GROUND-WATER QUALITY CLASSIFICATION AND RECOMMENDED SEPTIC TANK SOIL-ABSORPTION-SYSTEM DENSITY MAPS, CACHE VALLEY, CACHE COUNTY, UTAH

by

Mike Lowe, Janae Wallace, and Charles E. Bishop

SPECIAL STUDY 101
UTAH GEOLOGICAL SURVEY
a division of
2003 Utah Department of Natural Resources

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Cover Photograph: flowing well in the Cache Valley discharge area. Photo by Janae Wallace.

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ABSTRACT

Cache Valley in northern Utah is experiencing an increase in residential development. Most of this development, much of which uses septic tank soil-absorption systems for wastewater disposal, is on unconsolidated deposits of the basin-fill aquifer, a major source of drinking water. The purposes of our studies are to: (1) classify the ground-water quality of the principal aquifer, based mainly on total-dissolved-solids concentrations, to formally identify and document the beneficial use of the valley's ground-water resource, and (2) apply a ground-water flow model using a mass-balance approach to determine the potential impact of projected increased numbers of septic-tank systems on water quality in the Cache Valley basin-fill aquifer and thereby recommend appropriate septic-system density requirements to limit water-quality degradation.

The quality of water in the Cache Valley basin-fill aquifer is generally good. Cache Valley ground water is classified as Class IA (Pristine; 84 percent) and Class II (Drinking Water Quality; 16 percent), based on chemical analyses of water obtained from 163 wells sampled during fall 1997 and winter/spring 1998-99. Total-dissolved-solids concentrations in Cache Valley's principal aquifer range from 178 to 1,758 mg/L, and average 393 mg/L. Nitrate-plus-nitrite concentrations in Cache Valley's principal aquifer range from less than 0.02 to 35.77 mg/L, with an average (background) nitrate concentration of 0.68 mg/L.

Nitrogen in the form of nitrate is one of the principal indicators of pollution from septic tank soil-absorption systems. In the mass-balance approach, the nitrogen mass from the projected additional septic tanks is added to the current nitrogen mass and then diluted with the amount of ground-water flow available for mixing plus the water added by the septic-tank systems themselves. We used a U.S. Geological Survey ground-water flow model to estimate, for different areas of Cache Valley, ground-water flow available for mixing in the principal basin-fill aquifer, the major control on projected aquifer nitrate concentration in the mass-balance approach. While there are many caveats to applying this mass-balance approach, we think it is a useful and cost-effective approach to use in land-use planning.

The results of our ground-water flow modeling using the mass-balance approach indicate that three categories of recommended maximum septic-system densities are appropriate for development using septic tank soil-absorption systems for wastewater disposal: one-third, one-fifth, and one-tenth systems per acre (0.33, 0.2, and 0.1 systems/acre [0.13, 0.08, and 0.04 systems/hm^2]); these categories correspond to 3, 5, and 10 acres per septic system (1.2, 2, and 4 hm^2/system), respectively. The recommended maximum septic-system densities are based on hydrogeologic parameters incorporated in the ground-water flow model and geographically divided into 12 ground-water flow domains (background nitrate concentrations ranging from 0.09 to 6.58 mg/L) on the basis of flow-volume similarities. In addition to a map showing the model output results, we provide a land-use-planning map where model output boundaries have been adjusted to cultural and geographic features such as streets and water bodies.

INTRODUCTION

Cache Valley, Cache County, is a rural area in northern 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 on unconsolidated deposits of the principal basin-fill aquifer. Ground water, mostly from the basin-fill aquifer, provides almost all of the drinking-water supply in Cache 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 Cache Valley. Local government officials in Cache County have expressed concern about the potential impact that development may have on ground-water quality, particularly development that uses septic tank soil-absorption systems for wastewater disposal. Local government officials would like to formally identify current ground-water quality to provide a basis for defendable land-use regulations to protect ground-water quality; they would also like a scientific basis for determining recommended densities for septic-tank systems as a land-use planning tool.

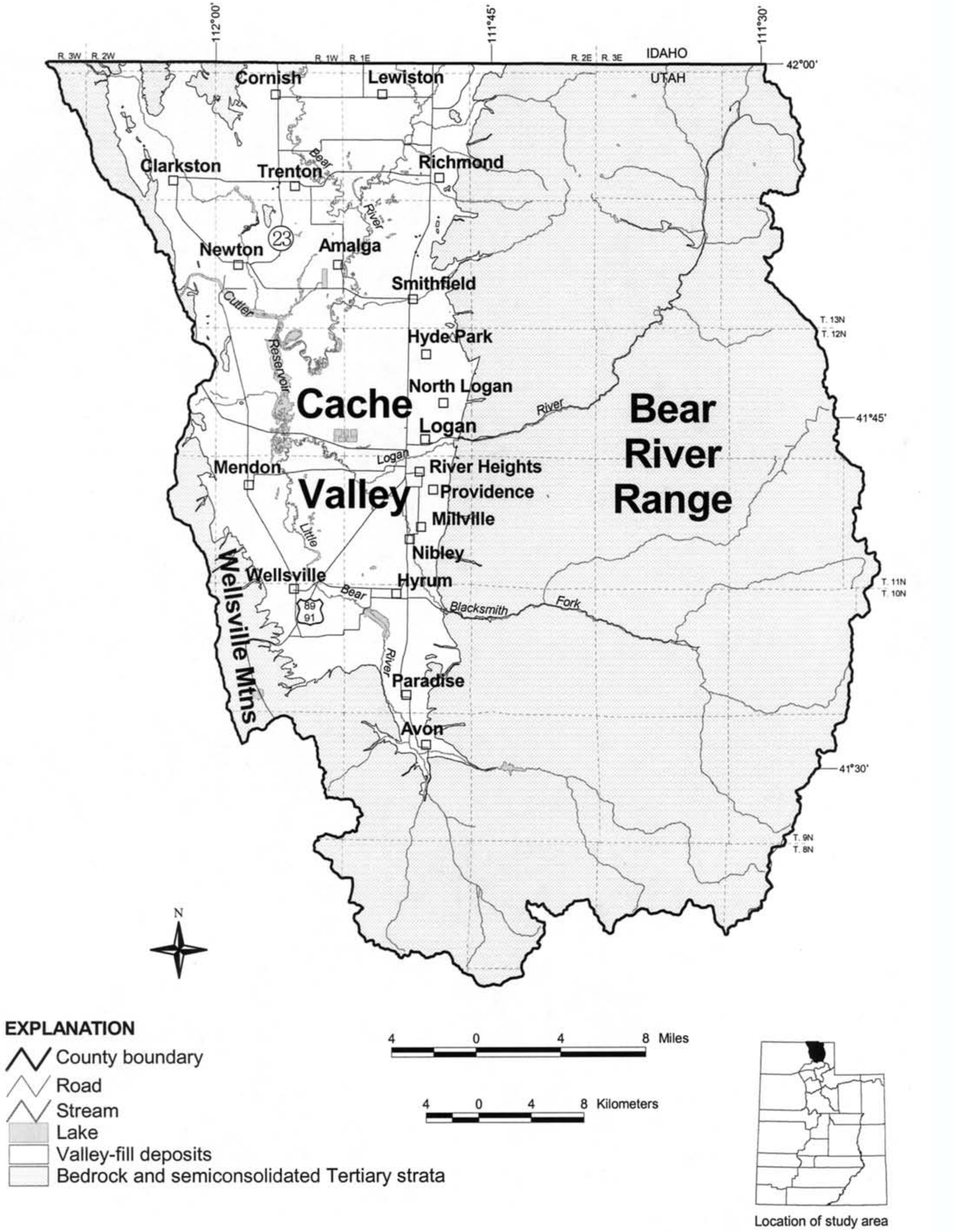

***Figure 1**. Geographic features, Cache Valley, Cache County, Utah.*

Purpose and Scope

The purposes of our studies are to: (1) classify the ground-water quality of the principal (drinking water) aquifers to formally identify and document the beneficial use of Cache Valley's ground-water resource, and (2) apply a ground-water flow model using a mass-balance approach to determine the potential impact of projected increased numbers of septic-tank systems on water quality in the basin-fill aquifer and thereby recommend appropriate septic-system-density requirements. Together, these two study components will provide land-use planners with a tool to use in approving new development in a manner that will be protective of ground-water quality.

Ground-Water Quality Classification

Ground-water quality classes under the Utah Water Quality Board classification scheme are based largely on total-dissolved-solids (TDS) concentrations (table 1) (for the ranges of chemical-constituent concentrations used in this report, including those for TDS, mg/L equals parts per million). If any contaminant exceeds Utah's ground-water quality (health) standards (and, if human caused, cannot be cleaned up within a reasonable time period), the ground water is classified as Class III, Limited Use ground water.

In order to classify the quality of ground water in the Cache Valley basin-fill aquifer, we selected 163 wells for sampling from three depth categories: (1) 37 of the wells are shallow wells (less than 100 feet [30 m] deep) completed in the principal aquifer, (2) 79 of the wells are of medium depth (100-200 feet [30-60 m]) completed in the principal aquifer, and (3) 42 of the wells are deep wells (greater than 200 feet [60 m] deep) completed in the principal aquifer. Depth is not known for five of the sampled wells presumed to be completed in the principal aquifer. We also sampled one well and a spring producing water from the shallow unconfined aquifer, but the results from these sources were not used in the ground-water quality classification because the shallow unconfined aquifer is generally not used for drinking water. The wells and spring were sampled by the Utah Division of Water Quality during fall 1997 and winter/spring 1998; the water samples were analyzed for general chemistry and nutrient content by the Utah Division of Epidemiology and Laboratory Services. Water from 15 of the wells was not analyzed for iron, water from six wells was not analyzed for sulfate, and water from another six wells was not analyzed for chloride. Water from 46 of the wells was analyzed for organics and pesticides, and water from 13 was analyzed for radionuclides. Wells yielding ground water that exceeded water-quality (health) standards in place at the time of sampling were resampled, sometimes multiple times, to verify results. A summary of the constituents analyzed for, ground-water quality (health) standards for some constituents, and selected water-quality data are presented in appendix A.

Septic-Tank Density/Water-Quality Degradation Analysis

To provide recommended septic-tank densities for Cache Valley using the mass-balance approach to evaluate potential water-quality degradation, we first used the digital ground-water flow model of Kariya and others (1994) to estimate ground-water flow available for mixing (dilution) in each of the model's cells (representing a specific land-surface area ranging from 0.2 to 1 square mile [0.5-2.6 km^2]) for the model's uppermost layer. We then (1) grouped cells into 11 ground-water flow domains (geographic areas having similar characteristics of flow-volume per unit area), and defined a 12th domain in the Clarkston area; (2) determined areas, ground-water flow volumes, estimated number of existing septic-tank systems, and ambient (background) nitrate concentrations for each domain; and (3) calculated projected

Table 1. *Ground-water quality classes under the Utah Water Quality Board's total-dissolved-solids- (TDS) based classification system (modified from Utah Division of Water Quality, 1998).*

Ground-Water Quality Class	TDS Concentration	Beneficial Use
Class IA/IB[1]/IC[2]	less than 500 mg/L[3]	Pristine/Irreplaceable/EcologicallyImportant
Class II	500 to less than 3,000 mg/L	Drinking Water[4]
Class III	3,000 to less than 10,000 mg/L	Limited Use[5]
Class IV	10,000 mg/L and greater	Saline[6]

[1]Irreplaceable ground water (Class IB) is a source of water for a community public drinking-water system for which no other reliable supply of comparable quality and quantity is available due to economic or institutional constraints; it is a ground-water quality class that is not based on TDS.
[2]Ecologically Important ground water (Class IC) is a source of ground-water discharge important to the continued existence of wildlife habitat; it is a ground-water quality class that is not based on TDS.
[3]For concentrations less than 7,000 mg/L, mg/L is about equal to parts per million (ppm).
[4]Water having TDS concentrations in the upper range of this class must generally undergo some treatment before being used as drinking water.
[5]Generally used for industrial purposes.
[6]May have economic value as brine.

nitrogen loadings in each domain based on increasing numbers of septic-tank soil-absorption systems, using the appropriate amount of wastewater and accompanying nitrogen load introduced per septic-tank system. Using an allowable degradation of ground water, with respect to nitrate, of 1 mg/L (the amount of water-quality degradation determined to be acceptable by local government officials), we were then able to derive septic-tank density recommendations for each domain. At the request of the Cache County Planning Department, a second septic-tank density map was produced with domain boundaries adjusted slightly to match geographic and cultural features to facilitate land-use planning purposes.

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 includes parts of both the northeastern and northwestern quadrants (A and B). The wells are numbered with this quadrant letter (A or B), followed by township and range, all enclosed in parentheses. The next set of characters indicates the section, quarter section, quarter-quarter section, and quarter-quarter-quarter section designated by letters a through d, indicating the northeastern, northwestern, southwestern, and

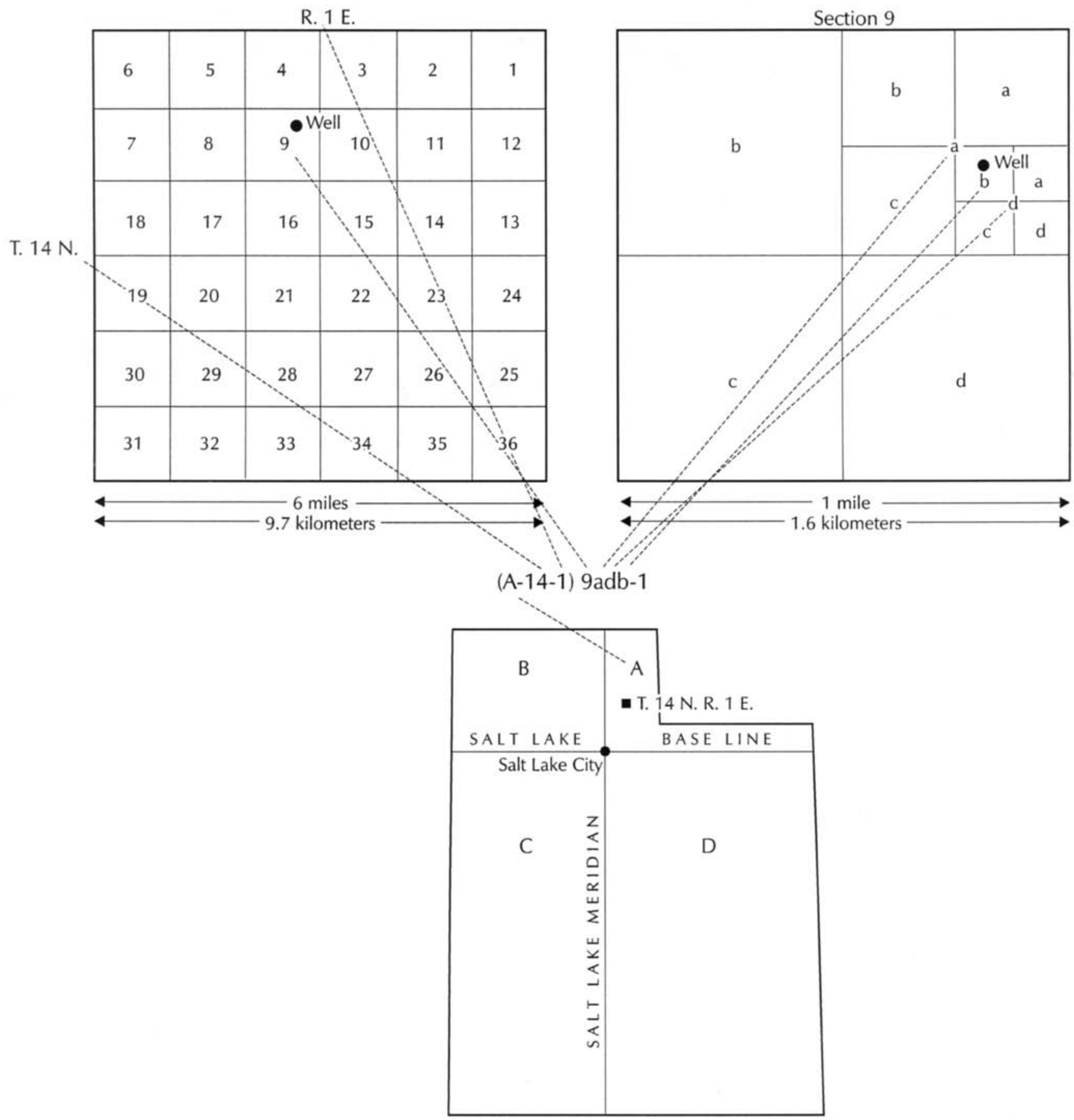

Figure 2. Numbering system for wells in Utah (see text for additional explanation).

southeastern quadrants, respectively. A number after the hyphen corresponds to an individual well within a quarter-quarter-quarter section. For example, the well (A-14-1) 9adb-1 would be the first well in the northwestern quarter of the southeastern quarter of the northeastern quarter of section 9, Township 14 North, Range 1 East (NW1/4SE1/4NE1/4 section 9, T. 14 N., R. 1. E.).

Location and Geography

Cache Valley (figure 1) is a north-south-trending valley with an area of about 660 square miles (1,710 km^2) in northeastern Utah and southeastern Idaho. About 365 square miles (945 km^2) of the valley is in Utah. Cache Valley is in the Cache Valley section of the Middle Rocky Mountains physiographic province (Stokes, 1977). In Utah, Cache Valley is bordered by the Bear River Range to the east, the Wellsville Mountains to the southwest, and Clarkston Mountain to the northwest. The valley floor ranges in elevation from about 4,400 to 5,400 feet (1,340-1,650 m). Peaks in the Wellsville Mountains and Bear River Range reach elevations above 9,000 feet (2,700 m).

The Bear River, the largest tributary to Great Salt Lake, flows through Cache Valley, entering Utah from the north and exiting Cache Valley between Clarkston Mountain and the Wellsville Mountains. Several large tributaries to the Bear River, including the Logan River, Blacksmith Fork, and Little Bear River, originate in the mountains surrounding Cache Valley in Utah.

Available population and land-use statistics are for Cache County as a whole; most people in the county live in Cache Valley. From 1990-2001, population in Cache County increased by 2.5 percent (Demographic and Economic Analysis Section, 2002). The July 1, 2001, population of Cache County is estimated at 93,372; projected population is 143,040 by 2030 (Demographic and Economic Analysis Section, 2000).

Climate

As is typical of the "back valleys" east of the Wasatch Range, Cache Valley is characterized by large daily and seasonal temperature ranges (Utah Division of Water Resources, 1992). Normal climatic information (1961-90 period) is available from four weather stations in Cache Valley (Logan Radio KVNU, Logan Utah State University, Richmond, and Trenton/Lewiston), and average climatic information is available from the Logan Utah State Experiment Station and the College Ward Utah State University Experiment Farm (Ashcroft and others, 1992); the information reported below is taken from Ashcroft and others (1992). Because the normal climatic information represents a more complete data set, those values are discussed herein. Temperatures reach a normal maximum of 90.0°F (32.2°C) (Richmond station) and a normal minimum of 10.2ºF (-12.1°C) (Trenton/Lewiston station); the normal mean temperature ranges from 44.8 to 48.5°F (7.1-9.2°C). Normal mean precipitation ranges from 16.6 to 19.5 inches (42.1-49.5 cm); normal mean evapotranspiration ranges from 40.9 to 45.3 inches (103.9-115.0 cm). The average number of frost-free days ranges from 112 at Trenton/Lewiston to 158 at Logan Utah State University.

PREVIOUS INVESTIGATIONS

Detailed geologic investigations in the Cache Valley area began with Bailey's (1927) studies of the geology of the Bear River Range and the Bear River Range (East Cache) fault. Williams (1948) studied Paleozoic rocks in the area, and included a measured section of the Swan Peak Formation in Green Canyon. Ross (1951) included a description of the Garden City and Swan Peak Formations in Green Canyon. Haynie (1957) examined the Worm Creek Quartzite Member of the St. Charles Formation in Green Canyon. Williams (1958) reported on further studies of stratigraphy and geologic history in Cache County. Galloway (1970) studied the structural geology of the eastern portion of the Smithfield quadrangle. Van Dorston (1970) studied the Swan Peak Formation in the Bear River Range. Gardiner (1974) studied the Nounan Formation in the Bear River Range and Wellsville Mountains. Mendenhall (1975) studied the structural geology and mapped the Richmond quadrangle in northeastern Cache Valley. Oaks and others (1977) summarized Middle Ordovician stratigraphy in northern Utah and southern and central Idaho, including the Bear River Range. Taylor and Palmer (1981) and Taylor and others (1981) studied Cambrian and Ordovician stratigraphy and paleontology in the Bear River Range and measured a section in Green Canyon. Morgan (1988) studied the petrology of the Garden City Formation in the Bear River Range. Oaks and Runnells (1992) studied the Wasatch Formation in the Bear River Range. Williams (1962) studied Bonneville lake-cycle deposits in Cache Valley.

Many investigators have studied the Salt Lake Formation in Cache Valley (Williams, 1948, 1964; Smith, 1953; Adamson 1955; and Adamson and others, 1955). Galloway (1970) redesignated the Salt Lake Group as the Salt Lake Formation. Modern studies of the Salt Lake Formation include those of Smith (1997), Goessel (1999), Goessel and others (1999), Oaks and others (1999), and Oaks (2000).

Mullens and Izett (1963), Mendenhall (1975), Oviatt (1986a,b), Brummer and McCalpin (1990), Evans and others (1991), Lowe and Galloway (1993), Barker and Barker (1993), and Biek and others (2001) produced 7.5-minute geologic quadrangle maps of the Cache Valley area. Dover (1985) mapped geology of the Logan 30' x 60' quadrangle. Lowe (1987) mapped the surficial geology of the Smithfield 7.5-minute quadrangle.

Peterson (1946) conducted an early investigation of the quantity of ground-water supply available in Cache Valley. Beer (1967) evaluated southern Cache Valley's basin-fill aquifer to determine those areas having the best potential for water development based on available water supply, chemical quality, and potential ground-water withdrawal rates. A detailed Cache Valley ground-water study was made by Bjorklund and McGreevy (1971). Anderson and others (1994) mapped ground-water recharge and discharge areas for Cache Valley's basin-fill aquifer. Kariya and others (1994) produced a ground-water flow model for the basin-fill aquifer. Lowe and Wallace (1999a,b, 2001; Wallace and Lowe, 1999) delineated ground-water quality of the basin-fill aquifer. Robinson (1999) characterized the chemistry and hydrostratigraphy of ground-water and surface-water interaction in the Cache Valley basin-fill aquifer. Erickson and Mortensen (1974) mapped soils in the Cache Valley area.

GEOLOGIC SETTING

Structurally, Cache Valley is bounded by north-striking, high-angle normal faults (the East Cache and West Cache fault zones) and forms the southern end of a series of half-grabens within an extensional corridor between the Wasatch and Teton normal fault systems (Evans and Oaks, 1996). Both the East Cache and West Cache fault zones have been subdivided into three segments and show evidence of recurrent Quaternary movement, including Holocene events (McCalpin, 1994; Black and others, 1999).

The mountains surrounding Cache Valley consist primarily of Precambrian to Permian sedimentary and metamorphic rocks, predominantly limestone, dolomite, shale, and quartzite (Williams, 1958; Bjorklund and McGreevy, 1971). The Tertiary Salt Lake Formation, primarily conglomerate and tuffaceous sandstone, is exposed in an almost continuous belt in the foothills surrounding the valley and underlies Quaternary deposits within Cache Valley (Williams, 1962; Evans and Oaks, 1996). The characteristics of stratigraphic units in the Cache Valley drainage basin are summarized in appendix B.

