RECOMMENDED SEPTIC TANK SOIL-ABSORPTION-SYSTEM DENSITIES FOR THE PRINCIPAL VALLEY-FILL AQUIFER, SANPETE VALLEY, SANPETE COUNTY, UTAH

by
Charles E. Bishop, Janae Wallace, and Mike Lowe

REPORT OF INVESTIGATION 259
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Cover Photo: View looking northwest of agricultural field near Moroni, Sanpete County, Utah.

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ABSTRACT

Sanpete Valley in central Utah is experiencing an increase in rural residential development. Most of this development is on unconsolidated deposits of the valley-fill aquifer system, the principal source of drinking water. Since much of this new development uses septic tank soil-absorption systems for wastewater disposal, local government officials believe there is a need to evaluate the potential for water-quality degradation due to domestic wastewater disposal. The purpose of our study is to apply a ground-water flow model to determine the potential impact of increased numbers of septic-tank systems on water quality in Sanpete Valley's principal valley-fill aquifer, and thereby recommend appropriate septic-system density requirements to limit water-quality degradation. 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 used here, 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.

For this study, we used nitrate (nitrate as nitrogen) data from ground water from 340 wells sampled and analyzed during 1996 and 1997 as part of a previous study in Sanpete and Arapien Valleys. The background (current average) nitrate concentration in the principal valley-fill aquifer is 3.3 mg/L. We used the Groundwater Modeling System, applied to a regional, three-dimensional, steady-state MODFLOW model, to estimate ground-water flow available for mixing in the principal valley-fill aquifer. Ground-water flow available for mixing is the major control on projected aquifer nitrate concentration in the mass-balance approach. Our ground-water flow analysis indicates that two categories of recommended maximum septic-system densities are appropriate for development using septic tank soil-absorption systems for wastewater disposal: 5 and 10 acres per system (2 hm^2/system and 4 hm^2/system). These recommended densities are based on hydrogeologic parameters incorporated in the ground-water flow simulation, and are geographically divided into three ground-water flow domains on the basis of flow-volume similarities.

INTRODUCTION

Sanpete Valley, Sanpete County, is a rural area in central Utah (figure 1) experiencing an increase in residential development. Most of this development is on unconsolidated deposits of the principal valley-fill aquifer, the most important source of drinking water for Sanpete County, and much of it uses septic tank soil-absorption systems for wastewater disposal. Local government officials in Sanpete County have expressed concern about the potential impact that development may have on ground-water quality, particularly development that uses septic tank soil-absorption systems for wastewater disposal. Local government officials would like a scientific basis for determining recommended densities for septic-tank systems as a land-use planning tool.

Purpose and Scope

The purpose of our study is to use a 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 valley-fill aquifer, and thereby recommend appropriate septic-system-density requirements. 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 used here, 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. This will provide land-use planners with a tool to use in approving new development in a manner that will be protective of ground-water quality.

We collected and analyzed ground-water samples for nitrate (nitrate as nitrogen) from 443 water wells (appendix) during the summer and autumn of 1996 and spring of 1997 as part of a previous study (Lowe and others, 2002) to determine sources of nitrate in ground water in Sanpete and Arapien Valleys; we used data from 340 of those wells (plate 1) for this study. We used the Groundwater Modeling System, applied to a regional, three-dimensional, steady-state MODFLOW model, to estimate ground-water flow available for mixing in the principal valley-fill aquifer. Using the nitrate data and the ground-water flow available for mixing, we performed mass-balance calculations to provide septic-tank system density recommendations.

Well Numbering System

The numbering system for wells in this study (appendix) is based on the federal government cadastral land-survey system that divides Utah into four quadrants (A-D) separated by the Salt Lake Base Line and Meridian (figure 2). The study

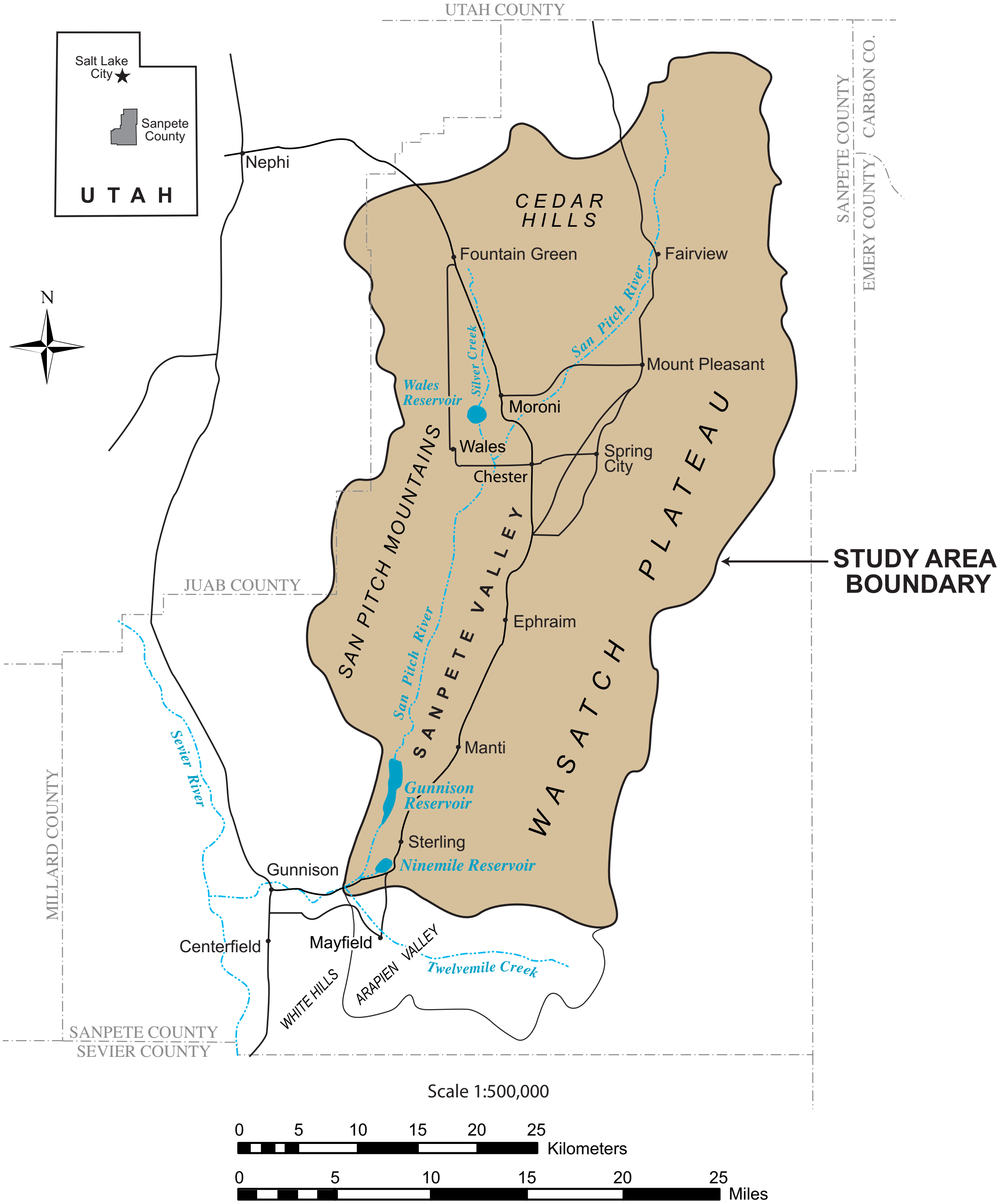


__Figure 1__. Sanpete Valley study area.

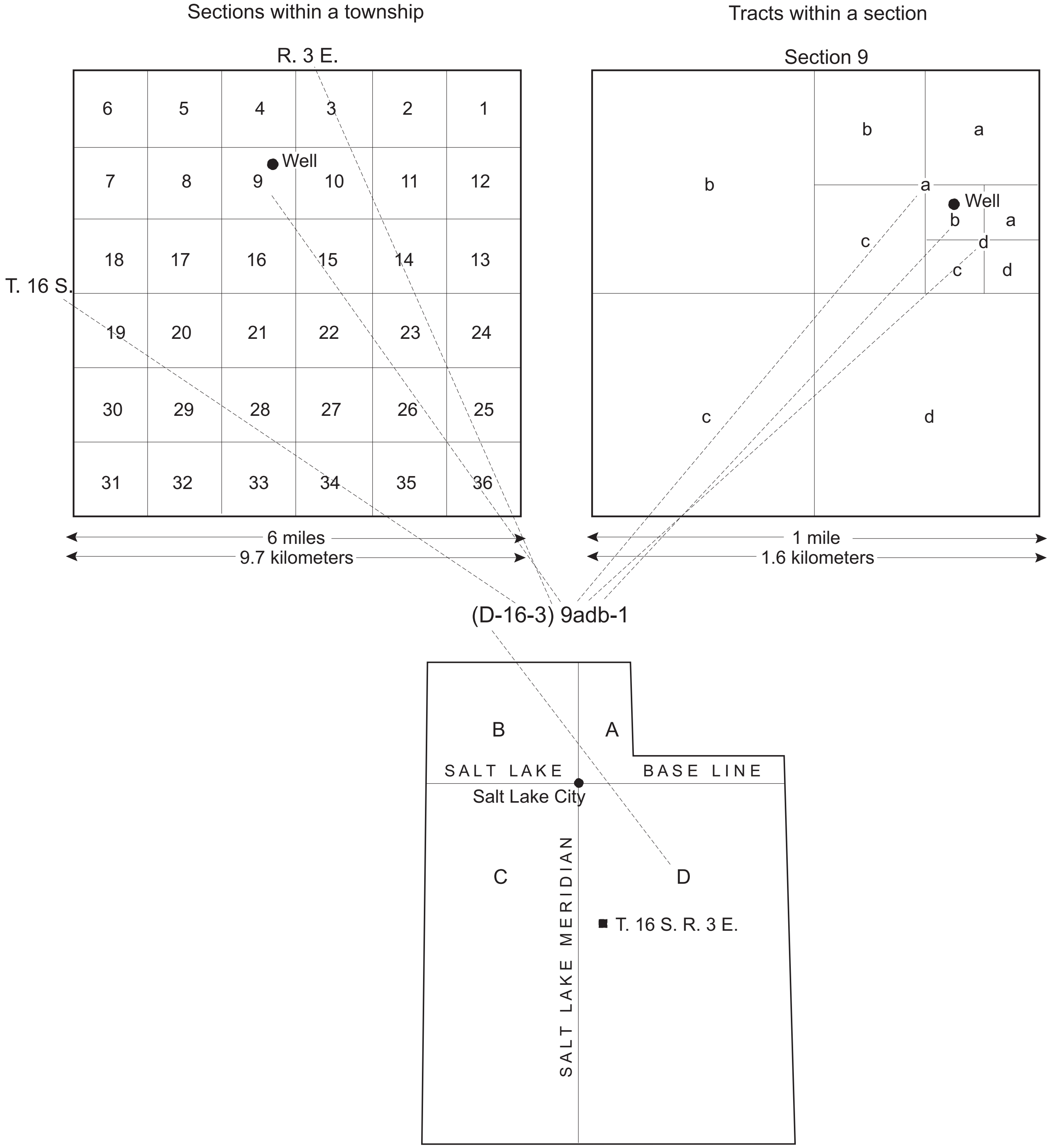


Figure 2. *Numbering system for wells in Utah (see text for additional explanation).*

area is entirely within the southeastern quadrant (D). The wells are numbered with this quadrant letter D, followed by township and range, enclosed in parentheses. The next set of characters indicates the section, quarter section, quarter-quarter section, and quarter-quarter-quarter section designated by letters a through d, indicating the northeastern, northwestern, southwestern, and southeastern quadrants, respectively. A number after the hyphen corresponds to an individual well within a quarter-quarter-quarter section. For example, the well (D-16-3)9adb-1 is the first well in the northwest quarter of the southeastern quarter of the northeastern quarter of section 9, Township 16 South, Range 3 East (NW¼ SE¼NE¼ section 9, T. 16 S., R. 3 E.).

Location and Geography

Sanpete Valley is in central Sanpete County (figure 1), central Utah, about 90 miles (150 km) south of Salt Lake City. Sanpete Valley is a north-south-trending, Y-shaped valley bordered on the east by the Wasatch Plateau, which reaches elevations at the drainage divide of more than 11,000 feet (3350 m), and on the west by the San Pitch Mountains (also known as the Gunnison Plateau), which reach a maximum elevation of about 9700 feet (3000 m). The valley is divided in the north by the Cedar Hills, which form the center of the Y and reach a maximum elevation of about 8300 feet (2530 m). Sanpete Valley is about 40 miles (60 km) long and up to 13 miles (21 km) wide. The valley floor has an area of about 240 square miles (620 km^2); it ranges in elevation from 7400 feet (2260 m) near the northern end of the eastern arm and 6300 feet (1920 m) at the northern end of the western arm to about 5240 feet (1600 m) in the southeastern end of the study area about 2 miles (3.2 km) southeast of Ninemile Reservoir.

The study area includes most of the 240 square-mile (620 km^2) valley floor in the lower part of the San Pitch River drainage basin (figure 1). The headwaters of the San Pitch River, the largest tributary of the Sevier River (Woolley, 1947), are in the eastern arm of Sanpete Valley. South of Moroni, the San Pitch River is joined by Silver Creek, an intermittent stream that drains the western arm of the valley. The San Pitch River flows south through Sanpete Valley to Gunnison Reservoir, where the valley narrows, and then into the Sevier River west of Gunnison, Utah.

Population and Land Use

Sanpete Valley is a rural area experiencing moderate population growth resulting in increased residential development; much of the existing and future development uses septic tank soil-absorption systems for wastewater disposal, though some areas are connected to sewers and maintain sewage lagoons. Sanpete County had a July 2005 population estimate of 25,454 (Demographic and Economic Analysis Section, 2006). Population is projected to grow another 1 percent annually over the next 20 years; by 2020 the population of Sanpete County is expected to reach 28,177 (Demographic and Economic Analysis Section, 2000).

Government and non-farm proprietors (private business owners) have provided most employment in Sanpete County throughout the past decade (Utah Governor's Office of Planning and Budget, unpublished data reported in Utah Division of Water Resources, 1999). Trade replaced agriculture as the third-largest employment provider in the county between 1994 and 1997; agriculture is expected to fall below the service industry in terms of number of employees by 2020 (Utah Governor's Office of Planning and Budget, unpublished data reported in Utah Division of Water Resources, 1999). Although employment in agriculture and the number of farms is decreasing, agricultural commodity production is expected to remain an important part of Sanpete County's economy.

Climate

Climate in the San Pitch River drainage basin ranges from semiarid in Sanpete Valley to subhumid in the surrounding uplands (Robinson, 1971). Only three weather stations in the study area record both temperature and precipitation: Moroni, Ephraim Sorensons Field, and Manti (Ashcroft and others, 1992). The area is characterized by large seasonal and daily temperature variations, especially during the summer (Robinson, 1971). Temperatures reach a normal maximum of 89.4°F (31.9°C) and a normal minimum of 9.8°F (-12.3°C), both recorded at the Moroni station; the normal mean monthly temperature ranges from 71.6°F (22.0°C) at Ephraim in July to 22.7°F (-5.2°C) at Moroni in January (Ashcroft and others, 1992). The average number of frost-free days in Sanpete Valley ranges from 103 at Moroni to 127 at Manti (Ashcroft and others, 1992).

Most of the precipitation in the San Pitch River drainage basin falls as snow in the mountains, particularly the Wasatch Plateau (figure 3), from November to April (Robinson, 1971). The months of June through August are generally the driest, although brief, intense thunderstorms can locally produce large precipitation totals (Robinson, 1971). Normal annual precipitation in the valley ranges from 9.85 inches (25.02 cm) in Moroni to 13.74 inches (34.89 cm) in Manti (Ashcroft and others, 1992). At elevations above 8000 feet (2500 m), the Wasatch Plateau receives an average of 24 inches (60 cm) of precipitation annually (normal climatic information is not available) (Ashcroft and others, 1992).

Normal annual evapotranspiration in Sanpete Valley ranges from 48.54 inches (123.29 cm) in Moroni to 45.62 inches (115.87 cm) in Ephraim (Ashcroft and others, 1992). Robinson (1971) noted that average annual evaporation in the San Pitch River drainage basin is 3.5 times greater than average annual precipitation; the ratio of normal annual evapotranspiration to normal annual precipitation ranges from 4.9 times at Moroni to 3.3 times at Manti, with an average for the three weather stations of 4.0 times.

Based on climatic data, most ground-water recharge from precipitation likely occurs along the Wasatch Plateau on the eastern margin of Sanpete Valley. Ground-water recharge from precipitation falling directly on the valley floor is likely highest in the northeast arm of Sanpete Valley (figure 3).

