RECOMMENDED SEPTIC TANK SOIL-ABSORPTION-SYSTEM DENSITIES FOR THE SHALLOW UNCONFINED AQUIFER IN CACHE VALLEY, CACHE COUNTY, UTAH

by

Charles E. Bishop, Janae Wallace, and Mike Lowe

REPORT OF INVESTIGATION 257
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Cover Photo:
Large spring systems are found in the lower central area of Cache Valley, this pool is part of the Spring Creek spring system.

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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 system, a major source of drinking water. Like many other Utah valleys, ground water in Cache Valley exists in a principal aquifer and, in the central parts of the valley where fine-grained sediments in the basin fill result in confined conditions in the principal aquifer, an overlying shallow unconfined aquifer. While the shallow unconfined aquifer is generally not a source of drinking water in most Utah valleys, it is in some areas of Cache Valley.

The purpose of our study is to construct and 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 Cache Valley's shallow unconfined aquifer, and thereby recommend appropriate septic-system density requirements to limit water-quality degradation to this aquifer. This follows a previous Utah Geological Survey septic-tank density evaluation for the principal aquifer that implemented a ground-water flow model that had previously been constructed by the U.S. Geological Survey. 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.

Prior to this investigation, few data were available regarding the shallow ground-water system in Cache Valley. Therefore, we installed 22 temporary monitoring wells in the shallow unconfined aquifer, and described the sediments penetrated by the wells. In 20 of these wells, we performed slug tests to estimate hydraulic conductivity for the aquifer. For 17 of these wells, we analyzed ground water for nitrate. The background nitrate concentration in the shallow unconfined aquifer based on data from the 17 monitoring wells is 2.7 mg/L. We developed a conceptual model for the shallow unconfined aquifer system in which (1) aquifer material consists of clay, sandy clay, and mixtures of fine sand, clay, and gravel, all primarily of lacustrine origin, (2) surface and ground water in the shallow unconfined aquifer are interconnected and readily exchanged, (3) no upward seepage from the confined portion of the principal aquifer yields water to the shallow unconfined aquifer, and (4) ground water in the shallow unconfined aquifer discharges to streams, springs, and is removed via evapotranspiration in the central parts of the valley.

Based on this conceptual model, we constructed a new ground-water flow model to estimate ground-water flow available for mixing in the shallow unconfined aquifer, the major control on projected aquifer nitrate concentration in the mass-balance approach. The average rate of ground-water flow in the shallow unconfined aquifer is 40 cubic feet per second (1000 L/s). The results of our ground-water flow modeling using the mass-balance approach indicate the recommended maximum septic-system density appropriate for development using septic tank soil-absorption systems for wastewater disposal is 25 acres per system (0.1 km^2/system). From the previous Utah Geological Survey study, recommendations for septic-tank density based on ground-water modeling using the mass-balance approach for the principal aquifer ranged from 3 to 10 acres per system (0.01-0.04 km^2/system); these previous recommendations should continue to be used except in areas where the shallow unconfined aquifer is used as a drinking water source.

INTRODUCTION

Cache Valley 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. Like many other Utah valleys, ground water in Cache Valley exists in a principal aquifer and, in the central parts of the valley where fine-grained sediments in the basin fill result in confined conditions in the principal aquifer, an overlying shallow unconfined aquifer. While the shallow unconfined aquifer is generally not used as a source of drinking water in most Utah valleys, it is in some areas of 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. The Utah Geological Survey conducted a previous study to determine recommended septic-tank density based on the hydrogeology of the principal aquifer, but that study did not provide adequate information for making recommendations for septic-tank density in those areas where the shallow unconfined aquifer is used as a drinking water source. Local government officials would like a scientific basis for determining recommended densities for septic-tank systems, considering both the shallow unconfined and principal aquifers, as a land-use planning tool.

Descriptions of previous work, geography, climate, ground-water conditions, ground-water contamination from septic-tank systems, and the mass-balance approach are presented in the appendix as background information. These descriptions have been updated from material presented in Lowe and others (2003).

PURPOSE AND SCOPE

The purpose of our study is to use a new ground-water flow model applying a mass-balance approach to determine the potential impact of projected increased numbers of septic-tank systems on water quality in the shallow unconfined aquifer and thereby recommend appropriate septic-system-density requirements. Lowe and others (2003) provide a similar tool for the principal aquifer in the Utah portion of Cache Valley using a previously existing ground-water flow model (Kariya and others, 1994). Together, these studies will provide land-use planners, state regulators, and consulting engineers and geologists with a tool to use in planning and approving new development in a manner that will be protective of ground-water quality.

We conducted a comprehensive review of published and unpublished geologic and hydrogeologic information to develop a conceptual model of the shallow unconfined aquifer system, including a water budget. Few existing data were available regarding the hydrogeology of the shallow unconfined aquifer. Therefore, we installed 22 temporary monitoring wells in the shallow unconfined aquifer and described the sediments penetrated by each well. We performed slug tests at 20 of the well sites to estimate hydraulic conductivity of the aquifer, and analyzed ground water from 17 of these wells for nitrate using a specific ion meter. Additionally, to account for the problem of representing the heterogeneity within the aquifer system using this small data set, we applied indicator geostatistics (Carle and Fogg, 1996; Carle, 1997) to reduce bias in the statistics derived from the collected hydraulic conductivity data.

Using the conceptual model, water budget, and hydraulic conductivity data, we constructed a new interpretive ground-water flow model to estimate ground-water flow available for mixing in the shallow unconfined aquifer, the major control on projected aquifer nitrate concentration in the mass-balance approach. Using the nitrate data and the ground-water flow available for mixing determined by the ground-water flow model, we applied a mass-balance approach to determine the potential impact of projected increased numbers of septic-tank systems on water quality in the shallow unconfined aquifer and thereby recommend appropriate septic-system density requirements for areas where this aquifer is used as a drinking water source. Lowe and others' (2003) recommendations for septic-tank system density for the principal aquifer should continue to be implemented in areas where the shallow unconfined aquifer is not used as a drinking water source.

CONCEPTUAL MODEL OF THE SHALLOW UNCONFINED AQUIFER SYSTEM

Introduction

Prior to constructing a ground-water flow model, we developed a conceptualization of the hydrology of the shallow unconfined aquifer system. This conceptualization forms the framework for model development and reduces the shallow ground-water system into significant component parts. This simplification of the hydrology system is an important first step because it is neither necessary nor feasible to incorporate all of the complexities of the system into the model. Our development of the conceptual model included the definition of the aquifer, estimates of water-budget components, and identification of hydrologic boundaries.

No data are available for ground-water conditions in the shallow unconfined aquifer prior to the settlement of Cache Valley, and the history of early water development in Cache Valley is poorly documented. Prior to settlement, Cache Valley was referred to as "Willow Valley" due to the large areas in the valley lowlands covered with willow trees (Peterson, 1946). Water-retaining depressions and/or sloughs, moorlands, wetlands, and ponds were scattered across the relatively flat valley floor. Pioneers settled Cache Valley in about 1858, an event immediately followed by the development of an irrigation system to support agriculture in the valley (Peterson, 1997). Today, a dense river and irrigation canal network controls surface-water flow within the valley and conveys water to Cutler Reservoir on the west side of the valley. Irrigation accounts for a significant amount of water use in the valley. This development of the lower valley floor accompanied by the import of water via irrigation, removal of native vegetation, and change to agricultural land use likely changed the character of ground-water flow in the shallow unconfined aquifer. Development also likely modified water levels in the low bottom areas of the valley, and resulted in the present distribution of shallow ground water in Cache Valley.

Today, the hydrologic system in the valley floor area of Cache Valley consists of (1) a surface-water system composed of the Bear River, Cutler Reservoir, and tributary streams, canals, and ditches, (2) a thin, non-continuous unsaturated zone affected by precipitation, seepage losses from irrigated fields, and evapotranspiration, (3) a shallow saturated unconfined ground-water system, and (4) the principal basin-fill aquifer. The unsaturated zone is relatively unimportant to our conceptual model, although it plays an important role in determining the nature of recharge to and evapotranspiration from the shallow unconfined aquifer, and the interaction between the surface-water and ground-water systems.

Surface-Water System

The primary sources of surface water in Cache Valley are the Bear River and precipitation that falls within the valley's watershed. Rivers and streams are a primary source of irrigation water in Cache Valley and all major streams that enter the valley are regulated. Approximately 372 cubic feet per second (11 m^3/s) of water is diverted to major canals each year to irrigate the valley (Kariya and others, 1994). Much of the valley floor is characterized by surface-water conveyances that are in contact with the shallow ground-water system, facilitating the exchange of surface and ground water.

The Bear River, the largest river in the watershed, flows southward from Idaho into Utah and is largely confined within its banks, due to incision into unconsolidated basin-fill deposits throughout much of its reach, before flowing to the northwest and entering Cutler Reservoir on the west side of the valley (figure 1). Mean annual flow of the Bear River at the Utah/Idaho state line for the period 1960–90 was about 1124 cubic feet per second (32 m^3/s), and mean annual flow leaving Cache Valley for the same period was about 1628 cubic feet per second (46 m^3/s); the river gains 504 cubic feet per second (14 m^3/sec) as it flows through the Utah part of Cache Valley (Kariya and others, 1994). In general, all surface-water courses are gaining streams in the lower parts of the valley, partly due to local seepage of ground water (Kariya and others, 1994; Myers, 2003). However, the Bear River and other Cache Valley rivers gain this ground water from the shallow unconfined aquifer, not the principal aquifer (Robinson, 1999).

Streams in the Bear River Range are typically perennial and become intermittent in the valley, particularly during the late summer and fall. Runoff from these streams typically reaches the mountain front from late winter to early summer where water is lost on the alluvial fans along the mountain front due to streambed leakage and/or is diverted for irrigation before flowing onto the valley floor. Streams originating in the Clarkston and Wellsville Mountains less commonly flow to the valley floor, but reach the bordering fans during the late winter and early spring where they are diverted for irrigation.

Cutler Reservoir is used for hydroelectric power production and regulation of flow of the Bear River and its tributaries. Cutler Reservoir, at the lowest elevation in the valley, receives all surface water flowing out of Cache Valley. The reservoir is shallow and has a maximum surface area of about 11 square miles (29 km^2) (Kariya and others, 1994). Seepage studies indicate Cutler Reservoir gains as much as 80 cubic feet per second (2 m^3/s) along its reach, a substantial part of which is due to ground-water seepage (Herbert and Thomas, 1992). In addition to Cutler Reservoir, Newton and Hyrum Reservoirs are also located on basin-fill deposits of the valley, but are not associated with the shallow unconfined aquifer.

Ground-Water System

A generalized model of the ground-water system in Cache Valley has a relatively deep unconfined aquifer near the mountain fronts, and confined and shallow unconfined aquifers in the central parts of the valley. The principal aquifer, as defined by Bjorklund and McGreevy (1971), Kariya and others (1994), and Myers (2003), consists of the deep unconfined and confined aquifers of the ground-water system. Overlying an upper confining layer is shallow ground water that is laterally continuous and forms the shallow unconfined aquifer.

The various prehistoric lakes that have occupied Cache Valley filled the Cache Valley basin with deposits highly variable in their ability to transmit water. The hydrogeologic framework of these sediments controls the vertical and horizontal ground-water flow. The complex framework formed by these basin-fill deposits was simplified by Robinson (1999) into a vertical series of units representing either ground-water producing zones or zones of confinement to vertical flow. Robinson (1999) described these zones, from top to bottom, as a shallow unconfined aquifer, upper confining unit, upper confined aquifer, lower confining unit, and lower confined aquifer. The upper and lower confined aquifers form the principal aquifer in the valley. Major zones of confinement are continuous, low-permeability layers generally greater than 60 feet (20 m) thick that correlate with fine-grained, lake-bottom deposits of the Bonneville and Little Valley lake cycles (Robinson, 1999). The limits of the confining units represent the extent of coarse sediment shed off the surrounding mountains. Confining units end within about a mile of the mountains on either side of the valley, where only the deep unconfined principal aquifer exists. The shallow unconfined aquifer, defined herein, consists of the basin-fill sediments above the upper confining layer; the shallow unconfined aquifer generally functions as a single hydrologic unit, even though it is a heterogeneous mixture of discontinuous lenses of clay, sand, and gravel in a silt and clay matrix.

The primary recharge area for the principal Cache Valley basin-fill aquifer is near the mountain fronts where no continuous layers of fine-grained materials exist to impede the downward movement of water (Anderson and others, 1994). In the primary recharge area, recharge occurs primarily from infiltration of snowmelt or rainfall runoff from the Bear River Range or Wellsville Mountains, seepage of water in canals and ditches diverted for irrigation along the margins of the valley, and from direct precipitation. Recharge along the east side of Cache Valley is greater than along the west side, primarily because of the greater amount of precipitation in the Bear River Range. Subsurface inflow from the adjacent mountains to the principal aquifer is relatively low because permeability of the consolidated rocks is generally low. Seepage from canals and the infiltration of unconsumed irrigation water are major sources of recharge to the shallow unconfined aquifer in the center of the valley, and recharge from the unconfined part of the principal aquifer along the margins of the confining beds is also important. The water level in the unconfined part of the principal aquifer adjacent to the shallow unconfined aquifer is above the highest extent of the confining layers, allowing recharge from the deep unconfined aquifer to the shallow unconfined aquifer. Robinson (1999) concluded, based on water chemistry and isotopic data, that no upward seepage from the upper confined aquifer to the shallow aquifer exists, even in areas with flowing wells (figure 2). In our conceptual model of the shallow unconfined aquifer, we incorporate the concept that confined portions of the principal aquifer do not contribute recharge to the shallow unconfined aquifer.

