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Analysis of Groundwater Quality  
in New Washoe City, Nevada

A thesis submitted in partial fulfillment of the  
Master of Science in Hydrogeology

By  
Wallace Alan McKay

|||

July 1991

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ACKNOWLEDGMENTS

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## ABSTRACT

Historic water quality problems, coupled with dramatic population increases, necessitated a water quality study in New Washoe City (NWC), Nevada. Analysis of 60 groundwater samples for fluoride (F), iron (Fe), and nitrate ( $\text{NO}_3^-$ ) indicate widely variable conditions throughout NWC. Fluoride levels in excess of 7 mg/l were found in domestic water supplies in southern and western NWC. In the west-central portion of the study area, iron levels in excess of their recommended 0.6 mg/l were commonly associated with chemically reducing indicators, such as low dissolved oxygen values ( $<0.2$  mg/l) and strong hydrogen sulfide odor.  $\text{NO}_3^-$  concentrations in excess of 45 mg/l are common in northeast NWC and may be associated with septic system contamination. Comparison of 1987 water analysis with those from a 1977 study indicate that nitrate contamination will continue to be a problem in northeast NWC, but that chemically reducing conditions downgradient to the west will inhibit nitrate migration via the process of denitrification.

## INTRODUCTION

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The primary population center of Washoe Valley is New Washoe City, in the northern portion of the valley. In New Washoe City, the number of homes has increased from 748 in 1974 to over 1,000 in 1980. This rapid residential growth has necessitated construction and installation of public water supply systems. The increased population has increased water demand and has caused changes in water quantity and quality. Additionally, the increased water quality in New Washoe City has been a problem, as large numbers of people rely on the water as a potable supply. This is a serious development, since the water is one of the major products.

A previous study by American and Canadian (A/C) scientists determined levels of nitrate (NO<sub>3</sub>), fluoride (F), and lead (Pb) in wells in New Washoe City. Although NO<sub>3</sub> is not a health hazard, it is a potential problem in areas of high nitrate concentration. Fluoride (F) is a health hazard in areas of high concentration. Lead (Pb) is a health hazard in areas of high concentration. This is, however, a potential problem on the part of drinking water. Nitrate (NO<sub>3</sub>) is a health hazard in areas of high concentration. This is, however, a potential problem on the part of drinking water. Fluoride (F) is a health hazard in areas of high concentration. This is, however, a potential problem on the part of drinking water. Lead (Pb) is a health hazard in areas of high concentration. This is, however, a potential problem on the part of drinking water.

## INTRODUCTION

### STATEMENT OF PROBLEM

Over the past 20 years, Washoe Valley, Nevada (Figure 1) has experienced a population increase from 1,000 in 1966 to over 3,000 in 1988. The reasons for this increase are twofold: 1) development pressures in the rapidly growing metropolitan areas of Carson City and Reno have resulted in a need for additional housing; and 2) a general demographic shift from urban to suburban and rural lifestyles.

The primary population center of Washoe Valley is New Washoe City, in the northeast portion of the valley. In New Washoe City, the number of homes has increased from 740 in 1979 to over 1,000 in 1988. With each residence relying on privately owned wells and individual septic systems, the previously mentioned population increase would be expected to cause changes in both groundwater quantity and quality. Additionally, the ambient water quality at New Washoe City has now become a problem, as large numbers of people rely on this source as a potable supply. Prior to suburban development, there was little use of the native groundwater.

A previous study by Armstrong and Fordham (1977) reported deleterious levels of nitrate ( $\text{NO}_3^-$ ), fluoride (F), and iron (Fe) in well waters in New Washoe City. Although  $\text{NO}_3^-$ , F, and Fe levels in New Washoe City groundwater are often in excess of state and federally recommended limits (Table 1), reports of unhealthful side effects have been rare. There is, however, a continued reluctance on the part of lending institutions to become financially involved with property in New Washoe City because water supplies fail to meet standards. The short-term solution for property owners and developers has thus far been the installation of costly water treatment systems which require frequent maintenance and yield only limited results.

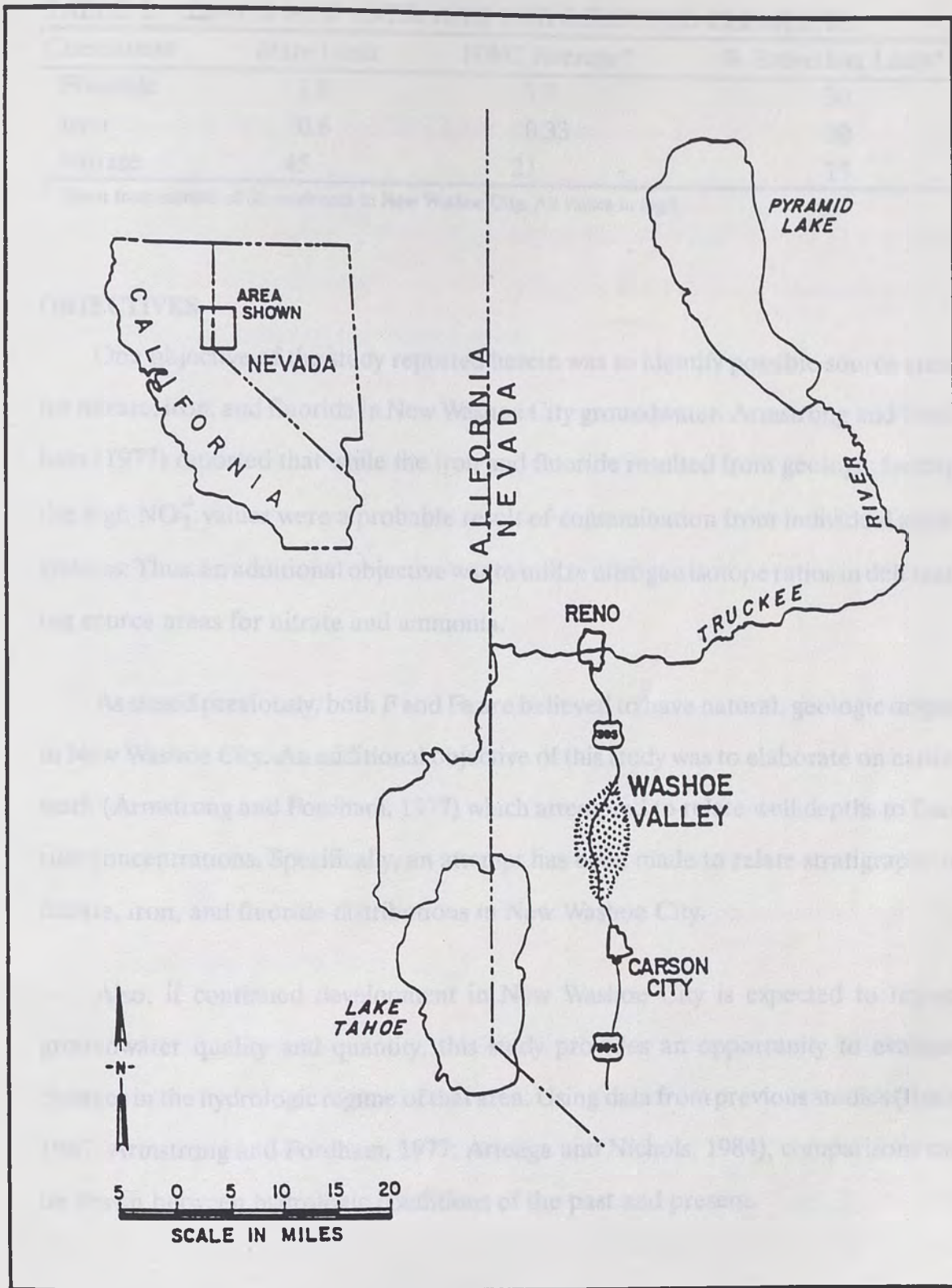


FIGURE 1. Location of Washoe Valley with Respect to Major Regional Features.

TABLE 1. LIMITS AND AVERAGES FOR SELECTED ELEMENTS.

Constituent	State Limit	NWC Average*	% Exceeding Limit*
Fluoride	1.8	1.7	30
Iron	0.6	0.33	20
Nitrate	45	21	15

\* Taken from sample of 60 residences in New Washoe City. All values in mg/l.

## OBJECTIVES

One objective of the study reported herein was to identify possible source areas for nitrate, iron, and fluoride in New Washoe City groundwater. Armstrong and Fordham (1977) reported that while the iron and fluoride resulted from geologic factors, the high  $\text{NO}_3^-$  values were a probable result of contamination from individual septic systems. Thus, an additional objective was to utilize nitrogen isotope ratios in delineating source areas for nitrate and ammonia.

As stated previously, both F and Fe are believed to have natural, geologic origins in New Washoe City. An additional objective of this study was to elaborate on earlier work (Armstrong and Fordham, 1977) which attempted to relate well depths to fluoride concentrations. Specifically, an attempt has been made to relate stratigraphy to nitrate, iron, and fluoride distributions in New Washoe City.

Also, if continued development in New Washoe City is expected to impact groundwater quality and quantity, this study provides an opportunity to evaluate changes in the hydrologic regime of that area. Using data from previous studies (Rush, 1967; Armstrong and Fordham, 1977; Arteaga and Nichols, 1984), comparisons can be drawn between hydrologic conditions of the past and present.

## PHYSICAL SETTING

### GENERAL

Centrally located between the Carson City and Reno–Sparks metropolitan areas, Washoe Valley occupies approximately 82 square miles, one-third of which is valley floor (Figure 2). The major hydrologic feature of Washoe Valley is Washoe and Little Washoe Lakes, respectively. Under average climatic conditions, the lakes occupy approximately 25 percent of the valley floor.

Historically, the economy of the valley was primarily ranching and farming, with alfalfa and undeveloped pasture utilizing much of the valley floor not occupied by lake. Since the 1960s, however, residential development has assumed an increasingly prominent role, and today is the dominant component of the valley economy.

### CLIMATE

Climatic conditions in Washoe Valley are typical of valleys located on the eastern flank of the Sierra Nevada Mountain Range. Winters are characterized by relatively cold temperatures and significant amounts of snow at higher elevations. Annual precipitation in the higher elevation portions of the valley is approximately 30 inches. Summers are typically dry with warm days and cool nights. The mean annual precipitation on the valley floor is 12 inches.

Evaporation and evapotranspiration (ET) are dominant processes in the hydrologic budget in Washoe Valley. Arteaga and Nichols (1984) report that evaporation from Washoe and Little Washoe Lakes comprise a significant percentage of outflow in the valley hydrologic budget. Based on an annual evaporation rate of 4.6 feet per year (ft/yr) and an average surface area of 4,900 acres, they estimate that over 22,000 acre-feet per year are lost to evaporation from the lake surfaces.

FIGURE 2. Location of Washoe Valley with respect to major Nevada cities.

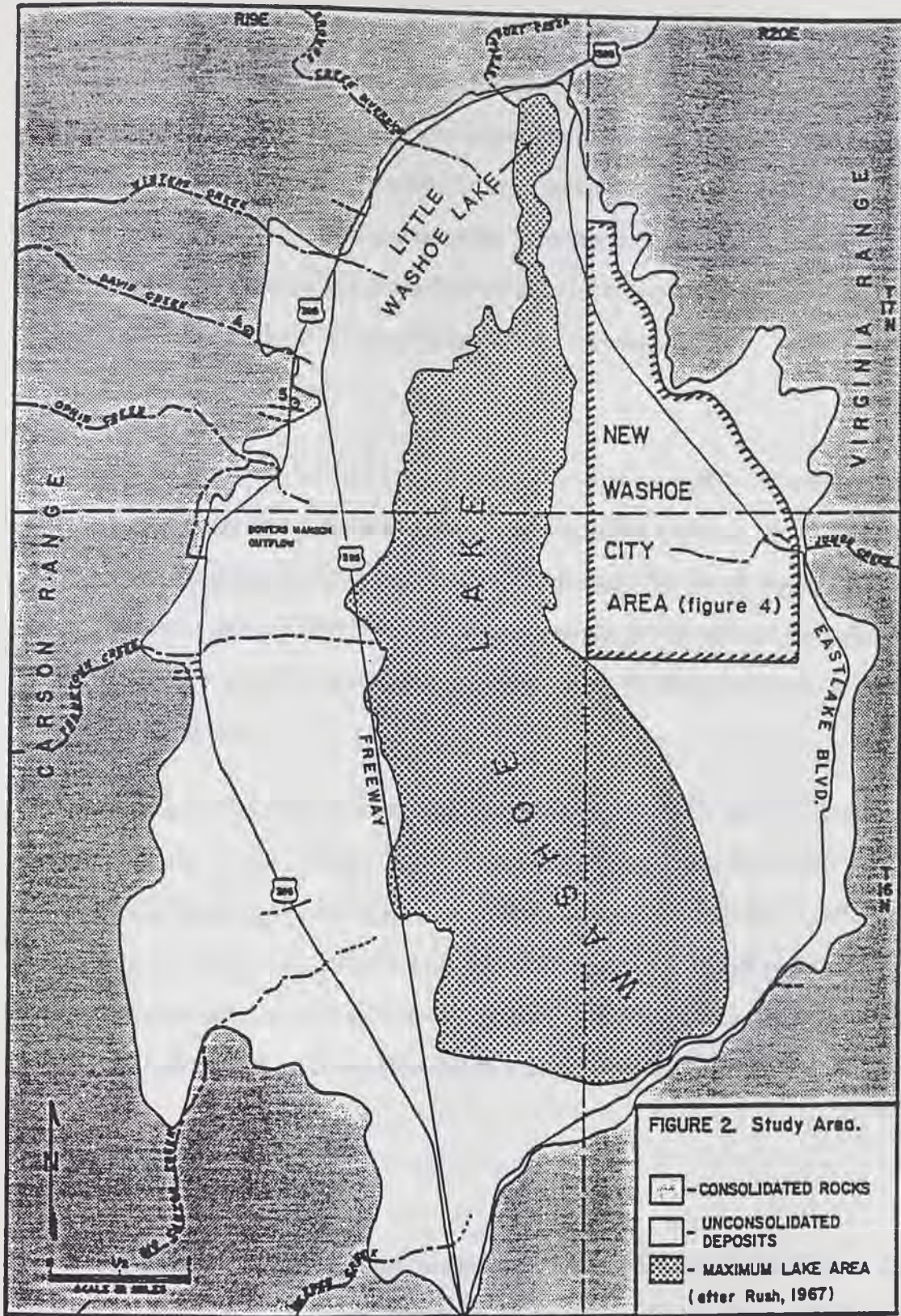


FIGURE 2. Location of Study Area with Respect to Washoe Valley.

Evapotranspiration, or ET, is the combined process of evaporation from soils and transpiration from plant uptake. In shallow groundwater areas inhabited by phreatophytic plants, ET can be a major source of outflow in the hydrologic budget. In Washoe Valley, water table depths of less than 10 feet, coupled with over 13,000 acres of various phreatophytes (hay crops, swamp grass, meadowgrass, rabbit brush, and tall sage) result in large amounts of ET annually. Arteaga and Nichols (1984) estimated that the combined effects were in excess of 27,000 acre-feet annually.

