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SCIENTIFIC INVESTIGATIONS REPORT 2005-5096
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Susong, D.D., Ground-water movement and nitrate in ground water, east Erda area, Tooele County, Utah, 1997-2000

Covariance of Nitrate and Sulfate

Elevated concentrations of dissolved solids and sulfate are present within the east Erda area in addition to high nitrate concentrations (figs. 6 and 7). Generally these areas occur in the same areas as elevated nitrate concentrations. Sulfate in ground water can be associated with mining activity, depending upon the type of ore body, and is naturally occurring in evaporite deposits. The covariance of sulfate with nitrate was investigated because sulfate was present in elevated concentrations in some samples from the east Erda area. Sulfate also is present in elevated concentrations in ground water contaminated from mining activities on the east side of the Oquirrh Mountains (Lambert, 1995). No statistically significant relation was determined between sulfate and nitrate in water samples from the east Erda area (fig. 8). Log transforms of the data did not improve the correlation. Subsets of the sulfate-nitrate data also were examined. The relation of sulfate to nitrate for water samples with nitrate concentrations greater than 3 mg/L, 5 mg/L, and 8 mg/L did not show a significant linear correlation (R2 < 0.50). Sulfate and nitrate concentrations in water from the USGS multiple-well site ((C-2-4)35dcc) did exhibit a stronger correlation (R2 = 0.61, p = <0.0023) (fig. 9).

A number of reasons may account for the poor correlation between sulfate and nitrate concentration in water from selected wells in the east Erda area (fig. 8). Sulfate and nitrate may simply not be related because they may be from entirely different sources, for example natural versus agricultural sources. They both may be derived from mining activities but, because of the long history of mining and smelting in the area, they may have been released at different times through different processes and may have entered the ground-water system along different paths. An additional complexity is that the wells from which samples were collected were, for the most part, production wells with long perforated intervals, and thus the data set is biased toward better quality water (low nitrate and sulfate concentrations). Much of this bias should have been removed by only examining data from wells with water that had a nitrate concentration of greater than 3 mg/L. However, this did not improve the correlations. Degradation of nitrate and (or) sulfate along the ground-water flow path also would reduce the correlation.

Data from the wells at site (C-2-4)35dcc indicate that sulfate and nitrate are related at this site in the nitrate plume (fig. 9). This site is located at the upper end of the known extent of the plume and water from wells at this site contains some of the highest nitrate concentrations measured. Sulfate concentrations here (less than 200 mg/L) are substantially less than the elevated sulfate concentrations measured elsewhere in the east Erda area (400-1,500 mg/L). The best correlation between sulfate and nitrate is in water from wells that have specific, short perforated intervals and a range of sulfate and nitrate concentrations.

In general, the spatial distribution of dissolved-solids and sulfate concentrations shows a similar pattern to that of nitrate concentration, with distinct areas of elevated concentration (figs. 6 and 7). Sulfate concentrations are clustered and the northern part of the nitrate plume generally has higher sulfate concentrations (fig. 7), which may indicate a local source in this area. Gates (1962) noted elevated sulfate concentrations in the Erda area, which may indicate a natural source or could be related to early mining and smelting activity. Gates (1962) mapped a fault in the subsurface on the basis of sulfate concentrations in ground water in the Erda area. However, there were substantially fewer wells in 1962 and the pattern of sulfate distribution is more complex than originally envisioned in 1962.

Other Water-Quality Constituents

Arsenic is a trace element that is naturally occurring in ground water in western Utah and is often associated with volcanic rocks and lacustrine evaporite deposits. It also is commonly present in ground-water contamination associated with mining activities (Hem, 1985; Focazio and others, 1999). Water from the upper well ((C-2-4)35dcc, 210 ft) of the USGS well cluster contained 206 µg/L of arsenic, which exceeded the new EPA (U.S. Environmental Protection Agency) standard of 10 µg/L. Water from this well also had a nitrate concentration of 15.7 mg/L (July 11, 2000). Arsenic concentration was not elevated in water from the deeper wells of the well cluster at this site. A review of the ground-water-quality data set showed that water from three other wells had elevated concentrations of trace metals, in particular, arsenic. Wells (C-3-4)12ddc-1, (C-3-4)13abb-1, and (C-3-4)14adb-1 are all located near the mouth of Pine Canyon (fig. 2, table 1). Unfortunately, the data set for trace metals is limited and cannot be used to determine if mining activities have affected ground-water quality throughout the east Erda area. After elevated arsenic concentrations were measured in water from well (C-2-4)35dcc-1, the Tooele County Health Department sampled five nearby wells in November 2000. Water from all these wells had low nitrate concentration (less than 5 mg/L) and arsenic concentration ranged from 2.4 to 4.1 µg/L, which is below the new EPA standard of 10 µg/L (Tooele County Health Department, written commun., 2000). All these wells, however, are completed below the zone of nitrate contamination and would not be expected to have elevated arsenic concentrations.

