Sanderson, Lowe, Wallace, Kneedy

GROUND-WATER SENSITIVITY AND VULNERABILITY TO PESTICIDES, UTAH AND GOSHEN VALLEYS, UTAH COUNTY, UTAH

UGS MP 02-10

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by

Ivan D. Sanderson
Utah Department of Agriculture and Food

and

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Utah Geological Survey

Irrigated fields in the vicinity of American Fork, Utah. Photo by Ron Ollis.

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TABLE OF CONTENTS

FIGURES

TABLES

PLATES

GROUND-WATER SENSITIVITY AND VULNERABILITY TO PESTICIDES, UTAH AND GOSHEN VALLEYS, UTAH COUNTY, UTAH

by

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ABSTRACT

The U.S. Environmental Protection Agency is recommending that states develop Pesticide Management Plans for four agricultural chemicals – alachlor, atrazine, metolachlor, and simazine – herbicides used in Utah in the production of corn and sorghum. This report and accompanying maps are intended to be used as part of these Pesticide Management Plans to provide local, state, and federal government agencies and agricultural pesticide users with a base of information concerning sensitivity and vulnerability of ground water to agricultural pesticides in Utah and Goshen Valleys, Utah County, Utah. We used existing data to produce pesticide sensitivity and vulnerability maps by applying an attribute ranking system specifically tailored to the Western United States using Geographic Information System analysis methods.

Ground-water sensitivity to pesticides is determined by assessing natural factors favorable or unfavorable to the degradation of ground water by pesticides applied to or spilled on the land surface. Hydrogeologic setting (vertical ground-water gradient and presence or absence of confining layers), soil hydraulic conductivity, retardation of pesticides, attenuation of pesticides, and depth to ground water are the five factors primarily determining ground-water sensitivity to pesticides in Utah and Goshen Valleys. Areas of high sensitivity are generally located along the valley margins where soils typically have relatively high hydraulic conductivity, and ground water is either shallow with no overlying confining layers or insufficient data are available to determine depth to shallow ground water.

Ground-water vulnerability to pesticides is determined by assessing how ground-water sensitivity is modified by the activities of humans. Ground-water sensitivity to pesticides, the presence of applied water (irrigation), and crop type are the three factors generally determining ground-water vulnerability to pesticides in Utah and Goshen Valleys. Areas of high vulnerability are primarily located along valley margins where ground water is at depths of less than 3 feet (1 m) or the depth to shallow ground water is unknown. Of particular concern are areas where influent (losing) streams originating in mountainous areas cross the valley margin; streams in these areas are the most important source of recharge to the basin-fill aquifer and efforts to preserve water quality in streams at these points would help to preserve ground-water quality in the entire basin.

Because of relatively high retardation (long travel times of pesticides in the vadose zone) and attenuation (short half-lives) of pesticides in the soil environment, pesticides applied to fields in Utah and Goshen Valleys likely do not represent a serious threat to ground-water quality. To verify this conclusion, ground-water sampling by the Utah Department of Agriculture and Food should be concentrated in areas of moderate and high sensitivity or vulnerability, typically along valley margins. Sampling in the central areas of the valleys characterized by low sensitivity and vulnerability should continue, but at a lower density than in areas of higher sensitivity and vulnerability.

INTRODUCTION

Background

The U.S. Environmental Protection Agency (EPA) is recommending that states develop Pesticide Management Plans (PMPs) for four agricultural chemicals that in some areas impact ground-water quality. These chemicals – herbicides used in production of corn and sorghum – are alachlor, atrazine, metolachlor, and simazine. All four chemicals are applied to crops in Utah. In some areas of the United States where these crops are grown extensively, these pesticides have been detected as contaminants in ground water. Such contamination poses a threat to public health, wildlife, and the environment. In many rural and agricultural areas throughout the United States – and particularly in the state of

Utah – ground water is the primary source of drinking and irrigation water.

This report and accompanying maps provide federal, state, and local government agencies and agricultural pesticide users with a base of information concerning vulnerability of ground water to agricultural pesticides in Utah and Goshen Valleys, Utah County, Utah (figure 1). This study, conducted jointly by the Plant Industry Division of the Utah Department of Agriculture and Food (UDAF) and the Utah Geological Survey (UGS), provides needed information on ground-water sensitivity and vulnerability to pesticides in the unconsolidated basin-fill aquifers of Utah and Goshen Valleys. Geographic variation in sensitivity and vulnerability, together with hydrologic and soil conditions that cause these variations, are described herein; plates 1 and 2 show the sensitivity and vulnerability, respectively, of the unconsolidated basin-fill aquifers in Utah and Goshen Valleys to agricultural pesticides.

Sensitivity to pesticides is determined by assessing natural factors favorable or unfavorable to the degradation of ground water by pesticides applied to or spilled on the land surface, whereas vulnerability to pesticides is determined by assessing human-induced factors and their response to natural factors. For this study, sensitivity incorporates hydrogeologic setting including vertical ground-water gradient, depth to ground water, and presence or absence of confining layers along with the soils' hydraulic conductivity, bulk density, organic content, and field capacity. Sensitivity also includes the influence of pesticide properties such as the capacity of molecules to adsorb to organic carbon in soil and the half-life of a pesticide under typical soil conditions. Vulnerability includes human-controlled factors such as whether agricultural lands are irrigated, crop type, and amount and type of pesticide applied.

Purpose and Scope

The purpose of this project is to investigate sensitivity and vulnerability of ground-water resources in Utah and Goshen Valleys, Utah to contamination from agricultural pesticides. This information may be used by federal, state, and local government officials and pesticide users to reduce the risk of ground-water pollution from pesticides, and to focus future ground-water quality monitoring by the UDAF.

The project scope is limited to the use and interpretation of existing data to produce pesticide sensitivity and vulnerability maps through the application of Geographic Information System (GIS) analysis methods. No new field work was conducted or data collected as part of this project.

GENERAL DISCUSSION OF PESTICIDE ISSUE

Introduction

Ground water is the primary source of water in many rural areas for human consumption, irrigation, and animal watering. Therefore, the occurrence of agricultural pesticides in ground water represents a threat to public health and the environment. Springs and drains flowing from contaminated aquifers may present a hazard to wildlife that live in or consume the water. When we better understand the mechanisms by which pesticides migrate into ground water, we are better able to understand what geographic areas are more vulnerable – and thus deserving of more concentrated efforts to protect ground water – than other less vulnerable areas. The ability to delineate areas of greater and lesser vulnerability allows us to apply mitigating or restrictive measures to vulnerable areas without interfering with the use of pesticides in the less vulnerable areas.

The rise of the United States as the world's foremost producer of agricultural products since the end of World War II may be attributed, to a significant extent, to widespread use of pesticides. Control of insect pests that would otherwise devour the developing crop, together with control of weeds that interfere with growth and optimum crop development, permit higher quality commodities in greater abundance at lower net cost. Effective use of pesticides often means the difference between profitability and financial ruin for an agricultural enterprise.

When evidence shows pesticides are degrading the environment, harming sensitive wildlife, or posing a public health threat, two regulatory courses of action are available: (1) ban further use of the offending chemical, or (2) regulate it so that judicious use mitigates the degradation or threat. Since the four subject herbicides play an essential role in crop production and profitability, banning them outright is unnecessarily severe if the desired environmental objectives can be met by regulation and more judicious use of these herbicides.

The case of DDT illustrates dilemmas faced by pesticide regulators. DDT was removed from widespread use in the United States in the 1970s because of its deleterious effects on bald eagles, ospreys, and peregrine falcons. Populations of these once-endangered species have recovered to a significant extent 25 years later (Environmental Defense Fund, 1997). An ongoing effort to extend the DDT ban worldwide is being hotly contested by advocates of its judicious use as a critical and inexpensive insecticide needed in developing countries to control mosquitoes that transmit the malaria parasite. It is further argued that, given the current regulatory apparatus, were the use of DDT to be re-evaluated today under rigorous scientific and regulatory criteria, it would be restricted to specific uses rather than prohibited (Okosoni and Bate, 2001).

The EPA has developed guidelines and provided funding for programs to address the problem of pesticide contamination of ground water, including a generic PMP to be developed by state regulatory agencies having responsibility for pesticides. Utah's generic plan was approved by the EPA in 1997 (Utah Department of Agriculture and Food, 1997). Its implementation involves, among other things, establishment of a GIS database containing results of analyses of samples collected from wells, springs, and drains showing concentrations of pesticides and other constituents that reflect water quality. Implementation of the PMP also involves development of a set of maps showing varying sensitivity and vulnerability of ground water to contamination by pesticides.

Since its inception in 1994, the UDAF sampling program has revealed no occurrences of pesticide contamination in any aquifer in over 1,500 samples tested statewide (Quilter, 2001). Under the generic PMP, should an instance of

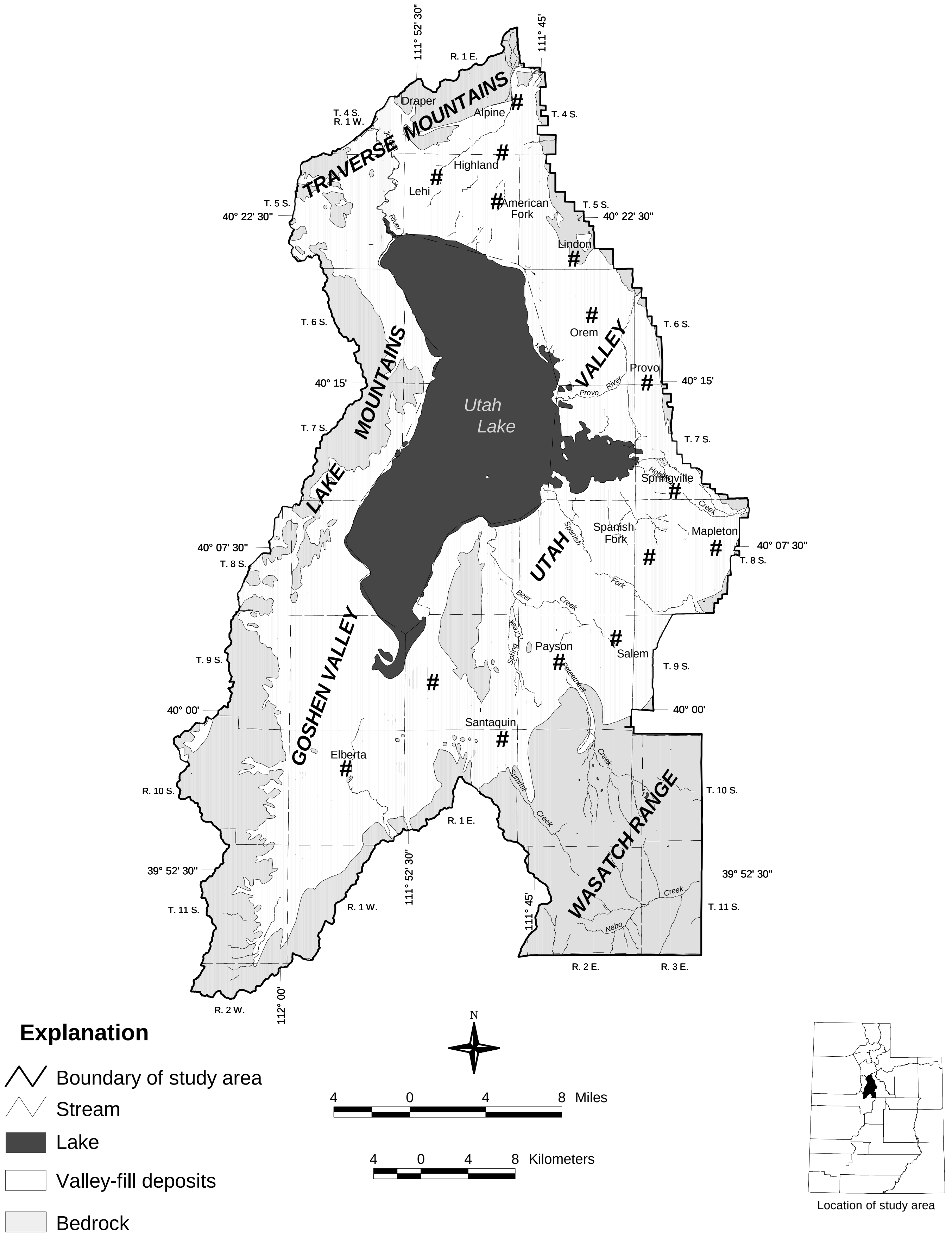

Figure 1. *Utah and Goshen Valleys, Utah County, Utah, location map.*

pesticide contamination be found and verified, a chain of events to monitor and evaluate the contamination is begun that may culminate in cancellation or suspension of the offending pesticide's registration at the specific local level (Utah Department of Agriculture and Food, 1997). Identification of the appropriate area for pesticide registration, cancellation, or suspension requires the specific knowledge presented in this report and on the accompanying maps of varying sensitivity and vulnerability of ground water to pesticide contamination, conditions that result in these variations, and their geographic distribution.

Federal government agencies have been aware of the growing problem of pesticide contamination of ground water since the early 1980s. Cohen and others (1984) reviewed data from occurrences of 12 pesticides in ground water in 18 states. Cohen and others (1986) reported at least 17 occurrences of pesticides in ground water in 23 states. By the early 1990s, EPA began formulating and implementing programs to address the problem.

In 1985 EPA published a standardized system for evaluating the potential for ground-water pollution on the basis of hydrogeologic setting (Aller and others, 1985). The method, known under the acronym DRASTIC, involves assigning numerical values to seven parameters and totaling a score. Under this system, the higher the score, the greater the assumed sensitivity of ground water to pesticide contamination. Ranges in the numerical score are easily plotted on GIS maps. Measured parameters include depth to the water table, recharge, aquifer media, soil media, topography, impact of the vadose zone, and hydraulic conductivity of the aquifer – with the beginning letter of key words in these parameters forming the acronym DRASTIC. Eventually, it became apparent that this method is unreliable in some settings and that it fails to consider the chemical characteristics of the potential contaminants and their interaction with soil and water in the vadose zone. As a result, no significant correlation exists between predicted pesticide detections and observed conditions (Banton and Villenueve, 1989). Other deficiencies are that characteristics of the aquifer media have little bearing on the behavior of pesticides moving through soil in the vadose zone, that areas adjacent to effluent (gaining) rivers and streams are often incorrectly identified as being the most sensitive, and that soil media, impact of the vadose zone, and depth to the water table are all asking the same fundamental questions in different ways. The assigned numerical values in the DRASTIC method poorly represent variables as actually observed. For example, depth to the water table should be logarithmic rather than linear because the potential for impacting ground water decreases much more rapidly with depth than is represented by the linear decrease in numerical scoring used in the method (Siegel, 2000).

