CONVERSION OF THE IDWR/UI GROUND WATER FLOW MODEL TO MODFLOW: THE SNAKE RIVER PLAIN AQUIFER MODEL (SRPAM)

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ABSTRACT

The ground-water flow model of the Snake River Plain aquifer developed and used by the Idaho Department of Water Resources (IDWR) and University of Idaho has been modified and calibrated several times since its creation in the 1970s. This report documents another step in the evolution of this model.

The most recent changes to the model include the conversion from a specially developed model code to the U.S. Geological Survey's MODFLOW code and an extension of the model domain to include the northeast corner of the Snake River Plain aquifer. Comparison of simulation results for the April 1980 through March 1981 period verified that the conversion to MODFLOW did not change any significant features of the model and that the previous model generated reproducible results. The equivalent model adapted to the MODFLOW code allows for easier and wider use among scientists and facilitates application of commercial user interfaces and provides greater opportunities for model enhancement.

Extension of the model domain to the northeast allows the inclusion of reaches of the Snake River that were previously not simulated. The introduction of 110 new model cells required that a localized calibration be performed that was consistent with the 1997 calibration of the previous model domain. A localized transient calibration was performed to the April 1980 through March 1981 period. The calibrated model replicated river gains and losses in the northeast portion of the model well; however, differences in simulated and measured aquifer heads were relatively large in some areas. Part of the difference is attributed to uncertainties in estimates of initial aquifer head and inconsistencies with the understanding of river gains and losses.

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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 underlain by the Snake River Plain aquifer (Figure 1), which is a source for nearly all municipal, domestic, irrigation, aquaculture, and industrial uses.

Several 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 IDWR and the U.S. Bureau of Reclamation (deSonneville, 1974). The model has undergone multiple revisions and improvements. This report, together with Cosgrove 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 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 numerical code. The application of MODFLOW 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 many benefits from conversion to the MODFLOW

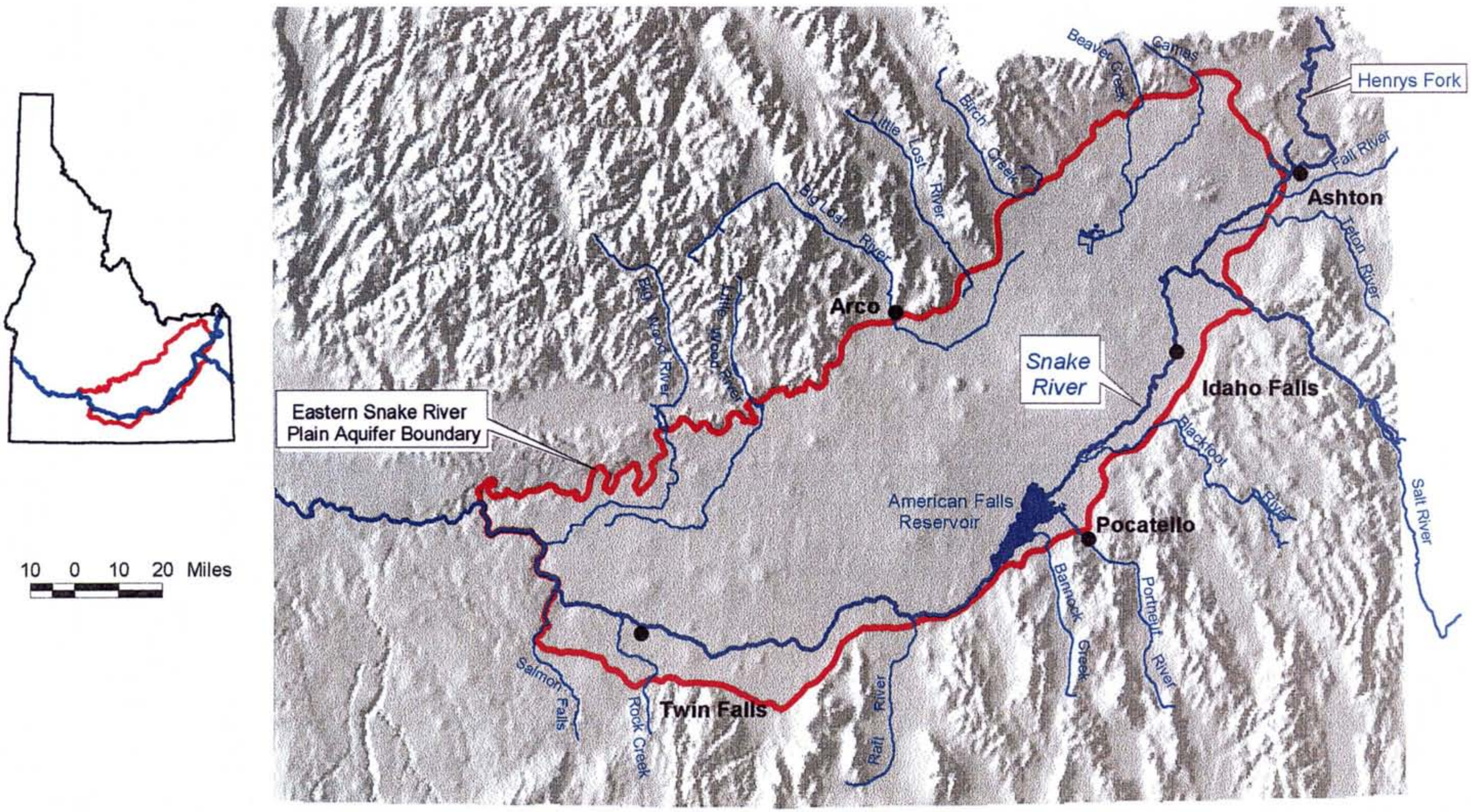

Figure 1. Map of the Snake River Plain.

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 converting 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 parts of the Snake River and tributaries in the northeast portion of the plain that were not simulated previously.

This report is one of two reports documenting work done on this project. This report documents the conversion of the IDWR/UI Ground Water Flow Model to MODFLOW, the expansion of the model domain to include the Henrys Fork (locally referred to as the North Fork) and Snake River above Lorenzo (locally referred to as the South Fork), and the localized calibration of the extended model. A companion report, "Description of the Snake River Plain Aquifer Model (SRPAM)" (Cosgrove and others, 1999), provides a more comprehensive documentation of the SRPAM model, along with comparisons between the SRPAM model and the USGS Snake River Plain Model.

These reports are the result of a combined effort of the U.S. Bureau of Reclamation, the University of Idaho, and IDWR. 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 refinement is strongly encouraged by the authors and specific 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 the project described in this report was to improve capabilities and documentation of the IDWR/UI Ground Water Flow Model. Objectives include:

1) Convert the model to the MODFLOW code,
2) Verify that the MODFLOW model creates no significant changes in model results from the previous model,
3) Modify the model to include the area around the Henrys Fork and the South Fork,
4) Provide the IDWR and USBR with a model that both agencies accept as suitable for planning and management,
5) Improve model documentation.

Development of the SRPAM is part of the continuing effort to improve water management and modeling capabilities on the eastern Snake River Plain. Additional improvements are anticipated as funding and further information become available.

This project was conducted as part of the U.S. Bureau of Reclamation's Snake River Resources Review project. This project is attempting to identify all of the interests in the Snake River and develop an array of tools that will help to describe the impact of river management decisions on the various interests. The inclusion of ground-water components in the program is in response to the increasing awareness of the interaction of ground water and surface water. The converted model (SRPAM) described in these reports will subsequently be used to develop analytical expressions (response functions) relating aquifer recharge and discharge at specific locations to river gains and/or losses in the Snake River. It is anticipated that these response functions will become elements of the array of water management tools forming the decision support system being developed under the Snake River Resources Review project. These products also will provide a means to further educate the public on surface- and ground-water relationships and can be used by IDWR and local water management agencies to develop resource management plans for 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-water 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 IDWR will increasingly be called upon to arbitrate in conjunctive management disputes and to evaluate mitigation plans. The IDWR also is engaged in planning managed recharge efforts on the eastern 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.

PREVIOUS MODEL DEVELOPMENT

INTRODUCTION

This section discusses the background of modeling on the eastern Snake River Plain and the salient features of the IDWR/UI Ground Water Flow Model Code. This background is presented to provide the reader with an understanding of the context in which the current model came to exist.

SNAKE RIVER PLAIN AQUIFER MODELING HISTORY

The first numerical model of the Snake River Plain aquifer was developed by the University of Idaho for the IDWR and the U.S. Bureau of Reclamation (deSonneville, 1974). This model subsequently evolved into a planning model used by the IDWR (Newton, 1978; Johnson and others, 1985; Johnson and Brockway, 1983; IDWR, 1997) and is currently referred to as the IDWR/UI Ground Water Flow Model. The model has been re-calibrated several times, most recently to the one-year period from April, 1980 through March, 1981 (IDWR, 1997). This calibration used the intensive water level measurements available from the U.S. Geological Survey's Regional Aquifer-System Analysis (RASA) program together with improved remote sensing information analyzed by the IDWR to determine the distribution of irrigation (land use). Transient calibration was conducted in 24 timesteps of 15.2 days duration for a simulation period of one year. Aquifer water levels and spring flows were compared to measured values at the 11th and 24th timesteps (mid-September and late March). The calibration and characteristics of the model are described more completely in IDWR (1997). This model served as the basis for the development of the new version referred to as the Snake River Plain Aquifer Model (SRPAM). Additional details on the model code and model limitations are provided in following sections.

