DESCRIPTION OF THE IDWR/UI SNAKE RIVER PLAIN AQUIFER MODEL (SRPAM)

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ABSTRACT

The water resources of the eastern Snake River Plain are often at the forefront of water issues in Idaho. The Snake River Plain aquifer, underlying the eastern Snake River Plain, is hosted in layered basalts and interbedded sediments and is an integral part of the basin water resources. In some places, the flow of the Snake River is composed predominantly of aquifer discharge. Aquifer water levels and spring discharges increased through the first half of the century, but have been declining in the past several decades. The long-term changes are in response to changes in recharge and discharge associated with surface and ground-water irrigation. These changes are driving conjunctive management of surface and ground-water resources and the use of a numerical ground water model to understand and help manage the aquifer.

The University of Idaho and the Idaho Department of Water Resources developed a two-dimensional finite difference model of the Snake River Plain aquifer in the 1970s. That model has evolved into the model documented in this report. Most recently, the model has been adapted to use the U.S. Geological Survey's MODFLOW code and the domain has been expanded to include the northeastern part of the aquifer system. The model has been calibrated to a one-year period from April 1980 to March 1981. The transient calibration was conducted in two parts. The first part was the original model domain, calibrated by the Idaho Department of Water Resources. The second part, the area near and including the extended domain in the northeast, was calibrated by the University of Idaho. Extending the domain resulted in revisions to the model water budget and created a discrepancy between estimated recharge and discharge components. Further work should be performed to improve the model's reliability. Priority should be given to improving the conceptual understanding and quantitative behavior of the interaction with the Snake River.

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INTRODUCTION

BACKGROUND

The water resources of the eastern Snake River Plain are often at the forefront of water issues in the State of Idaho. The high profile is due largely to intensive water use in the area by irrigated agriculture, hydropower, and aquaculture. These uses may sometimes be in conflict with environmental and recreation interests. This area is also underlain by the Snake River Plain aquifer (Figure 1), which is the water source for nearly all municipal and domestic needs in the area as well as for irrigation, aquaculture, and industrial needs.

Numerical ground-water flow models of the Snake River Plain aquifer have been developed and applied by state and federal agencies, universities, and private interests. The models vary in purpose, extent, and the computer code employed. The first numerical model of the aquifer was developed by the University of Idaho for the Idaho Department of Water Resources (IDWR) and the U.S. Bureau of Reclamation (deSonneville, 1974). The model has undergone multiple revisions and improvements. This report, together with Johnson and others (1999) documents another step in the evolution of the model.

The finite-difference model code developed by the University of Idaho and evolved by the University and the IDWR will be referred to as the IDWR/UI Ground Water Flow Model Code. The application of this code to the Snake River Plain aquifer

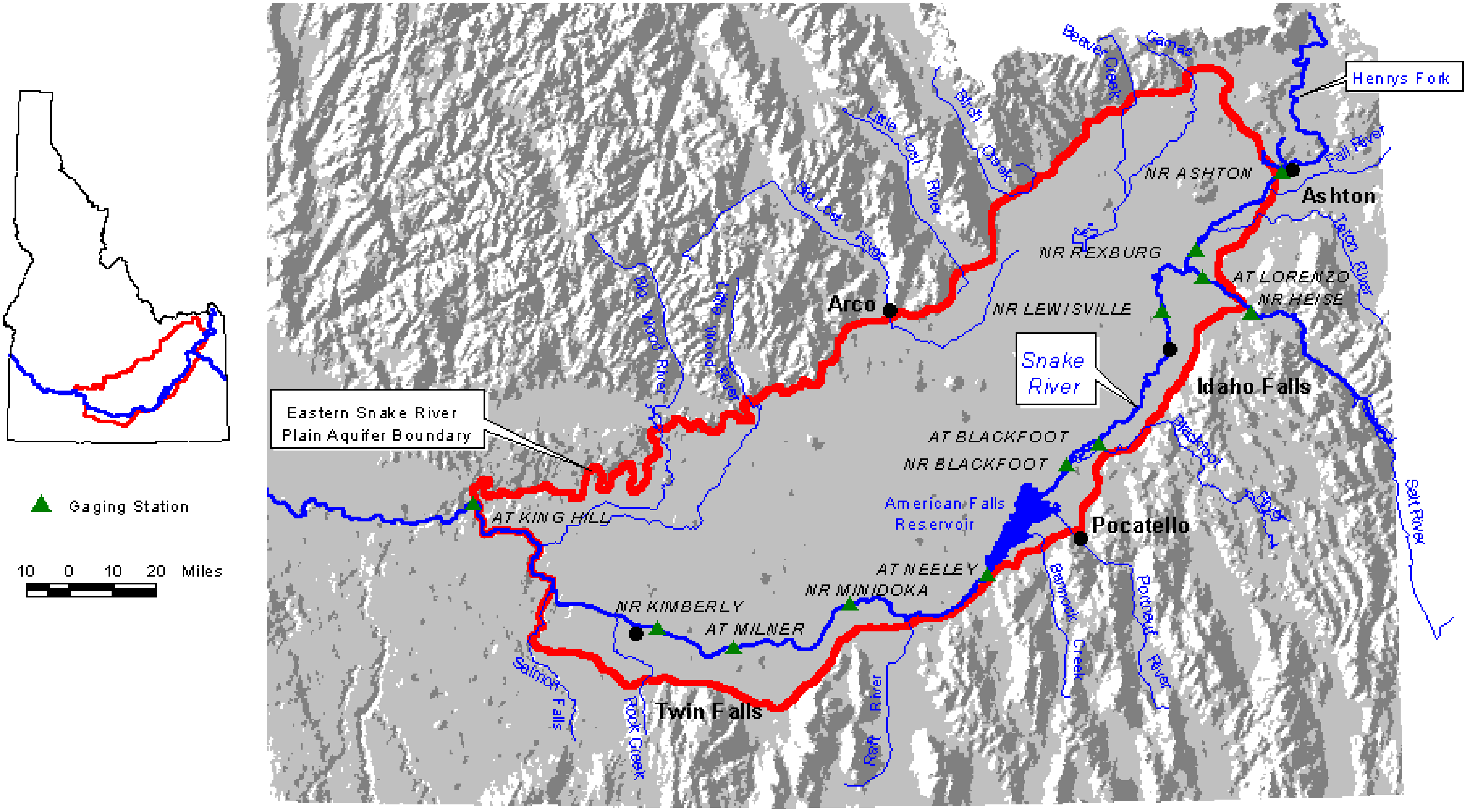


Figure 1. Snake River Plain Aquifer.

will be referred to as the IDWR/UI Ground Water Flow Model, following the convention established by the IDWR (IDWR, 1997). The IDWR has applied some version of this model as a planning and management tool for over two decades.

As part of this project, the IDWR/UI Ground Water Flow Model was converted to use one of the most widely used and accepted ground-water modeling codes, MODFLOW (McDonald and Harbaugh, 1988). The conversion to MODFLOW is not intended to create a new model, but to develop an equivalent model using a different code. The MODFLOW application to the Snake River Plain aquifer will be referred to as the Snake River Plain Aquifer Model (SRPAM), with the most recent version being SRPAM1.1. There are several benefits from conversion to the MODFLOW code including: a) the MODFLOW code is accepted as an industry standard, b) MODFLOW includes algorithms that simulate physical processes and have been verified against analytical solutions, c) MODFLOW is more familiar to a wider group of scientists and engineers, d) numerous user interfaces have been developed for MODFLOW, e) MODFLOW capabilities are continuously increasing, f) MODFLOW has a significant capability for treating more advanced features such as three-dimensional flow and variable grid spacing, and g) the MODFLOW code is well documented.

In addition to conversion of the IDWR/UI Ground Water Flow Model to the MODFLOW code, this project was established to improve model representation of the real system. This was achieved primarily by expansion of the model domain to include segments of the Snake River and tributaries in the northeast portion of the plain that were not previously simulated.

This report is one of two reports documenting work done on this project. This report provides a comprehensive documentation of the SRPAM1.1 model, along with comparisons between the SRPAM1.1 model and a model of the eastern Snake River Plain aquifer developed by the USGS during the 1980s, the USGS Snake River Plain Model. The reader should keep in mind that many of the assumptions made in early model development and evolution were not fully documented, so in many cases, this report records how the numerical model represents the physical system and not necessarily the rationale behind model design decisions. Detailed descriptions of model design decisions and calibration statistics from previous work are often not available. The *Recommendations* section addresses possible model enhancements to further improve the model. The companion report, “Conversion of the IDWR/UI Ground Water Flow Model to MODFLOW: The Snake River Plain Aquifer Model (SRPAM)" (Johnson and others, 1999), documents the conversion of the IDWR/UI Ground Water Flow Model to MODFLOW, the expansion of the model domain to include the Henrys Fork and South Fork region, and the localized calibration of the extended model.

These reports are the result of a combined effort of the U.S. Bureau of Reclamation, the University of Idaho, and the Idaho Department of Water Resources. The model described in the reports is intended to be a planning and management tool for use by both agencies. It is also intended that the model will evolve as further fiscal and data resources become available. Model refinements are suggested in the section on *Recommendations For Future Work.* The U.S. Bureau of Reclamation’s Snake River Resources Review program provided funding for this project.

PURPOSE AND SCOPE

The purpose of this project was to improve capabilities and documentation of the IDWR/UI Ground Water Flow Model. Objectives include:

1) Conversion of the model to a more widely used and versatile code that will readily accommodate future enhancements,
2) Verification that model conversion creates no significant changes in model results,
3) Modification of the model to include those refinements deemed most significant to the predictive capabilities on a regional scale,
4) Providing the IDWR and USBR with a model that both agencies accept as suitable for planning and management,
5) Improve model documentation.

This project was conducted as part of the U.S. Bureau of Reclamation's Snake River Resources Review. The Snake River Resources Review project is attempting to define all of the interests in the Snake River and develop models that will describe the impact of river operation options on the various interests. The inclusion of ground water components in the program is a response to the increasing awareness of the interaction of ground water and surface water. The model described in these reports will be used subsequently to develop analytical expressions (response functions) relating aquifer recharge and discharge at specific locations to spring discharge and flow in the Snake River. It is anticipated that these relationships will become elements of the array of water management tools forming the decision support system being developed under the Snake River Resources Review program. These products also will provide a means to further educate the public on surface and ground water relationships and assist in the development of mitigation plans between ground water and surface water users.

The IDWR's use of this model will be primarily for planning and management of the Snake River Plain aquifer. Increased ground water pumping and changes in surface irrigation practices in the last few decades have caused declines in ground-water levels and spring flows, sometimes impacting more senior surface water rights. The Department will increasingly be called upon to arbitrate in conjunctive management disputes and evaluate mitigation plans. The Department also is engaged in planning managed recharge efforts on the Snake River Plain. The model resulting from this effort, the Snake River Plain Aquifer Model (SRPAM) will be one of the tools employed to resolve these problems.

DESCRIPTION OF THE SNAKE RIVER PLAIN AQUIFER

GENERAL FEATURES

The Snake River Plain extends in an arcuate shape across most of southern Idaho and into eastern Oregon. The plain is divided into eastern and western portions based primarily on ground-water hydrology. The eastern Snake River Plain is the focus of this report and occupies an area of about 10,000 square miles extending northeast from King Hill to near Ashton (Figure 1). The boundaries of the plain, shown in Figure 1, were defined by the U.S. Geological Survey's Regional Aquifer- System Analysis (RASA) program (Lindholm, 1993). Elevation of the eastern plain varies from about 2600 feet above sea level in the southwest to over 5000 feet in the northeast.

Population within the plain is generally sparse, with most of the population residing along the eastern and southern margins of the plain in an agriculturally productive band near the Snake River. Much of the remainder of the plain is federal land managed primarily by the U.S. Bureau of Land Management. Portions of the plain are covered by rugged basalt outcroppings that include the Craters of the Moon National Monument.

The Snake River Plain enjoys an arid to semi-arid temperate climate. Precipitation ranges from about 8 to 14 inches per year, falling predominantly in the colder months. Irrigation is required for agricultural production. The crops grown vary with location; the major crops throughout the plain include potatoes, wheat, barley, alfalfa, and sugar beets. Dry edible beans and peas are grown in the southwestern part of the valley.

Irrigation on the eastern Snake River Plain began in the late 1800s using water from the Snake River and its tributaries. Garabedian (1992) describes changes in surface-water and ground-water irrigated areas on the eastern Snake River Plain that are shown graphically in Figure 2. Acreage irrigated by surface water has been declining since the mid-1940s. Since the onset of ground-water irrigation in the 1950s, the number of acres irrigated by ground water has been increasing steadily.

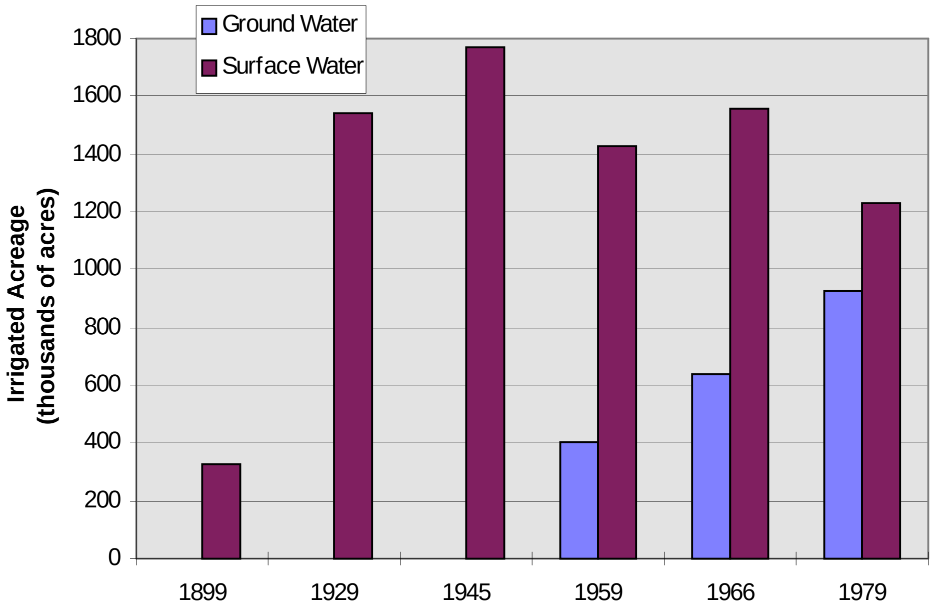


Figure 2. Changes in Surface and Ground Water Irrigated Acres on the eastern Snake River Plain. (After Garabedian, 1992.)

Irrigation practices are continually changing in response to technology and economic factors. Furrow, flood, and sub-irrigation were the dominant methods of water application into the second half of the twentieth century. In the 1980s and 1990s sprinklers commonly have replaced surface application methods, with a resulting decrease in the amount of water diverted per acre of agricultural land.

Recent changes in Idaho water law have dramatically affected water use and expansion of irrigation development on the Snake River Plain. A basin-wide adjudication of water rights was initiated in 1992 (Idaho Water Resources Board, 1996). Expansions of irrigated acreage before 1987 that were not within the requirements of the Prior Appropriation Doctrine were forgiven in legislation passed in 1996. A moratorium on expansion of irrigated acreage has been in effect for the Snake River Basin since 1992. The moratorium includes both surface and ground water irrigated lands within the basin (Idaho Water Resource Board, 1996). Conjunctive management rules were promulgated by the IDWR in 1996, essentially linking administration of ground and surface water right priorities. Water measurement districts were established in 1997 to provide records of ground-water pumpage for irrigation. Managed recharge of the Snake River Plain aquifer has been supported by the Idaho Legislature. Managed recharge, which has occurred at various locations through existing irrigation facilities, was estimated at 180,000 acre-ft (AF) in 1995, 169,000 AF in 1996, and 230,000 AF in 1997 (Idaho Water District #1 records).

GEOLOGIC SETTING

The surface of the Snake River Plain consists primarily of volcanic rocks, which, in most areas, are covered by a veneer of windblown or fluvial sediments. Exposed volcanic rocks are predominantly basalt, which in places such as the Craters of the Moon

National Monument, cover expansive areas. Sediment deposits overlying the basalt vary in thickness from zero to tens of feet.

The eastern Snake River Plain is composed of a series of relatively thin basalt flows and interbedded sediments. Flows range in thickness from a few feet to tens of feet. Welhan and Funderberg (1997) report median flow thickness near the Idaho National Engineering and Environmental Laboratory ranging from about 7 to 25 feet. Individual flows typically have a rubble or clinker zone at the top and bottom with a more massive interior containing fewer vesicles. Vertical fractures in the flow interiors form columnar basalt in places (Garabedian, 1992). Individual basalt flows generally are not areally extensive (Welhan and Funderberg, 1997). The collective thickness of basalt flows of the eastern Snake River Plain are estimated to exceed several thousand feet in places (Whitehead, 1986). More detailed descriptions of the geology of the eastern Snake River Plain are provided by Anderson (1991), Whitehead (1986), and Kuntz and others (1992).

The eastern plain is bounded structurally by faulting on the northwest and downwarping and faulting on the southeast (Whitehead, 1986). The plain is bounded by Yellowstone Group rhyolite in the northeast and Idavada volcanics in the southwest. Granitic rocks of the Idaho batholith, along with pre-Cretaceous sedimentary and metamorphic rocks, border the plain to the northwest (Garabedian, 1992).

SURFACE-WATER HYDROLOGY

The Snake River passes along the southern margin of the eastern Snake River Plain and is the exclusive surface water discharge mechanism for the eastern plain.

Ground water underflow out of the eastern plain is assumed to be minimal, making the flow of the Snake River at King Hill the approximate equivalent of basin discharge, excluding evaporation. Annual discharge of the Snake River at King Hill is shown in Figure 3. The cumulative discharge line in Figure 3 shows little change in slope. This indicates that despite significant changes in water use during the last several decades, there has been little change in basin outflow. A possible reason for the stability of the slope of the cumulative graph in Figure 3 is that human activities have apparently had a greater temporary impact on aquifer storage than on basin outflow.

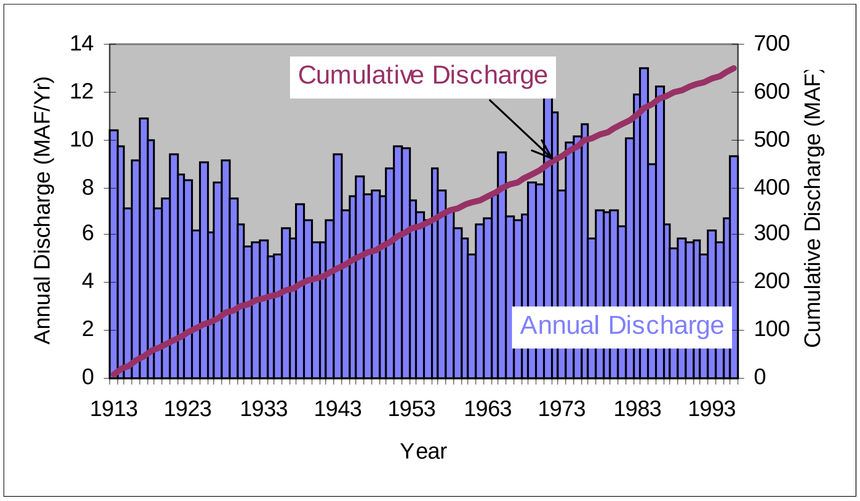


Figure 3. Annual and Cumulative Discharge of the Snake River near King Hill (U.S. Geological Survey data).

The Snake River is intensively managed for irrigation and hydropower generation. The average annual flow, major inflows and diversions at different points within the system are illustrated by river width in Figure 4. The flow in the Snake River is noticeably depleted at Milner Dam where substantial diversions are made for irrigation. A gradual increase in river flow below Milner Dam is due largely to aquifer discharge in the form of springs emitting from the wall of the Snake River canyon. North of Idaho Falls, in the eastern part of the plain, the Henrys Fork (locally referred to as the North Fork) joins the Snake River, locally referred to as the South Fork, shortly downstream from Lorenzo. The origin of the Henrys Fork is in the Island Park area to the northeast of the Snake River Plain. Headwaters of the Snake River are in Yellowstone Park in Wyoming. On average, yield of the Snake River at Lorenzo is about twice the yield of the Henrys Fork near Rexburg.

Figure 4. Conceptual Illustration of Variation in Average Annual Flow of the Snake River (after the U.S. Bureau of Reclamation, 1996).

Several reservoirs have been constructed on the Snake River and its tributaries for the purposes of irrigation, flood control, hydropower generation, and recreation. In some years, spring snowmelt exceeds system storage capacity and irrigation demands and water is spilled past Milner Dam. On average, about two million AF of water are discharged annually past Milner Dam (Figure 5). Some of this discharge is provided to meet downstream water rights and environmental needs.

Direct tributaries to the Snake River occur primarily from the east and south sides of the basin. Several streams along the northern margin disappear through seepage before flows can reach the Snake River (Figure 4). Only flows of the Big and Little Wood Rivers, Silver Creek, and Camas Creek may eventually reach the Snake River from the northern margin of the plain. Other streams on the northern margin of the plain, such as the Big and Little Lost Rivers, contribute recharge to the Snake River Plain aquifer, but do not directly discharge to the Snake River.

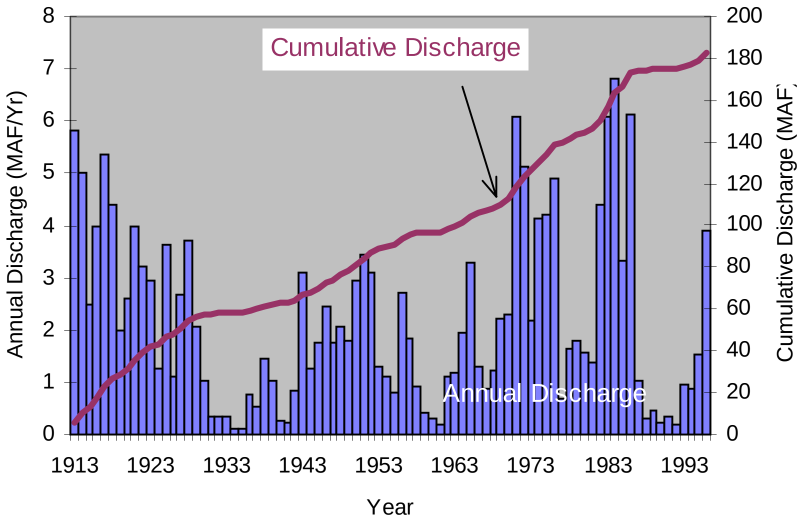


Figure 5. Historic Discharge of the Snake River at Milner Dam (U.S. Geological Survey Data).

An extensive network of irrigation canals provides water for over one million acres of irrigated land on the eastern Snake River Plain. Different reports provide different estimates of surface water irrigated land due to: 1) differences in the area being evaluated, 2) difficulties discriminating between ground-water and surface-water irrigated land in some places, and 3) the application of adjustments for non-productive lands (e.g. homesteads, roads, ditches) within an area that appears irrigated in satellite images. In 1980, the U.S. Geological Survey reported 2.1 million acres of irrigated land on the eastern Snake River Plain (Garabedian, 1992) within the boundaries shown in Figure 1. The IDWR estimated 1.4 million acres of irrigated land in 1992 (IWDR, 1997); however, the IDWR estimate did not include the south side of the Snake River near Twin Falls, nor most of the Henrys Fork area, which accounts for several hundred thousand acres.

Irrigation diversions consume a large proportion of the flow of the Snake River during irrigation season. Diversions of surface water for irrigation in the eastern Snake River Plain (including all tributaries) have diminished by about 20 percent from the nearly eight million AF/yr diverted in the early 1970s (see IDWR, 1997, Figure 16). Irrigation diversions have a significant impact on flow of the river; however, some of the diverted water returns to the river as either surface or ground water return flows. In addition, surface water diverted for irrigation also has a major effect on recharge of the Snake River Plain aquifer as will be discussed in the following section.

GROUND-WATER HYDROLOGY

The Snake River Plain aquifer underlies the eastern Snake River Plain. This highly productive aquifer is hosted in fractured basalts and interbedded sediments. The primary conduit for ground-water flow appears to be the highly permeable rubble zones that formed at the tops of the numerous basalt flows which comprise the Snake River Plain. Garabedian (1992) reports median specific capacity on a county basis for 176 wells across the eastern plain. The median values ranged from 4 to 950 gallons per minute per foot of drawdown, with the largest values occurring in counties near the center of the plain where Quaternary basalts are thickest. The lower values were found near the margins of the plain where Tertiary basalts and sediments predominate.