Rao and others (1985) developed indices for ranking the potential for pesticide contamination of ground water. The approach has been described as "a nice and widely acknowledged blend of process concepts and indexing methods. Conceptually the science is valid and the approach seems to work well" (Siegel, 2000). The method of Rao and others (1985) involves calculation of a retardation factor and an attenuation factor that characterize movement and persistence of pesticides in the vadose zone, respectively. These factors vary with different soil properties and different characteristics of specific pesticides. Equations for these indices enable calibration of hydrogeologic and other data to more realistically represent actual conditions. These indices, together with hydrogeologic data, provide the basis in this report for delineation of areas that are vulnerable to pesticide contamination of ground water.

Ground-Water Quality Standards

Maximum contaminant levels (MCLs) for pesticides in drinking water are established in R309-103-2.1, Utah Administrative Code, and also in 40 CFR 141.61. MCLs are given in table 1 below. Metolachlor is not listed in either regulation.

Table 1. *Maximum contaminant levels for pesticides in drinking water.*

Contaminant	Maximum Contaminant Level (MCL)	
Alachlor	0.002 µg/L	2 µg/L
Atrazine	0.003 µg/L	3 µg/L
Metolachlor	--	--
Simazine	0.004 µg/L	4 µg/L

Standards for crop irrigation and livestock watering have not been established. However, some crops would require even higher standards for herbicides than those set for human consumption to avoid crop damage.

Under Utah's PMP, if a pesticide is detected in ground water and confirmed by subsequent sampling and analysis as being greater than 25 percent of the established MCL, a process is set into motion that may eventually result in regulation or revocation of the pesticide's registration for use in the affected area as delineated in this report and the accompanying maps.

Ground-Water Contamination by Pesticides

The interplay between hydrogeological setting, ground-water recharge, soil conditions, pesticide use, and pesticide behavior in the vadose zone determines whether ground water in a particular area is likely to become contaminated with pesticides. The quantity and types of pesticides being applied are critical factors. Although pesticide use is highly variable and cannot be precisely monitored, the distribution of crop types and the quantities of pesticides sold to applicators may be used to obtain a general approximation. Ultimately, the only reliable method for detecting ground-water contamination by pesticides is an adequate ground-water monitoring program, with special emphasis on areas where these pesticides are being applied and areas where such application is most likely to impact ground water.

Vulnerability is determined on the basis of whether irrigation is used, what crops are being grown, and which pesticides are generally applied to particular crops. Areas of corn and sorghum production, in particular, would indicate areas where atrazine and similar herbicides might be used. Pesticide application should be monitored more closely in areas of corn and sorghum production than in other areas to ensure that these herbicides are not impacting ground water.

Mechanisms of Pollution

In areas of Utah and Goshen Valleys where ground water is unconfined, degradation of the basin-fill aquifer by pesticides would occur whenever chemicals infiltrate through the vadose zone to the aquifer. In confined aquifer settings, pesticides would need to find pathways through confining layers to cause water-quality degradation. Thus, the ability of soils at the application site to retard or attenuate the downward movement of pesticides, and the hydrogeologic setting where the pesticides are applied, have a fundamental effect on the likelihood that a pesticide will travel downward to the basin-fill aquifer. Surface irrigation could cause a decrease in the retardation and attenuation of pesticides in some settings – especially in areas where corn, sorghum, or soybeans are grown – because the types of pesticides evaluated in this study are commonly applied to those crops. Withdrawal of water from the basin-fill aquifer via water wells could cause changes in vertical head gradient that may increase the potential for water-quality degradation. Also, the wells themselves, if not properly constructed, could provide pathways for pesticides to reach the basin-fill aquifer.

PREVIOUS STUDIES

Early geologic work in Utah and Goshen Valleys included Gilbert's (1890) study of Lake Bonneville, which included descriptions of features in Utah and Goshen Valleys. Lindgren and Loughlin (1919) briefly described the unconsolidated deposits of Goshen Valley and delineated Lake Bonneville sediments as a separate Quaternary map unit. Lee (1924) included sections on Utah Valley in his discussion of the Great Salt Lake basin. Hunt and others (1953) studied and mapped the Quaternary deposits in northern Utah Valley, and Bissell (1963) studied and mapped the Quaternary deposits in southern Utah Valley, including portions of Goshen Valley; the focus of both of these studies was Lake Bonneville-related geology. Geologic mapping in the study area includes that of Bullock (1951), White (1953), Baker and Crittenden (1961), Baker (1964, 1973), Miller (1982), Davis (1983), and Machette (1992). Swenson and others (1972) mapped soils in Utah Valley, and Trickler and Hall (1984) mapped soils in Goshen Valley.

Richardson (1906) conducted one of the earliest studies of ground water in Utah Valley. Taylor and Thomas (1939) provided water-level measurements from more than 50 wells in the Lehi area. Thomas (in Hunt and others, 1953) compiled and evaluated ground- and surface-water data for northern Utah Valley, and identified four separate basin-fill aquifers based on potentiomentric-surface maps. Subitsky (1962) collected data from the records of selected wells and springs, as well as some water-quality information, for northern Utah Valley. Cordova and Subitsky (1965) updated Thomas' (in Hunt and others, 1953) data on ground-water conditions in northern Utah Valley. Cordova and Mower (1967) performed a large-scale aquifer test in southern Utah Valley. Cordova (1969) published selected hydrologic data for southern Utah Valley and Goshen Valley; Cordova (1970) summarized ground-water conditions in these valleys. Dustin and Merritt (1980) studied the hydrogeology of Utah Lake with emphasis on Goshen Bay. Clark and Appel (1985) provided the most recent description of ground-water conditions in northern Utah Valley. Brooks and Stolp (1995) described the ground-water system in southern Utah Valley and Goshen Valley and provided a three-dimensional ground-water flow model of the system.

SETTING

Physiography

Utah and Goshen Valleys (figure 1) are elongate, north-trending basins, with a combined area of about 660 square miles (1,700 km^2) (Cordova and Subitzky, 1965; Brooks and Stolp, 1995), located in the Wasatch Front valleys section of the Great Basin physiographic province (Stokes, 1977). Utah Valley is bounded by the Wasatch Range to the east and south, the Traverse Mountains to the north, and the Lake Mountains to the west. Goshen Valley is bounded by the East Tintic Mountains to the west, and by Long Ridge and West Mountain to the east. Numerous streams and rivers, originating in the Wasatch, Uinta, Lake, and Traverse Ranges, flow across the Utah Valley floor, discharging into Utah Lake, which is the base level for the drainage basin.

Extensional forces created Utah and Goshen Valleys. Utah Valley is a graben, down-dropped relative to its surroundings by the high-angle normal faults of the Wasatch fault zone to the east (Hunt and others, 1953), and by the Utah Lake normal fault zone to the west (Cook and Berg, 1961). The Utah Valley floor ranges in elevation from less than 4,500 feet (1,372 m) near Utah Lake to 5,200 feet (1,585 m) near the mountains (Clarke and Appel, 1985). The highest point in the drainage basin is Mt. Timpanogos, with an elevation of 11,750 feet (3,581 m). Maximum elevations of peaks in the Lake and Traverse Mountains are about 6,600 (2,012 m) and 7,600 feet (2,317 m), respectively.

Consolidated rocks in the Wasatch, Traverse, and Lake Mountains range in age from Precambrian to Tertiary and include sedimentary, metamorphic, and igneous rocks (Hintze, 1980); limestone and sandstone are the dominant lithologies (Clark and Appel, 1985, figure 3). The Tertiary Salt Lake Formation, primarily tuffaceous mudstones and pebble conglomerate with minor lacustrine limestone, is exposed in the Jordan Narrows and underlies Quaternary deposits within Utah and Goshen Valleys (Hunt and others, 1953).

The valley floor in Utah and Goshen Valleys is underlain by unconsolidated basin fill of varying thickness. The basin fill consists mostly of Quaternary fluvial and lacustrine deposits that interfinger with alluvial-fan deposits along the valley margins (Clark and Appel, 1985). Much of the floors of Utah and Goshen Valleys are covered with offshore lacustrine silt and clay deposited during the Bonneville lake cycle (Hunt and others, 1953; Bissel, 1963) between about 12 and 26 ka (Oviatt and others, 1992, figure 3). Deposition of fine-grained sediments during Lake Bonneville and even earlier deep-lake cycles resulted in several fine-grained layers in the basin fill, separated by coarser grained sediments. The thickness and relative proportion of fine-grained sediments increase toward the center of the valleys. The deepest water well for which records are available is completed in Quaternary basin fill at a depth of 1,200 feet (366 m) below the ground surface (Clarke and Appel, 1985). An oil test well near Spanish Fork is completed in Tertiary sediments at a depth of 13,000 feet (3,962 m) (Dustin and Merritt, 1980); it is not known if these Tertiary deposits are part of the Salt Lake Formation.

Climate

The climate is subhumid to semiarid in southern Utah Valley and Goshen Valley (Brooks and Stolp, 1995) and temperate to semiarid in northern Utah Valley (Clark and Appel, 1985), and is characterized by moderate winters and summers. Temperatures in the valleys range from a normal maximum of about 92.7°F (33.7°C), measured at the Utah Lake-Lehi and Elberta stations, to a normal minimum of about 14.6°F (-9.7°C), measured at the Utah Lake-Lehi station (Ashcroft and others, 1992). Normal annual temperature is 51.6°F (11°C) for southern Utah Valley, measured at the Spanish Fork Powerhouse (Brooks and Stolp, 1995) and about 50°F (10°C) near Elberta and Santaquin (Ashcroft and others, 1992). At the Utah Lake-Lehi, Alpine, and Mt. Timpanogos stations, the mean annual temperature is 48.6°F (9°C) for 1951-80 (Clark and Appel, 1985). The growing season (the number of consecutive frost-free days) in southern Utah Valley and Goshen Valley is from May to October (Brooks and Stolp, 1995). In northern Utah Valley the growing season is from May to mid- to late September, recorded at the Alpine and Utah Lake-Lehi stations (Ashcroft and others, 1992).

For southern Utah Valley and Goshen Valley, normal annual precipitation averages about 20.67 inches (52.5 cm) as recorded at the Spanish Fork Powerhouse station from 1948-92, 18.46 inches (46.9 cm) as recorded at the Santaquin station for data obtained between 1948-92, and 11.41 inches (29 cm) at Elberta for 1928-92 (Ashcroft and others, 1992). In northern Utah Valley, an average of 11.51 inches (29 cm) normal annual precipitation was recorded at the Utah Lake-Lehi station for 1928-92, and 17.54 inches (45 cm) for 1921-90 at the Alpine station. Precipitation by snowfall is common throughout Utah Valley from October through April, but snowstorms have been reported and are not uncommon during September and May (Ashcroft and others, 1992).

Population

From 1990-2000, population in Utah County increased by 39.8 percent (figure 2) (Demographic and Economic Analysis Section, 2001). The current population of Utah County is estimated at 368,536 with a projected population of 446,000 by 2010 (Utah County Planning Department, 1997; Demographic and Economic Analysis Section, 2001). Most of the people in Utah County live in Utah and Goshen Valleys.

GROUND-WATER CONDITIONS

Basin-Fill Aquifer

Ground water in unconsolidated basin-fill deposits in Utah and Goshen Valleys occurs under confined, unconfined, semiconfined, and perched conditions (figure 3) (Clark and Appel, 1985; Brooks and Stolp, 1995; Utah Division of Water Resources, 1997). Thomas (in Hunt and others, 1953) identified four distinct basin-fill aquifers based on potentiometric-surface mapping, but further study by Clark and Appel (1985) and Brooks and Stolp (1995) conclude that no evidence exists to support this contention except near Mapleton Bench between Hobble Creek and Spanish Fork Canyon. There, the surface is underlain by at least one thick, continuous clay layer with some sand and silt which isolate the unconfined aquifer from the main basin-fill aquifer system (Brooks and Stolp, 1995). In most of the basin-fill aquifer system, Clark and Appel (1985) and Brooks and Stolp (1995) conclude that horizontal and vertical movement of ground water occurs in coarser material, and water from deeper deposits is not isolated from water in shallower sediments (Brooks and Stolp, 1995). In their studies, Brooks and Stolp (1995) treat the aquifer as one main ground-water system having variable horizontal and vertical permeability.

The basin-fill aquifer is generally under unconfined conditions along the higher elevation valley margins in alluvial-fan and deltaic deposits adjacent to the surrounding mountains in Utah and Goshen Valleys where it typically consists of coarse, granular, permeable sediments (Utah Division of Water Resources, 1997) and confining layers are thin or absent. Unconfined conditions also exist in flood-plain deposits along stream channels, and in perched water-table aquifers in the benches (Clark and Appel, 1985). A shallow unconfined aquifer is generally present above the confining beds in the central parts of the valleys. Brooks and Stolp (1995) report unconfined conditions within about the upper 50 feet (15 m) of saturated basin-fill deposits in both Utah and Goshen Valleys, with both unconfined and confined conditions present in the main ground-water system. Clark and Appel (1985) describe confined conditions for a shallow aquifer ranging from 10 to 150 feet (3-46 m) thick that is thickest near the mountains and thin near Utah Lake, with the thickest upper confining layer present near Utah Lake. Leaky confined conditions exist in some parts of the aquifer based on water-level declines, indicating vertical movement of water from different water-bearing units. In addition, Clark and Appel (1985) describe a deeper confined aquifer that contains more than one water-bearing unit with a total aquifer thickness of 50 to 200 feet (15-61 m), thickest near the Geneva Steel plant; total thickness is unknown due to lack of wells penetrating the aquifer, but it is at least 600 feet (183 m) deep.

Depth to ground water in southern Utah Valley and Goshen Valley ranges from about 5 feet (1.5 m) below the land surface near Utah Lake to about 400 feet (12 m) below the surface near the mountains (Brooks and Stolp, 1995). Depth to ground water in northern Utah Valley ranges from 0 to about 300 feet (0-91 m) below the land surface (U.S. Geological Survey, 2001). Depth to ground water declined as much as 20 feet (6 m) in some parts of Utah Valley and as much as 12 feet (3.6 m) in northern Goshen Valley over the 30-year period from 1970 to 2000 (Burden and others, 2000, figure 20) (figure 4).