The U.S. Geological Survey made major contributions to the understanding of the aquifer and the water resources of the eastern Snake River Plain with the RASA program in the 1980s. This program included the development by the U.S. Geological Survey of a three-dimensional flow model of the Snake River Plain aquifer (Garabedian, 1992). The

Idaho National Engineering and Environmental Laboratory, located on the eastern Snake River Plain, also has developed numerous flow and transport models.

Ground water flow models also have been developed for portions of the plain. Johnson and others (1984) developed a two-dimensional flow model for the Mud Lake area. Spinazola (1994) developed a three-dimensional steady state flow model for the Mud Lake area. Wytzes (1980) developed a numerical ground-water model for the Henrys Fork and Egin Bench area, also in the northeastern part of the eastern Snake River Plain. Models of the Oakley Fan and Twin Falls area have been developed by Young and Newton (1989) and Cosgrove and others (1997), respectively. A ground water flow model currently is being developed by the University of Idaho for the Silver Creek drainage, south of Ketchum (oral communication with C. Robison, 1999).

IDWR/UI Ground Water Flow Model Code

The IDWR/UI Ground Water Flow Model Code was developed and first applied in the late 1970s to early 1980s. deSonneville (1974) developed the original Fortran code of the IDWR/UI Ground Water Flow Model Code. The code later was modified by University of Idaho hydrologists to expand the general modeling capabilities and to make the model easier to use.

The governing equations of the IDWR/UI Ground Water Flow Model Code are the same as those applied by MODFLOW, based upon the partial differential equations describing two-dimensional ground-water flow. The IDWR/UI Ground Water Flow Model uses a numerical solver called the iterative alternating-direction implicit solution to the finite difference approximation of the partial differential equation for ground-water flow (Bennett, 1976). Inter-block transmissivities are averaged using a logarithmic mean identical to the logarithmic mean available in the MODFLOW BCF-3 package. By contrast, most ground-water models, including the USGS Snake River Plain Model (Garabedian, 1992), use a harmonic mean for averaging inter-block transmissivities. The logarithmic mean behaves nearly the same as the harmonic mean except when the difference between inter-cell transmissivities is large. In these situations, the harmonic mean is significantly less than the logarithmic mean. The logarithmic averaging technique was initially implemented to improve the representation of inter-cell flow.

The IDWR/UI Ground Water Flow Model Code enables representation of head-dependent drains and hydraulically connected river reaches. The IDWR/UI Ground Water Flow Model Code has an option for model calibration that employs a parameter estimation routine that can be used to develop estimates of hydraulic conductivity, storativity and/or leakage parameters. The calibration option attempts to minimize the sum of squares of differences between target and simulated heads by adjusting model parameters. The calibration routine adjusts parameter values on a cell by cell basis.

The IDWR/UI Ground Water Flow Model Code is supported by the RECHARGE Program, a separate Fortran pre-processing program. The RECHARGE Program calculates net recharge to each model cell resulting from canal seepage, pumping withdrawals, deep percolation from irrigation, specified flux from river reaches which are not hydraulically connected, and tributary valley underflow. The magnitude of these elements is independent of aquifer water levels so they can be calculated independent of the numerical model and become input to the numerical model. The RECHARGE Program requires a comprehensive set of inputs including surface-water irrigated areas, crop distribution, climatological data, irrigation diversions and return flows, ground-water irrigated areas, canal wetted perimeter and length, seepage rates, precipitation rates, soil moisture capacity, tributary valley underflow rates, and river seepage characteristics. The RECHARGE Program calculates a net flux for each model cell for each stress period. Although setting up the inputs for the RECHARGE Program is time-consuming, the RECHARGE Program does provide a good method to process the wide range of data necessary to represent the net amount of water that must be specified into and out of each model cell. The RECHARGE Program is not Geographical Information System (GIS)-compatible and has limited capability for viewing the data. IDWR (1997) discusses some of the details of the calculation of recharge for the IDWR/UI Ground Water Flow Model. The reader is referred to the authors of that report for additional details regarding the calculation of recharge. Concepts and outdated input descriptions of the UI/IDWR Ground Water Flow Model Code and the RECHARGE Program are provided in Johnson and Brockway (1983).

LIMITATIONS OF THE IDWR/UI GROUND WATER FLOW MODEL

INTRODUCTION

It should be understood that a ground-water model of an area is a continually evolving tool to aid in understanding and simulating a ground-water system. All models are constrained by limitations in capabilities and, more significantly, by our understanding of the flow system. These limitations are never eliminated but may be reduced by continued effort. The limitations of the IDWR/UI Ground Water Flow Model and its application to the Snake River Plain aquifer that are presented in this section are not a criticism of previous work. The limitations are an expression of the current state of evolution of the model. The most significant limitations provided the incentive to embark on the next phase of evolution represented by this project. This project also is intended to be only one stage in the continued model evolution.

MODEL CODE LIMITATIONS

The IDWR/UI Ground Water Flow Model Code has several limitations that were deemed significant enough to warrant change to a new model code. These limitations do not necessarily adversely affect the current model applications but are likely to affect future requirements and applications of the code.

- The code is limited to two-dimensional flow. This limitation precludes development of multiple model layers. Although multiple layers were not used for the SRPAM in this project, it is likely that future versions of the Snake River Plain Aquifer Model will include multiple layers.
- The model is limited to a uniform grid size. The current changes to the Snake River Plain Aquifer Model do not require non-uniform spacing; however, this feature is likely to be needed in the future as hydrologic properties of specific areas become more well defined or specific areas require a finer resolution of analysis to address management or planning questions.
- The IDWR/UI Ground Water Flow Model Code has limited capabilities of representing head-dependent features (where flow to or from the aquifer is related to aquifer water level) such as rivers, springs, and boundaries. More recent ground-

water modeling codes, such as MODFLOW, provide opportunities to represent a wider variety of flow processes through head-dependent features.

- The credibility of the model code has not been established by use outside of the Snake River Plain aquifer.
- The model has not been developed or compiled to run on multiple computer platforms. It also has no compatibility with modern graphical user interfaces.
- The numerical solver within the IDWR/UI Ground Water Flow Model Code is valid; however, it may lack the capabilities provided by the multiple solvers available with codes such as MODFLOW.

Because of these limitations, it was decided to convert the existing model of the Snake River Plain aquifer to the MODFLOW code. The hydrologic properties represented in the existing IDWR/UI Ground Water Flow Model were not changed in the process. A description of the conversion and the verification is provided in a later section of this report.

LIMITATIONS OF THE APPLICATION TO THE SNAKE RIVER PLAIN AQUIFER

All model applications are imperfect representations of processes that function in the real world, and, therefore, they can always 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 the IDWR/UI Ground Water Flow Model and provides additional detail on those limitations that were addressed as part of this effort.

- The model does not simulate the appropriate interconnection of all surface and ground water. The areas in which there is probably significant interconnection of surface and ground water that is not treated by the model include:
    1. the Henrys Fork from Ashton to the confluence with the South Fork,
    2. the South Fork from Heise to the confluence with the Henrys Fork,
    3. the Snake River from the confluence of the Henrys and South Forks to Lewisville,
    4. the Snake River from Shelley to the At Blackfoot gage, and
    5. 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 2 shows the IDWR/UI Ground Water Flow Model grid (non-shaded cells) and the conformance to the RASA-defined boundary of the aquifer. The initial development of the IDWR/UI Ground Water Flow Model preceded the RASA work and, consequently, should not be expected to exactly duplicate the RASA-defined boundary. The Snake River Plain aquifer model developed by the U.S. Geological Survey (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 the IDWR/UI Ground Water Flow Model are of little regional significance and do not represent a need to adjust location of the model boundary. Differences in three areas deserve discussion: 1) The extreme western end near King Hill, 2) the area south of the Snake River near Twin Falls and Burley, and 3) the northeast end of the area, along and north of the Henrys Fork of the Snake River. These areas are discussed below.

  On the extreme western end of the model domain (Figure 2), the RASA-defined boundary extends about 12 miles further west than the IDWR/UI Ground Water Flow Model boundary. This area includes a length of the Snake River. Aquifer discharge along this length is, however, 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 westernmost extent of the IDWR/UI Ground Water Flow 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 IDWR/UI Ground Water Flow Model to the west. Additionally, there is little irrigated acreage in this area, also not warranting inclusion in the IDWR/UI Ground Water Flow Model.