In Cache Valley, many springs discharge from basin-fill deposits in the lower areas of the valley. These springs can discharge a large volume of water, with some springs discharging thousands of gallons per minutes (figure 3). Spring discharge eventually flows into streams or rivers, returns to the ground-water system by seepage, is used for irrigation and then returned to the ground-water system, or is lost due to evapotranspiration. Water-chemistry data from Cache Val-

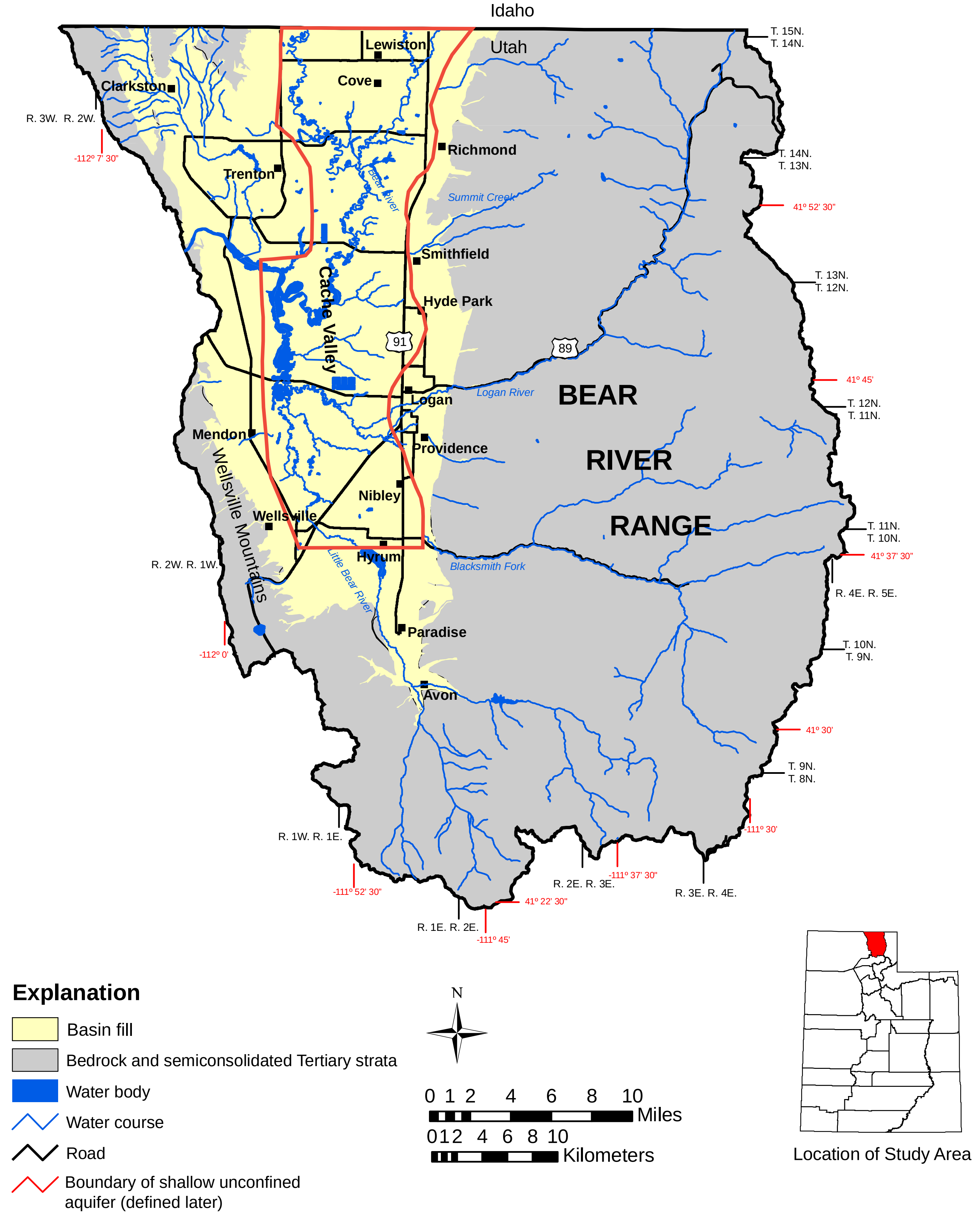

Figure 1. *Geographic features of Cache Valley area, Cache County, Utah.*

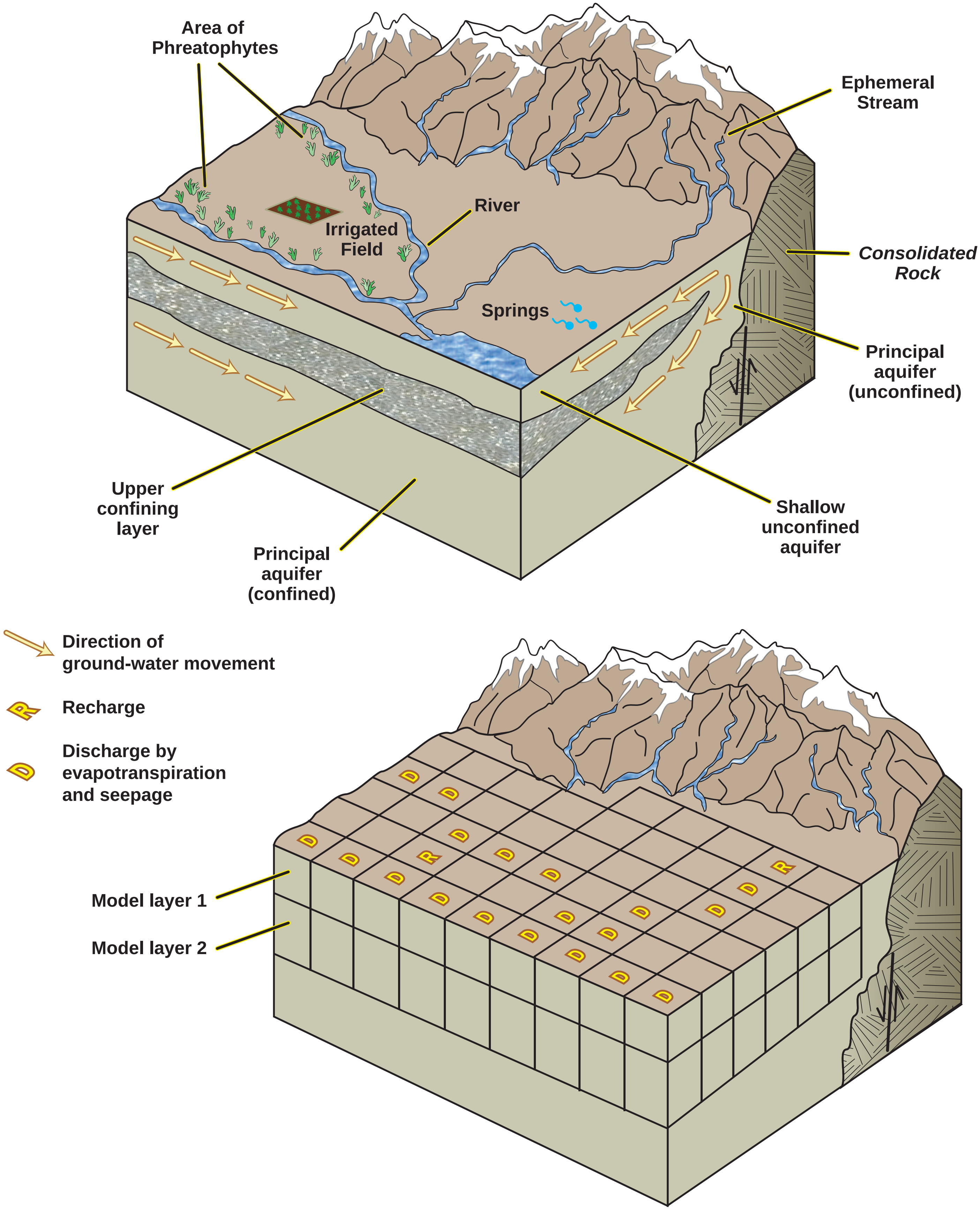

Figure 2. *Schematic three-dimensional diagram of the shallow unconfined aquifer in Cache Valley, and the same diagram with part of the basin fill represented by cells for computer simulation.*

Figure 3. *A pool of the Spring Creek spring system, in the low central area of Cache Valley (section 17, T. 11 N., R. 1 E., Salt Lake Base Line and Meridian). The Spring Creek spring system can discharge more than 2000 gallons per minute.*

ley indicate that spring discharge water is different than water in the principal aquifer, and that the Bear River and other rivers gain water similar to spring water (Robinson, 1999). Discharge from many of the springs varies seasonally and this variability is probably somewhat related to irrigation (Kariya and others, 1994). Kariya and others (1994) estimated springs produce about 138 cubic feet per second (4 m^3/s), or about 100,000 acre-feet per year (123.5 million m^3/yr) of water in Cache Valley. We consider these springs to be part of the shallow unconfined aquifer system.

The amount of discharge from the principal aquifer to rivers, reservoirs, springs, seeps, drains, and evapotranspiration is probably less than indicated in most basin-wide ground-water budgets (Kariya and others, 1994; Myers, 2003), because we believe the components of discharge to rivers, Cutler Reservoir, springs, seeps, drains, and evapotranspiration are probably mainly from the shallow aquifer. Discharge of water by springs, seeps, and seepage to rivers and streams, and, to a lesser extent, evapotranspiration controls the movement of ground water in the shallow unconfined aquifer in Cache Valley. In general, ground-water flow in the shallow unconfined aquifer is from the margins of the aquifer, mainly the east margin, toward the center and then to the west side and Cutler Reservoir.

The shallow aquifer in the central part of the valley is unconfined. However, in much of the area, the water table is in clays that generally overlie coarser material. The shallow aquifer system is composed of clay, sandy clay, fine sand, and gravelly clay deposits of mostly lacustrine origin. The depth to ground water from the land surface (water table) is generally less than 10 feet (3 m), but increases as the land-surface elevation increases. The configuration of the shallow water table depends on the hydraulic conductivity of the basin fill, the amount of recharge available, and the location of discharge points/areas (springs, seeps, and gaining stretches of stream and river beds). Local discharge areas act as a hydraulic buffer on nearby ground-water levels in the shallow aquifer. As the elevation of the water table increases, discharge to rivers and streams, springs, and evapotranspiration increases, thereby buffering the rise of the water table. As the water table declines, discharge to rivers and streams, springs and seeps, and evapotranspiration decreases, thereby reducing the decline in the water table.

The changes in spring discharge discussed above indicate a shallow ground-water system having a short flow path from the source of recharge to the point of discharge. Rates of recharge are variable because of differing percolation rates, slopes, and relative topographic positions. Recharge water moves downward to the shallow aquifer, travels a short horizontal distance, and then moves upward, discharging to springs, rivers, and/or into wetlands. High rates of evapotranspiration occur in areas where water accumulates at the surface. Figure 4 shows a simple conceptualization of these features for Cache Valley.

AQUIFER DATA

Well Drilling and Slug Testing

To characterize the lithology and hydrology of the shallow unconfined aquifer system, we drilled shallow wells at 22 sites in Cache Valley during October and November, 2004

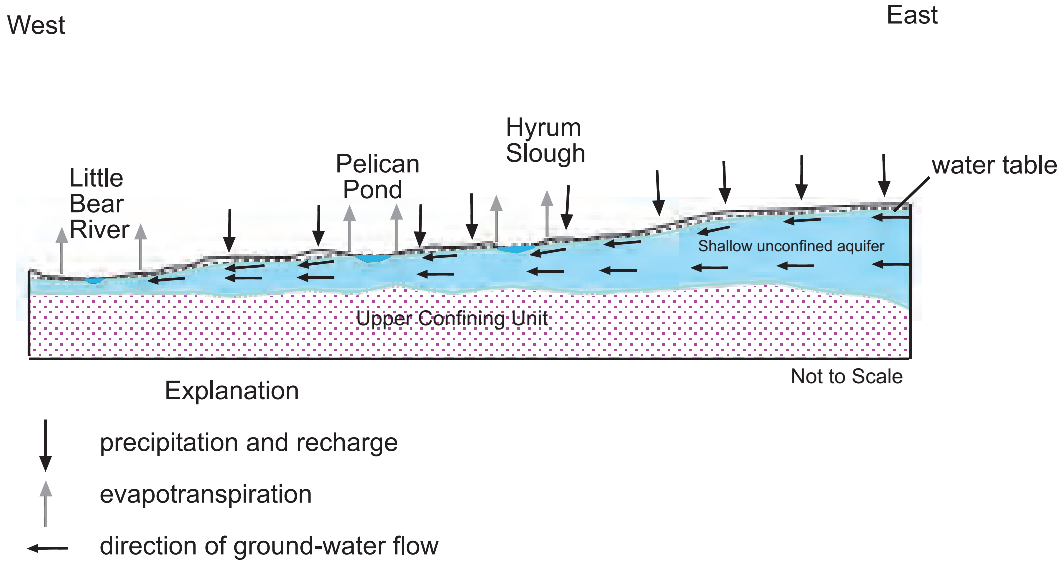

Figure 4. *Simple conceptual profile of the interaction of surface water, precipitation, evapotranspiration, and shallow ground-water flow in Cache Valley.*

(figure 5, table 1). The observation wells ranged in depth from 10 to 25 feet (3-8 m) below the land surface, and were constructed of 4-inch (10 cm), or 2-inch (5 cm) outside-diameter, schedule-40 polyvinyl chloride (PVC) casings. Well screens of 0.02-inch (0.05 cm) slots were set and backfilled with native materials in the annulus around the screens. We described the lithology of cuttings and measured and recorded water levels at each site.

To estimate the extent and geometry of the shallow unconfined aquifer (figure 6), we used the data from our shallow observation wells, drillers' logs of water wells, and published data from Anderson and others (1994), Kariya and others (1994), and Robinson (1999). We used drillers' logs of water wells and the location of artesian areas (Kariya and others, 1994) to define the extent of the non-leaking upper confining beds, which controls the area underlain by the shallow unconfined aquifer.

The water table in the shallow unconfined aquifer is typical of an unconfined, unstressed flow system in an area of subdued topographic relief; it generally mimics the topography. Where the water table intercepts the ground surface, seepage or springs develop. As the water table rises, more seepage zones develop. Depth to ground water in the fall of 2004 was generally less than 10 feet (3 m) within the area underlain by the shallow unconfined aquifer. Where no data were available, we estimated the water table to be at or near the land surface based on the existence of seepage zones or wet meadow areas. The configuration of the shallow-aquifer water table is shown on figure 7; the general direction of ground-water flow is from the outer edge of the upper confining layer to the valley lowlands, and then parallel to the basin axis toward the Bear River and/or Cutler Reservoir.

We performed slug tests on 20 of the observation wells to determine the hydraulic properties of subsurface sediments in the immediate vicinity of the wells (table 2). The slug tests involved measuring water-level response with a pressure transducer (calibrated with periodic electric-tape measurements of water depth) and recording readings on a data logger. The data were analyzed using the analytical solution developed by Bouwer and Rice (1976). The solution assumes a homogeneous, isotropic, areally extensive, unconfined aquifer. The method involves normalizing water-level change as a function of time. We used standard curve-matching techniques to match the slug-test data to theoretical type curves.

