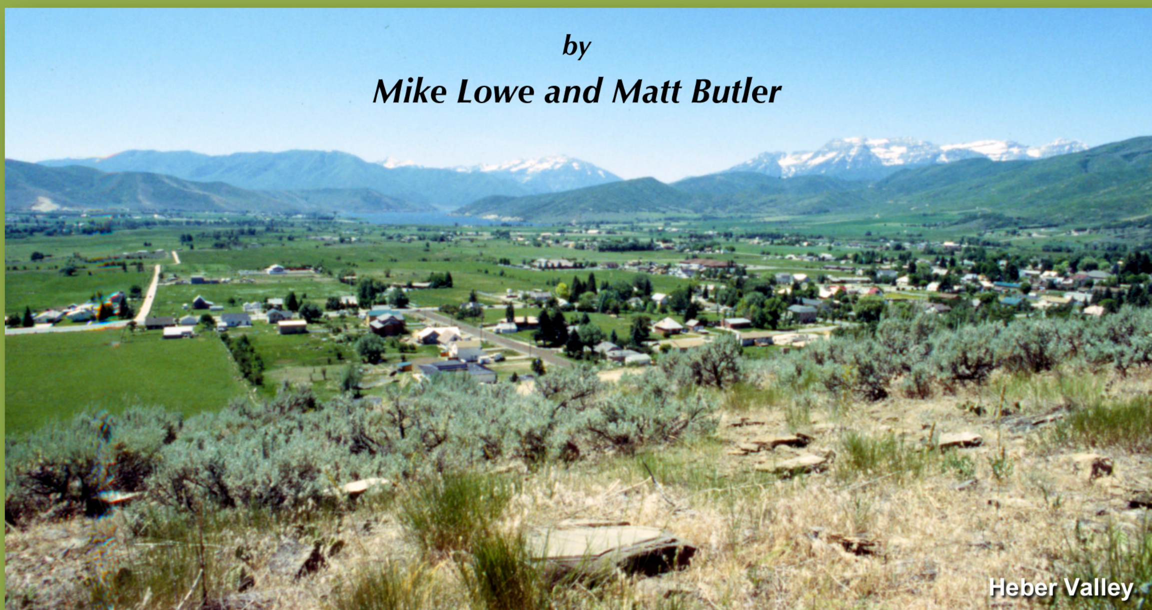
GROUND-WATER SENSITIVITY AND VULNERABILITY TO PESTICIDES, HEBER AND ROUND VALLEYS, WASATCH COUNTY, UTAH

by

Mike Lowe and Matt Butler



Heber Valley

Round Valley

MISCELLANEOUS PUBLICATION 03-5
UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources
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Utah Department of Agriculture and Food

2003

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Cover photographs by Mike Hylland:

Top - View southwest across Heber Valley towards Deer Creek Reservoir and Provo Canyon. Mt. Timpanogos (11,749 feet) forms the right skyline. Bottom - View northwest across alluvium (irrigated farmland) and alluvial fans in Round Valley to the foothills and high peaks of the Wasatch Range.

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TABLE OF CONTENTS

FIGURES

TABLES

PLATES

GROUND-WATER SENSITIVITY AND VULNERABILITY TO PESTICIDES, HEBER AND ROUND VALLEYS, WASATCH COUNTY, UTAH

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Mike Lowe and Matt Butler

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 Heber and Round Valleys, Wasatch 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. This is a first cut at developing pesticide sensitivity and vulnerability maps; better data and tools may become available in the future so that better maps can be produced.

Ground-water sensitivity to pesticides is determined by assessing natural factors favorable or unfavorable to the degradation of ground water by any 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 factors primarily determining ground-water sensitivity to pesticides in Heber and Round Valleys. Much of Heber and Round Valleys has high ground-water sensitivity to pesticides due to the lack of protective clay layers, and because of the relatively high hydraulic conductivity of soils in the area.

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 Heber and Round Valleys. Areas of high vulnerability are primarily located in areas where irrigation occurs and ground-water sensitivity to pesticides is high. Of particular concern are areas where ground water is shallow, which are commonly found near streams crossing the valley floors.

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 Heber and Round Valleys likely do not present a serious threat to ground-water quality. However, ground-water sampling by the Utah Department of Agriculture and Food in Heber and Round Valleys should be conducted at higher densities than in many other areas of Utah based on the high sensitivity and vulnerability of ground water in the valley-fill aquifers to pesticides.

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 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 Heber and Round Valleys, Wasatch County, Utah (figure 1). This study, conducted by the Utah Geological Survey at the request of the Plant Industry Division of the Utah Department of Agriculture and Food (UDAF), provides needed information on

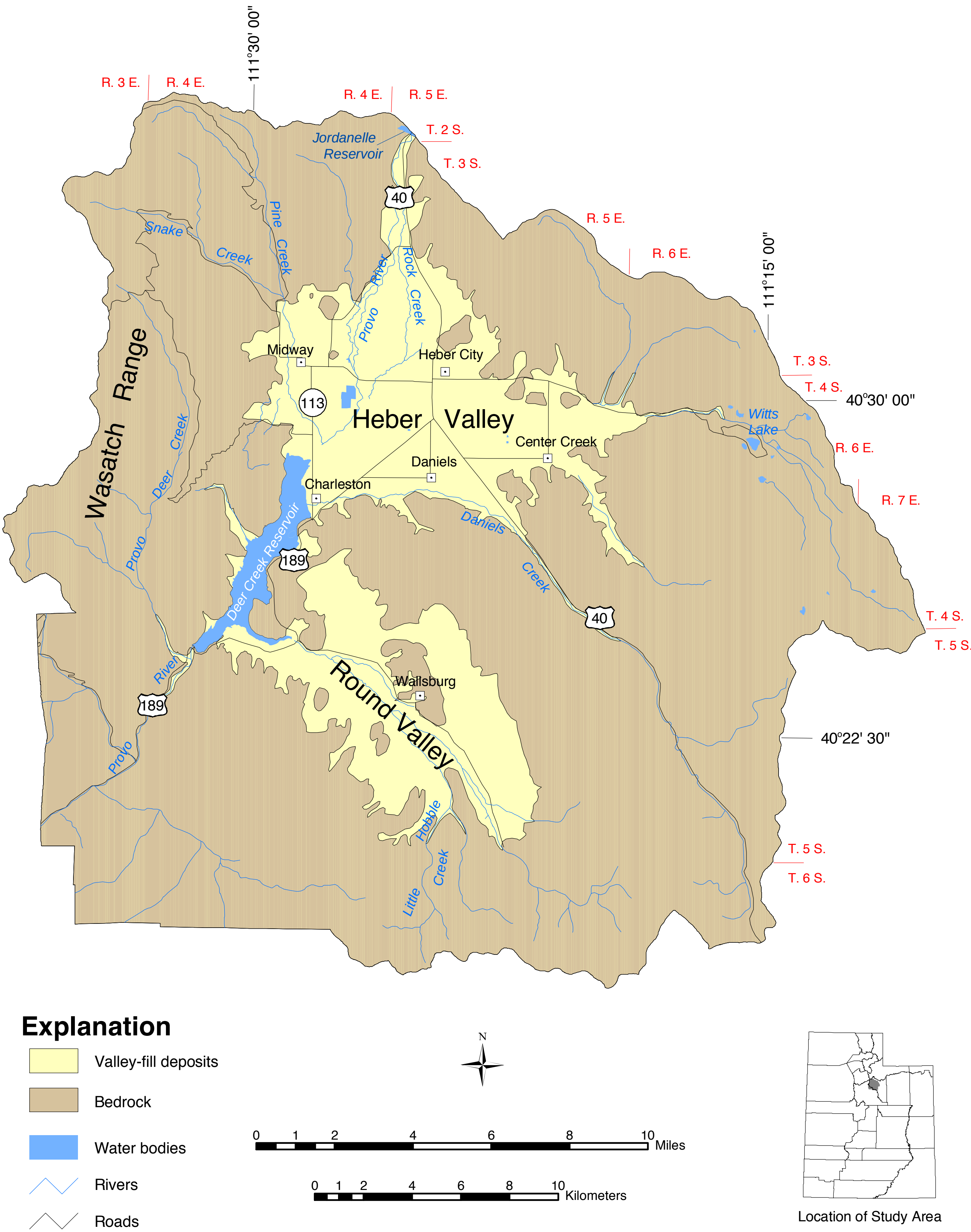

Figure 1. Heber and Round Valleys, Wasatch County, Utah, study area.

ground-water sensitivity and vulnerability to pesticides in the unconsolidated valley-fill aquifers of Heber and Round 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 valley-fill aquifers in Heber and Round 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 onto the land surface, whereas vulnerability to pesticides is determined by assessing how ground-water sensitivity is modified by the activities of humans. 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 Heber and Round 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. This is a first cut at developing pesticide sensitivity and vulnerability maps; better data and tools may become available in the future so that better maps can be produced. For example, maps that show the quantity of recharge to aquifers in Utah are not available. We used a GIS coverage developed by subtracting average annual evapotranspiration from average annual precipitation to estimate average annual recharge from precipitation. This coverage provides a rough estimate of the largely elevation-controlled distribution of ground-water recharge, but does not account for recharge at low elevations during spring snowmelt or during protracted storm events. Additionally, 1:500,000-scale digital soil maps used in this study are too general to accurately depict areas of soil versus areas of bedrock outcrop. Because organic carbon in soils is one controlling factor determining the potential for pesticides to reach ground water, the higher sensitivity and vulnerability of these rock outcrop areas are not reflected in our maps. To produce these maps, we needed to make some decisions based on our knowledge of the hydrogeology of the state and the types of data available; for example, we selected 3 feet (1 m) as the reference depth for applying pesticide retardation and attenuation equations. No new fieldwork was conducted nor data collected as part of this project.

GENERAL DISCUSSION OF PESTICIDE ISSUE

The information presented in this section was taken directly from Lowe and Sanderson (2003).

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, in part, 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. Because 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, establishing 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 developing 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 pesticide contamination be found and verified, a chain of events to monitor and evaluate the contamination would begin that could 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, and 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; the beginning letter of key words in these parameters forms the acronym DRASTIC. Eventually, many scientists concluded 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 Villeneuve, 1989). Other deficiencies with the DRASTIC method 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.

Rao and others (1985) developed indices for ranking the potential for pesticide contamination of ground water, which we have implemented in this study. 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 mg/L	2 mg/L
Atrazine	0.003 mg/L	3 mg/L
Metolachlor	—	—
Simazine	0.004 mg/L	4 mg/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 hydrogeologic 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 type of pesticide being applied is a critical factor. 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 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 Heber and Round Valleys where ground water is unconfined, degradation of the valley-fill aquifers 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 valley-fill aquifer. Surface irrigation could cause a decrease in the retardation and attenuation of pesticides in some settings – especially in areas where corn or sorghum are grown – because the types of pesticides evaluated in this study are commonly applied to those crops. Withdrawal of water from the valley-fill aquifers 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 valley-fill aquifers.

PREVIOUS STUDIES

Baker (1970) provided general information on ground- and surface-water resources for Heber and Round Valleys to aid in water rights management. Studies on geothermal springs near Midway included those of Baker (1968), Mundorff (1970), and Kohler (1979). Mundorff (1974) reported on ground- and surface-water quality for tributary drainages to Utah Lake, including Heber and Round Valleys. The most extensive study of ground-water conditions in Heber and Round Valleys to date, which included construction of a digital ground-water flow model for Heber Valley, was conducted by Roark and others (1991). Lowe (1995) mapped recharge areas for the principal valley-fill aquifers in Heber and Round Valleys. Hylland and others (1995) produced an engineering-geologic map folio which included information on shallow ground water and suitability of soils for septic-tank systems.