Ground-water flow direction in Utah Valley's principal aquifer is generally from the surrounding mountain fronts toward Utah Lake. In southern Utah Valley, ground water also flows toward Beer Creek and Benjamin Slough. In Go-

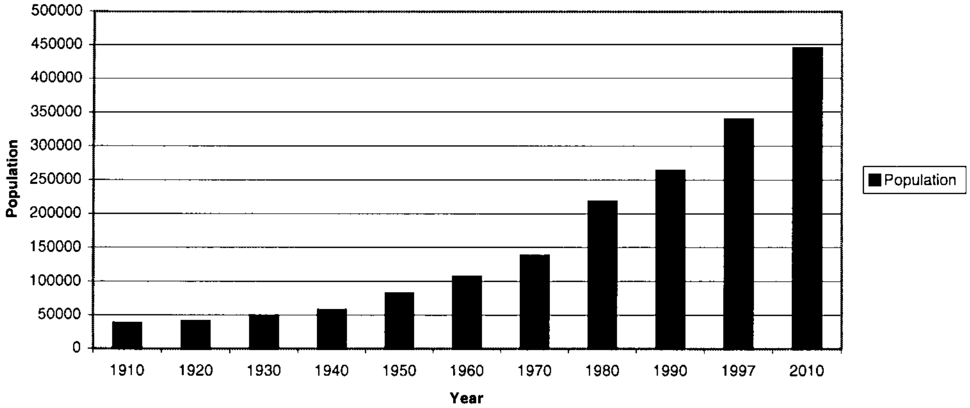

Figure 2. *Population growth chart, Utah County, Utah (Utah County Planning Department, 1997).*

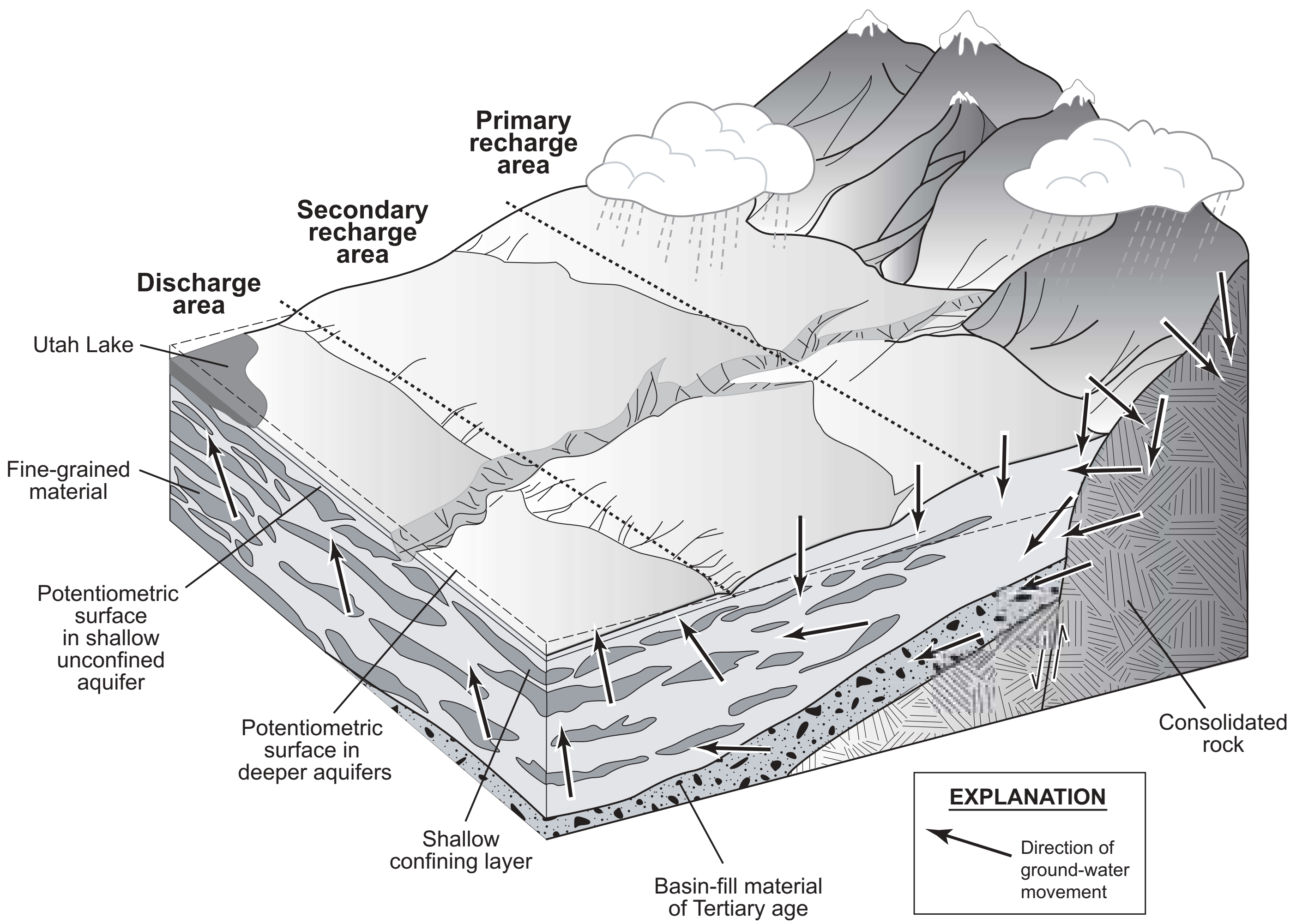

Figure 3. *Schematic block diagram showing the basin-fill ground-water system.*

shen Valley, ground water flows toward a ground-water withdrawal area south of Elberta (Brooks and Stolp, 1995). In northern Utah Valley, ground water also moves toward the Jordan River and Jordan Narrows (Clark and Appel, 1985).

Recharge to the valley-fill aquifer system in southern Utah Valley and Goshen Valley is from perennial streams and major canals, irrigation and precipitation, runoff, subsurface inflow from bordering mountains, and inflowing stream-channel deposits (Brooks and Stolp, 1995). Estimated recharge for southern Utah and Goshen Valleys for 1990 totals143,000 acre-feet (176 cubic hectometers) (table 2). Recharge to northern Utah Valley is mainly from precipita-

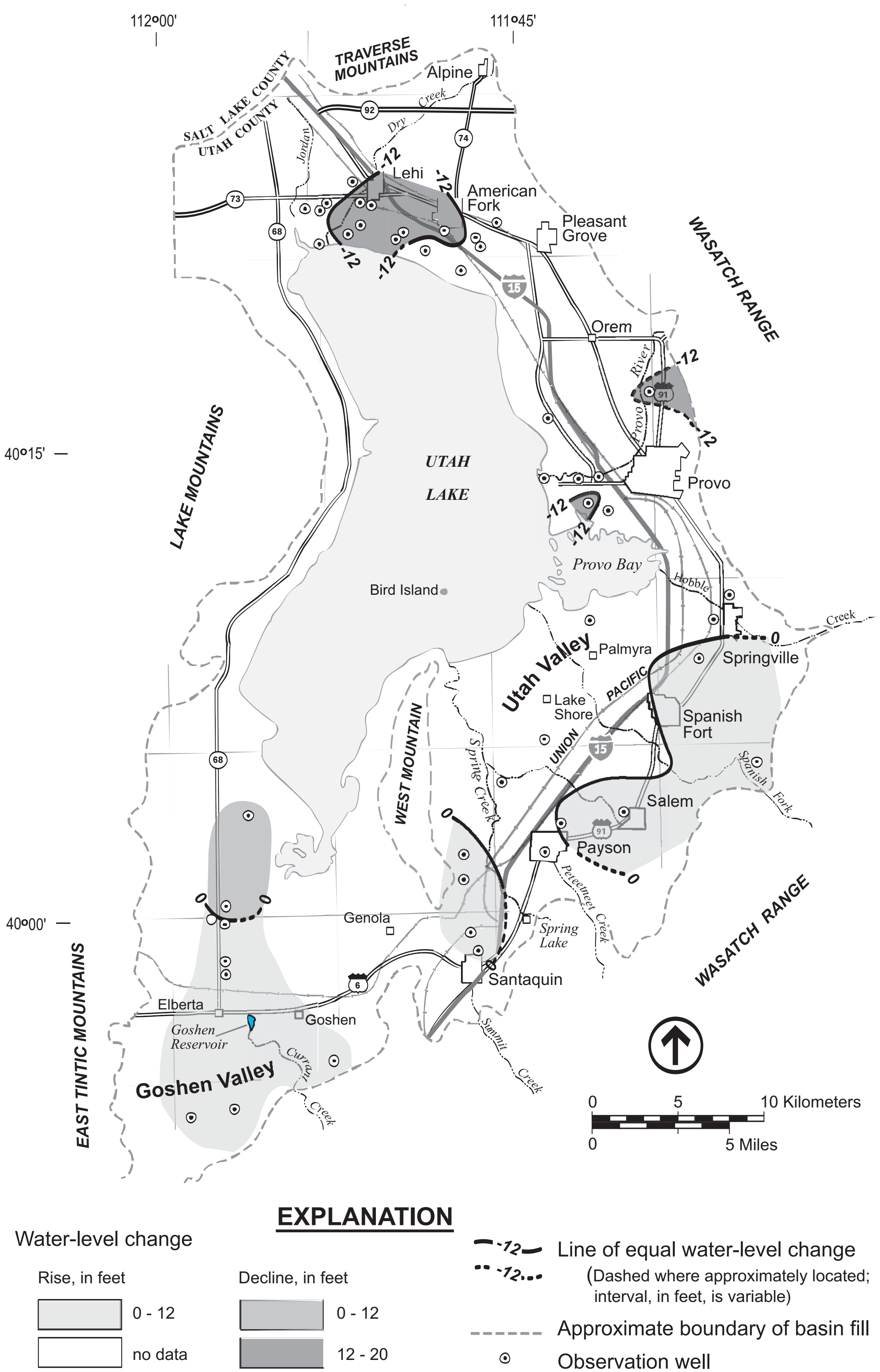

Figure 4. *Change in water level in Utah and Goshen Valleys from March 1970 to March 2000 (modified from Burden and others, 2000).*

Table 2. Estimated budget for the main ground-water system in the unconsolidated basin-fill deposits, southern Utah Valley and Goshen Valley, Utah, 1990 (after Brooks and Stolp, 1995).

Budget element	Annual Amount (acre-feet)		
	Southern Utah Valley	Goshen Valley	Study Combined
Recharge Type			
Perennial streams and major canals	33,400	8,100	41,500
Irrigation and precipitation	14,900	400	15,300
Intermittent and ephemeral runoff	6,400	400	6,800
Intervalley flow[1]	0	7,800	--
Subsurface inflow	[2]65,000	[2]13,000	[2,3]79,000
Total recharge (rounded)	120,000	30,000	143,000
Discharge Type			
Springs and drains	42,700	0	42,700
Evaporation	26,000	14,000	40,000
Pumped wells	14,000	13,500	27,500
Flowing wells	4,400	0	4,400
Perennial streams and major canals	20,700	2,200	22,900
Utah Lake	9,600	3,600	13,200
Sewer systems	5,000	0	5,000
Intervalley flow[1]	7,800	0	--
Total disharge (rounded)	130,000	33,000	156,000

[1]Intervalley flow not used for study area total.
[2]Calculated as a residual of the discharge minus all other forms of recharge.
[3]Total for study area does not equal sum of two valleys because of rounding error.

Table 3. Hydrologic Soil Groups and rankings for retention capacity, bulk density of soil characteristics, and fraction of organic content generalized for Utah soils. Soil description and organic content from National Soil Survey Center (1994). Field capacity calculated from specific-retention data based on sediment grain size (from Bear, 1972). Bulk density from Marshall and Holmes (1988).

Soil Group	Soil Description	Grain Size (mm) (Field Capacity)	Bulk Density Range (kg/L)	Organic Content, Fraction (F_{oc})
A	Sand, loamy sand, or sandy loam; low runoff potential and high infiltration rates even when thoroughly wetted; consists of deep, well to excessively drained sands or gravels with high rate of water transmission.	0.1 - 1 (5-6%)	1.6 - 2	2.44
B	Silt loam or loam; moderate infiltration rate when thoroughly wetted; consists of moderately deep to deep, moderately well to well-drained soils with moderately fine to moderately coarse textures.	0.015 - 0.15 (6-7%)	1.3 - 1.61	3.31
C	Sandy clay loam; low infiltration rates when thoroughly wetted; consists of soils with layer that impedes downward movement of water; soils with moderately fine to fine structure.	0.01 - 0.15 (7-7.5%)	1.3 - 1.9	3.99
D	Clay loam, silty clay loam, sandy clay, silty clay, and/or clay; highest runoff potential of all soil groups; low infiltration rates when thoroughly wetted; consists of clay soils with a high swelling potential, soils with a permanent high water table, soils with a hardpan or clay layer at or near the surface, and shallow soils over nearly impervious material.	0.0001 - 0.1 (6-15%)	1.12	3.35

tion within the Utah Lake drainage basin and was calculated only for the primary recharge area – a narrow band of permeable, unconsolidated sediment at the margins near the mountain fronts (Clark and Appel, 1985). Some recharge is from seepage from streams and irrigation water (Clark and Appel, 1985) (table 3). Estimated annual recharge for the ground-water reservoir in northern Utah Valley is 200,000 acre-feet (247 cubic hectometers) (Clark and Appel, 1985).

Discharge in southern Utah and Goshen Valleys was estimated to be about 156,000 acre-feet (192 cubic hectometers) in 1990, with 122,200 and 33,000 acre-feet (151 and 41 cubic hectometers) for southern Utah Valley and Goshen Valley, respectively (Brooks and Stolp, 1995). Discharge in both areas is by evapotranspiration, springs, drains, well-water withdrawal, streams, canals, seepage to Utah Lake, and by infiltration to the sewer systems (Brooks and Stolp, 1995). Discharge in northern Utah Valley includes evapotranspiration, well-water withdrawal, subsurface outflow, and by springs, drains, ditches, and streams (Clark and Appel, 1985). Average discharge recorded from 1972-82 was approximately 220,000 acre-feet (278 cubic hectometers) (Clark and Appel, 1985). For all of Utah Valley, the Utah Division of Water Resources (1997) reports recharge and discharge as balanced at 450,000 acre-feet (555 cubic hectometers) per year based on data recorded between 1963 and 1995.