The valley floor in Cache Valley is underlain by unconsolidated basin fill of varying thickness. The greatest thickness is near the eastern margin of the valley just south of Logan (Evans and Oaks, 1996). The basin fill consists mostly of fluvial and lacustrine deposits that interfinger with alluvial-fan and, to a lesser extent, deltaic and landslide deposits along the valley margins (Lowe, 1987; Lowe and Galloway, 1993; Evans and Oaks, 1996). Much of the Cache Valley floor is covered with offshore lacustrine silt and clay deposited during the Bonneville lake cycle between about 12 and 26 ka (Oviatt and others, 1992, figure 3). At least one other thick (up to 80 feet [24 m]), correlatable unit of offshore lacustrine silt and clay is present within the basin-fill deposits in Cache Valley; Lowe (1987) tentatively interprets these fine-grained sediments as having been deposited during the Little Valley lake cycle sometime between 90,000 and 150,000 years ago (Scott and others, 1983).

GROUND-WATER CONDITIONS

Introduction

Ground water in the Cache Valley area occurs in two types of aquifers: (1) fractured bedrock and Tertiary semi-consolidated rocks, and (2) unconsolidated deposits. The

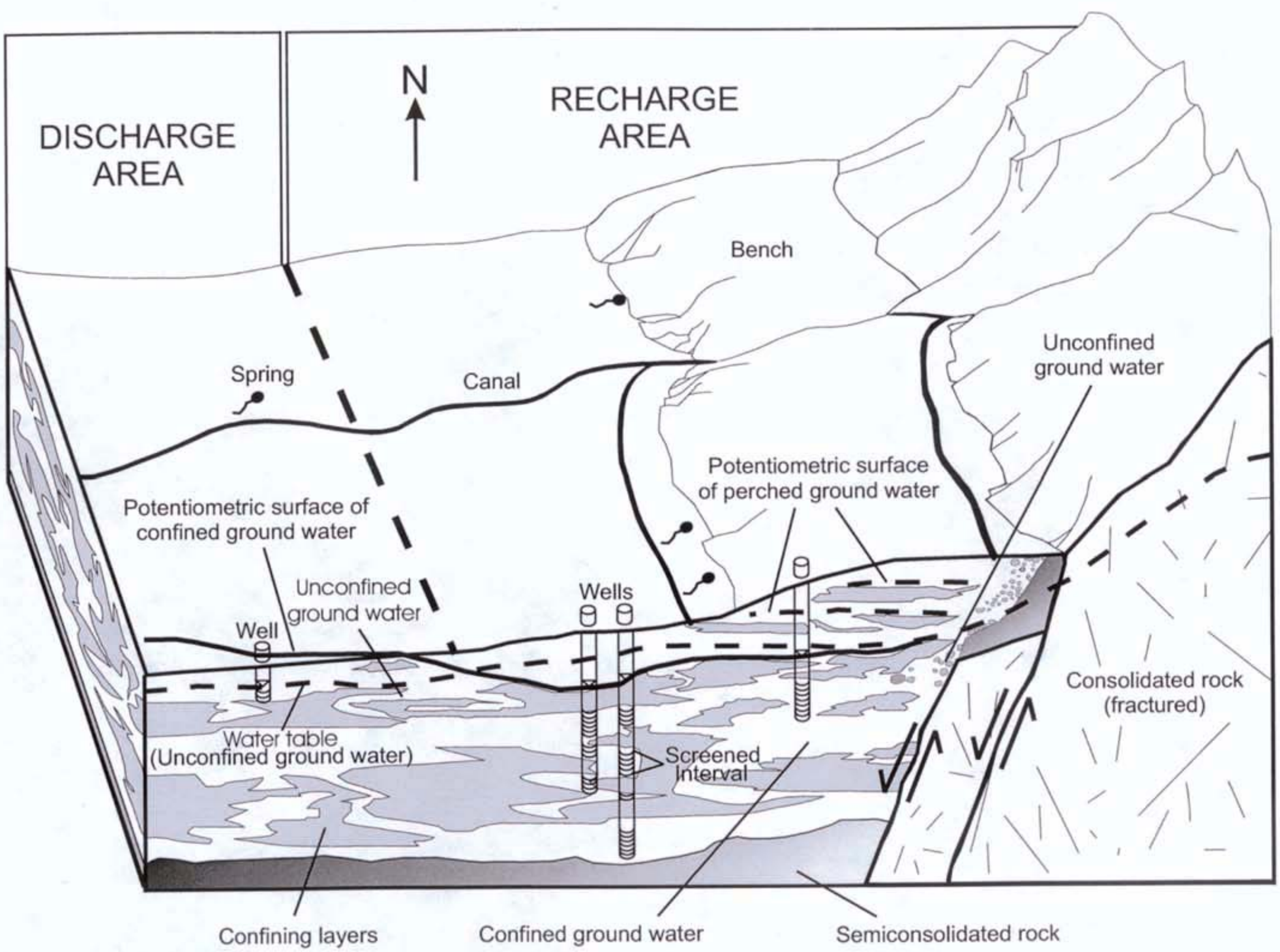

***Figure 3.** Schematic block diagram showing ground-water conditions in Cache Valley, Cache County, Utah (modified from Kariya and others, 1994).*

hydrostratigraphy of rock units in the Cache Valley drainage basin is summarized in appendix B. Ground water in fractured-rock aquifers is recharged primarily from infiltration of precipitation and stream flow, and flows primarily through fractures and, in carbonate units, through solution channels (Kariya and others, 1994). Although some wells and springs in fractured rock are used for public water supply in Cache Valley, some of the public water supply and most domestic water supply is obtained from wells completed in unconsolidated deposits of the basin-fill aquifer (Bjorklund and McGreevy, 1971).

Basin-Fill Aquifer

Occurrence

Ground water in Cache Valley occurs under perched, confined, and unconfined conditions (Bjorklund and McGreevy, 1971). The basin fill is more than several hundred feet thick at many locations in the valley center (Kariya and others, 1994). In the area between Smithfield and Newton, unconsolidated sediments are up to about 1,340 feet (410 m) thick (Bjorklund and McGreevy, 1971). Because the basin fill is unconsolidated sediment consisting of multiple, discontinuous layers of silt, sand, and gravel (deposited in fluvial, alluvial-fan, landslide, and nearshore lacustrine environments) separated by layers of silt and clay (primarily deposited in offshore lacustrine environments) (Bjorklund and McGreevy, 1971; Lowe, 1987, plate 2; Lowe and Galloway, 1993, plate 2), the principal aquifer consists of a complex multiple-aquifer system under both unconfined and confined conditions (Bjorklund and McGreevy, 1971; Kariya and others, 1994) (figure 3). Ground water in the principal aquifer is mostly under unconfined conditions along the margins of Cache Valley (Bjorklund and McGreevy, 1971), but is under leaky confined conditions in many areas of the center of the valley where many flowing wells exist (Kariya and others, 1994). Kariya and others (1994) attributed the leaky confined conditions to the discontinuous nature of clay and silt confining layers (figure 3). The boundary between unconfined and confined conditions is gradational near the margins of the basin. The confined portion of the principal aquifer is typically overlain by a shallow unconfined aquifer (Bjorklund and McGreevy, 1971) (figure 3).

Depth to Ground Water

Depth to ground water in unconsolidated deposits in Cache Valley ranges from at or near the ground surface in the central portion of the valley to more than 300 feet (90 m) along the valley margins (Bjorklund and McGreevy, 1971). Long-term water levels in Cache Valley's principal aquifer were relatively constant between 1945 and 1982 (Kariya and others, 1994), but declined as much as 13 feet (4 m) from March 1970 to March 2000 (Burden and others, 2000) (figure 4). Seasonal water-level changes range from a few feet (less than 1 m) to about 20 feet (6 m) (Kariya and others, 1994, figure 12). Water levels are generally highest in the summer in northern Cache Valley, Utah, lowest in the summer in southeastern Cache Valley, and show no consistent seasonal pattern of water-level fluctuations in southwestern Cache Valley (Kariya and others, 1994).

Ground-Water Flow

Ground-water flow in Cache Valley's principal aquifer is north-northwest in southern Cache Valley; in most of the valley, ground-water flow is typically from adjacent topographic highlands toward the valley center, generally toward the Bear River (Bjorklund and McGreevy, 1971, plate 4). Horizontal hydraulic gradients range from up to about 400 feet per mile (76 m/km) near the valley margins on the east side of the valley (Kariya and others, 1994) to less than 4 feet per mile (1 m/km) near the western margin of Logan (Beer, 1967).

Recharge and Discharge

Recharge to the basin-fill aquifer system is from infiltration of precipitation, streams, canals, ditches, and irrigated fields, and by subsurface inflow from consolidated rock along valley margins (Kariya and others, 1994) (table 2). Most recharge takes place in primary recharge areas (figures 5 and 6) along the valley margins where unconsolidated materials have the greatest permeability and vulnerability to surface sources of pollution (Bjorklund and McGreevy, 1971). Discharge from the basin-fill aquifer includes evapotranspiration, well-water withdrawal, and seepage to springs and Cutler Reservoir (Kariya and others, 1994) (table 2). Of the major streams in Cache Valley, the Bear River, including Cutler Reservoir, receives the largest amount of ground-water discharge as seepage to streams (Kariya and others, 1994).

Table 2. *1990 hydrologic budget for Cache Valley, Cache County, Utah (from Kariya and others, 1994).*

Recharge type	**Amount (cubic feet per second)**
Infiltration	57
Canal seepage	140
Stream seepage	3
Other*	96
TOTAL	296
Discharge type	**Amount (cubic feet per second)**
Springs	138
Evapotranspiration	87
Water wells	52
Seepage to streams	180
TOTAL	457

*Includes subsurface inflow from adjacent consolidated rock and seepage from ephemeral streams.

Ground-Water Quality

Ground-water quality in Cache Valley's principal aquifer is generally very good. Calcium, magnesium, and bicarbonate are the major dissolved constituents. Bjorklund and McGreevy (1971) found TDS concentrations to be mostly below 800 mg/L. However, warm saline ground water having TDS concentrations in excess of 1,600 mg/L has been documented near Newton and may be associated with fault zones (Bjorklund and McGreevy, 1971). Some ground water in the basin-fill aquifer also locally exceeds secondary (non-

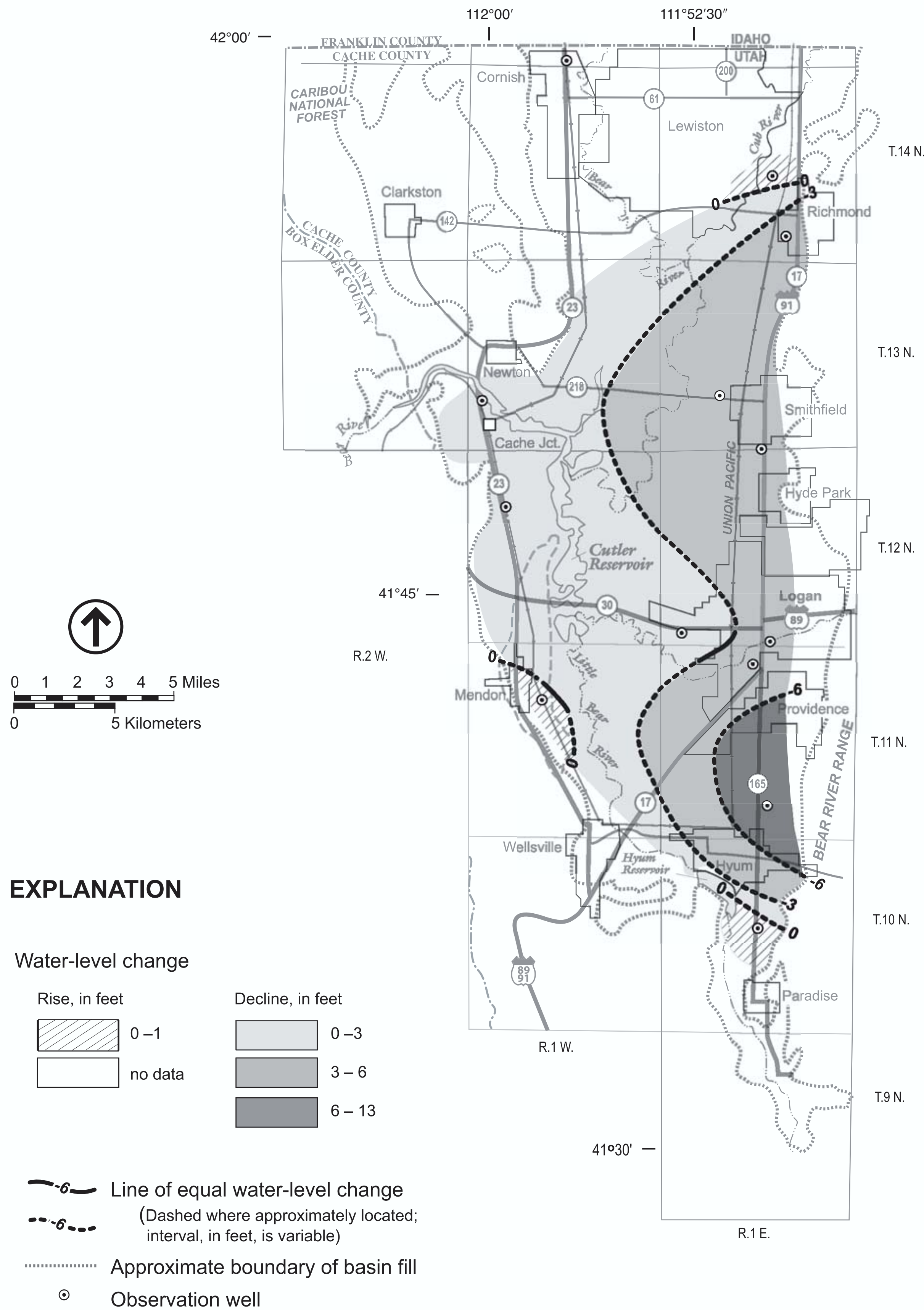

***Figure 4**. Change of water level in Cache Valley, Cache County, Utah, from March 1970 to March 2000 (modified from Burden and other, 2000).*

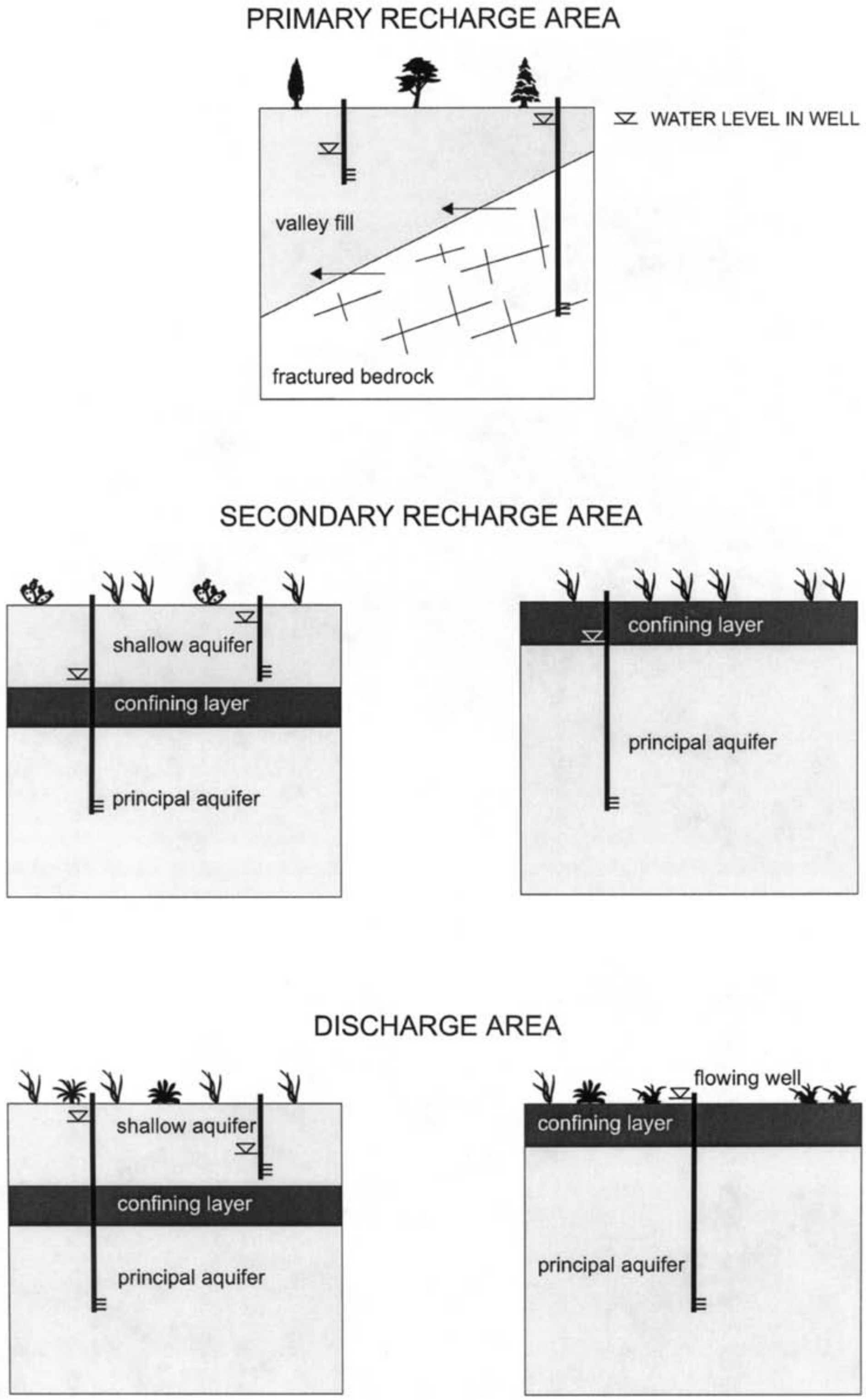

***Figure 5**. Relative water levels in wells in recharge and discharge areas (after Snyder and Lowe, 1998).*

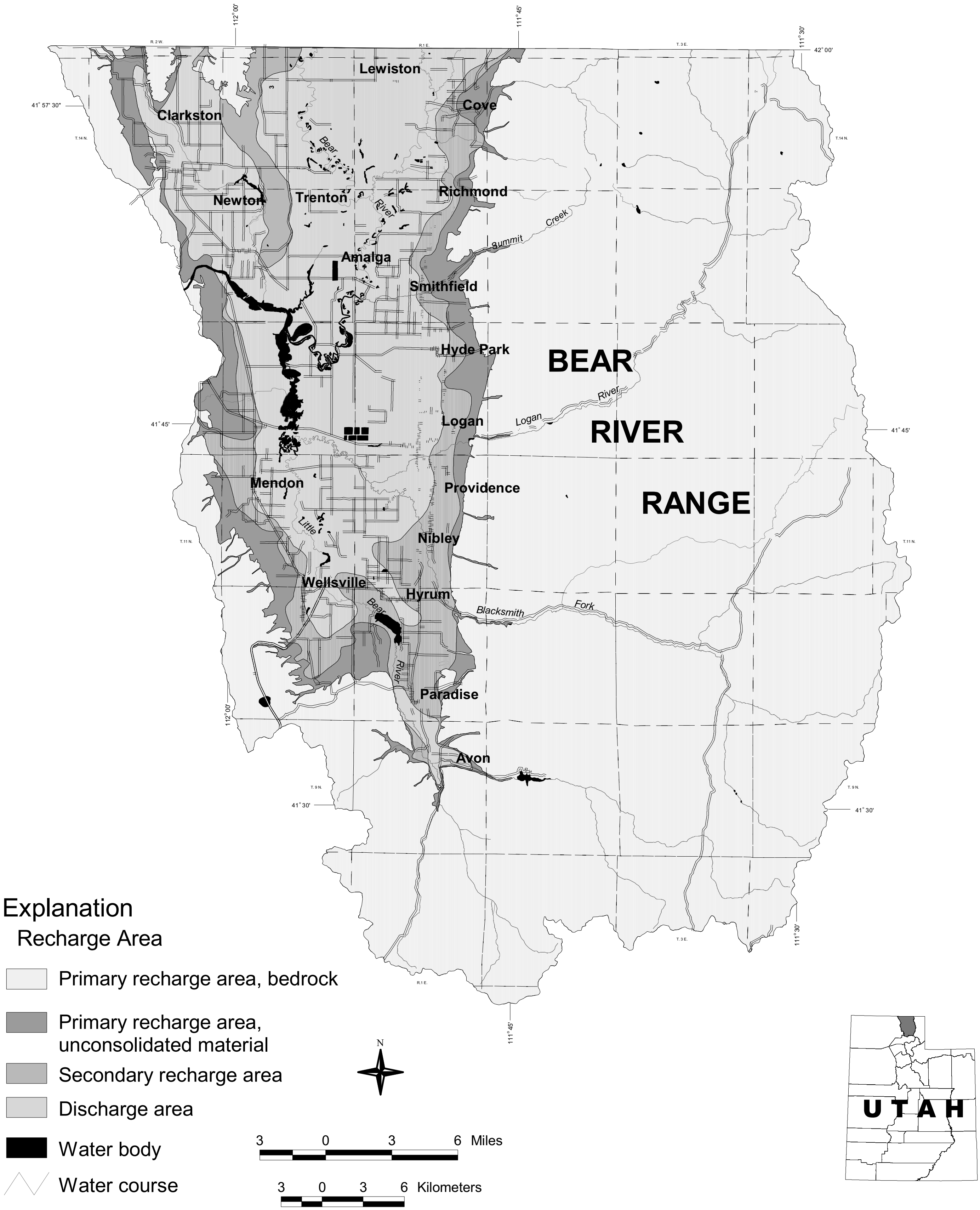

Figure 6. Recharge areas in Cache Valley, Cache County, Utah (after Anderson and others, 1994).

health-related) ground-water quality standards for chloride, fluoride, iron, nitrate, and sulfate (Beer, 1967; Bjorklund and McGreevy, 1971); we did not analyze for fluoride in our study.

GROUND-WATER QUALITY CLASSIFICATION

Introduction

Ground-water quality classification, based primarily on TDS (table 1), is a tool for local governments in Utah to use for managing potential ground-water contamination sources and for protecting the quality of their ground-water resources. The Utah Division of Water Quality's (1998) *Aquifer Classification Guidance Document* and Lowe and Wallace (1999a, b) outline why ground-water quality classification exists, what is required to classify ground-water quality, and why ground-water quality classification should be considered as a tool to protect ground-water quality. Basically, it is one way to implement an anti-degradation approach for managing ground-water resources using *differential protection* based on the quality or value of the ground-water resource. The policy of differential protection recognizes possible impacts on ground water from human activities, but limits any adverse impacts to pre-established acceptable levels tied directly to the existing ground-water quality. Ground-water quality classification is one of the principal means for implementing the differential protection policy because it establishes the quality of the ground-water resource. On behalf of Cache County, we petitioned the Utah Water Quality Board for formal classification of the principal aquifer in Cache Valley; based on that petition the Utah Water Quality Board formally adopted the ground-water quality classification as presented in this report on August 10, 2001.