## **GEOLOGY**

Washoe Valley is a cenozoic structural depression located on the western margin of the Great Basin in the Basin and Range physiographic province (Fenneman, 1931). To the west, Washoe Valley is bounded by the Carson Range of the Sierra Nevada, which crests at about 9,000 feet. The eastern margin of the valley is bounded by the Virginia Range, a pinion and sage covered range which has maximum elevations of 6,500 to 7,500 feet.

Geologic units range from recent lake deposits (sand, silt, clay) to Triassic metamorphic rocks in the Virginia Range. An intermediate Pleistocene unit of alluvial gravels and sands comprises a major aquifer in the eastern part of the valley in New Washoe City. North-south trending normal faults are found on both sides of the valley, with surficial scarps as high as 30 feet. The role of these faults in groundwater movement is uncertain and will be discussed in a later section.

## **HYDROLOGY**

### **Surface Water**

The most prominent feature on the valley floor is Washoe Lake (Figure 2), with an average surface area of approximately 7.5 mi<sup>2</sup>. According to Rush (1967), virtually

all of the water stored in Washoe and Little Washoe Lakes is "rejected groundwater recharge and impounded runoff from flash floods." There are several streams on the western portion of the valley, the most prominent being Ophir and Franktown Creeks, respectively. On the eastern side of the valley, Jumbo Creek is the only stream of note in the study area. As approximately one foot of precipitation per year falls on Washoe Lake, the total, direct contribution to lake storage from precipitation is about 4,900 acre-feet annually. Little Washoe Lake forms the headwaters for Steamboat Creek, a key tributary to the Truckee River.

### Groundwater

As noted previously by Rush (1967), the valley fill deposits (alluvial and lacustrine) provide a continuum between ground and surface water resources in Washoe Valley. Recharge to the valley fill reservoir occurs primarily through infiltration and seepage loss from streams and underflow from the fractured and faulted consolidated rocks of the Carson and Virginia Ranges, respectively. Thus, the sub-surface flow system in Washoe Valley possesses the typical components found in the Great Basin: 1) recharge areas at higher elevations; 2) areas of lateral groundwater flow at the valley flanks; and 3) a discharge area (Washoe Lake) at the valley floor.

Most groundwater in Washoe Valley is developed from the valley fill reservoir. Review of over 100 drillers' reports for New Washoe City indicate that approximately three-quarters of those wells are completed in sedimentary-type deposits. The remaining wells are completed in fractured granitic rocks in the eastern portion of the study area. Depth to groundwater varies from less than 5 feet near the lake to greater than 50 feet in the eastern portion of the study area.

In southern and western New Washoe City, lacustrine deposits of alternating clay and sand layers result in a series of semi-confined water-bearing zones. Flowing wells were historically common in the westernmost portion of New Washoe City near the lake. However, in the past two years, declining water levels have resulted in fewer flowing wells and the need for several residents to deepen existing wells. Additionally, at one home in the extreme southern portion of the study area a naturally occurring spring has been dry since July of 1987.

To evaluate present-day hydrologic conditions in New Washoe City, drillers' reports for approximately 50 sites were field checked for location and current water levels. Figure 3 is a water level contour map based on field measurements made in June 1988. Although the basic configuration of water level contours remain unchanged from earlier studies (Rush, 1967; Arteaga and Nichols, 1984), the water level declines noted above suggest transient conditions typical of climatic cycles (droughts) and/or excessive development. Temporal comparison of water levels for specific wells is difficult due to the lack of tabulated data in the previously mentioned reports. However, in wells which required deepening, water level declines were in excess of 15 feet.

### Hydraulic Parameters

Hydraulic conductivities (K) and transmissivities (T) were estimated at several locations based on specific capacity data from drillers' reports. K estimates ranged from 1 to  $10^3$  ft/day ( $10^{-4}$  to 1 cm/sec). T estimates ranged from 10 to  $10^4$  ft<sup>2</sup>/day. The wide variability in both parameters can be attributed to a variety of factors: 1) an equally large variability in the distribution of water-bearing rocks and sediments; 2) widely varying methods of well construction; and 3) similarly large differences in how the particular driller conducted the specific capacity test.

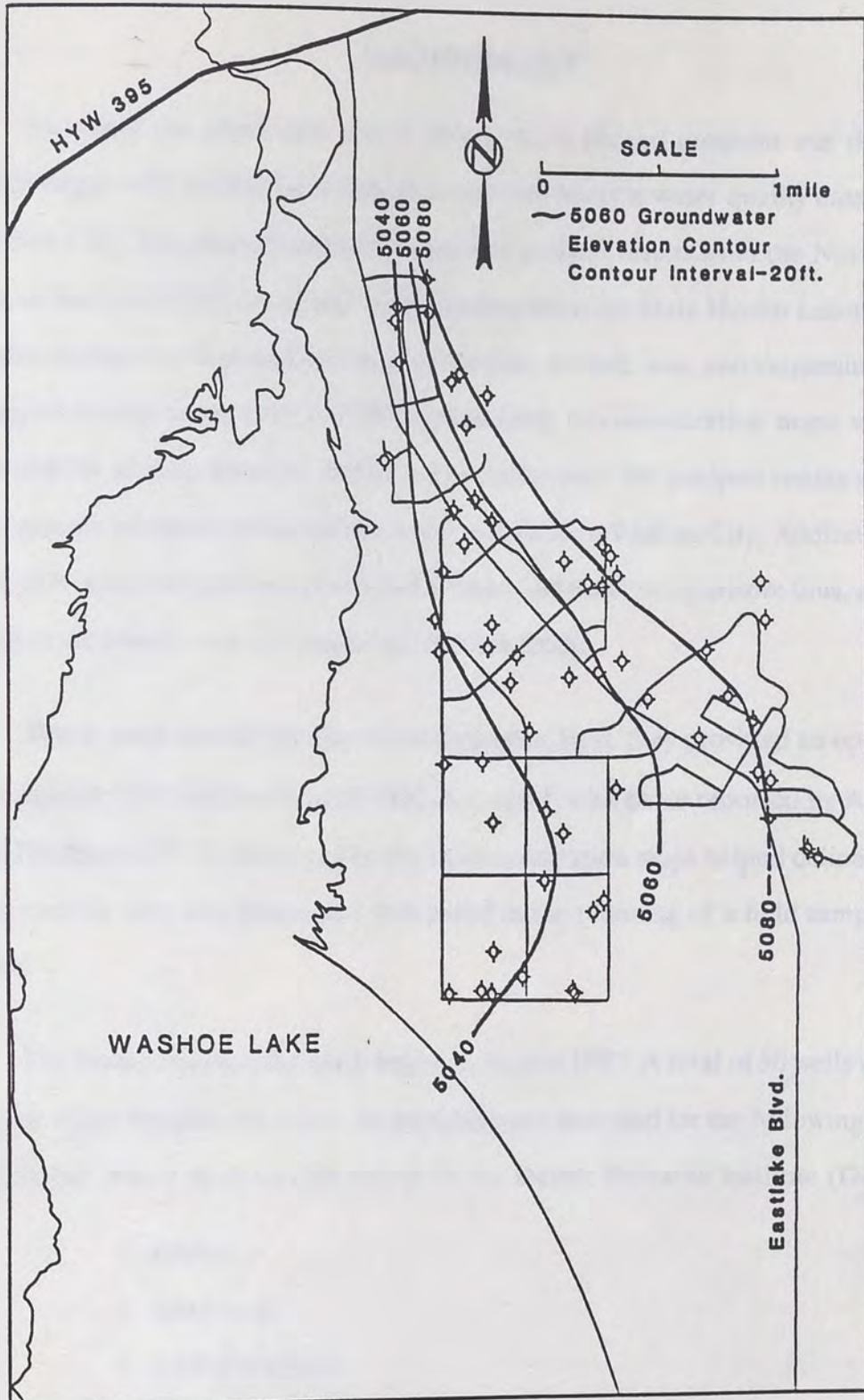


FIGURE 3. Groundwater Elevations Derived from Water Level Measurements in Northeast Washoe Valley - 1988.

## METHODOLOGY

To satisfy the previously stated objectives, a phased program was developed which began with a detailed review of recent and historic water quality data for New Washoe City. The primary source of data was analysis results from the Nevada Division of Health (NDH). A typical water analysis from the State Health Laboratory includes all major cations and anions, plus fluoride, arsenic, iron, and magnesium. Using analyses results from 1986 to 1987, preliminary isoconcentration maps were constructed for nitrate, fluoride, and iron. Perusal of over 100 analyses results suggested that arsenic contamination was not a problem in New Washoe City. Additionally, the lack of historic arsenic data precluded a "then and now" comparison; thus, a detailed analysis of arsenic was not conducted for this study.

These maps served two important purposes. First, they provided an opportunity to compare 1987 distributions of  $\text{NO}_3^-$ , Fe, and F with those reported by Armstrong and Fordham (1977). Additionally, the isoconcentration maps helped delineate those areas where data was sparse and thus aided in the planning of a field sampling program.

The field portion of the study began in August 1987. A total of 50 wells were chosen for water sample collection. All samples were analyzed for the following constituents in the Water Analysis Laboratory of the Desert Research Institute (DRI):

- nitrate;
- ammonia;
- total phosphate;
- iron; and
- fluoride.

Nitrate samples were filtered in the field through 0.45 micron filters, placed in 250 ml poly containers, and refrigerated for same-day submittal to the laboratory. Ammonia and phosphate samples were not filtered, but acidified with 1 + 1 sulfuric acid. Iron samples were acidified with reagent grade nitric acid, and also filtered in the field. No treatment (filtration or acidification) was required of fluoride samples.

In addition to the above, the following parameters were field measured at each site: pH, electrical conductivity (E.C.), temperature, dissolved oxygen (D.O.), and alkalinity and the results are included in the Appendix. All pH measurements were preceded by calibration with three buffers: 6.86, 7.41, and 9.18, respectively. Fresh buffers were made weekly, and were temperature equilibrated with sample temperature prior to calibration. Field measurements of D.O. were taken with YSI Model 57 meters and probes. The meter and probe were calibrated for the theoretical oxygen saturation for the temperature and elevation at each site. Probe membrane condition was checked at each site and replaced when necessary.

## **SITE SELECTION**

Selection of sample sites was determined by several factors. Chemical transition zones as delineated on isoconcentration maps were perceived as critical areas for sample collection. Although there was a preponderance of NDH data for certain areas and a scarcity in others, potential differences between analysis laboratories suggested a need to collect samples which, at times, overlapped or duplicated those collected for NDH. An additional factor in sample site selection was the ability to obtain permission from property owners to collect water samples from their wells. While the majority of New Washoe City residents were very cooperative in this study, the reluctance of oth-

ers to become involved hindered sample coverage in some areas. Figure 4 is a sample location map for this study.

Considering the high  $\text{NO}_3^-$  values, several possible tools exist which had potential application in delineation of source areas. Initially, small-scale tracer tests had been planned whereby a conservative compound, such as sodium bromide (NaBr), would be injected into the septic systems in anticipation of NaBr arrival at nearby wells. However, the existence of multiple pumping wells, uncertain gradients, and limited willing participants rendered this option logistically impractical. Additionally, the potential for slow groundwater travel times from septic systems to wells eliminated tracer tests as an option in a one-year study. Instead, a technique utilizing nitrogen isotope ratios ( $\text{N}^{15}/\text{N}^{14}$ ) was employed on a limited basis to help identify the source of nitrogen in New Washoe City groundwater. Based on the analytic results for the nitrogen species ( $\text{NO}_3^-$ ,  $\text{NH}_4^+$ ), 20 sites were chosen for collection of nitrogen isotope samples. Applying a technique developed by Kreitler (1974), nitrogen isotope ratios ( $\text{N}^{15}/\text{N}^{14}$ ) were used to help determine source areas for nitrate and ammonia. Isotope analysis were performed at the Conservation and Survey Division of the University of Nebraska in Lincoln, Nebraska.

To help establish groundwater flow directions and gradients, water levels were measured at approximately 50 wells. Although the inconsistent nature of well completions (e.g., depth, stratigraphic interval, well screen) renders a complete analysis difficult at best, results from this portion of the study were compatible with previous studies (Rush, 1967; Arteaga and Nichols, 1984).

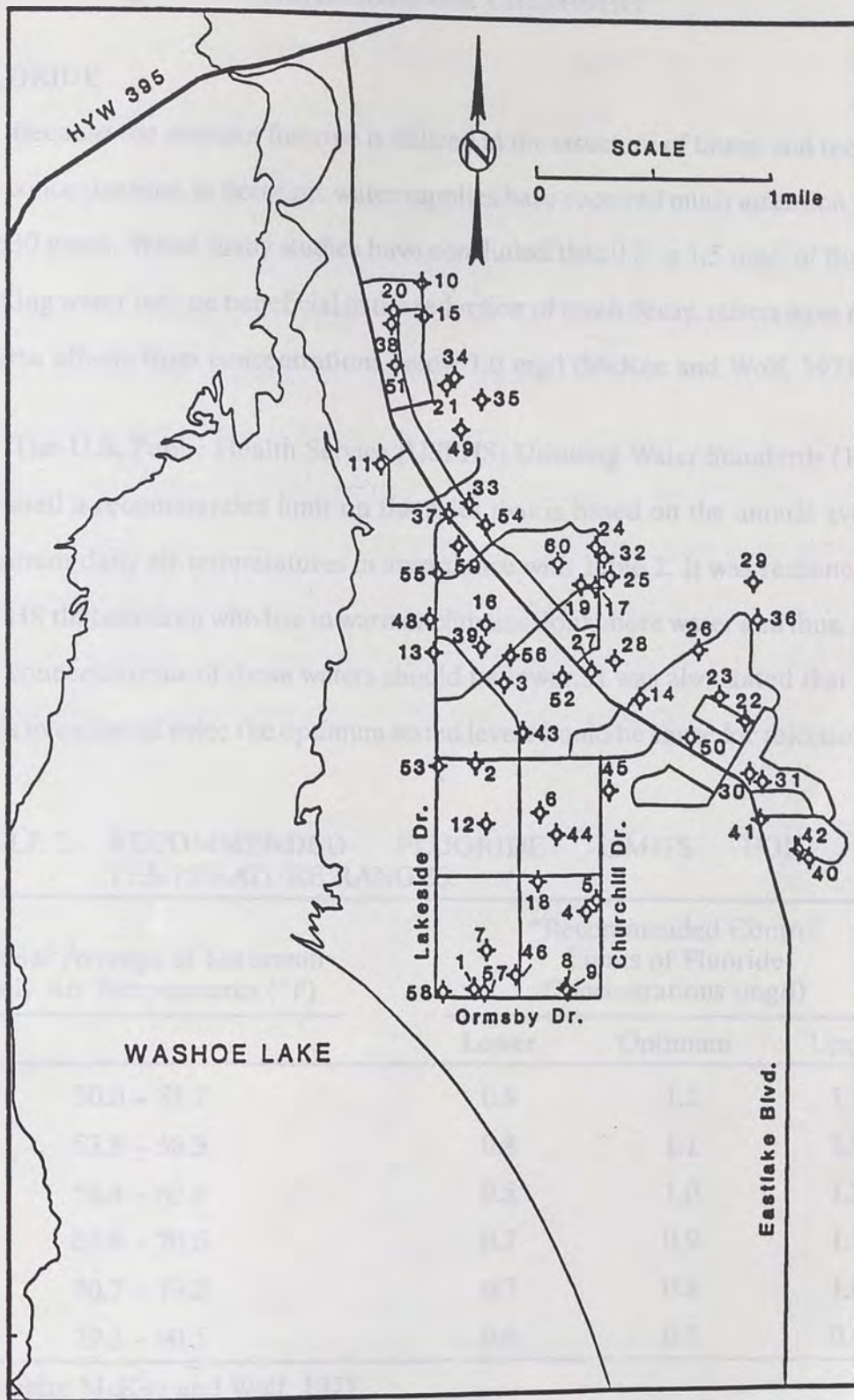


FIGURE 4. Location of Samples Collected in Northeast Washoe Valley.

