ANALYSIS OF SEPTIC-TANK DENSITY FOR THREE AREAS IN CEDAR VALLEY, IRON COUNTY, UTAH- A CASE STUDY FOR EVALUATIONS OF PROPOSED, SUBDIVISIONS IN CEDAR VALLEY

by

Mike Lowe, Janae Wallace, Charles E. Bishop

Utah Geological Survey

WATER RESOURCE BULLETIN 27

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Cover Photo: View of Cedar Valley looking east-southeast from Bauers Knoll toward the Hamiltons Fort area (photograph by Mike Lowe).

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ABSTRACT

Cedar Valley, Iron County, is experiencing an increase in residential development, much of which uses septic tank soil-absorption systems for wastewater disposal. Septic tank soil-absorption systems are considered one of the major potential sources of water-quality degradation, and public officials would like to have a scientific basis for determining recommended densities/lot sizes for septic-tank systems as a land-use planning tool. We performed site-specific mass balance-approach evaluations for three areas in Cedar Valley, situated on unconsolidated deposits of the principal valley-fill aquifer, as part of a U.S. Environmental Protection Agency Regional Geographic Initiative grant; these evaluations can be used as models for evaluations of proposed subdivisions in Cedar Valley.

We applied a mass-balance equation to three areas in southern Cedar Valley (the Hamiltons Fort, Bauers Knoll, and Mid Valley Estates areas) using site-specific ground-water flow available for mixing and site-specific ground-water-quality data to help with determining recommended septic-system density/lot size. We used an allowable degradation in water quality of 1 mg/L with respect to nitrate, but provided an additional analysis for the Bauers Knoll area to show the level to which septic-system density could be increased if higher levels of water-quality degradation were deemed acceptable. We used a mixing zone thickness of 60 feet (18 m) for all three areas.

The results of the mass-balance analyses varied considerably from one area to another, as did the applicability of the approach as a land-use management tool. For the Hamiltons Fort area to maintain an overall nitrate concentration of 3.15 mg/L, the total number of homes using septic tank soil-absorption systems should not exceed about 760; this corresponds to a total increase of approximately 660 new septic systems and a recommended average septic-system density of about 5.6 acres/system (0.02 km^2/system) in the area. For the Bauers Knoll area to maintain an overall nitrate concentration of 1.49 mg/L, the number of homes using septic tank soil-absorption systems should not exceed about 70; this corresponds to a total increase of approximately 20 septic systems and an average septic-system density of about 54 acres/system (0.2 km^2/system) in the area. We do not consider the mass-balance approach to be the best land-use management tool for the Mid Valley Estates area, where the amount of water from septic-tank effluent is three times more than the ground-water flow available for mixing, and there is an apparent upward vertical-head gradient in the aquifer. A public, valley-wide sewer system is a better alternative for domestic wastewater disposal in most areas in Cedar Valley, especially the Mid Valley Estates area.

INTRODUCTION

Cedar Valley, Iron County, is a rural area in Utah (figure 1) experiencing an increase in residential development. Most of this development, much of which uses septic tank soil-absorption systems for wastewater disposal, is situated on unconsolidated deposits of the principal valley-fill aquifer. Nitrate is the principal ground-water contaminant identified in previous studies in Cedar Valley (Joe Melling, Cedar City Manager, verbal communication, 1997). Nitrate is a useful indicator of human impact on ground-water quality and thus can aid in determining any deleterious effects of development.

Ground water provides almost all of the drinking-water supply in Cedar Valley. Preservation of ground-water quality and the potential for ground-water-quality degradation are critical issues that should be considered in determining the extent and nature of future development in Cedar Valley. Local government officials in Iron County have expressed concern about the potential impact that development may have on ground-water quality. Septic tank soil-absorption systems are considered one of the major potential sources of water-quality degradation, and public officials would like to have a scientific basis for determining recommended densities/lot sizes for septic-tank systems as a land-use planning tool.

Land-use planners have long used septic-tank-suitability maps to determine where these systems will likely percolate within an acceptable range. However, they are only now becoming aware that percolation alone does not remove many constituents found in wastewater, including nitrate.

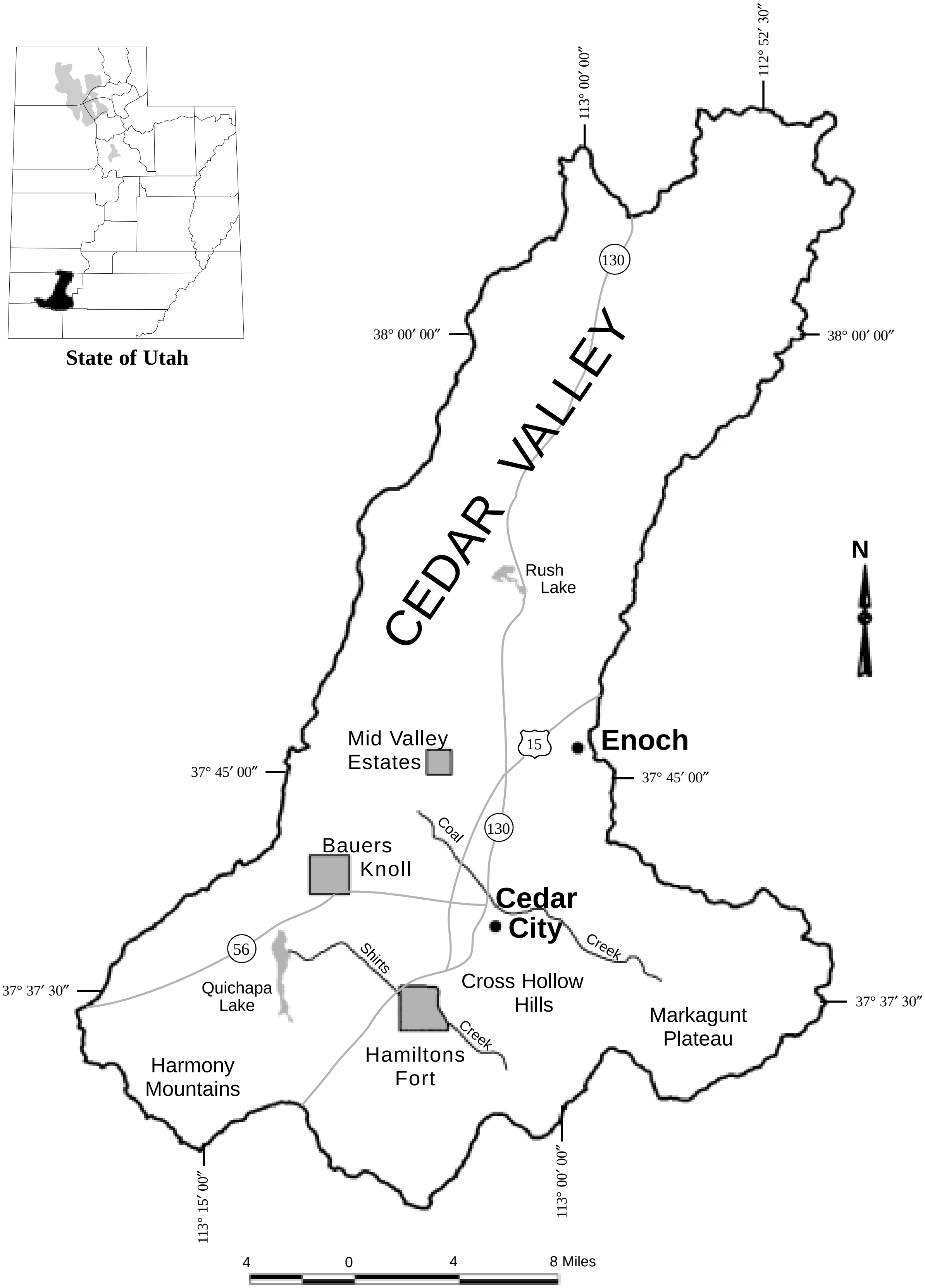

Figure 1. *Location map of Cedar Valley, Iron County, Utah. The three study areas are shaded.*

Ammonium from septic-tank effluent under aerobic conditions can convert to nitrate, contaminating ground water and posing potential health risks to humans (primarily very young infants). The U.S. Environmental Protection Agency's maximum contaminant level for drinking water (Utah ground-water-quality standard) for nitrate is 10 mg/L (for the ranges of nitrate and total-dissolved-solids concentrations used in this report, mg/L equals parts per million). With continued growth and installation of septic tank soil-absorption systems in new developments, the potential for nitrate contamination will increase. One way to evaluate the potential impact of septic-tank systems on ground-water quality is to perform a mass-balance calculation (Hansen, Allen, and Luce, Inc., 1994; Zhan and McKay, 1998). This type of analysis may be used as a gross model for evaluating the possible impact of proposed developments using septic-tank systems for wastewater disposal on ground-water quality and allowing planners to more effectively determine appropriate average development densities (lot sizes).

The results of this project, funded primarily by the U.S. Environmental Protection Agency through a Regional Geographic Initiative grant, provide a site-specific evaluation of acceptable building density for three areas in Cedar Valley utilizing individual wastewater systems. This study will provide a model for others conducting similar evaluations. It also helps underscore the need to protect ground-water quality in areas experiencing population growth.

Purpose and Scope

The purpose of this study is to assess the impact of septic tank soil-absorption systems on ground-water quality for three areas in Cedar Valley where septic tank soil-absorption systems are typically used for wastewater disposal. These areas have some existing development, but we anticipate that there will be additional development in the future. The Utah Geological Survey (UGS) evaluated the potential impact of the projected potential development on ground-water quality based on septic-tank-system densities using a mass-balance approach similar to an analysis conducted by Hansen, Allen, and Luce (1994) for Heber and Round Valleys, Wasatch County, Utah. The selection of the evaluated areas was made in consultation with local government officials. This study may be used as a model for other evaluations of the impact of proposed subdivision site(s) on ground-water quality and allow planners to more effectively determine appropriate development densities (lot sizes).

To evaluate the effects of increased numbers of septic systems on ground-water quality for subdivision sites, we obtained local aquifer parameters for formulating a more accurate mass-balance equation. The steps required to apply this approach included: (1) determining ground-water-flow transect-area acreage and aquifer mixing zone volume; (2) obtaining the number of existing septic-tank systems in the area; (3) determining ambient (background) nitrate concentration; (4) calculating, using the appropriate amount of wastewater and accompanying nitrogen load introduced per system (based on the literature search of Hansen, Allen, and Luce [1994]), projected nitrogen loadings based on the projected number of septic tank soil-absorption systems to be used in the proposed subdivisions; and (5) determining the volume of ground water available for mixing along the proposed ground-water-flow transect using the appropriate equations.

For each area, the scope of work included:

1. compiling existing topographic and geologic maps and drillers' logs,
2. determining local area acreage,
3. analyzing water-well drillers' logs to determine the nature, thickness, and extent of the aquifer and the likely mixing zone,
4. selecting wells to be sampled and analyzing water samples for nitrate in order to calculate background nitrate concentration for the area,
5. measuring water levels in existing wells, where possible, or using existing potentiometric surface maps to determine hydraulic gradient and ground-water-flow direction,
6. selecting observation wells and pumping wells and conducting aquifer tests over 24-hour periods,
7. computing volume of water available for mixing using specific-capacity and transmissivity data from drillers' logs, and adjusting transmissivities calculated from specific capacity by comparing values to measured transmissivities obtained from aquifer tests,
8. computing projected site-specific nitrate concentration using the Hansen, Allen, and Luce (1994) mass-balance approach, but using the site-specific parameters obtained from steps 1 through 6 above to determine the existing nitrogen load and the amount of ground water available for mixing, and
9. preparing this report summarizing findings.

Well Numbering System

The numbering system for wells in this study is based on the Federal Government cadastral land-survey system that divides Utah into four quadrants (A-D) separated by the Salt Lake Base Line and Meridian (figure 2). The study area is entirely within the southwestern quadrant (C). The wells are numbered with this quadrant letter C, followed by township and range, enclosed in parentheses. The next set of characters indicates the section, quarter section, quarter-quarter section, and quarter-quarter-quarter section, designated by the letters a through d, indicating the northeastern, northwestern, southwestern, and southeastern quadrants, respectively. A number after the hyphen corresponds to an individual well within a quarter-quarter-quarter section. For example, the well (C-36-12)2adb-1 would be the first well in the northwestern quarter of the southeastern quarter of the northeastern quarter of section 2, Township 36 South, Range 12 West (NW1/4SE1/4NE1/4 section 2, T. 36 S., R. 12 W.).

Location and Geography

Cedar Valley is in eastern Iron County, southwestern Utah, between 38°07'15" and 37°32'15" north latitude and 113°23'15" and 112°49' west longitude (figure 1). It is a northeast to southwest-trending, elongate valley bordered by

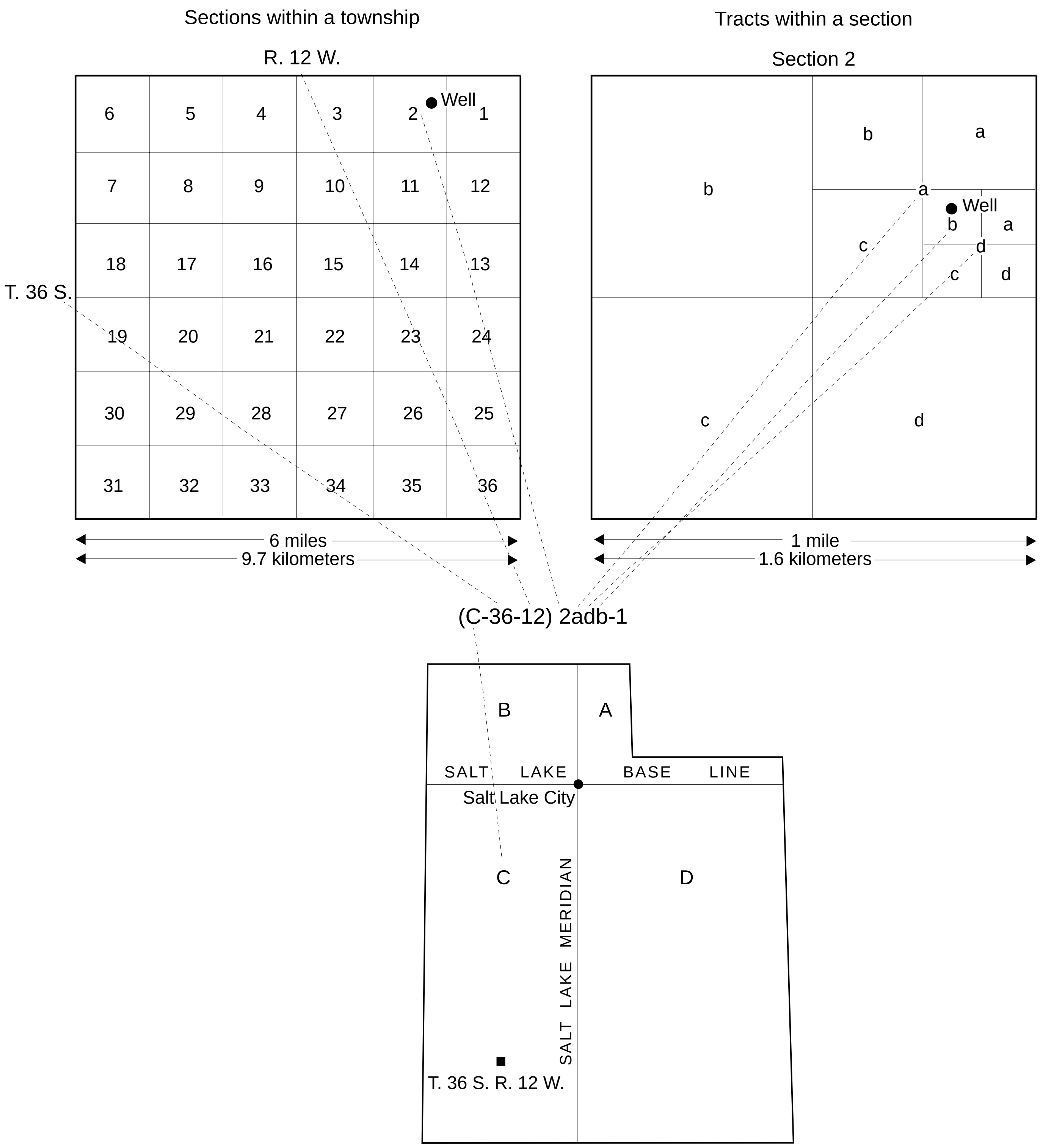

Figure 2. *Numbering system for wells in Utah (see text for additional explanation).*

the Black Mountains to the north, the Markagunt Plateau to the east, low-lying mountains and hills to the west, and the Harmony Mountains to the southwest. The floor of Cedar Valley is approximately 32 miles (51 km) long and ranges from 8 miles (13 km) wide at its northern boundary to less than 1 mile (1.6 km) wide in the south. The floor of Cedar Valley covers 170 square miles (440 km^2); its drainage basin encompasses more than 580 square miles (1,502 km^2). Elevations range from 11,307 feet (3,446 m) at Brian Head in the Markagunt Plateau to about 5,350 feet (1,631 m) at the outlet at Mud Springs Wash in the northwest part of the valley (Bjorklund and others, 1978).

Coal Creek, the principal perennial stream in Cedar Valley, flows westward from the Markagunt Plateau and has deposited a large alluvial fan in the Cedar City area (Bjorklund and others, 1978). Shirts Creek, a smaller perennial stream draining the Markagunt Plateau, enters Cedar Valley near Hamiltons Fort. Fiddlers Canyon Creek, one of the larger of the many smaller intermittent and ephemeral streams flowing westward from the Markagunt Plateau, enters Cedar Valley between Cedar City and Enoch. Quichapa Creek is a perennial stream flowing northeastward into the valley from the Harmony Mountains. Surface water flows westward out of Cedar Valley via Mud Springs Wash and Iron Springs Gap only during rare flash floods following excessive local precipitation (Bjorklund and others, 1978). Some spring runoff accumulates in Quichapa and Rush Lakes which are shallow playa lakes.

Population and Land Use

Iron County has the fourth-highest county growth rate in the state. Iron County's population increased from 17,349 in 1980 to 30,477 in 1998 (Utah Division of Water Rights, 1980, 1995; Demographic and Economic Analysis Section, 1999). Population is projected to grow another 2.6 percent annually over the next 22 years; by 2020 the population of Iron County is expected to be over 54,149 (Demographic and Economic Analysis Section, 1998).

Government and trade have provided the most employment in Iron County for more than a decade; these sectors are expected to continue to provide the most jobs, but employment in the service industry is expected to increase significantly (Utah Division of Water Resources, 1995, table 4-4). Although employment in agriculture is growing at a much lower rate, agricultural commodity production, mostly beef, dairy, and irrigated crops, will likely continue to be an important part of Cedar Valley's economy (Utah Division of Water Resources, 1995).

Climate

The climate of Cedar Valley is characterized by large daily temperature variations, moderately cold winters, and warm, dry summers. Temperatures in the valley range from a maximum of about 100°F (38°C) to a minimum of about 0° F (-18°C); the maximum daily temperature variation is greatest in the summer when fluctuations can be as much as 40°F (about 22°C) (Ashcroft and others, 1992). Mean annual temperature at the Cedar City Airport was 49°F (9°C) from 1961 to 1990 (Utah Division of Water Resources, 1995). The growing season (the number of consecutive frost-free days) in Cedar Valley averages 135 days (Ashcroft and others, 1992; Utah Division of Water Resources, 1995).

The Markagunt Plateau receives between 16 and 40 inches (41 and 102 cm) of precipitation annually (Utah Division of Water Resources, 1995), mostly as snow during the winter. Annual precipitation in Cedar Valley ranges from about 8 to 14 inches (20-36 cm) (Bjorklund and others, 1978). At the Cedar City Airport, mean annual precipitation was 11.5 inches (29.2 cm) and mean annual evapotranspiration was 34.4 inches (87.4 cm) from 1961 to 1990 (Utah Division of Water Resources, 1995). Most of the precipitation is generated in the winter and spring by humid air masses moving southeastward from the north Pacific (Bjorklund and others, 1978). Precipitation by snowfall is common in Cedar Valley during the months of December through March, but snowstorms have been reported and are not uncommon during April and even May (Bjorklund and others, 1978).

PREVIOUS INVESTIGATIONS

Early reconnaissance studies of the geology and physiography of southwestern Utah, including descriptions of the Cedar Valley area, were conducted by Gilbert (1875), Howell (1875), Powell (1879), and Dutton (1880). Research on the coal and ore deposits of the Cedar Valley region early in the 1900s was conducted by Lee (1907), Leith and Harder (1908), and Richardson (1909). Figure 3 shows the sources of modern geologic mapping investigations which were used for this study. Averitt (1962, 1967), Averitt and Threet (1973), Rowley (1975, 1976), Mackin and others (1976), Mackin and Rowley (1976), Rowley and Threet (1976), Maldonado and Moore (1993), Maldonado and Williams (1993a, b), and Moore and Nealey (1993) produced 7.5′ geologic quadrangle maps of the Cedar Valley area; the geologic maps of the Cedar City Northwest and Kanaraville quadrangles by Mackin and others (1976) and Averitt (1967), respectively, are particularly relevant to our study. Rowley (1978) mapped the geology of the Thermo 15′ quadrangle. Steven and others (1990) mapped the geology of the Richfield 1° x 2° quadrangle which includes the northern part of the study area. Averitt (1962), Threet (1963), Stewart and others (1972a, b), and Maldonado and others (1997) studied the structure of the Cedar Valley region. Huntington and Goldwait (1904), Mackin (1960), Averitt (1962), Hamblin (1970, 1984), Rowley and others (1978), Anderson and Mehnert (1979), Anderson (1980), and Anderson and Christenson (1989) studied the Hurricane fault zone and discussed its significance as a possible boundary between the Basin and Range and Colorado Plateau physiographic provinces. Blank and Mackin (1967) made a geologic interpretation of an aeromagnetic survey of the southwest part of the study area. Eppinger and others (1990) assessed the mineral resources of the Cedar City 1° x 2° quadrangle.

Meinzer (1911) conducted an early reconnaissance investigation of water resources in western Utah, including Cedar Valley which he called Rush Lake Valley. Thomas and Taylor (1946) completed the first comprehensive investigation of ground-water conditions in Cedar Valley. Subsequent ground-water investigations were conducted by Thomas and others (1952) and Sandberg (1963, 1966). Barnett and Mayo

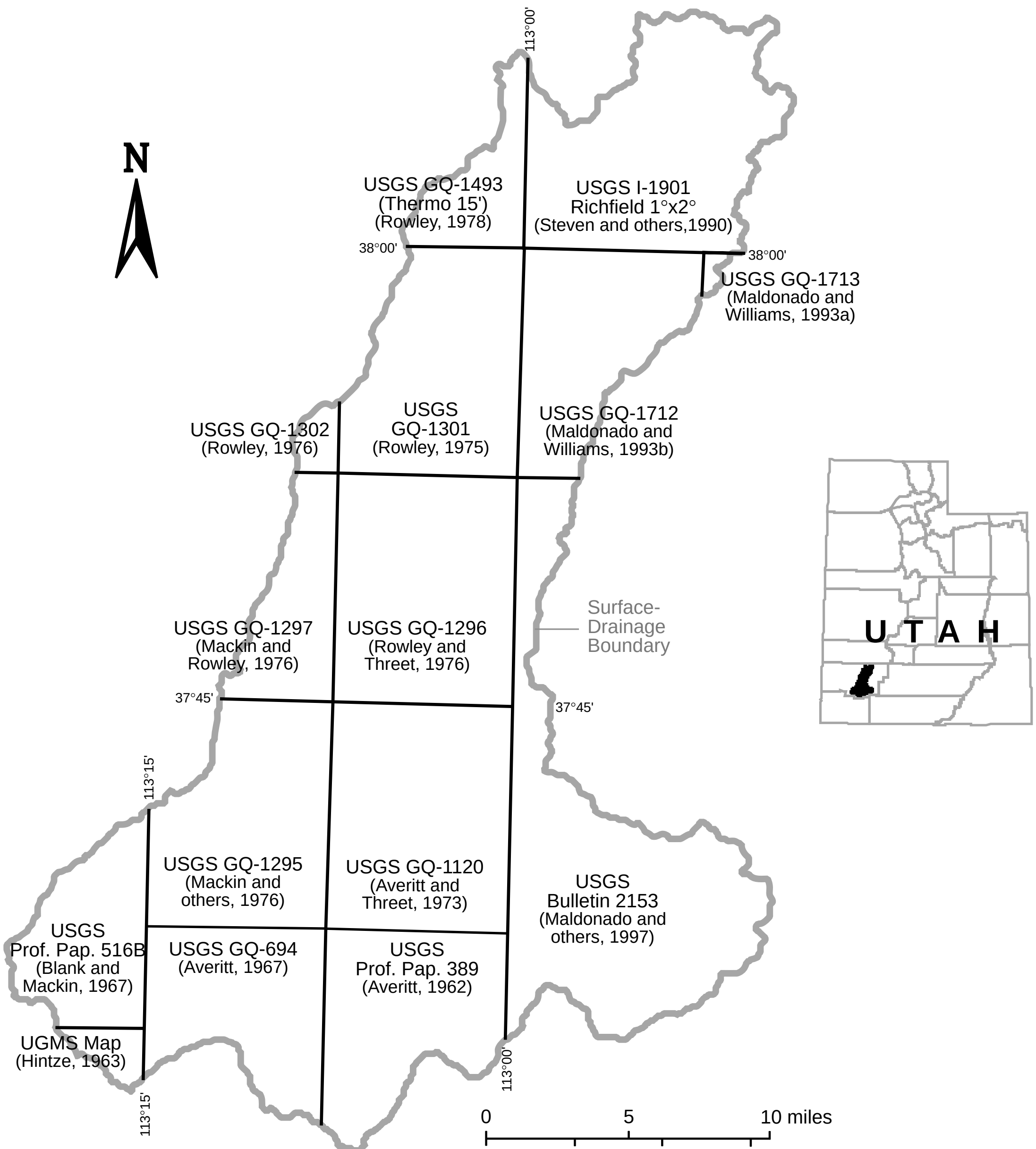

Figure 3. *Sources of geologic mapping in Cedar Valley, Iron County, Utah, which were used for this study.*

(1966) made recommendations regarding ground-water management and warned of a potential water-resources crisis in Cedar Valley. Bjorklund and others (1977, 1978) conducted the most recently completed study of ground-water conditions in Cedar Valley. Since then, the Utah Division of Water Resources, the Utah Division of Water Quality, and the U.S. Geological Survey have collected ground-water data periodically as part of an established monitoring network. Previous work on recommended septic-tank-system density/lot size in Cedar Valley includes Wallace and Lowe (1998a, 1999), Lowe and Wallace (1999a), and Lowe and others (1999).

GEOLOGIC SETTING

The Cedar Valley drainage basin lies in the transition zone between the Basin and Range and Colorado Plateau physiographic provinces (Stokes, 1977). Many geologists consider the Hurricane fault zone (figure 4), which probably first formed in the Pliocene, to be the boundary between the provinces (Anderson and Mehnert, 1979). The general location of the Hurricane fault zone is marked by the sheer Hurricane Cliffs which are up to 2,000 feet (610 m) high (Hamblin, 1970). The actual width of the fault zone, located at the

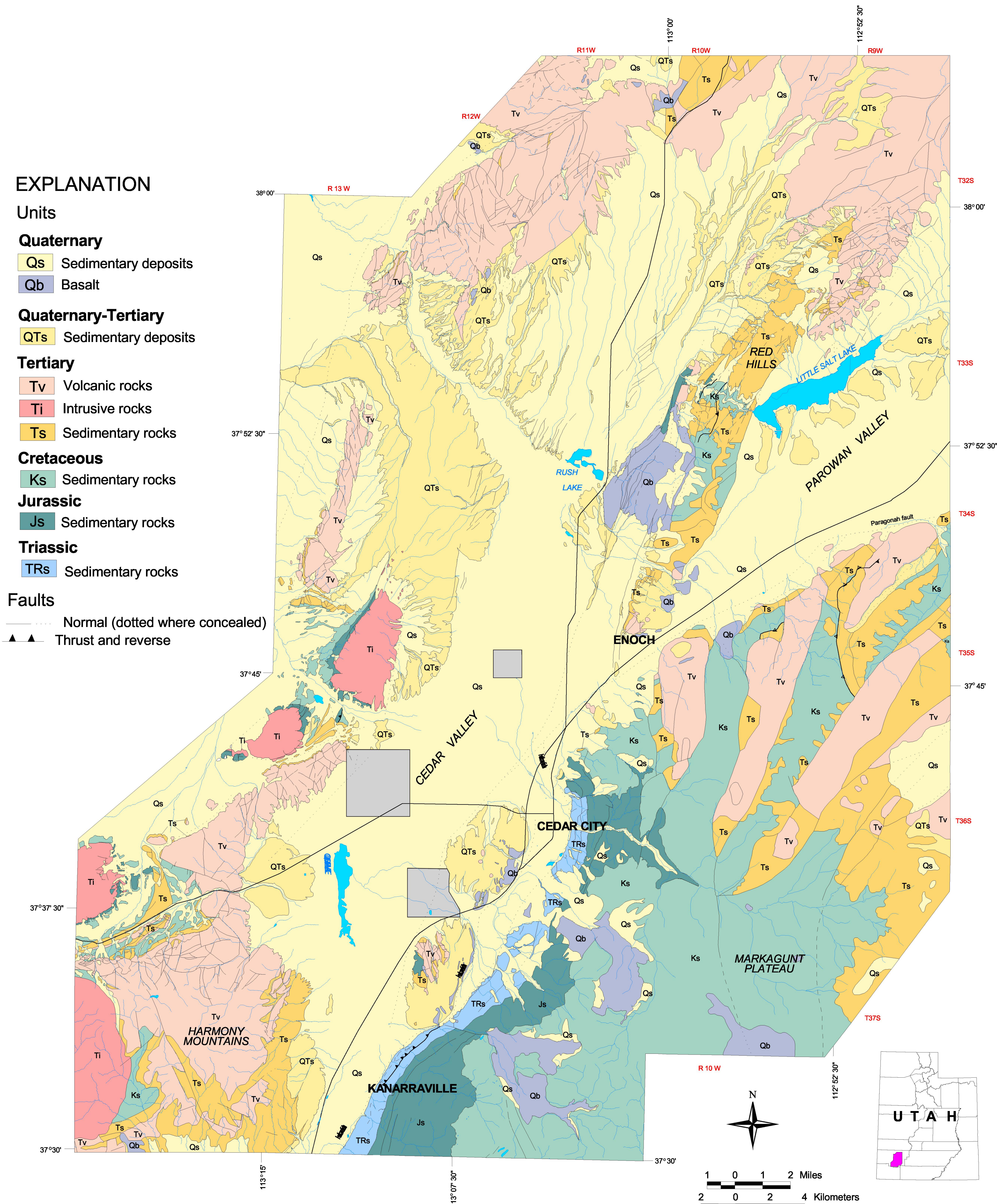

Figure 4. Simplified geologic map of Cedar Valley, Iron County, Utah. See figure 3 for sources of mapping. The three study areas are shaded.

base of the cliffs, is quite variable, but locally up to several miles wide (Averitt, 1962). South of Cedar City, in the Cedar Mountain quadrangle, for example, the Hurricane fault zone is about 3 miles (5 km) wide (Averitt, 1962). Although the Hurricane fault zone is considered seismically active and potentially capable of producing future surface-faulting earthquakes, most movement occurred during the Pliocene and Pleistocene; the elapsed time since the last surface-faulting event is likely between 5,000 and 10,000 years (Pearthree and others, 1998). Total vertical displacement along the Hurricane fault zone is estimated as between 1,500 and 4,000 feet (457 and 1,220 m) (Kurie, 1966; Anderson and Mehnert, 1979).