Cache Valley's near-surface basin-fill stratigraphy can be conceptually grouped into lithofacies based on observed and inferred material distributions. The sedimentary architecture of the shallow unconfined aquifer, primarily based on the observation well descriptions, lithologic data from drillers' logs, geophysical interpretations by Stanley (1972), and surficial geologic maps (McCalpin, 1989; Solomon, 1999), is shown on figure 8. This architecture shows an unordered sequence of material that would produce a heterogeneous ground-water flow system due to contrasts in horizontal and/or vertical hydraulic conductivities; the only continuous lithofacies is clay at the surface. Basin sediments have a high degree of heterogeneity, and values of hydraulic conductivity can span six orders of magnitude (Kariya and others, 1994). Sporadic areas of greater hydraulic conductivity provide preferential flow paths in the shallow unconfined aquifer. Discharge points for springs and seeps are related to these preferential flow paths. The geometry and interconnectedness of the areas of greater hydraulic conductivity are complex and highly variable, and thus difficult to map.

Stochastic Modeling

Our interpretive, three-dimensional ground-water flow simulation of the shallow unconfined ground-water system in Cache Valley required the inherently heterogeneous shallow aquifer materials (figure 8) be modeled as a single, discrete, continuous layer. To depict the complex hydrogeology and highly variable hydraulic parameters in a manner that reasonably represented the hydraulic conductivity distribution, we used a stochastic simulation approach based on the T-PROGS software as implemented in the Groundwater Mod-

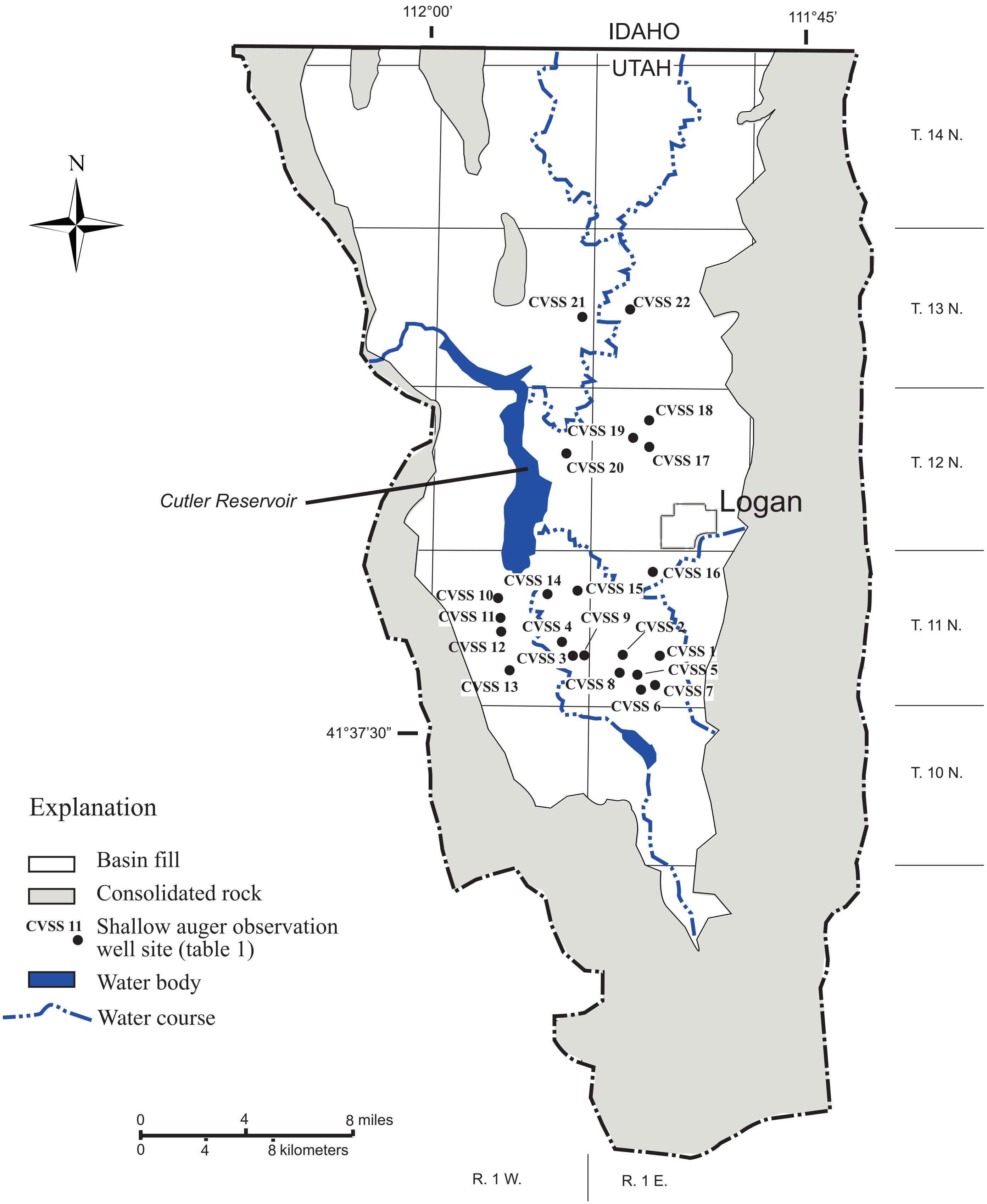

Figure 5. *Location of shallow observation well sites drilled during 2004, Cache Valley.*

Table 1. *Location, depth to ground water, and nitrate concentrations for shallow observation wells in Cache Valley. Well locations shown on figure 5.*

UGS observation wells identification number	Date drilled	Location	Elevation of land surface (feet above sea level)	Depth of auger hole (feet)	Depth to water from land surface (feet)	Nitrate concentration (mg/L)
CVSS1	10/19/2004	SWNWNW sec. 16, T. 11 N., R. 1 W.	4496	10	1.32	NM
CVSS2	10/19/2004	NWNWSW sec. 17, T. 11 N., R.1 W.	4471	15	3.33	1.5
CVSS3	10/19/2004	NWSWSW sec. 13, T. 11 N., R. 1 W.	4435	20	8	6.0
CVSS4	10/20/2004	SWSESE sec. 11, T. 11 N., R. 1 W.	4425	25	6.5	NM
CVSS5	10/20/2004	NWNWNW sec. 17, T. 11 N., R. 1 E.	4503	20	8	2.1
CVSS6	10/20/2004	SESWSW sec. 29, T. 11 N., R. 1 E.	4524	20	5.2	NM
CVSS7	10/21/2004	SWSWSW sec. 28, T. 11 N., R. 1 E.	4531	25	3.26	NM
CVSS8	10/21/2004	SWSWNE sec. 19, T. 11 N., R. 1 E.	4484	25	5.92	NM
CVSS9	11/2/2004	SWSWNE sec. 13, T. 12 N., R. 1 W.	4437	25	5.5	1.6
CVSS10	11/3/2004	NENESW sec. 4, T. 11 N., R. 1 W.	4421	25	1.25	2.8
CVSS11	11/3/2004	NENWNW sec. 9, T. 11 N., R. 1 W.	4417	15	1.75	1.5
CVSS12	11/4/2004	SWNESW sec. 9, T. 11 N., R. 1 W.	4419	15	1.07	0.6
CVSS13	11/4/2004	NESWSE sec. 16, T. 11 N., R. 1 E.	4431	10	0.73	4.4
CVSS14	11/17/2004	NWNESW sec. 3, T. 11 N., R. 1 W.	4410	15	0.54	0.4
CVSS15	11/17/2004	SESENW sec. 2, T. 12 N., R. 1 W.	4412	25	2.55	1.4
CVSS16	11/18/2004	SWNWNE sec. 6, T. 12 N., R. 1 E.	4431	25	5.66	4.2
CVSS17	11/18/2004	SWNESW sec. 17, T. 12 N., R. 1 E.	4445	25	1.33	1.3
CVSS18	11/19/2004	NESENW sec. 9, T. 12 N., R. 1 E.	4443	25	1.68	5.3
CVSS19	11/23/2004	SWNENW sec. 17, T. 12 N., R. 1 W.	4436	22	2.78	1.8
CVSS20	11/23/2004	NENESE sec. 14, T. 12 N., R. 1 W.	4420	25	3.53	3.1
CVSS21	11/24/2004	NENWNW sec. 25, T. 13 N., R. 1 E.	4419	15	2.35	6
CVSS22	11/24/2004	SWSWNE sec. 29, T. 13 N., R. 1 E.	4468	25	6.2	1.8

NM, not measured

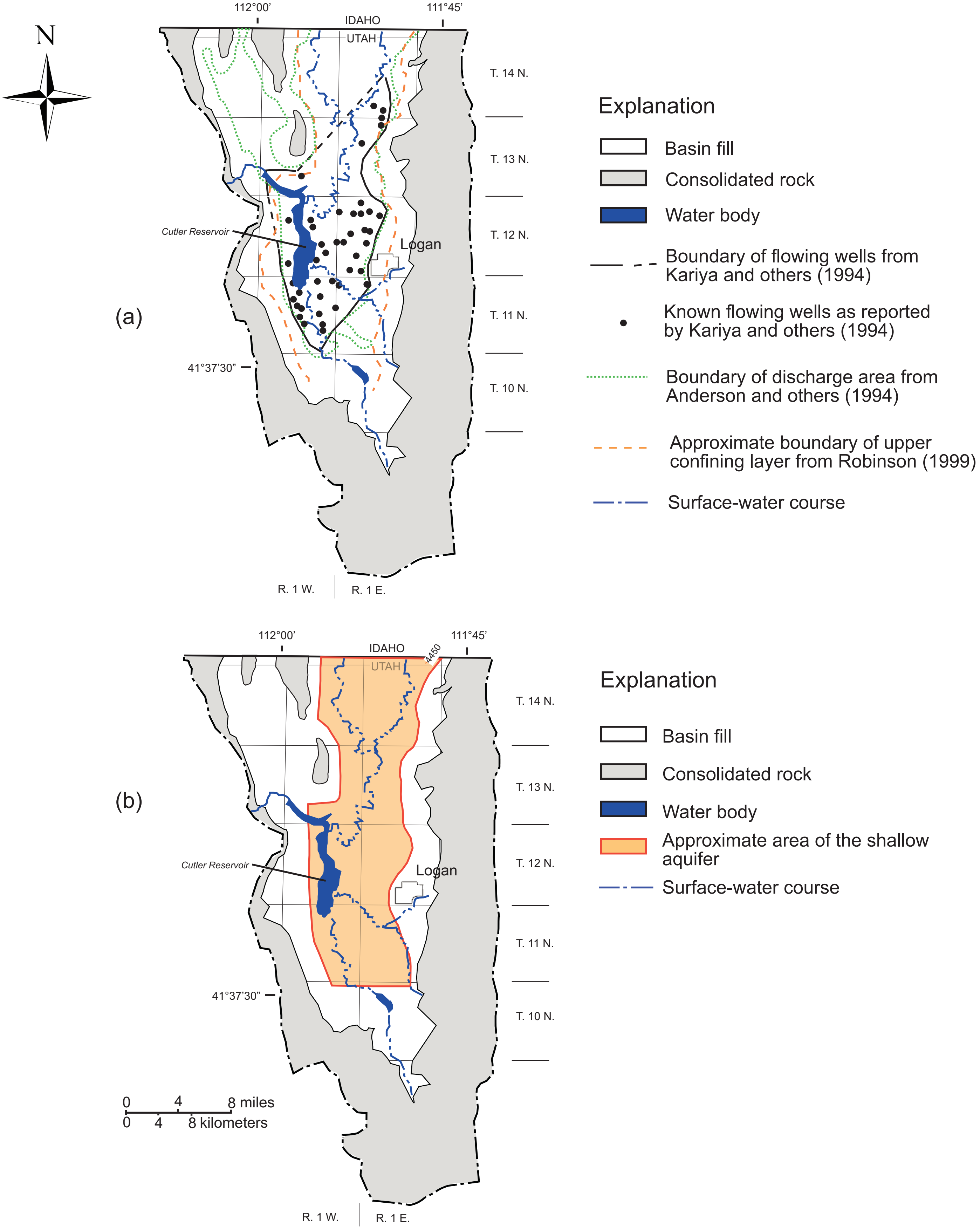

***Figure 6.** Boundaries from previous workers shown in (a) were used to determine the approximate area of shallow aquifer shown in (b).*

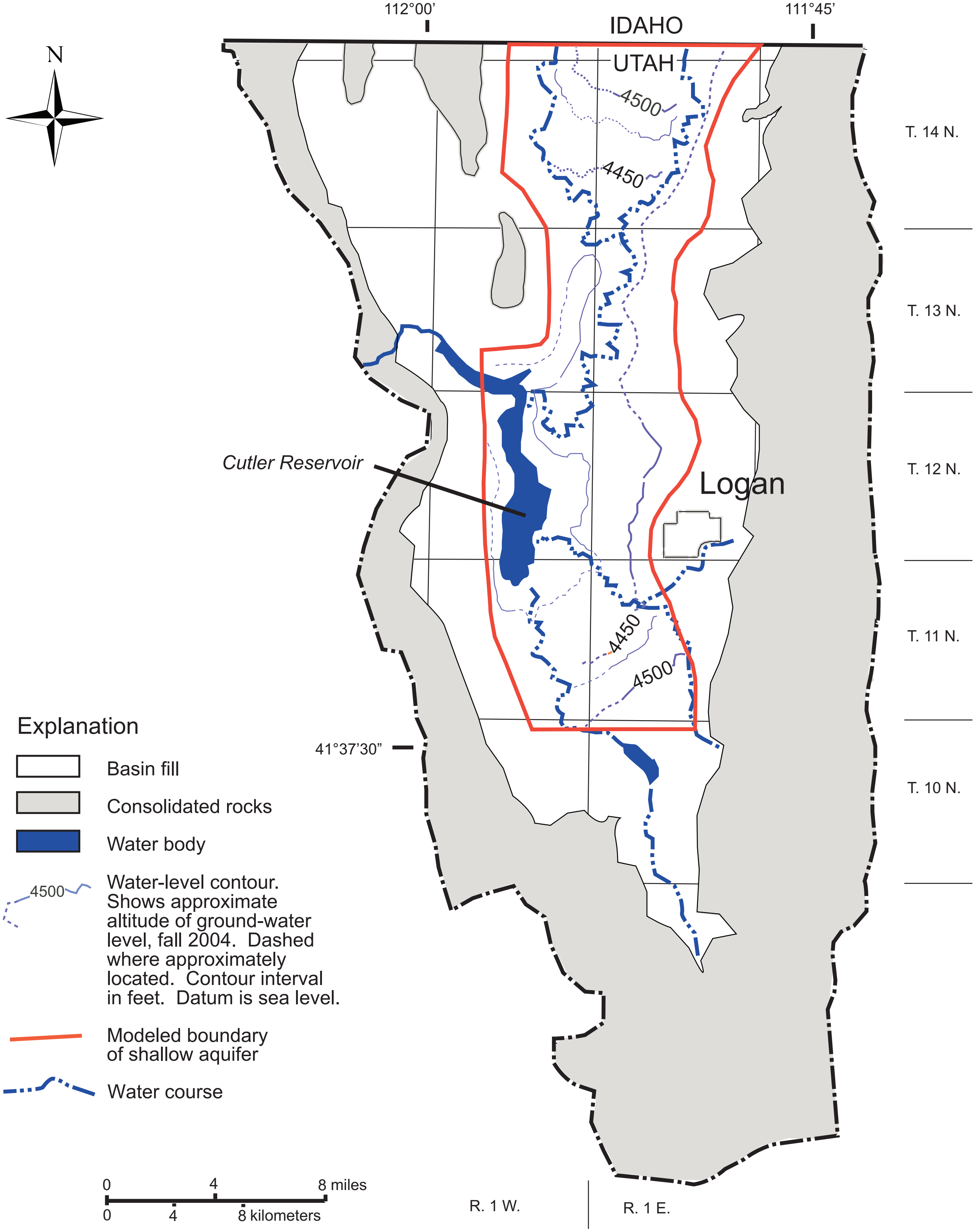

Figure 7. *Approximate ground-water levels in the shallow unconfined aquifer in Cache Valley, fall 2004.*