GROUND-WATER FLOW SIMULATIONS WITH PARTICLE TRACKING

The existing steady-state numerical simulation of the Tooele Valley ground-water system (Lambert and Stolp, 1999) used the USGS MODPATH software package (Pollock, 1994). This model was used to assess the transport and fate of nitrate in the east Erda area. Specifically, the steady-state model was used with particle tracking to determine if the nitrate in the east Erda area could have originated from mining and smelting activities in Pine Canyon. The steady-state simulations use long-term average conditions and do not account for the time required for surface recharge to reach the water table. Particle tracking only accounts for advective transport and does not simulate mechanical or molecular dispersion or chemical reactions. In each simulation the Tooele steady-state model was run to a closure of .0003 foot to try and eliminate as much cell flux discrepancy as possible.

To determine ground-water velocity, effective porosity for the basin-fill deposits must be estimated. Effective porosity is the pore space available for fluid flow and can often be equated to specific yield. Specific yield values for the ISRS area are estimated from transient-state simulations to vary from 0.075-0.10 (Lambert and Stolp, 1999, fig. 26). For this ground-water movement/velocity analysis, effective porosity was set at 0.20. This is a larger value than the corresponding specific yield, but is somewhat more in line with average effective porosity of basin-fill deposits. In southern Tooele Valley at Tooele Army Depot (TAD), porosity values were estimated to range from 0.23 to 0.25 (U.S. Army Corps of Engineers Hydrologic Engineering Center, 1996, p. 4-2; Weston Engineering, 1990, p. 14). Ground-water velocity and simulated travel times are directly proportional to porosity. Ground-water movement and flow directions are directly proportional to the hydrologic gradient and anisotropy. Any uncertainty in porosity values will affect the accuracy of travel times; that uncertainty has no effect on the direction of ground-water movement.

Three different nitrate sources/transport pathways were simulated: (1) Nitrate source from Pine Canyon smelter and tailings sites because of seepage to the underlying aquifer and with transport through the ground-water system; (2) Nitrate source from Pine Canyon smelter and tailings sites with transport through surface water in Pine Canyon creek and irrigation ditches and then seepage to the underlying aquifer; and (3) Nitrate from an unknown source along the Oquirrh Mountains with transport through the ground-water system.

In the first simulation, model layer 1 is not present and particles were inserted at the saturated level in model layer 2 at the Pine Canyon smelter and tailings sites. This simulates nitrate seepage into the basin-fill aquifer below these sites. Four particles per cell, evenly distributed on the top face, were simulated. Six cells representing the tailings pile and two cells representing the slag dump near Pine Creek were populated with four particles each. Simulated forward particle movement and flow paths are to the northwest toward the east Erda area, but they do not intersect the areas of maximum nitrate concentration (fig. 10). Simulated travel time to the area near the high nitrate concentrations was about 65 to 100 years. This implies that direct seepage of nitrate to the basin-fill aquifer from the Pine Canyon smelter and tailings sites is not a likely source/pathway for the nitrate in the east Erda area.

In the second simulation, the nitrate source is the Pine Canyon smelter and tailings sites with transport through surface water in Pine Canyon creek and irrigation ditches and seepage to the basin-fill aquifer once the nitrate-contaminated water is distributed throughout the east Erda area (fig. 11). The particle tracking (MODPATH) was set up to show the forward paths of particles starting at the simulated top of the saturated material for layer 2. Layer 1 is not simulated in this area of the model. One particle per cell, in the middle of the top face, was simulated. Fourteen cells representing Pine Creek were populated with a single particle each. Particles were inserted at the top of the saturated zone in model layer 2 in cells traversed by Pine Canyon creek and canals and irrigation ditches to represent the distribution of nitrate in surface water. In this simulation ground water is discharged to cells representing Mill Pond Spring (C-2-4)15cac-S1 north of Erda, a regional ground-water discharge point. Simulated flow paths indicate ground-water movement through the southern part of the nitrate plume (fig. 11). Travel time for these flow paths was about 57 to 113 years to near the area of nitrate contamination. This simulation indicates that the Pine Canyon smelter and tailings sites with transport through surface water in Pine Canyon creek and irrigation ditches could be a source and pathway for nitrate in the east Erda area.