PREVIOUS INVESTIGATIONS

Richardson (1907) performed an early reconnaissance of ground-water resources in Sanpete Valley. Robinson (1968,

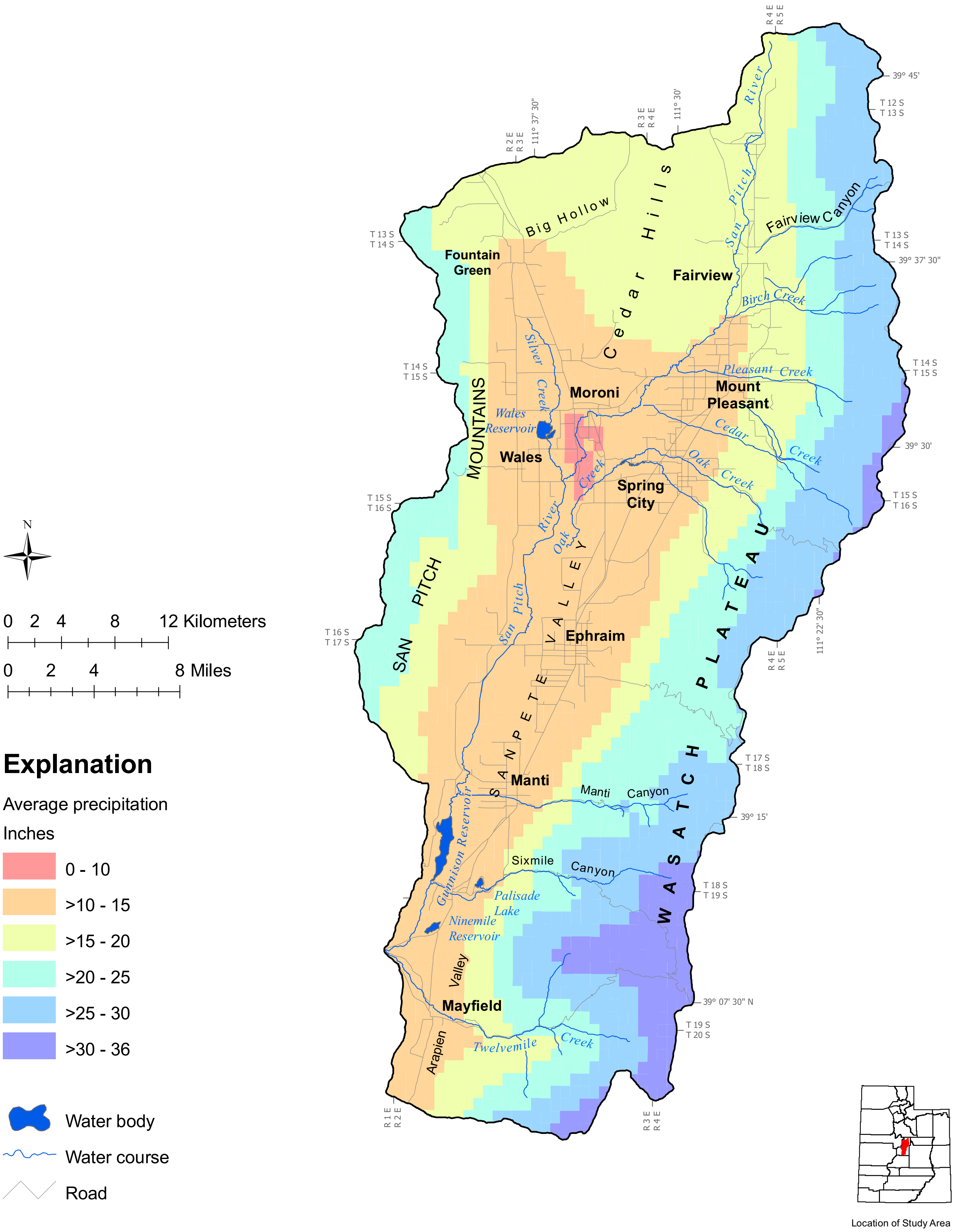


Figure 3. *Average annual precipitation for Sanpete Valley on a grided base. Data from the Utah Climate Center (1991) and Jensen and Dansereau (2001).*

1971) performed the first comprehensive assessment of ground-water resources in Sanpete Valley. Wilberg and Heilweil (1995) produced a ground-water flow model for Sanpete Valley. Horns (1995) studied nitrate contamination in the Moroni area, especially as it applied to siting of a public water-supply well. Snyder and Lowe (1996, 1998) mapped recharge and discharge areas for the principal valley-fill aquifers in Sanpete and Arapien Valleys. Wallace and Lowe (1997) mapped ground-water quality for the valley-fill aquifer in Sanpete and Arapien Valleys. Lowe and others (1999) evaluated the relationship of ground-water quality to ground-water recharge and discharge areas for several valley-fill aquifers in Utah, including Sanpete and Arapien Valleys. Lowe and others (2002) evaluated the water quality of the principal aquifer in Sanpete and Arapien Valleys, with emphasis on possible sources for existing nitrate in ground water; Wallace and Lowe (2005) used these data to petition the Utah Water Quality Board for ground-water quality classification for the principal aquifer in Sanpete and Arapien Valleys.

GEOLOGIC SETTING

General

The San Pitch River drainage basin is in the Basin and Range-Colorado Plateau transition zone (Stokes, 1977), which contains features characteristic of both the Basin and Range and Colorado Plateau physiographic provinces. Spieker (1946) described these features well, as follows:

> The eastern margin of the [Wasatch] plateau is a sweeping stretch of barren sandstone cliffs, a southward continuation of the Book Cliffs, surmounted by higher tabular masses, in all of which the strata dip at low angles and are essentially parallel, in the general habit of the Colorado Plateaus [sic]. On the western margin the strata plunge toward Sanpete and Sevier Valleys in the great Wasatch monocline, at the base of which the structure is complex and a variously deformed rock succession is broken by several angular unconformities; the geologic features here are typical of the Great Basin, and their eastern limit follows in a general way the western border of the plateau.

Stratigraphy

Stratigraphic units exposed in the Sanpete Valley area range from Jurassic to Quaternary in age. The general distribution of rock units is shown in figure 4. The San Pitch Mountains and Wasatch Plateau both consist of Jurassic to Tertiary sedimentary rocks. Tertiary limestone and mudstone cap both ranges. Cretaceous sandstones and conglomerates are steeply tilted on the east side of Sanpete Valley and unconformably underlie Tertiary rocks that are folded as a monocline in the Wasatch Plateau; these Cretaceous and Tertiary rocks form a syncline in the San Pitch Mountains. Underlying the Cretaceous units are the Jurassic Twist Gulch Formation and Arapien Shale; the Arapien Shale contains evaporite deposits (Wilberg and Heilweil, 1995). The Cedar Hills consist of the Tertiary volcaniclastic and pyroclastic Moroni Formation, mostly tuff and andesite (Witkind and Weiss, 1991). Consolidated rocks have a maximum combined thickness of more than 29,000 feet (9000 m).

Unconsolidated valley-fill deposits are at least 500 feet (150 m) thick in Sanpete Valley along the western margin (Robinson, 1971; Lawton and others, 1997). On the east side of the valley, between Ephraim and Manti, the valley fill may be up to 400 feet (120 m) thick, but generally ranges from 200 to 350 feet (60-110 m) thick and thins to 100 feet (30 m) or less in the southern end of the valley (Wilberg and Heilweil, 1995). The valley fill is predominantly fluvial and alluvial-fan deposits consisting mainly of poorly sorted gravel and gravelly sand, and, locally, sand and sandy silt, intermixed with silt and clay. The valley-fill deposits generally fine toward the valley center.

Structure

Sanpete Valley is bounded on the east by the Wasatch monocline, a 50-mile- (80 km) long structure along which strata dip to the west below Sanpete Valley from their near-horizontal dip atop the Wasatch Plateau, and become less steep beneath Sanpete Valley alluvium (Spieker, 1949a). The westward-facing downwarp of the Wasatch monocline is disrupted at many locations by north- and northeast-striking normal faults, which are commonly paired to form long, narrow grabens (Witkind and others, 1987). The strike of the monocline ranges from N. 20° E. to N. 30° E., and the flank dips range from 25 to 45 degrees (Spieker, 1949a). Westward-flowing consequent streams cut the tilted beds on the Wasatch monocline to form deep, sinuous canyons extending eastward into the Wasatch Plateau (Witkind and others, 1987). Along the base of the monocline is a narrow belt of Tertiary rocks that have been folded into a tilted Z-shaped sequence cut by several syngenetic faults, all likely the result of one or more thrusting events (Spieker, 1949a, 1949b).

The San Pitch Mountains, a north-south-trending, oval-shaped upland composed of sedimentary rocks that have been folded to form a southward-plunging syncline, is completely surrounded by valley lowlands (Witkind and others, 1987). The mountains are imprinted with two synforms that are part of the Gunnison thrust system: (1) a shallow, moderately closed, northward-trending synform in Tertiary strata, and (2) a deeper synform along the eastern front of the plateau, having an overturned eastern limb and consisting mostly of Jurassic and Cretaceous strata (Weiss and Sprinkel, 2000). Along the eastern margin of the San Pitch Mountains, the strata are intensely deformed into a gigantic Z-shaped structure (Gilliland, 1952). Several north-trending grabens (Witkind and others, 1987) interspersed in a complex zone of imbricate reverse faults characterize the southeastern margin of the mountains (Weiss and Sprinkel, 2000). To the north, the mountains are less faulted, and are marked by steep cliffs rising high above the adjacent valley floors (Witkind and others, 1987). Lawton (1985) and Lawton and others (1997) mapped thrust faults along the northeastern base of the San Pitch Mountains, emphasizing their most distinctive feature —a series of synorogenic, predominantly clastic deposits which record the foreland-breaking sequence of thrust deformation largely responsible for most structures in central Utah.

The Sanpete-Sevier anticline, a 65- to 70-mile- (100-110

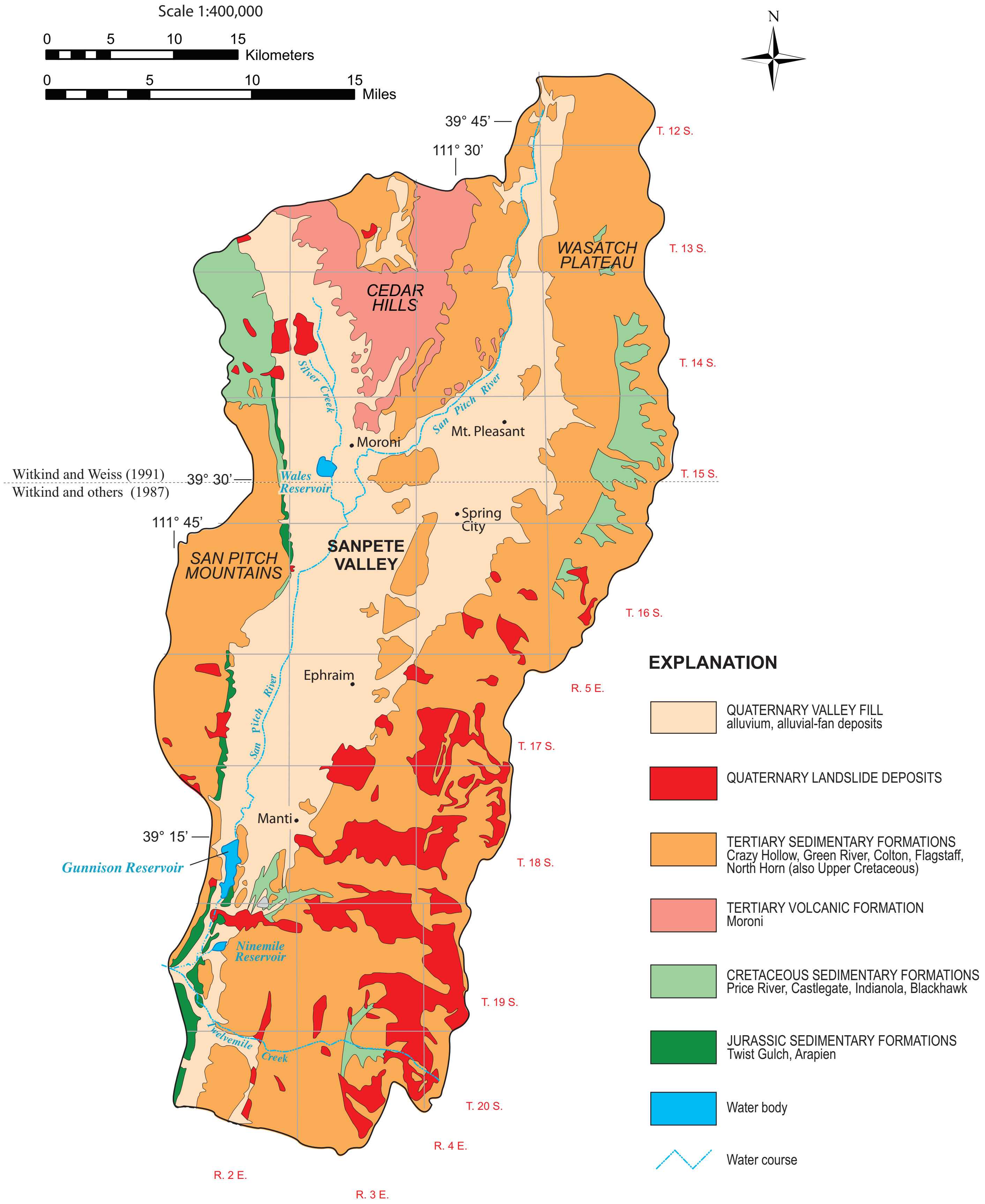


Figure 4. *Simplified geology and sources of geologic mapping for Sanpete Valley.*

km) long, sinuous antiform with structural relief of up to 20,000 feet (6100 m), underlies the Sanpete Valley alluvial fill (Gilliland, 1963); it is interpreted to be a large fault-propagation fold (Weiss and Sprinkel, 2000). The Sanpete Valley block has been down-dropped along its western margin by the Gunnison fault zone (Weiss, 1982; Hecker, 1993), which may have been active within the last 370 years (Fong, 1991). The structural relief on the Gunnison fault zone is greatest along the northern end of the San Pitch Mountains, and is as much as 4400 feet (1350 m) near Wales; the magnitude of displacement on the Gunnison fault zone decreases to zero at the south end of the mountains (Lawton, 1985; Weiss and Sprinkel, 2000). Local diapirism has modified structures in several places in Sanpete Valley (Weiss and Sprinkel, 2000), especially in the south where the Arapien Shale is exposed along the western valley margins.

GROUND-WATER CONDITIONS

Occurrence

Ground water in the Sanpete Valley area is obtained principally from unconsolidated deposits of the valley-fill aquifer (Wilberg and Heilweil, 1995). Ground water in the valley-fill aquifer of Sanpete Valley occurs under confined and unconfined conditions in unconsolidated deposits (figure 5) (Robinson, 1971). In areas where the principal valley-fill aquifer is under confined conditions, it is generally overlain by a shallow unconfined aquifer (figure 5).

The valley fill consists primarily of interfingered layers of clay, silt, sand, and gravel.

Sediments are generally coarser grained in alluvial fans along the mountain fronts and finer grained in the central portions of the valley.

Areas with confining layers thicker than 20 feet (6 m) and an upward ground-water gradient are called discharge areas, and may contain artesian wells (figure 7) (Anderson and others, 1994). The Sanpete Valley discharge area follows the lowlands along the San Pitch River from west of Mount Pleasant to Gunnison Reservoir, and along Silver Creek in the northwestern arm (figures 5, 7) (Snyder and Lowe, 1998). Secondary recharge areas are where confining layers are thicker than 20 feet (6 m) and the ground-water gradient is downward (figure 6) (Anderson and others, 1994). Fine-grained sediments in alluvial-fan deposits form a band of secondary recharge areas along the eastern edge of southern Sanpete Valley; along the northern San Pitch Mountains, alluvial-fan deposits are coarser than those on the eastern side of the valley, and secondary recharge areas are present only near the distal ends of alluvial fans (figures 5, 7) (Snyder and Lowe, 1998).

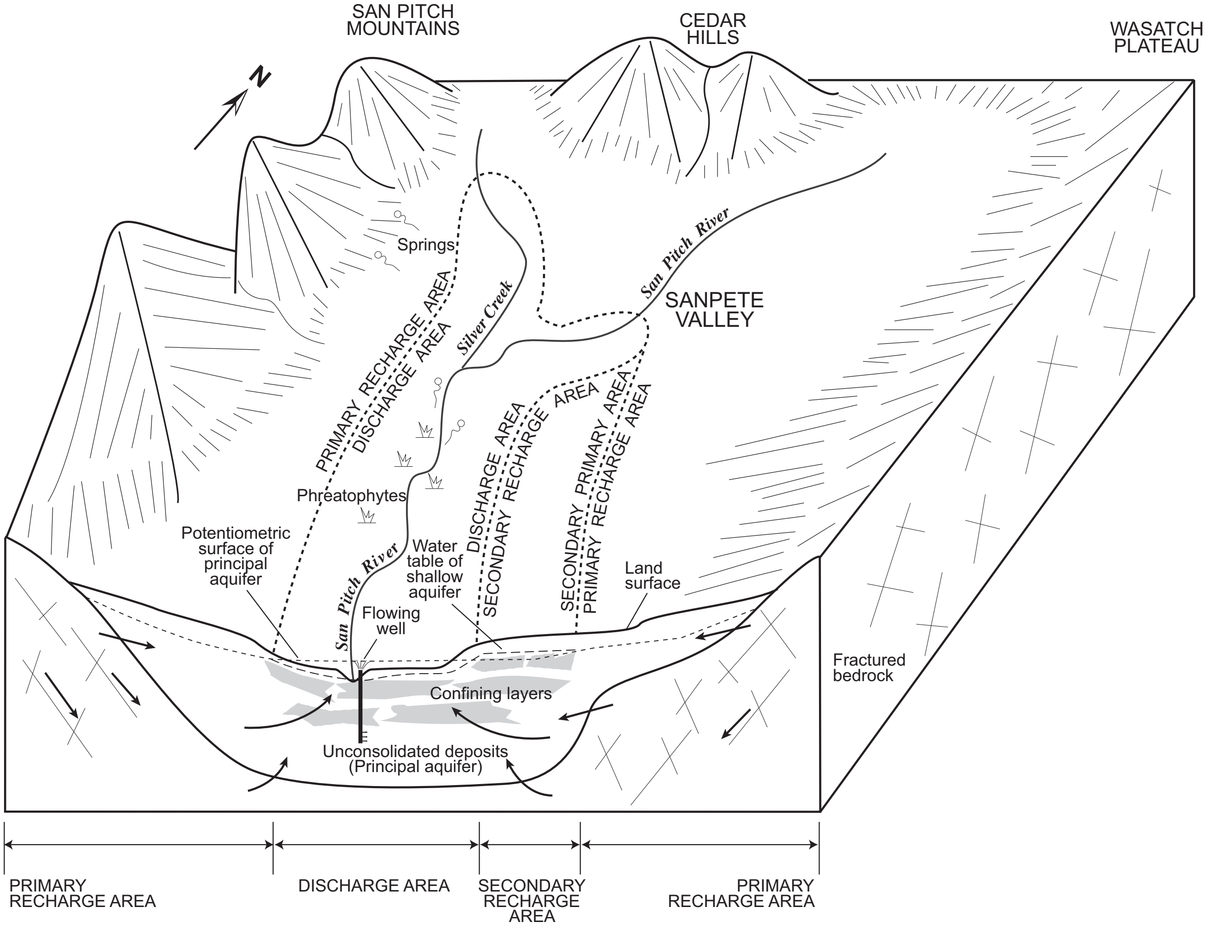


Figure 5. *Schematic block diagram showing recharge areas and direction of ground-water flow (arrows) in Sanpete Valley (from Snyder and Lowe, 1998).*

