DESERT RESEARCH INSTITUTE
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ANALYSIS OF GROUNDWATER QUALITY IN NEW WASHOE CITY, NEVADA

by

W. Alan McKay

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WATER RESOURCES CENTER

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W. Alan McKay[1]

prepared for

Department of Conservation and Natural Resources
Nevada Division of Environmental Protection
201 S. Fall Street
Carson City, Nevada 89710

Water Resources Center
Desert Research Institute
University of Nevada System

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[1] Hydrogeologist, Water Resources Center, Desert Research Institute, University of Nevada System

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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 (NO_3) indicate widely variable conditions throughout NWC. Fluoride levels in excess of 7 mg/l are found in domestic water supplies in southern and western NWC. In the west-central portion of the study area, iron levels in excess of the recommended 0.6 mg/l are commonly associated with chemically reducing indicators, such as low dissolved oxygen values (<2.0 mg/l) and strong hydrogen sulfide odor. NO_3 concentrations in excess of 45 mg/l are common in northeast NWC and are often 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.

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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, natural water quality conditions which existed prior to development (i.e., high fluoride and iron), have now become water quality problems, as greater numbers of people consume the suspect water.

A previous study by Armstrong and Fordham (1977) reported deleterious levels of nitrate (NO_3), fluoride (F), and iron (Fe) in well waters in New Washoe City. Although NO_3, F, and Fe levels in New Washoe City groundwater are often in excess of state and federally recommended limits, 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.

OBJECTIVES

One objective of the study reported herein was to identify, if possible, the 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 NO_3 values were a probable result of contamination from individual septic systems.

Considering the high 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

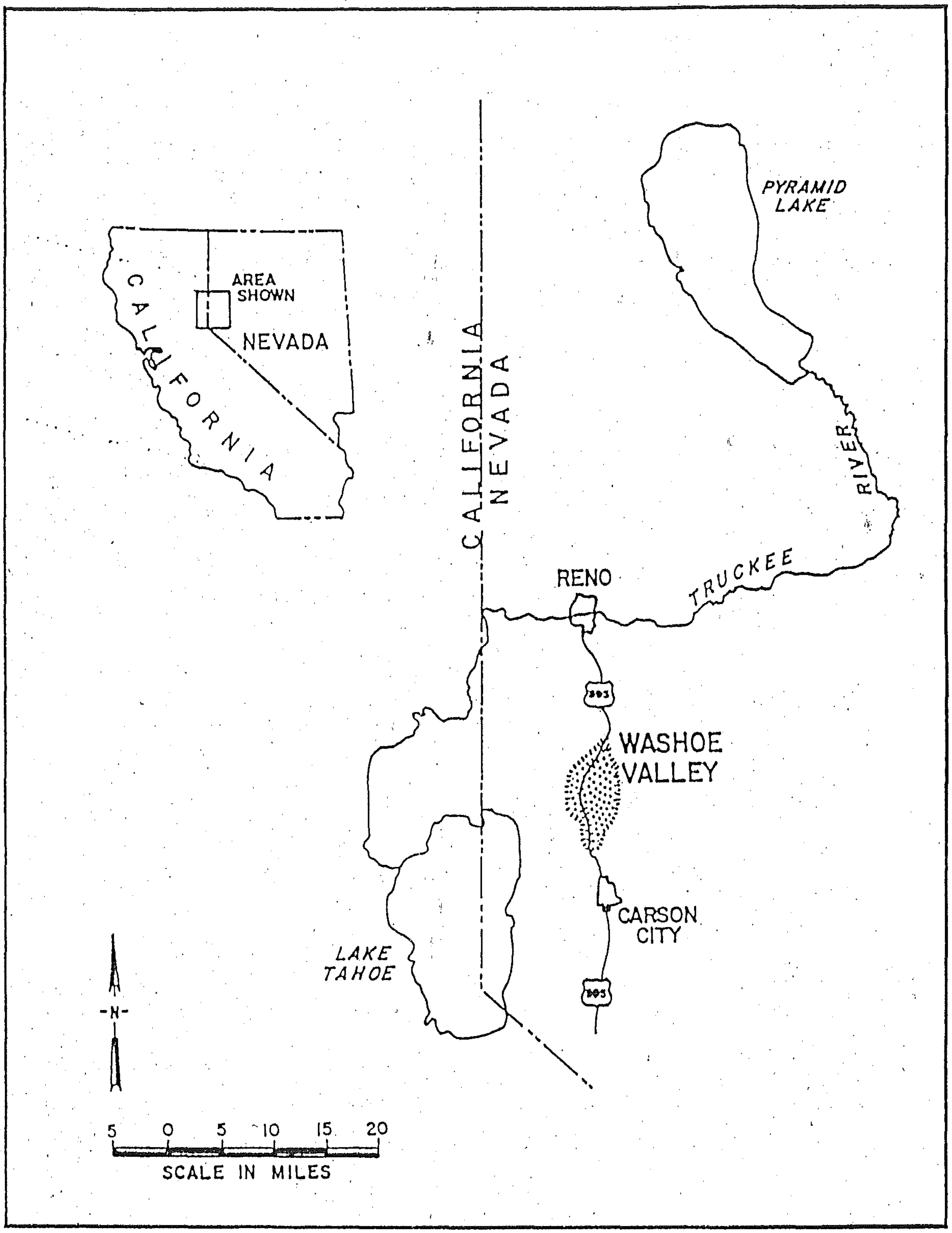

FIGURE 1. Location of Washoe Valley with Respect to Major Regional Features.

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 (N^{15}/N^{14}) was employed on a limited basis to help identify the source of nitrogen in New Washoe City groundwater.

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 stratigraphic interval with iron and fluoride concentrations in New Washoe City.

Last, 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 could 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 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 1960's, 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.

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

Previous investigators (Rush, 1967; Arteaga and Nichols, 1984) have noted that most groundwater in Washoe Valley is developed from what is generally

