GROUND-WATER SENSITIVITY AND VULNERABILITY TO PESTICIDES, UPPER BEAR RIVER VALLEY, RICH COUNTY, UTAH

by

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Utah Geological Survey

and

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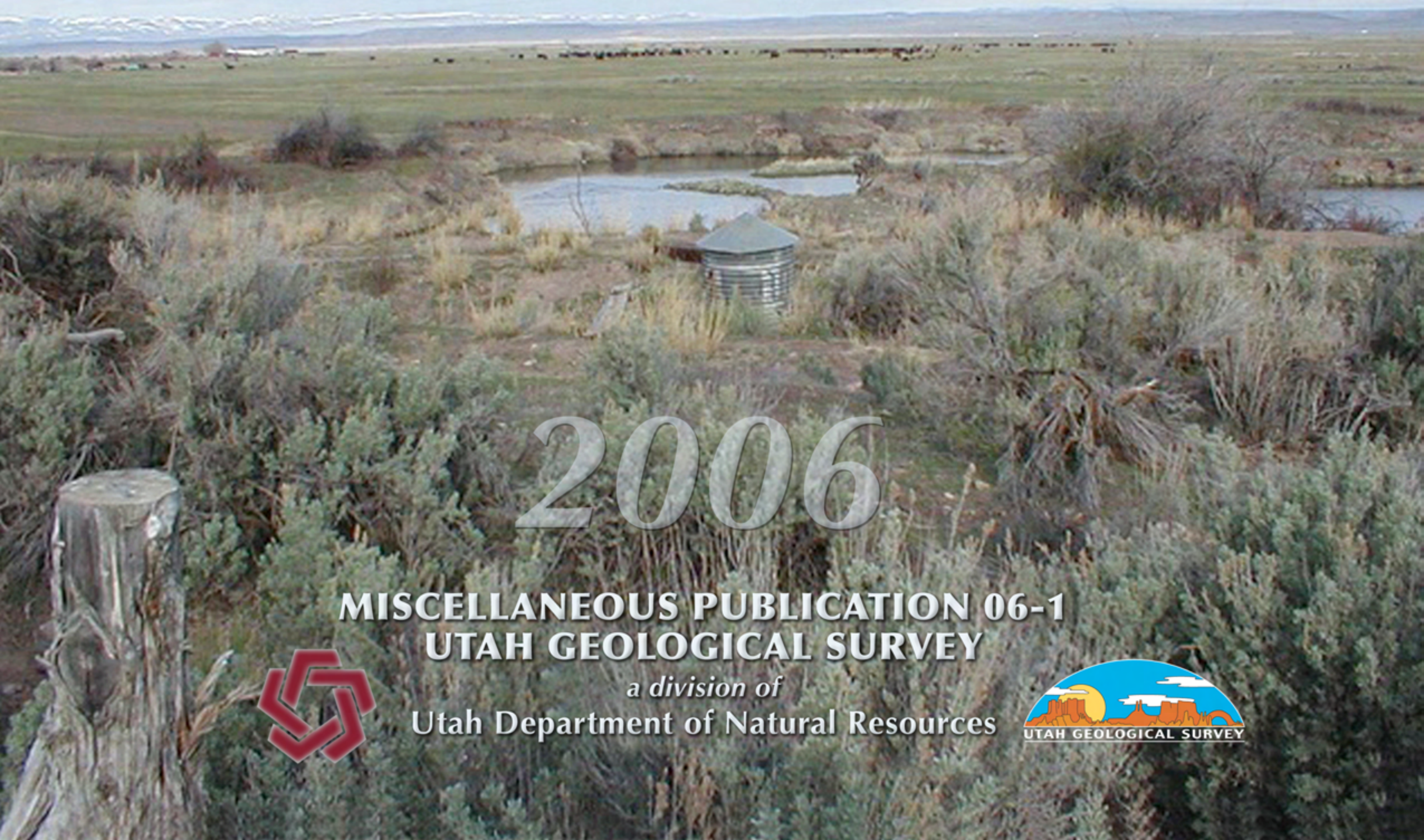
Utah Department of Agriculture and Food



2006

MISCELLANEOUS PUBLICATION 06-1
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Cover photo: View of pasture land in Upper Bear River Valley, Rich County, Utah

ISBN 1-55791-745-0

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ABSTRACT

The U.S. Environmental Protection Agency has recommended 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 upper Bear River Valley, Rich 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 attempt 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 (intrinsic susceptibility) 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 the valley-fill deposits of upper Bear River Valley. Much of the upper Bear River Valley's valley-fill deposits have high and moderate ground-water sensitivity to pesticides due to the presence of extensive primary recharge areas.

Ground-water vulnerability to pesticides is determined by assessing how ground-water sensitivity is modified by human activity. 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 the valley-fill deposits of upper Bear River Valley. Areas of high vulnerability are located primarily in areas where irrigation occurs and ground-water sensitivity to pesticides is high. Of particular concern are areas where influent (losing) streams originating in mountainous areas cross the valley margin; streams in these areas, along with the Bear River, are the most important source of recharge to the valley-fill aquifer, and efforts to preserve water quality in streams at these points would help to preserve ground-water quality in upper Bear River Valley.

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 upper Bear River Valley likely do not present a serious threat to ground-water quality. To verify this conclusion, future ground-water sampling by the Utah Department of Agriculture and Food in upper Bear River Valley should be concentrated in areas of moderate and high sensitivity or vulnerability, typically along valley margins. Sampling in the north-central area of the valley characterized by low sensitivity and vulnerability should continue, but at a lower density than in the areas of higher sensitivity and vulnerability.

INTRODUCTION

Background

The U.S. Environmental Protection Agency (EPA) has recommended 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 the sensitivity and vulnerability of ground water to agricultural pesticides in the valley-fill deposits of upper Bear River Valley, Rich County, Utah (figure 1). Geographic variation in sensi-

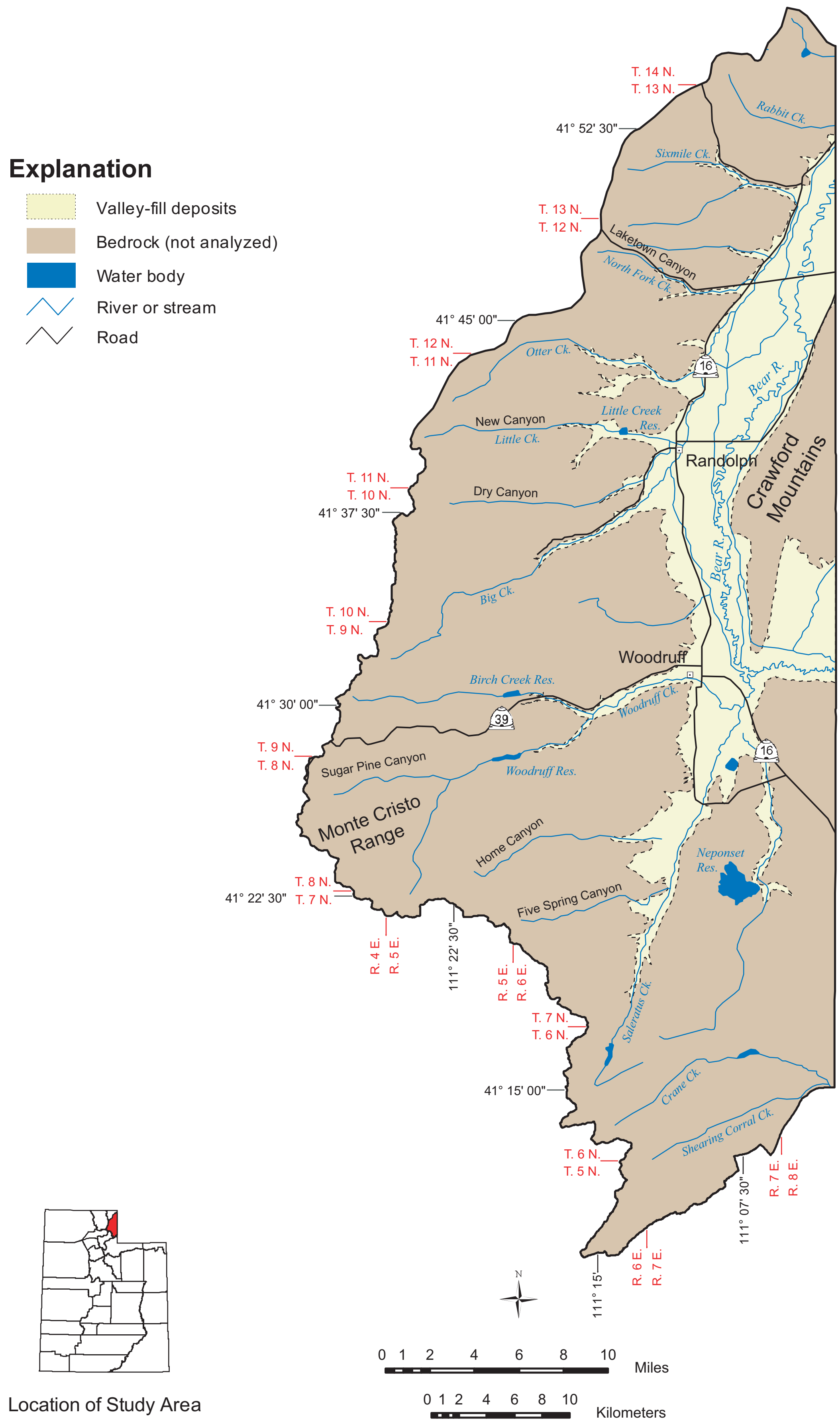

Figure 1. Upper Bear River Valley, Rich County, Utah, study area.

tivity 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 aquifer in upper Bear River Valley to agricultural pesticides.

Sensitivity to pesticides is determined by assessing natural factors favorable or unfavorable to the degradation of ground water by pesticides applied or spilled on the land surface, whereas vulnerability to pesticides is determined by assessing how ground-water sensitivity is modified by human activity. 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 hydraulic conductivity, bulk density, organic carbon content, and field capacity of soils. 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 type of pesticide applied.

Purpose and Scope

The purpose of this project is to investigate sensitivity and vulnerability of ground-water resources in the valley-fill deposits of upper Bear River Valley, Rich County, 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 Utah Department of Agriculture and Food.