Ground-Water Quality

Ground water in Utah Valley is generally good and suitable for most uses (Utah Division of Water Resources, 1997). Figure 5 shows concentration of total dissolved solids for the basin-fill aquifer. Ground water in southern Utah Valley has a range of total-dissolved-solids concentration from 200 to 2,200 mg/L (mg/L is approximately equal to ppm), with most between 200 and 400 mg/L (Brooks and Stolp, 1995). Magnesium and calcium are the major cations and bicarbonate is the major anion (Brooks and Stolp, 1995).

Poorer quality water is present in Goshen Valley, especially along the shore of Goshen Bay and south to the area surrounding the town of Goshen and along Currant Creek, where total-dissolved-solids concentration in ground water ranges from 1,000 to 10,000 mg/L (Price, 1985; Utah Division of Water Resources, 1997) (figure 5). Price (1985) attributes the saline nature of water quality here to an inferred north-trending fault zone between West Mountain and the Lake Mountains. Ground-water quality in northern Utah Valley is generally good with total-dissolved-solids concentrations ranging from less than 100 mg/L to more than 1,000 mg/L (Clark and Appel, 1985), with most wells having total-dissolved-solids values between 100 and 500 mg/L. Cations consist of calcium, magnesium, sodium, and potassium; anions consist of bicarbonate, sulfate, and chloride (Clark and Appel, 1985), with calcium bicarbonate as the dominant type.

METHODS

This study is limited to the use and interpretation of existing data to produce pesticide sensitivity and vulnerability maps through the application of GIS analysis methods. No new field work was conducted nor data collected as part of this project.

Ground-Water Sensitivity to Pesticide Pollution

Ground-water sensitivity to pesticides is determined by assessing natural factors favorable or unfavorable to the degradation of ground water by pesticides applied to or spilled on the land surface. We selected five factors that are most important in determining ground-water sensitivity to pesticides: hydrogeologic setting (vertical ground-water gradient and presence or absence of confining layers), soil hydraulic conductivity, retardation of pesticides, attenuation of pesticides, and depth to ground water.

Hydrogeologic Setting

Hydrogeologic setting is delineated on ground-water recharge-area maps which typically show: (1) primary recharge areas, (2) secondary recharge areas, and (3) discharge areas (Anderson and others, 1994); for our GIS analyses, we assigned hydrogeologic setting to one of these three categories. Primary recharge areas, commonly the uplands and coarse-grained unconsolidated deposits along basin margins, do not contain thick, continuous, fine-grained layers and have a downward ground-water gradient (figure 6). Secondary recharge areas, commonly at mountain-front benches, have fine-grained layers thicker than 20 feet (6 m) and a downward ground-water gradient (figure 6). Ground-water discharge areas are generally in basin lowlands. Discharge areas for unconfined aquifers occur where the water table intersects the ground surface to form springs, seeps, lakes, wetlands, or gaining streams (Snyder and Lowe, 1998) (figure 6). Discharge areas for confined aquifers occur where the ground-water gradient is upward and water is discharging to a shallow unconfined aquifer above the upper confining bed, or to a spring (figure 6). Water from wells that penetrate confined aquifers may flow to the surface naturally. The extent of both recharge and discharge areas may vary seasonally and from dry years to wet years.

Anderson and others (1994) used drillers' logs of water wells in Utah and Goshen Valleys to delineate primary and secondary recharge areas and discharge areas, based on the presence of confining layers and relative water levels in the principal and shallow unconfined aquifers. Although this technique is useful for gaining a general idea of where recharge and discharge are likely located, it is subject to a number of limitations. The use of drillers' logs requires interpretation because of the variable quality of the logs. Correlation of geology from well logs is difficult because lithologic descriptions prepared by various drillers are generalized and commonly inconsistent. Use of water-level data from well logs is also problematic because levels in the shallow unconfined aquifer are often not recorded and because water levels were measured during different seasons and years.

Confining layers are any fine-grained (clay and/or silt) layer thicker than 20 feet (6 m) (Anderson and others, 1994). Some drillers' logs show both clay and sand in the same interval, with no information describing relative percentages; these are not classified as confining layers (Anderson and others, 1994). If both silt and clay are checked on the log and

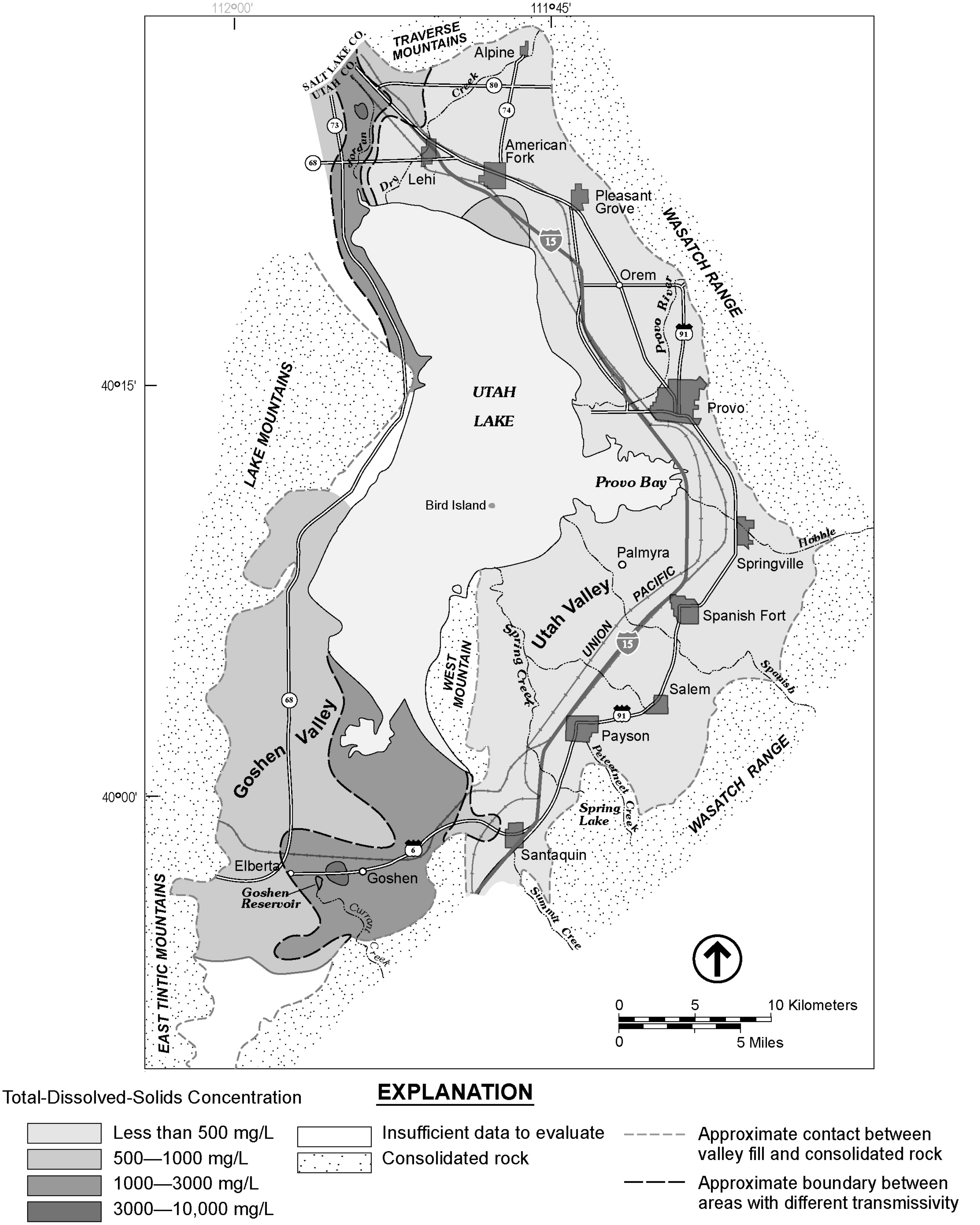

Figure 5. *Total-dissolved-solids concentrations for the basin-fill aquifer, Utah and Goshen Valleys, Utah County, Utah (modified from Price, 1985).*

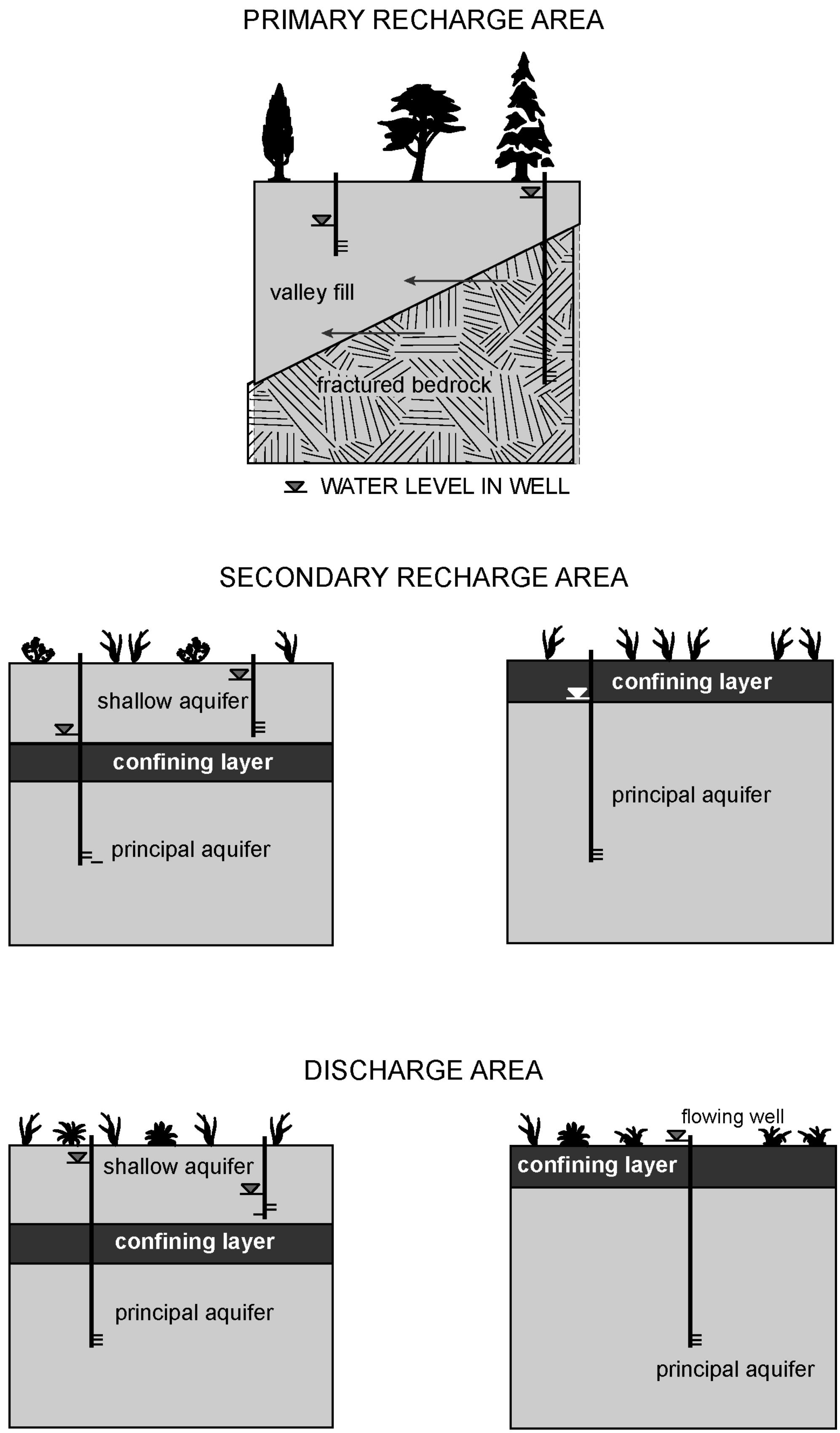

Figure 6. *Relative water levels in wells in recharge and discharge areas (Snyder and Lowe, 1998).*

the word "sandy" is written in the remarks column, then the layer is assumed to be a predominantly clay confining layer (Anderson and others, 1994). Some drillers' logs show both clay and gravel, cobbles, or boulders; these also are not classified as confining layers although in some areas in Utah and Goshen Valleys layers of clay containing gravel, cobbles, or boulders do, in fact, act as confining layers.

The primary recharge area for the principal aquifer system in Utah and Goshen Valleys consists of uplands surrounding the basin, together with basin fill not containing confining layers, generally located along mountain fronts (figures 3 and 6). Ground-water flow in primary recharge areas has a downward component. Secondary recharge areas, if present, are locations where there are confining layers, but ground-water flow still has a downward component. Secondary recharge areas generally extend toward the center of the basin to the point where ground-water flow is upward (figures 3 and 6). The ground-water flow gradient, also called the hydraulic gradient, is upward when the potentiometric surface of the principal aquifer system is higher than the water table in the shallow unconfined aquifer (Anderson and others, 1994). Water-level data for the shallow unconfined aquifer are not abundant, but exist on some well logs. When the confining layer extends to the ground surface, secondary recharge areas occur where the potentiometric surface in the principal aquifer system is below the ground surface.

Ground-water discharge areas, if present, generally occur at lower elevations than recharge areas. In discharge areas, the water in confined aquifers discharges to the land surface or to a shallow unconfined aquifer (figures 3 and 6). For this to happen, the hydraulic head in the principal aquifer system must be higher than the water table in the shallow unconfined aquifer. Otherwise, downward pressure from the shallow aquifer will exceed the upward pressure from the confined aquifer, creating a net downward gradient indicative of secondary recharge areas. Flowing (artesian) wells, indicative of discharge areas, are marked on drillers' logs and sometimes on U.S. Geological Survey 7.5-minute quadrangle maps. Wells with potentiometric surfaces above the top of the confining layer can be identified from well logs. Surface water, springs, or phreatophytic plants characteristic of wetlands can be another indicator of ground-water discharge. In some instances, however, this discharge may be from a shallow unconfined aquifer. An understanding of topography, surficial geology, and ground-water hydrology is necessary before using these wetlands to indicate discharge from the principal aquifer system.