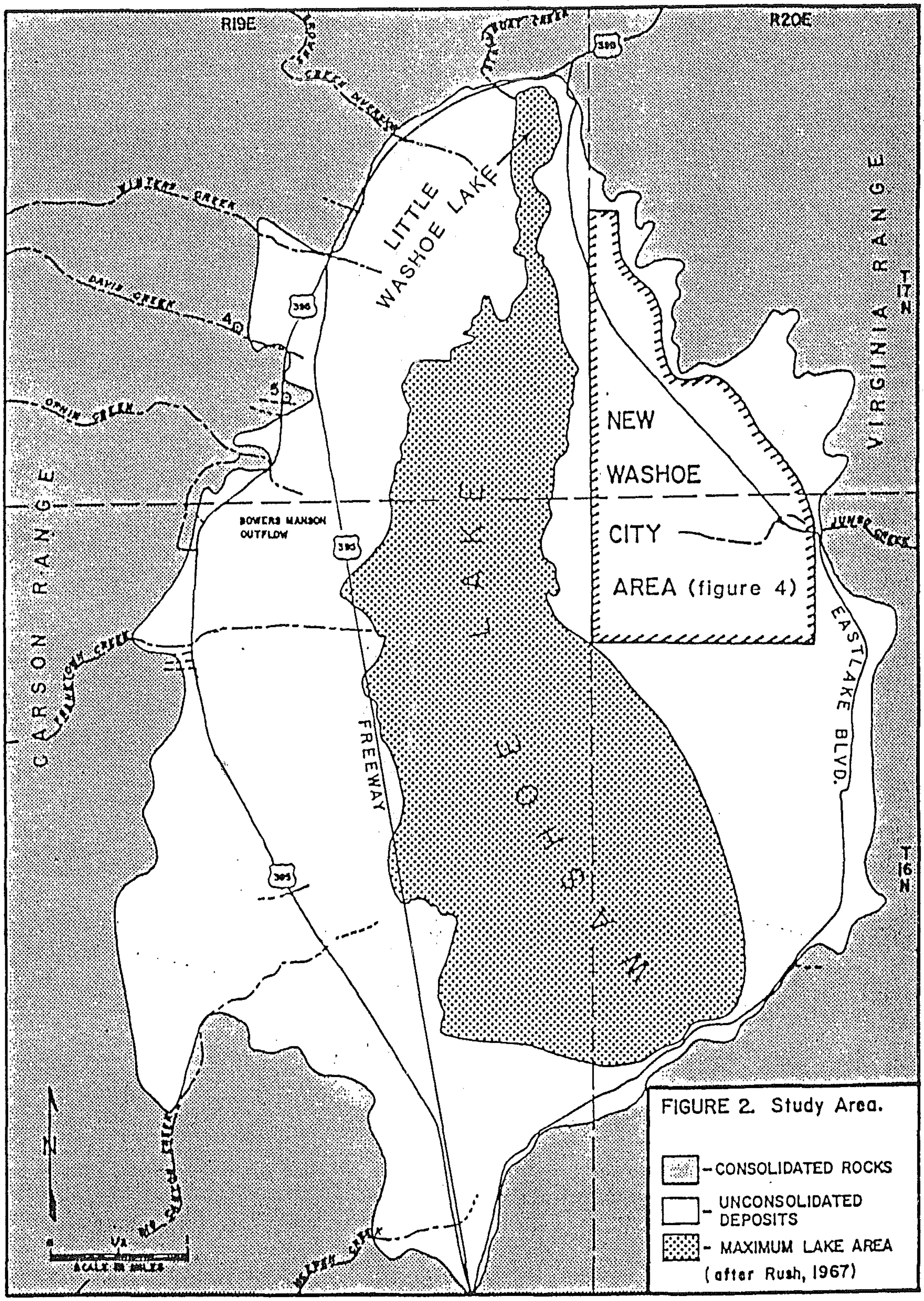

FIGURE 2. Location of Study Area with Respect to Washoe Valley.

termed 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.

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.

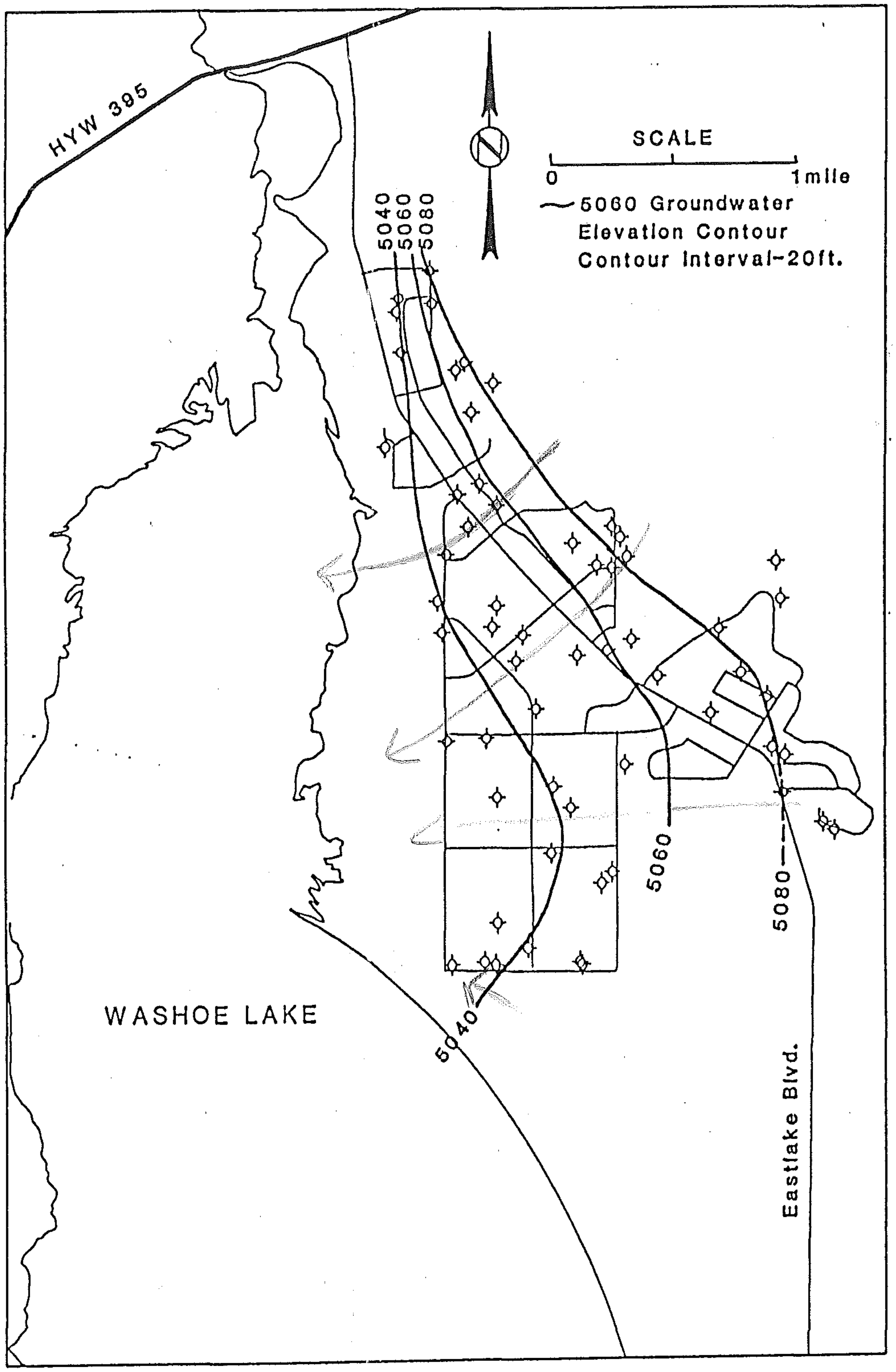

FIGURE 3. Groundwater Elevations Derived from Water Level Measurements in Northeast Washoe Valley - 1988.

METHODOLOGY

To reiterate, the objectives of the study were fourfold:

1. establish whether a relationship exists between residential development and changes in the hydrologic regime of New Washoe City;

2. delineate those areas with specific water quality problems;

3. identify possible sources for the various contaminants; and

4. offer alternative solutions to waste disposal and/or water supply problems.

To satisfy the above 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 analysis results from 1986 to 1987, preliminary isoconcentration maps were constructed for nitrate, fluoride, and iron.

These maps served two important purposes. First, they provided an opportunity to compare 1987 distributions of 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.

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.

Selection of sample sites was driven 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 others to become involved hindered sample coverage in some areas. Figure 4 is a sample location map for this study.

Based on the analytic results for the nitrogen species (NO_3, NH_4), 20 sites were chosen for collection of nitrogen isotope samples. Applying a technique developed by Kreitler (1974), nitrogen isotope ratios (N^{15}/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 precise analysis difficult at best, results from this portion of the study were compatible with previous studies (Rush, 1967; Arteaga and Nichols, 1984).