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 fieldwork was conducted or data collected as part of this project. This is a first attempt at developing pesticide sensitivity and vulnerability maps for this area; 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 prolonged storm events. Additionally, the digital soil maps used in this study are too generalized to accurately depict areas of soil versus 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 rock outcrop areas locally may not be reflected in our maps. To produce these maps, we needed to make some arbitrary decisions regarding the quality and types of data available based on our knowledge of the hydrogeology of the area; for example, we selected 3 feet (1 m) as the reference depth for soils for applying pesticide retardation and attenuation equations.

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 Utah Department of Agriculture and Food (UDAF) sampling program has revealed no occurrences of pesticide contamination in any drinking-water aquifer in over 2200 samples tested statewide (Quilter, 2004), although low levels of pesticides were detected in a 1998-2001 study of shallow ground water in the Great Salt Lake basin (Waddell and others, 2004). 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 letters of key words in these parameters form 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 Villenueve, 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 R309-200-5, Utah Administrative Code, and also in 40 CFR 141.61 Code of Federal Regulations. 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 µg/L
Atrazine	0.003 mg/L	3 µg/L
Metolachlor	—	—
Simazine	0.004 mg/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, an administrative process begins 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 upper Bear River Valley 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 require pathways through confining layers to cause water-quality degradation. Thus, the ability of soils at the application site to retard or attenuate pesticides during downward movement in the vadose zone, 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

The study area consists of the upper Bear River Valley in Rich County, Utah, including the towns of Randolph and Woodruff (figure 1). No previous work on ground-water conditions in the study area has been published. Glover (1990) presented data on the stream aquifer system, including ground-water conditions in the unconsolidated aquifer of adjoining portions of the upper Bear River Valley in Wyoming. Basic water-level data are provided from analysis of drillers' logs available from the Utah Division of Water Rights (2005) and U.S. Geological Survey (2005) monitoring wells.

Regional scale geologic cross sections, based on seismic reflection, well data, and surface geology by Coogan (1992) and Constenius (1996) show valley-fill geometry and thickness across the upper Bear River Valley. Evans (1991) investigated the geologic framework of the area related to modern seismicity and also constructed cross sections of the study area. Previous geologic mapping by quadrangle is shown in figure 2.

SETTING

Physiography

The entire Bear River basin comprises 7500 square miles (19,425 km^2) of land in Utah, Wyoming, and Idaho. In Utah, the upper Bear River is mostly in Rich County. The upper Bear River consists of the river from its headwaters in the Uinta Mountains to Bear Lake (Utah Division of Water Resources, 1992; Natural Resources Conservation Service, 2005). The Bear River flows west into the study area from Wyoming, and then flows north along the upper Bear River Valley before it veers northeast and returns to Wyoming. The Bear River ultimately drains into Great Salt Lake.

The study area is in northeastern Utah in the Bear River Valley section of the Middle Rocky Mountain physiographic province (Stokes, 1977), and is a 36-mile-long (58 km), north-south-trending valley that is bounded by mountains on its east and west sides (figure 1). The valley floor, the Bear River graben, is about 5 miles (8 km) wide at its widest point near Randolph (figure 1), and has an area of about 142 square miles (368 km^2). The highest elevation is Mount McKinnon, at 9081 feet (2766 m); the lowest is the northernmost valley floor at about 6000 feet (1829 m).

The study area is bounded on the west by the Monte Cristo Range, and on the east by the Crawford Mountains. The mountainous terrain on the east side of the study area consists of Paleozoic- through Mesozoic-age carbonate and clastic sedimentary rock formations (Dover, 1995). To the west, the Tertiary Wasatch Formation is exposed in hills that bound upper Bear River Valley (Dover, 1995).

The valley floor is underlain by primarily fluvial and alluvial unconsolidated deposits having thicknesses up to more than 300 feet (90 m) based on analysis of drillers' logs (Utah Division of Water Rights, 2005). Alluvial fans are found along the margins of the valley at many locations.

Climate

Four weather stations are within Rich County, but only two are located in upper Bear River Valley; climate data for the mountainous areas within the drainage basin are limited. These weather stations are: Randolph (elevation 6268 feet [1910 m]) and Woodruff (elevation 7540 feet [2298 m]) (Ashcroft and others, 1992). Temperatures reach an average maximum of 81.7°F (27.6°C) at Woodruff in July and an average minimum of –0.2°F (-17.9°C) in January at Randolph; the normal mean ranges from 38 to 39°F (3.3 to 3.9°C) at Randolph and Woodruff, respectively (Ashcroft and others, 1992). Average annual precipitation ranges from 9.04 inches (23 cm) at Woodruff to 11.2 inches (28 cm) at Randolph (Ashcroft and others, 1992). Normal annual evapotranspiration ranges from 39.99 to 40.21 inches (102 to 102.1 cm) at Woodruff and Randolph, respectively. The average number of frost-free days ranges from 50 to 56 at Randolph and Woodruff, respectively.

Population and Land Use

Unlike areas along the Wasatch Front, Rich County is experiencing limited growth. The population of Rich Coun-

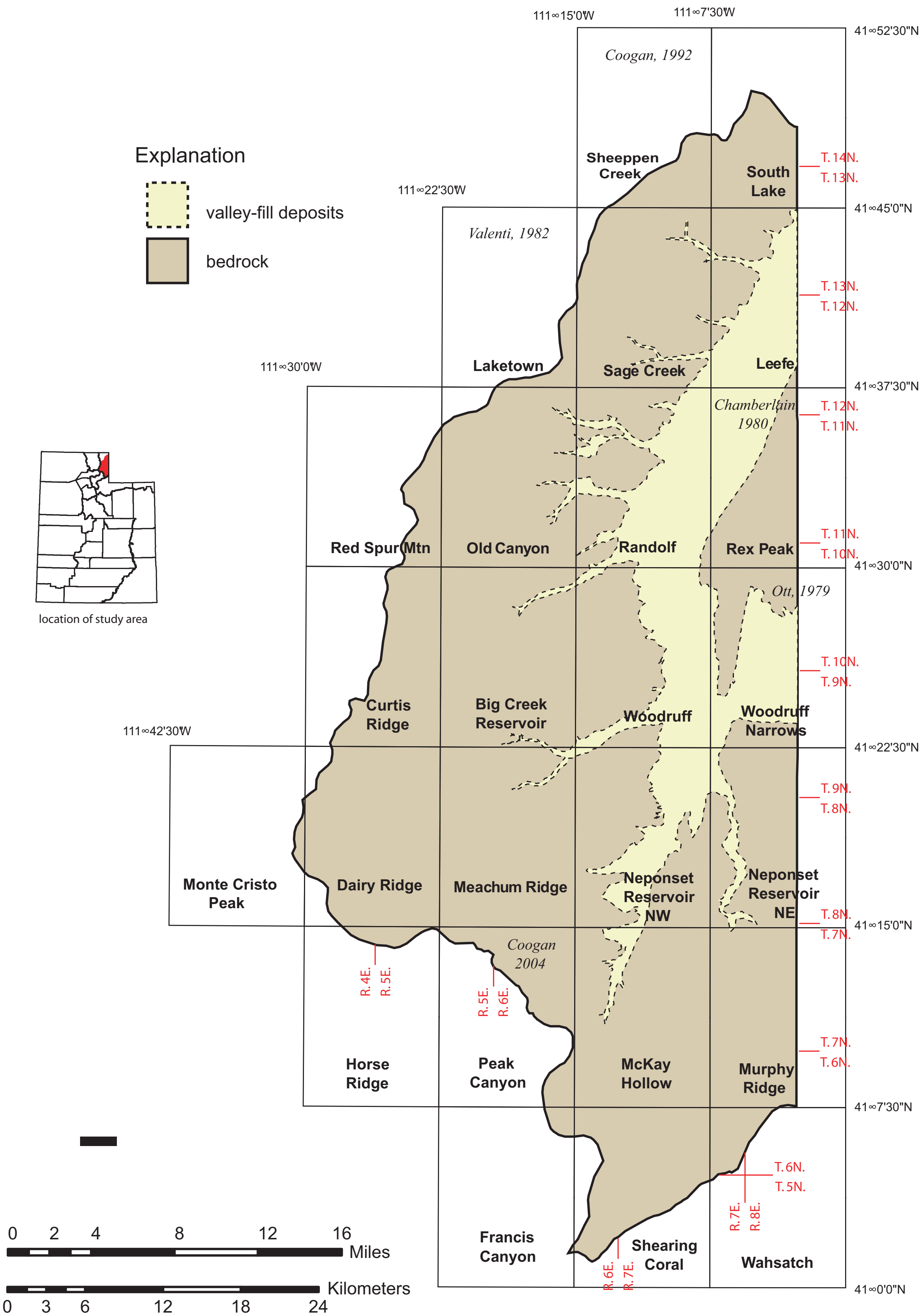

Figure 2. *Geologic and topographic (1:24,000 scale) quadrangle mapping used for upper Bear River Valley, Rich County, Utah.*

ty was 1966 in 2002 (Demographic and Economic Analysis Section, 2003), and is expected to increase to 2636 by 2030 (Demographic and Economic Analysis Section, 2005b). The increase in population in Rich County between 1990 and 2000 was 13.7% (Demographic and Economic Analysis Section, 2001), the second lowest growth rate (-0.5%) in the state from 2003 to 2004 (Demographic and Economic Analysis Section, 2005a). Most Rich County residents reside in unincorporated areas; the highest population in a municipality is in Randolph. Much of western Rich County is mountainous, but fertile lowlands along the Bear River support productive farms and livestock operations; three-fourths of land use along the Bear River Valley is for agriculture, primarily grazing. Livestock and livestock products provide most of the county's income (Utah Association of Counties, 2005).

GROUND-WATER CONDITIONS

Valley-fill Aquifers

Ground water resides in either unconsolidated valley-fill or bedrock aquifers beneath the upper Bear River study area. The unconsolidated valley fill consists primarily of flood-plain and terrace deposits that grade into alluvial and colluvial deposits along the valley margins. These deposits consist of sand and gravel with volumetrically minor layers of silt and clay. Thickness of the unconsolidated deposits varies across the study area. Based on existing cross sections, the valley fill thickens to the east towards the Crawford Mountains (figure 3); total thickness of undivided Eocene to Quaternary valley fill is up to 4000 feet (1220 m) (Evans, 1991; Coogan, 1992). Actual thickness of the unconsolidated valley is largely unconstrained, but is at least 300+ feet (90 m) in many places based on drillers' logs (Utah Division of Water Rights, 2005). Along the western valley margin and within east-flowing tributary drainages, unconsolidated valley fill is less than 100 feet (30 m) thick and rests directly on Tertiary bedrock (Evans, 1991; Coogan, 1992; Constenius, 1996; Utah Division of Water Rights, 2005).