Although the collective thickness of the basalt flows may be in excess of several thousand feet in places, the active portion of the aquifer often is thought to be limited to the upper several hundred feet of saturated thickness. Robertson (1974) states that “Although the real aquifer system is probably more than 1,000 feet thick, a thickness of 250 feet is used in this study based on the apparent layering effects of the aquifer.” Based on the presence of low permeability sedimentary layers encountered in a well drilled on the Idaho National Engineering and Environmental Laboratory, Mann (1986) suggests that the aquifer is 450-800 feet thick. Model studies by the U.S. Geological Survey (Garabedian, 1992) represent the aquifer as four layers with a collective thickness ranging from 500 to over 3,000 feet. Modeling by the IDWR and the University of Idaho (deSonneville, 1974; Newton, 1978; IDWR, 1997) represents the aquifer as a single layer ranging from 200 to 1,700 feet thick.

The Snake River Plain aquifer generally is considered unconfined; however, in some locations and under certain conditions the aquifer responds as a confined system. In some areas, low permeability lakebed sediments create local confining layers (Spinazola, 1994). The layered basalts and interbedded sediments also may produce conditions that appear locally confined, at least when subjected to short duration stress (Frederick and Johnson, 1996).

The Snake River Plain aquifer is recharged by irrigation percolation; canal, stream, and river losses; subsurface flow from tributary valleys; and precipitation directly on the plain. The aquifer discharges to the Snake River, to Snake River tributaries, springs along the Snake River and to ground-water pumping, primarily for irrigation. The relative magnitudes of the recharge and discharge components were evaluated by the USGS (Garabedian, 1992) and, more recently, by the IDWR (1997). Estimates from the USGS represent conditions in 1980 for the entire Snake River Plain (Figure 6). Estimates from the IDWR represent a projection to near equilibrium conditions (e.g. negligible change in storage) with the level of irrigation development that existed in 1992 (Figure 7). The IDWR work applied weather conditions that were averaged for 1950 to1981 and surface water diversions that were averaged for the period of 1982 to 1992. In the context of this report, evapotranspiration (ET) is used to describe the consumption of water by agricultural crops and not ground-water discharge via stream-bank or wetland plants. The USGS estimates include portions of the plain not included in the IDWR estimate due to differences in model boundaries (model extent is discussed in a later section). A comparison of Figures 6 and 7 shows several components (ET, pumpage and canal losses) which are explicitly shown in one of the water budget analyses but are embedded within other components in the other analysis. This is due to different presentation selections for the two water budgets. All of the components have been accounted for in both of the water budgets.

Incidental aquifer recharge from irrigation is a significant component of the water budget and has varied as irrigation practices have evolved. The 1980 water budget of the USGS (Garabedian, 1992), shown in Figure 6, shows that surface water irrigation contributes more than 50 percent of the total recharge to the aquifer. Historically, recharge from surface water irrigation increased as more land was brought into production up to the 1970s. Since the 1970s, a gradual conversion to sprinkler irrigation methods reduced the amount of incidental recharge from irrigation. In addition, ground-water use for irrigation has increased during the past several decades.

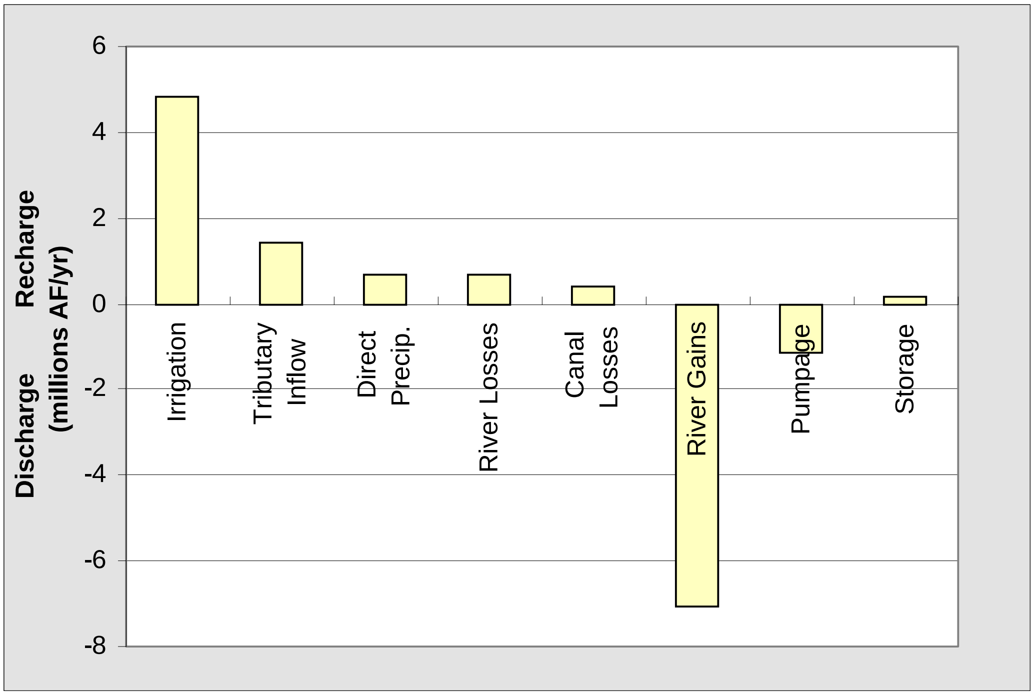


Figure 6. Snake River Plain Aquifer Estimated Annual Recharge and Discharge from April 1980 through March 1981 (after Garabedian, 1992).

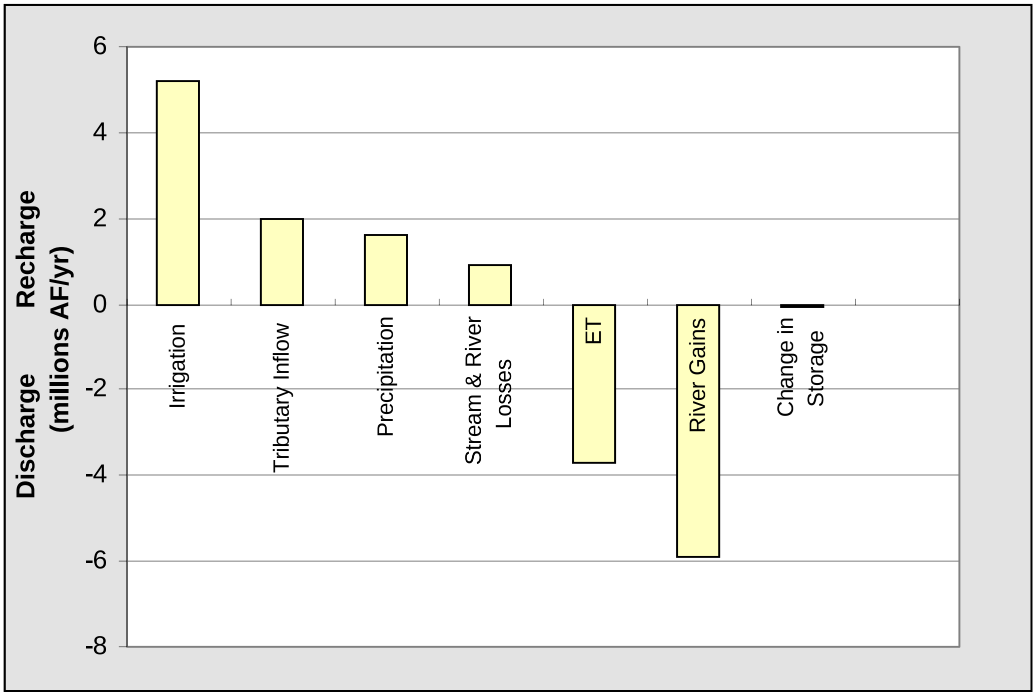


Figure 7. Snake River Plain Aquifer Estimated Annual Recharge and Discharge Assuming the Irrigation Development Level of 1992 and Near Equilibrium Conditions in the Aquifer (after IDWR, 1997).

Natural discharge from the Snake River Plain aquifer is primarily to the Snake River along two reaches: Kimberly to King Hill, and Blackfoot to Neeley. These reaches are defined by gaging stations shown in Figure 1. Spring discharge has varied in response to changes in weather, irrigated acreage, and irrigation practices. Discharge in the Kimberly to King Hill reach appears to have been impacted more than in the Blackfoot to Neeley reach (Figure 8). The effects of weather variation and irrigation recharge are apparent from the short-term variation of spring discharge. Maximum discharge occurs around October, near the end of irrigation season. The seasonal variation in the Blackfoot to Neeley and Milner to King Hill reaches is about 15 and 20 percent of the respective maximum reach gains (from interpretation of Kjelstrom, 1995).

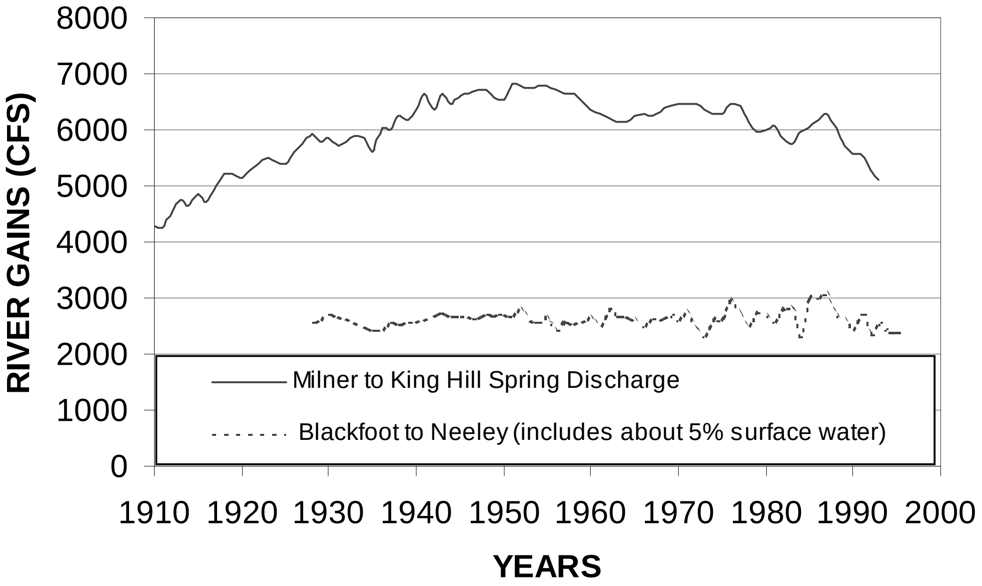


Figure 8. Average Annual Snake River Gains in the Milner to King Hill and Blackfoot to Neeley Segments. (From IDWR data.)

Other reaches of the Snake River also are hydraulically connected to the aquifer. In these segments, the river may gain or lose water, depending on river stage and the water level in the aquifer. The Neeley to Minidoka reach both gains and loses water, with gains generally exceeding losses. Further upstream, between Heise and Lorenzo, the South Fork of the Snake River is a seasonally losing stream (Kjelstrom, 1995). Average annual loss of this reach was 150 cfs in the 1980 water year. During that same period, the Lorenzo to Lewisville reach of the main stem of the Snake River and the lower Henrys Fork reach were estimated to have gained 290 and 120 cfs, respectively (Garabedian, 1992).

Contours of the potentiometric surface indicate that ground-water flow direction generally is parallel to the axis of the plain (Figure 9). Steep hydraulic gradients are apparent near the margins of the plain due to tributary valley inflow and lower transmissivity relative to the center of the plain. Steep gradients also are apparent near the Kimberly to King Hill discharge area due to convergence of flow lines and probable aquifer thinning. Near the center of the plain and near Mud Lake, steeper gradients presumably result from decreased transmissivity due to the volcanic rift zone and thick sediment deposits, respectively.

Aquifer water levels have changed significantly over the past several decades in response to changes in irrigation and variations in weather (Figure 10). The greatest changes in water level appear in a band traversing the south-central portion of the plain. Water level declines between 1980 and 1996 are as large as 15 feet in this area. Some portions of the Snake River Plain aquifer have experienced little decline or slight increases in water level.

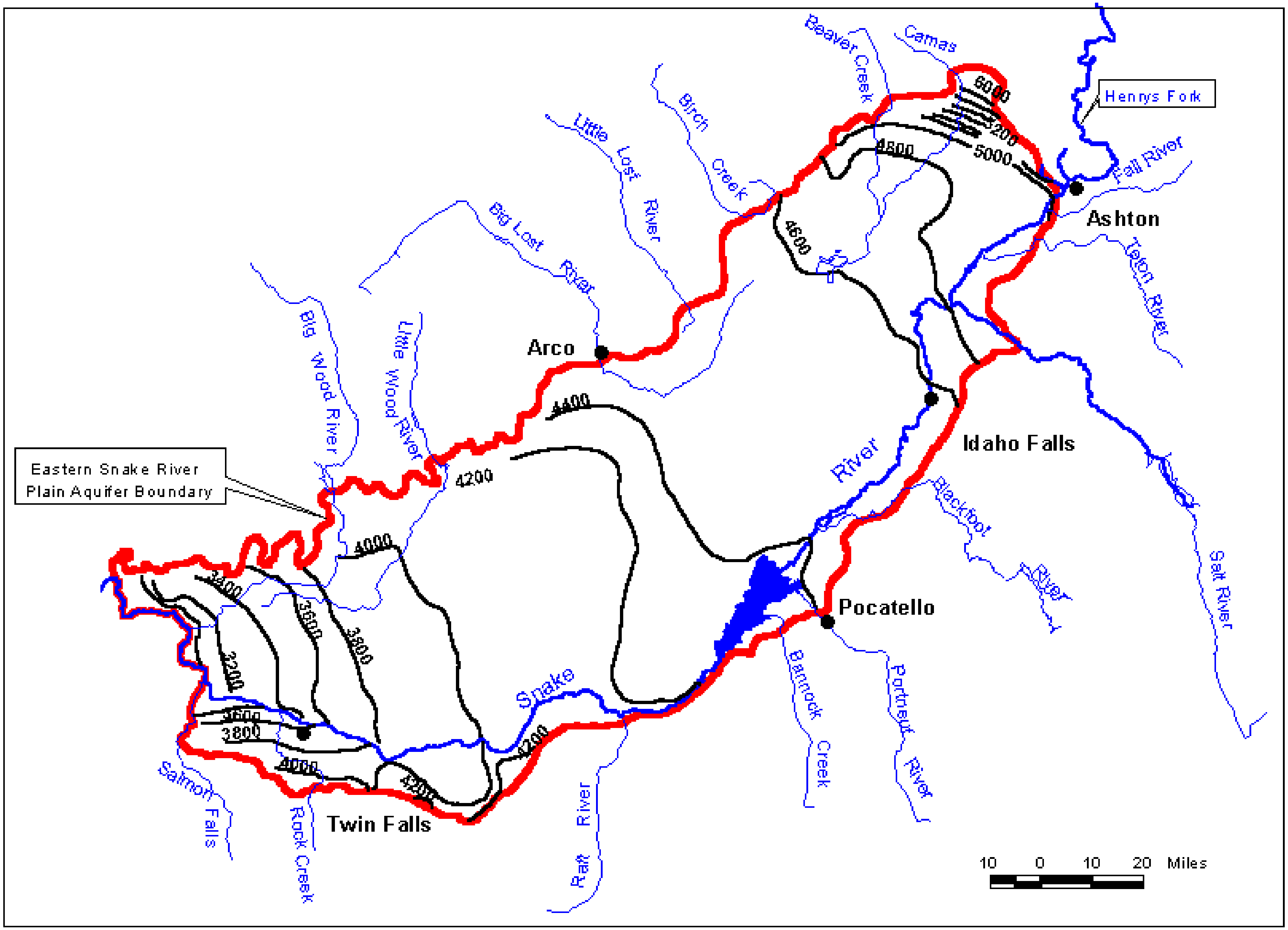


Figure 9. Potentiometric Surface of the Snake River Plain Aquifer, Water Table Contour Interval 200 ft. (after IDWR, March 1980).

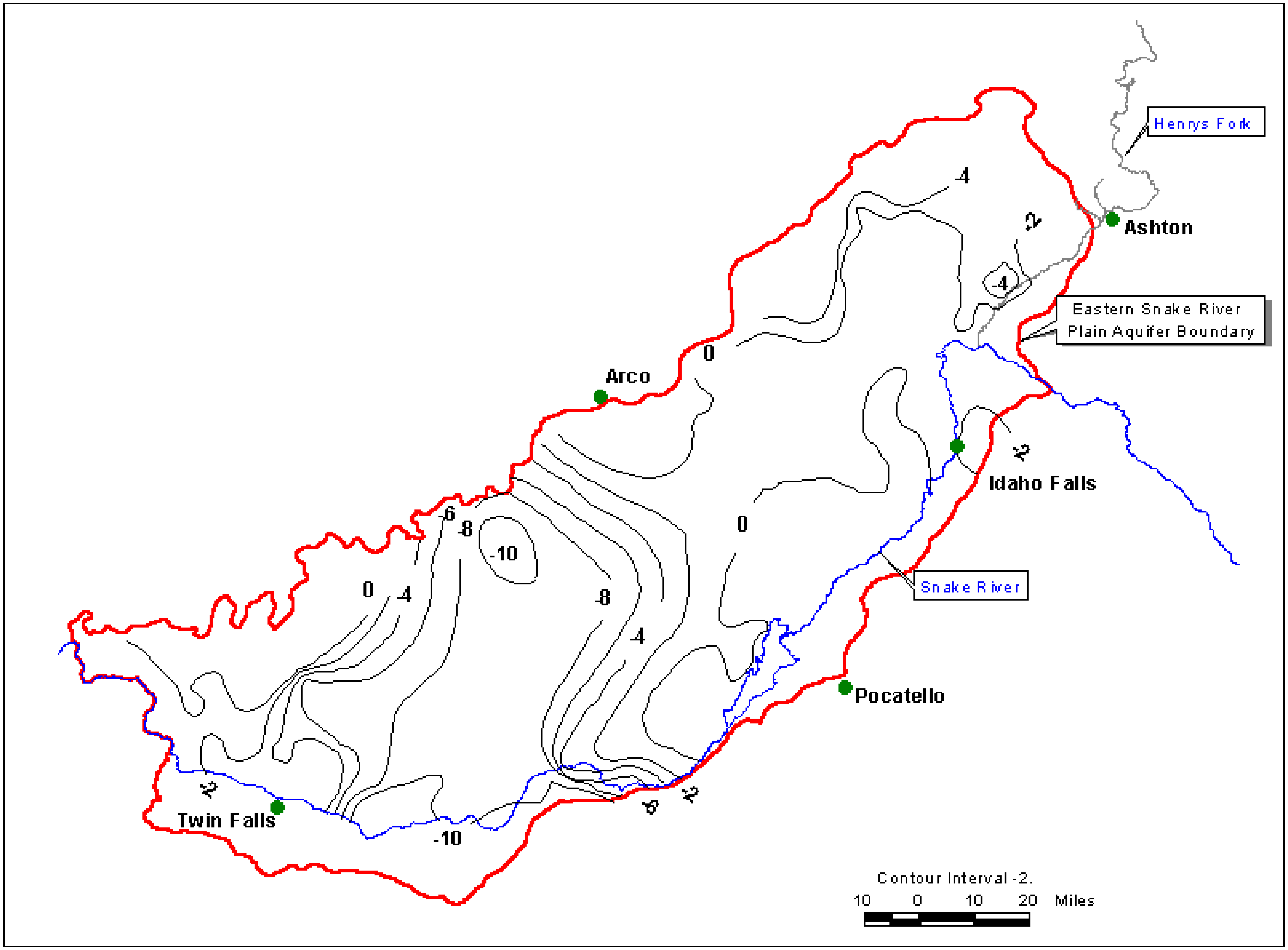


Figure 10. Water Level Changes in the Snake River Plain Aquifer from Spring 1980 to spring 1998 (after unplublished map from S. Bendixwsen, IDWR).

SRPAM1.1 MODEL DESCRIPTION

This section provides a consolidated description of the SRPAM1.1 model. A brief model history is presented. The model grid and boundaries are described, including the representation of rivers, tributary valley underflow and aquifer bottom, recharge and discharge, and aquifer properties. The appendix contains comparisons between the SRPAM1.1 model and the USGS Snake River Plain Model (Garabedian, 1992) to provide an understanding of the degree to which model construction and input are affected by interpretation and methods of the modeler.

BRIEF MODEL HISTORY

The first numerical model of the aquifer was developed by the University of Idaho for the Idaho Department of Water Resources (IDWR) and the U.S. Bureau of Reclamation (deSonneville, 1974). The model has undergone multiple revisions and improvements. The IDWR has applied some version of this model as a planning and management tool for over two decades. For the past decade, the model has been referred to as the IDWR/UI Ground Water Flow Model. As part of this project, the IDWR/UI Ground Water Flow Model was converted to use the MODFLOW code and the model domain was expanded to include the Henrys Fork and South Fork of the Snake River (Johnson and others, 1999). The converted and expanded model, referred to as SRPAM1.1, is the model documented in this report.

MODEL FEATURES

MODFLOW Packages Used in SRPAM1.1

The SRPAM1.1 implementation uses six MODFLOW packages: the BAS package, the BCF3 package, the Well package, the River package, the SIP package and the Output Control Package. The SRPAM implementation of these packages is briefly described below.

- The MODFLOW Basic Package contains grid and time characteristics of the model and the starting head array.
- The MODFLOW BCF3 input contains aquifer bottom, hydraulic conductivity, and specific yield arrays. Input in this file also sets the model domain as unconfined and applies the logarithmic interblock transmissivity averaging.
- The MODFLOW Well Package is used to represent the net recharge and discharge (non-head dependent) to each cell. The net recharge is determined using the RECHARGE Program (Johnson and Brockway, 1983). All recharge/discharge due to precipitation, canal seepage, tributary underflow, irrigation application, evapotranspiration and groundwater withdrawals is calculated for each model cell in the RECHARGE Program. The net recharge/discharge for each model cell is then represented as an injection or withdrawal from the aquifer using the MODFLOW Well package.
- The MODFLOW River Package is used to simulate those reaches of the Snake River that are modeled as head-dependent, as described above.
- The MODFLOW SIP Package was selected as the numerical solver. The closure criterion was set at 0.01 feet.

- A MODFLOW Output Control file is used to acquire the detailed output at specified stress periods.

Inter-block transmissivities in the SRPAM1.1 model are averaged using a logarithmic mean. In contrast, most other model applications use the harmonic mean for interblock averaging of transmissivity. The harmonic mean was the only option available in the original version of MODFLOW. MODFLOW routines have been modified in recent years, however, to include an optional logarithmic averaging method (Goode and Appel, 1992) identical to that employed by IDWR/UI Ground Water Flow Model. The revision is included in the BCF3 package that replaces the original MODFLOW BCF package (LAYAVG=20, LAYCON=21).

Model Grid

The SRPAM1.1 model grid consists of one unconfined layer of uniform 3.1 mile (5 km) square grid cells with 48 rows, numbered progressively from south to north, and 63 columns, numbered from west to east (Figure 11). The origin, in the southwest corner of the grid, is at latitude 42.28721696^{o} and longitude 115.19637586^{o} (location of the southwest corner of model cell 1,1). The Universal Transverse Mercator (UTM) zone 12 grid coordinates of the origin are a northing of 4,689,986.00 meters by an easting of 153,994.094 meters. The grid columns are oriented parallel to the central meridian of UTM Zone 12 (111^{o}00’00”). SRPAM1.1 uses a block-centered grid with node points in the center of cells.