  The RASA boundary extends south of the Snake River in the area near Twin Falls and Burley in contrast to the IDWR/UI Ground Water Flow Model which is bounded by the Snake River in this area. Downstream from Milner Dam (below Burley) the

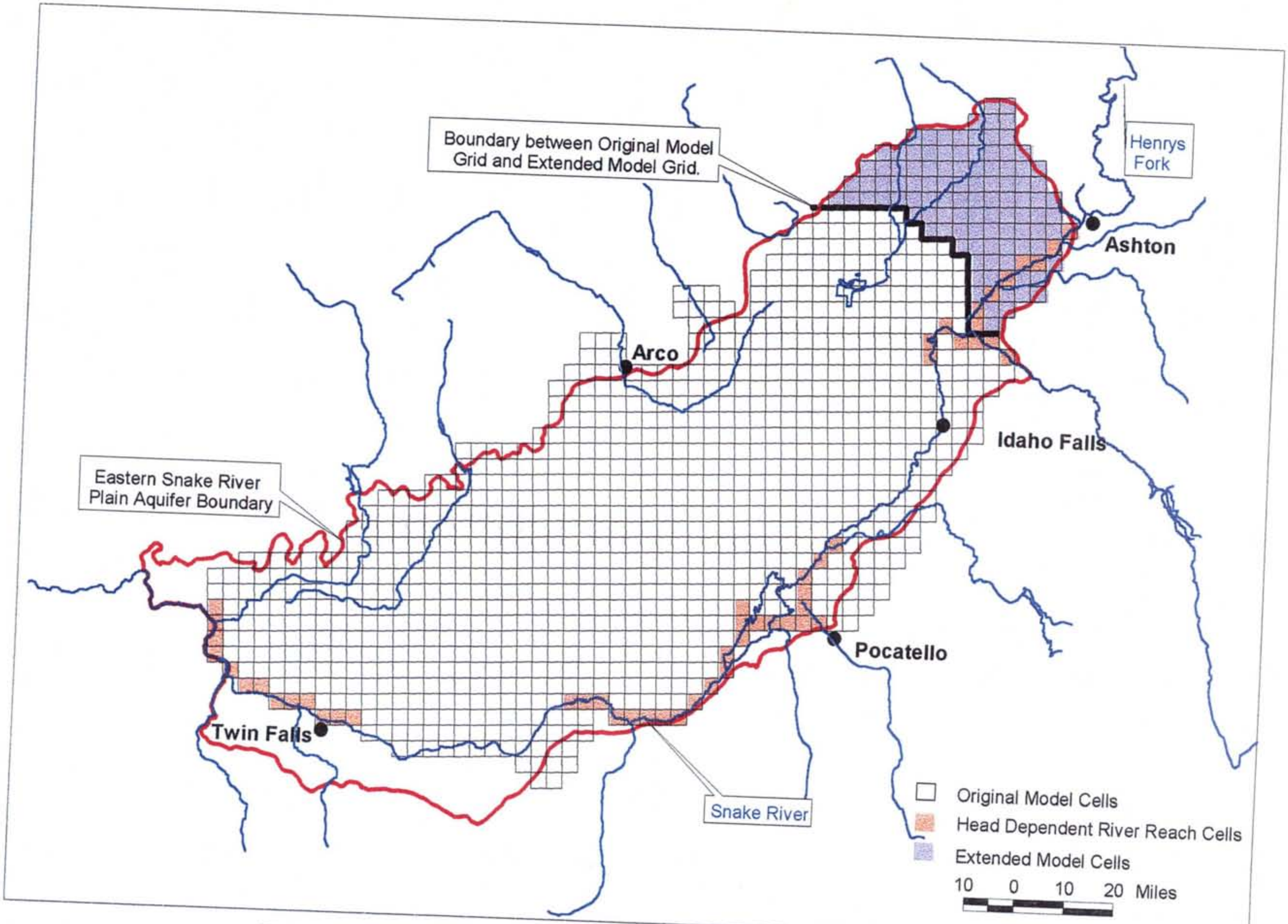

Figure 2. IDWR/UI Ground Water Flow Model Grid and RASA Boundary.

Snake River flows through a deeply incised canyon that likely separates aquifers on the north and south sides of the river. Ground-water communication beneath the river is thought to be negligible in this reach (Cosgrove and others, 1997). The Twin Falls area is hydrologically isolated by the canyon and presents no urgent need for appending to the IDWR/UI Ground Water Flow 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 throughout the Snake River Plain aquifer. The IDWR/UI Ground Water Flow Model boundary assigns a fixed rate of tributary valley 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 true, simulation conditions are similar for many of the tributary valleys. Changes to conditions in the Oakley Fan that would change tributary valley underflow could be accommodated by adjusting the tributary valley underflow value specified in the IDWR/UI Ground Water Flow Model. 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 basin-wide changes in water management.

In the northeast portion of the model area, the RASA boundary of the eastern Snake River Plain extends approximately 30 miles beyond the boundary of the IDWR/UI Ground Water Flow Model. This area includes the South and Henrys Forks of the Snake River. In much of the area, the rivers are hydraulically connected with the aquifer (or an overlying aquifer) and are a significant feature of the system. The IDWR/UI Ground Water Flow Model includes interactions with the Henrys Fork as analytical expressions relating boundary flux to simulated heads. A more thorough treatment of this area will improve the model capability of simulating interaction between the aquifer and rivers. SRPAM boundaries have been extended to approximately coincide with RASA-determined boundaries of the Snake River Plain aquifer including reaches of the Henrys Fork, the South Fork and the Teton Rivers (shaded cells in Figure 2).

Additional limitations include:

- 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 further data collection.
- Aquifer characteristics near the Snake River have a significant influence on model results. The understanding of the interactions should be improved and the corresponding model features should be updated.
- 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.
- Other limitations exist relative to current knowledge of aquifer bottom, confined and unconfined conditions, non-laminar flow, recharge and discharge distribution, and other factors.

This project addressed those limitations that were considered most significant to evaluating ground-water interactions with the Snake River. The first and second limitations were at least partially addressed by extending the model area to the RASA-defined boundary in the northeast. The extended domain includes hydraulically connected reaches of the Snake River: the South Fork and the Henrys Fork. Prior to expanding the domain, the model was converted to the MODFLOW code. Many of the other limitations remain and are discussed in the *RECOMMENDATIONS* section.

CONVERSION TO THE MODFLOW CODE

General Procedure

Data sets used in the IDWR/UI Ground Water Flow Model were converted to use the MODFLOW code. The converted model was named the Snake River Plain Aquifer Model (SRPAM) to uniquely identify it from previous additions and modifications. A model version number was also appended to the name to indicate the level of implemented changes. For example, SRPAM1.0 refers to a conversion of the IDWR/UI Ground Water Flow Model to the MODFLOW code with no changes in the model. It is essentially the same model as the earlier IDWR/UI Ground Water Flow Model. The same features in the IDWR/UI Ground Water Flow Model were employed in MODFLOW to provide the same mathematical representation. SRPAM1.1 is a subsequent version in which the model domain has been extended to more closely match RASA-defined boundaries of the Snake River Plain aquifer in the northeast part of the plain. This is part of the process of continually updating and evolving model applications.

This section discusses the model translation from the code developed by the University of Idaho (IDWR/UI Ground Water Flow Model) to MODFLOW 2.6 developed by the U.S. Geological Survey (McDonald and Harbaugh, 1988; Harbaugh, 1992; Hill, 1990; Prudic, 1989; Leake and Prudic, 1988; McDonald and others, 1992; Goode and Appel, 1992; Hsieh and Freckleton, 1993; Leake and others, 1994; Harbaugh, 1995; and Fenske and others, 1996). The following general procedures were involved in the conversion of the IDWR/UI Ground Water Flow Model to SRPAM1.0.

1. MODFLOW mechanisms and features equivalent to those used in the IDWR/UI Ground Water Flow Model were identified.
2. IDWR/UI Ground Water Flow Model data sets were converted to a format compatible with the MODFLOW code (version 2.6).
3. SRPAM1.0 results for the calibration year data (April 1980 through March 1981) were verified against corresponding results of the IDWR/UI Ground Water Flow Model.

The following sections individually address these procedures.

IDENTIFICATION OF EQUIVALENT FEATURES

The block-centered finite difference scheme of the IDWR/UI Ground Water Flow Model is similar to that of MODFLOW, making the translation between model codes relatively direct. Model features and the mathematical equations representing those features are quite similar in both models. MODFLOW includes several options not found in the IDWR/UI Ground Water Flow Model Code; however, uniformity between the codes was maintained by using only those MODFLOW features equivalent to features used in the IDWR/UI Ground Water Flow Model Code. Some differences between the IDWR/UI Ground Water Flow Model Code and MODFLOW warrant discussion.

Both model codes utilize the basic structure of a block-centered finite-difference code. A logarithmic function is used in the IDWR/UI Ground Water Flow Model Code to calculate average inter-block transmissivity. In contrast, most other model applications use the harmonic mean to determine average inter-block transmissivity. This method was the only option available in the original version of MODFLOW. However, MODFLOW routines (BCF package) have been modified in recent years to include an optional logarithmic averaging method (Goode and Appel, 1992) that is identical to that employed by the IDWR/UI Ground Water Flow Model. The revision is included in the BCF3 package that replaces the original MODFLOW BCF package. MODFLOW interblock averaging of aquifer transmissivity is identical to that of the IDWR/UI Ground Water Flow Model when parameters LAYAVG=20 and LAYCON=21 are set in the BCF3 package.

Several numerical solution algorithms are available in the MODFLOW code: the Strongly Implicit Procedure, Slice-Successive Over-Relaxation, and the Preconditioned Conjugate-Gradient Solver. The IDWR/UI Ground Water Flow Model uses an iterative, alternating-direction implicit solution to the finite-difference approximation of the partial differential equation for ground-water flow described by Bennett (1976). The solution methods of both models are legitimate; the primary difference may be in the rate of convergence to a solution. SRPAM versions 1.0 and 1.1 use the SIP solver; however, choice of the solver should have a negligible effect on results.

Time discretization is handled somewhat differently between model codes. Time in the IDWR/UI Ground Water Flow Model is discretized into timesteps. Ground-water elevations for fixed-head nodes and recharge/discharge nodes are constant during a timestep but can vary from one timestep to the next. Aquifer head is calculated at the end of each timestep. Terminology is somewhat different in MODFLOW. MODFLOW discretizes time into timesteps and stress periods. Fixed-head elevations (e.g. river stage) and recharge and discharge are allowed to vary from one stress period to the next. Stress periods may be subdivided into timesteps in which case aquifer head is calculated at the end of each timestep. No variations in recharge and discharge or fixed head features are permitted between timesteps within a stress period. The stress periods in SRPAM1.0 and SRPAM1.1 are 15.2 days in duration, identical to the timestep of the IDWR/UI Ground Water Flow Model. For convenience, the term "stress period" will be used to represent both IDWR/UI timesteps and MODFLOW stress periods.

