3, SO_4, Na, H^3. Billman septic tank waste.
LG128	21-62,15,332	30	High TDS, NO_3,Na,Cl,H^3. LDS farm return flow from sewage effluent irrigation.
LW010	21-61,31,411		TDS fluctuation. Low flow which ceased in 1971.

(continued)

Table 3-4, continued.

Designation	Location[1]	Depth (ft)	Ground-Water Character
LW014	22-62,04,322		Low SO_4. Low flow which ceased in 1971.
LW015	22-62,04,283		NO_3 build-up from 1970-1973. Return flow from Paradise Country Club.
LW033	21-62,22,442		High TDS, NO_3, Cl. Return flow of sewage effluent irrigation.
LW074	21-62,19,111		Low TDS, Na, K, Cl. Leakage from Campbell Reservoir.
LW075	21-62,19,111		Low TDS, Na, K, Cl. Leakage from Campbell Reservoir.
LW089	20-61,34,331		Low TDS, high H^3. Leakage from municipal water supply system.
LW091	21-61,20,114		Low Na, K, Mg, Cl, high H^3. Leakage from municipal water system in Dunes Hotel.
LW096	20-61,27,341		Low Na, K, Cl, SO_4. Unknown surface drainage area.
LW098	20-61,34,211		Low TDS. Unknown surface drainage area.

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1. Location given in Township (south), Range (east), section, and quarter sections.

(128 T.U.) characteristic of CRW return flow. Well LG060 is a shallow well used to dewater the foundation of the Clark County Sewage Treatment Plant (see Plate 3, label C.C.S.T.P.). From January 1972 to February 1973 nine analyses performed on samples from this well indicated nitrate concentrations ranged from 101 to 73 mg/l. Phosphate values ranged from less than 0.04 to 0.28 mg/l, the higher of which, although not necessarily indicating contamination, is above general background levels (approximately 0.10 mg/l). Ammonium levels were a constant 0.2 mg/l in the latter seven analyses from March 2, 1972 through February 1, 1973.

Spring LW033 exhibits high nitrate values for 12 observations between March 1971 and January 1973 (see Appendix III). Its location, down gradient from the above discussed sampling points, suggests that it too is monitoring return flows from the sewage treatment plant. Phosphate is also present above background concentration on nine sampling dates, and a concentration of 2.3 mg/l observed on April 5, 1972 is well above background. Also, ammonium was detected (0.1 mg/l) in the last six observations so that, although tritium concentration was only 25 T.U., this sample point was eliminated from the data base because of elevated nutrient concentrations.

Of the three springs and one well sampled on the southern end of Whitney Mesa (sections 4 and 5, T22S-R62E) only one spring, LW015, has an appreciably elevated concentration of nitrate. All four sampling points are down hydraulic gradient from the Paradise Valley Country Club which uses treated sewage effluent for golf course maintenance and thus it would be expected that more than one sample point would have high nitrate levels. Phosphate concentration at spring LW015 was of background level, and eight separate analyses for ammonium in 1973 reported 0.1 mg/l compared with twenty-five previous samples back to 1970 in which ammonium was not detected. It is not understood whether or not this difference in ammonium concentration is significant.

The disparity in nitrate levels among these sample points is not easily explained. Figure 3-5 is presented to show the temporal variation in nitrate and TDS for sample points LG039, LW013, and LW015. The sampling record for well LW014 was too short to provide any interpretive insight, and because of its erratic TDS increase measured on January 19, 1971 it was eliminated from further consideration. The seasonal nature of nitrate and TDS levels for spring LW013 (see Figure 3-5) indicates possible effects of natural variation in seasonal discharge and nutrient uptake by vegetation. During the summer months higher evaporation rates and increased plant use of water in and around the spring orifice may contribute to an increase in TDS, while nitrogen fixation in soil and plants cause lower nitrate concentration during this active growing period. Nitrate levels are within natural background concentrations (5-10 mg/l; George and Hastings, 1951) with seasonal highs in winter months when plant growth and concomitant nitrate fixation is minimal.

Spring LW015 exhibits a more erratic behavior with respect to both parameters. TDS increase slightly in the summer months but do not present such a distinct pattern as for spring LW013. Nitrate levels indicate irregular fluctuations imposed on a gradual upward trend between 1970 and 1973.

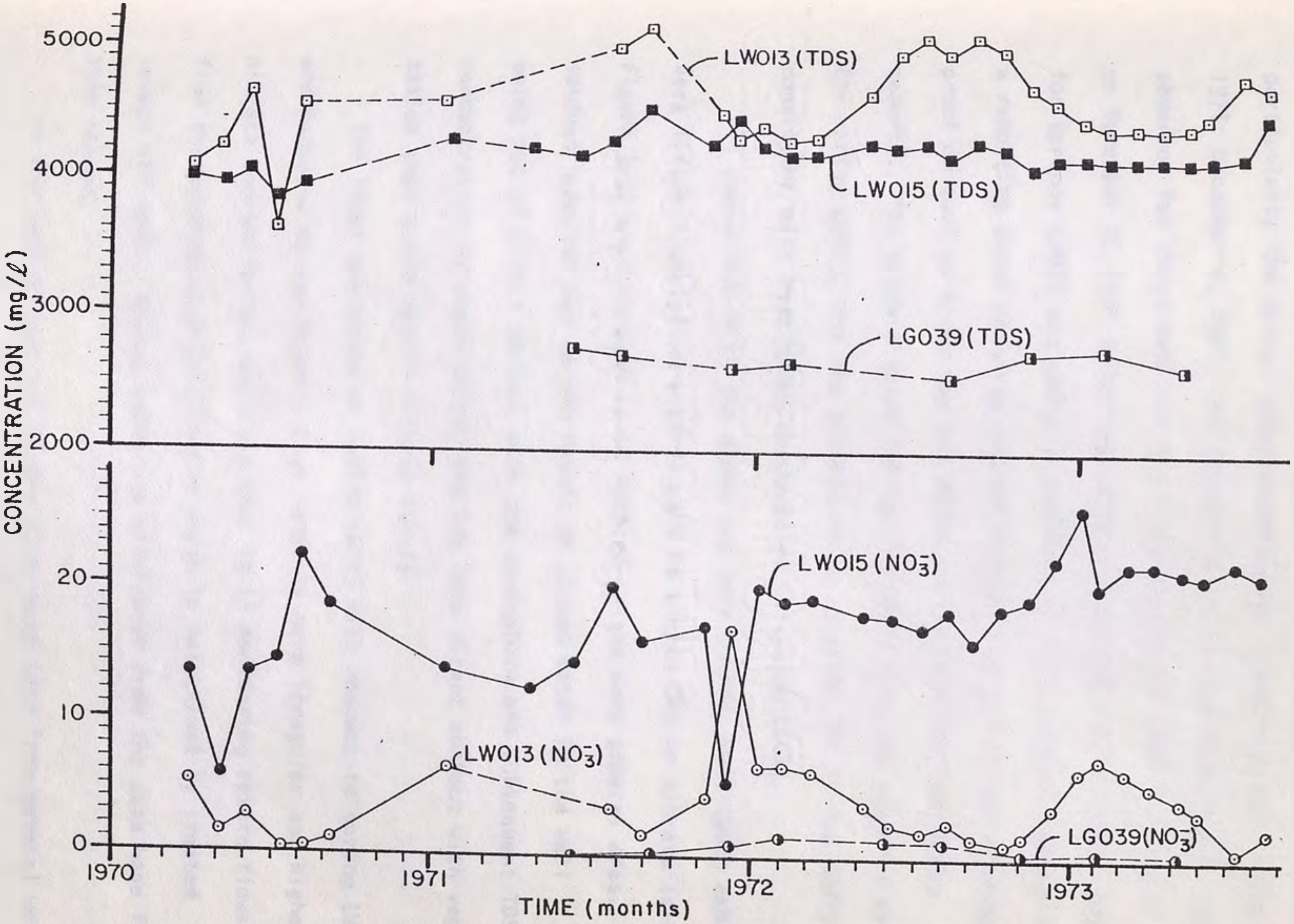


Figure 3-5. TDS and Nitrate Concentrations for Sample Points LW013, LW015, and LG039.

Precipitation records (U.S. Weather Bureau) were examined in an effort to explain irregular magnitudes of nitrate and TDS for spring LW015, particularly the spiked occurrences on May 4 and August 5, 1970; July 26, 1971; December 2, 1971; and January 4, 1973. No satisfactory relation was observed for these data nor for the spiked occurrence of nitrate on December 2, 1971 in spring LW013. Magnitudes of nitrate spikes for springs LW015 and LW013 on December 2, 1971 suggest that perhaps a reporting error occurred and the analyses were switched although proof of such an error was not found in the original laboratory reports. The nitrate value for spring LW015 fits the trend of values for spring LW013, and the nitrate value reported for spring LW013 is consistent with magnitudes encountered in spring LW015.

In comparison with the above two data points, well LG039 exhibited very little fluctuation with respect to either TDS or nitrate (see Figure 3-5) even through it is located in the same general area. This subdued behavior may be the result of ground water in the well being out of direct contact with the atmosphere and subsequent TDS concentration by evaporation, and its less direct contact with vegetation that could modify nitrate levels.

The lower elevation of spring LW015 with respect to spring LW013 and Paradise Valley Country Club, and its more irregular and higher nitrate concentration, suggests that it is monitoring return flows from the country club golf course which is maintained by treated sewage effluent. Spring LW015 was eliminated from the data base for this reason.

In the central portion of the study area data from several wells and springs indicate at first inspection confusing nitrate levels. Nitrate concentrations were above 20 mg/l in sample points LW090 and LG138 which border and are down hydraulic gradient from the Desert Inn (DI) and Las Vegas International Country Club (LVICC) golf courses respectively. Interviews with superintendents Jack Ziles (LVICC) and Kenney Bricknell (DI) confirmed that nitrogen-base fertilizers have been applied on a regular basis depending on temperature and moisture conditions and that heavy irrigation accompanies this application thus providing a nitrogen source for ground water in these areas.

On the other hand, spring LW084, located within the confines of the Sahara-Nevada Country Club (SNCC), and sample points LW072, LW060 and LG060 which are down hydraulic gradient from this golf course had nitrate concentrations less than 3.5 mg/l. These low nitrate values would not be expected in light of general golf course maintenance practices discussed above. However, in an interview, SNCC superintendent Hilding Hanson indicated that very little nitrogen fertilizer had been added to the golf course in recent years because soil tests showed high nitrogen fixation in the soils. Low nitrate levels at these sample points reflect this sparing use of nitrogen fertilizers.

Figure 3-6 is a plot of nitrate concentrations with time for LW060 which indicates that there is apparent seasonal control. High nitrate levels occur in the winter and spring months when plant metabolism is low while the summer months are characterized by low nitrate due to plant fixation. Secondary spikes may result from the

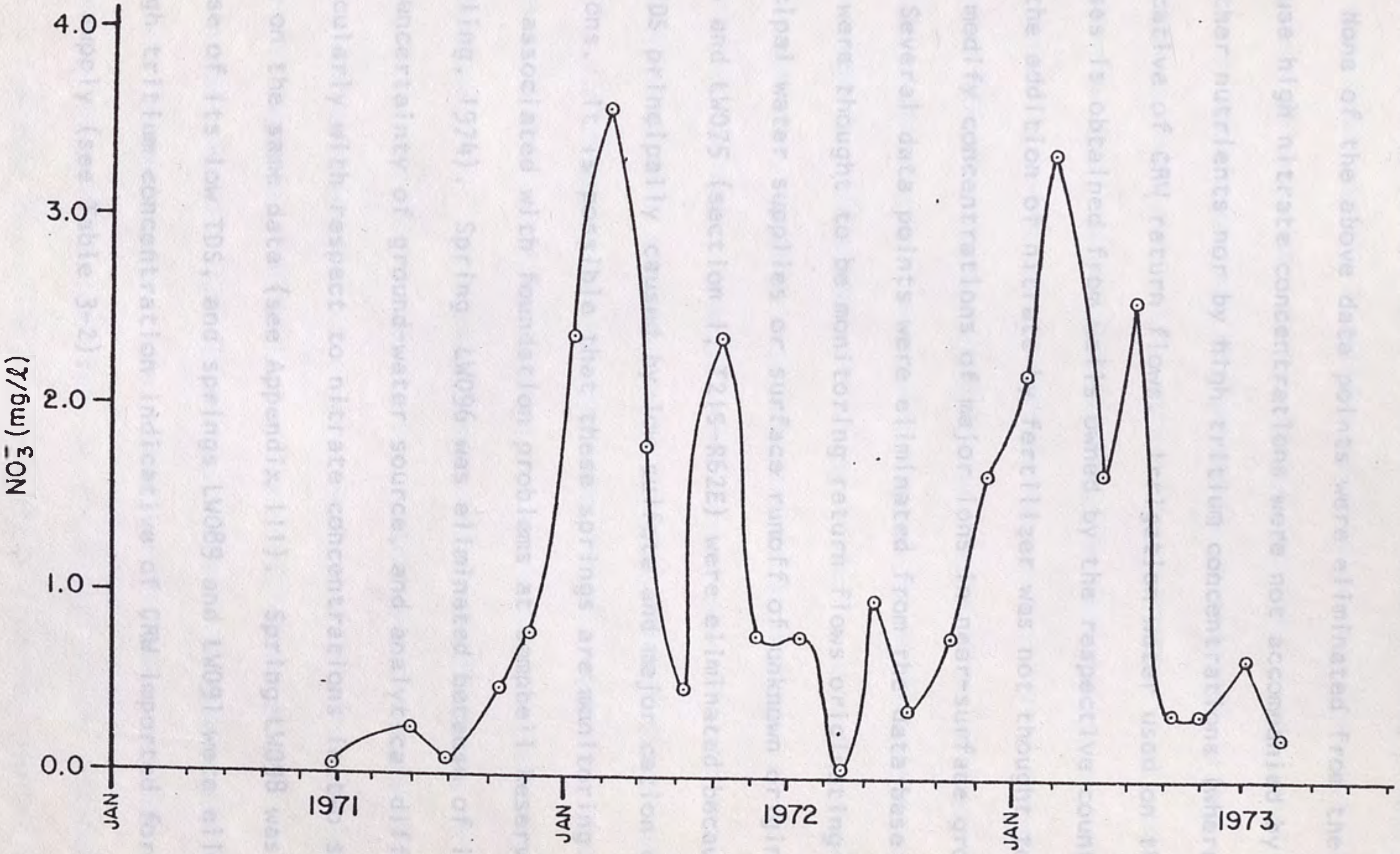


Figure 3-6. Nitrate Concentration for Spring LW060.

light fertilization of the Sahara Nevada Golf Course which occurs primarily in March and April (personal communication, Hilding Hanson, superintendent, SNCC).

None of the above data points were eliminated from the data base because high nitrate concentrations were not accompanied by high levels of other nutrients nor by high tritium concentrations (where sampled) indicative of CRW return flows. Irrigation water used on these golf courses is obtained from wells owned by the respective country clubs, and the addition of nitrate by fertilizer was not thought to substantially modify concentrations of major ions in near-surface ground water.

Several data points were eliminated from the data base because they were thought to be monitoring return flows originating from municipal water supplies or surface runoff of unknown origin. Springs LW074 and LW075 (section 1, T21S-R62E) were eliminated because of low TDS principally caused by low sulfate and major cation concentrations. It is possible that these springs are monitoring municipal water associated with foundation problems at Campbell Reservoir (Mindling, 1974). Spring LW096 was eliminated because of its low TDS, uncertainty of ground-water source, and analytical differences particularly with respect to nitrate concentrations in two samples taken on the same date (see Appendix III). Spring LW098 was eliminated because of its low TDS, and springs LW089 and LW091 were eliminated due to high tritium concentration indicative of CRW imported for municipal water supply (see Table 3-2).

Statistical Distribution of Hydrochemical Variables

Exclusion of those data points listed in Table 3-4 of the previous section leaves 35 sample points that are thought to be representative of natural near-surface ground water. These 35 data points provide the data base used for the remainder of this study. Specific sample dates from these 35 locations were selected for concomitant analyses and, as previously mentioned, are designated by an asterisk in Appendix III.

Before these data could be used to study the relationship between ground-water quality and lithofacies, the variability of each chemical constituent in wells and in springs was statistically examined to ascertain whether or not a particular sample type (well versus spring) might bias the chemical data with regard to surficial geology. In order to perform this analysis using Student's t-test, the distribution of the variates, in this case each chemical component or variable analyzed in the water samples, must have a normal distribution or be transformed to a variate having a nearly normal distribution.

The distribution of chemical constituents composing near-surface ground water was examined through the use of a computer program developed by Dr. V. L. Gupta, Desert Research Institute, Water Resource Center, University of Nevada System, which calculates measures of fitness for various distributions. Table 3-5 is a tabulation of meaningful results. In Table 3-5 the coefficient of correlation (r) is a measure of how well the empirical data agrees with several theoretical distributions. An r value of 1.0 would represent perfect fitness to the mathematical form of the distribution. Values less than 1.0 indicate deviation of the variate from the theoretical

Table 3-5. Comparison of Statistical Distribution of Water Chemistry Variables.

	Log-normal Distribution[1] r	Normal Distribution[2] r
Temp	.94	.96
	.99	.97
pH	.93	.93
HCO_3	.97	.99
Cl	.96	.86
SO_4	.99	.98
NO_3	.89	.77
Na	.97	.91
K	.96	.87
Ca	.97	.99
Mg	.98	.98
TDS	.98	.96

1. Log - normal distribution as calculated by Chow's Procedure.

2. Normal distribution as calculated by Gringorten's No. 1 Curve.

r = Coefficient of correlation between a selected distribution of the measured variate and the theoretical estimate of that distribution.

calculated distribution.

Based on r values, all variables except temperature, bicarbonate, and calcium more closely follow or are equally well approximated by the log-normal distribution (Chow, 1964) when compared to the normal distribution (Gringorton, 1963). That water quality data in general reflect log-normal distribution has been suggested and used in many investigations (Davis, 1966; Hitchon, _et al._ 1971; and Siegel, 1974). Because r values of the two distributions do not greatly differ for the three variables in which the normal distribution appears to be the favored form, all values of chemical constituents used for this study were transformed to an approximate normal variate by logarithmic transformation in order to stabilize variance and for convenience in statistical analyses.

Quality of Well Water Versus Spring Water

To determine if any statistically significant difference in water quality exists between well and spring samples, Student's t-test (Guttman, _et al._ 1971) was employed on log transformed values of chemical variables. The results of this analysis are summarized in Table 3-6. These results indicate that at the 95 percent confidence level, significant differences do exist in mean values of temperature, pH, and bicarbonate between well and spring sample types.

The significant variation in temperature may be due to several factors. Many of the springs were sampled in January 1973 while most wells were sampled in May 1973. The variation in sample temperature may be a result, then, of mean monthly air temperatures between these two months. However, visual inspection of well-spring pairs LG104 and LW072; LG039, LW013 and LW015; and LG036 and LW033 (see Appendix

Table 3-6. Summary of Student's t-Test for Log Values of Chemical Variables Between Well and Spring Samples.

Variable	Temp.	μ	pH	HCO3	Cl	SO_4	NO_3	Na	K	Ca	Mg	TDS
Mean Value												
wells	22.1	3144	7.48	186	219	1339	1.29	198	21	263	191	2449
springs	19.2	3263	7.66	267	215	1337	2.07	211	27	267	189	2550
t- statistic	2.39*	0.26	2.34*	2.12*	0.07	0.15	0.61	0.28	0.97	0.09	0.07	0.26

n = 35 observations.
* significant at the 95% confidence level; $t \geq 1.69$.

III) on specific sample dates in winter and spring months indicate that temperatures of ground water discharged from springs are generally two to three degrees colder than well waters. Because spring waters by nature of definition are flowing, discharging from the geologic framework, it is plausible that their lower temperatures are due to evaporational cooling upon discharge and contact with the atmosphere in contrast to well waters which are confined or surrounded by the geologic medium and therefore maintain a characteristic, higher temperature of that medium.

No satisfactory explanation has been developed for the significant difference in mean pH values and bicarbonate concentrations between well and spring samples. It can be said that the direction of change between the mean values of the two variables is consistent with carbonate chemical equilibrium. Equations 1 through 3 represent a set of simple carbonate equilibrium reactions which exert a major control on pH (Hem, 1970, p. 89):

$$CO_2(aq) + H_2O \rightleftarrows H_2CO_3(aq) \qquad (1)$$

$$H_2CO_3(aq) \rightleftarrows H^+ + HCO_3^- \qquad (2)$$

$$HCO_3^- \rightleftarrows H^+ + CO_3^{2-} \qquad (3)$$

Equation ~~3~~ 2 of this set shows that as bicarbonate concentration in a solution increases, i.e., as the equation goes to the left, hydrogen ion concentration decreases, which in turn raises the pH value of the solution.

Location of Wells Versus Springs

Because of the ground-water quality difference noted above between the two sample types, an examination of the location of wells versus springs was necessary to determine if either type of sample point was preferentially located and, therefore, would bias the study of water quality with regard to lithofacies location.

Student's t-test was applied to well and spring locations as measured by x and y coordinates in tenths of inches on a 15-minute topographic map (scale 1:62500) from a common origin in the southwest corner of the study area. Results, summarized in Table 3-7, show that the two types of sample points are areally intermixed. In addition, the number of springs and wells between sulfate and carbonate lithofacies is not too dissimilar, the carbonate lithofacies being monitored by nine springs and seven wells whereas the sulfate lithofacies is monitored by seven springs and 12 wells.

Bicarbonate Content, Sample Type, and Lithofacies.

The above information indicates that bicarbonate concentration is significantly greater in springs than in wells and, although significant difference cannot be found in location preference between sample types, there are more spring samples in what has been defined as the carbonate lithofacies. This suggests that high bicarbonate concentrations in near-surface ground water sampled in bicarbonate lithofacies may be the result of this lithofacies being monitored by more springs, with their higher bicarbonate content, than wells, with their lower bicarbonate content (see Table 3-6).

Table 3-7. Summary of Student's t-Test for Location Between Well and Spring Sample Sites.

Variable:	x-coordinate	y-coordinate
mean for wells	42.21	51.89
mean for springs	51.13	53.81
t-statistic	1.02	0.21

n = 35 observations.
* = significance at 95% level: $t \geq 1.69$.

In order to separate the effects of lithofacies from those of sample type on bicarbonate content of near-surface ground water, a two-way analysis of variance was performed (see Guttman, *et al*, 1971). A weighted analysis of variance was used to correct for the difference in sample size. Table 3-8 presents the results of the analysis. These results indicate that both lithofacies and sample type influence bicarbonate concentration at the 95 percent confidence level. These two effects (lithofacies and sample type) are separated in the analysis such that one does not influence the other. The small value of the mean square for the row titled "Interaction" (see Table 3-8) suggests that wells and springs are similarly affected by lithofacies.

Table 3-8. Analysis of Variance for Bicarbonate Concentration Between Lithofacies and Type of Sample Point (Wells Versus Springs).

Source	Sum of Squares	d.f.	Mean Square	F[1]
Lithofacies	1.30675	1	1.30675	5.87
Wells vs Springs	0.92921	1	0.92921	4.18
Interaction	0.18919	1	0.18919	0.85
Residuals	6.89811	31	0.22252	
Total	9.32326	34	2.64767	

1. Significant F(1, 31; 0.95) = 4.17

Chapter 4

SURFICIAL GEOLOGY, GROUND-WATER QUALITY RELATIONSHIPS

INTRODUCTION

The principal aim of this study is to define the relationship between surficial alluvial lithologies and the quality of near-surface ground water in Las Vegas Valley. Alluvial lithofacies were developed and described in Chapter 2, and their areal distribution in the valley is summarized in Figure 2-1. The major objectives of Chapter 3 were to establish sampling points thought to be representative of natural, near-surface ground water, to select an appropriate statistical distribution for the hydrochemical constituents of this ground water, and to indicate the relationship between hydrochemical concentration of measured variables and sample type and location.

Based on the above findings, Chapter 4 develops the relationship between lithofacies and ground-water quality through the use of the hydrochemical facies concept, thermodynamic mineral solubility concepts, and statistical methods involving correlation, factor analysis, and analysis of variance between water-quality variables and lithofacies.

CORRELATION ANALYSIS

Correlation Coefficients

To examine the association among all water quality variables measured in the 35 sample sites for this study, correlation coefficients were calculated by computer program from a statistical package provided by the Computer Center, University of Nevada System, Reno. The coefficients computed for 13 variables are listed in Table 4-1. These correlation coefficients are a measure of the proportion of variance of one variable that is associated with the variation of another variable. This association between variates is often called "explanation." The underlined values indicate correlation coefficients that "explain" over 50 percent of the variance in terms of another variable (the percent variance explained is obtained by squaring the correlation coefficient). The (*) value indicates coefficients that are statistically significant at the 95 percent confidence level.

Table 4-1 indicates that date and temperature have a significant negative correlation coefficient at the 95 percent level. Date was calculated as days between the date of sample and August 15th under the assumption that August 15th would be a good approximate date as to when ground water would be the warmest in the annual cycle. Therefore, it is expected that water temperature would decrease with increasing magnitude of the date value as indicated by the correlation coefficient. That the coefficient associates only 38 percent of the variation between the variates may be indicative of relatively small changes in ground temperatures between summer and winter months in Las Vegas Valley. Poor correlation of temperature with all chemical variables is interpreted to mean that temperature does not control their concentration levels.

Conductivity is highly correlated with chloride, sulfate, sodium, calcium, magnesium, and total dissolved solids. This indicates that plots of conductivity versus the above mentioned variables could be

Table 4-1. Correlation Matrix for Thirteen Chemical Variables.

VARIABLE	TEMP.	COND.	pH	HCO3	Cl	SO4	NO3	Na	K	Ca	Mg	TDS
DATE	-.62*	-.16	.21	-.25	-.11	-.12	-.03	-.14	-.11	-.08	-.19	-.15
TEMP.		.07	-.29	-.05	.06	.06	-.04	.09	-.10	.01	.11	.06
COND.			-.34	-.15	.79*	.86*	-.16	.94*	.77*	.82*	.78*	.98*
pH				.30	-.25	-.33	.12	-.24	-.17	-.40*	-.24	-.34*
HCO3					-.25	-.12	.09	-.12	-.08	-.25	.09	-.13
Cl						.39*	-.19	.80*	.52*	.56*	.44*	.67*
SO4							-.14	.77*	.71*	.83*	.82*	.94*
NO3								-.20	-.14	-.13	-.08	-.16
Na									.82*	.67*	.67*	.91*
K										.55*	.51*	.77*
Ca											.55*	.86*
Mg												.82*

n = 35 observations.

* = statistically significant at the 95% confidence level ($r \geq \pm 0.34$; tabulated in Steel, R., and Torrie, J., 1960, Principles and Procedures of Statistics; McGraw-Hill, N.Y.).

— = explains > 50 percent of variation between variables.

developed to predict concentration of the variables from conductivity readings alone. That the above variables do correlate well with conductivity is not surprising as they represent the major ions with the exception of bicarbonate in the ground water at all 35 sample points.

The high correlation between sodium and chloride may result because they have a common origin. Cations potassium, calcium, and magnesium also correlate significantly with chloride as does sulfate to a lesser extent. Chloride's positive correlation with sulfate indicates that concentration levels of these two anions change in the same manner and that they do not replace one another as the anion component of salts in general.

The high correlation of sulfate with sodium, potassium, calcium, and magnesium suggests the possible presence of sulfate salts composed of these cations.

For completeness it should be noted that nitrate and bicarbonate do not correlate well with other chemical variables. This implies that their concentrations are not predicted by any of the variables measured. Nitrate concentration was used as a contamination indicator for selection of data points. Its poor correlation with other chemical constituents, then, may indicate that its concentration is influenced by human activities or perhaps some geological control that does not reflect chemical change in other variables.