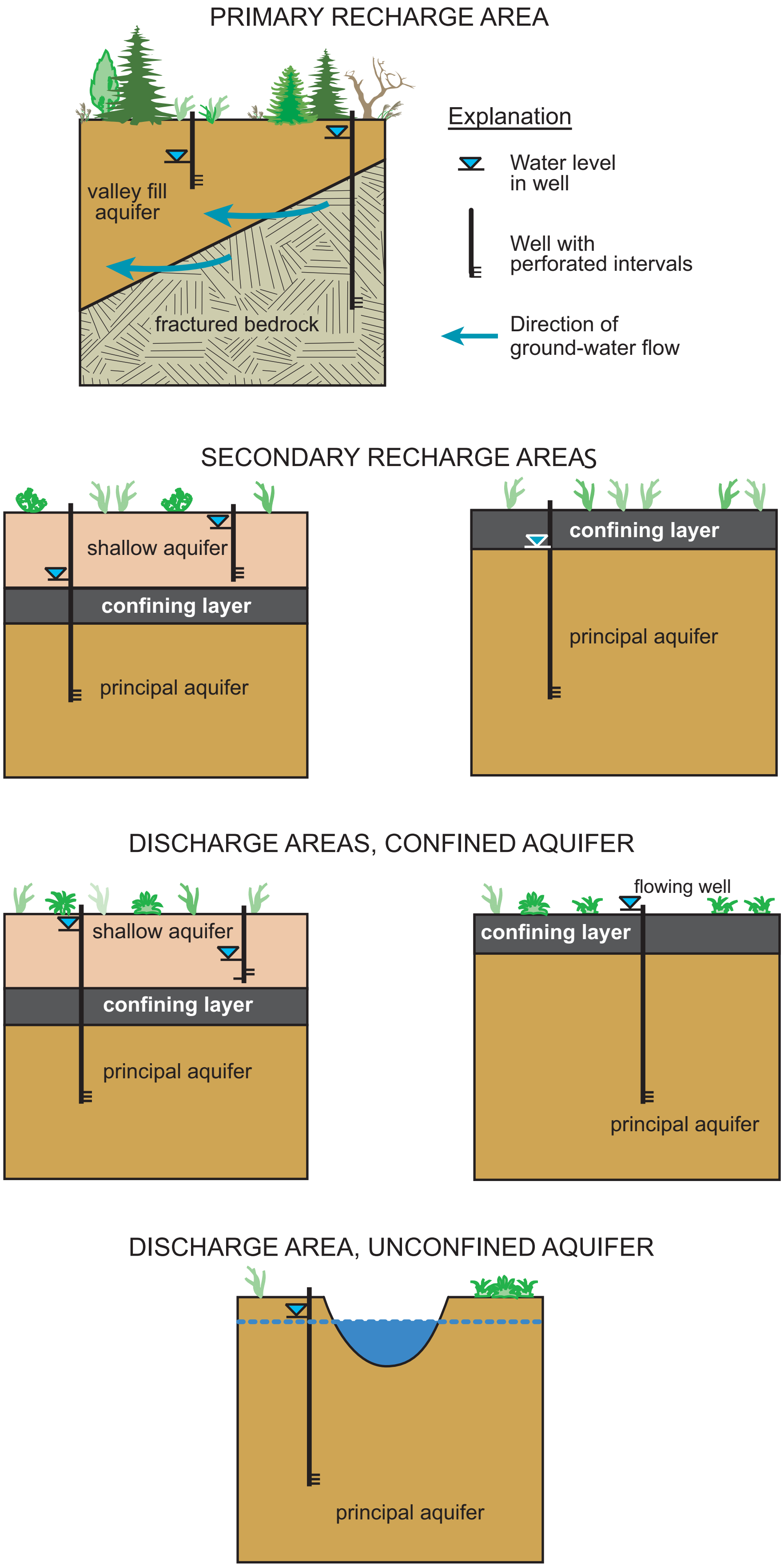


Figure 6. *Relative water levels in wells in recharge and discharge areas (modified from Snyder and Lowe, 1998).*

Figure 7. Recharge areas in Sanpete Valley (after Snyder and Lowe, 1998).

Primary recharge areas have no confining layers and a downward component of ground-water flow, and typically follow the valley margins, especially on alluvial fans (figures 5, 6, and 7). Unconfined conditions exist in the northeastern arm of Sanpete Valley, north of Fairview, where coarse-grained material predominates, and along the base of the Wasatch Plateau on the eastern side of Sanpete Valley. Along the western side of Sanpete Valley, the valley-fill aquifer is unconfined only in a narrow band. Because of the lack of thick (20 feet [6 m]), protective clay layers, these primary recharge areas are vulnerable to surface sources of ground-water contamination (Lowe and Snyder, 1996).

Streams are the main source of recharge to the basin-fill aquifer, with the majority located in the upper portions of the highly permeable alluvial-fan deposits at the mouths of canyons along the margins of the valley (Robinson, 1971). Most of the recharge from surface water is from perennial streams flowing from the Wasatch Plateau on the east side of Sanpete Valley, although the many smaller drainages entering the valley from the San Pitch Mountains on the west contribute some intermittent recharge (Wilberg and Heilweil, 1995), especially after snowmelt or during major precipitation events. Estimated surface-water recharge from streams and springs to the San Pitch River drainage basin is about 116,000 acre-feet per year (143 hm^3/yr), with approximately 54,000 acre-feet (67 hm^3) of surface water leaving the drainage basin annually (Robinson, 1971). Most surface-water inflow is diverted for irrigation purposes; recharge to the valley-fill aquifer from streams is estimated between 30,000 and 58,800 acre-feet per year (37 and 72.5 hm^3/yr) (table 1) (Wilberg and Heilweil, 1995).

Excess irrigation water, either diverted from streams or pumped from wells, is also an important source of recharge to the valley-fill aquifer, especially along the valley margins where unconsolidated deposits are more permeable (Robinson, 1971). About 116,900 acre-feet per year (144 hm^3/yr) of water is used for irrigation in Sanpete Valley above Gunnison Reservoir; about 29,000 acre-feet per year (36 hm^3/yr) of unconsumed irrigation water recharges the valley-fill aquifer (table 1) (Wilberg and Heilweil, 1995).

Subsurface inflow from fractured-rock units surrounding the San Pitch River drainage basin may contribute a relatively small amount of recharge to the valley-fill aquifer in Sanpete Valley. For example, the southeast-dipping Indianola Group in the northern San Pitch Mountains conveys a “sizable” quantity of water into Sanpete Valley from the Juab Valley drainage basin to the west (Bjorklund and Robinson, 1968, p. 40; Robinson, 1971, p. 21). However, Wilberg and Heilweil (1995) considered flow from fractured-rock units as minimal, and primarily providing discharge to springs and streams above the valley-fill/fractured rock contact; the ground-water budget in table 1 reflects this hypothesis.

Ground water is discharged from the valley-fill aquifer by evapotranspiration, seepage to the San Pitch River, wells, and alluvial-spring discharge (Wilberg and Heilweil, 1995). Much of the discharge from seepage to the San Pitch River and the alluvial-spring discharge likely contributed to the 54,000 acre-feet per year (67 hm^3/yr) surface flow out of the San Pitch River drainage basin as estimated by Robinson (1971). The average annual discharge from the valley-fill aquifer above Gunnison Reservoir ranges from 76,000 to 224,000 acre-feet per year (94-275 hm^3/yr) (Wilberg and Heilweil, 1995).

Evapotranspiration is about 41,000 to 116,000 acre-feet per year (50.6-143 hm^3/yr) of annual average discharge (table 1) (Wilberg and Heilweil, 1995). Robinson (1971) estimated that phreatophytes, principally saltgrass, wiregrass, greasewood, and rabbitbrush, covered about 45,200 acres (18,300 hm^2) of land in Sanpete Valley in the mid-1960s; they grew mostly southwest of Manti, where Sanpete Valley narrows and is constrained by bedrock outcrops that impede most ground-water flow out of the valley. In this

Table 1. *Components of the ground-water budget for the valley-fill aquifer in Sanpete Valley (from Wilberg and Heilweil, 1995).*

Component	Measured or estimated (acre-feet per year)	Steady-state calibration (acre-feet per year)
Recharge		
Seepage from tributaries	28,500-57,000	34,500
Infiltration of unconsumed irrigation water	29,000	29,000
Infiltration of precipitation on the valley floor	15,000	15,000
Seepage from the San Pitch River	1,500-1,800	400
Subsurface inflow from head-dependent cells	unknown	200
Total recharge (rounded)	74,000 - 102,800	79,100
Discharge		
Evapotranspiration	41,000-116,000	48,000
Seepage to the San Pitch River	18,500-80,300	17,200
Withdrawals from wells	5,200-16,800	10,300
Withdrawals from springs	11,000	3,600
Total discharge (rounded)	76,000 - 224,000	79,100

area, confined ground water is forced to the surface and forms a large marshy area extending as far north as Manti, about 2 miles (3.2 km) north of the north end of Gunnison Reservoir (Snyder and Lowe, 1998). This marshy area once extended to near Ephraim, about 6 miles (10 km) farther north (Robinson, 1971). Phreatophytes currently cover about 21,400 acres (8,700 hm^2). However, Wilberg and Heilweil (1995) consider the approximately 24,600 acres (10,000 hm^2) of irrigated pasture and grass hay categories to be generally phreatophytic.

Robinson (1971) conducted seepage runs (multiple water-flow measurements along a stream stretch to obtain an estimate of recharge to or discharge from ground water) on the San Pitch River in 1966 and determined that the major areas of surface-water gain from ground water were located just north of Fairview, west of Mount Pleasant to Moroni, above the bridge west of Ephraim, and within a phreatophyte patch north of Gunnison Reservoir. During 1988 seepage runs between Milburn and Gunnison Reservoir, most ground water discharged to the San Pitch River in the reach just south of Milburn to near Moroni (Sandberg and Smith, 1995). Ground-water discharge to the San Pitch River is estimated to be from 18,500 to 80,300 acre-feet per year (23-99 hm^3/yr) (Wilberg and Heilweil, 1995).

Ground-water discharge to wells is discussed above in the Well Yields section. Discharge from the valley-fill aquifer is about 4,000 acre-feet per year (5 hm^3/yr) from flowing wells and ranges from 1,200 to 12,800 acre-feet per year (1.5-16 hm^3/yr) from pumped wells (table 1) (Wilberg and Heilweil, 1995).

Robinson (1968, table 2) reported discharge from springs issuing from Quaternary alluvium scattered through Sanpete Valley. Wilberg and Heilweil (1995) estimate discharge from these springs to be about 11,000 acre-feet per year (13.6 hm^3/yr).

The potentiometric surface (figure 8) in the valley-fill aquifer is irregular and depends on the well depth, season, and the year water-level measurements are made (Robinson, 1971). The potentiometric surface generally conforms to the contour of the valley floor, and is steepest along the eastern valley margins near the mouths of canyons, and in the northwestern and northeastern arms of Sanpete Valley. The steeper hydraulic gradient in these primary recharge areas (figure 7), characterized by predominately coarse-grained valley-fill material, indicates greater ground-water recharge due to seepage from steams, and, to a lesser extent, greater amounts of recharge from direct precipitation on the valley floor (figure 3).

Ground-water flow is generally from higher elevation recharge areas to lower elevation discharge areas. In Sanpete Valley, ground water generally flows westward from the Wasatch Plateau and eastward from the San Pitch Mountains toward the San Pitch River and Silver Creek, and then southward toward Gunnison Reservoir.

Ground-Water Quality

Ground-water quality in Sanpete Valley's principal valley-fill aquifer is generally good and suitable for most uses. Ground water in the valley-fill aquifer is generally a mixed type containing calcium, sodium, magnesium, and bicarbonate ions; however, water from many wells, especially shallow ones on the west side of the valley, is a mixed type containing magnesium, sodium, sulfate, and chloride ions (Wilberg and Heilweil, 1995).

Lowe and others (2002) collected ground-water samples from 443 wells during the summer and autumn of 1996 and spring of 1997 to evaluate total-dissolved-solids (TDS) and nitrate concentrations. The Utah Division of Epidemiology and Laboratory Services performed the chemical analyses on the samples. Ground water from all sample locations was analyzed for the nutrients nitrate, nitrite, ammonia, and phosphate. Of the 443 wells, ground water from 118 wells was analyzed for general chemistry, 107 for dissolved metals, and 49 for organics and pesticides.

Total-dissolved-solids concentrations for wells tested for general chemistry plus 290 wells having converted specific conductance data (Lowe and others, 2002, figure 9) range from 216 to 2752 mg/L (figure 9); the average measured TDS concentration is 503 mg/L (Wallace and Lowe, 2005). Elevated levels of TDS in ground water are largely attributed to proximity to outcrops of the Arapien Shale and the Green River Formation (Lowe and others, 2002).

Nitrate, typically associated with human activities, has been identified in ground water in Sanpete Valley in previous studies. Nitrate concentration exceeding the Utah drinking-water standard (10 mg/L nitrate as nitrogen) was identified in a Moroni public-supply well in the 1990s (Horns, 1995); the well was replaced and taken off line. Nitrate concentrations for ground water in the principal valley-fill aquifer range from 0.02 to 40.2 mg/L, with a background (current average) concentration of 3.3 mg/L (Lowe and others, 2002). Of the water wells analyzed for nitrate, 86.5 percent yielded values less than 5 mg/L, and 3.5 percent exceeded 10 mg/L for nitrate and are considered high-nitrate wells (Lowe and others, 2002).

Utah drinking-water standards were exceeded for lead in two wells, arsenic (pre-2006 standard; the arsenic standard has been lowered [U.S. Environmental Protection Agency, 2006]) in two other wells, and copper in another well (Lowe and others, 2002). Of the 49 water wells tested for pesticides, seven wells yielded water having values above the detection limit, but within Utah drinking-water standards (Wallace and Lowe, 1997; Lowe and others, 2002).

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 and organic nitrogen 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 (U.S. Environmental Protection Agency, 2006). With continued population growth and installation of septic tank soil-absorp-

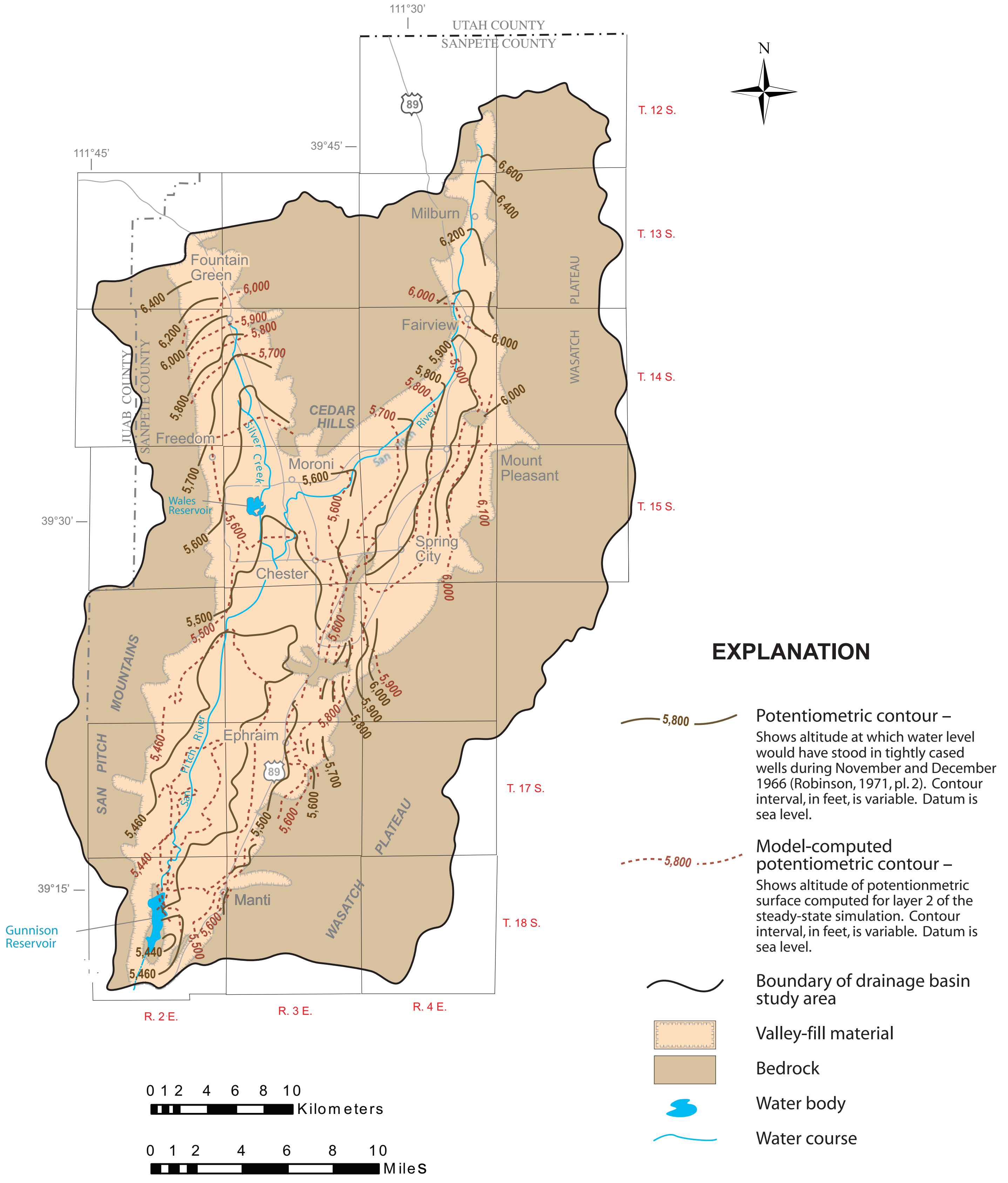


***Figure 8.** Potentiometric contours of measured and model-computed steady-state water levels for the valley-fill aquifer (modified from Wilberg and Heilweil, 1995).*