Four segments of the Snake River have been previously simulated as fixed-head nodes in the IDWR/UI Ground Water Flow Model. Use of fixed-head nodes to simulate the interaction between the river and aquifer requires that transmissivity or hydraulic conductivity of the cells containing the river be adjusted until the appropriate river gains and losses are simulated. In MODFLOW, an option is provided to control exchange of flow between the river and aquifer through a riverbed conductance term. Riverbed conductance was set to an arbitrarily large value in SRPAM1.0 and SRPAM1.1 to create a comparable computation using MODFLOW to that performed by the IDWR/UI Ground Water Flow Model. Three of the four Snake River segments were modeled as time-constant stage; that is, river stage did not vary with time. The simulation of these reaches can be reproduced in SRPAM1.0 and SRPAM1.1 using the MODFLOW River Package in which river stage does not vary with time (with an arbitrarily large value assigned to riverbed conductance). However, the reach near American Falls was simulated in the IDWR/UI Ground Water Flow Model as having time-variable, but fixed head. SRPAM1.0 and SRPAM1.1 used the MODFLOW River Package by varying river stage in each stress period to achieve equivalent results to the IDWR/UI Ground Water Flow Model.

Leakage from the aquifer in the alluvial sediments near the confluence of the Henrys Fork and South Fork of the Snake River was modeled in the IDWR/UI Ground Water Flow Model using a series of third-degree polynomials. This is customized computer programming in the IDWR/UI Ground Water Flow Model that is not a part of MODFLOW. Although the relationships could be incorporated into the MODFLOW code, other methods were preferred. The selected method for this interim product (only needed in SRPAM1.0) was to incorporate the leakage rate from the Henrys Fork area as part of the fixed recharge for that area (MODFLOW's Well Package). This recharge was added to appropriate SRPAM1.0 boundary cells in the northeast part of the model domain. The subsequent version, SRPAM1.1, did not need to include this feature because the hydrology of the Henrys Fork area was included explicitly.

The IDWR/UI Ground Water Flow Model has the capability to repeatedly simulate a series of stress periods. In this application, the recharge and discharge, river stage, and other time-variable inputs that vary from stress period to stress period are repeated in each repeated simulation. This feature allows multi-year simulations where the same series of inputs that represent the variation of conditions for one year are repeated year after year (the IDWR/UI Ground Water Flow Model uses semi-monthly stress periods). The IDWR/UI Ground Water Flow Model used this feature when simulating the more than 1000 stress periods in the 58 year duration base study (IDWR, 1997). MODFLOW and many of the MODFLOW user interfaces do not have this capability. Repetition of a series of stress periods must be specified explicitly or accomplished through custom developed batch programs.

The automatic calibration routine included in the IDWR/UI Ground Water Flow Model Code was used to assist in determining calibrated hydraulic conductivity and storativity distributions in the IDWR/UI Ground Water Flow Model. This method produces different values of hydraulic conductivity and storativity in each grid cell. There is no comparable automatic calibration routine available for MODFLOW. Furthermore, MODFLOW-based models are often divided into multi-cell regions of near-uniform hydraulic conductivity and storativity. Although this difference did not present problems in conversion to MODFLOW, it does represent a philosophical difference in calibration methodology.

DEVELOPMENT OF INPUT DATA SETS

Input data sets for SRPAM1.0 were created primarily by reformatting input data from the IDWR/UI Ground Water Flow Model. The model grid (5km on a side), origin, and model domain remained unchanged. Aquifer properties and recharge and discharge for each grid cell were taken directly from the arrays previously input to the IDWR/UI Ground Water Flow Model. Certain model parameters required special attention. Those model parameters were described in the previous section, and their adaptations to MODFLOW input are summarized below.

- The MODFLOW Well Package was used to represent the net recharge and discharge (non-head dependent) to each cell. The net recharge was determined from the RECHARGE Program (Johnson and Brockway, 1983).
- The MODFLOW Basic Package was created containing grid and time data for the model and the starting head array. Starting heads and all other arrays describing the spatial distribution of characteristics were taken from input arrays to the IDWR/UI Ground Water Flow Model.
- The MODFLOW BCF3 Package input was developed from aquifer bottom, hydraulic conductivity, and storativity arrays of the IDWR/UI Ground Water Flow Model. Input in this file also sets the model domain as unconfined and applies the logarithmic interblock transmissivity averaging.
- The MODFLOW River Package was used to simulate those reaches of the river that were previously simulated as fixed head nodes in the IDWR/UI Ground Water Flow Model. The river bottom was set to an arbitrarily low value so the reaches are always in contact with the water table. River stage was taken as the head of the fixed head nodes from the IDWR/UI Ground Water Flow Model input.
- The MODFLOW SIP Package was selected as the numerical solver. The closure criterion was set at 0.01 feet.
- A MODFLOW Output Control file was generated to acquire the detailed output at the ends of stress periods 11 and 24 to parallel the analysis of the IDWR/UI Ground Water Flow Model.

SRPAM1.0 Verification to the 1980 Data Set

After the IDWR/UI Ground Water Flow Model was converted to MODFLOW, comparisons were made between results of the SRPAM1.0 simulation and corresponding results of the IDWR/UI Ground Water Flow Model for the period April 1980 through March 1981. The results showed that a) the SRPAM1.0 input data sets were constructed correctly, and b) both model codes are similar. Data were converted in a manner to accommodate the differences in the models as noted in the previous section. This initial conversion and comparison was done to provide an incremental development and checking process and to minimize the potential for undiscovered differences and errors.

Aquifer head determined by SRPAM1.0 simulation of the April 1, 1980 to March 31, 1981 period satisfactorily matched that of the IDWR/UI Ground Water Flow Model simulation. The aquifer head simulated by SRPAM1.0 was within two feet of the IDWR/UI Ground Water Flow Model simulated head at all active model nodes. About 970 nodes were compared for stress periods 11 and 24. Head differences may have been less than two feet; however, rounding of model output prevented a comparison to a greater degree of accuracy. Considering the large number of model nodes, the substantial hydraulic gradient involved, and the degree of complication of the model (e.g. inclusion of recharge and discharge, river gains and losses, aquifer heterogeneity, unconfined conditions, and transient conditions), the similarity in results provided a high degree of confidence that the SRPAM1.0 model and the IDWR/UI Ground Water Flow Model produce essentially identical results when provided with comparable inputs.

The flux of water between the Snake River and the aquifer was also similar between the IDWR/UI Ground Water Flow Model and the SRPAM1.0 simulations. The comparison was performed for stress periods 11 and 24, after elapsed simulation periods of 5.5 and 12 months, of the 1980-81 calibration data set. Figure 3 shows that the flux in both models is quite similar. The differences in flux can probably be attributed to how the models calculate the flux in each cell. The IDWR/UI Ground Water Flow Model computes fluxes by approximating the volume of water entering and leaving a cell during an entire stress period and using an average head based on the head at the beginning and end of a stress period. MODFLOW calculates fluxes by the rate of water

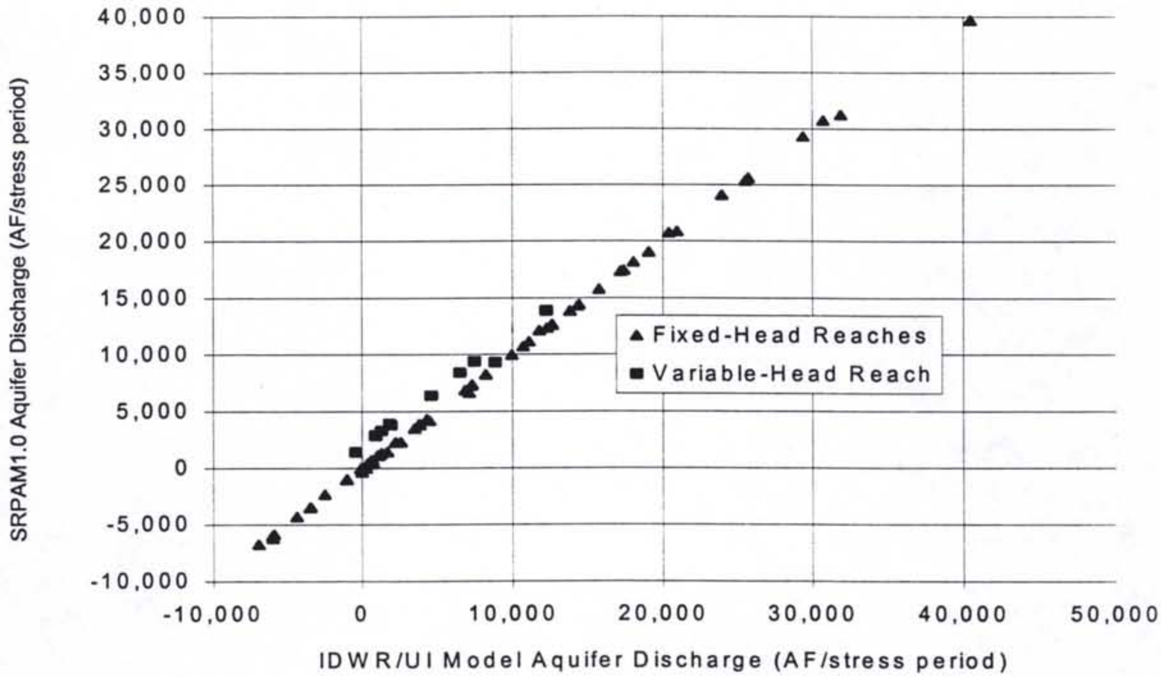

Figure 3. Comparison of River Reach Gains/Losses for SRPAM1.0 vs. IDWR/UI Ground Water Flow Model.

entering and leaving a cell at the end of the stress period. The largest differences occur in the American Falls area, where river stage is varied with time. Overall, the differences in simulated river gains/losses is less than 1 percent between the two models.

