Evaluation of Ground Water Models in the Treasure Valley, Idaho Area

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by

Donna M. Cosgrove, Ph.D.
Western Water Consulting, Inc.
Idaho Falls, Idaho

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Purpose

As competition rises for water resources in Idaho, many basins are experiencing the need for increased resource management. This competition for a limited resource has caused the State to initiate the Comprehensive Aquifer Management Planning (CAMP) process in many of the basins throughout the state. The CAMP process includes basin characterization, assessment of existing and projected water resource availability and use, and development of an aquifer management plan and technical tools for sustainable management of the resource. Of particular interest in the CAMP process is the impact to surface-water resources of ground-water use and the impact to both resources of changes in land use. Key to initiation of the CAMP process is an evaluation of existing water management tools, particularly water budgets and ground-water models, for each basin. Also key to the CAMP process is identification of data gaps and additional tool development required for effective future aquifer management.

Ground-water models are generally developed and calibrated for a specific purpose. Models vary as to numerical modeling method, areal extent, model purpose, model timeframe, etc. Each model is unique. Of particular interest in the modeling process is development of the model water budget. Many conceptual model assumptions are embedded in the model water budget. By assessing the existing models and water budgets in the western Snake Plain Aquifer, Idaho Department of Water Resources personnel will be better able to determine future modeling requirements for the CAMP process.

This report documents the assessment of existing ground-water models and water budgets in the western Snake Plain Aquifer, which includes both the Mountain Home area and the Treasure Valley. Multiple models and water budgets exist in this region, some dating back to the 1980s. The report describes each model including parameters such as model purpose, water budget development, areal extent, and modeling method used. The report provides tables comparing the parameters for each model and includes recommendations for tool development and data collection to meet the needs of the Treasure Valley CAMP process.

Some background information is provided on the topic of ground-water modeling in order to provide the reader with the necessary understanding of the impacts of various model design decisions. For a more comprehensive description of ground-water modeling, the reader is referred to Applied Groundwater Modeling (Anderson and Woessner, 1992).

Project Scope

The project scope is limited to review of seven existing ground-water models in the Treasure Valley area. The report is not intended as a critique of any of the models, rather as a description of each model. The report provides a comparison of the design and capabilities of the models and an assessment of each model's suitability to meet the needs of the CAMP process.

The assessment was done using available model documentation and discussions with model developers. Several of the models are thirty years old as of the writing of this report. Modeling methods have changed, as has our understanding of the hydrogeology and water use in the study area. The reader should keep in mind, however, that each model furthers our understanding of the hydrologic regime of the western Snake River Plain and acts as a building block for future model development.

This report is organized as follows. The study area and local hydrogeology are discussed. A brief background of ground-water modeling is provided. This background includes a description of the most important elements of ground-water modeling. Each assessed model is then detailed including a description of the most relevant design decisions made in the modeling process and the model water budget. After the description of each model, a section is provided with overall conclusions and recommendations.

Projected CAMP Modeling Needs

The CAMP process is a relatively new concept in the State of Idaho. The CAMP process is intended to provide a proactive management mechanism for an individual basin. The CAMP process enlists interested parties from both government and the private sector to participate in defining current and future water needs for a specific basin and how best to meet those needs. Ground-water modeling has the potential for providing tools which can help the CAMP assess the impacts of various aquifer management options, providing both the CAMP and IDWR with scientifically-based guidance to address difficult aquifer management decisions.

Experience in other basins in Idaho (Spokane Valley/Rathdrum Prairie and the eastern Snake River Plain) has shown that some of the most important water supply questions faced when managing aquifers are:

- What is the projected future water use for the basin?
- Is the water supply in the basin sufficient to meet future needs?
- How is climate change predicted to impact future water supplies?
- What impact does ground-water pumping have on aquifer water levels?
- What impact does ground-water pumping have on river gains/losses?
- What impact will changes in land use have on water supplies?

Despite the inherent uncertainty, ground-water models are the best tools available for answering some of these critical water supply questions. In addition to water supply, ground-water models can become the basis for water quality modeling.

The TVHP CAMP will require a combination of water management tools. The CAMP is likely to need a transient, multi-layer, regional ground-water model which has wide acceptance and trust and which can be used to predict some of the previously mentioned impacts. As localized questions or issues arise, it is likely that the CAMP will require sub-regional models to address specific questions, which a regional model has too coarse a scale to address.

Any model which is to be used in the CAMP process must have wide-spread acceptance. Experience in the Spokane Valley/Rathdrum Prairie (Hsieh and others, 2007) and the eastern Snake River Plain (Cosgrove and others, 2006) has shown that the best method for gaining such wide-spread acceptance is through an open model development process, in which the interested parties are invited to participate in and review the model development in order to gain a better understanding of modeling decisions and limitations.

Study Area

The study area entails the western Snake River Plain. The study area extends from Weiser, Idaho in the northwest to west of Twin Falls, Idaho in the southeast. Figure 1, from Newton (1991) shows the full extent of the study area. Areas of particular interest within the study area are the areas experiencing the most rapid growth. Figure 2 shows areas of extensive planned growth. The reader will note that most of the growth is occurring within the Treasure Valley area near Boise, Idaho. Most of the reviewed models focus on the Treasure Valley or sub-areas within the Treasure Valley. In addition to the areas of projected growth, the Mountain Home area (Figure 2) is also an area of high interest in CAMP planning. Mountain Home, though not experiencing rapid growth, is experiencing great competition for its ground water resources.

Area Hydrogeology

The geology within the study area is very complex, characterized by basalts and rhyolites which are exposed in the southeastern portion of the study area and are buried by complex layers of lake and river sediments throughout the central and northwestern portion of the study area. Newton (1991) describes the study area as a deep structural depression surrounded by high mountains on the northeast and southwest. The depression is filled with basalt and rhyolite. In the Treasure Valley area near Boise, Idaho, the overlying sediments are deep and highly complex, comprised of interbedded sediments from multiple sources, faulted and tilted by tectonic activity and highly eroded over time (Petrich, 2004). In some areas, the sediments are thousands of feet in thickness.

The hydrogeology within the study area is similarly complex. The Snake River enters the study area west of Twin Falls, Idaho, flowing to the west and then north towards Weiser, Idaho. The Boise River flows east to west through the upper portion of the study area (through the Treasure Valley) to its confluence with the Snake River northwest of Caldwell, Idaho. The Payette River flows southeast to northwest through the northernmost portion of the study area to its confluence with the Snake River north of Ontario, Oregon (Figure 1). Irrigation activity has greatly altered the hydrogeology within the Treasure Valley area. The area is traversed by many miles of canals (Lindgren, 1982, and Petrich and Urban, 2004), with localized shallow mounding of ground water during the irrigation season. Lake Lowell, a small irrigation reservoir, is located in the southwest portion of the Treasure Valley. As land evolves from agricultural use to residential use, the impact to local hydrology is altered.

Regional ground-water flow is generally towards the Snake River. Sub-regional flow is towards the Boise River (Newton, 1991). Figure 3 of Newton (1991) shows localized discharge to the Payette River in the northeast portion of the study area. Petrich (2004) characterizes flow in the northern portion of the study area to be restricted by a ground-water divide, with most flow westerly towards the Snake River and flow northeast of the divide towards the Payette River. All researchers report localized shallow aquifers, largely recharged by either Boise River leakage or irrigation canal leakage. Newton (1991) reports a perched aquifer under Mountain Home, Idaho. Squires and others (2007), in a consultant report, describe a moderately deep aquifer with significant recharge from the New York canal south of Eagle, Idaho and significant discharge to the Payette River to the north. Ralston (2008), also in a consultant report, argues that the theory is not yet fully supported. For more detail on the geology and hydrology of the area, the reader is directed to the cited reports.

Models Reviewed

Seven models were reviewed for this project. The reviewed models are:

- Lindgren Treasure Valley Model (1982)
- USGS western Snake Plain Model (1991)
- Treasure Valley Hydrologic Project (2004)
- University of Idaho M3 Eagle Area Model (2007)
- Pacific Groundwater Group M3 Eagle Area Model (2008)
- Bureau of Reclamation Purdam Drain Model (2008)
- Bureau of Reclamation New York Canal Linked Ground-water/Economic Model (2009)

The model descriptions will be presented in this report in order of publication date. The reader should infer no meaning from the order of presentation.

Ground-water Modeling Background

Ground-water models are numerical representation of complex physical systems. Models vary in purpose, complexity, modeling method used and model assumptions. The complexity of the physical system being modeled necessitates many simplifying assumptions in model development. In physical systems, such as hydrologic systems, the system is often not well understood and the model is being developed to provide insight into the processes controlling the physical system.

There are many aspects of a ground-water model which are important to understand. The model components which are most important in describing a specific model are:

- Model purpose

- Model areal extent
- Modeling method used
- Area discretization
- Model boundaries
- Time discretization
- Water budget
- Model calibration

A brief description of each of these components follows. Many underlying model assumptions are embedded in selection of some of these model parameters. In cases where this selection is important and, perhaps, not readily apparent, this report attempts to describe the selection and why it is important to understanding the specific model. For model areal extent, the seven models will be compared with each other in this section. All other model characteristics will be discussed in the individual model sections.

Model Purpose

Ground-water models are developed for many different purposes. The most common purposes include hydrogeologic characterization, aquifer management, scientific exploration and demonstration. Many models are designed to answer specific questions such as 'what impact would it have on the hydrology of the region to line the XYZ canal?' or 'what impact does ground-water pumping have on lake leakage?' Models are often developed to answer technical questions resulting from water use disputes. Most model documentation explicitly states the intended model purpose. The stated model purpose for each of the assessed models is discussed in the section for that particular model.

Model Areal Extent

The model areal extent is the physical area represented by the model. The areal extent is typically selected based on aspects of the physical system such as area of interest, aquifer extent, hydraulic boundaries (such as rivers and lakes) and physical boundaries (such as mountains and geologic faults). The evaluated models vary widely in areal extent. The model with the greatest areal extent is the USGS western Snake Plain model (Newton, 1991), which extends from west of Twin Falls, Idaho to Weiser, Idaho. Figure 1 shows the areal extent of the USGS model. Of the seven models reviewed, the Bureau of Reclamation model of the New York Canal (USBR, 2009) is the narrowest areal extent. For comparison purposes, Figures 3-8 show the smaller model areal extents superimposed on the USGS model boundaries. This provides the reader with an idea of the relative areal extent of the reviewed models.

Models are broadly characterized as regional or sub-regional models. Of the models evaluated for this study, the Lindgren Treasure Valley model, the USGS western Snake Plain model and the Treasure Valley Hydrologic Project model are characterized as regional models. The other four models are considered sub-regional.

Selection of the model areal extent can impact the selection of other boundary conditions or representation of recharge. Impacts from well pumping or introduction of recharge can be magnified if a model boundary is selected which is too small. As the impacts of the modeled recharge or discharge propagate through the aquifer, if an artificial boundary is hit, the impacts will be unable to naturally propagate further and will be intensified.

For a regional model, model boundaries are typically selected at natural physical or hydrologic boundaries. This selection minimizes unintended impacts introduced by an arbitrary boundary. For sub-regional models, boundaries are often selected which are sufficiently distant from the area of interest so that these magnified impacts are not realized.

Modeling Method Used

There are multiple modeling methods available for numerical ground-water modeling. The seven models evaluated for this study use two methods, one commonly used in ground-water modeling and the other less commonly used. The two methods used are finite difference modeling and analytic element modeling. These two methods will be discussed briefly.

Finite Difference Modeling

Finite difference modeling is the most commonly used method for numerical ground-water modeling. In a finite difference model, the physical model area is discretized (or divided) into sub-areas. These sub-areas would typically be anywhere from several hundred feet on a side to several miles on a side. Each of these sub-areas is referred to as a model cell. In a finite difference model, all model cells are contiguous. Numerical equations are developed to describe the flow of water between every model cell and each neighboring cell. The numerical equations are based on the Darcy Flow Equation (Fetter, 1988) and the basic conservation of mass equation (inflows minus outflows equals change in storage).

Finite difference modeling is accomplished using a model code. The model code simultaneously solves the flow equations for each model cell, calculating the resulting aquifer water level in the model cell and flows in and out of the model cell. The most commonly used ground-water modeling code is the USGS Modflow code. In the 1970s at the University of Idaho, a ground-water modeling code was developed by deSonneville (1972). Five of the reviewed models are finite difference models, four of which use Modflow and one of which uses the deSonneville code.

In finite difference modeling, model cells are always rectangular. The deSonneville (1972) code only enables uniform model cells (that is, square cells, all of the same dimension). Modflow allows for a variable grid size, allowing the modeler to have a more refined grid in a location of particular interest. The modeler is occasionally limited to uniform model cells when using Modflow, depending upon the selected numerical solver.

Finite difference models can be 2-dimensional (single layer) or 3-dimensional (multiple layer). Finite difference modeling allows for modeling of interaction between the aquifer and surface water bodies such as rivers and lakes. Model parameters (hydraulic conductivity, storativity, river-bed conductance, river elevation) can vary spatially, allowing for representation of heterogeneous systems. Hydraulic conductivity can be varied directionally, allowing for representation of anisotropic systems. The Modflow code can be used to represent either confined or unconfined aquifer conditions (Fetter, 1988). Finite difference models can be either steady state or transient (discussed in a later section). For more details on finite difference modeling, the reader is referred to either Anderson and Woessner (1992) or McDonald and Harbaugh (1983).

Finite difference models are very data-intensive. Each model cell must be populated with aquifer properties (hydraulic conductivity, storativity, riverbed conductance, etc.). Three-dimensional models require similar properties for both horizontal and vertical flow. Due to their data-intensive nature, finite difference models are relatively difficult to construct and to calibrate (discussed in a later section).

Analytic Element Modeling

A less commonly used ground-water modeling method is the analytic element modeling method (Strack, 1989). In this method, surface features are represented by analytic elements. Surface features can be wells, areal recharge, rivers, lakes, etc. Surface features can be line or point sources (or sinks) of water. Each analytic element is a numerical equation representing a specific hydrologic interaction (such as between the aquifer and a river or canal). Analytic elements can also be devised to represent no-flow boundaries or constant-flow boundaries. Since the analytic elements are based on analytic equations, each equation assumes an aquifer of infinite areal extent, therefore no distant boundary impacts are realized.

The analytic element model code solves the analytic element equations describing the flow between any modeled feature and the aquifer. Heterogeneity can be represented by adding more analytic elements, each with different hydraulic properties. Anisotropy cannot be modeled using analytic elements. Analytic elements can be used to model either confined or unconfined flow conditions. Analytic element models are restricted to steady state modeling (discussed in a later section), not allowing the user to evaluate aquifer changes over time. Some analytic element modeling codes also restrict the user to 2-dimensional (or single-layer) modeling. The two analytic element models evaluated in this study used GFLOW (Haitjema, 2007) as the analytic element modeling code. GFLOW restricts the modeler to 2-dimensional modeling.

The advantage of analytic element models is that they are less data-intensive than finite difference models. Analytic element models are relatively quick to develop, provide an exact solution and extend the solution to an infinite domain, removing concerns about model boundaries being too restricted. Highly complex systems can be represented, as there is no limit to the number of elements which can be used to represent the system.

Clearly, the greater the number of elements used, the longer it takes to construct, populate and calibrate the model.

Time Discretization

Ground-water modeling can represent either steady state or transient conditions. In steady state conditions, aquifer stresses (recharge and discharge) are applied until there are no further changes in aquifer water levels. This can be thought of as 'infinite time.' The aquifer stresses are applied until there are no further impacts propagating through the aquifer (equilibrium conditions). In real physical systems, it can take decades (or longer) to reach a true steady state or equilibrium. At any given time, the impacts of many aquifer stresses are slowly propagating through a physical system.

In transient modeling, aquifer stresses are changed over time and the numerical equations are solved for each time increment. In Modflow, the period of time at which aquifer stresses or river properties can be changed is called a stress period. In Modflow, stress periods can be further discretized into time steps. The numerical equations are solved at every time step, allowing the modeler to evaluate changes in aquifer conditions over time increments smaller than a stress period.

Model Boundaries

One of the most important components of ground-water model design is the selection of model boundaries. Once the areal extent of the model has been determined, model boundaries are established at the outer edges of the model, between model layers and to represent flow interactions with hydraulically connected surface water (rivers, lakes and canals). The represented model boundaries reflect the modeler's 'conceptual model'; that is, the modeler's understanding of flow direction, recharge and discharge mechanisms and rates, aquifer interaction with surface water features, and hydraulic connection between aquifer layers or at the model edges.

Water movement is controlled by the head differential, or potential, between two locations and by the aquifer's physical ability to move water. Water flows from high head to low head. This differential is called the gradient. The physical ability of the aquifer to transmit water is called hydraulic conductivity or transmissivity, which is a physical property of the aquifer and the fluid. The amount of water moving from one location to another is called the flux. The flux and gradient depend on how much water is moving through a set cross-sectional area of the aquifer. Flux and gradient are proportional; if flux is increased, the gradient is increased. Boundary conditions are established based on what can be measured or hypothesized in the physical system.

The most commonly used boundary conditions in ground-water modeling are:

- Head-dependent boundaries
- Specified head boundaries
- Specified flux boundaries
- No-flow boundaries
- Specified gradient boundaries (less commonly used, available only in the deSonneville (1972) code).

With head-dependent boundaries, the flux to or from the aquifer changes depending on the changing head differential between the aquifer and the hydraulically connected entity, such as a lake or river level. When the aquifer head is below the river level, the flow is out of the river into the aquifer. When the aquifer head is above the river level, the flow is out of the aquifer into the river. If the head differential becomes high enough, the aquifer becomes perched and seeps at a steady rate, not dependent on the head differential (that is, the aquifer and the river are no longer hydraulically connected). Drain cells are a special case of head-dependent boundaries. In a drain cell, the water is modeled as leaving the aquifer via the drain. The amount of water flowing from the aquifer depends on the head differential between the aquifer and the drain, as for river cells. Once the aquifer water level drops below the drain cell elevation, the drain shuts off. Modflow provides a special case of the head-dependent boundary called the general head boundary. The general head boundary acts as a head-dependent boundary removed some distance from the physical model boundary. This allows the modeler to numerically represent a more distant boundary, thus removing or reducing boundary effects, without making the model areal extent larger.

Specified head boundaries are boundaries where the modeler establishes the aquifer level in a specific model cell. This level is held at the established level, regardless of what is going on in neighboring model cells. Specified head boundaries might be used to represent aquifer levels near a large lake, where the lake controls the aquifer water levels.

Specified head boundaries have some special properties. In order to rigidly control the aquifer water levels, the boundary must act as an unlimited source or sink of water. Similarly, head-dependent boundaries act as a source or sink of water. When specified head boundary or head-dependent boundary conditions are used, it is important to account for water supplied by or drained by the boundary. This water should be accounted for as part of the final model water budget, or the model could inadvertently be adding water to the system which the modeler does not account for in the model water budget.

With specified flux boundaries, the modeler represents a fixed amount of water continually flowing through the boundary, in or out of the aquifer. A no-flow boundary is a special case of the specified flux boundary, where the specified flux is set to 0. Specified flux boundaries are typically used at model edges to represent tributary underflow into a model, flow from an adjacent aquifer or an impermeable aquifer edge.

Specified head and head-dependent boundaries represent water flowing between the aquifer and the modeled entity. For head-dependent or specified head boundaries, the modeler should quantify the amount of water flowing between the aquifer and the hydraulically connected river or lake and check those values against field-measured values. Similarly, water supplied to (or taken from) an aquifer by a specified head boundary should be tallied and compared with what is known of the physical system. Without making these comparisons, it is possible to achieve an apparent model fit without truly matching what is known of the physical system.

The specified gradient boundary available in the deSonneville (1972) code fixes the head differential between model cells. If the aquifer head drops in a neighboring cell, the head is dropped in the specified gradient cell to keep the gradient constant. Since gradient is proportional to flux, specifying the gradient has the net effect of specifying the flux between the two cells.

The reader can find more detailed discussion about model boundaries in Anderson and Woessner (1991) and McDonald and Harbaugh (1983).

Model Water Budget

The model water budget is a very important component of a ground-water model. The modeler creates the water budget prior to actual model development. The water budget represents all water coming into or out of the modeled area. The water budget represents water from natural sources (precipitation, tributary underflow, river leakage, evaporation) as well as water from anthropogenic uses: ground-water pumping, municipal use, surface water irrigation. For a transient model, the modeler must develop a water budget for every model stress period. Every water budget must be balanced (inflows minus outflows equals change in storage). In the study area, water budgets were developed for the Lindgren model (Lindgren 1982), the USGS model (Newton, 1991) and the Treasure Valley Hydrologic Project (Petrich and Urban, 2004). The University of Idaho M3 Eagle Model and the PGG M3 Eagle Model used a combination of water budget data from the Treasure Valley Hydrologic Project and data collected by Hydro Logic Inc. Since development of the reviewed models, the Bureau of Reclamation has published a report detailing the archiving of Treasure Valley water budget data in GIS format, which may interest the reader (Bureau of Reclamation, 2008). A separate water budget exists for the Mountain Home area (Harrington, 2004).

Model Calibration

Model calibration is the phase where the modeler establishes parameters to represent the physical characteristics of the system being modeled. The most common parameters set during calibration are hydraulic conductivity (both horizontal and vertical), aquifer storativity and riverbed conductance. During model calibration, the modeler makes initial estimates of the parameters to be calibrated, uses these estimates in the model code, runs the model and them compares model-generated aquifer water levels and discharge to field-measured values (calibration targets). The modeler then systematically adjusts the parameters and re-runs the model to establish a better fit with observed values.

Model calibration can either be done by trial and error or using an automated calibration routine, such as PEST (Doherty, 2000). Calibration which is done using an automated calibration routine tends to be a more thorough calibration, as the automated routine will run the model thousands of times, checking the model predicted values against observed values and automatically setting new model parameters for the next model run.

A model may have hundreds or thousands of model cells and each cell requires parameters such as horizontal hydraulic conductivity, vertical hydraulic conductivity (for 3-dimensional models), aquifer storativity (for transient models), riverbed and drain conductance for head-dependent aquifer boundaries. In reality, the observation data is typically only several hundred measured aquifer water levels and river discharges. This presents the dilemma of there being too many degrees of freedom in establishing calibrated aquifer properties. Several methods have been used to realistically be able to calibrate several thousand parameters with only several hundred observations. During trial and error calibration, the aquifer is typically zoned into regions of similar hydraulic properties. One set of aquifer parameters (hydraulic conductivity and storativity) is used to represent each zone. Several hundred model cells may be grouped into an individual zone. This greatly reduces the number of parameters being calibrated. The use of zones, however, can have the disadvantage of producing very sharp differences in parameters in neighboring zones. There can be several orders of magnitude in calibrated hydraulic conductivity in adjacent zones, which likely does not match the physical system.

Another method to overcome this data shortage is a concept applied in the PEST automated calibration program. PEST allows the modeler to establish pilot points, points at which the aquifer parameters will be estimated. PEST calibrates the parameters at the pilot points and interpolates the parameters in between the pilot points. This eliminates the sharp change in parameters which is often experienced when zones are applied.

The deSonneville (1972) ground-water modeling code has its own automated calibration routine. When using the deSonneville automated routine, the modeler takes observed aquifer water levels, interpolates them to generate 'observed' aquifer water levels at the location of each model cell center. The deSonneville automated routine then individually calibrates the aquifer parameters in each model cell to match these 'observed' aquifer water levels. This method has the potential for establishing calibrated parameters in adjacent model cells which are orders of magnitude different from each other.

It is not uncommon for the modeler to make changes to the conceptual model during model calibration. Adjustments may be made to the volume of recharge modeled or to some boundary condition in order to make the model-predicted values better match the observed values. There is a great deal of uncertainty in most elements of a model water budget, so it is quite common to adjust elements of the water budget during model calibration. Some of the reviewed models report such adjustments during model calibration.

Model calibration is greatly improved by a) having more observed data to calibrate the model parameters to and b) adjusting model parameters and re-running the model more times. The advent of automated calibration routines has provided a great improvement to ground-water model calibration.

Data Limitations

It is safe to say that all ground-water models are data limited. This is the nature of attempting to model highly complex physical systems. The reader should note that a more complex model requires much more detailed data. For example, by adding layers to a model, the modeler must populate that model with recharge/discharge data, hydraulic conductivity (both horizontal and vertical) and storativity values for every model cell. Similarly, by using a more refined model grid, the modeler must now populate more cells with recharge and discharge data and physical properties. The complexity of a model does not necessarily reflect a more detailed level of understanding of the physical system. In many 3-dimensional models, the modeler often has limited observed aquifer water levels in the distinct model layers. The modeler also has limited understanding of physical properties or vertical fluxes between aquifer layers and often resorts to using uniform estimates for aquifer properties or layer thickness for deeper model layers. Hydraulic conductivity of river or lake-bed sediments are also usually not well known and, therefore, estimated by the modeler.

Different Model Representations

The models reviewed in this report are all based on the same physical system, although they differ in overall areal extent and purpose. A review of these seven models shows that the models resulted in very different representations of the physical system. The models use differing numbers of model layers. The final arrays of hydraulic conductivities and storativities vary greatly, sometimes by orders of magnitude. This does not necessarily make any given model correct or incorrect. They are simply different numerical representations of the same physical system.

Many of the elements of a ground-water model are interrelated. The correlation between flux and gradient, for example, was discussed earlier. It is possible (probable) to develop a ground-water model which has errors in interrelated parameters which mask each other. For example, if too much recharge is estimated in the model water budget, this may be compensated for by having hydraulic conductivities which are too high. Such compensating errors are virtually impossible to detect and to avoid. Another aspect of ground-water modeling is that the solutions to the numerical equations are non-unique. That is, two different arrays of physical parameters assigned to the model cells may provide equally good model-predicted aquifer water levels. These two attributes of ground-water models, the non-unique solution and the potential for compensating errors, help to explain the differences in resulting aquifer properties between the seven reviewed models.