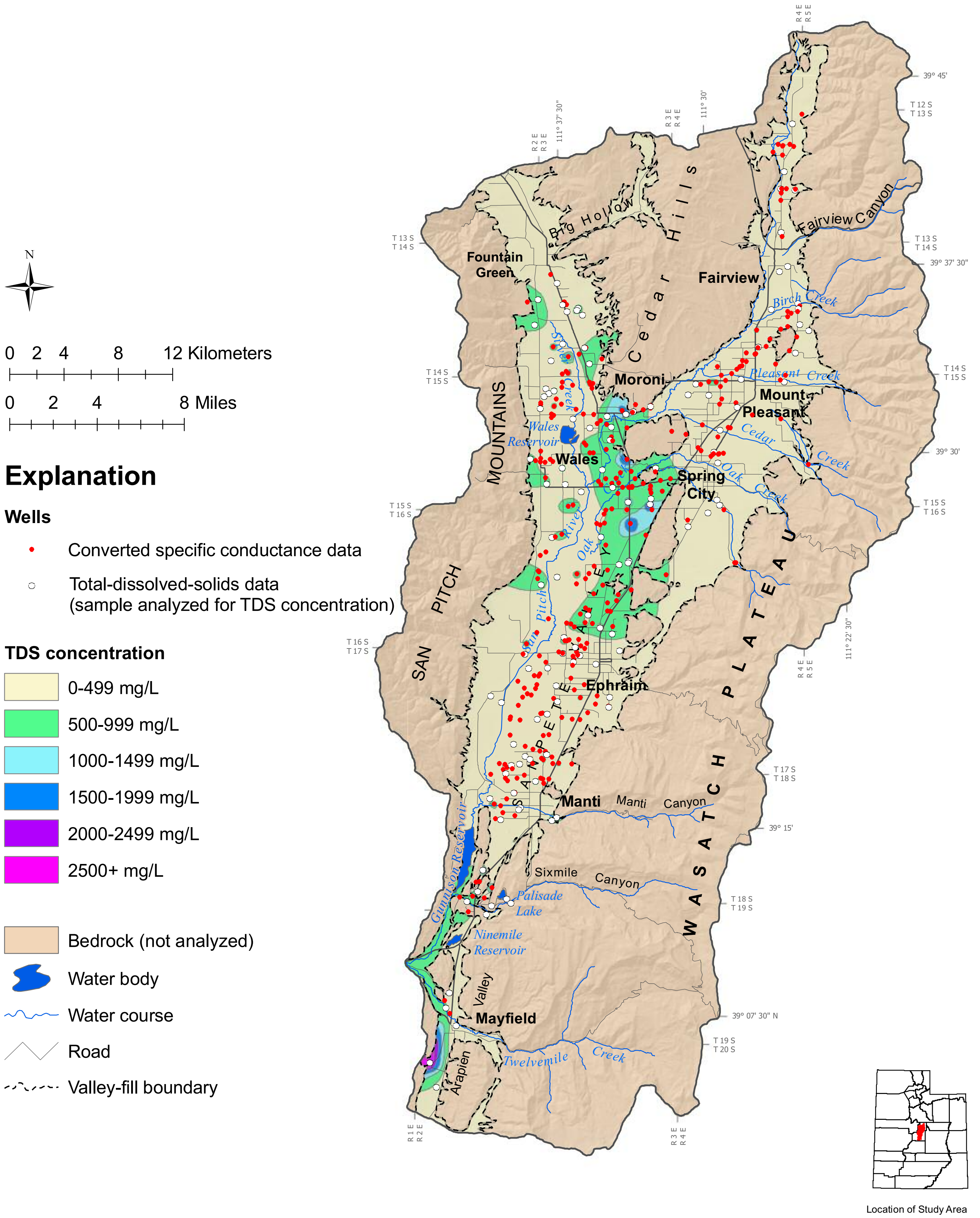


Figure 9. Total-dissolved-solids concentration for the principal valley-fill aquifer, Sanpete Valley (from Lowe and others, 2002).

tion 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, 1999a, 1999b; Wallace and Lowe, 1998a, 1998b, 1998c, 1999; 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 2) 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, 1999c).

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, 1999c). 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, mostly from the human urinary system, are commonly present in wastewater in septic tanks (table 2). Typically, almost all ammonia is converted into nitrate before leaving the septic-tank soil-absorption system drain field. Once nitrate passes below the zone of aerobic bacteria and the roots of plants, there is negligible attenuation as it travels farther through the soil (Franks, 1972). Once in ground water, nitrate becomes mobile and can persist in the environment for a long 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 Sanpete Valley discharges about 230 gallons (870 L) of effluent per day containing nitrogen (or nitrate as nitrogen) concentrations of around 55 mg/L. 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 Sanpete 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 an estimated discharge of 230 gallons (870 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, 2001) by Sanpete County's average 3.27 person household (U.S. Census Bureau, 2006). We used an estimated nitrogen loading of 55 mg/L of effluent per domestic septic tank based on (1) an average 3.27 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) (Andreoli and others, 1979, in Kaplan, 1988, p. 148); this number is close to Bauman and Schafer's (1985, in Kaplan, 1988, p. 147) nitrogen (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 Wilberg and Heilweil's (1995) ground-water flow model.

Table 2. *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

Limitations

Many limitations exist to any mass-balance approach (see, for example, Zhan and McKay, 1998; Wallace and Lowe, 1998a, 1998b, 1998c, 1999; Lowe and others, 2000, 2003). 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 simulation of ground-water flow, 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.
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 believe it is useful in land-use planning because it provides a general basis for making recommendations for septic-tank system densities. In addition, the approach is cost-effective and easily applied with limited information.

Ground-Water Flow Calculations

Introduction

We used the Groundwater Modeling System (Brigham Young University, 2003) applied to Wilberg and Heilweil's (1995) ground-water flow model for the valley-fill aquifer system in Sanpete Valley to estimate ground-water flow for our mass-balance approach assessment. We used Wilberg and Heilweil's (1995) model as it provides the best available representation of ground-water flow in the Sanpete Valley valley-fill aquifer. The model uses water levels and calibrated, measured, and estimated components of a ground-water budget to simulate ground-water flow. Water quality in the upper saturated zone is most affected by the quality of surface recharge, and is the zone with the greatest potential to be impacted by septic-tank systems. We subdivided the modeled area of Sanpete Valley into three domains having different volumetric flow ranges based on cell-to-cell flow characteristics using the steady-state ground-water flow in model layer one, the upper modeled zone.

Description of Wilberg and Heilweil's (1995) Model

Wilberg and Heilweil (1995) used the U.S. Geological Survey's modular three-dimensional, finite-difference, ground-water flow simulator (MODFLOW) (McDonald and Harbaugh, 1988) to test and refine their conceptual understanding of the flow system in Sanpete Valley. Their model discretizes the valley-fill aquifer into a quasi-three-dimensional grid of 80 rows by 40 columns, and three layers (figure 10). The model uses a vertical leakance term between layers, and assumes two-dimensional horizontal flow in the aquifer and one-dimensional vertical flow. The model's rectilinear grid has a uniform grid-cell spacing of 0.5 miles (0.8 km), resulting in a cell area of 0.25 square miles (0.65 km^2). The y-axis of the model is oriented north-south, parallel to the primary surface-water drainages and predominant direction of ground-water flow. The layer one rectilinear grid consists of 896 active cells representing an area of 224 square miles (580 km^2). Layer one represents approximately the upper 50 feet (15 m) of saturated valley-fill material. The steady-state simulation of layer one was used in this report. Layers two and three represent saturated valley-fill material deeper than 50 feet (15 m), and have areas of 174 square miles (451 km^2), and 77 square miles (200 km^2), respectively. Layer two is semi-confined, and layer three is confined.

In the model, recharge of the Sanpete Valley valley-fill aquifer occurs: (1) where perennial streams emerge from canyons to flow across coarse-grained deposits along the margins of the valley, allowing water to infiltrate readily to the underlying ground-water system, (2) where infiltration of unconsumed irrigation water and precipitation occurs, (3) from the upper reaches of the San Pitch River, and (4) from subsurface inflow north of Fairview. Fourteen perennial streams enter the valley and flow toward the San Pitch River; eleven of these are from the Wasatch Plateau and three are from the San Pitch Mountains. These tributaries contribute to the surface and subsurface water supplies. Before the time of large-scale irrigation, infiltration from streams flowing across the alluvial fans adjacent to the Wasatch Plateau was probably the main source of ground water; now the infiltration of unconsumed irrigation water is almost as important (Wilberg and Heilweil, 1995, table 3). Estimated recharge over the modeled area of Sanpete Valley from these sources ranges from 74,000 to 103,000 acre-feet per year (91-127 hm^3/yr) (Wilberg and Heilweil, 1995). Ground-water discharge in the Sanpete Valley model is primarily from (1) evapotranspiration in the marshes and wetlands, (2) seepage to the San Pitch River, and (3) withdrawals from wells and springs. The largest component of ground-water discharge in Sanpete Valley is evapotranspiration. Estimated discharge from the Sanpete Valley aquifer ranges from 76,000 to 224,000 acre-feet per year (94-275 hm^3/yr) (Wilberg and Heilweil, 1995).

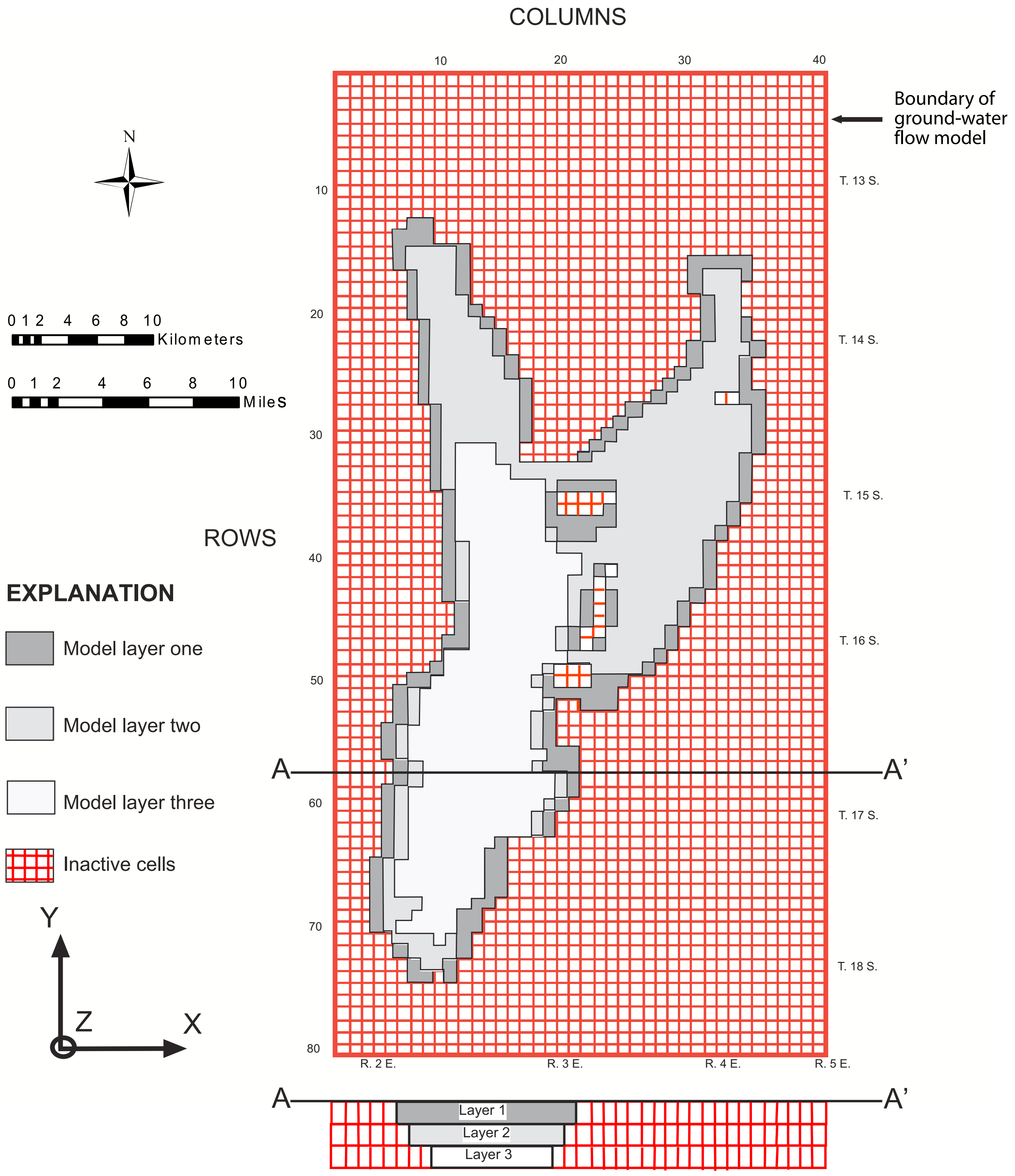


Figure 10. *Orientation and areal extent of the ground-water flow model and active cells within each layer for Sanpete Valley.*

Table 3. *Hydraulic-parameter values used in the Sanpete Valley ground-water flow model (based on data from Wilberg and Heilweil,1995).*

Locations	**Hydraulic conductivity (feet per day)**	**Transmissivity (feet squared per day)**	**Vertical leakance (feet per day per feet)**
Model Layer One			
Active cells around most of the perimeter of valley	2.5 - 10.0	—	—
Interior active cells in the main and arms of valley	15.0 - 50.0	—	—
Active cells around Wales	0.2 - 1.0	—	—
Between layers one and two			1.0 x 10^{-4}
Between layers one and two, where there is spring discharge in layer one			1.0 x 10^{-3}
Model Layer Two			
Active cells in the perimeter of valley	—	100 - 1000	—
Active cells in the center of valley	—	10,000	—
Between layers two and three			1.0 x 10^{-2}
Model Layer Three			
Active cells at some isolated location around the perimeter of valley	—	2000	—
Most of the active cells	—	20,000	—

The active cells in the model represent most of the Sanpete Valley unconsolidated aquifer, including both northern arms, where the Quaternary-age valley-fill thickness exceeds 50 feet (15 m). Inactive cells are not part of the solution, and represent unsaturated sediments or bedrock (which are not modeled). Figure 11 shows the area covered by the ground-water flow model compared to the valley-fill boundary.

Wilberg and Heilweil (1995) estimated hydraulic parameters based on single-well specific-capacity tests, a few multiple-well aquifer tests, and data from Robinson (1971), and assigned these values to the active cells in layers two and three of the model. Hydraulic conductivity values for layers two and three from these sources range from about 6 to 99 feet per day (2-30 m/d). Transmissivity values reported for the valley-fill sediments, used in layers two and three, range from 500 to 16,000 square feet per day (50-1500 m^2/d). No hydraulic conductivity data were available for layer one, and Wilberg and Heilweil (1995) initially used a uniform hydraulic conductivity of 50 feet per day (15 m/d) for layer one.

The steady-state simulation assumes the water flowing into the ground-water system equals the amount flowing out with no change in ground-water storage with time. Wilberg and Heilweil's (1995) calibration of the ground-water flow model was accomplished through a trial and error adjustment of the model's input data to modify the model's output. During the steady-state calibration of the model, input parameters were systematically varied and refined to a non-uniform distribution (table 3); for layer one the distribution of hydraulic conductivity ranges from 0.2 to 50 feet per day (0.06-15 m/d). The initial value of transmissivity used for layers two and three was 10,000 square feet per day (930 m^2/d). Wilberg and Heilweil (1995) subsequently modified these values to a non-uniform distribution, ranging from 100 to 10,000 square feet per day (9-930 m^2/d) for layer two and 2000 to 20,000 square feet per day (186-1860 m^2/d) for layer three. These changes were made to achieve a best fit between simulated and observed data (measured water levels and components of the ground-water budget). Hydraulic conductivities for layer one are lowest along the valley edge and increase basinward, except for an area around the town of Wales, where high hydraulic gradients indicate lower hydraulic conductivities. The vertical leakance used to represent confining units in the model was based on the vertical hydraulic conductivity determined by comparing simulated vertical-head differences between layers.

Wilberg and Heilweil (1995) based boundary conditions for the Sanpete Valley model on a simplified conceptual hydrologic model. They specified the lateral boundaries surrounding the active cells of the model as "no-flow" boundaries by assuming they coincide with low-permeability bedrock, except for five head-dependent cells north of Fairview in layer one, which simulate subsurface inflow from the valley-fill aquifer north of Fairview. The upper boundary of the model is a specified-flux boundary formed by using recharge, well, evapotranspiration, and drain packages of MODFLOW to simulate the infiltration and discharge of ground water. Cells in layer one with spring discharge are also assigned an increased vertical conductance.