The Markagunt Plateau, east of the Hurricane Cliffs, has some features characteristic of the Colorado Plateau physiographic province, such as high elevation and relief dominated by gently dipping sedimentary rocks that are locally disrupted by folds and faults. However, the aligned volcanic cones and prevalent northeast-trending block faults of the Markagunt Plateau are more typical of the Basin and Range physiographic province. Geomorphic features of the Markagunt Plateau include: (1) narrow, predominantly westward sloping, V-shaped valleys, (2) steep-sided sharp-crested ridges, (3) structurally controlled drainage alignments, (4) elongated closed basins, and (5) hillside trenches or depressions (Anderson and Christenson, 1989).

Cedar Valley to the west of the Hurricane Cliffs is characterized by geomorphic features typical of other closed basins in the Basin and Range physiographic province. The basin margins consist of broad alluvial-fan slopes that grade basinward into slightly undulating plains, the lowest depressions of which contain lakes, swamps, and dry alkali flats (Meinzer, 1911). A low divide, created by the alluvial fan deposited by Coal Creek, separates Cedar Valley into two basins. The south basin drains into saline Quichapa Lake; the north basin partly drains into Rush Lake, and water from Coal Creek may also drain to depressions farther south (Meinzer, 1911).

GROUND-WATER CONDITIONS

Introduction

Ground water in the Cedar Valley area occurs in two types of aquifers: fractured bedrock and unconsolidated deposits. Bjorklund and others (1978) report that the Upper Cretaceous bedrock units yield water to springs and a few wells, and Montgomery (1980) reports on the potential for water exploration in the Navajo Sandstone, but fractured bedrock aquifers are relatively unused in the Cedar Valley area. Ground water in the Cedar Valley area is obtained principally from unconsolidated deposits of the basin-fill aquifer (Thomas and Taylor, 1946; Sandberg, 1966; Bjorklund and others, 1978).

Basin-Fill Aquifer

Occurrence

Ground water in the Cedar Valley basin-fill aquifer occurs under confined, unconfined, and perched conditions in unconsolidated basin-fill deposits (figure 5) (Bjorklund and others, 1978). Based on water-well data, the thickness of Quaternary basin fill is estimated to be at least 1,000 feet (300 m) (Thomas and Taylor, 1946; Anderson and Mehnert, 1979), but a gravity survey indicates basin fill may be as much as 3,900 feet (1,200 m) thick in the eastern part of the complexly faulted Cedar Valley graben (Cook and Hardman, 1967). The unconsolidated basin fill consists primarily of Quaternary alluvial sediments, composed of discontinuous, lenticular, commonly elongated, poorly to well-sorted bodies of sand, clay, gravel, and boulders (Thomas and Taylor, 1946), interbedded with lava flows and containing some lacustrine and eolian deposits (Bjorklund and others, 1978). The basin-fill aquifer is generally under unconfined conditions along the higher elevation margins of Cedar Valley where it typically consists of coarse, granular, permeable sediments (Bjorklund and others, 1978) deposited primarily in alluvial fans (Thomas and Taylor, 1946).

The basin-fill aquifer is generally under leaky confined conditions in the central, lower elevation areas of the valley (figure 5) (Sandberg, 1966; Bjorklund and others, 1978) where water yielding coarser-grained deposits are capped by or contain intervening beds of low-permeability silt and clay (Bjorklund and others, 1978). The low-permeability sediments are extensive enough to locally form effective confining beds or layers, but they are not continuous enough to form major separations in the basin fill where the ground-water system acts as a single, complex aquifer (Thomas and Taylor, 1946). The boundary between confined and unconfined conditions is indefinite and gradational, and shifts as the potentiometric surface of the basin-fill aquifer system rises and falls with changes in recharge and discharge (Bjorklund and others, 1978). Upward ground-water gradients in the central, lower elevation areas of Cedar Valley were once sufficient to supply flowing (artesian) wells that covered an approximate area of 50 square miles (130 km^2) in 1939 (Thomas and Taylor, 1946, plate 18), including the Bauers Knoll and Mid Valley Estates subdivision areas, but no flowing wells have existed in Cedar Valley since 1975 (Bjorklund and others, 1978). Primary ground-water recharge areas, where the basin fill is coarse and lacks thick fine-grained layers, occupy the margins of Cedar Valley. The central part of the valley is a secondary ground-water recharge area, containing thick fine-grained layers, with an overall downward ground-water flow gradient (figure 5). Discharge areas, where ground-water flow has an upward gradient, are present near Quichapa Lake, Rush Lake, and in an area just west of the town of Enoch (Bjorklund and others, 1978). The discharge areas near Quichapa and Rush Lakes are manifested as ephemeral surface water.

Aquifer Characteristics

The alluvial deposits yield water at rates ranging from 1 to 4,000 gallons/minute (4-15,100 L/min) (Bjorklund and others, 1978). The most productive aquifers consist of beds of coarse, clean, well-sorted gravel and sand that readily yield large quantities of water to wells (Bjorklund and others, 1978). Sandberg (1966), based on data from 10 wells in the Cedar Valley basin-fill aquifer, calculated a range for specific capacity of 10 to 50 gallons/minute per foot of drawdown (12-58 L/min per m of drawdown) with an average of 28 gallons/minute per foot of drawdown (32 L/min per m of draw-

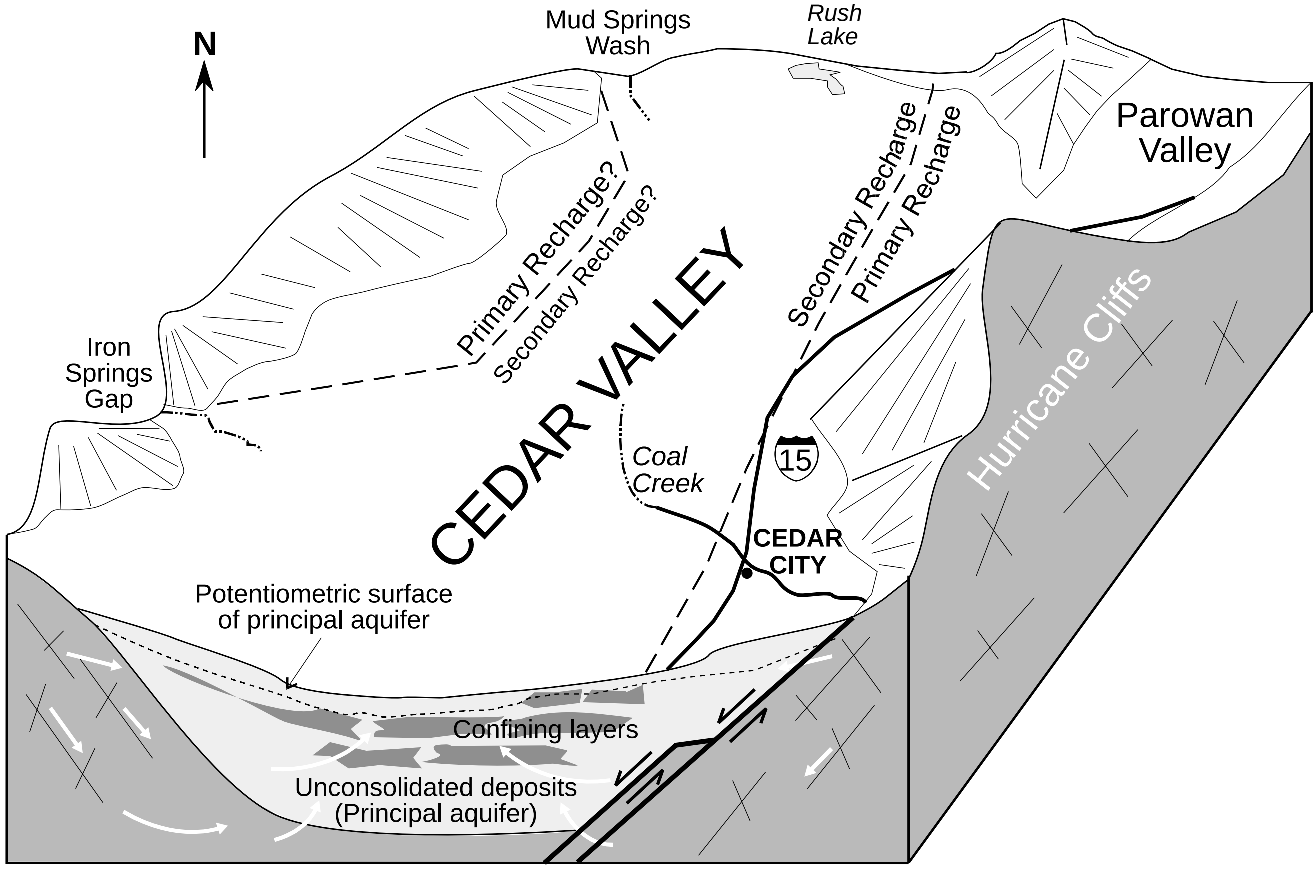

Figure 5. *Schematic block diagram showing ground-water conditions in Cedar Valley, Iron County, Utah.*

down). Bjorklund and others (1978) compiled data from six multiple-well aquifer tests completed in gravelly aquifer material in Cedar Valley and calculated a range for average hydraulic conductivity values of 13 to 251 feet/day (4-77 m/d), a transmissivity range of 2,540 to 52,000 square feet per day (230-4,830 m^2/d), and a storage coefficient range of 0.0005 to 0.2.

The Coal Creek alluvial fan, about 3 miles (5 km) north and northwest of Cedar City where the basin-fill aquifer is under leaky confined conditions, consists of coarse, well-sorted alluvium and has some of the highest transmissivities in Cedar Valley, estimated at about 20,000 square feet per day (2,000 m^2/d) (Bjorklund and others, 1978). Transmissivities in the Coal Creek alluvial fan decrease northward and westward to about 5,000 square feet per day (460 m^2/d) as the alluvial deposits become finer grained (Bjorklund and others, 1978). Near Enoch, Bjorklund and others (1978) estimated a transmissivity of 5,200 square feet per day (480 m^2/d) for an aquifer test on a well completed in the unconfined portion of the basin-fill aquifer.

Other areas with high transmissivities include the area just southwest of Quichapa Lake, where the basin fill is derived from Tertiary volcanic rocks in the mountains on the southwest side of Cedar Valley, and areas near and northeast of Rush Lake, where the basin fill contains permeable volcanic rock layers (Bjorklund and others, 1978). West of Quichapa Lake, Bjorklund and others (1978) estimated a transmissivity of about 42,000 square feet per day (3,900 m^2/d) for an aquifer test on a well completed in the leaky confined portion of the basin-fill aquifer. Transmissivities in the leaky confined aquifer in the Rush lake area range from 5,000 to 20,000 square feet per day (500-2,000 m^2/d) (Bjorklund and others, 1978).

Transmissivities are somewhat lower in southern Cedar Valley. Based on two aquifer tests and estimates from specific capacity data, Bjorklund and others (1978) calculated transmissivities ranging from 2,000 to 10,000 square feet per day (200-900 m^2/d) in the Hamiltons Fort/Kanarraville area.

The finer-grained silt and clay layers store large quantities of water, but have low transmissivities and do not readily yield water to wells. Of the estimated 20 million acre-feet (25 km^3) of water stored in Cedar Valley's basin-fill aquifer system (Bjorklund and others, 1978), only 20 percent, or 4 million acre-feet (4.9 km^3), are considered recoverable.

Potentiometric Surface

General: The potentiometric surface of ground water in the Cedar Valley basin-fill aquifer is irregular and depends on the well depth, season, and year when water-level measurements are made (Thomas and Taylor, 1946). In unconfined parts of the aquifer, the potentiometric surface corresponds to the water table; in the confined parts of the aquifer, the potentiometric surface represents the hydrostatic pressure, or head, a parameter controlling the elevation to which water will rise in wells. The potentiometric surface indicates horizontal ground-water flow direction, hydraulic gradient, and a predictable depth to water in wells in the unconfined portion of the aquifer.

Ground-water flow direction: Ground-water flow is generally from the higher elevation recharge areas to lower elevation discharge areas. In southern Cedar Valley, ground water flows northward from the Kanarraville area, northeastward from the Harmony Mountains, southeastward from the Eightmile Hills and west-northwestward from the North Hills toward Quichapa Lake (Bjorklund and others, 1978, plate 5). Ground water in the vicinity of the Coal Creek alluvial fan moves northward and northwestward from the apex of the fan and then either moves southward toward Quichapa Lake or westward toward Iron Springs Gap (Thomas and Taylor, 1946). Ground water in northern Cedar Valley generally moves northwestward toward Rush Lake and then continues toward Mud Springs Wash (Bjorklund and others, 1978). Hydraulic gradients are generally flat in the central, lower elevation areas of Cedar Valley, such as near Quichapa Lake. Hydraulic gradients are estimated to be about 25 feet/mile (5 m/km) at Iron Springs Gap and 50 feet/mile (9 m/km) at Mud Springs Wash (Sandberg, 1966).

Water levels in wells: Depth to ground water in wells ranges from near the ground surface in the central portion of the valley to about 250 feet (76 m) below the surface along the valley margins (Bjorklund and others, 1978). Most wells record static-water levels less than 100 feet (30 m) below the land surface. Depths to ground water in wells in the Coal Creek alluvial-fan area range from about 200 feet (60 m) near Cedar City to about 10 feet (3 m) in the distal portions of the fan (Bjorklund and others, 1978). Depths to ground water range from about 150 feet (46 m) along the mountain front to about 10 feet (3 m) in the lower portions of the valley in the Hamiltons Fort/Kanarraville area, from about 10 feet (3 m) near Quichapa Lake to about 100 feet (30 m) along the mountain front to the southwest, and from about 10 feet (3 m) near Rush Lake to about 50 feet (15 m) a few miles northeast of Rush Lake (Bjorklund and others, 1978).

Changes in water levels: The level at which water stands in wells in the Cedar Valley basin-fill aquifer varies in response to changes in the hydrostatic pressure of the ground water, which varies due to changes in the amount of water (1) withdrawn from pumping wells, (2) discharging by evapotranspiration, and (3) infiltrating and recharging the system from rainfall, irrigated lands, stream channels, and irrigation ditches (Thomas and Taylor, 1946). The changes in hydrostatic pressure can be either seasonal or long term.

The withdrawal of large amounts of ground water during the irrigation season causes seasonal changes in water levels (Sandberg, 1966), as does seasonal variation in precipitation and streamflow (Thomas and Taylor, 1946). There is a general pattern of declining water levels during the irrigation season, typically from May through September, and rising water levels from October through May (Bjorklund and others, 1978). Seasonal changes in ground-water levels exceeding 30 feet (9 m) were observed in 1974 in the center of the valley northwest of Cedar City, but water levels declined less than 5 feet in most areas along the western side of the valley during the same year (Bjorklund and others, 1978, figure 6).

Long-term changes in water level depend on annual average precipitation and evapotranspiration, and on average annual well pumpage. Between 1940 and 1974, the amount of ground-water discharge from wells, springs, and evapotranspiration exceeded recharge to the ground-water system which resulted in an overall decline in ground-water levels in the basin-fill aquifer. Due to concerns caused by declining water levels, the Utah State Engineer closed Cedar Valley's entire sub-basin to new appropriations of water rights in 1966; portions of Cedar Valley had already been closed to new appropriations since the 1940s (Utah Division of Water Resources, 1995). Average annual ground-water levels had declined as much as 30 feet (9 m) in some areas of Cedar Valley between 1940 and 1974, which was attributed primarily to withdrawal by wells (Bjorklund and others, 1978, figure 11). Between 1963 and 1993, water-level declines greater than 10 feet (3 m) were limited to the area west of Quichapa Lake (Barnett and Mayo, 1966), indicating long-term recharge and discharge are relatively in balance (Utah Division of Water Resources, 1995).

Recharge

Most recharge to the basin-fill aquifer comes directly or indirectly from precipitation within the Cedar Valley drainage basin (Sandberg, 1966). However, of the average 452,000 acre-feet (557 hm^3) of average annual precipitation that falls within the drainage basin, recharge to the basin-fill aquifer is estimated to be only about 40,000 acre-feet/year (49 hm^3/yr) as most of the precipitation is consumed by evapotranspiration before entering the aquifer system (Bjorklund and others, 1978). Negligible recharge to the basin-fill aquifer likely comes from direct precipitation on the valley floor, and is related to soil-moisture deficiencies in the unsaturated zone. Uptake by plants/phreatophytes typically utilizes the available amount of moisture from precipitation at the surface providing only a minor, if any, amount to percolate below the root zone to the zone of saturation (Thomas and Taylor, 1946).

Streams are the main source of recharge to the basin-fill aquifer, with the majority occurring in the upper portions of the highly permeable alluvial-fan deposits along the margins of the valley (Bjorklund and others, 1978). Although many smaller drainages entering Cedar Valley likely contribute some intermittent recharge, especially after snowmelt or during major precipitation events, Coal Creek supplies the greatest amount of recharge in Cedar Valley (Thomas and Taylor, 1946). Bjorklund and others (1978) identified ground-water mounds with water-table slopes radiating away from the fan axes under several alluvial fans. Urbanization and the accompanying introduction of impermeable materials (for example, pavement) may result in less recharge along alluvial fans, eventually altering flows in drainages and re-channeling water courses toward the valley where less favorable recharge areas exist (Utah Division of Water Resources, 1995).

Excess irrigation water, either diverted from streams or pumped from wells, is also an important source of recharge to the basin-fill aquifer, especially along the valley margins where unconsolidated deposits are most permeable (Thomas and Taylor, 1946). Most of the average annual flow of Coal Creek, about 24,000 acre-feet/year (30 hm^3/yr) is diverted for irrigation (Bjorklund and others, 1978).

Subsurface inflow from Parowan Basin in the north and the surrounding adjacent mountain blocks may contribute a relatively small amount of recharge to the basin-fill aquifer in Cedar Valley. Subsurface inflow from consolidated rock is likely greatest at the contacts between the basin fill and the Tertiary Wasatch Formation, Tertiary and Quaternary volcanic rocks, and the Jurassic Navajo Sandstone (Bjorklund and others, 1978).

Discharge

Ground water is discharged from the basin-fill aquifer by springs and seeps, evapotranspiration, wells, and subsurface outflow from the area (Sandberg, 1966). The average annual discharge in Cedar Valley is about 44,000 acre-ft (54 hm^3) (Bjorklund and others, 1978).

Springs and seeps in Cedar Valley issue from three main areas: (1) the Enoch/Rush Lake area near the contact between consolidated rock and unconsolidated deposits, (2) the area west of Rush Lake, and (3) the area near Quichapa Lake (Sandberg, 1966). However, springs and seeps account for only minor discharge in the basin-fill aquifer (Bjorklund and others, 1978). Thomas and Taylor (1946) estimated a total average annual natural discharge within Cedar Valley of about 4,700 acre-feet/year (6 hm^3/yr), but many of the springs and seeps that emanated in the Rush Lake and Enoch area in 1940 were dry by 1974 (Bjorklund and others, 1978).

Evapotranspiration represents about 3,600 acre-feet/year (4.4 hm^3/yr) of annual average discharge: about 2,000 acre-feet/year (2.5 hm^3/yr) by evapotranspiration by phreatophytes in Cedar Valley and by evaporation from the playas at Rush and Quichapa Lakes, and about 1,600 acre-feet/year (2 hm^3/yr) from areas where the potentiometric surface of the basin-fill aquifer is within 10 feet (3 m) of the ground surface (Bjorklund and others, 1978). Although estimated during the 1970s, the numbers likely reflect the current evapotranspiration rates (Utah Division of Water Resources, 1995).

Subsurface outflow from Cedar Valley is possible at three locations: Iron Springs Gap, Mud Springs Wash, and Kanarraville Creek Valley (Thomas and Taylor, 1946). Bjorklund and others (1978) estimated an average annual subsurface discharge from Cedar Valley of about 500 acre-feet/year (0.6 hm^3/yr) at Iron Springs Gap and 20 acre-feet/year (0.025 hm^3/yr) at Mud Springs Wash; they estimated subsurface discharge to Kanarraville Creek Valley as negligible.

Withdrawal from wells currently represents the greatest amount of ground-water discharge from the basin-fill aquifer (Utah Division of Water Resources, 1997). In 1975, almost 43,000 acre-feet (53 hm^3) of ground water was pumped for irrigation, municipal supply, domestic, and stock use (Bjorklund and others, 1978). By 1993, the annual pumpage had decreased to about 35,000 acre-feet (43 hm^3) (Utah Division of Water Resources, 1997). Annual pumpage varies considerably depending on cumulative departure from average annual precipitation and is considerably higher during drought years (Thomas and Taylor, 1946).

Water Quality

Ground-water quality in Cedar Valley is generally good and, although classified as hard, is suitable for most uses (Utah Division of Water Resources, 1995). Ground water in the basin-fill aquifer is generally classified as calcium- or magnesium-sulfate type. Sodium-chloride-type ground water is present near Rush Lake and calcium-bicarbonate-type ground water is present southwest of Quichapa Lake (Bjorklund and others, 1978). Thomas and Taylor (1946) reported total-dissolved-solids concentrations ranging from about 150 mg/L, just west of Quichapa Lake, to more than 1,700 mg/L for certain wells on the Coal Creek alluvial fan. Bjorklund and others (1978, table 5) reported total-dissolved-solids concentrations in ground water ranging from 166 to 2,752 mg/L. Sandberg (1966) reported total-dissolved-solids concentrations in ground water ranging from 281 to 3,750 mg/L.

The type of water and quantity of dissolved solids is largely influenced by local geology. Ground water with high total-dissolved-solids concentrations and high calcium and sulfate concentrations exists in the Coal Creek and Fiddlers Canyon alluvial-fan areas because Mesozoic-age rocks in the drainage basin contain abundant gypsum (Thomas and Taylor, 1946). Ground water with high total-dissolved-solids concentrations and high sodium and chloride concentrations exists near the playa areas of Rush and Quichapa Lakes (Bjorklund and others, 1978). Ground water in the area recharged by Quichapa Creek has low total-dissolved-solids concentrations and is the softest water in the basin-fill aquifer, because its drainage basin is underlain almost exclusively by Tertiary volcanic rocks which contain few soluble minerals.

In addition to calcium, sulfate, and chloride, another chemical constituent, nitrate, typically associated with human activities, has been identified in Cedar Valley. Nitrate concentrations in ground water have been analyzed and reported in two different ways in the literature for Cedar Valley: nitrate as nitrogen and nitrate as nitrate. The values for nitrate as nitrate are much higher than the corresponding values for nitrate as nitrogen. The Utah ground-water-quality (health) standard for nitrate as nitrogen is 10 mg/L, and 45 mg/L as for nitrate as nitrate.

Thomas and Taylor (1946, p. 107) reported nitrate-as-nitrate concentrations ranging from 0.0 to 260 mg/L for wells in Cedar Valley (table 1); they noted that the highest nitrate concentration in ground water was found in the Fiddlers Canyon alluvial-fan area, and that this high-nitrate ground water also contained high chloride and sulfate concentrations. Some of the wells in the Coal Creek alluvial-fan area were also high in nitrate and sulfate, but not high in chloride concentrations (Thomas and Taylor, 1946, p. 107). Sandberg (1966) reported nitrate-as-nitrate concentrations in Cedar Valley ranging from 1.0 to 109 mg/L (table 2). Bjorklund and others (1978) reported nitrate-as-nitrogen concentrations in Cedar Valley ranging from 0.0 to 14 mg/L (table 3).

Thomas and Taylor (1946) noted that nitrate concentrations over a few mg/L in shallow ground water is considered an indication of water-quality degradation typically associated with human-related activities. However, they noted (Thomas and Taylor, 1946, p. 110) that depths for most of the wells having high nitrate concentration in Cedar Valley exceed 100 feet (30 m), suggesting a geologic source of nitrate possibly associated with soluble salts in the valley fill rather than an anthropogenic origin.

Table 1. Nitrate concentration in ground water for water wells in Cedar Valley, Iron County, Utah (data from Thomas and Taylor, 1946).

Well location	Well depth (feet)	Nitrate (as NO_3) ppm
(C-34-11)36adc	200	2.8
(C-35-10)7cad	101	0.9
(C-35-11)1acc	150	4.2
(C-35-11)1ccd	156	2.5
(C-35-11)12ddd	250	2.7
(C-35-11)14ddd	158	125
(C-35-11)23bdc	100	260
(C-35-11)26bbb	140	144
(C-35-11)21dcc	180	10
(C-35-11)22dcc	61	17
(C-35-11)27aca	108	56
(C-35-11)27acc	113	13
(C-35-11)27adc	148	44
(C-35-11)32aca	175	11
(C-35-11)33aac	138	16
(C-35-11)19bda	175	0.0
(C-35-11)29abd	100	4.7
(C-36-11)5baa	132	10
(C-36-11)8aab	103	58
(C-36-11)8cab	200	18
(C-36-11)8cbb	60	21
(C-36-11)10bcc	195	8.5
(C-36-11)18ada	230	29
(C-36-11)7baa	167	12
(C-36-12)1aaa	366	0.5
(C-36-12)10ada	389	1.0
(C-36-12)9aaa	257	0.8
(C-36-12)12dac	200	0.8
(C-34-11)36cbc	60	0.0
(C-35-11)2ddd	40	0.0
(C-35-11)8ddd	178	0.9
(C-35-11)9add	151	1.3
(C-35-11)10dbd	90	22
(C-35-11)15dba	84	49
(C-35-11)16dba	104	13
(C-35-11)17dad	270	8
(C-33-11)29ccb	72	1.0
(C-33-11)30bca	60	0.0
(C-34-11)13bab	200+	1.2

Table 2. Nitrate concentration in ground water for water wells in Cedar Valley, Iron County, Utah (data from Sandberg, 1966).

Well location	Nitrate (as NO_3) ppm
(C-33-10)29adc	109
(C-33-12)11aaa	1.3
(C-34-11)36cdd	1.8
(C-35-11)13dda	20
(C-35-11)33aac	1.1
(C-35-12)34dcd	2.9
(C-36-11)18ada	27
(C-36-11)18bdc	6
(C-36-12)12dba	7.8
(C-36-12)20acc	2.4
(C-36-12)33bdc	0.8
(C-37-12)11aab	3.0
(C-37-12)23acb	1.0
(C-37-12)23bbd	66
(C-37-12)34abb	15

Table 3. *Nitrate concentration in ground water for water wells in Cedar Valley, Iron County, Utah (data from Bjorklund and others, 1978).*

Well location	Well depth (feet)	Nitrate (as N) ppm
(C-33-11)30bca	80	0.3
(C-34-10)31caa	365	2.6
(C-34-11)1daa	120	1.2
(C-34-11)9ccd	130	0.22
(C-34-11)23bdd	302	1.1
(C-34-12)36abb	—	0.35
(C-35-10)18cca	285	0.99
(C-35-11)26acd	700	14.0
(C-35-11)33aac	236	4.0
(C-35-12)20abc	—	0.5
(C-35-12)27bcd	255	0.26
(C-36-10)18bcd	147	0.69
(C-36-11)11bac	670	8.4
(C-36-12)32ccb	697	0.0
(C-37-12)11aaa	365	0.9

GROUND-WATER CONTAMINATION FROM SEPTIC-TANK SYSTEMS

Pathogens

As the effluent from a septic tank soil-absorption system leaves the drain field and percolates into the underlying soil, it can have high concentrations of pathogens, such as viruses and bacteria. Organisms such as bacteria can be mechanically filtered by fine-grained soils and are typically removed after traveling a relatively short distance in the unsaturated zone. However, in coarse-grained soils, or soils containing preferential flow paths like cracks, worm burrows, or root holes, these pathogens can reach the water table. Pathogens can travel up to 40 feet (12 m) in the unsaturated zone in some soils (Franks, 1972). Some viruses can survive up to 250 days (U.S. Environmental Protection Agency, 1987), which is the minimum ground-water time of travel for public water-supply wells or springs to be separated from potential biological contamination sources.

Household and Industrial Chemicals

Many household and industrial chemicals (table 4) are commonly disposed of through septic systems and, unless they volatilize easily, are not removed by percolation through soils in the unsaturated zone. Contamination from these chemicals can be minimized by reducing their disposal via septic-tank systems, maximizing the potential for dilution of those chemicals that do reach ground water (Lowe and Wallace, 1999b).