There were numerous geologic studies in the study area between 1964 and 2000. The geologic map coverages used as part of this project are shown on figure 2. Interpretation of unconsolidated Quaternary geology is based on unpublished mapping by the author.

SETTING

Physiography

Western Wasatch County includes portions of the Wasatch Range and Wasatch Hinterlands sections of the Middle Rocky Mountains Physiographic Province (Stokes, 1977). The western margin of Wasatch County consists of the eastern side of the north-south-trending Wasatch Range and includes high alpine terrain with several peaks above 10,000 feet (3,000 m) in elevation. The generally narrow, sharp-crested Wasatch Range has its maximum width of about 15 miles (24 km) in the Wasatch County area at its intersection with the Uinta Mountains trend (Stokes, 1986). Stokes (1986) attributes this greater width to intrusions of resistant igneous rock that are not found elsewhere in the range. Many areas at higher elevations in the Wasatch Range were glaciated during Pleistocene time. A number of perennial and ephemeral streams flow eastward or southward out of the rugged mountains of the Wasatch Range into Wasatch Valley, including Pine Creek, Snake Creek, and Provo Deer Creek. These streams ultimately flow into the Provo River.

The Wasatch Range along the western margin of Wasatch County consists of Precambrian- to Tertiary-age rock units (Bryant, 1992). Pre-Tertiary rocks are primarily limestone, shale, and sandstone. Tertiary rocks are mainly either conglomerates or igneous intrusions (Bryant, 1992). The principal Quaternary unconsolidated sediments in the Wasatch Range are colluvial, glacial, stream, and landslide deposits.

East of the Wasatch Range in the Wasatch Hinterlands section, is a north-south-trending belt of moderately rugged topography containing discontinuous, flat-bottomed valleys surrounded by hilly areas with sparse outcrops (Stokes, 1986). The valleys, sometimes called "back valleys of the Wasatch," include Heber Valley and Round Valley (Stokes, 1986). Streams flow into these valleys from the mountains and hills along the valley margins and into the Provo River, which flows out of the south end of Heber Valley through the Wasatch Range via Provo Canyon.

With the exception of the hills south of Heber Valley and surrounding Round Valley, which mainly consist of the Pennsylvanian-Permian-age Oquirrh Formation (Bryant 1992), pre-Cenozoic structures and rocks in the Wasatch Hinterlands section are largely covered by Tertiary rocks and by Quaternary unconsolidated deposits. The Tertiary units include volcanic rocks, volcaniclastic and nonvolcanic sandstone, and conglomerate; these rocks have been offset at many locations by high-angle normal and reverse faults.

A wide range of Quaternary unconsolidated sediments exist in the Wasatch Hinterlands section, including glacial, landslide, alluvial-fan, and stream deposits. Quaternary tufa has been deposited by hot springs in the Midway area. Unconsolidated valley-fill deposits in Heber Valley are mostly stream sediments deposited by the Provo River and its tributaries.

Climate

Three weather stations are in the study area (Snake Creek Powerhouse, 1928-92 period; Heber, 1938-92 period; and Deer Creek Dam, 1948-92 period). Temperatures reach

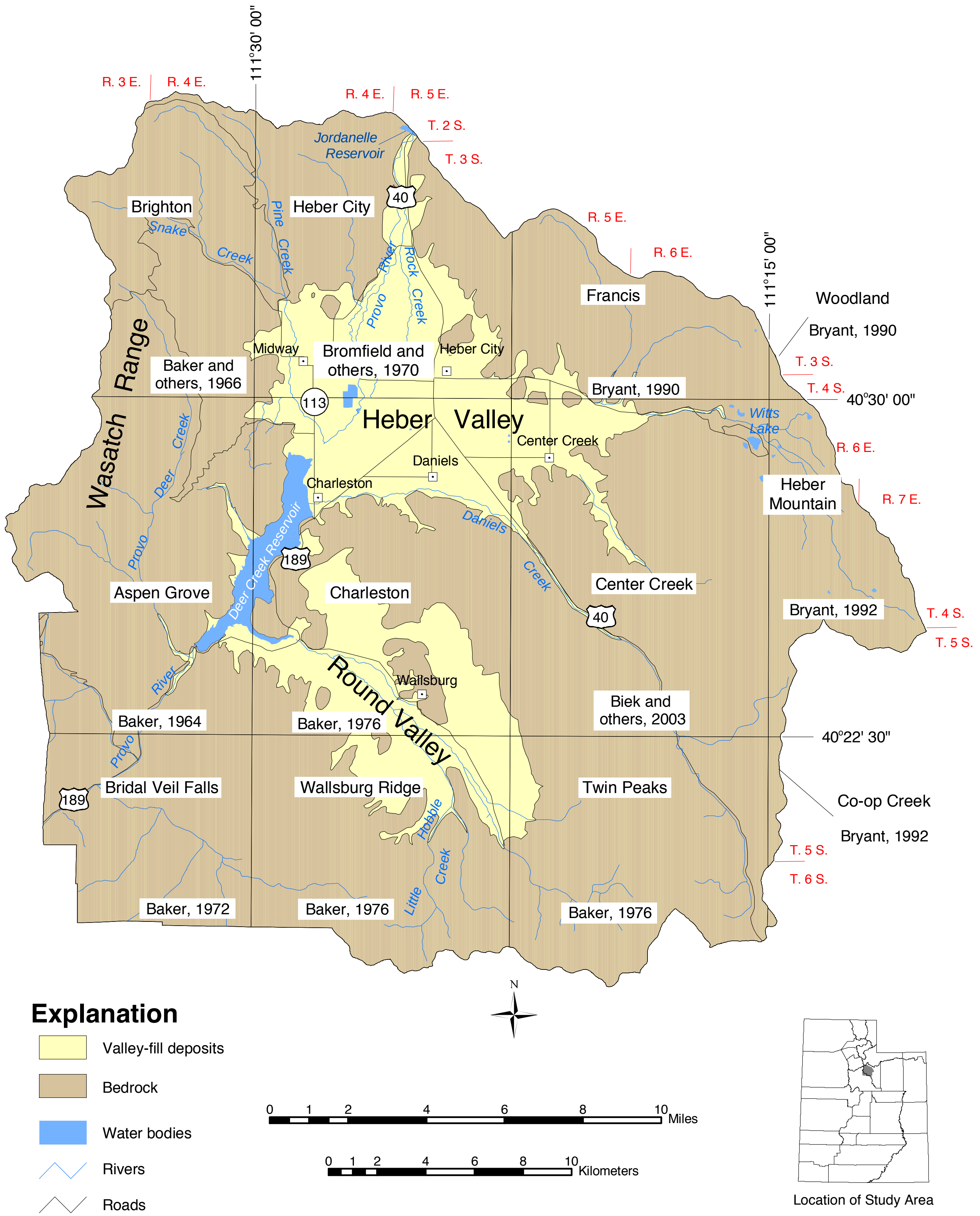

Figure 2. *Sources of bedrock geologic mapping for U.S. Geological Survey 7.5′ quadrangles in study area.*

a normal maximum (Heber station) of 86.5°F (30.27°C) in July and a normal minimum (Deer Creek Dam station) of 31.9°F (-0.1°C) in January (Ashcroft and others, 1992). The normal mean annual temperature ranges from 43.1°F at Snake Creek Powerhouse to 44.5°F at Heber (6.1-6.9°C) (Ashcroft and others, 1992). Normal annual precipitation ranges from 24.56 inches (62.38 cm) at Deer Creek Dam to 16.01 inches (40.67 cm) in Heber (Ashcroft and others, 1992). Normal annual evapotranspiration ranges from 43.43 to 46.04 inches (110.31-116.94 cm) at Snake Creek Powerhouse and Heber, respectively (Ashcroft and others, 1992). The average number of frost-free days ranges from 129 to 140 at the Heber and Snake Creek Powerhouse stations, respectively (Ashcroft and others, 1992).

Population and Land Use

From 1990 to 2000, population in Wasatch County increased by 50.8 percent (5,126 individuals) (Demographic and Economic Analysis Section, 2001). The July 2001 population of Wasatch County was estimated at 15,947 (Demographic and Economic Analysis Section, 2002) with a projected population of 31,236 by 2030 (Demographic and Economic Analysis Section, 2000). Heber and Midway are the largest towns, having 7,291 and 2,121 people in 2000, respectively (Demographic and Economic Analysis Section, 2001). Most people in Wasatch County live on the valley-fill deposits of Heber and Round Valleys.

Agriculture, primarily grazing, is the main land use in Wasatch County, with most of the land area administered by the U.S. Forest Service (Wasatch County Planning Commission, 2001). Trade and services are the two largest sources of employment, reflecting Wasatch County's tourist-based economy (Wasatch County Planning Commission, 2001).

GROUND-WATER CONDITIONS

Valley-Fill Aquifers

The principal source of water to wells in Heber and Round Valleys is the unconsolidated valley-fill sediments (Baker, 1970). However, springs discharging from consolidated rocks are the primary source of public water supplies for the communities of Center Creek, Charleston, Daniels, Heber City, Midway, and Wallsburg (Roark and others, 1991).

The valley-fill deposits consist of poorly sorted clay- to boulder-sized particles; the clay occurs in discontinuous layers in most of the valley-fill deposits (Roark and others, 1991). Tufa deposits in the Midway area interfinger with the unconsolidated sediments and are considered to be part of the valley-fill deposits (Roark and others, 1991). The valley-fill deposits thin towards the valley margins and are as much as 375 feet (114 m) thick in Heber Valley, but are generally less than 100 feet (30 m) thick in Round Valley (Roark and others, 1991).

Aquifer Characteristics

Aquifer characteristics such as transmissivity, storativity, and hydraulic conductivity are variable in the valley-fill aquifers. Hydraulic conductivity in the Heber Valley and Round Valley area ranges from 1 to about 200 feet per day (0.3 to 61 m/d), the highest values being in the Daniels and Charleston areas (Roark and others, 1991). One transmissivity value in the area exceeded 2,500 feet squared per day (232 m^2/d), but with the exception of the Daniels and Charleston areas, transmissivity in most of the valley-fill deposits in Heber Valley and Round Valleys is less than 500 feet squared per day (46 m^2/day) (Roark and others, 1991).

In general, the valley-fill deposits form a "single, essentially homogeneous, water-table aquifer" (Baker, 1970). However, artesian conditions occur at depths greater than 50 feet (15 m) in the lower areas of Heber Valley near Deer Creek Reservoir and Midway where numerous layers of clay and silt form confining layers (Roark and others, 1991). Also, tufa deposits in the Midway area are a confining layer (Roark and others, 1991). Artesian conditions have also been identified in Round Valley in the SE1/4NW1/4NE1/4 section 12, T. 5 S., R. 4 E., Salt Lake Base Line and Meridian; the extent of the confining beds is unknown, but is probably "localized in a small area" (Roark and others, 1991).