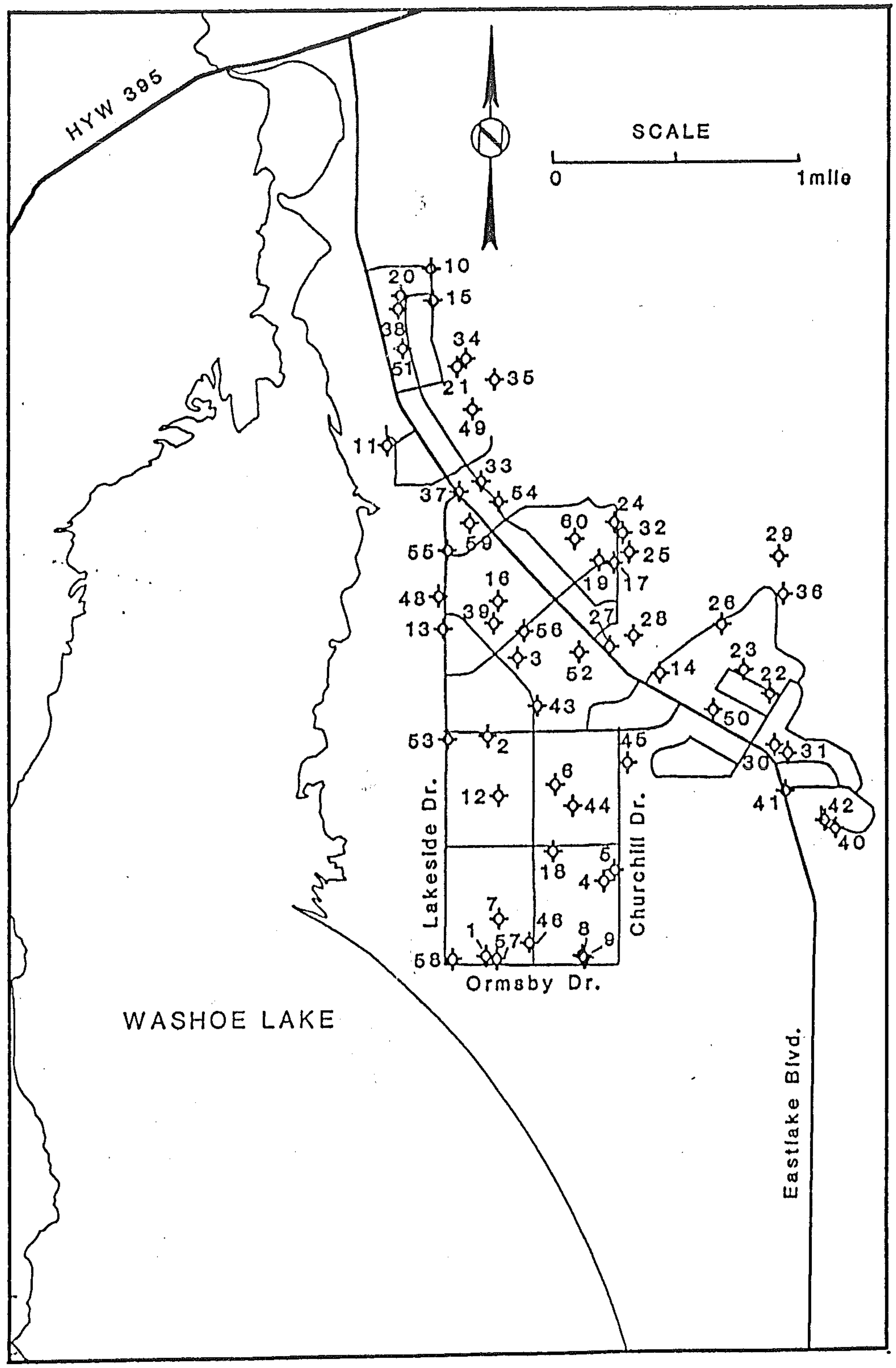

FIGURE 4. Location of Samples Collected in Northeast Washoe Valley.

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 1. 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 water supply. Table 2 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

TABLE 1. 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

TABLE 2. 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

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. 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.)

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).

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

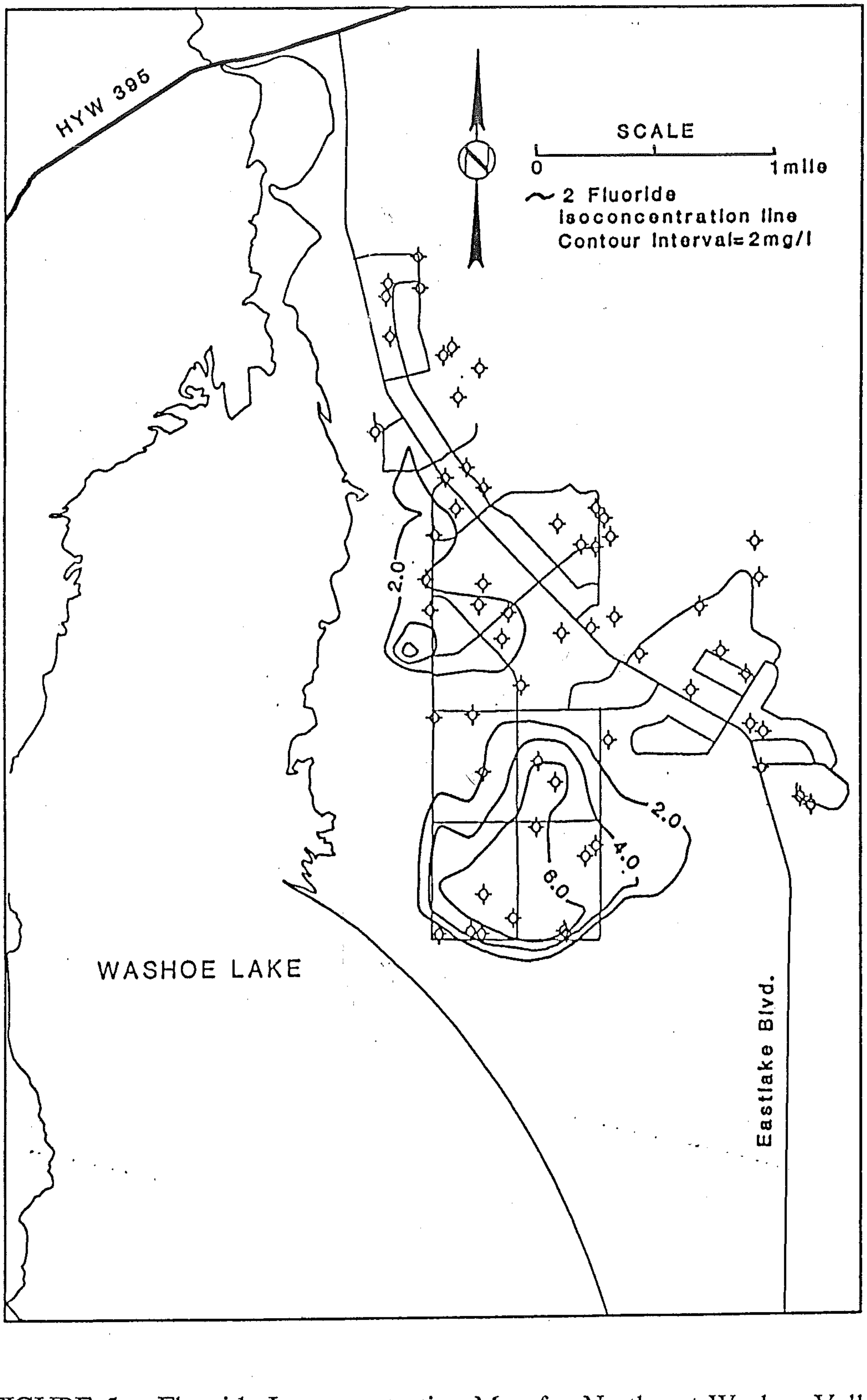

FIGURE 5. Fluoride Isoconcentration Map for Northeast Washoe Valley.

