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Trends in Nitrate and Dissolved-Solids Concentrations in Ground Water, Carson Valley, Douglas County, Nevada, 1985-2001

Water-Resources Investigations Report 03-4152

Nevada Basin and Range Study Unit
National Water-Quality Assessment Program

Carson Water Subconservancy District

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ABSTRACT

Analysis of trends in nitrate and total dissolved-solids concentrations over time in Carson Valley, Nevada, indicates that 56 percent of 27 monitoring wells that have long-term records of nitrate concentrations show increasing trends, 11 percent show decreasing trends, and 33 percent have not changed. Total dissolved-solids concentrations have increased in 52 percent of these wells and are stable in 48 percent. None of these wells show decreasing trends in total dissolved-solids concentrations. The wells showing increasing trends in nitrate and total dissolved-solids concentrations were always in areas that use septic waste-disposal systems. Therefore, the primary cause of these increases is likely the increase in septic-tank usage over the past 40 years.

INTRODUCTION

Douglas County, in western Nevada (fig. 1), is a rapidly developing area that depends on ground water for domestic and public water supply. The result of this development is degraded ground-water quality in some areas. For example, high nitrate concentrations have been found in the Indian Hills area of northern Douglas County in Carson Valley (Seiler and others, 1999; Thodal, 1996). Degradation of ground-water quality is possible over a wider area of Carson Valley as development continues. Once degraded, it can take many years for ground-water quality to improve, which can limit future growth. Water quality and ground-water levels have been monitored since 1985 in Douglas County to help ensure a reliable water supply. This ongoing monitoring is being done in cooperation with the Carson Water Subconservancy District and Douglas County. Although 16 years (1985-2001) of data exist, data have been analyzed only for changes in ground-water quality up to 1988 (Thodal, 1996). This report summarizes a further analysis of these data, including data collected up to 2001, to determine the causes of changes in nitrate and dissolved-solids concentrations through time.

WHY ARE NITRATE AND DISSOLVED-SOLIDS CONCENTRATIONS IMPORTANT?

The recognition that high concentrations of nitrogen, specifically nitrate, in drinking-water supplies could cause health problems was determined over 50 years ago by Comly (1945). Methemoglobin, a form of hemoglobin in the blood that is transformed so that it is unable to deliver oxygen, results in the disease called methemoglobinemia when