Phosphate

Phosphate, typically derived from organic material or some detergents, is discharged from septic-tank systems (Fetter, 1980). While phosphate (and phosphorus) is a major factor in causing eutrophication of surface waters (Fetter, 1980), it is generally not associated with water-quality degradation due to the use of septic-tank systems (Lowe and Wallace, 1999b). Phosphates are removed from septic-tank system effluent by absorption onto fine-grained soil particles and by precipitation with calcium and iron (Fetter, 1980). In most soils, complete removal of phosphate is common (Franks, 1972).

Nitrate

Ammonia and organic nitrogen are commonly present in effluent from septic-tank systems (table 4), mostly from the human urinary system. Typically, almost all ammonia is converted into nitrate before leaving the septic tank soil-absorption system drain field. Once nitrate passes below the zone of aerobic bacteria and the roots of plants, there is negligible attenuation as it travels farther through the soil (Franks, 1972). Once in ground water, nitrate becomes mobile and can persist in the environment for long periods of time. Areas having high densities of septic-tank systems risk elevated nitrate concentrations reaching unacceptable levels. In the early phases of ground-water-quality degradation associated with septic-tank systems, nitrate is likely to be the only pollutant detected (Deese, 1986). Regional nitrate contamination from septic-tank discharge has been documented on Long Island, New York, where many densely populated areas without sewer systems exist (Fetter, 1980).

A typical single-family septic-tank system discharges about 400 gallons (1,500 L) of effluent per day containing nitrate concentrations ranging from 30 to 80 mg/L (Hansen, Allen, and Luce, Inc., 1994). The U.S. Environmental Protection Agency maximum contaminant level for drinking water (Utah ground-water-quality standard) for nitrate is 10 mg/L. Therefore, distances between septic tank soil-absorption system drain fields and sources of culinary water must be sufficient for dilution of nitrate in the effluent to levels below the standard for ground-water quality.

We consider nitrate to be the key contaminant for use in determining the number or density of septic-tank systems that should be allowed in Cedar Valley. Projected nitrate concentrations in all or parts of aquifers can be estimated for increasing septic-tank-system densities using a mass-balance approach.

***Table 4.** Typical characteristics of wastewater from septic-tank systems (from Hansen, Allen, and Luce, Inc., 1994).*

Parameter	Units	Quantity
Total Solids	mg/L	680 - 1000
Volatile Solids	mg/L	380 - 500
Suspended Solids	mg/L	200 - 290
Volatile Suspended Solids	mg/L	150 - 240
BOD (Biological Oxygen Demand)	mg/L	200 - 290
Chemical Oxygen Demand	mg/L	680 - 730
Total Nitrogen	mg/L	35 - 170
Ammonia	mg/L	6 - 160
Nitrites and Nitrates	mg/L	<1
Total Phosphorus	mg/L	18 - 29
Phosphate	mg/L	6 - 24
Total Coliforms	**MPN/100#mL	10^{10} - 10^{12}
Fecal Coliforms	**MPN/100#mL	10^{8} - 10^{10}
pH	—	7.2 - 8.5
Chlorides	mg/L	86 - 128
Sulfates	mg/L	23 - 48
Iron	mg/L	0.26 - 3.0
Sodium	mg/L	96 - 110
Alkalinity	mg/L	580 - 775
P-Dichlorobenzene*	mg/L	0.0039
Toluene*	mg/L	0.02
1,1,1-Trichloroethane*	mg/L	0.0019
Xylene*	mg/L	0.0028
Ethylbenzene*	mg/L	0.004
Benzene*	mg/L	0.005

** Volatile organics are the maximum concentrations*
*** Most probable number*

THE MASS-BALANCE APPROACH

General Methods

We use a mass-balance approach for water-quality degradation assessments because it has been used elsewhere in the western United States (Hansen, Allen, and Luce, Inc., 1994; Wallace and Lowe, 1998a, b, c, 1999; Zhan and McKay, 1998; Lowe and Wallace, 1999a; Lowe and others, 1999) for land-use planning purposes, is easily applied, and requires few data. In the mass-balance approach to compute projected nitrate concentrations, the nitrogen mass from projected new septic tanks is added to the existing, ambient mass of nitrogen in ground water and then diluted with the ground-water flow available for mixing, plus water that is added to the system by septic tanks (Hansen, Allen, and Luce, Inc., 1994). The method of Hansen, Allen, and Luce, Inc. (1994) estimates a discharge of 400 gallons (1,500 L) of effluent/day for a domestic home, and determines a best-estimate nitrogen loading of 40 mg/L of effluent per domestic septic tank, with 80 mg/L and 30 mg/L per septic-tank system as appropriate high and low values, respectively, for nitrogen loadings. Zhan and McKay (1998) also estimate that septic-tank effluent averages 40 mg/L total nitrogen. Ground-water flow available for mixing is the difference between ground-water recharge and the sum of evapotranspiration and discharge to springs/seeps above the area of septic-tank-system influence for valley-wide evaluations, and is calculated based on aquifer-test data, mixing zone thicknesses, and length of flow path for site-specific studies using the following equation:

$$Q=KbLI$$

where:

Q = volume of discharge (cubic feet per second [m^3/sec]),
K = hydraulic conductivity (dimensionless),
b = mixing zone thickness (feet [m]),
L = length of the cross section of the aquifer through which water flows (miles [km]), and
I = hydraulic gradient (dimensionless).

The major control on nitrate concentration in aquifers when using the mass-balance approach is the amount of ground water available for mixing (Lowe and Wallace, 1997).

Limitations

There are many limitations to any mass-balance approach (see, for example, Zhan and McKay, 1998). We identify the following limitations to our application of the mass-balance approach and elaborate on several of the limitations in a subsequent discussion section.

1. Calculations are typically based on a short-term hydrologic budget, single aquifer test, and limited water-gradient data.
2. Background nitrate concentration is attributed to natural sources, agricultural practices, and use of septic-tank systems, but projected nitrate concentrations are based on septic-tank systems only and do not include nitrate from other potential sources (such as lawn and garden fertilizer).
3. Calculations do not account for localized, high-concentration nitrate plumes associated with individual or clustered septic-tank systems, and also assumes that the septic tank effluent from existing homes is in a steady-state condition with the aquifer.
4. The approach assumes negligible denitrification.
5. The approach assumes uniform, instantaneous ground-water mixing for the entire aquifer or entire mixing zone below the site.
6. Calculations do not account for changes in ground-water conditions due to ground water withdrawal from wells (see ground-water discharge section above).
7. Calculations are based on aquifer parameters that must be extrapolated to larger areas where they may not be entirely representative.
8. Calculations may be based on existing data that don't represent the entire valley.

Although there are many caveats to applying this mass-balance approach, we think it is useful in land-use planning because it provides a general basis for making recommendations for septic-tank-system densities. In addition, the approach is cost-effective and easily applied with limited information.

VALLEY-WIDE SEPTIC-SYSTEM DENSITY EVALUATION

Wallace and Lowe (1998a, 1999) applied a mass-balance equation to all of Cedar Valley using published reports containing ground-water budgets and ground-water-quality data to help with overall, gross, valley-wide planning. Figure 6 shows a plot of projected nitrate concentration in Cedar Valley's aquifer versus septic-tank density and number of septic-tank systems. Background nitrate concentration for Cedar Valley, based on limited data, is 5.5 mg/L (Conner and others, 1958; Joe Melling, Cedar City Manager, unpublished data, 1977-79; Quilter, 1996). Approximately 1,406 septic-tank systems exist in Cedar Valley (Joe Melling, verbal communication, July 29, 1997). Cedar Valley has an area of approximately 108,800 acres (440 km^2), so the average septic-tank-system density is about 77 acres/system (109 km^2/system). Based on Bjorklund and others' (1978, p. 17) estimated hydrologic budget, ground-water flow available for mixing in Cedar Valley is 52.5 cubic feet per second (1.49 m^3/s). For Cedar Valley to maintain an overall nitrate concentration of 6.5 mg/L (which allows 1 mg/L of degradation, a level of degradation determined to be acceptable in

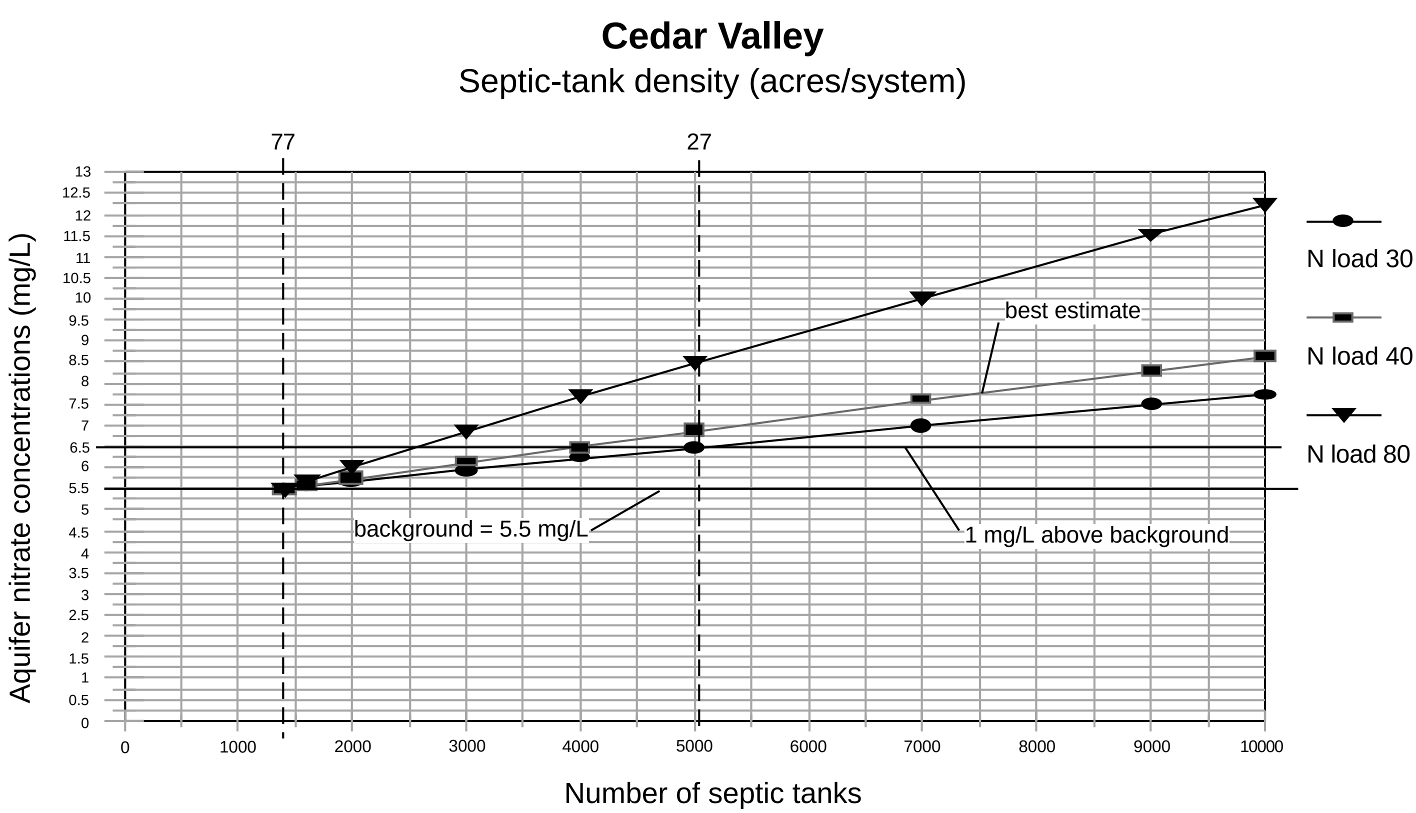

Figure 6. *Projected septic-tank-system density versus nitrate concentraion for the principal valley-fill aquifer in Cedar Valley, Iron County, Utah. N load 30, N load 40, and N load 80 refer to the low, best estimate, and high nitrogen loadings per liter of wastewater from septic-tank systems (Hansen, Allen, and Luce, Inc., 1994).*

Wasatch County, Utah [Hansen, Allen, and Luce, Inc., 1994]), the number of new homes using septic tank soil-absorption systems should not exceed 2,600 based on the best-estimate nitrogen load of 40 mg/L per septic-tank system (figure 6) (Wallace and Lowe, 1998a). This corresponds to a valley-wide maximum of 4,000 septic-tank systems and an average septic-tank-system density of about 27 acres/system (0.109 km^2/system) (Wallace and Lowe, 1998a).

SITE-SPECIFIC SEPTIC-SYSTEM DENSITY EVALUATIONS

Areas

As part of this study, we applied a mass-balance equation to three areas in southwestern Cedar Valley using site-specific ground-water flow available for mixing and site-specific ground-water-quality data to aid in determining recommended septic-system density/lot size. One area is located near Hamiltons Fort (figure 1) on the Shirts Creek (formerly known as Schurtz Creek) alluvial fan; Shirts Creek drains the Markagunt Plateau to the east of Cedar Valley. A second area, the Bauers Knoll area, is located in west-central Cedar Valley (figure 1) just east of the Eightmile Hills on the west side of Cedar Valley. The third area, the Mid Valley Estates area, is located in central Cedar Valley, just southwest of Enoch (figure 1). All three areas have some existing development, mostly single-family dwellings using septic-tank systems for wastewater disposal, but have the potential for additional development.

Variables Considered

We calculated septic-tank-system density versus water-quality degradation for each site based on an array of parameters that affect the amount of ground water available for dilution and based on a variable number of septic-tank systems reported in each area. According to the Southwest Utah Public Health Department (oral communication, 1999), the number of septic tanks in their database may not be current. They record 28 septic tanks in the Hamiltons Fort area, about 10 for the Bauers Knoll area, and about 195 in the Mid Valley Estates subdivision. We use these numbers for our computations, but compute additional scenarios by increasing the number of septic systems that are likely present based on the number of homes that exist in each area.

Zone of Mixing

Nitrates in septic-tank effluent have a limited vertical depth through which they disperse; much of an aquifer may remain relatively isolated from septic-tank effluent. Thus, a greater dilution of nitrate may be erroneously calculated if an actual aquifer thickness is used. A mixing zone, of some assumed thickness, at the top of an aquifer is a more useful concept than the actual aquifer thickness. Stratified mixing zones in the upper portions of aquifers have been documented in aquifer systems in Utah, including Tooele Valley (Steiger and Lowe, 1997).

Complete mixing within this mixing zone is assumed in the mass-balance approach used in this study; however, due to the laminar nature of ground-water flow in most aquifer systems, complete mixing is unlikely. Bauman and Schafer (1984) found that nitrate concentrations in aquifer systems with relatively low ground-water velocities, such as the Cedar Valley basin-fill aquifer, are not overly sensitive to the thickness of the mixing zone. The Montana Department of Environmental Quality (1996) set their mixing zone thickness to 16.4 feet (5 m). The aquifer systems in Montana are generally thinner than the systems we examine in this study. To reflect the relatively thick aquifer systems in Cedar Valley, we used a mixing zone thickness of 60 feet (18 m).

Hamiltons Fort Area

Location and Area

The Hamiltons Fort area is located about 5.5 miles (8.8 km) south of Cedar City, just southwest of Cross Hollow Hills (figure 1). It consists of approximately 4,200 acres (16.9 km^2) mainly centered around section 25, T. 36 S., R. 12 W., Salt Lake Base Line and Meridian. The land surface slopes gently to the west-northwest. Currently the area is mostly undeveloped (figure 7), although many developed lots exist just to the southeast of the area.

Surficial Geology

The Hamiltons Fort area is located on the distal portion of the Shirts Creek alluvial fan. Shirts Creek drains the faulted and folded Cedar Mountain portion of the Markagunt Plateau which has been uplifted along the Hurricane fault zone. Upgradient geologic units include from west to east: poorly consolidated Quaternary and Tertiary sediments; Quaternary pediment deposits; the Triassic Moenkopi and Chinle Formations; the Jurassic Moenave, Kayenta, Navajo, and Carmel (which includes the Entrada, Curtis, and Winsor Formations of Averitt, 1962) Formations; and the Cretaceous Dakota, Tropic, and Straight Cliffs Formations (figure 4) (Averitt, 1962; Mackin and others, 1976). The Quaternary units are the most relevant to this study.

Pleistocene and Holocene alluvial-fan and pediment deposits consist predominantly of unconsolidated silt, sand, and minor pebble gravel (Rowley, 1975; Mackin and others, 1976), and, locally, colluvium, landslide deposits, and bouldery debris-flow deposits.

The Tertiary and Quaternary sediments consist mostly of Miocene, Pliocene, and Pleistocene poorly consolidated light gray, tan or red, sandy fine-pebble to boulder conglomerate or, less commonly, coarse-grained sandstone or colluvium (Rowley, 1975, 1976; Mackin and others, 1976; Rowley and Threet, 1976). These sediments mantle hilly areas around the valley margins, are likely mostly alluvial in origin, and are locally interbedded with Quaternary-Tertiary basalt lava flows (Rowley, 1975, 1976; Mackin and others, 1976; Rowley and Threet, 1976).

Ground-Water Conditions

Occurrence: Ground water in the Hamiltons Fort area occurs under mostly leaky confined conditions in unconsoli-

Figure 7. *View of Hamiltons Fort area, Cedar Valley, Iron County, Utah (view to the east).*

dated basin-fill deposits. Based on water-well data, the Quaternary basin-fill deposits consist primarily of discontinuous bodies of finer grained clay, silt, and gravel and coarser grained sand and gravel; finer grained deposits are predominant in the upper layers and coarser grained deposits are predominant at depth (figure 8). These unconsolidated basin-fill deposits were primarily deposited as alluvial-fan sediments. The basin fill is coarser in the proximal parts of the fan and becomes finer in the distal parts.

Depth and transmissivity: Depth to ground water in wells is variable. Well depths range from 200 to 610 feet (61-185 m). Water levels, reported from drillers' logs of water wells and measured over many different years and seasons, range from 18 to 176 feet (5.5-54 m). Most wells have a static water level that is less than 100 feet (30 m) below the land surface. Transmissivities are somewhat lower in this part of the valley, relative to northeastern Cedar Valley. Based on two aquifer tests and estimates from specific capacity data, Bjorklund and others (1978) calculated transmissivities ranging from 2,000 to 10,000 square feet per day (200-900 m^2/d) in the Hamiltons Fort/Kanarraville area.

Ground-water flow: Ground-water flow is generally from the higher elevation recharge areas to lower elevation areas. In southern Cedar Valley, ground water flows northward from the Kanarra area (Bjorklund and others, 1978, plate 5) and eventually westward towards Iron Springs Gap (Thomas and Taylor, 1946). Ground-water-flow direction in the Hamiltons Fort area is generally to the west, toward Quichapa Lake. Recharge is likely from Cedar Mountain situated southeast of the Shirts Creek alluvial fan.

Existing Nitrate Concentrations

Ground water from 14 water wells near the Hamiltons Fort area was sampled and analyzed for nitrate concentration during March 1999. Drillers' logs are available for 9 of the 14 wells (appendix A). Depth of the completed wells ranges from 200 feet to 610 feet (61-186 m), and the sediment penetrated by the wells is dominated by gravel with minor clay and sand. Nitrate concentration values (table 5, figure 9) range from 0.1 to 7.46 mg/L, with an average nitrate concentration of 2.15 mg/L. Three wells, all located in section 31, T. 36 S., R. 11 W., Salt Lake Base Line and Meridian, have nitrate concentrations that exceed 7 mg/L.

No evident correlation exists between nitrate concentration and well depth or sediment type. For example, the well having the highest nitrate concentration of 7.46 mg/L is 400 feet (122 m) deep and penetrates an upper 25-foot-thick (8 m) clay layer underlain by gravel. The well having the second-highest nitrate concentration of 7.2 mg/L (7.2 ppm) is located less than 1/2 mile (0.8 km) to the south, is 290 feet (88 m) deep, and penetrates an upper 5-foot-thick (1.5 m) clay layer underlain by gravel. Located less than 100 feet (30 m) to the east is a 370-foot-deep (113 m) well which penetrates an upper 28-foot-thick (8.5 m) clay layer and has a nitrate concentration of 0.567 mg/L. All of the wells on the more distal portion of the Shirts Creek alluvial fan have nitrate concentrations below 1 mg/L.

The variable distribution of nitrate concentration for wells in such close proximity and similar depth indicates that a nitrate plume in ground water is unlikely in section 31. The

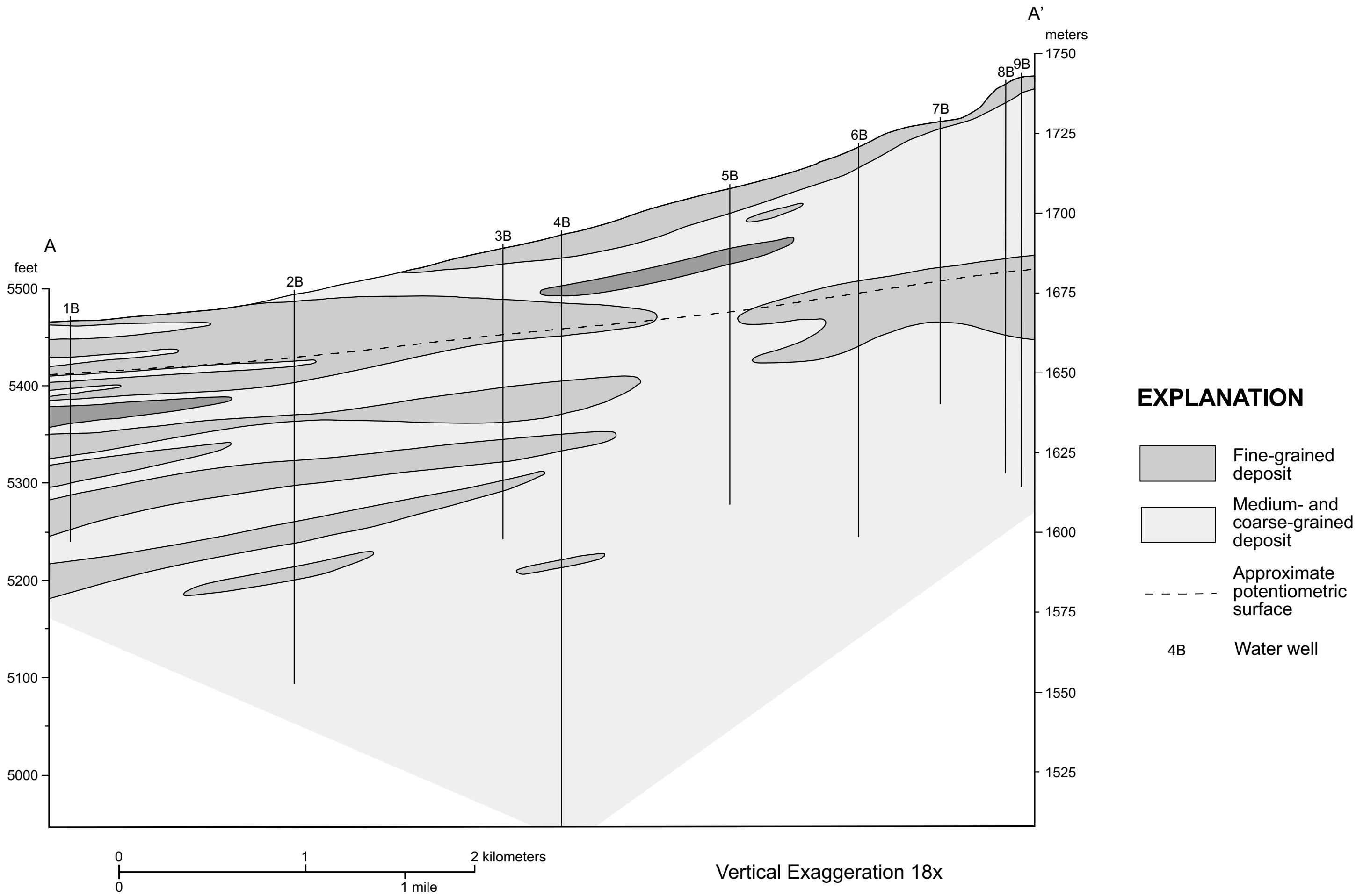

Figure 8. *Schematic geologic cross section of Hamiltons Fort area, Cedar Valley, Iron County, Utah. A-A′ shown on figure 9.*

Table 5. *Nitrate data for Hamiltons Fort area, Cedar Valley, Iron County, Utah.*

Well location	Well depth (feet)	Nitrate (mg/L)
(C-36-12) 24cbb	400?	0.99
(C-36-11) 30dbb-1	400	1.1
(C36-12) 23bdc	228	0.1
(C-36-11) 31acd	290	7.2
(C-36-11) 30dbb-2	610	1.13
(C-36-12) 24abd	300	1.0
(C-36-11) 31adb	210 (no log)	0.57
(C-36-11) 31aab	400	7.46
(C-36-11) 19ccd	200	0.64
(C-36-12) 31bad	no log	0.1
(C-36-11) 31ada	no log	7.12
(C-36-11) 31daa	400	0.64
(C-36-12) 25bdd-1	300	1.6
(C-36-12) 24acc	500 (no log)	0.4

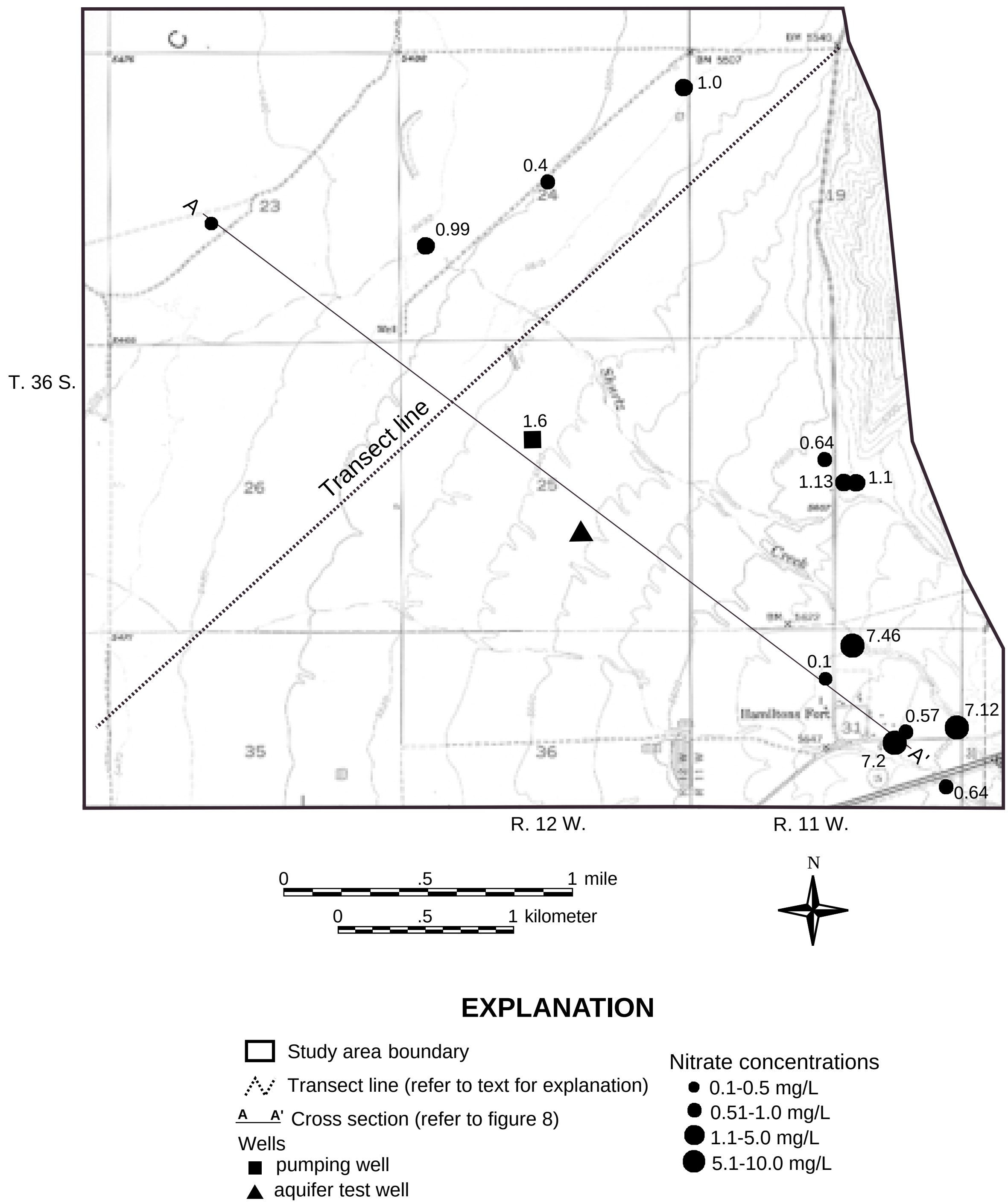

Figure 9. *Nitrate concentrations for the water wells in the Hamiltons Fort area, Cedar Valley, Iron County, Utah.*

most likely cause of elevated nitrate in one well is its proximity to a corral; for another, the most likely cause is its proximity to a septic-tank system. There is no obvious nitrate source associated with the third well which has a nitrate concentration above 7 mg/L. Naturally occurring nitrate in the Straight Cliffs Formation, which outcrops in the upper portion of the surface drainage basin, could also be responsible for some of the nitrate found in ground water in the Hamiltons Fort area.

Aquifer Test

General: To obtain transmissivity and other information about the aquifer in the Hamiltons Fort area, we conducted a 48-hour, multiple-well, constant-discharge-rate aquifer test between May 26 and May 28, 1999. This test was done in cooperation with Jim Mason of the U.S. Geological Survey. The test used two wells, a pumping well and an observation well. We originally planned to monitor both wells during the aquifer test; however, we could not install a probe to measure water levels in the pumping well. We monitored water levels in the observation well during the drawdown phase of the test using both a pressure transducer and data logger and an electric tape. During the recovery phase only the pressure transducer and data logger were used to monitor water levels. We compared these two data sources during the analysis of the drawdown data. The pressure transducer measured water levels in the observation well for four days before the start of the aquifer test and for four days after the recovery period. Regional water-level trends were determined using these data. A static (initial) water or piezometric level of 105.25 feet (32 m) below the top of the observation well's casing was measured before starting the aquifer test.