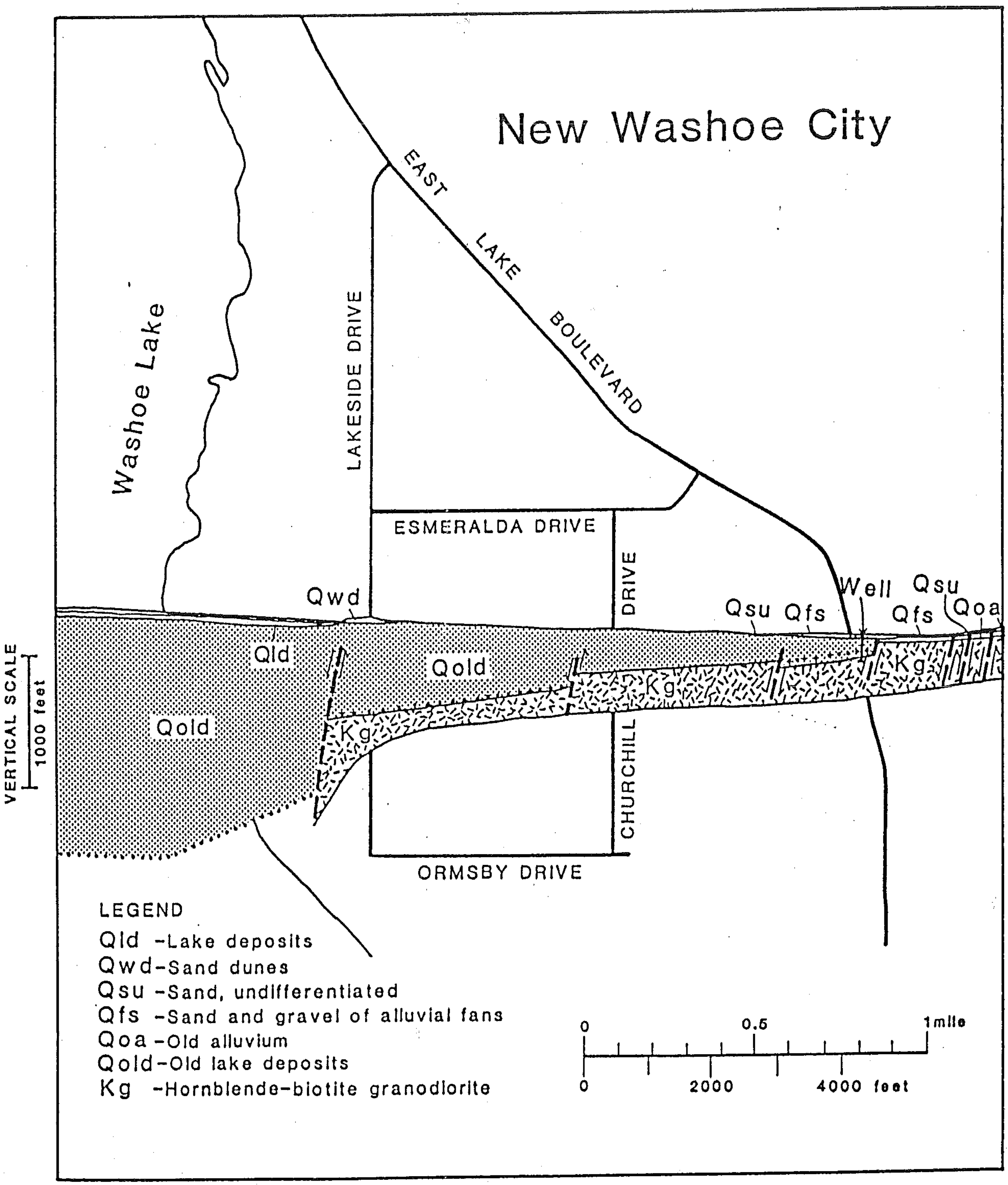

FIGURE 6. Diagrammatic Cross-Section Through South-Central New Washoe City (after Tabor and Ellen, 1976).

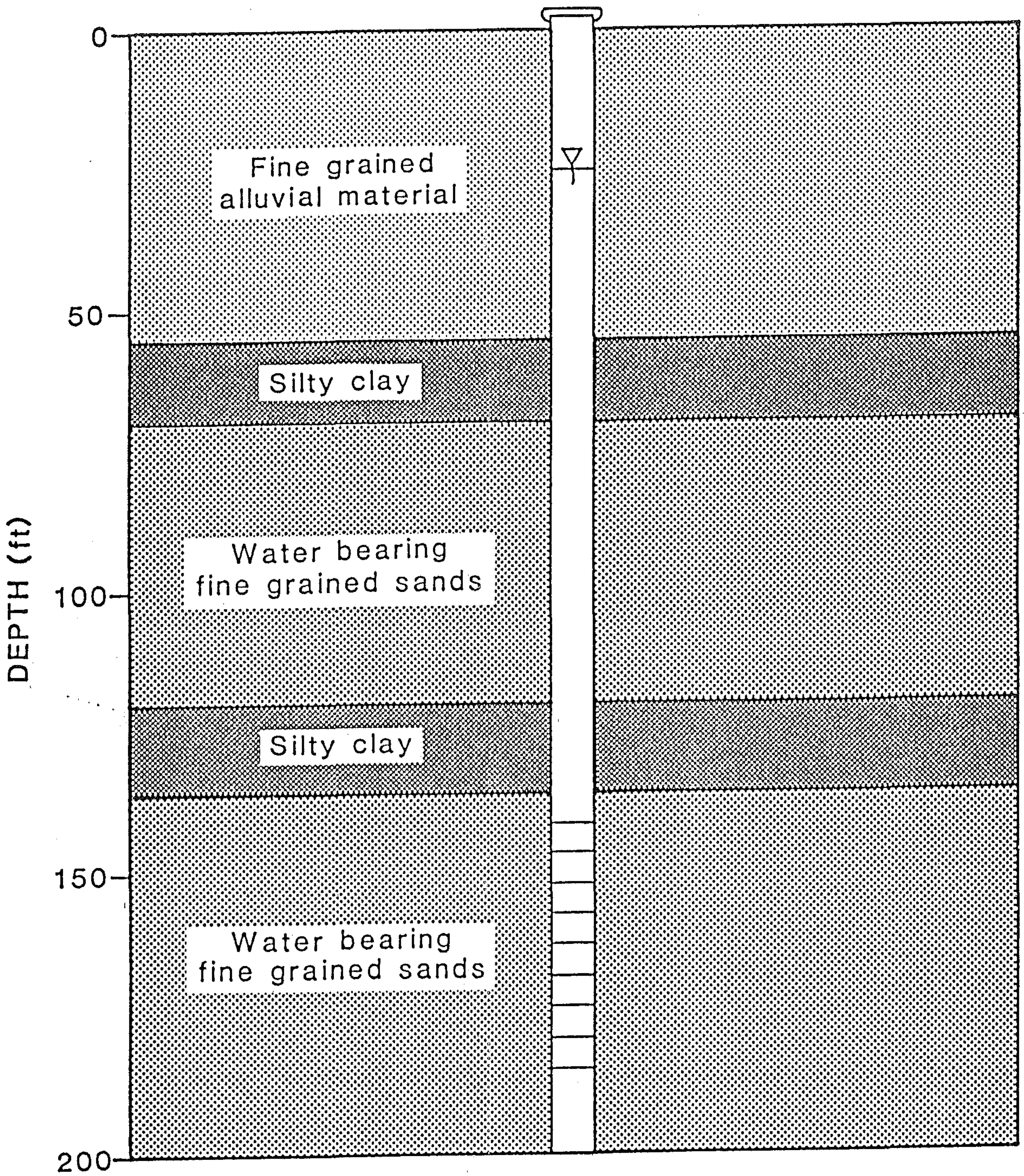

FIGURE 7. Stratigraphic Section for Typical Domestic Well in Southern New Washoe City.

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 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. 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 decreases 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, anion exchange reactions between fluoride and hydroxide are common in clay-rich environments 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.