Hydraulic Conductivity of Soils

Hydraulic conductivity is a measure of the rate at which soils can transmit water. Even though fine-grained soils may have low transmissivities, water is nevertheless eventually transmitted. Values for hydraulic conductivity of soils were obtained from soil percolation tests and "permeability" (hydraulic conductivity) ranges assigned to soil units mapped by the U.S. Department of Agriculture Natural Resources Conservation Service (formerly Soil Conservation Service; Swenson and others, 1972; Trickler and Hall, 1984). For our GIS analysis, we divided soil units into two hydraulic conductivity ranges: greater than, and less than or equal to 2 inches (5 cm) per minute. We categorized these by following criteria applied by the Utah Department of Environmental Quality's Division of Water Quality in permitting or not permitting septic tanks. For areas with insufficient hydraulic conductivity data, we applied the greater than 2 inches (5 cm) per minute GIS attribute ranking, described below, to be protective of ground-water quality.

Pesticide Retardation

Retardation (Rao and others, 1985) is a measure of the differential between movement of water and the movement of pesticide in the vadose zone. Since pesticides are adsorbed to organic carbon in soil they move more slowly through the soil than water, depending on the proportion of organic carbon in the soil. This relatively slower movement allows pesticides to be degraded more readily by bacteria and chemical interaction than would be the case if they traveled at the same speed as pore water in the vadose zone. The retardation factor (R_F) is a function of bulk density, organic carbon fraction, and field capacity of the soil and the organic carbon sorption distribution coefficient of the specific pesticide. Rao and others (1985) present the following equation:

$$R_F = 1 + (\rho b\ F_{oc}\ K_{oc})/\theta_{FC} \qquad (1)$$

where:

R_F = retardation factor;
ρb = bulk density (kg/L);
F_{oc} = fraction, organic carbon;
K_{oc} = organic carbon sorption distribution coefficient (mg/kg); and
θ_{FC} = field capacity (volume fraction).

For this study we used data from the Soil Survey Geographic (SSURGO) database (National Soil Survey Center, 1994), which provides digitized data for some soil areas of the state of Utah, including Utah and Goshen Valleys, at a scale of 1:24,000. Data include derived values for bulk density, organic carbon fraction, and field capacity (table 3).

We set variables in equation 1 at values that represent conditions likely to be encountered in the natural environment to establish a rationale for dividing high and low pesticide retardation for our GIS analysis. We used the organic carbon sorption distribution coefficient (table 4) for atrazine at a pH of 7, the pesticide among the four having the least tendency to adsorb to organic carbon in the soil (Weber, 1994). Applying a bulk density of 2.0 kilograms per liter (kg/L) and a field capacity of 5 percent, which represent the naturally occurring extremes that would result in the greatest sensitivity to ground-water contamination, retardation of pesticides relative to vertical ground-water movement ranges from a factor of 1 to 201 percent, depending on soil organic carbon content. Average organic carbon content in soils in Utah and Goshen Valleys is shown in figure 7; note that the lowest category of organic carbon content in soils in Utah and Goshen Valleys is 0 to 2.4 percent. Next, we standardized organic carbon content at a value of 0.1 percent – a value representing a reasonable minimum found in the natural environment at which ground-water quality would still be protected. At this level of organic carbon content, equation 1 results in a retardation factor of 5 percent, meaning that pesticides would travel 5 percent slower through soils in the vadose zone than water. Pesticides under these circumstances traveling downward in the vadose zone would reach the water table at a depth of 3 feet (1 m) within one year if ground-water recharge amounted to 6 inches (5 cm) or greater during the year. Greater proportions of the pesticide reach ground water at that depth with greater annual quantities of ground-water recharge. When ground-water recharge is less than 6 inches (15 cm), no pesticides reach a depth of 3 feet (1 m) in a one-year period (see attenuation discussion below). A natural division between low and high retardation exists at a value of 5 percent. Accordingly, values lower than 5 percent are designated as low retardation and are assigned a ranking value of 1. Values equal to or higher than 5 percent are designated as high retardation and are assigned a ranking value of 0.

Pesticide Attenuation

Attenuation (Rao and others, 1985) is a measure of the rate at which a pesticide degrades under the same conditions as characterized above under retardation. The rate of attenuation indirectly controls the depth to which a pesticide may reasonably be expected to migrate, given the specific conditions. The attenuation factor (A_F) is a function of depth (vertically) or length (horizontally) of the soil layer through which the pesticide is traveling, net annual ground-water recharge, half-life of the specific pesticide considered, and field capacity of the soil. Rao and others (1985) present the following equation:

$$A_F = \exp(-0.693\ z\ R_F\ \theta_{FC}/q\ t_{1/2}) \qquad (2)$$

where:

A_F = attenuation factor;
z = reference depth (or length);
R_F = retardation factor;
θ_{FC} = field capacity (volume fraction);
q = net annual ground-water recharge (precipitation minus evapotranspiration); and
$t_{1/2}$ = pesticide half-life (years).

We set variables in equation 2 at values that represent conditions likely to be encountered in the natural environment, similar to what was done to establish high and low pesticide retardation, to establish a rationale for dividing high and low pesticide attenuation for our GIS analysis. We used a retardation factor of 5 percent, calculated as described above; the half-life for simazine (table 4), the pesticide among the four with the longest half-life (Weber, 1994); a field capacity of 5.0 percent, together with the bulk density value of 2.0 used in the retardation factor calculation described above, which represent the naturally occurring extremes that would result in the greatest sensitivity to ground-water contamination. For a net annual ground-water recharge value of 6 inches (15 cm), equation 2 results in an attenuation factor of 0.02. This means that at the above-described values for variables in the equation, two percent of the pesticide originally introduced into the system at the ground surface would be detected at a depth of 3 feet (1 m) and would enter the ground water. For rates of annual ground-water recharge greater than 6 inches (15 cm), the calculated attenuation factor increases proportionally such that 50 percent of the original volume of pesticide would still be present at a depth of 3 feet (1 m) and would enter the ground water when the annual ground-water recharge rate is 3 feet (1 m). Accordingly, an attenuation factor of 0 is considered low, whereas 0.02 (2 percent) and above is considered high.

For this study, net annual recharge was calculated (using GIS analysis) by subtracting mapped normal annual evapotranspiration (Jensen and Dansereau, 2001) for the 30-year period from 1971 to 2000, from mapped normal annual precipitation (Utah Climate Center, 1991) for the 30-year period from 1961 to 1990. Data from two different 30-year periods were used because normal annual precipitation GIS data are not currently available for the 1971 to 2000 period and normal annual evapotranspiration GIS data are not available for the 1961 to 1990 period. This analysis revealed that all of the moisture produced by precipitation is consumed by evapotranspiration in most parts of the state, including Utah and Goshen Valleys. Therefore, ground-water recharge from precipitation is relatively low in many areas of Utah, including Utah and Goshen Valleys. The only localities in which evapotranspiration is less than precipitation are high-elevation forested areas. These are typically the source areas for surface streams which flow to valleys at lower elevations where they infiltrate the valley-fill sediment, accounting for a large part of ground-water recharge. Irrigation is another component of ground-water recharge, but is not easily measured.

To evaluate the relationship between ground-water recharge and pesticide attenuation, we used the same array of values for variables in the attenuation equation of Rao and others (1985) (equation 2) that we applied to the retardation equation (equation 1), described above. We used the organic carbon sorption distribution coefficient for atrazine (table 4) at a pH of 7 – the pesticide among the four having the least tendency to adsorb to organic carbon in the soil – and the half-life for simazine (table 4), the pesticide among the four with the longest half-life (Weber, 1994). Applying a bulk density of 2.0 kg/L (the maximum anticipated value to be encountered in soil types represented in Utah and Goshen Valleys), a retention capacity of 5.0 percent (the minimum

Table 4. *Pesticide organic carbon sorption distribution coefficients (K_{oc}) and half-lives ($T^1/_2$) for typical soil pHs (data from Weber, 1994).*

	K_{oc} (mg/kg)		$T^1/_2$ (Days)		$T^1/_2$ (Years)
	pH 7	pH 5	pH 7	pH 5	-
Atrazine	100	200	60	30	0.16
Simazine	200	400	90	-	0.25
Alachlor	170	-	20	60	0.05
Metolachlor	150	-	40	-	0.11

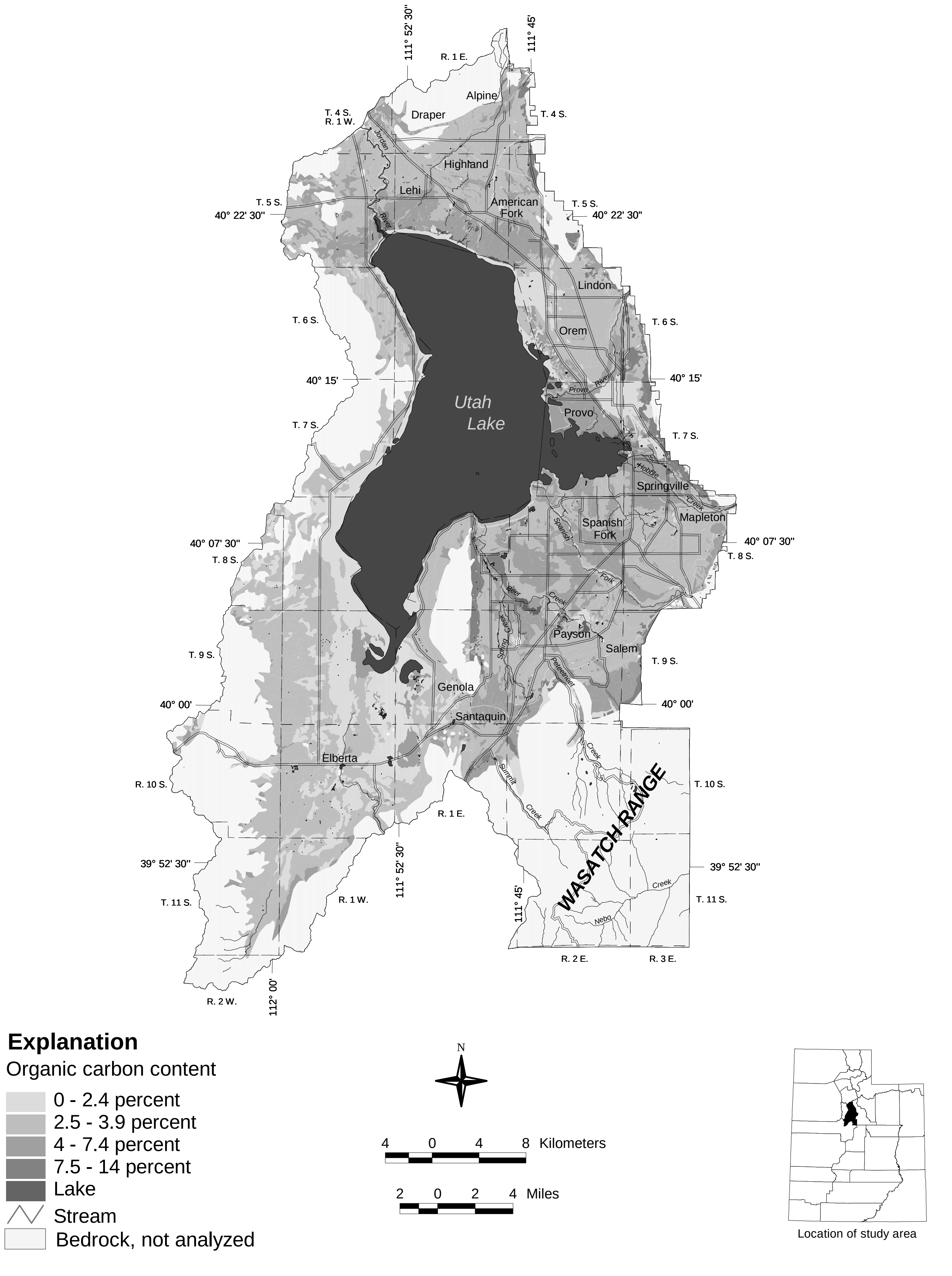

Figure 7. *Average organic carbon content in soils in Utah and Goshen Valleys, Utah County, Utah (data from National Soil Survey Center, 1994).*

anticipated value), and an organic carbon content of 0.1 percent (the minimum value expected in these soils), 100 percent of pesticides would be attenuated before reaching a soil depth of 3 feet (1 m) until ground-water recharge reached a rate of 6 inches (15 cm) per year. In Utah and Goshen Valleys, ground-water recharge would be derived mainly from irrigation. At higher values for organic carbon content, both the retardation factor and the attenuation factor increase dramatically. With greater proportions of organic carbon in the soil, calculations show no amount of pesticide reaching ground water even at hypothetical levels of ground-water recharge as high as 3 feet (1 m) per year.

The exercise of calculating values for retardation and attenuation factors according to hypothetical values for the equation variables enabled us to calibrate assigned rankings of pesticide sensitivity meaningfully according to naturally occurring conditions, thus overcoming one of the major objections to the DRASTIC method. Further, the exercise illustrates that organic soil content exerts a major control on the complex interplay of conditions that increase or decrease the likelihood that pesticides will find their way into the ground water. We found that even with a moderate organic carbon content in the soil, it is unlikely that pesticides will impact the ground water.

Although quantities of pesticides applied to the ground surface empirically would seem to have a direct bearing on the amount of pesticide impacting ground water, Rao and others' (1985) equations do not support this. Note that the quantity of pesticide applied to the ground surface does not enter into either equation as a variable; the half-life of the pesticide, however, is essential. The half-life of a pesticide under typical field conditions remains fairly constant. The larger the quantity of pesticide that is applied, the greater are the number of bacteria that develop to decompose and consume the pesticide over the same period of time. Furthermore, the quantity of pesticide needed to control weeds is quite small. The following recommended application rates (table 5) are provided by the manufacturers of the four herbicides evaluated as part of this study. Pre-emergent herbicides are typically applied once per year, either in the fall after post-season tillage or in early spring before weeds begin to germinate.

Table 5. *Maximum recommended application rates* for the four pesticides discussed in this report.*

Herbicide	Max. Application rate (lbs. AI** per acre)	Time interval
Atrazine	2.5	calendar year
Alachlor	4.05	Preemergence
Metolachlor	1.9	Preemergence
Simazine	4.0	Preemergence

*Data derived from labeling documentation provided by manufacturers; latest update as of January 2001.
**Active ingredient.