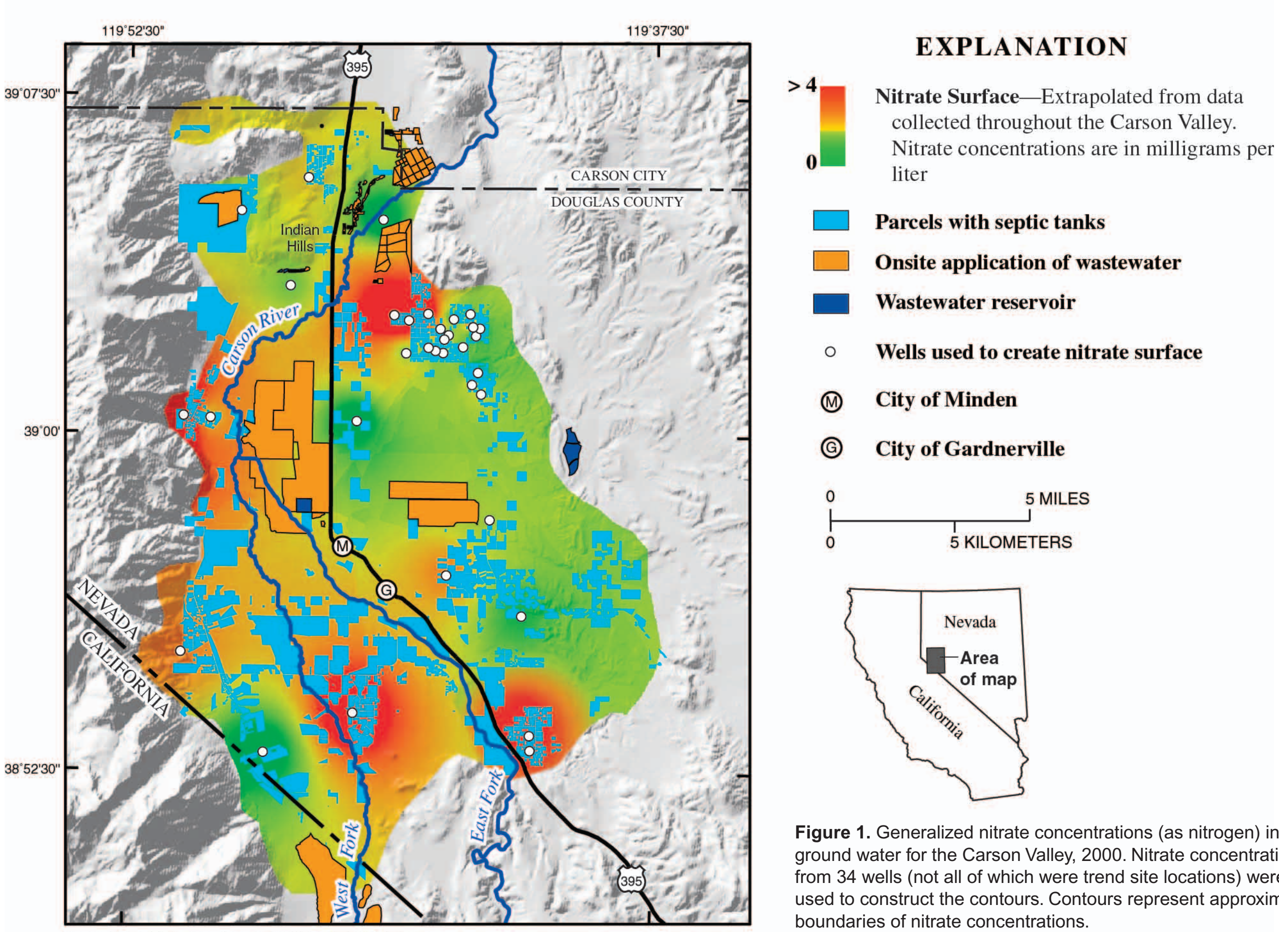

Figure 1. Generalized nitrate concentrations (as nitrogen) in ground water for the Carson Valley, 2000. Nitrate concentrations from 34 wells (not all of which were trend site locations) were used to construct the contours. Contours represent approximate boundaries of nitrate concentrations.

Base from U.S. Geological Survey digital data.
Shaded relief from 30-meter National Elevation Data set.

amounts become high enough to cause a bluish discoloration of the skin and can be fatal. Infants under the age of 6 months are more susceptible to this disease because they lack the appropriate enzyme that converts methemoglobin back to hemoglobin (Avery, 1999). Comly's research became widely accepted when subsequent investigations indicated a consistent pattern of high-nitrate drinking water in infantile methemoglobinemia cases. In 1975, the U.S. Environmental Protection Agency (USEPA) established a maximum contaminant level (MCL) for nitrate in drinking water of 10 mg/L (milligrams per liter) as nitrogen.

High nitrate concentrations also have been linked to hypertension (Malberg and others, 1978), central nervous system birth defects (Dorsch and others, 1984), certain cancers (Hill and others, 1973), non-Hodgkin's lymphoma (Ward and others, 1996; Weisenburger, 1991), and diabetes (Parslow and others, 1997). However, definitive relations are lacking and more research is needed to confirm the links (Spalding and Exner, 1993). Avery (1999) suggested that the correlation between high nitrate concentrations and reported cases of methemoglobinemia is not related to nitrate specifically, but to associated bacterial contamination that occurs with high nitrate concentrations in rural areas such as from septic tanks and farm animal waste.

Regardless of the human health concerns, it has been widely recognized that high concentrations of nitrogen in ground water can lead to increased plant and algal growth of lakes and streams that have ground-water inputs (Spalding and Exner, 1993). Nitrate concentrations in ground water that could have serious environmental effects may be much lower than the maximum USEPA drinking-water guideline of 10 mg/L because growth in some plant communities may be limited by nitrogen. This means that additional nitrogen caused by human activities around lakes and rivers may cause algal blooms and change the ecology of the surface-water system. Data collected by the Nevada Division of Environmental Protection on the Carson River show that at certain times, the Carson River has limited nitrogen available for plant growth (Pahl, 2002). This means additional nitrogen from ground water could cause detrimental effects to the river ecology.

View of a sewered housing development in Douglas County, Nevada, looking south to Jobs Peak (left) in the Carson Range.