The test was conducted using the existing pump in the pumping well running at its maximum capacity. Discharge rates during the aquifer test were measured using a Controlotron clamp-on portable multi-function flow meter and were approximately constant at 890 gallons per minute (56 L/s). Pumped water was conducted away and down gradient from the well in an 8-inch (20 cm) pipe for about 100 feet (30 m) and then in a cement-lined ditch for about another 1,000 feet (305 m), where it was discharged onto the ground surface.

Aquifer-test wells and pump: An examination of the drillers' logs (appendix B) and an onsite investigation provided the following information regarding the two wells used for the Hamiltons Fort area aquifer test. The pumping well is in the SW1/4SW1/4NE1/4 and the observation well is in the NW1/4SW1/4SE1/4 section 25, T. 36 S., R. 12 W., Salt Lake Base Line and Meridian (figure 9). The observation well is approximately 1,700 feet (517 m) southeast of the pumping well. Both wells were completed for agricultural use; however, the observation well has not been operable for about a decade. The pumping well is shallower (300 feet [91 m] deep) and located northwest of the observation well, which is 600 feet (183 m) deep; however, the perforated intervals overlap. The annular spacing between the discharge tube and the well casing prevented a probe from reaching the water level in the pumping well; therefore, water levels were not measured in the pumping well.

The pumping well was cable-tool drilled at an approximate surface elevation of 5,540 feet (1,689 m) with a 16- or 18-inch (41 or 46 cm) bit. The well was completed in November 1956 to a depth of 300 feet (91 m). The well's casing is 14 inches (36 cm) in diameter and is 1/4-inch (0.64 cm) steel with welded joints. The perforated interval is between 90 and 300 feet (27-91 m). The perforation size is unknown. The top of the well casing is about 2 inches (5 cm) above the ground surface. No completion information is available for the well, but we assume that a seal was not constructed. The pumping well was equipped with a reliable power source and a gate valve placed about 3 feet (1 m) from the well for controlling discharge from the well.

The observation well was rotary drilled at an approximate surface elevation of 5,552 feet (1,692 m) with an 18- or 20-inch (46 or 51 cm) bit. The well was completed in April 1971 to a depth of 600 feet (183 m). The well's casing diameter is 16 inches (41 cm) from the surface to 370 feet (113 m); the well is uncased below 370 feet (113 m). The well casing is 1/4-inch (0.64 cm) steel with welded joints. Perforated intervals are between 120 and 370 feet (37-113 m). The perforations are 3/16 x 3 inches (0.48 x 8 cm) and were done by mills knife. The well was gravel packed with 3/4-inch gravel from the surface to 370 feet (0-113 m) and no surface seal was constructed. The top of the well casing is about 8 inches (20 cm) above a cement collar. The observation well is equipped with a plug in the well-pump casing that allows a probe to be inserted between the discharge tube and the well casing for water-level measurements.

The pump used in the pumping well is a Kemble pump (vertical turbine) with a 50 horsepower, three-phase, 220/440 volts U.S. electrical motor. The maximum projected pumping rate is probably about 1,500 gallons per minute (95 L/s). The pump bowls are set at an unknown depth in the well.

Analysis: Data from early water-level measurements in the observation well, during the drawdown phase of the aquifer test (first 100 minutes), probably reflect some wellbore storage effects, resulting in a more gradual slope than expected (figure 10). A temporary problem with the pump at about 1,200 minutes into the drawdown phase of the test resulted in a decrease in flow rate and allowed partial recovery of the water level. The aquifer-test duration was not sufficient to include the longer-term drawdown data that would have helped in curve matching. We used water level measurements taken after 100 minutes in determining the transmissivity of the aquifer. Drawdown was about 1.5 feet (0.5 m) based on water-level measurements in the observation well during the test. The observed water-level changes were corrected for prepumping trends. Barometric effects on the water level were negligible, therefore no corrections were made in computing ground-water levels.

Curve matching using Neuman, Theis, and Hantush type curves and the Cooper-Jacob semilogarithmic approximation method were used to analyze drawdown data from the aquifer test (Theis, 1935; Cooper and Jacob, 1946, Hantush, 1960, Neuman, 1974). We used the computer program AQTESOLV for Windows (Hydrosolve, 1996) in these evaluations. This program generates "best fit" matches for a chosen analytical technique after a specified number of iterations, or can numerically fit aquifer test data to specific type curves. Calculated values from the different methods of analysis are very similar. Using the Hantush type curves, which we believe are more characteristic of the aquifer, we calculated a transmissivity of about 20,900 square feet per day (1,940 m^2/d). The drawdown data, corrected for the pre-

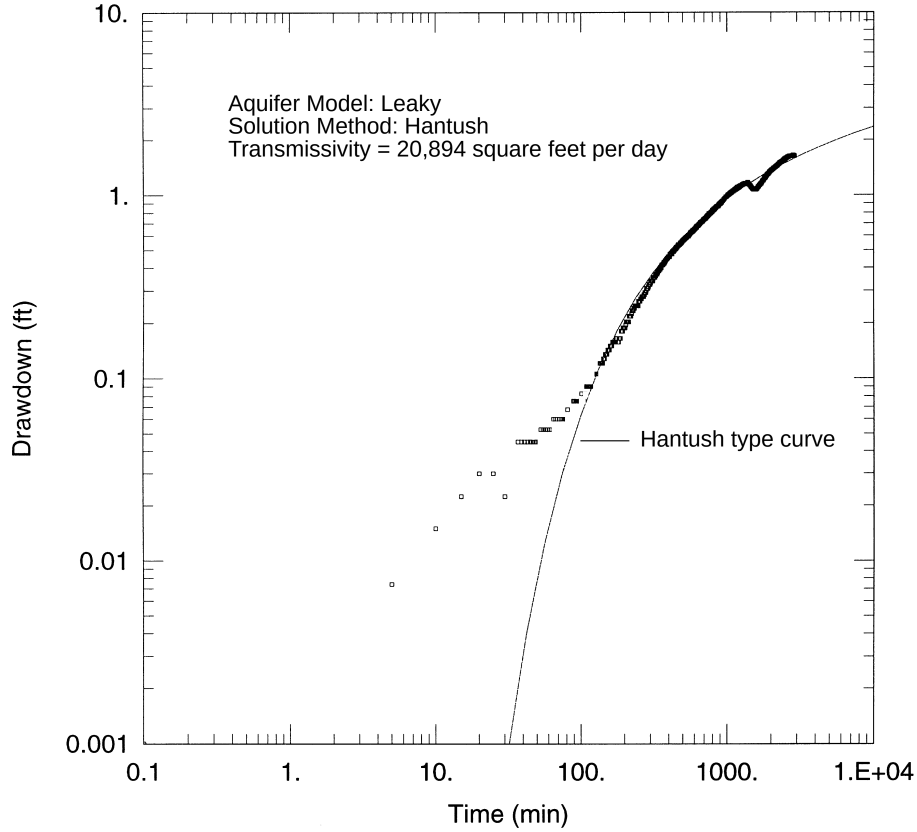

Figure 10. *Hamiltons Fort area, drawdown data plot, Cedar Valley, Iron County, Utah.*

pumping trends, are plotted against time in figure 10. The recovery phase test data compared favorably to the drawdown data.

Results

Figure 11 shows a plot of projected nitrate concentration in the Hamiltons Fort area of the Cedar Valley aquifer versus septic-tank density and number of septic-tank systems. Using the data presented in table 5, an average background nitrate concentration for the Hamiltons Fort area is calculated to be 2.15 mg/L. Based on public record documents, approximately 28 septic systems exist in the Hamiltons Fort area (Southwest Utah Public Health Department, written communication, 1999). The Hamiltons Fort area is approximately 4,200 acres (16.9 km^2), so the average septic-system density is about 150 acres/system (0.61 km^2/system). Based on the transmissivity obtained from the aquifer test described above, estimated ground-water flow available for mixing in the Hamiltons Fort area through a 3.5-mile (5.6 km) transect (figure 9) is 15 cubic feet per second (0.42 m^3/s) (table 6). For the Hamiltons Fort subdivision area to maintain an overall nitrate concentration of 3.15 mg/L (which allows 1 mg/L of degradation, a value adopted by Wasatch and Weber Counties as an acceptable level of degradation), the total number of homes using septic tank soil-absorption systems should not exceed 690 based on the best estimate nitrogen load of 40 mg/L (40 ppm) per septic-tank system (figure 11). This corresponds to an increase of approximately 660 new septic systems and an average septic-system density of about 5.5 acres/system (0.022 km^2/system) in the Hamiltons Fort area.

Figure 12 shows a plot of projected nitrate concentration in the Hamilton Fort area's aquifer versus septic-tank density and number of septic-tank systems assuming an existing number of 100 septic systems. We believe 100 septic tanks to be a more realistic estimate of the total number of systems in the Hamiltons Fort area based on a windshield survey. As above, using an average background concentration for the Hamiltons Fort area of 2.15 mg/L and an area of approximately 4,200 acres (16.9 km^2), the average septic-system density in this scenario is about 42 acres/system (0.17 km^2/system). Estimated ground-water flow available for mixing in the Hamiltons Fort area through a 3.5-mile (5.6 km) transect in the lower reaches of the alluvial fan in the subdivision area (figure 9) is 15 cubic feet per second (0.42 m^3/s). For the Hamiltons Fort area to maintain an overall nitrate concentration of 3.15 mg/L, the total number of homes using septic tank soil absorption systems should not exceed about 760 based on the best estimate nitrogen load of 40 mg/L per septic-tank system (figure 12). This corresponds to an increase of approximately 660 new septic systems and an average septic-system density of about 5.6 acres/system (0.02 km^2/system) in the Hamiltons Fort area.

Recommendations for Land-Use Planning

We believe the second scenario presented above is the most appropriate one to be applied to the Hamiltons Fort area. In this part of Cedar Valley, lots using septic-tank systems for wastewater disposal should be no smaller than 5.6 acres (0.02 km^2). The area could be served by an existing valley-wide public sanitary sewer system; this is the most appropriate option for domestic wastewater disposal.

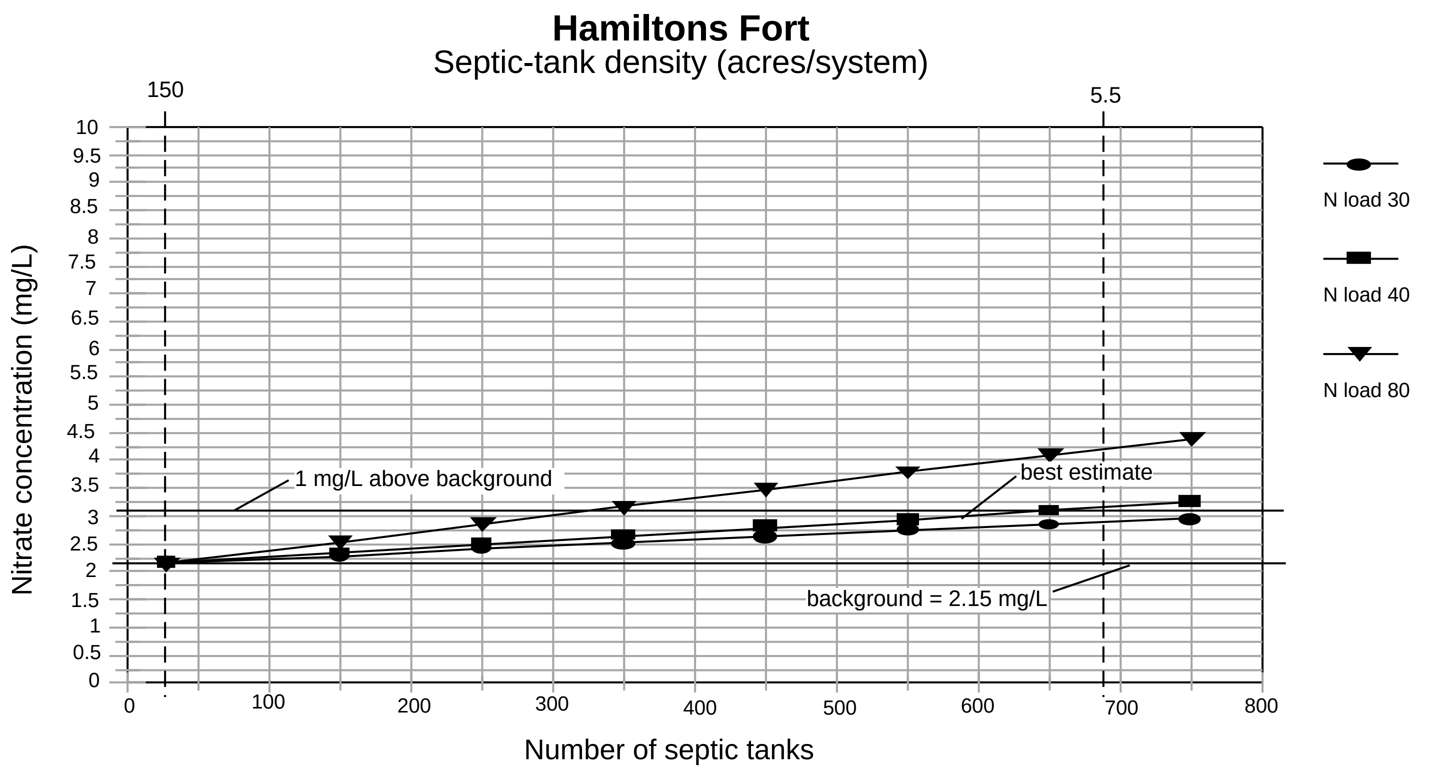

Figure 11. *Projected septic-tank-system density versus nitrate concentration for the Hamiltons Fort area in Cedar Valley, Iron County, Utah based on 28 existing septic systems and ground-water flow through a 3.5-mile transect. N load 30, N load 40, and N load 80 refer to the low, best estimate, and high nitrogen loadings per liter of wastewater from septic-tank systems (Hansen, Allen, and Luce, Inc., 1994).*

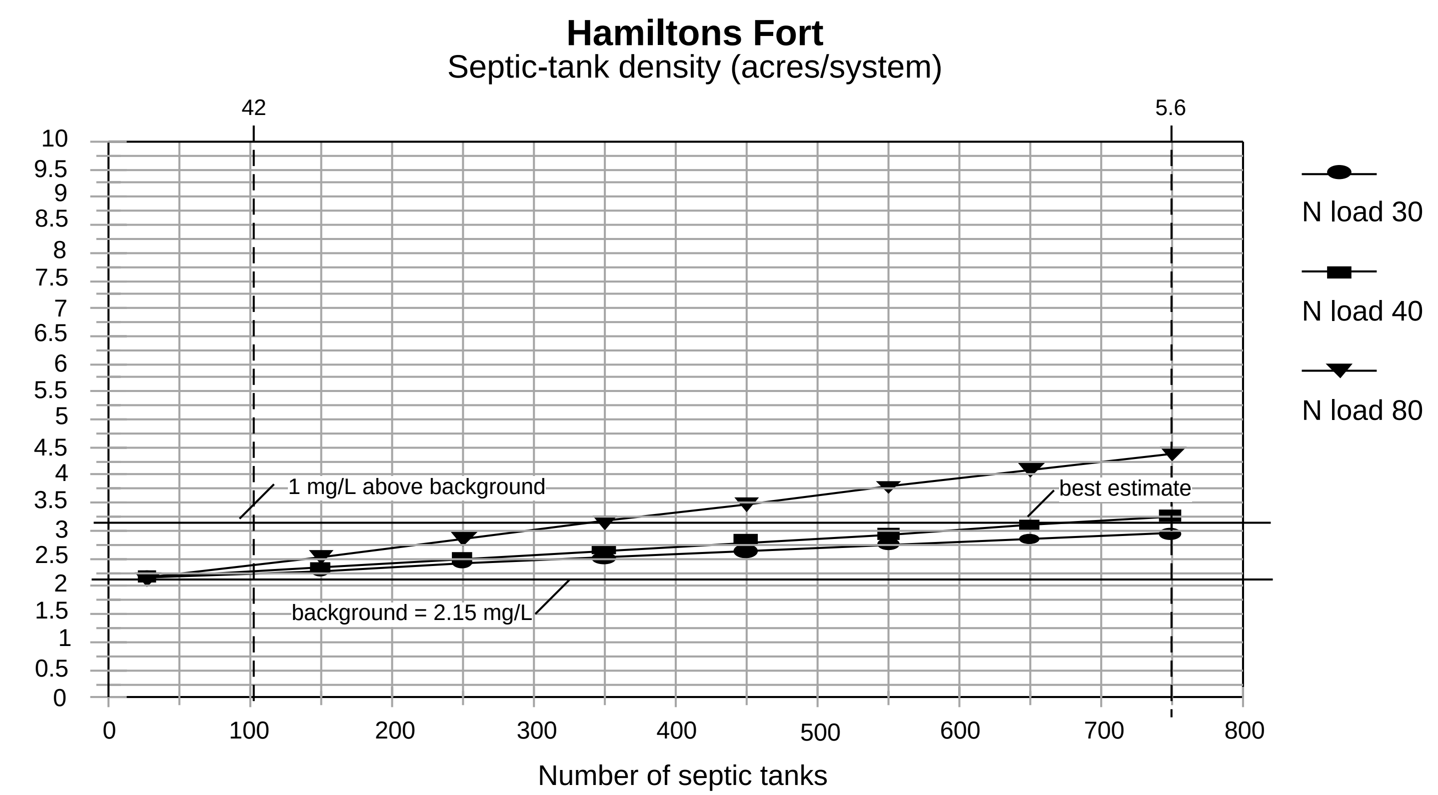

Figure 12. *Projected septic-tank-system density versus nitrate concentration for the Hamiltons Fort area in Cedar Valley, Iron County, Utah based on 100 existing septic systems. N load 30, N load 40, and N load 80 refer to the low, best estimate, and high nitrogen loadings per liter of wastewater from septic-tank systems (Hansen, Allen, and Luce, Inc., 1994).*

Table 6. *Parameters used to compute amount of ground water available for mixing, Cedar Valley, Iron County, Utah.*

PARAMETER	HAMILTONS FORT	BAUERS KNOLL	MID VALLEY ESTATES
hydraulic conductivity (K)	0.058 ft/min	0.013 ft/min	0.0025 ft/min
thickness of mixing zone (b)	60 ft	60 ft	60 ft
length of area (L)	18,480 ft	13,200 ft	5,280 ft
hydraulic gradient* (I)	0.014	0.00236	0.0038
volume of water available for mixing (Q)	900 ft^3/min; 15 ft^3/sec	24.2 ft^3/min; 0.4 ft^3/sec	2.71 ft^3/min; 0.045 ft^3/sec

*calculated from potentiometric surface contours shown in Bjorklund and others, 1978, plate 6.

Bauers Knoll Area

Location and Area

The Bauers Knoll area is located around the topographic high designated Bauers Knoll, just southeast of Iron Springs Gap and east of the Eightmile Hills (figures 1 and 13). It consists of approximately 3,800 acres (15.5 km^2) mainly centered in section 3, T. 36 S., R. 12 W., Salt Lake Base Line and Meridian. The land surface slopes very gently to the east.

Surficial Geology

The Bauers Knoll area is located on Pleistocene to Holocene basin-fill deposits. Sediments are derived predominantly from the complexly faulted Eightmile Hills to the west, and periodically from major flood events from the Markagunt Plateau to the east. Upgradient geologic units primarily include, from east to west, Quaternary fan and pediment deposits and Tertiary volcanic rocks (figure 4) (Mackin and others, 1976).

Pleistocene and Holocene basin-fill deposits consist of unconsolidated clay, silt, and sand, predominantly alluvial in origin. These deposits include sediments of a fairly extensive Pleistocene lake (Mackin and others, 1976). Pleistocene and Holocene alluvial-fan and pediment deposits consist predominantly of unconsolidated silt, sand, and minor pebble gravel (Rowley, 1975; Mackin and others, 1976), and, locally, colluvium, landslide deposits, and bouldery debris-flow deposits.

Ground-Water Conditions

Occurrence: Ground water in the Bauers Knoll area in Cedar Valley occurs primarily under confined conditions in unconsolidated basin-fill deposits (Bjorklund and others, 1978). Based on water-well data, the Quaternary basin fill consists primarily of clay and silt in the upper layers and clay, silt, and sand with minor coarser gravel at depth. Lacustrine silts and clays are common predominantly near the surface at depths less than 100 feet (30 m). Below 100 feet, the sediments generally consist of Quaternary alluvial-fan sediments in the form of discontinuous bodies of clay, silt, and minor sand and gravel. Sand and gravel layers are thin and more common at greater depths (>200 feet [61 m]) (figure 14). The alluvial sediments on the east side of the Bauers Knoll area were likely derived from the Markagunt Plateau to the east.

Depth and transmissivity: Depth to ground water in wells is variable. Well depths range from 132 to 820 feet (40-250 m). Water levels, reported from drillers' logs of water wells and measured over many different years and seasons, range from 15 to 210 feet (4.5-64 m) and average about 40 feet (12 m). Most wells have a static water level that is less than 100 feet (30 m) below the land surface. West of Quichapa Lake, Bjorklund and others (1978) estimated a transmissivity of about 42,000 square feet per day (3,900 m^2/d) for an aquifer test on a well completed in the leaky confined portion of the basin-fill aquifer.

Ground-water flow: Ground-water flow is generally from the higher elevation recharge areas to lower elevation areas. Recharge is likely primarily from the south end of the valley and a minor amount from the Eightmile Hills situated due west of the Bauers Knoll area. However, ground water flow direction in the Bauers Knoll area is generally to the north, toward Iron Springs Gap where ground water discharges out of the valley. Hydraulic gradients are generally flat in the central, lower elevation areas of Cedar Valley, such as near Quichapa Lake, and northwest of Quichapa Lake in the Bauers Knoll area.

Existing Nitrate Concentrations

Ground water from 10 water wells in the vicinity of the Bauers Knoll area was sampled and analyzed for nitrate concentration during June 1999. Drillers' well logs are available for 7 of the 10 wells (appendix A). Depths of the completed wells range from 132 to 538 feet (40-64 m), and the sediment penetrated by the wells generally consists of mixed clay, silt, and sand layers with minor sand and gravel horizons. Nitrate values range from 0.2 to 0.8 mg/L (0.2-0.8 ppm) (table 7, figure 15), with an average nitrate concentration of 0.49 mg/L. No wells have nitrate concentrations that exceed the Utah drinking water standard of 10 mg/L. The uniform distribution and low concentration of nitrate in wells may be attributed to the presence of a mostly continuous, relatively thick (typically greater than 50 feet [15 m] in all wells) confining layer.

Aquifer Test

General: To obtain transmissivity and other information about the aquifer in the Bauers Knoll area, we used a 24-

Figure 13. View of Bauers Knoll area looking toward the east.

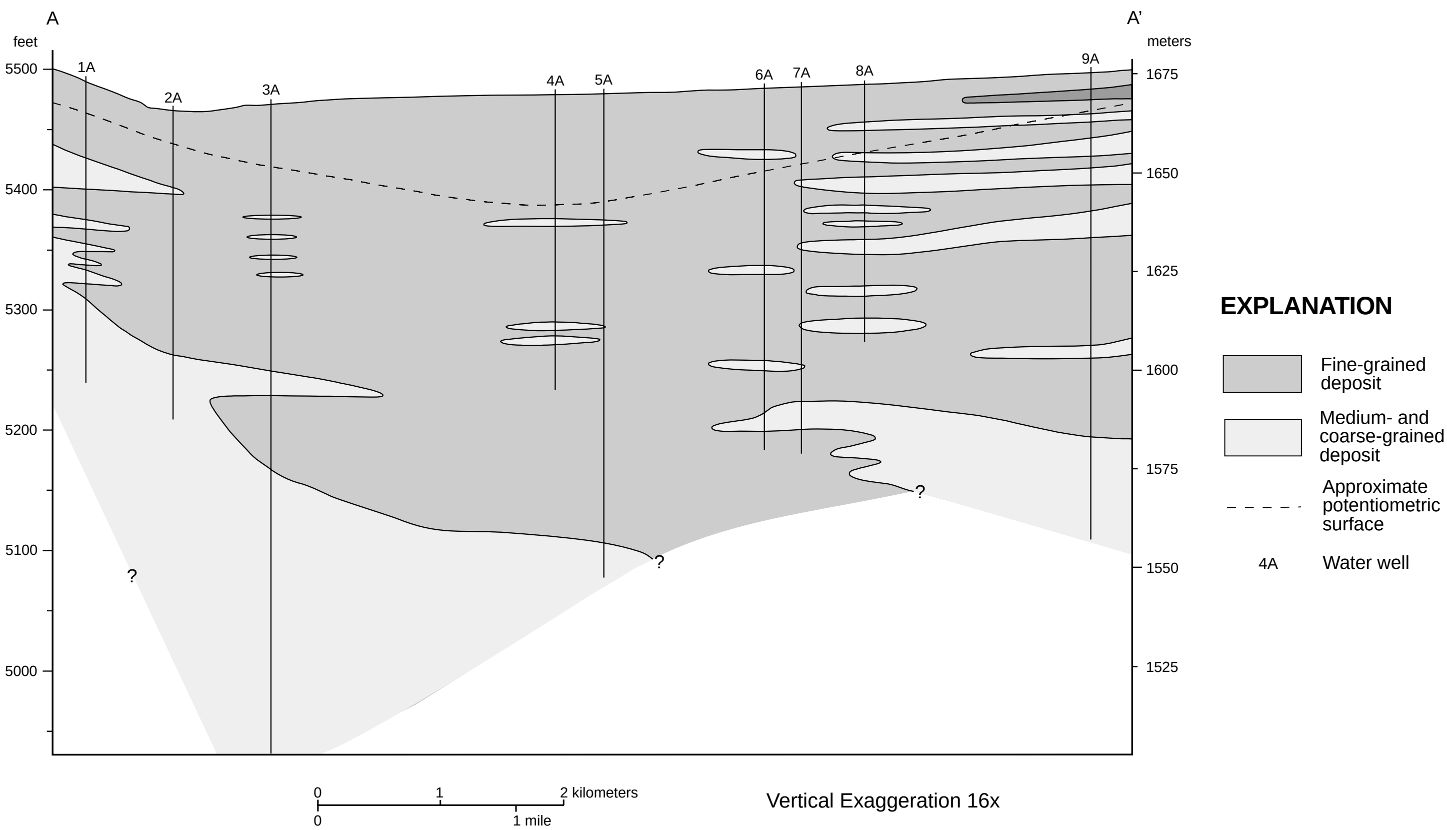

Figure 14. *Schematic geologic cross section of Bauers Knoll area, Cedar Valley, Iron County, Utah. Location of A-A′ shown on figure 15.*

hour, single-well, constant-discharge-rate aquifer test conducted from January 7 to January 8, 1999, by Sue Finstick, Bulloch Engineering. Bulloch Engineering also measured recovery of the well for an additional 24 hours from January 8 to January 9, 1999. The test used the existing pump in the well running at its maximum capacity. They measured discharge rates during the aquifer test using an in-line flow meter; rates were approximately constant at 165 gallons per

Table 7. *Nitrate data for Bauers Knoll area, Cedar Valley, Iron County, Utah.*

Well location	Well depth (feet)	Nitrate (mg/L)
(C-36-12)3aab	132	0.6
(C-36-12)9aaa	208	0.8
(C-36-12)3abb	no log	0.6
(C-36-12)2dbc	450	0.4
(C-36-12)11bcb	400	0.3
(C-36-12)10ada	389 (no log)	0.4
(C-36-12)11bda	304	0.2
(C-36-12)3ccd	538	0.8
(C-36-12)11aca	no log	0.3
(C-36-12)3dbb	517	0.5

minute (10.4 L/s). Bulloch Engineering monitored water levels in the well during the test using an electric tape. They measured a static (initial) water or piezometric level of 33.42 feet (10 m) below the top of the well casing before starting the aquifer test. We assumed that this water or piezometric level was horizontal and used this level for aquifer-test analysis.

Aquifer-test well and pump: The driller's log of the Mountain View Special Service District public water-supply well (appendix B), which was used for the single-well aquifer test, provided the following information. The well is located in the center of section 3, T. 36 S. R. 12 W., Salt Lake Base Line and Meridian (figure 15). The well was rotary drilled at an approximate surface elevation of 5,475 feet (1,669 m), with a 10- or 12-inch (25 or 30 cm) bit. The well was completed in November 1985 to a total depth of 517 feet (158 m). The well casing is 250 gage steel, welded at joints, and has a diameter of 8 inches (20 cm) from the surface to 517 feet (158 m). The casing was perforated from 375 to 571 feet (114-158 m) by mills knife. Perforation size is $^3/_{16}$ x $2^1/_2$ inches (0.5 x 6 cm). The well was gravel packed with $^3/_8$ inch gravel from 200 to 517 feet (61-158 m) and grouted (surface seal) from the surface to 200 feet (0-61 m) with cement.

The pump in the Mountain View Special Service District well is a 10-horsepower, three phase Grundfos brand stainless steel submersible pump. The pump is set at a depth of 130 feet (40 m). The maximum projected pumping rate is probably about 225 gallons per minute (14 L/sec).

Analysis: When the pump was turned on for the drawdown phase of the aquifer test, water was released down the well column. This prevented accurate water-level measurement during the early drawdown phase of the aquifer test (first minute); additionally, wellbore storage effects probably influenced the first two minutes of the test, resulting in a steeper slope than expected. After two minutes, this water-level problem ended. Therefore, we used water-level measurements taken during the rest of the drawdown phase of the aquifer test to calculate the transmissivity of the aquifer near the pumping well. Observed fluctuations or erratic behavior of the data was possibly caused by some water leaking out of the confining beds. The observed water-level change in the well was 16.08 feet (5 m) during the drawdown phase of the aquifer test.