Recharge and Discharge

Recharge to the valley-fill aquifers is from precipitation on the valley floor, infiltration of stream flow and unconsumed irrigation water, and subsurface flow from consolidated rocks (Roark and others, 1991). Recharge to the valley-fill deposits in Heber Valley is estimated to be about 154 cubic feet per second (111,600 acre-ft/yr, 4.4 m^3/s); recharge to the valley-fill deposits in Round Valley is estimated to be about 11 cubic feet per second (8,000 acre-ft/yr, 0.3 m^3/s) (Roark and others, 1991). The primary recharge area for Heber and Round Valleys consists of the valley floor and hill slopes surrounding the valleys below the surface-drainage divides. Keetley Valley, north of Heber Valley, and the east side of the hills east of Heber Valley are considered a secondary recharge area to Heber Valley because streams in these areas flow into the Provo River which recharges Heber Valley. Also, the nature and extent of fracturing in pre-Tertiary bedrock units in the hills has not been evaluated, principally because older rocks are covered by Tertiary rock units, and the potential for flow of ground water through the hills to Heber Valley is unknown.

Movement of ground water in the valley-fill aquifer in Heber Valley is generally toward the Provo River and down valley toward Deer Creek Reservoir (Roark and others, 1991). Movement of ground water in unconsolidated deposits in Round Valley is toward Main Creek (Round Valley Creek) and down valley toward Deer Creek Reservoir (Baker, 1970).

Discharge of ground water from the unconsolidated valley-fill deposits in Heber and Round Valleys is from evapotranspiration, and seepage to rivers, springs, and wells (Baker, 1970; Roark and others, 1991). Discharge from the valley-fill aquifer in Heber Valley also includes leakage to Deer Creek Reservoir, which is a ground-water discharge area (Roark and others, 1991). Discharge from the valley-fill deposits in Heber Valley is estimated to be 154 cubic feet per second (111,600 acre-ft/ yr, 4.4 cubic m^3/s); discharge from unconsolidated deposits in Round Valley is estimated to be 11 cubic feet per second (8,000 acre-ft/yr, 0.3 cubic m^3/s) (Roark and others, 1991).

Ground-Water Quality

Ground water in most unconsolidated deposits in Heber Valley and Round Valley is high-quality calcium-bicarbonate-type water with total-dissolved-solids concentrations generally less than 500 mg/L (Roark and others, 1991). Water samples analyzed as part of Wasatch County's petition to the Utah Water Quality Board for aquifer classification (Jensen, 1995) indicate that, with the exception of the Midway area, average total-dissolved-solids concentrations and nitrate levels in the valley-fill aquifers in Heber and Round Valleys are 284 and 1.87 mg/L, respectively (Jensen, 1995). Ground water in unconsolidated deposits near Midway, however, is calcium-sulfate-type and calcium-bicarbonate-sulfate-type water which may exceed total-dissolved-solids concentrations of 500 mg/L and may contain sulfate concentrations greater than 250 mg/L (Roark and others, 1991). Water samples analyzed as part of Wasatch County's aquifer classification petition (Jensen, 1995) indicate that average total-dissolved-solids concentrations and nitrate levels in the Midway area are 1,233 and 0.83 mg/L, respectively (Jensen, 1995).

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. As outlined in Seigal (2000), we combine a process-based model with an index-based model to produce sensitivity and vulnerability maps for Heber and Round Valleys. The index-based model assigns ranges of attribute values and ranks the ranged attribute values as conducive or not conducive to ground-water contamination by pesticides. The process-based model incorporates physical and chemical processes through mathematical equations addressing the behavior of certain chemicals in the subsurface), in this case retardation and attenuation of pesticides using methods developed by Rao and others (1985). No new fieldwork 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 onto 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 factors primarily determining ground-water sensitivity to pesticides in Heber and Round Valleys. Sensitivity represents the sum of natural influences that facilitate the entry of pesticides into 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 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 (confining layers) and have a downward ground-water gradient (figure 3). Secondary recharge areas, commonly mountain-front benches, have fine-grained layers thicker than 20 feet (6 m) and a downward ground-water gradient (figure 3). 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 (Lowe and Snyder, 1996) (figure 3). 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 3). 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.

Lowe (1995) used drillers' logs of water wells in Heber and Round Valleys to delineate primary 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 areas 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 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 of Utah 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 Heber and Round Valleys consists of uplands surrounding the basin, together with basin fill not containing confining layers (figure 3), generally located along mountain fronts. 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 (figure 3). 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

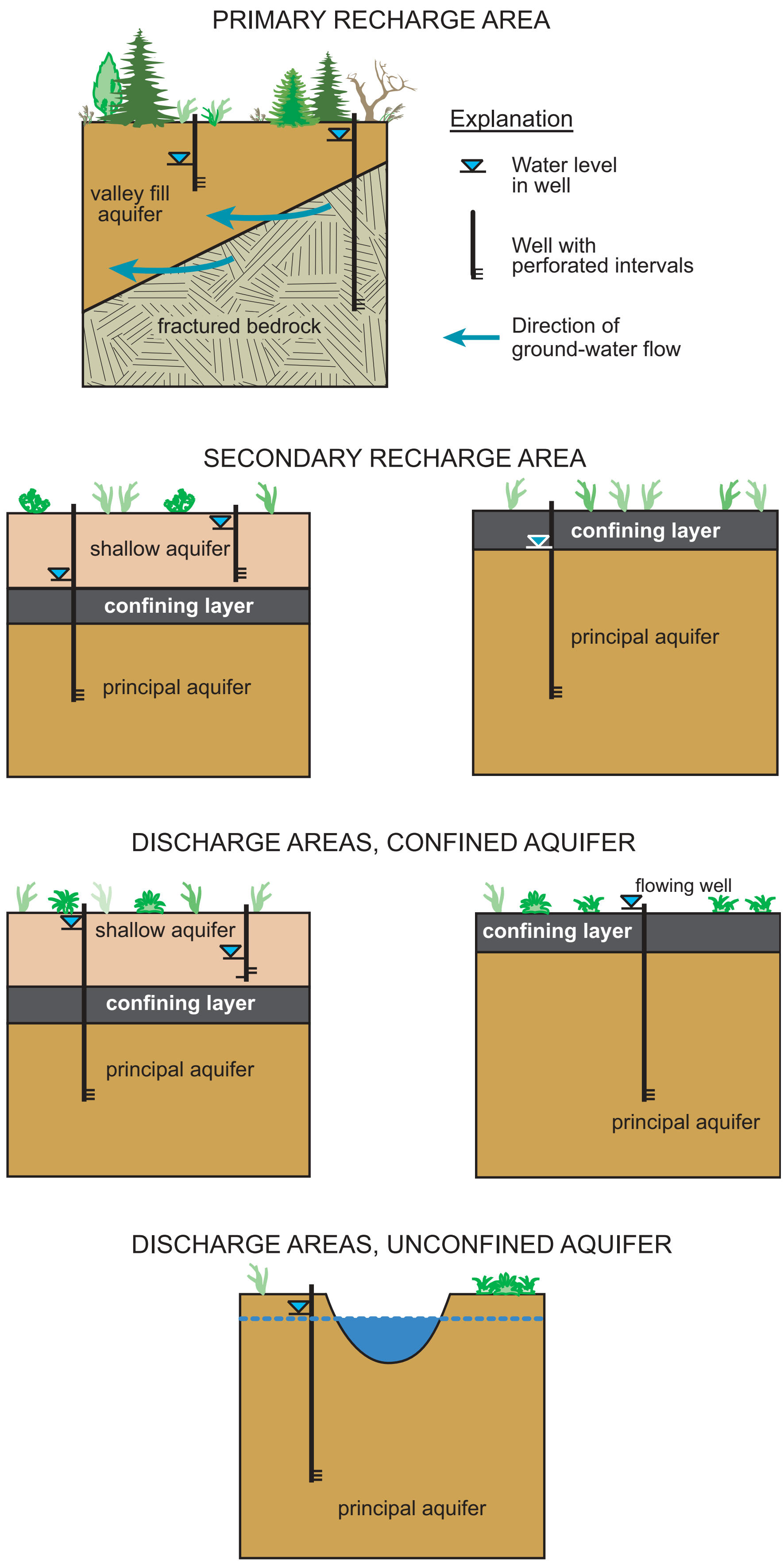

Figure 3. *Relative water levels in wells in recharge and discharge areas (modified from Snyder and Lowe, 1998).*

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 (figure 3). 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 exceeds 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 the 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's Soil Conservation Service (now Natural Resources Conservation Service; Woodward and others, 1976). For GIS analysis, we divided soil units into two hydraulic conductivity ranges: greater than or equal to, and less than, 1 inch (2.5 cm) per hour. We chose 1 inch (2.5 cm) per hour because it corresponds to the minimum allowable percolation rate permitting septic tanks under Utah Division of Water Quality administrative rules. For areas having no hydraulic conductivity data, we applied the greater than or equal to 1 inch (2.5 cm) per minute GIS attribute ranking, described below, to be protective of ground-water quality.

Pesticide Retardation

Pesticide retardation is a measure of the differential between movement of water and the movement of pesticide in the vadose zone (Rao and others, 1985). Because pesticides are adsorbed to organic carbon in soil, they move more slowly through the soil than water; the relative rate of movement of pesticides depends 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 rate as pore water in the vadose zone. The retardation factor (R_F) is a function of dry bulk density, organic carbon fraction, and field capacity of the soil and the organic carbon sorption distribution coefficient of the specific pesticide; a relatively low R_F indicates a higher potential for ground-water pollution. Rao and others (1985) present the following equation:

$$R_F = 1 + (\text{rb Foc Koc})/\text{q FC} \qquad (1)$$

where:

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

Retardation factors typically range from (1 + 4Kd) to (1 + 10 Kd) (Freeze and Cherry, 1979), where Kd is the product of the organic carbon sorption distribution coefficient (Koc) and the fraction of organic carbon, and based on typical unconsolidated sediment properties of bulk density (0.06-0.08 lb/in^3 [1.6-2.1 kg/L]) and porosity range (0.2 to 0.4). Dissolved constituents in ground water having low R_F values (around 1) such as nitrate (a relatively mobile cation), move through the subsurface at the same rate as the ground water, whereas dissolved constituents in ground water with R_F values that are orders of magnitude larger than one are essentially immobile (Freeze and Cherry, 1979). The relative velocity is the reciprocal of the retardation factor and describes the rate a mixture of reactive contaminant moves relative to solvent-free ground water.

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 Heber and Round Valleys, at a scale of 1:24,000. Data include derived values for bulk density, organic carbon fraction, and field capacity (table 2).