Table 2. *Hydraulic conductivity determined by slug tests, Cache Valley.*

UGS observation well identification number	**Date of test**	**Hydraulic conductivity (feet/min)**	**Hydraulic conductivity (feet/day)**
CVSS2	10/26/2004	2×10^{-5}	0.034
CVSS4	10/27/2004	1×10^{-5}	0.019
CVSS5	10/27/2004	2×10^{-5}	0.028
CVSS6	11/3/2004	1×10^{-5}	0.015
CVSS7	11/3/2004	7×10^{-6}	0.010
CVSS8	11/4/2004	1×10^{-5}	0.018
CVSS9	11/18/2004	1×10^{-5}	0.015
CVSS10	11/9/2004	1×10^{-5}	0.021
CVSS11	11/9/2004	2×10^{-6}	0.0035
CVSS12	11/9/2004	2×10^{-6}	0.0028
CVSS13	11/10/2004	1×10^{-5}	0.021
CVSS14	11/17/2004	1×10^{-5}	0.016
CVSS15	11/22/2004	4×10^{-6}	0.0050
CVSS16	11/22/2004	1×10^{-5}	0.015
CVSS17	11/22/2004	1×10^{-6}	0.0020
CVSS18	11/23/2004	1×10^{-5}	0.015
CVSS19	11/23/2004	1×10^{-5}	0.014
CVSS20	11/23/2004	1×10^{-5}	0.022
CVSS21	12/2/2004	2×10^{-5}	0.027
CVSS22	12/2/2004	2×10^{-5}	0.036

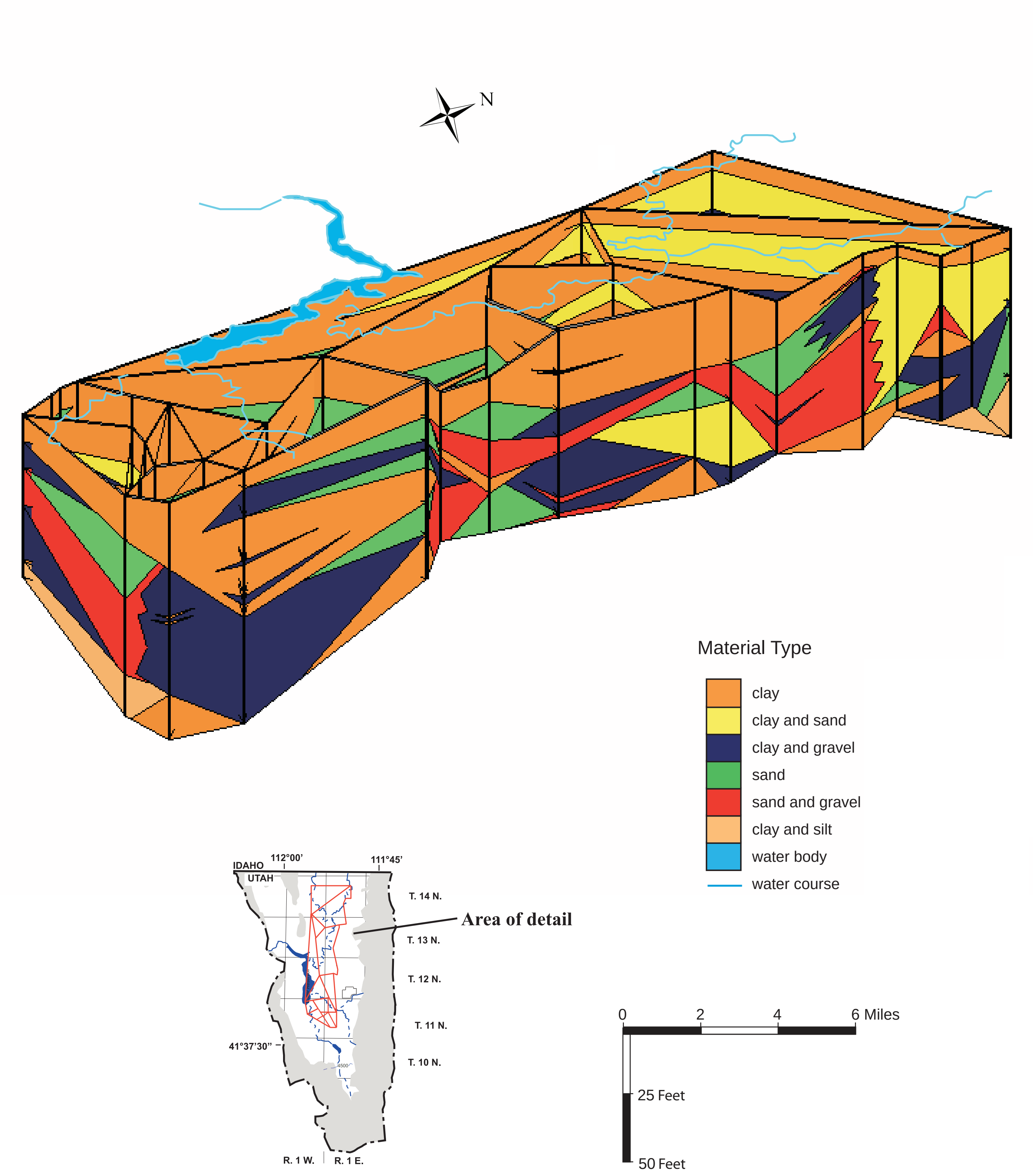

Figure 8. *Schematic geologic fence diagram of the shallow unconfined aquifer showing the division of lithofacies and aquifer heterogeneity. Intersections represents a composite section based on lithologic descriptions, geophysical interpretations, and geological mapping that are projected to the next composite section to fill in between. The top of the upper confining layer is below the base of the shallow unconfined aquifer.*

eling System (GMS) (Brigham Young University, 2003). The T-PROGS software uses a transition probability-based geostatistical approach for analysis of an unordered sequence of aquifer material by three-dimensional Markov chains (Carle and Fogg, 1996; Carle, 1997).

The transition probability approach provides a conceptual framework to integrate geologic insight and interpretation of source data into a simple and compact mathematical model. In this approach, it is possible to incorporate material proportions into the spatial relations model; the transitional probability method has been previously applied elsewhere to geological materials with variable characteristics (Gingerich, 1969; Krumbein and Dacey, 1969; Dacey and Krumbein, 1970; Miall, 1973; Ethier, 1975; Ritzi, 2000). Our first step in performing the transition probability analysis using the T-PROGS software was a review of the available data at each material intersection of our composite fence diagram (figure 8) to characterize the proportions, orientation, geometry, and pattern of material assemblages within the shallow unconfined aquifer. We used lithologic data to develop an indicator database representing the presence or absence of each material type at each fence diagram intersection (figure 8). We reduced the number of material combinations by reclassifying our lithologies into four material types–clay, sand and clay, sand, and sand and gravel–for stochastic simulations.

The reduced data sets are then used in a utility within T-PROGS, called GAMEAS, that computes a set of transition probability curves as a function of lag distance for each category for a given sample interval that represents the transition probability from material k to material j. The distribution of materials is characterized by the transition probability between different materials. Specifically, given that material k exists at h, the transitional probability $t_{jk}\,(h)$ gives the probability (P) that material j exists at location $x + h$, or the transition probability $t_{jk}\,(h)$ is defined as

$$t_{jk}\,(h) = P(j \ occurs \ at \ x + h \mid k \ \ occurs \ at \ h) \qquad (1)$$

where x is a spatial location, h is the lag (separation vector), and j and k denote material types.

The next step in the analysis is to develop a Markov chain model for the vertical direction consistent with the observed vertical transition probability data. It is assumed in a three-dimensional Markov chain model that spatial variability in any direction can be characterized by a one-dimensional Markov chain model. For a one-dimensional Markov chain model applied to a one-dimensional material data set, the continuous lag transition probability matrix T for any lag h can be written as

$$T(h_\phi) = \exp\,(R_\phi\, h_\phi) \qquad (2)$$

where h_ϕ denotes a lag length in the direction ϕ, and R_ϕ denotes an m x m transition rate matrix whose entry r_{ij} represents the rate of change from material i to material j per unit length of material i in the given direction

$$R_\phi = \begin{vmatrix} r_{11,\phi} & \cdots & r_{1k,\phi} \\ \vdots & \ddots & \vdots \\ r_{k1,\phi} & \cdots & \mathrm{r}_{kk,\phi} \end{vmatrix} \qquad (3)$$

with entries $r_{jk,\phi}$ representing the rate of change from materials j to materials k (conditional to the presence of j) per unit length in the direction ϕ. The rates are adjusted to ensure a reasonable fit between the Markov chain and the observed transition probability data.

Once the Markov chain is developed for the vertical direction, models of spatial variability are developed for the horizontal and dip directions. Our data are not sufficiently dense in these directions; however, transition rate matrices for the Markov chain can be developed using the same proportions assumed in the vertical model. The Markov chain models are converted into a continuous three-dimensional Markov chain model using the GAMEAS utility within T-PROGS. In the final phase of setting up the transition probability analysis using T-PROGS, we created a grid where each material type was specified to a corresponding grid cell to create a heterogeneous representation of the shallow unconfined aquifer (figure 9).

Indicator geostatistics are well suited to characterize sedimentary architecture with variable material types. The use of indicator simulation in this situation is desirable because the approach attempts to conform to existing data, and the results are mapped to cells that can be defined on a grid similar to the grid used in the ground-water flow simulation (see "Ground-Water Flow Calculations" below). This process preserves much of the aquifer heterogeneity present in the shallow unconfined aquifer, but not represented by our slug-test data.

Ground-Water Budget

The water budget for an aquifer identifies, quantifies, and accounts for all inflow, outflow, and changes in aquifer storage. Inflow minus outflow from the aquifer equals the change in ground-water storage of the aquifer. If inflow equals outflow, the change in storage is zero and the aquifer is in a steady-state condition. Steady-state conditions are also indicated by nearly constant ground-water levels, or by the absence of long-term trends of changing water levels. We developed a pseudo-ground-water budget to estimate the contribution of the different components of recharge and discharge to provide input for the simulation of the shallow unconfined ground-water system for the Utah part of Cache Valley. We used a pseudo-ground-water budget because of the poor quality of the water data available to us; various sources had different time frames, methods, budget-component definitions, and measurement reporting criteria. No direct measurements of inflow and outflow have been made for the shallow unconfined ground-water system in Cache Valley.

In some previous investigations, water budgets were summarized for the entire ground-water system in Cache Valley, including Beer (1967), Bjorklund and McGreevy (1971), Kariya and others (1994), and Myers (2003). Clyde and others (1984) developed a ground-water flow budget for the Utah part of Cache Valley. We reviewed each of these water budgets, but comparison of the respective components of inflow and outflow was difficult because of the data-source variabilities stated above.

Recharge to the Cache Valley principal basin-fill aquifer occurs by (1) infiltration of precipitation and unconsumed irrigation water, (2) water from perennial streams emerging from canyons, or canals flowing across coarse-grained deposits along the margins of the valley, and (3) subsurface

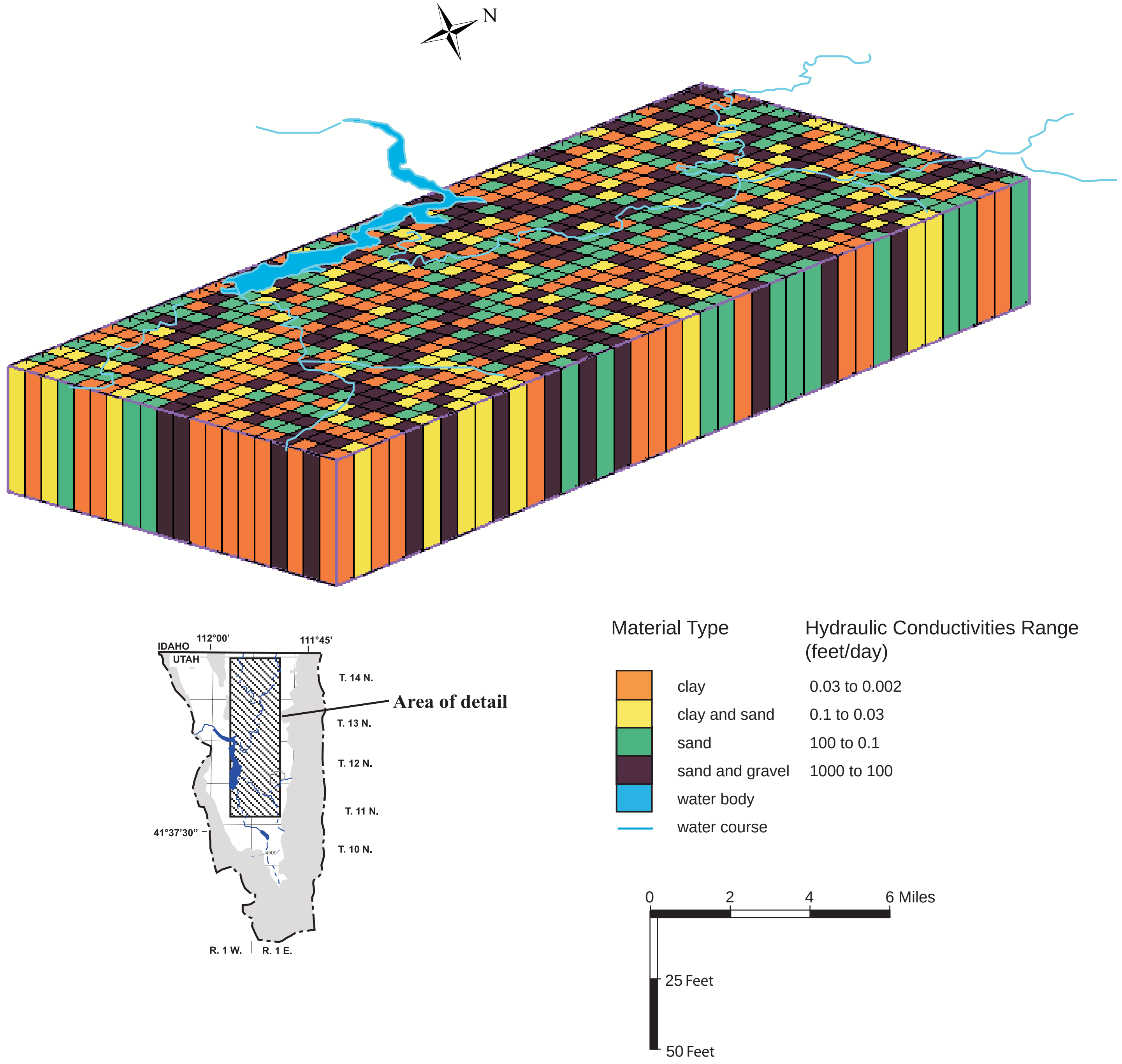

Figure 9. *Visual representation of the shallow unconfined aquifer after performing the transitional probability analysis using T-PROGS. Shown is the single layer vertical homogeneity, and horizontal heterogeneity for the shallow unconfined aquifer needed for the ground-water flow model and developed from figure 8 data.*

inflow. Estimated recharge over the area of Cache Valley in Utah and Idaho, modeled by Kariya and others (1994), is about 326,000 acre-feet per year (402 km^3/yr). Ground-water discharge in Cache Valley is primarily by (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. Estimated discharge over the Cache Valley area in Utah and Idaho, modeled by Kariya and others (1994), is about 325,000 acre-feet per year (400 km^3/yr). The total recharge in Cache Valley is about equal to the discharge (Bjorklund and McGreevy, 1971; Kariya and others, 1994; Robinson, 1999).