Ground water in the unconsolidated valley fill exists in both unconfined and confined aquifers. Wells completed in unconfined portions of the valley fill are dominated by interbedded sand and gravel and commonly are found near the valley margins and in tributary drainages (Utah Division of Water Rights, 2005). Based on drillers' logs, contiguous confining layers of clay exist near the valley margins in several locations. Artesian flow is noted on drillers' logs for a series of wells near the Bear River in the northern part of the study area, indicative of confining conditions in parts of the study area. Ground-water flow direction is from the valley margins toward the center of the valley, and then generally northward parallel to flow in the Bear River (figure 4); ground water moves perpendicular to the potentiometric-surface lines.

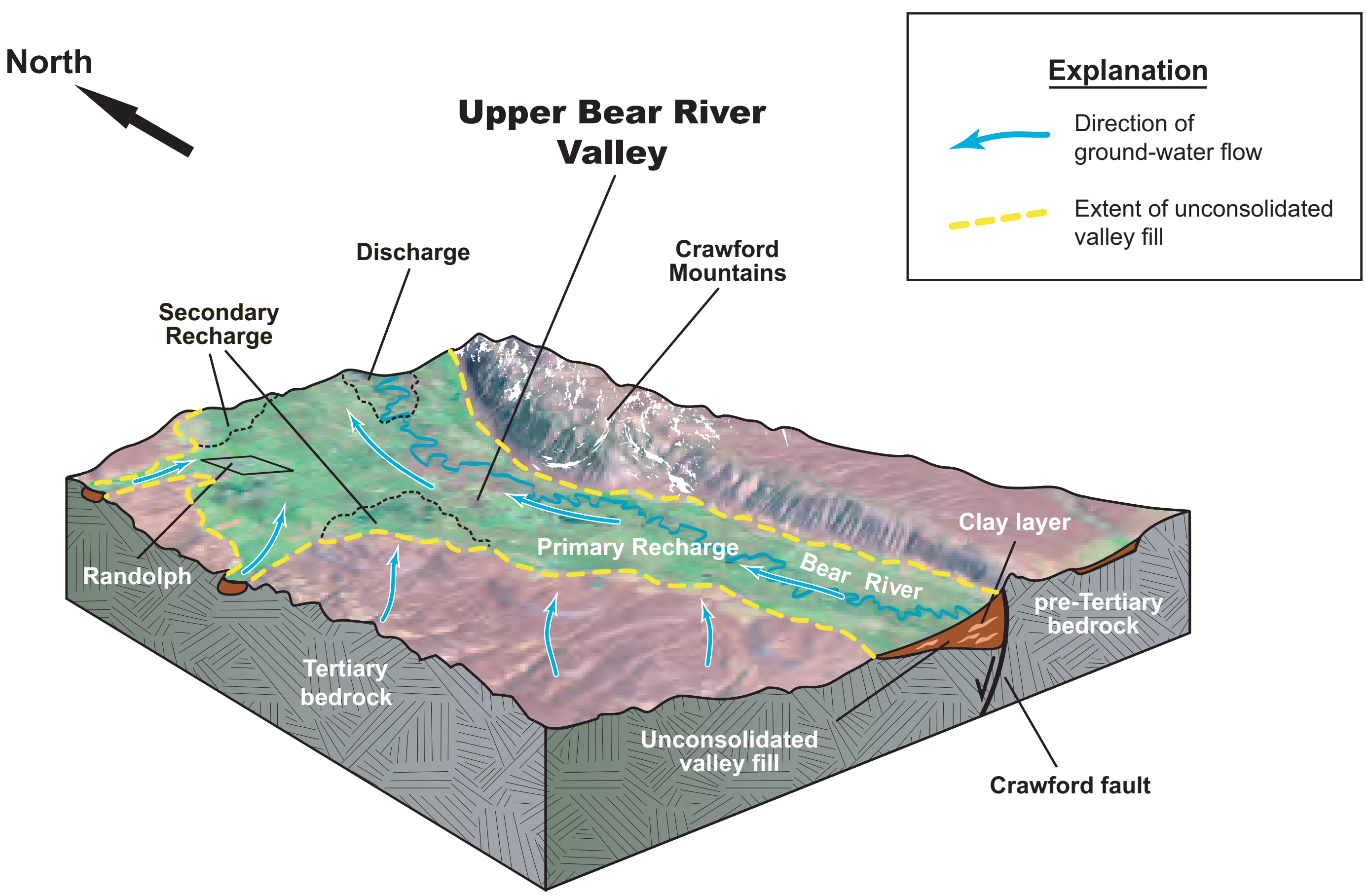

Figure 3. *Schematic block diagram showing direction of ground-water flow in upper Bear River Valley.*

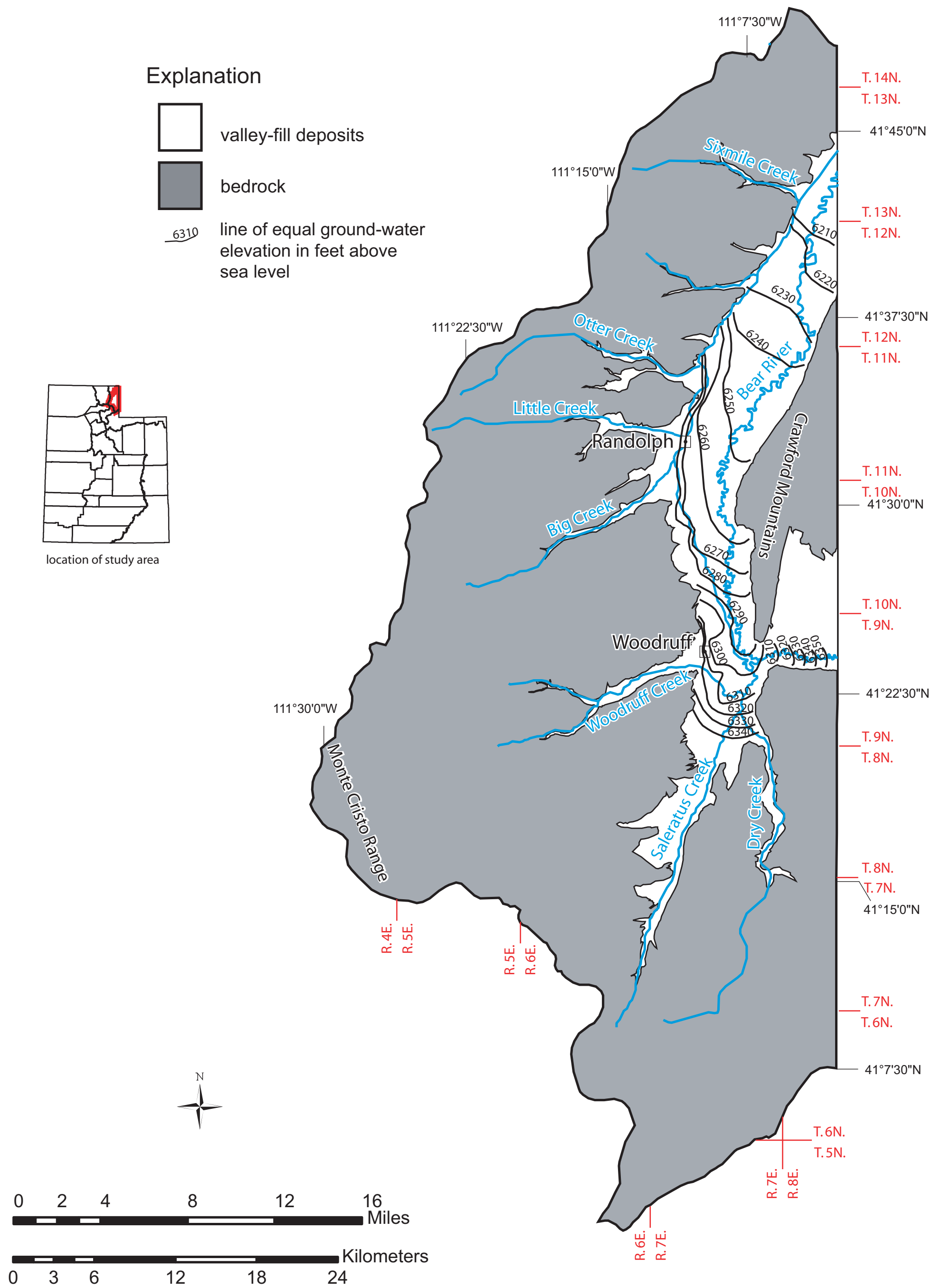

Figure 4. *Estimated ground-water elevations. Schematic potentiometric surface based on drillers' logs for the upper Bear River Valley, Rich County, Utah. Major drainages are shown in blue.*

Ground-water recharge in the valley-fill aquifer is from infiltration of precipitation, seepage primarily along the Bear River and smaller creeks in the western and southern portions of the study area, and subsurface inflow from underlying consolidated rocks. Primary recharge to the valley fill occurs along the valley margins where deposits consist of alluvial sand and gravel, and along the Bear River due to seepage from the stream channel into unconfined aquifers. The total volume of ground-water recharge for the study area is unknown.

Discharge from unconfined and confined aquifers occurs near the Bear River in the northern portion of the study area. Wells with artesian flow occur locally along the Bear River. Evapotranspiration along the Bear River and adjoining wetlands may represent a large but unconstrained amount of discharge. Subsurface discharge as out flow along the northeast edge of the study area is implied by ground-water level data (figure 4). Discharge from both irrigation and culinary wells may represent a volumetrically minor portion of total discharge.

Estimated transmissivities for analogous valley fill north of the study area along the Bear River near Cokeville, Wyoming, range from 2760 to 184,000 square feet (256 – 17,000 m^2) per day with a geometric mean of 11,600 square feet (1078 m^2) per day (Glover, 1990). Transmissivity and permeability of the Tertiary and Quaternary valley fill most likely decrease with depth and increased lithification of the sediments.

A schematic potentiometric surface based on drillers' logs shows ground-water elevations that decrease generally to the north along the valley axis (figure 4). Near the western valley margin between Randolph and Woodruff, ground-water elevations decrease to the east and the potentiometric surface slopes into the valley axis. The east sloping potentiometric surface may be the result of significant recharge from underlying and adjacent bedrock, east flowing tributary drainages, and a large irrigation canal along the west edge of the Bear River Valley. Significant recharge from pre-Tertiary bedrock of the Crawford Mountains is not apparent based on ground-water levels. Ground-water levels measured at three U.S. Geological Survey monitoring wells show annual and shorter term fluctuations (U.S. Geological Survey, 2005). Year-to-year changes in ground-water level are likely tied to changes in climate and precipitation and are not the direct result of ground-water withdrawal.