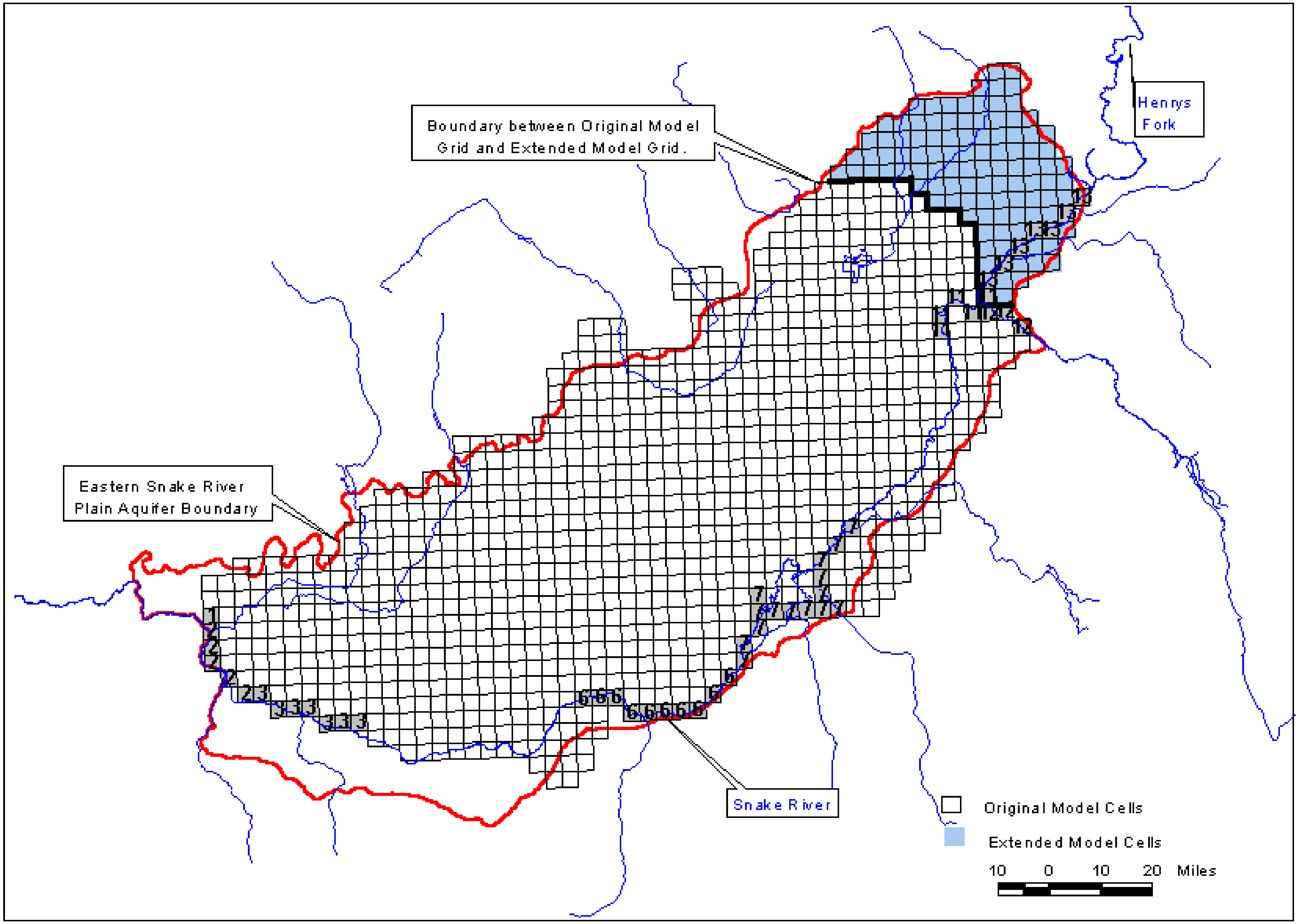


Figure 11. SRPAM1.1 Grid.
(Note: Reach Numbers are cited in Table A2).

Model Boundaries and Tributary Underflow

Model boundaries include no flow and specified-flux (underflow) along the margins of the plain and a head-dependent representation of some segments of the Snake River. Specified flux boundaries are used to represent underflow from surrounding tributary valleys including the Big Lost River, the Little Lost River, Warm Springs Creek, Deep Creek, Medicine Lodge Creek, Beaver Creek and Camas Creek, the Teton River, Big Bend Ridge, the Rexburg Bench, the South Fork of the Snake River, and the Portneuf River. Figure 12 shows the locations of model cells containing specified flux values representing underflow at tributaries. Table 1 lists the tributaries represented in SRPAM1.1 model (for the 1980 calibration year) and those used in the U.S. Geological Survey model (Garabedian, 1992) is presented in the Appendix. Specified flux is incorporated into the net recharge for each boundary cell with modeled underflow in the RECHARGE Program (Johnson and Brockway, 1983) which is described in the section *Calculation of Recharge and Discharge for SRPAM1.1*. Tributary valley specified flux is modeled as time-invariant; that is, the underflow values are constant throughout the entire simulation.

Representation of River Reaches

Some segments of the Snake River are treated as head-dependent flux boundaries, while others are represented as specified flux boundaries with recharge rates specified as input to the RECHARGE Program. The RECHARGE Program is not interactive with the

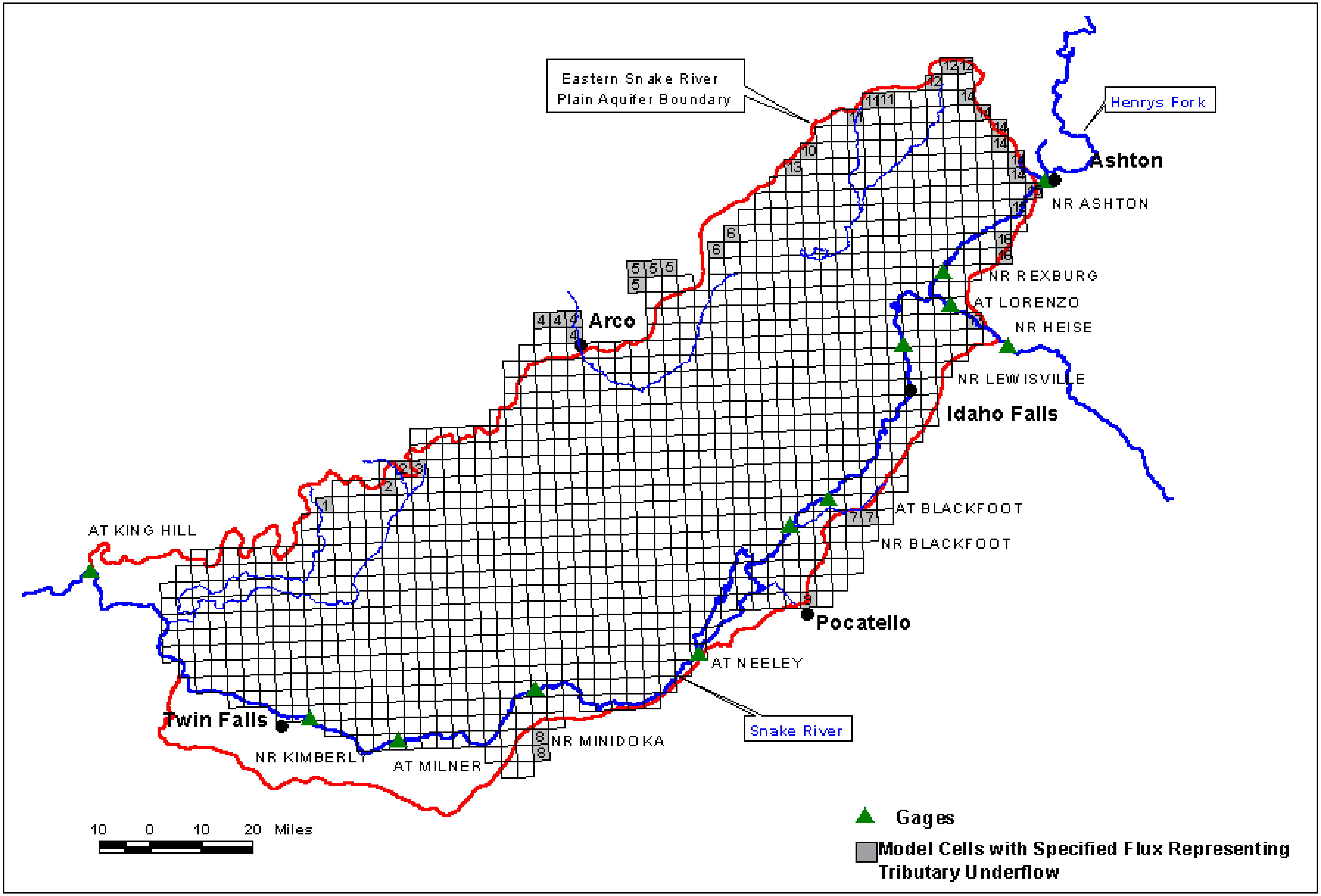


Figure 12. Model Cells with Specified Flux Representing Tributary Underflows.
(Note: Specified Flux Cell Numbers are cited in Table 1.)

Table 1. SRPAM1.1 Tributary Names and Assigned Numbers.

Tributary Name	Tributary Number
Big Wood River	1
Silver Creek	2
Little Wood River	3
Big Lost River	4
Little Lost River	5
Birch Creek	6
Blackfoot River	7
Raft River	8
Portneuf River	9
Medicine Lodge, Deep Creek & Warm Springs Creek	10,13
Beaver Creek	11
Camas and Big Bend Creeks	12,14
Henrys Fork	15
Other Reaches	16

ground water model, therefore only recharge and discharge components that are independent of aquifer head can be included in the RECHARGE Program calculations.

Non-head dependent, or perched, river segments are simulated in the Lewisville to Blackfoot and the Minidoka to Kimberly segments of the Snake River. In these segments, river losses are considered independent of aquifer head and are specified as time-variant input to the RECHARGE Program. The estimated magnitude of the river losses for the model calibration year are discussed in the section *Calculation of Recharge and Discharge for SRPAM1.1*. The assumption that these reaches are independent of aquifer water level is a simplifying assumption. Kjelstrom (1995) indicates that seepage in these reaches is to some degree dependent on aquifer water levels. However, the relatively small gains and losses in these reaches may have justified the simplifying assumption at the time the model was developed.

Head dependent, or hydraulically connected, river representation was limited to specific segments of the Snake River shown in Figure 11. Those segments, as bounded by gaging stations include:

Henrys Fork from Ashton to Rexburg
South Fork from Heise to Lorenzo
Henrys Fork (from Rexburg) and South Fork (from Lorenzo) to Lewisville
At Blackfoot to Neeley
Neeley to Minidoka
Kimberly to King Hill

In these river segments, simulated river gains and/or losses are partially controlled by simulated water-table elevations. Other features such as Camas Creek and Mud Lake may be in hydraulic communication with the aquifer but have not been represented as head-dependent features in the model.

Simulated river gains and losses in head-dependent river segments are controlled by input values of river stage, riverbed conductance, and elevation of riverbed bottom (for details see McDonald and Harbaugh, 1988). The values input for these items vary with location.

In the Kimberly to King Hill river segment, the river stage is used to represent average elevations of springs along the canyon wall. A very high aquifer stress in this area could cause water levels to drop sufficiently to cause a reversal in the direction of spring flow. Although such a large change in aquifer water levels is unlikely, the representation of springs in this area should be considered for modification in future versions of the model. In other segments the river stage is representative of the elevation of the river surface. In the Blackfoot to Neeley segment, river stage is simulated as time-variant during the 1980 calibration year. This was probably done to reflect high fluctuations in river stage due to operations at American Falls Dam. In all other segments, river stage is less variable and, therefore, is simulated as a constant value representing a time-averaged water level.

River conductance is a term used to represent the collective effects of river dimensions within a model cell and the hydraulic conductivity of riverbed and bank materials. In SRPAM1.1, river conductance is set to an arbitrarily large value in all river segments below Blackfoot. This results in river gains and losses being controlled by hydraulic conductivity of the model cells in which the river is represented. This was done to maintain consistency with earlier model versions (see Johnson and others, 1999 for more detail). In the river reaches upstream from Lewisville, including the Henrys Fork and South Fork, river conductance was calibrated to reproduce estimated river gains and losses during the calibration year.

Riverbed bottom elevation is a threshold where a river transitions between hydraulically connected and perched. In earlier model versions, the river reaches below Blackfoot were modeled as fixed head. By using a high river conductance value and a low river bottom elevation for these river reaches, the river gains simulated with the SRPAM1.1 version were consistent with the river gains simulated in earlier model versions. In the river reaches above Lewisville, the riverbed bottom elevation is set to about 30 feet below river stage.

Aquifer Bottom

The aquifer bottom was modeled at a uniform elevation of 3100’ above sea level throughout most of the SRPAM1.1 model area. In the model cells approaching the Kimberly to King Hill segment of the Snake River, the modeled elevation of the aquifer bottom slopes gradually to approximately 2550’ elevation. This slope in elevation is effected across approximately six model cells or 19 miles. This configuration was adapted to be consistent with the IDWR/UI Ground Water Flow Model. Reliable data on the elevation of the bottom of the aquifer were not available when the model was developed, so the choice of the elevation of the bottom of the aquifer was somewhat arbitrary. The uniform elevation of 3100’ feet was probably selected to be lower than the deepest known wells in the aquifer. During the model calibration, the hydraulic conductivities would have compensated for the unknown saturated thickness to achieve the desired simulated water levels.

MODEL CALIBRATION

The SRPAM1.1 model contains a combination of aquifer parameters previously calibrated for the IDWR/UI Ground Water Flow Model and aquifer properties calibrated during a localized calibration of the expanded model area (grayed cells in Figure 11) during the conversion to SRPAM1.1. Both areas were calibrated to transient conditions for the April 1, 1980 through March 31, 1981 period, using 24 stress periods of 15.2 days.

The model domain of the IDWR/UI Ground Water Flow model was calibrated and documented most recently in IDWR (1997). An automatic calibration routine was used to assist in the calibration of transmissivity and specific yield in the original model domain. Comparisons between simulated and measured values of aquifer head were made in the 11th (mid September) and 24th (end of March) stress periods. The calibrated aquifer properties were carried forward during the conversion to SRPAM1.1.

A localized calibration of hydraulic conductivities and specific yields in the expanded model area (the Henrys/South Fork region) was done as part of the conversion to SRPAM1.1. As part of the localized calibration of the Henrys/South Fork area, aquifer properties in the original model domain in the extreme northeast portion of the original model also were changed. Model cells approximately 6 rows into the original model domain were re-calibrated along with model cells in the expanded portion of the model. Additionally, river conductances in the expanded model domain were calibrated as part of the localized calibration. This model calibration was performed by a trial and error process of adjusting aquifer hydraulic conductivity, specific yield and river conductance to achieve a reasonable match between simulated and measured aquifer water levels and river gains and losses. For further details on model calibration, the reader is referred to IDWR (1997) and Johnson and others (1999). The following sections describe the water budget for the calibration period, the generation of initial conditions, and the estimation of recharge and discharge for the same period (April 1, 1980 through March 31, 1981).

Water Budget

Table 2 shows the water budget for the April 1, 1980 through March 31, 1981 period. Aquifer recharge and discharge during this period provided input for model calibration and is the base from which data sets for different time periods or development scenarios are developed.

The water budget for the model domain illustrates the relative magnitude of the major recharge and discharge components. It also provides an indication of the legitimacy of the conceptual model, based on how well independently derived terms balance. River gains and losses are based primarily on streamflow and diversion measurements. Changes in aquifer storage are based on estimates of specific yield and measured changes in water level. The net recharge component is estimated by the RECHARGE Program from data characterizing the irrigation systems, streams, and climate. The discrepancy is the difference between net recharge and discharge. Ideally, the discrepancy should be zero; however, the estimation of individual components of the water budget all contain some degree of error and the collective error is reflected by the discrepancy.

Initial Conditions

Initial estimates of the distribution of aquifer head are required for the transient model calibration period. Starting heads for the SRPAM1.1 model were derived from two sources. For the portion of the model that was converted from the original IDWR/UI Ground Water Flow Model, starting heads were taken from the original model starting heads. These initial heads were derived using RASA water level measurements from

Table 2. Conceptual Water Budget (1980-81 Calibration Year).

Component	Estimated Magnitude (AF/year)[1]
Net Recharge	**6,640,000**
Hydraulically Connected River Gains and Losses	
Above Lewisville[2]	-191,000
At Blackfoot to Neeley[2]	-1,706,000
Neeley to Minidoka[2]	-130,000
Milner to King Hill (North Side)[2]	-4,362,000
Total River Gains	**-6,389,000**
Change in Aquifer Storage[2]	**100,000**
Discrepancy	**351,000**

[1] positive value indicates recharge, negative value indicates aquifer discharge
[2] from Garabedian (1992)

early April, 1980 which were then interpolated to model cell centers. The specific set of water level measurements which were used to derive starting heads for the IDWR/UI Ground Water Flow Model is no longer available.

For the expanded portion of the model in the Henrys/South Forks area, 1980 RASA water-level measurements were contoured, the contours were adjusted to fit with contours published for that area by Wytzes (1978) and the contour interval was extrapolated to the RASA contours to the north which were published in Garabedian (1992). Contours representing the starting head conditions of April 1980 are available in Johnson and others (1999). Contouring of the measured starting heads introduces some error in the early stress periods of the model. However, a similar degree of error would be introduced by any other method of generation of starting heads. The reader is referred to Johnson and others (1999) for more details on generation of starting heads in the expanded model region.

Calculation of Recharge and Discharge for SRPAM1.1

Aquifer recharge and discharge for the April 1980 through March 1981 period were estimated using the RECHARGE Program (Johnson and Brockway, 1983) for mechanisms that are independent of aquifer head. The program calculates the net recharge resulting from irrigation diversions and pumping; evapotranspiration from irrigated and non-irrigated land; canal, river, and stream seepage that are not dependent on aquifer head; and underflow from tributary valleys. The program computes the net recharge to every cell within the model domain based on inputs provided for each of the twenty-four 15.2-day stress periods. Boundary underflow, although computed as part of the RECHARGE Program, was discussed in the previous section on model boundaries. The other components of recharge and discharge estimation are discussed in the following sections.

Surface Water Diversions and Irrigation

Diversion and application of surface water for irrigation is one of the dominant contributors to recharge of the Snake River Plain aquifer. For the 1980 model calibration year (April 1, 1980 through March 31, 1981), the estimated surface water diversions totaled 9.5 million AF. Only irrigation companies with service area within the active model domain are included in this total. This water was distributed to about 1.6 million acres of surface water irrigated land on the eastern Snake River Plain. A cell by cell map of surface water irrigated areas is shown in Figure 13. A small fraction of these total

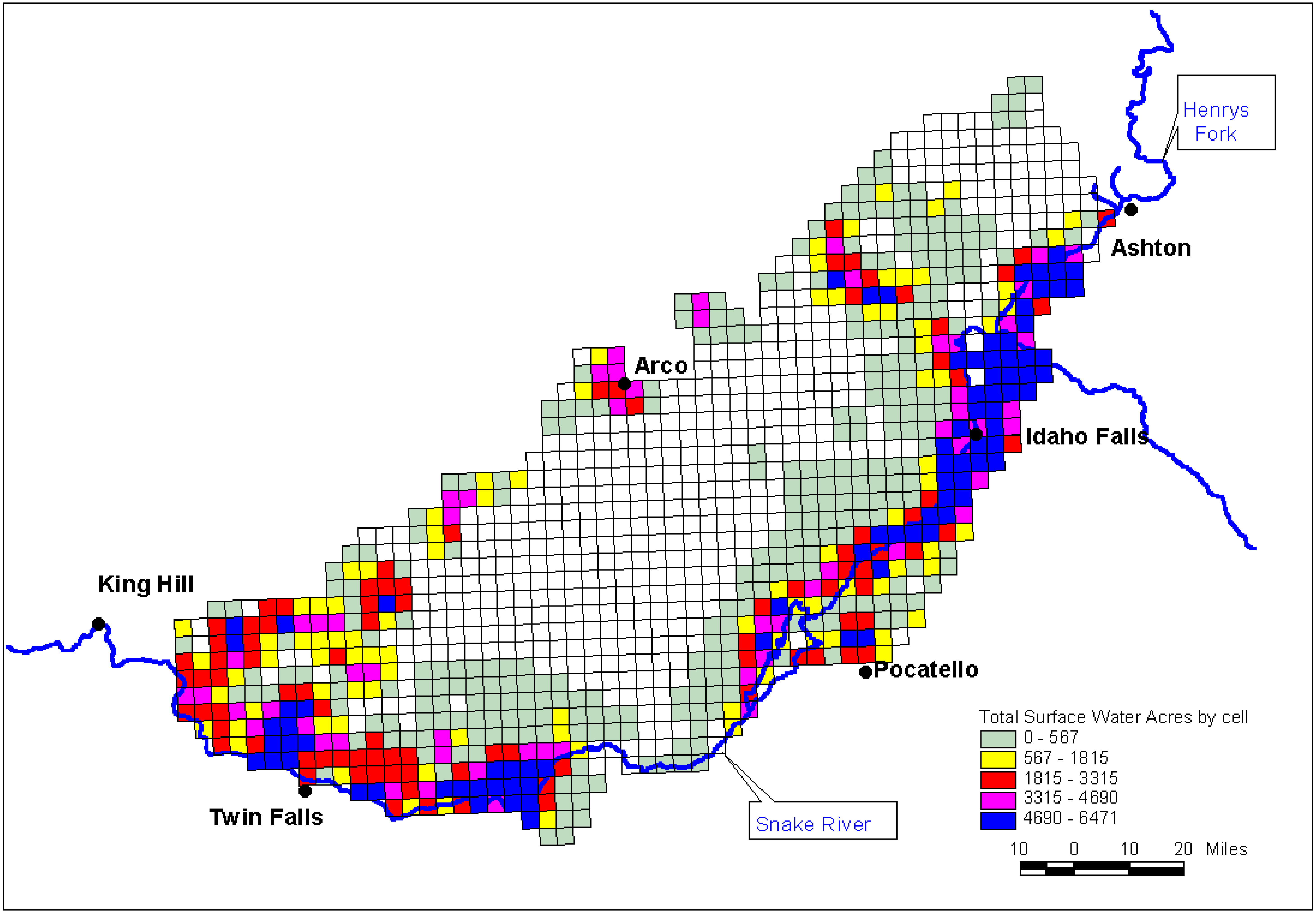


Figure 13. Surface Water Irrigated Acres.

diversions actually represent ground water pumping, so a small number of ground water irrigated acres is included for some of the irrigation units. Cell dimensions are 5 km square, with each cell containing a total of about 6,150 acres. It is apparent from Figure 13 that most of the surface water irrigated areas lie in close proximity to the Snake River.

Irrigation applications were determined as the difference between irrigation diversions and return flows, divided by the number of irrigated acres. Computations of irrigation application were performed for each 15.2-day stress period and for each of 69 irrigation units. Irrigation units may contain multiple canal companies and include canal companies that pump ground water such as those near Mud Lake (Table 3). Irrigation diversions for each 15.2-day stress period and each irrigation unit were determined from IDWR records. Return flows were estimated from records when available. Irrigated area information was developed from Landsat MSS data, as described in Anderson (1983). Canal and lateral seepage is included in the irrigation application calculated by this method. Consequently, canal seepage is distributed in proportion to the irrigated area present in each model cell. The net diversion (minus surface return flow), irrigated area, and application rate (including canal seepage losses) for each irrigation unit are presented in Table 4. Irrigation companies with unknown rates of diversion were grouped into Irrigation Unit #70 (Table 3). An average rate of application was assumed for lands associated with this unit.

Table 3. List of Irrigation Units.

Canal Company	No.	Canal Company	No.
Bannock Feeder Canal Co.	1	Roxanna Canal Co.	28
Texas Slough Irrigation and Canal	1	Saurey-Sommer Canal Co.	28
Liberty Park Irrigation Canal Co.	1	Wilford	28
Butte and Market Lake Canal	2	Westside Mutual Canal Co.	29
Butte and Market Lake & Grand	2	Martin Canal Co.	29
The Reid Canal	4	New Sweden Irr. District	29
Lenroot Canal Company	5	Woodvill Canal Co.	30
Sunnydell Irrigation District	5	Snake River Valley Irrigation Dist.	31
Parks and Lewisville Irrigation Co.	9	The New Lava Side Ditch	32
North Rigby Irrigation and Canal Co.	9	Riverside Ditch Co.	32
Rigby Canal and Irrigation Co.	9	Snake River Valley Irrigation Dist	32
Dilts Irrigation Co.	14	Danskin Ditch Co.	32
La Belle Irrigation	14	WearyRick Ditch Co.	32
Nelson-Corey Ditch	14	Trego Ditch Co.	32
Hill Petinger Ditch	14	Watson Slough Ditch and Irr.	32
Lowder Slough Canal Co.	14	Corbett Slough Ditch Co.	33
Burgess Canal and Irrigation Co.	15	Private Blackfoot River	33
Clark and Edwards Canal Co.	15	Blackfoot Irrigation Co.	33
Harrison Canal and Irrigation Co.	16	Last Chance	34
Rudy Irrigation and Canal co.	16	Twin Groves	34
Butler Island Canal Co.	16	Peoples Canal & Grndwtr.	35
Farmers Friend Irrigation Co.	18	Peoples Canal and Irrigation Co.	35
Enterprise Canal Co.	18	Aberdeen-Springfield Canal Co.	36
Falls River	21	Aberdeen-Springfield & Grndwtr.	36
East Teton Canal Co.	21	Bigler Slough	37
Teton Island Canal Co.	21	Pincock-Byington Ditch	37
Enterprise Irrigation District	21	Pincock-Garner Ditch	37
Teton Irrigation and Mfg. Canal Co.	21	City of Rexburg Canal Co.	38
Woodmansee and Johnson Canal	21	Rexburg Irrigation Co.	38
Progressive Irrigation Dist.	22	Fort Hall-Michaud Indian Service	42
Osgood Canal, Utah & Idaho	23	Fort Hall Indian Service	42
St. Anthony Union Canal Co.	24	Falls Irrigation District	43
Independent Canal Co.	24	Minidoka Irrigation District.	44
Egin Irrigation Dist.	24	Minidoka Irr. Dist. & Grndwtr.	44
Con Farmers & Island Ward	25	Burley Irrigation Dist. & Grndwtr.	45
Salem Union Co.	25	Burley Irrigation Dist.	45
Salem Irrigation Canal Co.	25	A&B Irrigation Dist.	46
Consolidated Farmers Canal Co.	25	A&B Irr. Dist. & Grndwtr.	46
Owners Mutual Irrigation Dist.	26	Milner Low Lift Irrigation Dist.	47
Idaho Irrigation Dist.	27	North Side Canal Co. & Grndwtr.	48

Table 3. List of Irrigation Units (concluded).