Bjorklund and McGreevy (1971) reported that ground-water levels had fluctuated annually from 1967 to 1969, mostly in the principal aquifer, but that overall, the ground-water levels had remained unchanged in Cache Valley. For our study, we assume that the ground-water system in Cache Valley, Utah, is in a steady-state condition; as a consequence, storage changes are not identified in the ground-water budget. Since we are assuming a steady-state system where discharge equals recharge, if the values of the ground-water discharge are known within a limited range, we can use the discharge values to narrow the possible range of other variables that influence ground-water flow. Values for discharge components of the budget, such as seepage to rivers, streams, and Cutler Reservoir, and flows from springs, seeps, and wet meadow areas are more readily available than recharge components of the budget.

Rivers and streams in the lower parts of Cache Valley, including Cutler Reservoir, gain ground water as seepage directly to their channels, or as inflow from springs along the reaches of the rivers. Springs and seeps discharge about 138 cubic feet per second (4 m^3/s) from the unconsolidated deposits of Cache Valley (Kariya and others, 1994). We estimate a substantial portion of this spring and seep discharge is from the Utah part of Cache Valley. High rates of evapotranspiration in the lower meadow areas of the valley, where the water table is near the land surface, also account for significant discharge (Kariya and others, 1994). Additional discharge from the principal aquifer occurs from both pumped and flowing wells.

Irrigation of agriculture and pastureland is still prevalent in Cache Valley. Recharge to the aquifer system by irrigation was estimated from land-use data, and losses from canals were provided from Soil Conservation Service (now Natural Resources Conservation Service) canal diversions estimates (in Kariya and others, 1994). Losses were distributed uniformly over irrigated land and along the length of the canals.

Bjorklund and McGreevy (1971) estimated that about 6 cubic feet per second (170 L/s) of ground water moves annually from Idaho to Utah in the subsurface. Ground water also moves by lateral flow into the deep unconfined aquifer, where some of that water recharges the shallow unconfined aquifer along the outer margins of the upper confining beds; from information in Kariya and others (1994), we estimate this recharge to the deep unconfined aquifer to be about 14 cubic feet per second (400 L/s).

Table 3 is our estimated ground-water budget for the Utah part of Cache Valley based on the above information. Insufficient data are available to prepare a ground-water budget specifically for the shallow unconfined ground-water system; however, the budget for the shallow unconfined system is smaller (by an unknown amount) than the budget for the entire aquifer system that includes the deep unconfined and confined parts of the principal aquifer system. This concept was used during ground-water flow model calibration.

Table 3. *Estimated ground-water budget for the basin-fill aquifer in Cache Valley. Modified form Bjorklund and McGreevy (1971) and Kariya and others (1994) to reflect the Utah part of Cache Valley.*

	ft^3/s
Discharge	
Seepage to rivers and Cutler Reservoir	110
Springs, seeps, and drains	120
Evapotranspiration	50
Withdrawal from wells	40
Total discharge	320
Recharge	
Infiltration from precipitation and unconsumed irrigation water	135
Seepage from canals and streams	120
Subsurface inflow	20
Other forms of recharge	45
Total recharge	320

The shallow unconfined aquifer appears to also be in a steady-state condition, as the aquifer's recharge appears approximately equal its discharge. Water levels of the shallow unconfined aquifer have likely remained constant for decades, as indicated by the persistent spring, slough, and wetland discharges documented by previous investigators.

Robinson (1999) concluded that ground water removed from the confined parts of the principal aquifer system is replaced by increased recharge from the deep unconfined parts of the principal aquifer; this is water that would otherwise recharge the shallow unconfined aquifer system. Therefore, increased withdrawal from the principal aquifer results in decreased recharge to the shallow unconfined aquifer. The shallow unconfined aquifer system also receives recharge from infiltration of precipitation and unconsumed irrigation water, and seepage from canals and streams. There are wells in the shallow unconfined aquifer, but we have no discharge data from them; however, they are few and have small discharges, thus we assume well discharge from the shallow unconfined aquifer is negligible.

Ground-Water Flow Calculations

Introduction

We used the Groundwater Modeling System (GMS) (Brigham Young University, 2003) applied to a three-dimensional, steady-state MODFLOW (Harbaugh and others, 2000) model to determine the available ground water in the unconsolidated basin-fill deposits of the shallow unconfined aquifer in the Utah part of Cache Valley. MODFLOW was preselected for this study because it was used by Kariya and others (1994) and Myers (2003) for their models of the valley, and is well documented and widely used. Our conceptual model of the shallow unconfined aquifer system, described above, formed the basis for establishing model boundaries, aquifer layers, and defining the extent of the shallow unconfined aquifer. The distribution and quantities of recharge and discharge are from previous evaluations of the aquifer system in the valley, and were modified by us. Figures 2 and 4 are schematic diagrams showing the general pattern of recharge, discharge, and ground-water flow in the shallow unconfined aquifer.

Computer Modeling

The steady-state computer model used in this study simulates many elements of the shallow basin-fill aquifer including (1) unconfined conditions, (2) evapotranspiration, (3) seepage to rivers, springs, seeps, wet meadowland, and Cutler Reservoir, (4) recharge from precipitation and irrigation water, and (5) subsurface inflow from the deep unconfined portion of the principal aquifer. For the steady-state simulation, we used 1969 data from Kariya and others (1994) and assumed recharge and discharge were equal. The 1969 data were used to allow direct comparison with the Kariya and other's (1994) and Myer's (2003) simulations of the principal aquifer in Cache Valley that used the 1969 data. Based on the observation wells and the distributions of springs, seeps, and wet meadowland, ground-water levels in the shallow unconfined aquifer were similar for 1969 and 2004. Water levels fluctuated between those time periods, but overall, the ground-water system appears to be in a steady-state condition.

We superimposed the area of the shallow unconfined aquifer onto a topographic map of Cache Valley, Utah, and discretized the area into a grid of rectangular cells, with each cell having homogeneous properties. The rectangular model grid is a two-layer Cartesian grid of 20 columns and 40 rows (figure 10). The model's rectilinear grid has a uniform grid-cell size of 1230 feet by 1155 feet (375 by 352 m) on each side, resulting in a cell area of 0.05 square miles (0.1 km^2). The y-axis of the model is oriented north-south, parallel to the axis of the valley and the primary surface-water drainage divides.

We designated the model cells in the finite-difference grid either active or inactive. Active cells delineate the lateral boundaries of the simulated ground-water system and correspond to the lateral extent of the shallow aquifer. For modeling purposes, we designated cells representing the deep unconfined part of the principal aquifer surrounding the shallow unconfined aquifer and consolidated rocks as inactive. Active cells in layers one and two represent an area of approximately 145 square miles (375 km^2). The thickness of layer one is variable, from 60 to 120 feet (20–40 m), while the thickness of layer two was arbitrarily set at 200 feet (60 m). We considered the sediments of layer two, below the shallow unconfined aquifer, to have a lower permeability than the sediments of layer one. Aquifer properties assigned to each active cell in the model represent the average value for the cell.

Boundaries of the shallow unconfined aquifer model control mathematically how the simulated ground-water system interacts with its surroundings. We based the boundaries, which conform to the approximate physical boundaries of the shallow unconfined aquifer, on our conceptual model of the system. We specified most of the lateral boundaries surrounding the active cells of the model as "variable head" boundaries, and assumed they coincide with permeable unconsolidated sediments of the principal aquifer. These lateral boundaries of the aquifer system allow ground water to flow into or out of the aquifer system. To simulate subsurface inflow from the north, and to maintain water levels in that area, we used general-head cells at the north end of layer one. We estimated recharge from the northern shallow unconfined aquifer (in Idaho) based on the valley-wide model of Kariya and others (1994). Initially, the flow rate was calculated across this boundary with the valley-wide model, and then the calculated conductance values were assigned to the general-head cells in the shallow unconfined aquifer model. The upper boundary of the model is a specified-flux boundary formed by using the recharge, evapotranspiration, river, general-head, 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.

Water levels in shallow wells indicate the aquifer modeled in layer one is essentially unconfined, and layer one was simulated as an unconfined layer (convertible layer in MODFLOW) that allows the water level to change causing the saturated thickness to vary. Layer one thickness was based on drillers' logs of water wells, and corresponds to the depth of the thick clay layer in the central parts of Cache Valley. Layer two corresponds to the upper confining unit of Robinson (1999). The thickness of this layer is arbitrarily set to 200 feet (60 m). Layer two is included primarily to account for assumed water stored in this interval, and a small quantity of water flowing through it.

The initial water-level distribution for model layer one is based on water levels measured in 2004. We assume these water levels represent the equilibrium conditions in the shallow aquifer. We based the value of hydraulic conductivity assigned to each model cell in layer one on the distribution shown in figure 9, with the specific values assigned to the model cells calculated from the transition probability analysis using T-PROGS. The results of slug tests (table 2) performed on observation wells penetrating mostly clay material constrain the range of assigned hydraulic conductivities for cells dominated by clay lithologies; other assigned hydraulic conductivities have been adjusted, relative to table 2, to reflect the dominant material type represented by the cell. Hydraulic conductivities were assigned directly to the model layers one and two.

Areal recharge from precipitation, irrigation water, and seepage from canals were combined and simulated as a specified-flux boundary with the recharge package of MODFLOW (Harbaugh and others, 2000). Recharge is applied to the top of the active cells in layer one. The distribution of precipitation was not known for Cache Valley, so we assumed precipitation to be uniform over the entire aquifer. We estimated ground-water recharge from leaking irrigation canals and infiltration from irrigated fields from diversion records, seepage studies, and crop data. We estimated areas of recharge to the shallow aquifer system from irrigation data provided in Kariya and others (1994). The distribution of seepage from canals was modified from Kariya and others (1994). The recharge rate we use for the shallow aquifer is

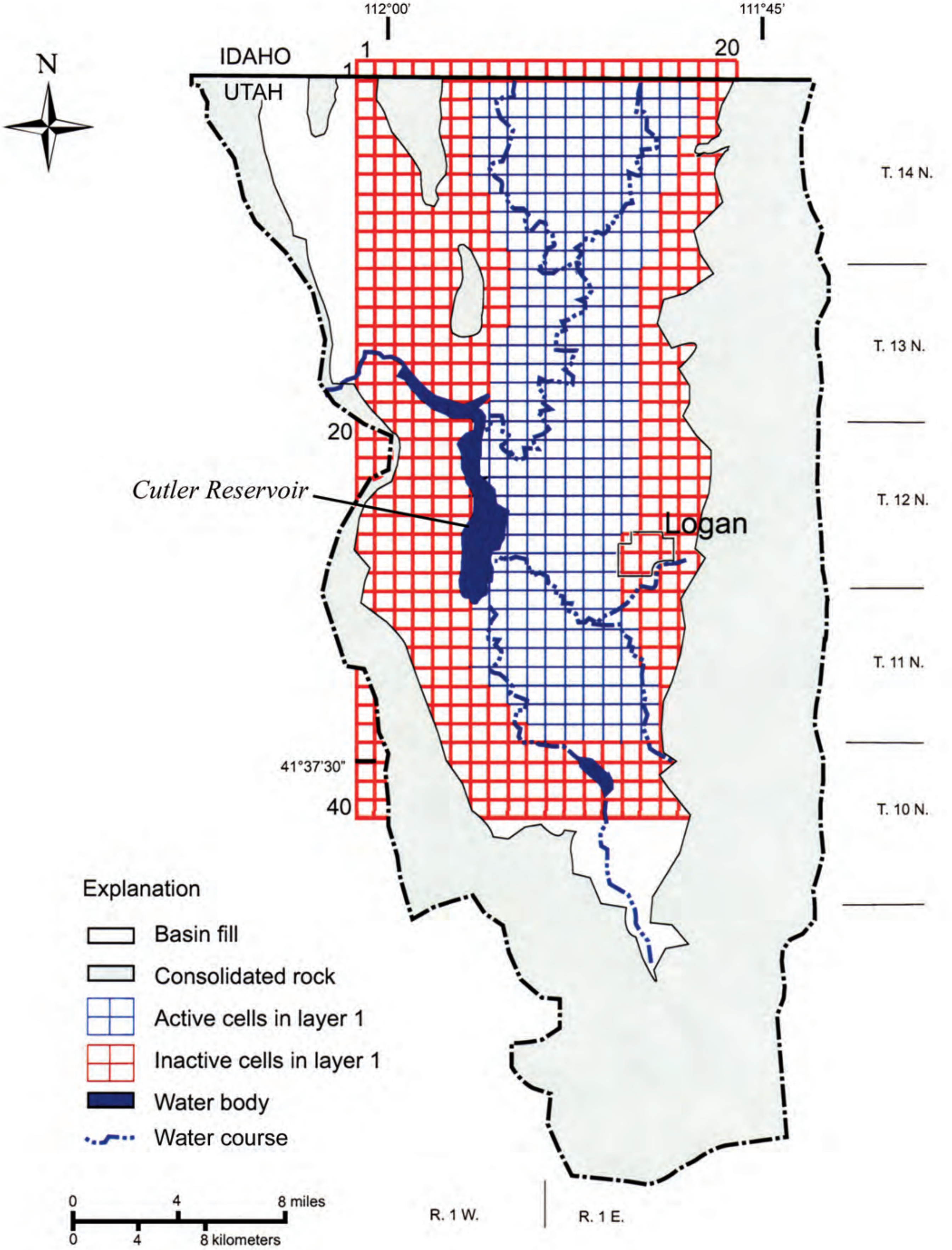

Figure 10. *Finite-difference grid used to simulate ground-water flow in the shallow unconfined aquifer in Cache Valley.*

within the ranges of recharge given by Kariya and others (1994). During the model calibration, we observed the model heads to be above the ground surface in various areas. We reduced the amount of recharge to lower the ground-water levels.