Models which are developed to represent greatly changing hydrologic conditions over a long period of time are most likely to better represent the physical system. The longer the period of the model for a transient calibration and the more variation in aquifer stress that occurs during the modeled period, the more likely it is that the model is a good representation of the physical system. Although the reviewed models vary greatly in transient period represented or variation in aquifer stress, each of these models has added to the base of understanding of the hydrogeology of the Treasure Valley.

Model Reviews

The following sections include the review of each of the seven models. The models are presented in chronological order. An attempt has been made to summarize each model with approximately the same level of detail, so the reader can gain some understanding of model comparison. Each model review contains sub-sections presenting a general description, the conceptual model used, the specific model description, a section detailing model calibration and documentation and a section discussing the potential use of the model for predictive purposes.

A table summarizing the most important aspects of each model is presented with each model description. The tables are organized identically, allowing the user to quickly compare characteristics between the various models. This means that some of the characteristics listed in the table are not applicable to some of the reviewed models. Table A-1 in Appendix A provides a more comprehensive list of model attributes for all seven models for comparison purposes. Table A-1 contains more detail than is appropriate for the body of this paper. The reader may find Table A-1 useful as a reference for more detailed questions on a particular model.

Lindgren Model

General Description

The Lindgren Treasure Valley Model was developed in 1982 as a University of Idaho master's thesis by J. Lindgren. The Lindgren model is the oldest of the reviewed models. The stated model purpose was to evaluate impacts of federal irrigation and flood control projects on the economy and hydrology of the Boise Valley.

Conceptual Model

The Lindgren model covers approximately 1,500 square miles. Figure 3 shows the areal extent of the Lindgren model, as compared with the USGS western Snake Plain Model. The Lindgren model was developed to represent 1971 water year conditions.

Lindgren's geologic conceptual model is that the Boise Valley is a giant trough underlain by old volcanics and sediments and filled with Tertiary stream and lake-bed sediments comprised of interbedded clays, silts and sands. Only the upper 1,000 ft or so are considered permeable enough to be water-bearing. Lindgren acknowledges the complexity of the subsurface but determined that, for a regional model, a single layer model representation was sufficient to capture the water-bearing properties of the sub-surface.

Lindgren's hydrologic conceptual model is that the sub-surface water flows generally to the west towards the Snake River. The Snake River and the Boise River are considered hydraulically connected to the aquifer. The Boise River is a gaining river in some reaches and a losing river in others. The Snake River is a gaining river throughout the model area. Lake Lowell is also considered to be hydraulically connected to the aquifer. Lindgren's hydrologic conceptual model includes some tributary underflow from the southeast.

The model water budget was developed to reflect average water conditions for the period. The major recharge components of the water budget are recharge from surface water irrigation, tributary underflow, precipitation and river/lake/canal leakage. The major discharge components are ground-water pumping and discharge to rivers. Lindgren determined lands irrigated by surface and ground water. He estimated crop demands, diversions and canal losses to determine net irrigation returns to the aquifer or depletions from the aquifer. He also estimated gains and losses for the river reaches and for Lake Lowell.

Model Description

The Lindgren model is a regional finite-difference ground-water model of the Treasure Valley Area. Figure 9 shows the model boundaries of the Lindgren model. The model is 2-dimensional (single layer) with 43 rows and 50 columns. The model cells are 1 mile square. There are approximately 1,500 active model cells. The aquifer is represented as a single layer, unconfined aquifer, approximately 1,000 feet thick. The model was created using the deSonneville code (1972).

The Lindgren model uses head-dependent boundaries for the Snake River, the Boise River and Lake Lowell. Tributary underflow from the south is represented as a specified-gradient boundary. No-flow boundaries are used elsewhere.

Lindgren developed both steady state and transient versions of the model. The transient model was calibrated to a 1-year period, April 1, 1970 to March 31, 1971. The transient model has 21 stress periods, 17 stress periods of 15.2 days length during the irrigation period, and 4 stress periods of 30.41 days length during the non-irrigation season.

Model Calibration and Documentation

Model calibration was done using an automated calibration routine provided as part of the deSonneville (1972) code. The steady state model was calibrated first, with hydraulic conductivity and river-bed conductance being calibrated in steady state. The ending steady state aquifer water levels were used as the starting water levels for the transient calibration. The transient calibration was used to calibrate specific yield (unconfined aquifer storage). Hydraulic conductivities resulting from the steady state calibration were held constant during the transient calibration.

Calibration was done using observed water levels in 420 wells and seepage from 6 river reaches. As previously mentioned, the observed water levels in the 420 wells were interpolated to each of the 1,500 active model cells and the automated calibration routine was used to individually calibrate aquifer properties in each of the 1,500 model cells. The sum of squares of the residuals (difference between observed and model-estimated water levels in each model cell) was used to gauge calibration success. For the steady state model, the reported average residual was 4.9 feet. For the transient calibration, aquifer water levels were compared at stress periods 11 and 21, the peak of the irrigation season and the end of the simulation. The starting and ending calibration target water levels were set equal (that is, it was assumed that the simulation was for an average year and there was no change in aquifer storage). Lindgren reports having to adjust the seepage term to improve the timing and volume of water applied. Adjustments like this are common during calibration. Lindgren also reports that seasonal water level variations throughout the Boise Basin range from 1 foot to 100 feet. One-foot seasonal variations are very difficult to capture in a simulation since they can be masked by uncertainty in either measurement or recharge estimation. The final transient calibration resulted in an average residual per node of 9.1 feet, averaged for stress periods 11 and 21.

Lindgren reports obtaining a better calibration fit by allowing an upper limit on specific yield of .34 (perhaps unreasonably high). Figure 10 shows the final potentiometric surface from the Lindgren model.

Figure 11, which is difficult to read, shows the final calibrated transmissivities for each model cell for the Lindgren model. The transmissivities are in in ft^2/d x 1,000. Although difficult to read, it can be seen in Figure 11 that single digit numbers represent lower transmissivities and multiple digit numbers represent higher transmissivities. A band of high transissivity runs through the central portion of the model, approximately where the Boise River is located. Also apparent from Figure 11 is that adjacent model cells may have transmissivities which are an order of magnitude different. Also, it can be seen that the model results in up to three orders of magnitude of difference in transmissivity over a 3 cell (3 mile) distance. This is a relic of how the automated calibration routine provided by the deSonneville (1972) code worked.

Figure 12, which is also difficult to read, shows the calibrated specific yields from the transient calibration of the Lindgren model. Specific yield is a unitless ratio. The values in Figure 12 are in hundredths and range from 1 to 34 (.01 to .34). Lindgren (1982) provides further detail on calibration statistics for the interested reader.

The Lindgren model is documented in a single report which is fairly comprehensive. The report describes the geologic and hydrologic concept and the model construction and calibration. The report is old enough to not benefit from modern graphic production software, so, in some cases, figures which might be expected are not presented or are of low quality. Table 1 summarizes the principle characteristics of the Lindgren model.

Table 1. Summary description of Lindgren model.

Model Purpose	Evaluate impacts of federal irrigation and flood control projects on the economy and hydrology of the Boise Valley.
Date Created	1982.
Representation of Area/Regional Hydrology	Conceptualizes flow direction from the southeast to the west, with dominant discharge to the Snake River. The Snake and Boise Rivers and Lake Lowell are modeled as hydraulically connected.
Water Budget	Prepared by the author representing 1971 conditions.
Areal Extent	1,500 square miles, centered over the Treasure Valley.
Modeling Method Used	Finite difference model using the deSonneville model.
Model Type (Steady State or Transient)	Steady state and transient models.
Transient Period Length	1 year transient model with 17 stress periods of 15.2 days and 4 stress periods of 30.41 days.
Number of Layers	1 layer.
Grid and Model Cell Size	43 rows x 50 columns with a uniform grid of 1 mile square cells. 1,500 active model cells.
Calibration Method	Automated calibration using deSonneville calibration package.
Calibration Period	April 1, 1970 through March 31, 1971.
Calibrated Parameters	Hydraulic conductivity and river-bed conductance during steady state calibration, specific yield during transient calibration.
Calibration Targets	Observation water levels in 420 wells and seepage from 6 river reaches.
Adequacy of Documentation	Model document is reasonably thorough. Graphics are somewhat limited and difficult to read.

Model Suitability for Predictive Use

There are two limitations to the Lindgren model which must be acknowledged when ascertaining the suitability of the model for predictive purposes. The first limitation is that the model was created to reflect 1971 conditions, now 40 years old. The model recharge and discharge are out of date relative to current water practices. The second limitation is that the model uses only a single aquifer layer to represent a complex sub-surface. This, in itself, is not a trait which would exclude use of the Lindgren model for predictive purposes. However, the user must be cautioned that it is a great simplification of a complex system.

Prediction of Water Administration and Management Alternatives to Meet Projected Demand for the Next 50 Years

Although the Lindgren model does include a transient version, the transient model was only calibrated to aquifer changes over a 1-year period. This would be considered too short a transient calibration period to support predictive analyses of 50-year impacts. If the impacts being evaluated do not create large changes in aquifer stress relative to the changes in aquifer stress experienced in a normal water year, one could potentially predict the 50-year impacts of changes using the Lindgren model.

Prediction of Impacts of New Water Rights

The impacts of new water rights could be evaluated as a change in aquifer condition. That is, model inputs could be constructed to reflect the location and magnitude of the stresses to be evaluated and the model results could be used to evaluate the changes to aquifer conditions and river gains/losses due to the proposed new water rights.

Predict Impacts of Water Rights Transfers

Similarly, the impacts of water rights transfers could also be evaluated as a change in aquifer condition. That is, model inputs could be constructed to reflect the location and magnitude of the stresses to be evaluated and the model results could be used to evaluate the changes to aquifer conditions and river gains/losses due to the proposed new water rights.

Predict Impacts of Changes in Land Use

Use of the Lindgren model to evaluate changes in land use would be more difficult. Since the model reflects 1971 water use, the current model recharge and discharge does not reflect current land and water use. The recharge/discharge data sets would have to be updated to current conditions to then be used to predict impacts from future changes in land use.

Evaluate Conceptual Mitigation Solutions for New Water Diversions

Conceptual mitigation solutions for new water diversion could be evaluated similar to impacts of new water rights by evaluating only the changes from the proposed mitigation solutions.

Evaluate Ramifications of Climate Changes

Climate change scenarios would be very difficult to evaluate using the Lindgren model again because the model recharge/discharge data sets do not reflect current conditions. Additionally, climate change scenarios would presumably include extensive changes in aquifer stresses which would likely exceed the range of conditions for which the Lindgren model was calibrated.

Assess Impact of Ground-water Use on Surface Water Supplies

The Lindgren model uses hydraulically connected boundaries for the Snake River, the Boise River and Lake Lowell, so the impacts of ground-water use on surface water supplies could be evaluated using the Lindgren model. This would likely be accomplished by looking at changes in water use conditions. Table 2 summarizes the potential utility of the Lindgren model for predictive purposes.

Table 2. Predictive ability of Lindgren model.

Prediction of Water Administration and Management Alternatives for 50 Years	Transient model only calibrated to 1 year of aquifer stresses, for 50-year predictions will likely exceed the range of stresses for which the model is calibrated. Also, the model is calibrated to 1971 conditions, so predictive scenarios may entail extensive work in updating the current recharge/discharge data set for the Lindgren model.
Prediction of Impacts of New Water Rights	Relatively good as long as impacts are evaluated as change in conditions.
Prediction of Impacts of Water Rights Transfers	Relatively good as long as impacts are evaluated as change in conditions.
Predictions of Impacts of Changes in Land Use	Would require re-analysis of land use and extensive updating of model recharge/discharge data sets prior to creating scenarios to predict changes in land use.
Evaluation of Conceptual Mitigation Solutions for New Water Diversions	Relatively good as long as impacts are evaluated as change in conditions.
Evaluation of Ramifications of Predicted Climate Changes	Would require re-analysis of water availability for surface water diversions. However, modeled changes in aquifer stresses would exceed the range of stresses used for model calibration.
Ability to Assess Impact of Ground Water Use on Surface Water Supplies	Could be evaluated as unit response of river reaches to changes in water use conditions.

USGS Western Snake Plain Model

General Description

The USGS western Snake Plain model was developed as part of the Regional Aquifer Systems-Analysis (RASA) program of the USGS in 1980-1981, published in 1991 (Newton, 1991). The model purpose was to explore the regional hydrogeology of the western Snake River Plain aquifer.

Conceptual Model

Of the seven models reviewed, the USGS model has the broadest areal extent, ranging from Weiser, Idaho in the north to just west of Twin Falls, Idaho in the south. The model is the only one of the seven models reviewed to include the Mountain Home, Idaho area. Figure 1 (from Newton, 1991) shows the areal extent of the USGS model. The model area covers approximately 7,000 square miles.

The USGS model entails a more detailed geologic conceptual model. The conceptual model entails a trough throughout the Boise Valley which is shallow at the edges and deep in the center, with a lower unit of volcanic rocks at varying depths, a middle unit of fine-grained sedimentary rocks interbedded with sand lenses and overlain by an upper unit of loosely consolidated sands and gravels. Figure 13 shows the geologic conceptual model.

Part of the goal of the RASA study was detailed delineation of water usage within the studied basins. Figure 14 shows the location of ground-water and surface-water irrigated areas within the western Snake River Plain. Figure 15 shows the location of irrigation wells in the USGS study area. Inspection of Figures 14 and 15 shows that most of the irrigation activity is centered in the Treasure Valley area. There are small pockets of activity around Mountain Home, Idaho and south of the Snake River near Bruneau, Idaho. There is a large, undeveloped region between Mountain Home, Idaho and the Treasure Valley, which is largely non-irrigable volcanics.

This discontinuity of irrigation activity and possible discontinuity of a productive aquifer created some challenges for modeling the western Snake River Plain as a whole. Personal correspondence with G. Newton indicates that there is some uncertainty regarding the continuity of the aquifer between Mountain Home, Idaho and the Treasure Valley region. The USGS model report (Newton, 1991) characterizes the aquifer below Mountain Home as perched, implying either a perched system or a lack of regional continuity.

Figure 16 shows the potentiometric surface for the USGS model area, based on 1980 water level measurements. Also shown on Figure 16 are the regional flow directions inferred from the potentiometric surface. Figure 16 shows regional flow to the Snake River, with localized flow to the Boise River and the Payette River. Figure 17 shows a generalized conceptual model of subsurface flow for a cross-section from the Snake

River, through Lake Lowell and the Boise River. The cross-section shows flow out of Lake Lowell and into the Boise River (at that locality) and the Snake River.

The primary sources of recharge to the model are infiltration from surface water irrigation, tributary underflow across model boundaries and precipitation. The primary sources of discharge are ground-water discharge to rivers and drains and ground-water pumping. Drains are used to represent areas where the water table is near land surface, primarily along portions of the Boise River.

The USGS model hypothesized a small amount of underflow entering the model from the east, along most of the eastern edge of the model. The boundary of the USGS model also extends west of the Snake River and includes underflow entering the model area from the west.

Model Description

The USGS model is a regional finite difference model developed using Modflow (McDonald and Harbaugh, 1983). The USGS model comprises both a steady state and transient version, representing 1980 water conditions. It is a 3-dimensional model with 25 rows, 72 columns and 3 layers. The model has a uniform grid with cells which are 2 mi x 2 mi. The model grid is rotated 45° clockwise from the north to better align the grid with the principal flow direction. The rotation also serves to reduce the number of inactive model cells. Figure 18 shows the USGS model grid. There are approximately 8,000 active model cells. Layer 1, which is represented as unconfined, is approximately 500 ft thick. Layers 2 and 3, both represented as confined, are 4,000 ft and 7,000 feet thick, respectively.

Figure 19 shows the model layering used to represent the subsurface. Comparison of the geologic conceptual model shown in Figure 13 with Figure 19 demonstrates the idea that ground-water models have difficulty capturing the complexity of the physical system. As previously noted, the subsurface geology of the Treasure Valley region is very complex. Modelers in this region are forced to generalize the complexity in order to achieve a reasonable, working model.

Model layer 1 represents an unconfined unit of sedimentary and volcanic rock. The top of layer 1 was generated as the potentiometric surface developed from 1980 water level measurements. The bottom of layer 1 was established as a uniform 500 feet below the top. Model layer 2 represents 4,000 feet of fine-grained sedimentary and volcanic rocks hosting a confined aquifer. Model layer 3 represents 7,000 feet of volcanic rocks, also hosting a confined aquifer.

The USGS model uses specified flux boundaries to represent tributary underflow for most of the model perimeter. No-flow boundary conditions are used at the bottom of layer 3. Head-dependent boundaries are used to represent river cells for the Snake River, the Payette River, the Boise River and Lake Lowell. Head-dependent drain cells are used to represent Boise River sediments and a portion of the Boise River. Figure 20 shows the boundary conditions for USGS model layer 1. Boundary conditions for USGS model layers 2 and 3 are shown in Figure 21.

The steady state model was developed using 1980-1981 water conditions as an average representation of hydrologic conditions. The transient model was designed to represent 1881-1980 conditions. Recharge and discharge were estimated in 10-year increments for the period. The 100-year period was selected to provide a transient model which spanned pre-development to current practices.

Model Calibration and Documentation

The USGS steady state model was calibrated to 1980 conditions, assuming that 1980 was an average year and that the basin was in a near-equilibrium state in 1980 (that is, not experiencing long-term water level gains or declines). The steady state calibration was done by trial and error. Each model layer was zoned into 11 sub-areas of similar hydrologic properties. Figure 18 shows the location of the sub-areas. Transmissivity and storativity were assumed uniform throughout each sub-area in each layer. Similar to the Lindgren model, the steady state calibration was used to calibrate transmissivity (and hydraulic conductivity in the unconfined layer) and the transient calibration was used to calibrate storativity and specific yield. This means that in the steady state calibration, 55 parameters (transmissivity in each of 11 sub-areas in each of three layers and vertical transmissivity for each zone between the layers) were calibrated. Observed water levels from 305 wells were used for the steady state calibration. Most of the measured wells were in layer 1, with very few available in layers 2 and 3 (again underscoring the difficulty of obtaining useful data for deeper model layers). River and drain conductance values were assigned rather than calibrated. The steady state calibration resulted in layer 1 hydraulic conductivity ranging from 4 to 43 ft/d. Transmissivity in Layer 2 ranged from 900 to 12,000 ft^2/d. Transmissivity in layer 3 was a uniform 8,600 ft^2/d. Vertical hydraulic conductivity between layers 1 and 2 ranged from 9 to 900 ft/d and was a uniform 22 ft/d between layers 2 and 3.

Newton (1991) refers to the transient model as a transient analysis. Book values were assigned for specific yield (0.1 in layer 1) and for storativity ($4x10^{-3}$ and $7x10^{-3}$ in layers 2 and 3, respectively). River gains and losses were estimated for each 10-year period and Newton reports the model-estimated gains and losses compared with the water budget estimates.

The USGS model is documented in a single model report, with supporting reports and maps for the region which were generated as part of the RASA analysis. The report quality is generally very good, providing the reader with all of the necessary detail. Table 3 summarizes the principle characteristics of the USGS model.

Table 3. Summary description of USGS model.

Model Purpose	Explore regional hydrogeology of the western Snake river Plain aquifer.
Date Created	Created in early 1980s, published in 1991.
Representation of Area/Regional Hydrology	Primary sub-surface flow is towards the Snake River. Small amounts of underflow along eastern and western boundaries of model. Snake River, Boise River, Payette River and Lake Lowell represented as hydraulically connected. Series of drains used to represent water table near land surface in vicinity of Boise River.
Water Budget	Developed for the RASA effort. Primary sources of recharge: surface irrigation, underflow and precipitation. Primary sources of discharge: river gains, discharge to drains and ground-water pumping.
Areal Extent	7,000 square miles.
Modeling Method Used	Finite difference model using Modflow.
Model Type (Steady State or Transient)	Steady state and transient models.
Transient Period Length	Ten 10-year stress periods, for a total of 100 years.
Number of Layers	3 layers. Layer 1 500 ft thick, unconfined. Layer 2 4,000 ft thick, confined. Layer 3 7,000 ft thick, confined.
Grid and Model Cell Size	25 rows x 72 columns, uniform grid, 2 miles square. Approximately 8,000 active model cells.
Calibration Method	Trial and error calibation using 11 zones in each model layer.
Calibration Period	1881-1980.
Calibrated Parameters	Horizontal hydraulic conductivity in layer 1 and horizontal transmissivity in layers 2 and 3, and vertical conductivity during steady state. Modelers used assigned values for river and drain conductances. Transient was an analysis: book values used for aquifer storage.
Calibration Targets	305 water level observations, primarily in layer 1.
Adequacy of Documentation	Documentation reasonably good.

Model Suitability for Predictive Use

There are several limitations to the USGS model which must be acknowledged when ascertaining the suitability of the model for predictive purposes. The first limitation is that the model was created to reflect 1980 conditions, now 30 years old. The model recharge and discharge are out of date relative to current water practices. Another limitation is that the transient model was not calibrated, it was done as an analysis. Therefore, caution should be used when using the USGS model for transient predictions. The modelers reported problems encountered during model calibration, particularly in the Mountain Home area but also along model boundaries. Calibration problems in the Mountain Home area could have been caused by a lack of data or by the assumption that the area was in equilibrium when, in fact, it was likely in a state of decline.

Prediction of Water Administration and Management Alternatives to Meet Projected Demand for the Next 50 Years

Despite being a transient analysis, the USGS model did a reasonable job of matching estimated river gains for the 100-year demonstration period. The 100-year period of the transient model would have included wide extremes in aquifer stresses, so using the model for 50-year predictions may have some potential.

Prediction of Impacts of New Water Rights

The impacts of new water rights could be evaluated as a change in aquifer condition. That is, model inputs could be constructed to reflect the location and magnitude of the stresses to be evaluated and the model results could be used to evaluate the changes to aquifer conditions and river gains/losses due to the proposed new water rights.

Predict Impacts of Water Rights Transfers

Similarly, the impacts of water rights transfers could also be evaluated as a change in aquifer condition. That is, model inputs could be constructed to reflect the location and magnitude of the stresses to be evaluated and the model results could be used to evaluate the changes to aquifer conditions and river gains/losses due to the proposed new water rights.

Predict Impacts of Changes in Land Use

Use of the USGS model to evaluate changes in land use would be more difficult. Since the model reflects 1980 water use, the current model recharge and discharge does not reflect current land and water use. The recharge/discharge data sets would have to be updated to current conditions to then be used to predict impacts from future changes in land use.

Evaluate Conceptual Mitigation Solutions for New Water Diversions

Conceptual mitigation solutions for new water diversion could be evaluated similar to impacts of new water rights by evaluating only the changes from the proposed mitigation solutions.

Evaluate Ramifications of Climate Changes

Climate change scenarios would be very difficult to evaluate using the USGS model, again because the model recharge/discharge data sets do not reflect current conditions. An advantage of the USGS model over the Lindgren model for predicting the impacts of climate change is that the USGS model transient analysis did span a period of extreme changes in aquifer stresses.

Assess Impact of Ground-water Use on Surface Water Supplies

The USGS model uses hydraulically connected boundaries for the Snake River, the Boise River, the Payette River and Lake Lowell, so the impacts of ground-water use on surface water supplies could be evaluated using the USGS model. This would likely be accomplished by looking at changes in water use conditions. Table 4 summarizes the potential utility of the USGS model for predictive purposes.

Table 4. Predictive ability of the USGS model.

Prediction of Water Administration and Management Alternatives for 50 Years	Transient analysis was done over a 100 year period of extensive changes in aquifer stress, so the USGS model has some potential for 50 year predictive ability. Modeler's noted some problems encountered during calibration.
Prediction of Impacts of New Water Rights	Relatively good as long as impacts are evaluated as change in conditions.
Prediction of Impacts of Water Rights Transfers	Relatively good as long as impacts are evaluated as change in conditions.
Predictions of Impacts of Changes in Land Use	Would require re-analysis of land use and extensive updating of model recharge/discharge data sets prior to creating scenarios to predict changes in land use.
Evaluation of Conceptual Mitigation Solutions for New Water Diversions	Relatively good as long as impacts are evaluated as change in conditions.
Evaluation of Ramifications of Predicted Climate Changes	Would require re-analysis of water availability for surface water diversions.
Ability to Assess Impact of Ground Water Use on Surface Water Supplies	Could be evaluated as unit response of river reaches to changes in water use conditions.

Treasure Valley Hydrologic Project Model

General Description

The Treasure Valley Hydrologic Project (TVHP) model was developed by a team of researchers led by C. Petrich. Development was jointly done by the University of Idaho Water Resources Research Institute and the Idaho Department of Water Resources. The model was published in 2004. Model development was funded by a collaborative group of stakeholders representing both private and government entities. A technical advisory committee (TAC) oversaw model design and development. The TAC was comprised of experts in the hydrology of the Treasure Valley and ground-water modeling. The TVHP design and construction was done in an open environment, allowing regional experts to oversee the modeling process and provide feedback on technical decisions.

The TVHP model purpose was to evaluate the effects of large-scale increases in ground-water withdrawals on regional ground-water levels and to evaluate the potential effects of altered recharge rates associated with conversion of agricultural land to urban use.

The TVHP was a large, well-funded, multi-year program which included extensive field work. Seven mass measurements were conducted (spring and fall of 1996, 1998 and 2000, and fall of 2001). Four deep wells were constructed in the study area. Each of the wells has multiple completions; that is, each well contains piezometers which sample discrete subsurface intervals, allowing researchers to characterize aquifer water levels and water chemistry in distinct subsurface intervals. The TVHP project also commissioned several seismic surveys and digitized geophysical well logs by Boise State University for subsurface characterization. The TVHP also included geochemical analyses in an attempt to characterize recharge and discharge zones and water residence times. In addition to the sub-surface characterization, seepage measurements were done as part of the TVHP by the U. S. Geological Survey in irrigation canal reaches, the Boise River and the New York Canal.