Bicarbonate's highest correlation is with pH. This correlation coefficient is just below the 95 percent significance level ($r>0.34$), but the coefficient does indicate that as pH increases so does bicarbonate concentration. This follows established carbonate equilibrium reactions (Garrels and Christ, 1965) previously discussed.

Factor Analysis

Factor analysis takes the correlation matrix and redistributes the associated variance among a set of statistical factors that represent linear combinations of the original variables (Kendall, 1968). It may be possible to then account for these factors in terms of known processes, in this case geological and chemical. Important results of R-mode, varimax factor analysis on log-transformed data for thirteen variables are summarized in Table 4-2.

Each of the three factors represent a statistically independent pattern of information. Factor 1 loadings indicate that TDS, conductivity, sodium, sulfate, magnesium, potassium, calcium, and chloride are highly intercorrelated and, therefore, high (low) magnitudes of these variables occur concomitantly. With the exception of silica (which was analyzed in only four samples) and bicarbonate, the six ions above represent the major constituents of the near-surface water. For this reason factor 1 may appropriately be called the "salinity" factor. Appropriate ionic combinations of these variables represent common salts which might be found in semi-arid and arid basins where evapotranspiration concentrates salts in ground water to the extent that precipitation occurs.

Water temperature and date are heavily but negatively loaded on factor 2, indicating the relationship discussed previously. As date increases temperature should decrease. Factor 2 may be called the "seasonal variation" factor.

The positive loading of bicarbonate and pH in factor 3 is as expected. As bicarbonate levels increase in ground water the hydrogen ion concentration would decrease, thereby increasing pH. This

Table 4-2. Results of R-mode, Varimax Factor Analysis of Thirteen Chemical Variables.

Factor	1	2	3	Communality[1]
Variable:				
TDS	.98			.99
µ	.96			.98
Na	.92			.88
SO_4	.90			.83
Mg	.83			.72
K	.82			.69
Ca	.79			.73
Cl	.67			.58
Temp		-.88		.79
Date		.86		.81
HCO_3	.01	-.15	.87	.77
pH		.42	.60	.59
NO_3	-.13		.35	.14

Total variance explained = 73%

---

1. Communalities represent the cumulative percent of variance explained by all three factors for the variable in question.

☐ = major loading.

n = 35 observations

relationship was previously summarized by equation (3) on page 68. This factor may be aptly termed the "alkalinity" factor.

Nitrate's highest loading is on factor three. Its low loading magnitude and communality value re-emphasizes the preceding statement that its concentration does not seem to be well related to other measured variables.

The behavior of nitrate in ground water for the system under study is questionable. Previously (see Chapter 3) an effort was made to eliminate data points that were thought to be nonrepresentative samples of natural ground water based on chemical nutrient concentrations and tritium levels. However, due to inconclusive evidence some observation points were deemed to be representative although they have above background concentration of nitrate. Because nitrate does not correlate well with any other variables (see Table 4-1), it loads weakly on all factors in factor analysis (see Table 4-2) and does not fit the distributions considered (see Table 3-6). Thus, nitrate was eliminated as a chemical variable and a second R-mode, varimax factor analysis was performed on the remaining variables for the 35 observation points. The results are summarized in Table 4-3.

Total variation explained increases slightly between the first and second factor trials, as is expected because of the removal of unexplained variation in nitrate concentration. This also implies that general causes, e.g., geology and chemical response, underlying the behavior among other variables are not the same as those controlling nitrate concentration. Therefore, the exemption of nitrate from the analysis technique permits the other variables better alignment with the three factors defined.

Table 4-3. Results of R-mode, Varimax Factor Analysis for Twelve Chemical Variables.

Factor	1	2	3	Communality[1]
Variable:				
TDS	.99			.99
μ	.97			.98
Na	.93			.88
SO_4	.91			.83
K	.83			.69
Mg	.82			.72
Ca	.80			.74
Cl	.69			.57
Temp.		-.88		.80
Date		.87		.81
HCO_3	-.04	-.17	.87	.83
pH		.41	.57	.61

Total variance explained = 79%

---

1. Communalities represent the commulative percent variance explained by all four factors for the variable in question.

☐ = Major loading.

n = 35 observations.

ANALYSIS OF VARIATION

Analysis of Difference Between Carbonate and Sulfate Lithofacies

To ascertain if any significant difference in concentration of hydrochemical variables exists in near-surface ground water between sulfate and carbonate lithofacies (see Figure 2-1), Student's t-test was administered to the hydrochemical data (reported in mg/l) for the 35 sample points. The results are summarized in Table 4-4. Nine variables have significant difference in log-mean concentration (mg/l) at the 95 percent confidence level between sulfate and carbonate units. In all cases except bicarbonate the variables had higher values in the sulfate lithofacies.

Increased concentrations of these chemical variables in the sulfate units may be due to several interrelated mechanisms. Sulfate-rich sediment types are more abundantly distributed along the eastern and southeastern portion of the study area which is the major ground-water discharge region of the valley. Ground water in this portion of the valley should be characterized by higher levels of dissolved constituents due to distance and, therefore, travel time through the alluvium. In addition, the sulfate units are generally composed of a greater percentage of fine-grained sediments. This allows for increased granular surface area and lower ground-water velocity, both of which lead to increased dissolution of mineral matter.

The particular increase in sulfate and chloride may be attributed to the greater solubility of these salts as opposed to carbonates. This is in part substantiated by the difference in bicarbonate mean values between the two designated types of geologic units. Carbonate units are in general up hydraulic gradient from sulfate units (see

Table 4-4. Summary of Student's t-Test Applied to Hydrochemical Variables Between Sulfate and Carbonate Lithofacies.

Variable	t-value[1]	Mean log values	
		sulfate units	carbonate units
Cond.	3.59*	3.59	3.40
Na	3.54*	2.44	2.15
TDS	3.53*	3.49	3.28
K	3.49*	1.53	1.18
Cl	3.44*	2.49	2.14
SO_4	3.13*	3.23	3.02
Ca	3.03*	2.52	2.31
HCO_3	2.30*	2.27	2.43
Mg	2.14*	2.34	2.21
pH	1.49	0.88	0.88
NO_3	1.04	0.05	0.39
Date	1.01	1.97	2.04
Temp.	0.01	1.32	1.32

---

1. Student's t-value calculated on mean log values.

n = 35 observations.

* = significant at the 95% significance level (critical t = 1.69; n = 34).

Plates 1 and 2); therefore, it might be expected that bicarbonate initially would be more abundant in this portion of the flow system and subsequently precipitate out to form calcareous units, leaving the ground water with a sulfate-chloride facies. As a result of evapotranspiration in the lower portion of the valley, sulfate-chloride salts would eventually precipitate.

The significant difference in magnesium, calcium, potassium, sodium, and consequently TDS and conductivity indicate deterioration of ground-water quality in the lower portions of ground-water flow path. Increase in sulfate may be explained in terms of observed increases in sulfate salts in the geologic units in the eastern and southeastern portion of the study area. Sodium and calcium sulfate salts have been reported in soil analyses by many investigators, including the Soil Conservation Service (Langan, _et al_. 1967, and Lloyd Rooke, personal communication); Dr. David Slemmons, Professor of Geology, Mackay School of Mines, University of Nevada; and Mr. Robert Pride, Soils Engineer, Converse, Davis and Associates, Las Vegas Office (personal communication). Mr. Pride indicated that glauberite ($Na_2Ca(SO_4)_2$), thenardite (Na_2SO_4), and mirabolite ($Na_2SO_4 \cdot 10H_2O$) salts are commonly encountered in soils from the west side of Las Vegas Wash in T21S and in the vicinity of Tropicana Avenue and Boulder Highway. The presence of these salts is important to foundation engineering because of their shrink-swell potential upon dehydration-hydration. To date, these salts have been successfully recognized in the near-surface sediments predominantly in the eastern and southeastern portion of the study area. The western portion of the study area is characterized by calcium carbonate precipitate in the form of caliche strata and nodules.

It should be emphasized that there is a significant difference in bicarbonate concentration between lithofacies (see Table 4-4). This concurs with the analysis of variance presented in Table 3-8, and indicates that bicarbonate content in near-surface ground water increases significantly in the carbonate lithofacies.

It is important to note that the variables date, temperature, pH, and nitrate do not significantly differ between the two defined geologic categories. Because concentration levels of calcium, magnesium, and bicarbonate vary with pH which in turn may be controlled by temperature (Hem, 1970) that can be subsequently related to time of year (cold seasons versus warm seasons) there is a strong inference that the statistically significant difference in calcium, magnesium, and bicarbonate between geologic categories is related to lithologic difference along the flow path, not to temperature and/or pH of the samples. That pH is not significantly different between categories suggests that the system is buffered against change even though there is significant variation in ions that might affect pH values.

The non-significant variation in nitrate between geologic categories implies that factors causing high/low concentration (see Appendix III) are not peculiar to a particular geologic unit. If high nitrate is due to human induced contamination, this influence is not restricted to either geologic category. Patt and Hess (1976) state that high nitrate concentration in wells centered around the Gilcrease Range, north of the present study area, may be due to oxidation of organic material incorporated within the alluvial fill. If such deposits exist and are indeed the cause of elevated nitrate levels reported in several of the sample points under consideration (see Appendix II), this type of organic deposit is not restricted to either geologic category presently considered. With the exception of noted gravel units, most surface units delineated on Plate 1 have a fine-grained lithology indicative of low energy environment of deposition that could facilitate the random growth of plants in shallow, slow moving water. Subsequent deposition could have preserved this organic material and provided a course of nitrate to ground waters. Haynes (1967) reports the occurrence of such buried organic material in the Tule Springs area. Core boring number 3 (see Appendix II and Plate 1) indicates the presence of decaying organic material in unit Qals along the present Las Vegas Wash. The characteristic lithologies of unit Qals are clay and silt, indicative of low energy environments of deposition favorable for the preservation of organic materials.

Analysis of Variance Among Three Lithologic Categories

In an effort to further delineate significant differences in water quality among geologic categories an analysis of variance was performed on mean logs of concentrations (mg/l) of hydrochemical variables (Snedecor and Cochran, 1969). Geologic units were divided into three categories based on the amount and form of gypsum observed during mapping of the surficial geology. These categories or treatments as they are referred to in experimental design are map units Qmg and Qgcs as treatment I, map unit Qals as treatment II, and map units Qs, Qsm, and Qfwv as treatment III. Treatment I units contain abundant gypsum in crystalline, sugar, and powder forms as present in the south-central portion of the study area. In hand specimen treatment II contains less apparent gypsum (usually present in powder form only) than treatment I. Units comprising treatment III are the previously defined carbonate units. The results of the F-test for variables among these three treatments are summarized in Table 4-5.

Seven variables show significant variation at the 95 percent confidence level (see Table 4-5). In all seven cases treatment I has the highest mean log value for the variable in question. This suggests that the presence of abundant gypsum in hand specimen is an indicator of significant increased dissolved constituents in shallow ground water. Such a relation would be expected between calcium sulfate and calcium carbonate treatments as defined above. Experimental data show that gypsum ($CaSO_4 \cdot 2H_2O$) is much more soluble than calcite ($CaCO_3$) and, therefore, higher concentrations of calcium and sulfate in water would be required to precipitate gypsum. Examination of Table 4-5 column entitled "difference between log means," indicates that significant difference in log means occurs at the 95 percent confidence level for both calcium and sulfate between treatments II and III and treatments III and I. No significant difference exsits between treatments I and II, although, as mentioned before, levels are higher for treatment I. These results might be expected in terms of lithologic differences used to differentiate mapping units and subsequent treatment categories. Both treatment categories I and II contain units composed of varying amounts of gypsiferous matrix. That treatment I has the highest mean log values of calcium and sulfate is consonant with its more extensive and better developed gypsum content as seen in hand specimen. Treatment III, termed the carbonate treatment, has relatively minor or very localized gypsum content and characterizes ground water that is significantly lower in calcium and sulfate concentrations.

The significant differences in potassium, sodium, and chloride

Table 4-5. Summary of Analysis of Variance for Chemical Variables and Pairwise t-Test of Differences Among Three Lithologic Categories.

Variable	F-value	Treatment[1]	mean log	Difference between mean logs	Tabulated Least Significant Difference at the 95% confidence level
Cl^-	11.12*	I	2.7855	x_1-x_2 = 0.3950**	x_1-x_2 = 0.2844
		II	2.3905	x_2-x_3 = 0.2410**	x_2-x_3 = 0.1998
		III	2.1495	x_3-x_1 = 0.6360**	x_3-x_1 = 0.2797
Na^+	10.33*	I	2.6620	x_1-x_2 = 0.5136**	x_1-x_2 = 0.2418
		II	2.3656	x_2-x_3 = 0.2172**	x_2-x_3 = 0.1699
		III	2.1484	x_3-x_1 = 0.5136**	x_3-x_1 = 0.2378
μ	10.09*	I	3.7206	x_1-x_2 = 0.1766**	x_1-x_2 = 0.1525
		II	3.5440	x_2-x_3 = 0.1408**	x_2-x_3 = 0.1071
		III	3.4032	x_3-x_1 = 0.3174**	x_3-x_1 = 0.1500
TDS	8.79*	I	3.6183	x_1-x_2 = 0.1723	x_1-x_2 = 0.1747
		II	3.4460	x_2-x_3 = 0.1611**	x_2-x_3 = 0.1227
		III	3.2849	x_3-x_1 = 0.3334**	x_3-x_1 = 0.1718
K^+	6.85*	I	2.6620	x_1-x_2 = 0.2963**	x_1-x_2 = 0.2378
		II	2.3656	x_2-x_3 = 0.2172**	x_2-x_3 = 0.1699

(continued)

Table 4-5, continued.

Variable	F-value	Treatment[1]	mean log	Difference between mean logs	Tabulated Least Significant Difference at the 95% confidence level
		III	2.1484	x_3-x_1 = 0.5135**	x_3-x_1 = 0.2418
Ca^{2+}	6.65*	I	0.3451	x_1-x_2 = 0.1875	x_1-x_2 = 0.2053
		II	0.1576	x_2-x_3 = 0.1576**	x_2-x_3 = 0.1442
		III	0.2053	x_3-x_1 = 0.3451**	x_3-x_1 = 0.2019
SO_4^{2-}	5.34*	I	3.3041	x_1-x_2 = 0.0997	x_1-x_2 = 0.2143
		II	3.2044	x_2-x_3 = 0.1889**	x_2-x_3 = 0.1506
		III	3.0156	x_3-x_1 = 0.2886**	x_3-x_1 = 0.2108
Mg^{2+}	3.14	I	2.4197	x_1-x_2 = 0.1132	x_1-x_2 = 0.1808
		II	2.3065	x_2-x_3 = 0.0955	x_2-x_3 = 0.1270
		III	2.2110	x_3-x_1 = 0.2087**	x_3-x_1 = 0.1778
HCO_3^-	3.03	I	2.3392	x_1-x_2 = 0.1005	x_1-x_2 = 0.2273
		II	2.2387	x_2-x_3 = 0.1936 **	x_2-x_3 = 0.1597
		III	2.4323	x_3-x_1 = 0.0931	x_3-x_1 = 0.2236
pH	1.08	I	0.8749	x_1-x_2 = 0.0006	x_1-x_2 = 0.0152
		II	0.8755	x_2-x_3 = 0.0070	x_2-x_3 = 0.0107
		III	0.8825	x_3-x_1 = 0.0076	x_3-x_1 = 0.0150

(continued)

Table 4-5, continued.

Variable	F-value	Treatment	mean log	Difference between mean logs	Tabulated Least Significant Difference at the 95% confidence level
Date	0.62	I	2.0059	$x_1 - x_2 = 0.0525$	$x_1 - x_2 = 0.2169$
		II	1.9533	$x_2 - x_3 = 0.0833$	$x_2 - x_3 = 0.1523$
		III	2.0366	$x_3 - x_1 = 0.0308$	$x_3 - x_1 = 0.2133$
NO_3^-	0.55	I	0.1314	$x_1 - x_2 = 0.1134$	$x_1 - x_2 = 1.0471$
		II	0.0180	$x_2 - x_3 = 0.3729$	$x_2 - x_3 = 0.7355$
		III	0.3909	$x_3 - x_1 = 0.2595$	$x_3 - x_1 = 1.0297$
Temp.	0.1677	I	1.2995	$x_1 - x_2 = 0.0243$	$x_1 - x_2 = 0.0853$
		II	1.3239	$x_2 - x_3 = 0.0061$	$x_2 - x_3 = 0.0599$
		III	1.3177	$x_3 - x_1 = 0.0182$	$x_3 - x_1 = 0.0839$

1. Treatment 2 comprised of unit Qals; treatment 1 comprised of units Qgcs or Qmg; treatment 3 comprised of units Qs, Qsm or Qfwv.

n = 35 observations; treatment 1 = 5 observations, treatment 2 = 14 observations, treatment 3 = 16 observations.

* Significant at the 95% confidnece level (critical F = 3.30).

** Significant difference at the 95% confidence level.

among the treatments can not be explained in a similar manner. Salts of these constituents are not recognized in developed geologic mapping units. Higher mean log values for these constituents may be due to interaction of various mechanisms previously discussed concerning the analysis of difference between two categories of sediment lithology, i.e., both the fine-grained nature of the sediments and their location in the lower reach of the ground water flow system are responsible for the high concentration of dissolved ions.

The significant difference at the 95 percent confidence level in mean log values of magnesium and bicarbonate (see Table 4-5) should not be given much interpretive significance. Although significant difference does exist between two lithologic categories as indicated by Student's t-test (see Table 4-5, compare last two columns), when data from treatments I, II, and III are combined the F-test indicates that there is no significant difference in variance for magnesium and bicarbonate among lithologic treatments. That treatment III has the highest mean log value of bicarbonate in accord with its carbonate lithology is mentioned for completeness.

Nitrate concentration shows no significant variation with the three treatments. This concurs with Student's t-test for difference in means between the two category divisions previously studied indicating that nitrate levels are not dependent upon any one of the treatments defined by the surficial geology. Simiarly, pH values show no preference among treatments, suggesting a buffered system.

HYDROCHEMICAL FACIES

Near-Surface Ground Water

Figure 4-1 is a trilinear diagram (Piper, 1944) developed from relative concentration in milliequivalents per liter (epm/l) of major ions present in near-surface ground water for 35 sample points. Data originating from sample points in carbonate lithofacies are designated with circles and data originating from sample points in sulfate units by squares. This figure indicates that the near-surface ground water has a predominantly calcium-magnesium, sulfate-chloride composition. Although data points from both lithofacies lie predominantly in the sulfate-chloride field, Figure 4-1 also indicates that the composition of near-surface ground water originating from carbonate units is slightly shifted to the left of the diagram, towards the carbonate-bicarbonate hydrochemical facies. This shift is consistent with the division between data points based on location with respect to surficial geology.

Table 4-6 summarizes the possible anion-cation hydrochemical facies as developed by Back (1961 and 1966) and subsequently modified by the present author for this study. Using the data in Appendix IV, five general hydrochemical facies can be recognized in the near-surface ground water of the Las Vegas Valley. These are listed at the bottom of Table 4-6. All samples exhibit a strong sulfate-chloride anion facies and a calcium-magnesium/magnesium-calcium cation facies as previously suggested by Figure 4-1. Because lithologic studies presented in Chapter 2 differentiate sediment into carbonate and sulfate lithofacies, the following discussion of hydrochemical facies and their relation to lithofacies will focus on bicarbonate and sulfate anion components of water-quality data.

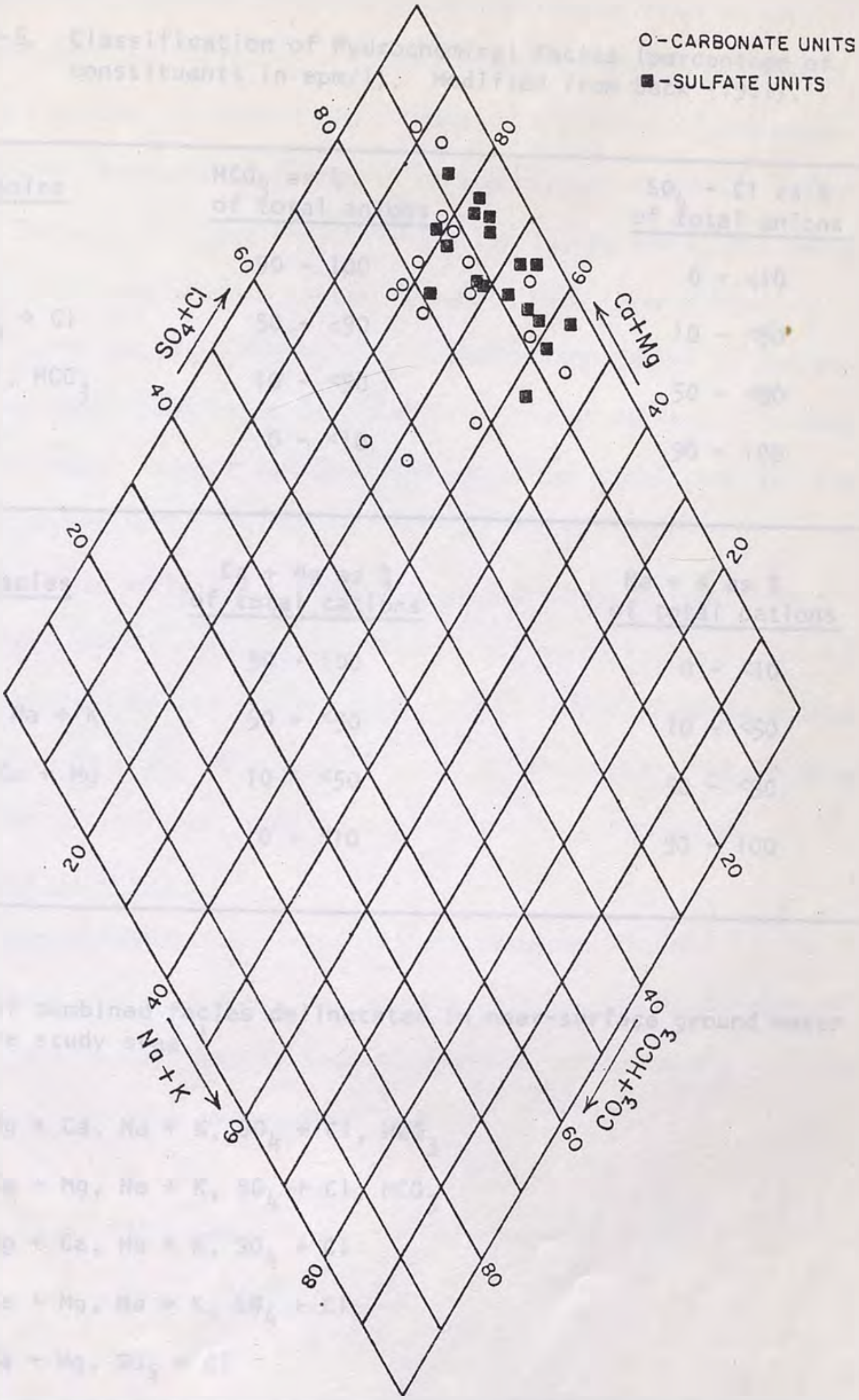


Figure 4-1. Trilinear Diagram of Chemical Concentration of Ions in Near-Surface Ground Water.

Table 4-6. Classification of Hydrochemical Facies (percentage of constituents in epm/l). Modified from Back (1961).

Anion facies	HCO_3 as % of total anions	SO_4 - Cl as % of total anions
HCO_3	90 - 100	0 - <10
HCO_3, SO_4 + Cl	50 - <90	10 - <50
SO_4 + Cl, HCO_3	10 - <50	50 - <90
SO_4 + Cl	0 - <10	90 - 100

Cation facies	Ca + Mg as % of total cations	Na + K as % of total cations
Ca + Mg	90 - 100	0 - <10
Ca + Mg, Na + K	50 - <90	10 - <50
Na + K, Ca + Mg	10 - <50	50 - <90
Na + K	0 - <10	90 - 100

Summary of combined facies delinetated in near-surface ground water of the study area [1]

A. Mg + Ca, Na + K, SO_4 + Cl, HCO_3

B. Ca + Mg, Na + K, SO_4 + Cl, HCO_3

C. Mg + Ca, Na + K, SO_4 + Cl

D. Ca + Mg, Na + K, SO_4 + Cl

E. Ca + Mg, SO_4 + Cl

---

1. For ion pairs, that ion composing > 50% of that pair is placed first.

Figure 4-2 indicates the areal distribution and predominance of these hydrochemical facies in the study area. Hydrochemical facies A and B are defined as having bicarbonate as a portion of the anion facies and are hereafter referred to as the partial carbonate hydrochemical facies. The remaining three facies (C, D, and E) are solely defined by sulfate-chloride concentration. These three facies are hereafter referred to as the sulfate hydrochemical facies in accord with the sulfate lithofacies designation discussed above and because the sulfate anion is more abundant than chloride in all near-surface ground-water samples.

Examination of Figure 4-2 shows a good spatial correspondence between those sample points designated as belonging to partial carbonate hydrochemical facies and the surficial distribution of carbonate lithofacies. This strongly suggests that a relationship exists between near-surface ground-water quality and designated lithofacies.

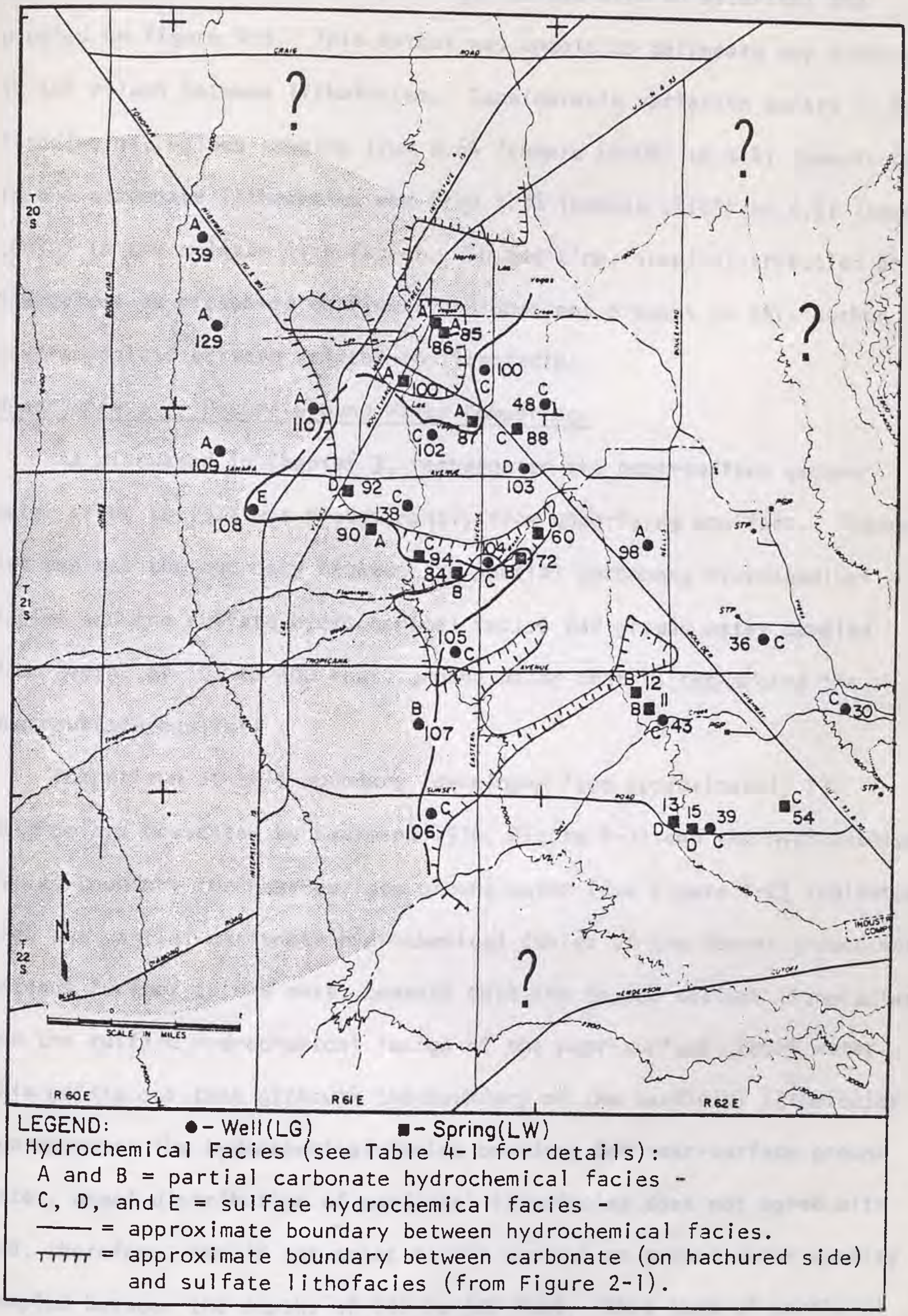
Sodium-Absorption-Ratio

The sodium-absorption-ratio(SAR) was examined for each of the 35 sample points to see if any areal pattern in principal cation composition existed in water quality data between the carbonate and sulfate lithofacies. SAR of a water is defined by

$$\mathrm{SAR} = \frac{(\mathrm{Na}^{+})}{\left(\dfrac{(\mathrm{Ca}^{2+})+(\mathrm{Mg}^{2+})}{2}\right)^{0.5}}$$

where ion concentrations are expressed in milliequivalents per liter (Hem, 1971, p. 228).