Depth to Ground Water

The closer ground water is to the land surface the more sensitive it is to being degraded by pesticides. Based on soil mottling, water encountered in test pits, or other information, soils with shallow ground water seasonally less than 3 feet (1 m) deep is one attribute of soil units mapped by the U.S. Department of Agriculture's Natural Resources Conservation Service (formerly Soil Conservation Service; Swenson and others, 1972; Trickler and Hall, 1984). Three feet (1 m) was selected as the depth-to-ground-water attribute used to evaluate sensitivity of geographic areas to pesticides. For areas where depth-to-ground-water data were not available in GIS format, we applied the less-than-3-feet (1 m) GIS attribute ranking, described below, to be protective of ground-water quality.

GIS Analysis Methods

We divided pesticide sensitivity into "low," "moderate," and "high" categories using hydrogeologic setting, soil hydraulic conductivity, soil retardation of pesticides, soil attenuation of pesticides, and depth to shallowest ground-water attributes as shown on table 6. Numerical ranking for each attribute category is arbitrary but reflects the level of importance we believe the attribute plays in determining sensitivity of areas to application of agricultural pesticides; for instance, we believe hydrogeologic setting is the most important attribute with respect to ground-water sensitivity to pesticides, and therefore weighted this attribute three times more heavily than the other attribute categories. A sensitivity attribute of low was assigned when the numerical ranking ranged from –2 to 0, a sensitivity attribute of moderate was assigned when the numerical ranking ranged from 1 to 4, and a sensitivity attribute of high was assigned when the numerical ranking ranged from 5 to 8.

Ground-Water Vulnerability to Pesticide Pollution

Ground-water vulnerability to pesticides is a measure of how natural factors favorable or unfavorable to the degradation of ground water by pesticides applied to or spilled on the land surface are modified by the activities of humans. We selected ground-water sensitivity to pesticides, presence of applied water (irrigation), and crop type as the three factors primarily determining ground-water vulnerability to pesticides. Our vulnerability map is based on 1995 land-use data.

Ground-Water Sensitivity

We consider ground-water sensitivity to be the principal factor determining the vulnerability of the basin-fill aquifer in Utah and Goshen Valleys to degradation from agricultural pesticides. Low, moderate, and high sensitivity rankings were assigned numerical values as shown in table 6 and described above.

Irrigated Lands

Irrigated lands are mapped from the Utah Division of Water Resources 1:24,000-scale Land Use/Water Related Use GIS data set. Areas of various water-use categories were either mapped from aerial photographs (pre-2000) or 5-meter (16 ft) resolution infared satellite data and then field checked (Utah Division of Water Resources metadata). The Utah and Goshen Valleys inventory was conducted in 1995 (Utah Division of Water Resources metadata). All polygons with standard type codes beginning with IA were selected to produce

Table 6. *Pesticide sensitivity, and the attribute rankings used to assign it, for Utah and Goshen Valleys, Utah County, Utah.*

Pesticide Retardation		Pesticide Attenuation		Hydrogeologic Setting		Soil Hydraulic Conductivity		Depth to Ground Water		Sensitivity	
Attribute	Ranking	Attribute	Ranking	Attribute	Ranking	Attribute	Ranking	Attribute	Ranking	Attribute	Ranking
High	0	High	0	Discharge Area	-4	Less than 1 inch/hour	1	Greater than 3 feet	1	Low	-2 to 0
				Secondary Recharge Area	-1					Moderate	1 to 4
Low	1	Low	1	Primary Recharge Area	2	Greater than 1 inch/hour	2	Less than 3 feet	2	High	5 to 8

the irrigated land coverage for this study. These data do not distinguish areas of sprinkler irrigation versus areas of flood irrigation; areas of flood irrigation are likely to be more vulnerable to degradation from pesticides than areas of sprinkler irrigation.

Agriculture Types

Agricultural lands are mapped from the Utah Division of Water Resources 1:24,000-scale Land Use/Water Related Use GIS data set, which includes categories of crop types. Areas of various crop-type categories were either mapped from aerial photographs (pre-2000) or 5-meter (16 ft) resolution infared satellite data and then field checked (Utah Division of Water Resources metadata). The Utah and Goshen Valleys inventory was conducted in 1995 (Utah Division of Water Resources metadata). We selected all polygons with standard type codes IA2a1 (corn), IA2a2 (sorghum), and IA2b5 (sweet corn; none in this category were in the data set) to produce the crop type coverage for this study, since these are the crop types to which the pesticides addressed are applied in Utah. Although the specific fields with these crops may vary from year to year, the general areas and average percentages of these crop types likely do not.

GIS Analysis Methods

We divided pesticide vulnerability into "low," "moderate," and "high" categories using pesticide sensitivity, areas of irrigated lands, and crop type as shown in table 7. Once again, numerical ranking for each attribute category is arbitrary, but reflects the level of importance we believe the attribute plays in determining sensitivity of areas to application of agricultural pesticides; for instance, we believe ground-water sensitivity to pesticides is the most important attribute with respect to ground-water vulnerability to pesticides, and therefore weighted this attribute two times more heavily than the other attribute categories.

RESULTS

Ground-Water Sensitivity

In order to assess ground-water sensitivity to pesticide contamination, several attribute layers were assembled as intermediate steps. Attribute layers include pesticide retardation/attenuation, hydrogeologic setting (recharge/discharge areas), hydraulic conductivity of soils, and depth to

Table 7. *Pesticide vulnerability, and the attribute rankings used to assign it, for Utah and Goshen Valleys, Utah County, Utah.*

Sensitivity		Corn/Sorghum Crops		Irrigated Land		Vulnerability	
Attribute	Ranking	Attribute	Ranking	Attribute	Ranking	Attribute	Ranking
Low	-2	No	0	No	0	Low	-2 to -1
Moderate	0					Moderate	0 to 2
High	2	Yes	1	Yes	1	High	3 to 4

shallow ground water. Data from these attribute layers were used to produce a ground-water sensitivity map using GIS analysis methods as outlined in table 6 (plate 1), and are described and summarized in the following sections.

Retardation/Attenuation

Retardation/attenuation was ranked as high throughout Utah and Goshen Valleys because net annual evapotranspiration exceeds net annual precipitation. Net annual recharge from precipitation is negative (figure 8). Most recharge that does occur from precipitation likely occurs during spring snowmelt, principally along the valley margins. Pesticides are generally applied after snowmelt. Up to several months may elapse between pesticide application and first irrigation, allowing attenuation to occur before downward migration of pesticides in the vadose zone commences under the influence of irrigation.

Hydrogeologic Setting

Ground-water recharge areas in Utah and Goshen Valleys were mapped by Anderson and others (1994) (figure 9). Their map shows that primary recharge areas, the areas most susceptible to contamination from pesticides applied to the land surface, make up about 40 percent of the surface area of the basin-fill aquifer. Primary recharge areas form a band around the outer margin of the basin-fill deposits (figure 9). Secondary recharge areas make up about 25 percent of the surface area of the basin-fill aquifer, forming a narrow band between primary recharge areas and discharge areas along the east side and northwest corner of Utah Valley, and the southern part of Goshen Valley (figure 9). Most of the central, lower elevations of Utah and Goshen Valleys are ground-water discharge areas (figure 9). Discharge areas (Utah Lake not included), which provide extensive protection to the principal aquifer from surface contamination from the application of pesticides, make up about 35 percent of the surface area of the basin-fill aquifer.

Hydraulic Conductivity of Soils

Surface application of pesticides is more likely to cause ground-water quality problems in areas where soils have higher hydraulic conductivity than in areas where hydraulic conductivity is low. Hydraulic conductivity data are from National Soil Survey Center (1994). About 59 percent of the surface area of the basin-fill aquifer has soil units mapped as having hydraulic conductivity greater than or equal to 2 inches per hour (5 cm/hr). Soils in this category are found along the basin margins (figure 10). About 32 percent of the surface area of the basin-fill aquifer has soil units mapped as having hydraulic conductivity less than 2 inches per minute; these soil units are primarily in the central part of the valley at lower elevations (figure 10). About 9 percent of the soil units within Utah and Goshen Valleys was not assigned hydraulic conductivity values; these soils are primarily along the margins of rivers (figure 10), and were lumped into the greater than or equal to 2 inches per minute (5 cm/ min) category for analytical purposes to be protective of water quality.

Depth to Shallow Ground Water

Surface application of pesticides is more likely to cause ground-water quality problems in areas of shallowest ground water than where ground water is relatively deeper. Depth to shallow ground water data are from National Soil Survey Center (1994). About 30 percent of the area overlying the basin-fill aquifer has soil units mapped as having depths to shallow ground water less than or equal to 3 feet (1 m); these areas are primarily in the central part of the valley at lower elevations (figure 11). About 13 percent of the surface area of the basin-fill aquifer has soil units mapped as having depths to shallow ground water greater than 3 feet (1 m); these areas are mapped principally along the margins of streams and in areas underlain by alluvial-fan deposits (figure 11), but are also expected (but not mapped, see below) along the margins of Utah and Goshen Valleys. However, almost 75 percent of the surface area of the basin-fill aquifer is underlain by soil units for which depth to shallow ground water is unknown. Most of these areas with no data are located along the margins of Utah and Goshen Valleys (figure 11). Areas without assigned depths to shallow ground water were lumped into the less than or equal to 3 feet depth category for analytical purposes to be protective of water quality.

Sensitivity Map

Plate 1 shows ground-water sensitivity to pesticides for Utah and Goshen Valleys, obtained using GIS methods and ranking techniques described above. Our analysis evaluates only the basin-fill aquifer; the surrounding uplands of the Wasatch Range and Lake Mountains are designated on plate 1 as "bedrock" and consist mainly of shallow bedrock in mountainous terrain.

The central part of Utah and Goshen Valleys is of low sensitivity (plate 1) because it is a discharge area characterized by ground-water gradients having upward flow. Pesticides used in this area are unlikely to degrade ground water because they have little opportunity to get into the aquifer. Additionally, the soils typically have low hydraulic conductivity. In this area, pesticides spilled or misapplied have a much greater potential to contaminate surface water than ground water.

Along the lower reaches of valley-margin alluvial fans, outward from the area of low sensitivity, is an area of moderate sensitivity (plate 1). This consists of primary and secondary recharge areas where pesticides that have been spilled or misapplied have a greater potential for impacting ground water. In areas of moderate sensitivity, the ground-water gradient has a downward component, but the aquifer is somewhat protected because it is partially confined or is at sufficient depth that pesticides would undergo chemical breakdown before they migrate to such depths.

Areas of high sensitivity are located primarily along the margins of Utah and Goshen Valleys (plate 1). In these areas, ground water is either shallow with no overlying confining layers, or insufficient data are available to make a less conservative assessment. Additionally, these areas typically have higher hydraulic conductivity. In some localities, perched water may be present above lenticular or discontinuous bodies of fine-grained sediment that form aquicludes. In some cases, shallow ground water may be erroneously

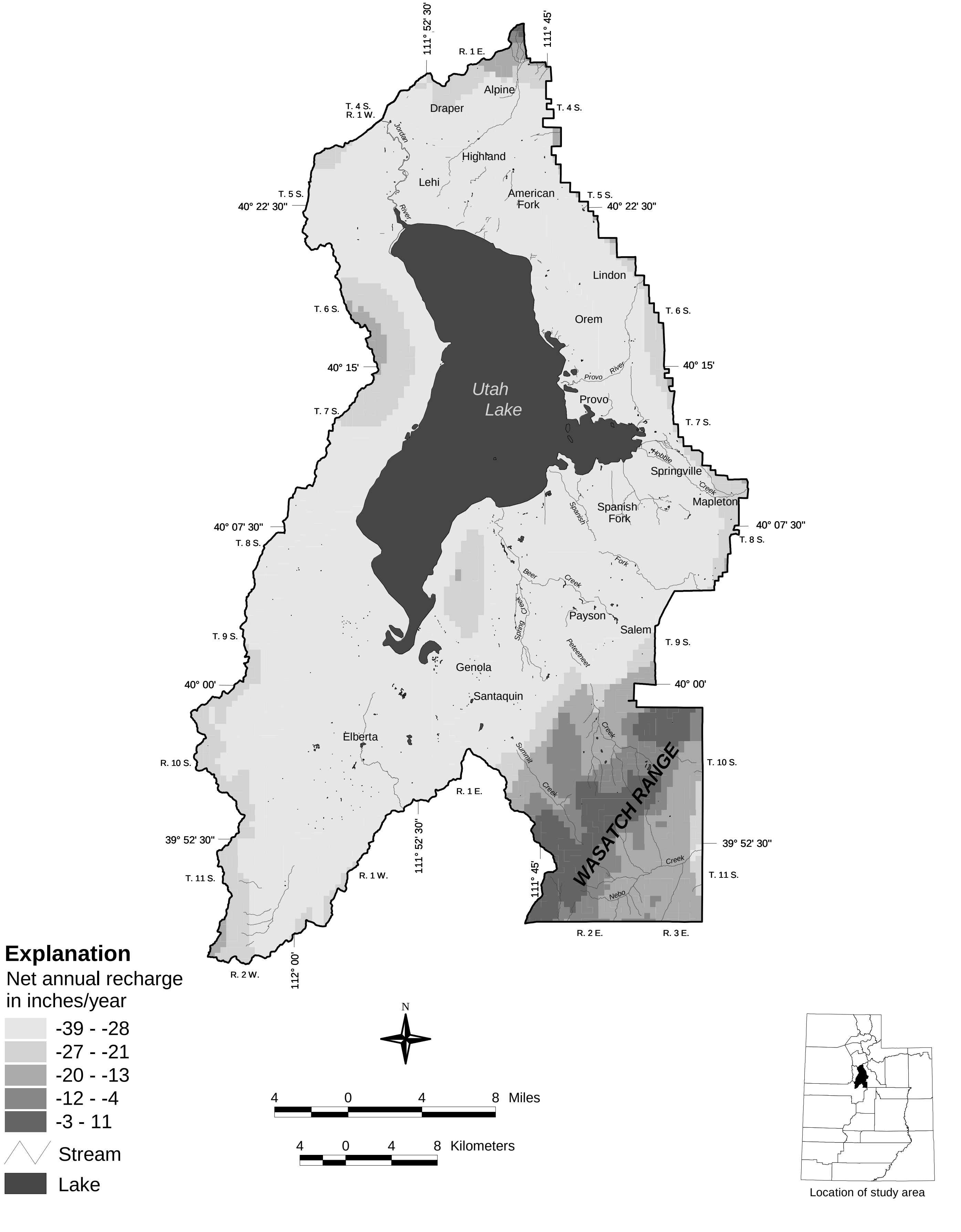

Figure 8. *Net annual recharge from precipitation for Utah and Goshen Valleys calculated using data from the Utah Climate Center (1991) and Jensen and Dansereau (2001). Although net annual recharge is negative in many areas, seasonally some recharge from precipitation may occur.*