Conceptual Model

Figure 4 shows the areal extent of the TVHP model, as compared with the USGS western Snake River Plain model. Although still a regional model, the TVHP model covers a significantly smaller areal extent than the USGS model. The TVHP model area covers approximately 3,000 square miles. Figure 2, which shows areas of highest planned development in the Treasure Valley area, shows the TVHP model boundary in pink. It can be noted in Figure 2 that two areas of projected growth extend just outside the boundary of the TVHP model: in the Eagle, Idaho area and at the southeast boundary of the model area.

Petrich (2004) describes the regional geology as a complex series of interbedded, tilted, faulted and eroded sediments extending to depths of over 6,000 ft. Petrich (2004) describes a shallow local flow system and a deeper regional aquifer system.

The model area is bounded by the Snake River on the southwest. The southeast boundary was selected to end at Lucky Peak Reservoir. Regional ground-water flow in this area was presumed to be to the southwest, towards the Snake River, so the southeast boundary was selected as a no-flow boundary along a ground-water divide apparent on potentiometric surface maps. The model is bounded by the foothills to the northeast. The northwest boundary was selected along a ground-water divide also apparent on potentiometric surface maps. North of the ground-water divide (outside the study area) is regional flow to the Payette River. South of the ground-water divide is regional flow to the Boise River. Selection of boundaries based on ground-water divides will be discussed below. Figure 22 shows the TVHP model boundaries.

A water budget was generated for the TVHP (Petrich and Urban, 2004 and Urban, 2004). Figure 23 shows the distribution of recharge for the TVHP model. Significant recharge occurs in the northern 2/3 of the model area, with a concentration of recharge along the New York Canal. Figure 23 shows relatively little net recharge in the southern portion of the model area. This water budget was later used, in part, by the University of Idaho for the M3 Eagle model and by Pacific Groundwater Group for their M3 Eagle model. The TVHP water budget also became the basis for the Bureau of Reclamation's distributed parameter database (Bureau of Reclamation, 2009). Table 5 shows the estimated inflows and outflows for the TVHP water budget.

Table 5. TVHP water budget inflows and outflows (from Petrich and Urban, 2004).

1996 Water Budget – Inflows	Annual flux (af-yr)
Canal seepage, seepage from rivers and streams, flood irrigation and precipitation, recharge by other uses, and recharge from rural domestic septic systems	1,008,000
Seepage from Lake Lowell	19,000
Underflow	8,000
Total Inflows	1,035,000
1996 Water Budget – Outflows	**af-yr**
Domestic and industrial withdrawals, municipal irrigation, self-supplied industrial, agricultural irrigation, rural domestic withdrawals, and stock watering	199,000
Discharge to rivers and streams	800,000
Total Outflows	999,000
Difference	+36,000

Model Description

The TVHP model is a regional finite difference model of Treasure Valley hydrology, constructed using Modflow. The model is a steady-state model representing water year 1996. The TVHP model is a 3-dimensional model with 61 rows, 49 columns and 4 layers, with a uniform 1 mi x 1 mi grid and 5,448 active model cells. Figure 24 shows the TVHP model grid.

The TVHP model layers were selected to represent the subsurface geology, as determined by field work, well log analysis and geophysics. Layer 1 is 200 ft thick and represents the coarse river and lake sediments. Layer 1 is represented in the model as unconfined. Layer 2 is 200 ft thick and represents intermediate sediments. Layers 3 and 4 are both 400 feet thick and represent deep Idaho group sediments. Layers 2 through 4 are represented in the model as confined aquifers.

The TVHP model used specified flux boundaries to represent tributary underflow from the northeast. No-flow boundaries were employed in the southeast and along the northern edge, representing ground-water divides, and at the bottom of layer 4. Constant head boundaries were used to represent the Snake River. In this area, the Snake River is a gaining river, with the aquifer underlying the Treasure Valley discharging to the river. Head-dependent river cells were used to represent the Boise River. General head boundaries were used to represent Lake Lowell. It is not clear why general head boundary cells were selected to represent Lake Lowell, however the general head boundary functions very similarly to a river boundary in Modflow. Head-dependent drain cells were used extensively throughout the Boise River sediments where the water table is close to land surface. Figure 24 shows the layer 1 boundary conditions for the TVHP model.

Model Calibration and Documentation

TVHP model calibration was done using PEST Pilot Points. Only a steady state model was calibrated. Petrich and Urban (2004) documents the reason for not doing a transient calibration as two-fold: a) transient water budget data were not available to the modelers at the time of the TVHP project to support a transient calibration and b) there were not sufficient long-term changes in aquifer water levels throughout the Treasure Valley to support a transient calibration. Approximately 200 observation wells were used for the TVHP calibration. Figures 25 through 28 show the location of observation wells in Layers 1 through 4, respectively. As can be seen in Figures 25 through 28, there are fewer and fewer observation wells in each successive layer. Additionally, it is often difficult to assign a water level observation to a specific layer: a well may be open to multiple aquifer layers and the measurement may reflect an average of several layers.

Calibration entailed the use of 44 PEST pilot points in each model layer. Layers 3 and 4 were combined during the calibration due to the lack of observation wells in Layer 4. Horizontal and vertical hydraulic conductivity were calibrated in each model layer. Table 6 (from Petrich and Urban, 2004) lists the number of calibration parameters in each layer. In addition to the previously mentioned observation wells, discharge data from canals and rivers were also used as calibration targets. Petrich and Urban (2004) also documents the use of several thousand parameters called 'prior information' used during model calibration. The prior information was predominantly used to prevent excessive heterogeneity from being introduced during calibration. However, several vertical water level differences were also used as prior information, helping PEST to more accurately calibrate the hydraulic conductivity in the respective model layers.

Table 6. Number of calibration parameters used for TVHP model calibration (from Petrich and Urban, 2004).

Parameter	Total Number of Parameters	Number of Tied Parameters	Comments
Layer 1 K_h	44	1	
Layer 2 K_h	44	2	
Layer 3 K_h	44	2	
Layer 1 K_v	44	36	Individual pilot point parameters tied to one of the following: PP4, PP7, PP9, PP16, PP19, PP23, PP28, and PP42
Layer 2 K_v	44	40	Individual pilot point parameters tied to one of the following: PP9, PP16, PP19, and PP42
Layer 3 K_v	44	40	Individual pilot point parameters tied to one of the following: PP9, PP16, PP19, and PP42
Underflow	6		Fixed values
Total Parameters	270	121	

Figure 29 shows the distribution of PEST pilot points and the calibrated horizontal hydraulic conductivity for layer 1. Figures 30 and 31 show the same data for layers 2 and combined layer 3/4, respectively. The distribution of vertical hydraulic conductivity for layers 1, 2 and combined layer 3/4 are shown in Figures 32 through 34, respectively. Figure 35 shows the simulated versus observed potentiometric contours for Layer 1. Figure 36 shows the TVHP model potentiometric contours for cross-sections at row 18 and column 36, giving the reader an idea of how the model represents sub-surface flow.

Table 7 shows the simulated inflows and outflows from the TVHP model. As previously mentioned, where head-dependent boundary conditions, such as drain cells, river cells, specified head cells and general head boundaries, are used in a ground-water model, care must be taken to account for water entering or leaving the model area via these cells, since these boundary conditions can be an unlimited source or sink of water.

Table 7. TVHP simulated inflows and outflows (from Petrich and Urban, 2004).

Base Simulation Inflows	Flux (ft3/day)	Flux (af-yr)
Constant head (Snake River)	28,891	242
Wells (underflow)	108,000	905
Drains	-	-
River leakage (Boise River)	5,784,138	48,467
Head-dependent boundaries (Lake Lowell)	1,537,895	12,886
Recharge (excluding recharge from underflow, wells, drains, river leakage, and head-dependent boundaries)	116,205,088	973,711
Total Inflows	123,664,008	1,036,211
Base Simulation Outflows		
Constant head (Snake River)	17,350,556	145,385
Wells	23,076,956	193,368
Drains	36,667,716	307,248
River leakage (Boise River)	46,486,872	389,525
Head-dependent boundaries (Lake Lowell)	81,962	687
Recharge	-	-
Total Outflows	123,664,064	1,036,212
Summary		
Inflows–Outflows	(56)	(0)
Percent discrepancy	0.00	0.00

Documentation of the TVHP model includes reports on the geochemical analyses, seepage studies, water budget, model development and predictions and an executive summary. TVHP is a very well documented model. Table 8 summarizes the principle characteristics of the TVHP model.

Model Suitability for Predictive Use

Prediction of Water Administration and Management Alternatives to Meet Projected Demand for the Next 50 Years

A primary limitation of the TVHP model is that it is steady state, so all predictions are limited to equilibrium predictions. No intermediate impacts are available. The TVHP model is a very recent regional model of the Treasure Valley area, providing a good tool for assessment of regional water administration questions.

The selection of model boundaries based on ground-water divides presents a problem for predictive scenarios. Scenarios which entail extreme changes in water use can potentially

Table 8. Summary description of the TVHP model.

Model Purpose	Evaluate the effects of large-scale increases in ground-water withdrawals on regional ground water levels and to evaluate the potential effects of altered recharge rates associated with conversion of agricultural land to urban use.
Date Created	2004.
Representation of Area/Regional Hydrology	Regional flow presumed to be southwest towards the Snake River. The northern boundary of the model is a ground-water divide, with flow to the south towards the Boise River and flow to the north of the divide (outside the model boundary) towards the Payette River. The southeast boundary is presumed to be a ground-water divide, with flow to the southwest towards the Snake River.
Water Budget	A water budget was developed for the TVHP. Sources of recharge include precipitation, recharge incidental to surface water irrigation, underflow and river leakage. Sources of discharge include agricultural and municipal and industrial pumping and aquifer leakage to rivers, drains and canals.
Areal Extent	3,000 square miles.
Modeling Method Used	Finite difference model using Modflow.
Model Type (Steady State or Transient)	Steady state.
Transient Period Length	N/A
Number of Layers	4 layers. Layer 1—200 ft thick, unconfined representing shallow sediments. Layer 2—200 ft thick, confined representing intermediate sediments. Layers 3 and 4—each 400 ft thick, representing confined deep sediments.
Grid and Model Cell Size	61 rows x 49 cols, uniform grid with 1 mi x 1 mi cells. 5,448 active model cells.
Calibration Method	Automated calibration using Pest Pilot Points. 44 pilot points in each of 3 layers (layers 3 and 4 combined for calibration).
Calibration Period	N/A
Calibrated Parameters	Horizontal hydraulic conductivity/transmissivity at each pilot point in each layer. Vertical conductivity at each pilot point between layers. River-bed and drain conductance.
Calibration Targets	Aquifer water levels in 200 observation wells. Additionally, several thousand pieces of prior information, observations used to prevent excessive heterogeneity.
Adequacy of Documentation	Very well documented model.

impact the location of a ground-water divide, thus increasing uncertainty in model predictions.

Another consideration in the use of the TVHP model for assessing management alternatives is that, as can be seen in Figure 2, several of the areas of highest projected growth in the Treasure Valley fall right on the TVHP model boundary. This will also introduce uncertainty to TVHP model predictions of impacts of growth in those areas.

Prediction of Impacts of New Water Rights

The TVHP model would be suitable for prediction of steady state impacts of new water rights. (See note above about the potential for changes in water use impacting boundaries based on ground-water divides.)

Predict Impacts of Water Rights Transfers

The TVHP model would be suitable for prediction of steady state impacts of water rights transfers within the Treasure Valley. (See note above about the potential for changes in water use impacting boundaries based on ground-water divides.)

Predict Impacts of Changes in Land Use

The TVHP model would be suitable for prediction of steady state impacts of changes in land use within the Treasure Valley. (See note above about the potential for changes in water use impacting boundaries based on ground-water divides.)

Evaluate Conceptual Mitigation Solutions for New Water Diversions

The TVHP model would be suitable for prediction of steady state impacts of conceptual mitigation solutions within the Treasure Valley. (See note above about the potential for changes in water use impacting boundaries based on ground-water divides.)

Evaluate Ramifications of Climate Changes

The TVHP model would be suitable for prediction of steady state impacts of climate changes within the Treasure Valley. (See note above about the potential for changes in water use impacting boundaries based on ground-water divides.)

Assess Impact of Ground-water Use on Surface Water Supplies

The TVHP model would be suitable for prediction of steady state impacts of ground-water use on surface water supplies within the Treasure Valley. (See note above about the potential for changes in water use impacting boundaries based on ground-water divides.) Table 9 summarizes the potential utility of the TVHP model for predictive purposes.

Table 9. Predictive ability of the TVHP model.

Prediction of Water Administration and Management Alternatives for 50 Years	TVHP model is steady state only. Potential limitations in predictive ability due to selection of boundaries based on ground-water divides. Also, some areas of potential growth outside current model boundaries.
Prediction of Impacts of New Water Rights	TVHP model suitable for steady state predictions. Large-scale changes in water use may alter boundaries based on ground-water divides.
Prediction of Impacts of Water Rights Transfers	TVHP model suitable for steady state predictions. Large-scale changes in water use may alter boundaries based on ground-water divides.
Predictions of Impacts of Changes in Land Use	TVHP model suitable for steady state predictions. Large-scale changes in water use may alter boundaries based on ground-water divides.
Evaluation of Conceptual Mitigation Solutions for New Water Diversions	TVHP model suitable for steady state predictions. Large-scale changes in water use may alter boundaries based on ground-water divides.
Evaluation of Ramifications of Predicted Climate Changes	TVHP model suitable for steady state predictions. Large-scale changes in water use may alter boundaries based on ground-water divides.
Ability to Assess Impact of Ground Water Use on Surface Water Supplies	TVHP model suitable for steady state predictions. Large-scale changes in water use may alter boundaries based on ground-water divides.

University of Idaho M3 Eagle Model

General Description

The University of Idaho (U of I) M3 Eagle model was developed by S. Douglas (2007) as a master's thesis at University of Idaho, in collaboration with Hydro Logic, Inc. of Boise, Idaho. The model purpose included evaluation of the ground water flow conditions in the area of the proposed M3 Eagle development, particularly to test out a hydrogeologic model proposed by Hydro Logic, Inc. (Squires and others, 2007), and to evaluate the possible impacts of proposed pumping from the M3 Eagle development. Development of the U of I M3 Eagle Model was funded by a developer interested in building a large subdivision near Eagle, Idaho.

Conceptual Model

Figure 37 shows the study area for the U of I M3 Eagle model. The focus area of interest, near the proposed development, is outlined in red in Figure 37. It can be seen in

Figure 37 that the model area was selected to be significantly greater than the focus area of interest, in order to minimize boundary effects. The model is a sub-regional model and covers an area of approximately 700 square miles (Figure 37).

The U of I M3 Eagle model employs a new interpretation of the hydrogeology for the area. Squires and others (2007) hypothesize that there is a highly productive sand aquifer, named the Pierce Gulch Sand aquifer, which is recharged by leakage from the New York Canal to the south of the study area and which flows north, discharging to the Payette River. Figure 38 (from Squires and others, 2007) shows a conceptual model of the Pierce Gulch Sand aquifer. The aquifer is bounded on the east by a fault plain. The bottom of the Pierce Gulch Sand aquifer is bounded by the low permeability Terteling Springs mudstone and is confined from above by clays and shallow sedimentary aquifers. Squires and others (2007) identified the existence and extent of these Pierce Gulch sands through interpretation of geophysical logs. Squires and others (2007) believe that this is the aquifer previously misidentified by researchers as the Willow Creek aquifer, which, according to Squires and others (2007) is truncated by the West Boise fault (Figure 39). The Pierce Gulch Sand aquifer is thought to be highly productive and to supply sub-surface water to the Eagle/Star/Meridian, Idaho area. Squires and others (2007) characterize the Pierce Gulch Sand aquifer as "benefit(ing) from a strong source of recharge from the southeast from surface water irrigation diversions and the upper Boise River…". The amount of recharge to the Pierce Gulch Sand aquifer from the south is not quantified in Squires and others (2007). To date, this hydrologic interpretation of sub-surface flow in the Eagle, Idaho area has yet to be corroborated by other researchers.

Douglas did extensive field work, collecting water level measurements and developing a potentiometric surface map which is shown in Figure 37. The steep contours in the northeast area are in the Willow Creek aquifer to the east of the fault shown on Figure 38. Douglas charactizes regional flow as generally southeast to northwest, based on the potentiometric surface map shown in Figure 37.

Douglas (2007) used precipitation recharge rates based on data from Urban (2004) and recharge rates from irrigation and septic systems developed by Hydro Logic, Inc. of Boise, Idaho. The model was developed using 2006 water use data.

Model Description

The U of I M3 Eagle model is a 3-dimensional, finite difference, steady state model, which was developed using Modflow. The model has 46 rows, 62 columns and 8 layers and uses a uniform grid with cells which are 0.5 mi x 0.5 mi. The U of I M3 Eagle model has 22,816 active model cells. Figure 40 shows the U of I M3 Eagle model grid. Douglas (2007) documents two models: a quasi-steady state model representing current conditions and a steady state model representing pre-development conditions.

The eight model layers were selected to represent the modeler's hydrologic and geologic concept of the region. Figure 41 shows a cross-section of the model, showing varying model layer thickness. Model layers 1 through 4 are thicker to the east and thin out to the west. This represents thicker granites and volcanics in the east part of the study area, thinning out to sediments in the west. In the Modflow representation, these layers do not completely disappear in the west, but are represented as only 1 foot thick. Table 10 shows the subsurface layers which are represented by the model layers. Of particular note is that layer 4 is a 3-foot thick confining clay layer, layers 5 through 7 total 650 feet of thickness and represent the hypothesized Pierce Gulch Sand aquifer, underlain by a deep clay and granite unit in layer 8.

The U of I M3 Eagle model uses specified flux boundaries to represent areal recharge and pumping. Head-dependent general head boundary cells are used in layer 8 (in the steady state model, and, presumably, in the quasi-steady state model) to represent the distant effects of the Snake River (shown in Figure 42) and in layers 6 and 7 to represent subsurface inflow (Figures 43 and 44). Head-dependent river cells are used to represent the Boise River, the Payette River and Black Canyon Reservoir. Douglas (2007) provides no figure showing the location of surface head-dependent boundaries. The general head boundaries assigned in layer 6 are in the southeast corner of the grid, running north-south and along the western edge, with a dozen or so general head boundary cells running east-west along the northwestern edge (Figure 43). The general head boundaries in layer 7 (Figure 44) are assigned along the whole southern edge. Douglas (2007) describes these boundaries as representing inflows on the southeastern side and outflows on the western and northwestern side. Douglas (2007) refers to the water level contours shown in Figure 37 in describing the inference of regional flow direction; however, the contours shown in Figure 37 at the base of the model area would indicate flow in a westerly direction at the southeast boundary and a northwesterly direction along the southwest edge. It is difficult to discern whether the contours shown in Figure 37 are representative of model layers 6 and 7 (two of the layers representing the Pierce Gulch Sand aquifer); nonetheless, Douglas (2007) refers to Figure 37 while describing placement of the general head boundaries in model layers 6 and 7. Selection of the location of the general head boundaries shown in Figures 43 and 44 is, however, consistent with the flow direction hypothesized by Squires and others (2007) for the Pierce Gulch Sand aquifer.

Model Calibration and Documentation

Model calibration was done using a combination of trial and error calibration and automated calibration using PEST pilot points. The trial and error calibration was done with zones and book values for hydraulic conductivity. Horizontal hydraulic conductivity and riverbed conductance were the calibrated parameters. Vertical hydraulic conductivity was assumed to equal 0.1 x horizontal hydraulic conductivity. Once field pumping test data were available, the estimated hydraulic conductivities from

the pumping tests were used in an automated calibration. The automated calibration entailed using 440 PEST pilot points. Douglas (2007) does not document how many pilot points are in each model layer. An effort was made to calibrate a transient version of the model, but there was insufficient data to support the transient model (Douglas, 2007).

Water levels from 137 wells were used for calibration. Additionally, approximately 540 interpolated water levels were used where there were insufficient measured values. It is not known how many observations were available in each model layer. As often happens, the conceptual recharge model was modified during calibration in order to achieve a better fit. Douglas (2007) documents six model evolutions before settling on the final model. The final model, Model 6, is presented in terms of calibration fit in the Pierce Gulch Sand aquifer. No final water budget is presented for the quasi-steady state model, comparing model simulated flows (including flows into and out of the model regime via the general head boundary cells) with estimated flows. Figure 45 shows maps of the calibrated hydraulic conductivities for layers 1 through 8 for the U of I M3 Eagle model. Figure 46 shows the model-generated water level contours for model layer 6.

The U of I M3 Eagle model is documented in a master's thesis. The document is fairly thorough, but as noted in the above discussion, some relevant information is not included. Table 11 summarizes the principle characteristics of the University of Idaho M3 Eagle model.

Model Suitability for Predictive Use

Prediction of Water Administration and Management Alternatives to Meet Projected Demand for the Next 50 Years

The U of I M3 Eagle model has some limited utility for predictive use. The model is a sub-regional model, but covers an area of approximately 700 sq mi, so the extent is large enough to warrant use for some management purposes. However, the model is steady state, restricting predictive use to equilibrium conditions, with no intermediate predictions available. Also, the model was designed to assess water use in the proposed Pierce Gulch Sand aquifer. The Pierce Gulch Sand aquifer is relatively isolated from surface activity in this model, so the model will have limited use for predicting the impacts of changes at land surface. It was not designed for such predictions. Another factor is that the hydrogeologic concept employed by this model is a new interpretation for the region and would benefit from further outside review.

Table 10. Description of model layers for University of Idaho M-3 Eagle model (from Douglas, 2007).

Layer Number	Layer Elevation (ft amsl)	Layer Thickness (ft)	Lithology of the Layer
1	~5,000 to 3,600	1,400	Granite (Idaho batholith) on the eastern side of the model domain; volcanics, Columbia River basalts in the northeastern area; and sediments covering the remainder of the model domain
2	3,600 to 2,700	900	Granite on the eastern side beneath Layer 1; Columbia River basalts in the northeast under Layer 1; and sediments covering the remainder of the model domain
3	2,700 to 2,503	197	Granite on the eastern side beneath Layer 2; and sediments covering the remainder of the model domain
4	2,503 to 2,500	3	Clay beneath the Boise River in the southeastern portion of the model domain; granite on the eastern side beneath Layer 3; and sediments covering the remainder of the model domain
5	2,500 to 2,350	150	Pierce Gulch Sand aquifer system dipping at an angle of approximately one degree in reality intersects the land surface in this layer of the model; the granite body extends between Layer 4 and the base of the model; and sediment composes the remaining areas
6	2,350 to 2,100	250	Layer 6 is composed primarily of Pierce Gulch Sand from the fault to the southwestern boundary of the model domain; the granite body extends through Layer 6 to the base of the model; and sediment composes the remaining areas
7	2,100 to 1,850	250	Pierce Gulch Sand dips into this layer; the granite body extends through Layer 7 to the base of the model; and sediment composes the remaining areas
8	1,850 to 0	1850	Clay largely composes this layer; and the granite body extends to the base of the model.

Table 2. Description of the layers of the model.

Prediction of Impacts of New Water Rights

The impacts of new water rights could be assessed in steady state using the U of I M3 Eagle model only if the new water rights are exclusively in the Pierce Gulch Sand aquifer.

Predict Impacts of Water Rights Transfers

The impacts of water rights transfers could be assessed in steady state using the U of I M3 Eagle model only if the water rights transfers are exclusively in the Pierce Gulch Sand aquifer.

Predict Impacts of Changes in Land Use

Impacts of changes in land use would be difficult to assess using the U of I M3 Eagle model, since the model was developed primarily to evaluate hydrologic conditions in the Pierce Gulch Sand aquifer and the model isolates the aquifer from surface activity.

Table 11. Summary description of the University of Idaho M3 Eagle model.

Model Purpose	Evaluate ground-water flow conditions in the vicinity of the proposed M3 Eagle development; test conceptual hydrogeologic model proposed by HLI and evaluate the impacts to the aquifer of proposed pumping in the M3 Eagle development.
Date Created	2007.
Representation of Area/Regional Hydrology	Focus is on modeling flows in the Pierce Gulch Sand aquifer. Flow is considered from the south to the north. Recharge is from leakage in the New York Canal and the Boise River. Discharge is to the Payette River to the north.
Water Budget	Based on 2006 water conditions. Precipitation recharge was derived from Urban (2004) and recharge from irrigation and septic systems was developed by HLI.
Areal Extent	700 square miles.
Modeling Method Used	Finite difference model using Modflow.
Model Type (Steady State or Transient)	Steady state.
Transient Period Length	N/A
Number of Layers	8 model layers. Layer 1-3 represent granites, volcanics and sediments and range from 1,400 ft to 1 ft in thickness. Layer 4 is a 3 ft aquitard. Layers 5-7 average 220 ft thickness and represent the Pierce Gulch Sand aquifer and Layer 8 is 1,850 ft thick and represents underlying clays and granites.
Grid and Model Cell Size	46 rows x 62 cols. Uniform grid of .5 mi x .5 mi. 22,816 active model cells.
Calibration Method	Trial and error and automated calibration using Pest pilot points.
Calibration Period	N/A
Calibrated Parameters	Horizontal hydraulic conductivity and riverbed conductance.
Calibration Targets	137 measured water level observations, 540 interpolated water levels. Distribution among aquifer layers unknown.
Adequacy of Documentation	Fairly good report. Some vital information missing.

Evaluate Conceptual Mitigation Solutions for New Water Diversions

The impacts of conceptual mitigation solutions for new water diversions could be assessed in steady state using the U of I M3 Eagle model only if the conceptual mitigation solutions for new water diversions are exclusively in the Pierce Gulch Sand aquifer.