Dissolved solids are derived mainly from minerals in rocks near the land surface and in the aquifer. Small amounts of contaminants added to the ground water generally do not significantly increase the dissolved-solids concentration of the ground water. However, changes in dissolved-solids concentrations over time may indicate altered ground-water circulation in aquifers that are stressed by large withdrawals or are receiving additional recharge from water that is high in dissolved solids. In Carson Valley, ground-water recharge sources that are potentially high in dissolved solids are lawn irrigation, agricultural runoff, and sewage effluent.

A secondary preferred drinking-water standard for total dissolved solids of 500 mg/L for public water supplies has been adopted for Nevada. If water supplies that meet the preferred standard are not available, the MCL of 1,000 mg/L is used, and this MCL is enforceable by the State (Nevada Bureau of Consumer Health Protection Services, 1980).

WHAT ARE THE SOURCES OF NITROGEN IN CARSON VALLEY?

A primary focus of this study is to identify sources of nitrate in ground water in Carson Valley. Several potential sources of nitrate exist that are derived from human activities in Carson Valley. These include nitrate from agriculture (urine and feces from livestock, fertilizer application to crops, etc.), irrigation using treated effluent that contains elevated nitrate concentrations, septic systems, and domestic application of fertilizer. Natural sources of nitrogen in the ground water are limited in Carson Valley, and nitrate concentrations in wells that have not been impacted by human nitrogen sources generally are less than 1 mg/L as nitrogen.

Rapid growth in Douglas County, Nevada, using septic-tank systems was important to consider when evaluating nitrate and total dissolved-solids concentrations in ground water.

Carson Valley has experienced rapid growth in areas outside of the existing public water and sewage systems of Minden and Gardnerville. This growth has led to the installation of septic systems at a rate of over 1,000 every 10 years (table 1).

Table 1. Increase of permitted septic systems in Carson Valley over time

Date range	Number of parcels with septic systems	Increase
1851-1970	446	
1971-1980	1,591	1,145
1981-1990	2,760	1,169
1991-2001	4,064	1,304

WHAT WAS MEASURED TO DETERMINE NITROGEN SOURCES?

Potential nitrogen sources in Carson Valley were identified with data from the Douglas County Multi-Agency Geographic Information Center. These data included locations of septic systems on a parcel basis (including when they were permitted), locations of wastewater irrigation systems, reservoir locations, and agricultural land uses. Potential nitrogen sources were compared annually to nitrate concentrations measured between 1985 and 2001. Nitrate concentrations in ground water generally exceeded 2 mg/L in the proximity of septic tanks (fig. 1). Total dissolved-solids concentrations exhibited a similar distribution to nitrate concentrations. For this study, more than 800 nitrate and total dissolved-solid concentrations analyses were examined, plotted, and analyzed statistically.