## GROUNDWATER CHEMISTRY

### FLUORIDE

Because the element fluorine is utilized in the structure of bones and teeth, fluoride concentrations in domestic water supplies have received much attention over the past 30 years. While many studies have concluded that 0.8 to 1.5 mg/l of fluoride in drinking water may be beneficial in the reduction of tooth decay, others have reported adverse affects from concentrations below 1.0 mg/l (McKee and Wolf, 1971).

The U.S. Public Health Service (USPHS) Drinking Water Standards (1962) established a recommended limit on fluorides that is based on the annual average of maximum daily air temperatures in accordance with Table 2. It was reasoned by the USPHS that children who live in warmer climates drink more water and thus, the fluoride concentrations of those waters should be lower. It was also stated that fluoride levels in excess of twice the optimum stated levels would be cause for rejection of that

TABLE 2. RECOMMENDED FLUORIDE LIMITS FOR GIVEN TEMPERATURE RANGES.

Annual Average of Maximum Daily Air Temperatures (°F)	*Recommended Control Limits of Fluoride Concentrations (mg/l)		
	Lower	Optimum	Upper
50.0 – 53.7	0.9	1.2	1.7
53.8 – 58.3	0.8	1.1	1.5
58.4 – 63.8	0.8	1.0	1.3
63.9 – 70.6	0.7	0.9	1.2
70.7 – 79.2	0.7	0.8	1.0
79.3 – 90.5	0.6	0.7	0.8

\* Source: McKee and Wolf, 1971

water supply. Table 3 is an abbreviated listing of fluoride limits for various parts of Nevada published by the NDH. As can be seen from Table 2, the maximum allowable fluoride limit for the Reno-Carson City area is 1.8 mg/l.

In New Washoe City, fluoride levels in excess of 1.8 mg/l are found in three areas, all of which lie along a north-south trending line. The isoconcentration map in Figure 5 indicates that the highest fluoride concentrations are found in the southern portion of the study area and gradually decrease to the north. In noting that groundwater temperatures also decreased northward, Armstrong and Fordham (1977) computed the correlation coefficient ( $r$ ) between fluoride concentrations above 1.8 mg/l and temperature and obtained a value of 0.284. Similar computations were made for this study and a slightly different  $r$ -value of 0.315 was obtained. Additionally, the correlation coefficient between fluoride concentrations and well depth was computed and an  $r$ -value of only 0.160 was obtained. (Note: correlation coefficients range from -1 to +1.

TABLE 3. FLUORIDE LIMITS FOR VARIOUS NEVADA LOCATIONS.

Town	Annual Average of Maximum Daily Air Temperatures (°F)	**Maximum Fluoride Level (mg/l)
Austin	60.9	2.0
Boulder City	77.2	1.6
Carson City	66.4	1.8
Elko	62.2	2.0
Las Vegas	78.7	1.6
Reno	66.7	1.8
Tonopah	64.9	1.8
Winnemucca	64.8	1.8

\*\* Source: Nevada Division of Health

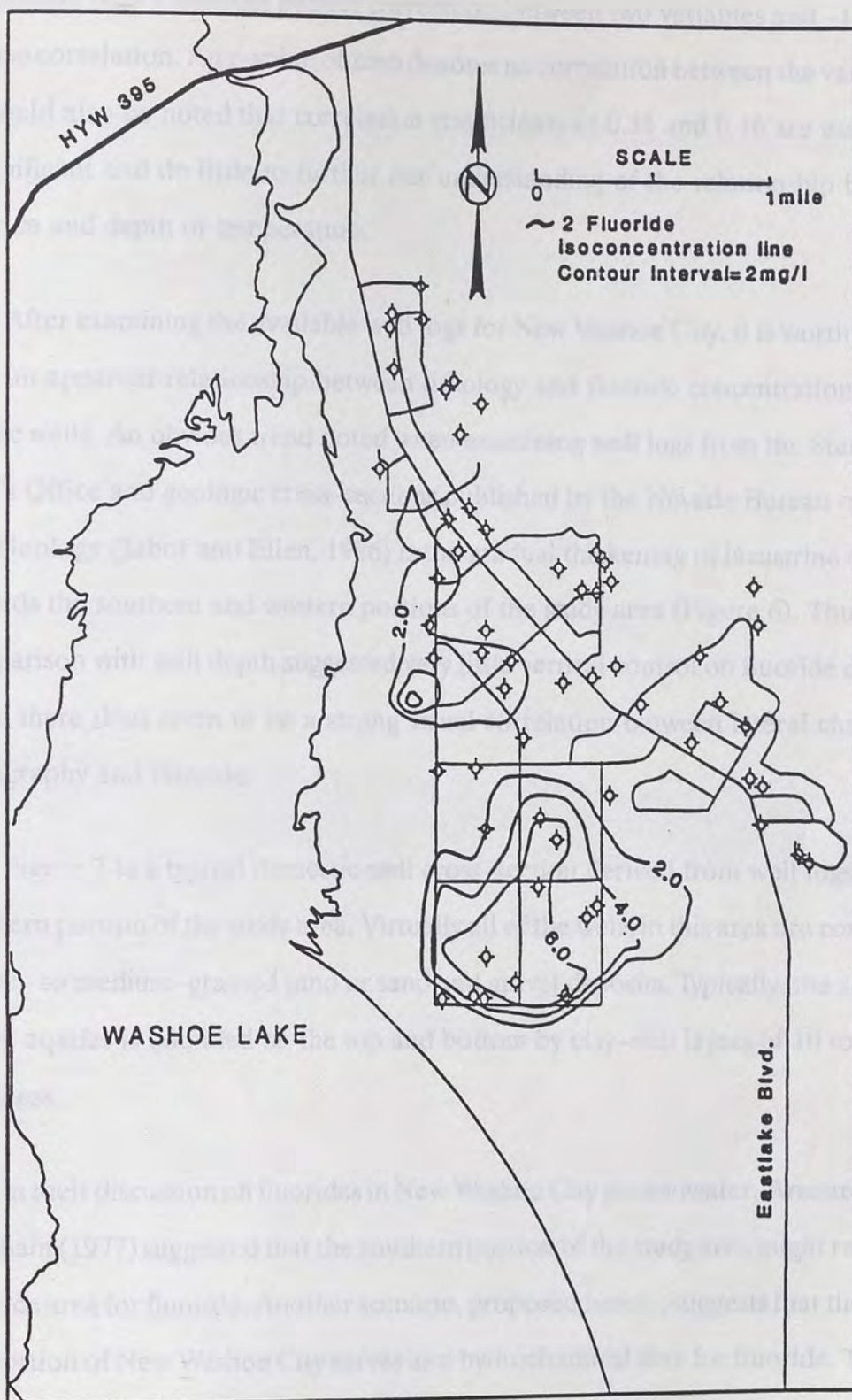


FIGURE 5. Fluoride Isoconcentration Map for Northeast Washoe Valley.

An  $r$ -value of  $+1$  signifies perfect correlation between two variables and  $-1$  perfect inverse correlation. An  $r$ -value of zero denotes no correlation between the variables.) It should also be noted that correlation coefficients of 0.31 and 0.16 are essentially insignificant and do little to further our understanding of the relationship between fluoride and depth or temperature.

After examining the available well logs for New Washoe City, it is worthwhile to note an apparent relationship between lithology and fluoride concentrations in domestic wells. An obvious trend noted when examining well logs from the State Engineer's Office and geologic cross-sections published by the Nevada Bureau of Mines and Geology (Tabor and Ellen, 1976) is the gradual thickening of lacustrine deposits towards the southern and western portions of the study area (Figure 6). Thus, while comparison with well depth suggested very little vertical control on fluoride distributions, there does seem to be a strong visual correlation between lateral changes in stratigraphy and fluoride.

Figure 7 is a typical domestic well cross-section derived from well logs for the southern portion of the study area. Virtually all of the wells in this area are completed in fine- to medium-grained sand or sand and gravel deposits. Typically, the sand and gravel aquifer is bounded on the top and bottom by clay-rich layers of 10 to 30 feet thickness.

In their discussion on fluorides in New Washoe City groundwater, Armstrong and Fordham (1977) suggested that the southern portion of the study area might represent a source area for fluoride. Another scenario, proposed herein, suggests that the southern portion of New Washoe City serves as a hydrochemical sink for fluoride. The reasoning for this is conceptually simple and relates to our knowledge of fluoride ion



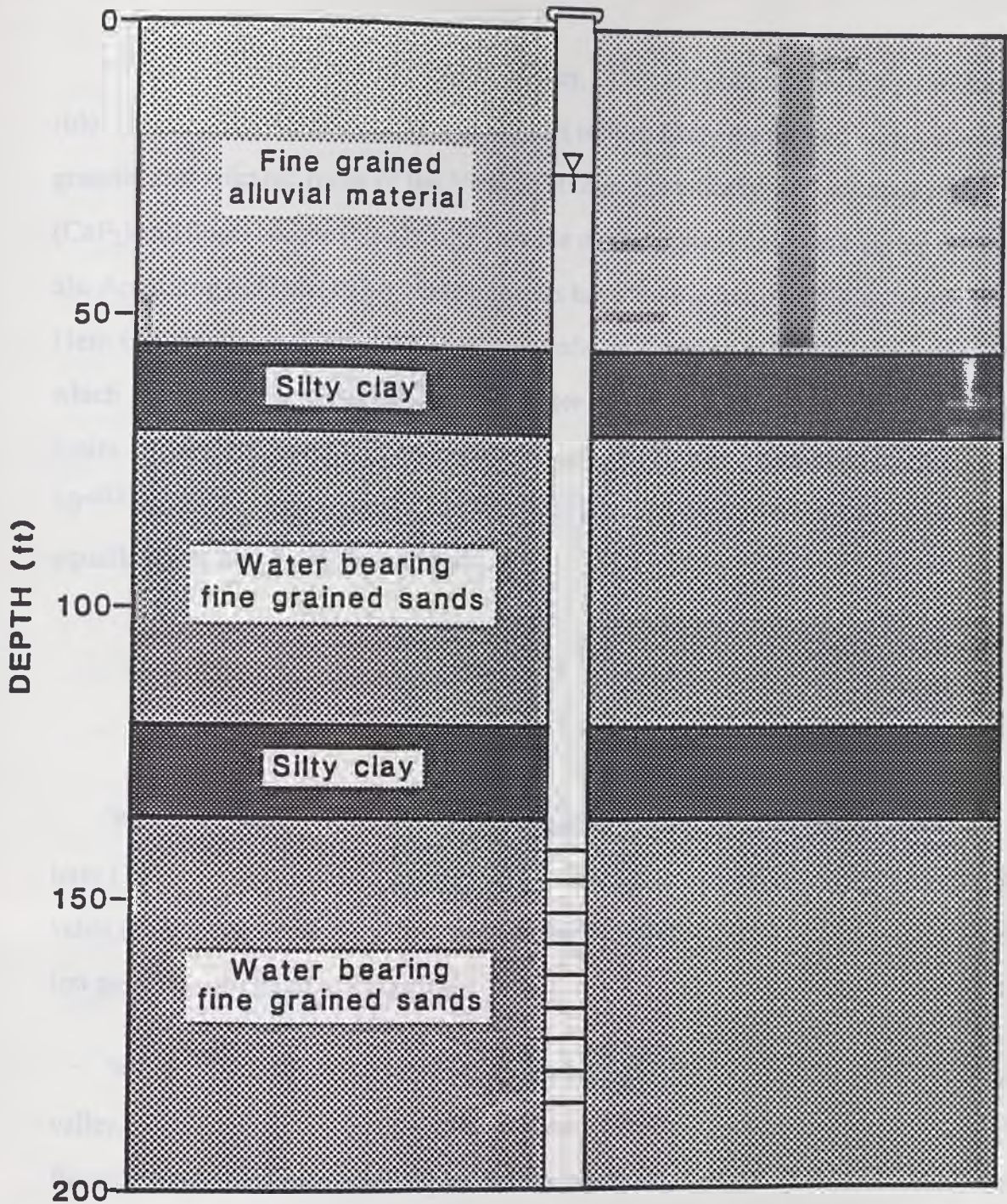


FIGURE 7. Stratigraphic Section for Typical Domestic Well in Southern New Washoe City.

chemistry, the hydrologic regime of New Washoe City, and bedrock geology in the Virginia Range.

Due to its ubiquity in igneous rocks (Hem, 1970), the primary source for the fluoride found in New Washoe City groundwaters is most likely the altered and unaltered granitic and volcanic rocks of the Virginia Range. Specifically, the minerals fluorite ( $\text{CaF}_2$ ) and fluor-apatite ( $\text{Ca}_5(\text{PO}_4)_3\text{F}$ ) are the most common fluoride-bearing minerals. According to Hem (1970), these minerals have "rather low solubilities"; however, Hem (1970) also states that there is very little information regarding the extent to which fluoride concentrations in groundwater might be controlled by the solubility limits of these minerals. The solubility product for fluorite given by Hem (1970) is  $10^{-10.57}$  at  $25^\circ\text{C}$ . This means that in the presence of an activity of 40 mg/l of  $\text{Ca}^{+2}$ , the equilibrium activity of  $\text{F}^-$  would be:

$$[\text{F}^-]^2 = 10^{-10.57} \times 10^{3.0} = 10^{-7.57}$$

$$[\text{F}^-] = 10^{-3.78} = 1.66 \times 10^{-4} \text{ moles/liter} = 3.2 \text{ mg/l}$$

While calcium analyses were not performed for this study, Armstrong and Fordham (1977) reported values for 27 wells in New Washoe City. The average calcium value from that study was 14.8 mg/l, well below the value expected for the formation of ion pairs or complexes with fluoride.

Water level contours indicate steep gradients in the easternmost portion of the valley, and a gradual flattening closer to Washoe Lake. Consequently, the aqueous fluoride ion (in addition to other weathering by-products) remains in solution for the flow path length, defined locally as the distance between the Virginia Range (recharge area) and the valley floor (discharge area). In addition to local topographic effects on

the hydraulic gradient, stratigraphic changes result in lower permeabilities in the very fine-grained, lacustrine sediments. Thus, as the potentiometric energy of the hydrologic system decrease west and south, so do groundwater velocities and the result is a stagnation effect where groundwater pumping and minor seepage into the lake account for the majority of the flux out of the system in that area. Consequently, the dissolved fluoride is concentrated in the western terminal portion of the groundwater flow system. It is in this region where the clay-rich stratigraphy provide a geochemically favorable host environment for the fluoride ion. Because of the similarities in ionic radii, substitution between fluoride and hydroxide are common in clay-rich environments (Bohn et al., 1985, p. 303) and the clays are generally enriched with respect to the hydroxide ion in the southern portion of the study area (Figure 8).