The similarity of aquifer head and fluxes indicates that SRPAM1.0 was converted correctly from the IDWR/UI Ground Water Flow Model. The similarity also adds credibility to previous investigations performed using this model. The comparison also demonstrates that the SRPAM1.0 input data sets are legitimate conversions of those developed in the IDWR/UI Ground Water Flow Model calibration by the IDWR (IDWR, 1997).

Predictive simulations (in contrast to replication of the calibration period) using SRPAM1.0 are not valid in the Henrys Fork area because the representation of Henrys Fork leakage via the custom programming does not allow the leakage to vary in response to changes in aquifer water levels. In SRPAM1.1, the Henrys Fork reach is represented as MODFLOW river cells, allowing the leakage to change in response to different aquifer stresses. This modification enhances the ability of the model to make predictive simulations in the Henrys Fork area.

EXTENSION OF MODEL DOMAIN (SRPAM1.1)

GENERAL PROCEDURE

This section discusses the extension of the model domain to the northeast to approximately agree with boundaries defined by the RASA program and modeled by Garabedian (1992). The extended area includes areas north and east of Mud Lake, the Henrys Fork of the Snake River below Ashton, and the South Fork below Heise. One of the primary reasons for extending the model is to improve the ability to simulate interactions of the ground water in these areas. The extension, which added 110 active model cells (shaded cells shown in Figure 2), represents about 1060 square miles. About 18 percent of the area in the extension is irrigated land. Most of the irrigated land is near the Henrys Fork of the Snake River and is irrigated by surface water. Recharge applied as irrigated water represents a major recharge component to the aquifer and was simulated in the IDWR/UI Ground Water Flow Model as tributary valley underflow.

The following procedures were involved in the development of SRPAM1.1.

1. SRPAM1.0 provided the base from which the model was expanded. In the development of SRPAM1.1, the characteristics of the SRPAM1.0 model (and consequently the IDWR/UI Ground Water Flow Model) were unchanged within the bounds of the previous model domain, except for recharge and discharge, hydraulic conductivity and storativity values in cells near the extended portion of the model.
2. Recharge and discharge were developed for the entire domain of SRPAM1.1 using the RECHARGE Program. Recharge within the original (SRPAM1.0) bounds was largely unchanged, but some of the original model cells did have minor changes to recharge. These changes were due to how irrigated acres which are not assigned to a specific canal company are handled.
3. Hydraulic conductivity, storativity, and river properties were calibrated in the expanded area based on measurements from the 1980 calibration year.
4. Results of the calibrated SRPAM1.1 model were compared to the IDWR/UI Ground Water Flow Model results for the 1980-81 calibration year to ensure that results from the two models were comparable.

The following sections discuss each of these steps in detail.

RECHARGE AND DISCHARGE ESTIMATION

Recharge and discharge data for the expanded area were developed in a manner consistent with that used for the rest of the model. Data from the April 1980 through March 1981 calibration data set (recharge and discharge) for the IDWR/UI Ground Water Flow Model was generated by the RECHARGE Program (IDWR, 1997). The RECHARGE Program determines the net recharge from precipitation, irrigation applications, evapotranspiration, canal and river seepage (not dependent on aquifer head), ground-water pumping, and tributary valley underflow (Johnson and Brockway, 1983). The input data sets to this program were updated to include the expanded area and the program was re-run to generate the net recharge for every grid cell in the model domain for 24 – 15.2 day time increments (model stress periods). Detailed maps of the individual components of recharge for SRPAM1.1 are available in Cosgrove and others (1999).

A combined recharge source term was generated by the RECHARGE Program for the calibration time period using 24 half-month timesteps from April 1980 through March 1981. The source term generated by the RECHARGE Program represents the calculated net recharge or discharge to the aquifer at each grid cell for each stress period including the extended model area.

The extended area had streams and rivers that were represented with a specified rate of seepage to the aquifer, or as hydraulically connected with the aquifer. Stream segments not hydraulically connected to the aquifer were represented as a specified flux and included in the net flux calculated by the RECHARGE Program. Additional segments were created to represent upper reaches of Camas and Beaver Creeks in the extended model domain.

River reaches representing the Henrys Fork and the South Fork of the Snake River were added to the expanded model domain using the MODFLOW River Package. A total of 15 MODFLOW river reaches were used to represent approximately 30 miles of the Snake River from Heise to Lorenzo, from Ashton to Rexburg and from Lorenzo and Rexburg to Lewisville. River stage for each reach was estimated from 7.5" U.S. Geological Survey topographic maps. River stage for the new reaches was held constant throughout the 24 stress period simulation. Initial riverbed conductance was obtained from the calibrated riverbed conductances published by Garabedian (1992) and was adjusted as part of the calibration process. River bottom was approximated as 30-40 feet below river stage in each cell.

Ground- and surface-water irrigated acres for 1980 were then used to develop the net recharge due to irrigation for each of the model cells in the extended area. The irrigated acres for 1980 for each model cell in the extended area were generated using GIS-based data (Goodell, 1988). The irrigated acres were determined by the IDWR by processing Landsat Multi-Spectral Scanner data covering the eastern Snake River Plain. The complete methodology used to obtain irrigated acreages is described in an unpublished IDWR report (Anderson, 1983).

Surface-water irrigated acres for each grid cell were assigned, when possible, to an irrigation entity or group of entities (individual diverter, canal company, etc.) associated with a specific diversion or diversions from the river. Recharge from surface-water irrigation was calculated as total diversion minus net evapotranspiration volume minus return flow. Net evapotranspiration was calculated as the evapotranspiration rate for that climatic zone multiplied by the number of acres serviced by each irrigation entity. The recharge for surface-water acres that was not assigned to a specific entity was based on an average recharge of the surface-water irrigated acres a) in the cell (provided other surface-water irrigation is present in the cell) or b) in the entire model domain (when no other surface-water irrigation exists in the cell). Irrigation diversions to each service area were taken from measurements reported by the Water District 1 watermaster annual report for the 1980-1981 water year (IDWR, 1981). Return flows were obtained from estimates by IDWR. Ground-water withdrawals for irrigation were set equal to the net evapotranspiration rate multiplied by the number of ground water irrigated acres in each model cell.

To compute net evapotranspiration rates, climatological data for 1980-81 were input for 11 climatic regions for each stress period based on the locations of representative weather stations. Three existing regions were extended to include all of the new cells. The data included total precipitation, average daily solar radiation, average mean daily temperature, average daytime wind speed and average daily minimum relative humidity. Total evapotranspiration was computed for predominant crops in each region using a method developed by the University of Idaho (Allen and Brockway, 1983) with

1980-81 climatological data as input. Their model computes an average evapotranspiration rate for each climatic region using the 1980 crop distribution report from the Agricultural Stabilization and Conservation Service. Net evapotranspiration was computed by subtracting effective precipitation from the average evapotranspiration.

Recharge from precipitation on non-irrigated areas was calculated for each climatic region as a portion of measured precipitation based on an assumed effectiveness in reaching the aquifer. However, parts of the measured precipitation can evaporate or be used by native vegetation. Effectiveness coefficients were chosen and were based on the predominant type of land cover in each climatic region and applied to the actual 1980-81 precipitation. The existing estimates were extrapolated to the extended area.

Tributary valley underflow was adjusted to fit the new model boundaries. Model cells representing tributary valley underflow for Warm Springs Creek, Deep Creek, Medicine Lodge Creek, Beaver Creek, Camas Creek and Big Bend Creek were moved to the extended boundaries and quantities of tributary valley underflow were re-adjusted. These values matched those used in the USGS Snake River Plain Model (Garabedian, 1992). Tributary valley underflow for the Rexburg Bench, the Teton River, the Henrys Fork and the South Fork of the Snake River were added at the appropriate boundary locations. Table 1 shows a comparison of the specified flux for tributary valley underflow between SRPAM1.0 and SRPAM1.1. The large difference in Henrys Fork underflow is attributable to moving the boundary. Most of the recharge for the Henrys Fork region is now entered as applied irrigation water rather than tributary valley underflow.

The net recharge to the model domain increased when the model domain was enlarged. SRPAM 1.0 (1980 calibration year data set) used a total net recharge of 6.0 million acre-ft (MAF)/year (including –0.07 MAF/year calculated by the model for the Henrys Fork area). Recharge in the entire domain of the new model as calculated by the RECHARGE Program increased to 6.6 MAF/year. Garabedian (1992) estimated that the upper reaches of the Snake River and the lower Henrys Fork gained 190,000 AF in 1980. These river gains were formerly accounted for in RECHARGE Program computations for SRPAM1.0 but are now discharged to the river cells representing the Henrys Fork and South Fork in SRPAM1.1. The net recharge to the expanded model domain is therefore about 6.4 MAF/year. This represents an increase in total recharge of about 7 percent over

Table 1. Estimated Tributary Valley Underflow for the SRPAM1.0 and SRPAM1.1 Models.