Results

Total-Dissolved-Solids Concentrations

The Utah Water Quality Board's drinking-water quality (health) standard for TDS is 2,000 mg/L for public-supply wells (table A.1). The secondary ground-water quality standard is 500 mg/L (U.S. Environmental Protection Agency, 2002) (table A.1), and is primarily due to potential adverse impacts on the taste of the water (Bjorklund and McGreevy, 1971). Plate 1 shows the distribution of TDS in Cache Valley's principal unconsolidated basin-fill aquifer based on our data for ground water sampled from 163 wells during fall 1997 and winter/spring 1998 (appendix A). Total-dissolved-solids concentrations range from 178 to 1,758 mg/L, and average background TDS is 393 mg/L. Most of the ground water in the principal aquifer has TDS concentrations generally less than 500 mg/L (plate 1). However, ground water in the northwestern part of Cache Valley has TDS concentrations generally between 500 and 750 mg/L, and ground water southwest of Amalga has TDS concentrations between 750 and 1,000 mg/L (plate 1). Three wells yielded ground-water samples that exceeded TDS concentrations of 1,000 mg/L. Two wells (1,468 and 1,758 mg/L TDS) of unknown depth are north of Lewiston, in an area where Bjorklund and McGreevy (1971) attributed elevated TDS to irrigation and drainage practices. One sample from a 24-foot-deep (7 m) well completed in the shallow unconfined aquifer at a mink ranch west of Nibley yielded ground water with a TDS concentration of 1,236 mg/L (not shown on plate 1).

Plate 2 shows the distribution of TDS with respect to perforated-interval category and hydrogeologic setting (recharge/discharge area category). Of the 163 wells sampled and analyzed for TDS, 37 are shallow wells (less than 100 feet [30 m] deep) completed in the principal aquifer, (2) 79 are medium-depth wells (100-200 feet [30-60 m] deep) completed in the principal aquifer, (3) 42 are deep wells (greater than 200 feet [60 m] deep) completed in the principal aquifer, and (4) one well and the spring are in and associated with the shallow unconfined aquifer. The determination that these sampled wells are completed in unconsolidated basin-fill deposits is based on drillers' logs of water wells; in some instances Tertiary semiconsolidated rock may have been logged as unconsolidated deposits. Depth is not known for five of the sampled wells presumed to be completed in the principal aquifer. Average TDS is 468 mg/L for water from deep wells, 327 mg/L for water from medium-depth wells, and 390 mg/L for water from shallow wells completed in the principal aquifer. Average TDS for water from the wells for which we have no depth information, typically older wells drilled or dug before well logs were required, is 845 mg/L. The spring (not shown on plates 1 and 2) yielded water with a TDS concentration of 368 mg/L. Figure 7 summarizes the percentage of wells in each perforated-depth interval category that are above or below 500 mg/L TDS. Figure 8 shows the non-linear relationship between TDS and perforated-interval depth; the correlation coefficient is 0.56, an indication that no strong statistical correlation exists between TDS and perforated-interval depth. Note that TDS in ground water in many of the wells with deeper perforated intervals is greater than 500 mg/L (figures 7a,b and 8); this pattern is especially prevalent in ground-water-discharge areas (figure 7b), and may be due to longer ground-water residence times and/or flow paths than ground water in wells with shallower perforated intervals.

With respect to hydrogeologic setting (plate 2), of the 163 wells sampled and analyzed for TDS, three are in primary recharge areas (15 percent of the surface area of basin-fill deposits), 42 are in secondary recharge areas (22 percent of the surface area of basin-fill deposits), and 118 are in discharge areas (63 percent of the surface area of basin-fill deposits) based on the recharge-area map of Anderson and others (1994). For ground water from primary-recharge-area wells, TDS ranges from 358 to 828 mg/L and averages 554 mg/L. For ground-water from secondary-recharge-area wells, TDS ranges from 232 to 664 mg/L and averages 366 mg/L. For ground water from discharge-area wells, TDS ranges from 178 to 1,758 mg/L and averages 399 mg/L. Figure 9 summarizes the percentage of wells in each hydrogeologic setting category that are above or below 500 mg/L TDS; no trend is apparent with respect to hydrogeologic setting and TDS, but our sampled wells are not well-distributed with respect to each category.

Nitrate Concentrations

The ground-water quality (health) standard for nitrate is 10 mg/L (table A.1) (U.S. Environmental Protection Agency,

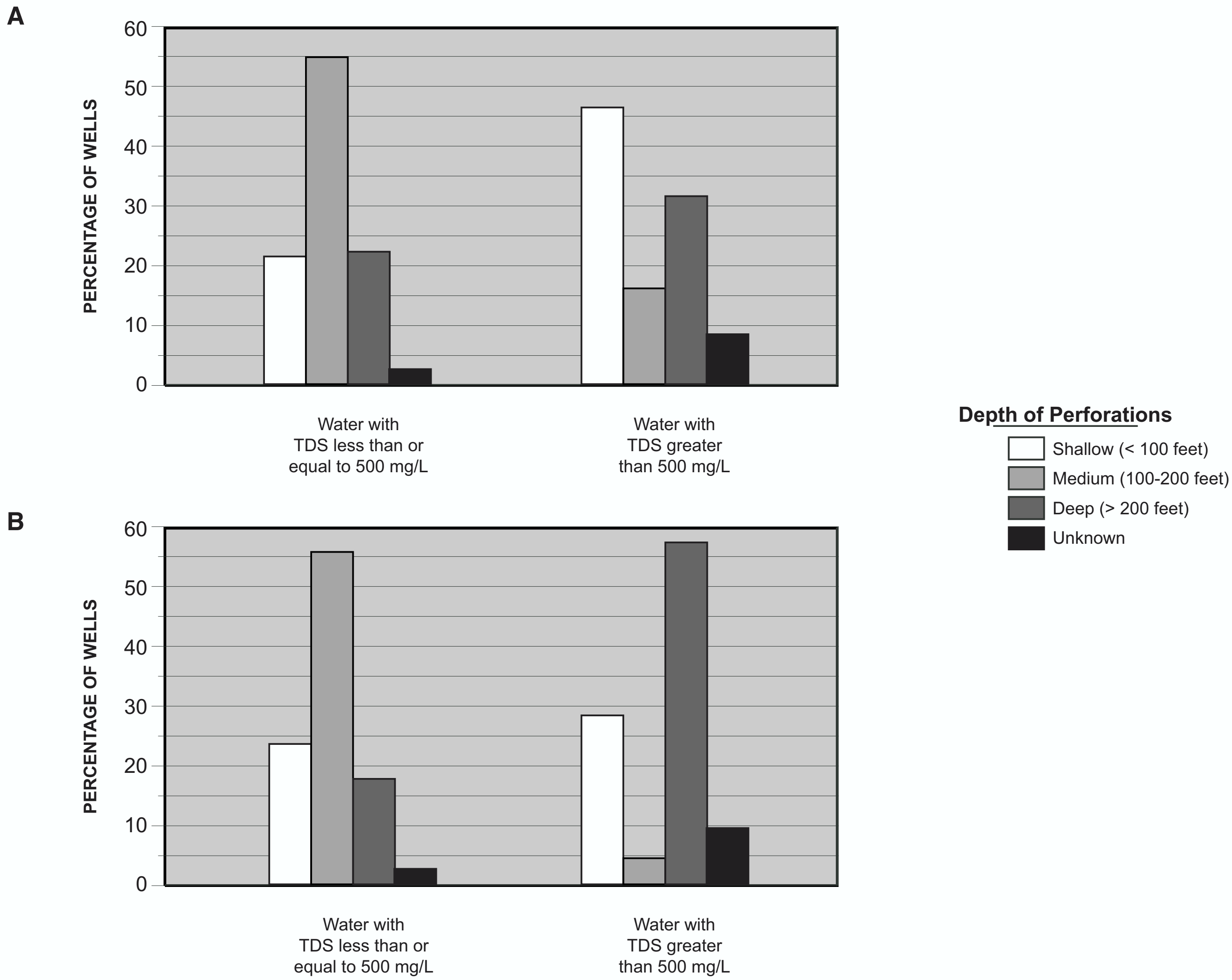

Figure 7. *Percentage of wells in shallow, medium, deep, and unknown perforation depth intervals above and below 500 mg/L total-dissolved-solids concentrations in Cache Valley, Cache County, Utah. Data for all wells are shown in a; data for discharge-area wells only are shown in b.*

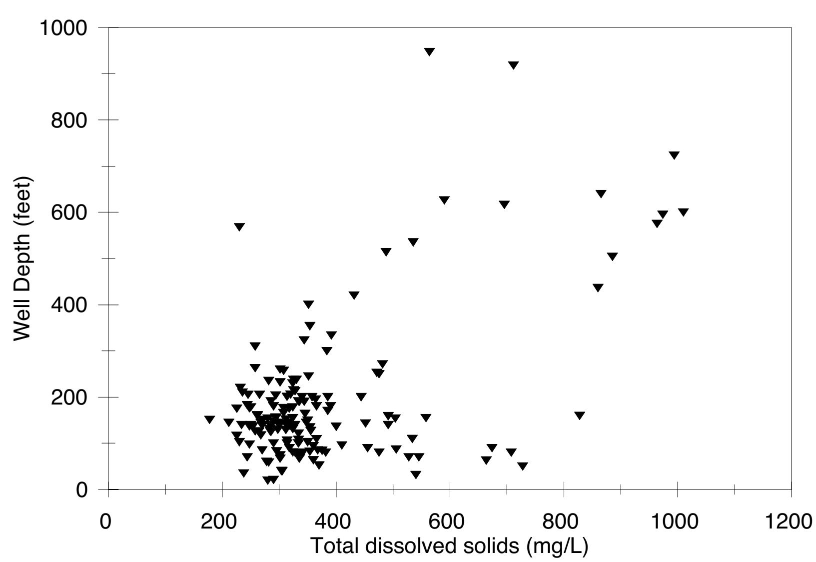

Figure 8. *Relationship between well depth and total-dissolved-solids concentrations in Cache Valley, Cache County, Utah. Correlation coefficient is 0.56.*

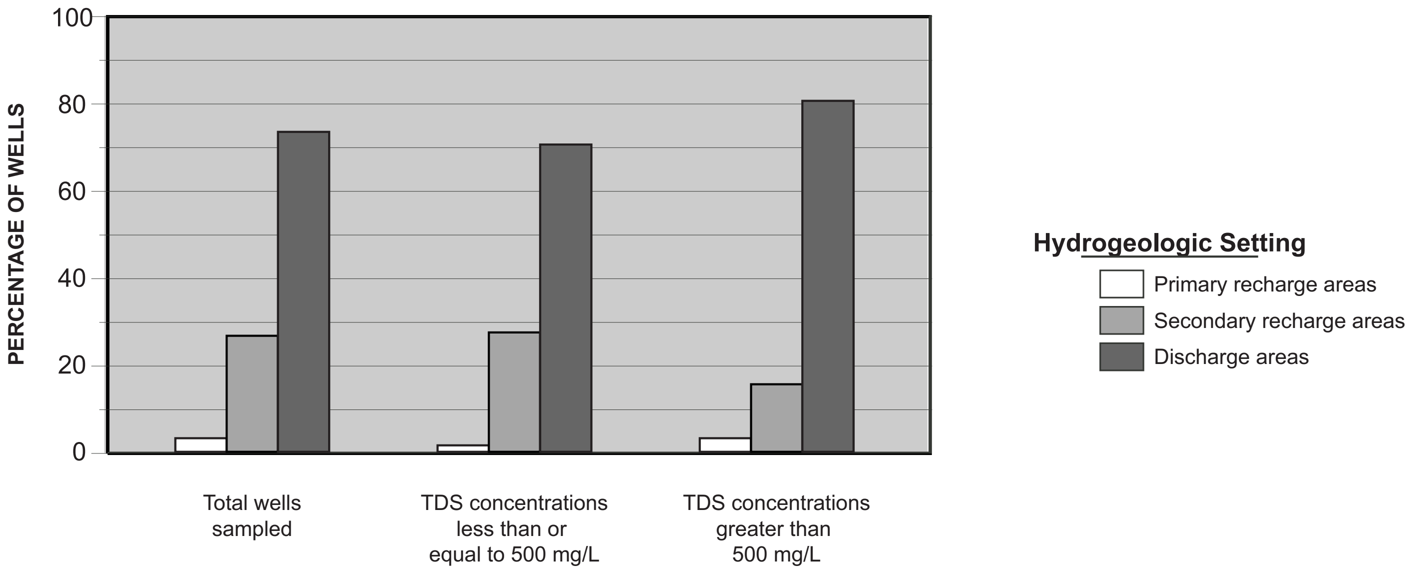

Figure 9. *Percentage of wells in each hydrogeologic setting sampled for TDS concentrations that are less than or equal to 500 mg/L and greater than 500 mg/L in Cache Valley, Cache County, Utah*

2002). More than 10 mg/L of nitrate in drinking water can result in a condition known as methoglobinemia, or "blue baby syndrome" (Comley, 1945) in infants under six months and can be life threatening without immediate medical attention (U.S. Environmental Protection Agency, 2002). This condition is characterized by a reduced ability for blood to carry oxygen. Nitrate-plus-nitrite concentrations in Cache Valley's principal aquifer (plate 3; appendix A) range from less than 0.02 to 35.77 mg/L, with an average (background) nitrate concentration of 0.68 mg/L. Thirty-eight wells were below the detection limit for nitrate of 0.02 mg/L (appendix A) for the laboratory analysis method listed in table A.1. Seven wells, one northwest of Lewiston, two near Clarkston, three southwest of Hyrum, and the mink ranch well with high TDS (not shown on plate 3), yielded water samples that exceed the ground-water quality (health) standard of 10 mg/L for nitrate. High nitrate levels may be attributed to contamination from septic-tank systems, feedlots, and/or fertilizer.

Plate 4 shows the distribution of nitrate concentrations with respect to perforated-interval category and hydrogeologic setting. The distribution of wells with respect to perforated-interval category and hydrogeologic setting is as described for TDS above. Average nitrate concentration is 0.57 mg/L for water from deep wells, 0.42 mg/L for water from medium-depth wells, and 1.05 mg/L for water from shallow wells completed in the principal aquifer. Average nitrate concentration for water from the wells for which we had no depth information is 6.4 mg/L. The spring (not shown on plates 3 and 4) yielded water with a nitrate concentration of 3.91 mg/L. Figure 10 summarizes the percentage of wells in each perforated-interval category that are less than 3 mg/L nitrate concentration, 3 to 10 mg/L nitrate, and greater than 10 mg/L nitrate; more than 60 percent of the wells that yield ground water having high-nitrate concentrations (>10 mg/L N) are either in the shallow perforated-interval category or have unknown perforated-interval depths. Figure 11 shows the relationship between nitrate concentration and perforated-interval category; the correlation coefficient of -0.2 indicates that no statistical correlation exists between nitrate concentration and perforated interval.

With respect to hydrogeologic setting (plate 4) based on the recharge-area map of Anderson and others (1994), nitrate concentration ranges from less than 0.02 to 11.91 mg/L and averages 3.5 mg/L for ground water from primary-recharge-area wells. For ground-water from secondary-recharge-area wells, nitrate concentration ranges from less than 0.02 to 20.62 mg/L and averages 0.58 mg/L. For ground water from discharge area wells, nitrate concentration ranges from less than 0.02 to 32.85 mg/L, and averages 1.9 mg/L. Figure 12 summarizes the percentage of wells in each hydrogeologic-setting category that are less than 3 mg/L nitrate concentration, 3 to 10 mg/L nitrate, and greater than 10 mg/L nitrate. Primary recharge areas have the highest average nitrate concentration (Wallace and Lowe, 1999a).

Dissolved-Iron Concentrations

The secondary ground-water quality standard for iron is 300 µg/L (table A.1) (U.S. Environmental Protection Agency, 2002), primarily to avoid objectionable staining to plumbing fixtures, other household surfaces, and laundry (Fetter, 1980; Hem, 1989). Water high in dissolved iron can also lead to the growth of iron bacteria which may lead to the clogging of water mains, recirculating systems, and, sometimes, wells (Driscoll, 1986). At concentrations over 1,800 µg/L, iron imparts a metallic taste to drinking water (Fetter, 1980). Dissolved concentrations of iron in Cache Valley's principal aquifer (plate 5) range from less than 20 to 7,560 µg/L, with an average (background) dissolved-iron concentration of 403 µg/L. A total of 82 wells yielded ground water that was below the detection limit for dissolved iron of 20 µg/L (appendix A) for the analysis method listed in table A.1. Forty-two wells yielded water samples that exceed the secondary ground-water quality standard for iron.

Plate 5 shows the distribution of dissolved-iron concen-

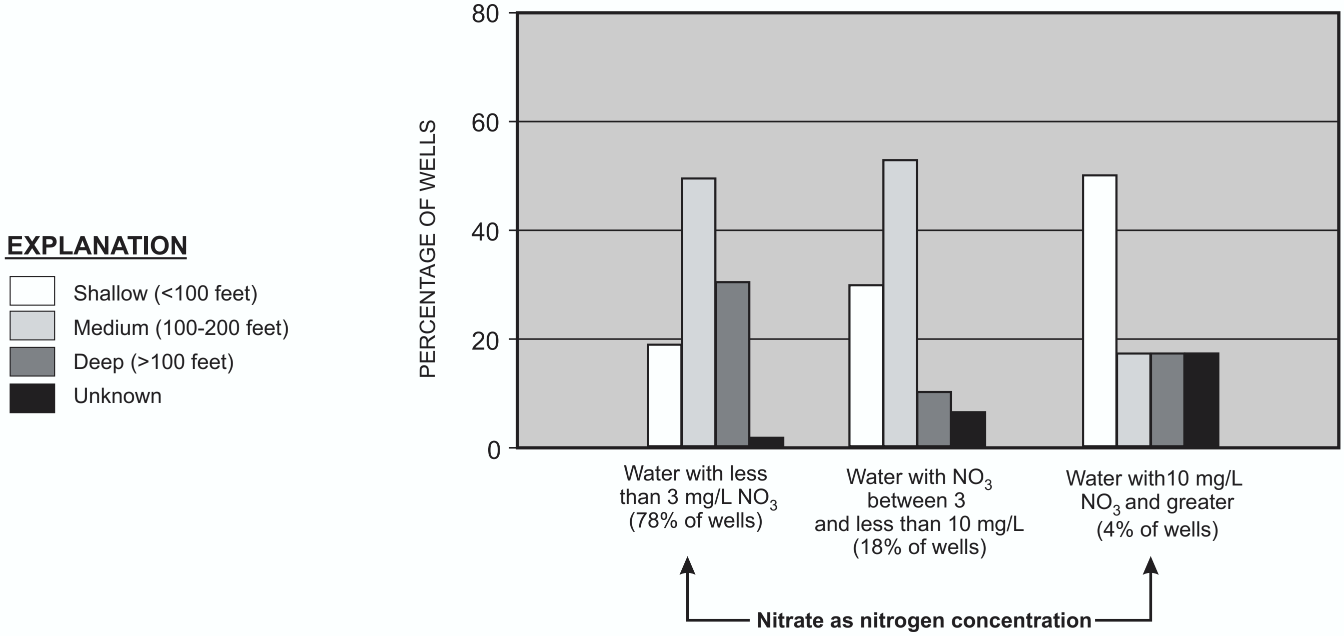

Figure 10. *Percentage of wells in shallow, medium, and deep perforation-depth intervals that are less than 3 mg/L, between 3 and 10 mg/L, and greater than 10 mg/L nitrate concentration in Cache Valley, Cache County, Utah.*

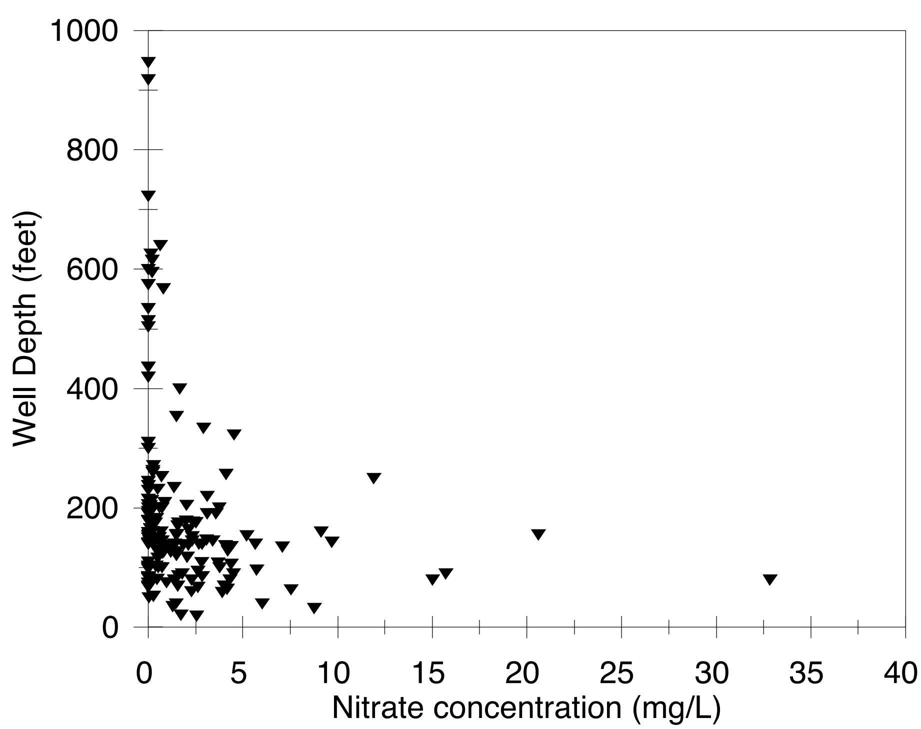

Figure 11. *Well depth versus nitrate concentration in Cache Valley, Cache County, Utah. Correlation coefficient is -0.2.*

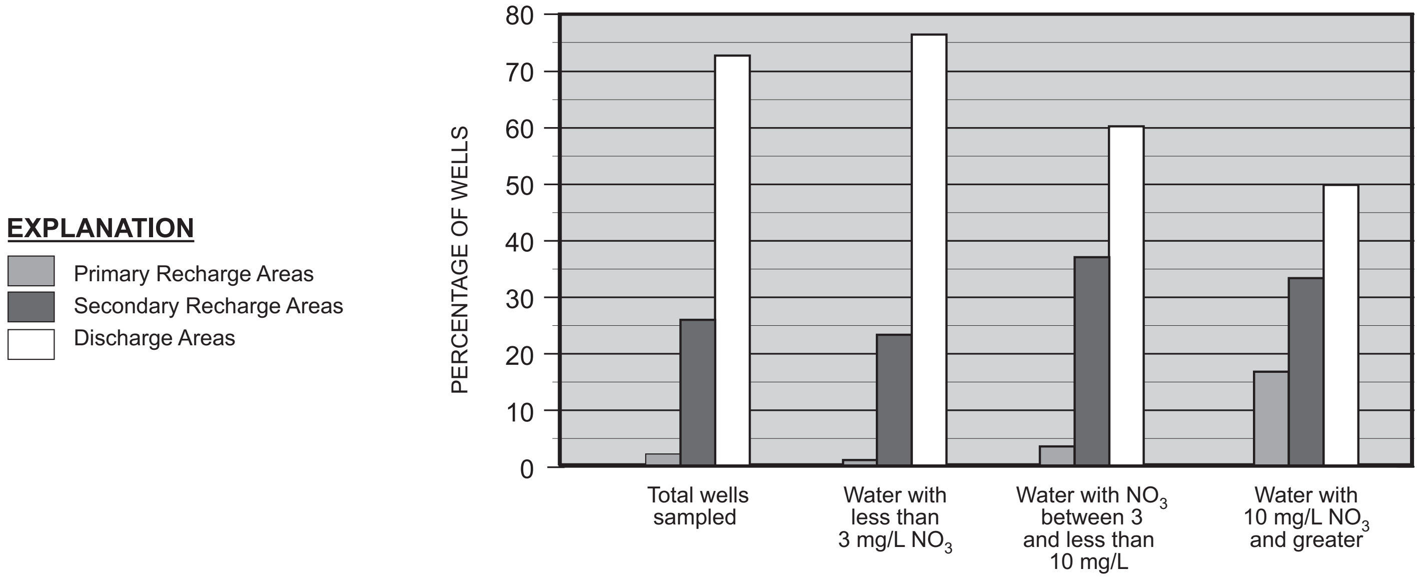

Figure 12. *Percentage of wells in each hydrogeologic-setting category that are less than 3 mg/L, between 3 and 10 mg/L, and 10 mg/L or greater nitrate concentration in Cache Valley, Cache County, Utah.*

tration with respect to perforated-interval category and hydrogeologic setting. Average dissolved-iron concentration is 204.5 µg/L for water from deep wells, 720.7 µg/L for water from medium-depth wells, and 597.9 µg/L for water from shallow wells completed in the principal aquifer. Figure 13 shows the relationship between dissolved-iron concentration and perforated-interval depth; the correlation coefficient is -0.1 indicating no statistical correlation exists between dissolved-iron concentration and perforated-interval depth.