We analyzed drawdown data from this aquifer test for hydrologic characteristics using standard techniques, including type-curve matching with Theis type curves, and a Cooper-Jacob semilogarithmic approximation method (Theis, 1935; Cooper and Jacob, 1946). We used the computer program AQTESOLV for Windows (Hydrosolve, 1996) in these evaluations. The Theis type curve and Cooper-Jacob semilogarithmic approximation method were for confined aquifer conditions. If the confining unit only leaks small amounts of water into the aquifer, the Theis method should produce reliable results. The Cooper-Jacob semilogarithmic approximation method is particularly applicable to data from production wells because drawdown in the well is heavily dependent on the pumping rate, and other factors used to calculate transmissivity thus quickly become less significant (Walton, 1988). Using these methods, we calculated a transmissivity of approximately 3,200 square feet per day (297 m^2/d) with both the Theis and Cooper-Jacob methods (figure 16). The recovery phase test data compared favorably to the drawdown data.

Results

Figure 17 shows a plot of projected nitrate concentration in the Bauers Knoll area of the Cedar Valley aquifer versus septic-tank density and number of septic-tank units. Average background nitrate concentration for the Bauers Knoll area is 0.49 mg/L (table 7, figure 15). Public records show approximately 10 septic systems exist in the Bauers Knoll area (Southwest Utah Public Health Department, written communication, 1999). The Bauers Knoll area is approximately 3,800 acres (15.5 km^2), so the average septic-system density is about 380 acres/system (1.5 km^2/system). Based on transmissivity calculations from the single-well aquifer test described above (Bulloch Engineering, written communication, 1999), estimated ground-water flow available for mixing in the Bauers Knoll area through a 2.3-mile (3.7 km) transect is 0.4 cubic feet per second (0.01 m^3/s) (figure 15). For this area to maintain an overall nitrate concentration of 1.49 mg/L (1.49 ppm), the total number of homes using septic tank soil absorption systems should not exceed 28 based on the best estimate nitrogen load of 40 mg/L per septic-tank system (figure 17). This corresponds to an increase of about 20 new septic systems and an average septic-system density of about 135 acres/system (0.55 km^2/system) in the Bauers Knoll area. If the acceptable level of degradation is raised and is based on the acceptable degradation nitrate level used for the Hamiltons Fort area, in order to maintain an overall nitrate concentration of 3.15 mg/L in this area, the total number of homes using septic tank soil absorption systems should not exceed 60 based on the best estimate nitrogen load of 40 mg/L per septic-tank system (figure 17). This corresponds to an increase of about 50 new septic systems and an average septic-system density of about 63 acres/system (0.25 km^2/system) for the Bauers Knoll area.

Figure 18 shows a plot of projected nitrate concentration in the Bauers Knoll area's aquifer versus septic-tank density and number of septic-tank systems assuming an existing number of 50 septic systems. We believe this is a more accurate estimate of the number of septic-tank systems in the area based on a windshield survey. As above, using an average background concentration for the Bauers Knoll area of 0.49 mg/L (table 7, figure 15) and an area of approximately 3,800 acres (15.5 km^2), the average septic-system density in this scenario is about 76 acres/system (0.31 km^2/system). The

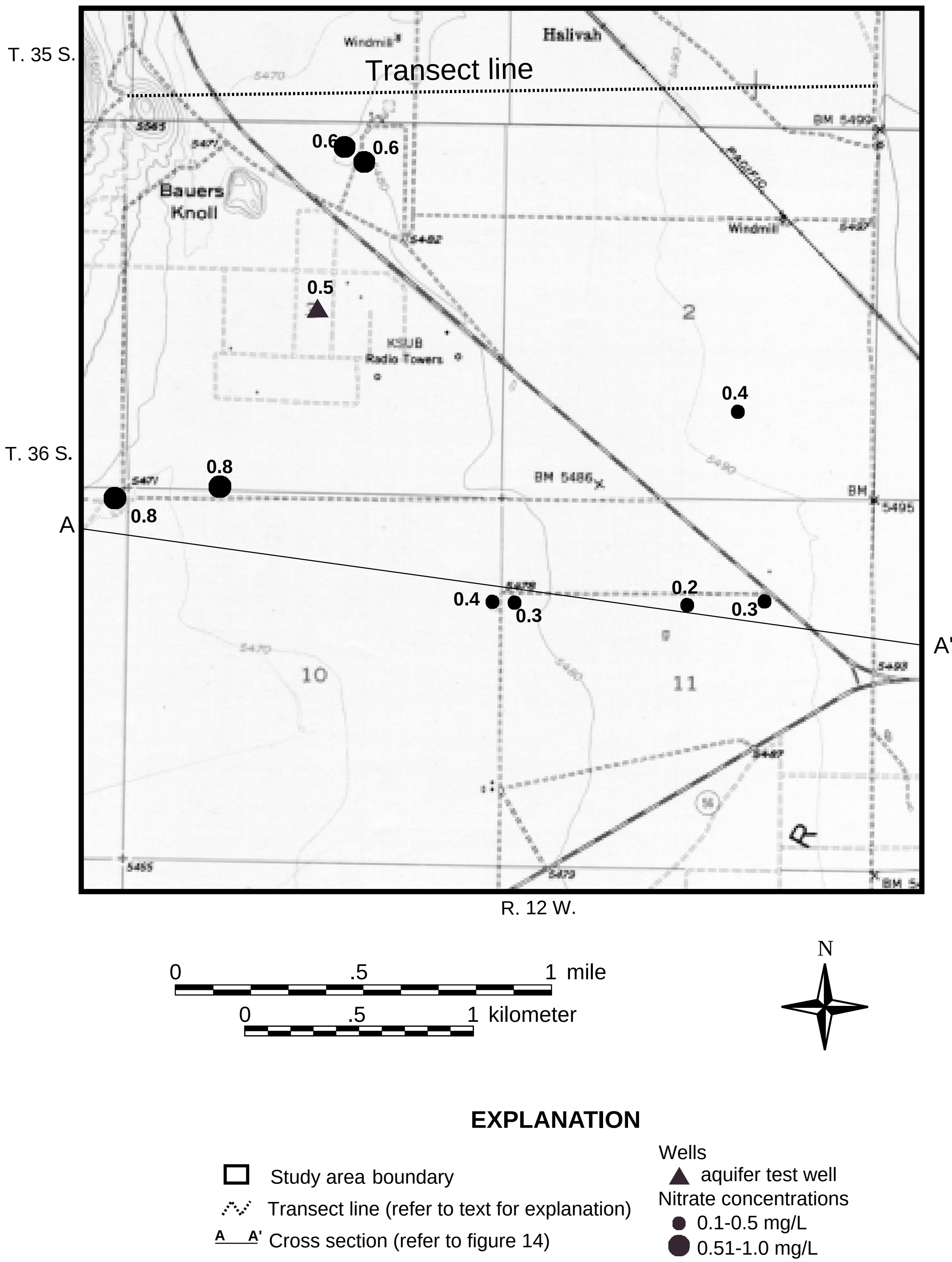

Figure 15. *Nitrate concentrations for the water wells in the Bauers Knoll area, Cedar Valley, Iron County, Utah.*

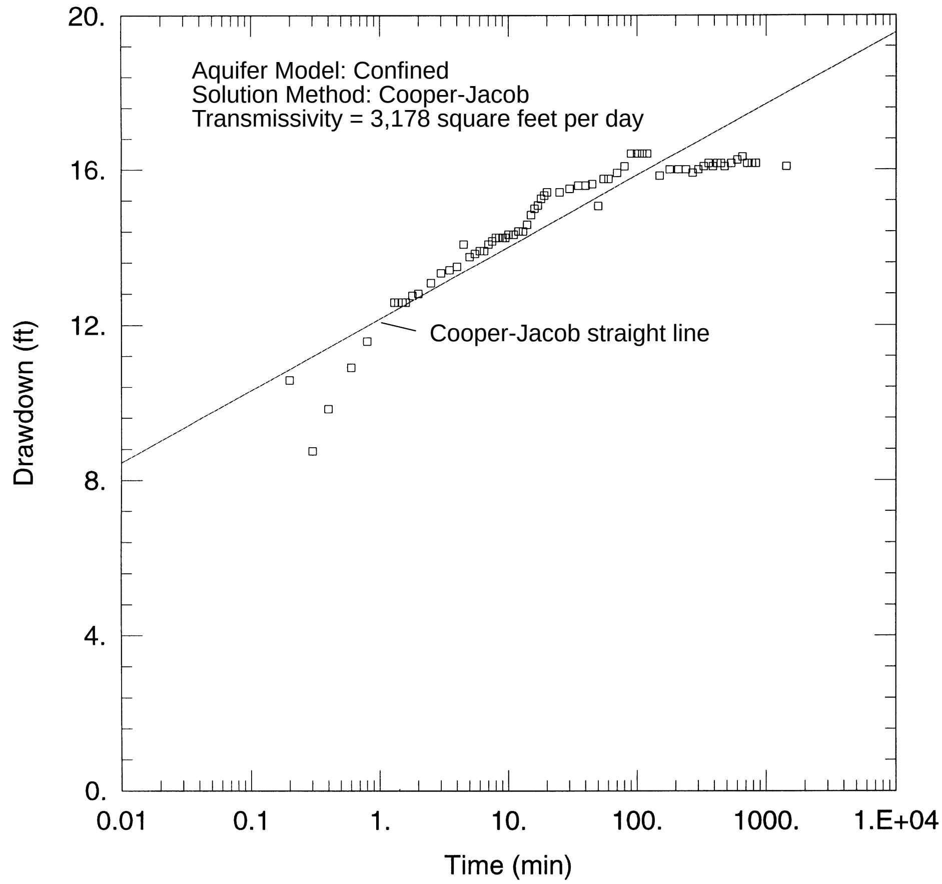

Figure 16. *Bauers Knoll area, drawdown data plot, Cedar Valley, Iron County, Utah.*

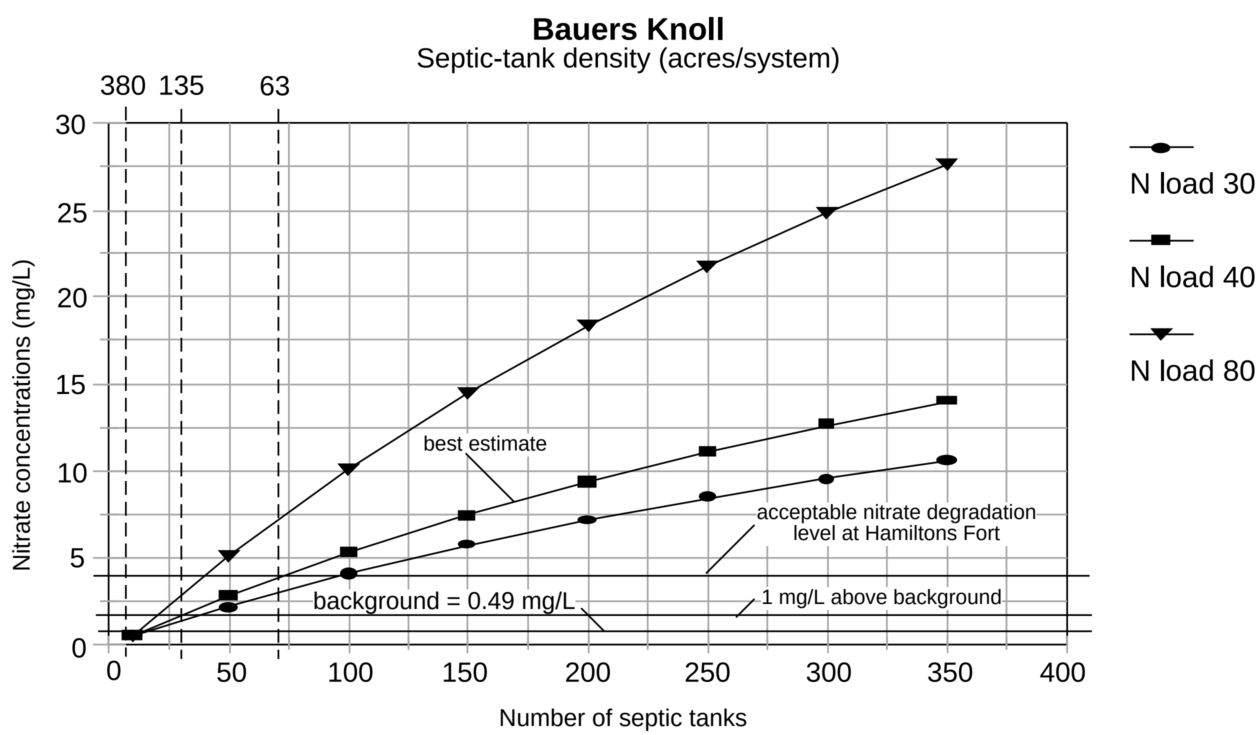

Figure 17. *Projected septic-tank system density versus nitrate concentration for the Bauers Knoll area in Cedar Valley, Iron County, Utah, based on 10 existing septic tanks. N load 30, N load 40, and N load 80 refer to the low, best estimate, and high nitrate loadings per liter of wastewater from septic-tank systems (Hansen, Allen, and Luce, Inc., 1994).*

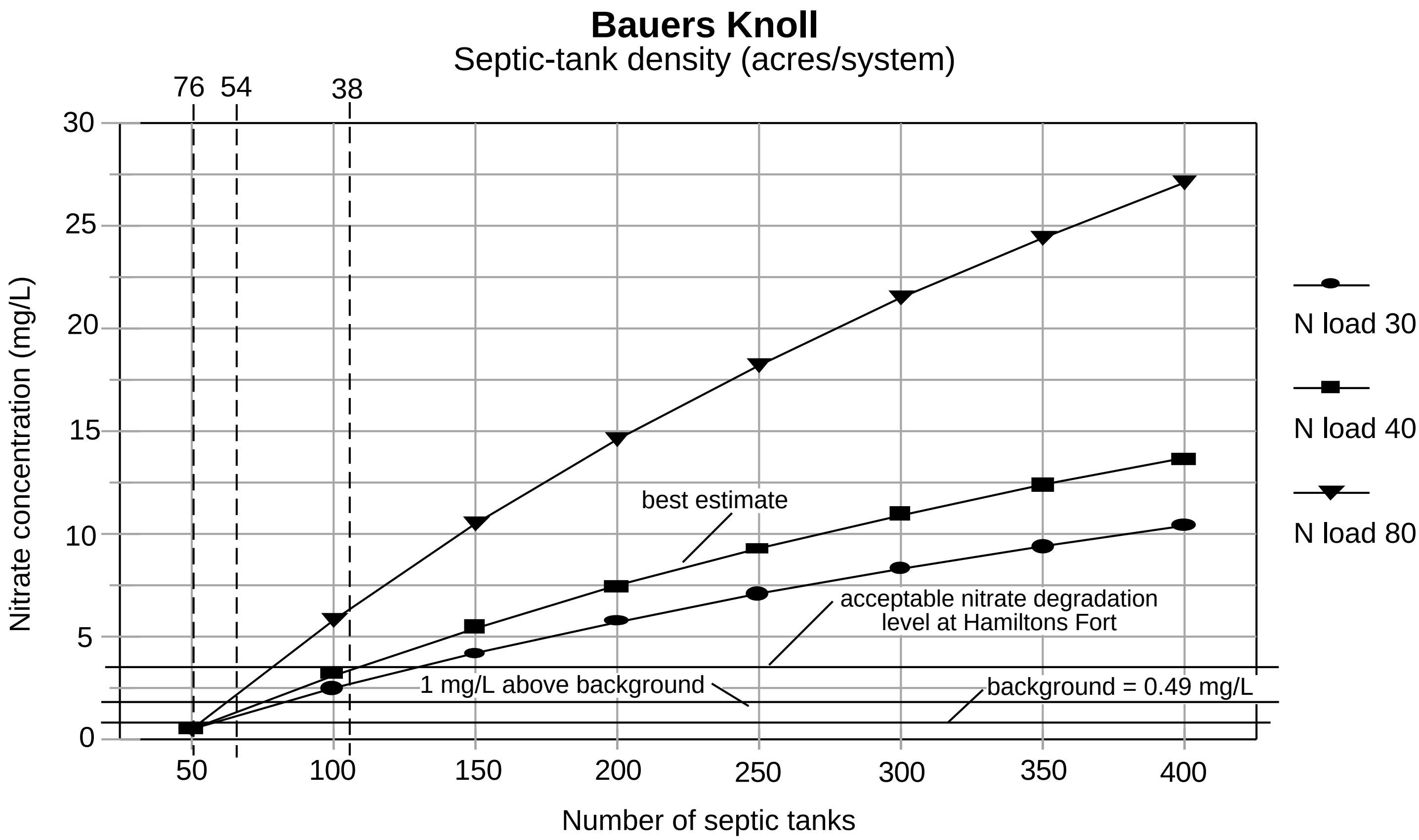

Figure 18. *Projected septic-tank system density versus nitrate concentration for the Bauers Knoll area in Cedar Valley, Iron County, Utah, based on 50 existing septic tanks. N load 30, N load 40, and N load 80 refer to the low, best estimate, and high nitrate loadings per liter of wastewater from septic-tank systems (Hansen, Allen, and Luce, Inc., 1994).*

estimated ground-water flow available for mixing through a 2.3-mile (3.7 km) transect (figure 15) in the Bauers Knoll area is 0.4 cubic feet per second (0.01 m^3/s). For the Bauers Knoll area to maintain an overall nitrate concentration of 1.49 mg/L, the total number of homes using septic tank soil-absorption systems should not exceed about 70 based on the best estimate nitrogen load of 40 mg/L per septic-tank system (figure 18). This corresponds to an increase of 20 new septic systems and an average septic-system density of about 54 acres/system (0.2 km^2/system) in the Bauers Knoll area. Again, if we use an acceptable level of degradation based on the acceptable degradation nitrate level used for the Hamiltons Fort area, in order to maintain an overall nitrate concentration of 3.15 mg/L in the Bauers Knoll area, the total number of homes using septic tank soil-absorption systems should not exceed 100 based on the best estimate nitrogen load of 40 mg/L per septic-tank system (figure 18). This corresponds to an increase of 50 new septic systems and an average septic-system density of about 38 acres/system (0.15 km^2/system) for the Bauers Knoll area.

Recommendations for Land-Use Planning

We believe the second scenario presented above, allowing only 1 mg/L degradation with respect to nitrate, is the most appropriate one to be applied to the Bauers Knoll area, because 50 is a more correct estimate of the current number of septic-tank systems in the area based on our field reconnaissance. In this area of Cedar Valley, lots using septic-tank systems for wastewater disposal should be no smaller than 54 acres (0.2 km^2). The area could be served by an existing valley-wide public sanitary sewer system; this is the most appropriate option for domestic wastewater disposal.

Mid Valley Estates Area

Location and Area

The Mid Valley Estates area (figure 19) is located in central Cedar Valley just west southwest of Enoch (figure 1). It consists of approximately 640 acres (2.6 km^2) in sections 8 and 9, T. 35 S., R. 11 W., Salt Lake Base Line and Meridian. The land surface slopes gently to the north and northwest.

Surficial Geology

The Mid Valley Estates area is located on basin-fill deposits in an area away from bedrock uplands. These basin-fill deposits contain both fine-grained (silt, clay, and fine sand) and coarse-grained (sand and gravel) facies. The coarse-grained facies in the basin-fill deposits contain chert, sandstone, limestone, and igneous clasts with traces of carbonaceous material and gypsum. Therefore, the basin fill

Figure 19. *View of Mid Valley Estates area looking toward the southeast.*

underlying the Mid Valley Estates area was likely deposited during periodic major flooding events from both the east and west, although sedimentation from Coal Creek during major flooding events likely predominates. Because of the multiple sources of deposition to this area, the sediment underlying the area is derived from a combination of all of the rock units discussed in both the Hamiltons Fort and Bauers Knoll areas. Based on the limited extent of the modern alluvial fans to the east and west of the Mid Valley Estates area and the episodic nature of modern flooding events from Coal Creek, we believe that much of the upper part of the basin fill was deposited during the Pleistocene under wetter climatic conditions.

Ground-Water Conditions

Occurrence: Ground water in the Mid Valley Estates area occurs under mostly confined conditions in unconsolidated basin-fill deposits (Bjorklund and others, 1978). Based on water well data, the deepest well in the area is 550 feet (168 m) and penetrates clay and silt in the upper layers and clay, silt, and sand with minor coarser gravel at depths greater than 100 feet (30 m). Gravel is more abundant in wells located to the east of the study area. Alluvial silts and clays dominate the basin-fill deposits near the surface and are common at depths less than 100 feet (30 m). Below 100 feet (30 m), the sediments consist of discontinuous bodies of clay/silt, and sand/gravel (figure 20). Available data indicate that vertical ground-water gradients in the area may be upward in some wells, in spite of the large proportion of coarse sediment in the basin fill.

Depth and transmissivity: Depth to ground water in wells is variable. Well depths range from 195 to 550 feet (59-168 m). Water levels, reported from drillers' logs of water wells sampled from various years and seasons, range from 20 to 42 feet (6-13 m), and average about 24 feet (7 m). Most wells have a static water level that is less than 100 feet (30 m) below the land surface. Bulloch Engineering (1998) estimated a transmissivity of about 12,000 square feet per day (1,115 m^2/d) from an aquifer test on a well completed in the confined portion of the basin-fill aquifer.

Ground-water flow: Ground-water flow is generally from the higher elevation recharge areas to lower elevation areas. Recharge is likely largely from Fiddlers Canyon situated due east of the site. Ground-water flow in the Mid Valley Estates area is generally to the north toward Rush Lake and then west toward Iron Springs Gap. Hydraulic gradients are generally flat in the central, lower elevation areas of Cedar Valley.

Existing Nitrate Concentrations

Ground water from two wells in the Mid Valley Estates area was sampled and analyzed for nitrate concentration during the 1980s. Drillers' logs are available for both of the wells (appendix A). Depth of completed wells ranges from 300 to 465 feet (91-142 m), and the wells generally penetrate mixed clay, silt, and sand layers, with minor sand and gravel beds. Nitrate values range from 0.6 to 0.72 mg/L (table 8, figure 21), with an average nitrate concentration of 0.66 mg/L. No wells have nitrate concentrations that exceed the Utah drinking water standard of 10 mg/L, although some wells to the east-northeast in the Enoch area do yield water with nitrate concentrations greater than 10 mg/L.

Aquifer Test

General: To obtain transmissivity and other information about the aquifer in the Mid Valley Estates area, we used a 19-hour, single-well, constant-discharge-rate aquifer test conducted from November 10 to November 11, 1998, by Sue Finstick, Ron Larson, Russ Applegate, Jared Baker, and Emily Bartlett of Bulloch Engineering, Cedar City, Utah. The test used the existing pump in the well running at its

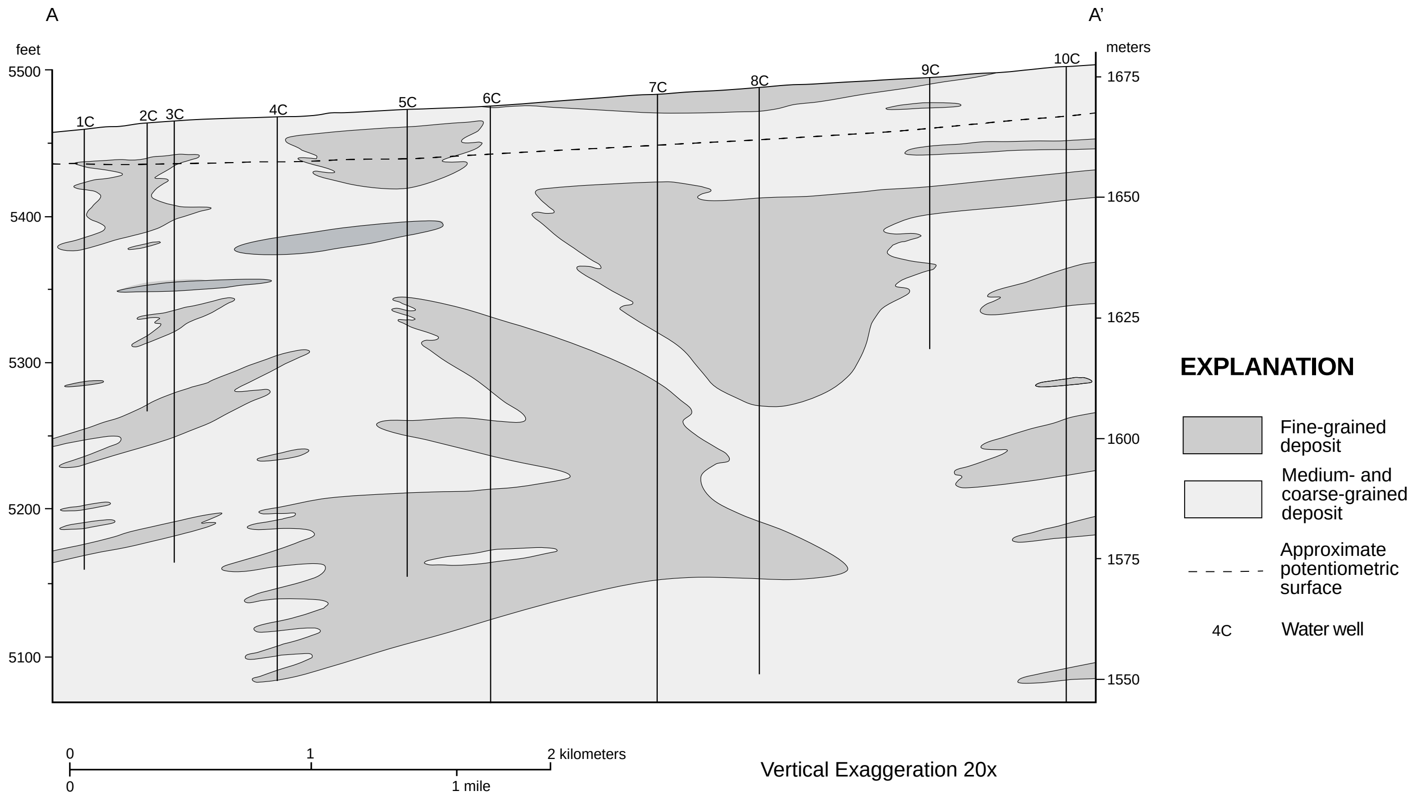

Figure 20. *Schematic geologic cross section of Mid Valley Estates area, Cedar Valley, Iron County, Utah. Location A-A′ shown on figure 21.*

Table 8. *Nitrate data for Mid Valley Estates area, Cedar Valley, Iron County, Utah.*

Well location	Well depth (feet)	Nitrate (mg/L)
(C-35-11)9abc	465	0.6
(C-35-11)8cdd-1	300	0.72

maximum capacity. Bulloch Engineering measured discharge rates during the aquifer test using an in-line flow meter; rates were approximately constant at 237 gallons per minute (15 L/s). Bulloch Engineering also measured recovery of the well for an additional 21 hours from November 11 to November 12, 1998. Bulloch Engineering monitored water levels in the well during the test using an electric tape. Before starting the aquifer test, Bulloch Engineering measured a static (initial) water or piezometric-surface level of 30.67 feet (9 m) below the top of the well casing. We assumed that this water or piezometric-surface level was horizontal, and we used this water level for the aquifer-test analysis.

Aquifer-test well: The driller's log provided the following information regarding the Angus Water Company well (appendix B) used in the Mid Valley Estates area aquifer test. The well is in the NW1/4 NW1/4 NE1/4 section 9, T. 35 S., R. 11 W., Salt Lake Base Line and Meridian (figure 21). The well was rotary drilled at a surface elevation of about 5,476 feet (1,669 m) with a 24-inch (61 cm) bit. It was completed at a total depth of 465 feet (142 m) as a municipal water well in December 1998. The well's casing is 250-gage, 12-inch-diameter (30 cm) steel with welded joints. Perforated intervals for the well are at 180 to 265 feet (55-81 m) and 345 to 465 feet (105-142 m). The perforations are 1/8 x 2.5 inches (0.32 x 6 cm) and were done by mills knife. The top of the well casing is about 8 inches (20 cm) above a cement collar. The well is equipped with a plug in the well cap that allows a probe to be inserted between the discharge tube and the well casing for water-level measurements. A surface seal was constructed from the surface to a depth of 100 feet (30 m), and a filter consisting of pea gravel was installed from 105 to 465 feet (32-142 m). No information is known about the pump.

Analysis: Water-level measurements during the early drawdown phase of the aquifer test (first minute) were scattered. This was probably due to wellbore storage effects and the release of water in the well column. After about one minute, the water level in the well stabilized and water-level measurements taken during the rest of the drawdown phase of the aquifer test were used in determining the transmissivity of the aquifer near the pumping well. The effect of leakage on the drawdown curve is expressed by the rapid decrease of the rate of water-level decline as the cone of depression spread. The curve flattens within 500 minutes of the start of the test as more of the discharge is derived from leakage and the water level stabilizes. At approximately this point, the well discharge is balanced by leakage from the semi-confining layer. The observed water-level change in the well was 56.75 feet (17 m) during the drawdown phase of the aquifer test.