SAR values for all sample points were calculated from water quality



LEGEND: ● - Well (LG) ■ - Spring (LW)
Hydrochemical Facies (see Table 4-1 for details):
A and B = partial carbonate hydrochemical facies -
C, D, and E = sulfate hydrochemical facies -
—— = approximate boundary between hydrochemical facies.
┬┬┬┬┬ = approximate boundary between carbonate (on hachured side) and sulfate lithofacies (from Figure 2-1).

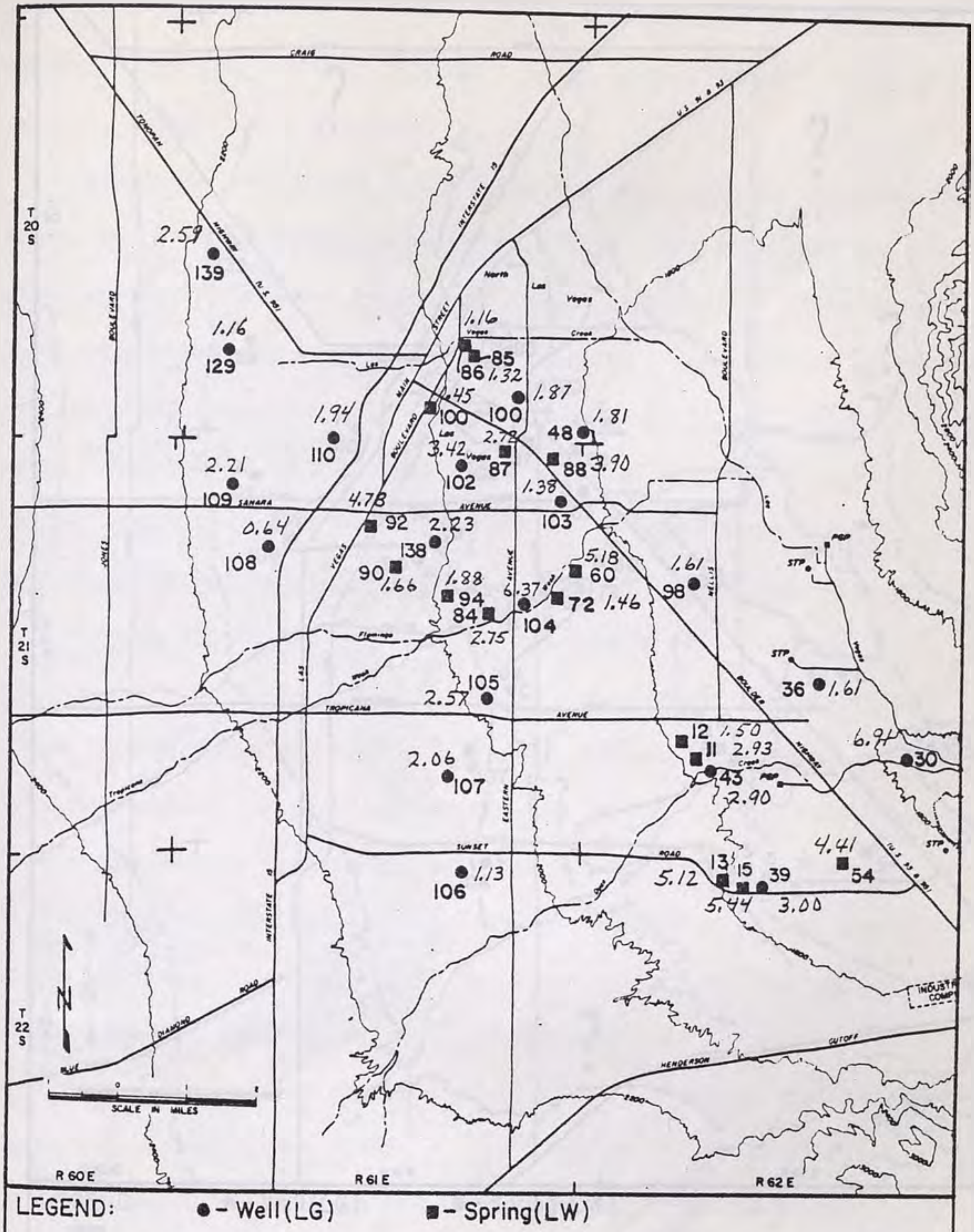
Figure 4-2. Areal Distribution of Hydrochemical Facies.

data in Appendix III (see sample dates marked with an asterick) and plotted on Figure 4-3. This author was unable to delineate any difference in SAR values between lithofacies. Considerable variation exists in both lithofacies, values ranging from 0.64 (sample LG108) to 4.41 (sample LW054) in the carbonate lithofacies and from 1.38 (sample LG103) to 6.91 (sample LG030) in the sulfate lithofacies. In addition, areal distribution of SAR values as presented on Figure 4-3 does not present to this author any recognized pattern related to lithofacies.

Near-Surface -- Deeper Ground Water Comparison

As discussed in Chapter 3, recharge to the near-surface ground water prior to 1973 was predominantly from underlying aquifers. Figure 4-4 depicts the boundary between the partial carbonate hydrochemical facies and the sulfate hydrochemical facies for ground water sampled from depths of 101 to 300 feet, ground water that is recharging the near-surface aquifer.

Comparison of this boundary (developed from approximately 230 data points presented by Kaufmann 1976, Figure 4-1) and the hydrochemical facies boundary for near-surface ground water (see Figure 4-2) indicates that the partial carbonate hydrochemical facies of the deeper ground water extends further to the east, beneath both the mapped sulfate lithofacies and the sulfate hydrochemical facies of the near-surface ground water. This points out that although the boundary of the surficial lithofacies approximates the hydrochemical-facies boundary for near-surface ground water, areal distribution of surficial lithofacies does not agree with and, therefore, should not exert direct control on ground-water quality sampled between the depths of 101 to 300 feet. This lack of surficial lithologic control on deep water quality is not surprising in light of the heterogeneous nature of alluvial-fill stratigraphy both areally and



$$\mathrm{SAR} = \frac{\mathrm{Na}^{+}}{\left(\frac{\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+}}{2}\right)^{0.5}}$$

with ion concentrations expressed in milliequivalents per liter.

Figure 4-3. Sodium-Absorption-Ratio for Near-Surface Ground Water. Calculations based on Hem (1971).

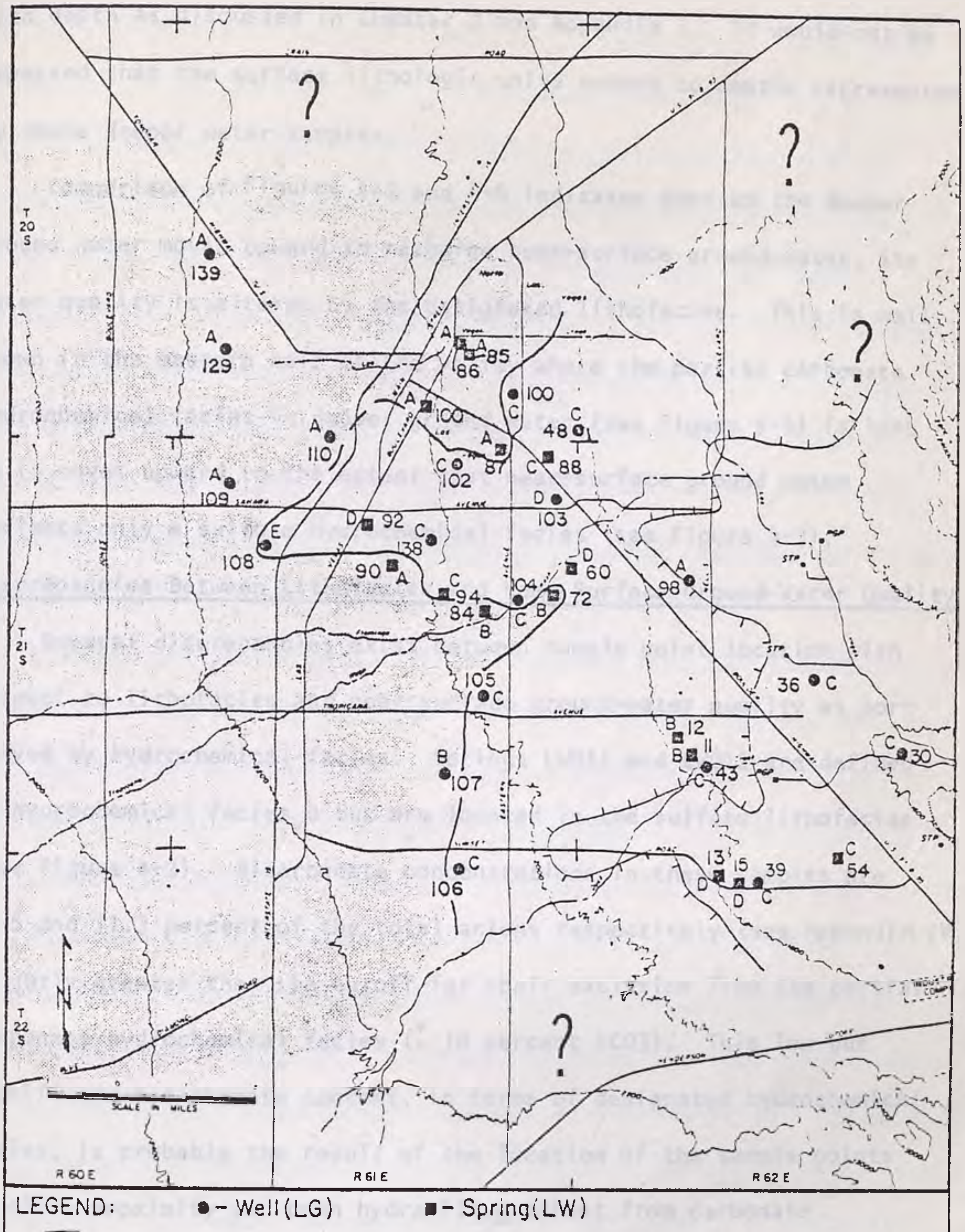


Figure 4-4. Distribution of Hydrochemical Facies in Near-Surface and Deeper Ground Water.

with depth as discussed in Chapter 2 and Appendix I. It would not be expected that the surface lithologic units extend to depths represented by these deeper water samples.

Comparison of Figures 4-2 and 4-4 indicates that as the deeper ground water moves upward to recharge near-surface ground water, its water quality is altered by the designated lithofacies. This is well shown in the eastern half of the valley where the partial carbonate hydrochemical facies in deeper ground water (see Figure 4-4) is lost as it moves upward to the extent that near-surface ground water reflects only a sulfate hydrochemical facies (see Figure 4-2).

Discrepancies Between Lithofacies and Near-Surface Ground-Water Quality

Several discrepancies exist between sample point location with respect to lithofacies and near-surface ground-water quality as portrayed by hydrochemical facies. Springs LW011 and LW012 are defined by hydrochemical facies B but are located in the sulfate lithofacies (see Figure 4-2). Bicarbonate concentrations in these samples are 11.6 and 11.3 percent of the total anions respectively (see Appendix IV), slightly greater than the cutoff for their exclusion from the partial carbonate hydrochemical facies ($\geq$ 10 percent HCO_3). This low but significant bicarbonate content, in terms of designated hydrochemical facies, is probably the result of the location of the sample points in close proximity and down hydraulic gradient from carbonate lithofacies unit Qsm (see Plate 1, Plate 2, and lithofacies boundary on Figure 4-2). Thus, one explanation is ground water from springs LW011 and LW012 may obtain its bicarbonate characteristic from carbonate lithofacies up hydraulic gradient.

Another possible explanation is that these springs represent a mixture of near-surface ground water and recharge ground water from the deeper 101 to 300 foot level. The deeper ground water has a bicarbonate hydrochemical facies at this location (see Figure 4-4). Spring LW012, known as Grapevine Spring, has been flowing since the turn of the century and has had a rather constant water quality (see Appendix III). These facts suggest that the spring has in part a deeper source which mixes with near-surface ground water to produce a mixed sulfate-bicarbonate hydrochemical facies. The escarpment along which these springs are located (see Plate 1) may be indicative of faulting which directs deep ground water upwards to recharge near-surface ground water.

Although sufficient long term water-quality data and flow records are not available for spring LW054, mixing of deep and shallow ground water may explain its anomalous sulfate hydrochemical facies (see Figure 4-2) whereas it is located in the carbonate lithofacies. Its location in the southeast corner of the study area places this spring in the general discharge portion of the ground water flow system and, therefore, it is likely monitoring a mixture of deeper, sulfate-rich ground water (see Figure 4-4) and bicarbonate near-surface ground water. In a similar manner, well LG098 is located on the boundary of the partial carbonate-sulfate hydrochemical facies for the deeper ground water (see Figure 4-4). This well, although located in the sulfate lithofacies, contains near-surface ground-water quality with a partial carbonate hydrochemical facies (see Figure 4-2). This facies is probably the result of mixing deeper ground water (101 to 300 feet deep) with near-surface ground water during the natural recharge process, particularly in light of the fact that it is located in the vicinity of an escarpment of probable fault origin (see Plate 1) which may control upward recharge.

Springs LW060 and LW094 and well LG106 exhibit sulfate hydrochemical facies but are located in carbonate lithofacies. In all cases, the sample points are very close to the carbonate-sulfate lithofacies boundary (see Figure 4-2). As discussed in Chapter 2 and Appendix I, this lithofacies boundary is an approximation due to subtle facies changes associated with alluvial fill stratigraphy. Local concentrations of sulfate in the form of gypsum are present in designated carbonate lithofacies close to this boundary and such occurrences are probably responsible for the observed hydrochemical facies at the above sample locations.

Spring LW087 has a partial bicarbonate hydrochemical facies but is located in the sulfate lithofacies. However, this spring is less than one-quarter of a mile down hydraulic gradient from the designated carbonate lithofacies (see Plate 1, Plate 2, and Figure 4-2) from which it is receiving significant bicarbonate content.

Well LG108 is the only sample in which hydrochemical facies cannot be explained with available data. Consistency in several water-quality analyses performed on this sample site located in the carbonate lithofacies indicates that analytical error is not responsible for the reported deficiency of bicarbonate in the near-surface ground water (see Appendix III). Field work indicated that there are no obvious lithologic variations in close proximity to the sample site that might produce the designated hydrochemical facies. This well is also located in close proximity to an escarpment which may be diverting sulfate enriched ground water from an unknown source upward to the near-surface ground water.

In summary, with the exception of a few sample points, near-surface ground-water quality data as delineated by hydrochemical anion facies reflects the separation of alluvial lithologies into sulfate and carbonate lithofacies. Near-surface ground water in the valley is characterized by having a predominantly sulfate-chloride hydrochemical anion facies, but sample points located in the carbonate lithofacies also contain, in most cases, a partial carbonate hydrochemical anion facies indicated by the presence of bicarbonate in concentrations exceeding 10 percent of the total anions. Similarly, those sample points located in the sulfate lithofacies do not exhibit for the most part a partial carbonate hydrochemical anion facies.

Comparison of water-quality data for ground water from 101 feet to 300 feet deep with near-surface ground water indicates that as the deeper water moves upward, i.e., recharges the near-surface water along the eastern portion of the valley, it changes from a mixed sulfate-bicarbonate hydrochemical facies to a sulfate hydrochemical facies. This sulfate dominance in the near-surface ground water is consonant with the presence of surficially mapped sulfate lithofacies in this portion of the valley. In addition, the above water-quality data implies that surficially mapped lithofacies in Las Vegas Valley extend to depths of at least 50 feet, but not to the 101 foot to 300 foot range. Examination of core borings and well logs as discussed in Chapter 2 also indicate that surficial lithologic descriptions may be generally extended to 50 feet in depth, but that sufficient detail is not available for lithologic interpretation of deeper alluvium in the study area.

THERMOCHEMICAL INVESTIGATIONS

Carbonate-Sulfate Activity

To establish more firmly the relation between lithofacies and hydrochemical facies, near surface ground-water quality was examined with respect to interaction between thermodynamic activities of sulfate and theoretical carbonate content. The theoretical carbonate content was calculated by U.S. Geological Survey Computer program WATEQ (Truesdell and Jones, 1974) from reported bicarbonate concentration at each sample point. The interaction between sulfate and carbonate can be summarized in an activity-activity diagram herein developed.

The activity of an ion is a measure of its effective concentration in a chemical reaction (Garrels and Christ, 1965, p. 5). One theoretical reaction that can be written between the ions and mineral species under consideration is

$$\underset{\text{(calcite)}}{CaCO_3} + SO_4^{2-} + 2H_2O \rightleftarrows \underset{\text{(gypsum)}}{CaSO_4 \cdot 2H_2O} + CO_3^{2-}. \qquad (1)$$

From this reaction an equation can be written relating the activity of carbonate ($[CO_3^{2-}]$) to the activity of sulfate ($[SO_4^{2-}]$) through the calculation of the standard free energy of reaction (G_r^o) and the thermodynamic equilibrium constant (K_T^o) at standard temperature and pressure. Such an equation plots as a straight line which divide the activity-activity diagram into sulfate and carbonate fields. Sulfate and carbonate water quality data for each sample point can then be plotted on the diagram with the anticipation that data points originating in sulfate lithofacies would plot in the sulfate field whereas data points located in the carbonate lithofacies should plot in the carbonate field.

The thermodynamic field boundary between sulfate and carbonate can be calculated for equilibrium conditions through the use of K_T^o and the Law of Mass Action (Garrels and Christ, 1965). The Law of Mass Action can be stated: "The product of the activities of the reaction products, each raised to the power indicated by 'its stoichiometric coefficient', divided by the product of the activities of the reactants, each raised to 'its stoichiometric coefficient', is a constant at a given temperature" (Garrels and Christ, 1965, p.6). Thus, if

$$aA = dD + eE, \qquad (2)$$

then

$$K_T = \frac{[D]^d \quad [E]^e}{[A]^a}, \qquad (3)$$

where

K_T = thermodynamic equilibrium constant at a given temperature,

$[A]^a$ = activity of a chemical species 'A' with stoichiometric coefficient 'a', and

$[A]^a$ = 1 for a solid (mineral).

Values of K_T for many mineral species have been calculated from free energy of formation by

$$\Delta Gr^o = -RT\ln K_T, \qquad (4)$$

where

ΔGr^o = standard free energy of reaction determined by calorimetric measurements (kcal),

R = gas constant (1.987×10^{-3} kcal/deg),

T = 298.15° Kelvin (25°C), and

$\ln$ = logarithm to the base e.

Equation (1) may be cast in terms of the logarithm to the base 10 (designated as log) in the form of equation (2) to yield:

$$\log K_T^{o} = \log\ [\text{gypsum}] + \log\ [CO_3^{2-}] - \log[\text{calcite}] - \log\ [SO_4^{2-}] \quad (5)$$

By definition log [gypsum] and log [calcite] = 0 and therefore, equation (5) reduces to

$$\log K_T^{o} = \log\ [CO_3^{2-}] - \log\ [SO_4^{2-}]. \quad (6)$$

Log K_T^{o} can be calculated from equation (4) by making the appropriate transformation from ln to log, multiplying by constants R and T, assuming a temperature of 25°C, and rearranging to give

$$\log K_T^{o} = \frac{-\Delta Gr^{o}}{1.3645}, \quad (7)$$

where $\Delta Gr^{o} = \Sigma\Delta G_f^{o}$ products $- \Sigma\Delta G_f^{o}$ reactants.

For the reaction in question

$$\Delta G_r^{o} = \Delta G_{f\ \text{gypsum}} + \Delta G_{f\ CO_3} - \Delta G_{f\ \text{calcite}} - \Delta G_{f\ SO_4} - 2\ \Delta G_{fH_2O}, \quad (8)$$

where

ΔG_f = free energy of formation for the mineral or ion species in question as determined by calorimetric measurement (kcal).

Using ΔG_f's tabulated by Robie and Waldbaum (1968) and Garrels and Christ (1965) to solve for ΔG_r^{o} in equation (8), equation (7) then reduces to

$$\log K_T^{o} = -3.16 .$$

Substitution of this value of log K_T^{o} into equation (6) and rearranging terms yields

$$\log\ [CO_3^{2-}] = \log\ [SO_4^{2-}] - 3.16 \quad (9)$$

which is an equation for a straight line that separates the activity-activity diagram into sulfate and carbonate fields. Selecting any value for log $[SO_4^{2-}]$, log $[CO_3^{2-}]$ is calculated from equation (9) and the two log activities are plotted to form the boundary line as indicated on Figure 4.5, line 1, Log $[SO_4^{2-}]$ versus log $[CO_3^{2-}]$ values for the 35 sample points are plotted on Figure 4-5 in which samples located in carbonate lithologies are designated by squares and those from sulfate-bearing lithologies with circles.

In general the distribution of points fall within, or close to, their respective fields, especially for those samples originating from carbonate lithologies. Only one carbonate point, LG106, falls unequivocally into the sulfate fields. The sulfate character of this data point was previously examined and thought to be linked to the relatively close association of its location to sulfate-rich lithologies in the Duck Creek drainage area.

Data points originating in sulfate lithologies have a wider scatter with many points plotting in the carbonate field (see Figure 4-5). Two general reasons for this behavior were examined: (1) temperature variation in the ground waters from 25^{o} C -- the standard temperature for which G_r^o and K_T^o are defined -- and (2) high magnesium to calcium ratio which inhibits the formation of calcite in favor of aragonite.

The boundary between fields was adjusted for a negative five degree temperature change by using the Gibbs-Helmholtz equation (Daniels and Alberty, 1966)

$$\log\left(\frac{K_2}{K_1}\right) = \frac{H^o(T_2 - T_1)}{2.303\ RT_1T_2}\ , \qquad (10)$$

where

K_1 = equilibrium constant at 25^{o}C,

K_2 = new equilibrium constant at T_2,

T_2 = temperature of interest = 20^{o}C; and

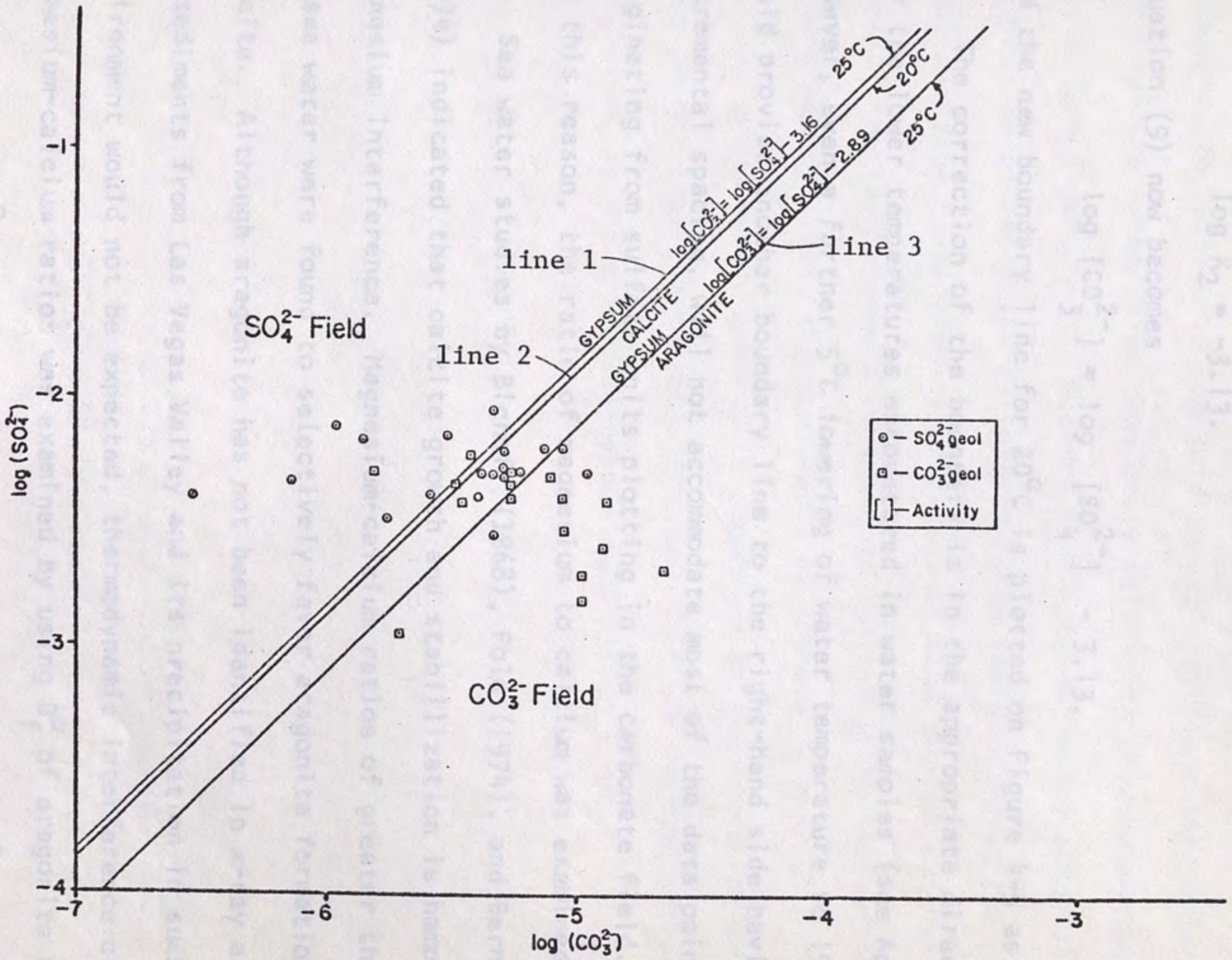


Figure 4-5. Log-Sulfate Activity Versus Log-Carbonate Activity for Near-Surface Ground Water.

H^o = enthalpy of reaction calculated from standard heats of formation H_f^o, using

$H^o = H_f^o$ products - H_f^o reactants,

and assuming enthalpy corrections for temperature other than 25°C are negligible. Rearranging equation (10) and solving for log K_2 yields

$$\log K_2 = -3.13.$$

Equation (9) now becomes

$$\log [CO_3^{2-}] = \log [SO_4^{2-}] - 3.13, \qquad (11)$$

and the new boundary line for 20°C is plotted on Figure 4-5 as line 2.