Thus, one conclusion that can be drawn from the available geologic, hydrologic, and chemical data is that the southern portion of New Washoe City, where fluoride concentrations are highest, acts as an areal sink for fluoride and possibly other solutes as well. Also noted in the southern portion of the study area was a domestic well with temperatures in excess of 50°C (122°F). Previous studies of geothermal waters all reveal fluoride values commonly in excess of drinking water standards (Garside and Schilling, 1979; McKay and Zimmerman, 1983; Ellis and Mahon, 1977). Although no other waters in this temperature range were noted during the study, the link between deep-seated geothermal activity and fluoride distributions in New Washoe City should be considered.

## IRON

Iron concentrations in groundwater are controlled by a complex array of thermodynamic and biologic factors, many of which aren't fully understood. While chemical

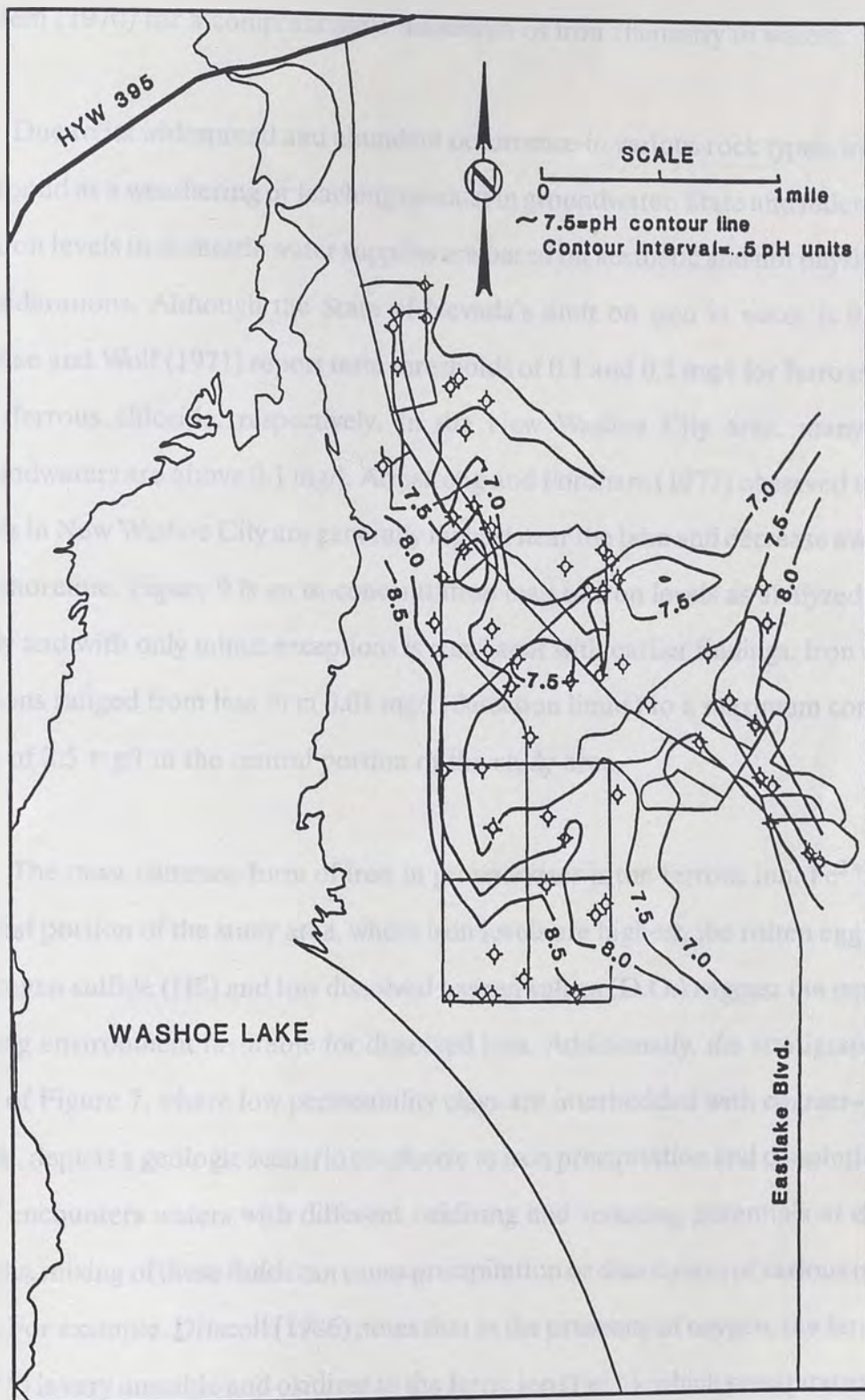


FIGURE 8. pH Contour Map for New Washoe City.

relationships observed in New Washoe City are discussed herein, the reader is referred to Hem (1970) for a comprehensive discussion of iron chemistry in waters.

Due to its widespread and abundant occurrence in various rock types, iron is often found as a weathering or leaching product in groundwater. State and federal limits for iron levels in domestic water supplies are based on aesthetic and not physiological considerations. Although the State of Nevada's limit on iron in water is 0.6 mg/l, McKee and Wolf (1971) report taste thresholds of 0.1 and 0.2 mg/l for ferrous sulfate and ferrous chloride, respectively. In the New Washoe City area, many of the groundwaters are above 0.1 mg/l. Armstrong and Fordham (1977) observed that iron levels in New Washoe City are generally highest near the lake and decrease away from the shoreline. Figure 9 is an isoconcentration map of iron levels as analyzed for this study and with only minor exceptions is consistent with earlier findings. Iron concentrations ranged from less than 0.01 mg/l (detection limits) to a maximum concentration of 2.5 mg/l in the central portion of the study area.

The most common form of iron in groundwater is the ferrous ion,  $\text{Fe}^{2+}$ . In the central portion of the study area, where iron levels are highest, the rotten egg odor of hydrogen sulfide (HS) and low dissolved oxygen values (D.O.) suggest the type of reducing environment favorable for dissolved iron. Additionally, the stratigraphic section of Figure 7, where low permeability clays are interbedded with coarser-grained sands, depicts a geologic scenario conducive to iron precipitation and dissolution. As a well encounters waters with different oxidizing and reducing potentials at different depths, mixing of these fluids can cause precipitation or dissolution of various iron species. For example, Driscoll (1986) notes that in the presence of oxygen, the ferrous ion ( $\text{Fe}^{2+}$ ) is very unstable and oxidizes to the ferric ion ( $\text{Fe}^{3+}$ ), which precipitate as ferric

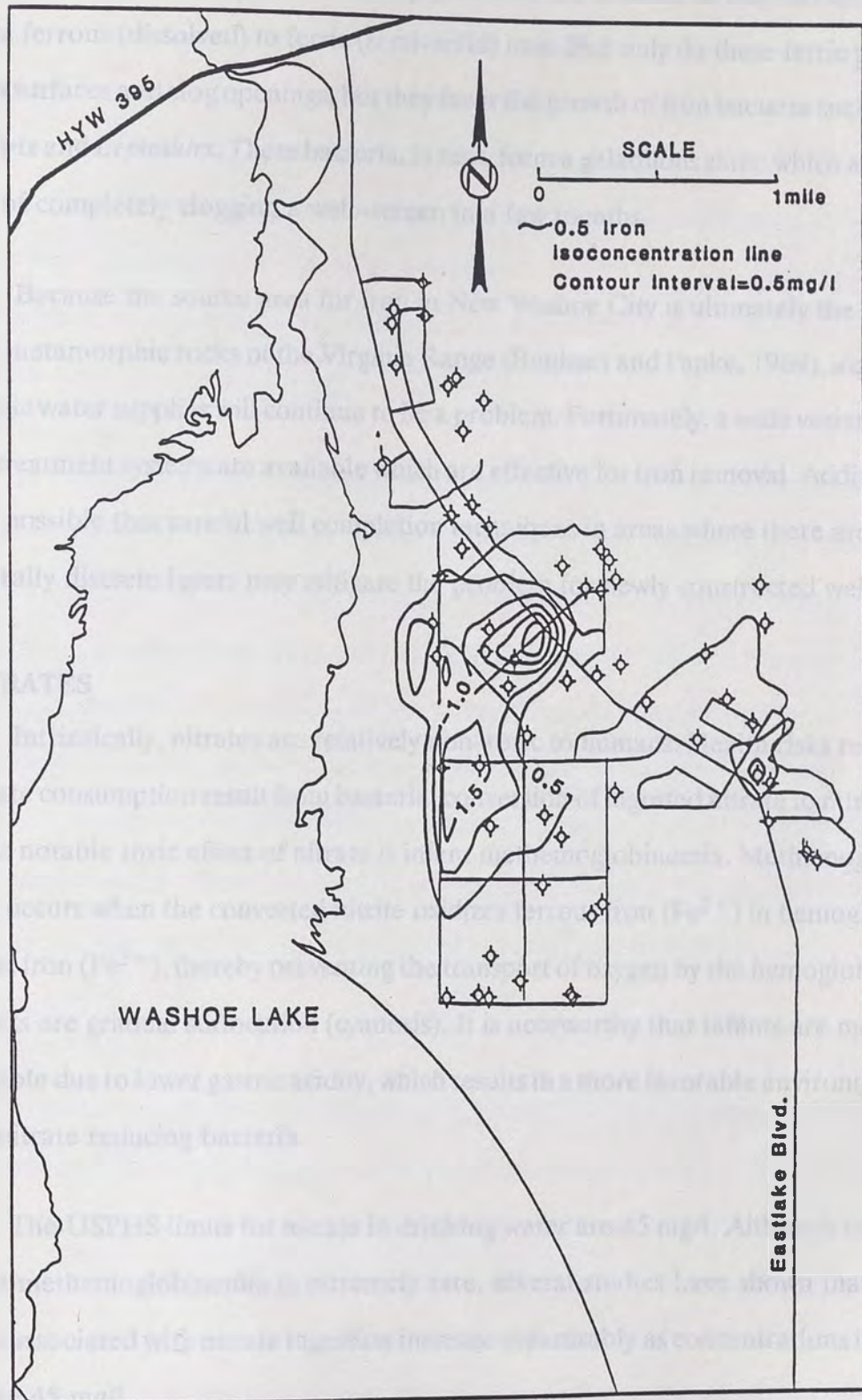


FIGURE 9. Iron Isoconcentration Map for New Washoe City.

oxide. Most iron-related water quality problems are a result of this sudden change from ferrous (dissolved) to ferric (semi-solid) iron. Not only do these ferric particles coat surfaces and clog openings, but they favor the growth of iron bacteria such as *Crenothrix* and *Leptothrix*. These bacteria, in turn, form a gelatinous slime which are capable of completely clogging a well-screen in a few months.

Because the source area for iron in New Washoe City is ultimately the igneous and metamorphic rocks of the Virginia Range (Bonham and Papke, 1969), iron in domestic water supplies will continue to be a problem. Fortunately, a wide variety of water treatment systems are available which are effective for iron removal. Additionally, it is possible that careful well completion techniques in areas where there are hydrologically discrete layers may mitigate the problem for newly constructed wells.

## NITRATES

Intrinsically, nitrates are relatively non-toxic to humans. Health risks related to nitrate consumption result from bacterial conversion of ingested nitrate to nitrite. The most notable toxic effect of nitrate is infant methemoglobinemia. Methemoglobinemia occurs when the converted nitrite oxidizes ferrous iron ( $\text{Fe}^{2+}$ ) in hemoglobin to ferric iron ( $\text{Fe}^{3+}$ ), thereby preventing the transport of oxygen by the hemoglobin. The results are gradual suffocation (cyanosis). It is noteworthy that infants are more susceptible due to lower gastric acidity, which results in a more favorable environment for the nitrate reducing bacteria.

The USPHS limits for nitrate in drinking water are 45 mg/l. Although mortality from methemoglobinemia is extremely rare, several studies have shown that health risks associated with nitrate ingestion increase measurably as concentrations increase above 45 mg/l.

### Nitrogen Behavior in Soils and Water

It is difficult to discuss nitrate contamination in New Washoe City without general reference to nitrogen behavior in the biosphere. Numerous diagrams may be found in the literature depicting what is generally known as the nitrogen cycle. The term is derived from the continuous cyclic exchange between combined nitrogen in soil and water and molecular nitrogen in the atmosphere. Figure 10 is one such diagram for that portion of the cycle which is thought to influence nitrogen chemistry in New Washoe City.

In soils and water, nitrogen behavior is controlled by biological and non-biological processes alike. Thus, predicting the occurrence or distribution of a particular species (i.e.,  $\text{NH}_4^+$ ,  $\text{NO}_3^-$ ,  $\text{N}_2$ ) is complicated by this functional interdependence. Because it is a prominent nutrient, the transformation of nitrogen in soil and water is often biochemical, and thus, depends on the availability of certain biota as catalysts in chemical reactions. Generally speaking, anthropogenic sources of nitrogen (fertilizer, septic leachate, feedlots) occur initially in the form of ammonia ( $\text{NH}_3$ ) or the aqueous ammonium ion ( $\text{NH}_4^+$ ). Thus, biochemical processes which affect nitrogen speciation usually involve the oxidation (loss of electrons) of  $\text{NH}_4^+$  to either  $\text{N}_2$  gas,  $\text{NO}_2^-$ , or, ultimately,  $\text{NO}_3^-$ .