Ground-Water Quality

Ground-water quality in upper Bear River Valley is generally good. No ground-water quality studies for the upper Bear River basin exist; water-quality information for this report is from the Utah Division of Drinking Water (Brett Shakespear, written communication, June 17, 2005). The concentration of total dissolved solids (TDS) ranges from 240 to 856 mg/L with an average of 457 mg/L. The poorest water quality (856 mg/L) is from four water wells at Bridgerland Village, but is considered Drinking Water Quality (TDS is less than 3000 mg/L) according to the Utah Water Quality Board's water-quality classification scheme. Nitrate concentration values range from less than 0.1 to 1.7 mg/L with an average concentration of 0.7 mg/L.

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 Siegel (2000), we combine a process-based model with an index-based model to produce sensitivity and vulnerability maps for upper Bear River Valley. 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 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 shallow ground water are the factors primarily determining ground-water sensitivity to pesticides in upper Bear River Valley. Sensitivity represents the sum of natural influences that facilitate the entry of pesticides into ground water.

Hydrogeologic Setting

Hydrologic setting methods, description, and terminology follow previous work by Anderson and others (1994) and Lowe and others (2004, 2005). Hydrogeologic setting is delineated based 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, illustrated schematically in figure 5. Primary recharge areas, commonly the uplands and coarse-grained unconsolidated deposits along valley margins, do not contain thick, continuous, fine-grained layers (confining layers) and have a downward ground-water gradient. Secondary recharge areas, commonly mountain-front benches, have fine-grained layers thicker than 20 feet (6 m) and a downward ground-water gradient. Ground-water discharge areas are generally in valley 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). Discharge areas for confined aquifers occur where the ground-water gradient is upward and water discharges to a shallow unconfined aquifer above the upper confining bed, or to a spring. 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.

We examined drillers' logs available from the Utah Division of Water Rights (2005) to delineate recharge and dis-

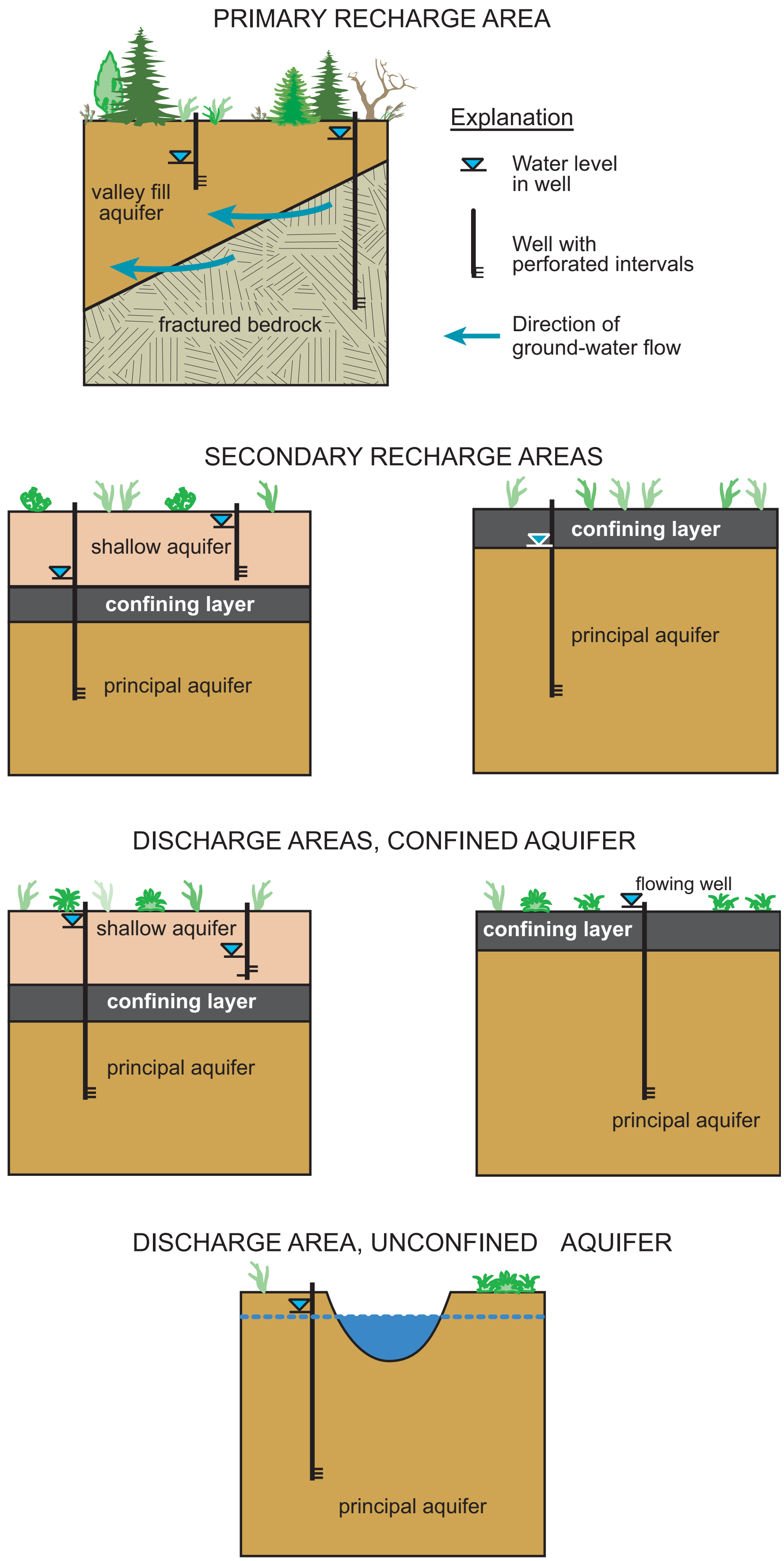

Figure 5. *Relative water levels in wells in recharge and discharge areas (modified from Snyder and Lowe, 1998).*

charge areas for the principal aquifer based on the presence of confining layers and relative ground-water levels. Although this technique is useful for acquiring 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; Anderson and Susong, 1995). 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 clay together with 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 most valleys consists of the uplands along the margins of the valley, as well as valley fill not containing confining layers (figure 5), generally located along the mountain fronts. Ground-water flow in primary recharge areas has a downward component. Secondary recharge areas, if present, are locations where confining layers exist, but ground-water flow still maintains a downward component. Secondary recharge areas generally extend toward the center of the valley to the point where ground-water flow is upward (figure 5). 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 exist where the potentiometric surface in the principal aquifer system is below the ground surface.

Ground-water discharge areas, if present, generally are 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 5). For the latter 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; Campbell and Lacy, 1982). 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 for 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 hour GIS attribute ranking, described below under Results, 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 through the soil slower 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) presented the following equation:

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

where:

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

Retardation factors typically range from (1 + 4Kd) to (1 + 10Kd) (Freeze and Cherry, 1979), where Kd is the product of the organic carbon sorption distribution coefficient (K_{oc}) and the fraction of organic carbon (F_{oc}), and based on typical unconsolidated sediment properties of dry 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 anion), move through the subsurface at the same rate as the ground water, whereas dissolved constituents in ground water having R_F values 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, 2004), which provides digitized data for some soil areas of the state of Utah, including Rich County, 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 to 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 14 and 42%, which represent naturally occurring conditions in upper Bear River Valley, and variable soil organic carbon content using

Table 2. *Hydrologic soil groups, field capacity, bulk density, and fraction of organic carbon content generalized for Utah soils. Soil description and organic content from National Soil Survey Center (2004). 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 Carbon 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 (14-21)	1.5 - 2 (1.75)	Variable and ranges from 0.4 to 3%
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 0.4 to 3%
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 0.4 to 3 %
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 0.4 to 3%
G	Gravel	2.0 and greater (less than 12)	2 (2)	0.4 %**

* F_{oc} is calculated from SSURGO organic matter data divided by 1.72 and is unique for soil polygons.
**No value for F_{oc} exists in the SSURGO database for gravel; we assigned the lowest value in the SSURGO data set.

Table 3. *Pesticide organic carbon sorption distribution coefficients (K_{oc}) 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

a water-table depth of 3 feet (1 m). Average organic carbon content in soils in upper Bear River Valley is shown in figure 6 and ranges from 0.4 to 3%; 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 from 2.3 to 42. This means the highest relative velocity from our data is 0.43 and the lowest is 0.024; the former indicates pesticide in ground water moves at a rate about 43% that of ground water free of pesticides, whereas the latter indicates that pesticides in ground water are essentially immobile.

A small percentage (1%) of pesticides traveling downward in vadose-zone material having an R_F of 3.6 could reach the water table at a depth of 3 feet (1 m) within one year if ground-water recharge exceeds 11 inches (28 cm) during the year, which is the highest amount of total recharge recorded for the mountains in study area. When ground-water recharge is less than 11 inches (28 cm) per year, as is the case for the valley-floor recharge from precipitation in upper Bear River Valley, no amount of pesticide will likely reach a depth of 3 feet (1 m) in a one-year period (see attenuation discussion below). For our GIS analysis, we divided pesticide retardation into two ranges: greater than, and less than or equal to 4.

Pesticide Attenuation

Pesticide attenuation is a measure of the rate at which a pesticide degrades under the same conditions as characterized above under pesticide retardation (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 travels, 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 and others (1985) presented 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 (m);
R_F = retardation factor (dimensionless);
θ_{FC} = field capacity (volume fraction);
q = net annual ground-water recharge (precipitation minus evapotranspiration) (m); and
$t_{1/2}$ = pesticide half-life (years).