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 relationships observed in New Washoe City are discussed herein, the

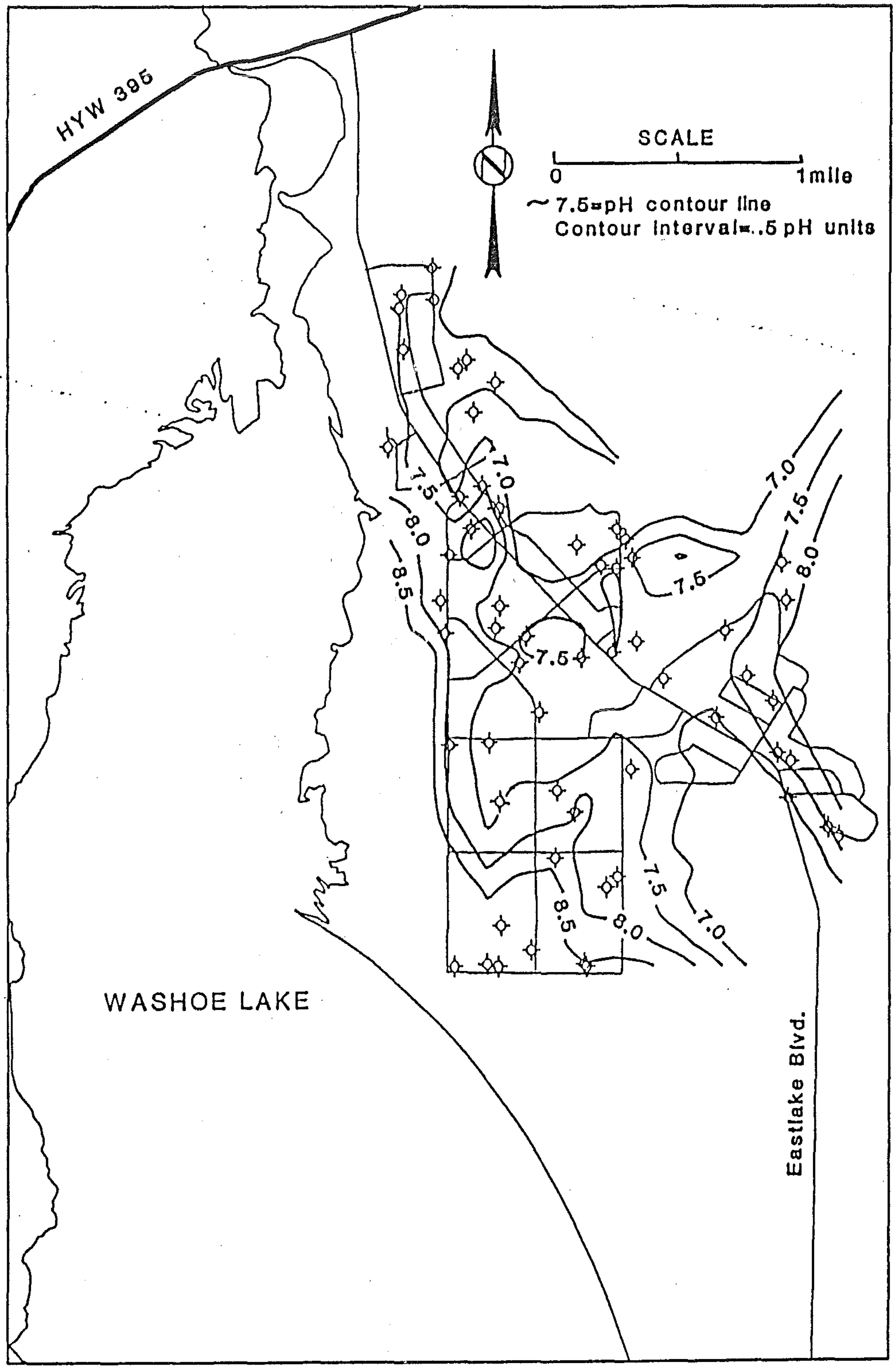

FIGURE 8. pH Contour Map for New Washoe City.

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 a plot of iron levels as analyzed for this study and with only minor exceptions is consistent with those earlier results. Iron concentrations ranged from less than 0.01 mg/l (detection limits) to a maximum concentration of 2.5 mg/l.

The most common form of iron in groundwater is the ferrous ion, Fe^{2+}. In the central portion of the study area, where iron levels are highest, the rotten egg odor of hydrogen sulfide (H_2S) 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.

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

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 (Fe^{2+}) in hemoglobin to ferric iron (Fe^{3+}), thereby preventing the transport of oxygen by the hemoglobin. The results are gradual suffocation (cyanosis). It is noteworthy

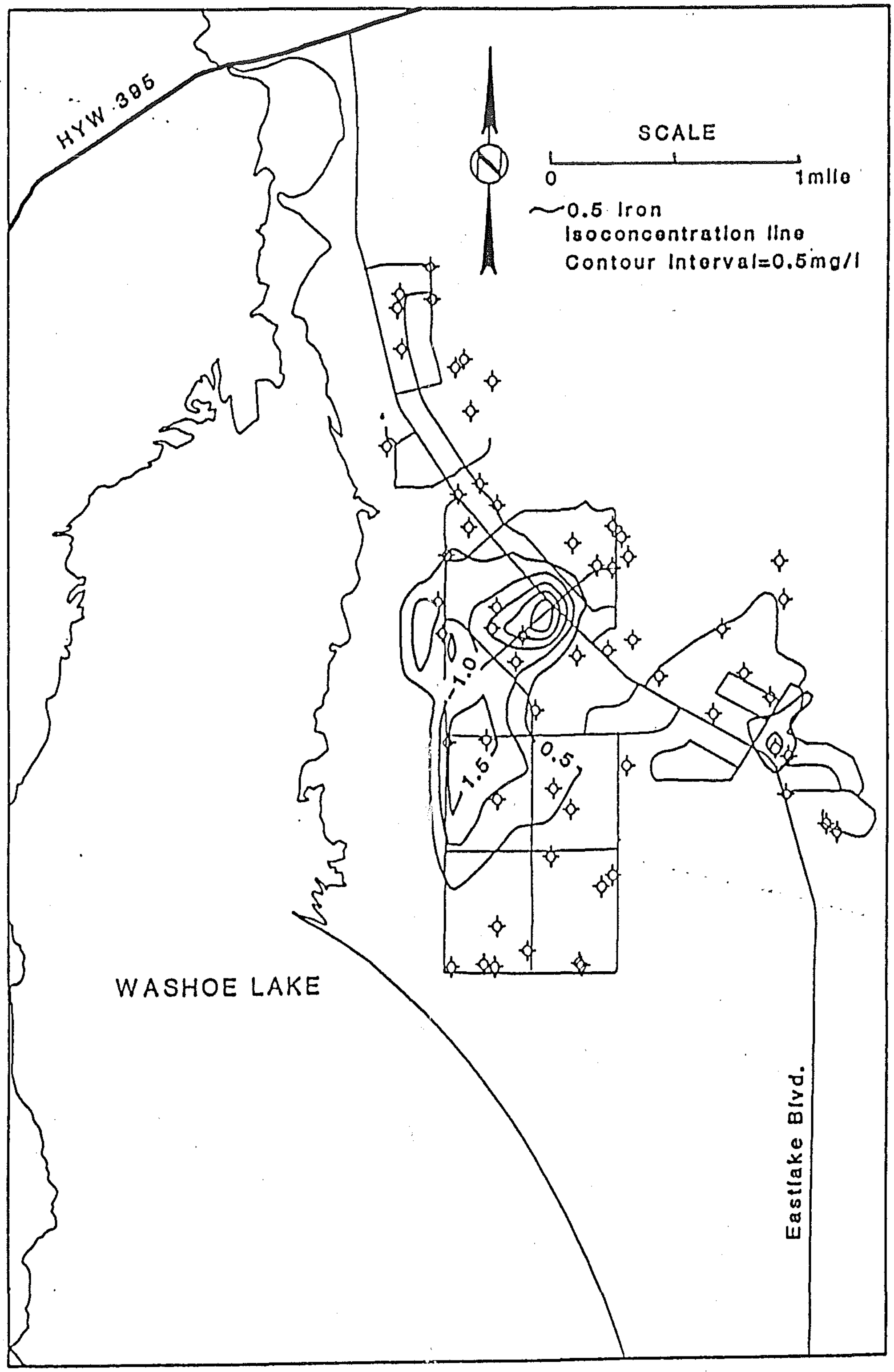

FIGURE 9. Iron Isoconcentration Map for New Washoe City.

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 injestion increase measurably as concentrations increase above 45 mg/l.

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 coloquially known as the nitrogen cycle. Figure 10 is one such diagram for that portion of the cycle which is thought to influence nitrogen chemistry 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 the northern portion of 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 in the northern part of New Washoe City. Generally speaking, the type of data distribution seen in Figure 11 indicates multiple 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 and historic farming activities in the area. For the northeast portion of the study area where nitrate concentrations are highest, farming activity was never extensive enough to influence nitrogen chemistry in the local groundwater. Additionally, the sporadic distribution of nitrate concentrations suggest less uniformly distributed source areas than would be expected from grazing activities.