In the third simulation, particles were inserted in layers 2 and 3 in areas of high nitrate concentration in the east Erda area and back tracked toward their origination points. The particle tracking (MODPATH) was set up to show the backward paths of particles from the two areas of highest nitrate concentration, both in layer 2 and layer 3. Two particles per row and column location, at the center of the cells representing layer 2 and layer 3, were simulated. Eleven cells in layer 2 and eleven cells in layer 3 represented the southernmost high nitrate area. Six cells in layer 2 and six cells in layer 3 represented the northernmost high nitrate area. Simulated flow paths indicate that subsurface recharge from the Oquirrh Mountains moves from the mountain front through the cells that simulated high nitrate concentrations (fig. 12). Travel time for these flow paths was about 3 to 68 years and point to a source to the east and southeast. This indicates that the source area could be an extensive area along the front of the Oquirrh Mountains. However, particles were inserted into cells near the boundary of the model, which is problematic because model boundary conditions may artificially induce flow in these areas.

These simulations provide some evidence that nitrate could be transported from the Pine Canyon smelter and tailings site to the ground water in the east Erda area. However, as with all model simulations, the results should not be overinterpreted. Particle-tracking simulations are subject to the same limitations as the model (Lambert and Stolp, 1999). For example, the number of particles and the cells where they are inserted will change the results of the simulations. Other results are possible. Near mountain fronts the stratigraphy of the basin-fill aquifers is extremely complex and this complexity is simplified in the model. The mountain fronts are also the boundary of the model and in these areas simulations are affected by the boundary conditions of the model. The canals and irrigation ditches in the east Erda area have been altered as lands in the area have been converted from agricultural use to residential subdivisions. These changes in the distribution system are not well documented and are not included in the simulations.

SOURCES OF NITRATE IN THE EAST ERDA AREA

Sources of nitrate in the east Erda area could not be clearly delineated in spite of considerable effort and expenditure of resources. However, the data collected to date indicate that septic systems are not the source of nitrate but that mining activities or agriculture could be a source. Other potential sources are naturally occurring nitrate deposits from soil microbial activity or application of nitrate fertilizers for agriculture or reclamation.

Septic Systems

Septic systems were considered a likely source of nitrate contamination to ground water at the beginning of this study because they are used throughout the area for disposal of domestic wastewater. Septic systems also have been shown to be a substantial source of nitrate contamination in numerous studies (Seiler, 1996; Wilhelm and others, 1994; Thurman and others, 1984; Reneau and others, 1989). Chemical constituents in the domestic wastewater stream can be used as tracers in ground water to determine if septic systems are the source of nitrate in ground water. In 1994, water samples were collected from 10 wells with water that contained elevated concentrations of nitrate (Steiger and Lowe, 1997). These samples were analyzed for MBAS, boron, and caffeine (table 1). MBAS and boron are common additives to detergents; caffeine is contained in human urine. The MBAS concentration was less than the minimum reporting limit of 0.02 mg/L in all the samples but one, which had a concentration of 0.03 mg/L. However, because the sample was just above the minimum reporting limit, its significance is questionable.
Several of the samples had elevated boron concentrations (greater than 20 µg/L). However, boron is a poor tracer in western Utah because evaporite deposits in basin-fill sediments can cause naturally high boron concentrations. This makes boron data difficult to interpret and it may or may not be an indicator of septic system effluent. Caffeine was measured at less than detection limits in all the samples, which indicates that nitrate in ground water is not from a septic source. However, the unsaturated zone generally extends more than 100 ft deep in much of the area and caffeine has been observed to be retarded in the deep unsaturated zone; therefore, if present in septic systems, caffeine may never have been transported to the ground water in this setting (R.L. Seiler, U.S. Geological Survey, oral commun., 1999).

The drilling of new wells in the east Erda area provided the strongest evidence that septic systems were not a source of nitrate. The USGS monitoring wells at site (C-2-4)35dcc were drilled upgradient of existing septic systems. Water from these wells contained nitrate concentrations greater than the drinking water standard of 10 mg/L. The nearest septic systems located upgradient of this site are about 2.5 mi away in an area where the unsaturated zone is estimated to be 200 to 400 ft thick. Thus, it is unlikely that nitrate contamination in the east Erda area comes from septic systems.

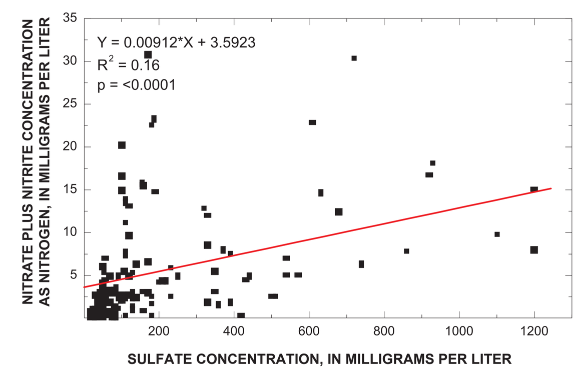

Figure 8. Linear least squares regression of nitrate plus nitrite as nitrogen and sulfate concentration for water from wells in the east Erda area, Tooele County, Utah.