With respect to hydrogeologic setting (plate 5) based on the mapping of Anderson and others (1994), dissolved-iron concentration averages 158 µg/L for ground water from primary-recharge-area wells. For ground water from secondary-recharge-area wells, dissolved-iron concentration averages 494 µg/L. For ground water from discharge-area wells, dissolved-iron concentration averages 416 µg/L. Average dissolved iron with respect to hydrogeologic setting may reflect longer average ground-water residence times in secondary recharge areas and discharge areas than in primary recharge areas. Geologic provenance (source rock for basin-fill sediment) likely is an important factor determining the distribution of dissolved iron in the basin-fill aquifer; for example, igneous rocks containing abundant pyroxene, amphibole, biotite, magnetite, and especially fayalite (iron olivine), have high iron content.

Sulfate Concentrations

The secondary ground-water quality standard for sulfate is 250 mg/L (table A.1) (U.S. Environmental Protection Agency, 2002), primarily because of odor/taste problems and because high-sulfate water can have a laxative effect (Fetter, 1980). Dissolved concentrations of sulfate in Cache Valley's principal aquifer (plate 6) range from less than 10 to 305 mg/L, with an average (background) sulfate concentration of 21 mg/L. A total of eighty-seven wells yielded ground water that was below the detection limit for sulfate of 10 mg/L (appendix A) for the analysis listed on table A.1. Only two wells yielded water samples that exceed the secondary ground-water quality standard for sulfate; most wells yielded ground water with sulfate concentrations below the detection limit of 10 mg/L, so statistical analysis of the distribution of sulfate concentrations with respect to perforated-interval depth and hydrogeologic setting do not produce meaningful results. Geologic provenance (source rock for basin-fill sediment) likely is an important factor determining the distribution of sulfate in the basin-fill aquifer; metallic sulfides in both igneous and sedimentary rocks are common sources of sulfur in its reduced form (Hem, 1989).

Chloride Concentrations

The secondary ground-water quality standard for chloride is 250 mg/L (table A.1) (U.S. Environmental Protection Agency, 2002), primarily because of the potential for its imparting a salty taste to drinking water (Hem, 1989). Chloride at concentrations over 500 mg/L can cause corrosion to wells and plumbing (Driscoll, 1986). Dissolved concentrations of chloride in Cache Valley's principal aquifer (plate 7) range from less than 3 to 515 mg/L, with an average (background) chloride concentration of 52 mg/L. Only one well yielded ground water below the detection limit for chloride of 3 mg/L (appendix A) for the analysis method listed in table A.1. Nine wells yielded water samples that exceed the secondary ground-water quality standard for chloride.

Plate 7 shows the distribution of chloride concentration with respect to perforated-interval category and hydrogeologic setting. The distribution of wells with respect to perforated-interval category and hydrogeologic setting is as described for TDS above. Average chloride concentration is 120 mg/L for water from deep wells, 20 mg/L for water from medium-depth wells, and 27 mg/L for water from shallow wells completed in the principal aquifer. Figure 14 shows the relationship between chloride concentration and perforated-interval depth; the correlation coefficient is 0.7 indicating a weak statistical correlation exists between chloride concentration and perforated-interval depth. This weak correlation may be due to longer ground-water residence time for water samples from deep wells.

With respect to hydrogeologic setting (plate 7) based on the map of Anderson and others (1994), dissolved-chloride concentration averages 53 mg/L for ground water from primary-recharge-area wells, 28 mg/L for ground water from secondary-recharge-area wells, and 60 mg/L for ground water from discharge-area wells. Geologic provenance (source rock for basin-fill sediment) likely is an important factor determining the distribution of chloride in the basin-fill aquifer; although chloride is present at low concentrations in many rock types it is more common in sedimentary rocks, especially evaporites (Hem, 1989). Bonneville lake-cycle sediments, and previous deep-lake-cycle sediments, make up much of the basin fill in Cache Valley and could also be sources of chloride.

Other Constituents

A water sample from one well near the confluence of the Little Bear River and the Bear River yielded an arsenic value of 100 μg/L, twice the ground-water quality standard of 50 μg/L. Gross alpha is below 5 pCi/L for all ground-water samples, so samples were not analyzed subsequently for specific radionuclides. Of water wells tested for pesticides, only one well yielded water with a value above the detection limit for atrazine, but the value was less than the upper limit for ground-water quality standards.

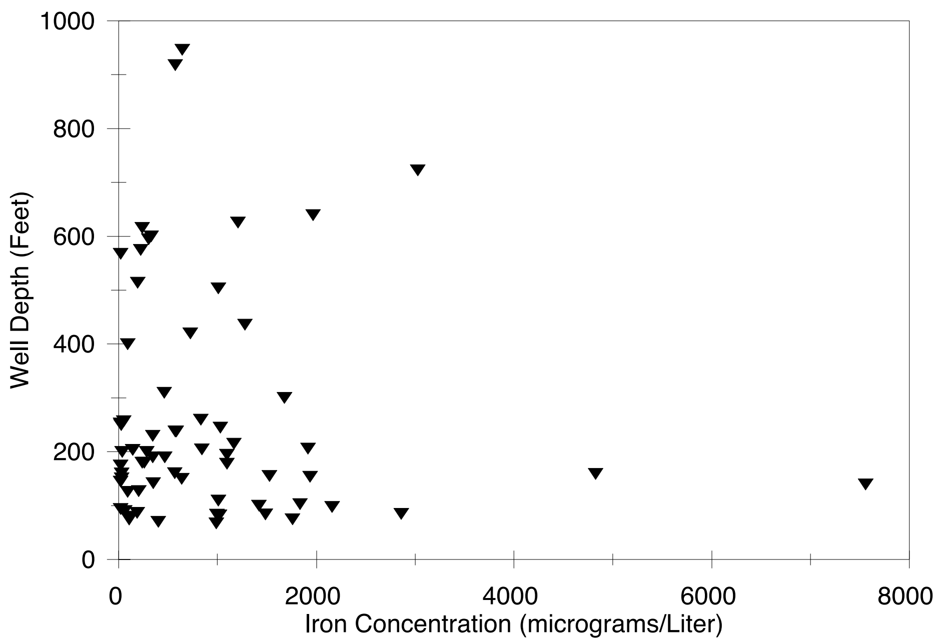

Figure 13. *Iron concentration versus well depth in Cache Valley, Cache County, Utah. Correlation coefficient is -0.1.*

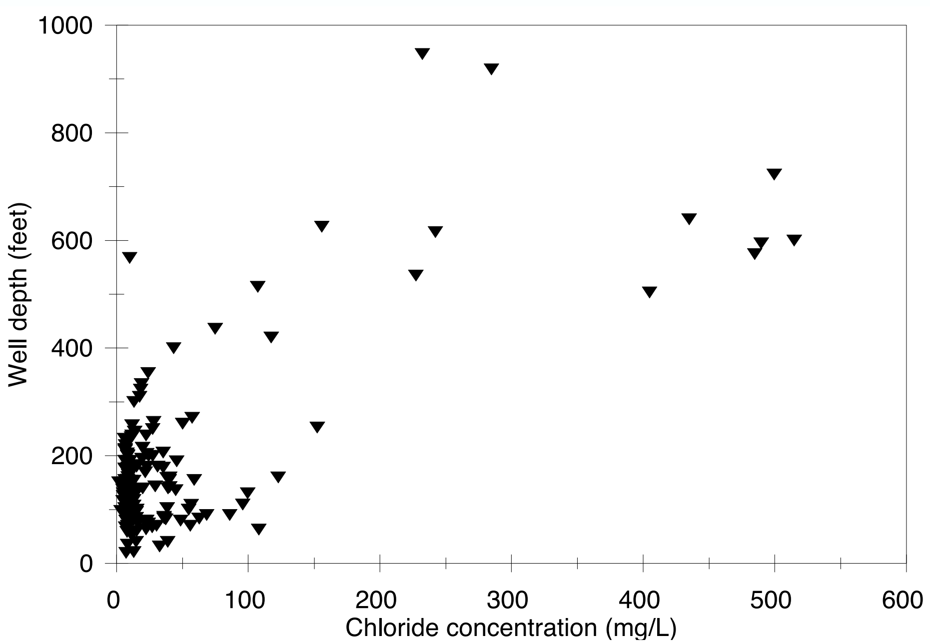

Figure 14. *Chloride concentration versus well depth in Cache Valley, Cache County, Utah. Correlation coefficient is 0.7.*

Resulting Ground-Water Quality Classification

The ground-water quality classification shown on plate 8 is based on the data from the 163 wells completed in the principal aquifer which were sampled between fall and winter of 1997-98 and spring of 1998 by the Utah Division of Environmental Quality. Some areas, where insufficient data exist, require extrapolation of ground-water quality conditions. The basis for our extrapolation was local geologic characteristics. The ground-water quality classes are as follows:

Class IA - Pristine ground water: For this class, TDS concentrations in Cache Valley range from 178 to 492 mg/L. Class IA is the predominant ground-water quality class in Cache Valley (plate 8). Areas having Pristine ground water cover about 84 percent of the total basin-fill material.

Class II - Drinking Water Quality ground water: For this class, TDS concentrations in Cache Valley range from 504 to 1,758 mg/L. Class II areas are present in the northern, northwestern, central, and southern parts of the valley in Utah (plate 8). The areas having Drinking Water Quality ground water cover about 16 percent of the total basin-fill material.

Class III - Limited Use ground water: For this class, no TDS values between 3,000 and 10,000 mg/L were identified. However, water from the seven wells completed in the principal aquifer that exceed ground-water quality standards (one arsenic, six nitrate) is considered Limited Use ground water. These wells could not be mapped as a discrete Class III area due to their sporadic distribution.

Land-Use Planning Considerations

Current beneficial uses of ground water: Ground water, most of which is from the basin-fill aquifer, is the most important source of drinking water in Cache Valley. The results of the ground-water quality classification for Cache Valley indicate that the basin-fill aquifer contains mostly high-quality ground-water resources that warrant protection. According to Steiger and others (1996), ground-water use in Cache Valley is as follows: 54 percent for irrigation, 19 percent for public supply, 19 percent for industry, and 8 percent for domestic and stock-watering purposes. There are 3,018 perfected water wells in Cache Valley, 60 of which are public-supply wells.

Potential for ground-water quality degradation: Potential contaminant sources in Cache Valley include underground storage tanks, leaking underground storage tanks, confined animal-feeding operations, areas served by public sewer systems, lagoons, landfills, rapidly developing areas with septic systems, and fertilizer distributors. Although the actual potential of contamination from these potential sources ranges from negligible to nearly certain (for instance, septic tanks), they do indicate that there is a potential for degradation of Cache Valley's valuable and mostly pristine ground-water resources.

Some ground-water quality degradation has already been documented. Approximately 600 underground storage tanks were identified in Cache County, 51 of which were categorized as leaking underground storage tanks (Ecosystems Research Institute, 1996). Twenty-five of the 51 tanks have since been closed. Petroleum hydrocarbon (TPH) leaks have been monitored at locations associated with leaking underground storage tanks by Ecosystems Research Institute (1996).

Possible land-use-planning applications of this ground-water quality classification: Ground-water quality classification is a tool that can be used in Utah to manage potential ground-water contamination sources and protect the quality of ground-water resources. As such, the wide range of land-use-planning applications of this tool have not been fully explored. Ground-water quality classification has been used in Heber Valley in Wasatch County and Ogden Valley in Weber County, in concert with septic-tank density/water-quality-degradation studies (Hansen, Allen, and Luce, Inc., 1984; Wallace and Lowe, 1998, 1999), to establish minimum lot sizes where septic-tank systems are used for wastewater disposal.

Using ground-water quality classification in conjunction with the septic-tank density/water-quality degradation analysis presented below to set maximum densities for development using septic-tank systems for wastewater disposal in Cache Valley is one possible application of the ground-water quality classification presented above. Additional potential uses include using ground-water quality classification as a basis for prohibiting the dumping of poor-quality water and other liquid or solid wastes into poorly lined or unlined canals, especially in vulnerable ground-water recharge areas. Ground-water quality classification can also be used to enhance restrictions on the siting of new potential pollution sources in drinking-water source-protection zones 1 and 2 for public water-supply wells.

SEPTIC-TANK DENSITY/WATER-QUALITY DEGRADATION ANALYSIS

Introduction

Land-use planners have long used septic-tank-suitability maps to determine where these systems will likely percolate within an acceptable range. However, percolation alone does not remediate many constituents found in wastewater, including nitrate. 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) (Comley, 1945). The U.S. Environmental Protection Agency's maximum contaminant level for nitrate in drinking water (Utah ground-water quality standard) is 10 mg/L. With continued population 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; Lowe and Wallace, 1999c, d; Wallace and Lowe, 1998a, b, c, 1999b; Lowe and others, 2000). 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 septic-system densities.

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 3) are commonly disposed of through septic systems and, unless they volatilize easily, are not remediated 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 via septic tanks (Lowe and Wallace, 1999e).

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, 1999e). 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 3), mostly from the human urinary system. Typically, almost all ammonia is con-

Table 3. *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	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	0.0200
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

verted 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 have existed (Fetter, 1980).

A typical single-family septic-tank system in Cache Valley discharges about 227 gallons (859 L) of effluent per day containing nitrate concentrations of around 55 mg/L; see discussion below. The U.S. Environmental Protection Agency (2002) maximum contaminant level for nitrate in drinking water (ground-water-quality [health] standard) 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 ground-water quality standard.

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 Cache Valley. Projected nitrate concentrations in all or parts of aquifers can be estimated for increasing septic-tank-system densities using a mass-balance approach.

The Mass-Balance Approach

General Methods

We use a mass-balance approach for water-quality degradation assessments because it is easily applied, requires few data, and provides a quantitative basis for land-use planning decisions. In the mass-balance approach to compute projected nitrate concentrations, the average nitrogen mass expected from projected new septic tanks is added to the existing, ambient (background) mass of nitrogen in ground water and then diluted with the known (or estimated) ground-water flow available for mixing, plus water that is added to the system by septic tanks. We used a discharge of 227 gallons (859 L) of effluent per day for a domestic home based on a per capita indoor usage of 70 gallons (265 L) per day (Utah Division of Water Resources, 2001a, p. 28; 2001b, p. 83-106) by Cache County's average 3.24 person household (U.S.Census Bureau, 2002). We used an estimated nitrogen loading of 55 mg/L of effluent per domestic septic tank based on: (1) an average of 3.24 people per household, (2) an average nitrogen loading of 17 g N per capita per day (Kaplan, 1988, p. 149), and (3) an assumed retainment of 15 percent of the nitrogen in the septic tank (to be later removed during pumping) (Andreoli and others, 1979, in Kaplan, 1988, p. 148); this number is close to Bauman and Schafer's (1985, in Kaplan, 1988, p. 147) nitrogen concentration in septic-tank effluent of 62 ± 21 mg/L based on the averaged means from 20 previous studies. Ground-water flow available for mixing, the major control on nitrate concentration in aquifers when using the mass-balance approach (Lowe and Wallace, 1997), was determined using the ground-water flow model of Kariya and others (1994).

Limitations

There are many limitations to any mass-balance approach (see, for example, Zhan and McKay [1998]; Wallace and Lowe, 1998a, b, c, 1999b). We identify the following limitations to our application of the mass-balance approach:

1. Calculations are typically based on a short-term hydrologic budget, a limited number of aquifer tests, 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 do not represent the entire valley.

Although there are many caveats to applying this mass-balance approach, we think that 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.

Ground-Water Flow Calculations

Introduction

We used the GMS (Boss International, Inc. and Brigham Young University, 1999) ground-water modeling system, applied to the regional, three-dimensional, steady-state MODFLOW (McDonal and Harbaugh, 1988) model of Kariya and others (1994), to determine the available ground-water flow in the upper portion of saturated, unconsolidated basin-fill deposits of the principal aquifer in the Utah portion of Cache Valley. The model simulated confined and unconfined conditions, withdrawal from wells, evapotranspiration, seepage to and from streams, areal recharge, seepage to drains, and seepage from consolidated rock.

Computer Modeling

We used Kariya and others' (1994) three-dimensional, finite-difference, numerical MODFLOW model (McDonald and Harbaugh, 1988) of ground-water flow for the basin-fill aquifer system in Cache Valley to provide cell-by-cell flow data under steady-state conditions. We apply Kariya and others' (1994) model as it provides the best representation currently available of the Cache Valley basin-fill aquifer, but Kariya and others (1994, p. 58) point out that "a ground-water model is a tool to simulate a simplified version of a ground-water system," and we acknowledge this tool may be improved upon by future investigators. For steady-state conditions, the model is constructed to represent a ground-water flow system in which there is no change in storage or long-term water levels – in other words, recharge and discharge from the system are exactly equal. Kariya and others' (1994) model was calibrated to assumed 1969 steady-state conditions, a year having the best available ground- and surface-water data.

Description of model of Kariya and others (1994)

Kariya and others (1994) used the U.S. Geological Survey modular three-dimensional, finite-difference, ground-water flow simulator (MODFLOW) (McDonald and Harbaugh, 1988) to test and refine their conceptual understanding of the flow system in Cache Valley. The area covered by the saturated unconsolidated basin-fill deposits was discretized into a non-uniform, horizontal, quasi-three-dimensional, rectangular grid consisting of 82 rows and 39 columns, with up to six vertical layers of cells. The grid represents an area smaller than the actual area of unconsolidated basin-fill because some deposits are not saturated. The model uses a vertical leakage term between the six vertical model layers, and assumes two-dimensional horizontal flow in the aquifer and one-dimensional vertical flow.

The model's rectilinear grid has a grid-cell spacing ranging from 0.5 miles (0.8 km) by 0.375 miles (0.6 km) to 1 mile (1.6 km) on each side, resulting in cell areas of 0.2 to 1 square mile (0.5-2.6 km^2). The y-axis of the model is oriented north-south, parallel to the axis of the valley and the primary surface-water drainages. Activity cells in layers one and two represent an area of approximately 660 square miles (1,789 km^2), with 282 square miles (730 km^2) in Utah. Layer one was simulated as an unconfined layer with an initial saturated thickness of 100 feet (30 m), with changes in the water levels causing the saturated thickness to vary from the initial 100 feet (30 m); within the basin-fill deposits represented by this layer, confined conditions may occur in some areas. Layer one simulates evapotranspiration, discharge from wells and springs, and seepage to streams, rivers, and a reservoir. Layer two simulates saturated valley-fill material from 100 to 200 feet (30-61 m) using a confined- or unconfined-layer option that allows the storage term to be converted from confined to unconfined in cells when calculated water levels drop below the top of the cell. Layers three through six were simulated using the confined-layer option. The depth of saturated basin-fill deposits simulated by layer three is from 200 to 300 feet (61-91 m), layer four from 300 to 500 feet (91-152 m), layer five from 500 to 1,000 feet (152-305 m), and layer six from 1,000 to 1,500 feet (305-457 m). Layer six allows simulation of pumping from deep municipal wells in the eastern part of the valley.

Kariya and others (1994) initially estimated hydraulic parameters based on single-well specific-capacity tests for layer one. Initial transmissivity values of layers two through six were computed by multiplying the estimated hydraulic-conductivity values for layer one by the thickness of each layer. During the steady-state calibration of the model, input parameters were systematically varied and refined to a non-uniform distribution. The final distribution of transmissivity values for layers two through four can be obtained by multiplying the final hydraulic conductivity of layer one by the thickness of the layer in question. During calibration, transmissivity values in layers five and six were reduced to the value for layer four to be more consistent with aquifer-test data. For layer one, to achieve a best fit between simulated and observed data the final values of hydraulic conductivity for the calibrated model ranged from 1 to 100 feet per day (0.3-31 m/d). Transmissivity values used in the calibrated model for layers two to four range from 100 to 18,000 square feet per day (9-1,672 m^2/d). The steady-state simulation assumes the water flowing into the ground-water system equals the amount flowing out, with no change in ground-water storage. The vertical leakage used to represent confining units in the model were calculated based on the vertical hydraulic conductivity determined by comparing simulated vertical-head differences between layers. Cells in layer one with spring discharge are assigned an increased vertical conductance.

Boundary conditions for the Cache Valley model were based on a simplified hydrologic model. Kariya and others (1994) specified the lateral boundaries surrounding the active cells of the model as "no-flow" boundaries by assuming they coincided with low-permeability bedrock, except where inflow from adjacent consolidated rock or unconsolidated basin-fill deposits was identified during the calibration of the model. To simulate subsurface inflow into the main ground-water system of Cache Valley, general-head cells were used at the boundary of layer one. The upper boundary of the model is a specified-flux boundary formed by using recharge, well, evapotranspiration, river, and drain packages of MODFLOW to simulate the infiltration and discharge of ground water. The lower boundary of the model is a no-flow boundary.

In the model, recharge of the Cache Valley basin-fill aquifer occurs: (1) where infiltration of unconsumed irrigation water and precipitation occurs, (2) where perennial streams emerge from canyons, or canals flow across coarse-grained deposits along the margins of the valley, allowing water to infiltrate readily to the underlying ground-water system, and (3) from subsurface inflow. Alluvial fans and deltas adjacent to the Bear River Range are important recharge areas. Twelve perennial streams enter the valley and flow toward the Bear River; ten of these are from the Bear River Range and three are from mountains on the west side of the valley. These tributaries contribute to the surface and subsurface water supplies. Before the time of large-scale irrigation, infiltration from streams flowing across the alluvial fans and deltas was probably the main source of ground water; now, the infiltration of unconsumed irrigation water is almost as important (Kariya and others, 1994). Estimated recharge over the modeled area of Cache Valley is 326,000 acre-feet per year (402 km^3/yr) (Kariya and others, 1994). Ground-water discharge in Cache Valley is primarily from: (1) seepage to the Bear, Cub, Logan, Blacksmith Fork, and Little Bear Rivers, (2) evapotranspiration in the marshes and wetlands, and (3) withdrawals from wells and springs. The largest component of ground-water discharge in Cache Valley is seepage to rivers; the net gain to flow in the Bear River (including Cutler Reservoir) from seepage between Smithfield and the Box Elder county line was 79 cubic feet per second (2.2 m^3/sec) (Herbert and Thomas, 1992). Estimated discharge over the modeled area of Cache Valley is 325,000 acre-feet per year (400 km^3/yr) (Kariya and others, 1994),

The model of Kariya and others (1994) did not simulate the approximately 45.5-square-mile (118 km^2) Clarkston Bench area, because this area has its own individual basin-fill ground-water system and is at a higher altitude than the ground-water system in Cache Valley. Consolidated rocks are at shallower depths in the Clarkston Bench area and the unconsolidated basin fill is thin (about 20 feet [6 m] thick, on average). Little is known of the thickness or extent of water-bearing material in the Clarkston Bench area. We considered the water table in the shallow sediments to be approximately the same as the unconsolidated basin-fill topography. Sand and gravel deposits yield water to a few wells in the Clarkston Bench area. Multiplying the volume of the unconsolidated basin-fill deposits by the average specific yield of sediments (0.25) such as those penetrated in the Clarkston Bench area yielded an amount of water available in the system (52.6 cubic feet per second [1.5 m^3/s]) . The available water was then evaluated over the average thickness and width of the basin-fill deposits.