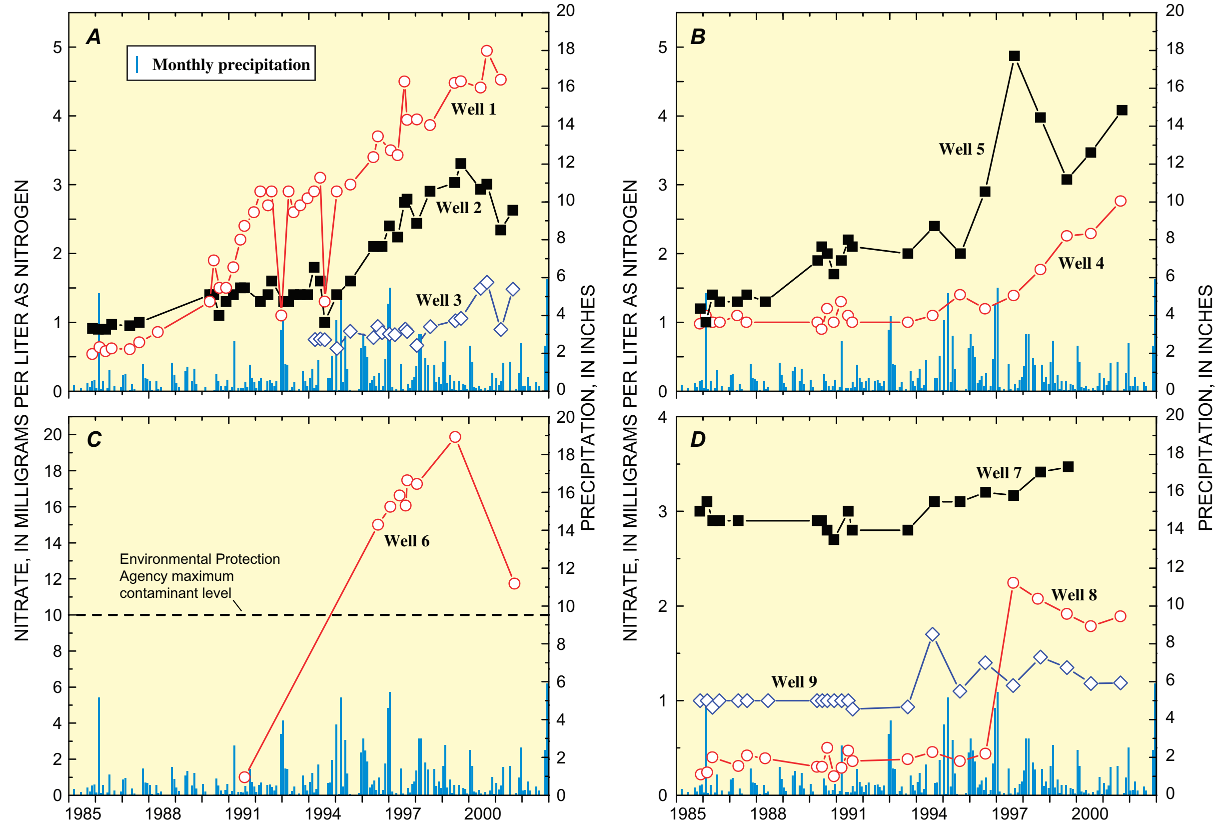

Figure 2. Trends in nitrate concentrations for selected wells in Carson Valley. Precipitation data from Minden is plotted for reference. U.S. Environmental Protection Agency maximum contaminant level for nitrate (as nitrogen) of 10 mg/L is shown in figure 2C. Well locations are shown in figure 4.