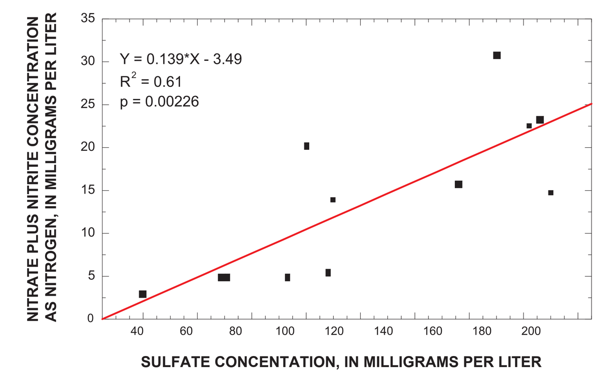

Figure 9. Linear least squares regression of nitrate plus nitrite as nitrogen and sulfate concentration for water from U.S. Geological Survey monitoring wells at site (C-2-4)35dcc, east Erda area, Tooele County, Utah.

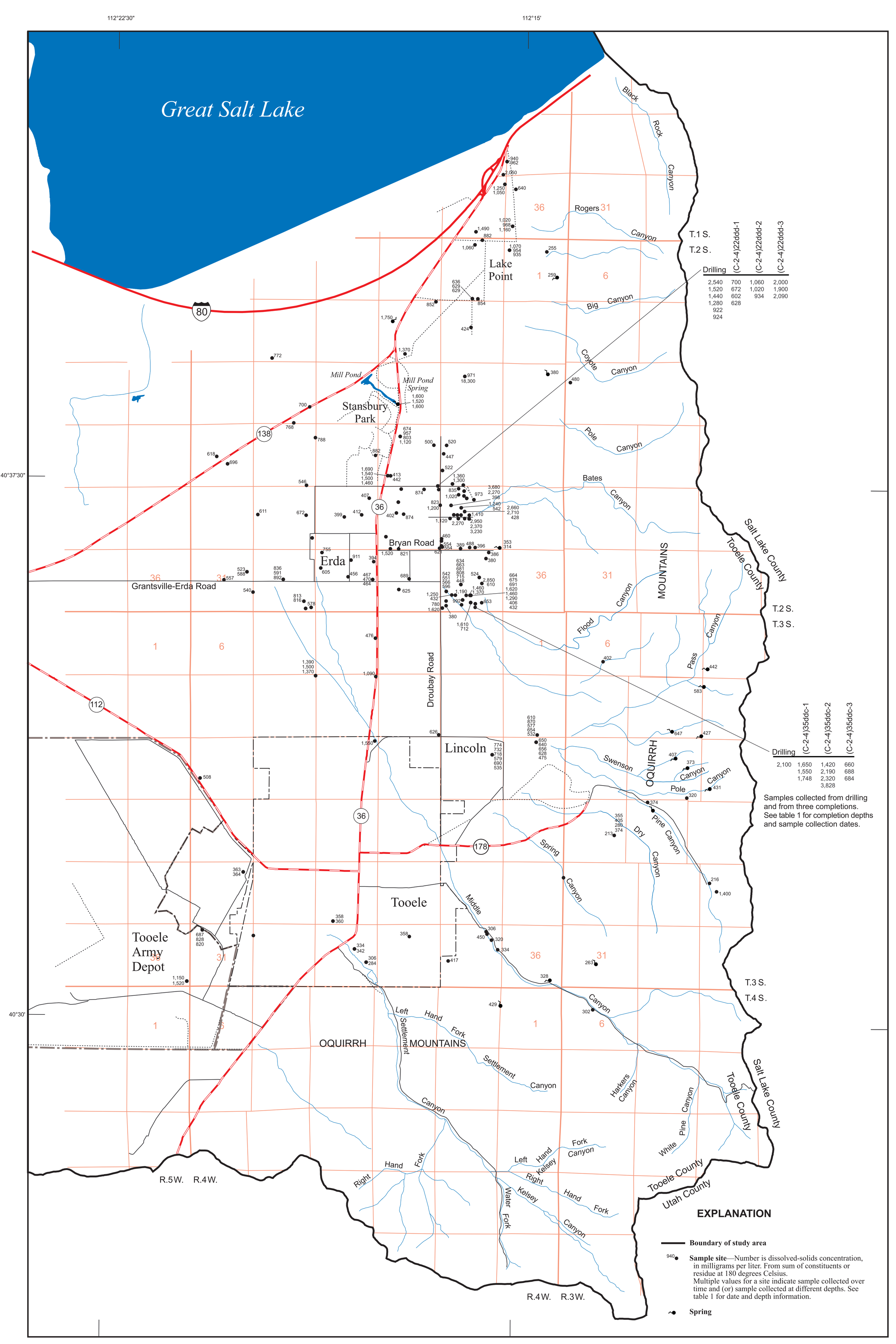

Figure 6. Dissolved-solids concentration in ground water, east Erda area, Tooele County, Utah.