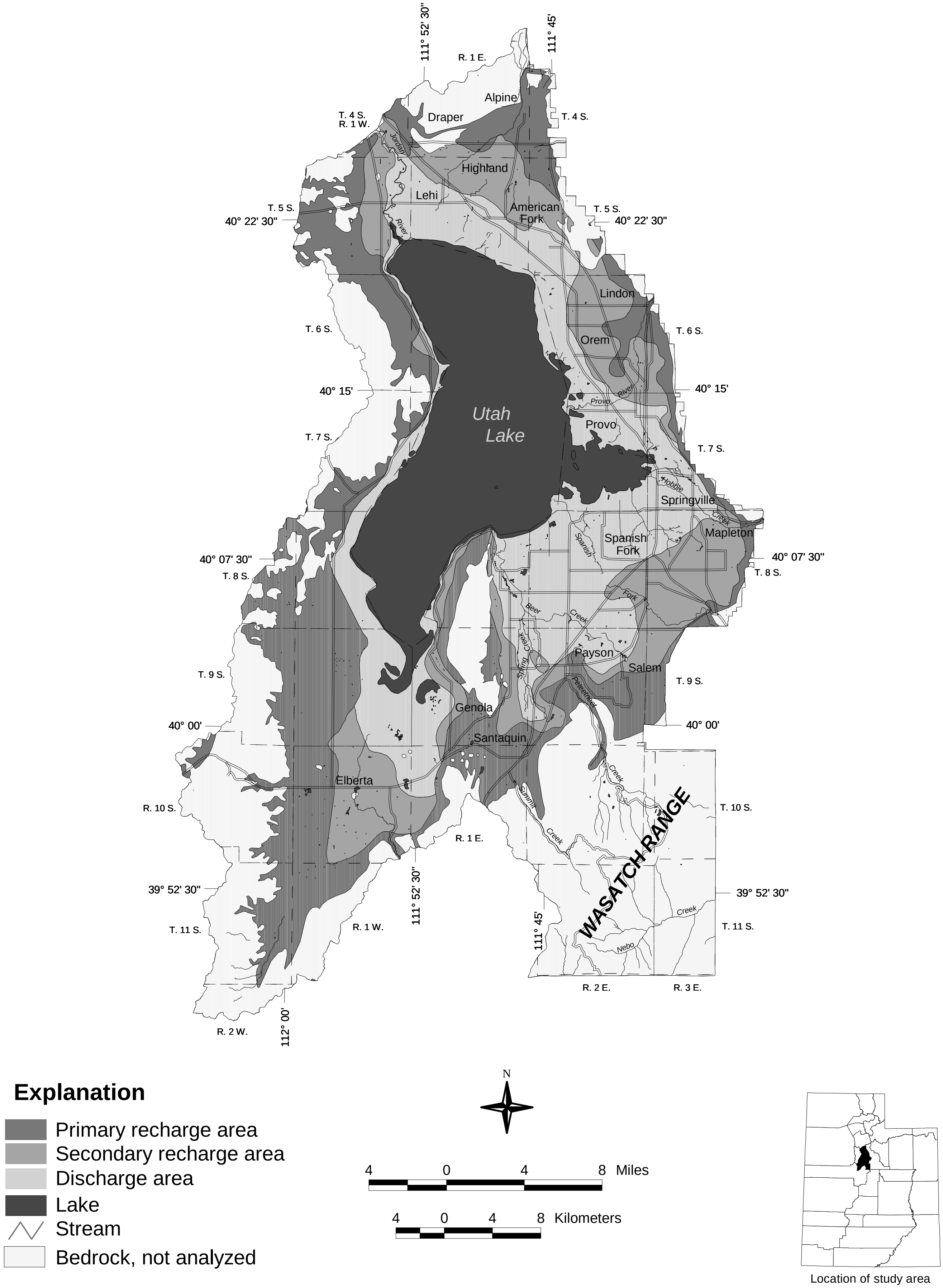

Figure 9. Recharge and discharge areas in Utah and Goshen Valleys, Utah County, Utah (from Anderson and others, 1994).

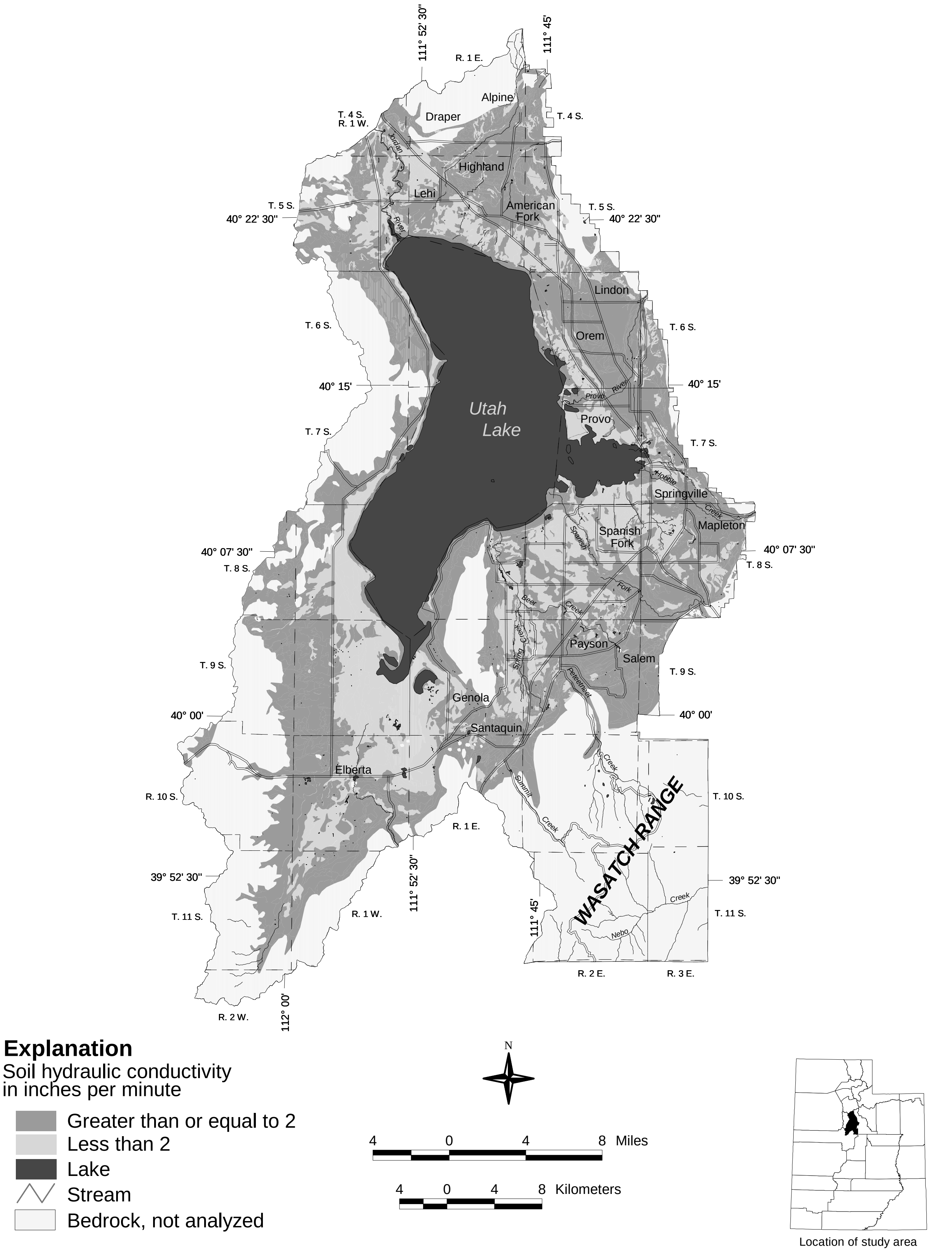

Figure 10. *Soil hydraulic conductivity in Utah and Goshen Valleys, Uah County, Utah (data from National Soil Survey Center, 1994).*

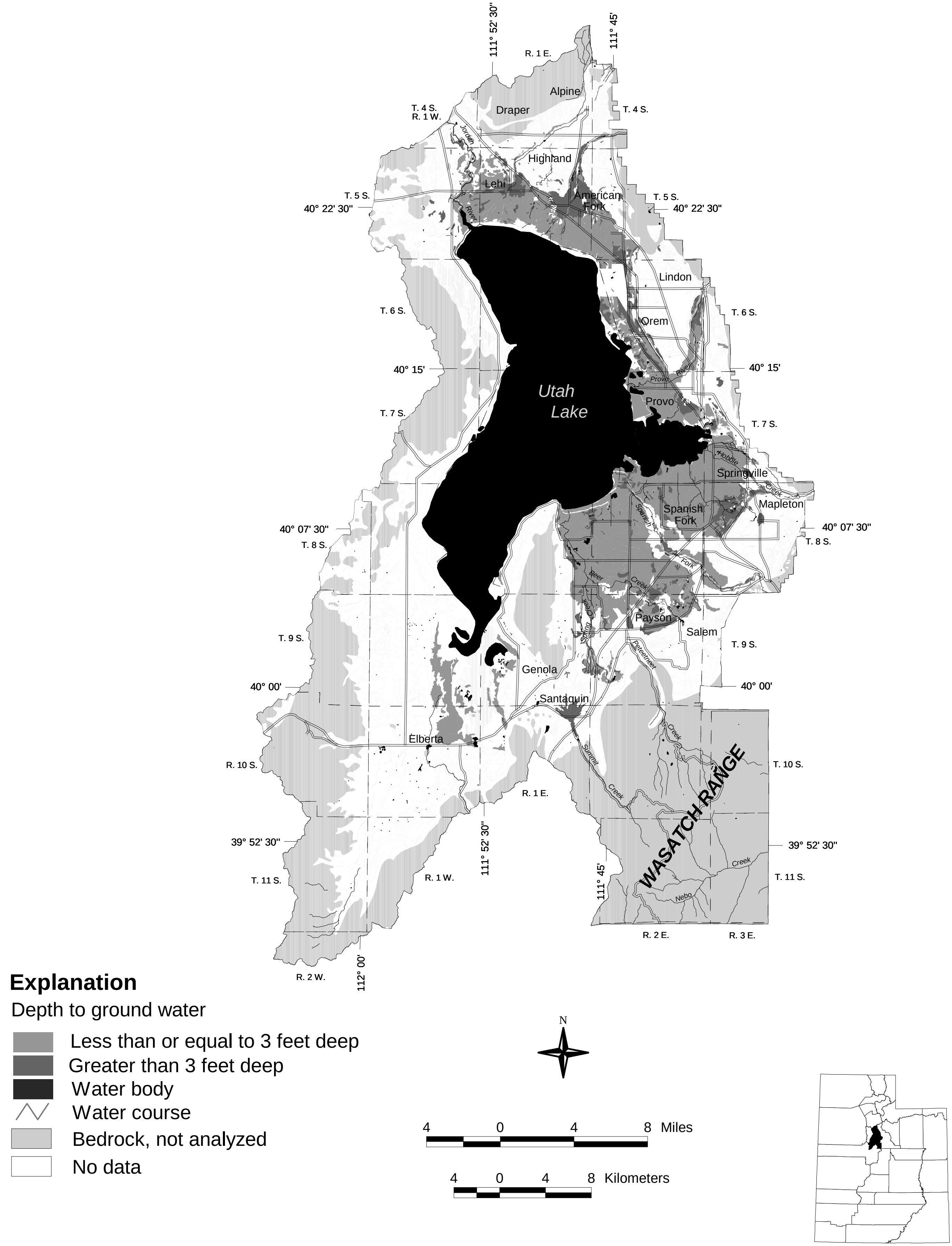

Figure 11. *Depth to ground water in Utah and Goshen Valleys, Utah County, Utah (data from National Soil Survey Center, 1994).*

reported on drillers' logs. Improved data quality is required to substantiate or discount these as areas of concern.

Ground-Water Vulnerability

In order to assess ground-water vulnerability to pesticide contamination—the influence of human activity added to natural sensitivity—we assembled two attribute layers as intermediate steps. Pertinent attribute layers include irrigated cropland and corn- and sorghum-producing areas in Utah and Goshen Valleys, combined into one attribute-layer map (figure 12). Using GIS methods as outlined in table 7, pertinent attribute layers, in turn, are combined with ground-water sensitivity, discussed in the previous sections, to produce a map showing ground-water vulnerability to pesticides (plate 2). Pertinent attribute layers, along with ground-water sensitivity, are described in the following sections.

Ground-Water Sensitivity

The most influential factor in ground-water vulnerability to pesticide contamination is ground-water sensitivity, described in the previous section. Sensitivity represents the sum of natural influences that facilitate the entry of pesticides into ground water. The prevailing influence of sensitivity manifests as similarity between the sensitivity and vulnerability maps (plates 1 and 2, respectively). However, a vulnerability assessment for a particular tract of land should not be made from the sensitivity map despite this similarity.

Irrigated Cropland

All of the cropland areas in Utah and Goshen Valleys are irrigated (figure 12), with the result that this factor does not influence configuration of the vulnerability map by itself. Irrigation is potentially significant because it is a source of ground-water recharge in the basin-fill aquifer.

Corn and Sorghum Crops

From the point of view of human impact, areas where corn and sorghum are grown (figure 12) are significant because the four herbicides considered in this report – alachlor, atrazine, metolachlor, and simazine – are used to control weeds in these crops. Areas of corn and sorghum crops are shown on the map of figure 12 as rectangles or circles (where center-pivot irrigation systems are used) concentrated in the central part of Utah and Goshen Valleys coinciding with the area of low sensitivity shown on the map of plate 1. The effect of areas of corn and sorghum production on vulnerability is to raise vulnerability from low to moderate.

Vulnerability Map

Plate 2 shows ground-water vulnerability to pesticides of the basin-fill aquifer for Utah and Goshen Valleys, obtained using GIS methods and ranking techniques described above. The surrounding uplands, mainly the Wasatch Range and Lake Mountains, are not included in the analysis because of shallow bedrock and mountainous terrain, and because they are not areas of significant agricultural activity.

Low-sensitivity areas and low-vulnerability areas roughly coincide, but have minor differences. Localities where corn and sorghum are grown appear as rectangle-like shapes of moderate vulnerability on plate 2 in the central part of the valley where low vulnerability otherwise predominates.