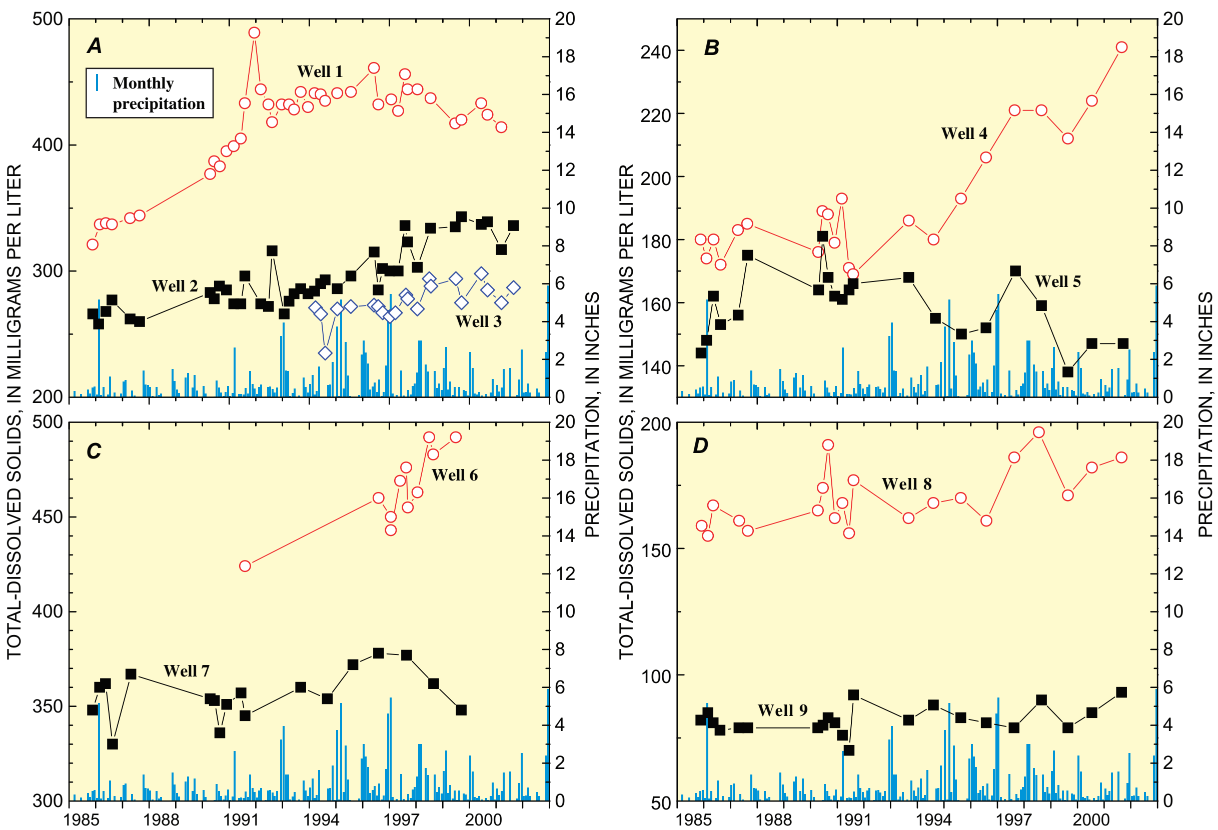

Figure 3. Trends in total dissolved-solids concentrations for selected wells in Carson Valley. Precipitation data from Minden is plotted for reference. Well locations are shown in figure 5.

HOW WERE TRENDS DETERMINED?

Changes in nitrate and total dissolved-solid concentrations over time were analyzed by studying graphical representation of the data and by comparing visual estimates of trends (figs. 2 and 3) to a nonparametric statistical test called Kendall's tau. Kendall's tau provides a consistent, unbiased quantitative test of whether the visual trends detected are real. The statistical test was conducted at a 95 percent confidence limit to reduce the probability of detecting a trend when none is present. The procedure adopted in this study was similar to the analysis used by Thodal (1996). Results of the trend analysis for each well using the Kendall's tau test are shown in figures 4 and 5.

WHAT WERE THE RESULTS OF THE STUDY?

Figure 1 shows a contour map of nitrate concentrations in 2000. The highest nitrate concentrations occurred near or directly under areas where there are high concentrations of parcels with septic tanks. Agricultural areas and areas where wastewater is irrigated onto fields generally do not appear to have elevated nitrate concentrations. This indicates that the source of nitrogen is probably either septic-tank leach fields or fertilizer applied to domestic lawns. Although it is not possible to distinguish between the two sources directly, it would be expected that if irrigation of fertilized lawns were the main cause of elevated nitrates, that a seasonal pattern of high nitrate concentrations might occur in shallow wells that have water levels close to the land surface. Seasonal patterns of nitrate and total dissolved-solids concentrations have not been observed in any of the long-term monitoring wells when quarterly nitrate sampling was part of the monitoring program and no correlation with monthly precipitation was observed (figs. 2 and 3). This indicates that nitrogen in the ground water is derived from a relatively constant source, such as leachate from septic tanks.