Canal Company	No.	Canal Company	No.
North Side Canal Co.	48	Bell Rapids Mutual Canal Co.	70
Poplar Irrigation District	49	Camas Creek	70
Big Wood Co, Am Falls#2, Pvt. L.	52	Mud Cr. Assoc. & Twin Falls Co.	70
Big Wood Canal Co. Dietrich	52	Medicine Lodge Creek	70
Big Wood (Dietrich) & Am. Falls	52	Mud Creek Water Users Assoc.	70
Big Wood Canal Co. N. Ritchfield	53	Beaver Creek	70
Big Wood Canal (N. Ritchf.) & Grndwtr.	53	Marsh Creek Water Users Assoc.	70
Big Wood Canal Co. N. Shoshone	54	Spring Slough	70
Big WoodCanal & Pvt. Little	54	Oakley Canal Co.	70
Carey Valley Reservoir Co.	55	Prvt. Sw, Tributary Valleys	70
Prvt. Little Wood Riv. & Tributaries	55	Twin Falls Canal Co.	70
Little Wood Canal Co.	56	Prvt. Snake River Tributaries	70
Little Wood Riv/Trib & Grndwtr.	56	Prvt. Blackfoot River Trib.	70
Little Wood Canal Co. & Grndwtr.	56	Prvt. Silver Creek and Tribs.	70
American Falls Res. Dist. #2	57	Prvt. Salmon Falls Cr. Diversions	70
American Falls Res. Dist. #2 & Grndwtr.	57	Magic Water Corp.	70
West Labelle & Long Island Co.	58	Prvt. Big Wood Tributaries	70
Island Irrigation co.	58	Thousand Springs Diversions	70
Level Canal Co.	61	North Side Pump Co.	70
Owsley Canal Co.	62	Private Big Wood River	70
Dobson and Stewart	63	Rock Ck. Dist. & Twin Falls Co.	70
Holly Water Users Assoc.	64	Private Malad River Diversion	70
Jefferson Irrigation Co.	65	Pearson Canal Co.	70
Jackett Canal Co.	66	District No. 45	70
Monteview Canal Co.	68	Salmon River Canal Co.	70
Producers	69	Baseline Canal Co.	70
Hamer Canal Co.	70		

Table 4. Summary of Irrigation Data for Irrigation Units for the 1980-1981 Calibration Year.

Project Number	Net Diversion ac-ft	Area ft^2	Application Rate ft/yr	Project Number	Net Diversion ac-ft	Area ft^2	Application Rate ft/yr
1	42118	9425	4.47	36	280500	65530	4.28
2	51331	20530	2.50	37	6498	889	7.31
3	51331	0	2.50	38	48182	5812	8.29
4	Not used			39	Not used		
5	69166	7664	9.02	40	Not used		
6	Not used			41	Not used		
7	Not used			42	19925	42043	0.47
8	8689	5148	1.69	43	19970	17317	1.15
9	143572	8991	15.97	44	303188	82051	3.70
10	Not used			45	271366	49334	5.50
11	Not used			46	50906	28176	1.81
12	Not used			47	60903	11219	5.43
13	Not used			48	1000571	159394	6.28
14	49780	6334	7.86	49	2838	2663	1.07
15	303105	21218	14.29	50	193600	13909	13.92
16	176734	17734	9.97	51	115800	13744	8.43
17	73930	4580	16.14	52	52400	17890	2.93
18	152679	19862	7.69	53	98400	28762	3.42
19	Not used			54	62200	15477	4.02
20	Not used			55	94000	15781	5.96
21	195554	32059	6.10	56	10500	24646	0.43
22	77820	26167	2.97	57	191300	36882	5.19
23	9294	8909	1.04	58	Not used		
24	431639	23031	18.74	59	Not used		
25	166983	14248	11.72	60	Not used		
26	3431	1268	2.71	61	6784	2234	3.04
27	242000	34527	7.01	62	46471	16697	2.78
28	66381	4506	14.73	63	1885	866	2.18
29	156291	28957	5.40	64	12284	4841	2.54
30	16776	2702	6.21	65	22890	10860	2.11
31	161100	22321	7.22	66	7122	2899	2.46
32	178500	18892	9.45	67	0	0	0.00
33	243000	23370	10.40	68	22887	5788	3.95
34	218500	23442	9.32	69	13132	3394	3.87
35	96000	12665	7.58	70	3033950	521379	5.82

The temporal variation of irrigation applications, including canal seepage and ground water pumping irrigation units near Mud Lake, is shown in Figure 14. It is apparent from the figure that most of the recharge to the system originates from irrigation applications and canal seepage. The maximum irrigation applications in the calibration year occurred in mid-July.

Ground Water Pumping

Ground water pumping was the dominant form of non-head dependent aquifer discharge during the 1980-1981 calibration year. The ground water pumping estimate generated by the RECHARGE Program (and ultimately input to the model) is equal to crop consumptive use minus precipitation on lands identified as ground water irrigated. It is assumed that all pumping in excess of crop demands returns to the aquifer. In most cases this is a reasonable assumption. It is also assumed, except in specially treated areas near Mud Lake, that ground water pumping occurs in the same cell in which the irrigated lands are present. Ground water irrigated areas (Figure 15) were determined from Landsat MSS data, similar to surface water irrigated acres. The calculation of crop consumptive use is described in the next section.

Consumptive Use and Evapotranspiration

Applied irrigation water is either consumed by the crop (ET) or results in aquifer recharge. Therefore, aquifer recharge from surface water irrigation is calculated as the difference between crop consumptive use and the sum of precipitation and irrigation applications. For ground water irrigated areas the difference between crop consumptive use and precipitation represents the net ground water use.

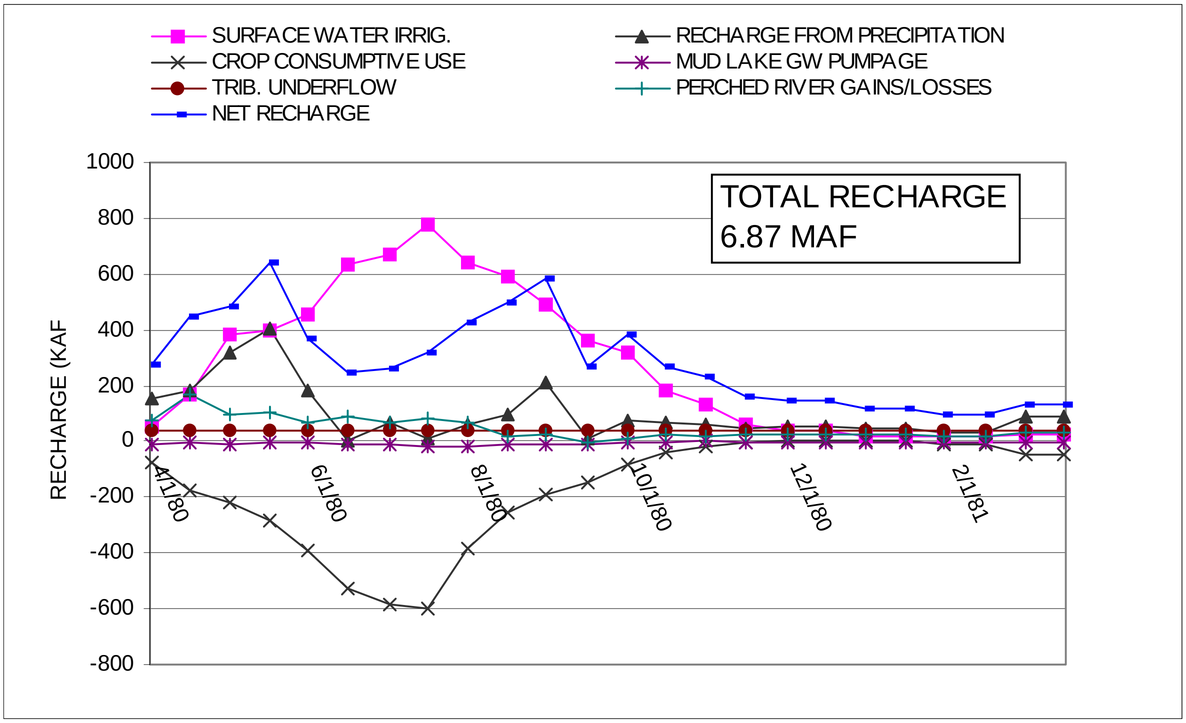


Figure 14. Time Distribution of Recharge for the 1980-1981 Calibration Data Set.

Crop consumptive use is estimated from measured climate data and crop distributions. The eastern Snake River Plain was divided into 12 climatic regions (Figure 16) for the original UI/IDWR Ground Water Flow Model; region 3 is located outside the ground water model area. These climatic regions extended far enough to cover the extended model boundaries, so no changes were made in assignment of climatic regions during model expansion. Weather conditions and crop distributions are determined for each region and control the evapotranspiration calculated for each region. Climate data are taken from nearby weather stations and crop distribution information was obtained from records of the USDA Agricultural Conservation and Stabilization Service. The annual crop consumptive use for the crop distribution of each region is color coded into Figure 16.

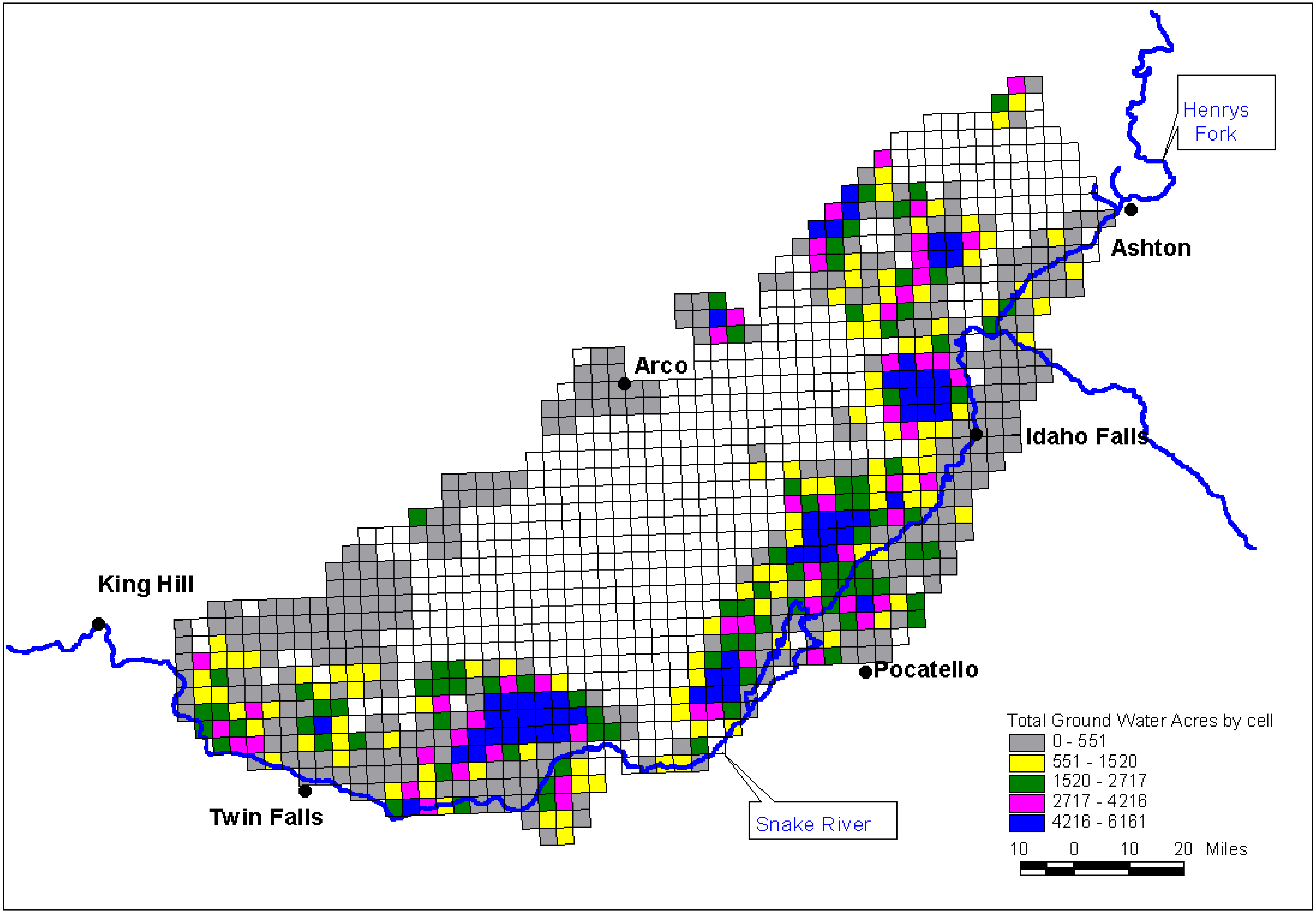


Figure 15. Ground Water Irrigated Acres.

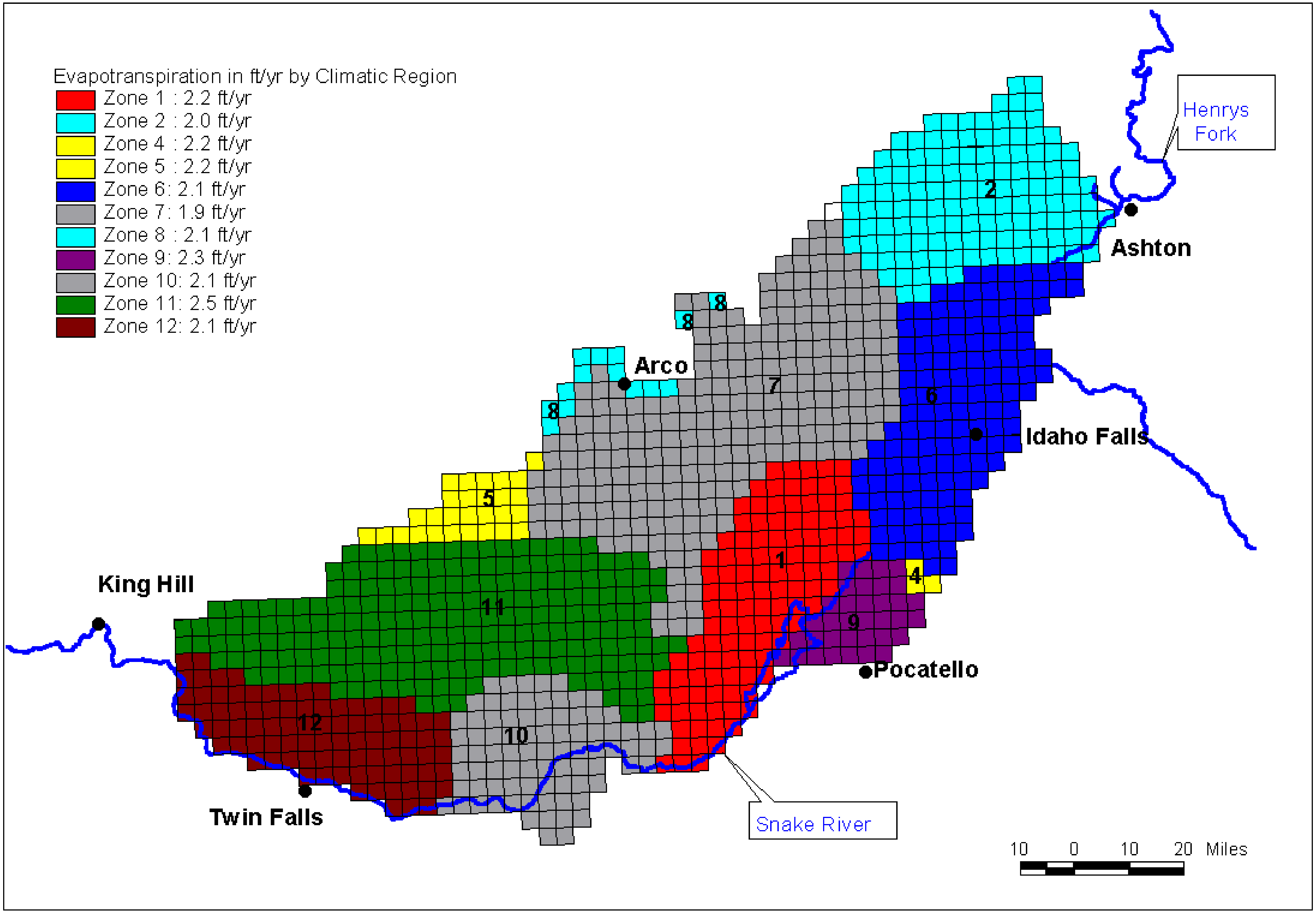


Figure 16. Climatic Regions and Annual Crop Consumptive Use.

Crop consumptive use during the 1980 calibration year varies greatly with time of year. Figure 14 shows that crop consumptive use reaches a maximum of nearly 600,000 AF per 15.2-day stress period in mid-July. This corresponds well with the timing of the maximum irrigation diversions. The crop consumptive use is very significant in the overall water budget and is the principle negative component shown in Figure 14, indicating water leaving the system. The shape of the crop consumptive use graph, combined with the irrigation application largely controls the shape of the graph of net recharge in Figure 14.

Evapotranspiration from non-irrigated lands partially controls recharge from precipitation on these lands. Crop consumptive use from non-irrigated agricultural land was not evaluated because the total area of non-irrigated agricultural land is minimal relative to irrigated land. However, evaporation and transpiration on non-agricultural land controls the amount of recharge that results from precipitation on these lands. Recharge estimates for non-irrigated lands were based on the amount of non-irrigated land within a cell, the soil cover and vegetation and weather characteristics. Figure 17 shows the estimated recharge on non-irrigated lands within the modeled area. Seven model cells in Figure 17 show a negative value of recharge on non-irrigated land. These values are small and are the result of errors resulting from data processing. Recharge from precipitation is greatest in areas of high precipitation and little soil cover.

The temporal variation of recharge from precipitation on irrigated and non-irrigated lands was bi-modal during the 1980 calibration year (Figure 14). The maximum rate of recharge occurred in spring as expected. A second, smaller peak occurred in late summer of the calibration year and probably is atypical.

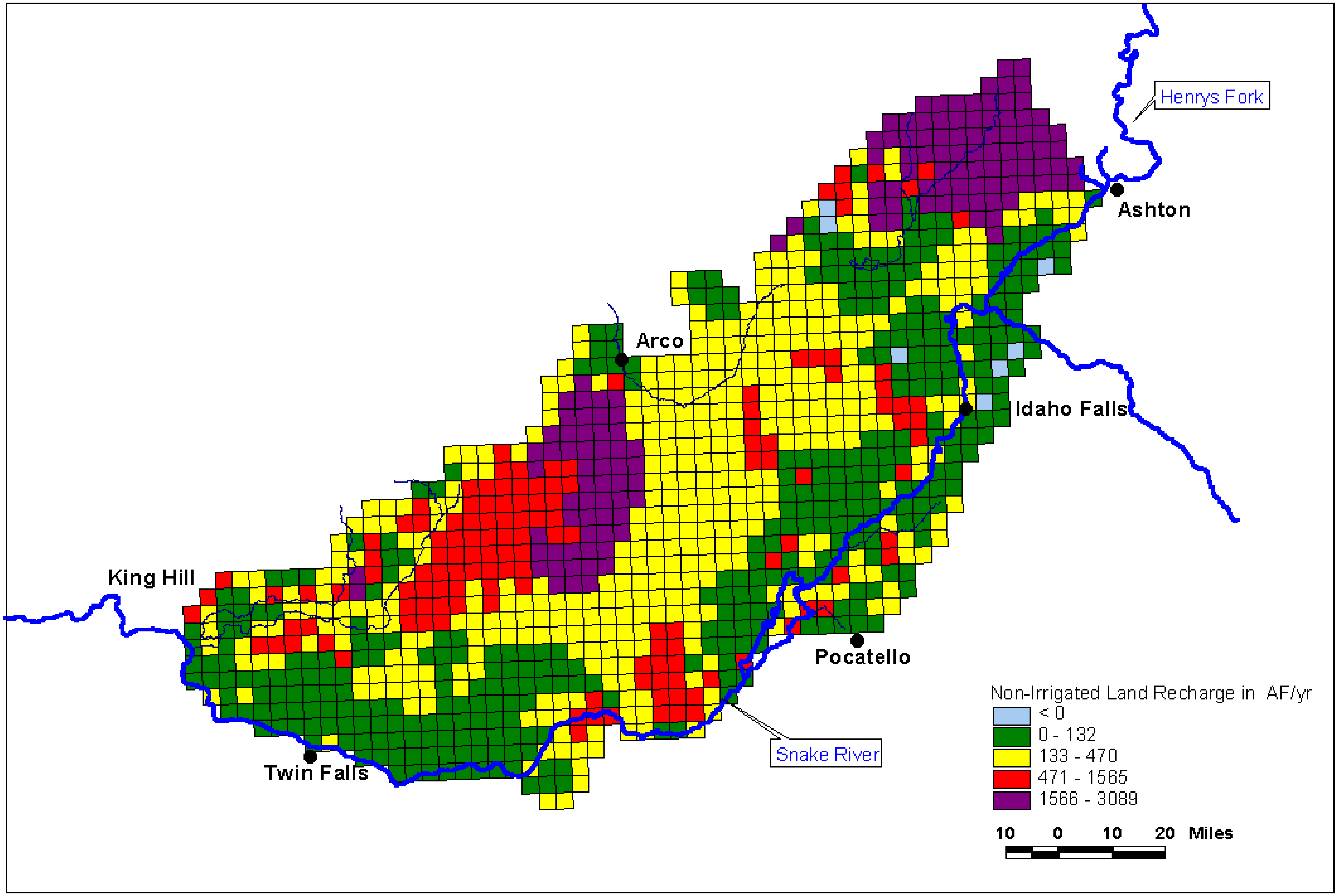


Figure 17. Estimated Recharge on Non-Irrigated Lands.

River, Stream, and Canal Losses

Some streams emerging from the mountains surrounding the plain lose water to the aquifer through seepage. In most locations the aquifer is sufficiently far below land surface that the stream losses are unaffected by aquifer water level. In these situations, stream recharge is included in the calculations of the RECHARGE Program as a specified flux to the aquifer.

The location of specified flux river nodes representing recharge from stream seepage is shown in Figure 18. Each cell with specified seepage shown in Figure 18 is assigned to a stream reach number. Table 5 lists the rate of flux for each stream reach number shown in Figure 18. Flux is uniformly divided among the cells within a reach. The temporal variation in total stream seepage shows a maximum in mid-April, as can be seen in Figure 14. The magnitude of this component is small relative to other elements contributing to the net recharge.

Tributary Valley Underflow

Figure 12 shows the location of model cells with fixed tributary underflow entering the model area. Each model cell with tributary underflow is assigned to an underflow zone. The annual rate of underflow and the tributary basin assigned to each underflow zone are listed in Table 6. Underflow is uniformly divided among cells composing an underflow zone and is time-constant as evident from Figure 14.

Table 5. Fixed Stream Seepage Values.