Water-level measurements could not be made during the first two minutes of the recovery phase of the aquifer test, because of water falling back into the well when the pump was turned off. After about two minutes, the water level in

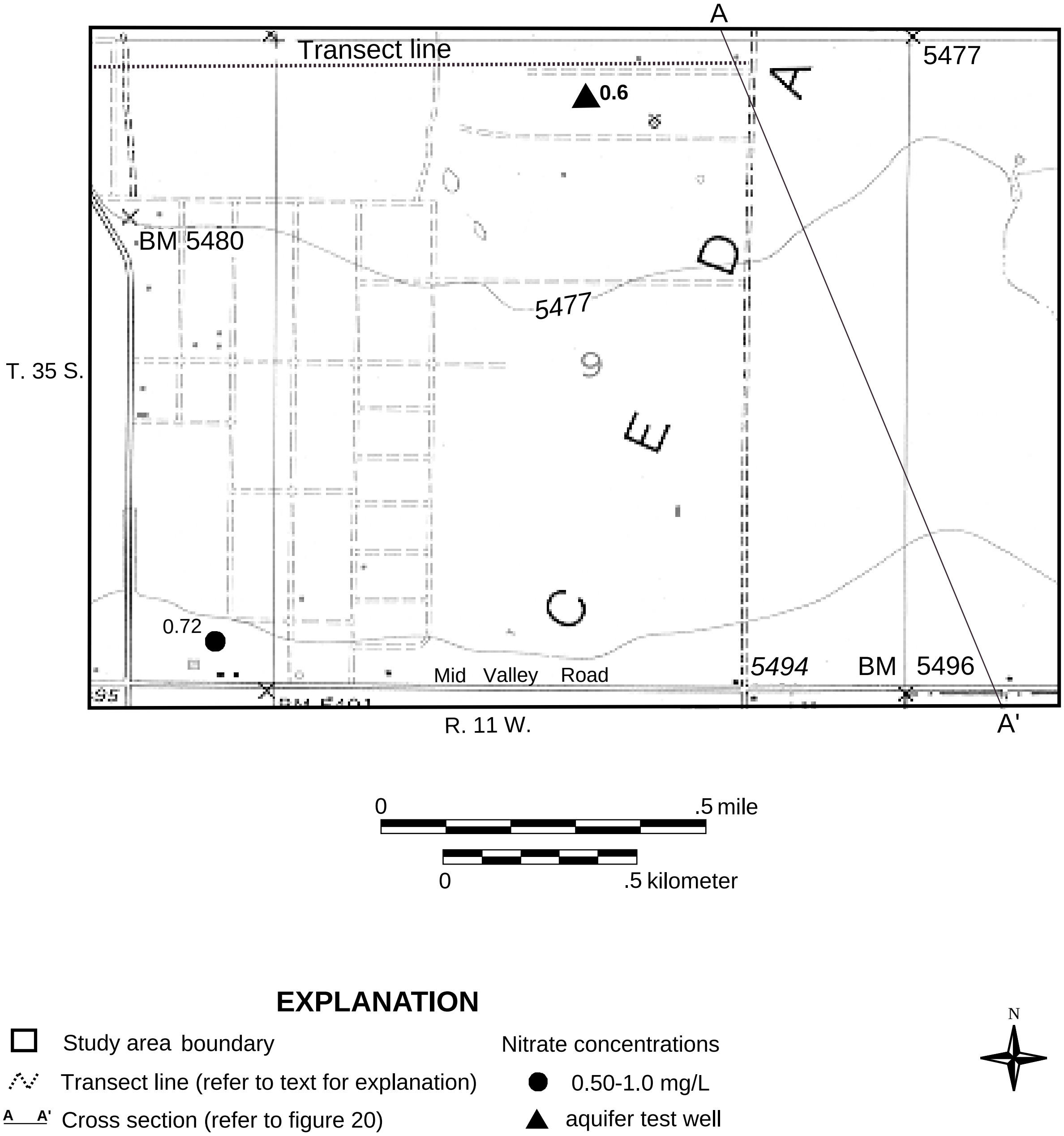

Figure 21. *Nitrate concentrations for the water wells in the Mid Valley Estates area, Cedar Valley, Iron County, Utah.*

the well stabilized and water-level measurements were taken during the rest of the recovery phase of the aquifer test and were used in determining the transmissivity of the aquifer near the pumping well. The water level recovered rapidly then leveled off to a steady rate of recovery. The observed water-level change in the well was 55.59 feet (17 m) during the recovery phase of the aquifer test (within 5 percent of the drawdown). The recovery data were used only to compare with the drawdown data.

We analyzed drawdown data from this aquifer test for hydrologic characteristics using standard techniques, including type-curve matching with Moench type curves for a leaky aquifer, and a Cooper-Jacob semilogarithmic approximation method (Moench, 1985; Cooper and Jacob, 1946). The Cooper-Jacob method is particularly applicable to data from production wells because drawdown in the well is heavily dependent on the pumping rate and the well's radius of influence is small; in this situation the Cooper-Jacob approximation is an appropriate solution to the drawdown curve (Walton, 1988). If the confining layer leakage is small then the Cooper-Jacob approximation should produce reliable results. We used the computer program AQTESOLV for Windows (Hydrosolve, 1996) in these evaluations. Using these methods, we calculated transmissivities of 830 square feet per day (76 m^2/d) with the Cooper-Jacob approximation, and 925 square feet per day (85 m^2/d) with the Moench method on the drawdown phase data, respectively. However, the Cooper-Jacob approximation was a very poor fit to a straight line, indicating leakage from the semi-confining layer. The transmissivity from the Moench method was used in the evaluation of septic-tank densities (figure 22).

Results

As at Hamiltons Fort and Bauers Knoll, we plotted projected nitrate concentration versus septic-tank density and number of septic-tank systems in the Mid Valley Estates area of Cedar Valley. Because the hydrogeologic setting for Mid Valley Estates area is unlike the other site-specific areas, we considered a different scenario for this region than the other two wetter areas of the valley. Average background nitrate concentration for the Mid Valley Estates area is 0.66 mg/L (table 8). Approximately 195 septic systems are on record in the Mid Valley Estates subdivision area (Southwest Utah Public Health Department, written communication, 2000). The Mid Valley Estates area is approximately 650 acres (2.6 km^2), so the average existing septic-system density is 3.3 acres/system (.013 km^2/system). Based on the aquifer test described above (table 6), estimated ground-water flow available for mixing in Mid Valley Estates area through a 1-mile (1.6 km) transect of the subdivision area (figure 21) is 0.045 cubic feet per second (0.001 m^3/s). The amount of water for dilution in this area is considerably lower than the other two study areas and the number of septic-tank systems considerably greater; the amount of flow from septic-tank systems is almost three times the amount from natural flow (table 9).

We do not believe that the mass-balance approach is applicable under a scenario in which effluent from septic-tank systems exceeds ground-water available for mixing; it is a graphical approach for determining how many new systems can be added based on dilution of nitrate from effluent by water, and cannot provide the number of systems that should be removed to reduce the concentration of nitrate from effluent to various levels. Therefore, we applied the mass-balance approach in a different manner by recalibrating parameters for the mass-balance equation assuming predevelopment conditions (that is, beginning with zero septic-tank systems), but using the current amount of water available for mixing and a typical background nitrate concentration of 0.6 mg/L. This computation shows that, if the mass-balance approach had been applied prior to development, the recommended total number of septic systems in this area with negligible flow, based on a 1 mg/L allowable degradation of nitrate concentration from 0.66 to 1.66 mg/L, would be two.

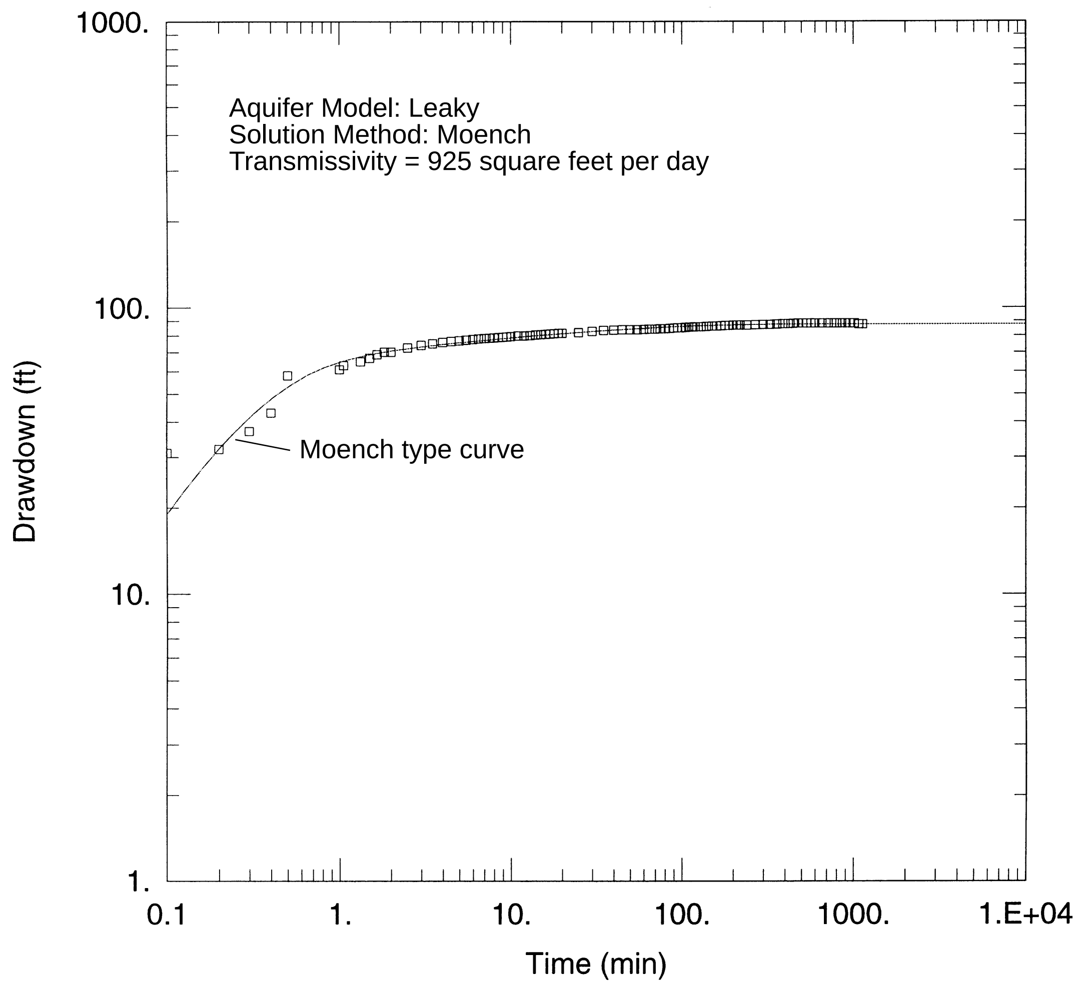

Figure 22. *Mid Valley Estates area, drawdown data plot, Cedar Valley, Iron County, Utah.*

Table 9. *Ground-water flow available for mixing versus amount of effluent from septic tanks in Cedar Valley, Iron County, Utah.*

Study Area	Flow, Q(cfs)	Number of Septic Tanks	Ratio of flow to septic tanks
Hamiltons Fort	15	100	~240X from Q
Bauers Knoll	0.4	50	~13X from Q
Mid Valley Estates	0.0045	195	~3X from septic tanks

Recommendations for Land-Use Planning

The mass-balance calculation indicates that in an area having minimal recharge, such as the Mid Valley Estates area, the use of septic-tank systems is not advisable. However, in the Mid Valley Estates area, there is an apparent upward vertical ground-water gradient that provides some protection to the underlying drinking-water aquifer. The mass-balance approach is probably not the best land-use management tool in this scenario. The Mid Valley Estates area currently has more than the recommended amount of septic tanks already established; in order to prevent potential ground-water contamination into the aquifer by effluent from septic-tank systems, one option is to maintain this upward vertical ground-water gradient in the aquifer, including during pumping of the public-supply well located at the eastern margin of the subdivision, as well as other nearby wells. This option would require agreements regarding pumping rates and volume extractions in the Mid Valley Estates area. If this option is implemented, we recommend that one or more monitoring wells completed in the upper part of the shallow, unconfined saturated zone be established within the area for use in verifying vertical head-gradient direction and monitoring it over time. We also recommend evaluating any nearby seeps located within 1,000 feet (300 m) of the area's borders. This distance is based on a local 250-day ground-water travel time, which is how long some of the longer lived biological contaminants can survive in the natural environment and present risk to humans. Perhaps the most beneficial option is to provide a community sanitary sewer system to the area and eliminate septic-tank systems for wastewater disposal.

Discussion

The graphs of projected nitrate concentration versus number of septic-tank systems and septic-tank density for each area are summarized in table 10. For the Hamiltons Fort area, the total number of septic tanks can be as great as 760 based on the amount of ground water available for dilution and approximately 100 existing septic systems. This corresponds to a septic-tank density of 5.6 acres/system (0.02 km^2/system). In the Bauers Knoll area, where the amount of ground water available for mixing and the existing number of septic-tank systems is lower, the total number of septic tanks can be as great as 100 or as low as 28 depending primarily on the number of existing septic systems and the chosen acceptable level of degradation of nitrate concentration. This corresponds to septic-tank densities of 38 and 135 acres/system (0.44-0.55 km^2/system), respectively. However, a total of 70 septic-tank systems, corresponding to an allowable increase of 20 new systems and an average septic-tank density of 54 acres/system (0.2 km^2/system), represents in our judgement the result based on the most realistic combination of variables applied in the calculations (50 currently existing systems in the approximately 3,800-acre [15.5 km^2] area) and an allowable degradation of ground-water quality with respect to nitrate of 1 mg/L.

We do not consider the mass-balance approach to be the best land-use management tool for the Mid Valley Estates area, where the amount of water from septic-tank effluent is three times more than the ground-water flow available for mixing, and the little available evidence indicates that the aquifer in this area may have an upward vertical-head gradient. Until the area can be connected to a sanitary sewer system, we recommend verifying that there is an upward vertical head gradient by establishing one or more monitoring wells into the shallow, unconfined saturated zone, managing ground-water withdrawals in the area to maintain the upward vertical-head gradient if it is verified that it exists, and monitoring seeps to ensure that effluent is not surfacing and presenting a danger of microbial contamination.

The drinking-water aquifers beneath all three study sites are under confined or semi-confined conditions due to the presence of relatively thick fine-grained layers in the basin fill. These fine-grained layers may provide some retardation of vertical ground-water movement in the mixing zone to depths from which most ground-water withdrawal from wells is occurring. However, the presence of nitrate in water from wells sampled in the Hamiltons Fort area may be evidence that water in the mixing zone is reaching the aquifer at depths tapped by domestic water wells. The confining or semi-confining units in this area likely do not attenuate or act as barriers to the downward movement of the septic-tank effluent. In general, insufficient information about the confining unit or ground-water gradients in the study areas exists to assess the possibility of effluent reaching the principal aquifer, although some evidence indicates there may be an upward vertical ground-water gradient in the Mid Valley Estates subdivision area at the perforation depth of the Angus Water Company well. In some areas, a natural downward ground-water gradient through the confining units may exist; under these conditions the confining units may slow the downward movement of the effluent, but not stop it. Heterogeneities within semi-confining and confining units, such as a sporadic distribution of sand and gravel lenses, may allow the communication of the septic-tank effluent with the principal aquifer within a relatively short time. Additionally, large pumping wells in the study areas could induce or increase local downward ground-water gradients and potentially cause movement of effluent through the confining unit. Wells themselves can also provide a path for effluent to reach the aquifer below the mixing zone via the well bore.

Ground-water flow available for mixing (table 10) is the primary factor determining recommended septic-system density/lot size using the mass-balance approach. Due to the greater amount of ground water available for mixing in the southeastern area of Cedar Valley in the Hamiltons Fort area, a greater number of septic systems can exist compared to the southwestern area of Cedar Valley in the Bauers Knoll area. Few septic-tank systems could be established in central Cedar Valley if the mass-balance approach was applied because of very low amounts of ground-water available for mixing. Because Cedar Valley has an arid climate and a relatively low rate of ground-water recharge, the overall amount of ground water available for mixing is relatively low and a public valley-wide sewer system is likely the best alternative for domestic wastewater disposal in most situations.

SUMMARY AND CONCLUSIONS

Cedar Valley is a rural area in southwestern Utah experiencing an increase in residential development. Much of this development is situated on unconsolidated deposits of the principal valley-fill aquifer and uses septic tank soil-absorption systems for wastewater disposal. Septic tank soil-absorption systems are considered one of the major potential sources of water-quality degradation, and public officials would like to have a scientific basis for determining recommended densities/lot sizes for septic-tank systems as a land-use planning tool. To evaluate the potential impact of septic-tank systems on ground-water quality and determine appropriate average development densities (lot sizes), we performed site-specific mass-balance-approach evaluations of three areas in Cedar Valley; these evaluations can be used as models for other similar evaluations of proposed subdivisions in Cedar Valley.

Ground water in the Cedar Valley area is obtained principally from unconsolidated deposits of the basin-fill aquifer (Thomas and Taylor, 1946; Sandberg, 1966; Bjorklund and others, 1978) where it occurs under confined, unconfined, and perched conditions (Bjorklund and others, 1978). The Quaternary basin fill consists primarily of alluvial sediments interbedded with lava flows and contains some lacustrine and eolian deposits (Bjorklund and others, 1978). The basin fill is estimated to be at least 1,000 feet (300 m) thick (Thomas and Taylor, 1946; Anderson and Mehnert, 1979), but may be as much as 3,900 feet (1,200 m) thick in the eastern part of the complexly faulted Cedar Valley graben (Cook and Hardman, 1967). The basin-fill aquifer is generally under unconfined conditions along the higher elevation margins of Cedar Valley where it typically consists of coarse, granular, permeable sediments (Bjorklund and others, 1978), but is generally under confined conditions in the lower elevation valley center where sediments are typically finer grained and less permeable.

Ground-water flow is generally from higher elevation recharge areas to lower elevation discharge areas. Most recharge to the basin-fill aquifer is from precipitation within the Cedar Valley drainage basin (Sandberg, 1966). Ground water is discharged from springs and seeps, evapotranspiration, wells, and subsurface outflow from the area (Sandberg, 1966), with wells being the greatest source of discharge (Utah Division of Water Resources, 1997). Ground-water quality in Cedar Valley is generally good and, although classified as hard, is suitable for most uses (Utah Division of Water Resources, 1995), although nitrate has been identified as a contaminant in previous studies (Joe Melling, Cedar City Manager, verbal communication,1997).

We applied the mass-balance approach to three areas in Cedar Valley (the Hamiltons Fort, Bauers Knoll, and Mid Valley Estates areas) using ground-water flow available for mixing and ground-water-quality data unique to each area to help determine recommended septic-system density/lot size. Ground water in the Hamiltons Fort area occurs under mostly leaky confined conditions in unconsolidated basin-fill deposits. Ground-water-flow direction in the Hamiltons Fort area is generally to the east, toward Quichapa Lake. Nitrate values from ground water in 14 sampled wells range from 0.1 to 7.46 mg/L, with an average nitrate concentration of 2.15 mg/L. We used a 48-hour, multiple-well, constant-discharge-rate aquifer test and analyzed the drawdown data using the Hantush type curves to calculate a transmissivity of 20,894 square feet per day (1,932 m^2/d). For our most realistic scenario, we use an existing number of 100 septic systems and a background nitrate concentration of 2.15 mg/L. Estimated ground-water flow available for mixing through a 3.5-mile (5.6 km) transect in the lower reaches of the alluvial fan in the area is 15 cubic feet per second (0.42 m^3/s). For the

Table 10. *Results of septic-tank density calculations for Hamiltons Fort, Bauers Knoll, and Mid Valley Estates study areas, Cedar Valley, Iron County, Utah (Nbmt*- not the best management tool) (Q* is the volume of water available for mixing).*

Study Area	**Acre/System**	**# Septic Tanks**	**New Lots**	**Q***
Hamilton's Fort	~5.6	760	660	15cfs
Bauers Knoll (nitrate 1.49 mg/L)	~54	70	20	0.4cfs
(nitrate 3.15 mg/L)	~38	100	50	0.4 cfs
Mid Valley Estates	nbmt*	195	—	0.045 cfs

Hamiltons Fort area to maintain an overall nitrate concentration of 3.15 mg/L, the total number of homes using septic tank soil-absorption systems should not exceed about 760 based on the best-estimate nitrogen load of 40 mg/L per septic-tank system (figure 12). This corresponds to an increase of approximately 660 septic systems and an average septic-system density of about 5.6 acres/system (0.02 km^2/system).

Ground water in the Bauers Knoll area east of the Eightmile Hills occurs primarily under confined conditions in unconsolidated basin-fill deposits (Bjorklund and others, 1978). Ground water flow is generally from the higher elevation recharge areas to lower elevation areas and then to the north, toward Iron Springs Gap. Nitrate values in ground water from 10 sampled wells range from 0.2 to 0.8 mg/L (0.2-0.8 ppm), with an average nitrate concentration of 0.49 mg/L. We used a 24-hour, single-well, constant-discharge-rate aquifer test and analyzed the drawdown data using the Cooper-Jacob semilogarithmic approximation methods to calculate a transmissivity of 3,148 square feet per day (291 m^2/d). For our most realistic scenario, we use an existing number of 50 septic systems and a background nitrate concentration 0.49 mg/L. Estimated ground-water flow available for mixing through a 2.3-mile (3.7 km) transect in the area is 0.4 cubic feet per second (0.01 m^3/s). For the Bauers Knoll area to maintain an overall nitrate concentration of 1.49 mg/L, the number of septic tank soil-absorption systems should not exceed about 70 based on the best-estimate nitrogen load of 40 mg/L per septic-tank system (figure 18). This corresponds to an increase of approximately 20 septic systems and an average septic-system density of about 54 acres/system (0.2 km^2/system). Septic-system density could be increased if higher levels of water quality degradation were deemed acceptable.

Ground water in the Mid Valley Estates subdivision area occurs primarily under confined conditions in unconsolidated basin-fill deposits (Bjorklund and others, 1978), and the little available evidence indicates that there may be an upward vertical ground-water gradient at the depths from which drinking water is withdrawn in this area. Ground-water flow is generally from the higher elevation recharge areas northward to lower elevation areas. Nitrate values from two sampled wells are 0.6 and 0.72 mg/L, with an average nitrate concentration of 0.66 mg/L. We used a 19-hour, single-well, constant-discharge-rate aquifer test and analyzed drawdown data using Moench type curves for a leaky aquifer to calculate a transmissivity of 925 square feet per day (85 m^2/d). Ground-water flow available for mixing in the Mid Valley Estates subdivision is considerably lower than in the Hamiltons Fort and Bauers Knoll areas. Existing septic-tank systems are producing three times more water than natural ground-water flow available for mixing. The area is already producing more septic-tank effluent than can effectively be diluted and there is an apparent upward vertical-head gradient, therefore the mass-balance approach is not the best management tool to be applied in this area. We recommend verifying that there is an upward vertical-head gradient by establishing one or more monitoring wells in the shallow, unconfined saturated zone, managing ground-water withdrawals in the area to maintain the upward vertical-head gradient if it is verified that it exists, and monitoring seeps to ensure that effluent is not surfacing and presenting a danger of microbial contamination until the area can be connected to a sanitary sewer system.

Ground-water flow available for mixing is the primary factor determining recommended septic-system density/lot size using the mass-balance approach. Due to the greater amount of ground-water available for mixing in the southeastern part of Cedar Valley in the Hamiltons Fort area, a greater number of septic systems can exist there than in the southwestern and central parts of Cedar Valley in the Bauers Knoll and Mid Valley Estates areas. However, because Cedar Valley is an arid area having relatively low ground-water recharge, overall ground-water flow available for mixing is relatively small and a public valley-wide sewer system is likely the best alternative for domestic wastewater disposal in most situations.

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APPENDIX A

Drillers' Logs of Sampled Wells

Utah Division of Water Rights
Water Well Log

LOCATION: N 2060 ft E 500 ft from SW CORNER of SECTION 24 T 36S R 12W BASE SL Elevation: feet

DRILLER ACTIVITIES:
ACTIVITY: # 1 NEW WELL
DRILLER: GARDNER DRILLING LICENSE #: 492
START DATE: 11/15/1994 COMPLETION DATE: 12/07/1994

BOREHOLE INFORMATION:

Depth(ft) From	To	Diameter(in)	Drilling Method	Drilling Fluid
0	400	14.5	R ROTARY	WATER

LITHOLOGY:

Depth(ft) From	To	Lithologic Description	Color	Rock Type
0	5	SILT		
5	70	CLAY		
70	73	SAND, GRAVEL		
73	90	CLAY		
90	125	GRAVEL, COBBLES		
125	128	CLAY		
128	160	SAND, GRAVEL		
160	170	CLAY, SAND		
170	198	CLAY		
198	204	SAND, GRAVEL		
204	235	GRAVEL, COBBLES		
235	255	CLAY		
255	283	GRAVEL, COBBLES		
283	295	CLAY		
295	306	CLAY, SAND, GRAVEL		
306	376	SAND, GRAVEL		
376	400	CLAY, SAND, GRAVEL		

WATER LEVEL DATA:

Date	Time	Water Level (feet) (-)above ground	Status
12/07/1994		60.00	STATIC

CONSTRUCTION - CASING:

Depth(ft) From	To	Material	Gage(in)	Diameter(in)
1	400	STEEL	.280	8.00

CONSTRUCTION - SCREENS/PERFORATIONS:

Depth(ft) From	To	Screen(S) or Perforation(P)	Slot/ Perforation Size	Screen Diameter/ Length Perforation(in)	Screen Type/ # Perforation
360	380	PERFORATION	.187	2.50	

CONSTRUCTION - FILTER PACK/ANNULAR SEALS

Depth(ft) From	To	Material	Amount	Density(pcf)
0	100	CEMENT		
100	140	PEA GRAVEL		
140	150	BENTONITE HOLE PLUG		
150	400	PEA GRAVEL		

Utah Division of Water Rights
Water Well Log

LOCATION: N 2740 ft E 2740 ft from SW CORNER of SECTION 30 T 36S R 11W BASE SL Elevation: feet

DRILLER ACTIVITIES:
ACTIVITY: #1 NEW WELL
DRILLER: GRIMSHAW & SONS WELL DRILLING INC LICENSE #: 514
START DATE: 02/10/1986 COMPLETION DATE: 03/13/1986

BOREHOLE INFORMATION:

Depth(ft) From	To	Diameter(in)	Drilling Method	Drilling Fluid
0	400	12	ROTARY	

LITHOLOGY:

Depth(ft) From	To	Lithologic Description	Color	Rock Type
0	25	CLAY		
25	35	COBBLES		
35	43	CLAY		
43	55	CLAY, BOULDERS		
55	120	BOULDERS		
120	379	CLAY, BOULDERS		
379	400	OTHER		BEDROCK

CONSTRUCTION - CASING:

Depth(ft) From	To	Material	Gage(in)	Diameter(in)
0	150	NEW	.250	12

CONSTRUCTION - SCREENS/PERFORATIONS:

Depth(ft) From	To	Screen(S) or Perforation(P)	Slot/ Perforation Size	Screen Diameter/ Length Perforation (in)	Screen Type/ # Perforation
150	400	PERFORATION	.25	2.50	8000

CONSTRUCTION - FILTER PACK/ANNULAR SEALS:

Depth(ft) From	To	Material	Amount	Density(pcf)
0	400	CEMENT		
100	400	GRAVEL		

GENERAL COMMENTS:

CONSTRUCTION INFORMATION:
Well head configuration: No data
Casing Joint Type: Weld
Perforator used: Mill
Well development: N/A
Pump: N/A
Comments: No data
Additional data not available

Utah Division of Water Rights
Water Well Log

LOCATION: N 1290 ft E 460 ft from SW CORNER of SECTION 23 T 36S R 12W BASE SL
Elevation: feet

DRILLER ACTIVITIES:
ACTIVITY: # 1 NEW WELL
DRILLER: Quinn, Frank N. LICENSE #: 111
START DATE: 02/18/1967 COMPLETION DATE: 03/07/1967

BOREHOLE INFORMATION:

Depth(ft) From	To	Diameter(in)	Drilling Method	Drilling Fluid
0	228	16	CABLE	

LITHOLOGY:

Depth(ft) From	To	Lithologic Description	Color	Rock Type
0	1	OTHER		SOIL
1	3	CLAY		
3	8	SAND, GRAVEL		
8	16	CLAY, SAND		
16	37	CLAY		
37	39	WATER-BEARING, SAND, GRAVEL		
39	45	CLAY, SAND, SANDY		
45	46	SAND		
46	55	CLAY		
55	58	SAND, GRAVEL		
58	70	CLAY		
70	73	CLAY, SAND, SANDY		
73	80	CLAY		
80	83	SAND, GRAVEL		
83	85	CLAY, GRAVEL		
85	93	CLAY		
93	95	CLAY, GRAVEL		
95	106	CLAY		
106	110	CLAY, GRAVEL		
110	114	SAND, GRAVEL		
114	139	CLAY	BROWN	
139	140	CLAY	GRAY	
140	144	GRAVEL		
144	167	CLAY		
167	178	CLAY, GRAVEL		
178	180	GRAVEL		
180	201	CLAY, GRAVEL		
201	203	GRAVEL		
203	209	CLAY, GRAVEL		
209	211	CLAY		
211	228	CLAY, GRAVEL		

WATER LEVEL DATA:

Date	Time	Water Level (feet) (-)above ground	Status
03/07/1967		18.00	STATIC

CONSTRUCTION - CASING:

Depth(ft) From	To	Material	Gage(in)	Diameter(in)
0	228	NEW	.25	16

CONSTRUCTION - SCREENS/PERFORATIONS:

Depth(ft) From	To	Screen(S) or Perforation(P)	Slot/ Perforation Size	Screen Diameter/ Length Perforation(in)	Screen Type/ # Perforations
55	83	PERFORATION	3	.38	152
110	114	PERFORATION	3	.38	96
140	144	PERFORATION	3	.38	84
178	180	PERFORATION	3	.38	60
201	203	PERFORATION	3	.38	60

Utah Division of Water Rights
Water Well Log

LOCATION: N 505 ft W 1665 ft from E4 CORNER of SECTION 31 T 36S R 11W BASE SL
Elevation: feet

DRILLER ACTIVITIES:
ACTIVITY: #1 NEW WELL
DRILLER: GRIMSHAW & SONS WELL DRILLING INC LICENSE #: 514
START DATE: 08/11/1989 COMPLETION DATE: 08/18/1989

BOREHOLE INFORMATION:

Depth(ft) From	To	Diameter(in)	Drilling Method	Drilling Fluid
0	290	8	ROTARY	

LITHOLOGY:

Depth(ft) From	To	Lithologic Description	Color	Rock Type
0	5	CLAY		
5	147	BOULDERS		
147	253	CLAY, COBBLES		
253	290	BOULDERS		

CONSTRUCTION - CASING:

Depth(ft) From	To	Material	Gage(in)	Diameter(in)
0	250	NEW	.188	8

CONSTRUCTION - SCREENS/PERFORATIONS:

Depth(ft) From	To	Screen(S) or Perforation(P)	Slot/ Perforation Size	Screen Diameter/ Length Perforation(in)	Screen Type/ # Perforation
250	290	PERFORATION	3	.19	640

CONSTRUCTION - FILTER PACK/ANNULAR SEALS:

Depth(ft) From	To	Material	Amount	Density(pcf)
0	10	BENTONITE		
10	290	GRAVEL		

WELL TESTS:

Date	Test Method	Yield (CFS)	Drawdown (ft)	Time Pumped (hrs)
08/18/1989	PUMP	.067	50	24

Utah Division of Water Rights
Water Well Log

LOCATION: N 2740 ft E 2840 ft from SW CORNER of SECTION 30 T 36S R 11W BASE SL
Elevation: feet

DRILLER ACTIVITIES:
ACTIVITY: #1 NEW WELL
DRILLER: PETERSEN PUMPS & WELLS LICENSE #: 26
START DATE: 06/16/1995 COMPLETION DATE: 08/29/1996

BOREHOLE INFORMATION:

Depth(ft) From	To	Diameter(in)	Drilling Method	Drilling Fluid
0	220	17.0	CABLE	
220	430	12.0	CABLE	
430	610	8.00	CABLE	

LITHOLOGY:

Depth(ft) From	To	Lithologic Description	Color	Rock Type
0	10	LOW-PERMEABILITY, CLAY, GRAVEL	TAN/RED	A SMALL SEEP AT 40'/CLAY IN BETWEEN THE BOULDER/HARD
10	20	LOW-PERMEABILITY, CLAY, COBBLES	TAN/RED	
20	30	LOW-PERMEABILITY, CLAY, BOULDERS	TAN/RED	
30	40	LOW-PERMEABILITY, CLAY, COBBLES	TAN/RED	
40	50	LOW-PERMEABILITY, CLAY, COBBLES	TAN/RED	
50	60	LOW-PERMEABILITY, CLAY, BOULDERS	TAN/RED	
60	70	LOW-PERMEABILITY, CLAY, COBBLES	TAN/RED	
70	80	HIGH-PERMEABILITY, CLAY, BOULDERS		
80	90	LOW-PERMEABILITY, CLAY, COBBLES		
90	100	HIGH-PERMEABILITY, CLAY, BOULDERS		
100	120	HIGH-PERMEABILITY, BOULDERS		
120	130	LOW-PERMEABILITY, CLAY, BOULDERS		
130	180	LOW-PERMEABILITY, CLAY, COBBLES		
180	190	HIGH-PERMEABILITY, BOULDERS		
190	220	LOW-PERMEABILITY, CLAY, BOULDERS	FROM WHITE TO RED	HARDER/GOOD WATER GRAVEL
220	240	WATER-BEARING, SAND, GRAVEL		
240	300	LOW-PERMEABILITY, CLAY, GRAVEL, BOULDERS		
300	310	HIGH-PERMEABILITY, BOULDERS		HARDER/WHITE TO RED/SEVERAL SMALL SEEPS
310	320	WATER-BEARING, LOW-PERMEABILITY, BOULDERS		
320	360	LOW-PERMEABILITY, BOULDERS		
360	400	LOW-PERMEABILITY, BOULDERS		
400	420	LOW-PERMEABILITY, CLAY, GRAVEL		
420	430	LOW-PERMEABILITY, GRAVEL		
430	440	WATER-BEARING, BOULDER		435' 1' WATER
440	450	LOW-PERMEABILITY, BOULDERS		
450	460	WATER-BEARING, LOW-PERMEABILITY, SAND, BOULDERS		
460	470	LOW-PERMEABILITY, COBBLES, BOULDERS		HARDEST/BROWN TO TAN/451' 6" WATER
470	480	LOW-PERMEABILITY, BOULDERS		SMALL LAYERED SAND/BROWN TO TAN/HARDEST
480	490	LOW-PERMEABILITY, COBBLES		
490	500	LOW-PERMEABILITY, BOULDERS		
500	520	LOW-PERMEABILITY, COBBLES, BOULDERS		

520	610	LOW-PERMEABILITY, CLAY, OTHER	SMALL SAND (WATER) LAYERS WITH MORE CLAY IN BETWEEN THE BOULDERS BROWN TO TAN/ HARDEST

WATER LEVEL DATA:

Date	Time	Water Level (feet) (-)above ground	Status
05/ /1996		176.00	STATIC

CONSTRUCTION - CASING:

Depth(ft) From	To	Material	Gage(in)	Diameter(in)
0	380		.280	12.0
350	600		.250	8.00

CONSTRUCTION - SCREENS/PERFORATIONS:

Depth(ft) From	To	Screen(S) or Perforation(P)	Slot/ Perforation Size	Screen Diameter/ Length Perforation(in)	Screen Type/ # Perforation
220	360	PERFORATION		8-10	
430	600	PERFORATION		5-8	

CONSTRUCTION - FILTER PACK/ANNULAR SEALS:

Depth(ft) From	To	Material	Amount	Density(pcf)
0	220	CEMENT NEAT	11	

WELL TESTS:

Date	Test Method	Yield (CFS)	Drawdown (ft)	Time Pumped (hrs)
08/29/1996	PUMP	.178	225	6
08/29/1996	PUMP	.457	274	46

GENERAL COMMENTS:

CONSTRUCTION INFORMATION:
Well head configuration: No data
Casing Joint Type: Welded
Perforator used: Mills
Pump: 350 gpm Sub
HP: 50
Intake Depth: 530 feet
Approx pump rate: 400 gpm
Well disinfected: Yes
Additional data not available

Utah Division of Water Rights
Water Well Log (C-36-12)24abd

LOCATION: S 1440 ft W 300 ft from NE CORNER of SECTION 24 T 36S R 12W BASE SL
Elevation: feet

DRILLER ACTIVITIES:
ACTIVITY: #1 WELL REPLACEMENT
DRILLER: GRIMSHAW & SONS WELL DRILLING INC. LICENSE #: 514
START DATE: 06/17/1986 COMPLETION DATE: 07/11/1986

BOREHOLE INFORMATION:

Depth(ft) From	To	Diameter(in)	Drilling Method	Drilling Fluid
0	300	16.0	ROTARY	

LITHOLOGY:

Depth(ft) From	To	Lithologic Description	Color	Rock Type
0	31	CLAY	RED	
31	47	CLAY, ANT SIZE		
47	75	CLAY	RED	
75	94	CLAY	WHITE	
94	188	CLAY, GRAVEL	RED	
188	264	CLAY, BOULDERS	RED	
264	279	CLAY, BOULDERS	BLUE	
279	300	CLAY, BOULDERS	WHITE	

CONSTRUCTION - CASING:

Depth(ft) From	To	Material	Gage(in)	Diameter(in)
0	200	NEW	.250	16.0

CONSTRUCTION - SCREENS/PERFORATIONS:

Depth(ft) From	To	Screen(S) or Perforation(P)	Slot/ Perforation Size	Screen Diameter/ Length Perforation(in)	Screen Type/ # Perforation
200	300	PERFORATION	.250	2.50	3200 MILLED

CONSTRUCTION - FILTER PACK/ANNULAR SEALS:

Depth(ft) From	To	Material	Amount	Density(pcf)
0	165	CEMENT		
165	300	3/8 GRAVEL		

GENERAL COMMENTS:
Additional data not available

Utah Division of Water Rights
Water Well Log

LOCATION: S 243 ft W 580 ft from E4 CORNER of SECTION 31 T 36S R 11W BASE SL Elevation: feet

DRILLER ACTIVITIES:
ACTIVITY: #1NEW WELL
DRILLER: GRIMSHAW & SONS WELL DRILLING INC LICENSE #: 514
START DATE: 03/26/1992 COMPLETION DATE: 04/08/1992

BOREHOLE INFORMATION:

Depth(ft) From	To	Diameter(in)	Drilling Method	Drilling Fluid
0	400	8	ROTARY	

LITHOLOGY:

Depth(ft) From	To	Lithologic Description	Color	Rock Type
0	23	CLAY, SILT	RED	RED
23	123	BOULDERS		CONGLOMERATE
123	152	CLAY, GRAVEL, BOULDERS		
152	370	CLAY, BOULDERS		
370	383	HARDPAN/MUDSTONE	YELLOW	MUDSTONE, YELLOW
383	400	HARDPAN/MUDSTONE	RED	RED MUDSTONE

CONSTRUCTION - CASING:

Depth(ft) From	To	Material	Gage(in)	Diameter(in)
0	280		.188	8
320	360		.188	8

CONSTRUCTION - SCREENS/PERFORATIONS:

Depth(ft) From	To	Screen(S) or Perforation(P)	Slot/ Perforation Size	Screen Diameter/ Length Perforation (in.)	Screen Type/ # Perforation
280	320	PERFORATION	.125	2.5	640
360	400	PERFORATION	.125	2.5	640

CONSTRUCTION - FILTER PACK/ANNULAR SEALS:

Depth(ft) From	To	Material	Amount	Density(pcf)
0	100	GROUT CEMENT		
100	400	GRAVEL SIZE 3/8		

Utah Division of Water Rights
Water Well Log

LOCATION: N 530 ft E 1110 ft from SW CORNER of SECTION 19 T 36S R 11W BASE SL
Elevation: feet

DRILLER ACTIVITIES:
ACTIVITY: #1 NEW WELL
DRILLER: BRADSHAW PRESTON & SONS LICENSE #: 114
START DATE: 06/15/1978 COMPLETION DATE: 07/06/1978

BOREHOLE INFORMATION:

Depth(ft) From	To	Diameter(in)	Drilling Method	Drilling Fluid
0	200	10.8	CABLE	

LITHOLOGY:

Depth(ft) From	To	Lithologic Description	Color	Rock Type
0	2	OTHER		LOAM
2	12	CLAY		
12	30	CLAY, SAND		
30	38	CLAY		
38	46	GRAVEL		
46	55	CLAY		
55	64	GRAVEL		
64	71	GRAVEL, BOULDERS		
71	200	GRAVEL		

WATER LEVEL DATA:

Date	Time	Water Level (feet) (-)above ground	Status
07/06/1978		112.00	STATIC

CONSTRUCTION - CASING:

Depth(ft) From	To	Material	Gage(in)	Diameter(in)
0	200	NEW	.219	10.8

CONSTRUCTION - SCREENS/PERFORATIONS:

Depth(ft) From	To	Screen(S) or Perforation(P)	Slot/ Perforation Size	Screen Diameter/ Length Perforation(in)	Screen Type/ # Perforation
125	197	PERFORATION	.38	2.50	800

CONSTRUCTION - FILTER PACK/ANNULAR SEALS:

Depth(ft) From	To	Material	Amount	Density(pcf)
0	38	CEMENT/GROUT		

Utah Division of Water Rights
Water Well Log
(C-36-11)31aab

LOCATION: S 886 ft E 2653 ft from NW CORNER of SECTION 31 T 36S R 11W BASE SL
Elevation:feet

DRILLER ACTIVITIES:
ACTIVITY: # 1 NEW WELL
DRILLER: GRIMSHAW & SONS WELL DRILLING INC LICENSE #: 514
START DATE: 02/26/1991 COMPLETION DATE: 03/06/1991

BOREHOLE INFORMATION:

Depth(ft) From	To	Diameter(in)	Drilling Method	Drilling Fluid
0	400	8	ROTARY	

LITHOLOGY:

Depth(ft) From	To	Lithologic Description	Color	Rock Type
0	25	CLAY		
25	132	BOULDERS		
132	400	CLAY, COBBLES		

WATER LEVEL DATA:

Date	Time	Water Level (feet)(-) above ground	Status
03/08/1991		170.00	STATIC

CONSTRUCTION - CASING:

Depth(ft) From	To	Material	Gage(in)	Diameter(in)
0	320	NEW	.188	8

CONSTRUCTION - SCREENS/PERFORATIONS:

Depth(ft) From	To	Screen(S) or Perforation(P)	Slot/ Perforation Size	Screen Diameter Length Perforation (in.)	ScreenType/ # Perforation
320	400	PERFORATION	2.50	.19	1280

CONSTRUCTION - FILTER PACK/ANNULAR SEALS:

Depth(ft) From	To	Material	Amount	Density(pcf)
0	10	BENTONITE		
10	400	GRAVEL		

WELL TESTS:

Date	Test Method	Yield (CFS)	Drawdown (ft)	Time Pumped (hrs)
03/08/1991	PUMP	.056	40	20
03/08/1991	PUMP	.056	80	10

Hamiltons Fort Subdivision Site Observation Well

Copied js 1/28/57
Exam. & Recorded mv 1/23/57
Exam. for filing
Final Copy checked
Indexed js 1/25/57
Well No. (C-36-12)25bdd-1

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Report No. 12695
Filed Dec. 31, 1956
Rec. By mv
Ret'd

Report of Well and Tunnel Driller

STATE OF UTAH

CU663

(Separate report shall be filed for each well or tunnel)

GENERAL INFORMATION:

Report of well or tunnel driller is hereby made and filed with the State Engineer, in accordance with the laws of Utah. (This report shall be filed with the State Engineer within 30 days after the completion or abandonment of well or tunnel. Failure to file such reports constitutes a misdemeanor.)

1. Name and address of ~~person, company or~~ corporation ~~boring or~~ drilling well ~~or tunnel~~ (Strike words not needed)

   B & B Drilling Company Beaver, Utah

2. Name and address of owner of well ~~or tunnel~~ (Strike Words not needed) Jay G. Thorley, Cedar City, Utah

3. Source of supply is in Iron County;

   (Leave blank) drainage area; (Leave blank) artesian basin

4. The number of approved application to appropriate water is 24425

5. Location of well ~~or mouth of tunnel~~ is situated at a point S. 2410 ft. and E. 2610 ft. from the NW Cor. Sec. 25, T36S, R12W, SLB&M.

   (Describe by rectangular co-ordinates or by one course and distance with reference to U. S. Government Survey Corner — Copy description from well owner's approved application)

6. Date on which work on well ~~or tunnel~~ (Strike words not needed) was begun October 28, 1956

7. Date on which work on well ~~or tunnel~~ was completed ~~or abandoned~~ (Strike words not needed) Nov. 18, 1956

8. Maximum quantity of water measured as ~~flowing~~ pumped or (Strike words not needed) on completion of well or ~~tunnel in sec.~~ ft. ; or in gals. per minute Date

DETAIL OF COLLECTING WORKS:

9. WELL: It is drilled, ~~dug, flowing~~ (Strike words not needed) or pump well. Temperature of water °F.

   (a) Total depth of well is 300 ft. below ground surface.

   (b) If flowing well, give water pressure (hydrostatic head) above ground surface ft.

   (c) If pump well, give depth from ground surface to water surface before pumping 52 ft. ; during pumping 140 ft.

   (d) Size and kind of casing 14 inch steel (If only partially cased, give details)

   (e) Depth to water-bearing stratum 96 ft. (If more than one stratum, give depth to each)

   (f) If casing is perforated, give depth from ground surface to perforations 90 ft.

   (g) Log of well 0-11 sur., 11-48 clay sandy, 48-52 gravel, 52-96 clay, 96-118 sandy gravel 118-135 gravel clay 135-141 gravel 141-184 clay 184-197 gravel boulder 197-223 clay 223-241 gravel sand 241-252 clay 252-254 gravel sand 254-265 clay sandy 265-279 gravel sand 279-283 clay sandy 283-295 sandy gravel 295-300 clay boulders

   (h) Well was equipped with cap, ~~valve, or~~ (Strike words not needed) cap to control flow.

Hamiltons Fort pumping well

Utah Division of Water Rights
Water Well Log

LOCATION: N 1310 ft W 50 ft from S4 CORNER of SECTION 25 T 36S R 12W BASE SL
Elevation: feet

DRILLER ACTIVITIES:
ACTIVITY: #1 NEW WELL
DRILLER: PETERSEN PUMPS & WELLS LICENSE #: 26
START DATE: 04/15/1992 COMPLETION DATE: 08/10/1993

BOREHOLE INFORMATION:
Depth(ft)

From	To	Diameter(in)	Drilling Method	Drilling Fluid
0	145	8.00	CABLE	

LITHOLOGY:
Depth(ft)

From	To	Lithologic Description	Color	Rock Type
0	45	CLAY	BLUE	
45	50	OTHER	CORAL	SANDSTONE
50	65	CLAY, OTHER	BLUE	CLAY ROCK
65	72	OTHER		ROCK
72	106	CLAY, OTHER	CORAL	CLAY ROCK
106	121	WATER-BEARING, OTHER		SANDSTONE
121	220	LOW-PERMEABILITY	BLUE	

WATER LEVEL DATA:

Date	Time	Water Level (feet) (-)above ground	Status
08/10/1993		72.00	

CONSTRUCTION - CASING:
Depth(ft)

From	To	Material	Gage(in)	Diameter(in)
0	121	NEW	.277	8.00

CONSTRUCTION - FILTER PACK/ANNULAR SEALS:
Depth(ft)

From	To	Material	Amount	Density(pcf)
0	20		1	5

WELL TESTS:

Date	Test Method	Yield (CFS)	Drawdown (ft)	Time Pumped (hrs)
08/08/1993	BAILER	.013	15	

GENERAL COMMENTS:
CONSTRUCTION INFORMATION:
Well head Configuration: No data
Casing Joint Type: Weld Perforator: Mills
PUMP: Submergible Horsepower: 1 Pump Intake: 105 feet
Approx max pump rate: no data Well disinfected: Yes

Utah Division of Water Rights
Water Well Log

LOCATION: S 510 ft E 540 ft from N4 CORNER of SECTION 3 T 36S R 12W BASE SL
Elevation: feet

ACTIVITY: #1 NEW WELL
DRILLER: AQUA 1 SERVICE LICENSE #: 27
START DATE: 09/18/1975 COMPLETION DATE: 09/24/1975

BOREHOLE INFORMATION:

Depth(ft) From	To	Diameter(in)	Drilling Method	Drilling Fluid
0	132	5	CABLE	

LITHOLOGY:

Depth(ft) From	To	Lithologic Description	Color	Rock Type
0	37	CLAY		
37	46	GRAVEL		
46	72	CLAY, GRAVEL		
72	76	CLAY, GRAVEL, SANDY		
76	78	GRAVEL		
78	83	CLAY, GRAVELY		
83	84	GRAVEL		
84	90	CLAY		
90	91	GRAVEL		
91	121	CLAY, GRAVEL, BOULDERS		
121	131	CLAY		
131	132	GRAVEL		

WATER LEVEL DATA:

Date	Time	Water Level (feet)(-) above ground	Status
09/19/1975		37.00	STATIC

CONSTRUCTION - CASING:

Depth(ft) From	To	Material	Gage(in)	Diameter(in)
0	132	NEW	.188	5

CONSTRUCTION - SCREENS/PERFORATIONS:

Depth(ft) From	To	Screen(S) or Perforation(P)	Slot/ Perforation Size	Screen Diameter/ Length Perforation(in)	Screen Type/ # Perforation
95	115	PERFORATION	.13	2.50	40
124	132	PERFORATION	.13	2.50	20

WELL TESTS:

Date	Test Method	Yield (CFS)	Drawdown (ft)	Time Pumped (hrs)
09/19/1975	BAILER	.062		

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Report No. 288
Filed June 22, 1939
Rec. By Mail
Rec. $1.00 Fee WBN

Report of Well and Tunnel Driller

CV 221

STATE OF UTAH

(Separate report shall be filed for each well or tunnel)

GENERAL INFORMATION:

Report of well or tunnel driller is hereby made and filed with the State Engineer, together with a filing fee of $1.00, submitted in accordance with Sections 100-3-22 and 100-2-14, Revised Statutes of Utah 1933, as amended by Session Laws of 1935. (This report shall be filed with the State Engineer within 30 days after the completion or abandonment of well or tunnel. Failure to file such report constitutes a misdemeanor.)

1. Name and address of person, ~~company or corporation boring~~ or drilling well ~~or tunnel~~ (Strike words not needed)

   Fred J. Perry Cedar City, Utah

2. Name and address of owner of well ~~or tunnel~~ (Strike words not needed) Erastus L. Jones, Cedar City, Utah

3. Source of supply is in Iron County;

   (Leave blank) drainage area; (Leave blank) artesian basin 12953

4. The number of approved application to appropriate water is ~~A-12953~~ C-19586

5. Location of well or mouth of ~~tunnel~~ is situated at a point 130 feet West, 60 feet South of the NE. corner NE¼ NE¼ of Sec. 9, T. 36 S., R. 12 W. SLB&M

   (Describe by course and distance with reference to U. S. Government Survey Corner — copy description from well owners' approved application)

6. Date on which work on well or ~~tunnel~~ (Strike words not needed) was begun May 10, 1939

7. Date on which work on well or ~~tunnel~~ (Strike words not needed) was completed ~~or abandoned~~ May 25, 1939

8. Maximum quantity of water flowing, pumped or dipped on completion of well ~~or tunnel~~ in (Strike words not needed)

   sec. ft. ; or in gals. per minute 10 ; Date May 25, 1939

DETAIL OF COLLECTING WORKS:

9. WELL: It is a drilled, ~~dug~~, flowing ~~or pump~~ well. (Strike words not needed) Temperature of water ° F.

   (a) Total depth of well is 257 ft. ft. below ground surface.

   (b) Pressure in lbs. per sq. inch at ground surface if flowing well not known

   (c) If pump well, give depth from ground surface to water surface before pumping ; during pumping

   (d) Size and kind of casing 6 inch black iron pipe (If only partially cased, give details)

   (e) Depth to water bearing stratum 210 (If more than one stratum, give depth to each)

   (f) If casing is perforated, give depth from ground surface to perforations 208

   (g) Log of well Clay to 66 feet. Fine gravel 2 feet. Clay to 208 feet fine gravel 5 feet. from 257 feet to bottom fine sand.

   (h) Well was equipped with ~~cap~~, valve, or to control flow. (Strike words not needed)

73-2276

Form 113—5M—12-60

Examined 1/6/75 WD
Recorded: B. C. 1/6/75 T. D. WD
Inspection Sheet
Copied

REPORT OF WELL DRILLER

STATE OF UTAH

no card

Application No. a-7969
Claim No.
Coordinate No. (C-36-12) 2dcb

GENERAL STATEMENT: Report of well driller is hereby made and filed with the State Engineer, in accordance with the laws of Utah. (This report shall be filed with the State Engineer within 30 days after the completion or abandonment of the well. Failure to file such reports constitutes a misdemeanor.)

(1) WELL OWNER:

Name Dell Dekkell
Address Cedar City Ut.

(2) LOCATION OF WELL:

County Iron Ground Water Basin (leave blank)

North ~~South~~ 1282 feet, East ~~West~~ 616 feet from S¼ Corner of Section 2, T. 36 S, R. 12 W SLBM ~~USM~~ (strike out words not needed)

(3) NATURE OF WORK (check):

New Well ☒ Replacement Well ☐ Deepening ☐ Repair ☐ Abandon ☐

If abandonment, describe material and procedure:

(4) NATURE OF USE (check):

Domestic ☐ Industrial ☐ Municipal ☐ Stockwater ☐
Irrigation ☒ Mining ☐ Other ☐ Test Well ☐

(5) TYPE OF CONSTRUCTION (check):

Rotary ☒ Dug ☐ Jetted ☐
Cable ☐ Driven ☐ Bored ☐

(6) CASING SCHEDULE: Threaded ☐ Welded ☒

12" Diam. from 160 feet to 0 feet Gage 3/16
" Diam. from feet to feet Gage
" Diam. from feet to feet Gage

New ☐ Reject ☐ Used ☐

(7) PERFORATIONS: Perforated? Yes ☒ No ☐

Type of perforator used milled
Size of perforations 3/16 inches by 3 inches
perforations from 450 feet to 160 feet
perforations from feet to feet
perforations from feet to feet
perforations from feet to feet
perforations from feet to feet

(8) SCREENS: Well screen installed? Yes ☐ No ☐

Manufacturer's Name
Type Model No.
Diam. Slot size Set from ft. to
Diam. Slot size Set from ft. to

(9) CONSTRUCTION:

Was well gravel packed? Yes ☒ No ☐ Size of gravel: Pee Gravel
Gravel placed from 450 feet to 100 feet
Was a surface seal provided? Yes ☒ No ☐
To what depth? 100' to 80 feet
Material used in seal: Cement
Did any strata contain unusable water? Yes ☐ No ☐
Type of water: Depth of strata
Method of sealing strata off:

Was surface casing used? Yes ☐ No ☐
Was it cemented in place? Yes ☐ No ☐

(10) WATER LEVELS:

Static level feet below land surface Date
Artesian pressure feet above land surface Date

LOG RECEIVED OCT 1 ... DIVISION ... WATER R...

(11) FLOWING WELL:

Controlled by (check) Valve ☐
Cap ☐ Plug ☐ No Control ☐
Does well leak around casing? Yes ☐ No ☐

(12) WELL TESTS:

Drawdown is the distance in feet the water level is lowered below static level.

Was a pump test made? Yes ☐ No ☐ If so, by whom?
Yield: gal./min. with feet drawdown after hours
Bailer test gal./min. with feet drawdown after hours
Artesian flow g.p.m. Date
Temperature of water Was a chemical analysis made? No ☐ Yes ☐

(13) WELL LOG:

Diameter of well 12 inches
Depth drilled 450 feet. Depth of completed well 450 feet.

NOTE: Place an "X" in the space or combination of spaces needed to designate the material or combination of materials encountered in each depth interval. Under REMARKS make any desirable notes as to occurrence of water and the color, size, nature, etc., of material encountered in each depth interval. Use additional sheet if needed.

DEPTH From	DEPTH To	Clay	Silt	Sand	Gravel	Cobbles	Boulders	Hardpan	Conglomerate	Bedrock	Other	REMARKS
0	10		X									
10	65	X										
65	103	X			X							
103	125	X										
125	155	X			X							
155	165	X										
165	175	X			X							
175	185				X							
185	190	X			X							
190	206				X							
206	210	X			X							
210	218	X										
218	220				X							
220	226	X										
226	232				X							
232	334	X										
334	348	X			X							
348	360	X										
360	369				X							
369	388	X										
388	395				X							
395	402	X										
402	429				X							
429	450					X						

Work started Aug 10, 1975 Completed Aug 20, 1975

(14) PUMP:

Manufacturer's Name
Type: H. P.
Depth to pump or bowles feet

Well Driller's Statement:

This well was drilled under my supervision, and this report is true to the best of my knowledge and belief.