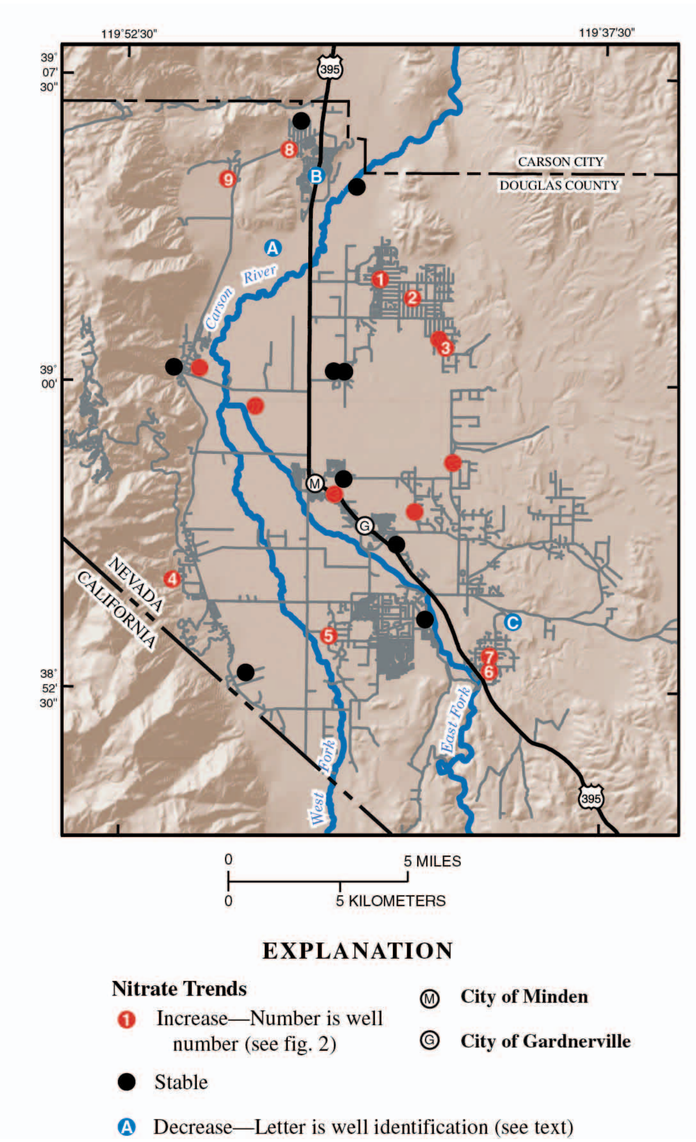

Figure 4. Trends in nitrate concentrations plotted by well location. Individual trends in nitrate concentrations of wells 1-9 are plotted in figure 2.

Analyses of nitrate and dissolved-solids concentrations were done on water samples from 27 monitoring wells in the Carson Valley that have long-term records (greater than 5 years of data from 1985 through 2001). Nitrate concentration data indicate that 56 percent of these wells (15 wells) show increasing trends over time, 11 percent (3 wells) show decreasing trends, and 33 percent (9 wells) did not change during the sampling period (fig. 4). Total dissolved-solids concentrations increased in 52 percent of these wells (14 wells) and were stable in 48 percent (13 wells). None of these wells show decreasing trends in total dissolved-solids concentrations (fig. 5).

In many cases, the increases in nitrate concentrations were not large, and in all but two wells nitrate concentrations were below the USEPA MCL for nitrate of 10 mg/L as nitrogen. However, in some locations the consistent increase in nitrate concentrations is apparent in more than 50 percent of the long-term monitoring wells, and some increases were on the order of five times the initial concentration recorded at the beginning of the monitoring program. These increases indicate that further increases are likely and may become more widespread in the valley. The age of the ground water in the Carson Valley aquifer system is not precisely known, but some age dating by Thomas and others (1999) indicated it takes about 30-40 years for recharge water to reach wells that are about 200 ft deep. This indicates that contamination could persist for a long time into the future even if all human inputs of nitrate are stopped. Figure 1 also shows that some of the highest nitrate concentrations are near the Carson River, indicating that nutrients may affect the ecology of the river in some places.

Most of the wells showing increasing trends are near the margins of the valley, where septic tanks are used in housing developments. The valley margins are not heavily used for agricultural purposes, so it is not likely these increases are caused by agricultural land uses.

Three of the 27 wells (wells A, B, and C; fig. 4) show decreasing trends in nitrate concentrations. The decreasing trends in two of the three wells (wells B and C) are small and represent decreases of approximately 1 mg/L over 16 years. Concentrations in the third well (well A) decreased by 6 mg/L in the early 1990's but have decreased at a much slower rate since that time. Although statistically significant, these decreasing trends are not characteristic of the monitoring network as a whole and likely represent local changes in nitrogen sources.

Figure 2 shows increasing trends in nine wells throughout Carson Valley. Increases began at different times in each well, which reflects different nitrogen sources and travel times of ground water in the aquifer. Figure 2*D* shows a sharp step increase in well 8, which indicates nitrogen arrived at the well suddenly. This may have been caused by the introduction of new septic tanks or domestic wells nearby or by changes in pumping rates in existing nearby wells. Other trends appear to be more gradual and consistent. Septic-tank use has occurred in most parts of the Carson Valley since 1970. From 1980 to the present (2001), few new areas have been developed, but parcel size has decreased over time and septic-tank density appears to have increased in many areas of the valley.