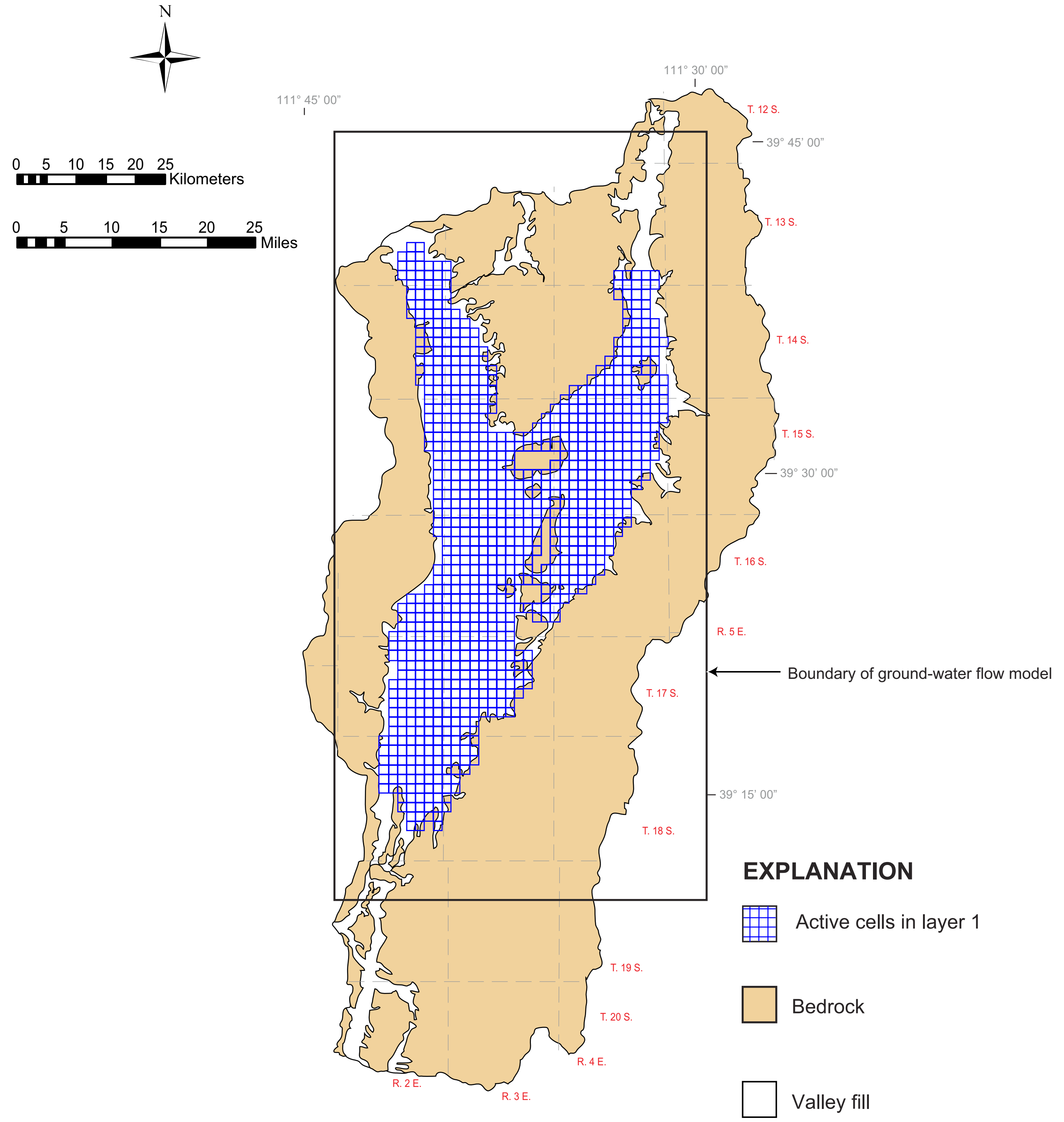


Figure 11. Location of ground-water flow model in relation to the valley-fill boundary. Shown are the active cells of layer one and the boundary for the model of Sanpete Valley (modified from Wilburg and Heilweil, 1995).

Layer one simulates no discharge from wells, only discharge from springs. Most of the water wells in the valley are simulated in model layer two. The lower boundary of the model is a no-flow boundary.

Wilberg and Heilweil (1995) considered the model calibrated because the calculated heads from the calibration approximate observed head values, surface-water flows are simulated within the right order of magnitude, and ground-water flow directions simulated by the model are reasonable. Wilberg and Heilweil (1995) determined that modeled water level, and the water budget are sensitive to changes in hydraulic conductivity for layer one. They also determined the model is sensitive to some of the head-dependent recharge and discharge conditions, such as evapotranspiration rates and river-bed conductance, which mostly affect layer one.

Results

The ground-water flow model used for this study is the best available tool to determine the water available for mixing with septic-tank effluent. Use of the simulation improved our understanding of the aquifer system and provided the volumetric flow budget needed for the septic tank mass-balance calculations. The model simulation provided a ground-water flow budget for the aquifer in relation to aquifer characteristics, water in storage, and volumes and rates of inflow and outflow.

We used a steady-state simulation with time-averaged and measured conditions; thus, the model cannot predict the transient response of the system, because it is not calibrated to transient conditions. This means we cannot use the model to predict flows in the system if new stresses are applied, such as adding a large well, to the system. The model, however, can simulate steady-state conditions and be used to evaluate various ground-water conditions.

Water quality in the upper part of the ground-water system is approximated by the quality of water that enters the system from the surface, and the water that enters the system in the subsurface. The upper part of the ground-water system is where nitrates associated with septic-tank systems are most likely to degrade water quality. In Sanpete Valley, we interpreted the upper part of the ground-water system to be represented by model layer one. This is a zone where uniform and complete mixing of wastewater and available ground water can occur. We used model-calculated cell-by-cell flows in this study to identify areas having similar flows of water in layer one for Sanpete Valley; we assumed mixing/dilution of septic-tank effluent occurs within this layer. Based on the spatial distribution of the cell-by-cell ground-water flow calculated by MODFLOW, we delineated three regions in Sanpete Valley based on flows within layer one (figure 12). We used the MODFLOW flow budget for each region to determine available ground-water flow in layer one for each region. These regions, which we designated as domains 1, 2, and 3, have areas of 56.5, 49, and 84 square miles (146, 127, and 218 km^2), and have average volumetric flows of 187, 83.5, and 138 cubic feet per second (5.29, 2.36, and 3.90 m^3/sec), respectively. We use the volumetric flows in the mass-balance calculations as the ground water available for mixing.

Limitations

Construction of a numerical model of a natural hydrogeologic system requires simplifying assumptions. Based on the simplifying assumptions used to build their regional ground-water flow model, Wilberg and Heilweil (1995) summarized the major limitations as: (1) subsurface inflow from consolidated rock to the valley-fill aquifer was not modeled, and (2) measured data for some hydrologic properties and certain ground-water budget components were not available. These assumptions and limitations reduce the model's scope of application and the hydrologic questions that can reasonably be addressed, and may influence the model results. The numerical model is a simplified and idealized approximation of the actual ground-water flow system; calculations made on the basis of the model may be inaccurate. Uncertainties are also associated with the inherent variability of parameters used in layer one of the model. Some of these parameters were derived during simulation and calibration of the model; others were derived from data for other model layers. Uncertainties within the conceptualized ground-water system for layer one are probably the single largest source of uncertainty in the ground-water flow simulation. Because of these uncertainties, we apply the results of our mass-balance approach using the calculated ground-water flow available for mixing in a conservative (protective of ground-water quality) manner.

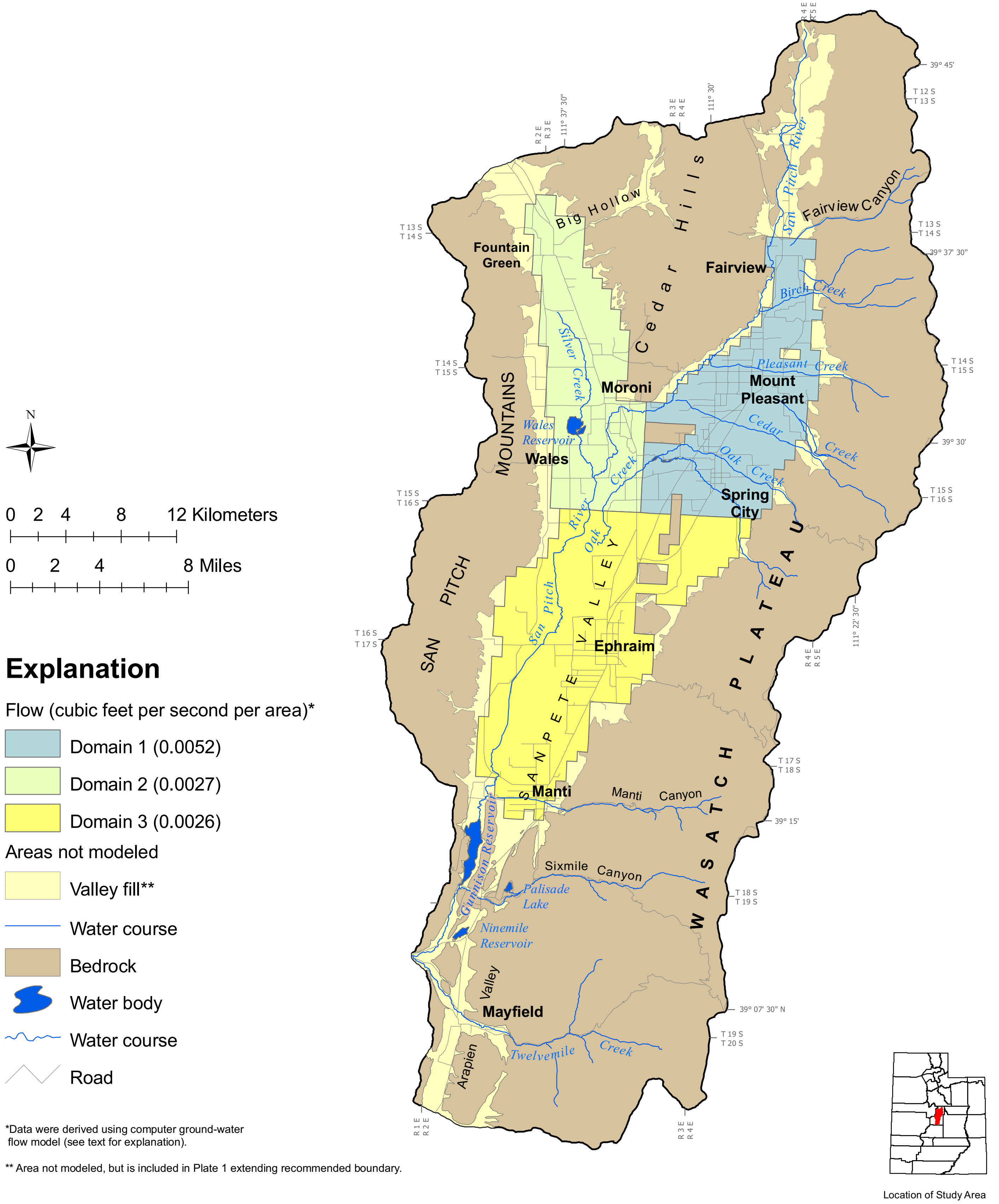
Mass-Balance Analysis

Introduction

We calculated projected domain-specific nitrate concentrations in the three ground-water flow domains (figure 12) by applying a mass-balance approach using domain-specific parameters–the existing nitrogen load (background nitrate concentration) and amount of ground water available for mixing (tables 4, 5), and our estimated 230 gallons per day (870 L/day) contributed by each septic-tank system, with an estimated nitrogen loading of 55 milligrams per liter of septic-tank effluent. The mass-balance approach predicts the impact of nitrate from use of septic-tank systems over a defined area.

We calculated one graph for each domain based on a range of parameters that affect the amount of ground water available for dilution. We obtained the number of septic-tank systems in each area by digitizing buildings representing homes in each domain from aerial photography; this digitized coverage was verified for accuracy by the Central Utah Health Department (George Johansen, written communication, March 2006). Tables 4 and 5 list the number of septic-tank systems estimated for each domain.

For this analysis, we used 732 septic tanks valley-wide; septic tanks for each domain range from a low of 125 (domain 2) to a high of 431 (domain 1) (tables 4 and 5). Background nitrate concentrations for each domain range from 2.3 mg/L (domain 3) to 3.4 mg/L (domain 2). For our mass-balance calculations, we allow a 1 mg/L degradation above current background levels of nitrate (a value adopted by Wasatch and Weber Counties as an acceptable level of degradation) as a reference point to evaluate the potential



*Data were derived using computer ground-water flow model (see text for explanation).

** Area not modeled, but is included in Plate 1 extending recommended boundary.

Figure 12. Ground-water flow domains in Sanpete Valley.

impact of increased numbers of septic-tank systems. Local government officials may choose a different nitrate concentration as an acceptable level of degradation.

In the mass-balance approach used here, the nitrogen mass from the projected additional septic tanks is added to the current nitrogen mass and then diluted with the amount of ground-water flow available for mixing plus the water added by the septic-tank systems themselves; we use the following equation to determine the projected nitrate concentration resulting from additional septic tanks, or to determine how many septic-tank systems can be added before exceeding a designated target nitrate concentration:

$$N_p = \frac{\left[(ST_T - ST_C)\,Q_{ST}\right] * N_L + \left[N_A\,(Q_M + [ST_T * Q_{ST}])\right]}{[ST_T * Q_{ST}] + Q_M}$$

where:

N_p is the projected nitrate concentration (mg/L),

N_A is the ambient (background) nitrate concentration for the domain (mg/L),

N_L is the estimated average nitrate concentration from each septic tank (mg/L),

ST_T is the total number of septic tanks in the system (variable, unitless),

ST_C is the current number of septic tanks (constant, unitless),

Q_{ST} is the flow rate from each septic tank (L/s), and

Q_M is the ground-water flow rate from the model (L/s).

To determine a recommended septic-system density, we divide the domain area acreage by the total number of septic tanks (ST_T) that exists at the projected nitrate concentration (N_P). We use the following equation to determine the resulting septic-tank system density:

$$\text{Tank Density} = \frac{\text{Domain acreage}}{ST_T}$$

where ST_T is defined above.

Results

Domain 1: Figure 13a shows a plot of projected nitrate concentration versus septic-tank density and number of septic-tank systems in domain 1 in the northeastern arm of Sanpete Valley (figure 12, plate 1). Background nitrate concentration for domain 1 is 2.9 mg/L (table 4). An estimated 431 septic systems exist in domain 1 (table 4). Domain 1 has an area of approximately 36,168 acres (14,637 hm^2), so the existing average septic-system density is 84 acres per system (34 hm^2/system). Based on our analyses (table 5), estimated ground-water flow available for mixing in domain 1 is 187 cubic feet per second (5.3 m^3/s). For domain 1 to maintain an overall nitrate concentration of 3.9 mg/L (which allows 1 mg/L of degradation), the total number of homes using septic tank soil-absorption systems should not exceed 11,000 based on the estimated nitrogen load of 55 mg/L per septic-tank system (figure 13a, table 5). This corresponds to a total increase of approximately 10,569 added septic systems and an average septic-system density of about 3.3 acres per system (1.3 hm^2/system) in domain 1 (table 5).

Domain 2: Figure 13b shows a plot of projected nitrate concentration versus septic-tank density and number of septic-tank systems in domain 2 in the northwest arm of Sanpete Valley (figure 12, plate 1). Background nitrate concentration for domain 2 is 3.4 mg/L (table 4). An estimated 125 septic systems exist in domain 2 (table 4). Domain 2 has an area of approximately 31,190 acres (12,623 hm^2), so the average septic-system density is 250 acres per system (100 hm^2/system). Based on our analyses (table 5), estimated ground-water flow available for mixing in domain 2 is 83.5 cubic feet per second (2.4 m^3/s). For domain 2 to maintain an overall nitrate concentration of 4.3 mg/L (which allows 1 mg/L of degradation), the total number of homes using septic tank soil-absorption systems should not exceed 4850 based on the estimated nitrogen load of 55 mg/L per septic-tank system (figure 13b, table 5). This corresponds to a total increase of approximately 4725 added septic systems and an average septic-system density of about 6.4 acres per system (2.6 hm^2/system) in domain 2 (table 5).

Domain 3: Figure 13c shows a plot of projected nitrate concentration versus septic-tank density and number of septic-tank systems in domain 3 in the central and southern part of

Table 4. *Parameters used to perform a mass-balance analysis for different ground-water flow domains in Sanpete Valley.*

Domain	Area (acres)	Flow* (cubic feet per second per acre)	Average nitrate concentration (background) (mg/L)	Number of wells sampled for nitrate	Current number of septic tanks permitted⁺
1	36,168	0.0052	2.9	83	431
2	31,190	0.0027	3.4	101	125
3	53,739	0.0026	2.3	156	176

*Data were derived using a computer ground-water flow simulation (see text for explanation).

⁺Septic systems were estimated by digitizing homes from aerial photography and confirmed by the Central Utah Health Department (George Johansen, written communication, March 2006).

Table 5. *Results of the mass-balance analysis using the best-estimate nitrogen loading of 55 mg N/L* for different ground-water flow domains in Sanpete Valley.*

Domain	Area (acres)	Flow amount (cfs)	Current density (acres/system)	Number of currrent septic tanks permitted	Projected number of total septic tanks	Calculated lot size recommendation (acres)	Lot-size recommended (acres)
1	36,168	187	84	431	11,000	3.3	5
2	31,190	83.5	250	125	4850	6.4	10
3	53,739	138	305	176	7800	7	10

*Best-estimate calculation is based on a nitrogen load of 17 g N per capita per day (from Kaplan, 1988) for a 3.27-person household and 230 gallons per household as the amount of water generated per household based on the 2001 Utah State Water Plan (Utah Division of Water Resources, 2001).