We set variables in equation 1 to values that represent conditions likely to be encountered in the natural environment (table 2) to establish a rationale for dividing high and low pesticide retardation for our GIS analysis, and we applied digital soil information unique for particular soil groups from SSURGO data for organic carbon. We used the organic carbon sorption distribution coefficient (table 3), at a pH of 7, for atrazine, the pesticide among the four having the least tendency to adsorb to organic carbon in the soil (Weber, 1994). We derived bulk density and field capacity from a soil texture triangle hydraulic properties calculator (Saxton, undated). To compute R_F values, we applied bulk density end members of 0.04 and 0.07 pounds per cubic inch (1.2 and 2.0 kg/L) and field capacity end members of 12 and 42 percent, which represent naturally occurring conditions in Heber and Round Valley aquifers, and variable soil organic carbon content using a water depth of 3 feet (1 m). Average organic carbon content in soils in Heber and Round Valleys is shown in figure 4 and ranges from 1.45 to 4.4 percent; the mass fraction of organic carbon was computed by dividing the organic matter parameter in the SSURGO data by a conversion factor of 1.72 (Siegel, 2000). We then applied the organic carbon content end members to compute the extreme R_F values; equation 1 results in retardation factors ranging 5 to 63. This means the highest relative velocity from our data is 0.2

Table 2. *Hydrologic Soil Groups, field capacity, bulk density, and fraction of organic content generalized for Utah soils. Soil description and organic content from National Soil Survey Center (1994). Field capacity based on sediment grain size calculated from a soil texture triangle hydraulic properties calculator (Saxton, undated). Bulk density from Marshall and Holmes (1988) and Saxton (undated).*

Soil Group	Soil Description	Grain size (mm) (Field Capacity %)	Bulk Density Range (kg/L) (average)	Organic Content, Fraction (Foc)*
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 (14-21)	1.5 – 2 (1.75)	Variable and ranges from 1.45 to 4.4%
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 (25-28)	1.3 - 1.61 (1.4)	Variable and ranges from 1.45 to 4.4%
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 (26)	1.3 – 1.9 (1.6)	Variable and ranges from 1.45 to 4.4%
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 (32-42)	1.2-1.3 (1.25)	Variable and ranges from 1.45 to 4.4%

* Foc is calculated from STATSGO organic matter data divided by 1.72 and is unique for soil polygons.

Table 3. *Pesticide organic carbon sorption distribution coefficients (Koc) and half-lives ($T^1/_2$) for typical soil pHs (data from Weber, 1994).*

	Koc (L/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

and the lowest, 0.016; the former indicates pesticide in ground water moves at a rate about 20 percent that of ground water free of pesticides, while the latter indicates that pesticides in ground water are essentially immobile.

A small percentage of pesticides traveling downward in vadose-zone material having an RF of 5 could reach the water table at a depth of 3 feet (1 m) within one year if ground-water recharge amounted to 22 inches (56 cm) or greater during the year, which is the highest amount of recharge calculated for the mountains in the Heber and Round Valleys area. When ground-water recharge is less than 17 inches (43 cm) per year, as is the case for the valley floors of Heber and Round Valleys, negligible amounts of pesticide will reach a depth of 3 feet (1 m) in a one-year period (see attenuation discussion below).

Pesticide Attenuation

Pesticide is a measure of the rate at which a pesticide degrades under the same conditions as characterized above under retardation attenuation (Rao and others, 1985). 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. Attenuation factors range between 0 and 1 (Rao and others, 1985); note that high attenuation factors represent conditions of low attenuation. Rao

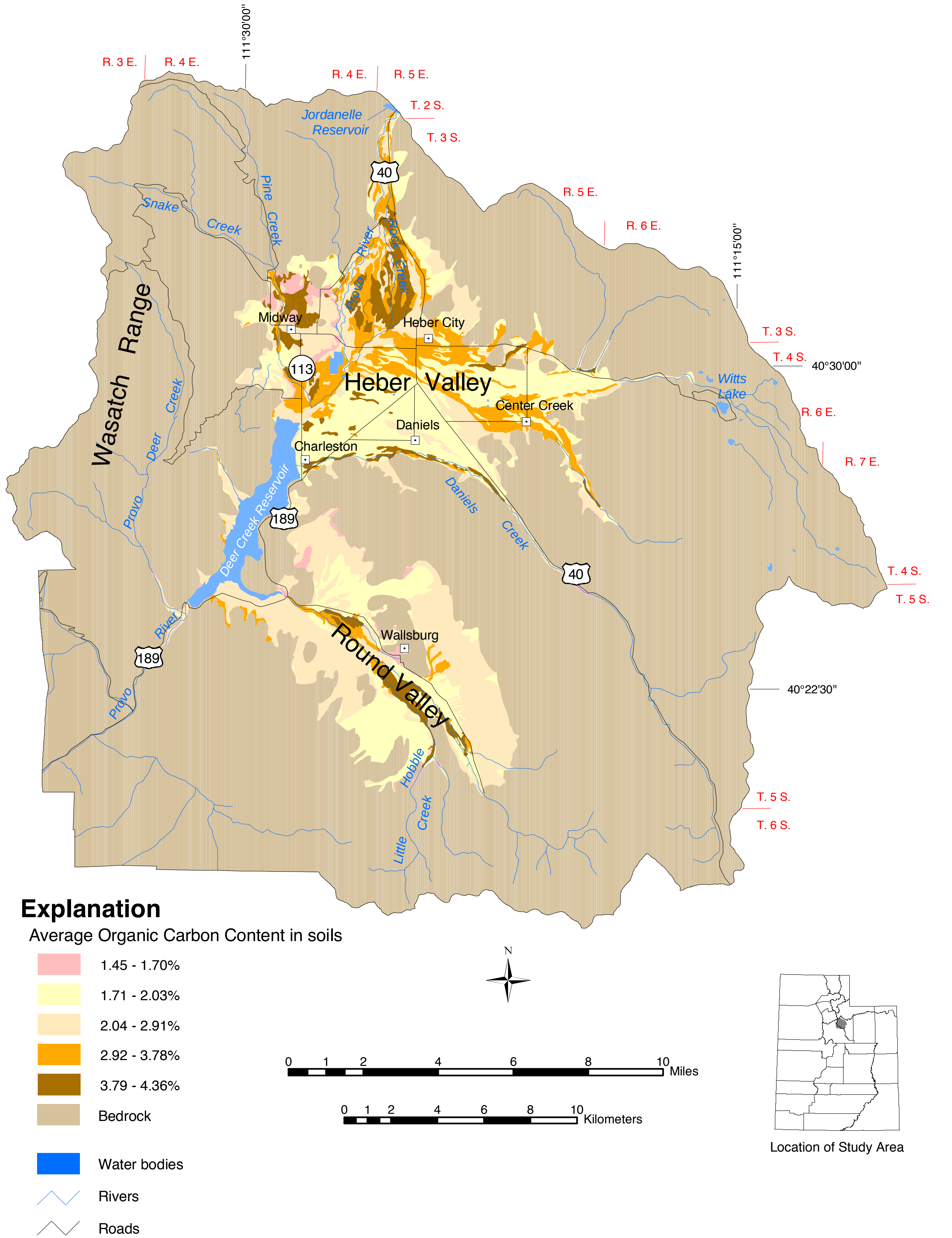

***Figure 4.** Average organic carbon content in soils in Heber and Round Valleys, Wasatch County, Utah (data from National Soil Survey Center, 1994).*

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

For this study, we calculated (using GIS analysis) net annual ground-water recharge 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 most of the moisture produced by precipitation is consumed by evapotranspiration in most parts of the state, including Heber and Round Valleys (figure 5). Therefore, ground-water recharge from precipitation is relatively low in many areas of Utah, including Heber and Round 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 that 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 it is not easily measured, and is not evaluated in our analysis.

Using equation 2, I calculated attenuation factors for ranges of values common to Heber and Round Valley soils, similar to our approach for retardation, to delineate high and low pesticide attenuation factors for our GIS analysis. To represent naturally occurring conditions that would result in the greatest sensitivity to ground-water contamination, we used a retardation factor of 5, calculated as described above; the half-life for simazine (table 5), the pesticide among the four with the longest half-life (Weber, 1994); a field capacity of 14 percent; and a bulk density value of 0.04 pounds per cubic inch (1.2 kg/L). For a net annual ground-water recharge value of 0 inches (0 cm), as is typical of the valley-floor areas of Heber and Round Valleys, equation 2 results in an attenuation factor approaching 0. This means that at the above-described values for variables in the equation, none of the pesticide originally introduced into the system at the ground surface would be detected at a depth of 3 feet (1 m) – no pesticides would reach ground water.

Although quantities of pesticides applied to the ground surface would intuitively 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 4) 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.

Depth to Shallow 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 or equal to 3 feet (1 m) deep is one attribute of soil units mapped by the Soil Conservation Service (now Natural Resources Conservation Service; Woodward and others, 1976). We selected 3 feet (1 m) as the depth-to-ground-water attribute used to evaluate sensitivity of geographic areas to pesticides. For areas where depth-to-ground-water data are not available in GIS format, we used data from Hylland and others (1995) for GIS analysis.

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 in table 5. Numerical ranking for each attribute category is arbitrary, but reflects the relative level of importance 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 added numerical ranking ranged from –2 to 0, a sensitivity attribute of moderate was assigned when the added numerical ranking ranged from 1 to 4, and a sensitivity attribute of high was assigned when the added numerical ranking ranged from 5 to 8.

Ground-Water Vulnerability to Pesticide Pollution

Ground-water vulnerability to pesticides is determined by assessing how ground-water sensitivity is modified by the activities of humans. In addition to ground-water sensitivity to pesticides, the presence of applied water (irrigation) and crop type are the factors primarily determining ground-water vulnerability to pesticides. The vulnerability map (plate 2) 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 Heber and Round Valleys to degradation from agricultural pesticides. Low, moderate, and high sensitivity rankings

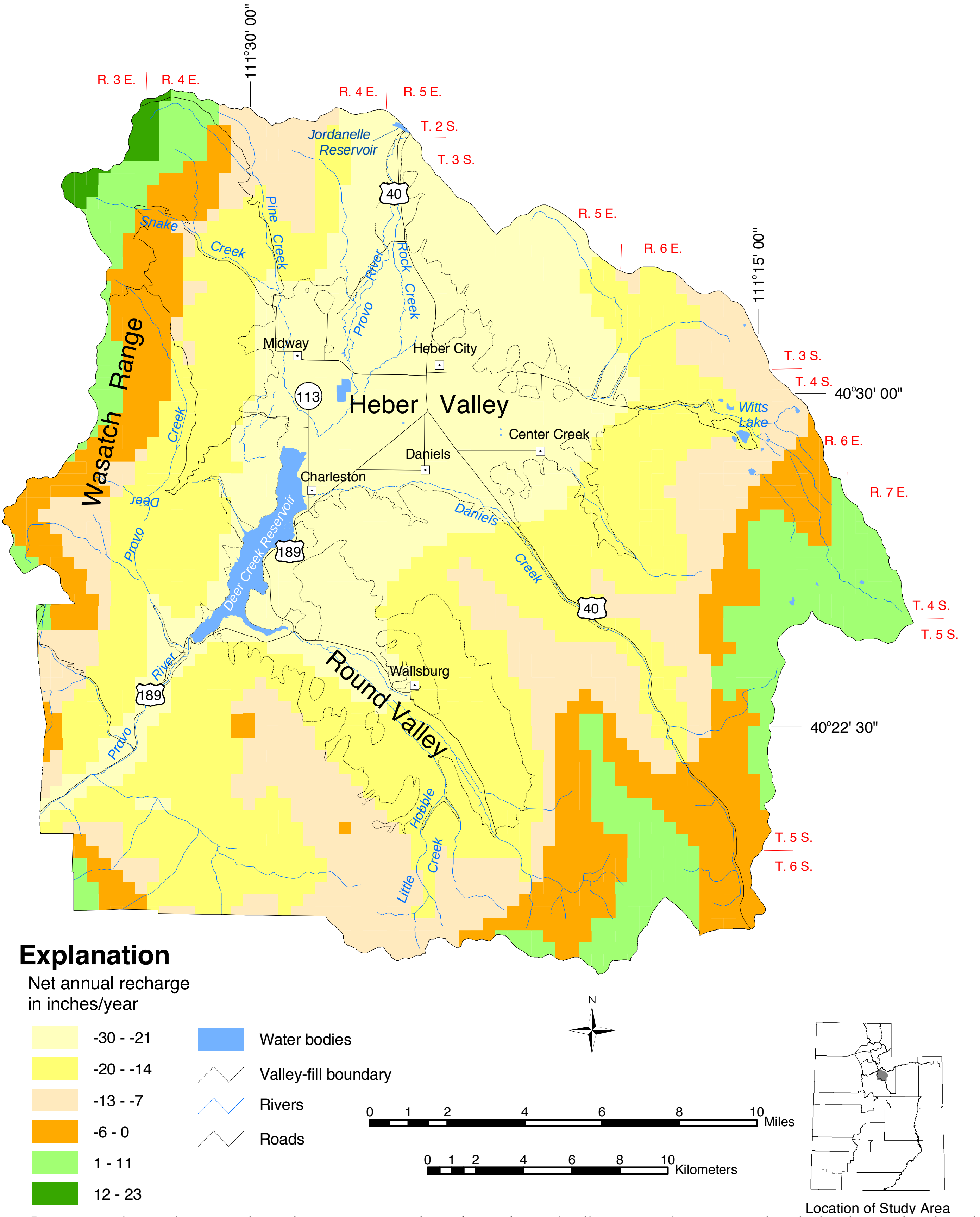

Figure 5. *Net annual ground-water recharge from precipitation for Heber and Round Valleys, Wasatch County, Utah, calculated using data from the Utah Climate Center (1991) and Jensen and Dansereau (2001). Although net annual recharge may be negative in some areas, seasonally some recharge from precipitation may occur.*