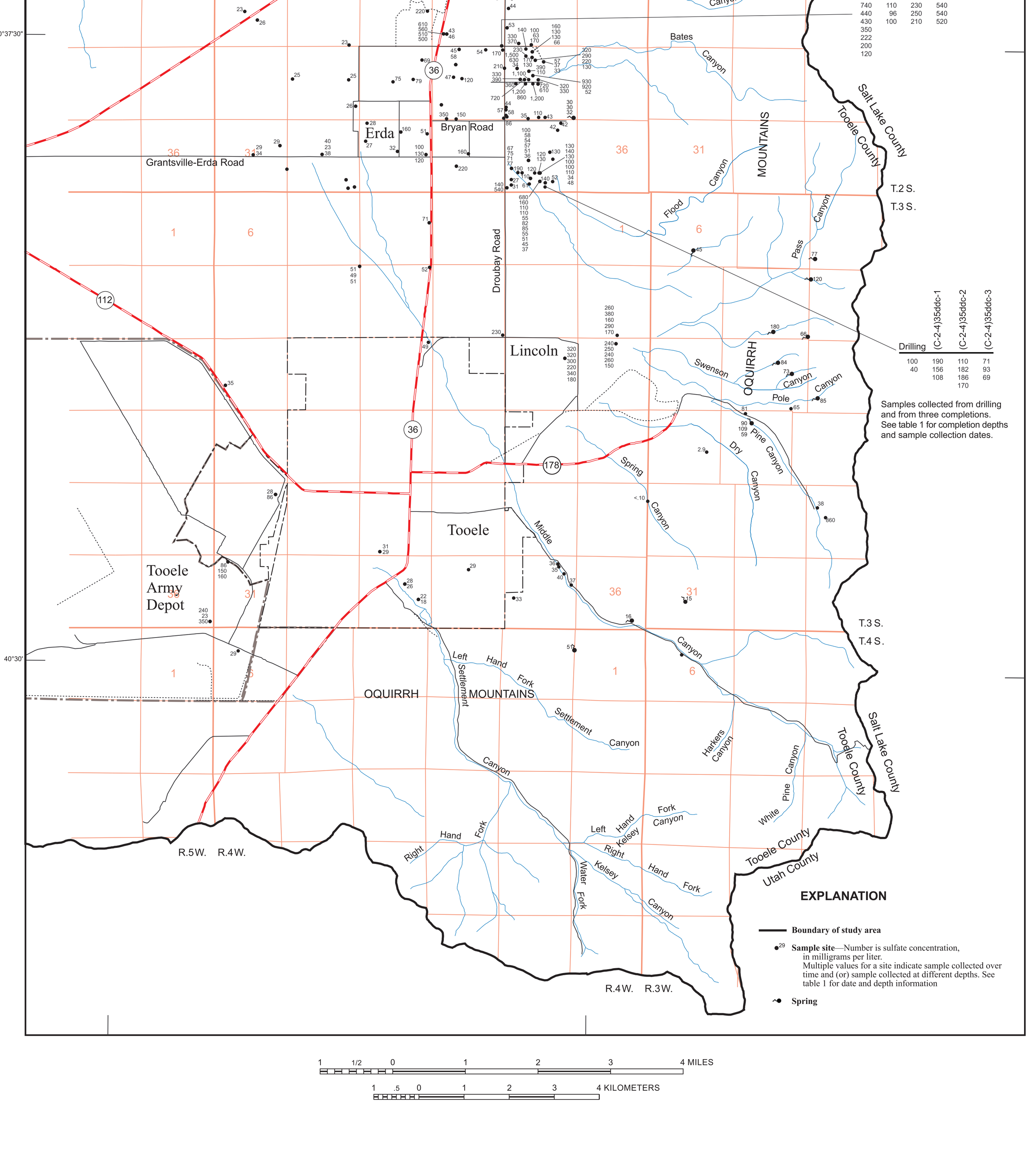

Figure 7. Sulfate concentration in ground water, east Erda area, Tooele County, Utah.