For this study, we calculated (using GIS analysis) net annual ground-water recharge by subtracting statewide 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 currently not 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 Utah, so that ground-water recharge from precipitation is relatively low in many areas of the state, including the study area (figure 7). 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, we calculated attenuation factors for ranges of values common to soils in upper Bear River Valley, similar to our approach for retardation, to delineate high and low pesticide attenuation factors for our GIS analysis. To represent naturally occurring conditions in this area that would result in the greatest sensitivity to ground-water contamination, we used a retardation factor of 4, calculated as described above; the half-life for simazine (table 3), the pesticide among the four with the longest half-life (Weber, 1994); a field capacity of 14%; and a bulk density value of 0.04 pounds per cubic inch (1.2 kg/L). For negative net annual ground-water recharge values, as are typical of the valley-floor areas of upper Bear River Valley, equation 2 results in an attenuation factor that approaches 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); therefore, 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'

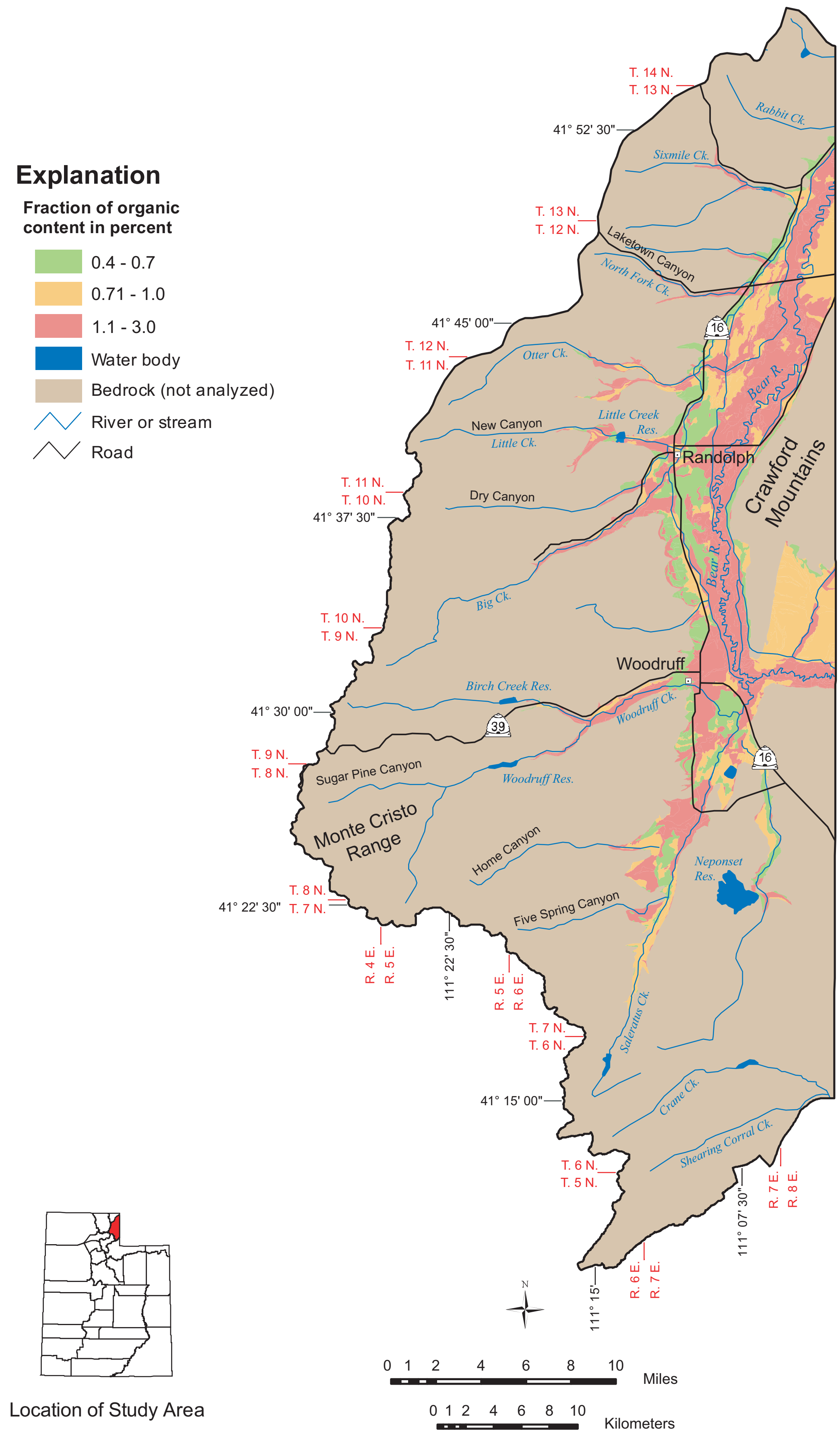

Figure 6. *Average organic carbon content in soils in upper Bear River Valley, Rich County, Utah (data from National Soil Survey Center, 2004).*

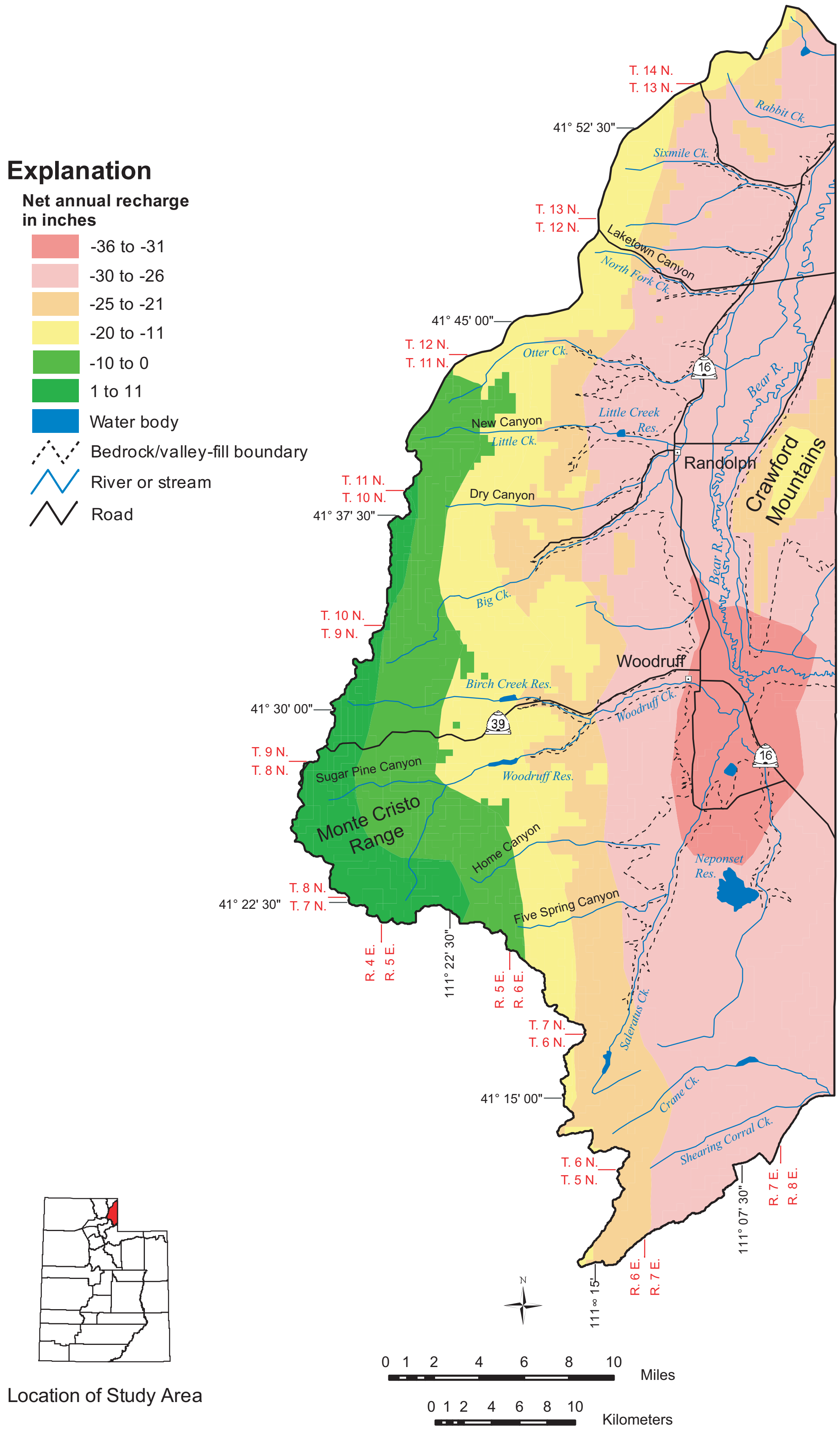

Figure 7. *Net annual ground-water recharge from precipitation in upper Bear River Valley, Rich County, Utah. Recharge calculated using data from the Utah Climate Center (1991) and Jensen and Dansereau (2001). Although net annual recharge may be negative in some areas, seasonally some recharge from precipitation may occur.*

(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 the number of bacteria that develops 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.

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.

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 having 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; Campbell and Lacey, 1982). 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 applied the less-than-3-feet (1 m) GIS attribute ranking, described below, to be protective of ground-water quality.

GIS Analysis Methods

We characterize pesticide sensitivity (intrinsic susceptibility) as "low," "moderate," or "high" based on the sum of numerical values (rankings) assigned to 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. Absolute 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 is assigned when the summed ranking ranges from –2 to 0, a sensitivity attribute of moderate is assigned when the summed ranking ranges from 1 to 4, and a sensitivity attribute of high is assigned when the summed ranking ranges from 5 to 8.

Ground-Water Vulnerability to Pesticide Pollution

Ground-water vulnerability to pesticides is determined by assessing how ground-water sensitivity to pesticides is modified by human activity. 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. Our analysis is based on 1996 land-use data.

Table 5. *Pesticide sensitivity and the attribute rankings used to asssign sensitivity for upper Bear River Valley, Rich County, Utah.*

<table>
<tr><th colspan="2">Pesticide Retardation Factor</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><th>Attribute</th><th>Ranking</th><th>Attribute</th><th>Ranking</th><th>Attribute</th><th>Ranking</th><th>Attribute</th><th>Ranking</th><th>Attribute</th><th>Ranking</th><th>Attribute</th><th>Ranking</th></tr>
<tr><td rowspan="2">High</td><td rowspan="2">0</td><td rowspan="2">Low</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 ft</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">High</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>

Ground-Water Sensitivity

We consider ground-water sensitivity (intrinsic susceptibility) to be the principal factor determining the vulnerability of the valley-fill aquifer in upper Bear River Valley to degradation from agricultural pesticides. Consequently, low, moderate, and high sensitivity rankings were assigned numerical values weighted more heavily than other factors, as shown in table 6.

Irrigated Lands

We mapped irrigated lands 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 upper Bear River basin inventory was conducted in 1996 (Utah Division of Water Resources metadata). We used all polygons having standard type codes beginning with IA 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

We mapped agricultural lands using 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 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 upper Bear River basin inventory was conducted in 1996 (Utah Division of Water Resources metadata). No polygons having standard type codes IA2a1 (corn), IA2a2 (sorghum), and IA2b5 (sweet corn) exist to produce the crop-type land coverage for this study; these are the crop types to which the pesticides addressed are applied in Utah, but were not analyzed for this study.