Table 4. *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	Pre-emergence
Metolachlor	1.9	Pre-emergence
Simazine	4.0	Pre-emergence

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

Table 5. *Pesticide sensitivity and the attribute rankings used to assign sensitivity for Heber and Round Valleys, Wasatch County, Utah.*

<table>
<tr><th colspan="2">Pesticide Retardation</th><th colspan="2">Pesticide Attenuation Factor</th><th colspan="2">Hydrogeologic Setting</th><th colspan="2">Soil Hydraulic Conductivity</th><th colspan="2">Depth to Ground Water</th><th colspan="2">Sensitivity</th></tr>
<tr><td>Attribute</td><td>Ranking</td><td>Attribute</td><td>Ranking</td><td>Attribute</td><td>Ranking</td><td>Attribute</td><td>Ranking</td><td>Attribute</td><td>Ranking</td><td>Attribute</td><td>Ranking</td></tr>
<tr><td rowspan="2">High</td><td rowspan="2">0</td><td rowspan="2">High</td><td rowspan="2">0</td><td>Confined Aquifer Discharge Area</td><td>-4</td><td rowspan="2">Less than 1 inch/hour</td><td rowspan="2">1</td><td rowspan="2">Greater than 3 feet</td><td rowspan="2">1</td><td>Low</td><td>-2 to 0</td></tr>
<tr><td rowspan="2">Secondary Recharge Area</td><td rowspan="2">-1</td><td rowspan="2">Moderate</td><td rowspan="2">1 to 4</td></tr>
<tr><td rowspan="2">Low</td><td rowspan="2">1</td><td rowspan="2">Low</td><td rowspan="2">1</td><td rowspan="2">Greater than or equal to 1 inch/hour</td><td rowspan="2">2</td><td rowspan="2">Less than or equal to 3 feet</td><td rowspan="2">2</td></tr>
<tr><td>Primary Recharge Area And Unconfined Aquifer Discharge Area</td><td>2</td><td>High</td><td>5 to 8</td></tr>
</table>

Table 6. *Pesticide vulnerability and the attribute rankings used to assign vulnerability for Heber and Round Valleys, Wasatch County, Utah.*

<table>
<tr><th colspan="2">Sensitivity</th><th colspan="2">Corn/Sorghum Crops</th><th colspan="2">Irrigated Land</th><th colspan="2">Vulnerabilty</th></tr>
<tr><td>Attribute</td><td>Ranking</td><td>Attribute</td><td>Ranking</td><td>Attribute</td><td>Ranking</td><td>Attribute</td><td>Ranking</td></tr>
<tr><td>Low</td><td>-2</td><td rowspan="2">No</td><td rowspan="2">0</td><td rowspan="2">No</td><td rowspan="2">0</td><td>Low</td><td>-2 to -1</td></tr>
<tr><td rowspan="2">Moderate</td><td rowspan="2">0</td><td rowspan="2">Moderate</td><td rowspan="2">0 to 2</td></tr>
<tr><td rowspan="2">Yes</td><td rowspan="2">1</td><td rowspan="2">Yes</td><td rowspan="2">1</td></tr>
<tr><td>High</td><td>2</td><td>High</td><td>3 to 4</td></tr>
</table>

were assigned numerical values as shown in table 6.

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 mapped from either aerial photographs (pre-2000) or 5-meter (16 ft) resolution infrared satellite data and then field checked (Utah Division of Water Resources metadata). The Heber and Round Valleys inventory was conducted in 1995 (Utah Division of Water Resources metadata). All polygons having standard type codes beginning with IA were selected to produce 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.

Crop Type

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 infrared satellite data and then field checked (Utah Division of Water Resources metadata). The Heber and Round 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 land coverage for this study, as these are the crop types to which the pesticides addressed are applied in Utah. Although the specific fields growing 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 6. Once again, numerical ranking for each attribute category is arbitrary, but reflects the relative level of importance the attribute plays in determining vulnerability of areas to application of agricultural pesticides. For instance, ground-water sensitivity to pesticides is the most important attribute with respect to ground-water vulnerability to pesticides, and therefore we weighted this attribute two times more heavily than the other attribute categories.

RESULTS

Ground-Water Sensitivity

To assess ground-water sensitivity to pesticide contamination, several GIS 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 shallow ground water. Data from these attribute layers were used to produce a ground-water sensitivity map (plate 1) using GIS analysis methods as outlined in table 5, and are described and summarized in the following sections.

Retardation/Attenuation

Retardation/attenuation is ranked as high (attenuation factors are low) throughout Heber and Round Valleys; for attenuation this is because net annual evapotranspiration exceeds net annual precipitation, and because of the short half-lives of pesticides in the soil environment. Net annual recharge from precipitation is negative in valley-floor areas (figure 5). Most recharge that does occur from precipitation is principally along the valley margins and likely occurs during spring snowmelt. Pesticides are generally applied after snowmelt. Up to several months may elapse between pesticide application and first irrigation, sufficient time for attenuation to occur before downward migration of pesticides in the vadose zone commences under the influence of irrigation.

Hydrogeologic Setting

Lowe (1995) showed that, due to the lack of thick clay layers above the valley-fill aquifers, only primary recharge areas and unconfined aquifer discharge areas are present in Heber and Round Valleys. Primary recharge areas, the areas most susceptible to contamination from pesticides applied to the land surface, exist throughout most of Heber and Round Valleys (figure 6), making up about 88 percent of the surface area of the valley-fill aquifers. The lower reaches of some streams in Heber and Round Valleys (figure 6) are unconfined aquifer discharge areas, which make up 12 percent of the surface area of the valley-fill aquifers, and are also very susceptible to contamination from pesticides applied to the land surface.

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 the National Soil Survey Center (1994). About 77 percent of the surface area of the valley-fill aquifer has soil units mapped as having hydraulic conductivity greater than or equal to 1 inch (2.5 cm) per hour. Soils in this category are found over much of the study area (figure 7). About 22 percent of the surface area of the valley-fill aquifer has soil units mapped as having hydraulic conductivity less than 1 inch (2.5 cm) per hour; these soil units are primarily in the eastern part of Heber Valley north of Heber City, and in northwestern Round Valley (figure 7). About 1 percent of the surface area of the valley-fill aquifer has soil units for which hydraulic conductivity values have not been assigned by the National Soil Survey Center (1994); these soil polygons are scattered throughout the study area (figure 7), and were grouped into the greater than or equal to 1 inch (2.5 cm) per hour 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 shallow ground water than where ground water is relatively deep. Depth to shallow ground-water data are from the National Soil Survey

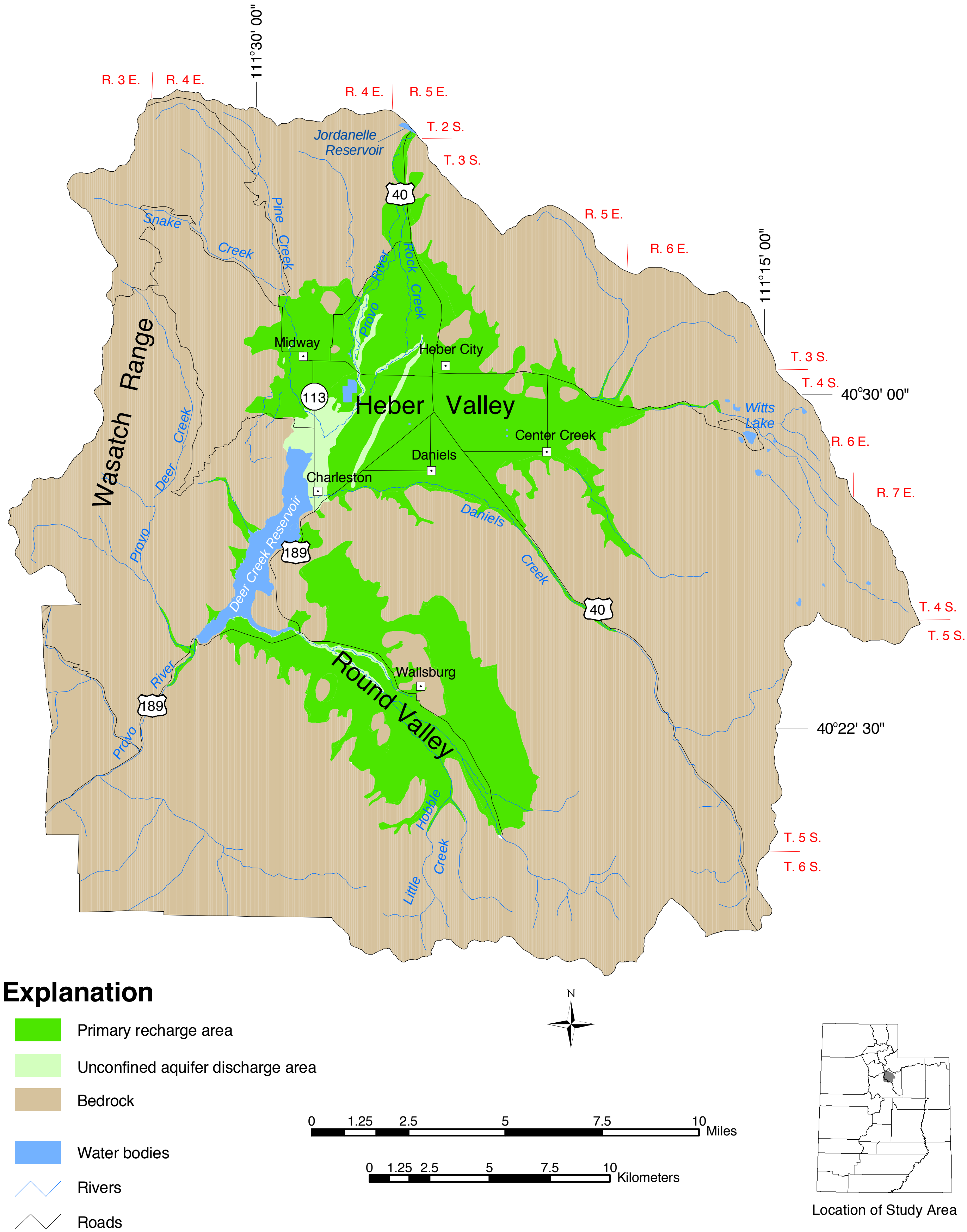

Figure 6. *Recharge and discharge areas in Heber and Round Valleys, Wasatch County, Utah (modified from Lowe, 1995).*