The correction of the boundary is in the appropriate direction for the lower temperatures encountered in water samples (see Appendix III). However, even a further 5°C lowering of water temperature to 15°C, which would provide another boundary line to the right-hand side having equal incremental spacing, will not accommodate most of the data points originating from sulfate units plotting in the carbonate field. For this reason, the ratio of magnesium to calcium was examined.

Sea water studies by Bichoff (1968), Fold (1974), and Berner (1974) indicated that calcite growth and stablilization is hampered by magnesium interference. Magnesium-calcium ratios of greater than 2.0 in sea water were found to selectively favor aragonite formation over calcite. Although aragonite has not been identified in x-ray analyses of sediments from Las Vegas Valley and its precipitation in such an environment would not be expected, thermodynamic interference of high magnesium-calcium ratios was examined by using G_f^o of aragonite for computation of G_r^o in equation (8) instead of calcite's G_f^o. With this new falue of G_r^o equation (7) becomes

$$\log K_T^o = - 2.89.$$

Substitution of this value into equation (6) and rearranging the terms provides the new boundary line equation

$$\log [CO_3^{2-}] = \log [SO_4^{2-}] - 2.89 \qquad (12)$$

which is plotted on Figure 4-5 as line 3.

This approach displaces the boundary in the appropriate direction to include in the sulfate activity field many data points from sulfate lithofacies previously falling in the carbonate activity field (see Figure 4-5). Absence of aragonite in the alluvial sediments may not be as important to this study as recognition of the possibility that relative concentration of dissolved magnesium to calcium might control the thermodynamic activity of ionic species in near-surface ground water. Thus, the hypothesis of lithologic control of near-surface ground-water quality is supported by the inclusion of most data points from the sulfate lithofacies in the sulfate activity field as defined by the aragonite-gypsum equilibrium curve.

Mineral Solubility

The degree of saturation of water with respect to a mineral is determined by the ratio of the ion activity product (IAP) for that mineral, calculated from water chemistry data, to the thermodynamically determined equilibrium solubility product (K_T) as calculated, say, from equation 3 or 4, page 104.

The activity of an ion (a) is a measure of its effective concentration in a chemical reaction (Garrels and Christ, 1965, p. 5,). In real solutions the activity of an ion is given by,

$$a = \delta m$$

where

a = activity,
δ = activity coefficient, and
m = molality of the ion = moles of the ion per 1000 grams of water.

The activity coefficient (δ) measures the effect of interaction among ions in solution. The theoretical value of δ is calculated by the Debye-Huckel equation modified by the MacInnes assumption to consider mean salt activity coefficients for high concentrations of dissolved constituents (Truesdell and Jones, 1974, p. 241),

$$\log \delta = \frac{-AZ^2 (I)^{0.5}}{1 + Ba (I)^{0.5}} + bI$$

where

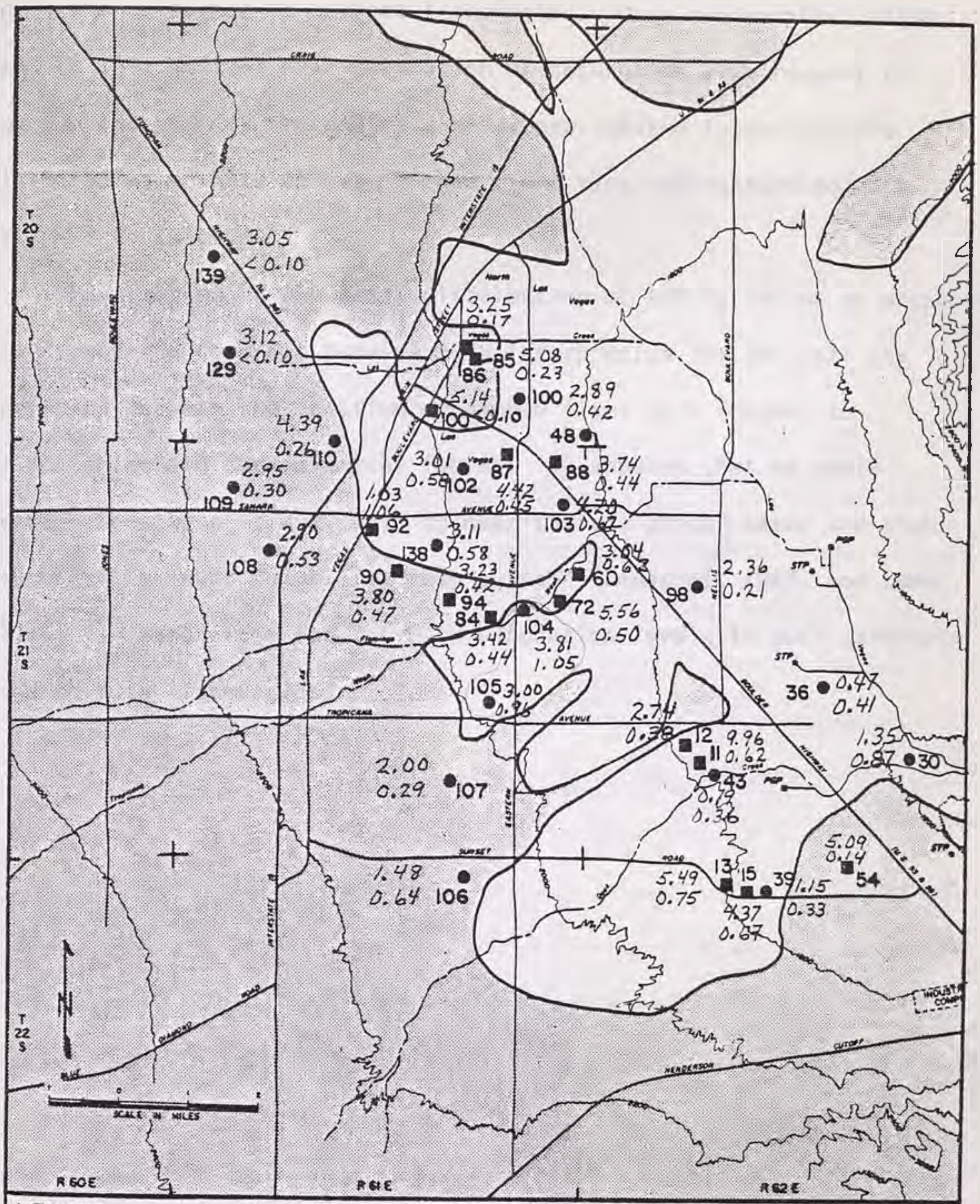
A and B = constants depending on the dielectric constant, density, and temperature.
Z = ionic charge.
$I = 1/2\Sigma m_i Z_i^2$ = ionic strength of the i^{th} ion.
a and b = adjustable parameters calculated from experimental mean salt single-ion activity coefficient.

The use of IAP and K_T for a system in equilibrium is derived from the Law of Mass Action discussed previously on page 104. Equation (3), page 104, indicates that if mineral species A is a pure solid in its reference state then $[A]^a = 1.0$ by definition and the numerator, $[D]^d$ $[E]^e$, is then an IAP which under equilibrium conditions is equal to K_T.

To assess the relation between ground-water chemistry and the mineralogy of the geologic framework, the IAP/K_T ratio was examined for each of the 35 sample points. When this ratio for a particular mineral is 1.0 the water is saturated with respect to that mineral; when this ratio is less than 1.0 the water is said to be undersaturated with respect to that mineral; and when this ratio exceeds a value of 1.0 the water is designated supersaturated with respect to that mineral and under favorable thermodynamic and environmental conditions precipitation of that mineral will occur.

For this study IAP/K_T ratios were calculated by computer program WATEQ originally developed by the United States Geological Survey (Truesdell and Jones, 1974) and updated by R. Jacobson and R. Spencer of the Desert Research Institute, Water Resources Center, University of Nevada System, Reno. The results are tabulated in Appendix V. To study the areal relation between mineral solubility in near-surface ground water with respect to the sulfate and carbonate lithofacies, the IAP/K_T ratios for calcite and gypsum were plotted on Figure 4-6. Gypsum and calcite were used because they represent the most common minerals identified in the respective lithofacies.

Thirty-three of the 35 samples exhibit saturation or supersaturation with respect to calcite. Only Wells LG036 and LG043 are undersaturated with respect to calcite (see Figure 4-6) and both of these sample



LEGEND: ● - Well(LG) ■ - Spring(LW)

Calcite IAP/K_T ratio is top number at each data point.

Gypsum IAP/K_T ratio is bottom number at each data point.

▨ = partial carbonate lithofacies.

☐ = sulfate lithofacies.

Figure 4-6. Areal Distribution of Mineral Solubility Data.

points are located in sulfate lithofacies. Only two samples, LG104 and LG 105, exhibit near-saturation or saturation with respect to gypsum and both of these sample sites are located in the sulfate lithofacies. These points, however, are also supersaturated with respect to calcite.

Examination of the areal distribution of IAP/K_T ratios as presented in Figure 4-6 does not provide much interpretive insight into the relation between the location of sample sites with respect to lithofacies and hydrochemical facies. It appears that an ample carbonate source is available to near-surface ground water and that carbonate's lower solubility than sulfate (Kauskopf, 1967, and Lamey, 1966) is responsible for its high saturation levels in both carbonate and sulfate lithofacies.

Chapter 5

SUMMARY AND CONCLUSIONS

Geologically, Las Vegas Valley is an alluvium filled basin characteristic of the Basin and Range physiographic province. The basin lowland is composed of intercalated gravel, sand, silt, and clay strata which are discontinuous on a small scale. When studied from valley-wide perspective these sediments grade from coarser materials on the west to finer sized materials in the eastern portion of the valley. The surrounding alluvial aprons are pediments. Mapping units defined on these pediments represent primarily erosional surfaces the oldest of which is the highest, the youngest the lowest. Clasts on the older surfaces are more extensively cemented by calcium carbonate than younger surfaces. The eastern pediment is underlain by highly gypsiferous strata in its southern and middle portions.

For the surficial mapping units (see Plate 1) vertical continuity to the depth of 50 feet is established through core borings that were logged in detail by soil engineering companies. These detailed logs, however, are present only in urbanized areas and lack of detail in well drilling logs prevents accurate stratigraphic control in outlying portions of the study area.

In surficial detail, defined mapping units can be classified as either having a dominance of calcareous or sulfate minerals in their matrix. Calcareous sediments exhibit one or more of the following; caliche strata between one and five feet thick cementing fine sediments or gravel, angular caliche fragments, rounded-dendritic caliche nodules, and/or carbonate hardpan within two feet of land surface in fine sand-sized sediments. Sulfate matrix can be distinguished in hand identification as having pulverulent, sugary and/or crystalline gypsum (selenite). Soils engineering companies and Soil Conservation Service also report the presence of deleterious sulfate salts of glauberite, thenardite, and mirabolite in surficial sediments.

As distinguished by field mapping units there is a distinct areal distribution of these two lithologies primarily defined by matrix composition (see Figure 2-1). The boundary between these two lithofacies, drawn on unit contacts, should not be considered exact because of the gradational nature of alluvial fill deposition. In general, however, the carbonate lithofacies is restricted to the western and southern portion of the valley and the sulfate to the eastern half of the valley.

Occurrence of ground water in the upper 50 feet of alluvium is primarily restricted to the central portion of the study area. Recharge to this near-surface reservoir in recent geologic time probably occurred through upward leakage from deeper aquifers as evidenced by spring mounds. Such natural recharge was evidenced until about 1940 by the presence of artesian wells and springs particularly in the northwestern portion of the study area. Hydraulic connection with deeper aquifers discussed by Maxey and Jameson (1948) and Malmberg (1965) is further documented by this author through interpretation of water level measurements collected from deep and shallow wells by Harrill (1975). In addition, low T.U. values indicative deep ground-water recharge are measured in sample points LG043, LG048, LW011, LW012 and LG041 (see Table 3-2). The former four data points are located along escarpments and indicate possible fault control of upward recharge to near-surface ground water (see Plate 1).

Comparison of a tritium mass balance model with average T.U. measure in near-surface ground water indicates that imported Colorado River water is not a major source of recharge. However, the average value of 25 T.U. in near-surface ground water indicates that surface water, perhaps overland flow and ponding from occassional in-valley precipitation does provide some recharge to the water table.

Near-surface ground water is much more saline than any source of natural recharge (see Table 3-3). Two major factors could be responsible for this salinity level; return flows from human activities and/or evapotranspiration concentrating effects.

Return flow to the near-surface ground water may have two effects. Leakage of imported Colorado River water from municipal water supply systems, as discerned by high tritium levels, tends to dilute salinity of natural near-surface ground water. On the other hand interpretation of nutrient data (nitrogen, phosphate, and ammonia nitrogen), chloride, TDS, and tritium levels indicates sample points that are monitoring return flows from sewage effluent irrigation, heavy fertilization and perhaps liquid waste disposal from chemical processing plants. High nitrate levels can be related to locally human-induced recharge but phosphate and ammonia nitrogen levels do not confirm or deny such interpretation. The behavior of nutrients in nature is not well understood and, therefore, it is suggested that all available data including other chemical constituents be carefully examined with respect to possible sources to delineate the presence of return flows in near surface ground water.

Based on the above analyses, 35 sampling points are thought to be indicative of natural near-surface ground water. These 35 sampling locations were used to study the relation between the surficial geology and the near-surface ground-water quality.

All major chemical variables from these 35 samples were found to closely fit a log-normal distribution and thus all measured values were transformed to log values for the following statistical analyses used to study the variance of the water-quality data.

Correlation coefficients were calculated for all pairs of the following thirteen variables: date of sample collection; field temperature of sample; and laboratory conductivity, pH, bicarbonate, chloride, sulfate, nitrate, sodium, potassium, calcium, magnesium, and TDS. Results (see Table 4-1) indicate the following:

1. Sample date and water temperature are inversely correlated as would be expected. That the date explains only 38 percent of the variation in temperature may be indicative of modifying effects of ground thickness on air and concomitant ground-water temperature.
2. Poor correlation of water temperature with all chemical variables implies that temperature does not strongly control their concentration levels or vice versa.
3. High correlation among conductivity, TDS, chloride, sulfate, sodium, calcium, and magnesium indicate that the latter five represent a major contribution to TDS and subsequently conductivity.
4. The high correlation between anions and cations suggests a common origin. Sodium's highest correlation is with chloride while potassium, calcium, and magnesium correlate more highly with sulfate.
5. Positive correlation between chloride and sulfate indicates that one does not replace the other as the major anion.
6. Nitrate and bicarbonate do not correlate well with other chemical variables nor with each other. This suggests that different factors control these variables than other measured chemical constituents discussed above.

R-mode, varimax factor analysis (see Table 4-2 and Table 4-3) re-emphasizes the inferences made above, and suggests that the variables may be grouped into three factors: factor 1 predominantly represents total salinity being composed of TDS, conductivity, sodium, sulfate, magnesium, potassium, calcium, and chloride; factor 2 is a predominantly seasonal factor composed of water temperature and adjusted sample collection date; and factor 3 predominantly represents alkalinity as measured by bicarbonate and pH. In a first trial nitrate was found to load in a positive manner with pH and bicarbonate. Because of its low communality value and lack of known chemical, geological or biological interaction with either pH of bicarbonate, nitrate was eliminated from the data base and a second factor analysis was performed. Because nitrate adds to the total variance but does not correlate well with other variables, its exclusion in this second trial leads to an increase in the total variance explained but the results in terms of the other variables remain essentially the same.

Student's t-test indicates that all major ions exhibit significant difference in concentration (at the 95 percent confidence level) between sulfate and carbonate lithofacies (see Table 4-4). In all cases except bicarbonate, the mean log concentrations are higher in the sulfate lithofacies possibly due to several interrelated mechanisms that would increase the amount of dissolved constituents: (1) this lithofacies is the furthest down gradient in the ground-water flow system; (2) mapping units which compose sulfate lithologies are finer grained allowing for more granular surface area and greater retention time for ground water flowing through this lithofacies; and (3) in general, sulfates are more soluble than carbonates.

The non-significant difference of date, temperature, pH, and nitrate between the two types of lithofacies is consonant with calculated correlation coefficients discussed previously. That pH does not differ between the lithofacies catagories indicates that the hydrochemical system is buffered with respect to changes in ionic composition of near-surface ground water. Nitrate's behavior suggests that its concentration due to return flows and/or natural concentration due perhaps to buried organics or nitrogenous strata is not restricted to any particular lithofacies.

Analysis of variance in hydrochemical variables among three lithologic categories indicates that gypsum content as qualitatively assessed by hand specimen reflects significant difference (at the 95 percent confidence level) in all hydrochemical ionic species except magnesium and bicarbonate (see Table 4-5). The more prevalent gypsum, the higher the mean log values are for TDS, chloride, sodium, potassium, calcium and sulfate.

A trilinear diagram plot (see Figure 4-1) of major ions found in water samples from the 35 sampling points defines near-surface ground water as having a calcium-magnesium, sulfate-chloride hydrochemical facies. There is a slight bicarbonate anion facies shift exhibited by those data located in carbonate lithofacies. Areal distribution of hydrochemical facies is in general agreement with lithofacies distribution (see Figure 4-2). That is, ground-water sample points exhibiting partial carbonate hydrochemical facies are for the most part located in the western portion of the study area where carbonate lithology is predominant.

SAR ratios calculated for the 35 near-surface ground-water sample points represent no general areal pattern in the study area (see Figure 4-3). Neither an increase nor a decrease was recognized in the ratio in the direction of hydraulic gradient. This suggests that either lateral flow is not extensive in near-surface ground water or that cation exchange of sodium for calcium and magnesium is not occurring with lateral flow.

Comparison of hydrochemical facies for near-surface ground water and ground water from the 101 to 300 ft zone (see Figure 4-4) suggests that as the deeper ground water moves upward to recharge the more shallow zone, it comes into contact with the sulfate lithofacies and changes from a partial carbonate to sulfate hydrochemical facies.

An activity diagram of sulfate versus theoretical carbonate content of near-surface ground water indicates that sulfate and carbonate ionic concentrations are in agreement with sampling locations with respect to sulfate and carbonate lithofacies (see Figure 4-5). Best agreement between sulfate lithofacies and sulfate ionic concentration in water samples is obtained when a high magnesium to calcium ratio is theoretically considered to inhibit calcite formation in favor of aragonite.

Thermodynamic mineral solubility calculations indicate that 32 of the 35 sample points are supersaturated with respect to calcium carbonate as represented by calcite (see Figure 4-6). On the other hand only two samples are near saturation or saturated with respect to sulfate mineral species, this in the form of gypsum. These two points are located in the sulfate lithofacies but are also supersaturated with respect to calcite.

The above analyses indicate that there is a direct relation between type of lithofacies and near-surface ground-water quality; that is, near-surface ground-water samples in the carbonate lithofacies has a partial carbonate hydrochemical facies where as near-surface ground water within the sulfate lithofacies is defined by only a sulfate hydrochemical facies. However, a cause-effect relationship between lithofacies and hydrochemical facies is not easily established.

The minerals used to differentiate the lithofacies, i.e., carbonate and sulfate, are of secondary origin most probably emplaced by evapotranspiration processes acting on both surface and ground water initially containing carbonate and sulfate ions (see Chapter 2). It could be argued that present carbonate enriched near-surface ground water is responsible for the deposition and concomitant formation of carbonate lithofacies in the western and southern portion of the study area where as the formation of the sulfate lithofacies are due to evapotranspiration processes acting upon sulfate enriched near-surface ground water. On the other hand, it could be argued that sediment mineralogy, established through a long depositional history, is imparting its chemical signature upon present near-surface ground-water quality.

Both of the above cases have probably been active throughout the hydrologic-geologic history of Las Vegas Valley. As discussed in Chapter 2, playa-type processes are responsible for accumulation of both carbonate and sulfate enriched strata through time. Sediments in the eastern portion of the valley have considerably more sulfate because of their relative close proximity to sulfate sources in the Sunrise-Frenchman mountain block boarding this side of the study area (see Figure 1-1 and Plate 1). Sediments in the western half of the study area are less influenced by eastern sulfate sources and are dominated by carbonates to the west found in the Spring Mountains and extensive alluvial fan deposits composed primarily of limestone-dolomite clasts (see Chapter 2, Plate 1, and Appendix I for description and location of lithologies). The enrichment of sulfate in the eastern portion of the study area is also enhanced by sulfate's greater solubility than that of carbonate. Some sulfate present in sediments in the western half of the study area could be leached over geologic time by both overland flow and ground water and subsequently redeposited in the eastern part of the valley, the lowest portion of the valley and principal discharge zone for ground water.

The magnitude of lateral flow in the near-surface ground water becomes a critical point with regards to deposition and subsequent definition of lithofacies based on secondary minerals. It could be argued that a strong lateral flow component active most recently in the near-surface ground water could be responsible for the areal distribution of carbonate verses sulfate lithofacies. According to the hydraulic potential map (see Plate 3) ground water would be moving from west to east across the study area. Concentration of ions in the ground water to the point of supersaturation from evapotranspiration processes would tend to first precipitate calcium carbonate out of solution due to its lower solubility (Krauskoptf, 1969) to form the carbonate lithofacies and then precipitate the more soluble calcium sulfate further down hydraulic gradient to form the sulfate lithofacies in the eastern part of the valley.

When considered jointly, several pieces of evidence gathered during this study suggest that the above situation is not very prominent. Statistically, analysis of variance for chemical variables among three categories of sediment lithologies (see Table 4-5) indicates that significantly higher values (at the 95 percent confidence level) of chloride, sodium, calcium, and potassium and higher values (but not significantly so at the 95 percent confidence level) of TDS and sulfate are found in treatment 1. The units which comprise this treatment (units Qgcs or Qmg, see Plate 1) are not located in the most distal portion of the ground-water flow system where it would be expected that dissolved solids would be most highly concentrated. This suggests that the effects of lateral flow are minor and that the larger concentration of calcium sulfate observed in these two map units is in part responsible for higher concentrations of the above dissolved constitutes rather than concentration due to lateral flow only.

The lack of any distinct pattern in SAR values (see Figure 4-3) in near-surface ground water may also suggest that lateral flow and concomitant cation exchange do not occur on any large scale.

Examination of calcite and sulfate solubility calculations (see Figure 4-6) indicate that near-surface ground water is supersaturated with respect to calcium carbonate in 32 of the 35 sample points. All sample points located in the sulfate facies except wells LG036, LG048, and LG043 are supersaturated with respect to calcite. If lateral flow and accompanying evapotranspiration processes are responsible for areally selective precipitation of carbonate and sulfate, secondary carbonate minerals should be found in the sulfate lithofacies because of carbonate's supersaturation and lower solubility than sulfate. This is to say that if the sulfate present in the sulfate lithofacies map units is being formed by lateral flow and evapotranspiration processes going on at present, then carbonate should precipitate out of solution before sulfate and, therefore, be found in the sulfate lithofacies. This is not the observed case. The sulfate lithofacies is relatively free of carbonate minerals (see Chapter 2, Plate 1, Appendicies I and II for lithologic description of map units found in sulfate lithofacies).

In light of the above discussion there are several pieces of evidence that suggests that lithofacies are imparting some control upon hydrochemical facies. If the concept of minimal lateral flow is accepted, the increase in bicarbonate content of near-surface ground water in the carbonate lithofacies suggests that this lithofacies is to some degree influencing the hydrochemical facies. In addition, the increase in mean log concentration values of all major constituents in treatment 1 map units presented in the analysis of variance (see Table 4-5) and as discussed above, indicates that these units, containing the most abundant gypsum, impart the highest dissolved solids to near-surface ground water. This is consonant with the fact that sulfate is the most soluble of the salts identified in the lithofacies, and it should be expected that ground water moving through these units would dissolve more minerals and, therefore, contain more total dissolved solids than elsewhere in the hydrogeologic system.

A third piece of evidence for lithofacies influencing near-surface ground-water quality lies in comparing the hydrochemical facies from the 101-300 ft zone (Kaufmann, 1976) with near-surface ground water quality (see discussion on pages 96-99). As indicated in Figure 4-4, ground water from the 101-300 ft zone in the east-central portion of the study area changes from a partial bicarbonate to a sulfate hydrochemical facies as it rises vertically to recharge near-surface ground water and comes into contact with sulfate lithofacies.

In summary, alluvial deposition in a playa-like environment from the Pliocene (?) through the Pleistocene Epoch has resulted in filling

Las Vegas Valley with both carbonate and sulfate enriched strata through surface and perhaps ground-water processes. The sulfate lithofacies is most heavily concentrated in the eastern portion of the study area where it is in close proximity to sulfate sources in the Sunrise-Frenchman Mountain block. The carbonate lithofacies is found in the western portion of the study area, deriving its carbonate content from sources to the west. Near-surface ground water in these lithofacies has an average TDS of approximately 3000 mg/l due to evapotranspiration processes, and represents a prodominantly sulfate hydrochemical facies due to the greater solubility of sulfate than carbonate. However, statistical techniques, hydrochemical facies interpretation, and thermochemical investigations indicate that lithofacies exert some influence on the quality of ground water presently encountered within 50 feet of land surface.

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APPENDIX I: Detailed Description of Surficial Geologic Map Units[1/] and Other Geologic Features in Las Vegas Valley, Nevada.

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1. See Plate 1 for Geologic Map.

INTRODUCTION

The purpose of this Appendix is to describe the geologic features observed by this author pertinent to the development of lithofacies described in Chapter 2, and to present this author's findings and review of other geologic features that have been discussed in other studies in Las Vegas Valley.

For these purposes this Appendix is divided into three parts; (1) the stratigraphic description of sediments found in both the alluvial aprons and basin lowland, (2) a discussion of prominent escarpments, and (3) a brief review of earth fissuring found in Las Vegas Valley.

ALLUVIAL APRONS

Mapping units on the alluvial aprons are primarily delineated by drainage and weathering patterns expressed on aerial photographs. Field investigations indicate that discerned patterns are related to different aged erosional surfaces developed on pediment surfaces called bajadas. Lithologic differences between surfaces on a particular bajada are slight because clast lithology is controlled by bedrock lithology of the mountains from which the alluvial aprons extend. For this reason mapping units used are more correctly defined as geomorphic units rather than stratigraphic and are so designated on Plate 1.

Differences between surfaces are generally related to the degree of induration by calcium carbonate cement (caliche) and minor changes in clast lithology. These differences are discussed under the appropriate section below.

Western Bajada: Mapping units on the western alluvial apron are divided into three surfaces, W1, W2, and W3. Unit W1 is a surface composed by a fanglomerate of predominatly rounded limestone and dolomite pebbles and cobbles cemented by calcium carbonate matrix. It is the highest and subsequently the oldest surface of the western bajada and is littered with fragments of broken fanglomerate. Test pits excavated to a depth of ten feet by local gravel companies and wash cuts (see Figure A1-1) exhibit laterally discontinous, graded lenses of clasts ranging from pebble to cobble size which are highly cemented with calcium carbonate.

Unit W2 is the next oldest surface. It is composed of uncemented, predominantly subangular to subrounded limestone-dolomite pebbles that show evidence of once having caliche rinds that have been subsequently abraded. Subsurface exploration pits exhibit tightly packed, thin discontinuous lenses of pebbles and cobbles slightly to heavily indurated by calcium carbonate cement.

Unit W3 is a surface where present day surface runoff is prevalent. Size of predominately limestone-dolomite clasts ranges from pebbles to cobbles which are present in distinct bars in many cases. Caliche fragments are rare. Stream-cut washes expose moderately sorted lenses of clasts indurated with fine sand and silt matrix with scattered pulverulent gypsum and occasional sand lenses. This surface has a distinctly fresher appearance than W1 and W2 and in general has shallow but numerous anastomosing channels.