Rivers in Cache Valley exchange water with the shallow aquifer system, gaining water if nearby ground-water levels are higher than the surface-water stage, and losing water if nearby ground-water levels are lower. We modeled permanent surface-water features using MODFLOW's river package (Harbaugh and others, 2000). The quantity of water exchanged is calculated by the model from the average stage of the water body, altitude of the bottom of the riverbed, transmissive properties of the riverbed (river conductance was for silty sand and assigned a value of 3 x 10^{-2} feet per day [0.1 m/d]), and model-calculated head for the upper model layer. We estimated the average stage and altitude of the bottom of the riverbed for each model cell from values obtained from 1:24,000-scale U.S. Geological Survey topographic maps; these estimates were used to simulate seepage to the Bear, Cub, Logan, Blacksmith Fork, and Little Bear Rivers (figure 11). Cutler Reservoir was modeled using MODFLOW's general-head package (Harbaugh and others, 2000) for each cell associated with Cutler Reservoir. Ground-water flow into or out of each general-head cell is head dependent. We set the head value for each general-head cell representing Cutler Reservoir equal to the elevation of the lake level on 1:24,000-scale U.S. Geological Survey topographic maps (figure 11). The general-head conductance of each cell ranged from 0.03 to 100 feet per day (0.1–328 m/d), calculated based on the hydraulic conductivities assigned to the cells representing Cutler Reservoir.

We simulated discharge to springs, seeps, and wet meadowlands with a head-dependent relationship referred to as the drain package (Harbaugh and others, 2000). We based the locations of simulated springs and seeps in layer one on areas of ground-water discharge identified by Bjorklund and McGreevy (1971) and Kariya and others (1994); these areas largely remain areas of discharge with springs and seeps, small channels containing water, wetland vegetation, and other signs of ground-water discharge, based on our 2004 observations of wet areas (figure 11). The drain package simulates a head-dependent flux for each cell to which it is assigned. Discharge is a function of simulated water level and drain conductance. The drain package uses a value for the hydraulic properties (conductance) of the spring, and simulated heads to compute a discharge if the model head is higher than the specified drain altitude. If the model head is lower, discharge is zero. We chose the average drain altitudes from values of land surface obtained from 1:24,000-scale U.S. Geological Survey topographic maps.

We simulated discharge to evapotranspiration in layer one with MODFLOW's evapotranspiration package (Harbough and others, 2000). We based modeled areas of evapotranspiration on areas of evapotranspiration mapped by Bjorklund and McGreevy (1971); these are agriculture areas in the lower altitude areas of the valley, and in riparian areas or areas of phreatophytes along major rivers. We assume that (1) evapotranspiration ceases when the water table exceeds 6 feet (2 m) below the land surface, (2) a maximum evapotranspiration rate is reached when the water table is at the land surface, and (3) at intermediate depths the evapotranspiration rate linearly decreases from the maximum rate to zero. We estimated the elevation of the evapotranspiration surface based on the land surface from 1:24,000-scale U.S. Geological Survey topographic maps.

Calibration

Comparison between measured and simulated heads, provide a simple, visual, qualitative calibration of a model. However, head data are generally not quantitative enough to develop a model that can be used for predictive purposes. Because of data limitations, we were able to perform only a simple calibration of the model, so the model should only be used as an interpretive tool for the overall shallow unconfined aquifer system.

Our simple calibration of the ground-water flow model involved successive adjustment and re-adjustment of model parameters representing aquifer characteristics and certain recharge and discharge components, in order to develop a model that reasonably represents the shallow unconfined aquifer system. We calibrated the ground-water flow model under steady-state conditions using the water levels collected during fieldwork and model parameters that were assigned in 1969 (collected over a range of time). We made changes only to parameters having a known range of values, principally horizontal hydraulic conductivity and areal recharge. At the end of the calibration process, we believe the model reasonably represents general ground-water flow conditions and provides an estimate of the amount of water available in the shallow unconfined aquifer based on comparisons of simulated and observed heads in model layer one. Throughout the model area, simulated hydraulic heads matched observed/estimated levels reasonably well (figure 12).

Results

The ground-water flow model used for this study is the best available tool to qualitatively determine the water available in the shallow unconfined aquifer for mixing with septic-tank effluent. The model is a simplified representation of the shallow ground-water system and does not represent local heterogeneities in aquifer properties, recharge, or discharge. The ground- water flow model, which predicts the volume of the shallow aquifer, is based on relatively limited information. We used the simulation to improve our understanding of the aquifer system, and the model water budget to determine the available ground-water flow in saturated unconsolidated basin-fill deposits of the shallow unconfined aquifer in the Utah part of Cache Valley. We used model-calculated cell-by-cell flows to identify areas with similar flows of water in layer one; we assume mixing/dilution of septic-tank effluent occurs within ground water modeled by this layer.

Based on the spatial distribution of the cell-by-cell flow terms calculated by MODFLOW, we determined all areas of the shallow aquifer have similar flow throughout the Utah part of Cache Valley. This was expected because of the heterogeneous nature of the shallow unconfined aquifer, with overall fine-grained deposits dispersed throughout it. The hydraulic conductivity distribution determined using the T-PROG software provided preferential pathways for ground-water flow to simulate courser grained facies within the

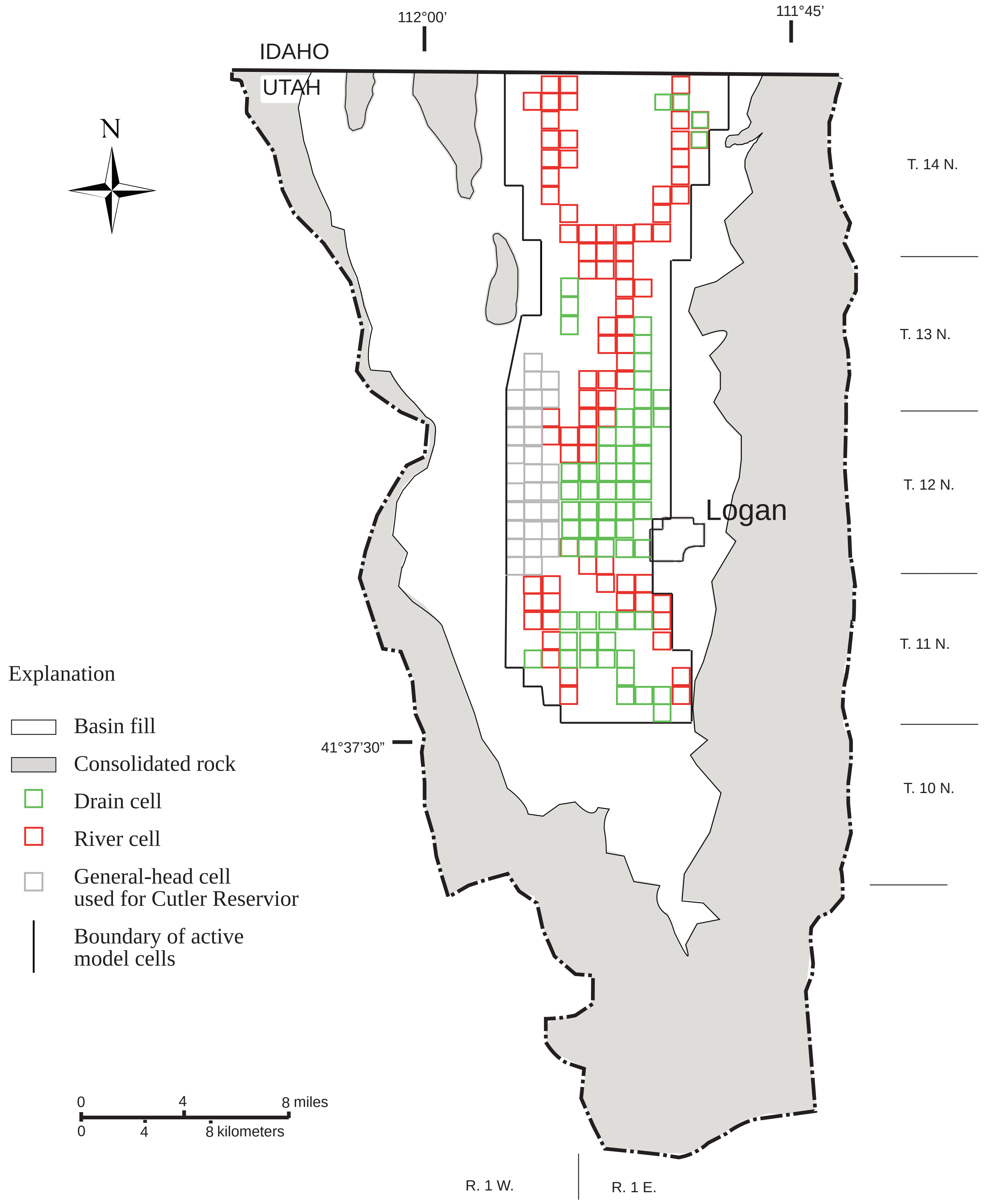

***Figure 11.** Distribution of model cells used to simulate discharge to rivers, springs, and seeps in the shallow unconfined aquifer, Cache Valley. Also shown are general-head cells used to represent Cutler Reservoir.*

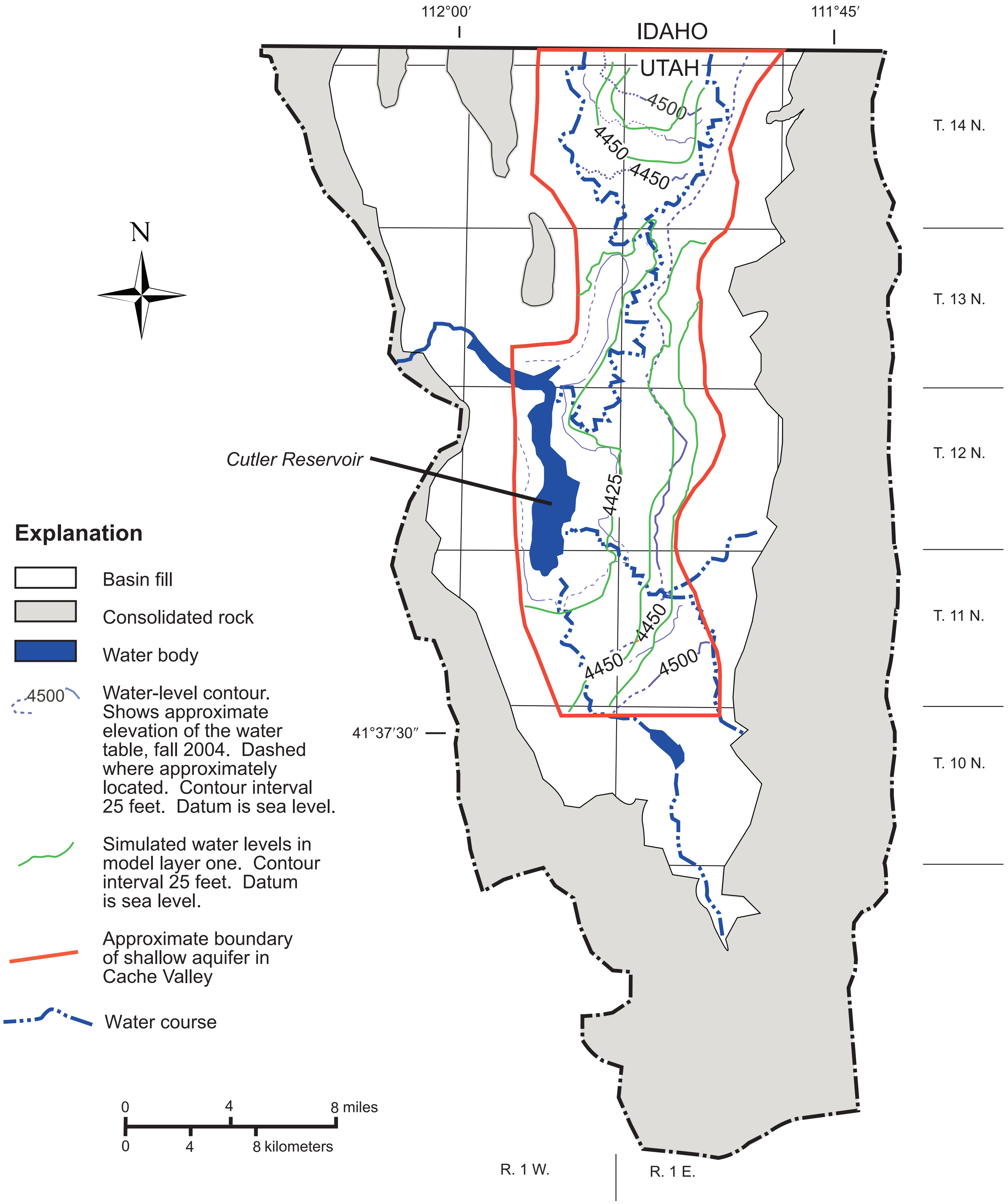

Figure 12. *Approximate ground-water elevations in the shallow unconfined aquifer, fall 2004, in Cache Valley, Utah, compared to simulated ground-water elevations.*

aquifer material as noted on drillers' logs of water wells and documented during the permitting of existing septic-tank systems. We then used the model flow budget to determine the available ground-water flow (volumetric flow) in saturated unconsolidated basin-fill deposits for the shallow unconfined aquifer in the Utah part of Cache Valley. Based on the modeling, we determined that an average volumetric flow of about 40 cubic feet per second (1000 L/s) is available for mixing with septic-tank effluent.