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 ($NH_3^+ \rightarrow NO_3^-$) 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 possibility.

Although spatial distributions of nitrate concentrations in New Washoe City are strongly indicative of septic system contamination, additional techniques were considered 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

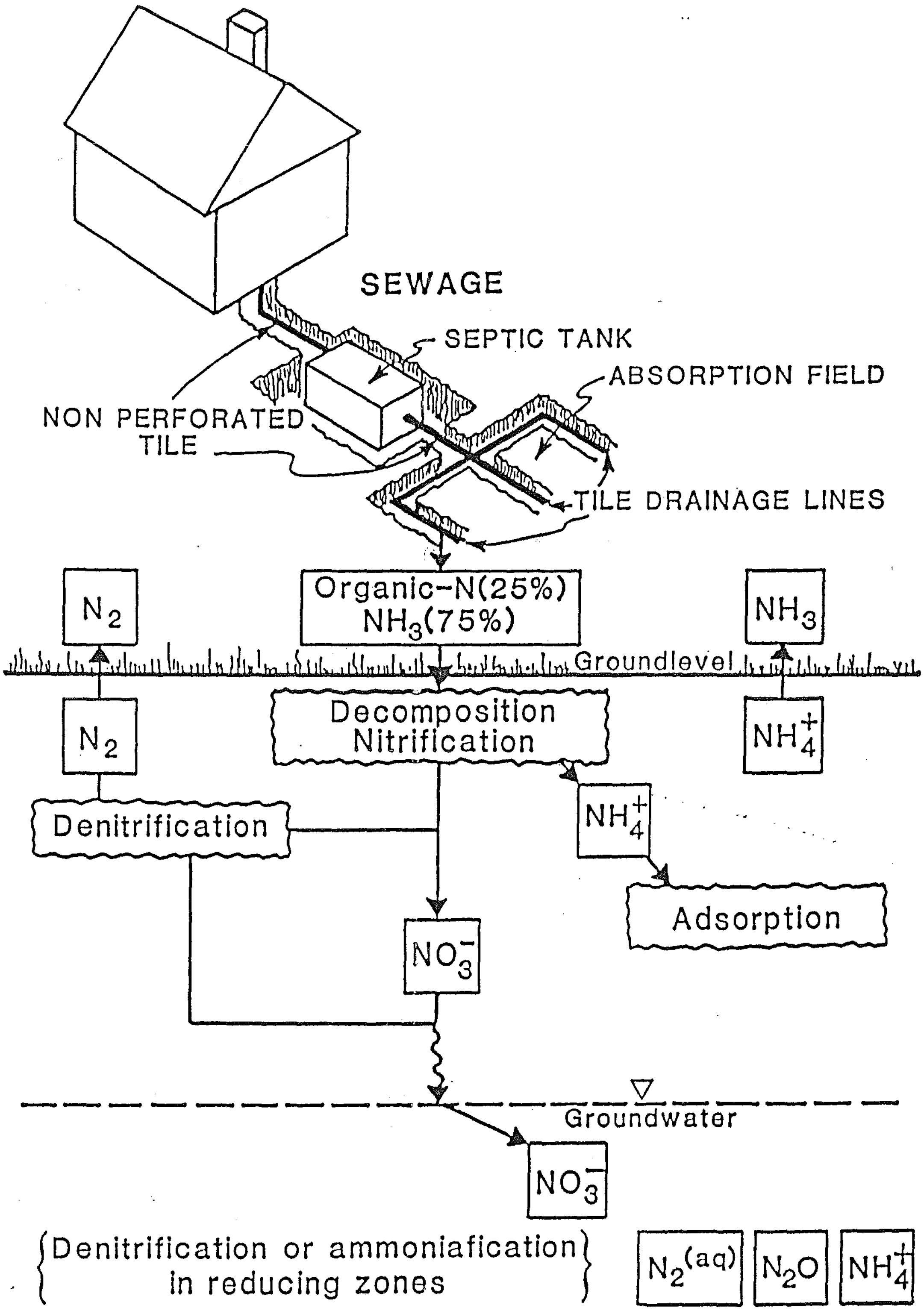

FIGURE 10. Diagrammatic Cross-Section of Nitrogen Cycle in New Washoe City (adapted from Canter and Knox, 1985).

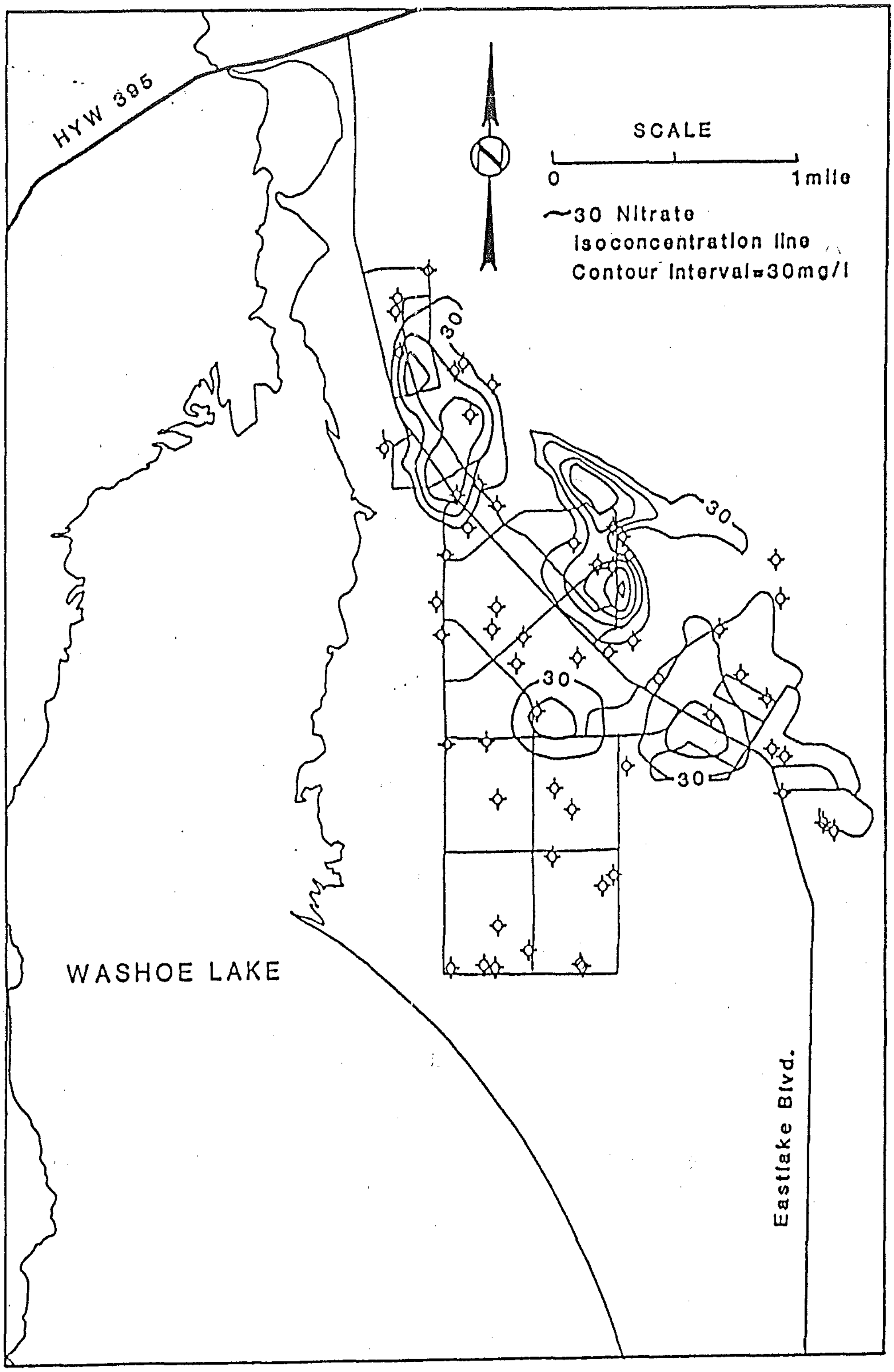

FIGURE 11. Nitrate Isoconcentration Map for New Washoe City.