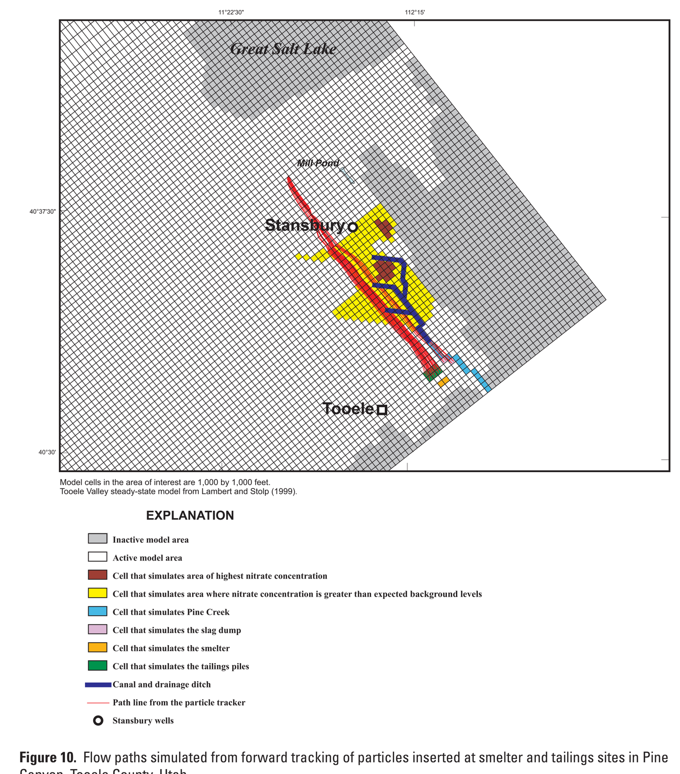

Figure 10. Flow paths simulated from forward tracking of particles inserted at smelter and tailings sites in Pine Canyon, Tooele County, Utah.

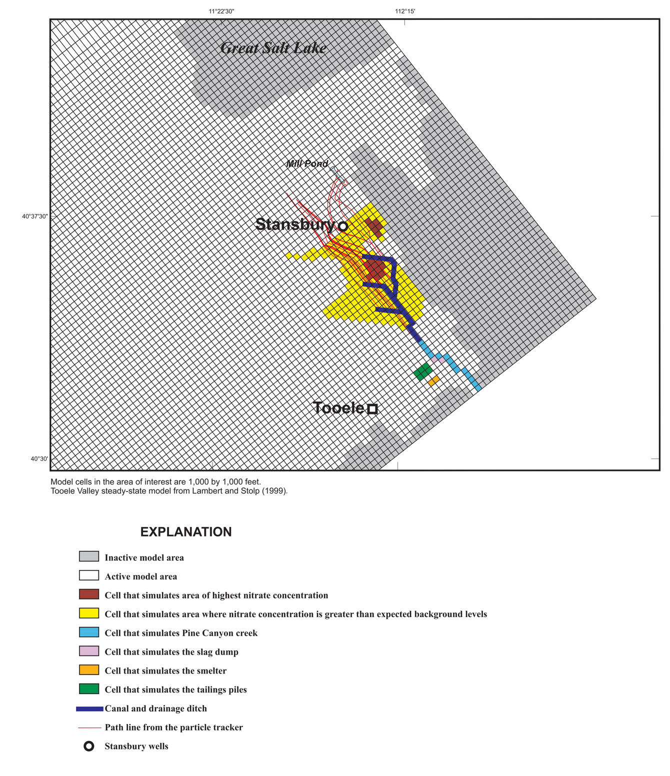

Figure 11. Flow paths simulated from forward tracking of particles inserted to represent surface-water distribution of contaminants from Pine Canyon creek and irrigation ditches in the east Erda area, Tooele County, Utah.

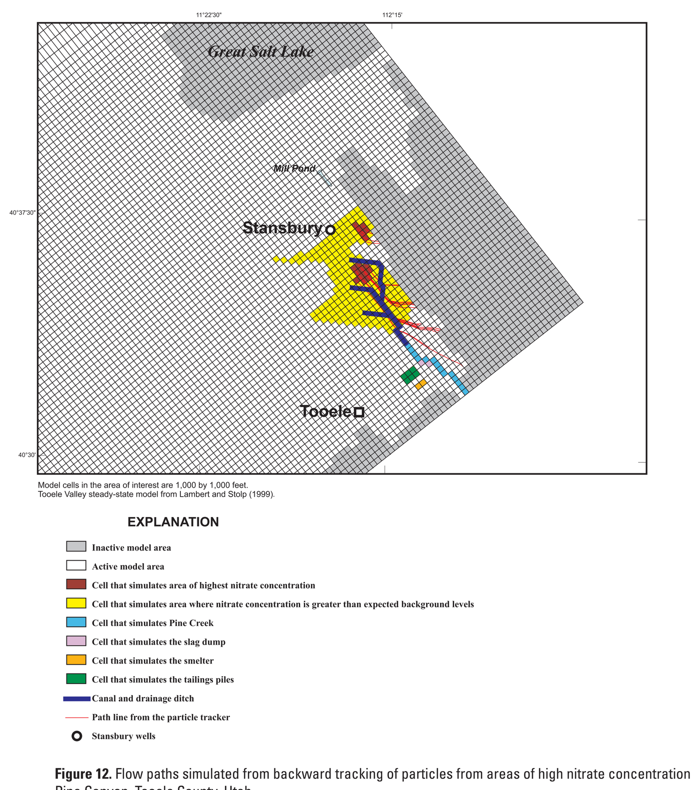

Figure 12. Flow paths simulated from backward tracking of particles from areas of high nitrate concentration in Pine Canyon, Tooele County, Utah.