The observation that nitrate concentrations are not increasing in all wells near areas that use septic tanks indicates that many factors can delay or prevent concentration increases. Important factors include (1) the length of time the septic tanks have been in use, (2) the efficiency of the

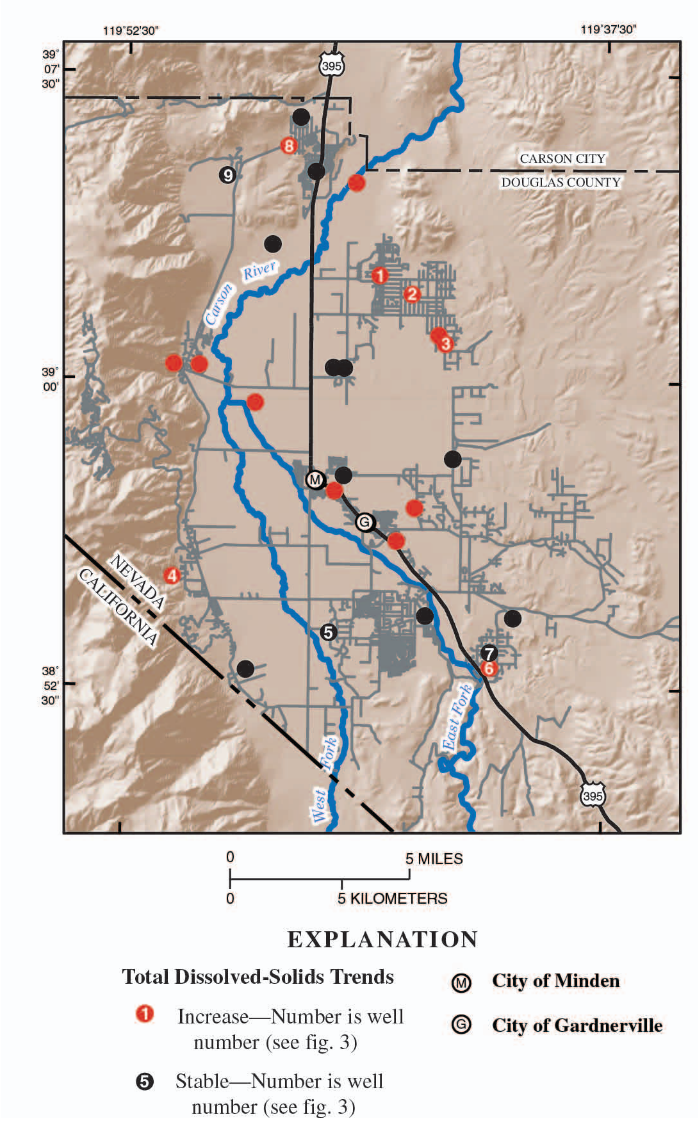

Figure 5. Trends in total dissolved-solids concentrations plotted by well location. Individual trends in total dissolved-solids concentrations of wells 1-9 are plotted in figure 3.

leach-field grasses in using nitrogen as a nutrient source, (3) the presence of clay layers above the point where ground water enters the well, and (4) the location of the well relative to septic tanks. Each of these factors is briefly discussed below.

The time it takes for water to go from the land surface to the water table may be many years. Therefore, increases in nitrate concentrations in wells may not occur until many years after a septic tank is installed. Septic-tank leach fields are designed to provide nutrients to the soil above the field. If the plants growing on the leach field are efficient at taking up the nitrogen, increase in nitrate concentrations may be small. Low-permeability clay layers above the intake for a well may prevent nitrate from the land surface from getting into the well. In Carson Valley, clay layers come from old fine-grained lake or river deposits and may be local or somewhat extensive. If a well is far enough away from a septic-tank leach field and is upgradient from the field, it is likely that the well will not be influenced by nitrate from this septic system. However, septic tanks from neighboring properties could influence downgradient wells.

A simple relation between nitrate concentrations in ground water and depth to water does not exist (fig. 6). Nitrate concentrations generally decrease with depth. The nitrate concentration at 250 ft below land surface is double the median concentration of all 27 wells sampled, which have a median depth to water of 160 ft below land surface. Nitrate concentrations in excess of 2 mg/L occur distinctly at approximate depths of 20 and 100 ft below land surface (fig. 6). Water from supply wells that are open to these intervals may have higher than average nitrate concentrations.

Total dissolved-solid concentrations also were found to be increasing in about 50 percent of the wells sampled. However, the same wells that had increasing nitrate concentrations were not always associated with statistically significant total dissolved-solids increases (figs. 2 and 3). This may be due to several reasons (1) the amount of nitrate increase may be small compared to the total dissolved-solids concentration in the water; therefore, an increase in nitrate may not be reflected in the total dissolved-solids concentration of the water in the well, (2) nitrate in the septic-tank leachate may be effectively taken up by roots, plant material, or bacteria in the soil, but other chemicals such as chloride and sodium that are associated with human wastewater may pass through to the aquifer and increase the total dissolved-solids concentration, (3) the nitrate and dissolved solids may not be from the same source in some areas, and (4) shallow wells may be affected by pumping, recharge, and climatic changes that may not affect nitrate concentrations. Nonetheless, total dissolved-solids concentrations generally are higher in the areas where there are higher concentrations of septic tanks.