Boundaries between these units vary from being very distinct on aerial photographs and in the field to gradational where very active

Figure A1-1. Map unit W1 containing laterally discontinuous, graded lenses of limestone-dolomite clasts. Unit is cemented with calcium carbonate.

surface drainage does not exist. Likewise, the boundary between these alluvial apron units and the basin lowland units is rather indistinct because surficial drainage tends to distribute apron clasts onto the lower lying sediments in thin, discontinuous patches. Additionally, the processes responsible for the development of alluvial aprons and deposition in the basin lowlands were probably concomitant to some extent producing interfingering of deposits that become even more intermixed upon subsequent reworking. This, along with the general decrease in clast size towards the distal portions of the apron, make differentiation of units difficult at the apron-lowland boundary.

The discussion above concurs with Lattman's investigation (1971) of the geomorphic history of the alluvial apron in the Kyle Canyon region north of the present study area. Lattman also found three distinct surfaces developed by erosion on the western bajada. These surfaces are differentiated by surface elevation and freshness of appearance. The oldest surface is the highest and has the best developed desert pavement and calichification while the youngest surface is the lowest having the poorest development of the above features.

The present investigation is also in general agreement with a study by Cooley, et al. (1973) concerning caliche surfaces on Red Rock Canyon fan, directly west of the area presently being considered. Some disagreement does occur in a small area along the southern boundary of the Cooley, et al. (1973) study where Tropicana wash is actively modifying the land surface. Correlation of map units indicates that surface W1 of the present study is the intermediate high level surface of Cooley, et al. (1973);

surface W2 matches both the A and B low level surfaces of Cooley *et al.* 1973); and surface W3 is equivalent to the modern washes.

Southern Bajada: In the south and southeastern portion of the study area the alluvial apron bordering the McCullough Range is a complex distribution of pedimented surfaces composed of volcanic clasts which have as their origin Mt. Davis and Patsy Mine Tertiary volcanics that form the McCullough Mountains. Differentiation of mapping units was principally accomplished by interpreting surface patterns on aerial photographs. Subsequent field checking permitted this investigator to discover differences in lithology, size distribution, and surface drainage networks that are responsible in part for the distinct patterns. Boundaries of some map units in the southeast are modified from an unpublished surficial geologic reconnaissance map prepared by Bingler and Luza of the Nevada Bureau of Mines.

The present study agrees with earlier works by Cooley *et al.* (1974) and Kaplan (1973). Both these authors map three different erosional surfaces on the southern bajada proper. Their oldest surface (upper surface) corresponds to surfaces S1 and S2 mapped by this author (see Plate 1), their middle erosional surface to S3 in the present study, and their lower surface to S4 in the present study. The surface designated S5 by this investigator is not in the study area considered by either Kaplan (1973) or Cooley, *et al.* (1974) and surface S6 is considered by them and the present author to be the modern drainage surface. The surfaces mapped for the present study are described below.

Unit S1 is the highest and subsequently the oldest surface of the southern bajada. Its subdued drainage pattern and light gray tone on aerial photographs are distinctive. The light gray tone is due to the dense surface lag of pebble size caliche fragments. Scattered, weathered, subrounded volcanic boulders and cobbles are also present. Incised gullies exhibit extensive, hard, fractured, crystalline caliche underlain by a dense caliche which entrains volcanic cobbles (see Figure A1-2). This latter strata is defined by Cooley, et al. (1974, p. 20) as boulder caliche.

Unit S3 forms the next apparently younger surface due to its lower topographic position than S1. Its mottled gray surface on aerial photographs is a result of dense lag composed of a mixture of volcanic pebbles and caliche fragments on interfluves and black volcanic clasts concentrated in drainages. Caliche development is not as laterally continuous as in unit S1 but is still extensive.

Unit S4 is topographically lower and therefore apparently younger than unit S3. Its speckled, dark gray mottled surface on aerial photographs is a result of the distribution of caliche fragments and volcanic cobbles and boulders. Well defined desert varnish on dense volcanic lag situated on the interfluves produces the dark gray surface while the light speckled appearance is due to the patchy concentration of caliche fragments (see Figure A1-3). Caliche is less extensive than Unit S3 but is still present in the interfluves as a discontinuous petrocalcic horizon containing cemented volcanic clasts of pebble through boulder size. Drainage bottoms also contain discontinuous boulder caliche which is similar to fanglomerate in appearance but not laterally continuous.

S6 is the lowest and subsequently the youngest surface on the

Figure A1-2. Crystalline caliche underlain by boulder caliche in map unit S1 . Boulders are of volcanic composition.

Figure A1-3. Surface of map unit S4 demonstrating desert varnish developed on volcanic clasts in foreground and caliche fragments in background which produce a speckled surface on aerial photographs.

southern bajada. Like units W3 and E3 on the western and eastern alluvial aprons respectively, it represents a surface of present day drainage. Its surface is dissected with numerous rills having an anastomosing pattern. Clasts composing the surface are predominantly subrounded pebbles and cobbles of volcanic and caliche litholgy. Some interfluves contain small boulder size volcanics distributed in fluvial bar-like form. Very minor caliche is present in the subsurface although some deeper drainages have boulder caliche at their bottoms.

The units described above have a distinctly calcareous matrix. However, on the distal end of the southern bajada, Paradise Mesa, Whitney Mesa, and the intervening lowland (unit Qgcs) contain abundant pulverulent gypsum in the matrix of their upper surfaces.

Paradise Mesa is separated from the bajada to the south by a major unnamed drainage, but its surface and that of Whitney Mesa have the appearance of an old alluvial surface perhaps comparable in age to unit S1 on the bajada proper. Although removal of the latter unit by erosion separates it from Paradise Mesa and Whitney Mesa by two and five miles respectively, previous interpretations by Longwell, et al. (1965), Kaplan (1973), and Cooley, et al. (1974) suggest that the surfaces of the two mesas may represent the distal portion of an old alluvial surface such as comprised by unit S1.

For the present study, surfaces of Paradise and Whitney Mesa are designated as unit S2 because of the uncertainty of age correlation and dissimilar lithologic composition between unit S1 and these surfaces. The interior portion of unit S2 is composed of moderate to dense lag of caliche fragments generally 6 inches or less in diameter beneath a moderate to light lag of subrounded to subangular volcanics. Towards the edge of

Paradise Mesa where active drainage is taking place caliche fragments are absent and the surface is composed of dense volcanic lag of predominately cobble size underlain by a silty sand matrix containing a large amount of gypsum. Aerial photographs show a distinct tone difference which effectively delineates this change; the caliche fragments have a light gray tone whereas the volcanics have a black tone. Exposures in test pits, active drainages, and railroad cut embankments emphasize the abundantly gypsiferous sand-silt nature of subsurface sediments which also contain subrounded volcanic pebbles in laterally discontinuous fluviatile lenses. Edges of the Whitney Mesa surface exhibit similar characteristics but there is an apparent decrease in the amount of gypsum present with depth Subsurface exposure in a road cut on Mountain View Boulevard (section 32 caa, T21S-R62E) and along the escarpment forming the Mesa (see figure A1-4) indicate that only a few feet of the upper surface contain gypsum. A two to five foot thick volcanic clast fanglomerate unit lies beneath this gypsiferous layer which is in turn underlain by about 100 feet of laterally continuous strata of reddish tan sands separated by dark red paleosols. These strata are case hardened at the surface and apparently internally indurated with calcium carbonate. Because of the vertical nature of exposure these lower sediments cannot be depicted on the geologic map but they are probably part of the Muddy Creek formation (Longwell, *et al*. 1965).

The surface between Paradise and Whitney Mesas is designated as unit Qgcs. It is composed of light to dense caliche fragment lag resting on highly pulverulent gypsiferous tan silty sand. At places pulverulent gypsum forms flower petal-like structures on the surface

Figure A1-4. East face of Whitney Mesa, section 32da, T21S-R62E. Light tan gypsiferous upper surface is underlain by fanglomerate which unconformably overlies alternating strata of light tan silty sand and reddish brown paleosols both of which are indurated with calcium carbonate cement. Total height of face is approximately 50 ft.

apparently filling solution channels in the sand. There are patches of dense volcanic cobble size lag scattered on the topographically higher portions of this unit.

Another distinctive bajada borders the southeastern portion of the study area. Unit S5 is composed of a dense surface lag of predominately red, pebble size, angular volcanic debris carried off the east and northeast portion of the McCullough Range. Gravel pits indicate the subsurface to be tightly packed volcanic cobbles with a fine sand matrix and no cementing agents. Because of its topographic position this investigator believes it is similar in age to unit S4 but has as a source of debris unit Tpm rather than unit Tmd.

For the most part the contacts of the above described units are delineated easily on aerial photographs due to tone and drainage pattern distinctions. However, interpretation is difficult both from aerial photographs and field studies in the area just south and east of Paradise Mesa (section 17a and b and section 9c, T22S-R62E). The confluence of several large, modern washes in this area has destroyed the distinctive mapping features associated with the units described above and has in part intermixed these units. A more detailed examination of this area is not warranted for the scope of this study.

Boundaries of the southern bajada with basin lowland deposits are rather sharp, occurring along active washes. Some difficulty was encountered in projecting the northern boundary of unit S6 in sections 22 and 23, T22S-R61E. This is an active fan wash area and small clasts from the bajada cover the underlying basin lowland units to form a thin gravel veneer. Additionally, the appearance of volcanic boulder caliche in arroyos cutting through basin lowland unit Qs in section 21d, T22S-R61E, suggests that development of the bajada was concomitant and interfingers with lowland depostion. Therefore, the placement of the bajada-lowland boundary is an interpretive decision and should be considered approximate.

Eastern Bajada: The eastern border of the study area is bounded by Frenchman and Sunrise Mountains composed of bedrock formations of Precambrian and Paleozoic age. For the present study these formations are described adequately by Longwell, et al. (1965). Lithologies of the bajada developed from the mountain front to the basin lowland reflect the lithology of that portion of the mountains which head the drainage of a particular surface on the bajada.

The middle and southern portions of this alluvial apron are a well defined pediment developed on the Muddy Creek Formation (unit Tmc) which consists of reddish tan, gravelly, gypsiferous sandy siltstone where exposed in many natural drainages. Strata of gypsum also crop out of the Muddy Creek. Such relations are not observed in the northern portion of this bajada where the Muddy Creek Formation is not exposed at the surface nor encountered in drilling logs at depth. In the northern portion the process of pedimentation has occurred on older, underlying alluvial fan gravels.

Most of the units delineated on the bajada can be differentiated on aerial photographs by color tone, topographic expression, and drainage pattern. However, active gravel mining and subsequent changes in natural drainage obscure several contacts particularly in sections 2 and 11, T21S-R62E.

As mentioned above the Muddy Creek Formation (Tmc) underlies the southern and middle portion of the eastern apron where it crops out along drainages and in window-like fashion beneath the younger overlying veneer of alluvial clasts. It is probably the oldest unit comprising the bajada, having been given a tentative age of Pliocene by Longwell, et al. (1965). Where it crops out in drainages near the mountain front (section 13, T21S-R62E), the unit contains many gypsiferous gravel lenses that grade downward into sandstones and siltstones. However, gravel units do not extend far down the bajada and as the formation approaches the present basin lowland, fine-grained units accompanied by gypsum strata one to five feet thick persist.

Based on its topographic expression surface E1 appears to be the next oldest unit on the eastern bajada. This surface is delineated on aerial photographs by its light gray color and incised rather linear drainage. Its steeper slope than surrounding surfaces may be due in part to faulting as expressed by escarpments that border portions of both the lower and upper boundary of this unit. The surface consists of a sparse lag of pebble size caliche rubble and occasional limestone-dolomite clasts with a deflation sand matrix. Wash cuts expose irregularly packed and laterally discontinuous lenses of limestone-dolomite pebbles intermixed with lenses of sugary gypsiferous silts and clay. Occasional cobble size limestone-dolomite clasts are scattered throughout.

Unit E2 forms a surface adjacent to unit E1. Its dendritic drainage pattern as seen on aerial photographs and surface composition of moderate to dense surface lag of predominantly pebble size caliche fragments and limestone-dolomite clasts with caliche rinds distinguish this unit. Modern washes disclose a very silty, thick bedded subsurface of pebble-sized subrounded limestone-dolomite clasts. No gypsum is apparent. High topographic position and lag of large caliche fragments suggests that this is an old surface which is presently undergoing destruction.

Unit E3 forms the largest surface on the eastern bajada. Its topographic position suggests that it is younger than the units described above but older than surface E4 to be discussed next. The E3 surface is composed of a dense lag of subangular to subrounded limestone-dolomite clasts with minor amounts of red sandstone ranging from boulder size at the mountain fronts to cobble size at the distal portion of the unit. Foundation excavations and modern washes disclose a subsurface of coarsely interbedded subangular limestone-dolomite boulders and cobbles tightly packed with a nongypsiferous sand matrix on the upper slope grading to interbedded lenses of subangular to subrounded limestone-dolomite cobbles and pebbles tightly packed with a gypsiferous sand matrix on the lower slopes.

Surface lag of unit E4 reflects the Precambrian igneous and metamorphic composition of the mountain front from which it originates. The surface is predominately composed of limestone-dolomite cobbles intermixed with granitic and metamorphic clasts which tend to darken the surface tone on aerial photographs. The size of lag grades from large cobbles at the proximal end to small cobbles and pebbles in the distal portion of the surface. The subsurface as exposed in washes in the upper portion of the unit is predominately intermixed, tightly packed, subrounded limestone-dolomite boulders and cobbles. Gypsum is not observed.

Unit E5 is essentially the same as unit W3 described on the western bajada. This unit which has been heavily quarried on the eastern bajada, consists of subrounded limestone-dolomite pebbles with scattered cobbles present in distinct fluvial bars. Wash cuts and quarries expose moderately sorted lenses of limestone-dolomite boulder to pebble-sized clases with occasional sand lenses. Fluviatile cut and fill structure is evident, and a negligible amount of gypsum is found. No caliche-type fragments or nodules are present.

The contacts of the above discussed bajada units with the basin lowland units are distinct on aerial photographs in the northern portions of the alluvial apron although field determinations proved difficult due to surface outwash and interfingering of the units as discussed previously. Gravel mining and farming have obscured this contact in the central portion of the bajada (sections 3, a and d; 10 a and d; and 15a, T21S-R62E). Additionally, most contacts between units on the bajada are not easily delineated on aerial photographs and care was needed in the field to establish approximate boundaries.

BASIN LOWLAND

Basin lowland deposits consists primarily of sand, silt, and clay generally intermixed to some degree. Some pebble and small cobble horizons are present. Distinction between mapping units is based on particle size, lithology, degree and type of cementing agent present, and topographic expression.

This investigator believes that the oldest basin lowland sediments belong to the Muddy Creek Formation which underlies and crops out along the eastern face of Whitney Mesa (see Figure A1-4). This formation has been given a Pliocene age by Longwell, et al. (1965, p. 49). These sediments closely resemble representative exposures in Muddy Valley, Nevada, from which Stock (1921) first proposed the name Muddy Creek Formation. The orangish, reddish tan, regular bedded, fine-grained sandstones, siltstones, and clay facies are extensively mapped by Longwell, et al. (1965, Plage 1) in the northeastern portion of Clark County, Nevada, and are thought to represent playa type deposits.

The next oldest basin lowland sediments are probably correlative to the Las Vegas Formation as defined by Haynes (1967) at Tule Springs, Nevada, just north of the present study area. Map units Qsm, Qsw, Qgcs and perhaps Qmg (see Plate 1) are probably middle to late Pleistocene in age based on (1) their lithologic similarity to the Las Vegas Formation described and dated by Haynes (1967) at Tule Springs, (2) late Pleistocene ostracod valves reported by Price (1966, p. 24), and (3) camel remains found in section 23a, T22S-R61E (personal communication, E. Bingler, Nevada Bureau of Mines). Reworking of these sediments has occurred through Holocene time, especially in the areas of Duck Creek and Tropicana, Flamingo, and Las Vegas Washes. This reworking plus the varied local environments of depostion (Haynes, 1967) make it difficult to assign relative ages to the various mapping units in the present study area. A relative time scale is established in the geologic map explanation (see Plage 1) based on tentative stratigraphic relations interpreted by this investigator. A description of all basin lowland units follows with the exception of Tmc which was previously discussed.

Unit Qsc is only locally exposed where quarrying, road cuts, or drainages have cut through overlying surficial deposits. Mappable exposures occur in the northern portion of the study area where it is composed of red or green clayey, silty sand layers of one foot or thicker strata. Strata may be weakly cemented by calcium carbonate, and occasional pebble lenses are present.

Unit Qs is distinguished by the occurrence of abundant calcium carbonate cement in layered light reddish tan to gray white, silty sands separated by paleosols as shown in Figure A1-5. Calcium carbonate takes the form of extensive caliche layers which crop out or form the surface and/or branch-shaped carbonate nodules growing within the sandy matrix. These nodules become fragmented when exposed to surface weathering. Core borings (see Plate 1 and Appendix I) indicate the existence of multiple layers of caliche intercalated with calcareous silty sands.

Unit Qsm contains the same calcareous silty sand but has a dense to moderate lag consisting of both subrounded to rounded carbonate nodules and limestone-dolomite cobbles and pebbles. The silty sand and presence of nodules in the lag suggests that unit Qsm may be essentially the same as unit Qs but contains coarse clastic lenses which produce limestone-dolomite lag when weathered at the surface. Core borings located in unit Qsm indicate the presence of gravel stringers with depth (see Plate 1 and Appendix I). Sugary gypsum is present in local areas.

Likewise, unit Qsw resembles unit Qs except its surface is composed of fine sandy silt and/or clay with or without moderately

Figure A1-5. Layered reddish tan sand, gray-white sand, and caliche strata composing map unit Qs near intersection of Tropicana Avenue on Decatur Blvd., section 24da, T21S-R60E. Strata are interbedded with 1 ft thick paleosols distinguished by their prismatic soil structure and chaotic appearance. Two paleosol layers are located just above spade portion and handle top of shovel.

dense lag of rounded caliche pebbles. The absence of limestone-dolomite pebbles distinguishes this unit from unit Qsm. Test pits dug by this investigator indicate that the fine materials become cemented with calcium carbonate within two feet of land surface suggesting this unit is similar to unit Qs.

Unit Qmg occupies areas of active drainage cut through unit Qsm in the southern half of the study area. Characteristic topography is one of rolling knolls dissected by active stream washes. The surface is composed of fine sand and silt with abundant gypsum in pulverulent and selenite crystal forms (see Figure A1-6). A surface lag may be present which consists of predominately rounded limestone-dolomite pebbles (or volcanics in the Whitney Mesa area) with rounded caliche fragments near upslope contacts with caliche-bearing units. The subsurface is exposed in many wash cuts particularly along a mile and one-half segment of Flamingo Wash starting at Maryland Parkway and transversing downstream to the east. Figure A1-7, a picture taken of the south bank of Flamingo Wash just east of Maryland Parkway (section 14 ccb, T21S-R61E), demonstrates fluviatile cut and fill structures associated with gravel lenses. Abundant pulverulent and sugary gypsum indurate all sediments, and strata in the bottom of washes are commonly cemented with calcium carbonate in and around the contact between unit Qmg and unit Qsm.

Unit Qgg is present in elongated lobate hills in the northeastern portion of the study area. This unit is composed of cobble to pebble-size gravel layers interbedded with silty sand layers all of which contain abundant gypsum. Both types of layers appear to be laterally

Figure A1-6. Selenite crystals in map unit Qmg at the intersection of Flamingo Wash and Maryland Parkway, section 14c, T21S-R61E.

Figure A1-7. Fluviatile cut and fill gravel lenses in map unit Qmg on the south bank of Flamingo Wash at Maryland Parkway, section 14ccb, T21S-R61E.

continuous and those observed are approximately three feet thick.

Qalg and Qals are present-day unconsolidated gravels and sand-silt-clay units respectively. Qalg is composed of interbedded lenses of subrounded to rounded cobbles, pebbles, and sand, the cobbles and pebbles being of predominantely limestone-dolomite lithology with occasional red sandstone clasts. The coarser clast material has abundant sandy-silt matrix and no gypsum or carbonate cement is apparent. This unit is located extensively in modern drainages in the northern part of the study area where flash flooding has been known to occur and also forms modern washes on the bajada surfaces, the clasts reflecting the predominant lithologies associated with the bajada in question.

Unit Qals is composed of sand to clay sized material with occasional pebble lenses indicative of fluvial deposition (see Figure A1-8). It forms on drainage surfaces that have very gentle slopes. Occasionally calcium carbonate but more commonly sulfate salts are found as surface residue and at depth within the unit.

Unit Qd is composed of eolian sand and silt which forms noticeable accumulations at the surface. In some instances this eolian material forms accumulations one foot thick or less at the base of vegetation while in other places large sand-dune fields have been formed (see Figure A1-9). It is certain that eolian sand is present at the surface in all basin lowland units discussed above and in some cases may distort the true size fraction comprising these various units at land surface.

ESCARPMENTS

Prominent escarpments aligned in a north-south direction are shown

Figure A1-8. Fluvial clay, silt, sand, and gravel lenses in map unit Qals. Upper portion of sediments is distorted due to soil-forming processes.

Figure A1-9. Sand dune field formed in the vicinity of Pecos and Oquendo Roads, section 36a, T21S-R61E.

on the geologic map (Plate 1). These features cut across present day drainages and have an approximate relief of a few to over 100 feet in a horizontal distance less than 500 feet.

Three general theories have appeared in the literature concerning the origin of escarpents in the study area: they are erosional in origin, they are fault controlled, or they are both. Price (1966) reviews the available evidence concerning these three theories, some of which is incorporated into the following discussion.

Several observations suggest that these escarpments are due to fault displacement. Maxey and Jameson (1948, p. 69) and Domenico _et al_. (1964, p. 15) documented the displacement and tilting of a blue clay horizon in alluvial fill along the major escarpment trending north-south through the center of downtown Las Vegas (sections 15, 22, 27, and 35, T20S-R61E). This horizon was recognized in drillers' well logs (Maxey and Jameson, 1948) at an approximate depth of 450 feet and its displacement along the escarpment at depth was estimated to be as much as 150 feet (Domenico, _et al_. 1964).

Eglington scarp to the north of and extending into the northwest portion of the study area (see Plate 1, section 1, T20S-R60E) is described by Haynes (1967, p. 55) to be of fault origin. Brecciated caliche, fissures, alignment of spring deposited tufas, localization of springs along the escarpment, and an 80-foot difference in elevation between a stratigraphic unit above and below the escarpment are evidence cited by Haynes. In addition Mifflin (see Orcutt and Cochran, 1967, Figure 3, p. 19) indicates an abrupt anomaly in an isolith map of potential aquifer sediments along the southern portion of the Eglington escarpment indicative of faulting.

Normal faulting is documented in two places in the northern portion of the study area. Normal displacement of three paleosols occurs at section 8daa, T20S-R61E in a trench cut as an eastern extension of Gowan Road (see Figure A1-10). The several fault planes which occur have a dip of 12° East and strike North 60° East. Because the location and orientation of these faults are not visible on the ground surface and because they are over a mile north of the nearest escarpment, their presence attests only to the fact that normal faulting has occurred in the valley. Similar normal faulting of red and green sandy beds occurs along Brooks Avenue (section 15 adb, T20S-R61E). Three fault planes, each having a dip of approximately 75° Southeast and striking North 45° East, were observed in a pipeline excavation (see Figure A1-11). Extension of these faults can be seen in the small knoll to the south of Brooks Avenue. Displacement on each fault was about two feet down to the southeast. These faults occur along an escarpment in this area where its present relief of about 30 feet would necessitate either additional displacement magnitude not documented in the observed faults or surficial vertical erosion along the escarpment face.

Displacement of beds is suggested along the escarpment to the northwest in sections 16 and 10, T20S-R61E. In section 10ddc, just north of Cheyenne Road, several caliche strata dip approximately 55° towards the northwest, forming ridges which strike parallel to the escarpment (see Figure A1-12). To the east caliche beds capping extensive portions of unit Qs (see Plate 1, sections 10 and 11, T20S-R61E) dip less steeply but in a similar orientation which suggests

Figure A1-10. Normal faulting of three paleosols exposed in trench cut along extension of Gowan Road, section 8dda, T20S-R61E. Paleosols are dark reddish brown strata having prismatic soil structure.

Figure A1-11. One of three normal faults cutting through red and green sandy strata on Brooks Ave, section 15adb, T20S-R61E. Displacement on upper red stratum is approximately two feet.

Figure A1-12. Caliche stratum dipping to the West (left hand side of photo) north of Cheyenne Road, section 10ddc, T20S-R61E.

faulting has occurred over a large area in the vicinity of escarpment development. The accentuated dip of the caliche strata shown in Figure A1-12 may be due to secondary rotation due to removal of uncemented sediments beneath caliche strata by fluid piping. Surface runoff from high intensity storms infiltrates through tensional cracks in the land surface piping sediments from beneath caliche units. Secondary rotation then occurs in the undermined caliche strata. Evidence for this mechanism is seen in surficial widening and deepening of initial tensional cracks (Passmore, 1975) and the subsequent deposition of piped sediments at land surface on lower terraces (see Figure A1-13). In section 16 several red sandy gravel units along the escarpment face have contorted attitudes. Because this deformation is very discontinuous and has no general symmetry this investigator believes that it is a result of secondary slumping along the escarpment.

An escarpment exists on the alluvial apron in the eastern portion of the study area. In section 34a, T20S-R62E, an escarpment separates map unit E1 from map unit E3 to the east, and it is evident that the slope of surface E1 is not continuous with the slope of surface E2. This investigator suspects that faulting in the general area of the present escarpment is responsible for the abrupt slope difference although no diagnostic displacement or deformation of stratigraphic units is observed.

Whitney Mesa in the southern portion of the study area is formed by an escarpment approximately 100 feet high (sections 32 and 33, T21S-R62E). There is an apparent southwest tilt of the upper terrace (section 4bbc, T21S-R62E) forming the Mesa, indicative of rotational

Figure A1-13. Author standing on sediments piped out from beneath tilted caliche strata located to the right (east) of photograph (see Figure 2-3), north of Cheyenne Road, section 10dd, T20S-R61E. Note lobate form of the deposit in mid-background which suggests its mud-flow-like nature.

movement but this may be due to subsequent localized slumping after escarpment formation. South of Whitney Mesa (sections 4 and 5, T22S-R62E) three small escarpments produce a step effect, each having a relief of about 30 feet with their terraces subtly sloping in a southwesterly direction as indicated on aerial photographs. The upper escarpment dies out to the north just before approaching the Mesa while the lower two join to form one lineation which can be traced northward on aerial photographs through the Mesa for about three miles. The lower two terraces show little evidence of having much surficial material deposited on them which may indicate that movement creating them occurred in recent geologic time.

Along the most western escarpment little field evidence is found to indicate faulting as a primary mechanism for formation of the feature. Possible faulting is found in section 13adc, T21S-R60E where a fine sand unit has a four degree dip to the North. This orientation, however, could be due to subsequent rotation of a small block from a slump caused by extensive dissection of the unit by surface-water runoff, or the dip may be of primary origin. Additionally, the strike of the apparent fault is North 90° East, which is perpendicular to the present escarpment.

Relations between stratigraphy and escarpments in the central portion of the study area are poorly defined. Urbanization has obscurred escarpments even in aerial photographs and the lack of detailed drilling logs in key locations across escarpment boundaries prevents definite interpretation.

Several mechanisms controlling fault genesis and therefore escarpment formation have been suggested. Las Vegas Valley occupies a portion of what has been described as a great shear zone having a length of 400 miles extending from northwestern Nevada to southeast Nevada roughly paralleling the San Andreas fault zone in California (Gianella and Callaghan, 1934; and Locke and Mayo, 1940). Structural bends in mountain ranges as they approach Las Vegas Valley from both the southwest and northeast are indicative of right lateral shear motion through the northern portion of the Valley (Longwell, et al. 1965). However, no definite evidence exists which would relate offset of bedrock units in mountain fronts or bedrock underlying valley-fill alluvium to surface faulting in the alluvium. Haynes (1967, p. 58) does suggest that the Eglington escarpment may be at least partially the result of such tectonism based on the southwestern tilt of Gilcrease flat which forms the upper terrace of the escarpment.