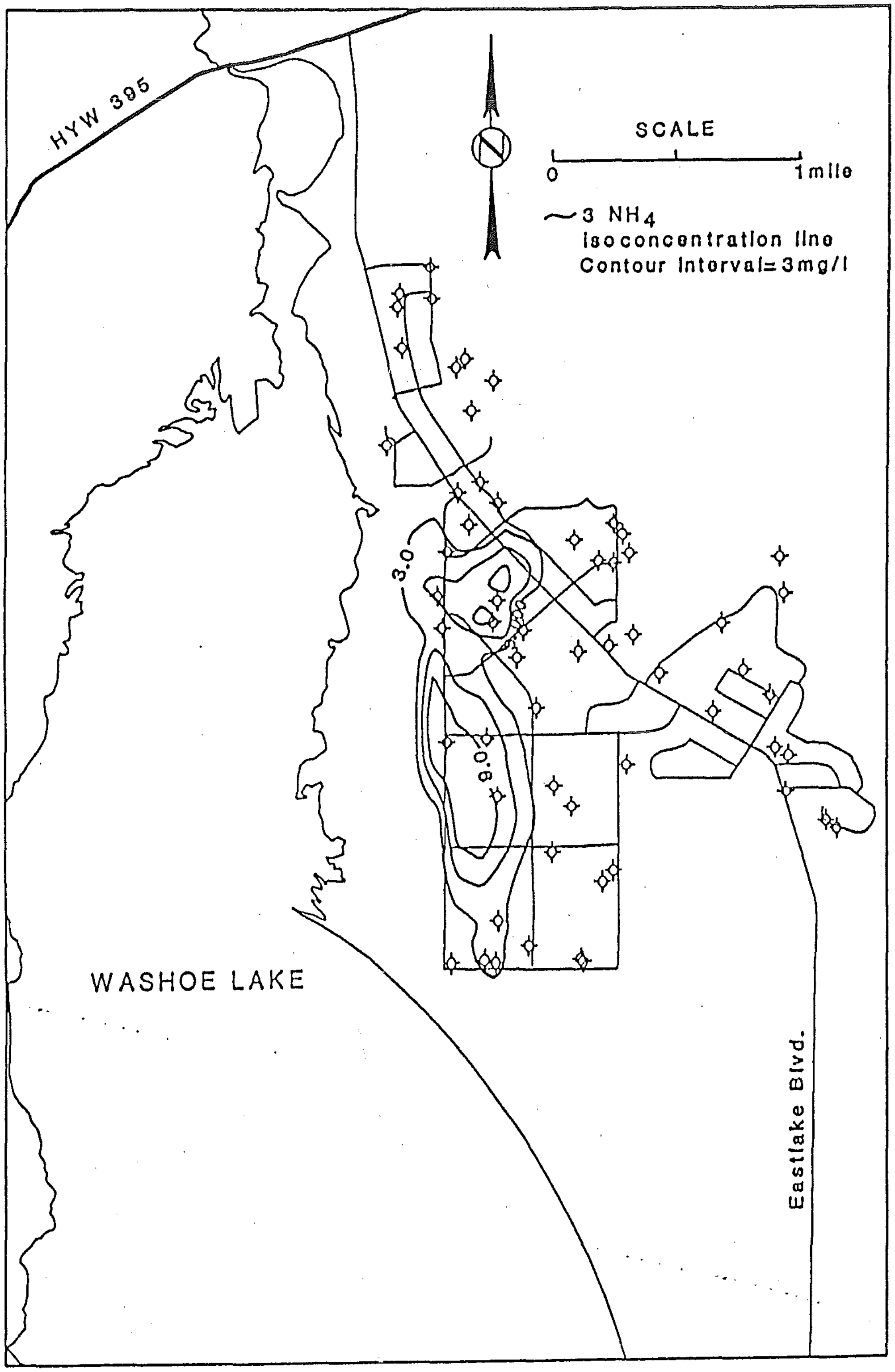

FIGURE 12. Ammonia Isoconcentration Map for New Washoe City.

the source of nitrate in groundwaters (Jones, 1973; Kreitler, 1974; Spalding et al., 1982). There are two naturally occurring stable isotopes of nitrogen, N^{14} and N^{15}. The N^{15} content of any nitrogen species (i.e., nitrate or ammonia) is expressed in terms of the nitrogen isotope ratio (δ) defined as follows:

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

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.

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 δN^{15} values in non-fertilized soils ranged from +2°/oo to +6°/oo. δN^{15} values from animal waste (humans and cattle) nitrogen ranged from +8°/oo to 16°/oo. δN^{15} values of artificial fertilizer ranged from -8°/oo to +6.2°/oo, with 90 percent of reported samples ranging from -3°/oo to +2°/oo (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 3 list the results of the nitrogen isotope analysis. Figures 13a and 13b are graphical plots of δN^{15} versus NO_3^- and NH_4^+, respectively, for the 20 groundwater samples. Both plots show a wide range in δN^{15} values with correlations of r = 0.61 and r = 0.45, respectively, with 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). 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 Labs) 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.

In November 1987 (4 months later) the well was sampled again for isotope collection and NO_3^- concentrations had dropped further to 146 mg/l. Although ad-

TABLE 3. N^{15} VALUES FOR 19 WELLS IN NEW WASHOE CITY.

Sample No.	NO_3 (mg/l)	δN^{15} °/oo
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

Sample No.	NH_4^+ (mg/l)	δN^{15} °/oo
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

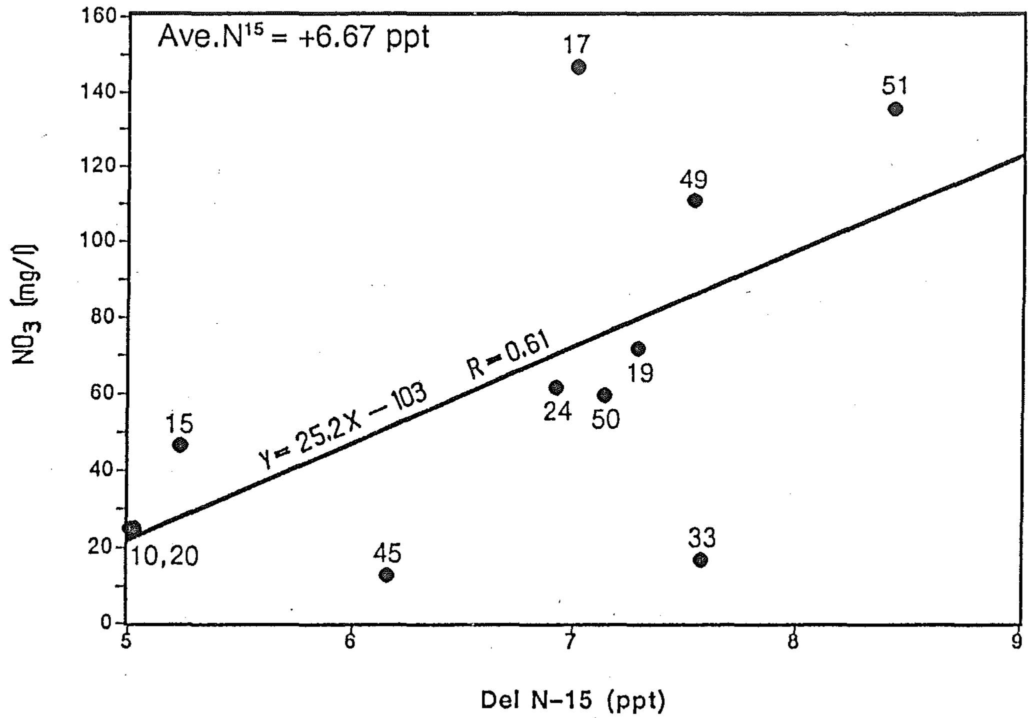

FIGURE 13a. N^{15} versus NO_3 Plot for Selected New Washoe City Wells.