Results

The ground-water flow model used for this study is the best available tool to qualitatively determine the available water for mixing with septic-tank effluent. Use of the simulation improved our understanding of the aquifer system and provided the volumetric flow budget needed for the septic-tank mass-balance calculations. The model simulation provided a ground-water flow budget for the aquifer in relation to aquifer characteristics, waters in storage, and volumes and rates of inflow and outflow. We used model-calculated cell-by-cell flows in this study to identify areas with similar flows of water in layer one; we assume mixing/dilution of septic-tank effluent will occur within ground water modeled by this layer.

Based on the spatial distribution of the cell-by-cell flow terms calculated by MODFLOW, we identified 11 regions in the Utah portion of Cache Valley with similar flows in layer one. We then used the MODFLOW flow budget for each region to determine the available ground-water flow or volumetric flows in saturated unconsolidated basin-fill deposits for the unconfined aquifer in the Utah portion of Cache Valley for each region. These regions, which we designated as domains, vary in area from 9.8 to 61.2 square miles (25-158 km^2) (table 4) and have volumetric flows from 33.2 to 398.4 cubic feet per second (0.9-11 m^3/sec) (table 5). We use the volumetric flows in the mass-balance calculations as the ground water available for mixing. Ground-water flow in the Clarkston Bench area, not evaluated in the model, was estimated as described above; the Clarkston Bench area was designated as a separate ground-water flow domain, for a total of 12 domains (plate 9).

Modeling Limitations

Simplifying assumptions are required to construct a numerical model of a natural hydrogeologic system. Some of these assumptions limit the scope of application of the model and the hydrologic questions that can reasonably be addressed, and may influence the model results. The numerical model is a simplified and idealized approximation of the actual ground-water flow system. Kariya and others (1994) summarized the major simplifying assumptions and their limitations on the regional ground-water flow model. The model assumed a small ground-water inflow at the valley margins, a layer-cake geology, and leaky aquitards throughout the basin; however, recent work by Oaks (2000) questions the validity of these assumption and their affect on ground-water flow in the model. We used a steady-state simulation with time-averaged and measured conditions; thus, the model cannot predict the transient response of the system, because it is not calibrated to transient conditions. This means we cannot use the model to predict flows in the system if new stresses were applied, such as adding a large well, to the system. The model, however, can simulate steady-state conditions and be used to evaluate various ground-water conditions.

Table 4. *Cities/towns and land area within each ground-water flow domain (plate 9) in Cache Valley, Cache County, Utah.*

Domain	Area (square miles)	Cities/towns
1	14.2	Cove
2	31.2	Lewiston
3	9.8	Cornish
4	45.5	Clarkston, Newton
5	39.3	Richmond, Trenton, Amalga
6	33.3	Benson
7	18.4	Smithfield, Hyde Park
8	22.6	Petersboro
9	19.0	Mendon
10	61.2	Young Ward, Nibley, College Ward, Wellsville
11	16.6	Mount Sterling
12	16.5	South Hyrum, Paradise, Avon

Septic-Tank-System/Water-Quality-Degradation Analyses

Introduction

We calculated projected domain-specific nitrate concentrations in the 12 ground-water flow domains (table 4, plate 9) by applying a mass-balance approach using domain-specific parameters such as the existing nitrogen load (background nitrate concentration) and amount of ground water available for mixing (flow volume; table 5), and our estimated 227 gallons per day (859 L/d) contributed by each septic-tank system with a estimated nitrogen loading of 55 mg/L of septic-tank effluent. The mass-balance approach predicts the impact of nitrate from use of septic-tank systems over a

Table 5. Parameters used to perform a mass-balance analysis for each ground-water flow domain in Cache Valley, Cache County, Utah.

Domain	Area (acres)	Flow* (cubic feet per second)	Average nitrate concentration (mg/L)	Number of wells sampled	Curent number of septic tanks+
1	9,086	26.6	0.74	5	100
2	19,956	40.4	5.47	4	300
3	6,245	33.2	0.8	2	110
4	29,138	52.6	2.72	5	530
5	25,167	108.0	3.01	5	500
6	21,291	47.0	0.73	17	190
7	11,756	66.7	0.3	25	200
8	14,453	67.5	0.09	4	100
9	12,130	58.8	0.92	7	250
10	39,169	398.4	0.35	62	800
11	10,625	91.0	6.58	12	100
12	10,528	99.3	0.63	14	400

* ground-water flow available for mixing; data were derived using ground-water computer model, except domain 4 (Clarkston Bench area; see text for explanation).

+ septic systems were estimated by the Bear River Health Department (Nick Galloway, in 2001); we used 227 gallons per household as the amount of water generated based on the 2001 Utah State Water Plan (Utah Division of Water Resources, 2001).

defined area.

We calculated one graph for each area based on a range of parameters that affect the amount of ground water available for dilution. We obtained the number of septic-tank systems in each area from the Bear River Health Department (Nick Galloway, written communication, 2001). Table 5 lists the number of septic-tank systems estimated for each domain. The total number of septic-tank systems in the valley currently is approximately 3,580 for all the domains, and ranges from a low of about 100 (domains 1 and 11) to a high of about 800 (domain 10) (table 5). Background nitrate concentration for each area ranges from 0.09 mg/L (domain 8) to 6.58 mg/L (domain 11).

Results

We herein present written descriptions of our mass-balance calculations for only domains 1 (figure 15a) and 4 (figure 15d) (figure 16). Calculations for domains 2, 3, and 5 through 12 were calculated in the same manner as domain 1, using the information on tables 4, 5, and 6 and figures 15b, 15c, and 15e through 15l.

Domain 1. Figure 15a shows a plot of projected nitrate concentration versus septic-tank density and number of septic-tank systems in domain 1 (figure 16) in northeastern Cache Valley (plate 9). Background nitrate concentration for domain 1 is 0.74 mg/L. Approximately 100 septic systems are in domain 1 (Nick Galloway, Bear River Public Health Department, written communication, 2001). Domain 1 has an area of approximately 9,086 acres (3,677 hm^2), so the existing average septic-system density is 0.011 systems per acre (0.005 systems/hm^2), or 91 acres per system (37 hm^2/system). Based on our analyses (table 7), estimated ground-water flow available for mixing in domain 1 is 26.6 cubic feet per second (0.76 m^3/s). For the domain 1 area to maintain an overall nitrate concentration of 1.74 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 1,525 based on the estimated nitrogen load of 55 mg/L per septic-tank system (figure 15a, table 6). This corresponds to a total increase of approximately 1,425 septic systems and an average septic-system density of about 0.17 systems per acre (0.07 systems/hm^2), or 6 acres per system (2.4 hm^2/system) in domain 1 (table 6).

Domain 4. Figure 15d shows a plot of projected nitrate concentration versus septic-tank density and number of septic-tank systems in domain 4 (Clarkston Bench area; figure 16) in northwesternmost Cache Valley (plate 9). Domain 4 differs from the rest of the domains because this area was not included in the ground-water model, so we calculated the amount of ground-water flow available for mixing based on volume of basin-fill deposits and specific yield of sediments of the type found in the basin-fill deposits in domain 4 as described in the section on "Description of model of Kariya and others (1994)." Background nitrate concentration for domain 4 is 2.72 mg/L. Approximately 530 septic systems are located in domain 4 (Bear River Public Health Department, written communication, 2001). Domain 4 has an area of approximately 29,138 acres (117.9 km^2), so the average septic-system density is 0.018 systems per acre (0.007 systems/hm^2), or 55 acres per system (22 hm^2/system). Based on our analyses (table 7), estimated ground-water flow available for mixing in domain 4 is 52.6 cubic feet per second (1.5 m^3/s). For the domain 4 area to maintain an overall nitrate concentration of 3.72 mg/L, the total number of homes using septic tank soil-absorption systems should not exceed 3,450 based on the estimated nitrogen load of 55 mg/L per septic-tank system (figure 15d). This corresponds to a total increase of approximately 2,920 septic systems and an average

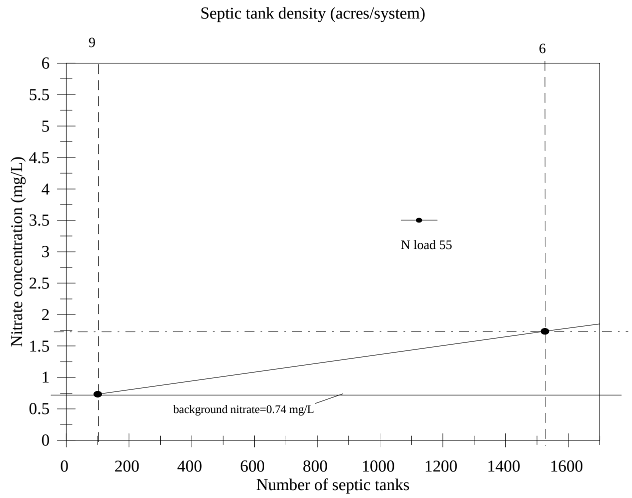

Figure 15a. *Projected septic-tank density versus nitrate concentration for domain 1 (table 4) in Cache Valley, Cache County, Utah, based on 100 existing septic tanks (see table 5). N load 55 refers to an estimated nitrate loading per liter of wastewater from septic-tank systems (see text for explanation).*

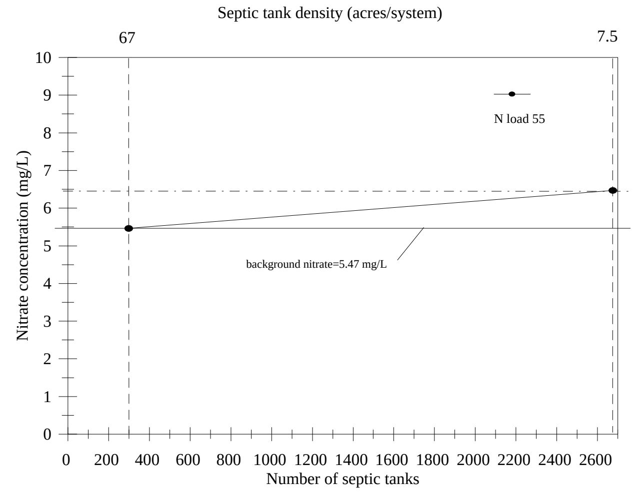

Figure 15b. *Projected septic-tank density versus nitrate concentration for domain 2 (table 4) in Cache Valley, Cache County, Utah, based on 300 existing septic tanks (see table 5). N load 55 refers to an estimated nitrate loading per liter of wastewater from septic-tank systems (see text for explanation).*

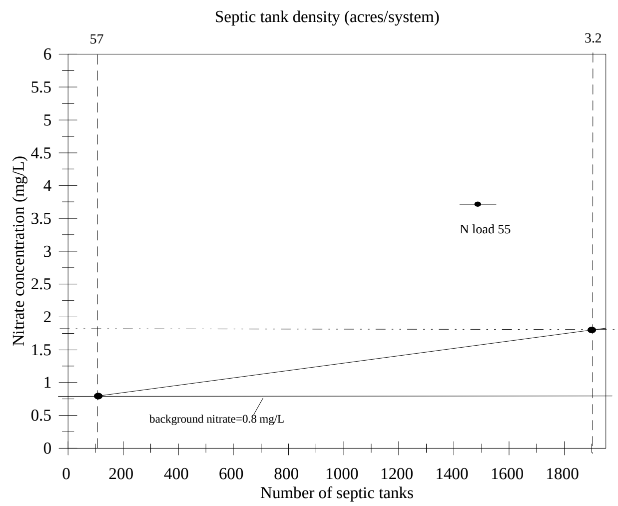

Figure 15c. *Projected septic-tank density versus nitrate concentration for domain 3 (table 4) in Cache Valley, Cache County, Utah, based on 110 existing septic tanks (see table 5). N load 55 refers to an estimated nitrate loading per liter of wastewater from septic-tank systems (see text for explanation).*

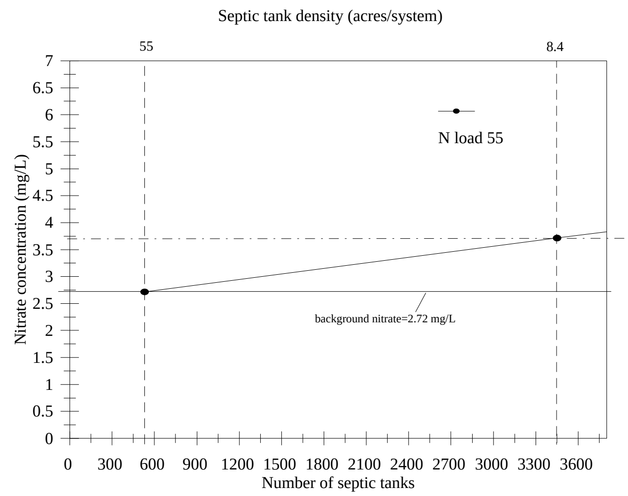

Figure 15d. *Projected septic-tank density versus nitrate concentration for domain 4 (table 4) in Cache Valley, Cache County, Utah, based on 530 existing septic tanks (see table 5). N load 55 refers to an estimated nitrate loading per liter of wastewater from septic-tank systems (see text for explanation).*

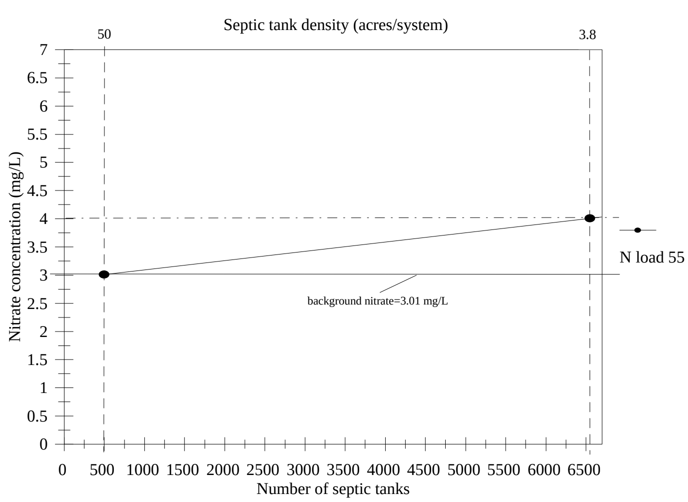

Figure 15e. *Projected septic-tank density versus nitrate concentration for domain 5 (table 4) in Cache Valley, Cache County, Utah, based on 500 existing septic tanks (see table 5). N load 55 refers to an estimated nitrate loading per liter of wastewater from septic-tank systems (see text for explanation).*

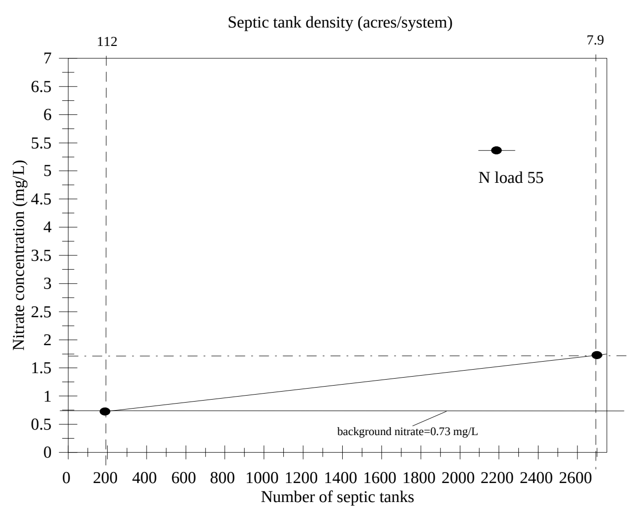

Figure 15f. *Projected septic-tank density versus nitrate concentration for domain 6 (table 4) in Cache Valley, Cache County, Utah, based on 190 existing septic tanks (see table 5). N load 55 refers to an estimated nitrate loading per liter of wastewater from septic-tank systems (see text for explanation).*

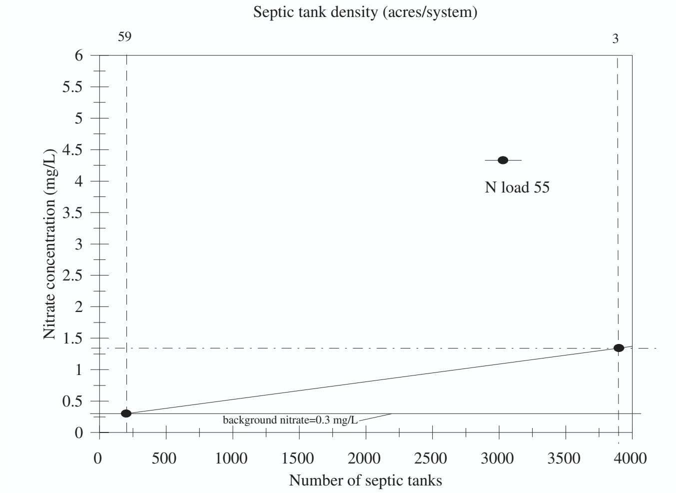

Figure 15g. *Projected septic-tank density versus nitrate concentration for domain 7 (table 4) in Cache Valley, Cache County, Utah, based on 200 existing septic tanks (see table 5). N load 55 refers to an estimated nitrate loading per liter of wastewater from septic-tank systems (see text for explanation).*

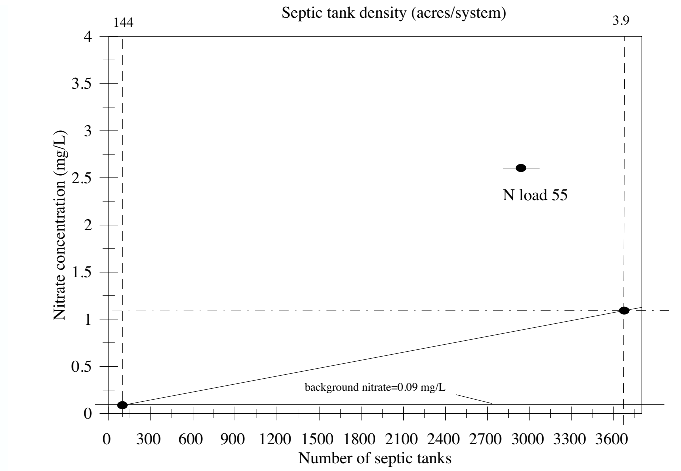

Figure 15h. *Projected septic-tank density versus nitrate concentration for domain 8 (table 4) in Cache Valley, Cache County, Utah, based on 100 existing septic tanks (see table 5). N load 55 refers to an estimated nitrate loading per liter of wastewater from septic-tank systems (see text for explanation).*

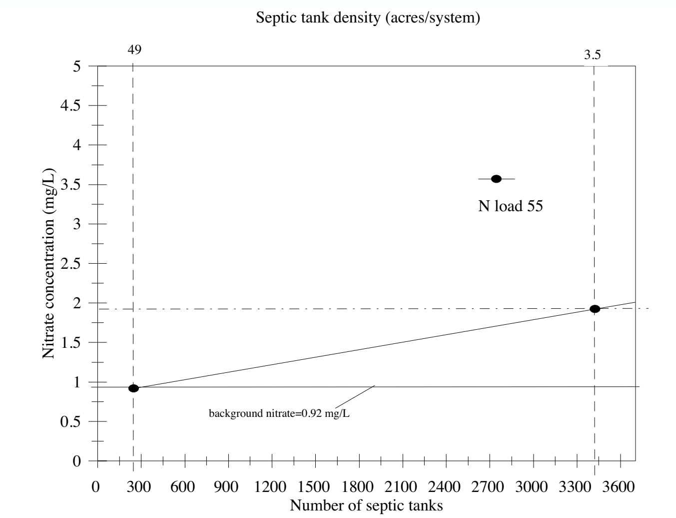

Figure 15i. *Projected septic-tank density versus nitrate concentration for domain 9 (table 4) in Cache Valley, Cache County, Utah, based on 250 existing septic tanks (see table 5). N load 55 refers to an estimated nitrate loading per liter of wastewater from septic-tank systems (see text for explanation).*

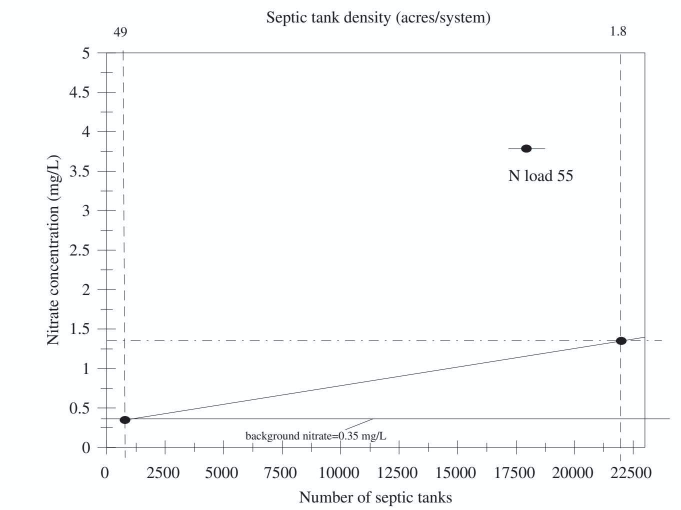

Figure 15j. *Projected septic-tank density versus nitrate concentration for domain 10 (table 4) in Cache Valley, Cache County, Utah, based on 800 existing septic tanks (see table 5). N load 55 refers to an estimated nitrate loading per liter of wastewater from septic-tank systems (see text for explanation).*

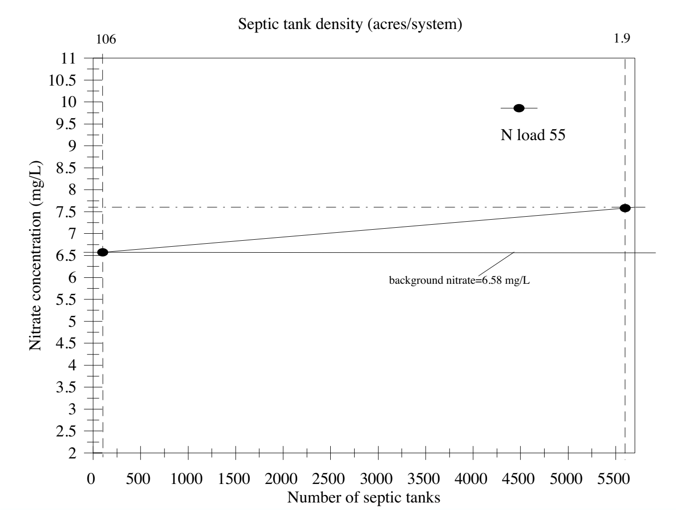

Figure 15k. *Projected septic-tank density versus nitrate concentration for domain 11 (table 4) in Cache Valley, Cache County, Utah, based on 100 existing septic tanks (see table 5). N load 55 refers to an estimated nitrate loading per liter of wastewater from septic-tank systems (see text for explanation).*