GIS Analysis Methods

We characterize pesticide vulnerability as "low," "moderate," and "high" based on the sum of numerical values (rankings) assigned to pesticide sensitivity, areas of irrigated lands, and crop type as shown in table 6. Once again, absolute numerical ranking for each attribute category is arbitrary, but reflects the relative level of importance the attribute plays in determining vulnerability of ground water to contamination associated with 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 (intrinsic susceptibility) 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 factors are variable and attenuation factors are ranked as low throughout upper Bear River Valley; the low attenuation factors are due to net annual evapotranspiration exceeding net annual precipitation. The area is dominantly characterized by high retardation factors due to the prevalent silt/clay soil types. Net annual recharge from precipitation is negative in valley-floor areas (figure 7). Most recharge that occurs 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.

Table 6. *Pesticide vulnerability and the attribute rankings used to assign vulnerability for upper Bear River Valley, Rich 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

Hydrogeologic Setting

We examined drillers' logs available from the Utah Division of Water Rights (2005) to delineate recharge and discharge areas for the principal aquifer based on the presence of confining layers and relative ground-water levels. The primary recharge area for the upper Bear River Valley occurs in coarse-grained alluvium and colluvium flanking the upper Bear River Valley and in coarse-grained sections of valley fill along the valley axis (figure 8). Primary recharge covers much of the upper Bear River Valley and east-flowing tributary drainages where ground-water gradients are downward and confining layers are not present. Wells near Woodruff show that much of the valley fill across the southern part of the Bear River Valley is primary recharge.

Secondary recharge occurs on valley margin terrace and flood-plain deposits having significant confining layers and downward ground-water gradients. Several laterally discontinuous zones of secondary recharge occur along the western margin of the upper Bear River Valley and extend eastward several kilometers from the valley margins (figure 8). Secondary recharge does not extend across the valley floor and is generally of limited extent.

Mapped discharge areas are generally in areas of relatively low elevation where upward ground-water gradients exist between confined and unconfined portions of the principal aquifer (figure 8). Flowing wells in the northern third of the study area define a discharge area along the Bear River. Discharge of both the unconfined and confined portions of the unconsolidated valley fill likely occurs along the Bear River in this area. Discharge is either used for irrigation, is consumed by phreatophytes, evaporates, or enters the Bear River along gaining reaches in the northern portion of the valley. Ground-water discharge from confined aquifers also occurs locally along tributary drainages west of the Bear River.

The ground-water recharge area map (figure 8) shows that primary recharge areas, the areas most susceptible to contamination from pesticides applied to the land surface, comprise about 80% of the surface area of the valley-fill aquifer. Secondary recharge areas make up an additional 12% of the surface area of the valley-fill aquifer. Ground-water discharge areas, which provide extensive protection to the principal aquifer from surface contamination from the application of pesticides, make up 8% of the surface area of the valley-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. Data from the National Soil Survey Center (2004) show about 94% of the surface area of the valley-fill aquifer in upper Bear River Valley has soil units mapped as having hydraulic conductivity greater than or equal to 1 inch (2.5 cm) per hour (figure 9); these soil units are mainly along the Bear River and within tributary canyons in the study area. About 6% 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.

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. National Soil Survey Center (2004) data show about 48% of the area overlying the valley-fill aquifer in upper Bear River Valley has soil units mapped as having shallow ground water less than or equal to 3 feet (1 m) deep; these areas are primarily along the Bear River in the central part of the study area (figure 10). About 5% of the surface area of the valley-fill aquifer has soil units mapped as having shallow ground water greater than 3 feet (1 m) deep. About 47% of the surface area of the valley-fill aquifer has soil units for which no SSURGO data exist. Areas without assigned depths to shallow ground water were grouped with the less than or equal to 3 feet (1 m) depth category for analytical purposes to be protective of water quality.

Pesticide Sensitivity Map

Plate 1 shows ground-water sensitivity (intrinsic susceptibility) to pesticides for upper Bear River Valley, constructed using the GIS methods and ranking techniques described above. We analyzed 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 upper Bear River Valley (98%) is of moderate and high sensitivity (plate 1) due to the predominant downward ground-water flow gradients (dominated by a primary and secondary recharge area hydrogeologic setting). Pesticides used in these areas may degrade ground water. 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 higher hydraulic conductivities, are areas of high sensitivity (plate 1); high-sensitivity areas comprise about 80% of the valley-fill aquifer area, 18% of the study area is of moderate sensitivity, and low sensitivity makes up 2% of the area.

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 in upper Bear River Valley (figure 11). Using GIS methods as outlined in table 6, 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

Figure 11 shows irrigated cropland areas in upper Bear River Valley. About 66% of the valley floor is irrigated. Irrigation is potentially significant because it is a source of ground-water recharge in the valley-fill aquifer.

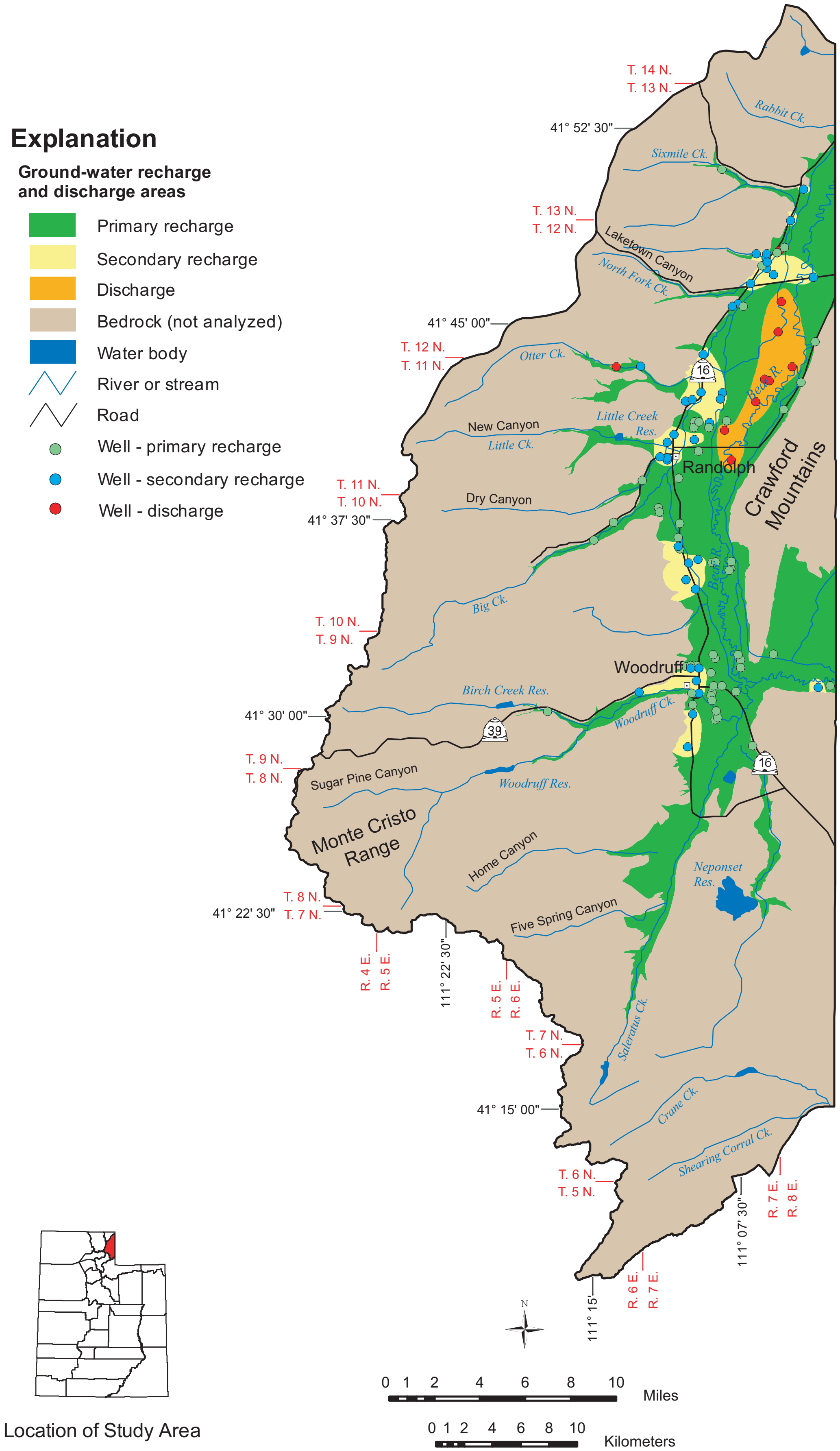

Figure 8. *Recharge and discharge areas in upper Bear River Valley, Rich County, Utah.*