Number	**Description**	**Specified Flux(AF/Yr)**
1	Snake River Below Milner	-23000
2	Snake River Minidoka to Milner	281400
3	Snake River Neeley to Minidoka	0[1]
4	Snake River Near Blackfoot to Neeley	0[1]
5	Snake River Shelley to Abv. Blackfoot	111350
6	Snake River Above Shelley	175800
7	Upper Big Wood River	52650
8	Middle Big Wood River	0
9	Lower Big Wood River	-20900
10	Upper Little Wood River	10600
11	Middle Little Wood River	26900
12	Lower Little Wood River	5900
13	Confluence of Big and Little Wood	7900
14	Malad River	0
15	Milner-Gooding Canal	146200
16	Big Lost River	51547
17	Little Lost River	47709
18	Medicine Lodge Creek	25992
19	Lower Beaver Creek	17532
20	Upper Camas Creek	32496
21	Camas Creek Below Confluence	4931
22	Mud Lake	16400
23	Snake River At Blackfoot to Near Blackfoot	140300
24	Upper Beaver Creek	12460

[1] simulated as hydraulically connected with the aquifer, therefore specified flux is not assigned.

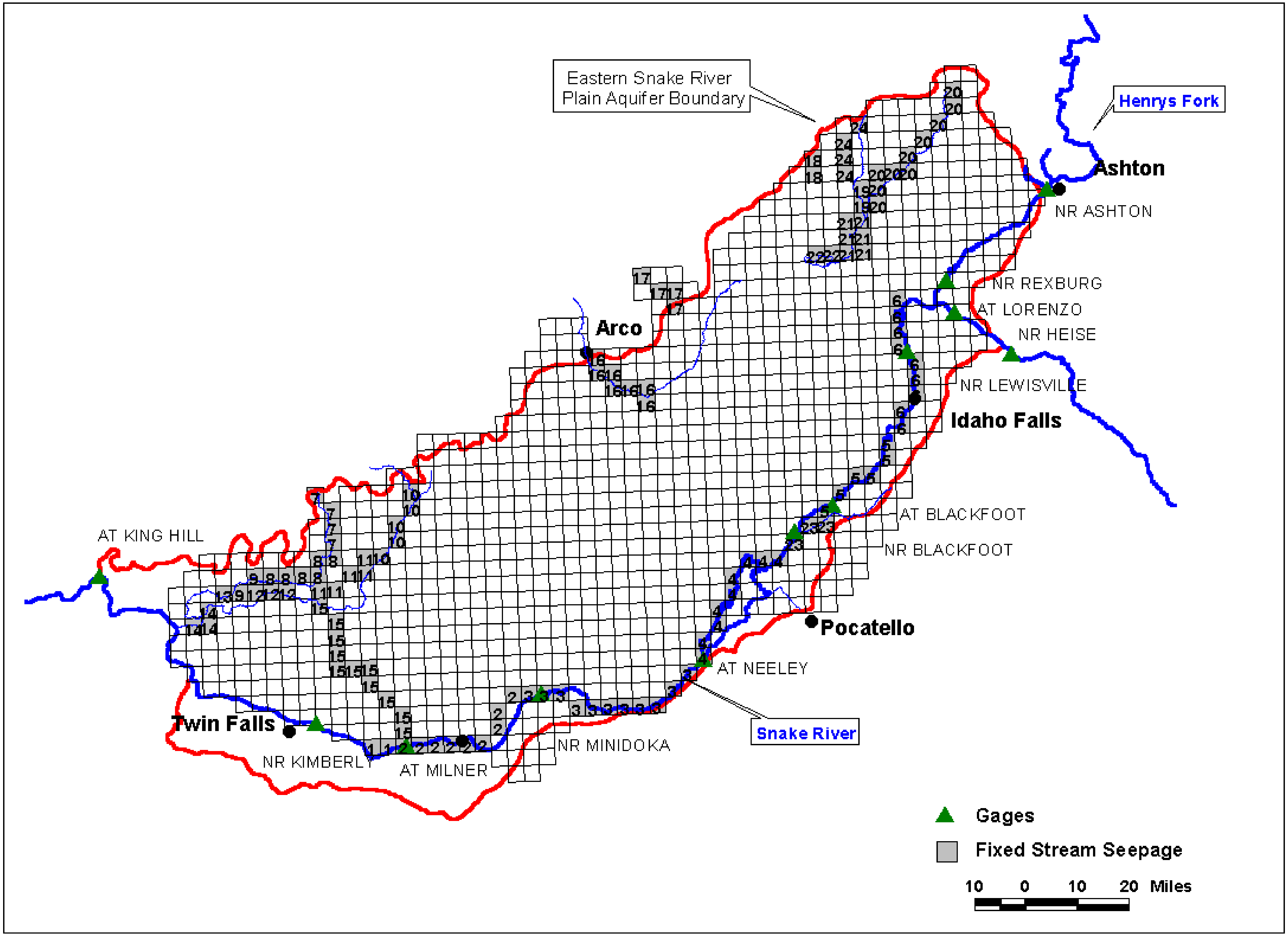


Figure 18. Location of Model Cells Representing Fixed Stream Seepage.

Table 6 Tributary Underflow Annual Rates.

Tributary Name	**Tributary Number**	**Underflow[1] AF/year**
Big Wood River	1	0
Silver Creek	2	38,000
Little Wood River	3	24,000
Big Lost River	4	114,000
Little Lost River	5	100,000
Birch Creek	6	70,000
Blackfoot River	7	25,000
Raft River	8	63,000
Portneuf River	9	22,600
Medicine Lodge, Deep Creek & Warm Springs Creek	10	15,700
Beaver Creek	11	62,000
Camas and Big Bend Creeks	12.14	296,000
Henrys Fork	15	19,000
Other Reaches	16,17	10,000
Total		859,300

[1] From IDWR (1997).

Net Recharge

The net recharge computed by the RECHARGE Program involves all of the above components. It does not include river gains and losses that are affected by aquifer water level (head-dependent). These gains and losses are simulated by the model. The computed net recharge to the model domain varies temporally and areally. The temporal variation (Figure 14) shows net recharge is predominantly related to surface water application (diversions minus return flows), evapotranspiration, and precipitation patterns. Tributary valley underflow represents a relatively small and time constant contribution to recharge. Seepage from perched streams (non-head dependent) is also relatively small but varies seasonally. The line representing off-site well pumpage (Figure 14) refers to cases where several miles separate the point of ground water pumping and application of the same water, for example, in the Mud Lake area. In the 1980 calibration year, maximum recharge occurred in late May and early September, when diversions were large but evapotranspiration was less than the maximum. In this particular year, recharge in early September was supplemented by significant precipitation.

The areal distribution of recharge shows that recharge is greatest in surface water irrigated areas where recharge rates are positive (Figure 19). Large recharge rates also are associated with a relatively few cells representing underflow from tributary valleys. Discharge in excess of recharge associated with net ground-water withdrawals are

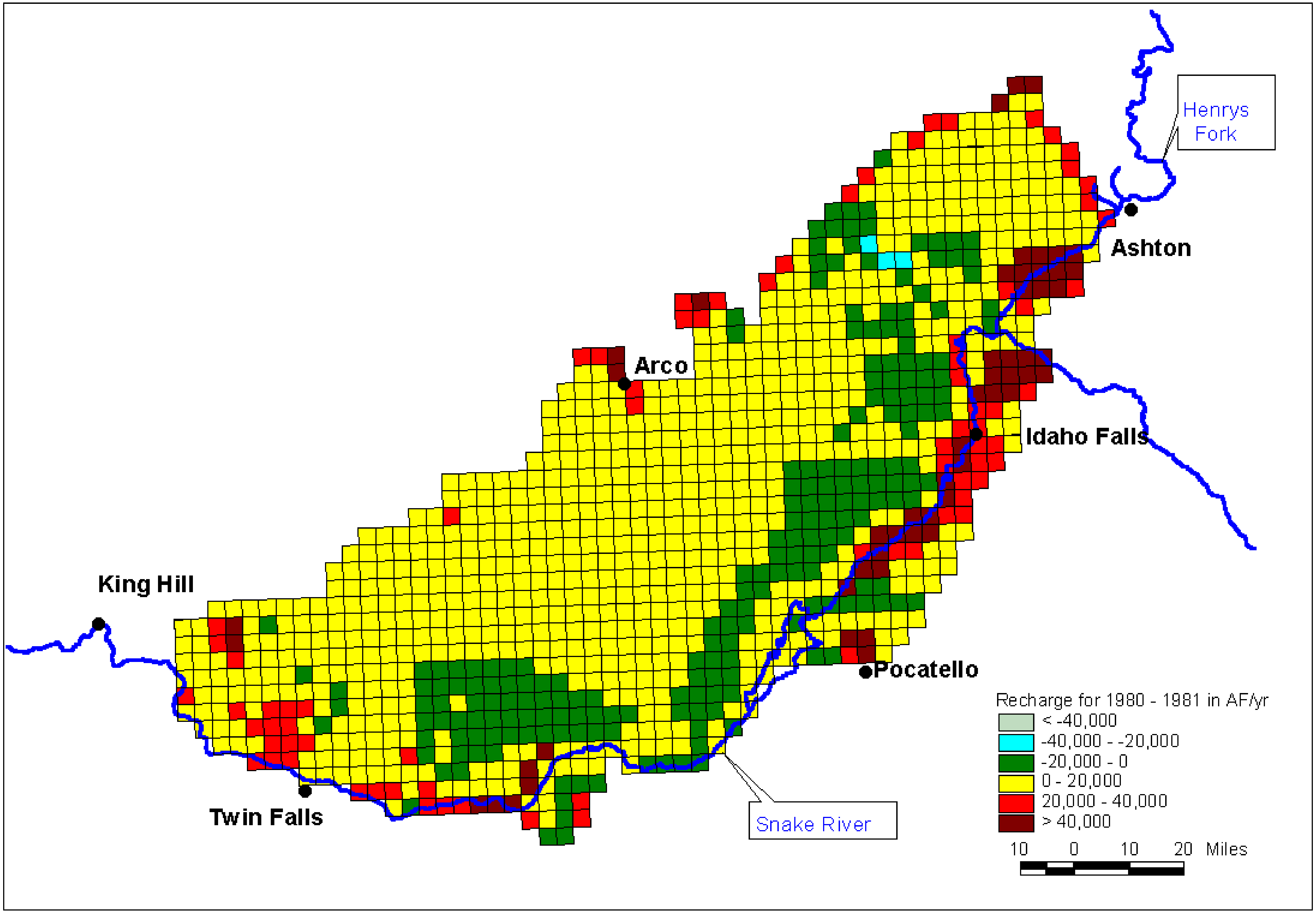


Figure 19. Areal Distribution of Recharge for 1980 - 1981 Calibration Data Set.

apparent in irrigated areas away from rivers where water is supplied primarily by ground water pumping. Most of the modeled area experiences only minor recharge due to precipitation.

DESCRIPTION OF CALIBRATED SRPAM1.1 MODEL

The SRPAM1.1 model was calibrated using the April 1980-March 1981 recharge data set. The original (non-extended) model domain was calibrated by IDWR hydrologists (IDWR, 1997) using the automated calibration routine available with the UI Ground Water Flow Model Code. The automated calibration routine adjusts selected parameters (hydraulic conductivity, storativity, etc.) on a node by node basis, based on the sum of squares of the differences between simulated and target heads. More detail on the automated calibration routine can be found in Johnson and Brockway, 1983. After conversion of the model to the MODFLOW code and extension of the model domain to include the Henrys Fork area, aquifer and river properties in the expanded domain were calibrated. This localized model calibration is discussed in more detail in Johnson and others (1999). Aquifer and river properties adjusted during calibration were hydraulic conductivity, specific yield and riverbed conductance.

Figure 20 shows the distribution of transmissivities for the calibrated SRPAM1.1 model. Transmissivity appears greatest near the center of the plain. Smaller values of transmissivity appear near the margins and in a band south of Arco, Idaho. Figure 21 shows the areal distribution of specific yields for the calibrated SRPAM1.1 model. Areas of high and low values of specific yield appear interspersed throughout the plain. Figure 22 shows a histogram of specific yields for the calibrated SRPAM1.1 model. The bi-

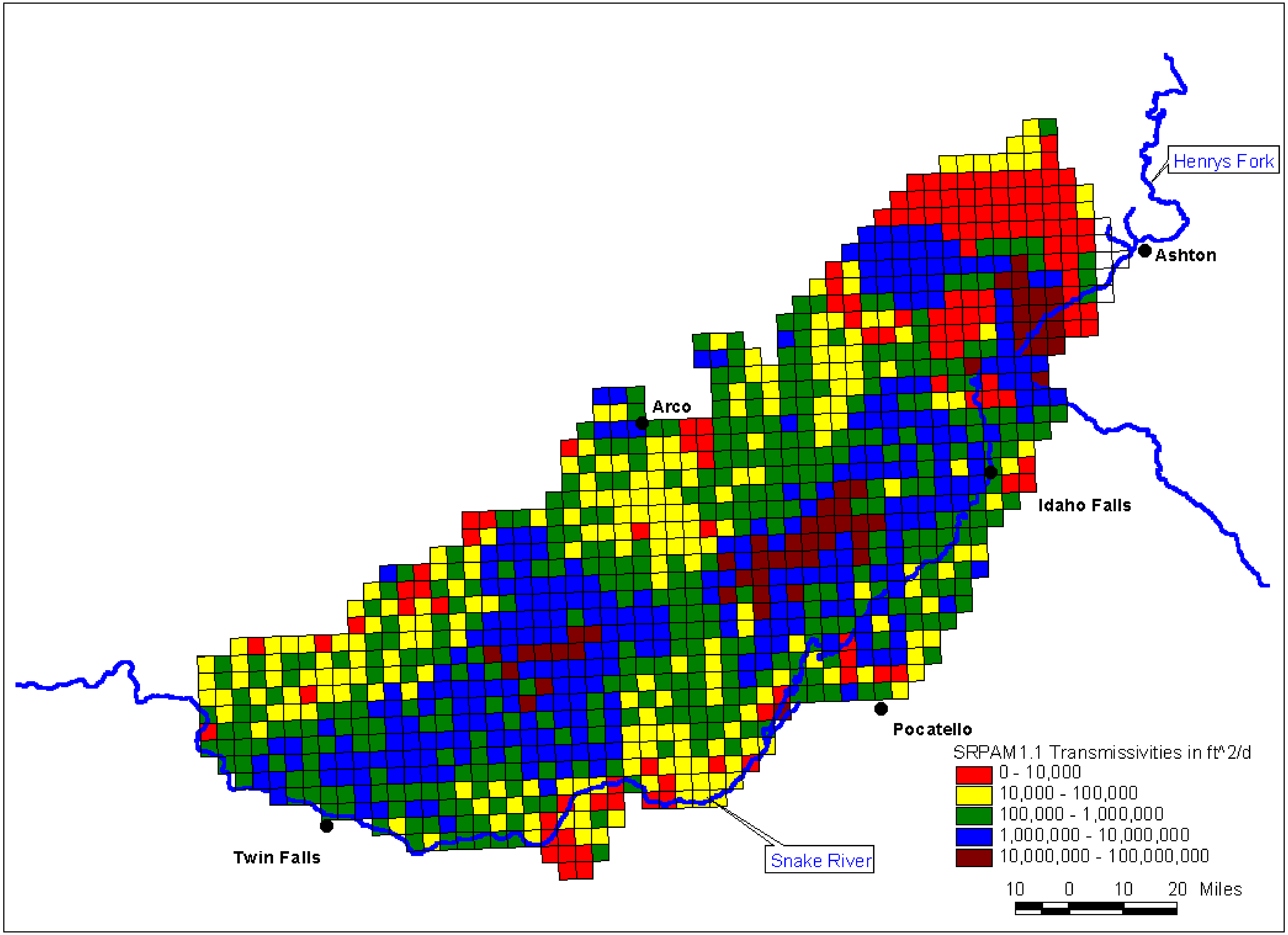


Figure 20. Areal Distribution of Calibrated Transmissivities for SRPAM1.1.

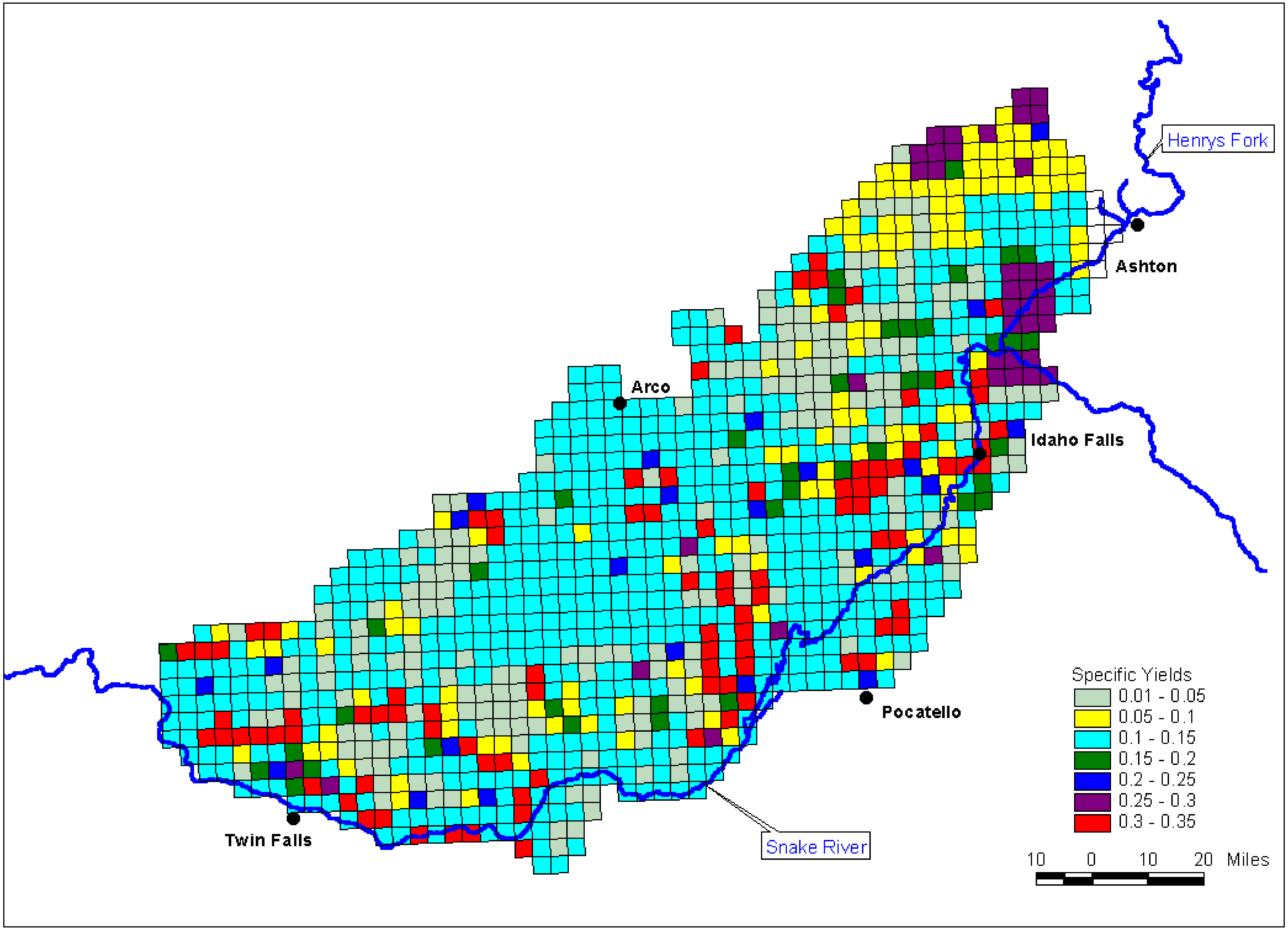


Figure 21. Areal Distribution of Calibrated Specific Yields for SRPAM1.1.

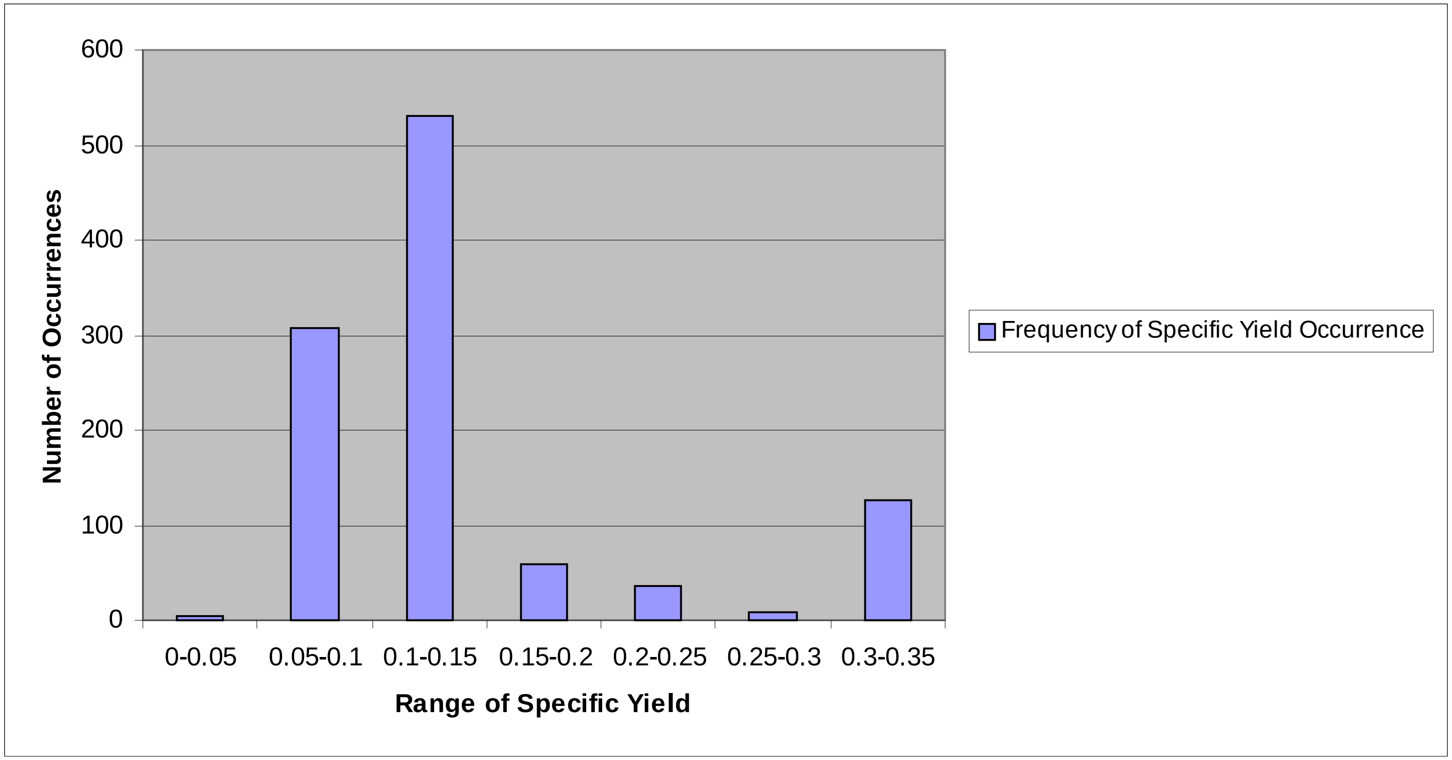


Figure 22. Histogram of Calibrated Specific Yields for SRPAM1.1.

modal nature of the histogram differs from an expected distribution of specific yields which would occur naturally in an unconfined system. The high number of model cells with specific yields in the .3 to .35 range may be a relic of the automatic calibration process and may not accurately reflect the physical system.

A table which compares river cell properties for SRPAM1.1 and the USGS Snake River Plain Model is in the Appendix. This table contains the calibrated riverbed conductance values for both models.

LIMITATIONS OF SRPAM1.1

All model applications are imperfect representations of the real world and therefore they always can be improved. The improvement process should involve prioritizing the needs associated with the limitations of any application. Further work should then address the limitations of highest priority. This section outlines the major limitations of SRPAM1.1.

- The model does not represent the appropriate interconnection of all potential surface water features with the aquifer. The areas in which there is probably significant interconnection of surface and ground water that is not treated by the model include:
    1. the Snake River from Shelley to the At Blackfoot gage, and
    2. Camas and Beaver creeks in the vicinity of Mud Lake.
- The model boundary does not conform to the boundary of the aquifer in all areas. Figure 11 shows the SRPAM1.1 model grid and the conformance to the RASA-defined boundary of the aquifer. The USGS Snake River Plain (Garabedian, 1992) followed the RASA-defined boundary in most areas, but deviated by several miles in some locations.