Mining and Smelting in Pine Canyon

Mining and smelting activity on the west side of the Oquirrh Mountains began in 1910 when the International Smelting and Refining Company (IS & R) opened a copper concentrator and smelter in Pine Canyon. This facility expanded to handle lead-zinc ores and continued operation through 1974 when it was closed. The mines, tunnels, and smelter on the west side of the Oquirrh Mountains discharged water to Pine Canyon creek that was used for irrigation in the east Erda area throughout this period.

The Carr Fork Mine and Smelter was constructed during 1973-79 in Pine Canyon and began production in 1979. An average of 5,200 acre-ft of water per year was pumped from the mine and discharged to Pine Canyon creek (Stolp, 1994). Water-level rises measured during 1972-76 in the east Erda area are postulated to be related to this discharge (Razem and Steiger, 1981). Mining was suspended in 1981 because of low copper prices and mining difficulties. The mine experienced complete flooding of production shafts in 1984 after a massive landslide buried an electric power substation that cut power to the mine. Water levels rose about 900 ft as the mine filled with an estimated 80 million gallons of water (Russell, 1984). After power was restored, dewatering commenced at a rate of about 4,200 gal/min. This water was discharged to Pine Canyon creek (Russell, 1984). Mining and milling were permanently terminated in 1985. Extensive reclamation work was done at the site during 1985-88 and most of the buildings, equipment, and waste dumps were reclaimed (Braxton and Buck, 1989). After reclamation, follow-up investigations by the Utah Department of Environmental Quality measured high nitrate concentrations (50 mg/L) at the IS & R smelter site in soil-water samples collected 10 ft below land surface (H. Sadik-Macdonald, written commun., 1995). Soils samples collected near the Carr Fork Mine and Smelter contained background concentrations of nitrate.

The quantity of ammonium nitrate in the mine at the time of flooding is not known; however, it would readily dissolve in water and was not recovered when the mine was dewatered. If large quantities of ammonium nitrate were in the mine, then water laden with nitrate was discharged into Pine Canyon creek and through the irrigation and drainage ditches in the east Erda area.

However, at the time of flooding the mine was in a pump-and-maintenance state, and it is unknown if there were large stores of explosives underground. The mine had not been in production for almost 2 years at the time of the flooding, but test blasting and testing of production methods were done during this time (Alex Reynoso, former blasting superintendent of Carr Fork Mine, oral commun., 2001). If only minimal stores of explosives were underground at the time of the flooding, the concentration of nitrate in the discharge water would have been substantially less than normal background concentrations.

Water also was discharged to Tooele Valley from the mining tunnels on the east side of the Oquirrh Mountains. The Elton Tunnel was 24,000 ft long and extended from its west portal in Pine Canyon to the mining areas on the east side of the Oquirrh Mountains. The tunnel was completed in 1941 and was used to transport ore to the International Smelter. Tunnel discharges of 4,000 to 7,000 acre-ft of water per year were measured during 1940-45 and flowed into Pine Canyon creek. The quality of this water was unknown and there is no evidence that these waters had high nitrate concentrations. Water-level rises in the east Erda area during 1941-58 are partly attributed to discharge from the tunnel (Gates, 1965). The tunnel began caving in in 1948 and was completely plugged by 1952. The portal of the tunnel was buried during reclamation of the site in 1985. Other tunnels also discharge water to the Pine Canyon drainage basin; however, water samples from these tunnels have had low concentrations of nitrate (Stolp, 1994).

Methods of human waste disposal from the International Smelter have not been documented. Septic systems may have been used or waste may have been piped to tailings impoundments or settling ponds. Here the solids would settle out and overflow from the settling ponds would have been returned to Pine Canyon creek. The overflow from the settling ponds could have contained high nitrate concentrations. This water would then have been distributed throughout the Pine Canyon/Erda area. The Carr Fork Project had septic tanks and leach fields.

Pine Canyon creek leaves Pine Canyon and turns north and westward where the flow from the creek has been diverted for irrigation in the east Erda area to a network of ditches. Discharge water from the mines and tunnels in the Pine Canyon area was used extensively for irrigation throughout the Lincoln and east Erda areas. Distribution of surface water from the Pine Canyon area that has elevated nitrate concentrations is a possible source of nitrate contamination in ground water in the east Erda area. However, limited water-quality samples of mining and smelting discharge did not contain elevated concentrations of nitrate and thus there is not any substantive evidence that mining activities were the source of nitrates in the Erda area. However, there are a number of time periods with little documentation of site activities and no water-quality data.