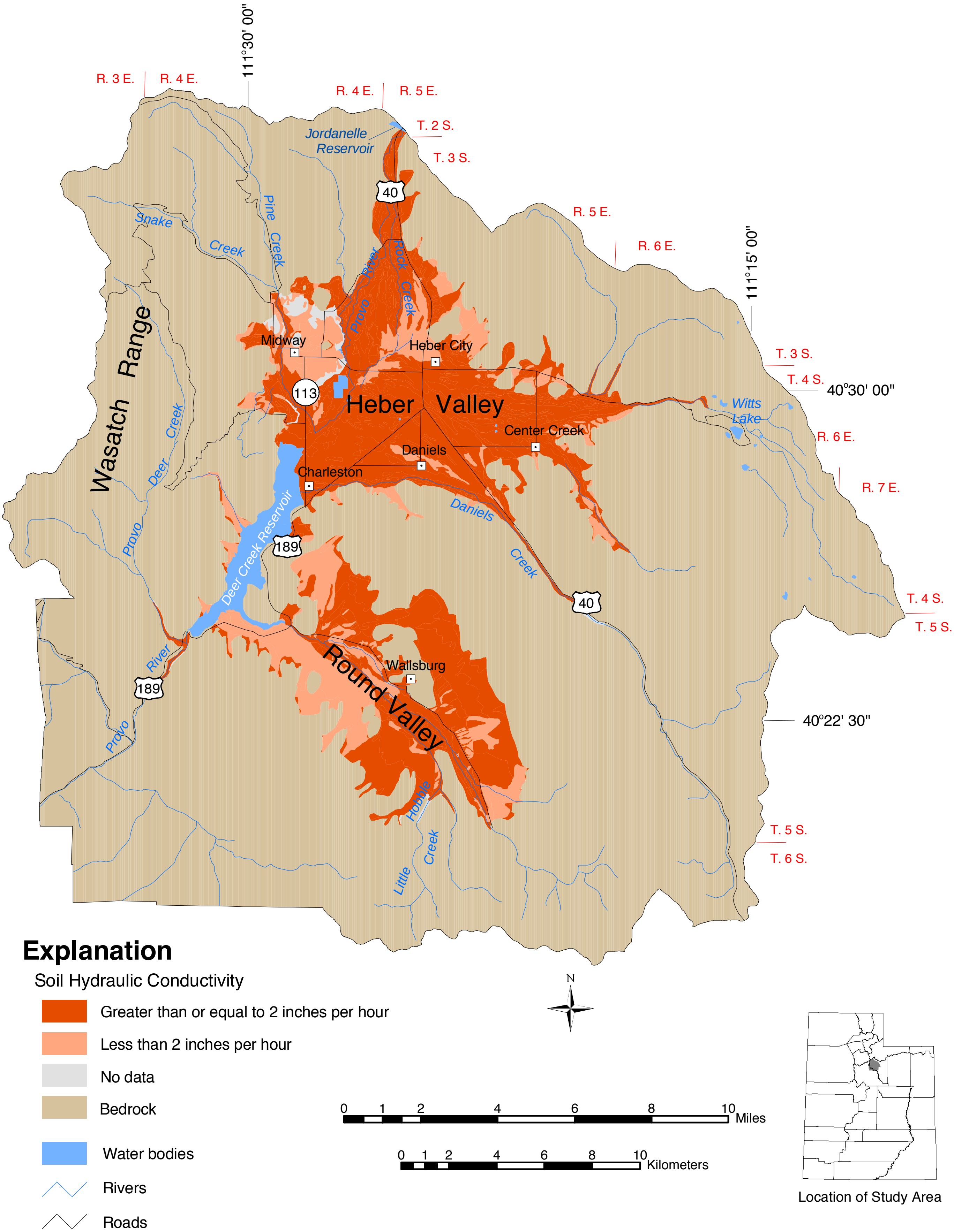

***Figure 7**. Soil hydraulic conductivity in Heber and Round Valleys, Wasatch County, Utah (data from National Soil Survey Center, 1994).*

Center (1994). About 30 percent of the area overlying the valley-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 along streams (figure 8). About 70 percent of the surface area of the valley-fill aquifer has soil units mapped as having no data (figure 8). Areas without assigned depths to shallow ground water would normally be grouped with the less than or equal to 3 feet (1 m) depth category for analytical purposes to be protective of water quality. However, mapping by Hylland and others (1995), based on soil mapping by Woodward and others (1976) and limited water-well data, shows that in these areas where polygons in the SSURGO data base were not attributed, the depth to shallow ground water is actually predominantly greater than 10 feet (3 m). Therefore, the polygons without depth to shallow ground-water data were lumped into the greater than 3 feet (1 m) category for analytical purposes.

Pesticide Sensitivity Map

Plate 1 shows ground-water sensitivity to pesticides for Heber and Round Valleys, obtained using GIS methods and ranking techniques described above. Our analysis evaluates only the valley-fill aquifer; the surrounding uplands are designated on plate 1 as "bedrock" and consist mainly of shallow or exposed bedrock in mountainous terrain.

Most of Heber and Round Valleys (82 percent) is of high sensitivity (plate 1) because of the lack of protective clay layers (primary recharge area hydrogeologic setting), and because of the relatively high hydraulic conductivity of soils in the study area. However, pesticides used in these areas are unlikely to degrade ground water because they have little opportunity to get into the aquifer as indicated by calculated retardation and attenuation factors. In this area, pesticides spilled or misapplied have a much greater potential to contaminate surface water than ground water. Alluvial-fan areas along the valley margins, where soils have lower hydraulic conductivities are areas of moderate sensitivity (plate 1). About 18 percent of the area overlying the valley-fill aquifer is mapped as having moderate sensitivity (plate 1).

Ground-Water Vulnerability

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 statewide attribute layers include irrigated cropland and corn- and sorghum-producing areas (not present) in Heber and Round Valleys (figure 9). Using GIS methods as outlined in table 8, 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). The pertinent attribute layers irrigated cropland and corn and sorghum crops, along with ground-water sensitivity, are described in the following sections.

Irrigated Cropland

Irrigated cropland areas in Heber and Round Valleys are shown on figure 9. About 44 percent of the valley floor is irrigated, and about 56 percent is not. Irrigation is potentially significant because it is a source of ground-water recharge in the valley-fill aquifer.

Corn and Sorghum Crops

From the point of view of human impact, areas where corn and sorghum are grown are significant because the four herbicides considered in this report – alachlor, atrazine, metolachlor, and simazine – are used to control weeds in these crops. Data from the Utah Division of Water Resources (1995) indicate that corn and sorghum are not grown in Heber and Round Valleys.

PesticideVulnerability Map

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

Areas of high vulnerability are primarily in irrigated areas where ground-water sensitivity to pesticides is high. About 65 percent of the surface area of the valley-fill aquifer is mapped as having high vulnerability (plate 2). Of particular concern are areas where ground water is shallow, as these are the areas most likely to be impacted by pesticide pollution. Areas of moderate vulnerability coincide, in general, with non-irrigated areas of moderate sensitivity. About 35 percent of the surface area of the valley-fill aquifer is mapped as having moderate vulnerability (plate 2).

CONCLUSIONS AND RECOMMENDATIONS

In Heber and Round Valleys, areas of irrigated land where the ground-water table is close to the land surface have the highest potential for water-quality degradation associated with surface application of pesticides. However, because corn and sorghum are generally not grown in Heber and Round Valleys, and because of the relatively high attenuation (short half-lives) of pesticides in water in the soil environment, pesticides likely do not represent a serious threat to ground-water quality. However, should corn or sorghum begin to be grown in Heber and Round Valleys, we believe ground-water monitoring for pesticides should be increased, and should be concentrated in areas of moderate and high sensitivity or vulnerability. Sampling and testing in areas of the valleys characterized by moderate sensitivity and moderate vulnerability should continue, but at a lower density than in the areas of higher sensitivity and vulnerability. The maps and accompanying 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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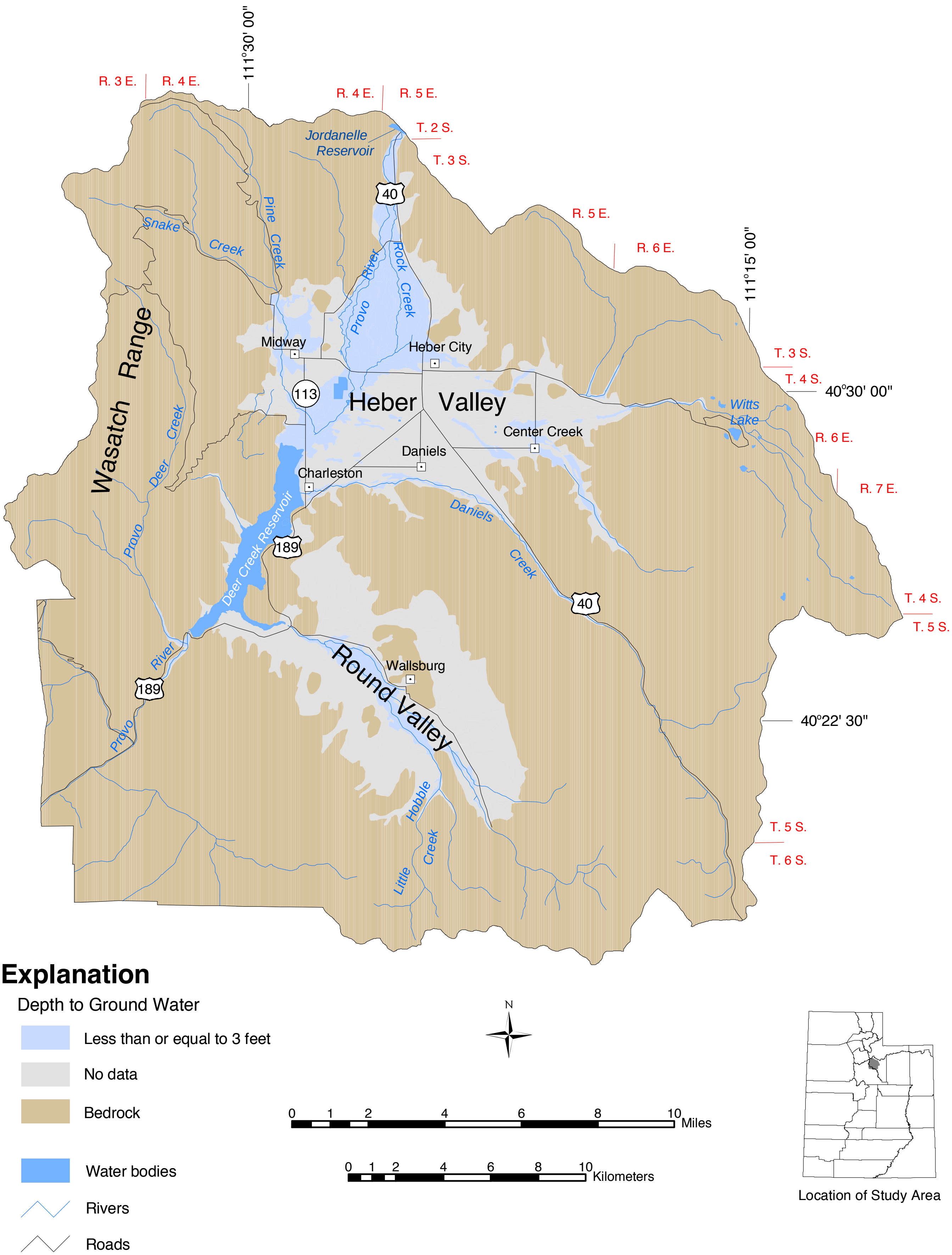

Figure 8. Depth to ground water in Heber and Round Valleys, Wasatch County, Utah (data from National Soil Survey Center, 1994; modified using data from Hylland and others, 1995).