Areas of moderate vulnerability coincide, in general, with areas of moderate or high sensitivity. The moderate-vulnerability areas occur along valley-margin benches where ground water is at great depths or confining layers protect the deeper basin-fill aquifer. An area of high sensitivity would be categorized as having moderate vulnerability if the land is not irrigated or if corn or sorghum are not grown there.

Areas of high vulnerability are located in primary recharge areas where ground water occurs at depths of less than 3 feet (1 m), or the depth to ground water is unknown, and in areas of moderate vulnerability where corn or sorghum are being grown. Of particular concern are areas where streams originating in mountainous areas cross the valley margin. Some of these localities fall within the high-vulnerability range. Recharge of ground water by such streams at these points is the second most important means of aquifer recharge in the basin fill (table 2). Therefore, efforts to preserve water quality in streams at these points would help to preserve ground-water quality in the entire basin.

CONCLUSIONS AND RECOMMENDATIONS

Precipitation is not the major source of ground-water recharge within Utah and Goshen Valleys, especially in the central parts of the valleys where ground-water gradients in the basin-fill aquifer are upward (ground-water discharge areas). The main sources of recharge to the basin-fill aquifer are subsurface inflow and surface streams that originate in areas of higher elevation, mainly in the Wasatch Range, and then flow into Utah Valley or Goshen Valley in primary recharge areas. Areas where rivers and streams cross coarse-grained alluvial fans represent the most urgent need for protection to preserve ground-water quality, based on the results of our ground-water sensitivity and vulnerability mapping. Other valley-margin areas, particularly those with unlined or poorly lined irrigation canals, also warrant measures to protect ground-water quality based on our mapping. However, because of relatively high retardation (long travel times of pesticides in the vadose zone) and attenuation (short half-lives) of pesticides in water in the soil environment, the application of pesticides to crops and fields in Utah and Goshen Valleys likely does not represent a serious threat to ground-water quality.

Based on these conclusions, we believe ongoing ground-water sampling in Utah and Goshen Valleys should be concentrated in areas of moderate and high sensitivity or vulnerability, typically along valley margins. Sampling in the central areas of the valleys characterized by low sensitivity and low vulnerability should continue, but at a lower density than in the areas of higher sensitivity and vulnerability. Areas where data are unavailable, particularly areas lacking shallow ground-water data, were treated conservatively (in a manner protective of ground-water quality), by assuming that the conditions most susceptible to pesticide pollution of ground water are present. This conservative treatment is par-

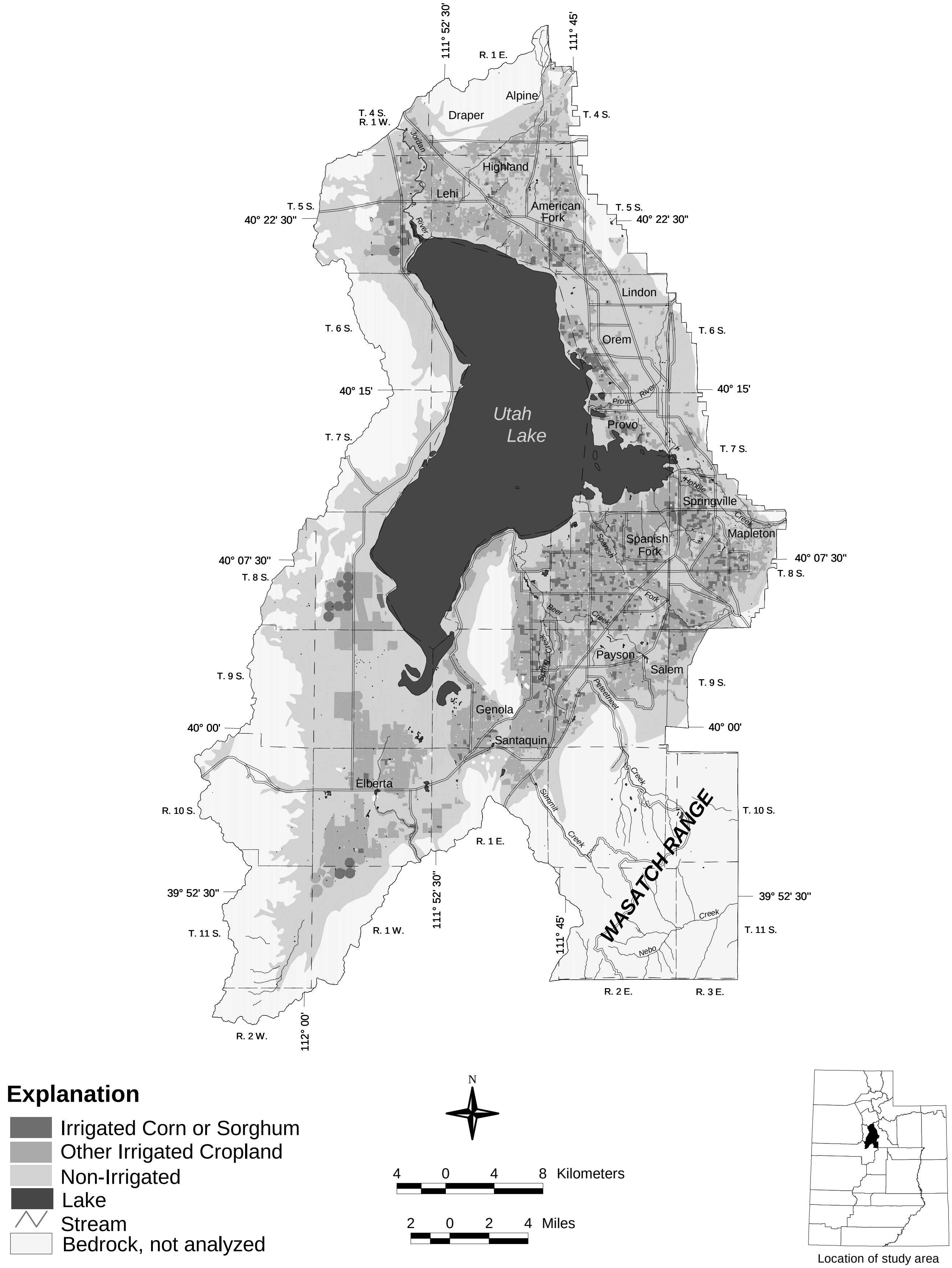

Figure 12. Irrigated cropland in Utah and Goshen Valleys, Utah County, Utah (unpublished GIS metadata from the Utah Division of Water Resources).

ticularly evident in valley-margin areas where depth to the water table is generally deep, but where GIS analysis presumed the water table to be shallow due to a lack of map data to the contrary. Therefore, our maps show higher sensitivity and vulnerability to pesticides than what actually may be the case in those areas. Ground-water sensitivity and vulnerability to pesticides in such areas should be re-evaluated if better data become available. The maps and this report are based on analyses of 1:24,000 or smaller scale data and are not meant for site-specific evaluations.

ACKNOWLEDGMENTS

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PLATE 1

GROUND-WATER SENSITIVITY TO PESTICIDES IN UTAH AND GOSHEN VALLEYS, UTAH COUNTY, UTAH

by Ivan Sanderson and Mike Lowe
Digital compilation by Matt Butler, Anne M. Johnson, and Alison Corey

Explanation

High sensitivity

Moderate sensitivity

Low sensitivity

Bedrock (not analyzed)

Water bodies

Water courses

Valley-fill boundary

Study-area boundary

1:150,000

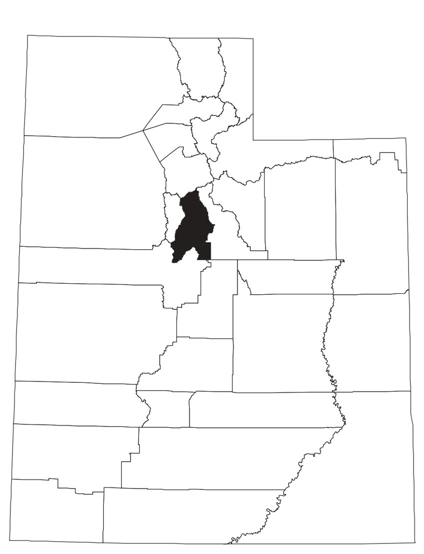
3 0 3 6 Miles

3 0 3 6 Kilometers

This map was funded by the Environmental Protection Agency

This map is a GIS product derived from a recharge/discharge area map by Anderson and others (1994), soil data from the National Soil Survey Center (1994), precipitation data from the Utah Climate Center (1991), evapotranspiration data from Jensen and Dansereau (2001), and land-use data from the Utah Division of Water Resources (1995). No additional field work was performed or data collected.

This map is based on 1:24,000 or smaller scale data and should not be used for site-specific evaluations.



Location Map

UTAH GEOLOGICAL SURVEY

UTAH GEOLOGICAL SURVEY
a division of
Department of Natural Resources

UTAH DEPARTMENT OF AGRICULTURE AND FOOD

PLATE 2

GROUND-WATER VULNERABILITY TO PESTICIDES IN UTAH AND GOSHEN VALLEYS, UTAH COUNTY, UTAH

by Ivan Sanderson and Mike Lowe
Digital compilation by Matt Butler, Anne M. Johnson, and Alison Corey

Explanation

- High vulnerability
- Moderate vulnerability
- Low vulnerability
- Bedrock (not analyzed)
- Water bodies
- Water courses
- Valley-fill boundary
- Study-area boundary

1:150,000

3 0 3 6 Miles

3 0 3 6 Kilometers

N W E S

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This map is a GIS product derived from a recharge/discharge area map by Anderson and others (1994), soil data from the National Soil Survey Center (1994), precipitation data from the Utah Climate Center (1991), evapotranspiration data from Jensen and Dansereau (2001), and land-use data from the Utah Division of Water Resources (1995). No additional field work was performed or data collected.

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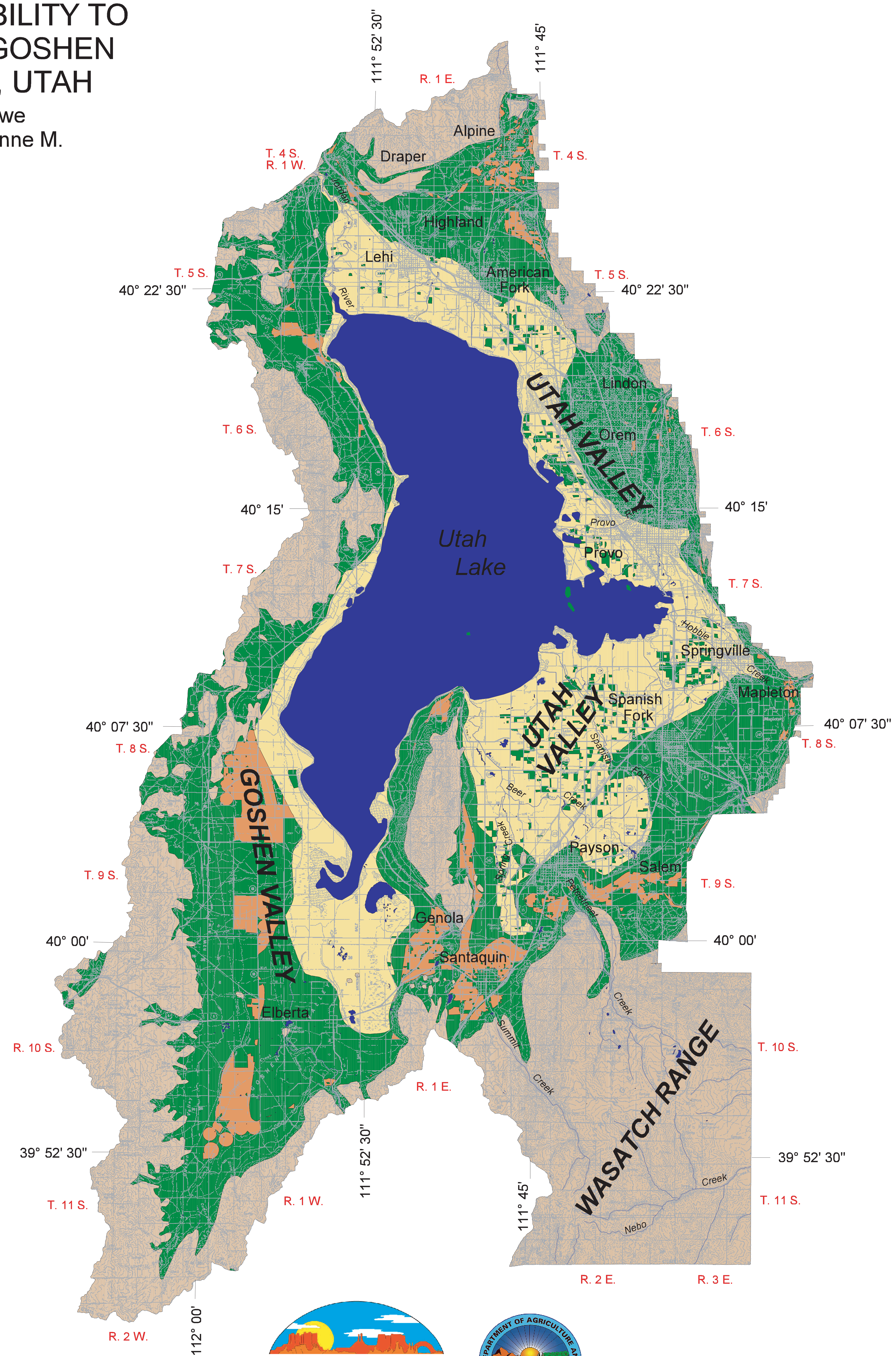

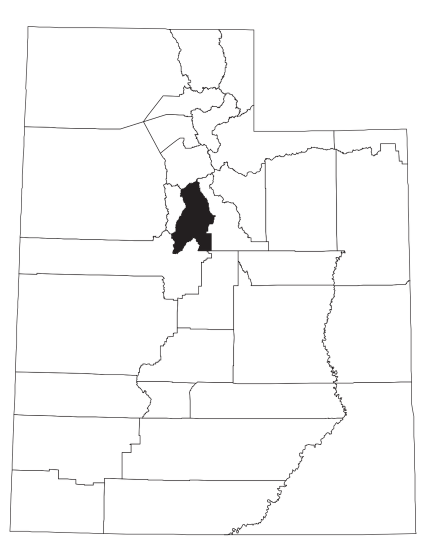

Location Map

UTAH GEOLOGICAL SURVEY
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