Modeling Limitations

In spite of many simplifying assumptions, the model reasonably reproduced the behavior of the shallow unconfined aquifer; the general shape and slope of the simulated water-table surface and overall hydraulic-head distribution match the geometry determined from field measurements. Some of the simplifying 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 model is an interpretive tool that we used to study how the shallow unconfined aquifer behaves, and was not truly quantitatively calibrated; it allowed us to understand some of the controlling parameters and system dynamics. We used a steady-state simulation with time-averaged and limited 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, such as adding a large well, are applied. The simplified boundary conditions and insufficient data to accurately calibrate the model also limit its accuracy. Additionally, no measured ground-water budget exists to compare to the budget we determined through ground-water flow simulation using the model.

Septic-Tank System/Water-Quality Degradation Analyses

We calculated projected nitrate concentrations in the shallow unconfined aquifer by using the mass-balance approach to predict the impact of nitrate from septic-tank systems over the modeled area. We derived the existing number of septic-tank systems (1508) in the area of the shallow unconfined aquifer by including only those septic tanks in the study area; the total number of septic tanks in the valley, as provided by the Bear River Health Department (Nick Galloway, Bear River Health Department, written communication, 2001), is 3580.

Figure 13 shows a plot of projected nitrate concentration versus septic-tank density and number of septic-tank systems in the area underlain by the shallow unconfined aquifer in Cache Valley. Based on data from 17 wells, the background nitrate concentration is 2.7 mg/L. As stated, approximately 1508 septic systems are in the area. The area underlain by the shallow unconfined aquifer has an area of approximately 93,000 acres (38,000 hm^2; 145 mi^2 [375 km^2]), so the existing average septic-system density is about 62 acres per system (25 hm^2/system). Based on our analyses, the estimated ground-water flow available for mixing in the shallow unconfined aquifer is about 40 cubic feet per second (1000 L/s). To maintain an overall nitrate concentration of 3.7 mg/L (which allows 1 mg/L of degradation, a value adopted by several Utah counties as an acceptable level of degradation), the total number of homes using septic tank soil-absorption systems should not exceed 3800 based on the estimated nitrogen load of 55 mg/L per septic-tank system (figure 13). This corresponds to a total increase of 2092 septic systems and an average septic-system density of about 25 acres per system (10 hm^2/system).

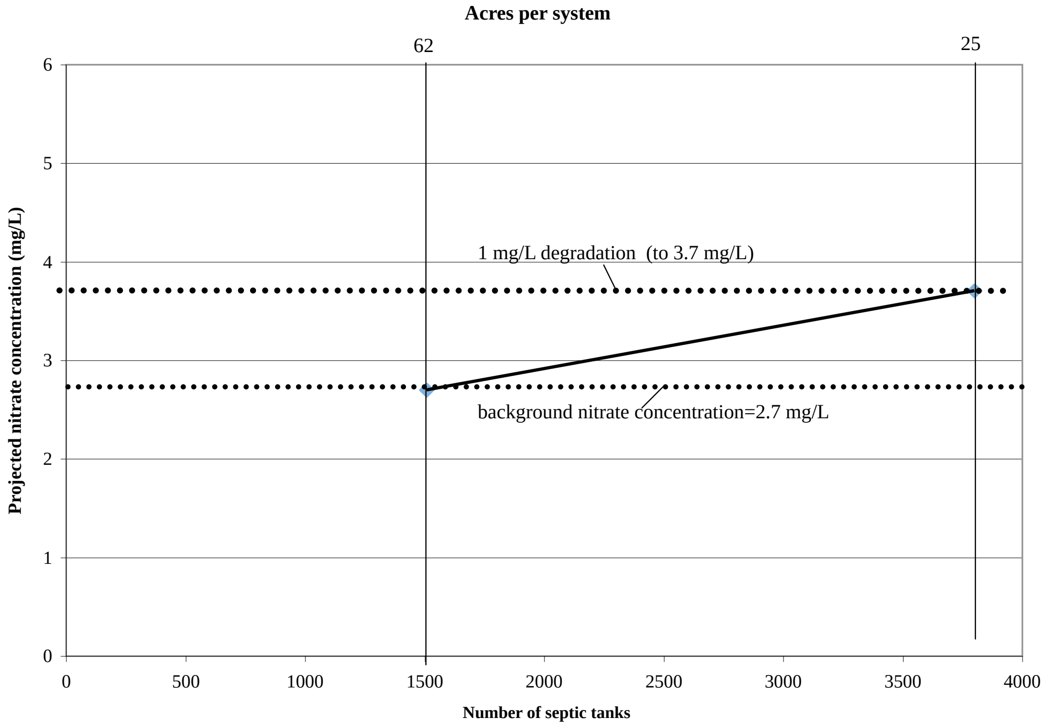

Figure 13. *Projected nitrate concentration versus number of septic-tank systems for the shallow unconfined aquifer in Cache Valley.*

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 graph of projected nitrate concentration versus number of septic-tank systems show the recommended septic-tank density based on the parameters described above. 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 maps (Lowe and others, 2003) and ground-water recharge/discharge-area maps (Anderson and others, 1994). 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.

This septic-tank system density recommendation is designed to be used as a guide for land-use planning 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. The septic-tank system density recommendation presented in this report should be used in areas where ground water from the shallow unconfined aquifer system is used or will be used as a drinking water resource; where water from the shallow unconfined aquifer system is not used, it may be more appropriate to use septic-tank system density maps for the principal aquifer, with lot-size recommendations of 3, 5 and 10 acres (1, 2, and 4 hm^2) (Lowe and others, 2003).

SUMMARY AND CONCLUSIONS

Ground water is the most important source of drinking water in Cache Valley. Some of this drinking water is from the shallow unconfined aquifer system. 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 the shallow unconfined aquifer system; 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. Based on a ground-water flow model constructed for this study, the estimated ground-water flow available for mixing in the shallow unconfined aquifer in the Utah portion of Cache Valley is about 40 cubic feet per second (1000 L/s). The mass-balance approach indicates that the recommended maximum septic-tank system density appropriate for development using septic tank soil-absorption systems for wastewater disposal in the area of the shallow unconfined aquifer in Cache Valley is 25 acres per system (10 hm^2/system); this recommendation is based on hydrogeologic parameters incorporated in the ground-water flow model we constructed. The septic-tank system density recommendation presented in this report should be used in areas where ground water from the shallow unconfined aquifer system is used or will be used as a drinking water resource; where water from the shallow unconfined aquifer system is not used, it may be more appropriate to use lot-size recommendations based on ground-water flow in the principal aquifer (3, 5 and 10 acres [1, 2, and 4 hm^2]) (Lowe and others, 2003). Overall, the amount of ground water available for dilution controls the potential impact of increasing numbers of septic-tank systems, and thus our recommended septic-tank soil-absorption system density.

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APPENDIX

BACKGROUND INFORMATION

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, 1958, 1962) conducted studies of stratigraphy and geologic history in Cache County, including Paleozoic rocks in the area and Bonneville lake-cycle deposits in Cache Valley. Erickson and Mortensen (1974) mapped soils in the Cache Valley area. Lowe (1987) and Lowe and Galloway (1993) constructed cross sections using drillers' logs of water wells to show aquifers and confining beds in basin-fill deposits in the Smithfield quadrangle.

Numerous investigations have focused on various aspects of ground water in Cache Valley. Peterson (1946) conducted an early investigation of the quantity of ground-water supply available in Cache Valley. Gardner and Israelsen (1954) and Israelsen and others (1955) discussed drainage of shallow unconfined ground water in Cache Valley. Strong (1962) discussed economic and legal aspects of ground-water development in Cache County. 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. McGreevy and Bjorklund (1970) compiled hydrogeologic data for Cache Valley. Bjorklund and McGreevy (1971) conducted a detailed ground-water study in Cache Valley. Clyde and others (1984) constructed the first ground-water flow model for Cache Valley. Herbert and Thomas (1992) performed a seepage study of the Bear River, including Cutler Reservoir, in Cache Valley. 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, 1999b, 2001; Wallace and Lowe, 1999a) 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. Lowe and Sanderson (2000) and Sanderson and Lowe (2002) assessed ground-water sensitivity and vulnerability to pesticides for the basin-fill aquifer in Cache Valley. Lowe and others (2003) classified ground water in the Utah portion of the Cache Valley basin-fill aquifer under the Utah Water Quality Board total-dissolved-solids concentration classification system, and made recommendations for septic-tank soil-absorption system density based on ground-water flow available for mixing. Myers (2003) produced a ground-water flow model for the basin-fill aquifer using Robinson's (1999) conceptual model of the confining beds in the central part of Cache Valley. Cache-Landmark Engineering, Inc., (2003) evaluated water rights and water demands for the city of Nibley. Oaks (2004) assessed potential decreased flows in artesian wells in the College Ward area. Lachmar and others (2004) discussed conceptual and MODFLOW ground-water models in Cache Valley. Bishop (2005) discussed the development of the ground-water flow model for the shallow unconfined aquifer used in this evaluation.

LOCATION AND GEOGRAPHY

Cache Valley (figure 1) is a north-south-trending valley with an area of about 660 square miles (1710 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 4400 to 5400 feet (1340-1650 m). Peaks in the Wellsville Mountains and Bear River Range reach elevations above 9000 feet (2700 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 2000 to 2005, population in Cache County increased by 12.7 percent (Demographic and Economic Analysis Section, 2006). The July 1, 2001, population of Cache County was estimated at 93,372 (Demographic and Economic Analysis Section, 2006); projected population by 2030 is 143,040 (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 than average climatic information, those values are discussed herein. Temperatures reach a normal maximum of 90.0ºF (32.2ºC) (Richmond station) and a normal minimum of 10.2ºF (-12.1ºC) (Trenton/Lewiston station); the normal mean temperature ranges from 44.8 to 48.5ºF (7.1-9.2ºC). 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.

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 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 30 and 12 ka (Oviatt and others, 1992, figure 2); during the Holocene, rivers and streams have locally reworked the lake sediments. At least one other thick (as much as 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 interpreted these fine-grained sediments as having been deposited during the Little Valley lake cycle sometime between 150,000 and 90,000 years ago (Scott and others, 1983).

GROUND-WATER CONDITIONS

Introduction

Ground water in the Cache Valley area is present in two types of aquifers: (1) fractured bedrock and Tertiary semiconsolidated rocks, and (2) unconsolidated deposits. 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 system (Bjorklund and McGreevy, 1971). The shallow unconfined aquifer, the focus of this study, is part of the basin-fill aquifer system, and a conceptual model of the shallow unconfined aquifer cannot be developed without understanding the entire system.

Basin-Fill Aquifer

Occurrence

Ground water in the basin fill of 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), and in the area between Smithfield and Newton, unconsolidated sediments are as much as about 1340 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; Lowe and Galloway, 1993), 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 A1). Ground water in the principal aquifer is mostly under unconfined conditions along the margins of Cache Valley (Bjorklund and McGreevy, 1971), but is under confined conditions (possibly leaky confined conditions) in many areas of the center of the valley where many flowing wells exist (Kariya and others, 1994). 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 A1). Kariya and others (1994) attributed the leaky confined conditions in the principal aquifer to the discontinuous nature of clay and silt confining layers (figure A1); however, Robinson (1999) developed a conceptual model of non-leaky confining layers separating the shallow unconfined aquifer from the principal aquifer.

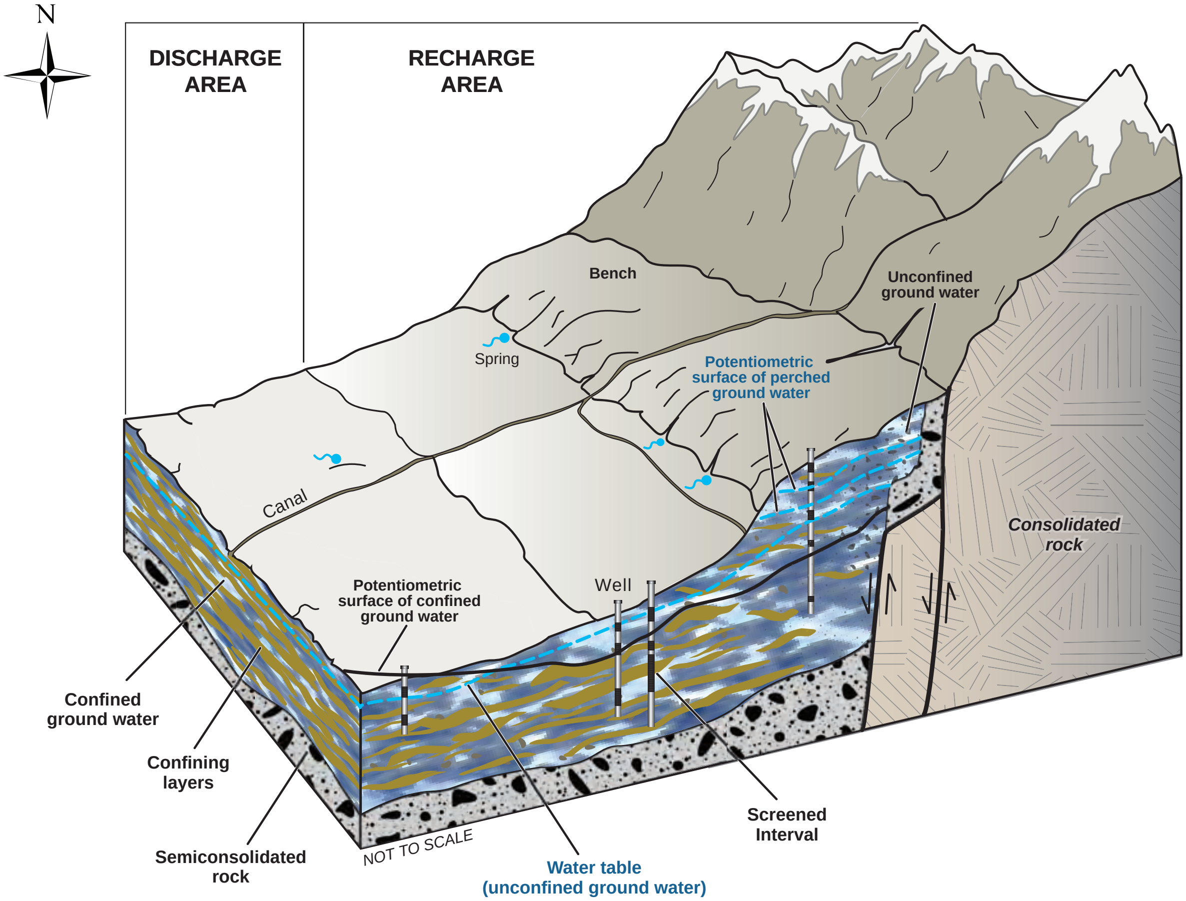

Figure A1. *Schematic block diagram showing ground-water conditions in Cache Valley, Cache County, Utah (modified from Kariya and others, 1994).*

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 part 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 A2). 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 fluctuation in southwestern Cache Valley (Kariya and others, 1994). Water-level changes in the principal aquifer affect recharge to and discharge from the shallow unconfined aquifer.