Nitrate from Natural Sources and Fertilizers

Natural sources of nitrate can cause elevated concentrations of nitrate in ground and surface water (Gellenbeck, 1994; Holloway and others, 1998). Natural soil nitrate formed by biological fixation by desert plants can leach downward to the ground water (Herczeg and Edmunds, 2000). However, in this case, nitrate contamination would be expected to be widely dispersed and not limited to the plume. Holloway and others (1998) determined that bedrock containing fixed nitrogen can be a source of nitrate to streams. Rocks in the Oquirrh Mountains are not known to have appreciable nitrogen concentrations. As part of the reclamation of the IS & R and Carr Fork mining and smelting sites in Pine Canyon, large amounts of fertilizers were applied to aid revegetation of graded areas (Braxton and Buck, 1989). Use of nitrogen fertilizers on agricultural lands in the east Erda area also is a possible source of nitrate contamination. Crops grown in the area historically have been alfalfa and grain. A review of historic aerial photographs of the area shows that irrigation generally was from surface waters from Pine and Middle Canyons. As Pine Canyon operations changed, irrigation ditches were moved or enhanced to take advantage of changing discharges. In recent decades the amount of irrigated acreage has been reduced as agricultural lands have been subdivided. There are no known records of fertilizer application to agricultural lands in the east Erda area, thus making it difficult to evaluate the application of nitrate fertilizers as a source of nitrate contamination in ground water in the area. Chicken farms in the Erda area also may have been a source of nitrate. Again, it is difficult to determine the magnitude of this source.

FUTURE MOVEMENT OF NITRATE PLUME

Future movement of the nitrate plume in the basin-fill aquifer in the east Erda area is difficult to predict with any certainty. However, general projections of future plume movements can be made on the basis of what has been learned to date about the spatial distribution of nitrate in the aquifer, ground-water flow direction, the hydrology of the basin-fill aquifer, and changes in nitrate concentration in water from selected wells. The southern boundary of the plume is unknown but probably extends south and east from T. 2, R. 4, Sec. 35 toward the mouth of Pine Canyon.

Data from the USGS monitoring wells at site (C-2-4)35dcc indicate that there is downward movement of nitrate in the basin-fill aquifer. A slight downward gradient in these wells indicates downward flow. In addition, diffusion and density-driven flow also are possible. Pumping from the deeper parts of the basin-fill aquifer also will induce downward flow. Continuing downward flow of nitrate-laden water could contaminate water in wells completed below the plume and argues for continued monitoring of water quality in the east Erda area and vigilance on the part of well owners.

Ground-water movement in the east Erda area generally is from the mountain front northwestward to discharge points in wetlands in the center of Tooele Valley and to Mill Pond Spring, (C-2-4)15cac-S1. The relation of ground water in the basin-fill aquifer, the bedrock high just to the north of the east Erda area, and Mill Pond Spring is not well understood. Because the general direction of ground-water flow is toward the northwest, the nitrate plume may eventually end up entering the complex flow system in this area and discharging to the wetlands and springs. Several municipal supply wells here also could be affected by the nitrate plume. The fate of the nitrate plume also may be affected by future ground-water development in the area because large withdrawals can accelerate ground-water flow and even change directions of ground-water flow.

SUMMARY

Nitrate contamination was discovered in ground water in the east Erda area of Tooele County, Utah, in 1994. In cooperation with Tooele County, the U.S. Geological Survey investigated the ground-water flow system and water quality in the eastern part of Tooele Valley to determine (1) the vertical and horizontal distribution of nitrate, (2) the direction of movement of the nitrate contamination, and (3) the source of the nitrate. The potentiometric surface of the upper part of the basin-fill aquifer indicates that the general direction of ground-water flow is to the northwest, the flow system is complex, and there is a ground-water mound probably associated with springs and (or) discharge from the Oquirrh Mountain block. The spatial distribution of nitrate reflects the flow system with the nitrate contamination split into a north and south part by the ground-water mound. The distribution of dissolved solids and sulfate in ground water varies spatially but not as consistently as the distribution of nitrate. Sulfate concentrations are elevated in the Erda area. Vertical profiles of nitrate in water from selected wells indicate that nitrate contamination generally is in the upper part of the saturated zone and in some wells has moved downward. Septic systems, mining and smelting, agriculture, and natural sources were considered to be possible sources of nitrate contamination in the east Erda area. Septic systems are not the source of nitrate because water from wells drilled upgradient of all septic systems in the area had elevated nitrate concentrations. Mining and smelting activity are a possible source of nitrate contamination, but data are not available to link contamination to mining sites. Agricultural sources of nitrate are present in the east Erda area, but again few data are available to quantify this source. The source(s) of nitrate in the east Erda area could not be clearly delineated in spite of considerable effort and expenditure of resources.

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Ground-Water Movement and Nitrate in Ground Water, East Erda Area, Tooele County, Utah, 1997-2000

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