According to the National Research Council (NRC, 1978), major nonbiological processes of the nitrogen cycle involve phase transformations rather than chemical reactions. These processes include volatilization of ammonia and other gaseous forms of nitrogen; sedimentation of particulate forms of organic nitrogen; and sorption (e.g., of the ammonium ion by clays). However, the dominant nonbiological control on nitrogen speciation is electron availability and, thus, redox potential. In fact, as pointed

# DOMESTIC SOURCES

# LIVESTOCK

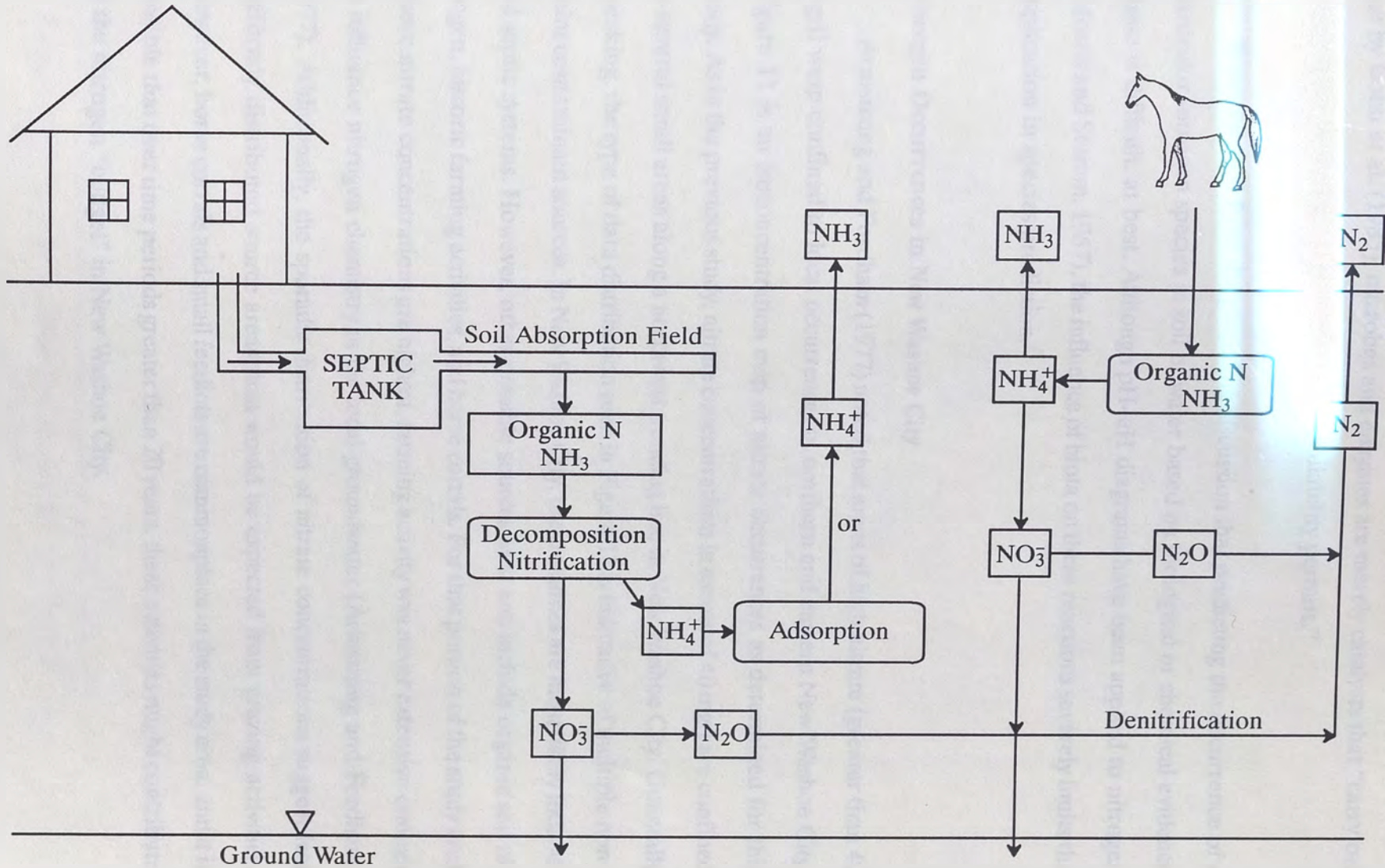


FIGURE 10. Diagrammatic Cross-Section of Nitrogen Cycle in New Washoe City (adapted from Canter and Knox, 1985).

out by Bohn et al. (1985), microbes and enzymes are merely catalysts that "carry out only those redox reactions that electron availability permits."

It can be seen from the preceding discussion that predicting the occurrence of a particular nitrogen species in soil or water based on biological or chemical evidence alone is difficult, at best. Although pH-eH diagrams have been applied to nitrogen (Morris and Stumm, 1967), the influence of biota on these reactions severely limits the application in species prediction.

### **Nitrogen Occurrences in New Washoe City**

Armstrong and Fordham (1977) noted that areas of high nitrate (greater than 40 mg/l) were confined to local occurrences in northern and eastern New Washoe City. Figure 11 is an isoconcentration map of nitrate occurrences as determined for this study. As in the previous study, nitrate concentrations in excess of 40 mg/l are confined to several small areas along a northwest trending line in New Washoe City. Generally speaking, the type of data distribution seen in Figure 11 is indicative of multiple non-point contaminant sources. In New Washoe City, these sources are most likely individual septic systems. However, other possible sources exist and include organic soil nitrogen, historic farming activities, and horse corrals. For that portion of the study area where nitrate concentrations are highest, farming activity was never extensive enough to influence nitrogen chemistry in the local groundwater (Armstrong and Fordham, 1977). Additionally, the sporadic distribution of nitrate concentrations suggest less uniformly distributed source areas than would be expected from grazing activities. However, horse corrals and small feedlots are commonplace in the study area, and it is possible that over time periods greater than 20 years, these activities might contribute to the nitrogen "budget" in New Washoe City.

FIGURE 11. Nitrate Isoconcentration Map of New Washoe City

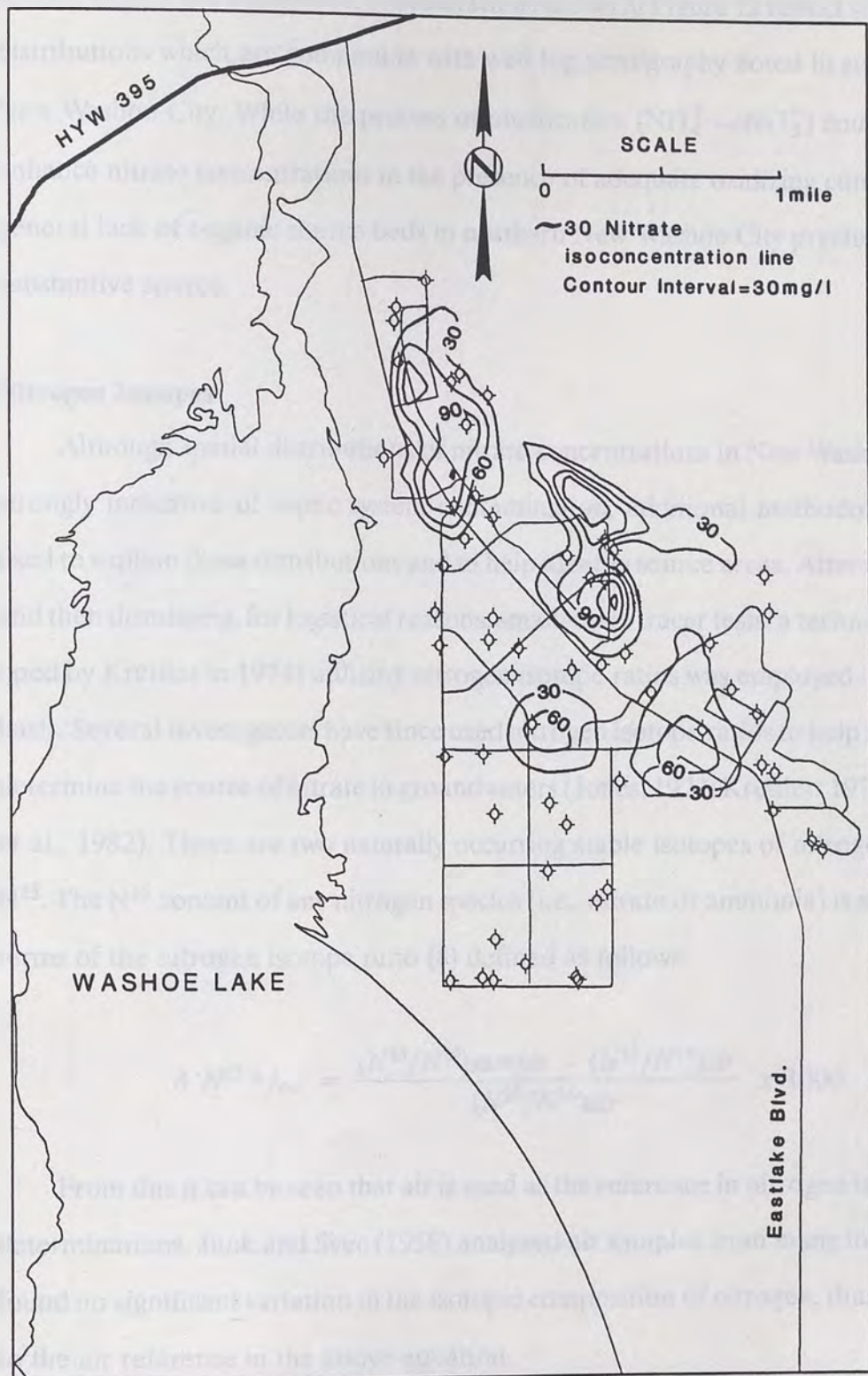


FIGURE 11. Nitrate Isoconcentration Map for New Washoe City.

The organic rich lake sediments noted previously provides an additional possible source. In fact, the ammonium concentrations shown in Figure 12 reflect stratigraphic distributions which are compatible with well log stratigraphy noted in southwestern New Washoe City. While the process of nitrification ( $\text{NH}_4^+ \rightarrow \text{NO}_3^-$ ) could certainly enhance nitrate concentrations in the presence of adequate oxidizing conditions, the general lack of organic source beds in northern New Washoe City preclude this as a substantive source.

### Nitrogen Isotopes

Although spatial distributions of nitrate concentrations in New Washoe City are strongly indicative of septic system contamination, additional methodologies were used to explain these distributions and to help identify source areas. After considering and then dismissing, for logistical reasons, small-scale tracer tests, a technique (developed by Kreitler in 1974) utilizing nitrogen isotope ratios was employed on a limited basis. Several investigators have since used nitrogen isotope ratios to help successfully determine the source of nitrate in groundwaters (Jones, 1973; Kreitler, 1974; Spalding et al., 1982). There are two naturally occurring stable isotopes of nitrogen,  $\text{N}^{14}$  and  $\text{N}^{15}$ . The  $\text{N}^{15}$  content of any nitrogen species (i.e., nitrate or ammonia) is expressed in terms of the nitrogen isotope ratio ( $\delta$ ) defined as follows:

$$\delta \text{ N}^{15} \text{ o} / \text{oo} = \frac{(\text{N}^{15}/\text{N}^{14})_{\text{sample}} - (\text{N}^{15}/\text{N}^{14})_{\text{air}}}{(\text{N}^{15}/\text{N}^{14})_{\text{air}}} \times 1000$$

From this it can be seen that air is used as the reference in nitrogen isotope ratio determinations. Junk and Svec (1958) analyzed air samples from many localities and found no significant variation in the isotopic composition of nitrogen, thus giving rise to the air reference in the above equation.

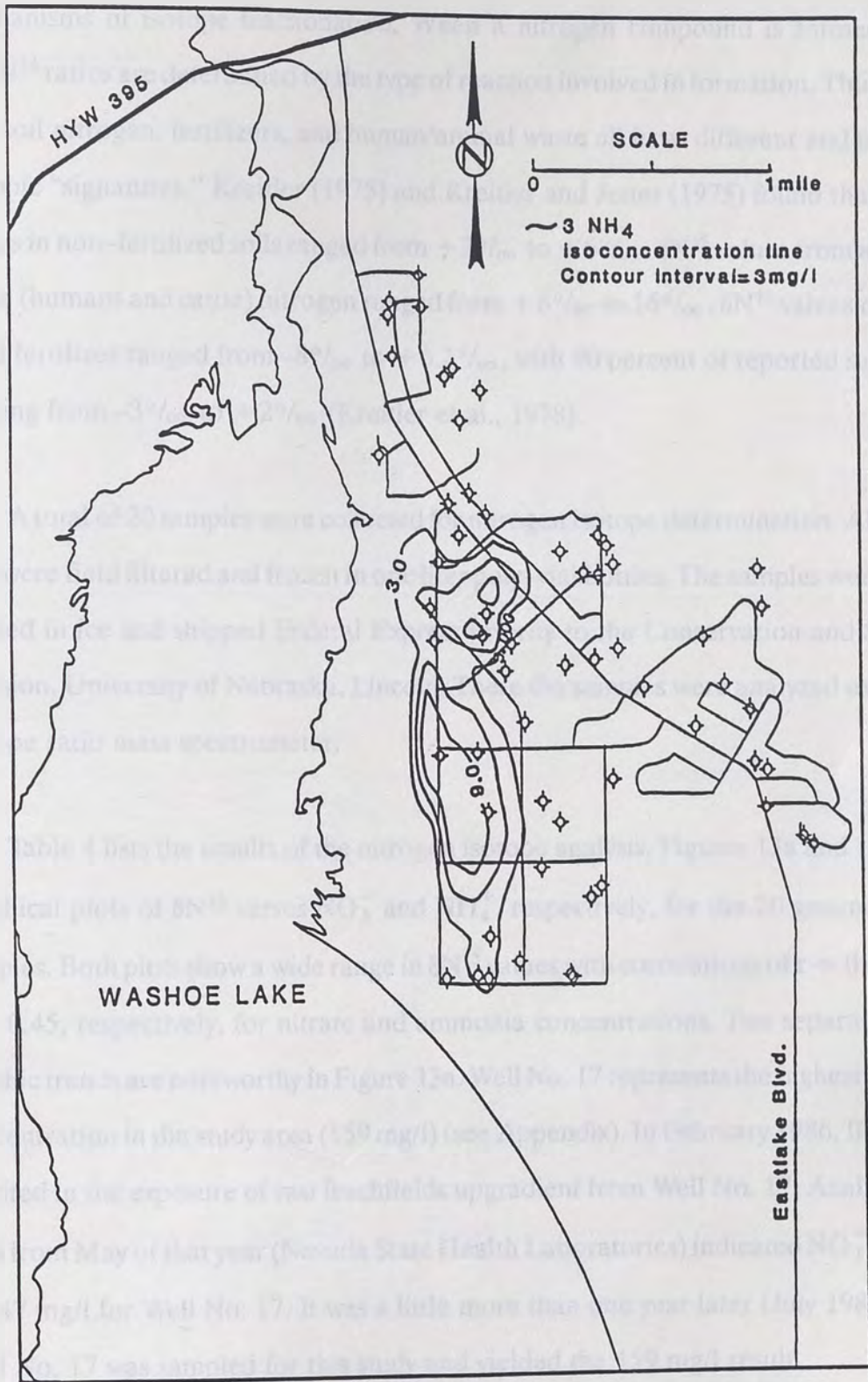


FIGURE 12. Ammonia Isoconcentration Map for New Washoe City.

The basic theory behind  $N^{15}/N^{14}$  ratios in source determination is derived from mechanisms of isotope fractionation. When a nitrogen compound is formed, the  $N^{15}/N^{14}$  ratios are determined by the type of reaction involved in formation. Thus, natural soil nitrogen, fertilizers, and human/animal waste all have different and unique isotopic "signatures." Kreitler (1975) and Kreitler and Jones (1975) found that  $\delta N^{15}$  values in non-fertilized soils ranged from  $+2\text{‰}$  to  $+6\text{‰}$ .  $\delta N^{15}$  values from animal waste (humans and cattle) nitrogen ranged from  $+8\text{‰}$  to  $16\text{‰}$ .  $\delta N^{15}$  values of artificial fertilizer ranged from  $-8\text{‰}$  to  $+6.2\text{‰}$ , with 90 percent of reported samples ranging from  $-3\text{‰}$  to  $+2\text{‰}$  (Kreitler et al., 1978).

A total of 20 samples were collected for nitrogen isotope determination. All samples were field filtered and frozen in one liter poly-vial bottles. The samples were then packed in ice and shipped Federal Express priority to the Conservation and Survey Division, University of Nebraska, Lincoln. There the samples were analyzed using an isotope ratio mass spectrometer.

Table 4 lists the results of the nitrogen isotope analysis. Figures 13a and 13b are graphical plots of  $\delta N^{15}$  versus  $NO_3^-$  and  $NH_4^+$ , respectively, for the 20 groundwater samples. Both plots show a wide range in  $\delta N^{15}$  values with correlations of  $r = 0.61$  and  $r = 0.45$ , respectively, for nitrate and ammonia concentrations. Two separate geographic trends are noteworthy in Figure 13a. Well No. 17 represents the highest nitrate concentration in the study area (159 mg/l) (see Appendix). In February 1986, flooding resulted in the exposure of two leachfields upgradient from Well No. 17. Analysis results from May of that year (Nevada State Health Laboratories) indicated  $NO_3^-$  values of 247 mg/l for Well No. 17. It was a little more than one year later (July 1987) that Well No. 17 was sampled for this study and yielded the 159 mg/l result.