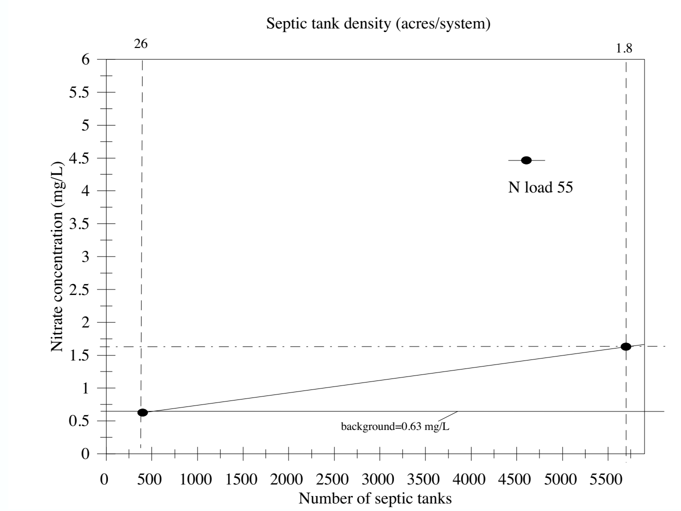

Figure 15l. *Projected septic-tank density versus nitrate concentration for domain 12 (table 4) in Cache Valley, Cache County, Utah, based on 400 existing septic tanks (see table 5). N load 55 refers to an estimated nitrate loading per liter of wastewater from septic-tank systems (see text for explanation).*

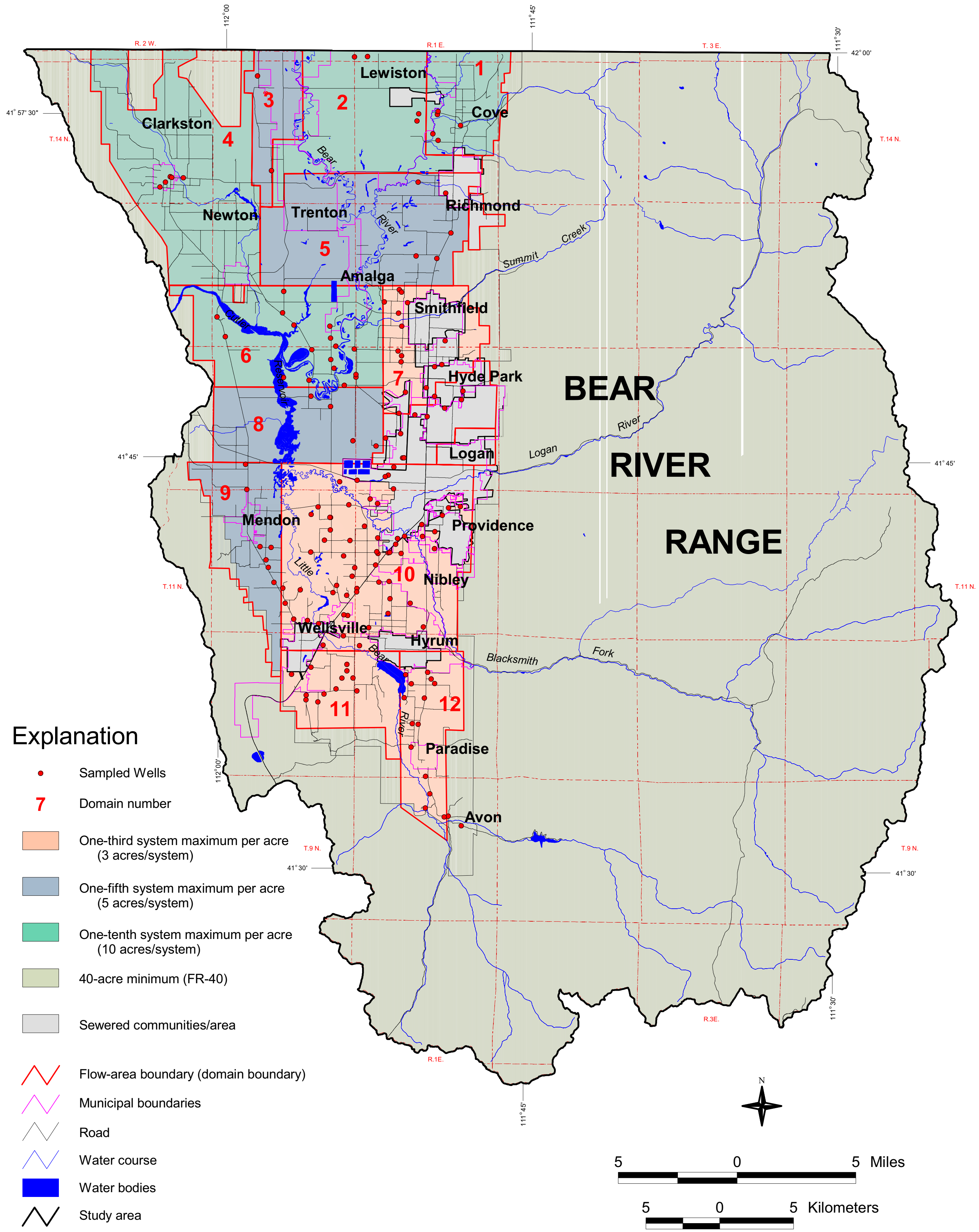

***Figure 16.** Recommended lot size for ground-water flow domains in Cache Valley, Cache County, Utah.*

septic-system density of about 0.12 systems per acre (0.05 systems/hm^2), or 8.4 acres per system (3.4 hm^2/system) in domain 4 (table 6).

Shallow Unconfined Ground-Water Issues

We have applied the mass-balance approach to the principal drinking-water aquifer in the basin fill of Cache Valley, because this is the resource we believe warrants the greatest efforts for protection. Some regulatory agencies may be concerned about the impact of septic tanks on all waters of the state, including shallow unconfined ground water in Cache Valley that is not currently used as a source of drinking water and, in much of the valley, is separated from the principal aquifer by thick clay confining layers. In many areas of Cache Valley there is also an upward ground-water gradient in the principal aquifer (discharge area, figure 6) that can prevent downward migration of poorer quality water in the shallow unconfined aquifer.

The shallow unconfined aquifer in Cache Valley was not a component of the Kariya and others (1994) ground-water flow model of the unconsolidated aquifer in Cache Valley. Because the shallow unconfined aquifer is relatively thin and is in proximity to surface sources of ground-water pollution, the shallow unconfined aquifer is where the impact of septic-tank systems is likely to be greatest. We performed a simple mass-balance evaluation of the shallow unconfined aquifer to help understand the effect of increasing numbers of septic tanks on water quality in the shallow unconfined aquifer; once again, we used nitrate as a proxy for all constituents in septic-tank system effluent. However, we note that negligible data exist for the shallow unconfined aquifer compared to the principal aquifer.

The general physical characteristics of the shallow unconfined aquifer are summarized in table 7. The thickness of the shallow unconfined aquifer as reported in Bjorklund and McGreevy (1971) was 10 to 20 feet (3-6 m), but the aquifer thickness is probably not continuous across the valley. We used 20 feet (6 m) as the thickness of the unconfined aquifer. We considered the unconfined aquifer to consist of fine sand, silt, and clay, and we used a hydraulic conductivity of 0.5 feet per day (0.15 m/d), a value typical for these types of sediment (Freeze and Cherry, 1979). We obtained the hydraulic gradient from the potentiometric surface map in Bjorklund and McGreevy (1971) for the unconsolidat-basin-fill deposits, and assumed this hydraulic gradient applied to the shallow aquifer; we used an average hydraulic gradient for the valley of 0.01 in our calculations. Using an average valley width of 7 miles (11 km), we obtained a volumetric flow rate of 3,696 cubic feet per day (105 m^3/d) for

Table 6. *Results of mass-balance analysis using an estimated nitrogen loading of 55 mg/L for each ground-water flow domain in Cache Valley, Cache County, Utah.*

Domain	Total # projected septic systems	Septic systems beyond current number	Current density		Calculated* density		Recommended density	
			acres/ septic system	septic system /acre	acres/ septic system	septic system /acre	acres/ septic system	septic system /acre
1	1,525	1,425	91	0.011	6	0.17	10	0.1
2	2,675	2,375	67	0.015	7.5	0.13	10	0.1
3	1,900	1,790	57	0.018	3.2	0.31	5	0.2
4	3,450	2,920	55	0.018	8.4	0.12	10	0.1
5	6,550	6,050	50	0.02	3.8	0.26	5	0.2
6	2,700	2,510	112	0.009	7.9	0.13	10	0.1
7	3,900	3,700	59	0.017	3.0	0.33	3	0.3
8	3,675	3,575	144	0.007	3.9	0.26	5	0.2
9	3,425	3,175	49	0.02	3.5	0.28	5	0.2
10	22,000	21,200	49	0.02	1.8	0.56	3	0.3
11	5,600	5,500	106	0.009	1.9	0.53	3	0.3
12	5,700	5,300	26	0.039	1.8	0.56	3	0.3

* best-estimate calculation is based on a nitrogen load of 17 g N per capita per day (from Kaplan, 1988) for a 3.24-person household and 227 gallons of wastewater per day for the Bear River Basin (Utah Division of Water Resources, 2001).

Table 7. Physical characteristics of the unconfined aquifer in Cache Valley, Cache County, Utah.

Thickness	20 feet
Hydraulic conductivity	0.5 feet per day
Hydraulic gradient	0.01
Average width	7 miles
Background nitrate	0.68 mg/L

the Utah part of Cache Valley. The Utah part of Cache Valley was assumed to be about 365 square miles (945 km^2). For our calculations we used a density of about 0.01 septic-tank systems per acre (0.004 systems/hm^2), or 100 acres per system (40 hm^2/system). We had no representative chemical data on the shallow unconfined aquifer, so we used the valley-wide average of 0.68 mg/L for the background nitrate loading for our calculations.

The effect of septic-tank systems on ground-water quality in the shallow unconfined aquifer is considerable. An additional 0.4 percent, or 10 septic tanks, increases the nitrate concentration from the background value of 0.68 mg/L to 4.8 mg/L, an increase of seven times. Similarly, an additional 3 percent, or 100 septic tanks, increases the nitrate concentration from the background value of 0.68 mg/L to 25 mg/L, a 36-fold increase. The accumulation of nitrate in the shallow unconfined aquifer is a cumulative effect of septic-tank disposal practices. The addition of the septic-tank effluent to the shallow unconfined aquifer is a substantial proportion of the volume of recharge water to the aquifer. Because water quality in the shallow unconfined aquifer is impacted by the quality of this recharge water, the implication of the nitrate loading with respect to the impact of septic-tank systems on ground water is that the shallow unconfined aquifer is probably already overloaded in some areas due to the number of septic-tank systems already in place. If the shallow ground-water system is determined by regulatory agencies to be a resource that should be protected from degradation from septic-tank systems, our mass-balance analysis indicates that no new septic-tank systems should be added to the ground-water system, and removal of existing systems, where feasible, would be beneficial to water quality in the shallow unconfined aquifer. However, because of the general lack of data regarding the shallow unconfined aquifer, data collection followed by construction of a ground-water flow model for the unconfined aquifer system may be warranted so that further analyses of septic-system density/water-quality degradation may be conducted.

Recommendations for Land-Use Planning

Our estimates of nitrate concentrations/water-quality degradation provide a conservative (worst case) first approximation of long-term ground-water pollution from septic-tank systems. The graphs of projected nitrate concentration versus number of septic-tank systems in each area show recommended septic-tank density for each domain based on the parameters described above. Due to the greater amount of ground-water available for mixing in the central areas of Cache Valley, a greater number of septic systems can exist in those areas compared to the northeastern area of Cache Valley, especially near Lewiston and Cove. However, the results of this study would be most effective in protecting ground-water quality through land-use planning when used in conjunction with ground-water quality classification and ground-water recharge/discharge-area maps. Additionally, switching from septic-tank systems to a well-engineered, well-constructed public sanitary sewer system, especially one that includes tertiary treatment capabilities, would be a preferred alternative where protection of ground-water quality is a primary issue; however, poorly engineered, poorly constructed public sanitary sewer systems could have even greater negative impacts on ground-water quality than septic-tank systems.

The ground-water flow generated domain boundaries on plate 9 do not coincide with geographic or cultural features that can be easily located on the land surface for application in land-use planning. Plate 10 shows the results of our septic-tank-system/water-quality degradation analysis with the domain boundaries shifted slightly to match geographic or cultural features; this facilitates application of our analysis in land-use planning. These maps are designed to be land-use-planning tools, especially in areas where public sanitary sewer systems are not available, not as an alternative to sewering; we believe development of public sanitary sewer systems should continue to be implemented where feasible. In addition, these maps are not suitable for subdivision-scale planning. In the future, if regulatory agencies determine that the shallow unconfined aquifer should be protected from degradation from septic-tank systems, either (1) additional data collection followed by construction of a ground-water flow model for the shallow unconfined aquifer system should be undertaken to allow further analyses of septic-tank system density/water-quality degradation, or (2) public sanitary-sewer-system development should be considered throughout Cache Valley.

SUMMARY AND CONCLUSIONS

Ground water is the most important source of drinking water in Cache Valley. Ground-water quality classification is a relatively new tool that can be used in Utah to manage potential ground-water contamination sources and protect the quality of ground-water resources. The results of the ground-water quality classification for Cache Valley, which was formally adopted by the Utah Water Quality Board on August 10, 2001, indicate that the basin-fill aquifer contains mostly high-quality ground-water resources that warrant protection. Eighty-four percent of the ground water in the basin-fill aquifer is classified as Class IA, and 16 percent is classified as Class II, based on chemical analyses of water from 163 wells sampled during fall 1997 and winter/spring 1998 (TDS range of 178 to 1,750 mg/L).

Septic tank soil-absorption systems are used to dispose of domestic wastewater in many areas of Cache Valley. Many constituents in septic-tank effluent are known to undergo little remediation in the soil environment as they travel through the unsaturated zone to the aquifer; dilution is the principal mechanism for lowering concentrations of these constituents once they have reached the aquifer. We used nitrate in septic-tank effluent as an indicator constituent for evaluating the dilution of constituents in wastewater that reach ground-water aquifers; this evaluation uses a mass-balance approach that is based principally on ground-water flow available for mixing with effluent constituents in the aquifer of concern. The mass-balance approach for the principal basin-fill aquifer in Cache Valley, Utah, indicates that three categories of recommended maximum septic-tank system densities are appropriate for development using septic tank soil-absorption systems for wastewater disposal in Cache Valley, Utah: one-third, one-fifth, and one-tenth systems per acre (0.13, 0.08, and 0.04 systems/hm^2), or 3, 5, and 10 acres per system (1.2, 2, and 4 hm^2/system); these recommendations are based on hydrogeologic parameters incorporated in the ground-water flow model and geographically divided into 12 ground-water flow domains on the basis of flow-volume similarities. The shallow unconfined aquifer is a limited source of drinking water in Cache Valley, Utah; however, our mass-balance analyses indicate that this aquifer is vulnerable to degradation from development using septic systems for wastewater disposal. If regulatory agencies desire to protect this shallow unconfined aquifer from water-quality degradation, we recommend that either (1) additional data collection followed by construction of a ground-water flow model for the shallow unconfined aquifer system be undertaken to allow further analyses of septic-tank system density/water-quality degradation, or (2) no new septic-tank systems be considered in Cache Valley, Utah.

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__APPENDIX A.1.__ EPA primary ground-water quality standards and analytical method for some chemical constituents sampled in Cache Valley, Cache County, Utah.

CHEMICAL CONSTITUENT	EPA ANALYTICAL METHOD	GROUND-WATER QUALITY STANDARD (mg/L)
Nutrients:		
total nitrate/nitrite	353.2	10.0
ammonia as nitrogen	350.3	-
total phosphorous and dissolved total phosphate	365.1	-
Dissolved metals:		
arsenic	200.9	0.05
barium	200.7	2.0
cadmium	200.9	0.005
chromium	200.9	0.1
copper	200.7	1.3
lead	200.9	0.015
mercury	245.1	0.002
selenium	200.9	0.05
silver	200.9	0.1
zinc	200.7	5.0
General Chemistry:		
total dissolved solids	160.1	2000^{+**} or ($500*^{++}$)
pH	150.1	between 6.5 and 8.5
aluminum*	200.7	0.05 to 0.2
calcium*	200.7	-
sodium*	200.7	-
bicarbonate	406C	-
carbon dioxide	406C	-

APPENDIX A.1. *(continued).*

CHEMICAL CONSTITUENT	EPA ANALYTICAL METHOD	GROUND-WATER QUALITY STANDARD (mg/L)
carbonate	406C	-
chloride*	407A	250
total alkalinity	310.1	-
total hardness	314A	-
specific conductance	120.1	-
iron*	200.7	0.3
potassium*	200.7	-
hydroxide	406C	-
sulfate *++	375.2	250
magnesium*	200.7	-
manganese*	200.7	0.5
Organics and pesticides:		
aldicarb	531.1	0.003
aldicarb sulfoxide	531.1	0.004
atrazine	525.2	0.003
carbofuran	531.1	0.04
2, 4-D	515.1	0.07
methoxychlor	525.2	0.4
methiocarb	531.1	-
dinoseb	515.1	0.007
dalapon	515.1	0.2
baygon	515.1	-
picloram	515.1	0.5
dicamba	515.1	-

APPENDIX A.1. *(continued).*

oxamyl	531.1	0.2
methomyl	531.1	-
CHEMICAL CONSTITUENT	**EPA ANALYTICAL METHOD**	**GROUND-WATER QUALITY STANDARD (mg/L)**
carbaryl	531.1	-
3-Hydroxycarbofuran	531.1	-
pentachlorophenol	515.1	0.001
2, 4, 5-TP	515.1	0.05
Radionuclides:		
Alpha, gross	600/4-80-032	15 pCi/L(picocuries per liter)
Beta, gross	600/4-80-032	4 millirems per year
U238MS Fil (Uranium)	600/4-80-032	0.030 mg/L
226Radium	600/4-80-032	5 pCi/L
228Radium	600/4-80-032	5 pCi/L

- no standard exists for this constituent
*for secondary standards only (exceeding these concentrations does not pose a health threat)
$^{+}$ maximum contaminant level is reported from Utah Administrative Code R309-103 (Utah Division of Water Quality)
**For public water-supply wells, if TDS is greater than 1,000 mg/L, the supplier shall satisfactorily demonstrate to the Utah Water Quality Board that no better water is available. The Board shall not allow the use of an inferior source of water if a better source of water (lower in TDS) is available
$^{++}$TDS and sulfate levels are given in the Primary Drinking Water Standards, R309-103- 2.1. They are listed as secondary standards because levels in excess of these recommended levels will likely cause consumer complaint

APPENDIX A.2. Water-quality data

Site #	Sample date	USGS Cadastral	Well Depth (feet)	NO_2+NO_3 (mg/L)	TDS (mg/L)	Field T (°C)	pH	Arsenic (µg/L)	Fe, Dissolved (µg/L)	Chlor-ide (mg/L)	SO_4 (mg/L)	Na (mg/L)	Alpha, gross (pCi/L)	Beta, gross (pCi/L)	226 Radium (pCi/L)	Total Hardness/ $CaCO_3$ (mg/L)
1	12-10-97	(B-14-2) 34aac	70	<.02	528	10	7.1	19	403	30.5	66	18.8	-	-	-	284.1
1.5	12-10-97	(B-14-2) 26cdb	35	1.31	238	6	7.3	<5	<20	8.5	<10	7.46	-	-	-	227.3
2	10-15-97	(B-14-2) 26cda	32	8.78	540	11.9	7.2	12	<20	33	31.2	31	-	-	-	437.2
2.5	12-10-97	(B-14-2) 35bbb	80	32.85	708	9.6	7	12	<20	49	49	31.8	-	-	-	417.1
"		"	-	35.77	-	-	-	-	-	-	-	-	-	-	-	-
3	10-15-97	(B-14-2) 26ddb	90	15.72	674	10.5	7.3	15	65.5	86	98.8	40.2	4.14	<10	1.09	484.9
"	-	"	-	8.67	-	-	-	-	-	-	-	-	-	-	-	-
"	-	"	-	6.51	-	-	-	-	-	-	-	-	-	-	-	-
5	10-15-97	(B-14-1) 5add	110	0.03	534	15.4	7.8	27	1010	96	80.5	92.9	-	-	-	245.2
7	12-10-97	(B-14-1) 28bdd	70	1.57	244	5.9	7.7	<5	<20	8.5	<10	7.75	-	-	-	237.3
555	5-13-97	(A-15-1) 31cdc	-	12.17	1758	9.5	7.5	-	-	360	305	326	-	-	-	737.6
556	5-13-97	(A-15-1) 31dcc	-	9.25	1468	9.7	7.9	-	-	312.5	269	265	-	-	-	643.8
14	10-15-97	(A-14-1) 15abb	40	6.02	306	13.2	7.4	<5	<20	15	<10	10.2	-	-	-	293.2
14.5	12-09-97	(A-14-1) 15cdc	175	1.6	226	9.7	7.6	<5	<20	7	<10	12.2	-	-	-	181.4
15	12-16-97	(A-14-1) 22bad	59	3.93	282	10.1	7.8	<5	<20	8	<10	6.21	-	-	-	262.4
16	10-15-97	(A-14-1) 10dcc	83	<.02	296	13.5	7.7	25	998	63	<10	42.9	-	-	-	202.1
17	12-09-97	(A-14-1) 34adb	52	0.28	370	10.6	7.1	<5	<20	11.7	<10	13.8	-	-	-	244.1
20	12-09-97	(A-14-1) 14caa	220	3.13	232	8.6	7.4	<5	<20	7	<10	10.5	-	-	-	204.6
20.5	12-09-97	(A-13-1) 11bbb-	21	1.73	290	6.8	7.7	<5	<20	13	<10	14.8	-	-	-	214.5
501	5-13-98	(A-14-1) 16ddd	180	0.19	286	10.1	7.9	-	-	31.5	<10	33.5	-	-	-	208.6
502	5-13-98	(A-14-1) 16dda	260	0.26	302	10.9	7.9	39	834	50.5	<10	53.6	-	-	-	177.5
504	5-13-98	(A-14-1) 34bdd		7.74	394	10.6	7.6	-	-	16	<10	9.71	-	-	-	353.9
22	12-10-97	(B-13-1) 30cba	109	2.82	366	11.8	7.6	16	<20	57	22	86.2	-	-	-	118.3
25	12-10-97	(B-13-1) 22cbc	436	<.02	860	7.4	7.8	<5	1280	75	<10	137	-	-	-	427.3
26	12-10-97	(B-13-1) 27bcc	50	0.04	728	9.5	7	<5	2770	250	<10	138	7.68	17.3	<.5	302.9
26.5	12-11-97	(B-12-1) 1cbc	595	0.23	974	16.4	7.5	<5	307	490	<10	97.3	-	-	-	534.5
27	12-11-97	(A-13-1) 31ccc	626	0.16	590	15.5	7.2	46	1210	156	<10	141	-	-	-	232.7
27.5	12-11-97	(A-12-1) 2add	575	<.02	964	9.8	8	<5	228	485	<10	97.9	-	-	-	581.1
28.5	12-16-97	(B-12-1) 11bad	616	0.23	696	18	7.5	<5	243	242.5	<10	89	-	-	-	317.2
29	12-11-97	(B-12-1) 11ccd	947	0.03	564	20.2	7.7	<5	646	232.5	<10	75	-	-	-	323.1
30	12-11-97	(B-13-1) 35ccd	600	<.02	1010	16.5	7.5	<5	332	515	<10	94.5	-	-	-	532.8
31	12-11-97	(B-13-1) 35daa	640	0.64	866	15	7.7	<5	1970	435	<10	96.8	-	-	-	496.4
31.5	12-11-97	(B-13-1) 35aaa		2.34	260	5.8	7.9	<5	<20	8	<10	9.26	5.98	<10	<.5	203
32	12-10-97	(B-13-1) 27bda	918	<.02	712	19.6	7.1	<5	575	285	<10	107	-	-	-	351.7
33	12-16-97	(B-12-1) 13bcb	568	0.81	230	7.4	8	<5	21.8	10	<10	21.8	-	-	-	123.3
34	12-11-97	(B-13-1) 36cca	723	<.02	994	13.9	7.5	<5	3030	500	<10	94.8	-	-	-	545.3
35	12-16-97	(B-13-1) 31acc	90	4.51	456	9.1	7.8	13	<20	68.5	35	71.3	-	-	-	213.3
36	12-16-97	(B-12-1) 12acc	504	<.02	886	12.4	7.6	13	1010	405	<10	85.1	-	-	-	468
37	12-11-97	(A-12-1) 6cbc	514	<.02	488	11.6	7.7	<5	196	107.5	<10	68	-	-	-	268.5
38	12-11-97	(A-12-1) 6cbb	535	<.02	536	14.1	7.8	<5	<20	227.5	<10	60.2	-	-	-	334.5
40	12-11-97	(B-12-1) 24dad	310	<.02	258	10.4	7.6	5.4	466	17.5	<10	31.5	-	-	-	177.1
41.5	12-10-97	(A-13-1) 29adc	100	3.79	290	10.5	7.1	<5	<20	9.5	<10	8.77	-	-	-	207.8
42	12-02-97	(A-12-1) 8aab	142	<.02	312	12.5	7.7	12	351	40.5	<10	61	-	-	-	168.7
43	12-10-97	(A-12-1) 5ada	75	0.98	334	10.3	7.3	<5	1760	16	<10	24.8	-	-	-	192.1
44	12-03-97	(A-12-1) 17daa-2	19.6	2.55	280	17.7	7.5	<5	<20	7.5	<10	19.1	-	-	-	178.4
44.5	12-09-97	(A-13-1) 34dab	175	0.39	318	9.8	7.6	<5	23.5	12	<10	6.77	-	-	-	297
45	12-03-97	(A-12-1) 20add	145	3.43	318	16.6	7.4	<5	<20	15.5	11	23.1	5.23	<10	<.5	205.9
45.5	12-03-97	(A-12-1) 9bbd	67	<.02	336	10.3	7.7	100 (120)	992	27	<10	80.9	-	-	-	135.2
46	12-10-97	(A-13-1) 33bbb	147	3.09	290	12.1	7.2	<5	<20	6.5	<10	14.1	-	-	-	188.6
46.5	12-09-97	(A-12 -1) 10cdc	190	<.02	344	11.6	7.8	<5	467	10	<10	44.9	-	-	-	239
47	12-16-97	(A-12-1) 9ccb	235	1.38	282	13.6	7.8	<5	<20	11.7	12	34.8	-	-	-	188
47.5	12-09-97	(A-12-1) 14baa	152	2.33	312	7.8	7.6	7.7	<20	11	<10	11.3	-	-	-	285.4
48.5	12-03-97	(A-12-1) 20caa-1	118	2.08	268	18	7.5	<5	<20	13	<10	20.6	-	-	-	213.5
49	12-10-97	(A-13-1) 29bba	257	4.12	308	9.6	7	<5	57	12	<10	9.33	-	-	-	206