Maxey and Jameson (1948, p. 70) and Domenico, et al. (1964, p. 14) suggest that escarpments in the study area (see Plate 1) originate from faulting due to differential compaction of underlying sediments caused by a decrease in artesian head within the alluvial fill. These investigators have shown that the percentage of finer, more compressible sediments increases from the western to eastern part of the Valley which is consonant with the fact that the eastern side of each escarpment is the downthrown portion. Mindling (1971 and 1974) indicates that fault escarpments tend to occur where compressibility contrasts are greatest and appear parallel to contours of equal bulk modulus of compression in the alluvial sediments. This evidence strongly supports the differential compaction theory. It is interesting to note, however, that Mifflin's results cited previously (see Orcutt and Cochran, 1967, Figure 3, page 19) indicate that based on differential compaction theory

Eglington escarpment, at least at its southern extent, should be downfaulted to the west contrary to its observed manifestation. In summary, evidence suggests that the major mechanism for fault origin of escarpments is differential compaction of alluvial sediments but that tectonism may also be involved as suggested by evidence concerning Eglington escarpment.

Price (1966) suggests, and tends to favor in the majority of his discussion, a lakeshore erosional origin for escarpments in the Valley. Citing evidence that the toe of each major escarpment is at the same approximate elevation throughout its length and alluding briefly to high saddles in the Muddy Mountains to the east as possible drainage spillways out of the Valley, Price (1966, p. 26) maintains that a lake with an approximate maximum depth of 600 feet might have existed in Las Vegas Valley and that the escarpments represent wave cut remnants of an adjusting shoreline as the lake level dropped.

The present investigator recognizes the fact that escarpments have undergone erosional cutback but finds no other evidence that a large lake existed to the east of the most western escarpment. Such a large body of water suggested by Price should have left rather prominent terraces surrounding the Valley. Such terraces do not exist or have not been recognized. In addition, present surficial and near-surface sediments do not represent typical lacustrine sediments east of the western most escarpment. A lake of the proposed size and depth might have associated with it beach and deltaic deposits of characteristic sediment size and structure and deep water deposits of extensive clay units, none of which have been identified in the stratigraphy mapped by this investigator or reported by others.

EARTH FISSURING

Areas of fissuring in the form of ground-surface ruptures and cracks are indicated on Plate 1. Figure A1-14 taken in the same location as Figure A1-12, north of Cheyenne Road, shows a fissure cutting through hard, indurated caliche. The lateral extent is over one-hundred feet and it is associated with more than ten fissures in this general area. Rotation of caliche beds as discussed in the proceeding section may be due to sediment piping along these fissures. Figures A1-15 is an aerial photograph taken just east of the east-west runway of North Las Vegas Airport (section 18a, T20S-R61E). Abbreviated continuation of these features for approximately one mile to the south attests to their extensive nature.

Mindling (1971) reviewed the existing data concerning fissures up through 1971 and concluded that their development is related both to natural deformation associated with escarpments and to removal of ground water by pumping, especially in areas of large volume withdrawal by municipal wells. Recent work by Passmore (1975) and observations by this investigator and other Desert Research Institute, Water Resource Center personnel indicate that initial weaknesses in the ground surface appear to be extended vertically, laterally, and horizontally predominately by surface-water runoff during flash flood events. Figure A1-16 is a picture of a deep fissure west of Simmons Road (section 18d, T20S-R61E) which developed during and a few days after a flash flood event on July 3, 1975. Detailed investigation of the fissuring phenomoena is now under way by Water Resource Center personnel.

Figure A1-14. Fissure cutting through hard caliche north of Cheyenne Road, section 10ddc, T20S-R61E.

Figure A1-15. Aerial photograph of fissure development just east of the east-west runway of North Las Vegas Airport. Picture taken from 200 ft. Note tire tracks for scale.

Figure A1-16. Fissure developed during and after flash flood event west of Simmons Road, section 18d, T20S-R61E.

APPENDIX II: Lithologic Description[1] of Sediments Encountered in Borings Located in the Study Area.[2]

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1. Descriptions are generalized in some cases.

2. See Plate 1 for location of borings.

BORING NO. 1 SOURCE: Converse, Davis and Associates

PROJ. NO.: N-75-849-A

DEPTH (ft.)	LITHOLOGY
0	Silty, lt brn cobbles w/occasional boulders to 18"
5	Cemented sandy gravel, lt brn
10	Cobbles, boulders, and sandy gravel
15	
20	
25	
30	
35	
40	
45	
50	
55	
60	

BORING NO. 2 SOURCE: Converse, Davis and Associates

PROJ. NO.: N-72-824-A

DEPTH (ft.)	LITHOLOGY	DEPTH (ft.)	LITHOLOGY
0	Silty sand, brn, med dense	60	brown, stiff
5		65	
10	Silty clay, brown, stiff to very stiff	70	Clayey silt, white, stiff, w/some sand and gravel
15	Silty clay, white, v stiff	75	
20	gray, v stiff	80	
25		85	
30	brown, v stiff	90	
35	white, v stiff	95	
40	brown, v stiff	100	
45		105	
50	white, stiff	110	
55	occasional med to coarse gravel	115	
60		120	

BORING NO. 3 SOURCE: Converse, Davis and Associates

PROJ. NO.: N-70-448-A

DEPTH (ft.)	LITHOLOGY	DEPTH (ft.)	LITHOLOGY
0		60	Clayey sand and silt, lt gray
5		65	
10		70	
15	Sandy silt, yellow, slightly cemented	75	
20		80	
25		85	
30	decayed organics	90	
35	Clayey, organic stained	95	
40	Silty clay, gray, slightly cemented, organic stained	100	
45		105	
50	Clayey silt, gray-brn, sl cemented, organic stained	110	
55	Sand, red-brown	115	
60		120	

BORING NO. 4 SOURCE: Converse, Davis and Associates
PROJ. NO.: N-72-813-E

DEPTH (ft.)	LITHOLOGY
0	Clayey sand, brown, dense, w/fine to medium gravel
	Sandy clay, brown, firm
5	Sandy clay, brown, soft
10	Silty clay, brown, soft, w/some very fine to medium sand
15	Clayey sand, gray, loose
20	
25	
30	
35	
40	
45	
50	
55	
60	

BORING NO. 5 SOURCE: Converse, Davis and Associates
PROJ. NO.: N-74-892-E

DEPTH (ft.)	LITHOLOGY
0	Silty sand, lt brn, w/trace gravel
	Sandy clay, brn, w/trace gravel
5	Silty clay w/gypsum
10	Sandy silt, brn, w/layers of silty sand
15	Silty sand, lt brn, w/streaks of clayey silt and gravel
	Sandy gravel, lt brn
	Silty sand, brn, w/streaks of sandy silt
20	
25	
30	
35	
40	
45	
50	
55	
60	

BORING NO. 6 SOURCE: Converse, Davis and Associates

PROJ. NO.: N-75-812-A

DEPTH (ft.)	LITHOLOGY
0	Silty sand, med dense, w/evidence of sulfates
	Sandy silt, lt brn, firm, w/evidence of sulfates
5	Sandy clay, lt brn, firm
	Silty clay, red-brown, stiff
10	Sandy silt, lt brn, stiff
15	
20	
25	
30	
35	
40	
45	
50	
55	
60	

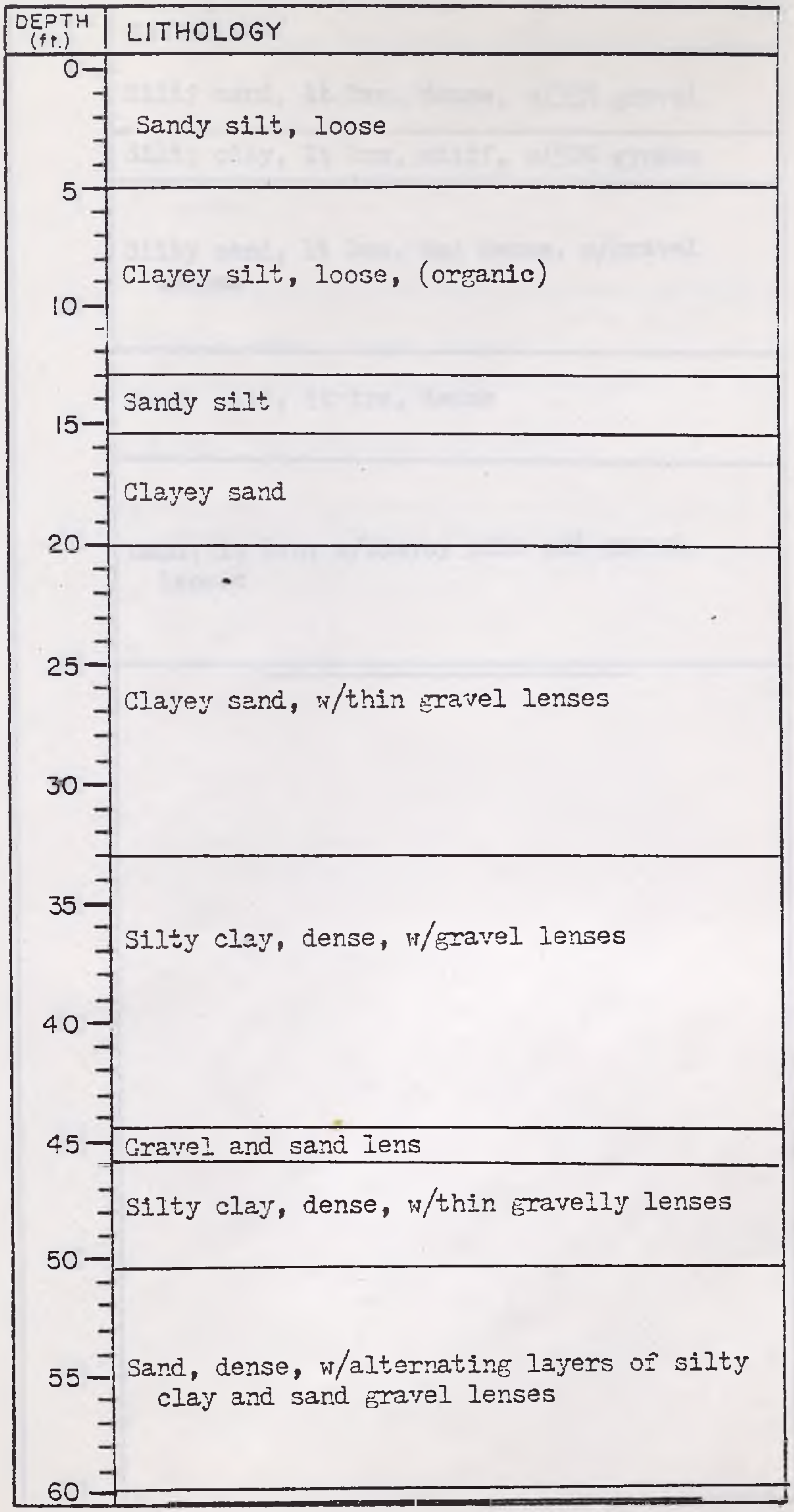
BORING NO. 7 SOURCE: Converse, Davis and Associates

PROJ. NO.: N - 75 - 820 - AH

DEPTH (ft.)	LITHOLOGY	DEPTH (ft.)	LITHOLOGY
0		60	Sand, brn, med dense
5	Silty clay, brn, soft	65	Sandy gravel, brn and gray, dense Cem sand & gravel, brn/gray
10		70	Silty clay, red brn, stiff Gravelly sand, brn, dense
15	Clay and silty clay, yel-brn, w/ streaks of sandy silt	75	Silty clay, gray to brn, stiff Gravelly sand, brn, dense Silty clay, lt gray, stiff, w/scattered gravel
20	Clayey silt, brn, soft	80	
25		85	Silty clay, lt brn, w/red brown streaks, stiff, w/ partially cemented pockets
30	Clay and silty clay, brn-green, soft to firm w/ sand seams	90	
35		95	Clay, red brn, v stiff, partially cemented locally
40		100	
45	Silty clay, gray and red brown (mottled), soft to stiff	105	
50	Sand, brn, med dense, w/silt	110	
55	Silty clay gray to brn (mottled), soft to firm	115	
60		120	

BORING NO. 8 SOURCE: United Testing Laboratories

PROJ. NO.: none



BORING NO. 9 SOURCE: Converse, Davis and Associates
PROJ. NO.: N-69-395-A

DEPTH (ft.)	LITHOLOGY
0	Silty sand, lt brn, dense, w/35% gravel
	Silty clay, lt brn, stiff, w/50% gypsum
5	Silty sand, lt brn, med dense, w/gravel lenses
10	
	Sandy silt, lt brn, dense
15	
20	Sand, lt brn, w/clayey silt and gravel lenses
25	
30	
35	
40	
45	
50	
55	
60	

BORING NO. 10 SOURCE: Converse, Davis and Associates
PROJ. NO.: N-75-806-EA

DEPTH (ft.)	LITHOLOGY
0	
5	Silty clay, lt brn, stiff to partially cemented
10	
	Clayey sand, brown, dense
15	Silty clay, brown, very stiff
20	Clayey sand, brown, very dense
25	
30	
35	
40	
45	
50	
55	
60	

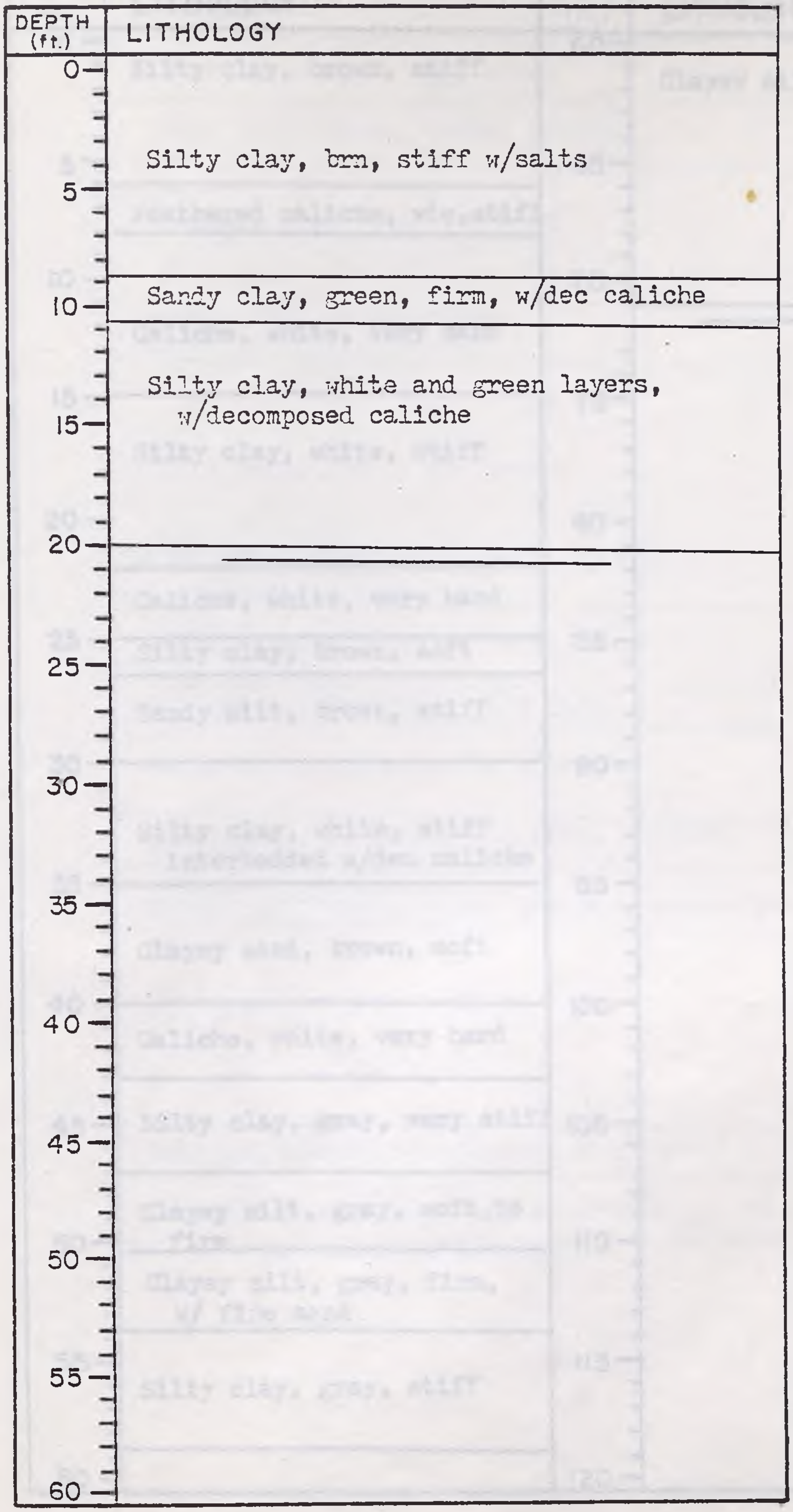
BORING NO. 11 SOURCE: Converse, Davis and Associates

PROJ. NO.: N - 75 - 844 - A

DEPTH (ft.)	LITHOLOGY	DEPTH (ft.)	LITHOLOGY
0	Sandy clay, brn, firm	60	
5		65	Clay, lt brn, stiff
10	Clay, brn, firm	70	Cemented sand, lt brn, dense w/black gravel
15	Caliche, fractured, weathered, hard	75	
20	Sand, lt brn, cemented, hard	80	
25	Clay, brn, stiff	85	Clay, green, stiff, w/ streaks of cemented sand
30	Sandy clay, green, stiff Clay, lt brn, stiff	90	
35	Clayey sand, white, dense	95	
40	Clay, green, firm Clayey sand, wht, med dense	100	
45	Clay, green, stiff w/ 3" streak caliche	105	
50		110	
55	Gravel, black, med dense w/green clay	115	
60		120	

BORING NO. 12 SOURCE: Converse, Davis and Associates

PROJ. NO.: N-76-867-A



Silty clay, brn, stiff w/salts

Sandy clay, green, firm, w/dec caliche

Silty clay, white and green layers, w/decomposed caliche

BORING NO. 13 SOURCE: Converse, Davis and Associates

PROJ. NO.: N-72-815-A

DEPTH (ft.)	LITHOLOGY	DEPTH (ft.)	LITHOLOGY
0	Silty clay, brown, stiff	60	Clayey silt, brown, stiff
5	Weathered caliche, wte,stiff	65	
10	Caliche, white, very hard	70	
15	Silty clay, white, stiff	75	
20	Caliche, white, very hard	80	
25	Silty clay, brown, soft Sandy silt, brown, stiff	85	
30	Silty clay, white, stiff interbedded w/dec caliche	90	
35	Clayey sand, brown, soft	95	
40	Caliche, white, very hard	100	
45	Silty clay, gray, very stiff Clayey silt, gray, soft to firm	105	
50	Clayey silt, gray, firm, w/ fine sand	110	
55	Silty clay, gray, stiff	115	
60		120	

BORING NO. 14 SOURCE: Converse, Davis and Associates
PROJ. NO.: N-72-856-A

DEPTH (ft.)	LITHOLOGY
0	Gravelly sand, lt brn, dense
	Sandy clay, brown, dense, w/gravel
5	Caliche, gray/brn, very hard
10	Sandy clay, white, firm
15 20	Silty sand, green, med dense
	Decomposed caliche w/soft white and green silty clay
25	Decomposed caliche, lt brown, hard
	Caliche, lt brn/gray, very hard
30	Silty clay, white, soft, w/gravel
	Sandy clay, lt brn/white, firm, w/gravel
35	Decomposed caliche
	Silty clay, white, firm, w/sand and gravel
40	Decomposed caliche w/silty clay
45	Caliche, slightly weathered, very hard
	Decomposed caliche w/soft silty clay
50 55 60	

BORING NO. 15 SOURCE: Geolabs, Inc.

PROJ. NO.: none

DEPTH (ft.)	LITHOLOGY	DEPTH (ft.)	LITHOLOGY
0		60	Clayey sand, white, med dense
5	Silty clay, brown/white, firm to stiff	65	
10	Decomposed caliche, med hd	70	Silty clay, green/gray, gravelly, soft to firm
15	Sandy gravel, white, med dense, interbedded w/ stiff silty clay	75	
20	Gravel, lt brn Sand, w/coarse to fine grav	80	
25	Gravel, lt brn, cemented, limestone, hard to v hard Sandy clay, lt brn, partially cemented, stiff	85	
30	Caliche, white, very hard	90	
35	Clayey sand, lt brn/white/gray, dense, w/small gravel and cemented nodules	95	
40		100	
45		105	
50	Silty clay, green, firm	110	
55		115	
60		120	

BORING NO. 16 SOURCE: Converse, Davis and Associates
PROJ. NO.: N-74-867-A

DEPTH (ft.)	LITHOLOGY
0	
	Silty clay, lt brn, stiff
5	
	Caliche, very hard
10	Silty clay, lt brn, hard
	Weathered caliche, hard
15	
20	Decomposed caliche, w/silty clay in voids, hard
25	
30	
35	
40	
45	
50	
55	
60	

BORING NO. 17 SOURCE: Geolabs, Inc.

PROJ. NO.: none

DEPTH (ft.)	LITHOLOGY	DEPTH (ft.)	LITHOLOGY
0	Silty sand, tan	60	
5	Gravelly sand, med dense, high salt concentration	65	Sandy clay, tan, v stiff
10	Sandy clay, tan and gray mottled, v stiff, w/ interbedded gravel	70	
15		75	
20	Sandy clay, gray, med stiff becomes more cemented and more dense with depth	80	
25	Sandy clay, white, v tight Caliche, very dense	85	
30	Sandy clay, white, v stiff, cemented	90	
35	Clayey sand, tan, med dense partially cemented	95	
40	Sandy clay, tan, stiff, w/ gravel lenses	100	
45		105	
50	Sandy clay, reddish brown and white mottled, some cementation	110	
55		115	
60	Sandy clay, tan, stiff w/ gravel lenses, some cementation	120	

BORING NO. 18 SOURCE: Converse, Davis and Associates
PROJ. NO.: N-76-866-A

DEPTH (ft.)	LITHOLOGY
0	
5	Sandy gravel, lt brn, v dense, partially cemented
10	
	Cemented sand and gravel, lt brown and black, hard
15	
20	Clayey sand, green and brn layers, dense
25	
	Cemented sand and gravel, brn/blk, hard
30	Clayey sand, green and gray, dense w/gravel
	Sandy gravel, gray and black, dense, partially cemented
35	
	Sandy clay, brown, soft
	Sandy gravel, gray and blk, dense, w/clay
40	
45	
50	Silty clay, gray, stiff, w/decomposed caliche gravel
55	
60	

BORING NO. 19 SOURCE: Converse, Davis and Associates

PROJ. NO.: N-69-549-A

DEPTH (ft.)	LITHOLOGY	DEPTH (ft.)	LITHOLOGY
0		60	
5	Silty sand, lt brn, loose, w/gravel lenses	65	Silty clay, red brn/gray, hard, w/gravel lenses
10	Caliche, hard	70	
	Clayey gravel, lt gray, dense		
15	Caliche, hard	75	
			Silty clay, red brn/gray, stiff, w/caliche gravel
20	Gravel, lt brn, dense, w/ clayey sand	80	
25		85	Clayey gravel, red brn, dense
	Caliche, hard		
30		90	Caliche
			Clayey gravel, red brn, dense
			Caliche
35	Silty clay, red brn, hard, w/caliche gravel	95	Clayey gravel, red brn, dense
			Caliche
40	Gravel, lt brn, dense, w/ silty sand	100	
45	Clay, brn, hard w/caliche gravel	105	
50		110	
55		115	
60		120	

BORING NO. 20 SOURCE: Geolabs, Inc.

PROJ. NO.: none

DEPTH (ft.)	LITHOLOGY	DEPTH (ft.)	LITHOLOGY
0	Silty sand, lt brn, loose Sand, brn, med dense	60	Sand and grav, vari-colored
5	Sand & grav, brn & wht Caliche, hard	65	Silty clay and gravel, brn, stiff Silty clay and gravel, brn, w/2" streaks caliche
10	Silty clay, brn, firm, w/lenses Grav & sand, brn & wht to blk Caliche, v hard	70	Silty clay, wht, stiff, w/trace gravel
15	Silty clay, lt brn and wht (mottled), firm	75	Silty clay, brn, stiff, w/ lenses
20	Caliche, hard Silty clay, wht to gray, hard	80	
25	Silty clay, lt brn, stiff	85	
30		90	
35	Gravel and silty clay, wht, firm	95	
40		100	
45		105	
50	Silty clay and gravel, brn, firm	110	
55		115	
60		120	

BORING NO. 21 SOURCE: Converse, Davis and Associates
PROJ. NO.: N-73-856-A

DEPTH (ft.)	LITHOLOGY
0	Clayey sand, lt brn, dense, w/gravel
	Caliche, dense
5	Sandy silt, lt brn, w/dec caliche as gravel w/gypsum
	Cemented sand and gravel, brn, hard
10	Caliche
	Silty clay, brn, stiff w/caliche gravel
15	Sandy clay, brn, stiff w/dec caliche
	Decomposed caliche, very hard
20	Sandy clay, lt brn, stiff w/caliche gravel
25	Gravelly sand, blk/wht, very dense
	Silty clay, brn, stiff w/dec caliche
30	Caliche, very hard
35	Gravelly clay, brn/blk, firm
40	
45	
50	
55	
60	

BORING NO. 22 SOURCE: Converse, Davis and Associates

PROJ. NO.: N-73-865-A

DEPTH (ft.)	LITHOLOGY	DEPTH (ft.)	LITHOLOGY
0		60	
	Clayey, sandy gravel, lt brn, med dense		Silty clay, brn, firm
5		65	
	Caliche, hard		Caliche, weathered/ decomposed, hard
10	Sandy clay, gray, v stiff	70	
15	Caliche, hard	75	Silty clay, brn, soft
20		80	
25	Silty clay, brn, stiff, w/decomposed caliche gravel	85	
30		90	
35		95	
	Sandy clay, lt brn, stiff		
40	Silty clay, brn, firm	100	
45		105	
	Sandy clay, brn, firm		
	Silty sand, brn, dense		
50	Clayey gravel, brn, dense	110	
	Silty clay, brn, firm		
55		115	
	Sandy clay, lt brn, stiff		
60		120	

BORING NO. 23 SOURCE: Converse, Davis and Associates
PROJ. NO.: N-75-876-EA

DEPTH (ft.)	LITHOLOGY
0	Gravelly sand, lt brn/gray, dense
	Sandy gravel, white, v dense, partially cemented
5	Gravelly sand, gray-black, very dense
	Sand and gravel, gray-blk, v dense to hard, partially cemented
10	Clayey silt, gray, stiff, numerous sea shells
	Silty clay, lt brn, stiff
	Sandy gravel, gray-black, dense
15	Clayey silt, lt brn, stiff
	Sandy gravel, lt brn/blk, v dense
20	
25	
30	
35	
40	
45	
50	
55	
60	

APPENDIX III: Chemistry Data[1] for Wells and Springs[2] Monitoring Near-Surface Ground Water.

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1. Temperature in degrees Centigrade, conductivity in μmohs, ionic concentration in mg/l, and TDS is summed. Data used for concomitant analyses marked with an asterisk.

2. Wells designated as LG followed by general description, depth in feet, and location by Township, Range, section, and quarter sections. Springs designate as LW followed by general description and location by Township, Range, section, and quarter sections.