TABLE 4.  $N^{15}$  VALUES FOR 19 WELLS IN NEW WASHOE CITY.

Sample No.	$NO_3$ (mg/l)	$\delta N^{15}$ ‰
10	24.8	+5.01
15	46.5	+5.23
17	146.6	+7.01
19	71.7	+7.29
20	24.8	+5.03
24	61.5	+6.92
33	16.8	+7.58
45	12.8	+6.16
49	110.7	+7.54
50	59.4	+7.14
51	135.5	+8.43

FIGURE 10. Scatter plot of  $\delta N^{15}$  vs.  $NO_3$  for 19 wells in New Washoe City.

Sample No.	$NH_4^+$ (mg/l)	$\delta N^{15}$ ‰
1	5.4	+3.68
2	7.2	+4.18
7	3.3	+2.81
12	3.4	+3.97
13	7.5	+3.78
16	3.4	+2.55
39	10.4	+3.68
48	6.3	+4.64

FIGURE 11. Scatter plot of  $\delta N^{15}$  vs.  $NH_4^+$  for 10 wells in New Washoe City.

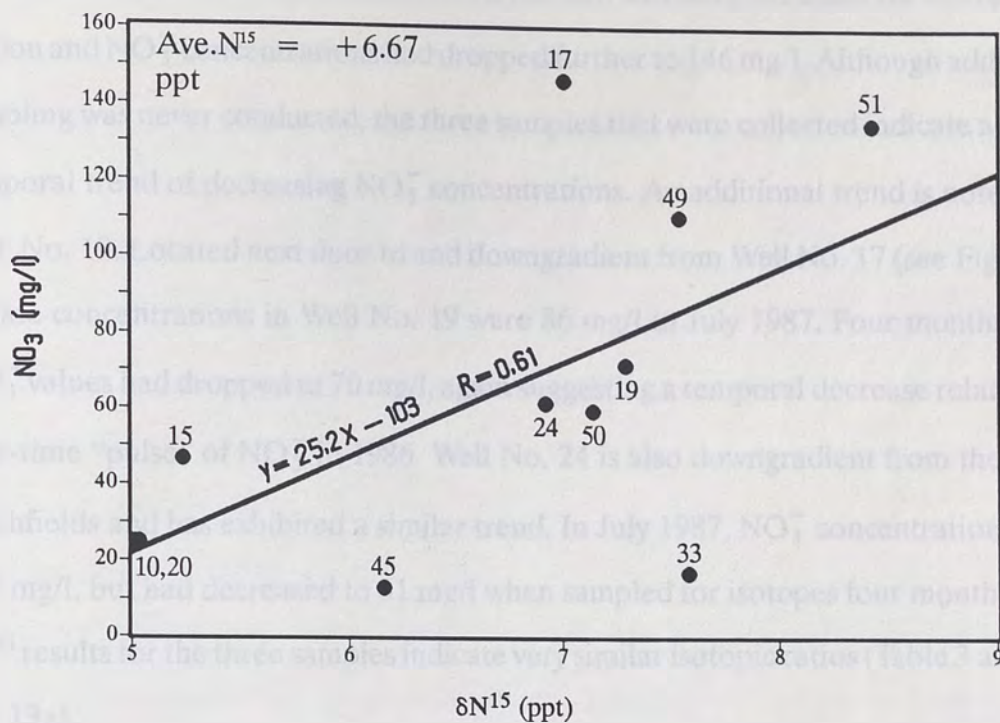


FIGURE 13a.  $N^{15}$  versus  $NO_3^-$  Plot for Selected New Washoe City Wells.

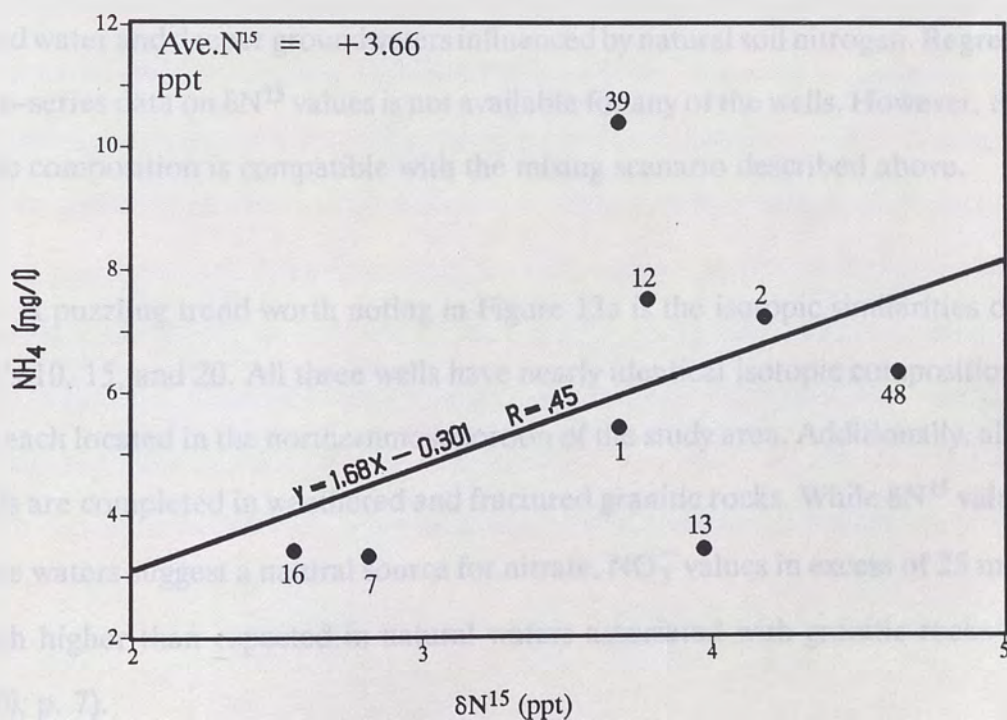


FIGURE 13b.  $N^{15}$  versus  $NH_4^+$  Plot for Selected New Washoe City Wells.

In November 1987 (4 months later), the well was sampled again for isotope collection and  $\text{NO}_3^-$  concentrations had dropped further to 146 mg/l. Although additional sampling was never conducted, the three samples that were collected indicate a strong temporal trend of decreasing  $\text{NO}_3^-$  concentrations. An additional trend is noted with Well No. 19. Located next door to and downgradient from Well No. 17 (see Figure 4), nitrate concentrations in Well No. 19 were 86 mg/l in July 1987. Four months later,  $\text{NO}_3^-$  values had dropped to 70 mg/l, again suggesting a temporal decrease related to a one-time "pulse" of  $\text{NO}_3^-$  in 1986. Well No. 24 is also downgradient from the failed leachfields and has exhibited a similar trend. In July 1987,  $\text{NO}_3^-$  concentrations were 103 mg/l, but had decreased to 61 mg/l when sampled for isotopes four months later.  $\delta\text{N}^{15}$  results for the three samples indicate very similar isotopic ratios (Table 3 and Figure 13a).

In each of the three wells, the  $\delta\text{N}^{15}$  value suggests a mixture of septic contaminated water and deeper groundwaters influenced by natural soil nitrogen. Regrettably, time-series data on  $\delta\text{N}^{15}$  values is not available for any of the wells. However, the isotopic composition is compatible with the mixing scenario described above.

A puzzling trend worth noting in Figure 13a is the isotopic similarities of Well No.'s 10, 15, and 20. All three wells have nearly identical isotopic compositions and are each located in the northernmost portion of the study area. Additionally, all three wells are completed in weathered and fractured granitic rocks. While  $\delta\text{N}^{15}$  values for these waters suggest a natural source for nitrate,  $\text{NO}_3^-$  values in excess of 25 mg/l are much higher than expected in natural waters associated with granitic rocks (Hem, 1970, p. 7).

Figure 13b shows  $\delta N^{15}$  versus  $NH_4^+$  values for several wells located close to Washoe Lake. Early in the study,  $NH_4^+$  concentrations in excess of 1.0 mg/l were thought to be related to individual septic systems in that part of New Washoe City. However, additional factors, including low dissolved oxygen values, high iron levels ( $> .5$  mg/l), and the rotten egg odor of hydrogen sulfide, suggested reducing conditions favorable for the natural formation of the ammonium ion. The low  $\delta N^{15}$  values ( $< 5.0$ ) are strongly suggestive of natural soil nitrogen as the source for the  $NH_4^+$  in these waters.

### **Nitrogen Mass Balance**

In an attempt to quantify potential nitrogen sources, some simple mass balance calculations were derived. Because of its non-conservative nature, and tendency to transfer from the aqueous to gaseous phase, nitrogen doesn't lend itself to classic mass balance calculations where all possible inputs and outputs are considered. Thus, a technique used by Patt and Hess (1976) was applied. The first step in quantifying nitrogen sources and reproducing observed  $NO_3^-$  and  $NH_4^+$  requires an estimation of the volume of groundwater affected by nitrogen producing activities in New Washoe City. This requires: 1) an estimate of the area, A, underlain by affected, or potentially affected, groundwaters; 2) an estimate of the thickness, or vertical extent of the affected groundwater; and, 3) an estimate of the porosity of the material comprising the affected aquifer(s). Given the large variability in rock and soil type in New Washoe City, this was the most difficult parameter to estimate. The value initially chosen was 0.30, which, for sands and silts is low but for fractured and weathered bedrock is a little high.

The volume of affected groundwater was estimated as follows:

$$\text{Area} = 3 \text{ mi}^2, \text{ or } 7.8 \times 10^6 \text{ m}^2$$

$$\text{Average Saturated Thickness} = 5 \text{ m}$$

$$\text{Estimated Average Porosity} = 0.3$$

$$\text{Volume} = (7.8 \times 10^6 \text{ m}^2) \times (5 \text{ m}) \times (0.3) = 1.2 \times 10^7 \text{ m}^3 \text{ or, } 1.2 \times 10^{10} \text{ liters of water}$$

**Septic System Leachate:** All homes in New Washoe City are on individual septic systems. From Canter and Knox (1985), the following septic tank effluent averages are for a family of four:

$$\text{Volume of Effluent Annually: } 58,400 \text{ gallons, or } 221,000 \text{ liters}$$

$$\text{Average Nitrogen (total) in Septic Tank Effluent: } 30 \text{ mg/l (from Feth, 1966; Canter and Knox, 1985)}$$

$$\text{Thus, in one year, the total nitrogen contribution from one household would be: } (221,000 \text{ liters}) \times (30 \text{ mg/liter}) = 6.6 \times 10^6 \text{ mg.}$$

$$\text{Using 1,000 as the current number of households in New Washoe City, the total annual nitrogen contribution from septage would be: } 6.6 \times 10^9 \text{ mg.}$$

$$\text{Assuming that the average home has been in New Washoe City for 10 years, the total 10-year nitrogen contribution would be: } 6.6 \times 10^{10} \text{ mg.}$$

The computed resulting nitrogen concentration in affected groundwater is:

$$\frac{6.6 \times 10^{10} \text{ milligrams N}}{1.2 \times 10^{10} \text{ liters}} = 5.5 \text{ mg/l as N,}$$

or, assuming complete conversion, 23.6 mg/l as  $\text{NO}_3$  (nitrate).

**Animal Corral Leachate:** Because no permit is required to own or keep horses in New Washoe City, estimating the precise number of horses in the study area is difficult. However, field observations, coupled with information from the local veterinarian (R. Warner, Personal Communication) suggests that approximately 30 percent of all homeowners own a horse. Thus, the total nitrogen added to the shallow groundwater system from corral leachate is estimated as follows, assuming that an average horse passes  $5.8 \times 10^7$  mg nitrogen per year (Patt and Hess, 1976):

*300 homes with 1 horse per home = 300 horses*

*300 horses x ( $5.8 \times 10^7$  mg (N)) =  $1.7 \times 10^{10}$  mg/yr*

*Using the 10-year assumption above, yields:  $1.7 \times 10^{11}$  mg (N) contributed by corral leachate.*

*Combining septic and corral leachate estimates yields a total nitrogen contribution to groundwater over a 10-year period of:*

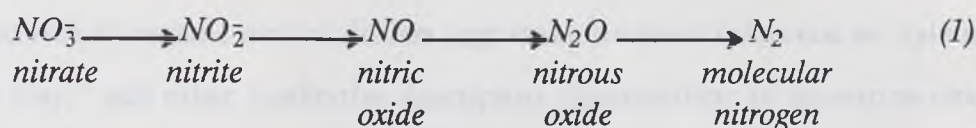
$$\frac{2.3 \times 10^{11} \text{ milligrams (N)}}{1.2 \times 10^{10} \text{ liters}} = 19 \text{ mg/l as N,}$$

*or, assuming complete conversion, 83 mg/l as  $\text{NO}_3^-$ .*

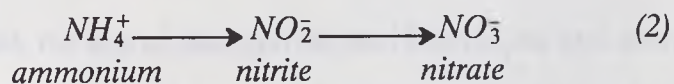
**Losses Due to Denitrification:** The average  $\text{NO}_3^-$  concentration from the 60 samples collected for this study was 21 mg/l as  $\text{NO}_3^-$ . Up to now, only nitrogen inputs have been considered in the mass balance estimates. However, based on the estimated contributions from septic and corral leachates, there are 62 mg/l  $\text{NO}_3^-$  unaccounted for in the shallow groundwater system, or, 75 percent of the total. As the NRC (1978) has pointed out, "most studies of nitrogen balances have indicated a large deficit of nitrogen that can be attributed only to denitrification." The inability to quantify losses due to denitrification (and other processes such as fixation) hinders most attempts at nitro-

gen mass balance calculations. Broadbent and Clark (1965) reported losses from 1 to 75 percent, and in a recent study, Tinker (1991) completely omitted this term in mass balance estimates due to "lack of published research."

However, by understanding the basic mechanisms of nitrogen speciation, and integrating these with a knowledge of stratigraphic and geochemical conditions in the study area, one may develop a realistic scenario for nitrogen distributions in New Washoe City. Generally speaking, denitrification is carried out by bacteria in oxygen-poor environments. In the absence of oxygen, the denitrifying bacteria use nitrate as a terminal electron acceptor, resulting in the following sequential process:



Conversely, in the presence of oxygen, the aqueous ammonium ion ( $\text{NH}_4^+$ ) is converted (oxidized) to  $\text{NO}_3^-$ , a process known as nitrification. Nitrification is conducted primarily by aerobic bacteria which obtain their energy by oxidizing reduced forms of nitrogen:



It can be seen from both processes that the ultimate fate of nitrogen is dependent on the availability of oxygen in the soil and water environment. Oxygen availability is, in turn, a function of initial D.O. concentration in water, soil type, infiltration rates, depth to groundwater, and the presence or absence of confining, or impervious, strata. Collectively, these parameters help define the hydrogeologic regime of an area, and it

is this functional relationship between hydrogeology and oxygen availability which influences nitrogen occurrences in New Washoe City.