Tributary Name	Tributary Number	SRPAM1.0 Underflow[1] (AF/year)	SRPAM1.1 Underflow[2] (AF/year)
Big Wood	N/A	0	0
Silver Creek	2	38,000	38,000
Little Wood	3	24,000	24,000
Big Lost	4	114,000	114,000
Little Lost	5	100,000	100,000
Birch Creek	6	70,000	70,000
Blackfoot River	7	25,000	25,000
Raft River	8	63,000	63,000
Portneuf	9	22,600	22,600
Medicine Lodge Cr., Deep Cr., & Warm Springs Cr.	10	40,400	15,700
Beaver Creek	11	59,200	62,000
Camas and Big Bend Creeks	12.14	266,700	296,000
Henrys Fork	15	588,000	19,000
Teton River	16	0	3,000
South Fork	17	0	7,000
TOTAL		1,410,900	859,300

[1] from IDWR (1997)

[2] from IDWR (1997) and calculated from RECHARGE Program inputs.

the entire domain. The recharge values calculated for the two models do not balance due to errors inherent in recharge estimation. The current, more detailed, estimates are thought to be superior to previous estimates, which included much of the recharge as rough estimates of tributary valley underflow.

The net recharge to the expanded model area (110 cells) was estimated as 1.51 MAF/year. This is substantially larger than the previous estimate of underflow from this area of .98 MAF/year for the IDWR/UI Ground Water Flow Model. However, the estimated recharge for the expanded model area compares favorably with the 1.48 MAF/year estimated by Garabedian (1992) for approximately the same area. The potential for relatively large errors in recharge estimates in this area is a result of the large volumes of irrigation water diverted and applied in portions of the extended model domain. Uncertainty in the volume of irrigation return flows also contributes to errors in the calculation of recharge. Despite the uncertainties, it is believed that the current estimates for recharge are more accurate than previous estimates of underflow from the same area because more measured inputs are used in the calculation.

The inclusion of the Henrys Fork area in the RECHARGE Program affected net recharge estimates in parts of the old model domain close to the expansion. In about 35 model cells in the northeast portion of the old model domain the estimated net recharge collectively decreased by approximately 46,000 AF/year. Insignificant changes occurred in isolated cells throughout the original model domain as a result of changes in the average irrigation application rate applied to areas with unmeasured diversions.

STARTING HEADS IN THE EXPANDED MODEL DOMAIN

Starting heads for the expanded model domain of SRPAM1.1 were derived by contouring water level measurements taken in the northeast part of the eastern Snake River Plain as part of the RASA study in March, 1980 and obtained from the Boise USGS District Office. The water level measurements were contoured using a commercial software program. Figure 4 shows the water level contours from the measured wells. Most of the water level measurements used to generate these contours were in the area covered by the Wytzes model (1980). The localized contours are consistent with contours for that region published in Wytzes (1980). The detailed

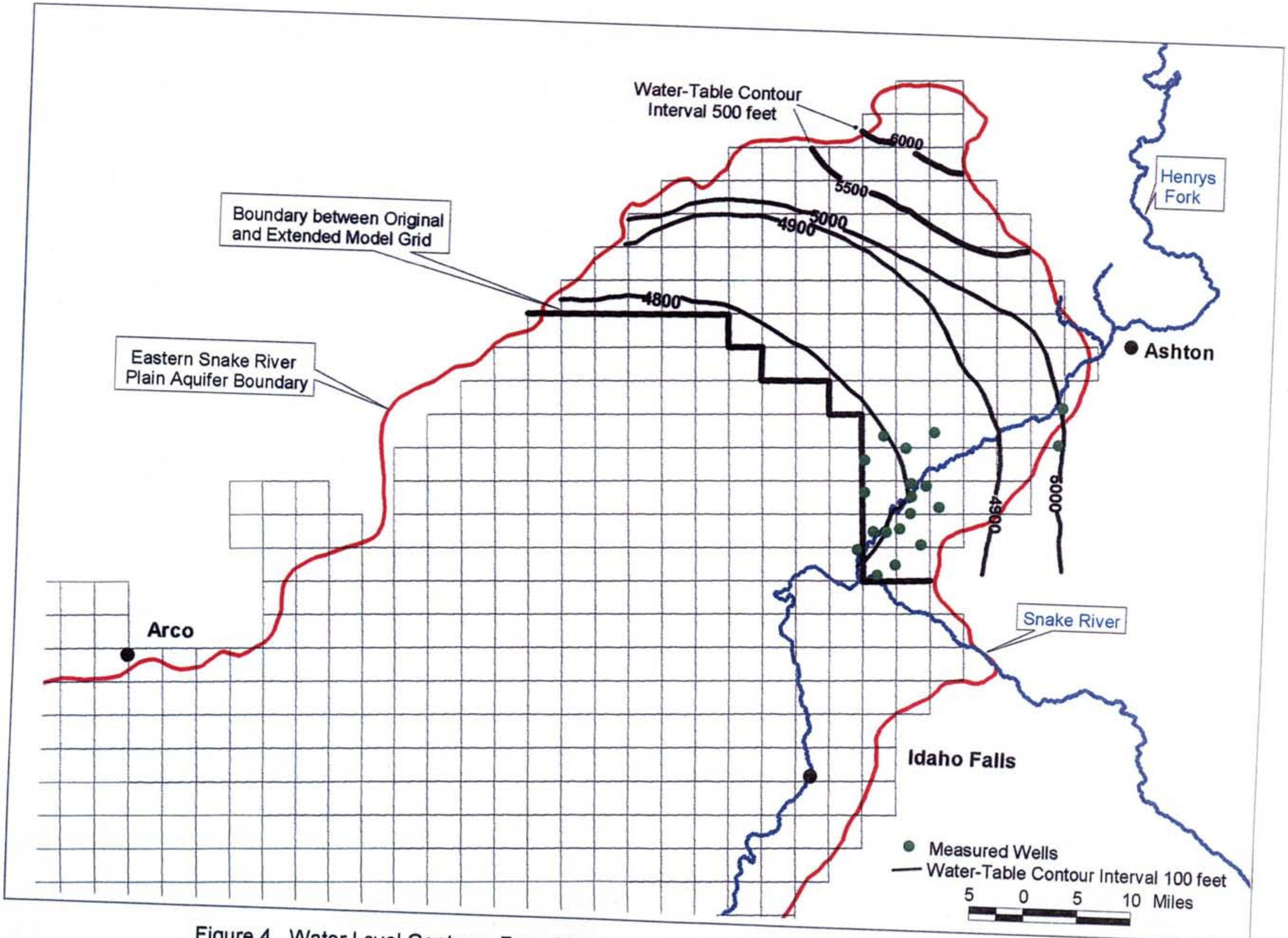

Figure 4. Water Level Contours From Measured Wells in the Expanded Model Area.

contours in the Henrys Fork area were extrapolated to the water level contours to the north developed during the RASA study (Garabedian, 1992). The contours were then visually interpolated to determine starting heads for each of the new model cells. Starting heads for SRPAM1.0 were used for the original (non-expansion) portion of SRPAM1.1.

GROUND-WATER BUDGET

It is believed that the recharge estimates in the expanded model area of SRPAM1.1 are an improvement over previous underflow estimates; however, the greater recharge has resulted in a discrepancy in the overall aquifer water budget (Table 2). The ground-water budget is based on interpretations of measured data and net recharge estimates generated by the RECHARGE Program. The net recharge component is estimated by the RECHARGE Program from entered data characterizing the irrigation systems, streams, and climate. Changes in aquifer storage are based on estimates of storativity and measured changes in water level. River gains and losses are based primarily on streamflow measurements.

Table 2. Conceptual Ground-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
Above 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	**100,000**
Discrepancy	**351,000**

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

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. During model calibration, the discrepancy resulted primarily in incorrect simulation of changes in aquifer storage. Although calibration of the entire model domain may be warranted based on examination of head differences and water budget discrepancies, it was beyond the scope of this project to recalibrate the entire model domain.

INITIAL DISTRIBUTION OF AQUIFER PROPERTIES

Hydraulic conductivity and storativity values for the SRPAM1.0 implementation were obtained from the calibrated values in the IDWR/UI Ground Water Flow Model (IDWR, 1997). These values were left unchanged in the SRPAM1.1 implementation, except for the cells near the northeast boundary of the SRPAM1.0 model grid. Values in these cells were re-calibrated as part of the calibration of the expanded area of the SRPAM1.1 model.

Initial estimates of hydraulic conductivity and storativity of cells in the expanded model domain of SRPAM1.1 were interpolated from the USGS Snake River Plain Model (Garabedian, 1992). Hydraulic conductivity values for the USGS model were determined by summing the transmissivity of individual layers and dividing by the total saturated thickness. This integrating of layers neglects impedance to vertical flow simulated in the three-dimensional USGS model. Zoned averages of the USGS model hydraulic conductivity and storativity values for the expansion area were uniformly applied in SRPAM1.1 as initial values subject to calibration.

CALIBRATION IN THE EXPANDED DOMAIN

Hydraulic conductivity and storativity were calibrated only in the expanded area and adjacent cells. Calibration included several cells within the boundaries of the

IDWR/UI Ground Water Flow Model to ensure continuity between the previous model domain and the added grid cells. No other calibration of the model was done.

The expanded area was calibrated to measured and estimated aquifer head and river gain and loss data. Due to the sparsity of water level measurements in this area, model-predicted head was compared to a combination of selected heads in observation wells, water levels estimated from the RASA water level contours and water levels in the original model domain previously used in calibration of the IDWR/UI Ground Water Model. Simulated water levels in SRPAM1.1were compared with water levels in 65 model cells. Figure 5 shows the location of model cells containing calibration points with the color denoting the source of the target data. Water-level data were interpolated to model cell centers using a commercially available interpolation program. Calibration of the 110 new model cells and approximately 30 cells in the non-extended model domain was accomplished by trial and error, attempting to minimize differences between target water levels in the network of observation wells and simulated water levels in corresponding model cells.