  In most locations, differences between the RASA boundary and the boundary of SRPAM1.1 are of little regional significance and do not represent a need to adjust location of the model boundary. Differences in two areas deserve discussion: 1) the extreme western end near King Hill, and 2) the area south of the Snake River near Twin Falls and Burley. These areas are discussed below.

On the extreme western end of the model domain (Figure 11), the RASA-defined boundary extends about 12 miles further west than the SRPAM1.1 model boundary. This area includes a length of the Snake River. Where aquifer discharge is negligible relative to the section immediately upstream. Covington and Weaver (1990) identify about 48 cfs of spring discharge emanating from about 20 springs along the Snake River in the reach beyond the western-most extent of the SRPAM1.1 model boundary and within the RASA-defined boundary of the eastern Snake River Plain. This represents about one percent of the total spring discharge in the reach from Milner Dam to King Hill, and does not provide sufficient justification for extending the boundaries of the SRPAM1.1 model to the west.

The RASA boundary extends south of the Snake River in the area near Twin Falls and Burley in contrast to the SRPAM1.1 model which is bounded by the Snake River in this area. Downstream from approximately Milner Dam (below Burley) the Snake River flows through a deeply incised canyon that likely separates aquifers on the north and south sides of the rivers. Ground-water communication beneath the river is considered to be negligible in this reach (Cosgrove and others, 1998). The Twin Falls area is hydrologically isolated by the canyon and presents no urgent need for appending to the SRPAM1.1 model. Further upstream, near Burley, the RASA boundary includes a portion of the Oakley Fan. In this reach, ground water may flow north beneath the Snake River (Young and Newton, 1989). This hydrologic connection implies that water use in the Oakley Fan can impact aquifer water levels within the Snake River Plain aquifer. The SRPAM1.1 model boundary assigns a fixed rate of underflow to the boundary, implying that ground water on the south side of the boundary is in a state of equilibrium. Although the assumption of equilibrium is not entirely valid, simulation conditions are similar for many of the tributary valleys. At some time in the future, it may be desirable to develop a basin-wide model representing the Snake River Plain aquifer and the major tributaries. This would allow prediction of impacts on the Snake River from scenarios incorporating changes in water management in both the plain and in tributary valleys.

- Aquifer and river characteristics near the Snake River have a significant influence on model results. Field studies and data analyses should be initiated to learn more about the interaction between the aquifer and the river. The results of these investigations would enable improvements to the conceptual model and to the numerical model, particularly in areas such as riverbed conductance and river gains and losses.
- The model is two-dimensional and not capable of representing vertical flow in areas of significant vertical hydraulic gradient. Vertical flow may be significant in areas such as the Henrys Fork and Rigby Fan, the Mud Lake area, the American Falls area, the Rupert area, and near the Milner to King Hill reach of the Snake River. A three-dimensional model may be warranted in these areas, but development of a valid model will require substantial effort and data.
- The model has been calibrated to limited changes in aquifer water level over a one-year period. An improved estimate of the distribution of aquifer properties could be developed from long-term calibration. The long-term calibration should include periods in which significant changes occurred in aquifer recharge, discharge and

water levels. Pre-development to current year (approximately 100 years) or the 1950s to current year may be appropriate calibration periods.

- Expansion of the model domain to include the Henrys/South Forks of the Snake River changed the original model water budget for the calibration year. Part of a re-calibration effort should include water budget refinement and calibration of model parameters to match the revised water budget.
- Other limitations exist relative to current knowledge of aquifer bottom, confined and unconfined conditions, non-laminar flow, recharge and discharge distribution, and other factors.

RECOMMENDATIONS FOR FUTURE WORK

This project represents one step in a series of efforts to continually improve and upgrade the Snake River Plain Aquifer Model. The conversion of the model to use the MODFLOW code has opened more possibilities for model enhancements. Some suggested improvements in the Snake River Plain aquifer modeling process are described below. The order of the items does not imply importance or priority.

1. <u>Evaluation of spring discharge and the relation to water levels.</u>

   Springs in the Kimberly to King Hill and Blackfoot to Neeley segments of the Snake River are of great significance to water users and exert a major control on aquifer simulations. Therefore, the ability to simulate the response of spring discharge in these reaches to changes in aquifer recharge or discharge is critical. Our understanding of how spring discharges respond to changes in aquifer water levels is inadequate. Springs at different elevations may respond to greatly different degrees to aquifer pumping. The treatment of this mechanism in the model is greatly oversimplified. Field investigations should be initiated to help further our understanding of this vital part of the hydrologic system.

2. <u>Develop an improved method for aquifer recharge accounting.</u>

   Net recharge to the Snake River Plain model must be input for every grid cell and stress period. Recharge is currently determined as the net of many inputs representing irrigation diversions and pumping, canal seepage, precipitation, evapotranspiration, and underflow. SRPAM currently relies on a Fortran program to perform the necessary calculations and determine net recharge. The program logic is valid; however, improved methods are available through the use of geographic information systems and databases. Conversion to new methods should allow for cataloging and documenting all of the basic data that is used to generate model input data sets. A systematic method can improve quality control procedures and reduce time investments in future work.

3. Changes to the Snake River Plain Aquifer Model (SRPAM).

There are several changes that can be made to the SRPAM model to make it more representative of the real system. Those changes include:

a) Representation of all reaches of the Snake River as river cells in MODFLOW. This is especially important in reaches such as the Shelley to Blackfoot reach where Kjelstrom (1995) indicates the river may be hydraulically connected with the aquifer.

b) Verification, and possibly calibration, of the model to the time period from pre-development to current time. Model calibration should be performed over the widest possible ranges of stress. Such calibration provides greater confidence in model results, especially when model predictions are within the range of stress from recharge and discharge to which the model was calibrated. This calibration should include inverse modeling techniques to help understand uncertainties and guide future data collection.

c) Conversion of the model inter-block transmissivity averaging scheme from the logarithmic mean to the harmonic mean. This conversion would make the model compatible with a wider range of user interfaces. As time progresses, however, the user interfaces are developing the capability to support the logarithmic mean and this need diminishes. Changing the averaging technique would probably require model re-calibration.

d) Inverting the rows in the existing SRPAM grid. Some user interfaces are not compatible with the bottom-up row numbering used in the SRPAM grid. Converting to the more widely used top-down row numbering will increase compatibility. This need will also diminish as user interfaces become more flexible.

e) Expansion of the model domain to include the area south of the Snake River. Ground water in the Twin Falls area is probably hydrologically separated from the rest of the Snake River Plain aquifer by the deeply incised Snake River canyon. The area south of the river is, however, the largest single tract of irrigated land in Idaho, and has an impact on flows and quality of the Snake River. Evaluations of basin-wide changes in agriculture practices, and the potential impacts on the Snake River, must include the Twin Falls tract. Inclusion of this area in the ground water model may enhance use of the model for system planning.

f) Area-specific refinements in the model. The conceptual and numerical model may be improved in specific areas through more detailed investigations. These investigations should focus on areas of greatest uncertainty in aquifer characteristics and in areas of greatest interest.

These efforts will probably result in a refinement of the model grid and layers in the selected areas.

Modeling of an aquifer system should be treated as a continuous and ongoing process, with the door always left open to make improvements. The above recommendations are provided as ideas to fuel the process of continued model evolution.

APPENDIX

This appendix provides a comparison of the SRPAM1.1 model with the USGS Snake River Plain Model (Garabedian, 1992). This comparison is provided to enable the reader to compare how two very similar models of the same region represent the physical characteristics of the area being modeled. The models were designed and implemented by different authors. The model boundaries are compared. Comparisons of physical properties such as transmissivity and specific yields are provided. A comparison is made of tributary underflow and distribution of aquifer recharge for the same water year. River representation in the two models also is discussed.

The reader should keep in mind that many of the decisions on SRPAM model design and generation of input data for the SRPAM model were made in the early 1970s. Evolution of the model since its development has not been fully documented, so the rationale behind many of the model assumptions is unknown. The following comparison is provided as a general guideline to the reader, for the purpose of demonstrating that two numerical models developed with different resources, by different modelers and at different times actually produce very comparable results.

COMPARISON OF MODEL BOUNDARIES FOR SRPAM1.1 VERSUS THE USGS SNAKE RIVER PLAIN MODEL

Both SRPAM1.1 and the USGS Snake River Plain Model generally conform to the RASA-defined boundaries of the Snake River Plain aquifer. SRPAM1.1 follows the RASA-defined boundary in most areas, but deviates by several miles in the extreme northeast near Ashton, Idaho and in the extreme southwest near King Hill, Idaho. Figure A1 (from Garabedian, 1992) shows the conformance of the USGS model to the RASA-defined aquifer boundary. Figure 11 shows the SRPAM1.1 grid and the conformance to the RASA-defined boundary of the aquifer.

In most locations, differences between the RASA boundary and the boundary of SRPAM1.1 are of little regional significance. Differences in two areas, the extreme western end near King Hill and the area south of the Snake River near Twin Falls and Burley are significant and are discussed in the main body of this report.

The USGS transient model is a three layer, three-dimensional model, versus the one layer, two-dimensional SRPAM1.1. The USGS model contains 21 rows and 51 columns compared with the 48 rows and 65 columns of SRPAM1.1. The USGS model cells are 4 miles square versus 3.1 miles square for the SRPAM1.1 model cells. The SRPAM1.1 grid is oriented approximately north-south/east-west; the USGS grid is oriented southwest-northeast more parallel to the axis of the Snake River Plain. Approximately the same hydrologic features are represented in both models. For more information concerning the USGS model grid, the reader is referred to Garabedian (1992).

COMPARISON OF TRIBUTARY UNDERFLOW FOR SRPAM1.1 VERSUS THE USGS SNAKE RIVER PLAIN MODEL

SRPAM1.1 and USGS model underflow estimates are very similar for many tributaries but differ greatly in some areas. Table A1 lists the estimated tributary

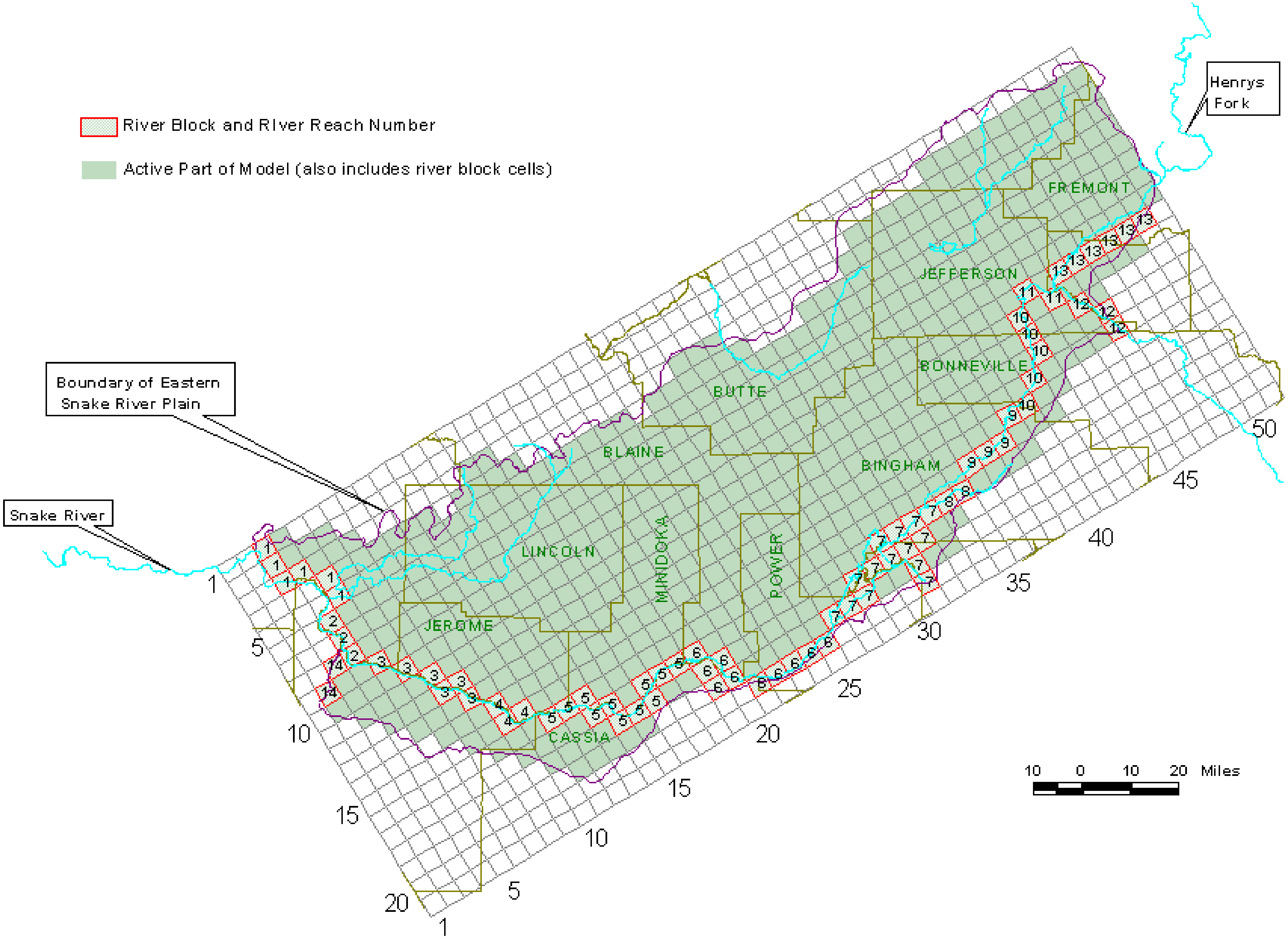


Figure A1. USGS Model Grid (after Garabedian, 1992).

Table A1. Estimated Tributary Underflow Values for the SRPAM1.1 and USGS Models.

Tributary Name	**Tributary Number**	**SRPAM Underflow[1] (AF/year)**	**USGS Underflow[2] (AF/year)**	**Difference (Positive indicates SRPAM Underflow is Higher)**
Big Wood River	1	0	10,000	-10,000
Silver Creek	2	38,000	53,000	-15,000
Little Wood River	3	24,000	18,000	6,000
Big Lost River	4	114,000	295,000	-181,000
Little Lost River	5	100,000	155,000	-55,000
Birch Creek	6	70,000	78,000	-8,000
Blackfoot River	7	25,000	13,000	12,000
Raft River	8	63,000	84,000	-21,000
Portneuf River	9	22,600	63,000	-40,400
Medicine Lodge, Deep Creek & Warm Springs Creek	10,13	15,700	39,000	-23,300
Beaver Creek	11	62,000	62,000	0
Camas and Big Bend Creeks	12.14	296,000	266,000	30,000
Henrys Fork	15	19,000	3,000	6,000
Other Reaches	16,17	10,000	166,000	-156,000
Total		859,300	1,305,000	-455,700

[1] from IDWR (1997)

[2] from Garabedian (1992)

[3] Garabedian (1992) specified reaches that may be included in other reaches of IDWR (1997), these do not include tributaries to the south side of the Snake River near Twin Falls.

underflow values for SRPAM1.1 and the USGS model. The largest difference in tributary underflow values is for the Big Lost River valley. The difference may be partially attributed to differences in boundary locations. Additionally, tributary underflow values are very difficult to estimate and are subject to great error.

COMPARISON OF MODELING OF RIVER REACHES FOR SRPAM1.1 VERSUS THE USGS SNAKE RIVER PLAIN MODEL

River reaches are modeled somewhat differently in the two models. As mentioned in the main body of this report, some of the reaches of the Snake River are modeled in SRPAM1.1 as head-dependent river reaches using the MODFLOW River package and other reaches are modeled as specified seepage reaches. All of the head-dependent reaches in the original, non-extended portion of SRPAM1.1 are modeled using an extremely high river conductance and arbitrarily small riverbed bottom elevation. This creates conditions identical to the earlier model version where flow is controlled by hydraulic conductivity of the river cell. In the USGS Snake River Plain Model, all of the cells representing Snake River reaches are modeled as head-dependent reaches using the MODFLOW River package, however, some of the reaches may be perched. Table A2 shows a comparison of river reaches on a reach by reach basis for the two models. River segment gains and losses were compared between the two models. Because the river segments from the Lewisville gage to the At Blackfoot gage are modeled in SRPAM1.1 as specified flux cells, and the same reach is represented as head-dependent river cells in the USGS model, a comparison of river gains and losses in these cells is not valid. Table

Table A2. Comparison of River Cells for SRPAM1.1 versus the USGS Model.

SRPAM					Segment		USGS Model				
Row	Column	Stage (elev)	Conductance	River Bottom	Number	Name	Row	Column	River altitude	Conductance	River Bottom
14	6	2855	1.00E+08	1111	1	Hagerman to King Hill	1	3	2600	1.16E+04	2600
							2	3	2650	1.16E+04	2650
							3	3	2725	1.16E+04	2725
							3	4	2800	1.16E+04	2800
							4	5	2900	1.16E+04	2900
							5	5	3050	3.46E+06	3050
9	8	3150	1.00E+08	1111	2	Buhl to Hagerman	6	4	3050	3.46E+06	3050
11	6	3035	1.00E+08	1111			7	4	3000	3.46E+06	3000
12	6	3020	1.00E+08	1111			8	4	3050	3.46E+06	3050
13	6	2940	1.00E+08	1111							
7	13	3502	1.00E+08	1111	3	Kimberly to Buhl	9	5	3100	1.12E+05	3100
7	14	3562	1.00E+08	1111			10	6	3150	1.12E+05	3150
7	15	3644	1.00E+08	1111			11	7	3200	1.12E+05	3200
8	10	3270	1.00E+08	1111			12	7	3300	1.12E+05	3300
8	11	3300	1.00E+08	1111			13	8	3600	1.12E+05	3600
8	12	3422	1.00E+08	1111							
9	9	3225	1.00E+08	1111							
					4	Milner to Kimberly	14	9	3700	5.18E+06	3700
							15	9	3850	5.18E+06	3850
							15	10	3850	5.18E+06	3850
					5	Minidoka to Milner	16	11	4130	1.73E+04	4100
							16	12	4130	1.73E+04	4100
							16	13	4130	1.73E+04	4100
							17	13	4130	1.73E+04	4100
		Non-Head Dependent					17	14	4130	1.73E+04	4100
							18	14	4130	1.73E+04	4100
							18	15	4130	1.73E+04	4100
							17	16	4130	1.73E+04	4100
							18	16	4130	1.73E+04	4100
							17	17	4130	1.73E+04	4100
							17	18	4150	1.73E+04	4120
7	32	4195	1.00E+08	1111	6	Neeley to Minidoka	17	19	4190	1.73E+05	4160
7	33	4195	1.00E+08	1111			18	19	4190	1.73E+05	4160
7	34	4195	1.00E+08	1111			18	20	4190	1.73E+05	4160
7	35	4195	1.00E+08	1111			19	19	4190	1.73E+05	4160
7	36	4195	1.00E+08	1111			19	20	4190	1.73E+05	4160
8	29	4135	1.00E+08	1111			20	21	4190	1.73E+05	4160
8	30	4150	1.00E+08	1111			20	22	4190	1.73E+05	4160
8	31	4165	1.00E+08	1111			20	23	4190	1.73E+05	4160
8	37	4205	1.00E+08	1111			20	24	4200	1.73E+05	4170
9	38	4230	1.00E+08	1111			20	25	4240	1.73E+05	4210
10	39	4300	1.00E+08	1111	7	Near Blackfoot to Neeley	19	26	4355	3.85E+03	4325
11	39	4354.3	1.00E+08	1111			19	27	4355	3.85E+03	4325
12	40	4354.3	1.00E+08	1111			18	28	4355	3.85E+03	4355
13	40	4354.3	1.00E+08	1111			19	28	4355	3.85E+03	4355
13	41	4354.3	1.00E+08	1111			18	29	4355	3.85E+03	4355
13	42	4354.3	1.00E+08	1111			17	30	4380	3.85E+03	4380
13	43	4354.3	1.00E+08	1111			18	30	4355	3.85E+03	4355
13	44	4354.3	1.00E+08	1111			17	31	4380	9.50E+05	4380
14	40	4354.3	1.00E+08	1111			18	31	4355	9.50E+05	4355
14	44	4354.3	1.00E+08	1111			19	31	4360	9.50E+05	4360
15	44	4354.3	1.00E+08	1111			20	31	4370	9.50E+05	4370
13	45	4380	1.00E+08	1111			17	32	4380	9.50E+05	4380
16	44	4360	1.00E+08	1111			18	32	4380	9.50E+05	4380
17	45	4380	1.00E+08	1111			17	32	4400	9.50E+05	4400

Table A2. Comparison of River Cells for SRPAM1.1 versus the USGS Model.

SRPAM					Segment		USGS Model				
Row	Column	Stage (elev)	Conductance	River Bottom	Number	Name	Row	Column	River altitude	Conductance	River Bottom
18	46	4400	1.00E+08	1111	8	At Blackfoot to near Blackfoot	17	34	4440	8.64E+05	4410
							17	35	4475	8.64E+05	4445
					9	Shelley to At Blackfoot	16	36	4500	1.12E+05	4470
							16	37	4530	1.12E+05	4530
							16	38	4560	1.12E+05	4530
							15	39	4600	1.12E+05	4570
		Non-Head Dependent			10	Lewisville to Shelley	15	40	4625	2.16E+05	4595
							14	41	4700	2.16E+05	4670
							11	42	4760	2.16E+05	4730
							12	42	4750	2.16E+05	4720
							13	42	4740	2.16E+05	4710
30	52	4760	5.00E+04	4730	11	Lorenzo to Lewisville	10	43	4770	2.16E+06	4740
31	52	4770	2.16E+06	4740			11	44	4800	2.16E+06	4770
32	53	4785	1.00E+06	4750							
31	54	4800	3.00E+06	4760							
32	55	4810	6.00E+07	4770							
31	55	4820	1.00E+07	4790							
31	56	4850	2.10E+05	4820	12	Heise to Lorenzo	12	45	4860	1.73E+05	4830
30	57	4900	2.10E+05	4870			13	46	4950	1.73E+05	4920
							14	46	4980	1.73E+05	4950
33	55	4810	6.05E+04	4780	13	Ashton to Roberts	10	46	4815	6.05E+04	4785
34	56	4820	3.00E+05	4785			10	45	4810	6.05E+04	4780
35	57	4835	3.00E+05	4800			10	47	4830	6.05E+04	4800
36	58	4870	1.50E+05	4830			10	48	4860	6.05E+04	4830
36	59	4920	1.50E+05	4880							
37	60	5000	3.00E+04	4970			10	49	4910	6.05E+04	4880
38	61	5080	3.00E+04	5050			10	50	5000	6.05E+04	4970
					14	Salmon Falls	8	3	3200	1.16E+05	3200
							9	2	3400	1.16E+05	3400

A3 shows a comparison of the modeled river reach gains and losses for both models as well as the target reach gains and losses for the USGS model.

COMPARISON OF RECHARGE/DISCHARGE FOR SRPAM1.1 VERSUS THE USGS SNAKE RIVER PLAIN MODEL

Head-independent recharge and discharge were compared for the SRPAM1.1 model versus the USGS Snake River Plain Model. The USGS model cells were aggregated into 40 zones, presented by Garabedian (1992), for the purpose of data presentation. The same zones were translated to the SRPAM1.1 model grid. Net recharge within each zone for each model was calculated, with some assumptions:

1. Recharge was not compared in zones where the model boundaries do not coincide (the King Hill, Twin Falls and Oakley Fan areas).
2. The difference in handling of the Snake River between the two models made comparison of zones with modeled river reaches difficult. Some reaches modeled as head-dependent in the USGS model are represented as specified seepage in SRPAM1.1. All zones are included in the comparison, however for zones containing river reaches the comparison may be less valid.
3. Grid orientation and spacing are unequal between the two models—therefore zone boundaries are inexact when translated to the SRPAM1.1 grid and comparisons are only approximate.
4. The USGS model uses both the Recharge and the Well package to input recharge. Recharge from these two packages was summed for the comparison with SRPAM1.1.

Table A3. Comparison of Simulated River Gains and Losses in SRPAM1.1 versus the USGS Model.