It is interesting to note that the line along which nitrate values are highest is coincident with a prominent change in topography and geology in New Washoe City. Using East Lake Boulevard (ELB) as a convenient reference line (Figure 14), one can see a discrete shift from fractured and weathered granitic rocks and soils north and east of ELB, to lacustrine dominated sedimentary deposits west and south of ELB. Well logs for the western portion of the study area (Figure 7) indicate an environment dominated by alternating layers of fine-grained sands, silts, and semi-confining clay layers. Also unique to the stratigraphy in this portion of the study area are very fine-grained deposits rich in organic matter; drillers logs make frequent reference to "tule mud," "black clay," and other qualitative descriptors characteristic of lacustrine environments throughout the Great Basin (Mifflin and Wheat, 1979). Geochemically, the groundwater from these deposits is characterized by high concentrations of iron (Figure 9) and ammonia (Figure 12), the sour odor of hydrogen sulfide ( $H_2S$ ), and, most importantly, dissolved oxygen values well below theoretical saturation for those elevations and temperatures.

In this environment, the fate of nitrogen derived from septic and corral leachates is influenced by a two step process: 1) in the shallow sub-surface ( $< 3$  m), the soil-water environment is well aerated, allowing for the oxidation of ammonia to nitrate (eqn. 2). (The quantity of corral-nitrogen fixed or de-gassed at the surface is unknown, however, estimates from previous studies are as high as 75 percent (NRC, 1978)); and 2) as advective processes transport the nitrate downward, anaerobic conditions prevail, and nitrate is reduced via denitrification (eqn. 1). It is possible that in some instances, sep-

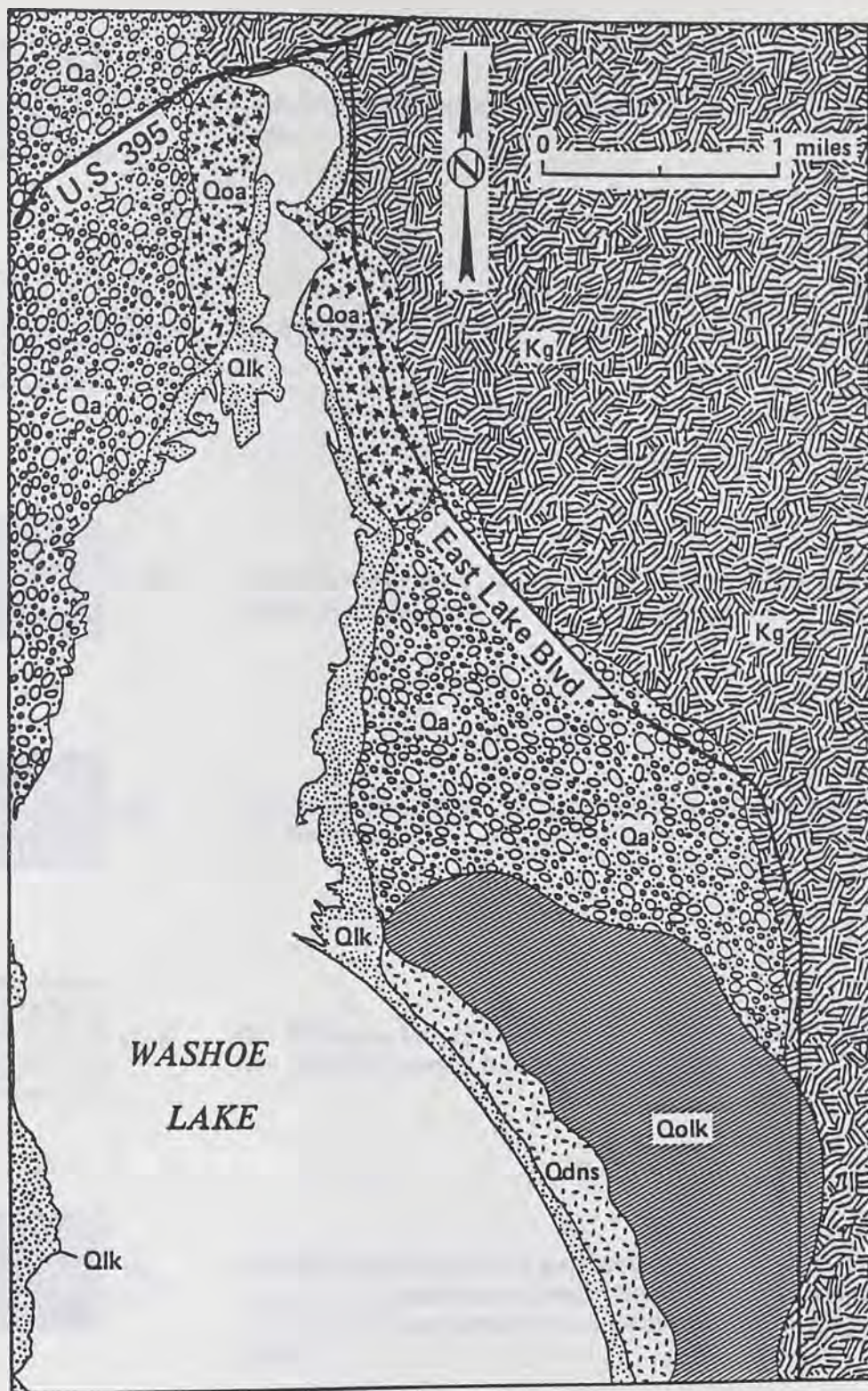
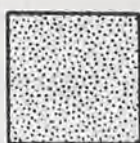
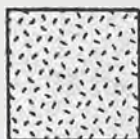


FIGURE 14. Surficial Geologic Map of New Washoe City (adapted from Tabor and Ellen, 1976). Description of Individual Units on Following Page.



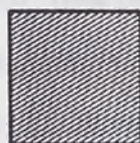
Qlk

**Lake Deposits:** Includes well bedded silts, sands, and clays.



Qdns

**Sand Dunes:**



Qolk

**Old Lake Deposits:** Fine to coarse sand and silt in thin beds. Locally diatomaceous.



Qa

**Undifferentiated Sand:** Windblown sand, alluvial outwash, and slope wash.



Qoa

**Old Alluvium:** Mostly sand, gravels, and boulders. Poorly to well bedded. Granitic boulders highly weathered.



Kg

**Undifferentiated Igneous and Metamorphic:** Includes granodiorites, andesite flows, and metatuffs. Granitic and andesitic outcrops are generally well weathered and highly fractured.

FIGURE 15. Description of Surficial Geologic Units from Previous Page (adapted from Tabor and Ellen, 1976).

tic leachfield depths at or near the shallow water table result in ammonia transport directly to the groundwater. However, nitrogen isotope (Figure 13b) and the previously mentioned geochemical indicators were strongly suggestive of a natural, organic genesis for the observed nitrogen.

To the north and east of ELB (Figure 14), there is a dramatic change in geology and soil type. Here, soils are poorly developed, very coarse textured, and well-drained. Many of the wells in this area are completed in fractured and weathered granitic rocks or very coarse-grained, cobbly alluvium. Additionally, septic leachfields in this area are generally completed in coarse-grained alluvial material. Although depth to groundwater is usually greater than 10 meters, dissolved oxygen values were often at, or above, theoretical saturation for those elevations and temperatures, suggesting aerobic conditions. These aerobic or, oxygen-rich conditions will thus, give rise to the nitrification process outlined in equation 2.

## TEMPORAL VARIATIONS

Central to this study is the question of how continued development in New Washoe City is influencing the groundwater quality in the area. To address this question, it was necessary to compare and contrast historic data with results from the current study. The primary source of historic chemistry data for New Washoe City is the study conducted by Armstrong and Fordham (1977). In that report, over 150 water analyses were used in constructing isoconcentration maps for fluoride, iron, and nitrate in New Washoe City. Regrettably, however, the only chemical analyses included in that report are from the 27 wells chosen for the monitoring portion of that investigation.

For this study, every attempt was made to re-sample as many of those 27 wells as possible. In those instances where home ownership had remained unchanged, residents were generally cooperative in continuing their support of groundwater research in Washoe Valley. However, in approximately two-thirds of the homes involved in the 1977 study, ownership had changed and there was often a greater reluctance on the part of these residents to participate in the current effort. As a result, of the 60 wells sampled for this study, only 10 are duplicate sites from the 1977 investigation. Fortunately, however, comparisons can be made between 1977 and 1987 results for those 10 sites, and should provide some indication of the temporal changes occurring in groundwater quality.

Figures 16a, b, and c are simple bar graphs which compare current fluoride, iron, and nitrate concentrations with 1977 values from the 10 wells. As might be expected due to the geologic nature of its origin, fluoride levels have remained relatively constant over the past 10 years.

Figure 16b shows a moderate decrease in iron levels for several wells. While temporal variations in redox conditions could help explain these decreases, the consistent trend of decreasing values suggests a more likely possibility. Although analytic techniques for iron determination (atomic adsorption) have remained consistent for the past 15 years, sampling methodology has not. Review of historic sampling techniques indicate that filtering and acidification of water samples in the field was not standard procedure in many projects prior to 1977. Failure to acidify and filter water samples in the field would result in the potential dissolution of iron oxide particles when acid was added to the sample in the laboratory. Thus, elevated iron concentrations could be expected from water samples which had not been field filtered prior to 1977.

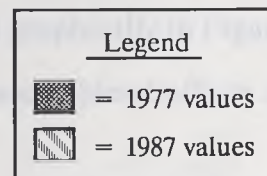
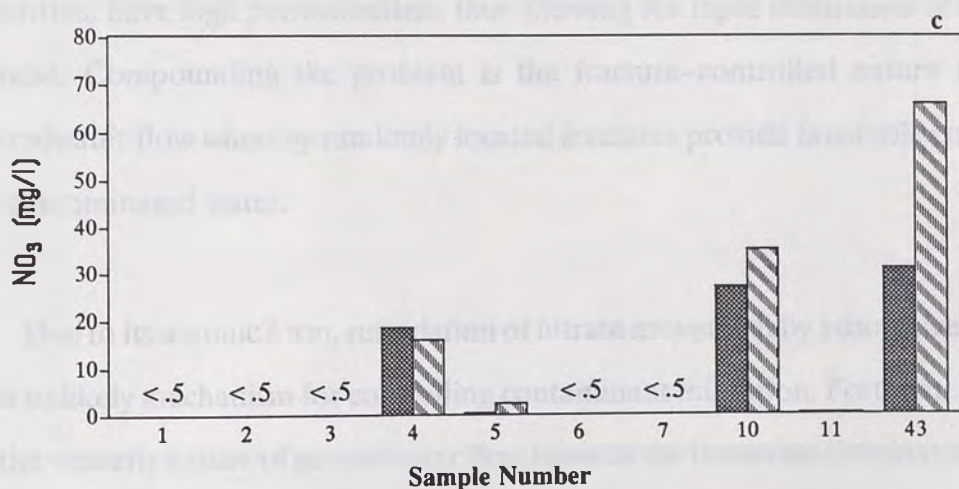
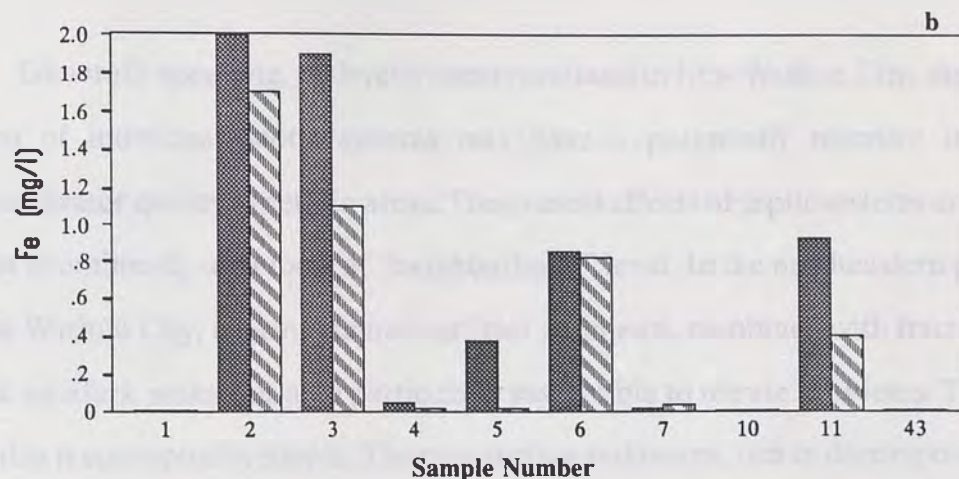
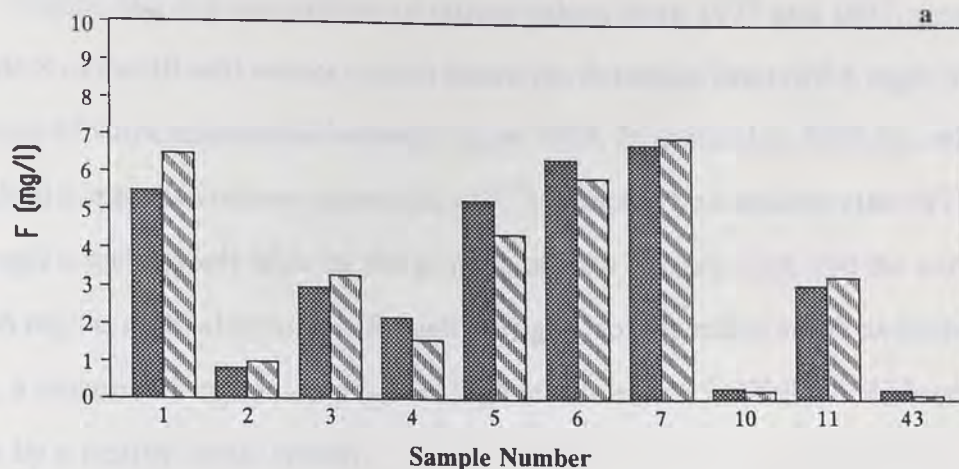


FIGURE 16a, b, c. Comparison of 1977 Chemistry with 1988 Chemistry for Selected Wells.

Figure 16c is a comparison of nitrate values from 1977 and 1987, respectively. While 8 of the 10 well waters remain below the detection limit of 0.5 mg/l, Well No.'s 10 and 43 show substantial increases since 1977. In particular, Well No. 43 shows a twofold increase in nitrate values since 1977. It should be noted that the 1977 value of 31 mg/l is exceedingly high for this portion of New Washoe City, and the current level of 66 mg/l is quite alarming. Although nitrogen isotope ratios aren't available for this site, a reasonable explanation for the high nitrate values in Well No. 43 is contamination by a nearby septic system.

Generally speaking, as development continues in New Washoe City, the proliferation of individual septic systems may have a potentially negative impact on groundwater quality in certain areas. The present effects of septic systems are realized most prominently on a local or "neighborhood" level. In the northeastern portion of New Washoe City, coarse-grained surficial sediments, combined with fractured bedrock aquifers, make this area particularly susceptible to nitrate problems. The reason for this is conceptually simple. The near surface sediments, rich in decomposed granitic detritus, have high permeabilities, thus allowing for rapid infiltration of leachfield effluent. Compounding the problem is the fracture-controlled nature of deeper groundwater flow whereby randomly located fractures provide favorable conduits for the contaminated water.