Evaluate Ramifications of Climate Changes

Impacts of climate change would be difficult to assess using the U of I M3 Eagle model, since the model was developed primarily to evaluate hydrologic conditions in the Pierce Gulch Sand aquifer and the model isolates the aquifer from surface activity.

Assess Impact of Ground-water Use on Surface Water Supplies

Impacts of ground-water use on surface water supplies would be difficult to assess using the U of I M3 Eagle model, since the model was developed primarily to evaluate hydrologic conditions in the Pierce Gulch Sand aquifer and the model isolates the aquifer from surface activity. Table 12 summarizes the potential utility of the University of Idaho M3 Eagle model for predictive purposes.

Pacific Groundwater Group M3 Eagle Model

General Description

The Pacific Groundwater Group (PGG) M3 Eagle model (PGG, 2008a) was developed by Pacific Groundwater Group of Seattle, Washington in collaboration with Hydro Logic, Inc. of Boise, Idaho. This model was also funded by the M3 Eagle developer.

The stated model purpose for the PGG M3 Eagle model was to assess ground-water level declines associated with the proposed pumping from the M3 Eagle development and:

> "Development of model layering to represent hydrostratigraphic units and definition of hydraulic boundary conditions based on hydrogeologic interpretation by HLI."

The referenced hydrogeologic interpretation is the same conceptual model used by the U of I M3 Eagle model and hypothesized by Squires and others (2007).

Conceptual Model

The PGG M3 Eagle model is a sub-regional model, focusing on the area of the proposed M3 Eagle development. The model areal extent, compared with the USGS western Snake Plain Aquifer model, is shown in Figure 6. Figure 47 shows a closer view of the model area. Outlined in green in Figure 47 is the location of the proposed M3 Eagle

Table 12. Predictive ability of the University of Idaho M3 Eagle model.

Prediction of Water Administration and Management Alternatives for 50 Years	The U of I M3 Eagle model is a sub-regional model, but covers an area of approximately 700 square miles, thus has more utility for assessing management alternatives than many sub-regional models. The model is steady state only, therefore only equilibrium solutions are possible. The model was primarily intended to model flows in the Pierce Gulch Sand aquifer, thereby limiting the model's usefulness for predictions other than impacts to the Pierce Gulch Sand aquifer.
Prediction of Impacts of New Water Rights	Limited to new water rights in the Pierce Gulch Sand aquifer. Steady state only.
Prediction of Impacts of Water Rights Transfers	Limited to water rights transfers in the Pierce Gulch Sand aquifer. Steady state only.
Predictions of Impacts of Changes in Land Use	The U of I M3 Eagle model isolates surface activity from the Pierce Gulch Sand aquifer through a constructed aquitard. It would have limited ability to predict impacts of changes in land use.
Evaluation of Conceptual Mitigation Solutions for New Water Diversions	The U of I M3 Eagle model isolates surface activity from the Pierce Gulch Sand aquifer through a constructed aquitard. It would have limited ability to predict impacts of proposed mitigaton solutions.
Evaluation of Ramifications of Predicted Climate Changes	The U of I M3 Eagle model isolates surface activity from the Pierce Gulch Sand aquifer through a constructed aquitard. It would have limited ability to predict impacts of climate change.
Ability to Assess Impact of Ground Water Use on Surface Water Supplies	The U of I M3 Eagle model isolates surface activity from the Pierce Gulch Sand aquifer through a constructed aquitard. It would have limited ability to predict impacts of ground water use on surface water supplies.

development. The model covers an area that is 20 x 26 miles, approximately 520 square miles.

The hydrologic conceptual model is the same that was previously discussed for the U of I M3 Eagle model, so the reader is referred to that discussion. Figure 48 shows the regional flow conceptualized for the PGG M3 Eagle model Pierce Gulch Sand aquifer.

Model recharge and discharge were estimated using data collected by HLI, Inc and values published by the TVHP project. Municipal and irrigation pumping rates and recharge from irrigation and septic systems were estimated by HLI. Precipitation recharge rates were derived from Urban (2004).

Model Description

The PGG M3 Eagle model is a finite difference model developed using Modflow. It is a 3-dimensional model with approximately 120 rows and 120 columns (exact numbers are not reported) and 7 model layers. The PGG M3 Eagle model has approximately 18,200 active model cells. The model uses a variable grid spacing with cell sides ranging from 330 ft to 2,460 ft. In a model grid with variable grid spacing, many of the model cells are rectangular. The model grid refinement (area of smallest model cells) is centered on the area of interest, the location of the proposed M3 Eagle development.

The model layers represent subsurface strata as follows:

- Layer 1: 50 ft thick shallow sediments
- Layers 2-4: evenly distributed intermediate aquifer sediments. Layer thickness depends on model location, layer 4 is considered an aquitard
- Layers 5-7: evenly distributed Pierce Gulch Sand aquifer

Layer thicknesses were not reported but thickness depends on location within the model grid.

The PGG M3 Eagle model used specified flux boundaries for areal recharge and pumping. The represented pumping (municipal, irrigation and industrial) was primarily in layers 5-7. Head-dependent model cells were used for the Boise and Payette Rivers and for Lake Lowell. Additionally, Layers 5-7 have general head boundary cells to represent sub-surface inflow from the Snake River and inflow to the Pierce Gulch sands from New York Canal leakage to the south of the model boundary.

Specified head boundaries were used in the southeast, west and north to represent aquifer control by rivers. No-flow boundaries were used along the balance of the model perimeter and below model layer 7. There are also some no-flow model cells embedded in the model to represent the vertical no-flow zone created by the West Boise Eagle fault system (Figure 48). Figure 49 shows the model grid and the boundary conditions used for Layer 1 and Layers 5-7.

A constant ratio of 10 was used to represent horizontal to vertical hydraulic conductivity. That is, horizontal hydraulic conductivity was presumed to be a constant order of magnitude greater than vertical horizontal hydraulic conductivity.

Model Calibration and Documentation

The PGG M3 Eagle model was calibrated by trial and error. Each model layer was divided into 7 geohydrologic zones. Steady state calibration was accomplished using 37 observed aquifer water levels: 13 in the Pierce Gulch Sand aquifer layers and 24 in other layers. During model calibration, aquifer transmissivities were limited to values determined during pumping tests. It was found that with these limits, it was difficult to match observed aquifer water levels. The decision was made to create two models, one which more closely honored the pumping test transmissivity data and one which more closely matched the observed aquifer water level data (aquifer head). These two model versions were named the T-match (for transmissivity match) and the H-match (for head match). In order to more closely match aquifer heads, the transmissivities were allowed to range higher than those estimated from pumping tests. PGG used these two model versions to provide a range of predicted impact in their final predictive scenarios.

Steady state calibration was used to calibrate hydraulic conductivities. The transient calibration was used to calibrate aquifer storage parameters. Transient calibration was done using data from three pumping tests: a 9-day test, a 7-day test and a 30-day test. The H-match model was apparently easier to calibrate to the transient conditions. Figure 50 shows the location of the pumping and observation wells used for the transient calibration.

Figures 51 and 52 show the hydraulic conductivity for layers 1 through 4 of the PGG M3 Eagle model. Figure 53 shows the final hydraulic conductivity for layers 5-7 for both the T-match and H-match versions of the model. Table 13 shows the water budget for the PGG M3 Eagle model. Figure 54 shows the final potentiometric maps predicted by the Tmatch and Hmatch versions of the PGG M3 Eagle model. After model calibration, the developers used the model for predictive scenarios, estimating future drawdowns resulting from the proposed M3 development. For these scenarios, the general head boundary cells in the southeast corner of the model were modified to be specified flux cells, using the final water budget shown in Table 13. By modifying these boundaries, the developers were able to avoid inducing more recharge from the general head boundary model cells during the long-term pumping scenario, which would potentially mask the long-term impacts of the proposed development.

Table 13. Steady state model water budget for PGG M3 Eagle Model (from PGG, 2008a).

Water Budget Component	Boundary Type	Model Layer	Tmatch Net Inflow (cfs)	Hmatch Net Inflow (cfs)
Recharge	Recharge	Uppermost Active	542.44	542.44
Boise River Seepage	River	Layer 1	-573.27	-567.18
Payette River Seepage	River	Layers 1, 2, 3	-388.20	-387.58
Lake Lowell Seepage	River	Layer 1	16.59	16.73
Dry Creek Seepage Inflow	Wells	Layer 1	3.95	3.95
Domestic Pumping	Wells	Layer 3	-13.94	-13.93
Municipal, Industrial & Irrigation Pumping	Wells	Layers 5-7	-75.83	-75.83
Boise River Alluvial Aquifer Inflow	CHB	Layer 1	86.51	80.12
Boise River Alluvial Aquifer Outflow	CHB	Layer 1	10.76	10.91
Payette River Alluvial Aquifer Inflow	CHB	Layer 1	282.45	282.46
Payette River Alluvial Aquifer Outflow	CHB	Layer 1	-1.94	-1.93
PGSA Inflow from SE Model Boundary	GHB	Layers 5-7	102.79	101.86
PGSA Outflow at SW Model Boundary	CHB	Layers 5-7	6.33	6.52
Payette River Valley Fill Outflow	CHB	Layers 5-7	1.93	1.94
Willow Creek Aquifer Along NE Model Boundary	CHB	Layers 5-7	-0.46	-0.37
Model Mass Balance Error			*<1%*	*<1%*

After model calibration, it was determined that municipal, industrial and irrigation pumping were under-estimated by approximately 30% in the original model water budget. The steady state and transient models were re-calibrated and are documented in a PGG memorandum dated November, 2008 (PGG, 2008b). The model re-calibration resulted in higher hydraulic conductivities in the layers containing the Pierce Gulch Sand aquifer.

The PGG M3 Eagle model is documented in a series of technical memos from PGG to HLI. Since the model development evolved somewhat over time, a single model description report would be useful, but does not yet exist. Table 14 summarizes the principle characteristics of the PGG M3 Eagle model.

Model Suitability for Predictive Use

Prediction of Water Administration and Management Alternatives to Meet Projected Demand for the Next 50 Years

The PGG M3 Eagle model has some limited utility for predictive use. The model is a sub-regional model, but covers an area of approximately 520 sq mi, so the extent is large enough to warrant use for some management purposes. A transient version of the model exists, however the transient model was calibrated to pumping tests that were of short duration (the maximum test was 30 days), localized and over a relatively small range of aquifer stresses, limiting the utility of this model for transient predictions. Also, the model was designed to assess water use in the Pierce Gulch Sand aquifer. The Pierce Gulch Sand aquifer is relatively isolated from surface activity in this model, so the model will have limited use for predicting the impacts of changes at land surface. It was not designed for such predictions. Another factor is that the hydrogeologic concept employed by this model is a new interpretation for the region and would benefit from further outside review.

Prediction of Impacts of New Water Rights

The impacts of new water rights could be assessed using the PGG M3 Eagle model only if the new water rights are exclusively in the Pierce Gulch Sand aquifer.

Predict Impacts of Water Rights Transfers

The impacts of water rights transfers could be assessed using the PGG M3 Eagle model only if the water rights transfers are exclusively in the Pierce Gulch Sand aquifer.

Evaluate Conceptual Mitigation Solutions for New Water Diversions

The impacts of conceptual mitigation solutions for new water diversions could be assessed using the PGG M3 Eagle model only if the conceptual mitigation solutions for new water diversions are exclusively in the Pierce Gulch Sand aquifer.

Table 14. Summary description of the PGG M3 Eagle model.

Model Purpose	Assess ground water level declines associated with proposed M3 Eagle development pumping. Demonstrate the hydrogeological concept developed by HLI.
Date Created	2008.
Representation of Area/Regional Hydrology	Focus is on modeling flows in the Pierce Gulch Sand aquifer. Flow is considered from the south to the north. Recharge is from leakage in the New York Canal and the Boise River. Discharge is to the Payette River to the north.
Water Budget	Irrigation and septic system recharge rates and municipal and irrigation pumping rates developed by HLI. Precipitation recharge from Urban (2004).
Areal Extent	520 square miles.
Modeling Method Used	Finite difference model developed using Modflow.
Model Type (Steady State or Transient)	Steady state and transient.
Transient Period Length	30-day calibration, model length extended later for longer predictions.
Number of Layers	7 layers. Layer 1, 50 ft thick shallow sediments. Layers 2-3, evenly distributed intermediate aquifer sediments. Layer 4, thin aquitard. Layers 5-7, evenly distributed Pierce Gulch Sand aquifer. Layer thicknesses not reported.
Grid and Model Cell Size	Approximately 120 row x 120 col. Variable grid spacing with cells ranging from 330 ft to 2460 ft on a side. Approximately 18,200 active model cells.
Calibration Method	Trial and error.
Calibration Period	Calibrated to 3 pumping tests (9 days, 7 days and 30 days)
Calibrated Parameters	Horizontal hydraulic conductivity during steady state calibration, aquifer storage during transient calibration.
Calibration Targets	37 water level observations (13 in Pierce Gulch Sand aquifer, 24 in other aquifers).
Adequacy of Documentation	Model documented in series of memos. Not all model information available.

Evaluate Ramifications of Climate Changes

Impacts of climate change would be difficult to assess using the PGG M3 Eagle model, since the model was developed primarily to evaluate hydrologic conditions in the Pierce Gulch Sand aquifer and the model isolates the aquifer from surface activity.

Predict Impacts of Changes in Land Use

Impacts of changes in land use would be difficult to assess using the PGG M3 Eagle model, since the model was developed primarily to evaluate hydrologic conditions in the Pierce Gulch Sand aquifer and the model isolates the aquifer from surface activity.

Assess Impact of Ground-water Use on Surface Water Supplies

Impacts of ground-water use on surface water supplies would be difficult to assess using the PGG M3 Eagle model, since the model was developed primarily to evaluate hydrologic conditions in the Pierce Gulch Sand aquifer and the model isolates the aquifer from surface activity. Table 15 summarizes the potential utility of the PGG M3 Eagle model for predictive purposes.

Bureau of Reclamation Purdam Drain Model

General Description

The Purdam Drain model was developed in 2008 by RD Schmidt at the Bureau of Reclamation. The model was initially developed to support water rights litigation regarding flows in the Purdam Drain. The model purpose was to assess the impact of irrigation activities on the ground-water component of return flow to the constructed portion of the Purdam Drain. Model development also served to demonstrate the utility of analytic element modeling and a recently developed, GIS-based hydrologic database (U.S. Bureau of Reclamation, 2008) for modeling interactions between shallow ground water and surface water entities.

Conceptual Model

The Purdam Drain model is a highly localized model which deals strictly with the interaction between ground-water flow in the upper-most gravels and surface water entities (rivers and canals). The model covers an area of approximately 100 square miles. The model boundary is shown in Figure 55 and the location within the Treasure Valley is shown in Figure 8.

Table 15. Predictive ability of the PGG M3 Eagle model.

Prediction of Water Administration and Management Alternatives for 50 Years	The PGG M3 Eagle model is a sub-regional model, but covers an area of approximately 520 square miles, thus has more utility for assessing management alternatives than many sub-regional models. The model is both steady state and transient, however the transient calibration was matched to data from localized, short term pumping tests, so the range of stresses used to develop the model is very limited. The model was primarily intended to model flows in the Pierce Gulch Sand aquifer, thereby limiting the model's usefulness for predictions other than impacts to the Pierce Gulch sands.
Prediction of Impacts of New Water Rights	Limited to new water rights in the Pierce Gulch sands.
Prediction of Impacts of Water Rights Transfers	Limited to water rights transfers in the Pierce Gulch sands.
Predictions of Impacts of Changes in Land Use	The PGG M3 Eagle model isolates surface activity from the Pierce Gulch sands through a constructed aquitard. It would have limited ability to predict impacts of changes in land use.
Evaluation of Conceptual Mitigation Solutions for New Water Diversions	The PGG M3 Eagle model isolates surface activity from the Pierce Gulch sands through a constructed aquitard. It would have limited ability to predict impacts of proposed mitigaton solutions.
Evaluation of Ramifications of Predicted Climate Changes	The PGG M3 Eagle model isolates surface activity from the Pierce Gulch sands through a constructed aquitard. It would have limited ability to predict impacts of climate change.
Ability to Assess Impact of Ground Water Use on Surface Water Supplies	The PGG M3 Eagle model isolates surface activity from the Pierce Gulch sands through a constructed aquitard. It would have limited ability to predict impacts of ground water use on surface water supplies.

Schmidt (2008) characterized flow in the area of the Purdam Drain model as being controlled by a northwest-southeast trending fault, causing the local flow to be predominantly to the northwest, towards the Boise River. The Purdam Drain model assumes hydrologic interaction between ground-water flow in shallow gravels and Ten Mile Creek, Mason Creek, the Boise River, the New York Canal and Purdam Drain.

The Purdam Drain model water budget represents hydrologic conditions during irrigation season. The water budget represents farm infiltration and precipitation.

Model Description

The model is an analytic element model developed using GFLOW. The Purdam Drain model is a single layer, steady state model. Schmidt did not report the number of analytic elements used. Head-specified line source analytic elements were used to represent Ten Mile Creek, the Purdam Drain, the Riedenbaugh Canal, Mason Creek, the Boise River and the New York Canal. Analytic elements were also constructed to represent spatially-distributed farm infiltration and precipitation. Figure 56 shows the location of the head-specified analytic elements used for the Purdam Drain model.

As with finite difference models, use of a head-specified boundary in analytic element modeling allows the flow between the surface water element and the ground-water system to fluctuate depending on the head differential between the surface water element and the ground-water elevation.

Model Calibration and Documentation

The Purdam Drain model was calibrated using a trial and error method. The hydraulic conductivity of the upper gravels of the aquifer and the river-bed conductance of the represented canals, rivers and drains were calibrated. Water level measurements from 55 observation wells (shown in Figure 56) were used for calibration. Additionally, an unspecified number of seepage measurements from the Riedenbaugh Canal were used during calibration.

Schmidt (2008) reports a reasonably good fit between the model and the observation data, attributing differences to model uncertainty and uncertainty in the measured data. Because the Riedenbaugh Canal was the only surface water source represented in the Purdam Drain model which had seepage measurements, the other rivers, canals and drains were calibrated solely based on nearby aquifer water levels. Figure 57 shows the water level contours predicted by the Purdam Drain Model.

The Purdam Drain model is documented with a single, short report (Schmidt, 2008). The model was meant primarily for internal use by the Bureau of Reclamation, but it was felt that the Purdam Drain model served as a good example of the use of analytic element modeling as an alternative to finite difference modeling for answering localized questions regarding conjunctive management issues. Table 16 summarizes the principle characteristics of the Purdam Drain model.

Model Suitability for Predictive Use

Prediction of Water Administration and Management Alternatives to Meet Projected Demand for the Next 50 Years

The Purdam Drain model is a steady state model and, therefore, is only able to predict impacts at equilibrium. No transient predictions are available using the Purdam Drain model. Also, the model was developed only for a very small sub-region (approximately 100 square miles), so any use of the model for evaluation of administrative or management alternatives would be restricted to a highly localized region.

Prediction of Impacts of New Water Rights

The impact of new water rights in the vicinity of the Purdam Drain could be assessed at steady state relatively easily using the Purdam Drain model. As the model is steady state, there is no opportunity for evaluating the seasonal impacts of changes.

Predict Impacts of Water Rights Transfers

Similarly, the impact of water rights transfers in the vicinity of the Purdam Drain could be assessed at steady state relatively easily using the Purdam Drain model. As the model is steady state, there is no opportunity for evaluating the seasonal impacts of changes.

Predict Impacts of Changes in Land Use

The steady state impacts of changes in land use in the vicinity of the Purdam Drain could be assessed using the Purdam Drain model. As the model is steady state, there is no opportunity for evaluating the seasonal impacts of changes.

Evaluate Conceptual Mitigation Solutions for New Water Diversions

Impacts of proposed mitigation solutions for new water diversions could only be assessed if the mitigation solutions are in the immediate vicinity of the Purdam Drain. There is again no opportunity for evaluating seasonal impacts of proposed mitigation.

Evaluate Ramifications of Climate Changes

Climate changes could be evaluated only in steady state and only in the immediate vicinity of the Purdam Drain.

Assess Impact of Ground-water Use on Surface Water Supplies

The Purdam Drain model was designed specifically to address the interaction between surface water and ground water use. Steady state evaluation of ground-water/surface-water impacts in the vicinity of the Purdam Drain are what the Purdam Drain model is best suited for. Table 17 summarizes the potential utility of the Purdam Drain model for predictive purposes.

Table 16. Summary description of the Purdam Drain model.

Model Purpose	Assess the impact of irrigation activities on the ground water component of return flow to the constructed portion of the Purdam Drain.
Date Created	2008.
Representation of Area/Regional Hydrology	Represents the interaction of flow in the shallow gravel deposits with Ten Mile Creek, Mason Creek, the Purdam Drain, the Boise River, the New York Canal and the Riedenbaugh Canal. Regional flow in the vicinity of the model is considered to be to the northwest towards the Boise River.
Water Budget	Based on the Bureau of Reclamation GIS-based lower Boise Valley water budget representing 1996 conditions. The model represented farm irrigation infiltration and precipitation.
Areal Extent	100 square miles.
Modeling Method Used	Analytic element model developed using GFLOW.
Model Type (Steady State or Transient)	Steady State.
Transient Period Length	N/A
Number of Layers	1 layer representing unconfined flow in the shallow gravels.
Grid and Model Cell Size	N/A. Unreported number of analytic elements representing farm irrigation infiltration and precipitation and head-specified line sources representing Ten Mile Creek, the Purdam Drain, the Riedenbaugh Canal, Mason Creek, the New York Canal and the Boise River.
Calibration Method	Trial and error.
Calibration Period	N/A
Calibrated Parameters	Aquifer hydraulic conductivity and river-bed conductance.
Calibration Targets	Water levels from 55 observation wells and an unspecified number of seepage measurements from the Riedenbaugh Canal.
Adequacy of Documentation	The report is somewhat brief.

Table 17. Predictive ability of the Purdam Drain model.

Prediction of Water Administration and Management Alternatives for 50 Years	Predictions limited to steady state in the immediate vicinity of the Purdam Drain.
Prediction of Impacts of New Water Rights	Predictions limited to steady state in the immediate vicinity of the Purdam Drain. Data sets fairly easy to construct.
Prediction of Impacts of Water Rights Transfers	Predictions limited to steady state in the immediate vicinity of the Purdam Drain. Data sets fairly easy to construct.
Predictions of Impacts of Changes in Land Use	Predictions limited to steady state in the immediate vicinity of the Purdam Drain. Data sets fairly easy to construct.
Evaluation of Conceptual Mitigation Solutions for New Water Diversions	Predictions limited to steady state in the immediate vicinity of the Purdam Drain. Data sets fairly easy to construct.
Evaluation of Ramifications of Predicted Climate Changes	Predictions limited to steady state in the immediate vicinity of the Purdam Drain. Data sets fairly easy to construct.
Ability to Assess Impact of Ground Water Use on Surface Water Supplies	Predictions limited to steady state in the immediate vicinity of the Purdam Drain. Data sets fairly easy to construct.

Bureau of Reclamation New York Canal Model

General Description

RD Schmidt, at the Bureau of Reclamation, developed a localized model of ground-water and surface-water interaction at the New York Canal (U.S. Bureau of Reclamation, 2009). The New York Canal model was developed as a demonstration model to be linked to an economic model to test the viability and utility of a linked ground-water/economic model to predict the economic ramifications of water management decisions. The New York Canal model was also developed to model the interaction between agricultural, municipal and industrial well use and flows in the New York Canal. The model was used to generate unit response functions to describe the hydrologic interaction. The unit response functions were then used within an economic model to predict the economic impacts.

Conceptual Model

The New York Canal model is a very localized model, covering an area of approximately 12 square miles. Figure 58 shows the portion of the New York Canal represented in the model. The size of the New York Canal model relative to the USGS model is shown in Figure 9. The hydrology which is being modeled is the interaction between ground-water flow in the shallow gravels, pumping in agricultural, municipal and industrial wells; and flows in the New York Canal. From a regional standpoint, it was acknowledged that the Snake River and the Boise River exert influence on local ground-water levels, so these two rivers were modeled as distant boundaries.

The model water budget was derived from Bureau of Reclamation hydrologic data for the Treasure Valley (U. S. Bureau of Reclamation, 2008). No areal recharge was represented: only irrigation season pumping levels from nearby wells.

Model Description

The New York Canal model is an analytic element model, developed using GFLOW (Haitjema, 2007). It is a single layer, steady state model. The model uses 709 head-specified line source/sink elements representing the New York Canal and the Elijah, Aaron and Wilson Drains. 155 flow-specified elements were used to represent agricultural and municipal and industrial wells in the model area. Additionally, an unspecified number of head-specified line source/sink elements were included to represent the distant effects of the Snake and Boise Rivers. Figure 59 shows the location of the head-specified line source/sink elements and the specified flux (well) elements used for the New York Canal model.

The single layer of the New York Canal model represents flow in the shallow gravels near the New York Canal. No interaction with deep aquifers is modeled.

Model Calibration and Documentation

The New York Canal model was calibrated using a trial and error method. Calibrated parameters were aquifer hydraulic conductivity and streambed conductance. Seepage estimates in six reaches of the New York Canal (Figure 58) were used as calibration targets. An unspecified number of water level observations from nearby wells were also used. Figure 60 shows the aquifer head conditions predicted for one of the scenarios of the New York Canal model.

The New York Canal model is documented in a single report which discusses both the hydrologic model and the economic model. The report is reasonably comprehensive. Table 18 summarizes the principle characteristics of the New York Canal model.

Model Suitability for Predictive Use

Prediction of Water Administration and Management Alternatives to Meet Projected Demand for the Next 50 Years

The New York Canal model is a steady state model and, therefore, is only able to predict impacts at equilibrium. No transient predictions are available using the New York Canal model. Also, the model was developed only for a very small sub-region (approximately 12 square miles), so any use of the model for evaluation of administrative or management alternatives would be restricted to a highly localized region.