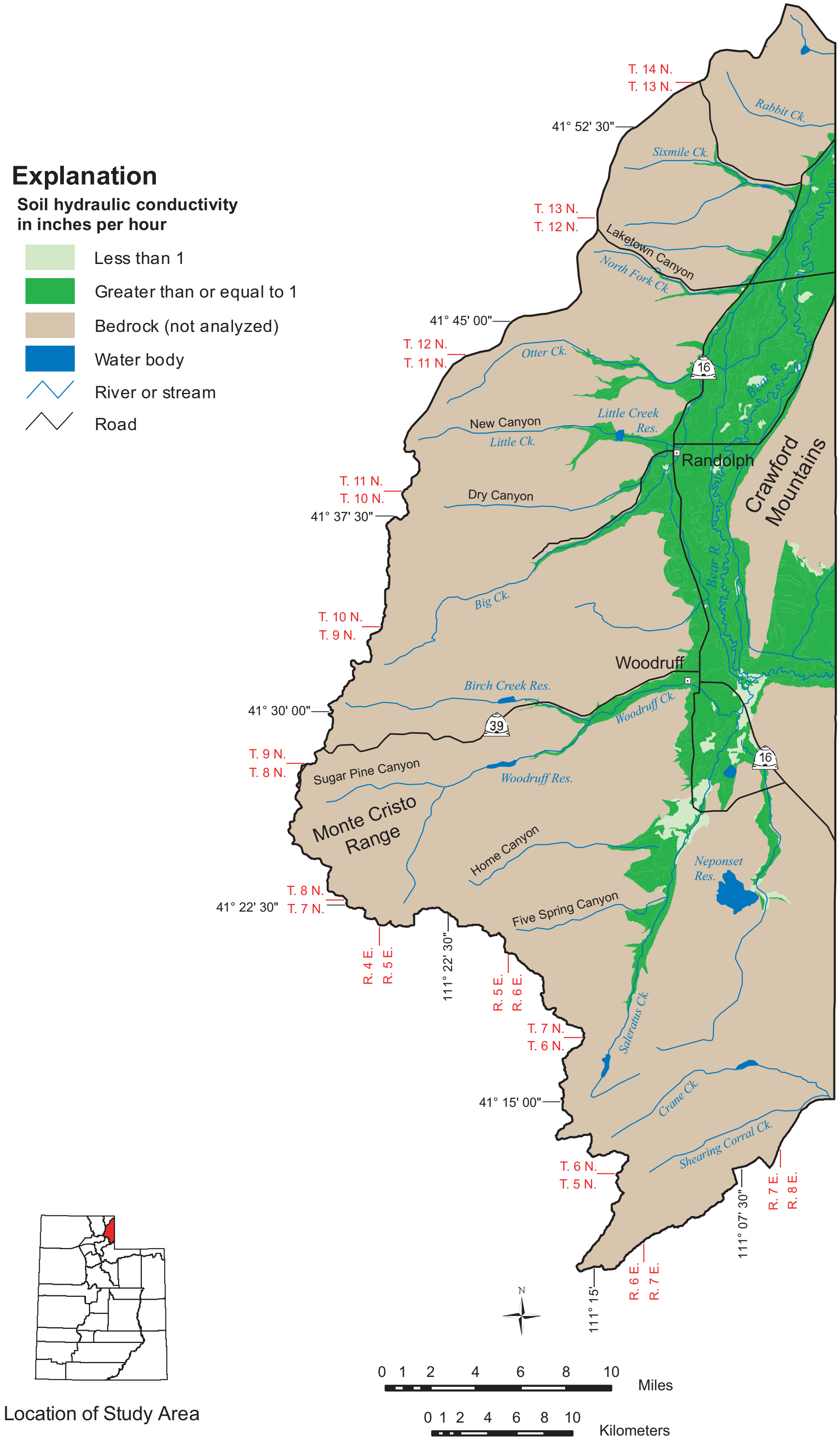

Figure 9. *Soil hydraulic conductivity in upper Bear River Valley, Rich County, Utah (data from National Soil Survey Center, 2004).*

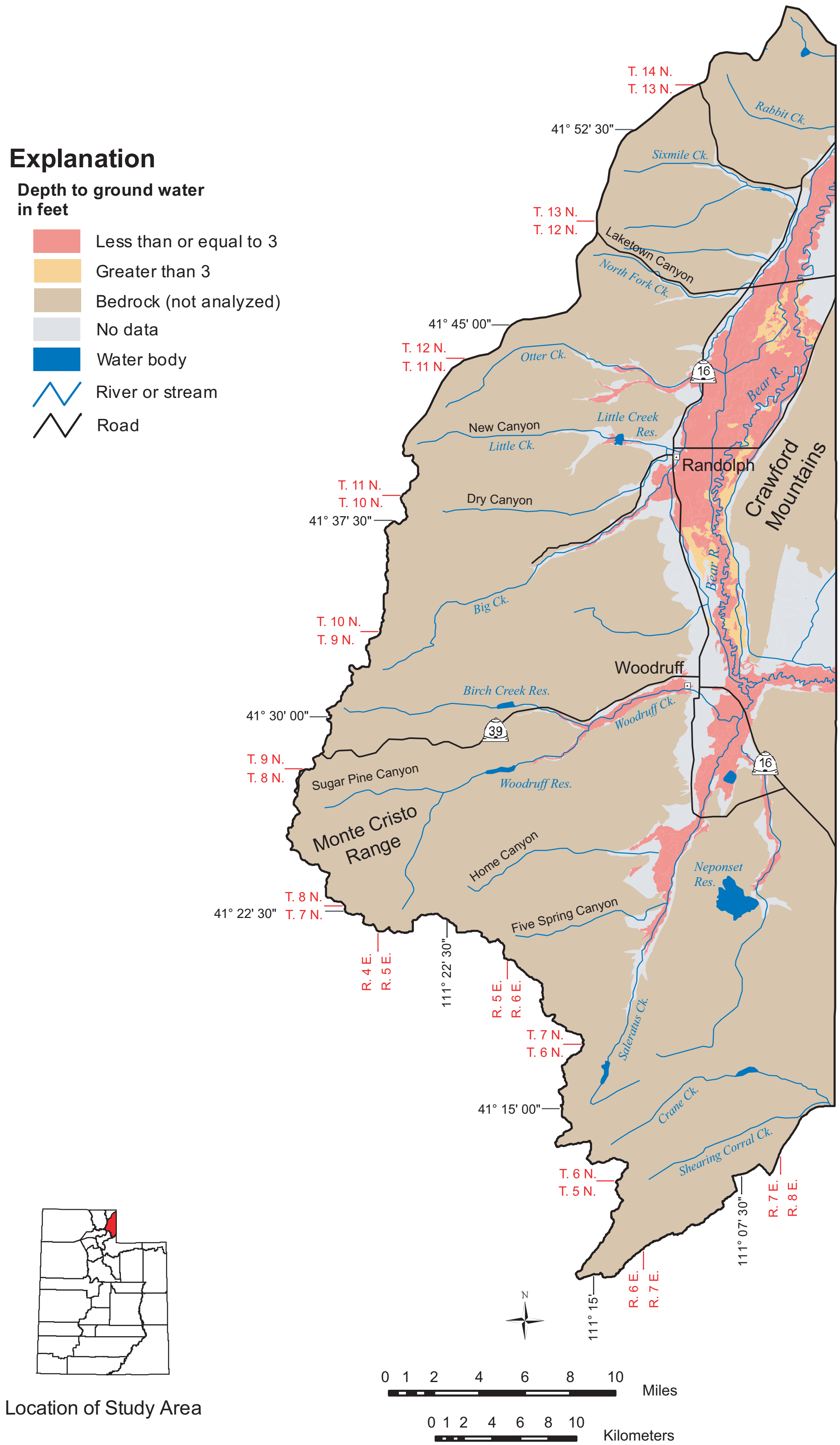

Figure 10. *Depth to shallow ground water in upper Bear River Valley, Rich County, Utah (data from National Soil Survey Center, 2004).*

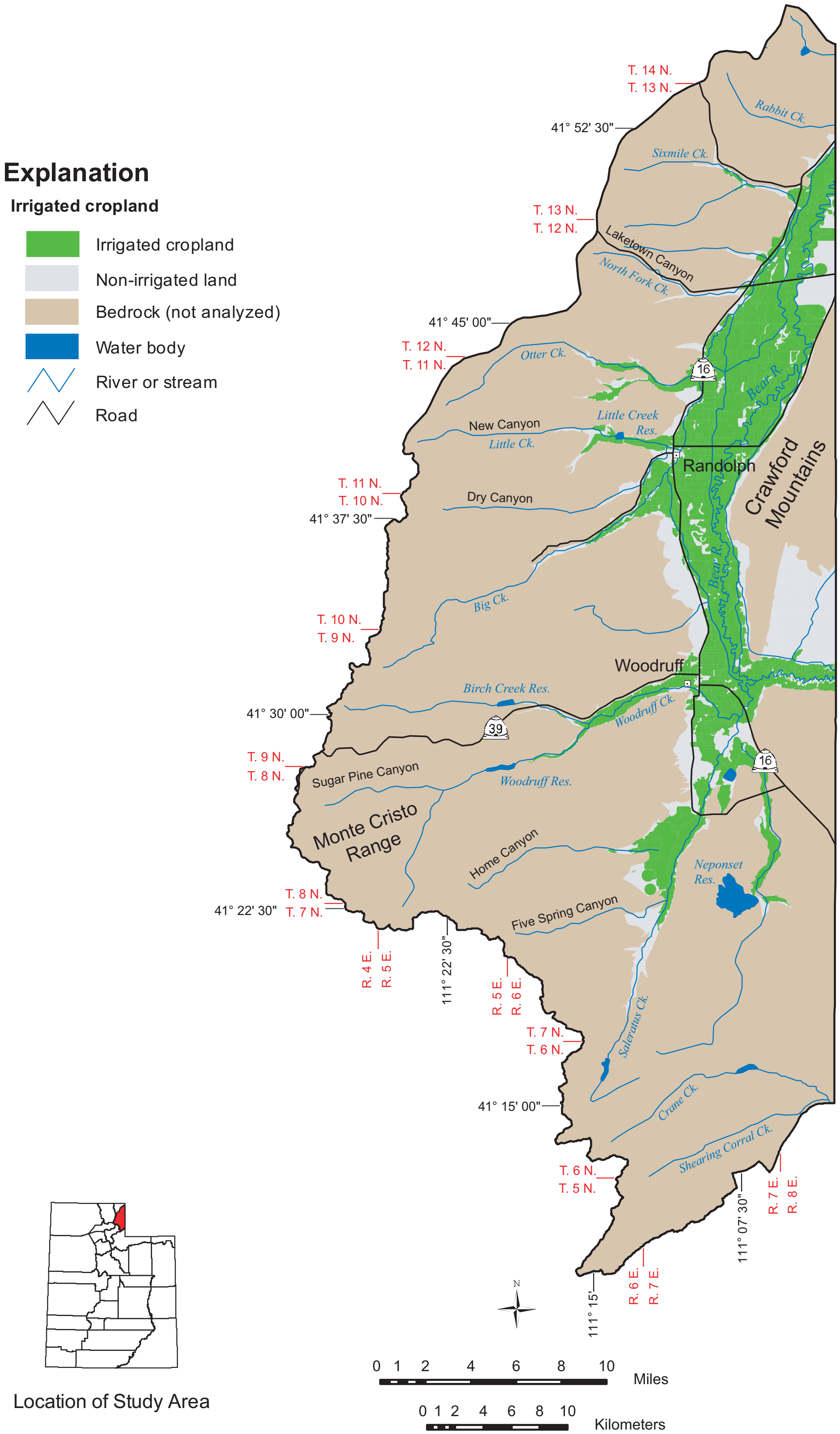

Figure 11. Irrigated and non-irrigated cropland in upper Bear River Valley, Rich County, Utah (unpublished data from Utah Division of Water Resources). The pesticides addressed in this study are mainly applied to corn and sorghum, currently not cultivated in the study area.

Corn and Sorghum Crops

In terms 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. Corn and sorghum crops are not grown in the study area.

Pesticide Vulnerability Map

Plate 2 shows ground-water vulnerability to contamination from pesticides of the valley-fill aquifer for upper Bear River Valley, constructed using the 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 98% of the surface area of the valley-fill aquifer is mapped as having high and moderate 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 or high sensitivity, or irrigated areas where ground-water sensitivity to pesticides is low. About 2% of the surface area of the valley-fill aquifer is mapped as having low vulnerability. Low-sensitivity areas without irrigated cropland have low vulnerability to contamination associated with application or spilling of pesticides on the land surface.