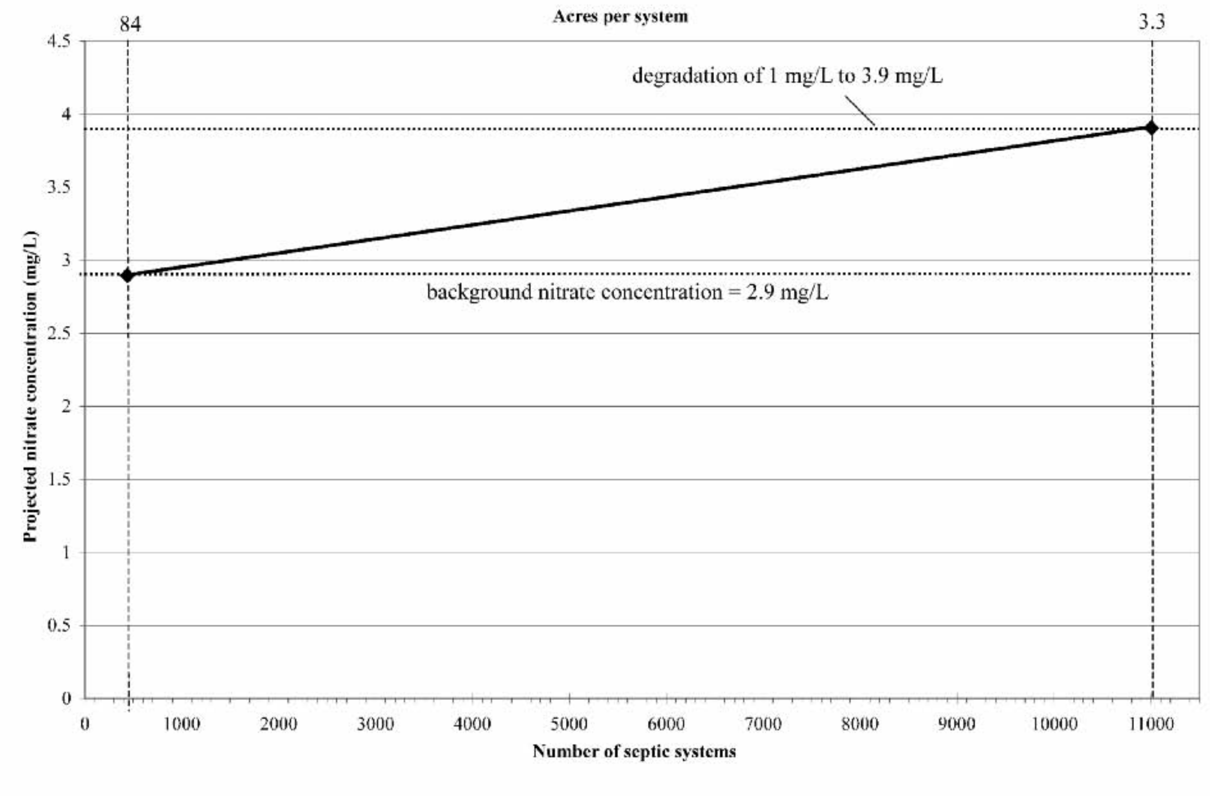


Figure 13a. *Projected septic-tank density versus nitrate concentration for domain 1 in Sanpete Valley based on 431 existing septic tanks (see tables 4 and 5).*

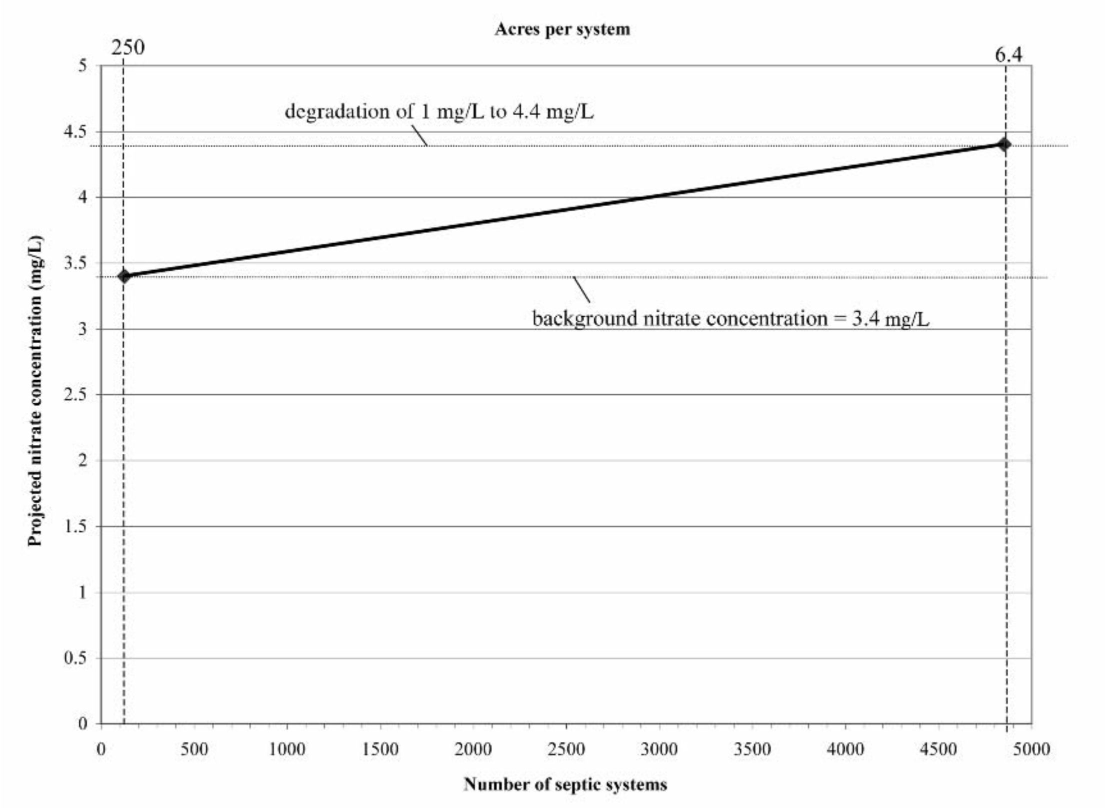


Figure 13b. *Projected septic-tank density versus nitrate concentration for domain 2 in Sanpete Valley based on 125 existing septic tanks (see tables 4 and 5).*

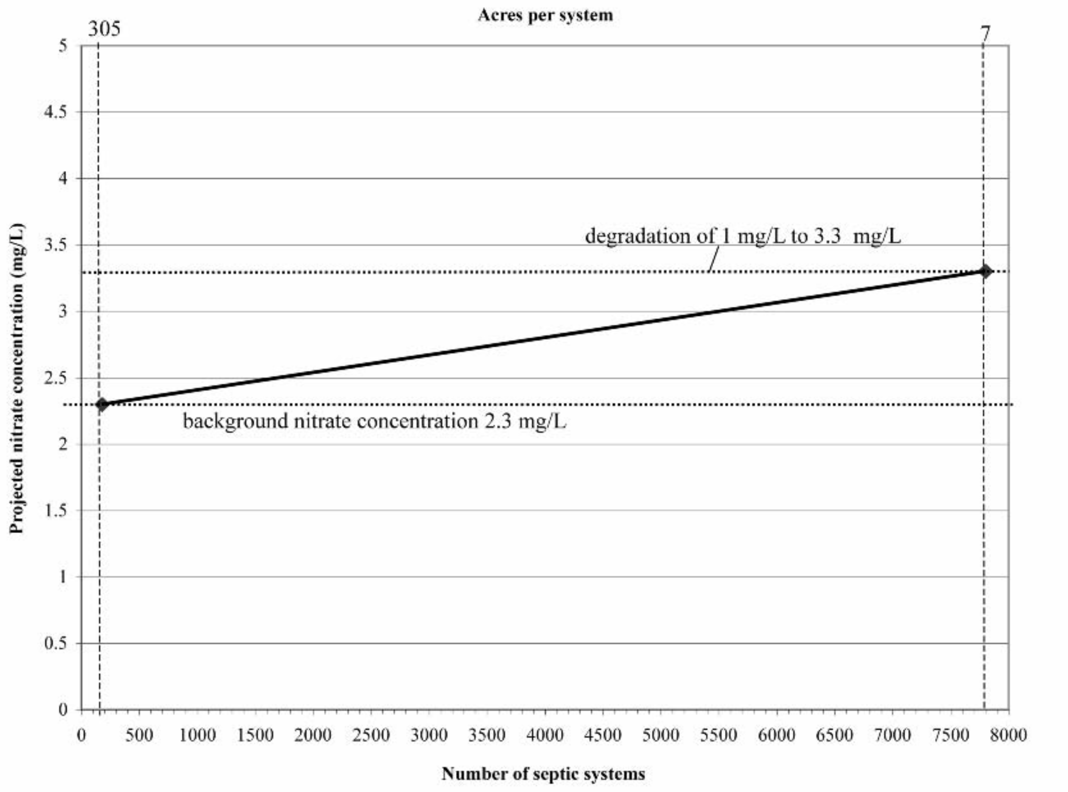


Figure 13c. *Projected septic-tank density versus nitrate concentration for domain 3 in Sanpete Valley based on 176 existing septic tanks (see tables 4 and 5).*

Sanpete Valley (plate 1). Background nitrate concentration for domain 3 is 2.3 mg/L (table 4). An estimated 176 septic systems exist in domain 3 (table 4). Domain 3 has an area of approximately 53,739 acres (21,748 hm^2), so the average septic-tank system density is 305 acres per system (123 hm^2/system). Based on our analyses (table 5), estimated ground-water flow available for mixing in domain 3 is 138 cubic feet per second (3.9 m^3/s). For domain 3 to maintain an overall nitrate concentration of 3.3 mg/L (which allows 1 mg/L of degradation), the total number of homes using septic tank soil-absorption systems should not exceed 7800 based on the estimated nitrogen load of 55 mg/L per septic-tank system (figure 13c, table 5). This corresponds to a total increase of approximately 7624 septic systems and an average septic-system density of about 7 acres per system (3 hm^2/system) in domain 3 (table 5).

Recommendations for Land-Use Planning

These analyses of nitrate concentrations/water-quality degradation provide a conservative (worst case) first approximation of long-term ground-water pollution from septic-tank systems. The graphs of projected nitrate concentration versus number of septic-tank systems in each area show recommended septic-tank density for each domain based on the parameters described above. For land-use planning purposes, we believe two categories of recommended maximum septic-tank system densities are appropriate for development using septic tank soil-absorption systems for wastewater disposal: 5 and 10 acres per system (2 and 4 hm^2/system) (table 5; plate 1); these recommended lot sizes are larger than the calculated lot sizes to be protective of ground-water quality in view of the many limitations and simplifying assumptions in the ground-water flow calculations. Our lot-size recommendations apply to development using septic systems for wastewater disposal, and are not relevant to development using well-engineered, well-constructed sewer lagoon systems. However, poorly engineered, poorly constructed sewer lagoon systems could have even greater negative impact on ground-water quality than septic-tank systems.

This 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.

SUMMARY AND CONCLUSIONS

Ground water from the principal valley-fill aquifer is the most important source of drinking water in Sanpete Valley. Septic tank soil-absorption systems are used to dispose of domestic wastewater in many areas of Sanpete Valley. Many constituents in septic-tank effluent are known to undergo negligible 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 (converted from organic nitrogen and ammonia) in septic-tank effluent as an indicator for evaluating the dilution of constituents in wastewater that reach the principal valley-fill aquifer system; this evaluation uses a mass-balance approach based principally on ground-water flow available for mixing with effluent constituents in the aquifer of concern. The mass-balance approach for the principal valley-fill aquifer in Sanpete Valley indicates that two categories of recommended maximum septic-tank system densities are appropriate for development using septic tank soil-absorption systems for wastewater disposal: 5 and 10 acres per system (2 and 4 hm^2/system) (plate 1). These recommended minimum lot sizes are based on hydrogeologic parameters incorporated in a ground-water flow model and geographically divided into three ground-water flow domains on the basis of flow-volume similarities. Overall, the amount of ground water available for dilution controls the potential impact of increasing numbers of septic-tank systems, and thus our recommended lot size.

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Appendix

Nitrate-plus-nitrite concentration data for Sanpete Valley, Sanpete County, Utah

Well ID #	Location	Depth of well (feet)	Sampling date	Nitrogen NO_2+NO_3 dissolved (mg/L as N)
11	(D-13-4) 1aaa-1	105	7/16/96 0:00	0.04
13	(D-13-4) 1dbb-1	90	7/16/96 0:00	0.20
20	(D-13-4) 11adc-1	147	7/16/96 0:00	1.81
21	(D-13-4) 11dcb-1	105	7/17/96 0:00	1.55
25	(D-13-4) 12bdd-1	165	7/16/96 0:00	0.59
26	(D-13-4) 12cbb-1	100	7/16/96 0:00	1.95
27	(D-13-4) 12cbb-2	100	7/16/96 0:00	2.02
28	(D-13-4) 12ccc-1	74	7/16/96 0:00	5.55
32	(D-13-4) 12dbb-1	148	7/16/96 0:00	0.55
33	(D-13-4) 13cbd-1	82	9/17/96 0:00	0.77
36	(D-13-4) 23daa-1	85	9/17/96 0:00	2.32
37	(D-13-4) 24cba-1	101	9/17/96 0:00	0.28
39	(D-13-4) 24cbb-1	103	9/17/96 0:00	2.60
40	(D-13-4) 24cbc-1	130	9/17/96 0:00	1.40
38	(D-13-4) 24dba-1	100	7/30/96 0:00	0.29
43	(D-13-4) 24dba-2	100	7/30/96 0:00	0.43
49	(D-13-4) 26aaa-1	75	7/16/96 0:00	2.23
55	(D-13-4) 35add-1	140	9/17/96 0:00	2.50
59	(D-13-4) 36cbc-1	135	7/16/96 0:00	2.26
65	(D-14-2) 13cad-1	80	8/7/96 0:00	6.97
66	(D-14-2) 13daa-1	95	10/18/96 0:00	3.39
68	(D-14-2) 24dac-1	130	8/12/96 0:00	0.02
76	(D-14-3) 7bdd-1	82	8/6/96 0:00	3.79
78	(D-14-3) 7ddb-1	92	7/24/96 0:00	4.13
80	(D-14-3) 17cbc-1	80	7/31/96 0:00	4.03
81	D-14-3 17cbc-2	133	7/31/96 0:00	3.90
82	(D-14-3) 17cca-1	100	5/13/97 0:00	0.43
83	(D-14-3) 17ccb-1	100	9/18/96 0:00	2.46
84	(D-14-3) 17dcd-1	140	8/6/96 0:00	20.71
"	" "	"	9/14/99 0:00	19*
92	(D-14-3) 20aba-1	105	11/6/96 0:00	18.34
"	" "	105	8/28/97 0:00	18.76
"	" "	105	9/14/99 0:00	18.2*
92b	(D-14-3) 20bbb pond	-	8/28/97 0:00	3.22
93	(D-14-3) 20ada-1	125	9/18/96 0:00	16.95
"	" "	"	11/6/96 0:00	15.16
"	" "	"	9/14/99 0:00	5.99*
95	(D-14-3) 20bba-1	151	8/6/96 0:00	3.07
103	(D-14-3) 28cbc-1	160	5/13/97 0:00	4.65
104	(D-14-3) 28cbc-2	62	7/23/96 0:00	4.46
105	(D-14-3) 28cbc-3	90	11/6/96 0:00	4.49
"	" "	"	9/14/99 0:00	2.04*
"	" "	"	8/28/97 0:00	21.10
106	(D-14-3) 29cbb-1	82	9/18/96 0:00	0.25
112	(D-14-3) 30dbc-1	90	8/13/96 0:00	4.92
115	(D-14-3) 31acb-1	147	8/6/96 0:00	0.08
116	(D-14-3) 32aab-1	89	7/24/96 0:00	7.74
122	(D-14-3) 32bac-1	65	7/24/96 0:00	1.32
119	(D-14-3) 32cca-1	170	7/24/96 0:00	1.64
120	(D-14-3) 32ccb-1	45	7/24/96 0:00	7.28
121	(D-14-3) 32cdb-1	158	7/24/96 0:00	0.05
123	(D-14-3) 33aac-1	147	7/31/96 0:00	2.13
126	(D-14-3) 33bdc-1	164	7/30/96 0:00	5.60
141	(D-14-4) 11aad-1	70	7/17/96 0:00	3.91
146	(D-14-4) 12bab-1	148	7/23/96 0:00	1.70
148	(D-14-4) 13dac-1	495	7/17/96 0:00	0.52
149	(D-14-4) 13ddb-1	225	7/17/96 0:00	0.49

Appendix (continued)

Well ID #	Location	Depth of well (feet)	Sampling date	Nitrogen NO_2+NO_3 dissolved (mg/L as N)
150	(D-14-4) 13ddc-1	260	7/18/96 0:00	1.41
156	(D-14-4) 22ddd-1	27	9/18/96 0:00	2.61
157	(D-14-4) 23abb-1	100	7/30/96 0:00	1.44
159	(D-14-4) 23ddd-1	45	7/17/96 0:00	2.96
161	(D-14-4) 24aba-1	230	7/17/96 0:00	<.02
162	(D-14-4) 24bab-1	140	7/17/96 0:00	3.45
163	(D-14-4) 24bac-1	105	9/26/96 0:00	1.53
164	(D-14-4) 24bad-1	182	7/17/96 0:00	1.79
165	(D-14-4) 24bdb-1	175	9/17/96 0:00	4.33
166	(D-14-4) 24cdb-1	90	8/13/96 0:00	4.91
167	(D-14-4) 24dac-1	85	7/17/96 0:00	1.15
168	(D-14-4) 25abd-1	105	7/18/96 0:00	4.11
169	(D-14-4) 25cdc-1	100	9/18/96 0:00	4.44
170	(D-14-4) 25dcc-1	145	7/18/96 0:00	21.58
"	" "	"	11/4/96 0:00	14.58
"	" "	"	9/14/99 0:00	12.2*
172	(D-14-4) 26bda-1	93	9/18/96 0:00	6.61
173	(D-14-4) 26cac-1	83	10/22/96 0:00	2.77
176	(D-14-4) 27cdd-1	79	7/22/96 0:00	2.71
179	(D-14-4) 27dad-1	103	7/18/96 0:00	4.36
181	(D-14-4) 27dda-1	80	7/18/96 0:00	4.09
184	(D-14-4) 33cbb-1	45	7/18/96 0:00	1.22
185	(D-14-4) 33cdc-1	50	7/22/96 0:00	1.36
186	(D-14-4) 33dad-1	55	7/22/96 0:00	2.85
183	(D-14-4) 33dcd-1	60	7/22/96 0:00	1.35
187	(D-14-4) 34aaa-1	83	9/17/96 0:00	1.96
188	(D-14-4) 34aab-1	78	7/22/96 0:00	2.78
193	(D-14-4) 34bca-1	50	7/18/96 0:00	1.44
189	(D-14-4) 34bda-1	49	7/22/96 0:00	1.03
191	(D-14-4) 34cbb-1	63	7/23/96 0:00	3.06
192	(D-14-4) 34cca-1	65	7/22/96 0:00	3.06
195	(D-14-4) 35dba-1	384	7/17/96 0:00	1.20
200	(D-14-5) 19cdc-1	325	9/18/96 0:00	2.11
206	(D-15-2) 24dbb-1	160	8/8/96 0:00	1.21
207	(D-15-2) 24dbc-1	225	8/8/96 0:00	0.09
209	(D-15-2) 24dda-1	120	8/8/96 0:00	0.22
216	(D-15-3) 4bbd-1	180	7/24/96 0:00	5.72
217	(D-15-3) 4bda-1	318	7/31/96 0:00	3.36
218	(D-15-3) 4bdb-1	111	7/31/96 0:00	6.98
220	(D-15-3) 5bbc-1	151	7/25/96 0:00	3.17
221	(D-15-3) 5bdd-1	146	7/31/96 0:00	0.20
222	(D-15-3) 6add-1	56	7/30/96 0:00	0.77
223	(D-15-3) 6cab-1	38	8/7/96 0:00	17.78
"	" "	"	8/27/97 0:00	0.32
"	" "		9/14/99 0:00	0.4*
224	(D-15-3) 6cad-1	45	5/21/97 0:00	8.09
"	(D-15-3) 6cad-1	45	8/28/97 0:00	-
225	(D-15-3) 6ccd-1	66	5/21/97 0:00	0.36
"	" "	"	8/28/97 0:00	-
226	(D-15-3) 6dbd-1	71	5/21/97 0:00	21.65
"	" "	"	8/28/97 0:00	0.53
226b	(D-15-3) 6dbd pond	"	8/28/97 0:00	0.53
227	(D-15-3) 6dcd-1	86	7/25/96 0:00	0.12
228	(D-15-3) 7aad-1	51	5/13/97 0:00	0.81
229	(D-15-3) 7aca-1	60	5/21/97 0:00	0.04
230	(D-15-3) 7bbc-1	105	8/7/96 0:00	5.24
231	(D-15-3) 7bbc-2	100	8/7/96 0:00	1.89
232	(D-15-3) 7bcc-1	475	8/7/96 0:00	0.03
236	(D-15-3) 7dbc-1	63	8/7/96 0:00	1.14
237	(D-15-3) 7dbc-2	110	8/7/96 0:00	0.47
238	(D-15-3) 7dcb-1	222	8/7/96 0:00	0.10
239	(D-15-3) 8acc-1	65	7/31/96 0:00	0.25