River Segment	**SRPAM1.1 Simulated River Gain or Loss (-) cfs**	**USGS Model Simulated River Gain or Loss (-) cfs**	**Measured River Gain or Loss (-)[1] cfs**
Henrys Fork, Ashton To Rexburg	130	30	120
South Fork, Heise to Lorenzo	-130	-180	-150
Snake River, Lorenzo to Lewisville	270	40	290
Snake River, Near Blackfoot to Neeley	2640	2640	2620
Snake River, Neeley to Minidoka	-110	20	180
Snake River, Milner to King Hill	5874	4030	6540

[1] from Garabedian (1992)

Figure A2 shows the USGS model zones overlain on the SRPAM1.1 model grid. Figure A3 shows both the USGS model recharge and the SRPAM1.1 recharge (repeated from Figure 19) mapped to the SRPAM1.1. Figure A3 was generated using the average annual recharge applied in the transient USGS model for the 1976-1980 time period and the 1980-81 calibration data set for the SRPAM1.1 model. Comparison of the two maps in Figure A3 shows that recharge for the two models is almost identically distributed, despite being derived using very different methods.

Figure A4 shows a scatter plot of recharge aggregated by USGS model zone for the two models. The line in Figure A4 is a line of equal recharge. Data points falling on the line represent zones where the USGS model recharge equals the SRPAM1.1 recharge. Data points falling to the right of the line represent zones where the USGS recharge is higher. Data points falling above the line represent zones where the SRPAM1.1 recharge is higher. With the exception of one zone (zone 17), the aggregated recharge for each zone is reasonably well centered around the line of equal recharge. Zone 17 represents the Heise area and includes many river cells, which may explain the difference in recharge between the two models. Table A4 lists the summed recharge by zone for the two models.

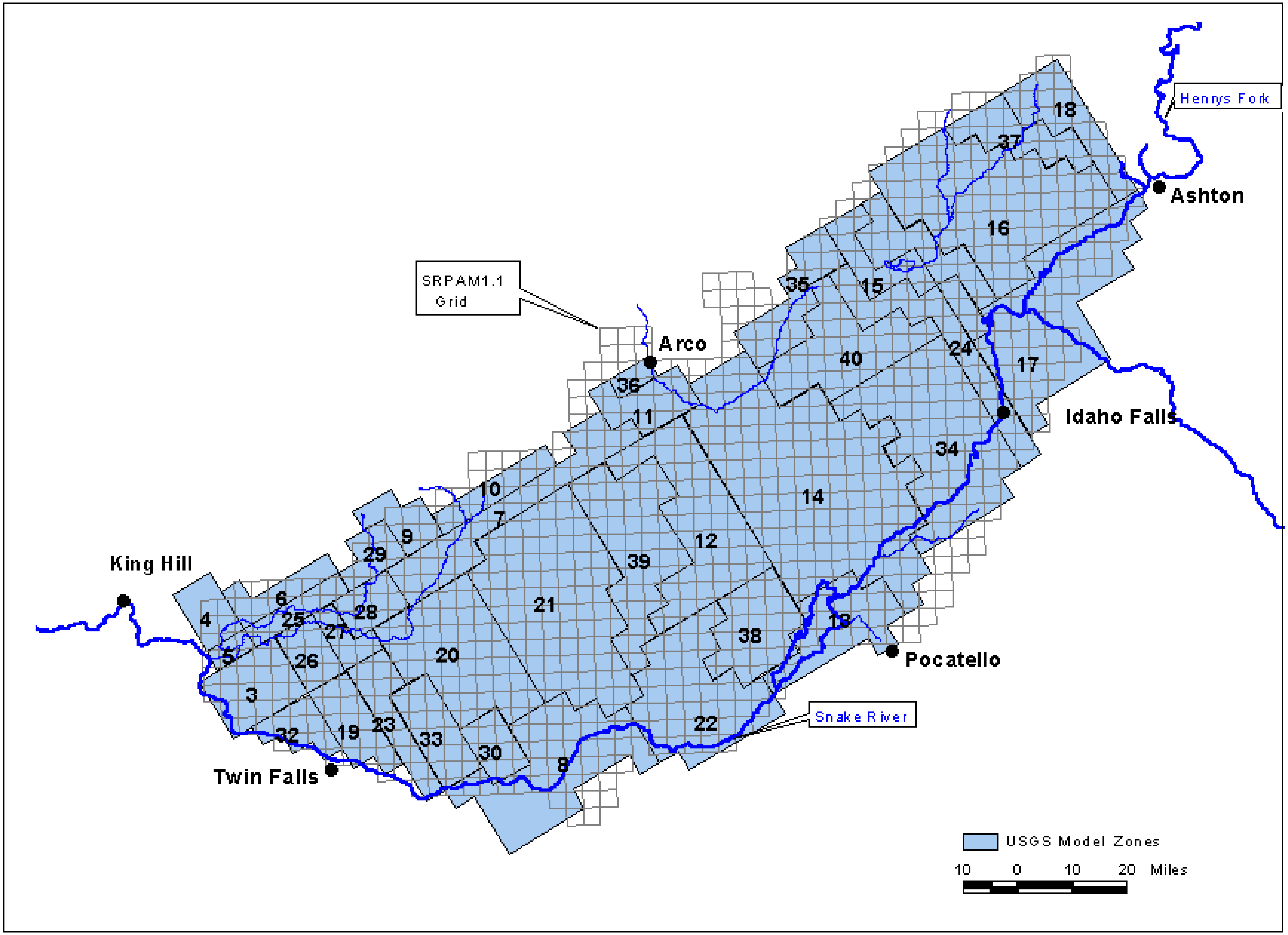
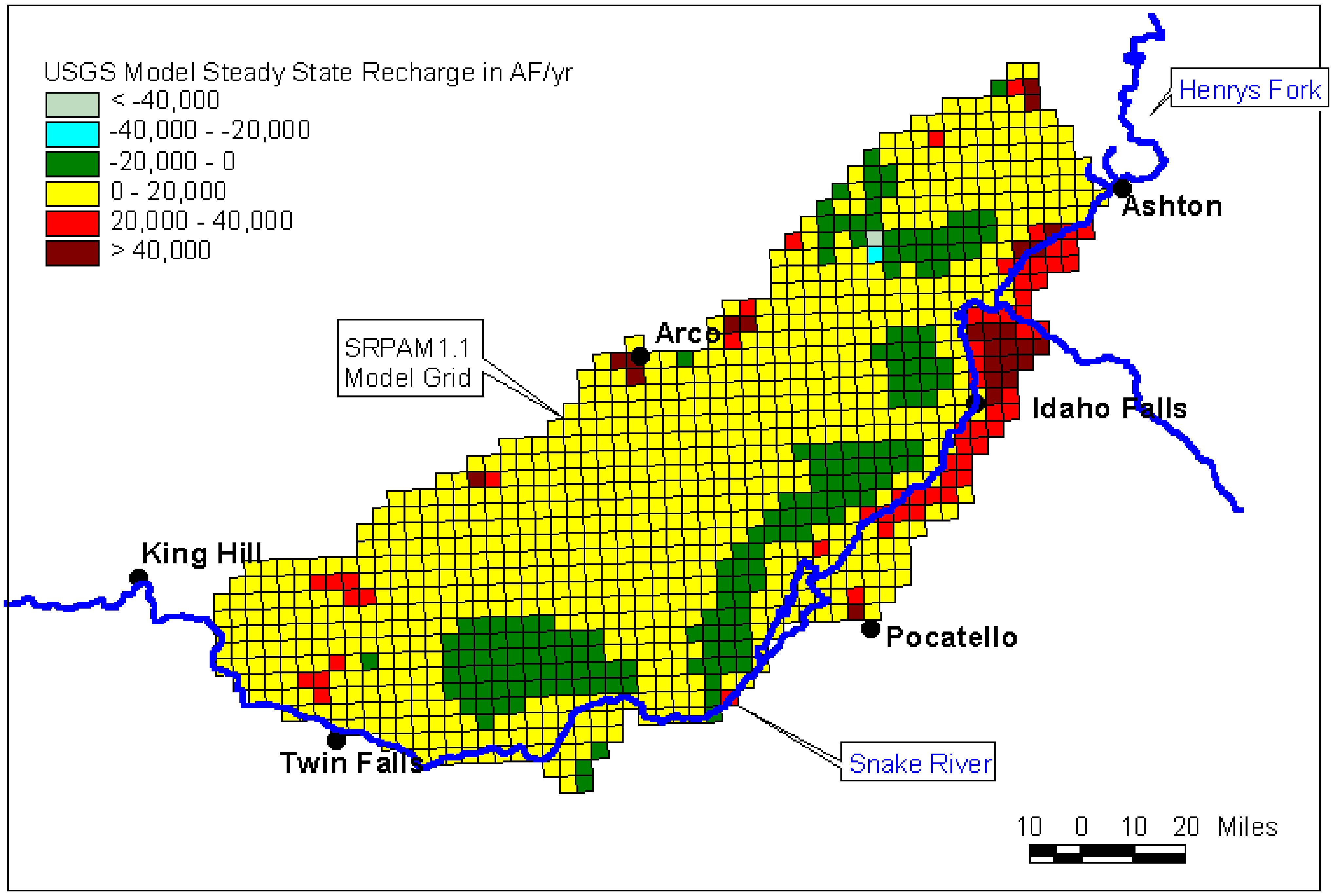
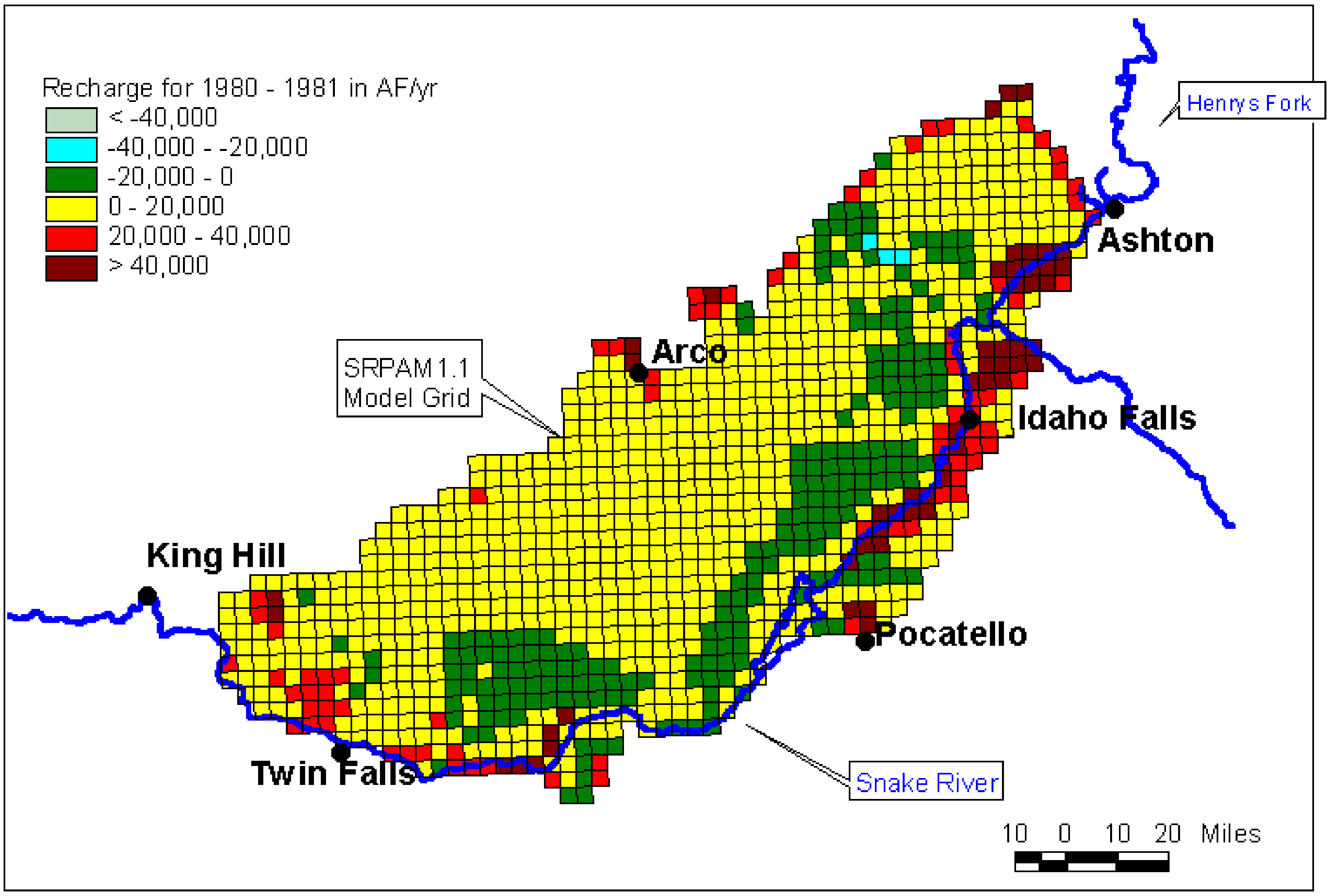


Figure A2. USGS Model Zones Overlain on SRPAM1.1 Model Grid.



USGS Model Recharge Mapped to SRPAM1.1 Model Grid.



SRPAM1.1 Model Recharge.

Figure A3. Areal Distribution of Head-Independent Recharge for the USGS and the SRPAM1.1 Models (1980 - 1981 Water Year).

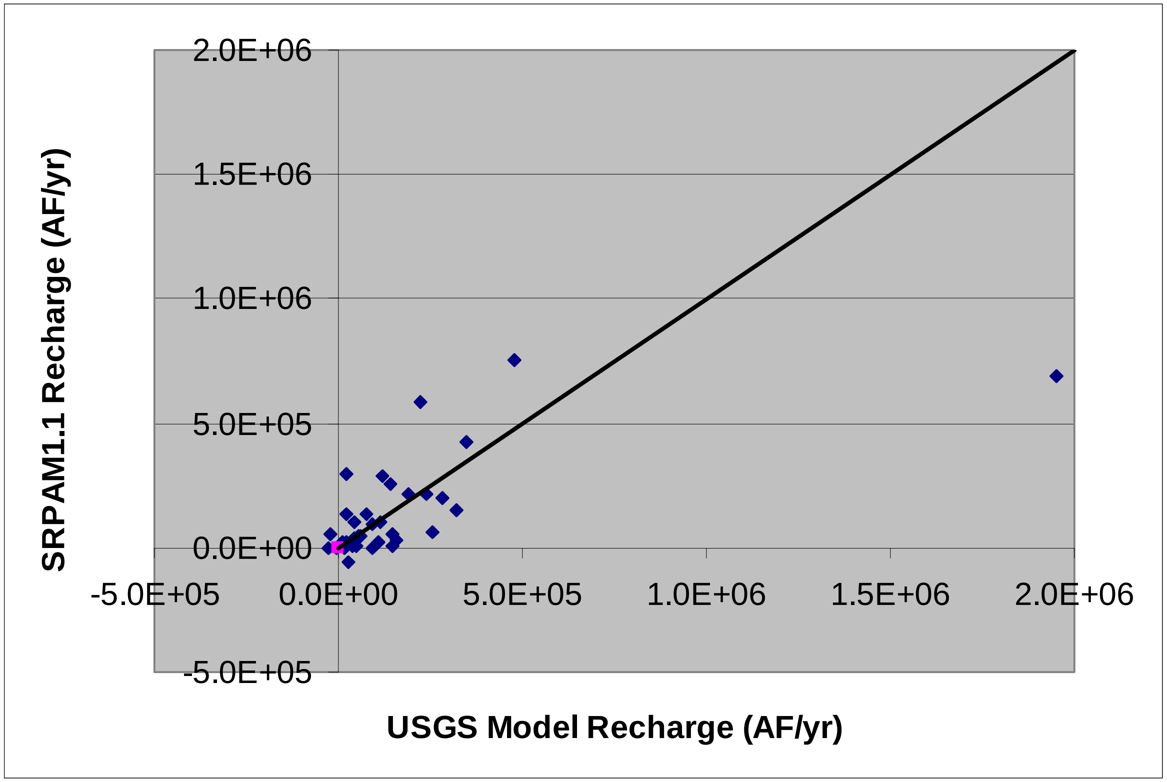


Figure A4. Scatter Plot of SRPAM1.1 Recharge Values versus the USGS Model 1976-1980 Average Annual Recharge.

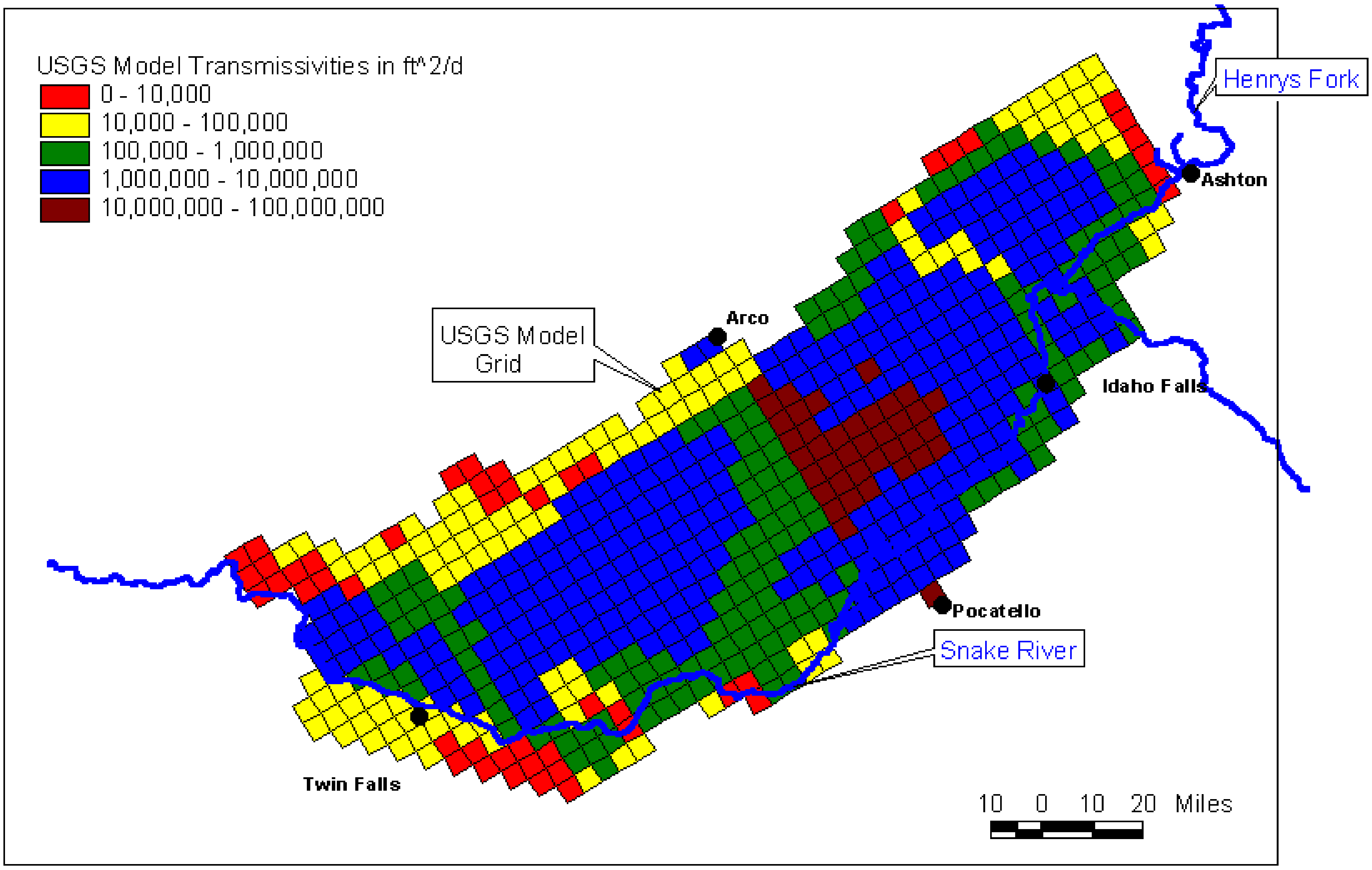
Table A4. Sum of Recharge by Zone for USGS Model vs. SRPAM1.1.

Zone	USGS Recharge (AF/yr)	SRPAM1.1 Recharge (AF/yr)
2	284389.7	195663.0
3	119737.4	286837.0
4	37740.6	6378.0
5	23652.1	138834.0
6	48853.5	2516.0
7	90503.6	97204.0
8	348280.4	425651.0
9	9476.9	23146.0
10	155986.7	28994.0
11	44705.2	103690.0
12	20466.7	19546.0
13	241205.0	213265.0
14	222353.1	588931.0
15	25208.8	-57373.0
16	144468.2	4614.0
17	1951808.7	687944.0
19	189491.8	212340.0
20	-5132.8	-5543.0
21	-26214.8	1864.0
22	92935.9	-3111.0
23	78369.8	131882.0
24	20539.1	293858.0
25	110043.5	20135.0
26	44097.0	41746.0
27	55079.6	44430.0
28	145184.9	58168.0
29	7261.4	13774.0
30	17042.2	-4818.0
31	-23724.5	55926.0
32	141398.7	252838.0
33	113902.3	102436.0
34	478450.0	751865.0
35	252723.4	62518.0
36	320306.0	149230.0
38	5299.5	8675.0
39	58054.9	50346.0
40	12474.1	3035.0

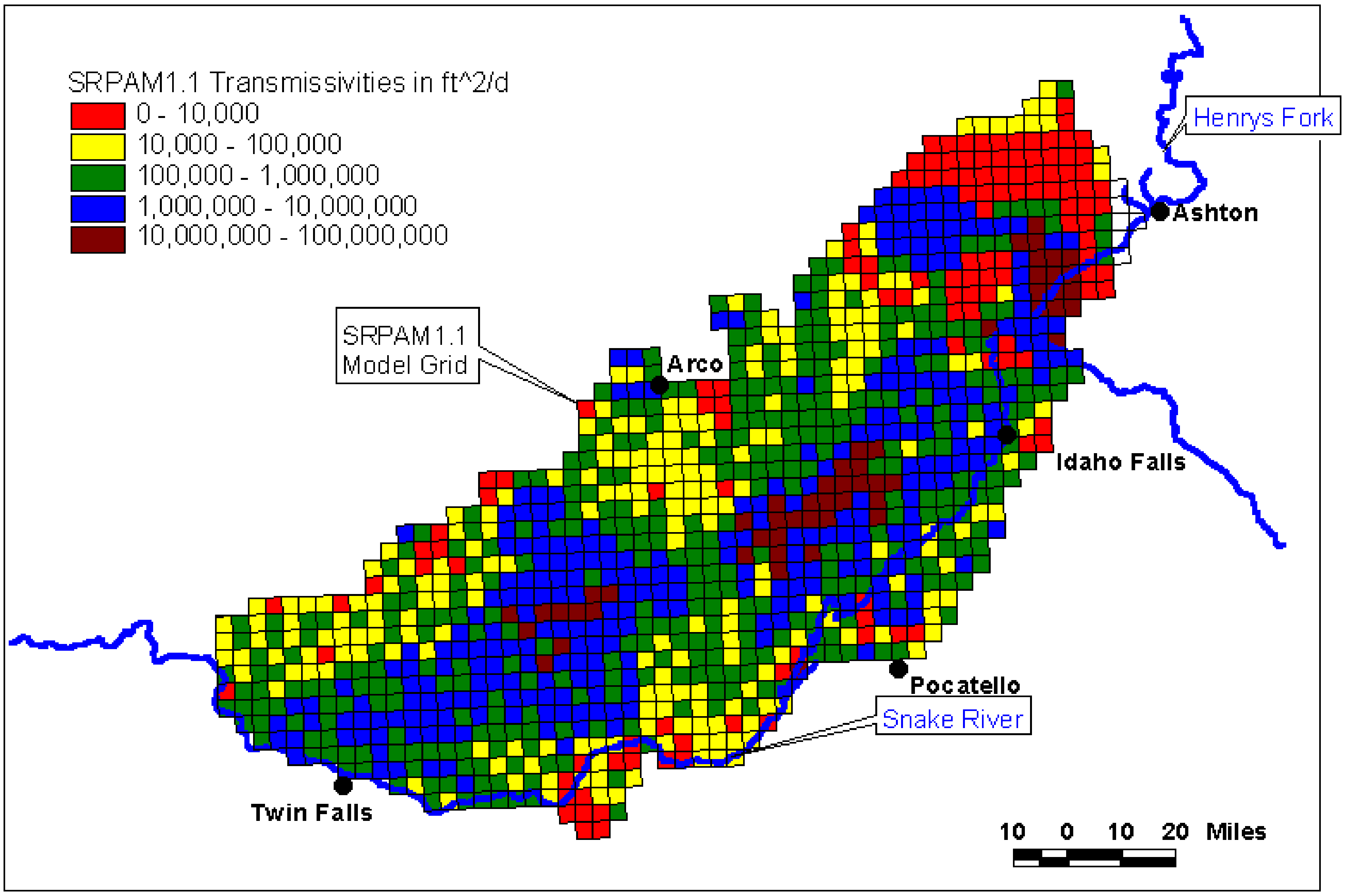
COMPARISON OF AQUIFER PROPERTIES FOR SRPAM1.1 VERSUS THE USGS SNAKE RIVER PLAIN MODEL

Transmissivities and specific yields were compared between SRPAM1.1 and the USGS Snake River Plain Model (Garabedian, 1992). Transmissivities for the unconfined layer in the USGS model were calculated by multiplying hydraulic conductivities by layer thickness. The transmissivities were then summed for the three transient USGS model layers. Figure A5 shows the areal distribution of transmissivities for the USGS model and for SRPAM1.1 (repeated from Figure 20). A comparison of the two maps in Figure A5 shows that transmissivities in the two models are similarly distributed across the Snake River Plain and are of similar magnitude. Both models were calibrated using measured water levels for the 1980-1981 time period, but using different calibration methods, yet the distribution of transmissivities is similar between the two models.