CONCLUSIONS AND RECOMMENDATIONS

In upper Bear River Valley, areas of irrigated land where the ground-water table is near the land surface have the highest potential for water-quality degradation associated with surface application of pesticides. However, 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. We believe ground-water monitoring for pesticides should be concentrated in areas of moderate and high sensitivity or vulnerability, particularly in areas where corn or sorghum may be grown. Sampling and testing in areas of the valley characterized by moderate sensitivity and moderate vulnerability should continue, but at a lower density than in the areas of higher sensitivity and vulnerability.

ACKNOWLEDGMENTS

This project was funded by the U.S. Environmental Protection Agency. Critical review comments were provided by Kimm Harty and Robert Ressetar, Utah Geological Survey. Kim Nay, Utah Geological Survey, produced some of the computer drawings for the project.

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Plate 1

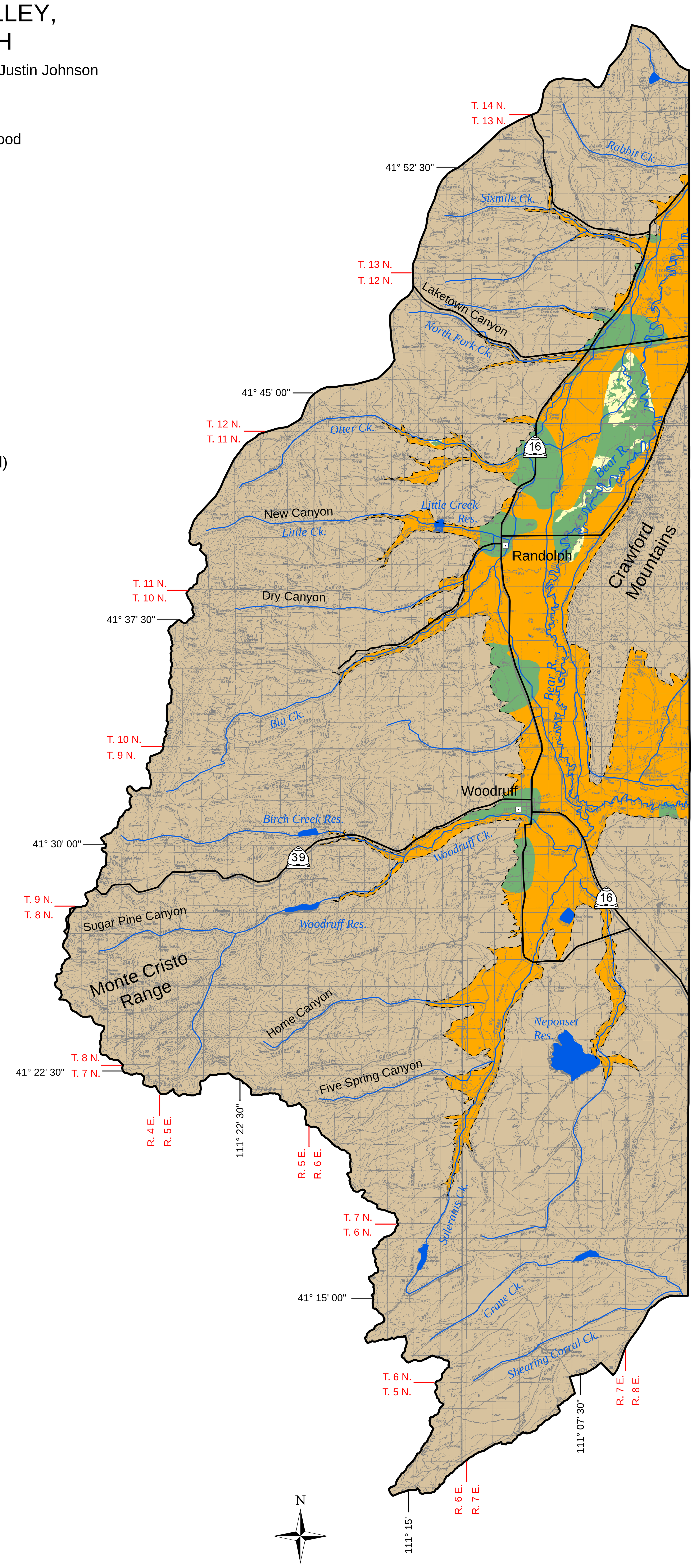
GROUND-WATER SENSITIVITY TO PESTICIDES IN UPPER BEAR RIVER VALLEY, RICH COUNTY, UTAH

By Mike Lowe, Janae Wallace, Stefan Kirby, and Justin Johnson
Utah Geological Survey
and
Anne Johnson and Rich Riding
Utah Department of Agriculture and Food

Explanation

Ground-Water Sensitivity Ranking

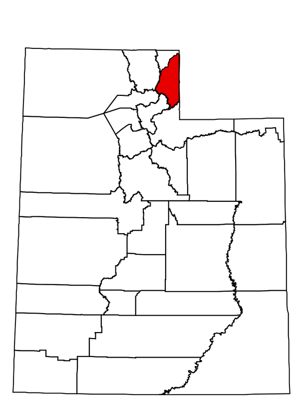
- Low
- Moderate
- High
- Bedrock (not analyzed)
- Water body
- River or stream
- Valley-fill boundary
- Road



0 1 2 4 6 8 10 Miles

0 1 2 4 6 8 10 Kilometers

1:145,000*



Location of Study Area

Projection: UTM
Zone: 12
Units: Meters
Datum: NAD 83
Spheroid: GRS 1980

Topographic base map from U. S. Geological Survey
1:100,000-scale digital images: Logan (1984), Ogden (1986)

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 (2004), 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 (unpublished). No additional fieldwork 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.

*This map is intended for use at a scale of 1:145,000. If viewed/plotted at a smaller scale, it may not be accurate for the purposes for which it is intended.

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Plate 2

GROUND-WATER VULNERABILITY TO PESTICIDES IN UPPER BEAR RIVER VALLEY, RICH COUNTY, UTAH

By Mike Lowe, Janae Wallace, Stefan Kirby, and Justin Johnson
Utah Geological Survey
and
Anne Johnson and Rich Riding
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Explanation

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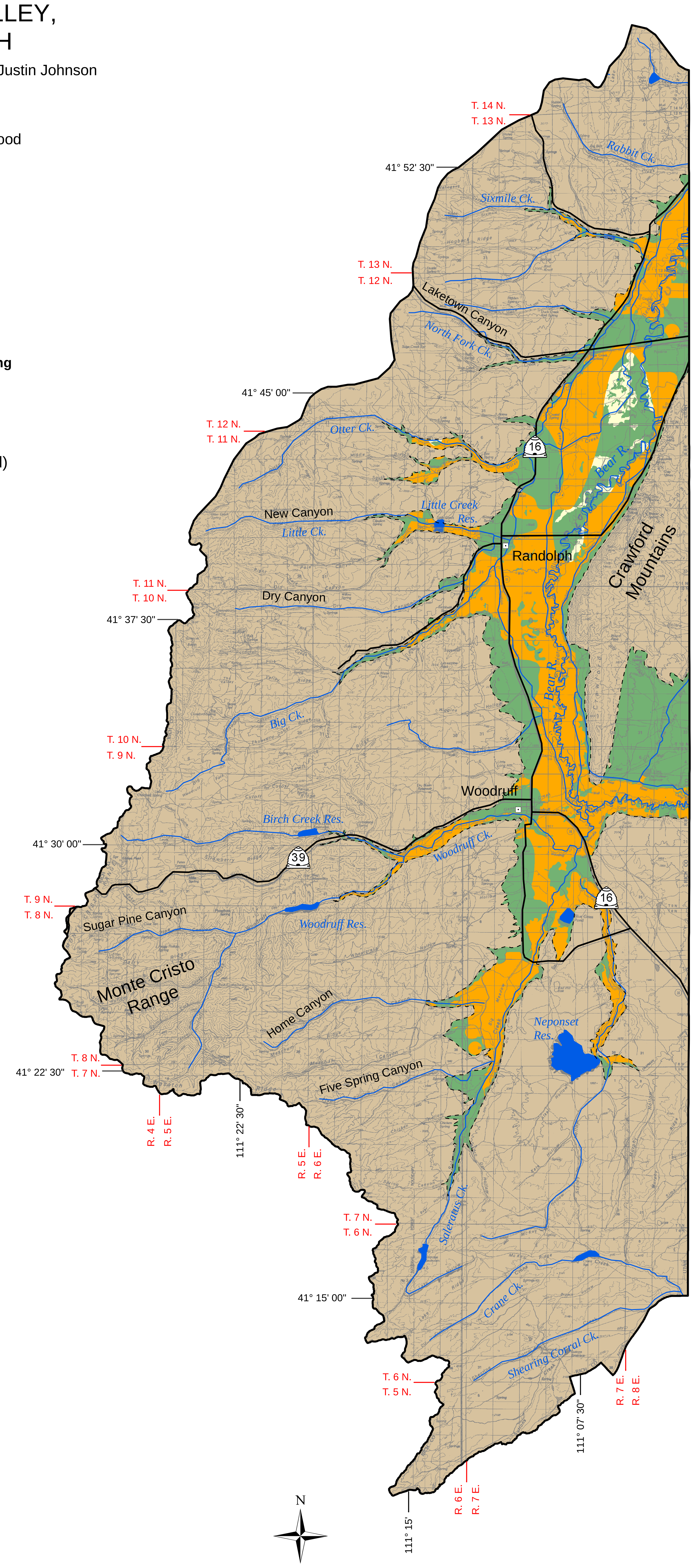

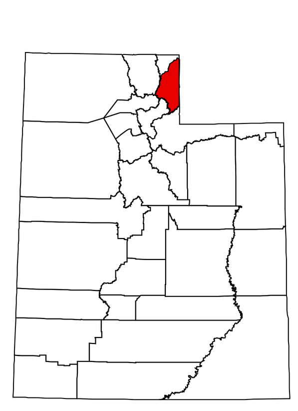

Location of Study Area

0 1 2 4 6 8 10 Miles

0 1 2 4 6 8 10 Kilometers

1:145,000*

Projection: UTM
Zone: 12
Units: Meters
Datum: NAD 83
Spheroid: GRS 1980

Topographic base map from U. S. Geological Survey 1:100,000-scale digital images: Logan (1984), Ogden (1986)

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