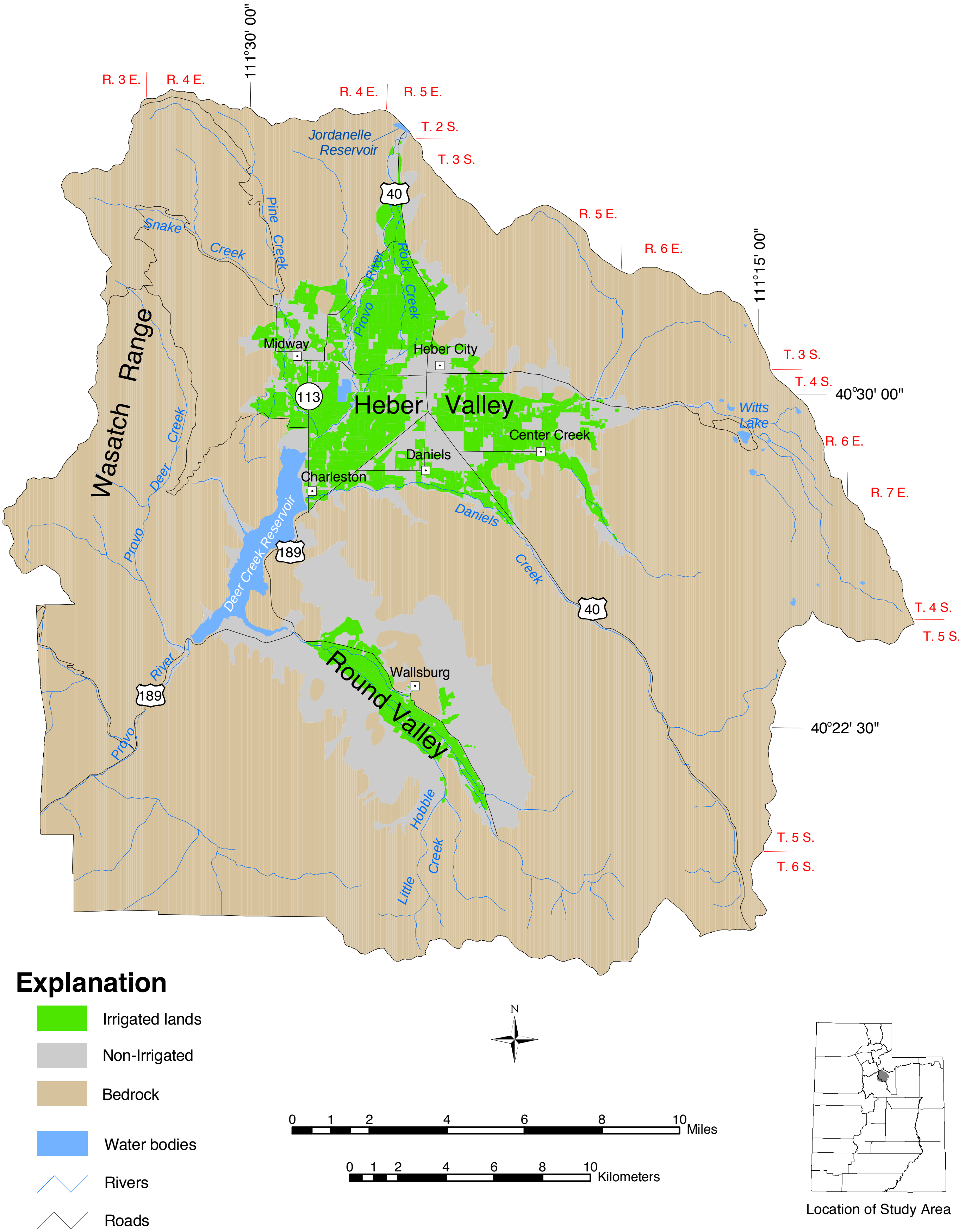

Figure 9. *Irrigated cropland in Heber and Round Valleys, Wasatch County, Utah (data from Utah Division of Water Resources, 1995).*

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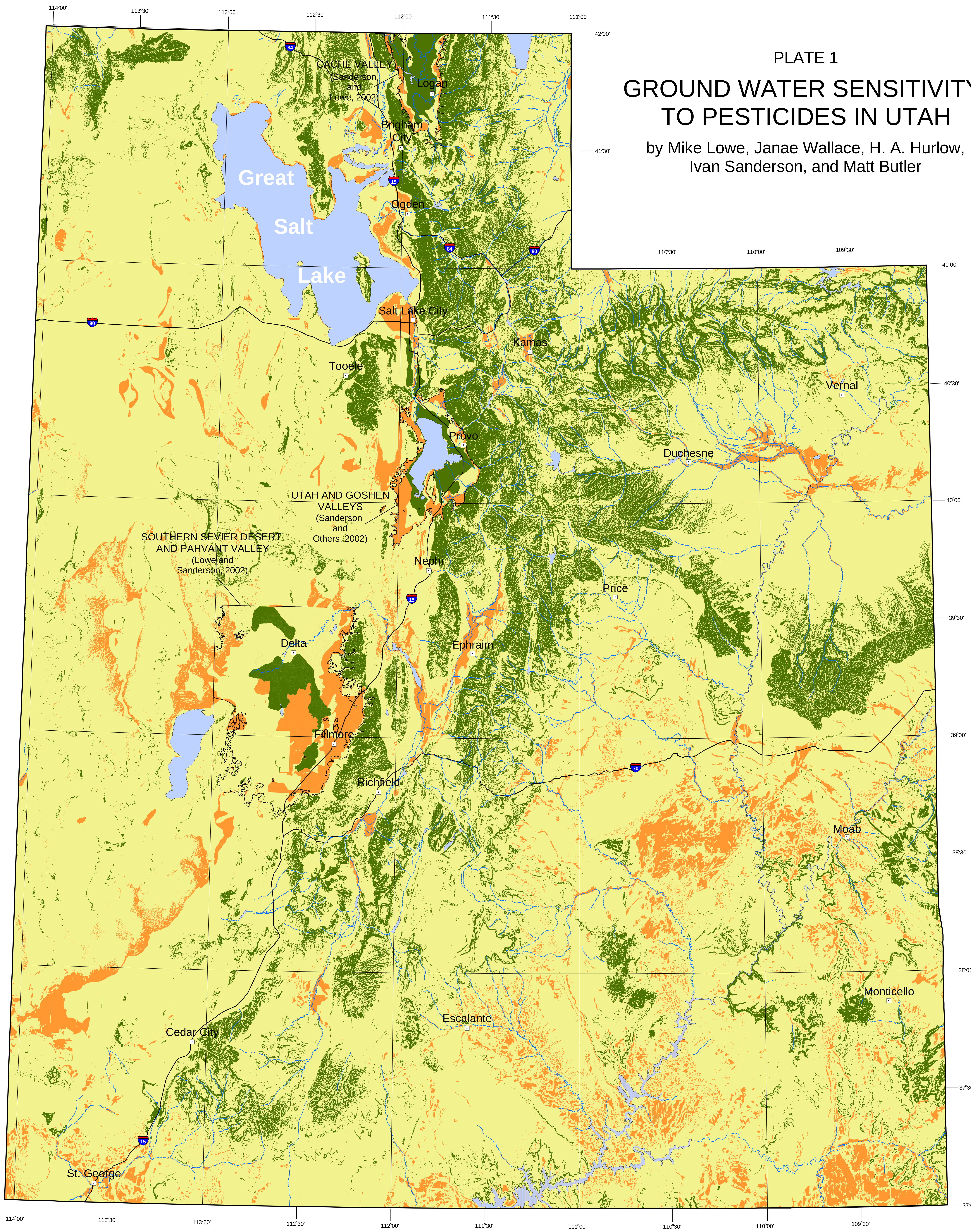
PLATE 1

GROUND WATER SENSITIVITY TO PESTICIDES IN UTAH

by Mike Lowe, Janae Wallace, H. A. Hurlow, Ivan Sanderson, and Matt Butler



Explanation

Low sensitivity

Moderate sensitivity

High sensitivity

Cities

Roads

Water courses

Water bodies

Boundary of valley-specific study (see Appendix C)