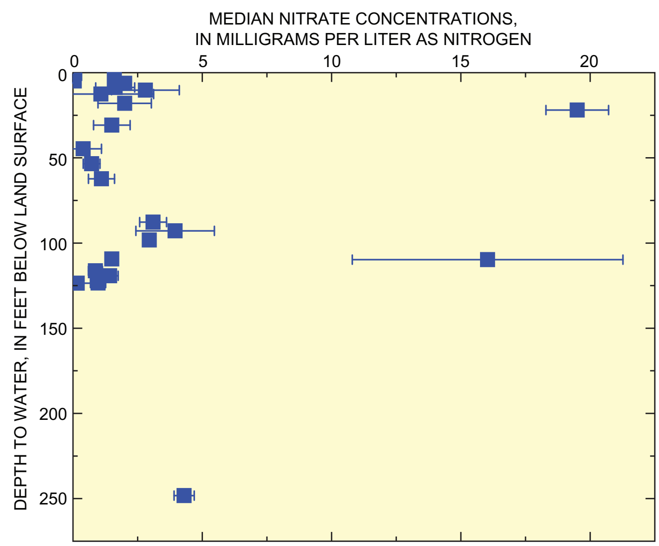

Figure 6. Median nitrate concentrations versus depth to water of the 27 long-term monitoring wells. Error bars are one standard deviation.

WHAT FURTHER WORK IS NEEDED?

Further work is needed in all parts of Carson Valley to refine estimates of the length of time it takes for water to travel from the areas of recharge to wells that are used for either public or domestic water supply. By using ground-water age-dating techniques, an estimate of how long the increasing trends might persist and what the extent of the problem might be for future generations could be answered. Differentiating between fertilizer applications and sewage sources of nitrate can be undertaken by using stable isotopes of nitrogen. Fertilizer and sewage sources generally have distinct isotopic signatures, and these signatures could be distinguished with statistically significant sampling. A detailed analysis of the amount of nitrogen being added to the ground water (a mass-balance calculation) by human activities is needed to address how high the nitrate concentrations may rise over time. Because nitrate is formed by the combination of nitrogen and oxygen, monitoring of dissolved-oxygen concentrations in ground-water samples would be helpful for determining the amount of nitrate that could be expected at each sampling site. Finally, the number of wells in the monitoring network is adequate to give only a broad overview of where nitrate and total dissolved solids are a problem in the valley. The addition of wells to the network would provide a more complete areal coverage of the valley, especially in areas of increasing urbanization, thus providing decisionmakers with a better understanding of the problem.

SUMMARY

The results of this study indicate that nitrate and total dissolved-solids concentrations are increasing in over 50 percent of the wells sampled over a 16-year period in Carson Valley. However, nitrate and total dissolved-solids increases are not always in the same wells. Mapping of land use in Carson Valley indicates that the likely cause of these increases is related to the increase in septic-tank usage over the past 40 years. Nitrate and total dissolved-solids concentrations in 2001 were mostly below the USEPA MCL for nitrate and the Nevada State secondary MCL for total dissolved solids; however, increased output from septic tanks as population grows in the valley may continue the upward trend in these constituents. Even without further population growth, the residence time of water in the aquifer indicates that high nitrate and total dissolved-solids concentrations will continue in parts of the valley for possibly the next 30 to 40 years until some equilibrium is reached. Sufficient data are not available to determine whether this equilibrium will be above or below the USEPA MCL for nitrate and the State MCL for total dissolved solids.

This study was done in cooperation with the Carson Water Subconservancy District and is part of the Nevada Basin and Range Study Unit component of the National Water Quality Assessment (NAWQA) program of the U.S. Geological Survey.

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Irrigation using treated sewage effluent was considered in evaluating the concentrations of nitrate and total dissolved solids in ground water.

For more information:

For information on hydrologic data and reports relating to the NAWQA Program in Nevada:

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Additional information for NAWQA can be found by accessing the NAWQA "homepage" on the World Wide Web at:

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