River properties in the fifteen model cells representing about 30 miles of the Henrys Fork and the Snake River between Heise and Lewisville also were calibrated. Riverbed conductances were adjusted during calibration in an attempt to match river gains and losses while maintaining the best possible match to measured aquifer water levels in the area. Calibration attempted to match measured river gains and losses for three stream segments in the area (segments 11, 12 and 13) shown in Figure 6. Table 3 provides a comparison of simulated river gains and losses from the calibrated model to measured values for those three river segments.

Calibration accuracy in the expanded model area was measured by the mean absolute error (MAE) and the root mean square (RMS) of the differences in simulated and target heads for the observation network of 65 points. The comparison was made for a stress period representing early September, 1980 (stress period 11) and for the end of

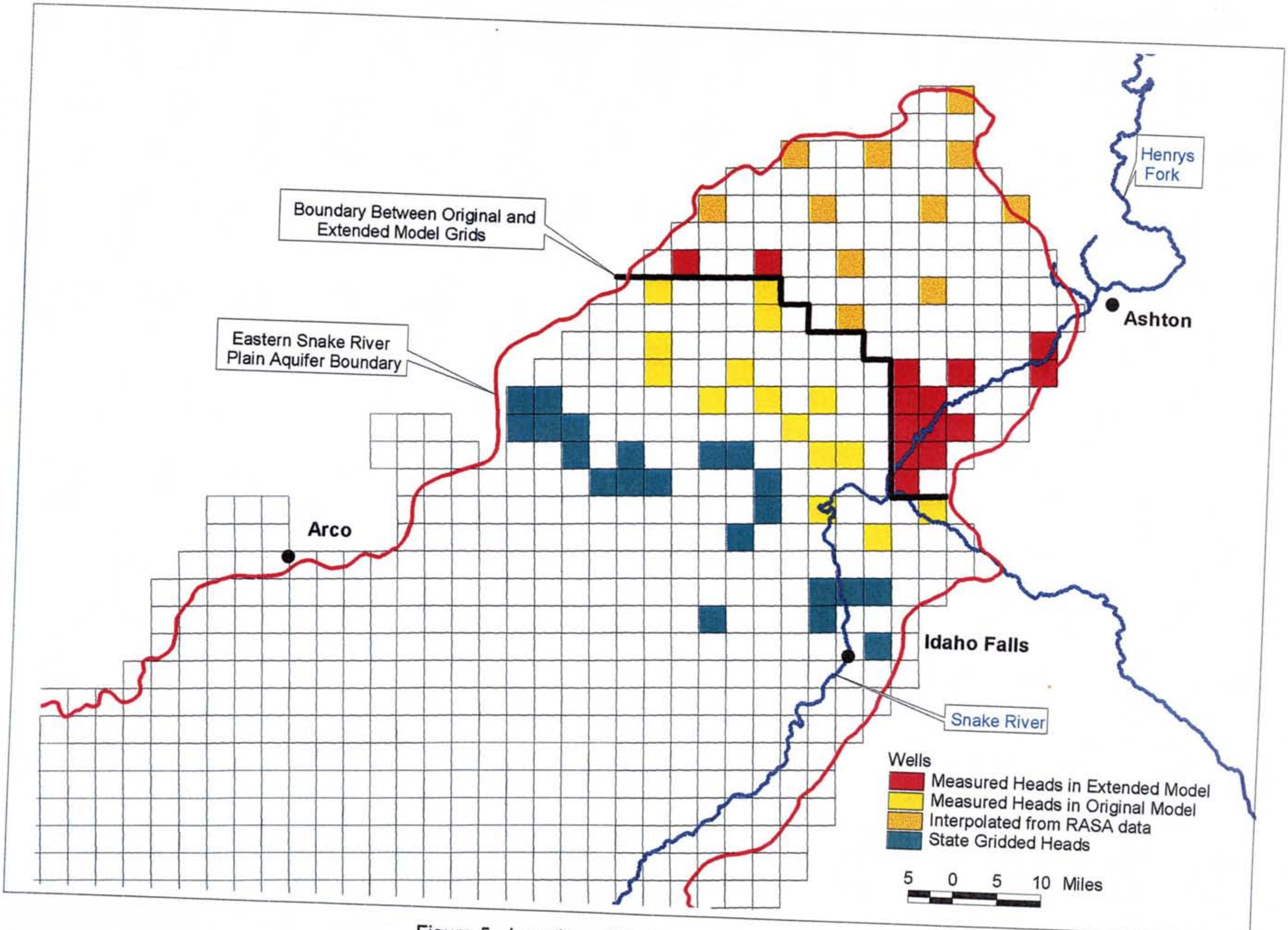

Figure 5. Location of Model Cells Containing Water Level Calibration Targets.

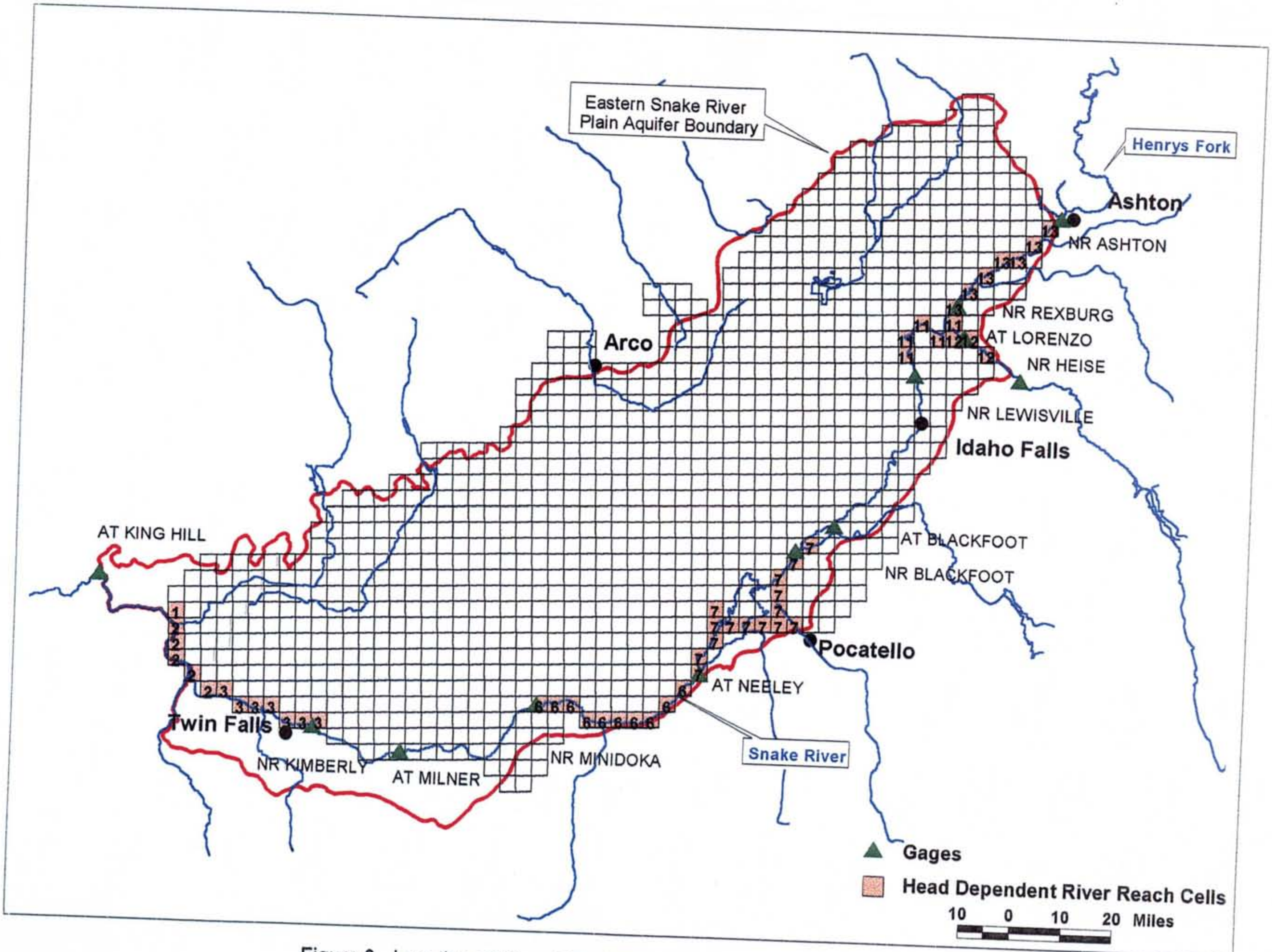

Figure 6. Location of River Reaches Used in Model Calibration.

Table 3. Simulated and Measured River Segment Gains and Losses. (Units in cfs for the April 1980 through March 1981 water year).			
River Segment	Simulated River Gain or Loss (-)	Measured River Gain or Loss (-)[1]	Percent Difference (Negative indicates SRPAM1.1 value is lower.)
Henrys Fork, Ashton To Rexburg	110	120	-8%
South Fork, Heise to Lorenzo	-130	-150	-13%
Snake River, Lorenzo to Lewisville	270	290	-7%

[1] from Garabedian (1992).

the simulation in March, 1981 (stress period 24). The resulting MAE for the 65 cells containing observation points was 15 feet for stress period 11, and the RMS was 19 feet. At the end of stress period 24, the MAE was 14 feet and the RMS was 20 feet. Additionally, the MAE and RMS were individually calculated for target water level measurements in the expanded model area, target water level measurements in the original model area and the RASA-interpolated water levels. Table 4 shows the RMS and MAE for these three categories of comparison. A scatter plot of target (interpolated to cell centers) versus simulated heads for two stress periods representing early September and late March (end of simulation) is presented in Figure 7. The diagonal line in Figure 7 represents the case where the target head equals the simulated head. Data points falling to the right of the diagonal line represent cells where the target head is higher than the simulated head. Data points to the left of the line represent cells where the simulated head is higher than the target head.