Site #	Sample date	USGS Cadastral	Well Depth (feet)	NO_2+NO_3 (mg/L)	TDS (mg/L)	Field T (°C)	pH	Arsenic (µg/L)	Fe, Dissolved (µg/L)	Chlor-ide (mg/L)	SO_4 (mg/L)	Na (mg/L)	Alpha, gross (pCi/L)	Beta, gross (pCi/L)	226 Radium (pCi/L)	Total Hardness/ $CaCO_3$ (mg/L)
50	12-03-97	(A-12-1) 16dbc	67	2.64	302	17.4	7.4	<5	<20	7	<10	12.9	-	-	-	272.4
51	12-16-97	(A-13-1) 15bad	166	0.11	308	6.4	7.9	17	<20	17.5	31	14.2	-	-	-	0.045
51.5	12-03-97	(A-12-1) 30aaa	161	0.23	262	15.1	7.6	5.6	571	9	<10	22.8	-	-	-	214.4
52	12-10-97	(A-13-1) 16abb	154	5.2	504	10.3	7	<5	<20	13	13	26.2	-	-	-	415.6
53	12-03-97	(A-12-1) 10bcc	106	4.38	314	13.5	7.5	<5	<20	10	<10	16.6	-	-	-	266.7
54	12-03-97	(A-12-1) 15cbc	177	2.37	308	15.6	7.3	<5	<20	6.5	<10	12.1	-	-	-	250.2
55	12-10-97	(A-13-1) 20add	125	0.78	264	8.2	7.2	<5	<20	5.5	<10	8.72	-	-	-	251
55.5	12-09-97	(A-12-1) 15aca	60	2.29	278	11.1	8.1	<5	<20	15.5	24	47.8	-	-	-	151
56	12-09-97	(A-12-1) 3cac	135	7.08	354	9	7.4	<5	<20	15.5	<10	11.2	-	-	-	325.7
57	12-09-97	(A-12-1) 13dba	94	2.63	360	10.3	7.4	<5	22	5.5	<10	13.2	-	-	-	333
58	12-10-97	(A-13-1) 21cbb	140	2.68	234	10.4	7.2	<5	<20	5	<10	8.08	-	-	-	195.6
59	12-03-97	(A-12-1) 28cbb		0.86	248	17.5	7.6	<5	<20	10.5	15	12.9	-	-	-	<.01
60	12-16-97	(A-12-1) 11dcb	205	2.03	266	9.4	7.7	<5	<20	4	<10	4.33	5.19	<10	<.5	265.3
61	12-03-97	(A-12-1) 28bcc	74	<.02	302	15.2	7.5	<5	111	24	20	33.8	-	-	-	205
61.5	12-10-97	(A-13-1) 28bba	85	2.85	270	7.9	7.1	<5	<20	10	<10	6.21	-	-	-	269.1
889	5-13-98	(A-12-1) 9bac		0.26	346	10.8	8.2	-	-	35.5	<10	83.9	-	-	-	123.9
63	12-02-97	(B-12-1) 32cda	63	7.56	664	9	7.2	5.7	<20	108	11	36.6	-	-	-	408.7
63.5	11-20-97	(B-11-1) 24cdb	145	0.27	348	10.4	7.6	<5	<20	7	92	6.55	-	-	-	305
64.5	11-20-97	(B-11-1) 27bbb	400	1.66	352	10	7.6	<5	94.5	43.5	<10	56.2	-	-	-	194.4
65	12-02-97	(B-12-1) 29cda	200	0.02	358	11.8	8.3	<5	287	8.5	<10	112	-	-	-	34.7
65.5	12-02-97	(B-11-1) 27aab	100	<.02	334	9.8	7.5	<5	1420	55	<10	45.1	-	-	-	206.1
66	12-02-97	(B-11-1) 16cdb	121	1.52	334	10.6	7.5	<5	<20	7.5	<10	50.5	3.99	<10	-	196.3
66.5	12-02-97	(B-11-1) 34bda	160	0.67	262	9.2	7.6	<5	31.9	40.5	<10	21.9	-	-	-	207.8
67	12-02-97	(B-11-1) 16acb-1	82	<.02	354	8.7	7.4	14	1020	37.5	<10	57.8	-	-	-	188.7
67.5	11-20-97	(B-11-1) 35bcb	40	1.46	304	10.4	7.5	<5	<20	39	<10	22.2	-	-	-	247.7
68	11-20-97	(B-11-1) 1ccc	206	0.03	320	10.2	7.8	<5	1920	35.5	<10	32.3	-	-	-	187.8
68.5	12-03-97	(B-11-1) 35aba	195	<.02	364	8.6	7.5	19	1100	19.5	<10	21.8	-	-	-	251.7
69	12-02-97	(B-11-1) 27cbd	126	1.22	258	9.5	7.8	<5	94.2	8.5	<10	20.6	-	-	-	210.1
69.5	11-20-97	(A-11-1) 6abd	183	0.43	244	12.4	7.8	<5	<20	15.5	<10	15.6	-	-	-	202.3
70	11-20-97	(B-11-1) 14cba	238	<.02	330	10.8	7.5	11	585	12	48	15.7	-	-	-	271.9
70.5	11-20-97	(A-11-1) 7bdd	125	1.46	286	10.9	7.6	<5	<20	8	22	8.05	-	-	-	260.9
71.5	12-02-97	(B-11-1) 36abb	245	<.02	352	10.1	7.4	26	1030	14	<10	19.4	-	-	-	314.3
72	11-20-97	(B-11-1) 2cad	420	<.02	432	11	7.7	<5	726	117.5	<10	49.2	-	-	-	259.8
72.5	11-20-97	(B-10-1) 2aca		<.02	350	7.4	7.4	<5	1840	38.5	<10	30.1	-	-	-	240.1
73	12-02-97	(B-11-1) 2cca	238	<.02	326	9.4	7.5	<5	574	22.5	<10	24.9	-	-	-	197.5
73.5	11-20-97	(B-11-1) 1ccc	155	0.05	324	10.7	7.7	<5	1530	40	16	32.6	-	-	-	250.1
74	11-20-97	(B-11-1) 35acc-3	84	<.02	376	9.5	7.5	6.3	1490	36.5	<10	30.1	-	-	-	280.9
75	11-20-97	(B-11-1) 11dcd	230	<.02	324	11.2	7.6	<5	347	7.5	70	9.34	-	-	-	288.8
76	11-20-97	(B-11-1) 11daa	190	<.02	336	11.5	7.7	<5	349	46	27	33.6	-	-	-	242.6
77	11-20-97	(B-11-1) 13dbc	100	0.56	314	11	7.6	<5	<20	15.5	57	10.4	-	-	-	264.2
78	12-02-97	(B-11-1) 25bbc	150	<.02	350	10.9	7.4	22	642	10.2	68	12.5	-	-	-	304.4
79	11-20-97	(B-11-1) 13aab	81	0.47	324	11.6	7.6	<5	<20	13	46	15.4	-	-	-	245.1
80	12-02-97	(B-12-1) 36caa	263	0.25	258	12.4	7.8	<5	<20	28.5	<10	17.4	-	-	-	222
81	12-02-97	(B-11-1) 16bbc	140	<.02	270	10	7.5	11	7560	20	<10	32.6	-	-	-	174.8
82	12-02-97	(B-11-1) 36dcc	180	<.02	366	10	7.3	<5	261	15.5	11	14	-	-	-	297.4
83	12-02-97	(A-11-1) 31dbc	137	4.09	254	-	-	<5	<20	5	<10	4.22	-	-	-	253.9
84	12-02-97	(B-11-1) 25aca	200	0.29	340	10.2	7.5	<5	<20	14.5	90	6.28	12.1	10.2	<.5	307.5
85	11-20-97	(B-11-1) 1dab	178	<.02	324	10.4	7.6	<5	1100	35.5	<10	36.5	<2	<10	<.5	182.5
86	11-20-97	(B-11-1) 24add	130	0.46	298	10.1	7.6	<5	<20	6	61	5.6	-	-	-	256.7
87	11-20-97	(B-11-1) 21bac	129	4.21	312	10.4	7.5	<5	<20	10	<10	19.1	-	-	-	250.2
87.5	12-02-97	(B-11-1) 21bdd	140	2.85	250	11.2	7.4	<5	<20	10.2	<10	10.7	-	-	-	214.7
88	12-02-97	(A-12-1) 31bcd	176	2.54	248	11.7	7.9	<5	<20	9.5	<10	14.2	-	-	-	214.5
412	12-16-97	(A-11-1) 19bbc	100	0.75	334	9.8	7.8	<5	<20	10.5	62	8.25	-	-	-	292.3
413	12-16-97	(A-11-1) 30bbb	213	0.18	328	11.8	7.6	<5	<20	6.5	69	8.15	-	-	-	258
414	12-16-97	(A-11-1) 31ccd	159	<.02	492	11.6	7.5	<5	4830	38.5	31	37.1	-	-	-	347.1

Site #	Sample date	USGS Cadastral	Well Depth (feet)	NO_2+NO_3 (mg/L)	TDS (mg/L)	Field T (°C)	pH	Arsenic (µg/L)	Fe, Dissolved (µg/L)	Chlor-ide (mg/L)	SO_4 (mg/L)	Na (mg/L)	Alpha, gross (pCi/L)	Beta, gross (pCi/L)	226 Radium (pCi/L)	Total Hardness/ $CaCO_3$ (mg/L)
415	12-03-97	(A-11-1) 30bcb	201	0.61	314	12.3	7.7	<5	<20	8.5	73	6.18	-	-	-	288.9
416	12-02-97	(A-11-1) 30cac	24	34.67	1236	12	7.4	40	20	297.5	88	206	-	-	-	596.8
89	11-19-97	(A-11-1) 18daa	-	0.75	298	10.5	7.8	<5	<20	6	32	127	-	-	-	6.6
90	11-20-97	(A-12-1) 32bad	116	0.5	226	15.4	7.7	<5	<20	5	<10	5.53	-	-	-	213.4
90.5	11-19-97	(A-11-1) 2caa	191	3.58	334	11.3	7.5	<5	<20	9.5	<10	8.25	-	-	-	330.9
91	11-20-97	(B-12-1) 29dcc	103	0.4	230	14.7	7.8	<5	<20	6.5	11	7.97	-	-	-	184
91.5	11-19-97	(A-11-1) 3daa	154	<.02	280	9.4	7.7	41	1940	10.7	<10	18.1	-	-	-	247
92	11-19-97	(A-11-1) 17bdd	127	1.4	284	10.6	7.6	<5	<20	6.5	26	6.88	-	-	-	266.3
92.5	11-19-97	(A-11-1) 17aab	155	1.47	294	9.1	7.6	<5	<20	6.5	28	7.38	-	-	-	271.6
93	11-19-97	(A-11-1) 20cad	80	1.38	342	9.5	7.6	<5	<20	7.5	62	6.97	-	-	-	227.4
93.5	11-19-97	(A-11-1) 6daa	145	2.32	268	11.6	7.5	<5	<20	7.5	<10	12.8	-	-	-	178.3
94.5	11-19-97	(A-11-1) 7ddd	140	1.41	284	10.9	7.5	<5	<20	6.5	28	7.41	-	-	-	226.7
95.5	11-19-97	(A-11-1) 10caa	151	0.57	178	9.7	7.9	<5	<20	<3	<10	2.73	-	-	-	188.2
96	11-20-97	(A-12-1) 32dbc	98	<.02	248	9.8	7.8	24	2160	3.5	<10	5.52	-	-	-	241.1
96.5A	11-19-97	(A-11-1) 8ddc	138	1.58	294	10.8	7.5	<5	<20	7.5	23	7.21	-	-	-	287.7
"	11-19-97	(A-11-1) 8ddc	138	2.12	318	10.4	7.4	<5	<20	7.7	25	8.21	-	-	-	240.2
97.5	11-19-97	(A-11-1) 17dac	139	1.88	300	10.1	7.6	<5	<20	8.5	28	7.27	<2	<10	<.5	284.2
98	11-20-97	(A-12-1) 33bca	145	0.09	212	17.6	7.6	<5	22.4	5.5	<10	4.36	-	-	-	211.4
98.5	11-19-97	(A-11-1) 19aaa	138	0.7	270	11.9	7.6	<5	<20	7	43	5.36	-	-	-	235.1
99	11-19-97	(A-11-1) 9adb	191	3.14	286	10.2	7.5	<5	<20	6.5	12	8.45	-	-	-	260.1
99.5	11-19-97	(A-11-1) 28cab	164	2.14	346	11.2	7.5	<5	<20	9.3	61	6.92	-	-	-	311.2
100.5	11-18-97	(A-11-1) 33daa	232	0.51	302	-	-	<5	<20	6.2	62	5.56	-	-	-	240.3
101	11-19-97	(A-11-1) 32baa	140	0.26	328	10.9	7.5	<5	<20	5.5	94	5.66	<2	<10	<.5	253.4
102	11-19-97	(A-11-1) 9ddb	205	0.06	246	10.6	7.8	<5	842	8	<10	6.02	-	-	-	242.1
105	11-19-97	(A-11-1) 15bdc	143	9.71	452	11.1	7.3	<5	<20	29.5	28	16.5	-	-	-	258.1
106.5	11-19-97	(A-11-1) 18add	151	0.58	270	11.1	7.6	<5	34.8	6	30	5.59	-	-	-	245.1
107.5	11-19-97	(A-11-1) 9ccb	156	1.54	294	12.9	7.5	<5	<20	8.5	19	6.77	-	-	-	283.2
108	11-19-97	(A-11-1) 3dcb	127	0.83	356	10.5	7.3	<5	204	14	15	8.8	-	-	-	321.5
108.5	11-19-97	(A-11-1) 17bdd	131	1.16	284	10.6	7.6	<5	<20	5.5	26	6.63	-	-	-	190
109.5	11-19-97	(A-11-1) 29acc	131	1.25	324	9.9	7.7	<5	<20	100	64	6.78	-	-	-	259.5
410	12-16-97	(A-11-1) 16aaa	-	3.91	368	8.7	7.4	<5	246	11	21	7.46	-	-	-	265.3
411	12-16-97	(A-11-1) 19dad	-	4.03	546	12.7	7.4	<5	<20	56	83	41.2	-	-	-	260.4
110.5	11-18-97	(B-10-1) 10caa	210	0.89	236	8	7.8	<5	<20	6.5	<10	4.16	-	-	-	224.3
111	11-17-97	(B-10-1) 14cbc	200	0.76	386	11.4	7.3	<5	37.7	27.5	16	26.2	-	-	-	255
112	11-18-97	(B-10-1) 14bcc	87	1.6	506	-	-	<5	191	36.5	79	18.4	-	-	-	288.7
113	11-18-97	(B-10-1) 11bca	136	4.37	400	-	-	<5	<20	45	<10	20.5	-	-	-	351.9
114	11-17-97	(B-10-1) 14dcb	253	0.71	472	12.8	7.6	<5	23.9	152.5	15	62.2	-	-	-	290.7
115	11-17-97	(B-10-1) 14adb-1	80	15.04	476	10.3	7.3	<5	93.2	21	<10	25.9	-	-	-	201.2
"		"		17.58	-	-	-	-	-	-	-	-	-	-	-	
116	11-18-97	(B-10-1) 13bac	155	20.62	558	-	-	<5	<20	59	13	30	<2			424.8
"		"		9.02	-	-	-	-	-	-	-	-	-	-	-	
"		"		21.33	-	-	-	-	-	-	-	-	-	-	-	
117	11-17-97	(B-10-1) 12dda	250	11.91	476	8.4	7.5	7.3	28.9	27.5	12	23.6	-	-	-	321.2
"		"		15.31	-	-	-	-	-	-	-	-	-	-	-	
417	5-13-98	(B-10-1)13a	140	5.67	492	10.1	7.7	-	-	39.5	33	35.2	-	-	-	302.2
419	5-13-98	(A-10-1)18a	160	9.13	828	9.4	7.4	-	-	123	50	99.9	-	-	-	489
420	5-13-98	(B-10-1)7b	271	0.27	482	11.3	7.7	-	-	57.5	15	43	-	-	-	317.5
421	5-13-98	(B-10-1)12d	178	1.99	250	12.3	7.7	-	-	9	<10	8.3	-	-	-	235.3
118.5	11-18-97	(A-9-1) 11dcc	204	0.1	294	9.2	8	<5	145	23	<10	15.6	-	-	-	251.6
119	11-18-97	(A-10-1) 16cba	180	<.02	390	11.5	8	<5	241	23	<10	135	-	-	-	6.6
119.5	11-18-97	(A-10-1) 34ccb	200	3.75	444	10.4	7.4	<5	<20	24.5	10	23.6	-	-	-	338.2
120	11-18-97	(A-10-1) 9cba	300	<.02	384	9.6	7.4	6.1	1680	13.5	<10	17.7	-	-	-	253.3
120.5	11-18-97	(A-10-1) 10cdb	354	1.49	354	13.6	7.6	<5	<20	24	11	27.5	-	-	-	174.2
121	11-18-97	(A-10-1) 28caa	108	3.68	334	11.9	7.6	<5	<20	13	18	10.2	-	-	-	234.6
123	11-18-97	(A-10-1) 21caa	85	<.02	368	-	-	<5	2860	15	36	15.5	<2	-	-	239.4

Site #	Sample date	USGS Cadastral	Well Depth (feet)	NO_2+NO_3 (mg/L)	TDS (mg/L)	Field T (°C)	pH	Arsenic (µg/L)	Fe, Dissolved (µg/L)	Chlor-ide (mg/L)	SO_4 (mg/L)	Na (mg/L)	Alpha, gross (pCi/L)	Beta, gross (pCi/L)	226 Radium (pCi/L)	Total Hardness/ $CaCO_3$ (mg/L)
124	11-18-97	(A-10-1) 9cdd	215	<.02	326	-	-	<5	1170	20	<10	24.1	3.44	-	-	257.1
125	11-18-97	(A-10-1) 21dbd	96	5.73	410	12.5	7.6	<5	<20	15	18	24.9	-	-	-	344.9
126	11-18-97	(A-10-1) 15cbb	80	4.33	382	10.5	7.5	<5	<20	23	16	22.2	-	-	-	322
127	11-18-97	(A-10-1) 10bcc	323	4.53	344	10.9	7.4	<5	<20	18.5	<10	22.1	-	-	-	206.7
128	11-18-97	(A-9-1) 10bbc	90	1.8	318	11.2	7.4	<5	<20	13	<10	10.8	-	-	-	210.7
129	11-18-97	(A-9-1) 3cab	170	1.57	386	12.1	7.5	6.1	<20	22	12	19.4	-	-	-	319
131	11-18-97	(A-10-1) 10cdd	334	2.93	392			<5	<20	19.3	27	20.8	-	-	-	289
132	11-18-97	(A-9-1) 11bcc	64	4.17	360	10	7.8	<5	<20	22.5	10	14.4	-	-	-	333
133	11-18-97	(A-9-1) 10adc	80	2.31	328			<5	<20	12	12	11.5	-	-	-	303.7

APPENDIX B. *Generalized stratigraphy of Cache Valley, Cache County, Utah and surrounding areas; sources of information (superscript numbers in Geologic Units column) from: (1) Bjorklund and McGreevy (1971), (2) Oviatt (1986a, b), (3) Hintze (1988), (4) Evans and others (1996), (5) Biek and others (2001).* (ft = feet, m = meters)

System	Geologic Units	Dominant Lithologies and Thickness	Depositional Environment and Remarks	Hydrostratigraphic Characteristics
Quaternary	Surficial deposits [1,2,3,4]	Consist of clay, silt, sand, gravel, and boulders valley fill: 0-1,340 ft; 0-408 m	Valley fill- primarily poorly sorted, poorly stratified, alluvial, colluvial, and mass-wasting deposits overlain by, or interfingered with, lacustrine deposits of horizontally bedded, well-sorted sediments from Quaternary lake cycles.	Principal aquifer of Cache Valley. Has low to high permeability and yields small to large quantities of ground water.
Tertiary	Salt Lake Formation [1,2,3,4]	Consists primarily of tuff, tuffaceous and calcareous siltstone, sandstone, conglomerate, marl, and freshwater limestone; white to light shades of tan, brown, yellow, green, and gray. thickness: 0-6,100 ft; 0-1,859 m	Deposition by alluvial, colluvial, volcanic, and mass-wasting events. Some of the formation was waterlain and in part reworked.	Generally low to moderate permeability. The fanglomerate facies has high permeability locally. Yields water to a few wells and springs.
	Wasatch Formation [1,2,3,4]	Red to reddish-brown conglomerate. Poorly sorted clasts accumulated from erosion of surrounding bedrock units. Matrix typically poorly consolidated sand and/or silt. thickness: 0-460 ft; 0-140 m	Conglomerate deposited by alluvial, colluvial, and mass-wasting events in response to adjacent bedrock uplift during the Sevier orogeny.	Generally low permeability; however, solution of carbonates within formation has increased permeability locally. Yields water to many small springs, especially at basal contact.