N

Scale 1:750,000

0 12.5 25 50 75 100 Miles

0 12.5 25 50 75 100 Kilometers

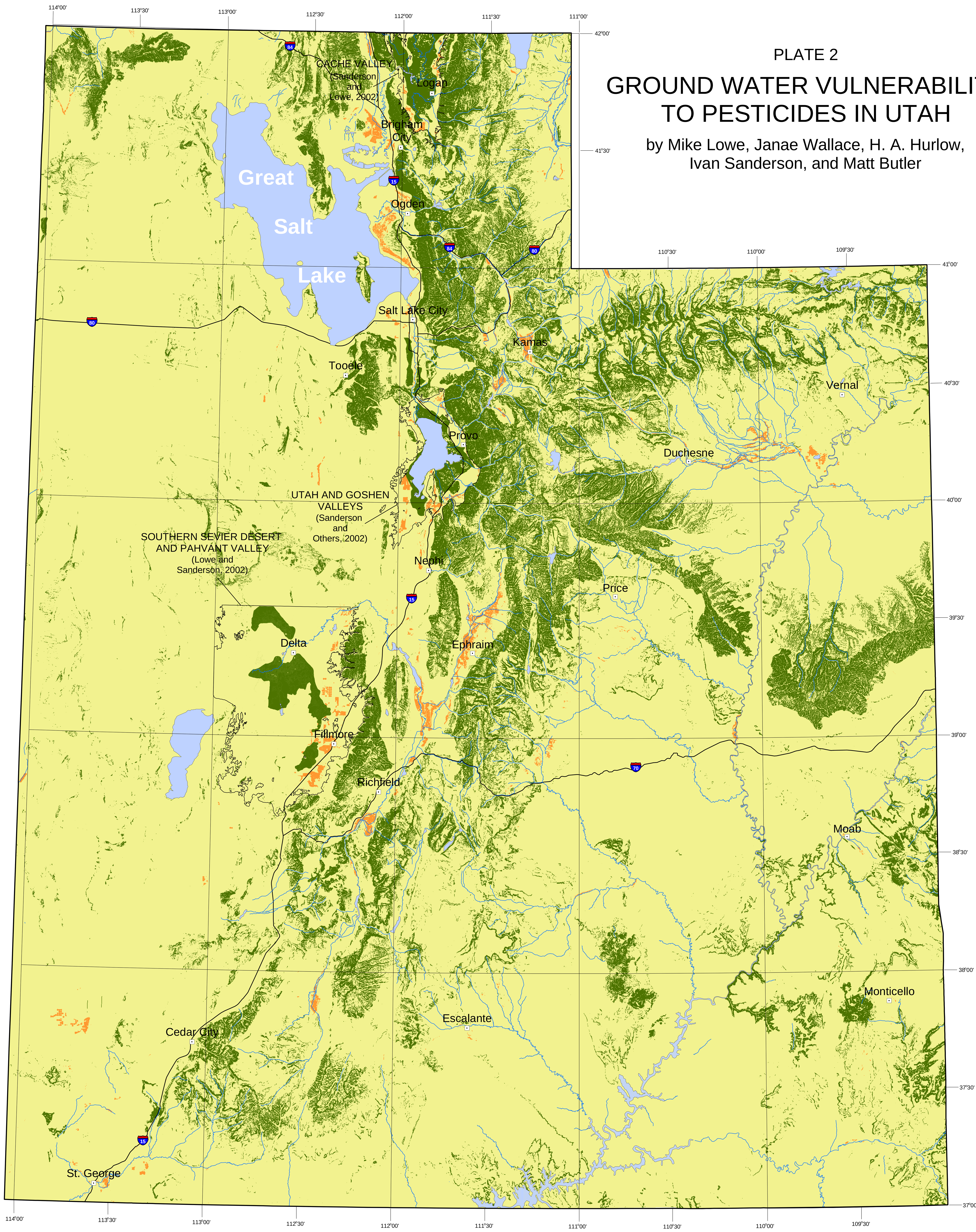
UTAH GEOLOGICAL SURVEY

UTAH GEOLOGICAL SURVEY a division of Department of Natural Resources

PLATE 2

GROUND WATER VULNERABILITY TO PESTICIDES IN UTAH

by Mike Lowe, Janae Wallace, H. A. Hurlow, Ivan Sanderson, and Matt Butler



Explanation

- Low vulnerability
- Moderate vulnerability
- High vulnerability
- Cities
- Roads
- Water courses
- Water bodies
- Boundary of valley-specific study (see Appendix C)

N

Scale 1:750,000

0 12.5 25 50 75 100 Miles

0 12.5 25 50 75 100 Kilometers

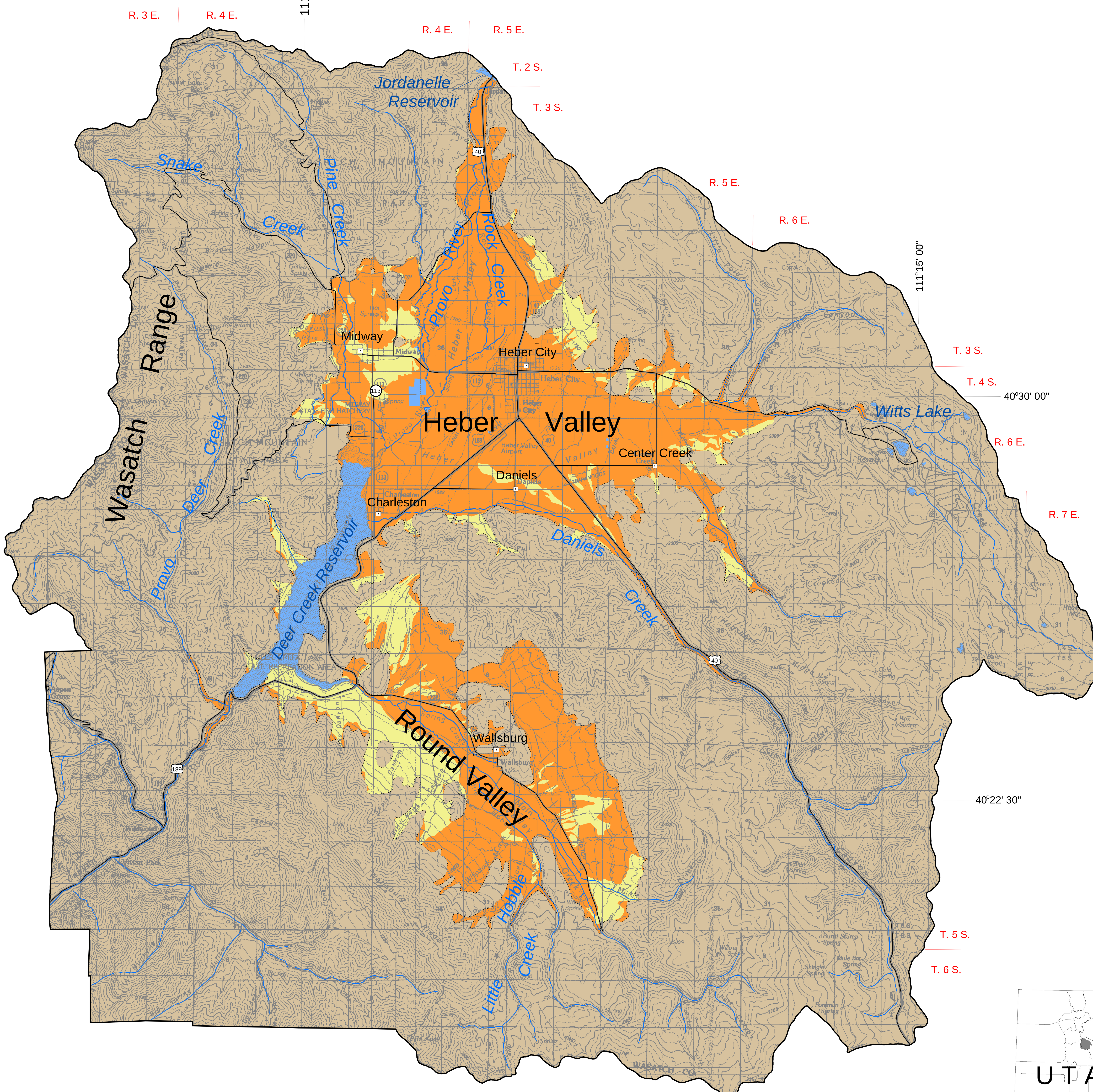
UTAH GEOLOGICAL SURVEY

UTAH GEOLOGICAL SURVEY a division of Department of Natural Resources

Plate 1

GROUND-WATER SENSITIVITY TO PESTICIDES IN HEBER AND ROUND VALLEYS, WASATCH COUNTY, UTAH

by Mike Lowe and Matt Butler



Explanation

Sensitivity of valley-fill deposits

- Moderate sensitivity
- High sensitivity
- Bedrock - not evaluated
- Water bodies
- Rivers
- Valley-fill boundary
- Roads
- Study-area boundary

N

1: 50,000

Contour Interval = 50 Meters

0 1 2 3 4 5 Miles

0 1 2 3 4 5 Kilometers

This map is a GIS product derived from a recharge/discharge area map by the Wasatch County GIS department, soil data from the National Soil Survey Center (1999), precipitation data from 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 of Study Area

Projection: UTM
Zone: 12
Units: Meters
Datum: NAD27
Spheroid: Clarke 1866

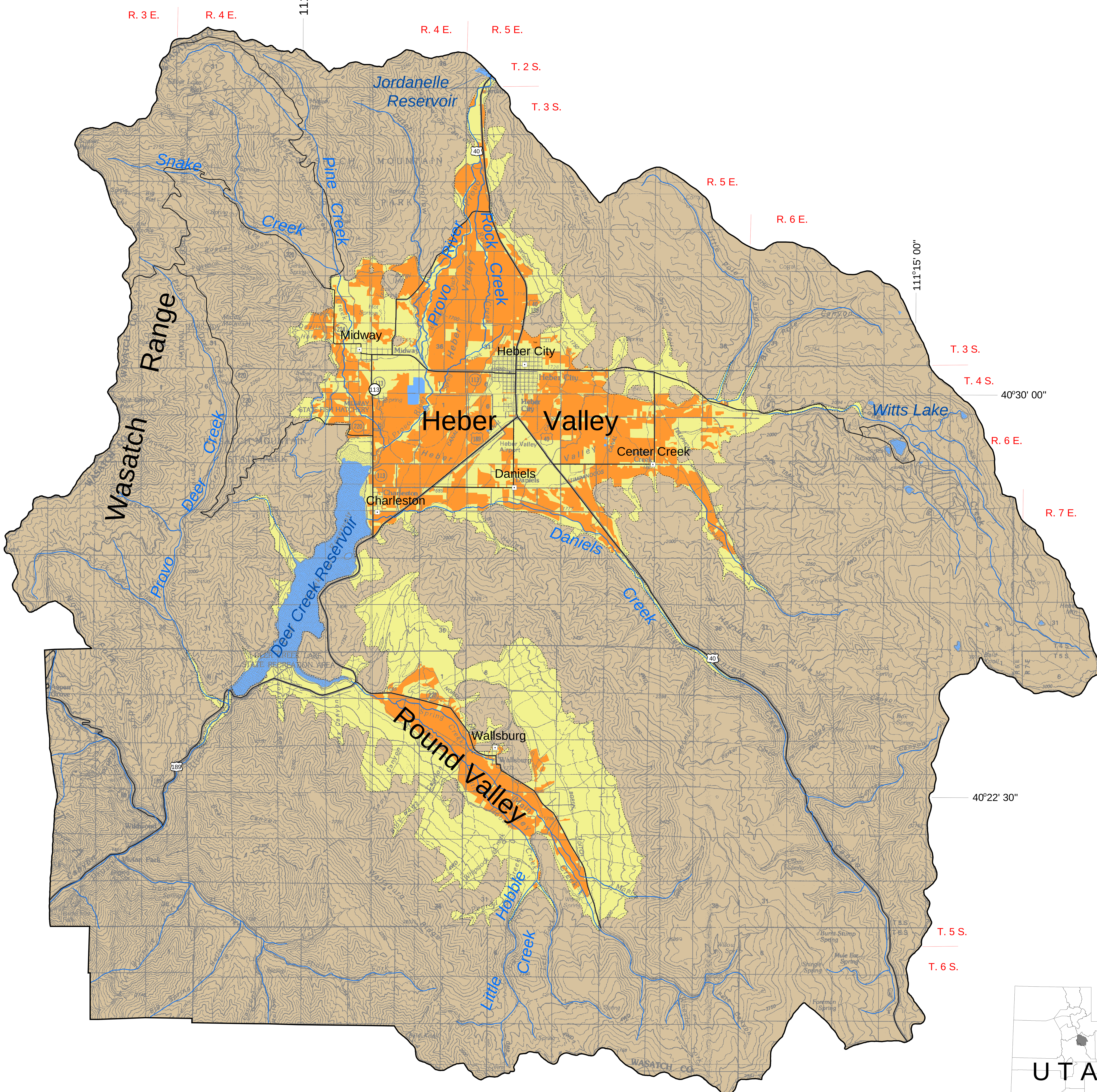
Topographic base map from U.S. Geological Survey
1:100,000-scale images: Salt Lake City (1980) and Provo (1975)

UTAH GEOLOGICAL SURVEY
UTAH GEOLOGICAL SURVEY a division of Department of Natural Resources

Plate 2

GROUND-WATER VULNERABILITY TO PESTICIDES IN HEBER AND ROUND VALLEYS, WASATCH COUNTY, UTAH

by Mike Lowe and Matt Butler



Explanation

Vulnerability of valley-fill deposits

- Moderate vulnerability
- High vulnerability
- Bedrock - not evaluated
- Water bodies
- Rivers
- Valley-fill boundary
- Roads
- Study-area boundary

N

1: 50,000

Contour Interval = 50 Meters

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