A problem encountered during the localized calibration was that the starting heads in the expanded model domain were low when compared with the river stage elevations. Because both the starting heads and the river stage were based upon the best data available, it was felt that alteration of either data set would be inappropriate. This discrepancy caused the situation where river reaches which were expected to be gaining reaches were losing and were sometimes perched above the aquifer. The hydraulic conductivities and storativities which were necessary to bring the water table up to a

Table 4. Root Mean Squared and Mean Absolute Error for Differences Between Simulated and Target Heads.

	Stress Period 11	Stress Period 24
RMS (ft.) for Cells in Original Model Domain	12.5	14.0
RMS (ft.) for Cells in Extended Model Domain	23.5	28.5
RMS (ft.) for RASA-Interpolated Heads		6.7
RMS (ft.) for all Target Cells	19.1	19.6
MAE (ft.) for Cells in Original Model Domain	10.3	12.1
MAE (ft.) for Cells in Extended Model Domain	19.8	22.9
MAE (ft.) for RASA-Interpolated Heads		6.3
MAE (ft.) for all Target Cells	15.0	14.5

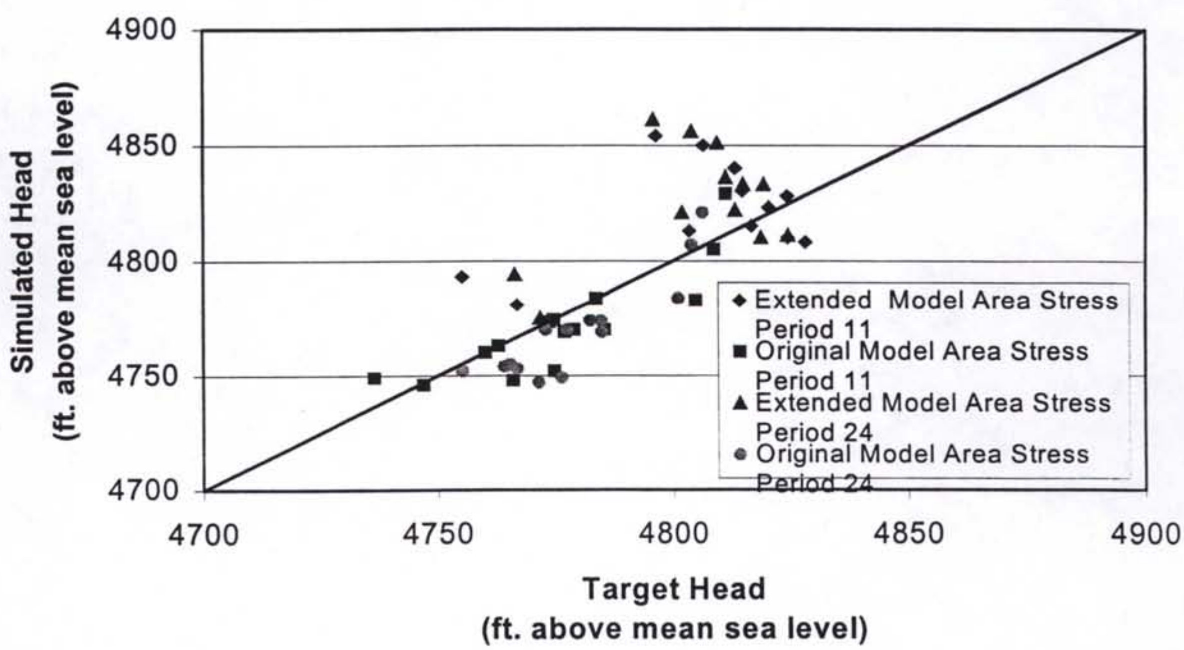

Figure 7. Scatter Plot of Simulated Heads vs. Target Heads for Stress Periods 11 and 24.

sufficiently high level to make these gaining reaches caused a lowering of water levels extending approximately twelve cells into the original model domain. In the final calibrated model, some of the water levels in the original model domain are up to 20 feet lower than in the original model (Figure 8). This problem underscores the lack of accurate water level data available for model calibration. It was felt that the original river stage data and the river reach gain and loss targets were sufficiently accurate to warrant accepting this discrepancy with the original model.

COMPARISON OF SRPAM1.1 RESULTS TO THE IDWR/UI GROUND WATER FLOW MODEL RESULTS

The calibration of the SRPAM1.1 was intended to minimally alter characteristics of the original model domain included in the IDWR/UI Ground Water Flow Model. Effects of the extension and calibration of the model domain in the northeast part of the plain are evaluated by comparing the April 1980 through March 1981 simulation results for the SRPAM1.1 and IDWR/UI Ground Water Flow Models. The magnitudes of the differences in simulated heads between the two models are shown by color coding on a cell by cell basis in Figure 8. The greatest differences are found in the northeast portion of the IDWR/UI Ground Water Flow Model domain adjacent to the extended area and where recharge and discharge were affected by addition to the model domain and water levels were affected by the localized model calibration. Hydraulically connected river gains and losses collectively varied by less than 0.4 percent in either stress period 11 or 24 for those river reaches present in both model domains.

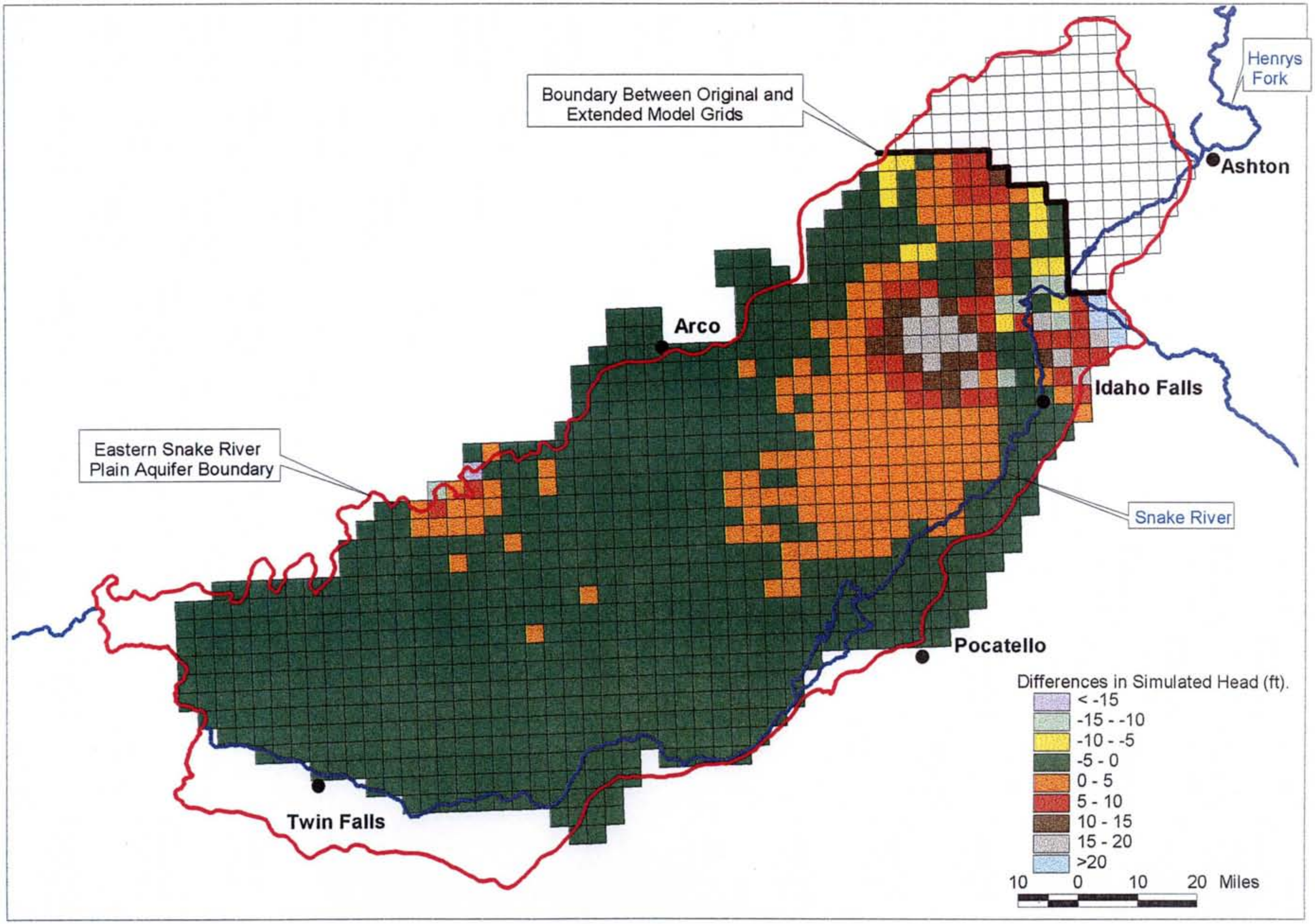

Figure 8. Differences in Simulated Head Between SRPAM1.1 and IDWR/UI Ground Water Flow Model. (A negative indicates that the IDWR/UI Ground Water Flow Model simulated head is lower than the SRPAM1.1 simulated head.)

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. Evaluation of spring discharge and the relation to water levels.

   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. Develop an improved method for aquifer recharge accounting.

   Net recharge to SRPAM 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 tributary valley 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 GIS 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 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.

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