Name Grimshaw Drilling (Person, firm, or corporation) (Type or print)
Address Rt 1 Box 72 Cedar City Ut.
(Signed) [signature] (Well Driller)
License No. 290 Date Oct 1, 1975

Utah Division of Water Rights
Water Well Log

LOCATION: N 1076 ft E 82 ft from W4 CORNER of SECTION 11 T 36S R 12W BASE SL Elevation: Feet

DRILLER ACTIVITIES:
ACTIVITY: #1 NEW WELL
DRILLER: AQUA 1 SERVICE LICENSE #: 27
START DATE: 09/10/1995 COMPLETION DATE: 09/30/1995

BOREHOLE INFORMATION:
Depth(ft)

From	To	Diameter(in)	Drilling Method	Drilling Fluid
0	400	14.7	MUD ROTARY	BENTONITE

LITHOLOGY:
Depth(ft)

From	To	Lithologic Description	Color	Rock Type
0	360	CLAY, SAND		
360	400	SAND, GRAVEL		

WATER LEVEL DATA:

Date	Time	Water Level (feet) (-)above ground	Status
09/30/1995		103.00	STATIC

CONSTRUCTION - FILTER PACK/ANNULAR SEALS:
Depth(ft)

From	To	Material	Amount	Density(pcf)
0	120	BENSEAL GROUT	(BAGS)	90
120	400	GRAVEL PACK	3/8	

GENERAL COMMENTS:
CONSTRUCTION INFORMATION:
Well head configuration: well cap
Casing joint type: welded
Perforator Used: no data available
ADDITIONAL INFORMATION NOT AVAILABLE

Utah Division of Water Rights
Water Well Log

LOCATION: S 1750 ft W 2050 ft from NE CORNER of SECTION 11 T 36S R 12W BASE SL Elevation: feet

DRILLER ACTIVITIES:
ACTIVITY: # 1 NEW WELL
DRILLER: GRIMSHAW & SONS WELL DRILLING INC LICENSE #: 514
START DATE: 11/19/1996 COMPLETION DATE: 11/28/1996

BOREHOLE INFORMATION:

Depth(ft) From	To	Diameter(in)	Drilling Method	Drilling Fluid
0	304	12.5	ROTARY	BENTONITE

LITHOLOGY:

Depth(ft) From	To	Lithologic Description	Color	Rock Type
0	40	CLAY	RED	
40	63	CLAY, OTHER	LITE BROWN	LOTS OF SMALL CHARCOAL CHIPS
63	177	CLAY	BROWN	
177	264	CLAY	BROWN/GREEN	
264	270	SAND	YELLOW	
270	286	GRAVEL, SMALL-ANT SIZE TO PEA GRAVEL		
286	304	CLAY	RED	

WATER LEVEL DATA:

Date	Time	Water Level (feet) (-) above ground	Status
11/28/1996		30.00	STATIC

CONSTRUCTION - CASING:

Depth(ft) From	To	Material	Gage(in)	Diameter(in)
0	264	STEEL	.188	6.00

CONSTRUCTION - SCREENS/PERFORATIONS:

Depth(ft) From	To	Screen(S) or Perforation(P)	Slot/ Perforation Size	Screen Diameter/ Length Perforation (in)	Screen Type/ # Perforation
264	304	PERFORATION	.125	2.50	6 ROW

CONSTRUCTION - FILTER PACK/ANNULAR SEALS:

Depth(ft) From	To	Material	Amount	Density(pcf)
0	18	BENTONITE		
18	304	PEA GRAVEL 1/4-3/8		

WELL TESTS:

Date	Test Method	Yield (CFS)	Drawdown (ft)	Time Pumped (hrs)
11/26/1996	SEE FILE	.000		

GENERAL COMMENTS:

CONSTRUCTION INFORMATION:
Well head configuration: No data
Casing Joint Type: Weld
Perforator used: Milled
Additional data not available

Utah Division of Water Rights
Water Well Log

LOCATION: N 155 ft E 1365 ft from SW CORNER of SECTION 3 T 36S R 12W BASE SL
Elevation: feet

DRILLER ACTIVITIES:
ACTIVITY: # 1 NEW WELL
DRILLER: GRIMSHAW & SONS WELL DRILLING INC LICENSE #: 514
START DATE: 08/30/1996 COMPLETION DATE: 10/04/1996

BOREHOLE INFORMATION:
Depth(ft)

From	To	Diameter(in)	Drilling Method	Drilling Fluid
0	538	24.0	ROTARY	BENTONITE

LITHOLOGY:
Depth(ft)

From	To	Lithologic Description	Color	Rock Type
0	73	CLAY	RED	CEDAR CANYON CLAY/RED
73	147	CLAY	BLUE	LAKE BOTTOM/BLUE
147	156	CLAY, GRAVEL	BLUE	SM. GRAVEL/CLAY BLUE
156	209	CLAY	BLUE	BLUE
209	234	WATER-BEARING, HIGH - PERMEABILITY COBBLES	RED	CEDAR CANYON/RED
234	308	CLAY		
308	441	WATER- BEARING, HIGH-PERMEABILITY, BOULDERS		
441	538	WATER-BEARING, LOW- PERMEABILITY CLAY COBBLES	YELLOW	CLAY/YELLOW

WATER LEVEL DATA:

Date	Time	Water Level (feet) (-)above ground	Status
10/04/1996		32.20	STATIC

CONSTRUCTION - CASING:
Depth(ft)

From	To	Material	Gage(in)	Diameter(in)
0	238	STEEL	.375	16.0

CONSTRUCTION - SCREENS/PERFORATIONS:

Depth(ft) From	To	Screen(S) or Perforation(P)	Slot Perforation Size	Screen Diameter/ Length Perforation(in)	Screen Type/ # Perforation
238	538	PERFORATION	.125	2.50	16 ROW

CONSTRUCTION - FILTER PACK/ANNULAR SEALS:
Depth(ft)

From	To	Material	Amount	Density(pcf)
0	200	GROUT	23	12
200	538	3/8" PEA GRAVEL		

GENERAL COMMENTS:

CONSTRUCTION INFORMATION:
Well head configuration: Grouted to 200 feet
Casing Joint Type: Weld
Perforator used: Milled
Well Development: See paperwork on file
Comments: A 3" gravel tube was placed in well to 200' well did take a lot of gravel while test pumping.
Additional data not available

Bridal Path Subdivision Site Pumping Well

Form 113—5M—12-60

Examined
Recorded: B. C. T. B.
Inspection Sheet
Copied

REPORT OF WELL DRILLER

STATE OF UTAH

Application No. a-6357 (73-2289)
Claim No.
Coordinate No.

GENERAL STATEMENT: Report of well driller is hereby made and filed with the State Engineer, in accordance with the laws of Utah. (This report shall be filed with the State Engineer within 30 days after the completion or abandonment of the well. Failure to file such reports constitutes a misdemeanor.)

(1) WELL OWNER:
Name Mountain View Special Service District
Address Cedar City, Utah 84720

(2) LOCATION OF WELL:
County Iron Ground Water Basin (leave blank)
~~North~~ South 66 feet, East ~~West~~ 2699 feet from W¼ Corner of Section 3, T 36 S, R 12 W SLBM / USM (strike out words not needed)

(3) NATURE OF WORK (check): New Well ☐ Replacement Well X Deepening ☐ Repair ☐ Abandon ☐
If abandonment, describe material and procedure:

(4) NATURE OF USE (check): Domestic ☐ Industrial ☐ Municipal X Stockwater ☐ Irrigation ☐ Mining ☐ Other ☐ Test Well ☐

(5) TYPE OF CONSTRUCTION (check): Rotary XX Dug ☐ Jetted ☐ Cable ☐ Driven ☐ Bored ☐

(6) CASING SCHEDULE: Threaded ☐ Welded XX
8" Diam. from 357 feet to 0 feet Gage .250
" Diam. from feet to feet Gage
" Diam. from feet to feet Gage
New X Reject ☐ Used ☐

(7) PERFORATIONS: Perforated? Yes XX No ☐
Type of perforator used Milled
Size of perforations 3/16 inches by 2 1/2 inches
3200 perforations from 517 feet to 357 feet
perforations from feet to feet
perforations from feet to feet
perforations from feet to feet
perforations from feet to feet

(8) SCREENS: Well screen installed? Yes ☐ No XX
Manufacturer's Name
Type Model No.
Diam. Slot size Set from ft. to
Diam. Slot size Set from ft. to

(9) CONSTRUCTION:
Was well gravel packed? Yes XX No ☐ Size of gravel: 3/8
Gravel placed from 517 feet to 200 feet
Was a surface seal provided? Yes XX No ☐
To what depth? 200 feet
Material used in seal: Cement
Did any strata contain unusable water? Yes ☐ No XX
Type of water: Depth of strata
Method of sealing strata off:

Was surface casing used? Yes ☐ No ☐
Was it cemented in place? Yes ☐ No ☐

(10) WATER LEVELS:
Static level 55 feet below land surface Date 11-7-85
Artesian feet above land surface Date

RECEIVED
LOG RECEIVED
NOV 03 1985
WATER RIGHTS

(11) FLOWING WELL:
Controlled by (check) Valve ☐ Cap ☐ Plug ☐ No Control ☐
Does well leak around casing? Yes ☐ No ☐

(12) WELL TESTS: Drawdown is the distance in feet the water level is lowered below static level.
Was a pump test made? Yes X No ☐ If so, by whom? Rhodes Pump Sales
Yield: 172 gal./min. with 16 feet drawdown after 10 hours
" 305 " 21 " 4 "
" 440 " 34 " 3 "
Bailer test gal./min. with feet drawdown after hours
Artesian flow g.p.m. Date
Temperature of water Was a chemical analysis made? No ☐ Yes ☐

(13) WELL LOG: Diameter of well 8 inches
Depth drilled 517 feet. Depth of completed well 517 feet.

NOTE: Place an "X" in the space or combination of spaces needed to designate the material or combination of materials encountered in each depth interval. Under REMARKS make any desirable notes as to occurrence of water and the color, size, nature, etc., of material encountered in each depth interval. Use additional sheet if needed.

DEPTH From	DEPTH To	Clay	Silt	Sand	Gravel	Cobbles	Boulders	Hardpan	Conglomerate	Bedrock	Other	REMARKS
0	4			X								
4	62	X										(Red & Blue)
62	70				X							
70	103	X										(Black)
103	129				X							
129	147	X										(Red)
147	211		X		X							
211	232	X										
232	240	X			X							
240	275	X										
275	342	X				X						
342	358	X										
358	380	X			X							
380	397	X										
397	404	X				X						
404	409	X										
409	442					X						
442	453	X			X							
453	485					X						
485	517	X			X							

Work started 10-23, 1985 Completed 11-4, 1985

(14) PUMP:
Manufacturer's Name Grundfos
Type: Submersible H. P. 10
Depth to pump or bowles 130 feet

Well Driller's Statement:
This well was drilled under my supervision, and this report is true to the best of my knowledge and belief.
Name Grimshaw & Sons Well Drilling, Inc (Person, firm, or corporation) (Type or print)
Address 4814 N 600 E, Cedar City, Ut 84720
(Signed) [signature] (Well Driller)
License No. 514 Date 11-6, 1985

Utah Division of Water Rights
Water Well Log

LOCATION: S 470 ft E 310 ft from N4 CORNER of SECTION 9 T 35S R 11W BASE SL
Elevation: feet

DRILLER ACTIVITIES:
ACTIVITY: #1 WELL REPLACEMENT
DRILLER: GRIMSHAW & SONS WELL DRILLING INC LICENSE #: 514 START DATE: 10/06/1998
COMPLETION DATE: 12/04/1998

BOREHOLE INFORMATION:

Depth(ft) From	To	Diameter(in)	Drilling Method	Drilling Fluid
0	465	24	ROTARY	BENTONITE

LITHOLOGY:

Depth(ft) From	To	Lithologic Description	Color	Rock Type
0	43	CLAY, SILT	RED	
43	56	SILT, GRAVEL	LT BROWN	CLAY
56	68	CLAY	LT BROWN	CLAY
68	81	GRAVEL		
81	105	CLAY	BROWN	
105	109	WATER-BEARING, LOW-PERMEABILITY, CLAY, GRAVEL		SOME GRAVEL
109	143	WATER-BEARING, HIGH-PERMEABILITY, GRAVEL		
143	168	WATER-BEARING, HIGH-PERMEABILITY, COBBLES		
168	224	WATER-BEARING, LOW-PERMEABILITY, CLAY, GRAVEL		
224	234	WATER-BEARING, HIGH-PERMEABILITY, GRAVEL		
234	303	CLAY		
303	315	WATER-BEARING, HIGH-PERMEABILITY, GRAVEL		
315	333	CLAY		
333	337	WATER-BEARING, LOW-PERMEABILITY, CLAY, GRAVEL		
337	416	CLAY		
416	445	WATER-BEARING, LOW-PERMEABILITY, CLAY, GRAVEL		SOME GRAVEL
445	465	CLAY		

WATER LEVEL DATA:

Date	Time	Water Level (feet) (-) above ground	Status
12/04/1998		20.00	STATIC

CONSTRUCTION - CASING:

Depth(ft) From	To	Material	Gage(in)	Diameter(in)
0	180	STEEL	.250	12.0
265	345	STEEL	.250	12.0

CONSTRUCTION - SCREENS/PERFORATIONS:

Depth(ft) From	To	Screen(S) or Perforation(P)	Slot/ Perforation Size	Screen Diameter/ Length Perforation(in)	Screen Type/ # Perforation
180	265	PERFORATION	.125	2.50	12 ROW
345	465	PERFORATION	.125	2.50	12 ROW

CONSTRUCTION - FILTER PACK/ANNULAR SEALS:

Depth(ft) From	To	Material	Amount	Density(pcf)
0	100	GROUT		12
105	465	PEA GRAVEL 3/8"		

GENERAL COMMENTS:
CONSTRUCTION INFORMATION:
Well Head Configuration: 100' cf 4" grave tube
Casing Joint Type: weld
Perforator Used: milled
WELL DEVELOPMENT: no data
Additional data not available

Utah Division of Water Rights
Water Well Log

LOCATION: N 60 ft W 160 ft from S4 CORNER of SECTION 8 T 35S R 11W BASE SL
Elevation: feet

DRILLER ACTIVITIES:
ACTIVITY: #1 WELL REPLACEMENT
DRILLER: B & B Drilling Co. LICENSE #: 126
START DATE: 09/04/1971 COMPLETION DATE: 11/20/1971

BOREHOLE INFORMATION:

Depth(ft) From	To	Diameter(in)	Drilling Method	Drilling Fluid
0	300	10	ROTARY	

LITHOLOGY:

Depth(ft) From	To	Lithologic Description	Color	Rock Type
0	52	CLAY		
52	61	SAND		
61	70	CLAY		
70	82	SAND		
82	205	CLAY, SAND		
205	300	SAND, GRAVEL		

WATER LEVEL DATA:

Date	Time	Water Level (feet) (-)above ground	Status
11/20/1971		45.00	STATIC

CONSTRUCTION - CASING:

Depth(ft) From	To	Material	Gage(in)	Diameter(in)
0	300		10	

CONSTRUCTION - SCREENS/PERFORATIONS:

Depth(ft) From	To	Screen(S) or Perforation(P)	Slot/ Perforation Size	Screen Diameter/ Length Perforation(in)	Screen Type/ # Perforations
200	300	PERFORATION	.19	3	

CONSTRUCTION - FILTER PACK/ANNULAR SEALS:

Depth(ft) From	To	Material	Amount	Density(pcf)
0	300	GRAVEL		

WELL TESTS:

Date	Test Method	Yield (CFS)	Drawdown (ft)	Time Pumped (hrs)
11/20/1971	PUMP	1.114	158	10

APPENDIX B

Drillers' Logs of Aquifer Test Wells

M 111 2M 10-56

Hamiltons Fort Pumping Well

Copied js 1/28/57
Exam. & Recorded mv 1/23/57
Exam. for filing
Final Copy checked
Indexed js 1/25/57
Well No. (C-36-12)25bdd-1

PAGE (Leave Blank)

Report No. 12695
Filed Dec. 31 1956
Rec. By mv
Ret'd

Report of Well and Tunnel Driller

STATE OF UTAH

CU663

(Separate report shall be filed for each well or tunnel)

GENERAL INFORMATION:

Report of well or tunnel driller is hereby made and filed with the State Engineer, in accordance with the laws of Utah. (This report shall be filed with the State Engineer within 30 days after the completion or abandonment of well or tunnel. Failure to file such reports constitutes a misdemeanor.)

1. Name and address of ~~person, company or~~ corporation ~~boring~~ or drilling well ~~or tunnel~~ (Strike words not needed)

   B & B Drilling Company Beaver, Utah

2. Name and address of owner of well ~~or tunnel~~ (Strike Words not needed) Jay G. Thorley, Cedar City, Utah

3. Source of supply is in Iron County;

   drainage area; (Leave blank) artesian basin (Leave blank)

4. The number of approved application to appropriate water is 24425

5. Location of well ~~or mouth of tunnel~~ is situated at a point S. 2410 ft. and E. 2610 ft. from the NW Cor. Sec. 25, T36S, R12W, SLB&M.

   (Describe by rectangular co-ordinates or by one course and distance with reference to U. S. Government Survey Corner — Copy description from well owner's approved application)

6. Date on which work on well ~~or tunnel~~ (Strike words not needed) was begun October 28, 1956

7. Date on which work on well ~~or tunnel~~ was completed ~~or abandoned~~ (Strike words not needed) Nov. 18, 1956

8. Maximum quantity of water measured as ~~flowing~~ pumped or (Strike words not needed) on completion of well or ~~tunnel in sec.~~ ft. ; or in gals. per minute Date

DETAIL OF COLLECTING WORKS:

9. **WELL:** It is drilled, ~~dug, flowing~~ (Strike words not needed) or pump well. Temperature of water °F.

   (a) Total depth of well is 300 ft. below ground surface.

   (b) If flowing well, give water pressure (hydrostatic head) above ground surface ft.

   (c) If pump well, give depth from ground surface to water surface before pumping 52 ft. ; during pumping 140 ft.

   (d) Size and kind of casing 14 inch steel (If only partially cased, give details)

   (e) Depth to water-bearing stratum 96 ft. (If more than one stratum, give depth to each)

   (f) If casing is perforated, give depth from ground surface to perforations 90 ft.

   (g) Log of well 0-11 sur., 11-48 clay sandy, 48-52 gravel, 52-96 clay, 96-118 sandy gravel 118-135 gravel clay 135-141 gravel 141-184 clay 184-197 gravel boulder 197-223 clay 223-241 gravel sand 241-252 clay 252-254 gravel sand 254-265 clay sandy 265-279 gravel sand 279-283 clay sandy 283-295 sandy gravel 295-300 clay boulders

   (h) Well was equipped with cap, ~~valve, or~~ (Strike words not needed) cap to control flow.

Examined
Recorded: B. C. 1-4-72 T. B. R.J.M.
Inspection Sheet 1-5-72 B.M.
Copied 1-5-72 B.M.

Hamiltons Fort Observation Well

REPORT OF WELL DRILLER

STATE OF UTAH

Application No. a6497
Claim No.
Coordinate No. (C-36-12) 25 cda

GENERAL STATEMENT: Report of well driller is hereby made and filed with the State Engineer, in accordance with the laws of Utah. (This report shall be filed with the State Engineer within 30 days after the completion or abandonment of the well. Failure to file such reports constitutes a misdemeanor.)

(1) WELL OWNER:

Name Thorley Bros.
Address Cedar City Utah

(2) LOCATION OF WELL:

County Iron Ground Water Basin (leave blank)

North 1310 feet, West W 50 feet from S 1/4 Corner 3256 M
of Section 25, T. 36 S, R. 12 W-SLBM (strike out words not needed)

(3) NATURE OF WORK (check):

New Well ☒ Replacement Well ☐ Deepening ☐ Repair ☐ Abandon ☐
If abandonment, describe material and procedure:

(4) NATURE OF USE (check):

Domestic ☐ Industrial ☐ Municipal ☐ Stockwater ☐
Irrigation ☒ Mining ☐ Other ☐ Test Well ☐

(5) TYPE OF CONSTRUCTION (check):

Rotary ☒ Dug ☐ Jetted ☐
Cable ☐ Driven ☐ Bored ☐

(6) CASING SCHEDULE:

Threaded ☐ Welded ☒
16" Diam. from 0 feet to 370 feet Gage 1/4
" Diam. from feet to feet Gage
" Diam. from feet to feet Gage
New ☒ Reject ☐ Used ☐

(7) PERFORATIONS:

Perforated? Yes ☒ No ☐
Type of perforator used milled
Size of perforations 3/16 inches by 3 inches
perforations from 120 feet to 370 feet
perforations from feet to feet
perforations from feet to feet
perforations from feet to feet
perforations from feet to feet

(8) SCREENS:

Well screen installed? Yes ☐ No ☒
Manufacturer's Name
Type Model No.
Diam. Slot size Set from ft. to
Diam. Slot size Set from ft. to

(9) CONSTRUCTION:

Was well gravel packed? Yes ☒ No ☐ Size of gravel: 3/4
Gravel placed from 0 feet to 370 feet
Was a surface seal provided? Yes ☐ No ☒
To what depth? feet
Material used in seal:
Did any strata contain unusable water? Yes ☐ No ☒
Type of water: Depth of strata
Method of sealing strata off:

Was surface casing used? Yes ☐ No ☐
Was it cemented in place? Yes ☐ No ☐

(10) WATER LEVELS:

Static level feet below land surface Date
Artesian pressure feet above land surface Date

LOG RECEIVED:

(11) FLOWING WELL:

Controlled by (check) Valve ☐
Cap ☐ Plug ☐ No Control ☐
Does well leak around casing? Yes ☐ No ☐

(12) WELL TESTS:

Drawdown is the distance in feet the water level is lowered below static level.

Was a pump test made? Yes ☐ No ☐ If so, by whom?
Yield: gal./min. with feet drawdown after hours
Bailer test gal./min. with feet drawdown after hours
Artesian flow g.p.m. Date
Temperature of water Was a chemical analysis made? No ☐ Yes ☐

(13) WELL LOG:

Diameter of well 16 inches
Depth drilled 600 feet. Depth of completed well 370 feet.

NOTE: Place an "X" in the space or combination of spaces needed to designate the material or combination of materials encountered in each depth interval. Under REMARKS make any desirable notes as to occurrence of water and the color, size, nature, etc., of material encountered in each depth interval. Use additional sheet if needed.

DEPTH From	DEPTH To	Clay	Silt	Sand	Gravel	Cobbles	Boulders	Hardpan	Conglomerate	Bedrock	Other	REMARKS
0	38		X									
38	83			X								
83	89				X							
89	132	X		X								
132	143				X							
143	194	X		X								
194	202				X							
202	336	X		X								
336	243				X							
243	254			X								
254	267				X							
267	272			X								
272	308					X						
308	326			X								
326	335					X						
335	341	X										
341	600				X	X	X					

Work started April 2, 1970 Completed April 29, 1971

(14) PUMP:

Manufacturer's Name
Type: H. P.
Depth to pump or bowles feet

Well Driller's Statement:

This well was drilled under my supervision, and this report is true to the best of my knowledge and belief.

Name Grimshaw Drilling Co. (Person, firm, or corporation) (Type or print)
Address R # 1 Box 71 Cedar City
(Signed) J. A. Grimshaw (Well Driller)
License No. 240 Date Aug 17, 1971

RECEIVED OCT 20 1971 WATER RIGHTS OFFICE

Form 113—5M—12-60

Bauers Knoll Pumping & Observation Well

Examined ____
Recorded: B. C. ____ T. B. ____
Inspection Sheet ____
Copied ____

REPORT OF WELL DRILLER

STATE OF UTAH

Application No. a-6357 (73-2289)
Claim No. ____
Coordinate No. ____

GENERAL STATEMENT: Report of well driller is hereby made and filed with the State Engineer, in accordance with the laws of Utah. (This report shall be filed with the State Engineer within 30 days after the completion or abandonment of the well. Failure to file such reports constitutes a misdemeanor.)

(1) WELL OWNER:
Name Mountain View Special Service District
Address Cedar City, Utah 84720

(2) LOCATION OF WELL:
County Iron Ground Water Basin ____ (leave blank)
~~North~~ South 66 feet, East ~~West~~ 2699 feet from W¼ Corner of Section 3, T 36 S, R 12 W SLBM ~~USM~~ (strike out words not needed)

(3) NATURE OF WORK (check): New Well ☐ Replacement Well ☒ Deepening ☐ Repair ☐ Abandon ☐
If abandonment, describe material and procedure: ____

(4) NATURE OF USE (check):
Domestic ☐ Industrial ☐ Municipal ☒ Stockwater ☐
Irrigation ☐ Mining ☐ Other ☐ Test Well ☐

(5) TYPE OF CONSTRUCTION (check):
Rotary ☒ Dug ☐ Jetted ☐
Cable ☐ Driven ☐ Bored ☐

(6) CASING SCHEDULE: Threaded ☐ Welded ☒
8" Diam. from 357 feet to 0 feet Gage 250
____" Diam. from ____ feet to ____ feet Gage ____
____" Diam. from ____ feet to ____ feet Gage ____
New ☒ Reject ☐ Used ☐

(7) PERFORATIONS: Perforated? Yes ☒ No ☐
Type of perforator used Milled
Size of perforations 3/16 inches by 2 1/2 inches
3200 perforations from 517 feet to 357 feet
____ perforations from ____ feet to ____ feet
____ perforations from ____ feet to ____ feet
____ perforations from ____ feet to ____ feet
____ perforations from ____ feet to ____ feet

(8) SCREENS: Well screen installed? Yes ☐ No ☒
Manufacturer's Name ____
Type ____ Model No. ____
Diam. ____ Slot size ____ Set from ____ ft. to ____
Diam. ____ Slot size ____ Set from ____ ft. to ____

(9) CONSTRUCTION:
Was well gravel packed? Yes ☒ No ☐ Size of gravel: 3/8
Gravel placed from 517 feet to 200 feet
Was a surface seal provided? Yes ☒ No ☐
To what depth? 200 feet
Material used in seal: Cement
Did any strata contain unusable water? Yes ☐ No ☒
Type of water: ____ Depth of strata ____
Method of sealing strata off: ____

Was surface casing used? Yes ☐ No ☐
Was it cemented in place? Yes ☐ No ☐

(10) WATER LEVELS:
Static level 55 feet below land surface Date 11-7-85
Artesian pressure ____ feet above land surface Date ____

(11) FLOWING WELL:
Controlled by (check) Valve ☐ Cap ☐ Plug ☐ No Control ☐
Does well leak around casing? Yes ☐ No ☐

LOG RECEIVED: RECEIVED NOV 08 1985 NOV 1 WATER RIGHTS ~~CEDAR CITY~~ RECEIVED NOV 1 2 1985

(12) WELL TESTS: Drawdown is the distance in feet the water level is lowered below static level.
Was a pump test made? Yes ☒ No ☐ If so, by whom? Rhodes Pump Sales
Yield: 172 gal./min. with 16 feet drawdown after 10 hours
" 305 " 21 " 4 "
" 440 " 34 " 3 "
Bailer test ____ gal./min. with ____ feet drawdown after ____ hours
Artesian flow ____ g.p.m. Date ____
Temperature of water ____ Was a chemical analysis made? No ☐ Yes ☐

(13) WELL LOG: Diameter of well 8 inches
Depth drilled 517 feet. Depth of completed well 517 feet.

NOTE: Place an "X" in the space or combination of spaces needed to designate the material or combination of materials encountered in each depth interval. Under REMARKS make any desirable notes as to occurrence of water and the color, size, nature, etc., of material encountered in each depth interval. Use additional sheet if needed.

From	To	Clay	Silt	Sand	Gravel	Cobbles	Boulders	Hardpan	Conglomerate	Bedrock	Other	REMARKS
0	4			X								
4	62	X										(Red & Blue)
62	70				X							
70	103	X										(Black)
103	129				X							
129	147	X										(Red)
147	211		X		X							
211	232	X										
232	240	X			X							
240	275	X										
275	342	X				X						
342	358	X										
358	380	X			X							
380	397	X										
397	404	X				X						
404	409	X										
409	442					X						
442	453	X			X							
453	485					X						
485	517	X			X							

Work started 10-23, 1985 Completed 11-4, 1985

(14) PUMP:
Manufacturer's Name Grundfos
Type: Submersible H. P. 10
Depth to pump or bowles 130 feet

Well Driller's Statement:
This well was drilled under my supervision, and this report is true to the best of my knowledge and belief.
Name Grimshaw & Sons Well Drilling, Inc. (Person, firm, or corporation) (Type or print)
Address 4814 N 600 E, Cedar City, Ut 84720
(Signed) [signature] (Well Driller)
License No. 514 Date 11-6, 1985

Mid Valley Estates Pumping and Observation Well

WLI

WELL DRILLER'S REPORT
State of Utah
Division of Water Rights

For additional space, use "Additional Well Data Form" and attach

Well Identification

WATER RIGHT APPLICATION: 73-143(U13700)

Owner *Note any changes*

Angus Water Company Incorporated
P.O. Box 145
Cedar City, UT 84720

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DEC 18 1998
WATER RIGHTS
SALT LAKE

Contact Person/Engineer: ______

Well Location *Note any changes*

COUNTY: Iron
SOUTH 470 feet EAST 310 feet from the N¼ Corner of
SECTION 9, TOWNSHIP 35S, RANGE 11W, SLB&M.

Location Description: (address, proximity to buildings, landmarks, ground elevation, local well #) Cedar City Valley

Drillers Activity Start Date: 10-6-98 Completion Date: 12-4-98

Check all that apply: ☐ New ☐ Repair ☐ Deepen ☐ Abandon ☒ Replace ☐ Public Nature of Use: IRR, DOM

DEPTH (feet) FROM	TO	BOREHOLE DIAMETER (in)	DRILLING METHOD	DRILLING FLUID
465	0	24"	Rotary	Bentonite

Well Log

DEPTH (feet) FROM	TO	WATER	PERMEABLE high	PERMEABLE low	UNCONSOLIDATED CLAY	SILT	SAND	GRAVEL	COBBLES	BOULDER	OTHER	CONSOLIDATED ROCK TYPE	COLOR	DESCRIPTIONS AND REMARKS (include comments on *water quality* if known.)
0	43				X	X							Red	
43	56					X		X					clay Light Brown	
56	68				X								"	
68	81							X						
81	105				X								Brown	
105	109	X		X	X			X						Some gravel
109	143	X	X					X						
143	168	X	X						X					
168	224	X		X	X			X						
224	234	X	X					X						

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WATER RIGHTS
CEDAR CITY

Static Water Level

Date Dec 4 1998 Water Level 20 feet Flowing? ☐ Yes ☒ No

Method of Water Level Measurement Electric If Flowing, Capped Pressure ______ PSI

Point to Which Water Level Measurement was Referenced Top of casing

Height of Water Level reference point above ground surface ______ feet Temperature 58 ☐ °C ☒ °F

(continued on next page)

Construction Information

DEPTH (feet) FROM	TO	CASING: CASING TYPE AND MATERIAL/GRADE	WALL THICK (in)	NOMINAL DIAM. (in)	DEPTH (feet) FROM	TO	SLOT SIZE OR PERF SIZE (in)	SCREEN DIAM. OR PERF LENGTH (in)	SCREEN TYPE OR NUMBER PERF (per round/interval)
345	265	Steel	250	12"	465	345	1/8	2 1/2	~~[illegible]~~ 12 row
180	0	Steel	250	12"	265	180	1/8	2 1/2	12 row

SCREEN ☐ PERFORATIONS ☐

Well Head Configuration: 100' of 4" Grave tube Access Port Provided? ☒ Yes ☐ No

Casing Joint Type: Weld Perforator Used: Milled

DEPTH (feet) FROM	TO	FILTER PACK / GROUT / PACKER / ABANDONMENT MATERIAL: ANNULAR MATERIAL, ABANDONMENT MATERIAL and/or PACKER DESCRIPTION	Quantity of Material Used (if applicable)	GROUT DENSITY (lbs./gal.,# bag mix, gal./sack etc.)
465	105	Pea Gravel 3/8"		
100	0	Grout		12 bag

Well Development / Pump or Bail Tests

Date	Method	Yield	Units Check One: GPM	CFS	DRAWDOWN (ft)	TIME PUMPED (hrs & min)

Pump (Permanent)

Pump Description:________ Horsepower:______ Pump Intake Depth:______feet

Approximate maximum pumping rate:________ Well disinfected upon completion? ☐ Yes ☐ No

Comments

Description of construction activity, additional materials used, problems encountered, extraordinary circumstances, abandonment / procedures. *Use additional well data form for more space.*

Well Driller Statement

This well was drilled or abandoned under my supervision, according to applicable rules and regulations, and this report is complete and correct to the best of my knowledge and belief.

Name ~~[illegible]~~ Grimshaw & Sons Well Drilling, Inc **License No.** 514

(Person, Firm, or Corporation – Print or Type)

Signature [signature] **Date** 12-15-98

(Licensed Well Driller)