Because the New York Canal model does not include areal recharge, the model is further limited for predictive scenario use.

Prediction of Impacts of New Water Rights

The impact of new water rights in the immediate vicinity of the modeled portion of the New York Canal could be assessed at steady state relatively easily using the New York Canal model. As the model is steady state, there is no opportunity for evaluating the seasonal impacts of changes.

Predict Impacts of Water Rights Transfers

Similarly, the impact of water rights transfers in the vicinity of the modeled portion of the New York Canal could be assessed at steady state relatively easily using the New York Canal model. As the model is steady state, there is no opportunity for evaluating the seasonal impacts of changes.

Predict Impacts of Changes in Land Use

The New York Canal model does not represent areal recharge, so impacts of changes in land use would require more work and would be restricted to the immediate vicinity of the modeled portion of the New York Canal.

Evaluate Conceptual Mitigation Solutions for New Water Diversions

Impacts of proposed mitigation solutions for new water diversions could only be assessed if the mitigation solutions are in the immediate vicinity of the modeled portion of the New York Canal. There is again no opportunity for evaluating seasonal impacts of proposed mitigation.

Evaluate Ramifications of Climate Changes

The New York Canal model is inappropriate for predictions of the ramifications of climate changes.

Table 18. Summary description of the New York Canal model.

Model Purpose	Model the interaction between ground-water flow in shallow gravels and a portion of the New York Canal. Demonstrate the viability of developing an integrated ground-water/economic model.
Date Created	2009.
Representation of Area/Regional Hydrology	Interaction between ground-water flow in shallow gravels and the New York Canal, the Elijah, Aaron and Wilson drains. The model also contains far-field elements representing Lake Lowell and the Boise and Snake Rivers, but only represents the hydrology in the immediate vicinity of the modeled portion of the New York Canal.
Water Budget	Developed based on irrigation-season pumping in agricultural and municipal and industrial wells. No areal recharge is represented.
Areal Extent	12 square miles.
Modeling Method Used	Analytic element modeling using GFLOW.
Model Type (Steady State or Transient)	Steady state.
Transient Period Length	N/A
Number of Layers	1 layer representing shallow gravels.
Grid and Model Cell Size	N/A. 709 analytic elements representing head-specified line source/sinks and 155 analytic elements representing flow-specified recharge/discharge (wells).
Calibration Method	Trial and error.
Calibration Period	N/A
Calibrated Parameters	Aquifer hydraulic conductivity and stream-bed conductance.
Calibration Targets	Seepage in six reaches of the New York Canal. Number of aquifer water level observations used during calibration not reported.
Adequacy of Documentation	Reasonably good report.

Assess Impact of Ground-water Use on Surface Water Supplies

The New York Canal model was designed specifically to address the interaction between surface water and ground water use. Steady state evaluation of ground-water/surface-water impacts in the vicinity of the modeled portion of the New York Canal are what the New York Canal model is best suited for. Table 19 summarizes the potential utility of the New York Canal model for predictive purposes.

Table 19. Predictive ability of the New York Canal model.

Prediction of Water Administration and Management Alternatives for 50 Years	Predictions limited to steady state in the immediate vicinity of the modeled portion of the New York Canal. Note that the New York Canal model only covers a 12 square mile area.
Prediction of Impacts of New Water Rights	Predictions limited to steady state in the immediate vicinity of the modeled portion of the New York Canal. Data sets fairly easy to construct.
Prediction of Impacts of Water Rights Transfers	Predictions limited to steady state in the immediate vicinity of the modeled portion of the New York Canal. Data sets fairly easy to construct.
Predictions of Impacts of Changes in Land Use	Predictions limited to steady state in the immediate vicinity of the modeled portion of the New York Canal. Data sets fairly easy to construct.
Evaluation of Conceptual Mitigation Solutions for New Water Diversions	Predictions limited to steady state in the immediate vicinity of the modeled portion of the New York Canal. Data sets fairly easy to construct.
Evaluation of Ramifications of Predicted Climate Changes	The New York Canal model is inappropriate for evaluation of the impacts of climate changes.
Ability to Assess Impact of Ground Water Use on Surface Water Supplies	Predictions limited to steady state in the immediate vicinity of the modeled portion of the New York Canal. Data sets fairly easy to construct.

Results and Recommendations

Strengths and Limitations of Reviewed Models

This section discusses the strengths and limitations of each reviewed model. The strengths and limitations are assessed based on: a) currency and accuracy of model data, b) rigor of model development and c) utility to the CAMP.

Lindgren Model

The Lindgren model has the attribute of being a transient model, therefore capable of predicting impacts over time. The Lindgren model is also one of the better calibrated of the reviewed models, using a greater number of observation points and an automated calibration routine.

The Lindgren model has the inherent limitation of being developed more than thirty years ago. Much has changed in the understanding of the Treasure Valley hydrogeology and in water use practices in that thirty years. Another limitation of the Lindgren model is that it is a single layer model. Although much of the interesting surface water/ground water interaction happens near the surface, the Treasure Valley subsurface environment is so complex that a regional model would need to have multiple layers to provide an adequate representation of subsurface processes.

USGS Western Snake Plain Aquifer Model

The USGS western Snake Plain Aquifer model has the strength of being both a transient and multi-layer model. With the broadest areal extent, there is no question that the USGS model area will cover any water issue in the western Snake Plain. Another attribute of the western Snake Plain Aquifer model is that the transient model was built to span water use from pre-development to the early 1980s, a very broad range of aquifer stress conditions.

The USGS model also has the inherent drawback of being developed a long time ago. Although the model was published in the early 1990s, the model represents water use conditions in the early 1980s. Another limitation of the USGS model is that the transient model was not truly calibrated to the transient conditions due to a lack of measured observation data. The transient model is more of a demonstration model showing model results against inferred flow conditions.

With its broad areal extent, the USGS model suffered from having large model areas with little data. Within the model boundary, there are many square miles with little hydrologic activity at the surface and little understanding of the sub-surface. The model layering in the USGS model was somewhat simplified, with model layers being a fixed thickness. Our current understanding of the Treasure Valley sub-surface environment supports a more complex model layering.

Treasure Valley Hydrologic Project Model

Of the regional models, the Treasure Valley Hydrologic Project model is the most recent and the best developed. The model, published in 2004, was developed with technical oversight provided by interested water users. The TVHP model is the most rigorously developed model of the seven models reviewed. The TVHP model is also the most thoroughly calibrated model of the seven models reviewed, using many observation data points and having undergone an exhaustive automated calibration.

One of the greatest limitations of the TVHP model is that it is only a steady state model. Assessment of impacts to hydrologic conditions in the Treasure Valley require not only the final, steady state solution, but also the transient solution. The areal extent of the TVHP is also a limitation. As can be seen in Figure 2, several of the areas of projected growth in the Treasure Valley extend beyond the TVHP model boundary.

The selection of a groundwater divide for the northern boundary of the TVHP is also a potential limitation. The groundwater divide was selected to delineate water flowing north towards the Payette River (outside of the TVHP model area) from water south of the divide flowing towards the Boise River. Groundwater divides can shift over time as hydrologic conditions change. There is also some argument that some of the water within the model area may discharge to the Payette River drainage, so the northern boundary may have been better selected to include the Payette River. Additional investigation is needed to determine hydrologic conditions along the northern boundary.

University of Idaho M3 Eagle Model

The University of Idaho M3 Eagle model is a recent sub-regional model. The model has a complex representation of the subsurface hydrology of the Treasure Valley. The model was reasonably well calibrated using an automated calibration routine.

A drawback of the U of I M3 Eagle model is that it is only steady state. Attempts to calibrate a transient model were unsuccessful. The U of I M3 Eagle model was primarily developed to assess flow conditions in the Pierce Gulch Sand aquifer. Interactions between near-surface hydrogeologic conditions and the Pierce Gulch Sand aquifer are modeled only to a limited degree.

PGG M3 Eagle Model

The PGG M3 Eagle model is a multi-layer, transient, sub-regional model. The PGG M3 Eagle model also is a complex representation of the Treasure Valley subsurface.

The PGG M3 Eagle model was primarily developed to assess flow conditions in the Pierce Gulch Sand aquifer. Interactions between surface hydrology and the proposed Pierce Gulch Sand aquifer are modeled only to a limited degree.

Another concern is that calibration of the PGG M3 Eagle model was accomplished using only 37 observation wells. Considering the model has over 12,000 model cells, this is too few observations to produce a thorough calibration. Similarly, although the PGG M3 Eagle model is a transient model, it was calibrated to a 30-day pumping test. No long term calibration was attempted or accomplished. The model may not be useful in predicting drawdowns 50 years into the future, based on a 30-day calibration of localized pumping.

Bureau of Reclamation Purdam Drain Model and Bureau of Reclamation New York Canal Model

These two analytic element models were developed primarily to demonstrate the utility of analytic element modeling for exploring the interaction between flow in shallow gravels and surface water bodies. Each model serves a purpose in addressing highly localized questions, but neither model is suitable for exploring more regional hydrologic questions.

Recommendations

Of the seven models reviewed, the Treasure Valley Hydrologic Project model is the best-developed model. To be truly useful to the CAMP, however, the TVHP model should a) have some of the model boundaries extended, b) have some of the model boundary conditions re-visited and c) be calibrated as a transient model. The hypothesis of the Pierce Gulch Sand aquifer should be further investigated.

It is reasonably clear from the reviewed models that a regional model of the Treasure Valley should terminate somewhere northwest of Mountain Home. There is insufficient data to support a regional model of the entire western Snake River Plain aquifer. Ground-water modeling is a time-consuming, expensive undertaking and resources should be focused in the area of highest current and future water use.

Analytic element models show some promise for providing a rapid means of modeling near-surface hydrologic questions. A true strength of the analytic element modeling method is that the models are relatively quick to put together and provide meaningful steady state results. A drawback is that analytic element models are limited to steady state conditions.

Development of sub-regional, finite difference models may prove to be too expensive an option for answering questions posed by the CAMP. If this route is chosen, though, sub-regional models should honor the agreed-to conceptual model used in the regional model and should be developed in an open environment, with extensive technical review.

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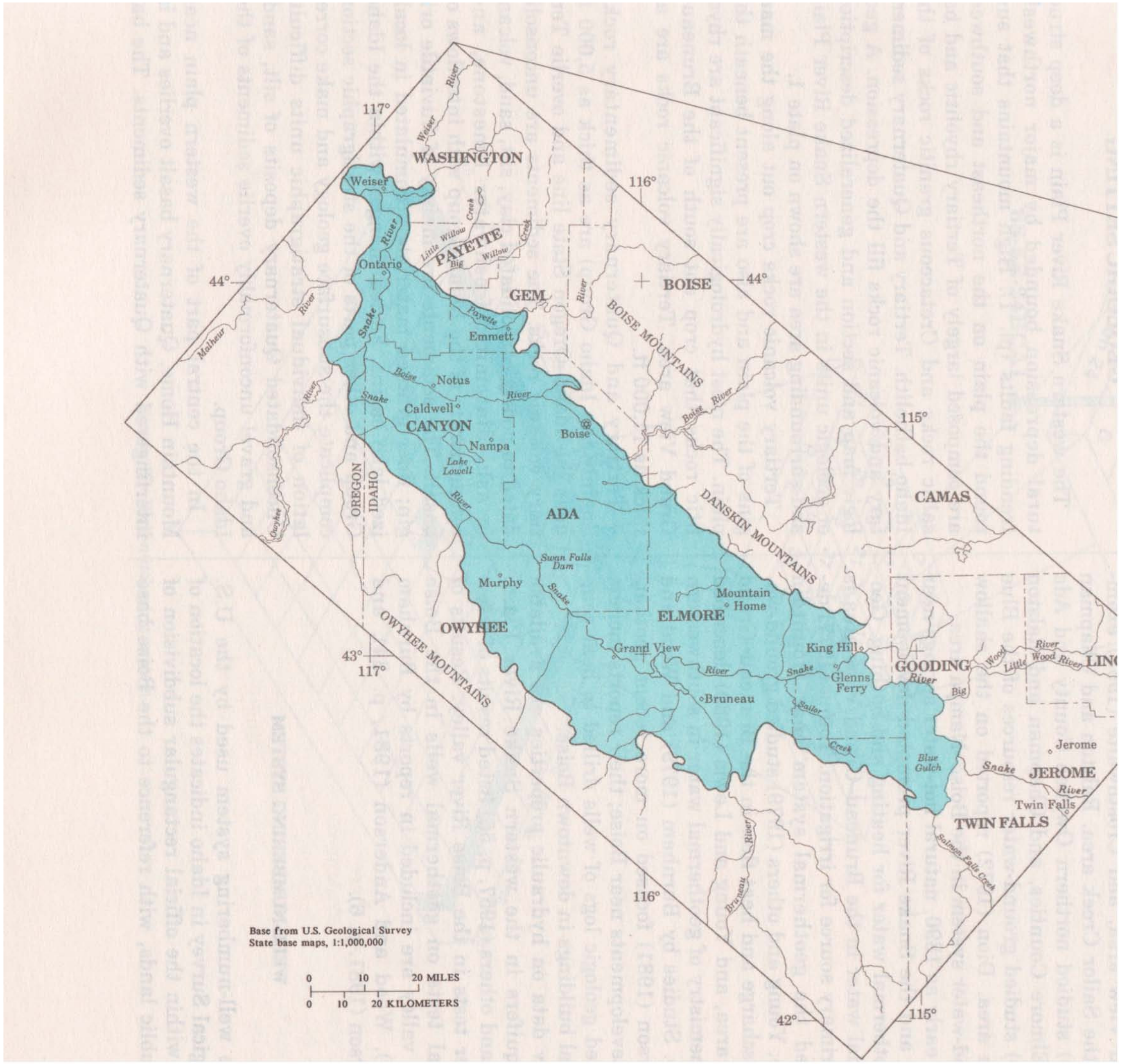

Figure 1. Study area (from Newton, 1991).

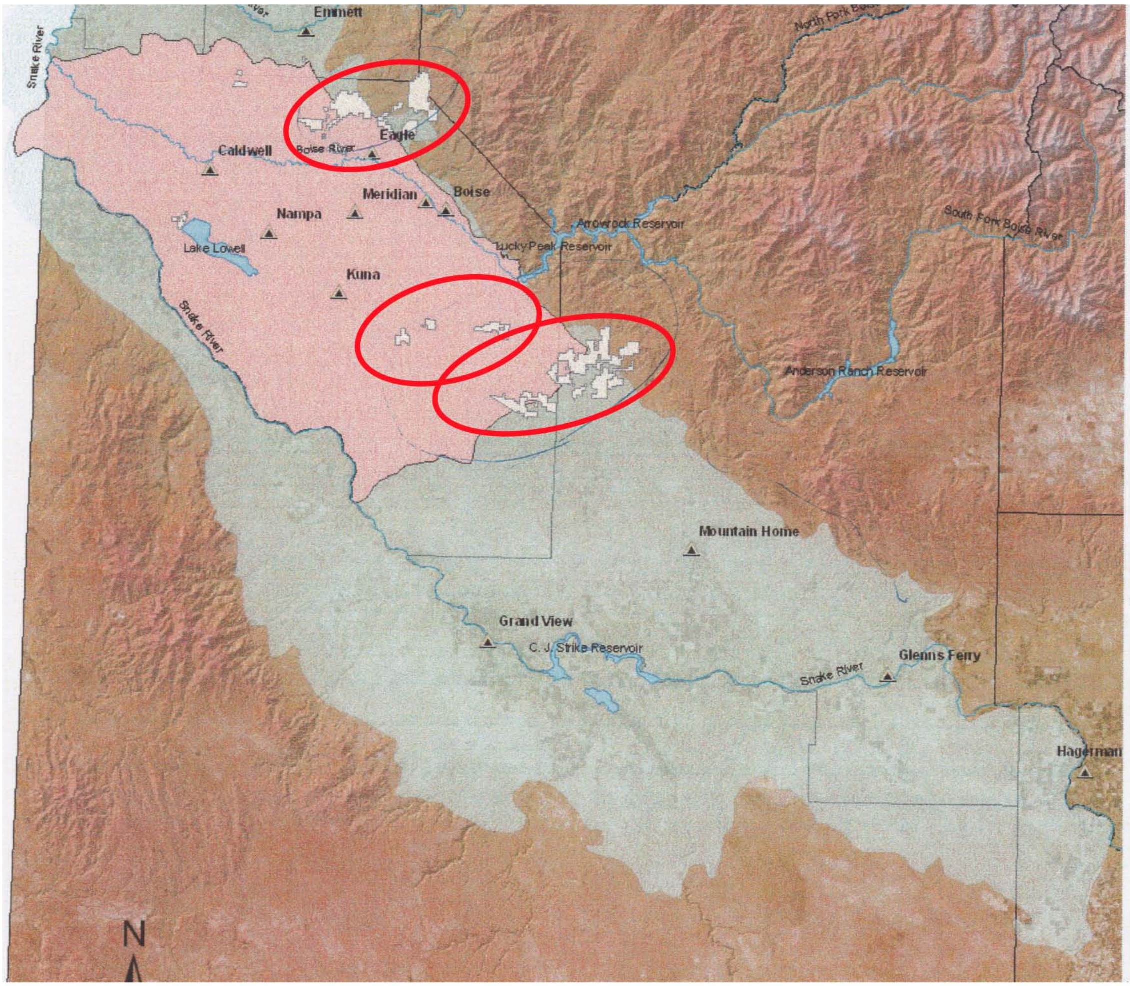

Figure 2. Locations of greatest projected growth within the study area (map courtesy of IDWR).

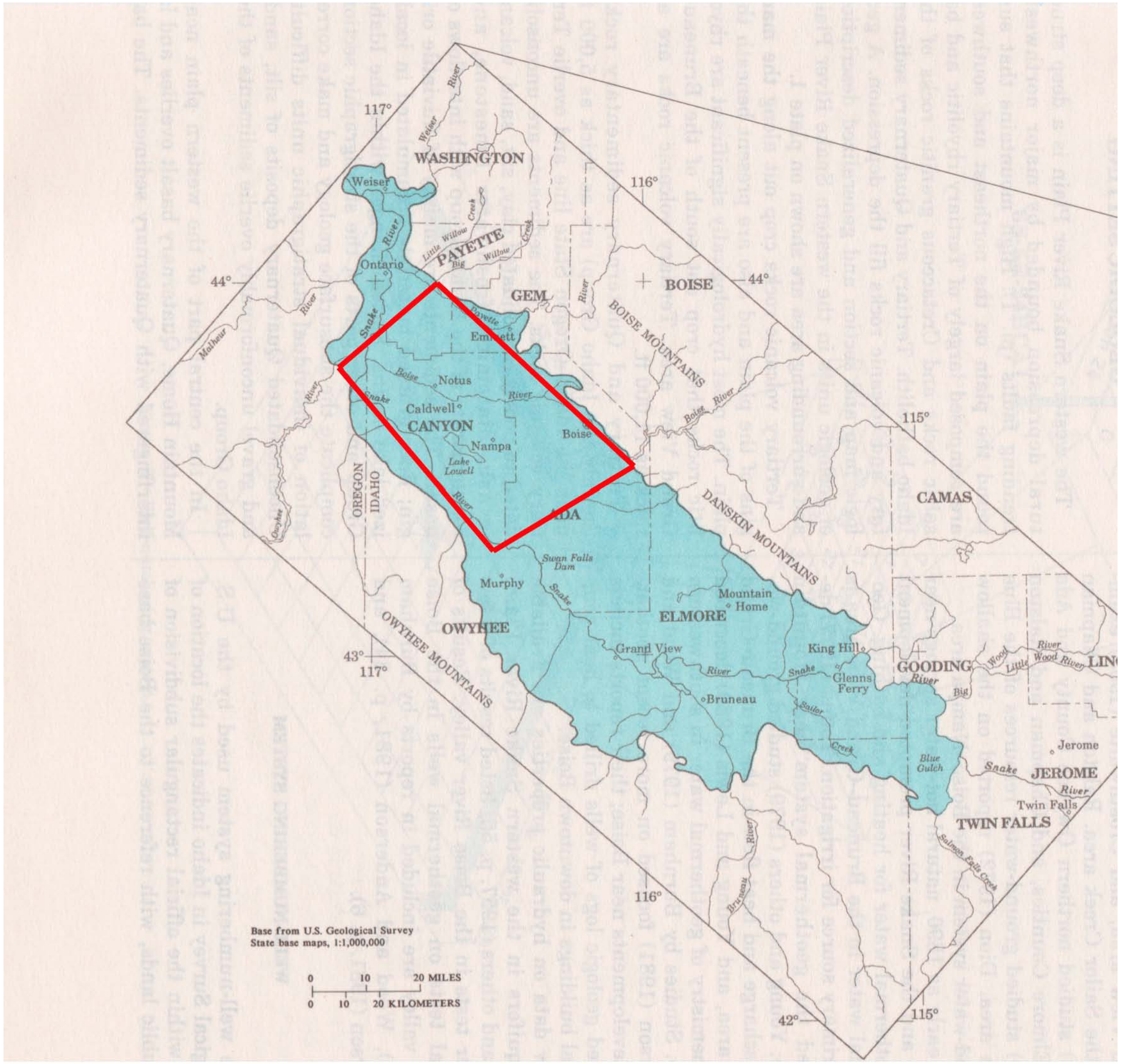

Figure 3. Approximate areal extent of the Lindgren Treasure Valley model (adapted from Newton, 1991).

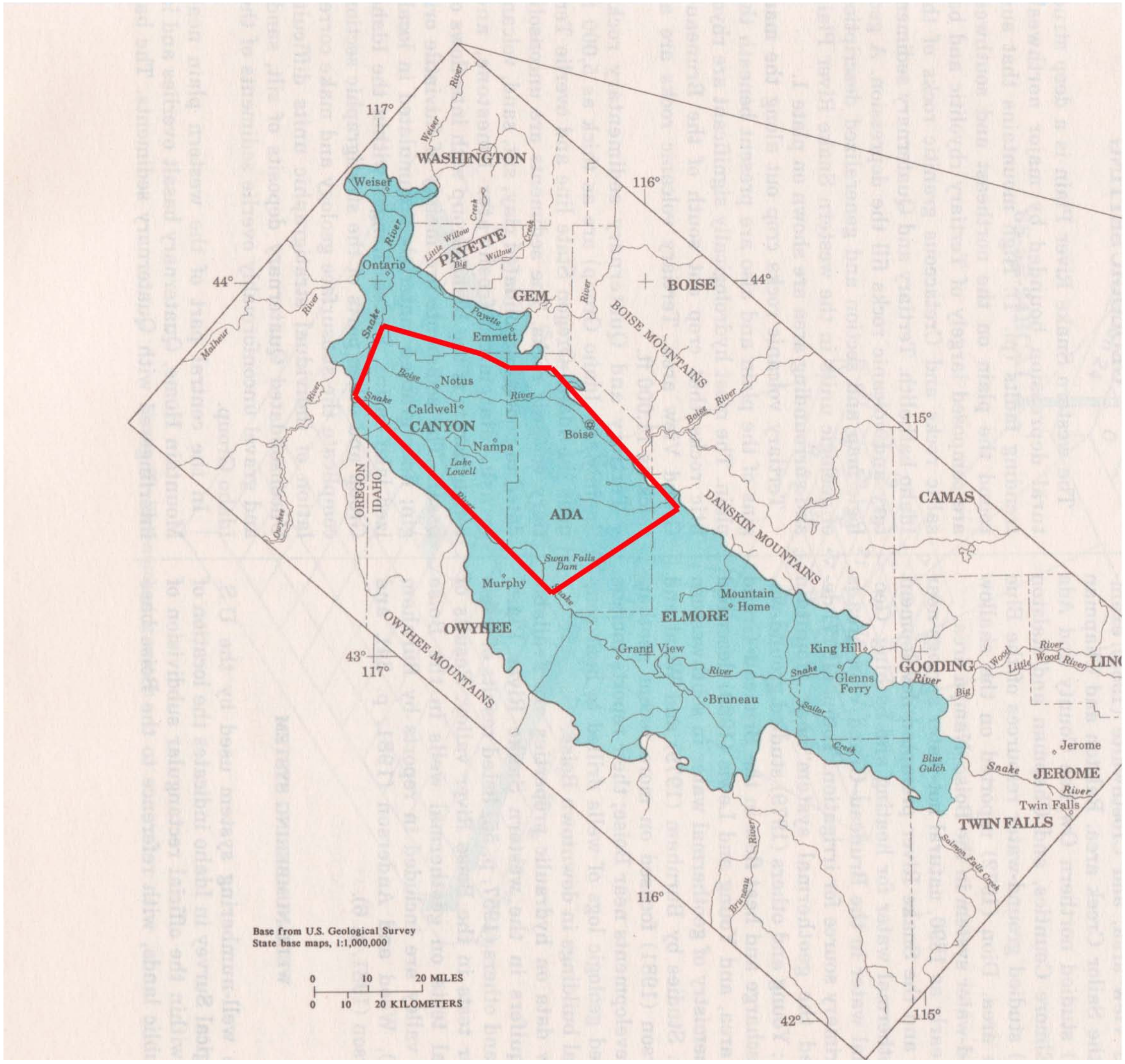

Figure 4. Approximate areal extent of the Treasure Valley Hydrologic Project model (adapted from Newton, 1991).