L6 30 DUCK CK AT HWY 30 21S 62E 26 821 2

DATE	NO.	TEMP	COND	PH	HCO3	CL	SO4	PO4	NO3	NA	K	CA	MG	NH4	F	TDS
6- 9-71	897	-99.0	8777	7.70	270	1168	3228	-.10	1.6	865	111	637	456	.0	1.8	6616
9-18-71	755	19.8	8369	7.70	260	1306	3289	-.10	.2	897	100	616	433	.0	1.7	6771
12- 3-71	960	17.8	8080	7.18	229	1337	3264	-.10	1.0	958	109	597	482	2.6	1.9	6669
2- 2-72	1004	17.0	8399	7.28	299	1326	3339	-.08	2.3	925	126	588	469	2.6	1.6	6906
7-31-72	1988	23.3	8608	7.95	188	1330	3289	-.08	.3	972	109	558	438	2.6	1.6	6719
11- 3-72	1769	19.9	8379	7.26	263	1283	3062	-.08	3.8	903	111	581	424	2.6	1.7	6521
2- 8-73	1986	17.8	8097	7.30	190	1283	3189	-.08	4.2	971	109	512	414	.1	1.7	6402
5- 9-73	2076	25.6	7909	7.10	196	1272	2998	-.08	.3	862	104	576	397	.4	-99.0	6217
8- 1-73	2203	22.2	8966	7.30	213	1337	2903	-9.99	.2	875	113	549	397	.4	-10.0	6275

L6 31 GIBSON RD 63 22S 62E 11 322 1

DATE	NO.	TEMP	COND	PH	HCO3	CL	SO4	PO4	NO3	NA	K	CA	MG	NH4	F	TDS
6- 8-71	897	-99.0	4157	7.70	86	975	372	-.10	186.0	240	23	291	199	.0	.6	2121
9-18-71	791	24.8	4396	7.96	76	1008	377	-.10	22.0	286	23	297	169	.0	.6	2220
12- 3-71	986	22.2	3988	7.68	98	1018	367	-.10	36.0	282	23	294	169	1.5	.6	2233
2- 3-72	1139	28.0	4289	7.84	98	1035	379	-.08	28.0	271	21	300	171	1.5	.7	2253
5- 8-72	1807	24.8	4198	7.90	93	1058	389	-.08	37.0	264	22	329	178	1.5	.6	2381
8- 2-72	1981	27.8	4609	7.72	87	1076	448	-.08	28.0	296	23	321	189	1.5	.7	2474
11- 2-72	1760	23.3	4775	7.96	100	1138	413	-.08	37.0	306	29	344	189	1.5	.6	2494
2- 8-73	1986	23.3	4826	7.93	97	1188	440	-.08	46.0	325	29	372	194	1.5	.8	2586
5- 8-73	2087	24.8	4820	7.54	99	1193	412	-.08	50.0	206	22	349	201	.1	-99.0	2568
8- 1-73	2202	26.7	4176	7.59	102	1182	483	-9.99	37.0	313	21	357	203	.1	-10.0	2621

L0 38 AK UP CROSS 15 21S 62E 15 841 1

DATE	NO.	TEMP	COND	PH	HCO3	CL	SO4	PO4	NO3	NA	K	CA	MG	NH4	F	TDS
6-10-71	903	-99.9	6287	7.70	268	427	3097	-.10	53.0	674	41	446	354	.0	1.6	5215
9-18-71	788	18.0	5808	7.68	268	398	3050	.18	51.0	638	37	432	341	.0	1.6	5070
12- 3-71	991	17.8	5383	7.46	269	378	2830	-.10	41.0	625	37	399	340	2.0	1.6	4788
2- 3-72	1180	17.0	5918	7.45	269	367	2870	-.08	32.0	575	30	388	353	2.0	1.8	4753
3- 2-72	1304	16.1	5696	7.60	272	436	3094	-.04	42.0	649	39	417	399	2.0	1.6	5178
5- 4-72	1418	20.0	6044	7.40	298	449	3379	-.04	39.0	659	39	471	420	2.0	1.6	5590
7-31-72	1588	24.8	6391	7.79	301	496	3276	-.06	28.0	671	42	443	369	2.0	1.8	5817
11- 3-72	1773	19.9	5665	7.53	270	372	2839	-.04	22.0	555	42	464	325	2.0	1.9	4752
2- 9-73	1997	19.3	5785	7.58	271	408	3075	-.04	36.0	605	30	419	391	2.0	1.8	5101
5- 8-73	2072	20.0	6402	7.58	310	481	3378	-.04	35.0	667	40	449	429	.2	-99.0	5627
8- 2-73	2219	20.0	6831	7.52	333	481	3327	-9.99	50.0	705	43	474	409	.1	-10.0	5999

DATE	NO.	TEMP	COND	PH	HCO3	CL	SO4	PO4	NO3	NA	K	CA	MG	NH4	F	TDS
LG 36 COUNTY SOP SR				21S 62E 22 341 1												
6- 9-71	403	-99.0	2000	7.50	65	656	2754	-.10	58.0	254	28	480	110	.0	1.0	5284
9-14-71	745	20.5	5543	7.24	64	708	2370	-.10	1.8	507	23	471	209	.0	1.0	4302
9-14-71	743	20.6	0000	0.11	63	091	3455	-.10	.0	1117	33	455	306	.0	.4	5380
10- 5-71	925	18.8	4045	7.65	54	600	1900	-.40	.4	667	10	420	256	10.0	1.0	3023
2- 8-72	4170	40.0	3459	7.52	94	514	1380	-.04	2.2	265	15	724	208	1.0	.0	2095
3- 2-72	1802	40.1	3000	7.43	425	568	1387	.04	2.1	284	10	838	282	5.2	1.1	2022
5- 8-72	1496	22.2	3847	7.47	38	597	1274	-.04	5.8	221	15	200	208	8.4	.0	2804
7-11-72	4545	22.8	4017	7.92	40	542	1292	-.04	-.1	380	12	262	295	8.4	.9	2678
11- 8-72	1771	20.0	3034	7.21	30	612	1218	-.04	-.1	250	14	285	297	8.4	.0	2504
*2- 9-73	1955	19.4	4730	7.58	30	628	1458	-.04	-.1	318	17	201	228	8.4	1.0	2036
5- 8-73	2074	22.2	4819	8.52	45	654	1580	-.04	-.1	308	12	202	204	11.0	-99.0	3050
8- 2-73	2221	21.1	4088	7.50	40	808	1618	-1.99	-.1	382	10	710	244	10.0	-19.0	3023
LG 37 COUNTY SRP 01				21S 62E 22 341 1												
6- 9-71	444	-99.0	8450	7.54	90	900	3602	-.10	130.0	1525	30	532	358	.0	1.0	8051
9-14-71	7.2	28.8	287	7.90	157	0	220	-.04	.8	12	4	72	34	.0	.4	434
LG 39 [illegible]				22S 62E 34 222 2												
8-11-71	[illegible]	-99.0	[illegible]	[illegible].30	[illegible]	700	1800	-.10	[illegible]	[illegible]	20	770	179	.0	1.2	[illegible]
9-14-71	[illegible]	[illegible]	[illegible]	[illegible].57	[illegible]	758	[illegible]	-.10	[illegible]	[illegible]	[illegible]	754	101	.0	1.3	[illegible]
10- 5-71	[illegible]	[illegible]	[illegible]	[illegible].15	[illegible]	726	[illegible]	-.10	[illegible]	[illegible]	[illegible]	788	100	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible].13	[illegible]	738	[illegible]	-.03	1.[illegible]	[illegible]	[illegible]	780	100	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible].58	00	[illegible]	[illegible]	-.06	[illegible]	[illegible]	[illegible]	710	100	[illegible]	[illegible]	[illegible]
11- [illegible]	[illegible]	[illegible]	[illegible]	[illegible].13	102	768	[illegible]	-.10	[illegible]	[illegible]	[illegible]	780	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible].15	[illegible]	728	[illegible]	-.10	[illegible]	[illegible]	[illegible]	800	[illegible]	[illegible]	[illegible]	[illegible]
*[illegible] 4-7[illegible]	[illegible]	[illegible]	4038	7.45	[illegible]	726	[illegible]	-.04	-.1	[illegible]71	[illegible]	295	197	[illegible].0	-99.0	[illegible]658
LG 41 UPPER LVH [illegible]				20S 62E 30 124 1												
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.4	[illegible]	10	[illegible]	[illegible]	.0	1.0	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.0	1.[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible].5	1.[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.5	1.[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible].5	1.[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.1	-99.0	[illegible]

DATE	NO.	TEMP	COND	PH	HCO3	CL	SO4	PO4	NO3	NA	K	CA	MG	NH4	F	TDS
LG 43 NO NAME SP 56			21S 62E 29 434 1													
6-11-71	505	-99.0	3749	7.22	246	364	1460	-.100	.2	245	39	420	169	.0	1.6	2820
9-14-71	748	20.6	3703	7.52	172	373	1435	-.100	-.1	233	41	303	161	.0	1.7	2712
12-3-71	856	14.4	3219	6.85	165	355	1265	-.100	.6	230	34	303	158	1.5	1.6	2434
2-1-72	1151	20.0	3316	7.10	226	362	1262	-.004	1.6	235	37	315	159	1.5	1.6	2486
8-1-72	2216	22.2	3320	6.93	190	366	1172	-9.999	-.1	235	36	236	162	1.5	-10.0	2302
8-2-72	1618	22.2	3511	7.73	190	365	1263	-.004	1.9	231	30	287	165	1.5	1.6	2447
11-2-72	1755	10.4	3407	6.95	200	372	1229	-.004	.2	222	36	290	166	1.5	1.7	2417
2-8-73	1952	20.0	3221	6.93	149	365	1254	-.006	-.1	229	38	275	161	.2	1.7	2397
*5-4-73	2043	21.1	3236	6.73	90	373	1205	-.004	-.1	217	36	256	160	.0	-99.0	2295
LG 46 CAMPBELL RES 40			21S 62E 19 111 2													
6-10-71	501	-99.0	874	7.60	186	23	275	-.100	.6	18	3	96	44	.0	.3	551
9-14-71	751	22.2	839	7.64	166	21	266	-.100	.5	22	3	73	46	.0	.3	514
12-3-71	993	20.0	807	7.46	180	28	286	-.100	-.1	23	3	90	49	1.2	.3	570
2-1-72	1154	21.0	886	7.54	171	26	314	-.004	.7	24	2	90	49	1.2	.3	592
8-2-72	1612	22.8	1074	7.85	165	38	373	-.006	.5	34	3	109	61	1.2	.5	701
11-1-72	1776	21.7	959	7.34	129	36	344	-.004	-.1	33	3	78	58	1.2	.2	616
2-5-73	1954	21.1	1030	7.55	162	42	383	-.004	-.1	37	4	97	59	.1	.4	701
5-4-73	2053	22.0	1196	7.76	177	69	419	-.004	-.1	40	3	117	64	.1	-99.0	799
8-3-73	2222	23.3	1332	7.20	193	60	459	-9.999	.6	44	2	131	69	.1	-10.0	868
LG 48 CHARLSTON BLVD 40			20S 61E 36 444 2													
6-9-71	691	-99.0	2765	7.50	225	117	1308	-.100	-.1	148	26	202	208	.0	.4	2121
9-13-71	739	22.2	2723	7.55	175	129	1258	-.100	-.1	168	20	196	200	.0	.3	2065
12-3-71	862	18.0	2272	7.07	216	126	1110	-.100	-.1	135	23	192	173	1.2	.3	1866
2-1-72	1149	21.0	2487	7.20	196	125	1181	-.004	.3	134	68	171	192	1.2	.3	1969
7-31-72	1542	23.3	2578	7.80	120	124	1185	-.004	.6	135	26	150	190	1.2	.2	1871
11-1-72	1752	20.6	2838	6.86	92	126	1168	-.004	-.1	125	24	136	184	1.2	.2	1810
2-12-73	1959	20.6	2302	7.40	157	113	1090	-.004	-.1	127	23	155	171	.1	.3	1757
*5-4-73	2051	22.2	2305	7.55	127	120	1083	-.04	-.1	137	20	136	180	.1	-99.0	1739
8-2-73	2218	23.3	2482	7.37	134	124	1140	-9.999	.1	120	22	143	184	.1	-10.0	1808
LG 50 LVVW WELL WATR 20			21S 62E 35 441 1													
5-17-71	471	-99.0	5196	7.85	196	1067	1071	-.100	2.4	608	30	300	146	.0	1.2	3322
6-11-71	528	21.0	6730	7.62	193	1486	1269	-.100	1.7	932	35	397	178	.0	1.1	4395

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   DATE      NO.    TEMP     COND     PH      HCO3   CL     SO4    PO4     NO3     NA      K     CA     MG     NH4     F      TDS
LG 60 COSTP DEWATER SW          21S 62E 27 224 2
  1- 0--0   1414  -99.0     6002    7.54     202    748    3423    .12   101.0   1015     59    524    310     .0     1.4    6201
  2- 1-72   1297   19.0     7255    7.51     207    696    3510   -.04    44.0    966     79    504    333     .0     1.6    6306
  3- 2-72   1307  -99.0     7306    7.73     204    740    3544    .10    90.0   1040     69    502    319     .2     1.4    6471
  6- 1-72   1459   21.1     7204    7.50     190    716    3550    .20    92.0   1067     62    496    332     .2     1.3    6422
  7-31-72   1547   22.2     7076    7.70     200    808    3548    .20    84.0   1047     43    540    329     .2     1.4    6512
  9- 6-72   1655   21.1     7075    7.55     190    704    3886    .16    47.0   1207     73    507    335     .2     1.3    6989
 12- 5-72   1701   18.9     8024    8.20     190    750    3953    .28    86.0   1183     53    440    342     .2   -99.0    6905
  1-15-73   1880   19.9     8088    7.98     195    743    3756-99.00    83.0   1196     67    502    341     .2     1.4    6786
  2- 1-73   1915   18.0     6533    8.23     186    526    3390    .16    73.0    781     56    450    350     .2   -99.0    5710

LG 98 DILLINGHAM 25             21S 62E 08 433
  4-18-73   2026   29.0     2121    7.95     279    137     705-99.00     1.5    112      6    177    126     .1      .3    1402
* 5- 3-73   2040   23.3     2030    7.43     204    133     767   -.04      .4    114      7    179    122     .1   -99.0    1462
  9- 6-73   2255   21.1     1822    8.00     257    120     690-99.00      .8     98      2    187    110    5.3  --99.0    1339

LG 99 N W GOLF CRS 26           21S 62E 09 122
  4-18-73   2025   21.1     5302    7.57     189    442    2345-99.00    14.5    422     59    395    356     .3      .9    4275
  5- 9-73   2081   25.5     5001    7.59     198    416    2235   -.04    95.0    403     56    365    352     .3   -99.0    4019
  9- 6-73   2254   21.1     4726    8.00     371    403    2154-99.00   140.0    359     67    335    339     .5   -99.0    3979

LG140 SW 25TH NO ELM 12         20S 61E 35 144
  4-18-73   2023   20.0     3281    7.66     266    121    1646-99.00     2.5    181     20    292    215     .3      .2    2508
* 5- 9-73   2070   23.3     2157    7.75     144    116    1525   -.04     1.7    167     18    262    208     .3   -99.0    2371

LG141 DILLMAN 31                21S 62E 21 314
  4-18-73   2027   21.1     9941    7.60     278    807    4975-99.00      .7   1540     93    522    475     .4     1.4    8550
  5- 9-73   2082   25.7     9610    7.46     127    799    5100   -.04    12.4   1571     27    511    467     .4   -99.0    8550

LG102 STIRDREK 20               21S 61E 02 213
  4-18-73   2022   20.0     5412    7.67     427    280    2808-99.00      .8    447     45    440    372     .2      .4    4603
* 5- 9-73   2087   24.4     4492    7.58     208    212    2270    .16      .5    363     26    333    317     .2   -99.0    3624
  9- 7-73   2264   26.7     4261    7.09     409    216    2238-99.00      .4    382     35    300    311     .2   -99.0    3684
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DATE	NO.	TEMP	COND	PH	HCO3	CL	SO4	PO4	NO3	NA	K	CA	MG	NH4	F	TDS
LG103 MOTOR VEHCLS 10				21S 62E 01 434												
4-18-73	2021	-99.0	3469	7.64	173	238	1625	-99.000	4.4	141	23	433	171	.2	.4	2721
* 5- 9-73	2078	23.3	3521	7.74	179	239	1733	.04	8.0	122	23	478	172	.2	-99.0	2863
9- 6-73	2256	28.9	3704	8.11	215	348	1694	-99.000	5.5	237	49	489	150	.5	-99.0	3079
LG104 PETERSON 8				21S 61E 13 223												
4-18-73	2029	16.7	7533	7.67	300	427	3973	-99.000	.3	942	169	498	360	.2	.5	6518
* 5- 9-73	2086	21.7	6678	7.46	306	408	3646	.04	.8	778	123	517	370	.2	-99.0	5993
9- 6-73	2260	27.8	59410	7.78	492	12890	31384	-99.000	175.0	13975	4560	750	2602	2.1	-99.0	66580
9- 7-73	2263	26.1	53640	7.85	476	9494	27516	-99.000	198.0	11950	3865	717	2416	2.1	-99.0	56392
LG105 JARRETT 16				21S 61E 23 412												
4-18-73	2030	19.4	4877	7.69	240	292	2617	-99.000	.0	329	22	534	303	.1	.0	4216
*5- 9-73	2085	22.2	4560	7.37	242	282	2662	.04	.6	299	14	519	308	.1	-99.0	4203
9- 6-73	2261	21.1	4716	7.83	235	294	2690	-99.000	.8	347	32	515	313	.1	-99.0	4307
LG106 ENGELSTAD 46				22S 61E 23 412												
*5- 9-73	2083	24.4	3177	7.18	173	203	1620	.04	-.1	111	12	416	194	.0	-99.0	2641
9- 6-73	2253	27.8	2700	7.94	99	175	1640	-99.000	1.8	109	9	362	192	.0	-99.0	2538
LG107 MESTPAVIK 31				21S 61E 26 332												
4-18-73	2071	21.1	2349	7.65	195	106	1022	-99.000	.2	167	9	200	117	.1	.4	1717
*5- 9-73	2084	23.9	2246	7.41	222	100	1004	.04	.3	152	10	217	119	.1	-99.0	1711
9- 6-73	2252	24.4	2200	8.12	235	107	1012	-99.000	3.0	173	9	203	114	.1	-99.0	1737
LG108 H OF T15MILD WY36				21S 61E 08 134												
4-18-73	2028	21.7	3251	7.62	193	129	1733	-99.000	34.0	87	9	444	187	.4	.3	2718
*5- 9-73	2090	27.2	2658	7.49	190	112	1349	-.004	77.0	58	8	361	163	.4	-99.0	2221
9- 6-73	2259	21.1	2307	7.95	209	113	1102	-99.000	74.0	76	8	336	140	.4	-99.0	1952
LG109 VV AMR OKY 39				21S 61E 05 323												
4-17-73	2033	21.7	2045	7.77	263	189	1192	-99.000	1.7	191	12	191	189	.8	.3	2096
*5- 9-73	1520	24.4	2903	7.64	263	187	1237	-.004	66.0	187	12	219	197	.8	-99.0	2235
9- 6-73	2257	21.1	2864	8.03	258	190	1270	-99.000	62.0	203	8	210	203	.8	-99.0	2273

DATE	NO.	TEMP	COND	PH	HCO3	CL	SO4	PO4	NO3	NA	K	CA	MG	NH4	F	TDS
LG110 JOSEPHS 35			20S 61E 33 342													
3- 2-73	1966	25.6	2706	7.67	246	158	1110	-99.000	3.3	161	20	117	216	.0	.4	1907
4-18-73	2012	21.1	2974	7.66	298	181	1275	-99.000	2.0	178	26	171	235	.4	.4	2213
*5- 9-73	2089	25.6	2922	7.53	434	172	1210	-.064	2.0	171	22	196	239	.4	-99.0	2226
9- 6-73	2259	23.9	2763	7.93	378	173	1212	-99.000	.3	182	30	204	236	.3	-99.0	2223
19- 4-72	-0	.0	0	.00	378	0	0	.000	.0	0	0	0	0	.0	.0	0
LG178 AK LOS FARM 30			21S 62E 16 332													
4-11-73	2026	17.8	5551	8.05	336	558	1999	8.83	91.0	716	104	326	159	.0	.9	4128
LG129 LV EXPWY NO VV 10			20S 61E 30 442													
*2- 5-73	1924	19.4	1170	7.87	239	67	314	-99.000	9.3	79	6	88	53	.0	.3	733
LG138 2832 HO. PKWY 6			21S 61E 10 144													
*2- 6-73	1925	13.3	3806	7.85	162	182	1976	-99.000	40.0	225	55	316	276	.0	.3	3150
LG139 1850 SYCAMORE 17			20S 61E 19 422													
*7-18-73	2150	-99.0	1982	7.65	383	138	519	-99.000	52.0	154	75	92	107	.2	.3	1276
LW 10 STEVENS SPRING			21S 62E 31 411 1													
4-15-70	32	16.0	7065	7.70	576	1190	2605	.31	-.5	615	45	579	540	.0	3.5	5861
5- 4-70	41	15.6	6074	7.55	563	735	2655	.25	-.4	660	79	612	540	.0	3.4	5561
8- 5-70	128	23.1	997	7.68	112	26	449	.28	-.5	25	10	195	20	.0	.3	781
LW 11 UNNAMED SPRING			21S 62E 29 434 3													
3-30-70	17	-99.9	4762	7.50	359	758	2164	.10	-.5	456	55	505	332	.0	2.5	4447
5- 4-70	45	18.6	5807	7.40	341	901	1954	.18	-.4	466	54	518	336	.0	2.4	4400
6- 5-70	66	26.2	4190	7.75	365	734	2471	-.110	-.5	520	75	610	366	.0	2.6	4958
7- 6-70	99	22.3	4216	7.25	378	731	2111	.40	2.9	408	49	562	300	.0	2.5	4353
8- 5-70	129	23.9	1555	7.80	107	45	988	.18	-.5	33	13	38	25	.0	.3	1195
9-11-70	186	20.0	4846	7.80	341	790	1906	.30	3.1	438	53	525	300	.0	1.6	4184
9-11-70	187	20.0	5608	7.34	433	833	2076	.18	-.9	449	56	460	301	.0	1.8	4390
12-16-70	314	-99.9	5300	7.25	352	846	2205	.16	1.1	519	58	498	318	.0	.7	4699
1-19-71	343	-99.9	6023	7.61	391	797	2419	-.110	.2	578	61	596	348	.0	1.8	4993
4-23-71	453	17.2	5746	7.34	445	699	2344	1.20	.2	487	62	568	308	.0	2.3	4690
7-26-71	653	22.8	5634	7.27	421	776	2270	.18	.1	471	52	530	302	.0	1.9	4560
8-1[illegible]-71	730	24.0	6072	7.37	452	787	2178	.36	1.3	483	55	553	311	.0	1.7	4593
5- 4-72	1413	13.3	4221	7.59	374	666	1732	.16	.8	301	39	435	214	.0	1.8	3374
*7-10-72	1577	23.3	4356	7.71	384	441	1704	.18	-.1	293	35	470	207	.1	1.8	3291

DATE	NO.	TEMP	COND	PH	HCO3	CL	SO4	PO4	NO3	NA	K	CA	MG	NH4	F	TDS
LW 12 GRAPEVINE SPRING 21S 62E 29 422 1																
4-15-70	34	21.3	2331	7.29	219	334	1002	.12	2.2	120	41	304	150	.0	1.0	2062
6- 4-70	40	21.1	2208	7.52	217	166	1202	-.10	2.7	126	21	291	158	.0	1.0	2075
6- 5-70	67	22.2	2116	7.75	222	151	1124	-.10	1.9	136	21	287	147	.0	.9	1978
7- 6-70	100	20.6	2156	7.75	221	158	997	.25	2.2	121	22	223	150	.0	1.0	1783
8- 5-70	130	20.0	2173	8.10	220	159	1178	-.10	1.8	128	24	267	152	.0	1.1	2018
9-11-70	148	20.3	2600	7.84	227	160	1103	-.10	2.4	129	22	275	136	.0	.9	1905
9-11-70	149	20.3	2585	7.93	225	148	1092	.25	2.2	132	24	272	145	.0	1.0	1927
4-23-71	454	20.6	2579	7.31	220	159	1145	.16	2.0	164	22	285	144	.0	1.0	2030
7-26-71	650	22.2	2576	7.41	228	162	1205	-.10	1.7	131	22	277	148	.0	1.0	2060
9-11-71	761	24.5	2524	7.65	222	162	1147	-.10	1.9	121	24	275	147	.0	1.0	1988
12- 2-71	921	16.0	2656	7.46	225	168	1137	.20	2.1	132	24	286	143	.0	1.0	2004
1- 4-72	1074	16.9	2555	7.71	221	163	1144	-.10	2.9	127	23	278	141	.0	1.0	1989
2- 1-72	1180	19.0	2614	7.42	225	163	1139	-.10	2.5	124	21	275	143	.0	1.0	1980
* 7-10-72	1576	21.3	2653	7.48	225	161	1171	.12	1.1	123	21	271	144	.1	1.0	2004
LW 13 WHIT. MESA SP. 1 22S 62E 05 141 1																
3-30-70	14	-99.9	5178	7.61	229	1245	1403	-.10	5.1	470	42	548	250	.0	1.2	4077
6- 4-70	43	24.2	5013	7.03	219	1390	1353	-.10	1.3	514	46	560	246	.0	1.3	4219
6- 3-70	69	34.4	4427	7.30	231	1270	1734	.11	2.8	588	47	580	292	.0	1.3	4629
7- 6-70	101	21.8	4138	7.55	214	1100	1214	.15	0.0	488	43	426	230	.0	1.2	3608
8- [illegible]-70	131	24.4	4763	7.90	183	1364	1617	.21	-.5	500	62	610	290	.0	1.3	4535
9-11-70	196	25.6	5419	7.39	236	1274	1667	.20	.9	525	53	690	250	.0	1.3	4477
9-11-70	197	26.6	6503	7.75	239	1243	1834	.16	1.5	588	59	590	246	.0	1.5	4681
1-19-71	347	13.9	5889	7.80	216	1121	1829	-.10	6.5	632	54	598	243	.0	1.3	4591
7-26-71	637	23.3	6867	7.75	284	1187	2038	-.10	3.4	678	62	583	291	.0	1.3	4983
8-31-71	729	24.0	7168	8.05	290	1286	2058	-.10	1.4	664	68	626	294	.0	1.5	5104
11-11-71	810	16.1	6409	7.65	267	1112	1822	-.10	4.3	592	57	518	258	.0	1.2	4496
12- 2-71	920	13.0	5828	7.57	240	917	1841	-.10	17.0	606	59	476	227	.0	1.0	4263
1- 3-72	1070	15.0	6054	7.76	249	1068	1775	-.10	6.6	584	66	546	245	.0	1.3	4364
2- 1-72	1181	13.0	6175	7.78	250	993	1757	-.10	6.6	536	53	519	238	.0	1.4	4227
3- 3-72	1274	-99.0	5632	7.81	243	1069	1753	-.10	6.3	536	57	511	239	.0	1.3	4292
5- 4-72	1397	20.0	6148	7.68	279	1126	1880	-.04	3.9	586	60	559	255	.0	1.4	4609
6- 1-72	1468	20.4	6436	7.63	291	1242	1986	-.04	2.4	655	65	569	280	.0	1.4	4904
7-10-72	1562	21.7	7009	7.78	291	1252	2104	-.04	1.9	630	65	591	282	.0	1.4	5070
8- 7-72	1637	22.2	6953	7.63	291	1223	1992	-.08	2.6	631	63	589	283	.0	1.4	4928
9- 7-72	1662	20.0	6566	7.66	307	1249	2100	.08	1.2	647	68	592	283	.0	1.4	5093
10- 1-72	1676	21.1	6674	7.41	307	1258	1955	-.04	.6	670	74	590	283	.0	1.3	4983
11- 7-72	1811	16.1	6458	7.54	294	1146	1888	-.04	1.5	601	61	555	263	.0	1.4	4661
12- 4-72	1843	16.6	6344	7.62	286	1130	1843	.06	3.8	592	59	542	256	.0	1.4	4568