Appendix (continued)

Well ID #	Location	Depth of well (feet)	Sampling date	Nitrogen NO_2+NO_3 dissolved (mg/L as N)
241	(D-15-3) 8cdd-1	63	8/6/96 0:00	0.30
242	(D-15-3) 8dbc-1	76	7/31/96 0:00	0.22
248	(D-15-3) 10ccb-1	30	8/6/96 0:00	27.00
"	" "	"	11/6/96 0:00	29.28
"	" "	"	9/14/99 0:00	0.13*
249	(D-15-3) 10dba-1	185	5/13/97 0:00	0.63
250	(D-15-3) 10dad-1	66	8/6/96 0:00	10.65
"	" "	"	11/6/96 0:00	9.10
"	" "	"	9/14/99 0:00	17.5*
251	(D-15-3) 11bdb-1	92	8/28/97 0:00	0.76
253	(D-15-3) 11cba-1	65	8/28/97 0:00	2.68
254	(D-15-3) 11cbd-1	60	5/13/97 0:00	5.59
255	(D-15-3) 3dcd-1	240	8/28/97 0:00	1.16
256	(D-15-3) 12bcc-1	100	9/18/96 0:00	0.02
257	(D-15-3) 12bcb-1	100	9/18/96 0:00	2.39
258	(D-15-3) 12bcb-2	104	7/31/96 0:00	0.47
259	(D-15-3) 13daa-1	101	8/15/96 0:00	3.05
260	(D-15-3) 15ada-1	80	5/13/97 0:00	2.20
261	(D-15-3) 15bbc-1	215	7/31/96 0:00	0.62
263	(D-15-3) 15bca-1	185	8/8/96 0:00	0.18
264	(D-15-3) 15cbd-1	40	7/31/96 0:00	4.66
265	(D-15-3) 15cca-1	151	8/28/97 0:00	1.10
266	(D-15-3) 15cdc-1	108	7/31/96 0:00	1.40
268	(D-15-3) 9 dcd-1	340	5/13/97 0:00	6.43
269	(D-15-3) 16abc-1	245	8/7/96 0:00	2.96
271	(D-15-3) 16bdb-1	425	8/7/96 0:00	1.03
272	(D-15-3) 17ddd-1	40	7/31/96 0:00	1.24
273	(D-15-3) 19bcb-1	264	8/12/96 0:00	0.17
274	(D-15-3) 19cad-1	165	8/8/96 0:00	<.02
275	(D-15-3) 19cbc-1	103	8/8/96 0:00	0.33
276	(D-15-3) 19cca-1	92	8/12/96 0:00	<.02
279	(D-15-3) 19dcb-1	173	8/12/96 0:00	0.03
281	(D-15-3) 21ada-1	258	8/28/97 0:00	1.15
285	(D-15-3) 21bbb-1	82	7/31/96 0:00	1.21
282	(D-15-3) 21bcd-1	78	8/19/96 0:00	1.39
283	(D-15-3) 21bdd-1	139	8/19/96 0:00	1.49
290	(D-15-3) 22dad-1	99	8/20/96 0:00	1.19
293	(D-15-3) 25bbd-1	97	8/20/96 0:00	0.47
294	(D-15-3) 25bca-1	160	8/20/96 0:00	5.93
295	(D-15-3) 25cad-1	100	8/20/96 0:00	0.30
296	(D-15-3) 25dad-1	118	8/20/96 0:00	0.95
298	(D-15-3) 26bcb-1	85	8/15/96 0:00	1.71
299	(D-15-3) 26cac-1	171	8/20/96 0:00	0.47
300	(D-15-3) 26ccd-1	115	8/21/96 0:00	<.02
301	(D-15-3) 26dca-1	85	8/14/96 0:00	1.93
302	(D-15-3) 26ddd-1	76	8/20/96 0:00	0.25
303	(D-15-3) 27acb-1	120	8/15/96 0:00	0.25
305	(D-15-3) 27caa-1	100	8/15/96 0:00	1.86
306	(D-15-3) 27cca-1	178	8/15/96 0:00	0.31
307	(D-15-3) 27dcb-1	85	8/20/96 0:00	2.58
308	(D-15-3) 28acc-1	85	8/15/96 0:00	1.20
309	(D-15-3) 28daa-1	151	8/19/96 0:00	2.26
310	(D-15-3) 28dbc-1	82	8/19/96 0:00	2.56
311	(D-15-3) 28dcd-1	133	8/19/96 0:00	1.94
314	(D-15-3) 29ccc-1	92	8/21/96 0:00	0.02
315	(D-15-3) 30aaa-1	47	8/19/96 0:00	9.68
"	" "	"	11/6/96 0:00	7.78
316	(D-15-3) 30cba-1	120	8/12/96 0:00	5.09
319	(D-15-3) 30cdb-1	120	10/22/96 0:00	3.18
325	(D-15-3) 32aac-1	107	8/14/96 0:00	0.41
326	(D-15-3) 32cca-1	40	8/21/96 0:00	1.90
327	(D-15-3) 32cda-1	72	8/21/96 0:00	1.97

Appendix (continued)

Well ID #	Location	Depth of well (feet)	Sampling date	Nitrogen NO_2+NO_3 dissolved (mg/L as N)
331	(D-15-3) 34aaa-1	110	8/14/96 0:00	<.02
332	(D-15-3) 34aab-1	105	8/14/96 0:00	0.19
334	(D-15-3) 34aba-2	100	8/14/96 0:00	0.71
337	(D-15-3) 34bab-1	105	8/14/96 0:00	1.01
339	(D-15-3) 34bda-1	81	8/14/96 0:00	0.21
341	(D-15-3) 34ccd-1	95	8/14/96 0:00	2.26
342	(D-15-3) 34dad-1	98	8/20/96 0:00	0.71
343	(D-15-3) 35aaa-1	65	8/20/96 0:00	0.44
345	(D-15-3) 35bba-1	100	8/20/96 0:00	<0.2
346	(D-15-3) 35ada-1	200	8/20/96 0:00	0.05
347	(D-15-3) 35dad-1	-	5/20/97 0:00	5.66
"	" "	-	9/14/99 0:00	35.4*
"	" "	-	8/27/97 0:00	-
348	(D-15-3) 35dda-1	68	8/14/96 0:00	20.03
"	" "	"	9/14/99 0:00	5.94*
351	(D-15-3) 36bad-1	66	8/20/96 0:00	6.21
352	(D-15-3) 36cbb-1	409	5/20/97 0:00	7.22
"	" "	"	8/28/97 0:00	-
353	(D-15-4) 1bba-1	280	9/18/96 0:00	0.56
354	(D-15-4) 1bcb-1	230	7/30/96 0:00	0.37
356	(D-15-4) 2aad-1	180	7/18/96 0:00	0.41
360	(D-15-4) 3bbd-1	41	9/17/96 0:00	3.04
363	(D-15-4) 4bad-1	90	5/13/97 0:00	0.29
364	(D-15-4) 4cba-1	180	5/13/97 0:00	0.10
365	(D-15-4) 4bcb-1	62	7/23/96 0:00	9.21
"	" "	"	9/14/00 0:00	0.08*
367	(D-15-4) 5aca-1	46	7/23/96 0:00	8.94
"	" "	"	9/14/99 0:00	0.14*
368	(D-15-4) 5bca-1	110	7/23/96 0:00	0.12
369	(D-15-4) 5bdc-1	102	7/23/96 0:00	3.01
370	(D-15-4) 5dca-1	72	9/17/96 0:00	5.55
376	(D-15-4) 6ddb-1	98	7/30/96 0:00	<.02
377	(D-15-4) 9aad-1	80	9/17/96 0:00	1.66
378	(D-15-4) 9add-1	102	9/17/96 0:00	0.35
379	(D-15-4) 9bab-1	85	7/23/96 0:00	2.17
381	(D-15-4) 9bca-1	60	5/13/97 0:00	3.41
385	(D-15-4) 10dca-1	73	7/18/96 0:00	1.98
387	(D-15-4) 11ddd-1	94	9/17/96 0:00	<.02
392	(D-15-4) 16aca-1	100	7/23/96 0:00	1.67
393	(D-15-4) 16acb-1	205	7/23/96 0:00	0.37
395	(D-15-4) 16bcd-1	91	7/30/96 0:00	3.47
396	(D-15-4) 16ccb-1	99	9/17/96 0:00	3.40
399	(D-15-4) 17bad-1	55	9/18/96 0:00	3.53
402	(D-15-4) 18dbd-1	76	8/15/96 0:00	3.50
398	(D-15-4) 20add-1	120	10/21/96 0:00	1.69
403	(D-15-4) 20bca-1	80	7/31/96 0:00	6.59
404	(D-15-4) 20bdc-1	100	7/31/96 0:00	5.71
405	(D-15-4) 20daa-1	122	10/21/96 0:00	1.40
406	(D-15-4) 20dab-1	100	10/21/96 0:00	1.04
408	(D-15-4) 20dbd-1	80	10/21/96 0:00	1.39
409	(D-15-4) 21cab-1	125	10/21/96 0:00	1.25
410	(D-15-4) 21cba-1	100	10/21/96 0:00	2.11
411	(D-15-4) 21cbb-1	60	10/21/96 0:00	1.03
412	(D-15-4) 21ccc-1	100	10/21/96 0:00	1.65
425	(D-15-4) 31ddc-1	112	9/24/96 0:00	1.47
428	(D-15-4) 32daa-1	86	10/21/96 0:00	2.05
431	(D-15-4) 33ccb-1	120	10/21/96 0:00	1.50
436	(D-15-5) 30bba-1	500	10/22/96 0:00	0.11
443	(D-16-2) 13aaa-1	263	8/13/96 0:00	<.02
444	(D-16-2) 13dda-1	324	8/13/96 0:00	<.02
445	(D-16-2) 13ddb-1	221	8/13/96 0:00	<.02
446	(D-16-2) 24aac-1	216	8/13/96 0:00	2.68

Appendix (continued)

Well ID #	Location	Depth of well (feet)	Sampling date	Nitrogen NO_2+NO_3 dissolved (mg/L as N)
442	(D-16-2) 24add-1	196	8/13/96 0:00	2.25
455	(D-16-2) 36dab-1	238	8/13/96 0:00	<.02
459	(D-16-3) 1bbb-1	107	8/20/96 0:00	4.53
441	(D-16-3) 2cbc-1	120	8/20/96 0:00	1.69
460	(D-16-3) 3aaa-1	100	8/14/96 0:00	0.02
463	(D-16-3) 4aaa-1	175	8/20/96 0:00	0.04
464	(D-16-3) 4aac-1	126	8/14/96 0:00	<.02
466	(D-16-3) 4dac-1	128	8/20/96 0:00	<.02
467	(D-16-3) 4dbc-1	122	8/20/96 0:00	<.02
468	(D-16-3) 4dbd-1	142	8/20/96 0:00	<.02
476	(D-16-3) 7aad-1	164	8/21/96 0:00	2.46
477	(D-16-3) 7abc-1	85	9/19/96 0:00	0.72
478	(D-16-3) 7aca-1	105	8/21/96 0:00	5.12
481	(D-16-3) 7ccd-1	121	9/19/96 0:00	1.23
483	(D-16-3) 9abd-1	144	8/14/96 0:00	2.00
488	(D-16-3) 9cdd-1	132	9/25/96 0:00	1.49
489	(D-16-3) 9daa-1	132	8/14/96 0:00	0.73
490	(D-16-3) 11aca-1	400	8/28/97 0:00	<0.02
494	(D-16-3) 15 ada-1	130	5/15/97 0:00	9.32
"	" "	"	9/14/99 0:00	9.69*
"	" "	"	8/28/97 0:00	-
495	(D-16-3) 15dbb-1	162	8/21/96 0:00	6.46
"	" "	"	5/15/97 0:00	0.07
"	" "	"	8/28/97 0:00	-
496	(D-16-3) 15add-1	100	9/24/96 0:00	15.15
"	" "	"	5/15/97 0:00	10.93
"	" "	"	9/14/99 0:00	9.14*
497	(D-16-3) 16aac-1	153	9/25/96 0:00	<.02
498	(D-16-3) 16caa-1	131	8/21/96 0:00	<.02
499	(D-16-3) 16ccd-1	125	8/21/96 0:00	<.02
500	(D-16-3) 15ccb-1	140	8/28/97 0:00	6.45
502	(D-16-3) 17dcc-1	142	8/21/96 0:00	<.02
507	(D-16-3) 19aba-1	136	9/24/96 0:00	<.02
508	(D-16-3) 19aca-1	168	9/24/96 0:00	4.49
509	(D-16-3) 20acc-1	137	8/21/96 0:00	<.02
510	(D-16-3) 21adc-1	147	8/21/96 0:00	7.10
511	(D-16-3) 21bbc-1	152	8/21/96 0:00	0.03
512	(D-16-3) 21cda-1	98	8/21/96 0:00	4.24
514	(D-16-3) 22cdd-1	255	5/15/97 0:00	7.83
515	(D-16-3) 23cbc-1	267	5/15/97 0:00	0.13
516	(D-16-3) 24aba-1	170	8/20/96 0:00	<.02
520	(D-16-3) 27bad-1	103	8/22/96 0:00	9.50
521	(D-16-3) 27bdc-1	121	9/24/96 0:00	5.45
522	(D-16-3) 27cba-1	300	8/22/96 0:00	3.87
525	(D-16-3) 27dac-2	85	9/25/96 0:00	3.13
526	(D-16-3) 27cbc-1	267	8/28/97 0:00	3.80
527	(D-16-3) 28bcc-1	142	9/24/96 0:00	12.75
"	" "	"	8/27/97 0:00	12.16
531	(D-16-3) 28cba-1	158	9/24/96 0:00	<.02
528	(D-16-3) 28ccb-1	110	9/24/96 0:00	8.67
529	(D-16-3) 28daa-1	178	8/28/97 0:00	0.87
530	(D-16-3) 28dac-1	33	8/22/96 0:00	4.85
533	(D-16-3) 29add-1	172	9/24/96 0:00	<.02
534	(D-16-3) 29add-2	157	9/24/96 0:00	0.16
535	(D-16-3) 29dbd-1	198	5/15/97 0:00	<0.02
536	(D-16-3) 30cdc-1	186	8/13/96 0:00	0.33
537	(D-16-3) 30dad-1	146	9/24/96 0:00	4.73
539	(D-16-3) 31dda-1	140	9/19/96 0:00	1.41
541	(D-16-3) 32bbd-1	158	8/28/97 0:00	<0.02
542	(D-16-3) 32aad-1	140	5/15/97 0:00	11.44
543	(D-16-3) 32adb-1	128	9/23/96 0:00	9.28
544	(D-16-3) 32bbb-1	198	9/19/96 0:00	3.47

Appendix (continued)