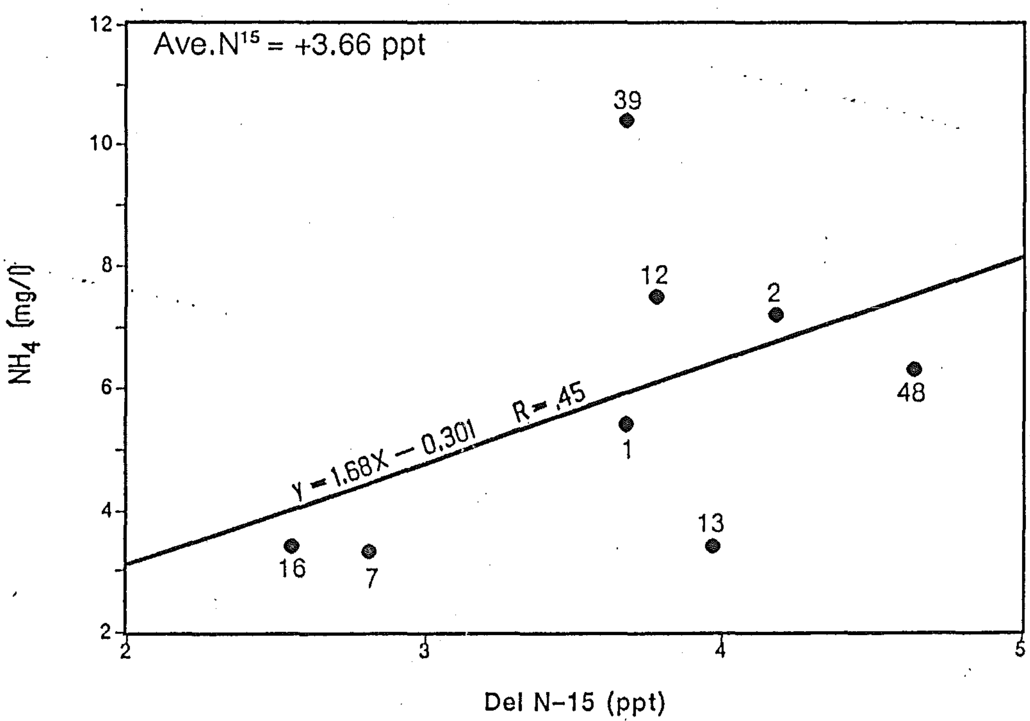

FIGURE 13b. N^{15} versus NH_4 Plot for Selected New Washoe City Wells.

ditional sampling was never conducted, the three samples that were collected indicate a strong temporal trend of decreasing 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, NO_3^- values had dropped to 70 mg/l, again suggesting a temporal decrease related to a one-time "pulse" of NO_3^- in 1986. Well No. 24 is also downgradient from the failed leachfields and has exhibited a similar trend. In July 1987, NO_3 concentrations were 103 mg/l, but had decreased to 61 mg/l when sampled for isotopes four months later. δN^{15} results for the three samples indicate very similar isotopic ratios (Table 3 and Figure 13a).

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

The other 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. Each well is completed in fractured granitic rocks and are located such that there is minimal exposure to upgradient sewage disposal.

Figure 13b shows δN^{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 δN^{15} values (<5.0) are strongly suggestive of natural soil nitrogen as the source for the NH_4 in these waters.

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 14a, 14b, and 14c 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 14b shows a significant 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 14c is a comparison of nitrate values from 1977 and 1987, respectively. While 8 of the 10 well waters remain unchanged, Well No.'s 10 and 43 show significant 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 will have a negative impact on groundwater

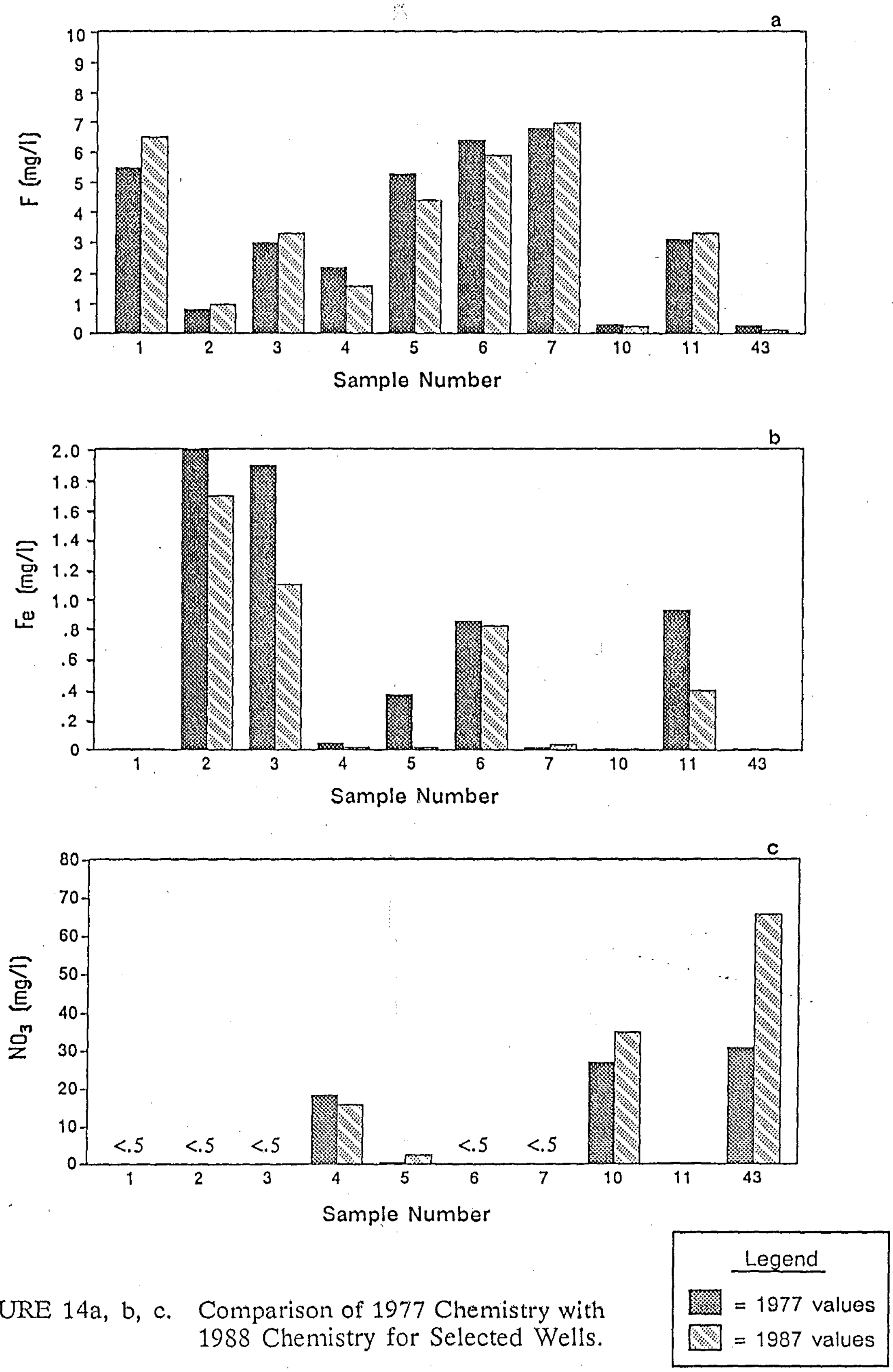

FIGURE 14a, b, c. Comparison of 1977 Chemistry with 1988 Chemistry for Selected Wells.

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. It is this process of denitrification which provides the best explanation for continued low nitrate concentrations in the western and southern portions of New Washoe City.

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 concentrations 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. No significant 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 are effective at nitrate removal by denitrification. Thus, in an area where one might expect nitrate concentrations to increase as the number of homes upgradient increase, no significant change has occurred in 10 years.

Contamination of domestic water by nearby septic systems remains 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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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 (µmhos/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	6.6	.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