DATE	NO.	TEMP	CCND	PH	HCO3	CL	SO4	PO4	NO3	NA	K	CA	MG	NH4	F	TDS
LW 13 (continued)																
1- 4-73	1858	-99.0	6177	7.62	270	1081	1827	-.04	6.5	560	57	514	243	.0	1.4	4443
2- 1-73	1923	14.4	10023	7.29	259	1055	1822	-.04	7.4	564	57	519	240	.0	-99.0	4391
3- 5-73	2003	14.4	6028	7.84	265	1066	1798	-.04	6.3	557	53	534	238	.0	-99.0	4382
4- 1-73	1960	14.4	6013	7.81	264	1066	1783	.16	5.1	549	51	527	237	.0	-99.0	4349
* 5- 3-73	2036	17.8	6020	7.60	268	1098	1834	-.04	4.3	574	56	538	253	.1	-99.0	4490
5-31-73	2111	20.0	6676	7.87	298	1244	1986	-.04	3.1	628	58	589	285	.2	1.3	4941
7- 3-73	2132	26.5	6992	7.76	236	1307	2100	-.04	.0	699	98	589	296	.1	-99.0	5285
8- 1-73	2183	23.1	6037	7.78	188	1287	2212	-.04	1.8	656	6	606	294	.1	-99.0	5195
LW 14 WHIT. MESA SP. 2 22S 62E 04 322 1																
6-19-70	70	17.7	1540	7.40	257	206	409	.13	3.3	120	19	132	72	.0	1.2	1089
6- 5-70	71	25.6	1548	7.25	266	215	396	.11	2.0	132	21	150	75	.0	1.1	1122
7- 6-70	102	23.3	1610	7.55	269	228	448	.38	-.5	126	21	156	70	.0	1.2	1153
8- 5-70	132	25.8	2145	7.39	297	393	439	.33	-.5	166	28	205	101	.0	1.4	1480
9-12-70	198	23.3	1664	8.00	239	230	329	.15	.4	129	23	140	66	.0	1.1	1036
9-12-70	199	23.3	1738	8.02	240	223	402	.10	-.9	137	24	138	75	.0	1.3	1118
1-19-71	241	13.9	4818	7.74	247	895	1246	-.10	2.7	347	66	491	198	.0	1.0	3368
LW 15 WHITNEY NESA SEEP 22S 62E 04 233 1																
3-30-70	15	-99.9	5004	7.60	232	1000	1603	-.10	13.3	553	50	438	227	.0	1.1	4000
5- 4-70	66	20.0	5500	7.71	225	975	1621	-.10	5.9	586	54	407	214	.0	1.0	3978
6- 5-70	72	26.6	4157	7.65	232	930	1712	-.10	13.4	656	66	300	236	.0	1.0	4029
7- 6-70	103	21.7	4237	7.75	232	966	1460	-.10	14.2	602	52	368	234	.0	1.1	3820
8- 5-70	133	22.5	4318	7.82	203	972	1547	-.10	22.1	625	60	410	220	.0	1.0	3957
9-11-70	200	23.1	6234	7.81	236	975	1627	-.10	18.6	550	56	440	205	.0	1.1	3988
9-11-70	201	23.1	5699	7.96	238	1022	1750	.10	13.9	600	64	444	236	.0	1.1	4248
1-19-71	342	18.3	5699	7.60	214	951	1843	-.10	13.9	603	55	492	222	.0	1.0	4286
4-22-71	433	20.0	6746	7.27	240	931	1831	-.10	17.4	595	57	429	221	.0	1.1	4201
6-14-71	541	21.5	5931	7.45	241	946	1796	-.10	14.2	520	57	474	237	.0	1.1	4159
7-26-71	636	23.9	5714	7.75	246	965	1863	-.10	20.0	585	56	448	229	.0	1.1	4288
8-31-71	728	24.0	6172	7.95	244	997	1956	-. 10	16.0	632	63	471	250	.0	1.2	4506
11-11-71	839	21.1	6831	7.69	239	916	1841	-. 10	17.0	556	62	445	232	.0	1.0	4227
12- 2-71	919	13.0	6132	7.62	261	1084	1754	-.10	5.5	594	63	535	250	.0	1.1	4420
1- 3-72	1062	20.0	5726	7.78	278	915	1828	-.10	20.0	594	59	448	222	.0	1.0	4204
2- 1-72	1182	13.0	5617	7.63	243	905	1818	-.10	19.0	574	55	449	221	.0	1.1	4162
3- 3-72	1273	-99.0	5411	7.80	239	917	1812	-.10	19.0	583	57	449	222	.0	1.0	4178
5- 4-72	1398	21.0	5513	7.66	249	898	1874	-.04	18.0	585	59	459	218	.0	1.0	4235
6- 1-72	1467	21.1	5466	7.74	247	893	1843	.08	17.9	602	61	444	231	.0	1.1	4214
7-10-72	5840	23.3	5840	7.72	254	898	1887	-.04	17.0	587	57	452	225	.0	1.1	4249
8- 7-72	1636	25.6	5899	7.81	253	902	1805	-.04	18.2	569	58	453	225	.0	1.1	4155
9- 7-72	1661	24.4	5412	7.85	249	897	1903	-.04	16.0	565	58	453	216	.0	1.1	4227

DATE	NO.	TEMP	COND	PH	HCO3	CL	SO4	PO4	NO3	NA	K	CA	MG	NH4	F	TDS
LW 15 (continued)																
10- 1-72	1678	23.9	5511	7.66	252	894	1830	-.04	18.1	587	60	463	225	.0	1.1	4202
11- 7-72	[illegible]	20.0	5829	7.55	255	889	1719	-.04	19.0	583	58	451	220	.0	1.1	4065
12- 4-72	1744	[illegible]	5634	7.71	253	889	1791	.08	22.0	587	56	443	222	.0	1.1	4136
1- 4-73	1859	-99.00	5712	7.62	251	883	1818	-.04	26.0	580	57	440	213	.1	1.2	4141
2- 1-73	1924	18.1	5537	7.49	251	868	1820	-.04	20.2	565	57	441	213	.1	-99.00	4107
3- 5-73	2002	[illegible]	5421	7.84	252	883	1797	-.04	22.0	567	55	456	220	.1	-99.00	4125
4- 1-73	[illegible]	15.6	5508	7.71	254	870	1802	-.04	22.0	573	54	464	221	.1	-99.00	4131
* 5- 1-73	2035	[illegible]	5620	7.61	243	874	1799	-.04	21.7	564	56	450	221	.8	-99.00	4106
5-11-73	2110	[illegible]	5570	7.88	252	902	1791	-.04	21.0	570	53	454	227	.1	1.1	4143
7- 2-73	2131	25.6	5544	7.44	236	886	1846	-.04	22.0	575	81	429	225	.1	-99.00	4181
[illegible]	2141	[illegible]	5406	7.87	188	1157	1864	-.04	21.0	611	53	445	236	.1	-99.00	4479
LW 33 T[illegible] T9 9IJCK CK			21S 62E 22 442 1													
1-11-70	192	[illegible]	5598	7.34	257	1014	2335	.30	3.1	538	61	640	350	.0	1.8	5070
9-11-70	193	11.3	6650	7.98	241	1090	2655	.44	3.4	596	73	656	356	.0	1.9	5550
0-23-71	462	10.4	6896	7.32	232	1002	2828	.20	25.6	650	46	593	368	.0	1.6	5629
7-26-71	697	22.3	7870	7.30	284	1123	3210	.12	19.6	833	42	664	418	.0	1.7	6441
1-30-71	714	21.0	7765	7.60	266	1000	3000	-.100	19.1	768	50	613	406	.0	1.4	5996
11-10-71	836	12.2	7040	7.60	229	959	2644	.14	33.0	695	47	506	362	.0	1.4	5441
12- 2-71	91F	1.0	6994	7.49	232	991	2765	-.100	30.0	695	51	575	371	.0	1.5	5594
3- 2-72	1262	-99.00	6843	7.66	233	1012	2886	-.100	32.0	709	55	573	373	.0	1.6	5756
0- 5-72	-0	19.0	6644	7.20	229	981	2837	2.30	34.0	706	50	583	363	.1	1.7	5671
5- 0-72	1386	16.5	7097	7.44	250	1019	2947	.18	30.0	742	50	620	384	.1	1.6	5917
7-10-72	1575	23.3	8216	7.63	264	1126	3405	.18	36.5	844	46	691	426	.1	1.7	6706
1- 0-72	1628	25.6	8107	7.56	267	1096	3341	.12	34.0	869	43	645	421	.1	1.7	6582
1- 0-73	1867	-99.00	7160	7.52	231	962	2969	.20	40.00	709	53	625	365	.1	1.7	5828
1-16-73	1881	9.4	7097	7.56	228	976	2963	.10	37.6	730	64	581	373	.1	1.8	5829
LW 54 LVRM HFW FON0			21S 62E 34 443 1													
6-11-71	[illegible]	26.0	3026	8.00	160	583	660	.14	-.1	279	24	149	133	.0	1.3	1820
12- 2-71	911	6.0	2520	8.02	150	426	600	-.100	1.0	245	10	139	114	.0	1.0	1610
1- 4-72	1051	15.6	2576	8.04	148	442	588	-.100	2.2	240	17	140	113	.0	1.0	1616
2- 1-72	1183	[illegible]	2502	8.01	164	418	568	-.100	2.9	237	17	129	111	.0	1.0	1556
*5- 3-72	[illegible]	24.4	2918	8.13	157	517	700	-.004	-.1	303	25	144	130	.0	1.3	1097

DATE	NO.	TEMP	COND	PH	HCO3	CL	SO4	PO4	NO3	NA	K	CA	MG	NH4	F	TDS
LH 80 FLAM WASH 3			21S 61E 12 413 1													
7-26-71	541	23.3	4962	7.59	332	383	2550	-.10	-.1	340	20	429	378	.0	.6	4264
8-11-71	733	24.0	4679	7.65	315	331	2222	-.10	.3	285	19	437	333	.0	.6	3783
9-27-71	786	10.0	4892	7.77	327	399	2542	-.10	.1	451	23	466	380	.0	.7	4322
11-11-71	807	15.6	5280	7.74	324	395	2389	-.10	.5	344	23	445	375	.0	.8	4132
12- 2-71	922	14.0	4555	7.68	332	533	2307	-.10	.0	312	25	455	390	.0	.8	4186
1- 4-72	1072	8.1	4290	7.79	321	298	2115	-.10	2.4	285	21	434	300	.0	.8	3594
2- 1-72	1177	8.0	3703	8.10	311	286	1904	-.10	3.6	223	23	391	260	.0	.7	3185
3- 3-72	1272	-99.0	4085	8.02	304	278	2109	-.10	1.0	256	20	385	293	.0	.7	3493
4- 5-72	1334	19.3	4504	7.47	322	368	2413	-.04	.5	313	20	426	349	.0	.7	4076
5- 4-72	1385	21.0	4307	7.94	347	330	2319	-.04	2.4	302	20	434	332	.0	.7	3911
6- 1-72	1459	27.9	2912	6.87	303	175	1395	-.04	.8	156	24	311	184	.0	.6	2396
7-10-72	1588	25.0	4712	7.64	323	326	2470	-.04	.8	299	19	439	332	.1	.7	3985
8- 7-72	1635	24.4	4026	7.63	332	327	2315	-.04	-.1	295	19	434	372	.1	.7	3886
9- 5-72	1741	29.6	4390	7.54	296	328	2144	.14	1.0	285	26	379	310	.1	.6	3622
10- 1-72	1806	29.6	4510	7.35	329	341	2352	-.04	.4	307	20	427	339	.2	.7	3869
11- 7-72	1808	16.1	4530	7.51	335	312	2274	-.04	.0	292	21	408	319	.2	.7	3792
12- 4-72	1841	13.1	-99999	7.64	336	284	2190	-.04	1.7	290	24	406	307	.1	.8	3665
1- 5-73	1869	-99.0	4325	7.82	341	271	2209	-.04	2.2	280	24	396	306	.2	.8	3651
1-31-73	1905	11.1	3850	7.94	325	221	1954	-.04	3.4	223	26	379	261	.2	-99.0	3227
3- 5-73	2001	17.3	4350	7.92	335	253	2060	-.04	1.7	255	23	407	284	.1	-99.0	3454
4- 1-73	2016	17.9	4042	7.72	322	245	2049	-.04	2.6	250	23	402	277	.1	-99.0	3407
*5- 2-73	1931	24.4	3036	7.37	281	243	1993	.28	.4	236	15	378	263	.6	-99.0	3268
5-30-73	2100	30.6	4434	7.72	330	310	2353	-.04	.4	294	20	424	325	.2	.5	3890
7- 2-73	2113	22.2	5000	7.87	330	335	2550	-.04	.7	355	42	438	355	.1	-99.0	4242
8- 1-73	2178	25.6	4785	7.70	262	326	2548	-.04	.3	346	22	442	349	.1	-99.0	4152
LH 72 FLAM WSH AT EHREN			21S 61E 13 123 1													
1- 4-72	1041	8.1	3473	8.00	370	174	1774	-.10	2.2	190	29	380	238	.0	.8	2969
2- 1-72	1178	8.0	3448	7.94	354	162	1684	-.10	5.0	176	30	359	236	.0	.7	2827
7-11-72	1587	27.2	4900	7.40	387	264	2573	.40	2.6	366	36	474	325	.0	-.0	4320
11- 7-72	1794	-99.9	3580	7.77	390	170	1750	-.04	2.3	193	32	380	236	.[illegible]	.8	2951
12- 6-72	1842	11.1	-99999	7.72	380	176	1789	-.04	3.0	202	33	367	237	.1	.9	2995
1- 5-73	1870	-99.0	3601	7.70	381	172	1791	.08	6.0	106	33	366	247	.3	.8	2999
3- 5-73	2000	11.4	3625	7.92	308	172	1771	-.04	3.7	185	28	374	236	.1	-.0	2950
4- 1-73	2017	17.3	3406	7.85	355	159	1692	-.04	3.3	172	25	369	225	.1	-.0	2820
*5- 7-73	1982	17.8	2538	7.76	265	120	1402	-.04	.6	129	15	317	167	.2	-99.0	2281
5-30-73	2108	22.2	3288	7.85	301	156	1645	-.04	.5	166	28	338	221	.2	.8	2733

DATE	NO.	TEMP	COND	PH	HCO3	CL	SO4	PO4	NO3	NA	K	CA	MG	NH4	F	TDS
LW 74 FLAM RES DRAIN 1			21S 62E 19 111 4													
1-6-72	1078	16.1	1842	8.01	253	157	645	-.10	8.7	95	5	187	99	.0	.4	1322
2-1-72	1179	16.8	1877	7.99	123	156	631	-.10	7.7	84	4	174	100	.0	.4	1218
7-11-72	1588	30.4	1891	7.41	177	155	645	1.08	3.4	169	13	182	38	.0	-99.0	1293
11-7-72	1795	10.1	1135	7.37	225	46	375	-.04	2.3	30	3	127	59	.0	.4	753
1-5-73	1872	-99.0	1193	7.52	223	52	405	-.04	3.4	36	3	135	62	.2	.4	806
3-5-73	1998	17.8	1347	7.78	222	70	433	-.04	.5	39	3	150	66	.2	-99.0	872
4-1-73	2018	17.8	1465	7.66	217	78	451	-.04	4.0	41	3	152	68	.2	-99.0	904
5-2-73	1967	10.9	1400	7.75	211	89	465	-.04	4.2	40	-1	149	72	-.1	-99.0	923
5-30-73	2097	27.3	1445	7.81	221	99	487	-.04	4.9	42	3	152	80	-.1	.4	977
7-2-73	2123	22.8	1498	7.93	215	112	511	-.04	4.1	44	21	160	77	.1	-99.0	1035
8-1-73	2179	13.9	1482	8.00	176	123	545	-.04	4.9	43	4	166	80	.1	-99.0	1057
LW 75 FLAM RES DRAIN 2			21S 62E 19 111 5													
6-14-71	545	21.7	1083	7.85	227	46	319	-.10	3.0	38	4	114	48	.0	.4	684
8-31-71	732	20.6	876	7.48	224	26	257	-.10	2.7	24	3	102	45	.0	.4	571
7-10-72	1579	20.0	1353	7.99	179	116	404	-.04	3.4	110	5	107	46	.0	-99.0	879
11-7-72	1796	17.8	2249	7.46	232	217	748	-.04	10.4	137	5	199	114	.0	.4	1545
1-5-73	1873	-99.0	2401	7.76	247	236	820	-.04	15.4	137	5	204	134	.1	.5	1682
LW 84 SAHARA-NEV. C.C.			21S 61E 14 142													
* 1-31-73	1908	12.2	2716	7.52	355	135	1280	-.04	3.3	142	18	290	172	.0	.8	2215
LW 85 LEROY APTS.			20S 61E 26 331 1													
* 1-15-73	1874	14.4	2433	7.84	395	88	1080	-.04	8.9	108	18	165	210	.0	.3	1871
LW 86 MRLNO PKWY HARRS			20S 61E 26 331 2													
* 1-15-73	1875	17.2	1878	7.72	316	66	748	-.04	9.1	82	9	137	146	.0	.3	1353
LW 87 PALLARD NO ESTRN			21S 61E 02 111													
* 1-15-73	1876	19.4	4119	7.67	365	213	2076	.20	13.3	276	88	257	317	.0	.5	3421
LW 88 MONT HAROS			21S 61E 01 211													
* 1-15-73	1877	23.3	4503	7.61	321	312	2184	-.04	12.3	397	41	258	320	.0	.3	3683

APPENDIX IV: Principal Ionic Components for Establishing Hydrochemical Facies in Near-Surface Ground Water.[1/]

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1. Original data used to calculate percents are marked by asterick in Appendix III.

Station	% epm Ca + Mg of total cations	% epm Na + K of total cations	% epm HCO_3 of total anions	% epm SO_4 + Cl of total anions	Facies	% major anion & cation
LG030	60.4	39.6	3.2	96.8	C	SO_4 = 61.2 Na = 36.9
LG036	69.7	30.3	1.3	98.7	C	SO_4 = 62.4 Mg = 39.5
LG039	70.7	29.3	3.8	96.3	C	SO_4 & Cl=48.2 Mg = 37.1
LG043	71.5	28.5	4.3	95.7	C	SO_4 = 67.4 Mg = 36.3
LG048	76.9	23.1	7.4	92.6	C	SO_4 = 80.5 Mg = 52.8
LG098	78.7	21.3	19.1	80.9	A	SO_4 = 65.5 Mg = 41.6
LG100	79.6	20.4	6.5	93.5	C	SO_4 = 84.8 Mg = 45.1
LG102	72.2	27.8	6.0	94.0	C	SO_4 = 83.4 Mg = 44.0
LG103	84.1	15.9	6.5	93.5	D	SO_4 = 78.0 Ca = 51.0
LG104	60.5	39.5	5.4	94.6	C	SO_4 = 82.1 Na = 36.1
LG105	79.3	20.7	5.9	94.1	C	SO_4 = 82.3 Mg = 39.2
LG106	87.7	12.3	6.7	93.3	C	SO_4 = 79.8 Ca = 49.6
LG107	75.0	25.0	13.3	86.7	B	SO_4 = 76.4 Ca = 39.4
LG108	92.0	8.0	9.1	90.9	E	SO_4 = 81.7 Ca = 52.7
LG109	76.3	22.9	12.2	87.8	A	SO_4 = 72.9 Mg = 45.6

(continued)

Station	% epm Ca + Mg of total cations	% epm Na + K of total cations	% epm HCO_3 of total anions	% epm SO_4 + Cl of total anions	Facies	% major anion & cation
LG110	78.6	21.4	19.1	80.9	A	SO_4 = 67.8 Mg = 52.8
LG129	70.9	29.1	31.7	68.3	A	SO_4 = 53.0 Ca & Mg = 35.5
LG138	77.5	22.5	5.4	94.6	A	SO_4 = 84.1 Mg = 45.7
LG139	64.6	35.4	29.9	70.1	A	SO_4 = 51.5 Mg = 42.5
LW011	73.6	26.4	11.6	88.5	B	SO_4 = 65.5 Ca = 40.6
LW012	81.2	18.8	11.3	88.7	B	SO_4 = 74.8 Ca = 43.3
LW013	64.4	35.6	6.0	94.0	D	SO_4 = 51.9 Ca = 36.2
LW015	61.0	39.0	6.0	94.0	D	SO_4 = 56.7 Na = 36.8
LW054	56.4	43.6	8.1	91.9	C	SO_4 = 45.9 Cl = 46.0 Na = 41.6
LW060	79.2	20.8	8.7	91.3	D	SO_4 = 78.4 Mg = 42.3
LW072	83.1	16.9	11.8	88.3	B	SO_4 = 79.1 Ca = 44.5
LW084	81.2	18.8	16.0	84.0	B	SO_4 = 73.5 Ca = 41.0 Mg = 40.1
LW085	83.2	16.8	20.6	79.4	A	SO_4 = 71.5 Mg = 56.3
LW086	83.2	16.8	22.9	77.1	A	SO_4 = 68.9 Mg = 53.0
LW087	73.2	26.8	10.8	89.2	A	SO_4 = 78.3 Mg = 49.1

(continued)

Station	% epm Ca + Mg of total cations	% epm Na + K of total cations	% epm HCO_3 of total anions	% epm SO_4 + Cl of total anions	Facies	% major anion & cation
LW088	68.2	31.8	8.8	91.2	C	SO_4 = 76.4 Mg = 45.8
LW090	82.2	17.8	11.2	88.8	A	SO_4 = 81.8 Mg = 45.1
LW092	60.0	40.0	1.9	98.1	D	SO_4 = 85.5 Ca = 45.4
LW094	79.5	20.5	9.8	90.2	C	SO_4 = 78.2 Mg = 45.2
LW100	75.7	24.3	35.6	64.4	A	SO_4 = 51.9 Mg = 52.6

Summary[1] of facies delineated in near-surface ground water of the study area.

A. Mg + Ca, Na + K, SO_4 + Cl, HCO_3

B. Ca + Mg, Na + K, SO_4 + Cl, HCO_3

C. Mg + Ca, Na + K, SO_4 + Cl

D. Ca + Mg, Na + K, SO_4 + Cl

E. Ca + Mg, SO_4 + Cl

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[1] For ion pair, that ion composing 50% of that pair is placed first. See Table 4-1 for chemical makeup of various facies.

APPENDIX V: Saturation Index[1] for Water-Quality Data from 35 Data Points.

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[1] IAP/KT ratio calculated by computer program WATEQ (Truesdell and Jones, 1974)

Sample	Dominant Mineral Species[1]	IAP/KT
LG030	dolomite	2.655
	calcite	1.347
	anhydrite	0.981
	aragonite	0.902
	gypsum	0.865
	calcite (MH)[2]	0.151
LG036	calcite	0.465
	gypsum	0.409
	anhydrite	0.401
	aragonite	0.304
	dolomite	0.284
LG039	dolomite	1.499
	calcite	1.148
	aragonite	0.756
	anhydrite	0.335
	gypsum	0.332
	calcite (MH)	0.131
LG043	anhydrite	0.366
	gypsum	0.359
	calcite	0.185
	aragonite	0.122
LG048	dolomite	1.957
	calcite	0.917
	aragonite	0.608
	anhydrite	0.203
	gypsum	0.195
	calcite (MH)	0.104
LG098	dolomite	6.850
	calcite	2.362
	aragonite	1.572
	calcite (MH)	0.268
	anhydrite	0.220
	gypsum	0.205
LG100	dolomite	12.010
	calcite	2.891
	aragonite	1.924
	anhydrite	0.446
	gypsum	0.416
	calcite (MH)	0.328
LG102	dolomite	16.090
	calcite	3.010
	aragonite	2.009
	anhydrite	0.637
	gypsum	0.578
	calcite (MH)	0.340
	huntite	0.130
	hydromagnesite	0.126
LG103	dolomite	12.650
	calcite	4.204
	aragonite	2.797
	anhydrite	0.720
	gypsum	0.671
	calcite (MH)	0.477
LG104	dolomite	18.200
	calcite	3.807
	aragonite	2.518
	anhydrite	1.090
	gypsum	1.051
	calcite (MH)	0.433
	huntite	0.111
LG105	dolomite	9.166
	calcite	2.954
	aragonite	1.958
	anhydrite	1.002
	gypsum	0.957
	calcite (MH)	0.336
LG106	dolomite	1.908
	calcite	1.483
	aragonite	0.990
	anhydrite	0.702
	gypsum	0.638
	calcite (MH)	0.168
LG107	dolomite	4.025
	calcite	2.003
	aragonite	1.335
	anhydrite	0.318
	gypsum	0.293
	calcite (MH)	0.227
LG108	dolomite	6.660
	calcite	2.895
	aragonite	1.919
	anhydrite	0.556
	gypsum	0.532
	calcite (MH)	0.330
LG109	dolomite	14.580
	calcite	2.954
	aragonite	1.972
	calcite (MH)	0.334
	anhydrite	0.333
	gypsum	0.303
	huntite	0.100

Sample	Dominant Min Species	IAP/KT
LG110	dolomite	44.870
	calcite	4.388
	aragonite	2.937
	huntite	1.353
	hydromagnesite	0.805
	calcite (Mg)	0.493
	anhydrite	0.288
	gypsum	0.255
LG129	dolomite	9.589
	calcite	3.123
	aragonite	2.042
	calcite (MH)	0.358
LG138	dolomite	11.970
	calcite	3.114
	aragonite	1.941
	gypsum	0.575
	anhydrite	0.487
	calcite (MH)	0.355
LG139	dolomite	19.760
	calcite	3.046
	aragonite	2.031
	calcite (MH)	0.345
	huntite	0.233
	hydromagnesite	0.150
LW011	dolomite	88.760
	calcite	9.961
	aragonite	6.628
	huntite	1.947
	calcite (MH)	1.129
	anhydrite	0.667
	gypsum	0.620
LW012	dolomite	7.178
	calcite	2.735
	aragonite	1.820
	anhydrite	0.4084
	gypsum	0.381
	calcite (MH)	0.310
LW013	dolomite	22.600
	calcite	5.486
	aragonite	3.552
	gypsum	0.752
	anhydrite	0.710
	calcite (MH)	0.628
LW015	dolomite	14.900
	calcite	4.365
	aragonite	2.825
	gypsum	0.666
	anhydrite	0.629
	calcite (MH)	0.500
LW054	dolomite	43.590
	calcite	5.094
	aragonite	3.401
	calcite (MH)	0.575
	anhydrite	0.157
	gypsum	0.143
LW060	dolomite	11.960
	calcite	3.038
	aragonite	2.028
	anhydrite	0.685
	gypsum	0.622
	calcite (MH)	0.343
LW072	dolomite	25.670
	calcite	5.557
	aragonite	3.597
	calcite (MH)	0.637
	gypsum	0.496
	anhydrite	0.468
LW084	dolomite	9.454
	calcite	3.418
	aragonite	2.106
	gypsum	0.444
	calcite (MH)	0.388
	anhydrite	0.365
LW085	dolomite	47.370
	calcite	5.078
	aragonite	3.199
	huntite	0.842
	calcite (MH)	0.560
	hydromagnesite	0.260
	gypsum	0.231
	anhydrite	0.200
LW086	dolomite	17.390
	calcite	3.247
	aragonite	2.093
	calcite (MH)	0.372
	gypsum	0.163
	anhydrite	0.151
	huntite	0.115