Bear River Range

System	Geologic Units	Dominant Lithologies and Thickness	Depositional Environment and Remarks	Hydrostratigraphic Characteristics
Pennsylvanian/ Permian?	Wells Formation [2,5]	Fine- to medium-grained, gray to brown, calcareous, quartz sandstone and interbedded gray limestone. thickness: 600-900 ft; 183-275 m	Marine deposition.	Ground water dependent on abundance of fractures and dissolution cavities.
Mississippian	Monroe Canyon Limestone [2,5]	Upper part is gray to gray-brown cherty limestone; middle consists of yellow-brown, medium-bedded, poorly exposed siltstone; lower is a gray to brown-gray, thick-bedded, massive, cliff-forming limestone. thickness: 560-1,150 ft; 171-351 m	Marine deposition. Contains corals, crinoids, chert, and oolitic beds.	Ground water dependent on abundance of fractures and dissolution cavities.

	Geologic Units	Dominant Lithologies and Thickness	Depositional Environment and Remarks	Hydrostratigraphic Characteristics
Mississippian	Little Flat Formation [2,5]	Gray, brown, light-yellow, and orange quartz sandstone and siltstone; with minor limestone, phosphatic limestone, dolomite, shale, and chert. thickness: 1,010-1,206 ft; 308-368 m	Marine deposition. The formation may thin northward, or thickness may vary due to bedding plane thrust faults.	Ground water dependent on abundance of fractures and dissolution cavities.
	Lodgepole Limestone [2,5]	Medium- to dark-gray limestone consisting of micrite, biomicrite, and biosparite with chert layers throughout. thickness: 600-700 ft; 183-213 m	Marine deposition. Common fossils include brachiopods, corals, gastropods, and bryozoa.	Ground water dependent on abundance of fractures and dissolution cavities.
	Leatham Formation [2,5]	Thin-bedded, gray, black, and brown siltstone and limestone. thickness: 0-90 ft; 0-27 m	Marine deposition. Unit is sporadically present throughout the range.	Unit too thin to contain a substantial amount of water.
Devonian	Beirdneau Formation [2,5]	Upper part is 30 to 60 ft (10 to 20 m) thick, gray, resistant limestone. Remainder is thin- to medium-bedded, gray, tan, yellow, and brown arenaceous dolomite which grades upward to a predominantly tan, yellow, and white sandstone. thickness: 524-1,087 ft; 160-331 m	Marine and marginal marine deposition. Cross-bedding, thin laminations, ripple marks, and mud cracks are common. Unit thins northward.	Ground water dependent on abundance of fractures and dissolution cavities.
	Hyrum Dolomite [2,5]	The upper part is a cliff-forming, massive, medium- to dark-gray dolomite. Lower is thin- to medium-bedded, yellow, gray, and tan dolomite and limestone. thickness: 220-1,011 ft; 67-308 m	Marine deposition.	Ground water dependent on abundance of fractures and dissolution cavities.
	Water Canyon Formation [2,5]	Upper part is purple, gray, brown, yellow, and white interbedded dolomite, siltstone, intraformational breccia, and calcareous sandstone. The lower part is a light-gray, white, and light-brown, thin-bedded argillaceous dolostone with local intraformational breccia. thickness: 210-600 ft; 64-183 m	Marine deposition.	Ground water dependent on abundance of fractures and dissolution cavities.
Silurian	Laketown Dolomite [2,5]	Massive, cliff-forming, light-gray, fine- and medium-crystalline, medium- to thick-bedded dolomite. thickness: 1,150-1610 ft; 351-496 m	Marine deposition. Contains sparse corals, brachipods, cephalopods, and algal mats.	Ground water dependent on abundance of fractures and dissolution cavities.

System	Geologic Units	Dominant Lithologies and Thickness	Depositional Environment and Remarks	Hydrostratigraphic Characteristics
Ordovicain	Fish Haven Dolomite [2,5]	Dark-gray to black, thick-bedded, fine to medium dolomite, with rare bioturbated sandy layers. Chert nodules present near top of formation. thickness: 0-490 ft; 0-149 m	Marine deposition. Local absence of the formation is due to structural thinning. Formation contains rare remnants of algal mats, tabulate and rugose coral, and evidence of bioturbation.	Ground water dependent on abundance of fractures and dissolution cavities.
	Swan Peak Formation [2,5]	Upper part is light-brown to white and tan, well indurated, medium-grained quartzite. Middle part is purple and gray quartzite. Lower part is interbedded blue, green, gray, and brown shale with minor, thin-bedded quartzite and gray limestone. thickness: 0-400; 0-122 m	Nearshore-marine deposition. Upper part contains burrows; middle part contains burrows, ripple marks, brachiopod fragments, disarticulated trilobites and cephalopods.	Ground water dependent primarily on abundance of fractures and possible minor dissolution cavities.
	Garden City Formation [2,5]	Upper part is thin- to medium-bedded, medium- to light-gray limestone and minor dolomitic limestone. Lenses of black chert are common. Lower part consists of crystalline and fossiliferous limestone. Numerous intraformational conglomerate beds in formation. thickness: 1,160-1,400; 354-427 m	Marine deposition.	Ground water dependent on abundance of fractures and dissolution cavities.
Cambrian	St. Charles Formation [2,5]	Dolomite and limestone, thin- to medium-bedded, light- to dark-gray; contains chert layers. Worm Creek Member at the base of the formation is light-gray, pink, and tan quartzite and arkose. thickness: 770-1,070 ft; 235-326 m	Marine and marginal-marine deposition.	Ground water dependent on abundance of fractures and dissolution cavities.
	Nounan Limestone [2,5]	Thin-bedded to massive dolomite. Thin- to medium-bedded, light- to dark-gray limestone, silty limestone, and sandstone. thickness: 800-1,200; 244-366 m	Marine and marginal-marine deposition.	Ground water dependent on abundance of fractures and dissolution cavities.
	Bloomington Formation [2,5]	Upper member is olive-drab to light-brown shale and dark blue-gray limestone with intercalated orange to rusty-brown silty limestone; the middle unit consists primarily of medium- to thick-bedded limestone; the lower unit consists of interbedded shale and limestone. thickness: 1,400-1,500 ft; 427-457 m	Marine deposition.	Low permeability. Ground water presence dependent on fractures and solution cavities in interbedded limestones. Shale layers act as aquitards.

System	Geologic Units	Dominant Lithologies and Thickness	Depositional Environment and Remarks	Hydrostratigraphic Characteristics
Cambrian	Blacksmith Limestone [2,5]	Medium- to thin-bedded, light-gray to dark-gray limestone. Interbedded silty limestone, siltstone, and dolomite. thickness: 330-700 ft; 101-213 m	Marine deposition. Oolitic limestone common.	Ground water dependent on abundance of fractures and dissolution cavities.
	Ute Limestone [2,5]	Medium- to thin-bedded, finely crystalline, light- to dark-gray, silty limestone. Olive-drab fissile shale interbedded throughout unit. Thin-bedded tan to brown dolomite exposed at base of formation. thickness: 400-800 ft ; 122-244 m	Marine deposition. Triolobite *Ehmaniella* present in basal units.	Ground water dependent on abundance of fractures and dissolution cavities.
	Langston Formation [2,5]	This unit consists of dolomite, limestone, shale, and mudstone; colors are grey, green, and tan. Upper part is dolomite, middle part is predominantly shale, and the lower part is shale with interbeded limestone. thickness: 200-810 ft; 61-247 m	Marine deposition. Abundant fossils.	Ground water dependent on abundance of fractures and dissolution cavities.
Cambrian / Percambrian	Geertsen Canyon Quartzite [2,5]	Pale-buff to white or flesh-pink quartzite, locally streaked with pale red or purple. Coarse grained; small pebbles occur throughout unit and increase in abundance toward the base of the unit. thickness: 2,225-2,550 ft; 678-777 m	Nearshore-marine deposition.	High fracture density; often supports large amounts of ground water.
Percambrian	Mutual Formation [2,5]	Coarse- to medium-grained, commonly gritty, locally pebbly, grayish-red to pale-purple or pink quartzite. thickness: 1,128 ft; 343 m	Nearshore marine deposition. Abundant cross-bedding.	Presence of water dependent on fracture density. One well in formation apparently flows at a high rate in adjacent Ogden Valley.

Wellsville Mountains

Pennsylvanian/ Permian	Oquirrh Formation [1,5]	Interbedded sandstone, sandy limestone and limestone. Sandstones generally weather to yellowish brown or orange, and the limestones are light gray. thickness: 4,500-6,600; 1,371-2,012 m	Marine deposition. Thin layer of colluvium typically covers the formation, making in hard to determine thickness. Fusulinids in formation above 1,800 ft (550m).	Ground water dependent on abundance of fractures and dissolution cavities.

	Geologic Units			Depositional Environment and Remarks	
Pennsylvanian	West Canyon Limestone [1,5]		Medium-gray, cherty limestone, sandy limestone, and minor shale. thickness: 400 ft; 145 m	Marine deposition. Contains *Idiognathodus.*	Ground water dependent on abundance of fractures and dissolution cavities.
Mississippian	Great Blue Limestone [1,5]	Upper member	Upper part is cherty gray limestone. Lower part is interbedded olive-gray shale and limestone. thickness: 475 ft; 156 m	Marine deposition.	Ground water dependent on abundance of fractures and dissolution cavities.
		Lower member	Medium- to dark-gray, cliff-forming limestone. thickness: 550 ft; 168 m	Marine deposition. Some beds are oolitic; fossils, particularly corals, are common throughout.	Ground water dependent on abundance of fractures and dissolution cavities.
	Humbug Formation [1,5]		Brown, calcareous, dolomitic sandstone with interbedded sandy limestone or limestone. thickness: 820 ft; 250 m	Marine deposition. The Humbug Formation in the Wellsville Mountains is likely correlative with the upper part of the Little Flat Formation in the Bear River Range.	Ground water dependent on abundance of fractures and dissolution cavities.
	Deseret Limestone [1,5]		Cherty limestone and minor sandstone, thin phosphatic shale and black chert in lower part. thickness: 91 ft; 28 m	Marine deposition.	Unit is too thin to contain a substantial amount of water.
	Lodgepole Limestone [1,5]		Medium- to dark-gray limestone. The upper and lower parts are cliff forming; the middle is slope forming. Chert common in cliff-forming units. thickness: 970 ft; 296 m	Marine depositon. Fossils abundant including well-preserved crinoids, corals, brachiopods, gastropods, and conodonts.	Ground water dependent on abundance of fractures and dissolution cavities.
Devonian	Beirdneau Formation [1,5]		Medium- to light-gray dolomite, interbedded yellowish-orange shale, and minor sandy dolomite or dolomitic sandstone. thickness: 0-347 ft; 0-106 m	Marine deposition.	Ground water dependent on abundance of fractures and dissolution cavities.

System	Geologic Units		Dominant Lithologies and Thickness	Depositional Environment and Remarks	Hydrostratigraphic Characteristics
Devonian	Hyrum Formation [1,5]		Dark- to medium-gray medium-crystalline dolomite. Includes several local quartzite beds, which pinch out in the southern part of Cache Valley. thickness: 490 ft: 149 m	Marine deposition.	Ground water dependent on abundance of fractures and dissolution cavities.
	Water Canyon Formation [1,5]	Grassy Flat Member	Light-gray to white fine-grained dolomite, grayish-orange-weathering, fine-grained sandstone, and interbedded dolomite. thickness: 857 ft; 261 m	Marine deposition. Some of the sandstones contain fish-bone fragments and chert nodules. A few thin beds of limestone contain small gastropods.	Ground water dependent on abundance of fractures and dissolution cavities.
		Card Member	Light-gray weathering, very fine-grained laminated dolomite. thickness: 428 ft; 131 m	Marine deposition. Nonfossiliferous.	Ground water dependent on abundance of fractures and dissolution cavities.
Silurian	Laketown Dolomite [1,5]	Upper	Light- to medium-gray, coarsely crystalline dolomite. thickness: 550 ft; 168 m	Marine deposition. Contains rugose corals and silicified brachiopods.	Ground water dependent on abundance of fractures and dissolution cavities.
		Tony Grove Lake Member	Medium-gray, finely crystalline dolomite. Upper 60 feet of lower unit contains chert nodules and irregular blobs and strings of silica. thickness: 561 ft; 171 m	Marine deposition. Contains rugose corals, and silicified brachiopods.	Ground water dependant on abundance of fractures and dissolution cavities.
Ordovician	Fish Haven Dolomite [1,5]		Medium- to dark-gray dolomite. Sandy, bioturbated dolomite at the base of formation. thickness: 197 ft; 60 m	Marine deposition. Colonial corals and small rugose corals are abundant in formation.	Unit is too thin to contain a substantial amount of water.
	Swan Peak Formation [1,5]		Upper part is white to purple quartzite. Dark olive-gray shale in lower part. thickness: 50-300 ft; 15-91 m	Marine deposition. Fossils in shale include trilobites, brachiopods, cephalopods, graptolites, and ostracods.	Ground water dependent on abundance of fractures.
	Garden City Formation [1,5]		Limestone, silty limestone, and intraformational limestone conglomerate; chert is common in the upper beds and may occupy more than 50 percent of the total volume of certain beds. thickness: 1,334-1,390 ft; 407-424 m	Marine deposition. Fossils in shale include trilobites, brachiopods, cephalopods, graptolites, and gastropods.	Ground water dependent on abundance of fractures and dissolution cavities.

System	Geologic Units		Dominant Lithologies and Thickness	Depositional Environment and Remarks	Hydrostratigraphic Characteristics
	St. Charles Limestone [1,5]	Dolomite member	Thin- to thick-bedded, finely to medium-crystalline, light- to medium-gray, cliff-forming dolomite. Pink chert common in member. thickness: 990 ft; 302 m	Marine deposition.	Moderately fractured limestone. Source of Bluerock Springs in adjacent Box Elder County.
Cambrian		Worm Creek Quartzite Member	Thin-bedded, fine- to medium-grained, medium- to dark-gray, calcareous quartzitic sandstone. Grains are well-rounded and well-sorted. thickness: 70-178 ft; 21-54 m	Nearshore marine deposition.	Less fractured than upper member. Formation is too thin to hold a substantial water supply.
	Nounan Dolomite [1,5]	Upper	Interbedded dolomite, sandy dolomite, dolomitic sandstone, and thin limestone. thickness: 545 ft; 166 m	Marine deposition. Limestone is fossiliferous.	Ground water dependent on abundance of fractures and dissolution cavities.
		Lower	Thin- to thick-bedded, finely crystalline, medium-gray, cliff-forming dolomite. thickness: 729 ft; 222 m	Marine deposition.	Ground water dependent on abundance of fractures and dissolution cavities.
	Bloomington Formation [1,5]	Calls Fort Shale Member	Olive-drab to light-brown shale and dark blue-gray limestone with intercalated orange to rusty-brown silty limestone; intraformational conglomerate common throughout unit. thickness: 300 ft; 91 m	Marine deposition.	Low permeability. Water presence dependent on fractures and solution cavities in interbedded limestones.
		Middle limestone member	Cliff-forming, thin- to very thick-bedded medium-gray, cliff-forming limestone, oolitic limestone, and local intraformational limestone conglomerate. thickness: 650 ft; 198 m	Marine deposition.	Ground water dependent on abundance of fractures and dissolution cavities.
		Hodges Shale Member	Slope- and ledge-forming, thin-bedded, medium-gray limestone, oolitic limestone, and intraformational conglomerate with lesser interbedded light olive-gray shale. thickness: 330 ft; 101 m	Marine deposition.	Ground water dependent on abundance of fractures and dissolution cavities.

System	Geologic Units			Dominant Lithologies and Thickness	Depositional Environment and Remarks	Hydrostratigraphic Characteristics
Cambrian	Blacksmith Limestone [1,5]			Medium- to thin-bedded, light-gray to dark-gray limestone. Interbedded silty limestone, siltstone, and dolomite. thickness: 800 ft; 244 m	Marine deposition.	Ground water dependent on abundance of fractures and dissolution cavities.
	Ute Limestone [1,5]			Medium- to thin-bedded, finely crystalline, light- to dark-gray silty limestone. Olive-drab fissile shale interbedded throughout unit. Thin-bedded tan to brown dolomite exposed at base of formation. thickness: 650 ft ; 198 m	Marine deposition.	Ground water dependent on abundance of fractures and dissolution cavities.
	Langston Formation [1,5]			Dolomite, limestone, shale and mudstone; gray, green to tan. thickness: 400 ft; 122 m	Marine deposition.	Ground water dependent on abundance of fractures and dissolution cavities.
	Brigham Group [1,5]	Geertsen Canyon Quartzite	Lower member	Pale-buff to white and tan quartzite with irregular streaks and lenses of cobble conglomerate that decreases in abundance down section. Basal 275 to 365 ft (90-120 m) is strongly arkosic, and feldspar clasts increase down section. thickness: 3,500 ft; 1067 m	Marine and marginal marine deposition.	Ground water dependent on abundance of fractures.
? Precambrian		Browns Hole Formation	Quartzite member	Medium- to fine-grained, well-round, well-sorted, terracotta-colored quartzite. Locally underlain by red to black, scoriaceous to amygdoloidal volcanic breccias. thickness: 250-350 ft; 76-107 m	Nearshore marine deposition. Small to large-scale cross-bedding in quartzite.	Presence of water dependent on fracture density.
		Mutual Formation		Coarse- to medium-grained, commonly gritty, locally pebbly, grayish-red to pale-purple or pink quartzite. thickness: 2,200-2,600 ft; 670-790 m	Nearshore marine deposition. Abundant cross-bedding.	Presence of water dependent on fracture density.
		Inkom Formation		Upper part is very fine-grained, dark-green sandstone underlain by laminated dark-green to olive-drab siltstone; lower part is light gray-weathering tuff. thickness: 394 ft; 120 m	Nearshore marine deposition.	Low permeability.

System	Geologic Units		Dominant Lithologies and Thickness	Depositional Environment and Remarks	Hydrostratigraphic Characteristics
Precambrian	Brigham Group	Caddy Canyon Quartzite	Medium-grained, medium- to thick-bedded, vitreous quartzite. Part of unit may be light-gray to white, but rocks are generally tan, gray, green, or purple. thickness: 1,000 ft; 305 m	Marine deposition.	Presence of water dependent on fracture density.
	Papoose Creek Formation [1,5]		Dark-gray to olive-drab siltstone with interbedded light-gray to greenish-gray, fine-grained quartzitic sandstone. Thin, wavy, and discontinuous bedding. thickness: 750-1,500 ft; 228-457 m	Marine deposition.	Presence of water dependent on fracture density.
	Kelley Canyon Formation [1,5]		Thin-bedded, dark-gray to black argillite, weathering to tan, dark gray, greenish gray, and silver; commonly has alternating dark-gray and greenish-gray interbeds. thickness: 700 ft; 215 m	Marine deposition.	Presence of water dependent on fracture density.

Clarkston Mountain

Pennsylvanian/ Permian	Oquirrh Formation [4,5]	Interbedded sandstone, sandy limestone, and limestone. Sandstones generally weather to yellowish-brown or orange, and the limestones are light-gray. thickness: 4,500-6,600; 1,371-2,012 m	Marine deposition. Thin layer of colluvium typically covers the formation, making it hard to determine thickness. Fusulinids in formation are above 1,800 ft (550m).	Ground water dependent on abundance of fractures and dissolution cavities.
Ordovician/ Silurian	Laketown Dolomite, Fish Haven Dolomite, Swan Peak Formation undifferentiated [4,5]	Lithologies similar to those in the Wellsville Mountains. These three formations are found in a brecciated, fault-bounded block near Short Divide.	Marine deposition.	Ground water dependent on abundance of fractures and dissolution cavities.
	Laketown Dolomite Fish Haven Dolomite undifferentiated [4,5]	Medium- to very thick-bedded, medium- to coarsely crystalline dolomite with local black and light-brown chert nodules and lenses. thickness: 2,100 ft; 640 m	Marine deposition.	Ground water dependent on abundance of fractures and dissolution cavities.
Ordovician	Swan Peak Formation [4,5]	Upper part forms prominent cliffs and ledges of very thick-bedded, white to gray to pink orthoquartzite. Lower 100 feet (30 m) consists of slope- and ledge-forming, thin- to medium-bedded, moderate-brown orthoquartzite with abundant fucoidal markings; lesser interbedded olive-gray shale, and minor thin-bedded limestone. thickness: 574 ft; 175 m	Marine deposition.	Ground water dependent on abundance of fractures.

System	Geologic Units		Dominant Lithologies and Thickness	Depositional Environment and Remarks	Hydrostratigraphic Characteristics
Ordovician / Cambrian	Garden City Formation [4,5]		Limestone, silty limestone, and intraformational limestone conglomerate; chert is common in the upper beds and may occupy more than 50 percent of the total volume of certain beds. thickness: 1,764 ft; 538 m	Marine deposition.	Ground water dependent on abundance of fractures and dissolution cavities.
Cambrian	St. Charles Limestone [4,5]	Upper	Thick- to very thick-bedded, medium- to dark-gray, medium- to coarsely crystalline dolomite, with local light-brown chert nodules. thickness: 700 ft; 213 m	Marine deposition.	Ground water dependent on abundance of fractures and dissolution cavities.
		Middle	Thin- to medium-bedded, medium-gray limestone with thin interbeds of intraformational limestone conglomerate and fossil hash throughout. thickness: 250 ft; 76 m	Marine deposition.	Ground water dependent on abundance of fractures and dissolution cavities.
		Lower	Interbedded, thin-bedded, silty and sandy carbonate between two beds of medium- to very thick-bedded, gray to brown to red feldspathic sandstone. thickness: 70 ft; 21 m	Marine deposition.	Ground water dependent on abundance of fractures and dissolution cavities.
	Nounan Dolomite [4,5]	Upper	Thin- to medium-bedded, light- to dark-gray, locally oolitic, variably sandy and silty dolomite and limestone, and interbedded, locally iron-stained and micaceous calcareous siltstone and fine-grained sandstone. thickness: 500 ft; 152 m	Marine deposition.	Ground water dependent on abundance of fractures and dissolution cavities.
		Lower	Cliff-forming, thick- to very thick-bedded, medium- to coarsely crystalline, light- to medium-gray dolomite. thickness: 800-1200 ft; 244-366 m	Marine deposition.	Ground water dependent on abundance of fractures and dissolution cavities.
	Bloomington Formation [4,5]	Calls Fort Shale Member	Brown-weathering, laminated to very thin-bedded shale and micaceous siltstone with some interbedded gray limestone and intraformational conglomerate. thickness: 429 ft; 131 m	Marine deposition.	Low permeability. Water presence dependent on fractures and solution cavities in interbedded limestones.

System	Geologic Units		Dominant Lithologies and Thickness	Depositional Environment and Remarks	Hydrostratigraphic Characteristics
Cambrian	Bloomington Formation[4,5]	Middle limestone member	Thin- to very thick-bedded medium-gray, cliff-forming limestone, oolitic limestone, and local intraformational limestone conglomerate. thickness: 444 ft; 135 m	Marine deposition.	Ground water dependent on abundance of fractures and dissolution cavities.
		Hodges Shale Member	Slope- and ledge-forming, thin-bedded, medium-gray limestone, oolitic limestone, and intraformational conglomerate, and lesser interbedded light olive-gray shale. thickness: 439 ft; 134 m	Marine deposition.	Ground water dependent on abundance of fractures and dissolution cavities.