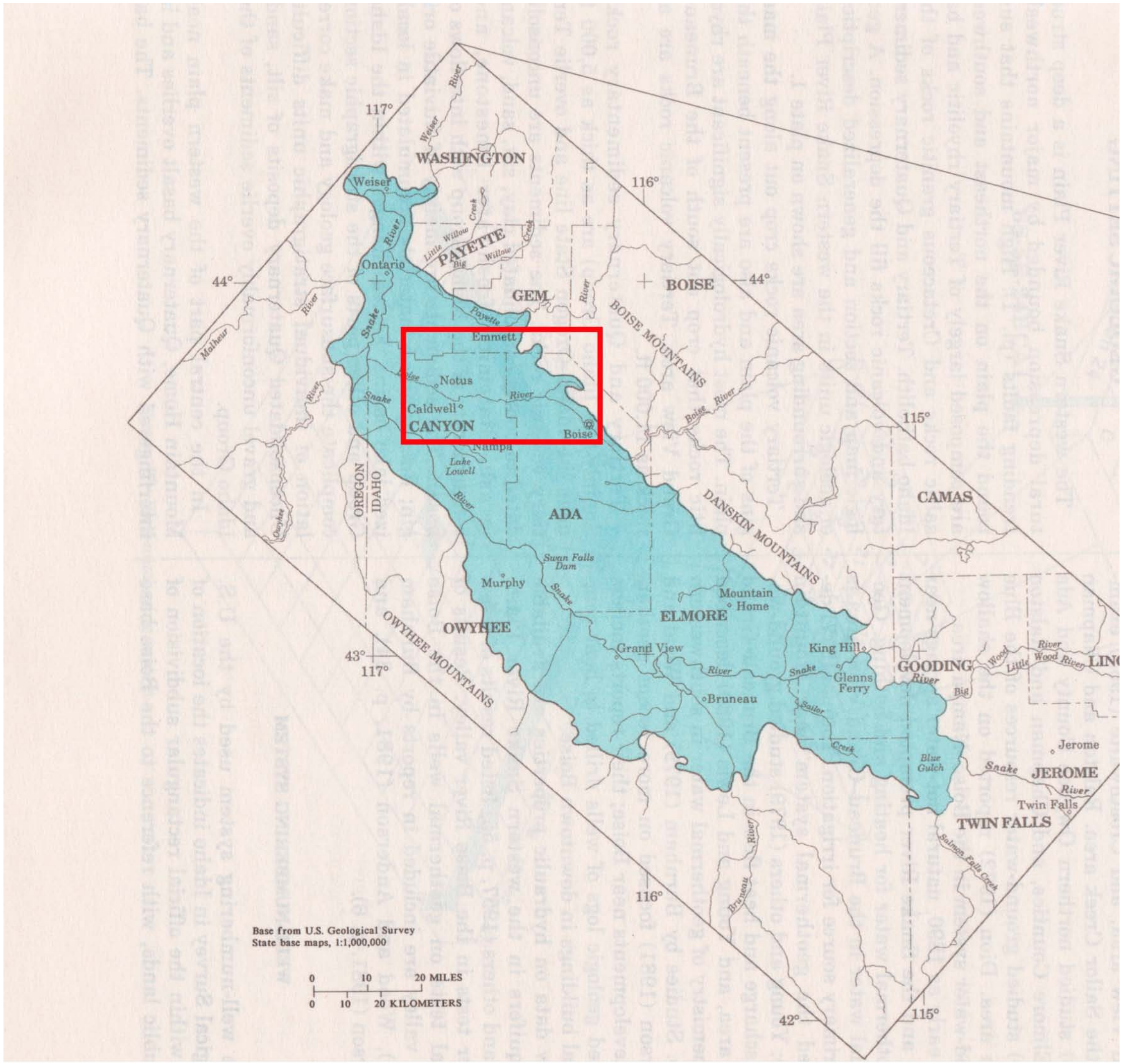

Figure 5. Approximate areal extent of the University of Idaho M3 Eagle Model (adapted from Newton, 1991).

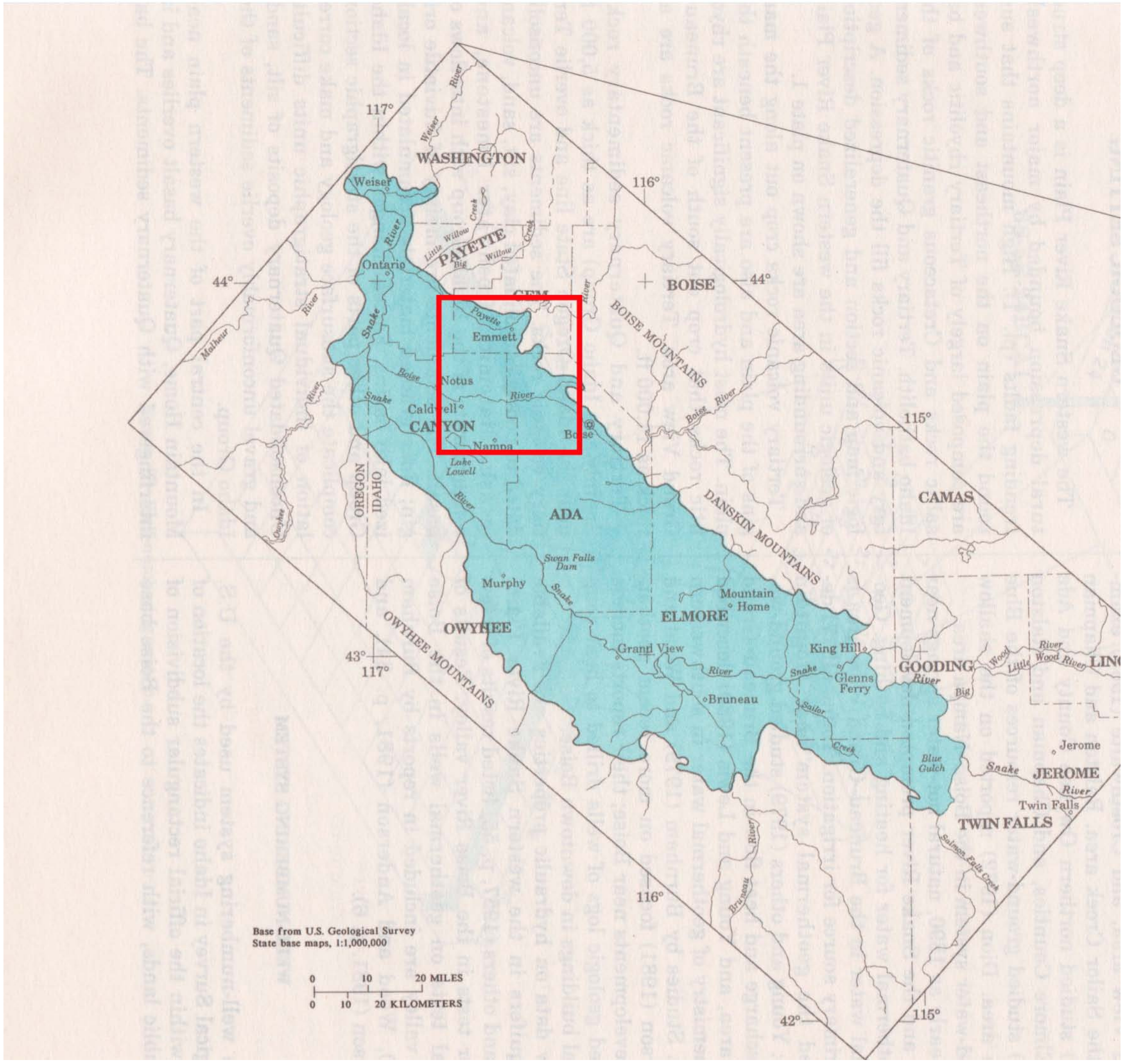

Figure 6. Approximate areal extent of the Pacific Groundwater Group M3 Eagle Model (adapted from Newton, 1991).

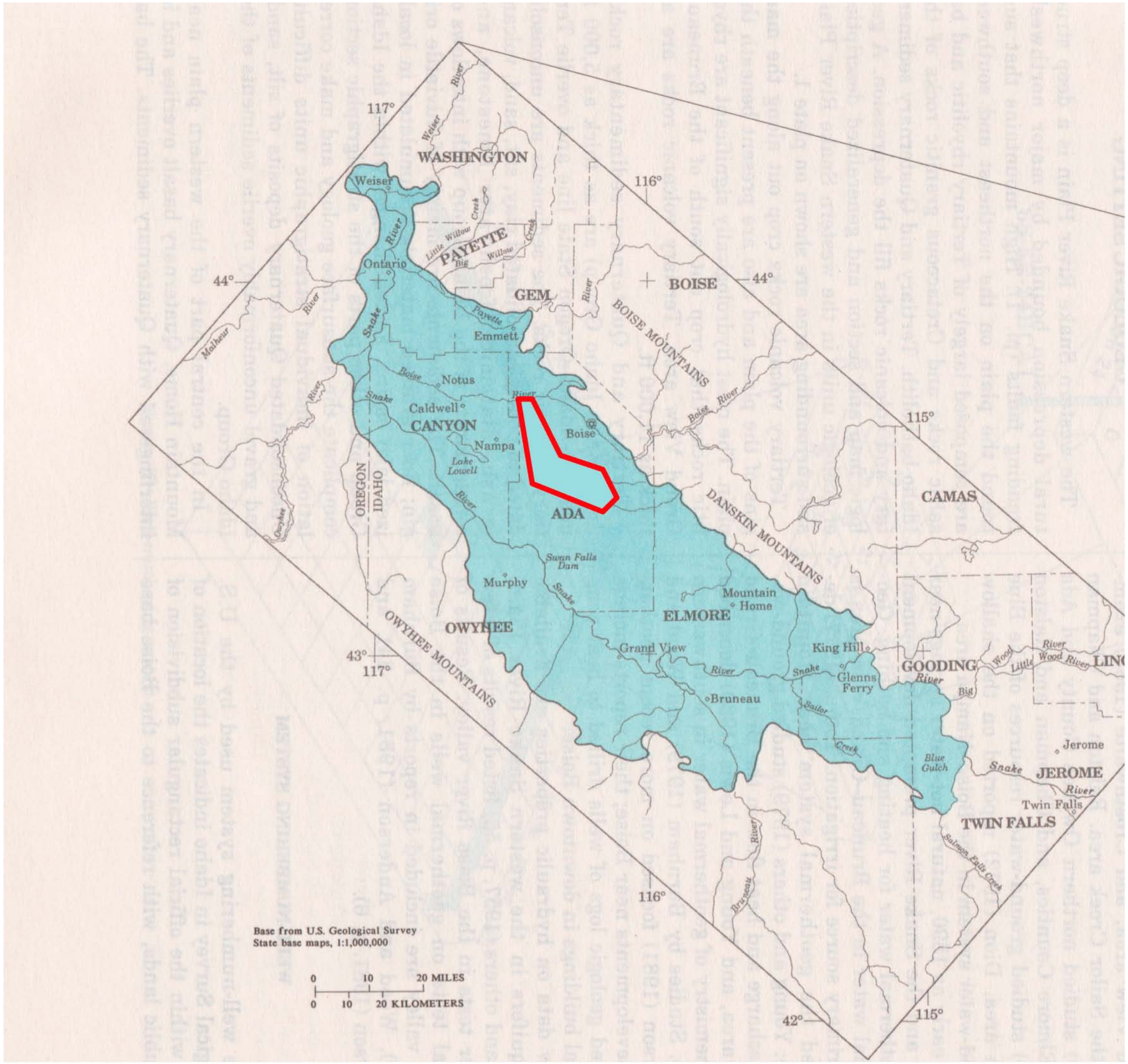

Figure 7. Approximate areal extent of the Bureau of Reclamation Purdam Drain model (adapted from Newton, 1991).

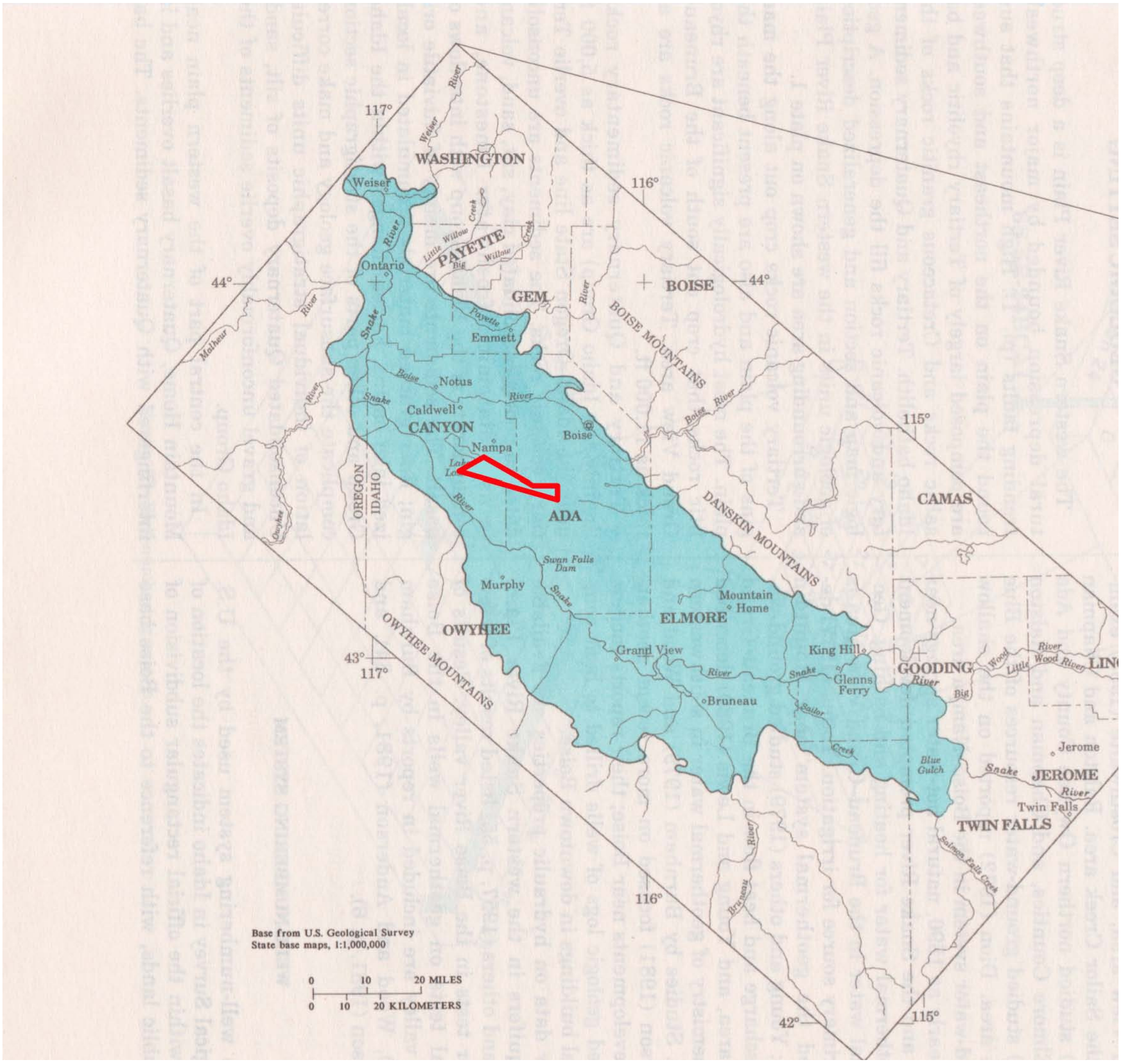

Figure 8. Approximate areal extent of the Bureau of Reclamation New York Canal Model (adapted from Newton, 1991).

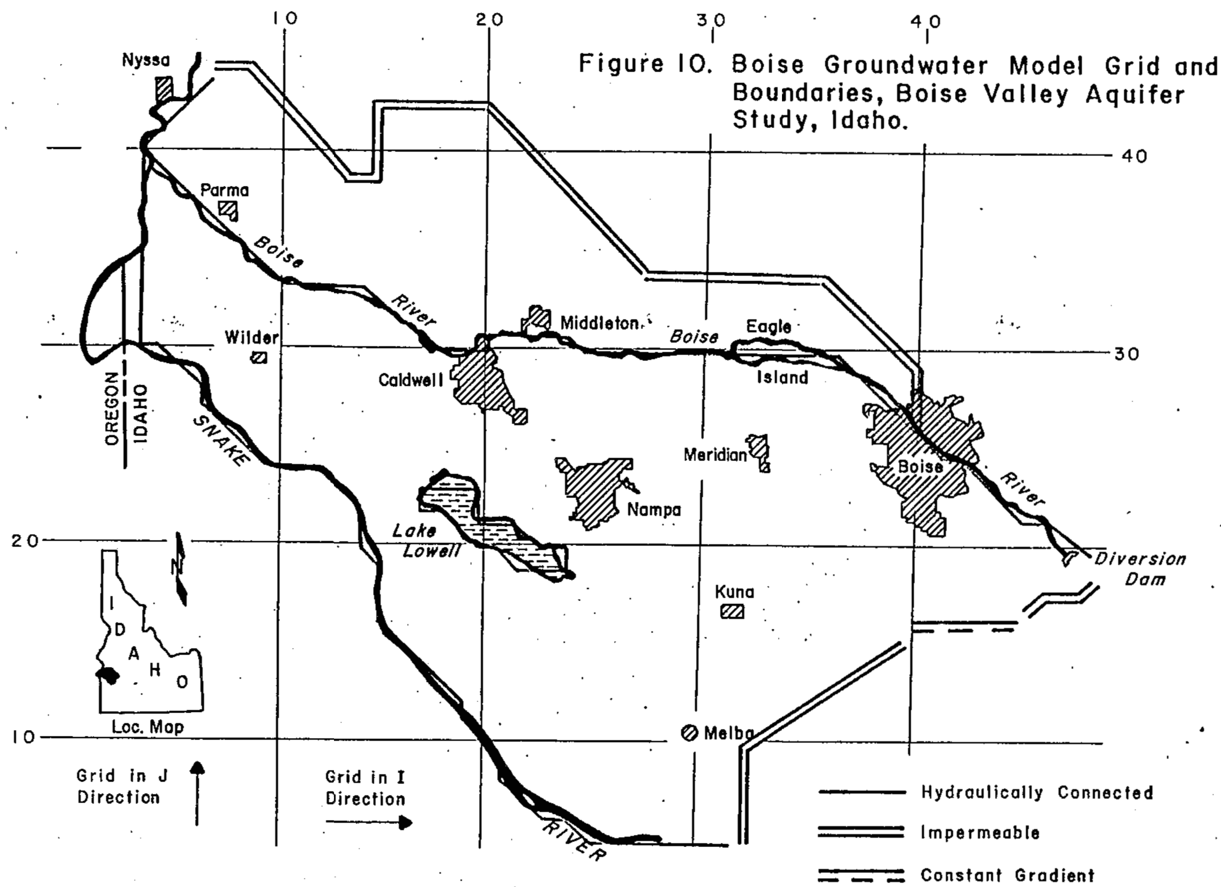

Figure 9. Lindgren Treasure Valley Model boundaries and location (from Lindgren, 1982).

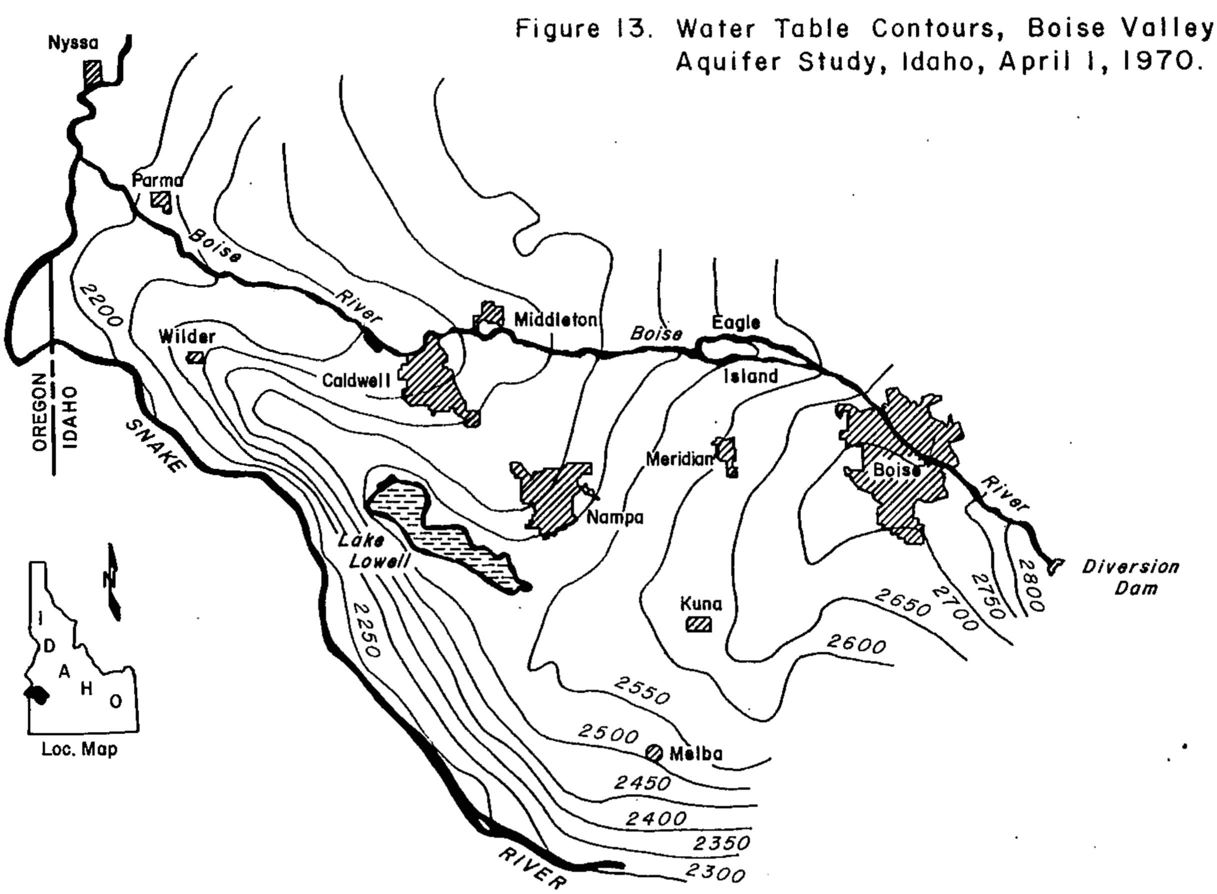

Figure 10. Potentiometric surface as predicted by the Lindgren Treasure Valley Model (from Lindgren, 1982).

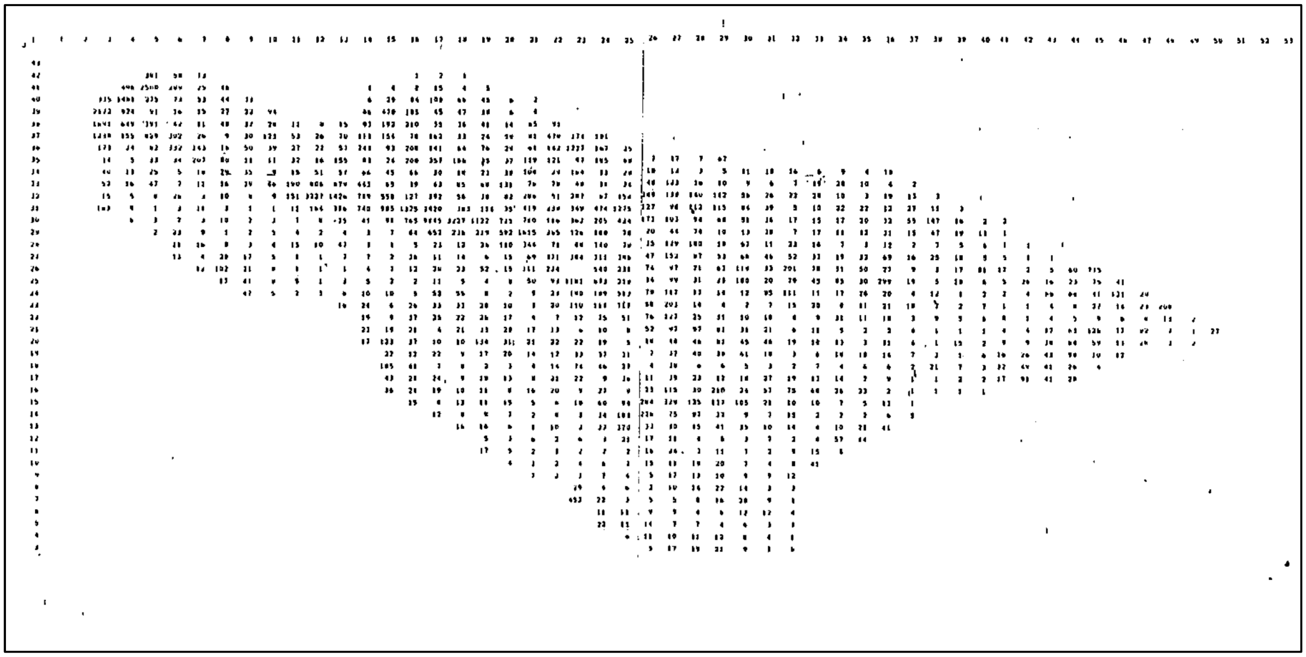

Figure 11. Calibrated transmissivities (ft^2/d x 1000) for Lindgren model (from Lindgren, 1982).