A zone-based comparison of transmissivity also is useful. Transmissivities were calculated and then averaged within the zones shown in Figure A2. Similarly, the hydraulic conductivities for the single, unconfined layer of SRPAM1.1 were multiplied by aquifer thickness to obtain transmissivities and averaged within each zone. Figure A6 shows a log-scale scatter plot of transmissivities for the USGS model versus SRPAM1.1. The diagonal line in Figure A6 represents a line of equal transmissivity (i.e. a data point falling on the line indicates that for that particular zone, the USGS model transmissivity and the SRPAM1.1 transmissivity are the same). The approximately equal distribution of points above and below the line of equal transmissivity indicates that neither model



USGS Model Transmissivities.



SRPAM1.1 Model Transmissivities.

Figure A5. Areal Distribution of Transmissivities for the USGS and SRPAM1.1 Models.

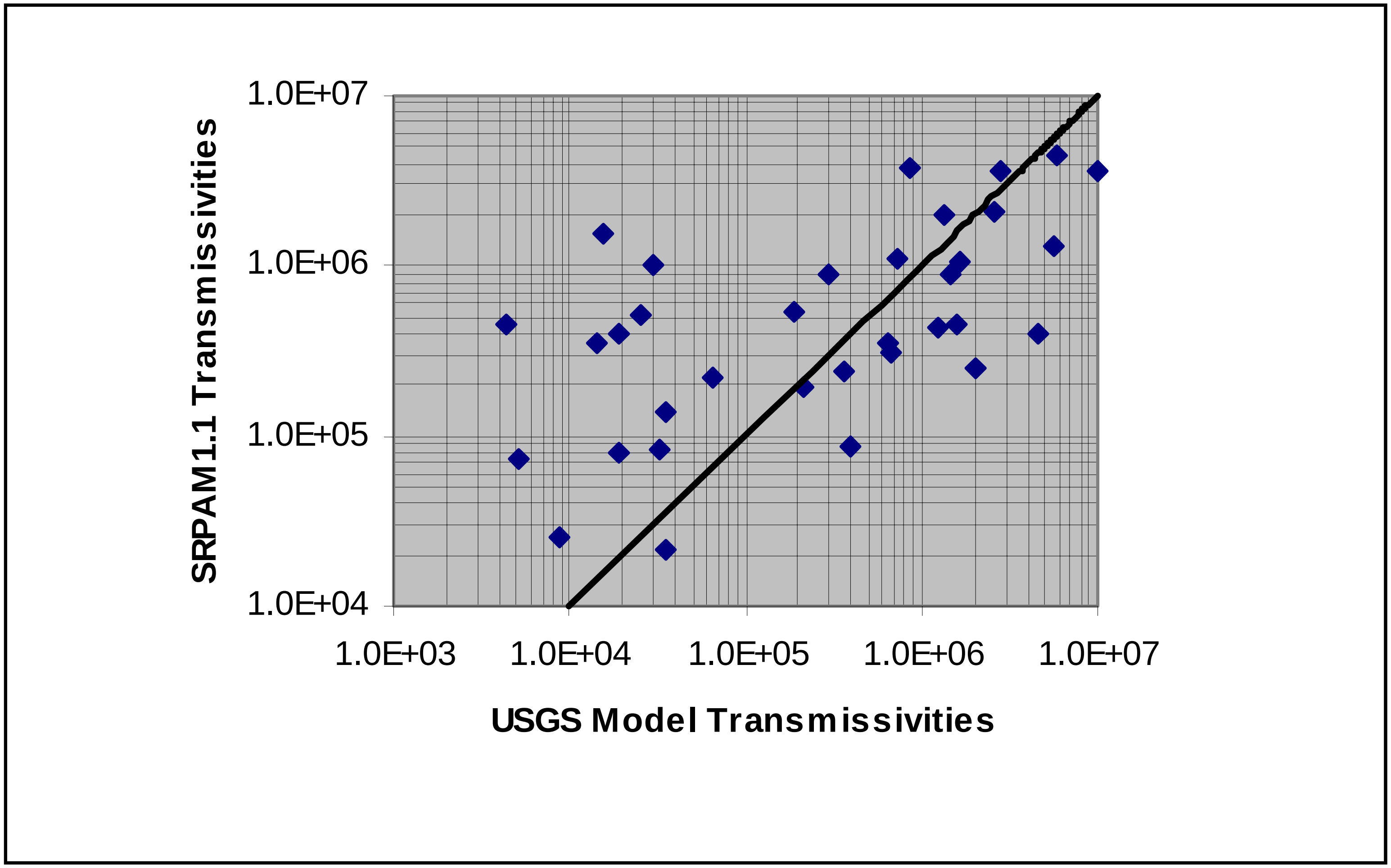
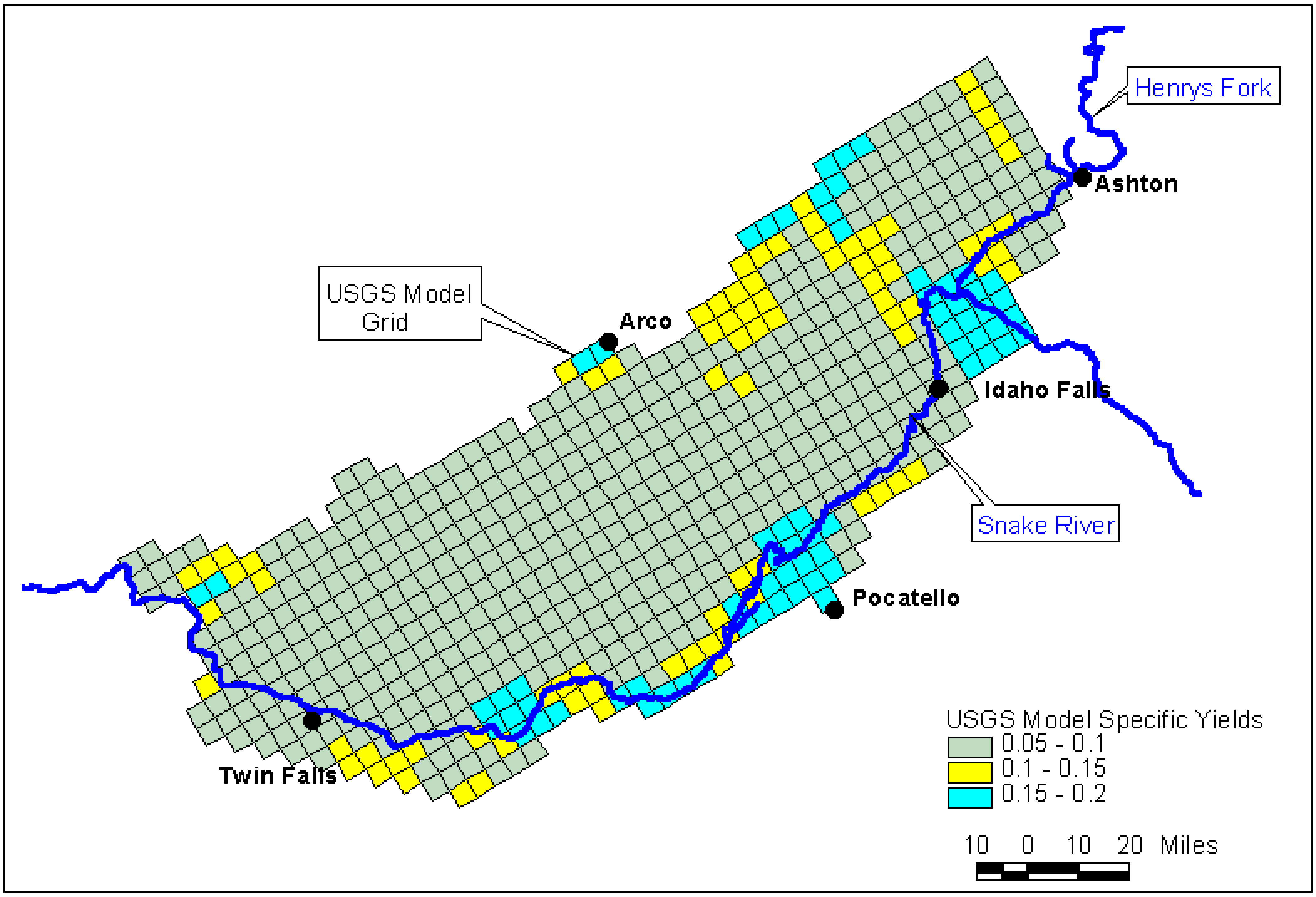


Figure A6. Log Scatter Plot of SRPAM1.1 Transmissivities versus the USGS Model Transmissivities (ft^2/day).

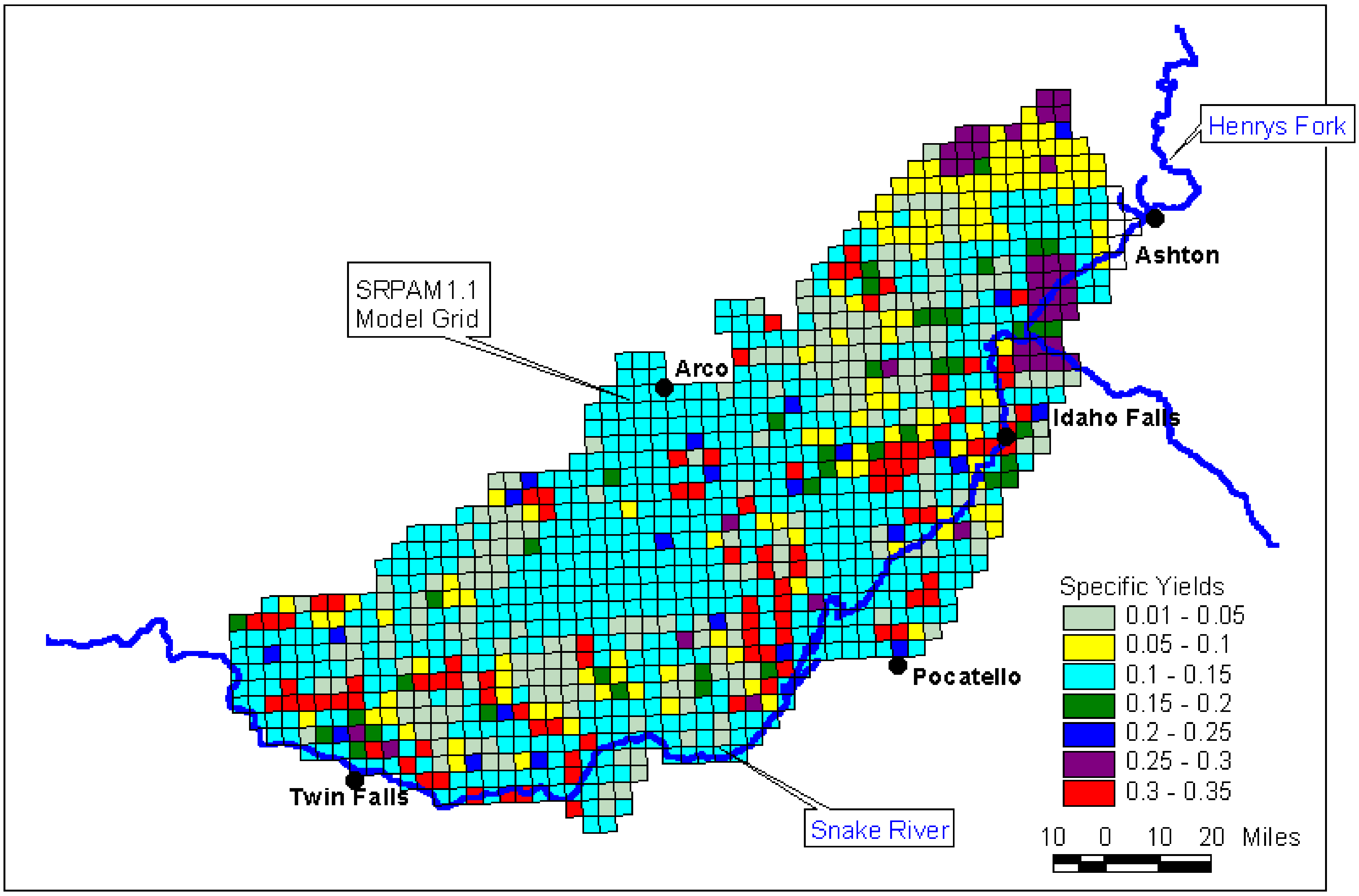
is particularly biased towards low or high transmissivities. Figure A6 does, however, show a great variation in the transmissivity values within each model, an expected condition for a regional model of a heterogeneous system such as the Snake River Plain aquifer.

Similarly, specific yields were compared for the two models. Figure A7 shows the areal distribution of specific yield values for the USGS and the SRPAM1.1 (repeated from Figure 21) models. Specific yields for both models were averaged for the 40 zones previously described. The specific yield for the upper-most, unconfined layer of the USGS model was compared with the specific yield for the SRPAM1.1. Figure A8 shows a scatter plot of the USGS model specific yields versus the SRPAM1.1 specific yields. The diagonal line represents the line of equal specific yield (i.e. any data point falling on the line indicates that for that particular zone, the USGS specific yield equals the SRPAM1.1 specific yield). The number of data points falling above the line indicates a bias towards higher specific yields in the SRPAM1.1 model. On the average, the specific yields in the SRPAM1.1 model are approximately 50% higher than the specific yields in the USGS model. Higher specific yields will cause the SRPAM1.1 model to store or release more water per unit change in aquifer water level. Figure A9 shows a histogram of specific yield values for the USGS Model. This figure is provided for comparison with Figure 22.

Comparison of these two figures also indicates a bias towards higher specific yields in the SRPAM1.1 model. Table A5 shows the average transmissivities and specific yields for the forty zones for both the SRPAM1.1 and the USGS models.



USGS Model Specific Yields.



SRPAM1.1 Specific Yields.

Figure A7. Areal Distribution of Specific Yields for the USGS Model and SRPAM1.1 Model.

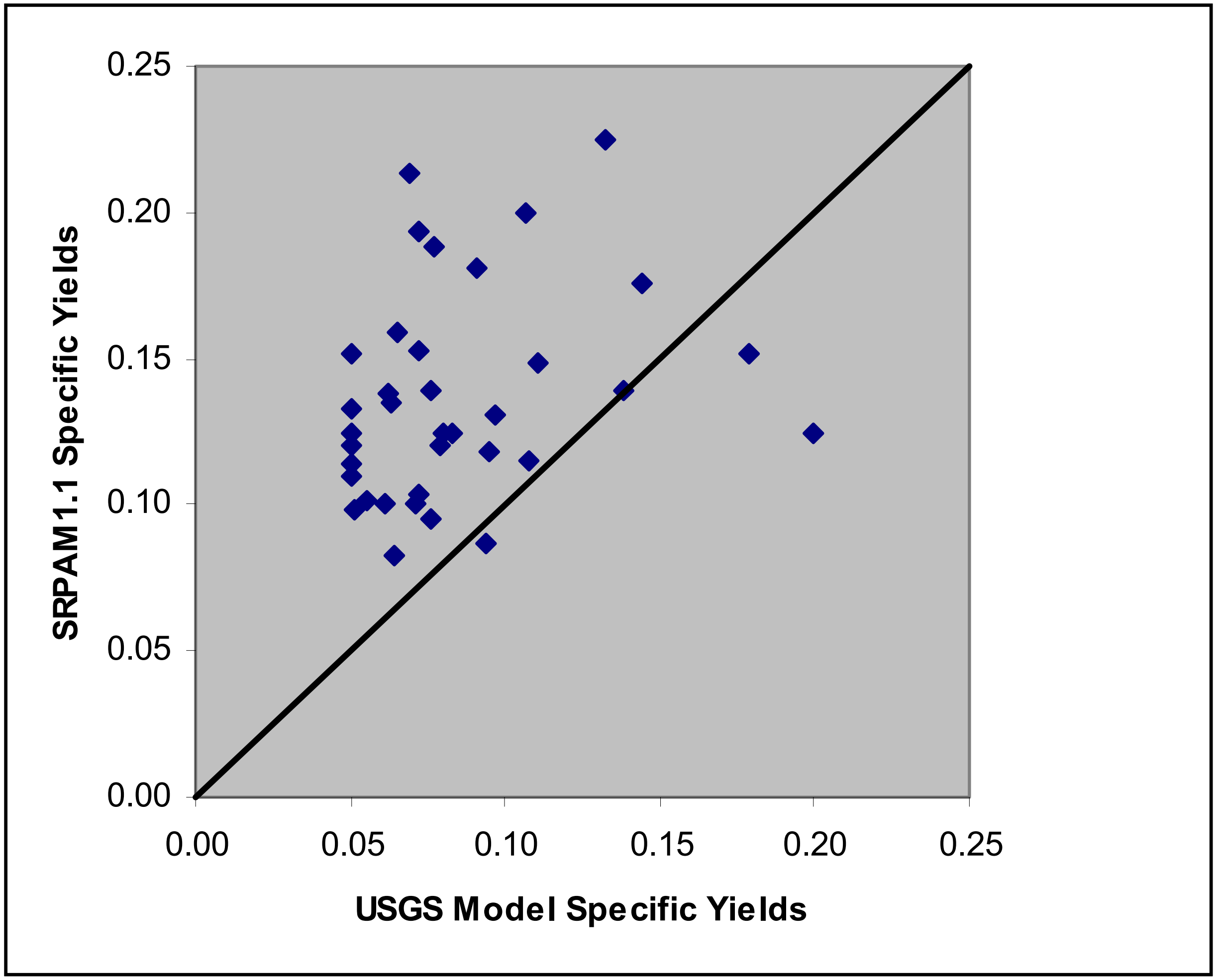


Figure A8. Scatter Plot of SRPAM1.1 Specific Yields versus USGS Model Specific Yields.

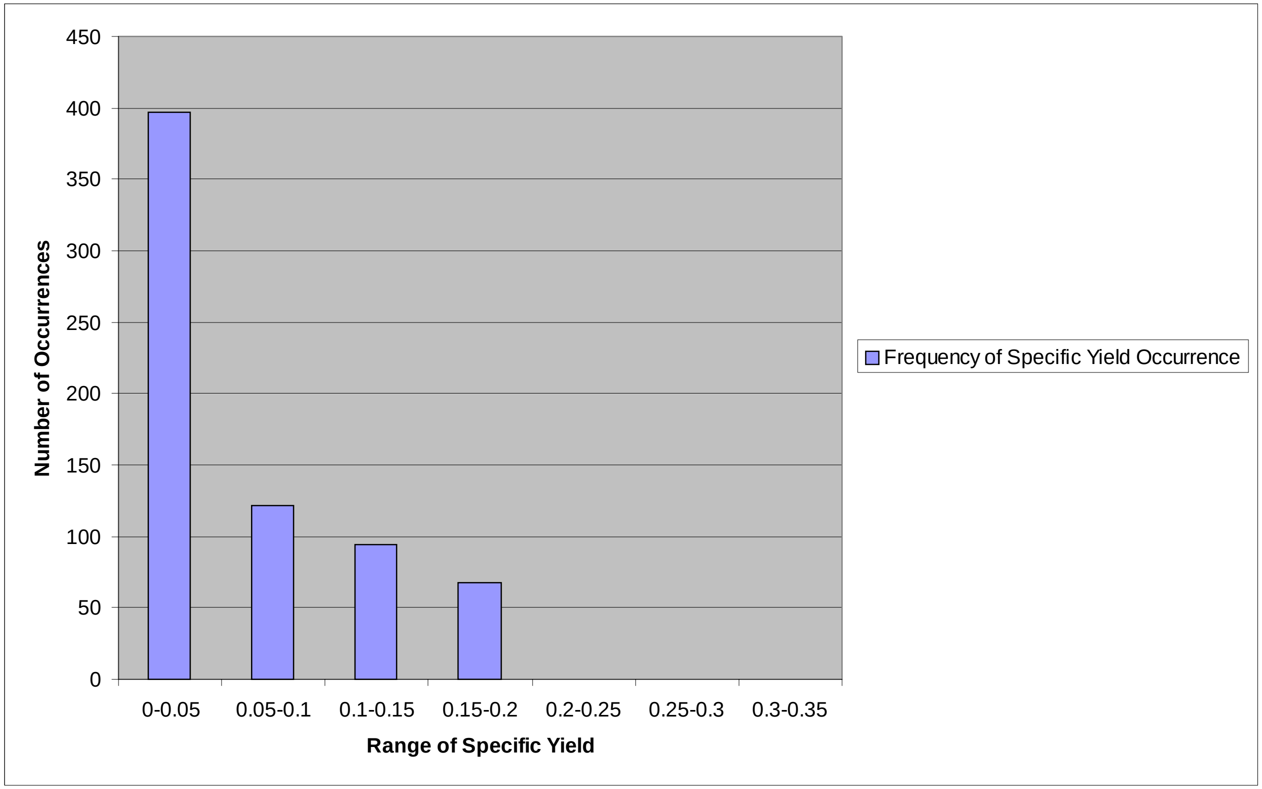


Figure A9. Histogram of Calibrated Specific Yields for USGS Model.

Table A5. Average Transmissivity and Specific Yield by Zone for USGS Model and SRPAM1.1.

Zone	USGS Model Average T	SRPAM1.1 Average T	USGS Model Average S	SRPAM1.1 Average S
2	15763.2	1517269.3	0.08	0.14
3	1458750.0	877321.7	0.07	0.16
4	8791.7	25593.3	0.13	0.22
5	1605000.0	448286.7	0.11	0.20
6	34519.2	21413.3	0.09	0.09
7	14385.7	353793.3	0.05	0.11
8	186675.4	537473.1	0.11	0.15
9	5071.6	72022.5	0.08	0.10
10	19175.8	78694.0	0.07	0.15
11	29647.4	1012044.0	0.08	0.13
12	290489.0	878928.1	0.05	0.15
13	4513341.1	399727.3	0.18	0.15
14	9842705.8	3672191.1	0.06	0.13
15	66087.9	220718.7	0.11	0.11
16	1215813.6	426152.2	0.07	0.10
17	673866.9	316048.3	0.14	0.18
19	2599473.3	2051280.0	0.07	0.19
20	1354483.8	1959910.2	0.05	0.11
21	5914849.4	4526596.4	0.05	0.12
22	216398.6	193312.1	0.10	0.12
23	718541.3	1087116.3	0.05	0.10
24	2032815.0	245672.5	0.10	0.13
25	35109.6	137976.7	0.08	0.26
26	641125.0	345094.4	0.07	0.10
27	388321.8	86588.3	0.06	0.10
28	32905.3	81870.0	0.06	0.10
29	18705.0	397925.0	0.08	0.13
30	25003.6	521565.0	0.08	0.12
31	4431.5	445472.5	0.09	0.18
32	869583.3	3734762.4	0.08	0.19
33	2759163.6	3687558.9	0.05	0.12
34	1675394.7	1064266.3	0.06	0.14
35	360216.4	237521.4	0.14	0.14
36	5598800.0	1305149.9	0.20	0.13
38	966950.3	488624.1	0.07	0.21
39	1451764.6	2029540.0	0.05	0.13
40	1618044.3	330801.0	0.06	0.08

CONCLUSION

Comparison of the SRPAM1.1 model parameters with the USGS Snake River Plain Model parameters demonstrates some degree of variability in modeling assumptions and calibrated values. However, comparison of the two models shows a high degree of similarity in the distribution of recharge, the calculated river gains and losses and the distribution of transmissivities, three properties which exert great control on modeling results. This high degree of similarity provides confidence that each model reflects a reasonably accurate representation of conditions within the modeled area. Further work should be done to understand what effect the differences exert on predictive results.

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