Due to its anionic form, retardation of nitrate movement by adsorptive processes is an unlikely mechanism for controlling contaminant migration. Fortunately, however, the westerly nature of groundwater flow towards the lacustrine dominated reducing environment promotes the process of denitrification described graphically in Figure 10. Even more difficult to quantify than denitrification are the combined effects of

nitrogen fixation in soils and plants; however, with respect to the fate of corral-related leachate, these could be the more dominant processes controlling nitrogen losses. Thus, it is the combined effects of denitrification and fixation which provide the best explanation for continued low nitrate concentrations in the western and southern portions of New Washoe City.

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## CONCLUSIONS AND RECOMMENDATIONS

A study was initiated in 1987 to assess the hydrologic and hydrochemical conditions in New Washoe City. Previous studies had identified significant water quality problems relating to excessive levels of iron, fluoride, and nitrate. Central to the current study was the question of how continued residential development in New Washoe City was impacting the hydrologic regime of the area.

Review of past and present hydrologic conditions indicate that water levels have declined measurably during the 1987-1988 period. One consequence of water level declines has been the need for several residents to deepen existing wells. Because these declines in the shallow groundwater levels coincide with severe drought conditions, the exact cause of the decline is uncertain. Under normal climatic conditions, groundwater development might be viewed as the primary cause for water level declines. However, the severity of the drought, coupled with the relatively shallow (< 50 feet) nature of the water table/potentiometric surface, suggest that a lack of sufficient recharge might be contributing to the declines.

Fluoride concentrations in excess of public health limits (1.8 mg/l) are common in the southern and western portions of the study area. The linear nature of fluoride distributions suggest a possible relationship to structural features. Additionally, concentrations are highest in areas where the groundwater gradients are flat, suggesting that the hydrologically stagnate zones are acting as sinks for fluoride. Two possibilities exist for source areas. The altered igneous rocks of the Virginia Range are abundant in fluoride bearing minerals and probably contribute to the "fluoride budget." Additionally, thermal waters (> 40°C) in the southern portion of New Washoe City are a likely source for the high fluoride levels in that area. If, in fact, the observed fluoride concen-

trations are related to a deeper hydrologic system, the declining water levels noted earlier could result in higher fluoride levels in wells. Current fluoride levels in 11 wells were compared to values for the same wells in 1977. Moderate changes have occurred in fluoride concentrations during that period.

Although not a significant health problem, iron concentrations in excess of 0.5 mg/l are common in the central and southern portions of New Washoe City. Most of the wells with high iron concentrations are completed in organic rich lacustrine sediments and are characterized by low dissolved oxygen values ( $< 3.0$  mg/l), high ammonia levels ( $> 1.0$  mg/l), and the "rotten egg" odor of hydrogen sulfide. Domestic water treatment technology appears quite successful in removing most of the iron, however, the previously mentioned hydrogen sulfide odor remains a significant aesthetic problem for many homes in the south-central portion of the study area.

Due to the anthropogenic nature of the source, nitrate contamination has received the most attention with respect to water quality problems in New Washoe City. Several isolated areas in the northern and eastern parts of the study area had nitrate levels in excess of 40 mg/l. Nitrogen isotope ratios ( $N^{15}/N^{14}$ ) yielded inconclusive results, although the results were compatible with a scenario of mixed waters. Recent evidence of septic system failure was supported by elevated nitrate levels in several wells downgradient from the failed system. Although flow directions are to the west, chemically reducing conditions in the western portion of the hydrologic regime appear to promote nitrate removal by denitrification. Thus, in an area where one might expect nitrate concentrations to increase as the number of homes upgradient increase, no substantial change has occurred in 10 years.

Simple mass balance calculations also suggested horse corral leachate as a possible source of nitrate contamination in New Washoe City. Previous studies have shown that nitrogen losses due to fixation and degassing can be significant when considering surface sources (fertilizers, feedlots, corrals); however, shallow groundwater depths coupled with intermittently favorable infiltration conditions indicate that corrals should be considered in any management plan dealing with water quality protection.

The effects of water level declines on groundwater quality were not considered in detail for this study. Previous studies in the Las Vegas Valley, Tucson Basin, and San Joaquin Valley have all shown a clear relationship between declining water levels and water quality degradation. However, at one site in southern New Washoe City (Sample #1), elevated temperatures, diminished spring flows, and high fluoride values suggest that declining water levels may be influencing the migration of geothermal waters to the shallow groundwater system.

Contamination of domestic water by nearby septic systems appears to be a problem in parts of New Washoe City. A solution to this problem could be found in alternate methods of sewage disposal. On a very local level, this might include the construction of mound-type leachfields or some other type of engineered system. An example would be an alternating bed or trench system. A three-field system can be constructed in which each field contains 50 percent of the required adsorption area. With two beds always in operation, 100 percent of the required infiltration surface is provided. The third field is alternated into service on a semi-annual or annual schedule. Thus, each field is in service for one to two years, then "rested" for six months to one year, allowing for rejuvenation. On a community level, a locally managed and maintained wastewater treatment plant could help mitigate the problem of nitrate contamination.

Because none of the disposal suggestions address the problem of fluoride and iron contamination, an alternate solution should be sought. Although affordable, domestic water treatment systems are effective at iron removal, the cost of removing high fluoride concentrations is prohibitive to the individual homeowner. Consequently, a community water supply would seem to provide the most feasible solution to long-term water quality problems in New Washoe City. Obviously, the siting of adequately yielding water supply wells presents a unique problem in eastern Washoe Valley. In those areas where nitrate levels are low, fluoride and/or iron are a problem. Conversely, in the areas free of iron and fluoride, the risk of nitrate contamination is higher. The primary exception is the southeastern portion of New Washoe City. Generally speaking, the wells in this area were completed in fractured or partially decomposed granitic rocks and seemed to provide consistently high quality water. If sufficient yield could be obtained from a well or wells in this area, such a solution would be recommended.

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Well No.	County	City	Depth (ft)	Water Type	Flow (gpm)	Static Head (ft)	Dynamic Head (ft)	Water Quality Parameters
1	Clark	Las Vegas	100	Artesian	100	100	100	...
2	Clark	Las Vegas	150	Artesian	150	150	150	...
3	Clark	Las Vegas	200	Artesian	200	200	200	...
4	Clark	Las Vegas	250	Artesian	250	250	250	...
5	Clark	Las Vegas	300	Artesian	300	300	300	...
6	Clark	Las Vegas	350	Artesian	350	350	350	...
7	Clark	Las Vegas	400	Artesian	400	400	400	...
8	Clark	Las Vegas	450	Artesian	450	450	450	...
9	Clark	Las Vegas	500	Artesian	500	500	500	...
10	Clark	Las Vegas	550	Artesian	550	550	550	...
11	Clark	Las Vegas	600	Artesian	600	600	600	...
12	Clark	Las Vegas	650	Artesian	650	650	650	...
13	Clark	Las Vegas	700	Artesian	700	700	700	...
14	Clark	Las Vegas	750	Artesian	750	750	750	...
15	Clark	Las Vegas	800	Artesian	800	800	800	...
16	Clark	Las Vegas	850	Artesian	850	850	850	...
17	Clark	Las Vegas	900	Artesian	900	900	900	...
18	Clark	Las Vegas	950	Artesian	950	950	950	...
19	Clark	Las Vegas	1000	Artesian	1000	1000	1000	...
20	Clark	Las Vegas	1050	Artesian	1050	1050	1050	...
21	Clark	Las Vegas	1100	Artesian	1100	1100	1100	...
22	Clark	Las Vegas	1150	Artesian	1150	1150	1150	...
23	Clark	Las Vegas	1200	Artesian	1200	1200	1200	...
24	Clark	Las Vegas	1250	Artesian	1250	1250	1250	...
25	Clark	Las Vegas	1300	Artesian	1300	1300	1300	...
26	Clark	Las Vegas	1350	Artesian	1350	1350	1350	...
27	Clark	Las Vegas	1400	Artesian	1400	1400	1400	...
28	Clark	Las Vegas	1450	Artesian	1450	1450	1450	...
29	Clark	Las Vegas	1500	Artesian	1500	1500	1500	...
30	Clark	Las Vegas	1550	Artesian	1550	1550	1550	...

APPENDIX

SELECTED WATER QUALITY PARAMETERS FOR NEW WASHOE CITY WELLS

Map No. (Figure 3 in text)	Collection Date	Address	NO3 (mg/l)	TPO4 (mg/l as P)	F (mg/l)	Fe (mg/l)	NH4 (mg/l)	D.O. (mg/l)	pH	EC ( $\mu$ mhos/cm)
1	30-Jul-87	3685 Ormsby	<.01	.05	6.5	.05	5.9	0.8	7.8	405
2	30-Jul-87	3005 Lyon	<.01	.38	.99	1.7	7.9	1.8	7.4	346
3	30-Jul-87	275 Puma	<.01	.25	3.3	1.1	.19	2.5	7.5	276
4	30-Jul-87	3675 Machen	16.39	.08	1.5	.02	<.01	6.1	7.3	453
5	30-Jul-87	3655 Machen	2.39	.13	4.4	.02	.03	3.3	7.7	395
6	30-Jul-87	3485 Clark	.04	.22	5.9	.83	.19	2.9	7.6	295
7	3-Aug-87	3810 Lyon	<.01	.03	7.0	.04	3.5	1.1	8.6	414
8	3-Aug-87	3475 Ormsby	.04	.04	6.9	.05	.14	2.9	8.6	371
9	3-Aug-87	3475 Ormsby	<.01	.07	7.2	.08	.91	2.5	8.2	363
10	3-Aug-87	1005 Dunbar	35.4	.02	.24	.05	<.01	7.8	7.1	328
11	3-Aug-87	220 Bruce	.31	.56	3.3	.41	1.5	9.1	7.7	334
12	6-Aug-87	3640 Clark	.04	.24	2.0	.86	8.3	2.5	7.5	370
13	6-Aug-87	2275 Lakeshore	<.01	.19	3.6	.36	5.0	2.1	7.8	424
14	6-Aug-87	200 McClellan	28.9	.13	.13	<.01	<.01	8.0	7.4	212
15	6-Aug-87	1110 Dunbar	32.5	.03	.21	<.01	<.01	6.8	7.0	330
16	6-Aug-87	2285 Rabbit	.08	.22	1.4	1.2	8.4	2.6	7.4	680
17	11-Aug-87	2485 Chipmunk	159.03	.02	.11	<.01	<.01	7.8	7.0	658
18	11-Aug-87	3450 Nye	.04	.14	7.0	.01	.56	3.0	8.3	388
19	11-Aug-87	185 Coyote	86.8	.02	.14	<.01	<.01	5.8	7.1	582
20	12-Aug-87	1225 Brenda	24.09	.05	.28	<.01	<.01	7.9	7.1	309
21	12-Aug-87	1415 Lord	52.27	.03	.23	.01	.05	7.8	7.3	221
22	12-Aug-87	4100 Bluewing	.04	.01	.17	.06	<.01	2.3	7.9	404
23	12-Aug-87	4085 Bluewing	3.18	.02	.15	<.01	<.01	4.8	7.8	346
24	14-Aug-87	2165 Chipmunk	103.21	.15	.12	<.01	<.01	8.8	6.5	449
25	14-Aug-87	2450 Chipmunk	22.9	.08	.11	<.01	<.01	8.5	7.5	186
26	14-Aug-87	290 McClellan	27.6	.11	.10	.02	<.01	8.8	7.2	185
27	14-Aug-87	3060 E. Lake	26.75	.06	.14	.01	<.01	5.9	7.0	234
28	14-Aug-87	3026 Sydney	25.16	.09	.14	<.01	<.01	7.4	7.2	224
29	31-Aug-87	375 McClellan	13.3	.04	.08	.02	.02	5.3	7.6	238

Map No. (Figure 3 in text)	Collection Date	Address	NO3 (mg/l)	TPO4 (mg/l as P)	F (mg/l)	Fe (mg/l)	NH4 (mg/l)	D.O. (mg/l)	pH	EC (µmhos/cm)
30	31-Aug-87	4255 Gander	< .01	.01	.15	1.3	< .01	3.8	7.6	379
31	31-Aug-87	4265 Gander	.62	.01	.15	.04	< .01	3.9	7.6	387
32	31-Aug-87	2360 Chipmunk	17.7	< .01	.08	.05	< .01	4.0	7.7	258
33	25-Sep-87	1860 Brenda	36.8	.06	.18	< 0.02	< .01	7.8	7.5	212
34	25-Sep-87	1400 Lord	28.09	.03	.26	< 0.02	< .01	6.0	6.9	173
35	25-Sep-87	1490 Guffey	19.3	.07	.19	0.02	< .01	8.6	7.1	167
36	25-Sep-87	425 Sparrow	0.97	.01	.11	0.03	.02	3.7	7.9	282
37	25-Sep-87	1810 E. Lake	98.3	.15	.11	< 0.02	< .01	7.2	7.1	333
38	12-Oct-87	1255 Brenda	.08	.08	.42	2.7	< .01	1.7	7.5	258
39	12-Oct-87	2390 Beaver	< .01	.33	2.2	1.6	10.27	2.3	7.4	513
40	12-Oct-87	4390 Jumbo Way	< .01	.02	.06	1.0	< .01	1.5	7.7	433
41	12-Oct-87	4305 E. Lake	3.63	.02	.07	< 0.02	< .01	8.8	7.1	355
42	14-Oct-87	S. Jumbo Way	1.1	.02	.16	< 0.02	< .01	2.2	7.5	410
43	14-Oct-87	3000 White Pine	66	.26	.13	< 0.02	< .01	9.3	7.1	332
44	14-Oct-87	3255 Pershing	< .01	.11	6.5	0.23	.53	2.1	8.1	334
45	14-Oct-87	3220 Churchill	22.46	.05	.29	< 0.02	< .01	6.7	7.6	256
46	21-Oct-87	3925 White Pine	.04	.04	7.0	.08	.29	4.1	8.8	392
48	21-Oct-87	2155 Lakeshore	< .01	.33	.81	.80	6.9	2.7	7.6	273
49	21-Oct-87	1485 Lord	107.6	.06	.28	.03	< .01	9.2	6.7	486
50	29-Oct-87	4025 E. Lake	64.2	.23	.32	< 0.01	< .01	5.5	7.1	338
51	29-Oct-87	1395 Brenda	97.9	.11	.21	0.02	.09	9.5	7.0	565
52	26-May-88	2960 Eagle	9.9	.12	.15	< 0.01	< .005	4.9	7.5	189
53	26-May-88	Lakeside @ Esmer.	< .01	.32	.76	1.7	10.6	4.0	7.6	360
54	26-May-88	1870 Brenda	22.3	.08	.17	< 0.01	< .005	5.3	7.0	167
55	26-May-88	1990 Lakeshore	< .01	.38	3.34	0.56	3.67	2.9	7.8	325
56	26-May-88	240 Coyote	< .01	.21	2.24	2.5	.10	2.38	7.5	353
57	26-May-88	3645 Ormsby	< .01	.02	5.7	< 0.01	3.67	3.3	8.5	377
58	26-May-88	3585 Ormsby	< .01	.18	4.1	0.02	.80	1.5	8.6	354
59	26-May-88	1955 E. Lake	.79	.11	1.1	0.08	.37	3.1	8.5	211
60	26-May-88	2390 Chukar	38.1	.27	.18	0.01	< .005	8.8	6.6	155