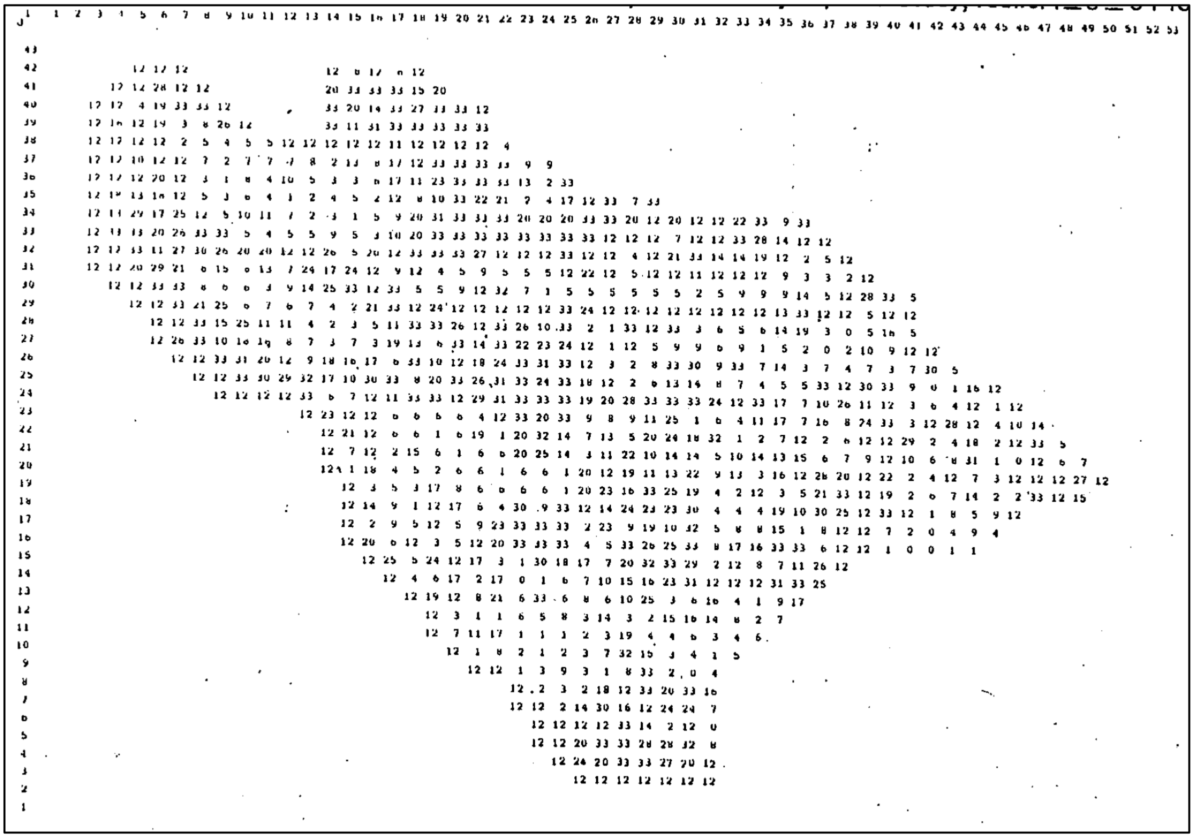

Figure 12. Calibrated specific yield values (unitless) for each model cell for Lindgren Treasure Valley Model. Values are in thousandths. From Lindgren (1982).

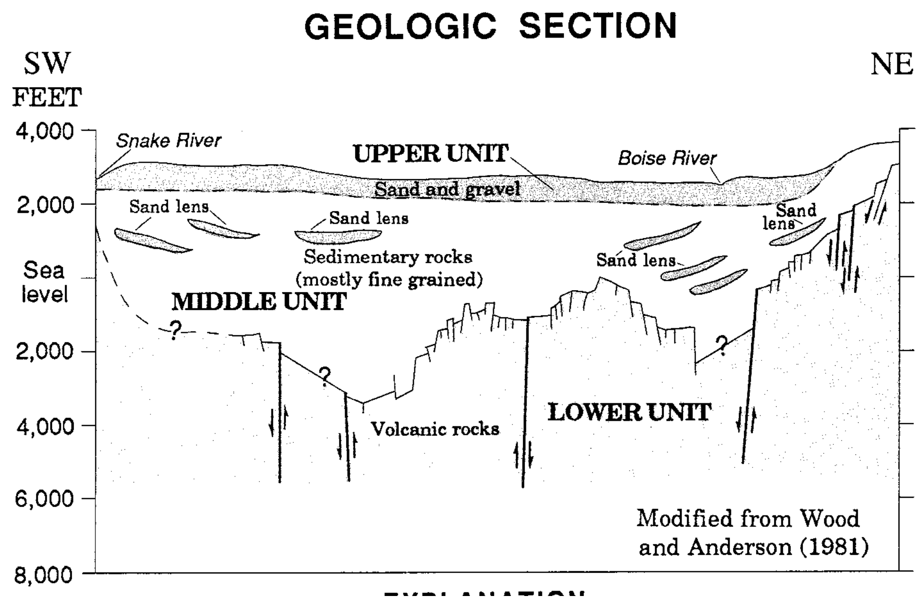

Figure 13. Geological conceptual model east-west cross-section through the northern part of the USGS model (from Newton, 1991).

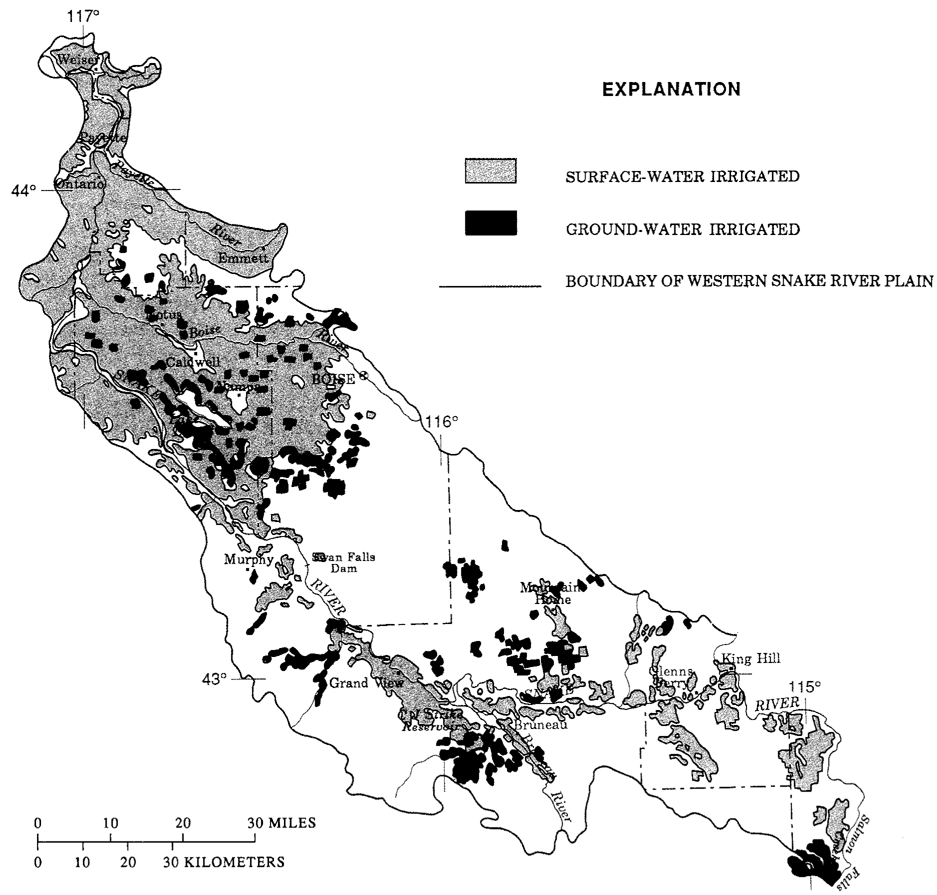

Figure 14. Surface- and ground-water irrigated areas in the USGS model (from Newton, 1991).

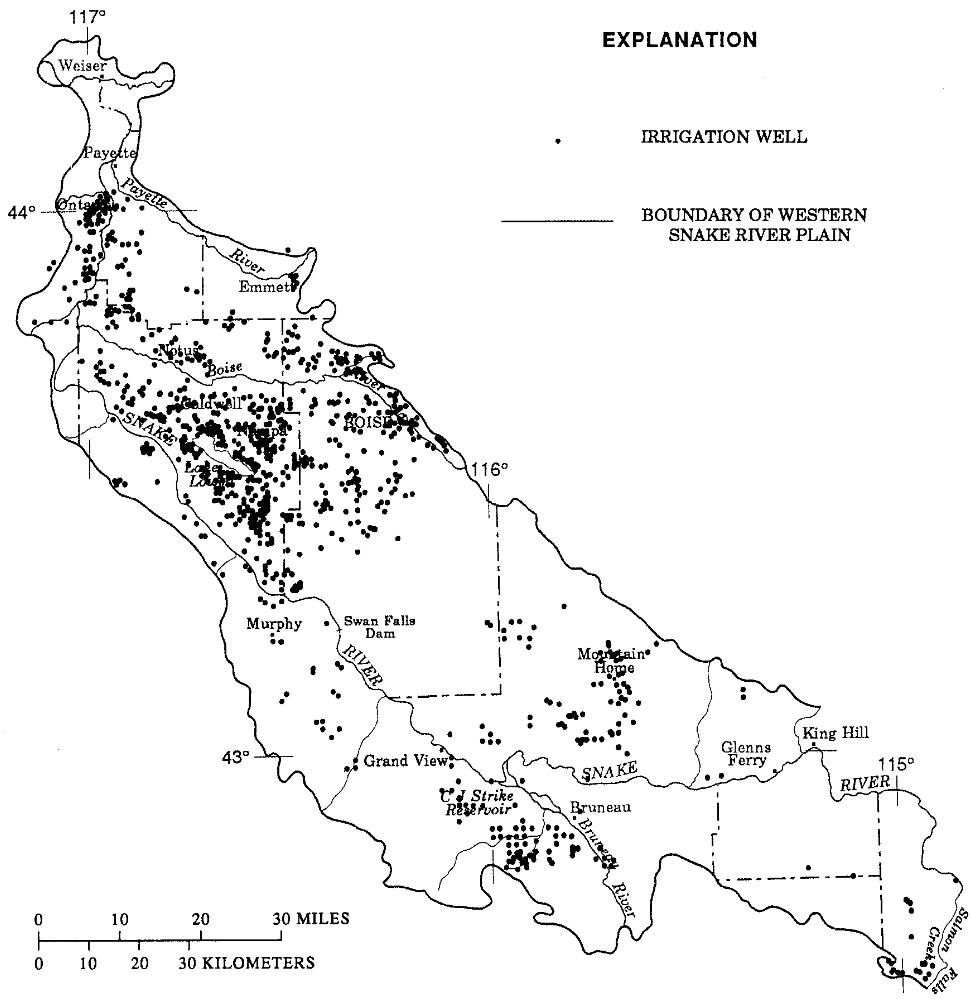

Figure 15. Location of irrigation wells in the western Snake River Plain (from Newton, 1991).

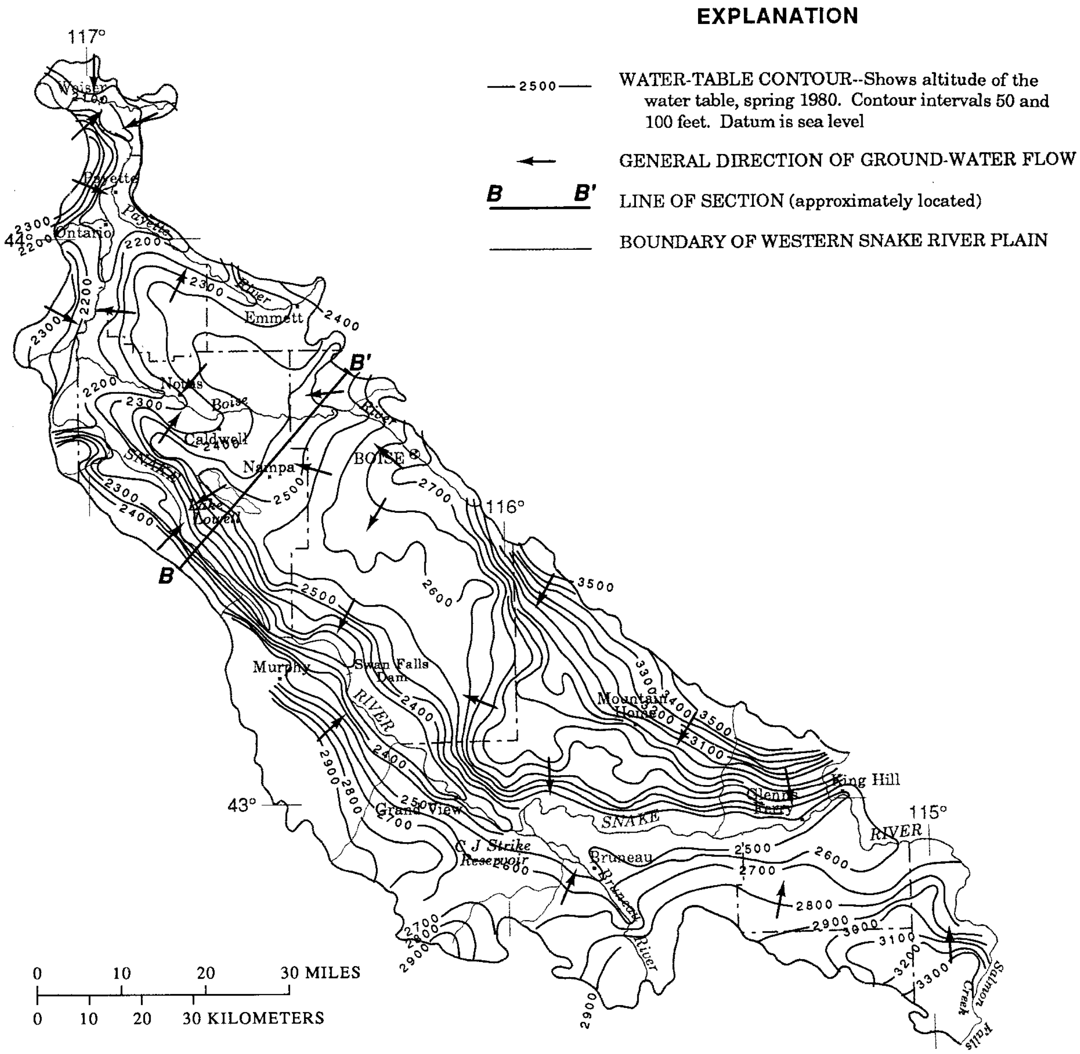

Figure 16. 1980 water level contours and inferred flow directions (from Newton, 1991).

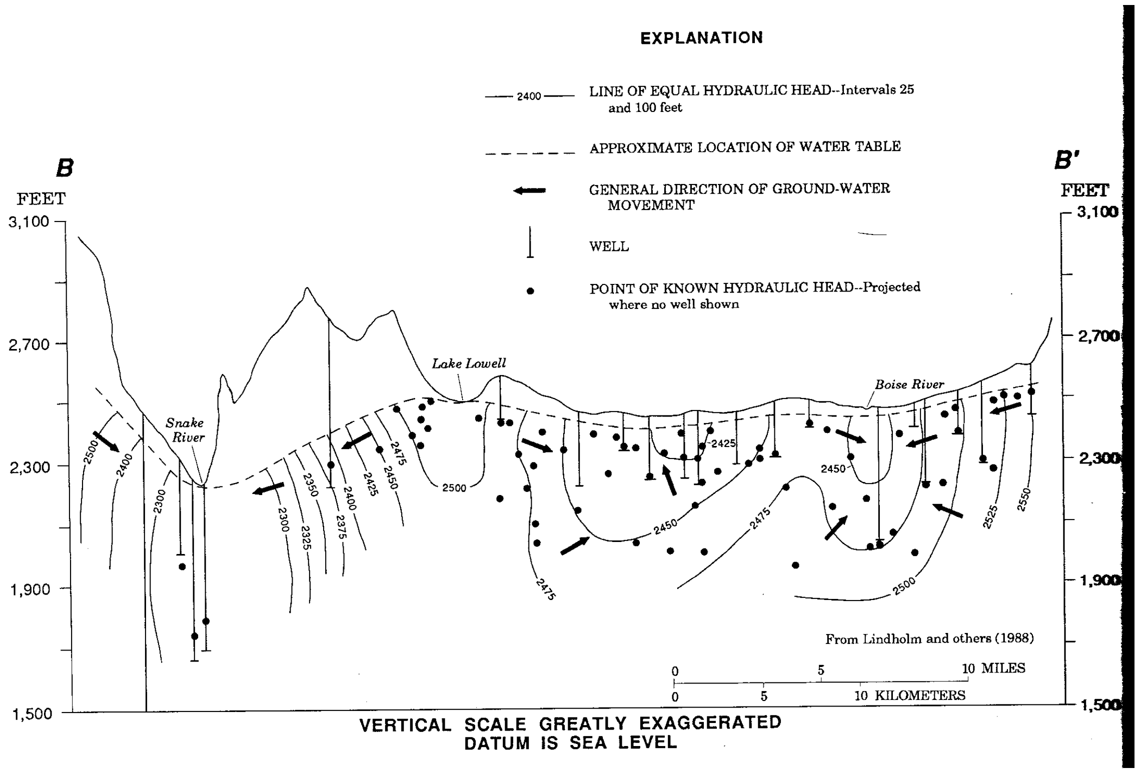

Figure 17. Generalized conceptual flow model for cross-section through Lake Lowell and Boise River in northern portion of the USGS model (from Newton, 1991).

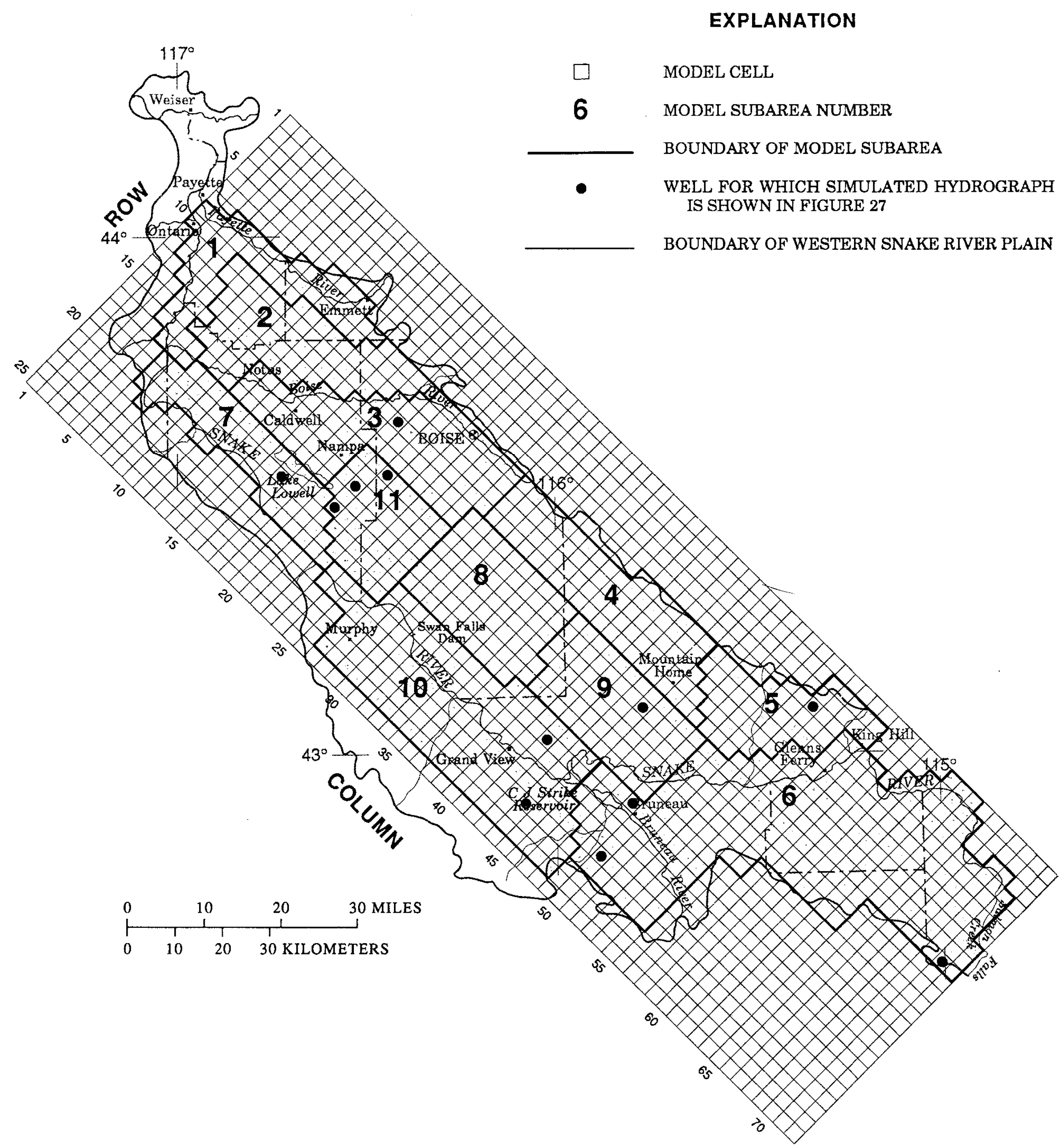

Figure 18. USGS model grid and model subareas (from Newton, 1991).

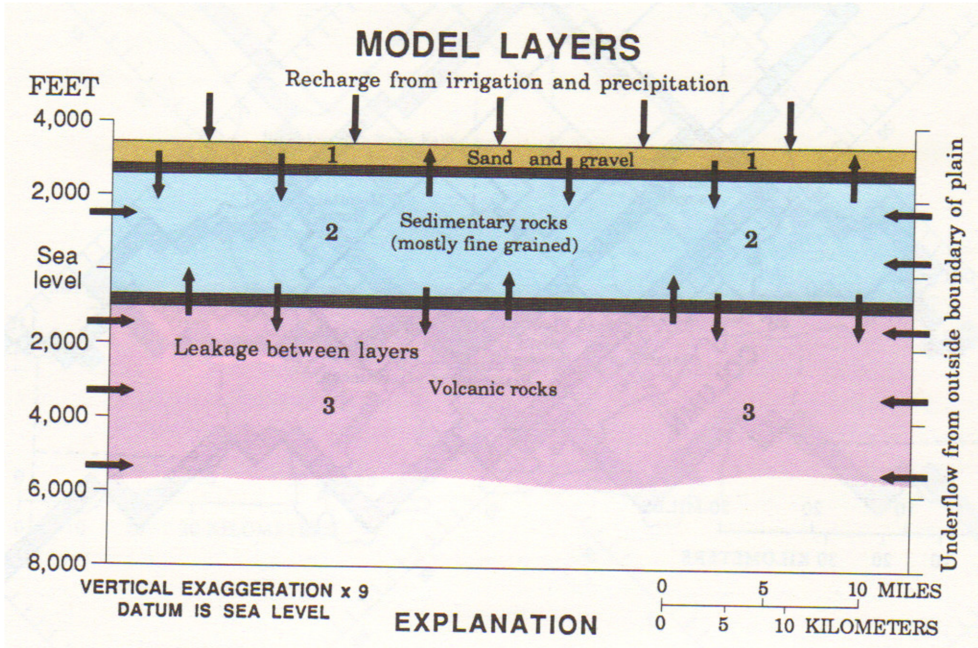

Figure 19. USGS model representation of subsurface (adapted from Newton, 1991).

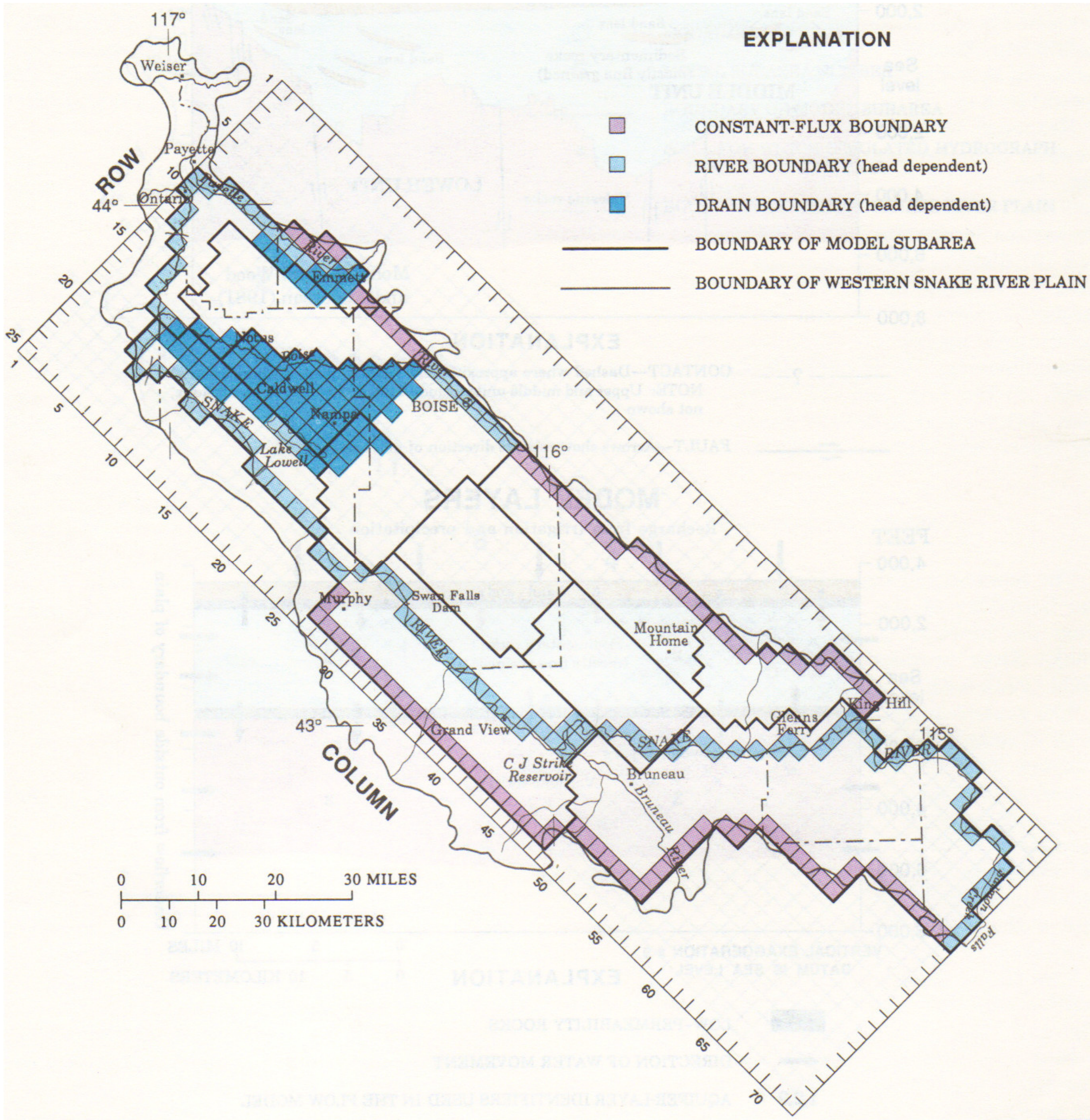

Figure 20. USGS model layer 1 boundary conditions (from Newton, 1991).