Well ID #	Location	Depth of well (feet)	Sampling date	Nitrogen NO_2+NO_3 dissolved (mg/L as N)
546	(D-16-3) 32bda-1	256	9/19/96 0:00	4.78
548	(D-16-3) 32cab-1	312	9/23/96 0:00	2.01
549	(D-16-3) 32ccc-3	173	5/14/97 0:00	<0.02
545	(D-16-3) 32cad-1	68	9/23/96 0:00	1.89
551	(D-16-3) 32ccc-2	168	5/14/97 0:00	0.44
552	(D-16-3) 32ccd-1	222	10/1/96 0:00	<.02
553	(D-16-3) 32cda-1	231	9/23/96 0:00	0.32
554	(D-16-3) 32dca-1	154	9/23/96 0:00	3.03
556	(D-16-3) 32dcd-1	174	10/1/96 0:00	0.31
557	(D-16-3) 32dda-1	162	9/23/96 0:00	2.67
558	(D-16-3) 33aca-1	201	9/24/96 0:00	3.22
560	(D-16-3) 33bca-1	118	8/22/96 0:00	7.83
561	(D-16-3) 33cad-1	147	9/24/96 0:00	0.07
562	(D-16-3) 33ccb-1	105	9/23/96 0:00	0.07
566	(D-16-3) 34cbd-1	64	8/22/96 0:00	9.71
"	" "	"	11/6/96 0:00	8.70
"	" "	"	9/14/99 0:00	10.4*
568	(D-16-3) 34bca-1	82	5/15/97 0:00	2.79
570	(D-16-4) 4bab-1	125	10/21/96 0:00	1.46
571	(D-16-4) 5abc-1	121	10/22/96 0:00	3.24
574	(D-16-4) 6dba-1	82	8/20/96 0:00	2.78
575	(D-16-4) 6dca-1	100	9/24/96 0:00	4.30
579	(D-16-4) 7ccd-1	150	9/24/96 0:00	5.46
582	(D-16-4) 16adc-1	172	10/21/96 0:00	0.28
583	(D-16-4) 16adc-2	118	10/21/96 0:00	1.71
589	(D-17-2) 1aba-1	158	9/25/96 0:00	2.44
591	(D-17-2) 1bab-1	162	10/8/96 0:00	2.48
594	(D-17-2) 1cba-3	168	10/8/96 0:00	1.13
595	(D-17-2) 1cbb-1	161	10/8/96 0:00	1.00
596	(D-17-2) 1cbb-2	182	10/8/96 0:00	<.02
597	(D-17-2) 1dac-1	173	10/9/96 0:00	2.52
599	(D-17-2) 11ddb-1	257	10/8/96 0:00	<.02
600	(D-17-2) 12add-1	246	10/7/96 0:00	3.94
601	(D-17-2) 12bac-1	253	10/7/96 0:00	3.46
603	(D-17-2) 12dab-1	230	10/7/96 0:00	3.48
604	(D-17-2) 12dba-1	222	10/7/96 0:00	3.72
605	(D-17-2) 12dbd-1	195	9/25/96 0:00	3.60
606	(D-17-2) 12ddc-1	202	10/7/96 0:00	3.44
607	(D-17-2) 13aba-1	200	10/7/96 0:00	2.48
608	(D-17-2) 13bba-1	179	10/8/96 0:00	<.02
609	(D-17-2) 13bdb-1	201	10/7/96 0:00	2.37
610	(D-17-2) 13bdd-1	205	10/8/96 0:00	<.02
611	(D-17-2) 13cbb-1	237	10/8/96 0:00	<.02
612	(D-17-2) 14abb-1	230	9/25/96 0:00	<.02
613	(D-17-2) 14baa-1	337	9/25/96 0:00	<.02
616	(D-17-2) 14cbc-1	185	10/8/96 0:00	1.97
617	(D-17-2) 14ddd-1	179	10/8/96 0:00	0.12
619	(D-17-2) 15acc-1	166	9/25/96 0:00	<.02
622	(D-17-2) 22dbd-1	345	9/25/96 0:00	1.13
623	(D-17-2) 23acc-1	246	10/9/96 0:00	<.02
625	(D-17-2) 23caa-1	234	10/9/96 0:00	<.02
624	(D-17-2) 23daa-1	217	10/9/96 0:00	0.04
626	(D-17-2) 24aad-1	183	10/16/96 0:00	3.09
627	(D-17-2) 24aad-2	80	10/16/96 0:00	3.46
628	(D-17-2) 24adc-1	205	9/25/96 0:00	2.04
629	(D-17-2) 24bab-1	197	9/25/96 0:00	2.82
630	(D-17-2) 25aad-1	203	10/16/96 0:00	0.04
631	(D-17-2) 25cbd-1	109	10/8/96 0:00	1.70
633	(D-17-2) 25dcd-1	120	10/8/96 0:00	0.89
635	(D-17-2) 25ddc-2	127	10/8/96 0:00	1.00
637	(D-17-2) 26abc-1	183	5/14/97 0:00	<0.02
638	(D-17-2) 26dbd-1	243	10/16/96 0:00	2.28

Appendix (continued)

Well ID #	Location	Depth of well (feet)	Sampling date	Nitrogen NO_2+NO_3 dissolved (mg/L as N)
641	(D-17-2) 35cac-1	145	10/8/96 0:00	1.74
642	(D-17-2) 35cba-1	180	10/8/96 0:00	<.02
640	(D-17-2) 35cbb-1	147	10/8/96 0:00	1.38
643	(D-17-2) 35cca-1	182	10/8/96 0:00	1.43
644	(D-17-2) 35cdc-1	46	10/8/96 0:00	2.05
645	(D-17-2) 35daa-1	105	10/8/96 0:00	3.08
646	(D-17-2) 35dbb-1	220	10/16/96 0:00	<.02
647	(D-17-2) 35dbc-1	147	10/8/96 0:00	2.29
648	(D-17-2) 36ada-1	87	10/9/96 0:00	2.15
649	(D-17-2) 36bbd-1	96	10/8/96 0:00	1.90
651	(D-17-2) 36bda-1	104	9/25/96 0:00	3.73
654	(D-17-2) 36dbb-1	124	10/16/96 0:00	2.54
659	(D-17-3) 3acc-1	97	10/3/96 0:00	0.32
661	(D-17-3) 4bbb-1	92	10/1/96 0:00	0.18
664	(D-17-3) 5aac-1	198	10/1/96 0:00	1.09
665	(D-17-3) 5acc-1	171	5/14/97 0:00	2.25
666	(D-17-3) 5ada-1	182	10/9/96 0:00	2.65
667	(D-17-3) 5bad-1	204	10/1/96 0:00	0.38
668	(D-17-3) 5cad-1	136	10/2/96 0:00	3.02
669	(D-17-3) 5cad-2	265	10/1/96 0:00	2.48
671	(D-17-3) 5cac-1	-	10/9/96 0:00	2.32
672	(D-17-3) 5cda-1	151	10/1/96 0:00	3.27
674	(D-17-3) 5cdd-2	149	10/1/96 0:00	6.89
675	(D-17-3) 5dba-1	229	10/1/96 0:00	6.32
676	(D-17-3) 5dbb-1	98	10/9/96 0:00	1.98
677	(D-17-3) 6acd-1	100	10/2/96 0:00	2.72
678	(D-17-3) 6bca-1	249	9/25/96 0:00	3.92
679	(D-17-3) 6cdd-1	171	9/25/96 0:00	5.17
681	(D-17-3) 6cdd-2	193	10/7/96 0:00	0.55
682	(D-17-3) 6daa-1	131	10/1/96 0:00	1.45
684	(D-17-3) 7bbd-1	199	10/7/96 0:00	2.70
686	(D-17-3) 7dcd-1	186	10/1/96 0:00	3.10
688	(D-17-3) 8baa-1	235	10/1/96 0:00	3.19
690	(D-17-3) 8cac-1	209	10/2/96 0:00	3.07
694	(D-17-3) 8ddd-2	83	10/1/96 0:00	1.97
695	(D-17-3) 9baa-1	90	10/1/96 0:00	3.20
706	(D-17-3) 15cbb-1	205	10/1/96 0:00	1.06
712	(D-17-3) 16bdd-1	145	10/2/96 0:00	2.27
713	(D-17-3) 16ddd-3	210	5/14/97 0:00	-
"	" "	"	10/2/96 0:00	0.52
714	(D-17-3) 16cda-1	160	10/2/96 0:00	1.54
717	(D-17-3) 16ddd-1	160	10/3/96 0:00	0.29
720	(D-17-3) 17bad-2	78	10/1/96 0:00	3.32
722	(D-17-3) 17dba-1	140	10/2/96 0:00	2.03
726	(D-17-3) 18adc-1	178	10/2/96 0:00	4.96
724	(D-17-3) 18dbb-2	158	10/16/96 0:00	5.07
725	(D-17-3) 18dbd-1	136	10/2/96 0:00	2.40
727	(D-17-3) 19bca-1	131	10/16/96 0:00	4.01
730	(D-17-3) 20bdc-1	70	10/2/96 0:00	3.34
732	(D-17-3) 20dba-1	157	10/2/96 0:00	1.31
734	(D-17-3) 21bbc-1	135	10/2/96 0:00	1.01
742	(D-17-3) 30bac-1	165	10/16/96 0:00	0.65
743	(D-17-3) 30ccc-1	160	10/9/96 0:00	<.02
747	(D-17-3) 31ada-1	77	10/9/96 0:00	8.57
748	(D-17-3) 31bad-1	126	10/9/96 0:00	<.02
"	" "	"	9/14/99 0:00	3.45*
749	(D-17-3) 31bba-1	186	10/9/96 0:00	3.19
750	(D-17-3) 31caa-1	100	10/9/96 0:00	0.09
752	(D-17-3) 31dba-1	74	10/2/96 0:00	3.19
754	(D-17-3) 32cab-1	152	10/2/96 0:00	3.46
756	(D-18-2) 1aad-1	73	10/9/96 0:00	0.29
757	(D-18-2) 1aad-2	60	10/9/96 0:00	0.85

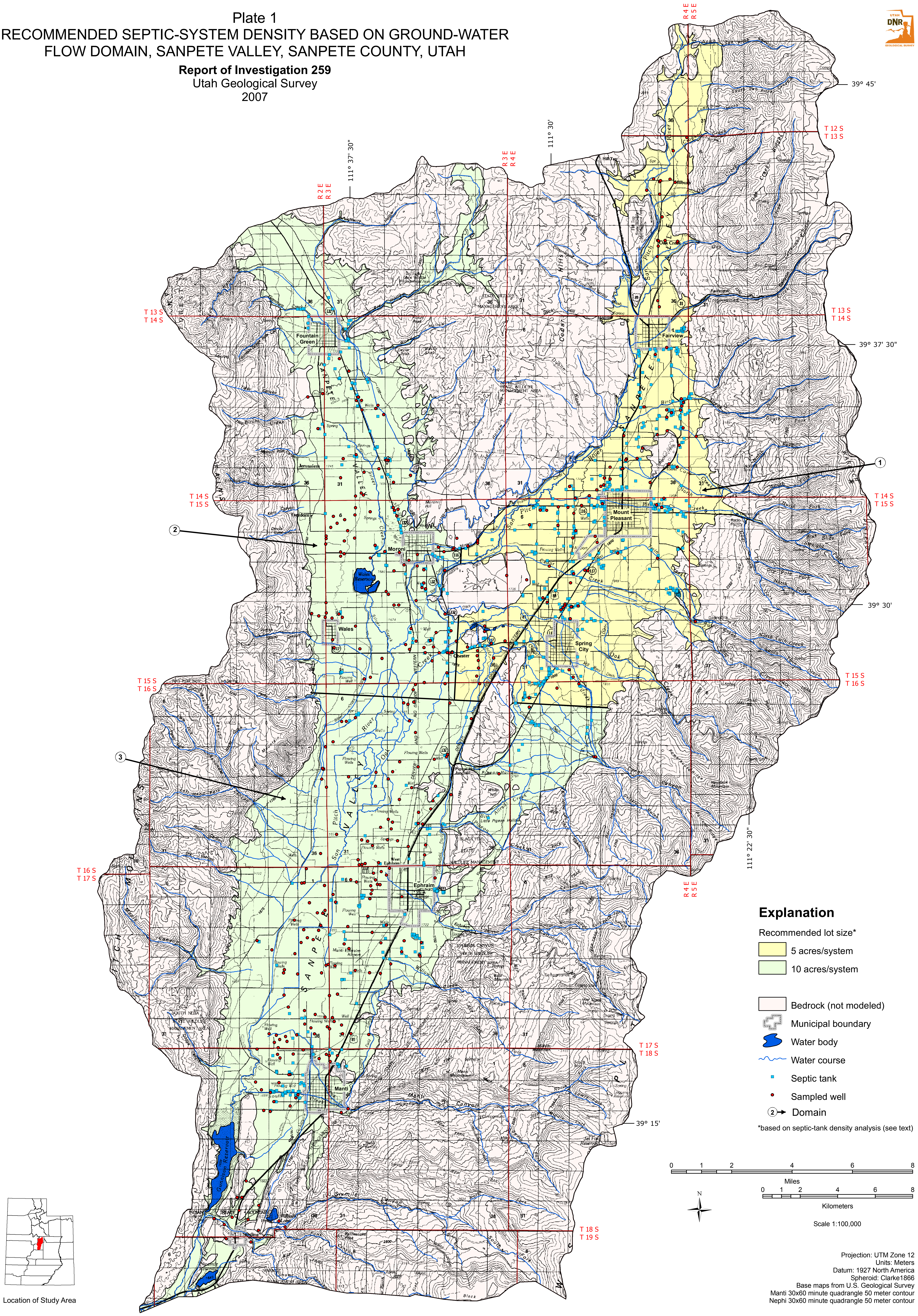
Appendix (continued)

Well ID #	Location	Depth of well (feet)	Sampling date	Nitrogen NO_2+NO_3 dissolved (mg/L as N)
758	(D-18-2) 1aca-1	64	10/9/96 0:00	3.38
759	(D-18-2) 1bba-1	76	10/16/96 0:00	0.95
760	(D-18-2) 1bbd-1	60	9/25/96 0:00	0.15
770	(D-18-2) 2aac-1	71	10/16/96 0:00	2.22
764	(D-18-2) 2abd-1	152	10/17/96 0:00	0.91
768	(D-18-2) 2bac-1	121	10/8/96 0:00	1.65
769	(D-18-2) 2bba-1	108	9/25/96 0:00	1.35
771	(D-18-2) 2bda-1	147	10/8/96 0:00	1.12
772	(D-18-2) 2dca-1	46	10/16/96 0:00	0.28
773	(D-18-2) 2dcd-1	41	10/16/96 0:00	0.65
775	(D-18-2) 3abb-1	65	5/14/97 0:00	<0.02
776	(D-18-2) 10abb-1	60	10/16/96 0:00	2.21
777	(D-18-2) 10adc-1	42	5/14/97 0:00	<0.02
780	(D-18-2) 11add-1	-	10/17/96 0:00	2.12
781	(D-18-2) 11bac-1	145	10/16/96 0:00	<.02
782	(D-18-2) 11bcc-1	39	10/16/96 0:00	2.22
784	(D-18-2) 11cca-1	118	10/16/96 0:00	1.86
785	(D-18-2) 11daa-1	85	10/9/96 0:00	1.05
786	(D-18-2) 11dad-1	135	10/9/96 0:00	<.02
787	(D-18-2) 11dcd-1	80	10/16/96 0:00	1.68
791	(D-18-2) 14bbb-1	123	10/16/96 0:00	0.84
792	(D-18-2) 15aab-1	107	10/16/96 0:00	0.83
796	(D-18-2) 27bdc-1	75	11/5/96 0:00	40.16
"	" "	"	8/27/97 0:00	45.30
"	" "	"	9/14/99 0:00	33.4*
797	(D-18-2) 27ccd-1	60	11/5/96 0:00	1.16
798	(D-18-2) 34abd-1	60	11/5/96 0:00	22.42
"	" "	"	9/14/99 0:00	0.09*
799	(D-18-2) 33aac-1	100	11/5/96 0:00	2.72
800	(D-18-2) 28ddd-1	50	11/5/96 0:00	4.45
802	(D-18-2) 32ada-1	43	11/5/96 0:00	0.74
803	(D-18-2) 33abd-1	80	11/5/96 0:00	7.25
"	" "	"	9/14/99 0:00	4.72*
805	(D-18-2) 33acb-1	63	11/5/96 0:00	2.26
808	(D-18-2) 33cab-1	260	11/5/96 0:00	4.41
810	(D-18-2) 34bcb-1	60	5/14/97 0:00	0.05
811	(D-18-2) 34cda-1	137	11/5/96 0:00	0.83
815	(D-18-2) 35cad-1	63	10/23/96 0:00	0.33
816	(D-18-2) 35dcc-1	85	10/23/96 0:00	0.53
"	" "	"	10/23/96 0:00	0.53
818	(D-18-3) 6bac-1	66	10/9/96 0:00	0.86
819	(D-18-3) 6bcc-1	85	10/8/96 0:00	1.97
824	(D-18-3) 7dcd-1	90	10/10/96 0:00	6.20
825	(D-18-3) 18baa-1	80	10/10/96 0:00	5.02
826	(D-19-2) 3bbd-1	265	11/5/96 0:00	<.02
828	(D-19-2) 4baa-1	99	11/5/96 0:00	3.76
835	(D-19-2) 20dcb-1	60	11/5/96 0:00	0.63
836	(D-19-2) 29bdc-1	200	11/5/96 0:00	11.86
"	" "	"	9/14/99 0:00	0.36*
837	(D-19-2) 32aac-1	166	10/23/96 0:00	0.62
842	(D-20-2) 6dcd-1	200	10/23/96 0:00	0.04
845	(D-20-2) 18aaa-1	140	10/23/96 0:00	0.36
997	(D-16-3) 32 cbb-1	200	9/24/96 0:00	0.04
998	(D-15-3) 35bbb-1	no log	8/21/96 0:00	0.18
999	(D-15-3) 9cad-1	300	5/13/97 0:00	0.97
1001	(D-19-2) 29bdc-1	-	5/14/97 0:00	0.40
1002	(D-19-2) 29bab-1	-	5/14/97 0:00	0.33
1006	(D-15-3) 35bbb-1	-	5/13/97 0:00	3.69

* These highlighted wells were sampled by the Utah Geological Survey; all others were sampled by the Utah Division of Water Quality.

Plate 1
RECOMMENDED SEPTIC-SYSTEM DENSITY BASED ON GROUND-WATER FLOW DOMAIN, SANPETE VALLEY, SANPETE COUNTY, UTAH

Report of Investigation 259
Utah Geological Survey
2007



Explanation

Recommended lot size*

🟨	5 acres/system
🟩	10 acres/system
▢	Bedrock (not modeled)
▨	Municipal boundary
🟦	Water body
～	Water course
■	Septic tank
●	Sampled well
②→	Domain

*based on septic-tank density analysis (see text)

0 1 2 4 6 8
Miles

0 1 2 4 6 8
Kilometers

N

Scale 1:100,000

Projection: UTM Zone 12
Units: Meters
Datum: 1927 North America
Spheroid: Clarke1866
Base maps from U.S. Geological Survey
Manti 30x60 minute quadrangle 50 meter contour
Nephi 30x60 minute quadrangle 50 meter contour