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 in both the principal aquifer and shallow unconfined aquifer 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 as much as 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 A1). Most recharge takes place in primary recharge areas (figures A1, A3, and A4) 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 in-cludes evapotranspiration, well-water withdrawal, and seepage to springs and Cutler Reservoir (Kariya and others, 1994) (table A1). 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).

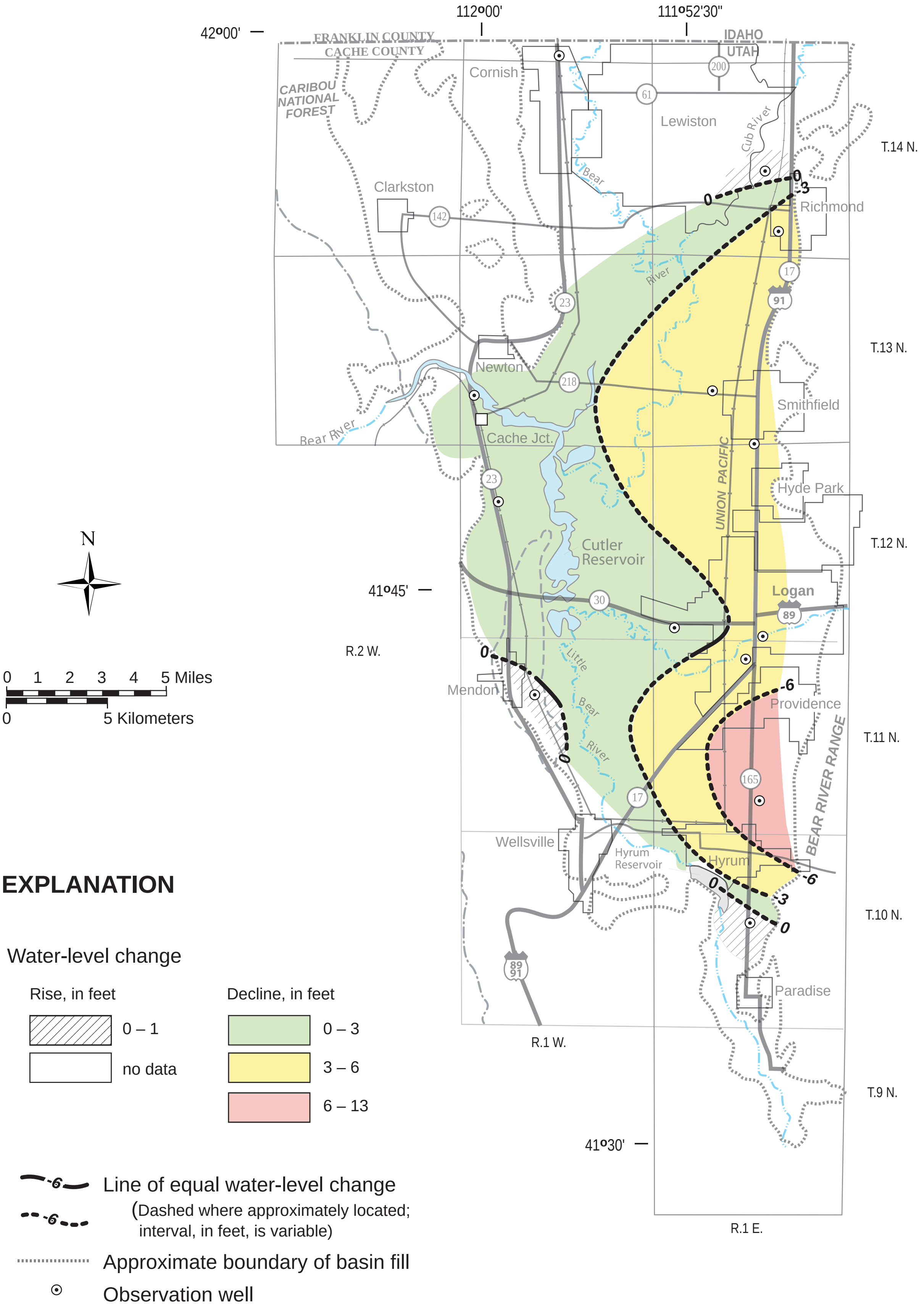

Figure A2. *Change of water level in Cache Valley, Cache County, Utah, from March 1970 to March 2000 (modified from Burden and others, 2000).*

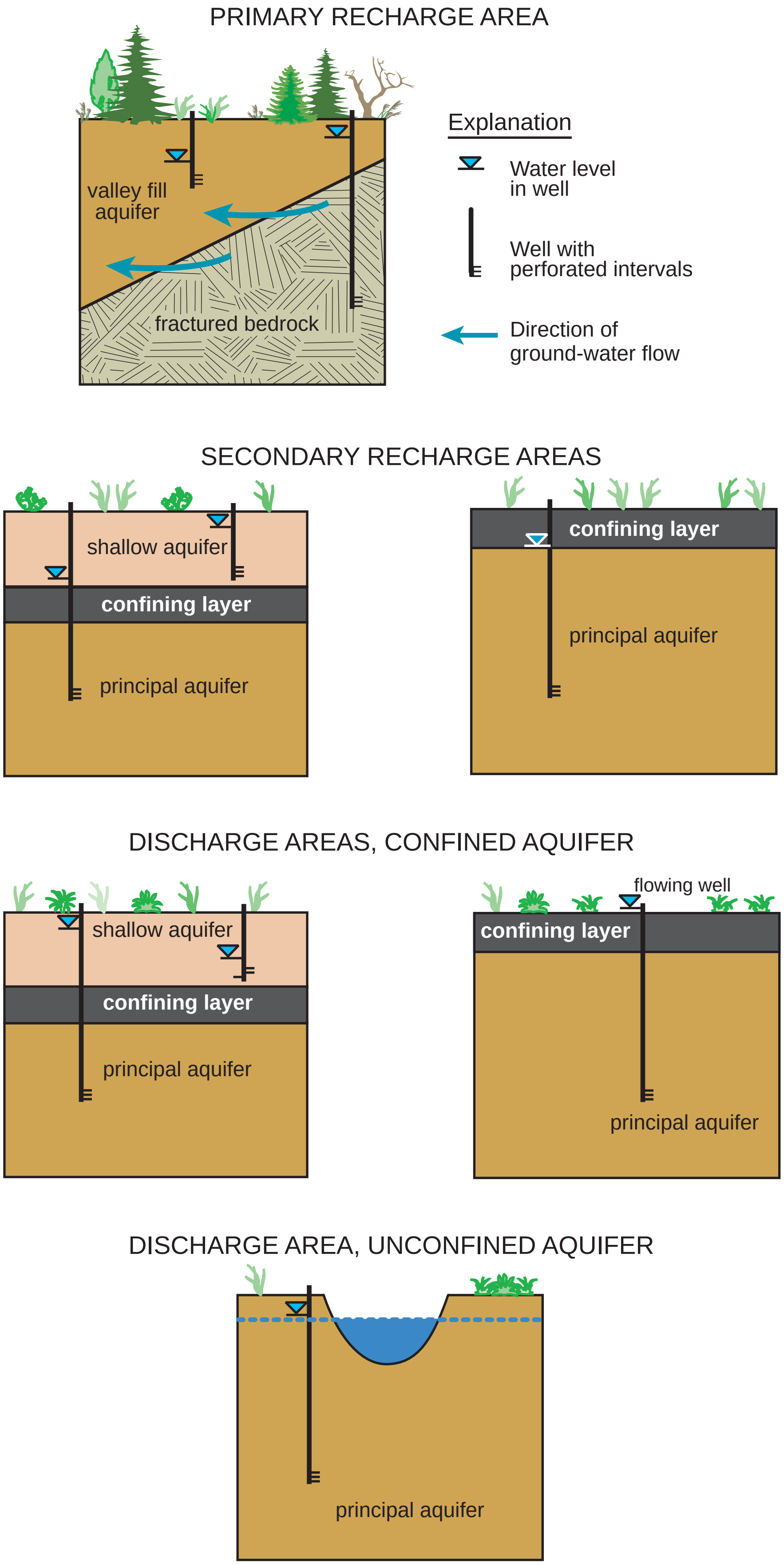

Figure A3. *Relative water levels in wells in recharge and discharge areas (modified from Snyder and Lowe, 1998).*

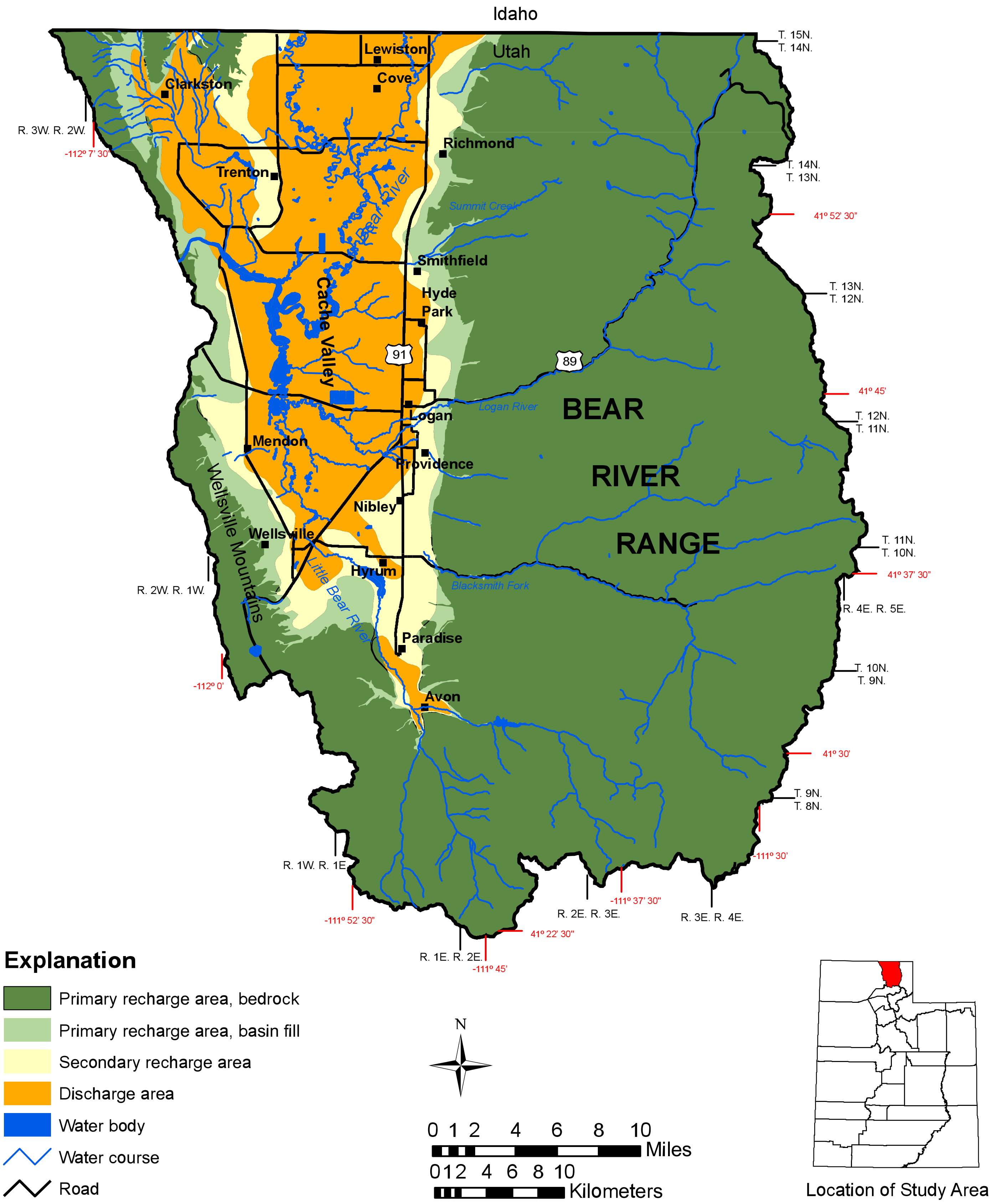

***Figure A4.** Recharge areas in Cache Valley, Cache County, Utah (after Anderson and others, 1994).*

Table A1. *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) documented total-dissolved-solids (TDS) concentrations to be mostly below 800 mg/L. However, warm saline ground water having TDS concentrations in ex-cess of 1600 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 federal primary (health-related) ground-water quality standards for nitrate and fluoride, and federal secondary (non-health-related) ground-water quality standards for chloride, iron, and sulfate (Beer, 1967; Bjorklund and McGreevy, 1971; U.S. Environmental Protection Agency, 2002; Lowe and others, 2003). Few water-quality data exist for the shallow unconfined aquifer.

SEPTIC-TANK DENSITY/WATER-QUALITY DEGRADATION ANALYSIS

Introduction

Land-use planners have long used septic-tank suitability maps to determine where wastewater from 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, 1999d; Wallace and Lowe, 1998a, 1998b, 1998c, 1999b; Lowe and others, 2000, 2003). 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 A2) 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 adsorption 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 wastewater in septic tanks (table A2), mostly from the human urinary system. Typically, almost all ammonia is converted into nitrate before leaving the septic tank soil-absorption system drain field. Once nitrate passes below the zone of aerobic bacteria and the roots of plants, there is negligible attenuation as it travels

Table A2. *Typical characteristics of wastewater in 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

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 230 gallons (860 L) of effluent per day containing nitrogen (or nitrate as nitrogen) 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 230 gallons (860 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), (3) 265 liters per capita per day water use, and (4) an assumed retainment of 15 percent of the nitrogen in the septic tank (to be later removed during pumping) (And-reoli and others, 1979, in Kaplan, 1988, p. 148); this number is close to Bauman and Schafer's (1985, in Kaplan, 1988, p. 147) nitrogen (or nitrate as nitrogen) concentration in septic-tank effluent of 62 ± 21 mg/L based on the averaged means from 20 previous studies. We determined ground-water flow available for mixing, the major control on nitrate concentration in aquifers when using the mass-balance approach (Lowe and Wallace, 1997), using a ground-water flow model we constructed for this study.

Limitations

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

1. Calculations of ground-water available for mixing are based on a computer model and subject to the model limitations.

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 assume 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 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.