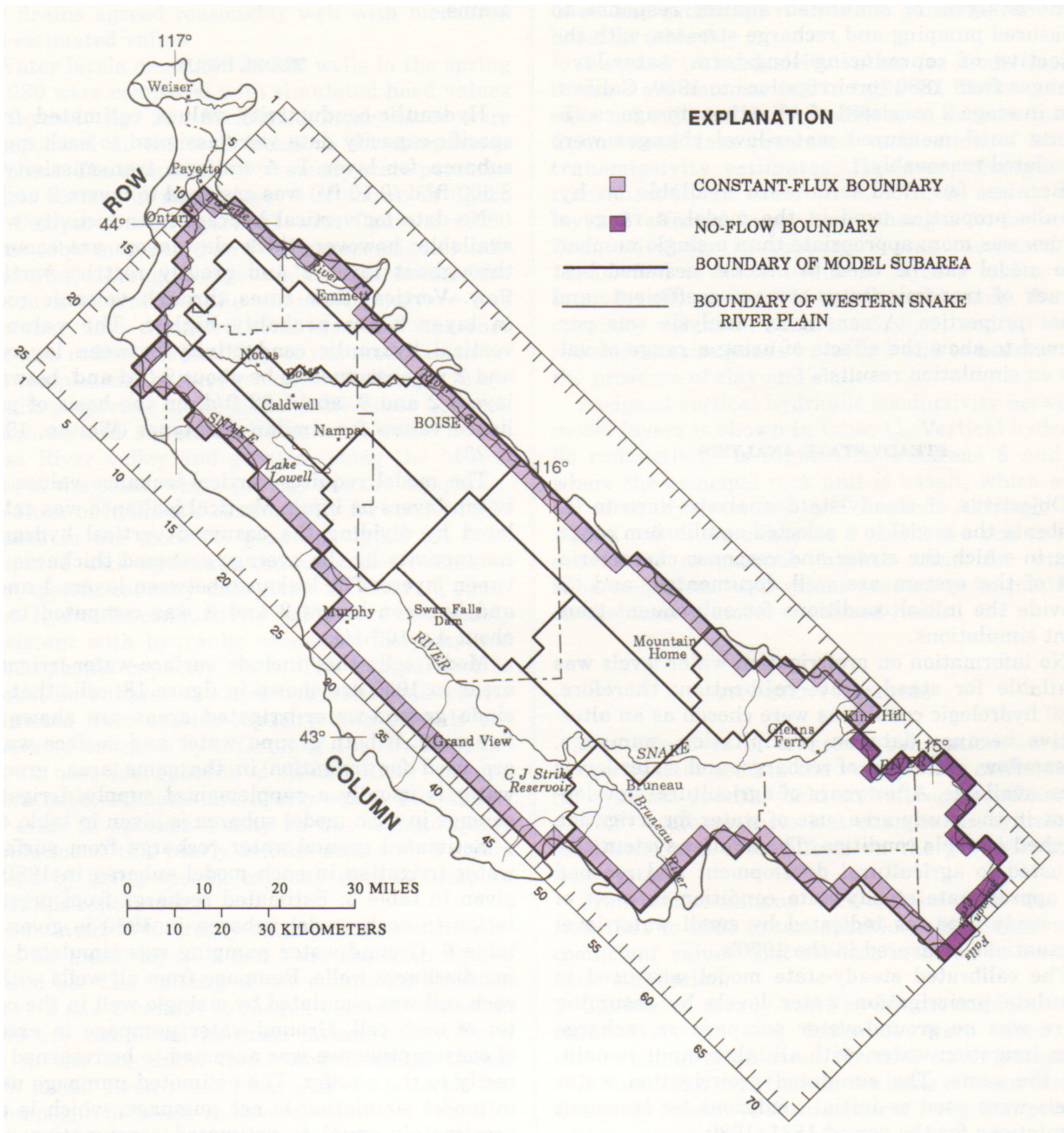

Figure 21. USGS model layers 2 and 3 boundary conditions (from Newton, 1991).

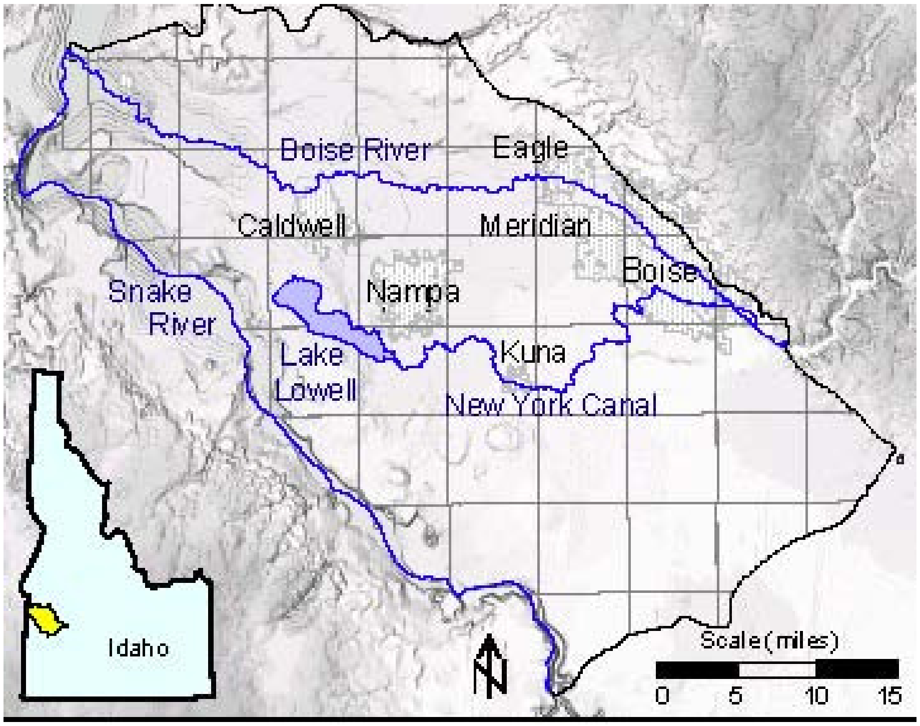

Figure 22. Treasure Valley Hydrologic Project model boundary (from Petrich and Urban, 2004).

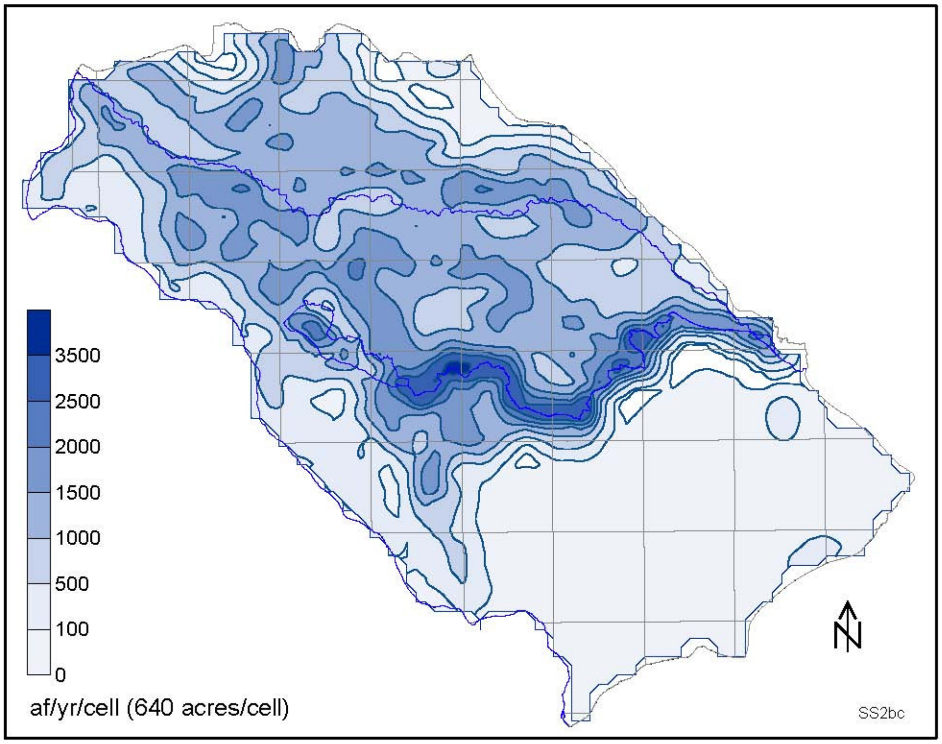

Figure 23. Treasure Valley Hydrologic Project areal distribution of recharge (from Petrich and Urban, 2004).

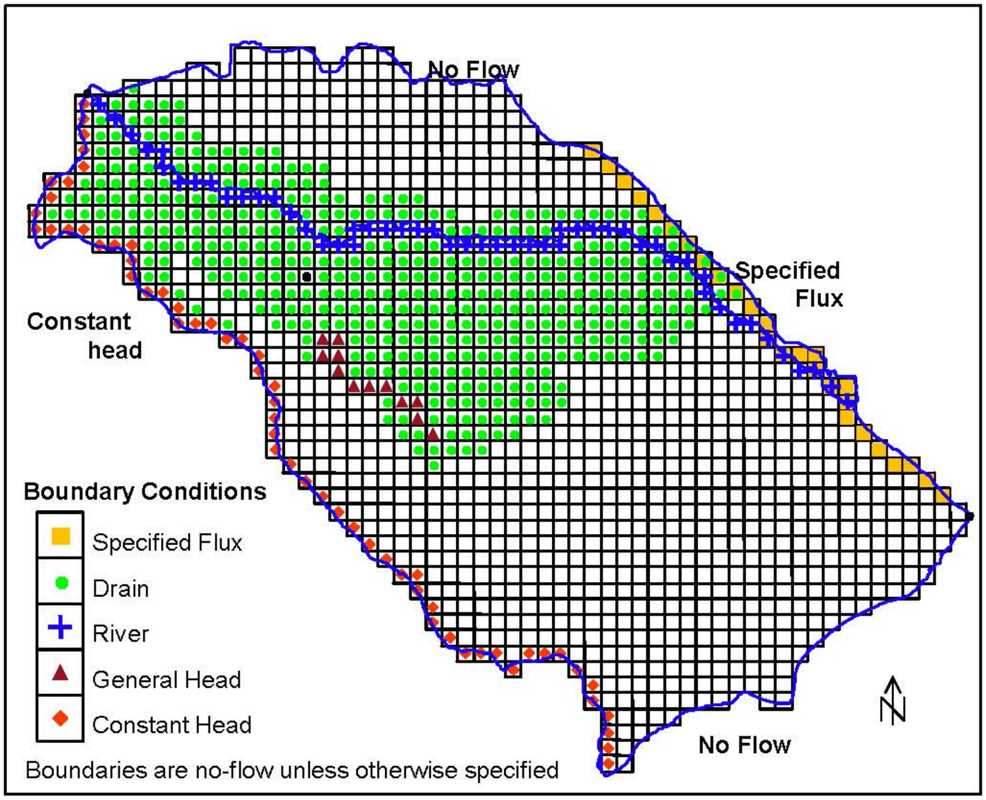

Figure 24. Treasure Valley Hydrologic Project model grid and boundary conditions (from Petrich and Urban, 2004).

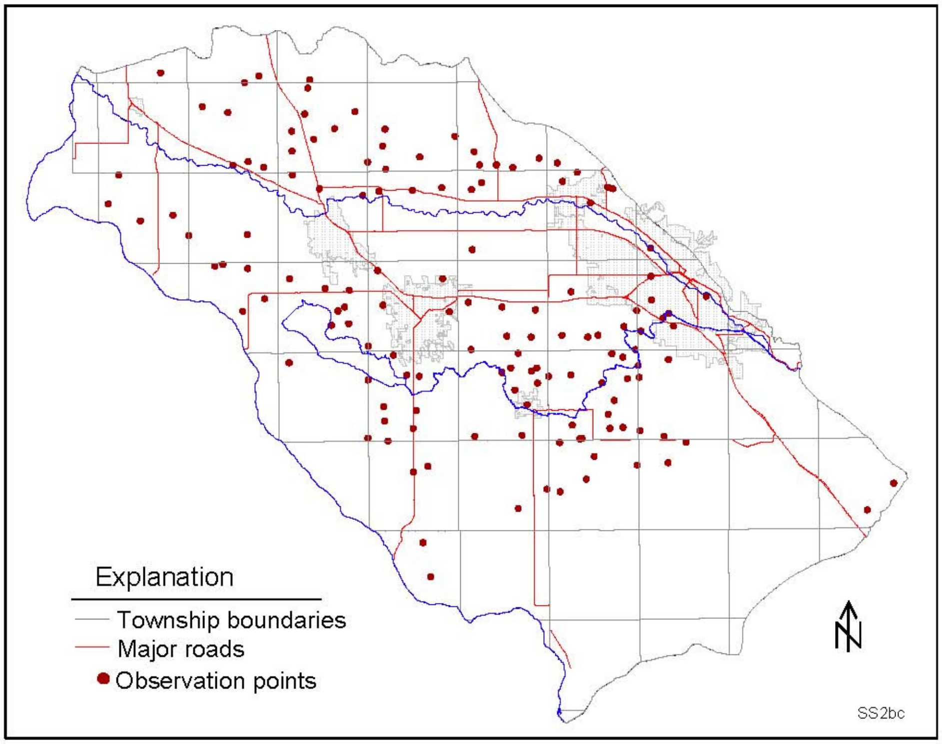

Figure 25. Location of TVHP water level observations, layer 1 (from Petrich and Urban, 2004).

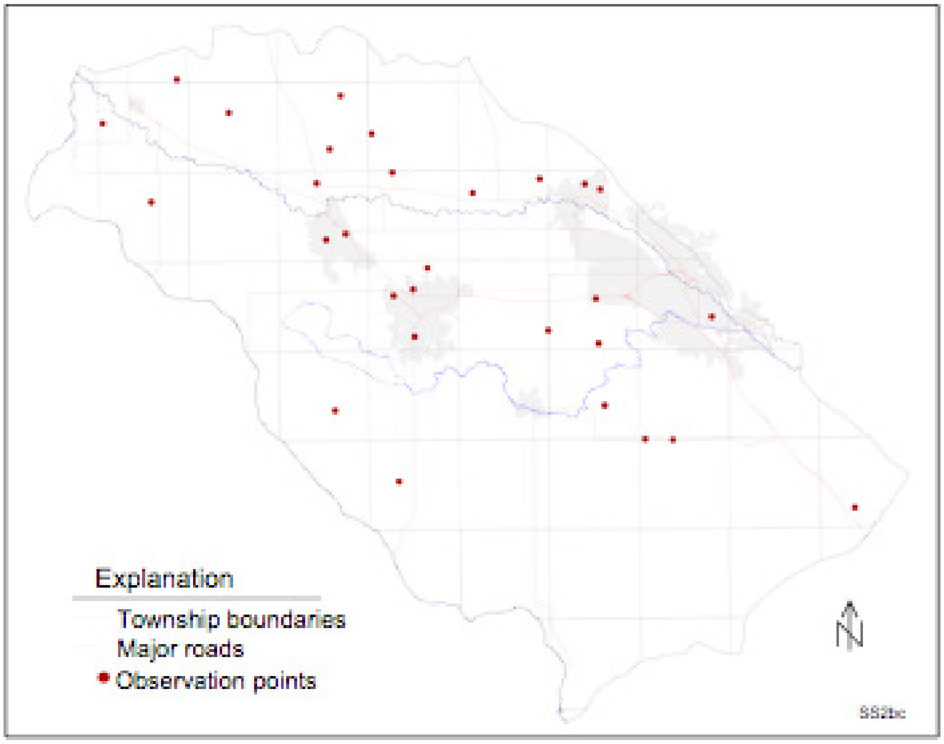

Figure 26. Location of TVHP water level observations, layer 2 (from Petrich and Urban, 2004).

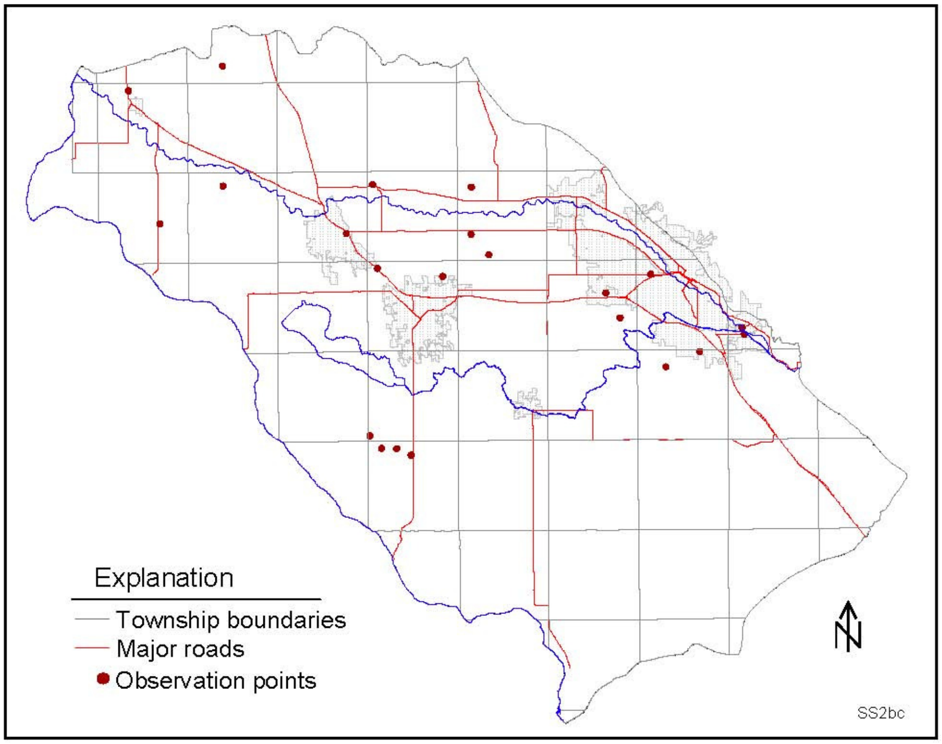

Figure 27. Location of TVHP water level observations, layer 3 (from Petrich and Urban, 2004).

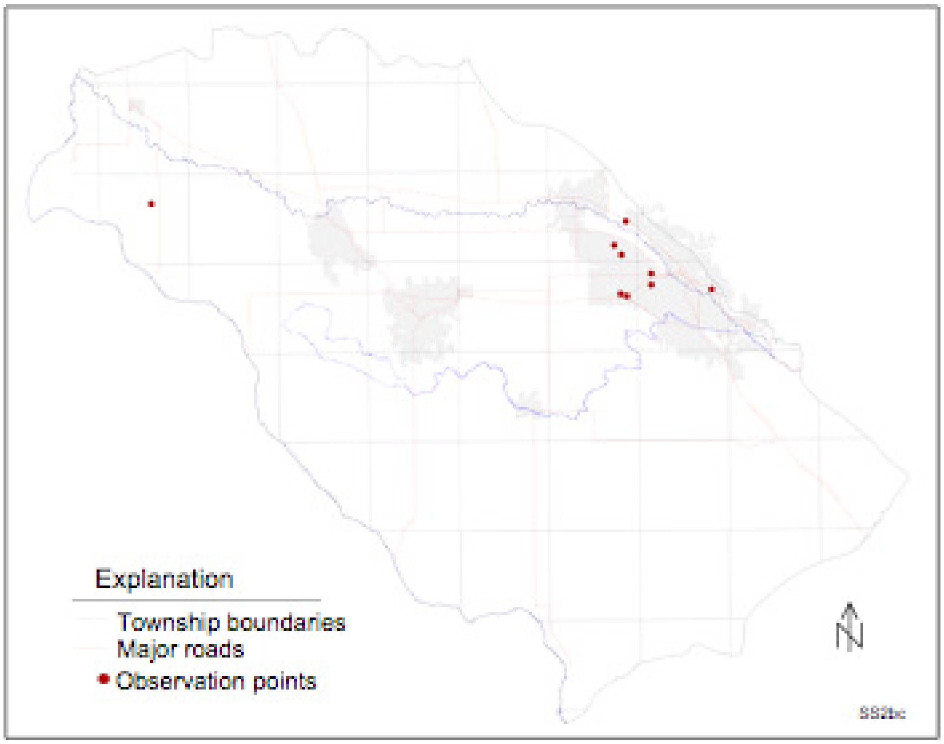

Figure 28. Location of TVHP water level observations, layer 4 (from Petrich and Urban, 2004).

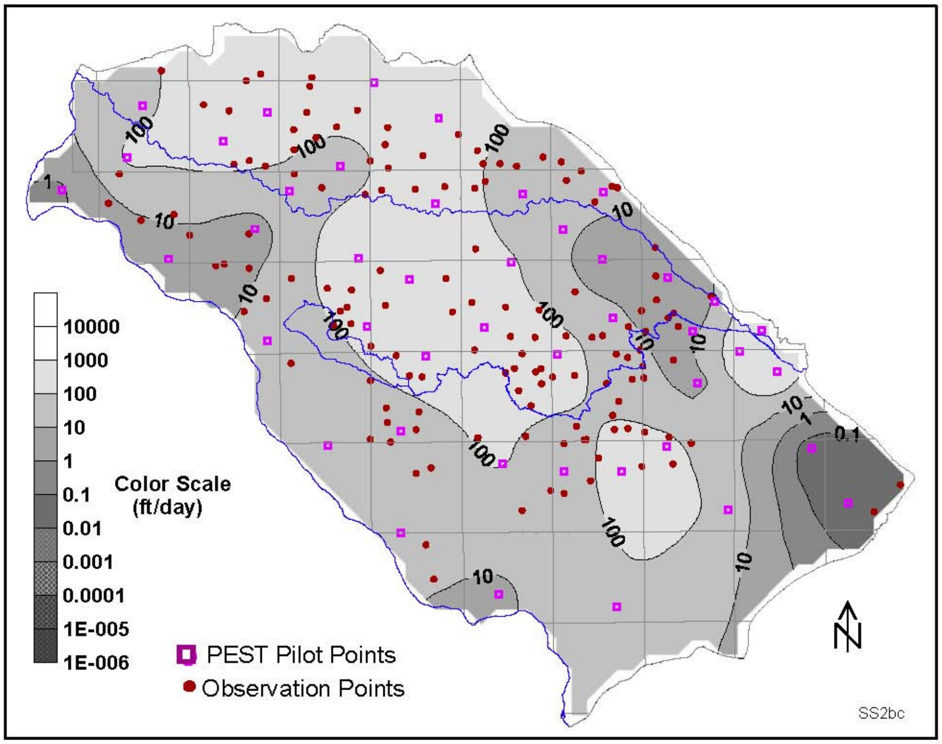

Figure 29. Estimated horizontal hydraulic conductivity distribution, layer 1 for TVHP model (from Petrich and Urban, 2004).

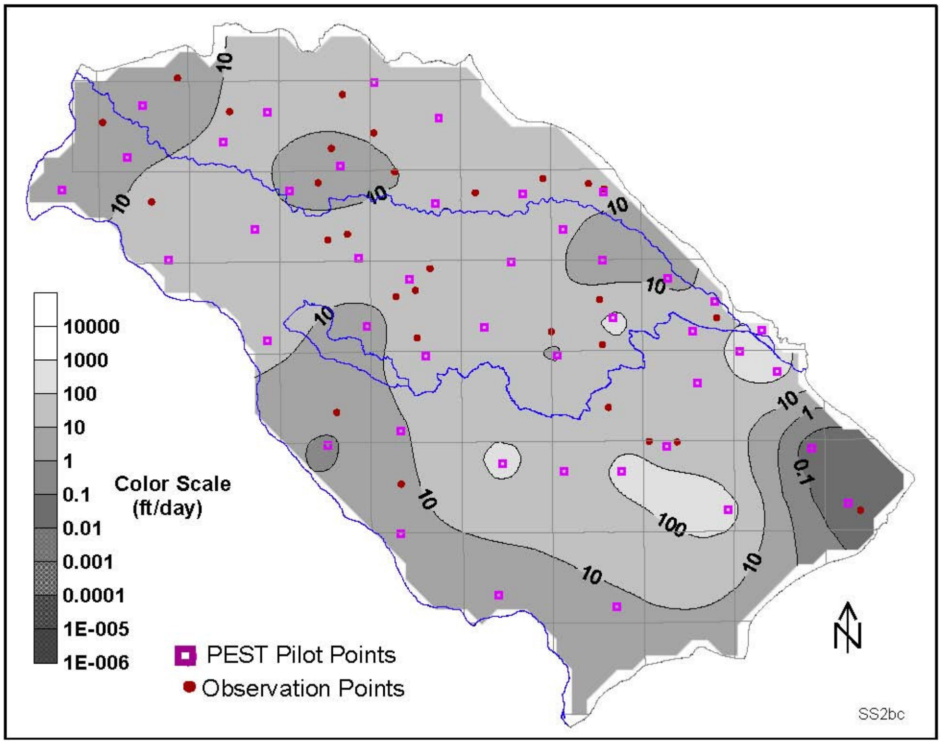

Figure 30. Estimated horizontal conductivity distribution, layer 2 of TVHP (from Petrich and Urban, 2004).

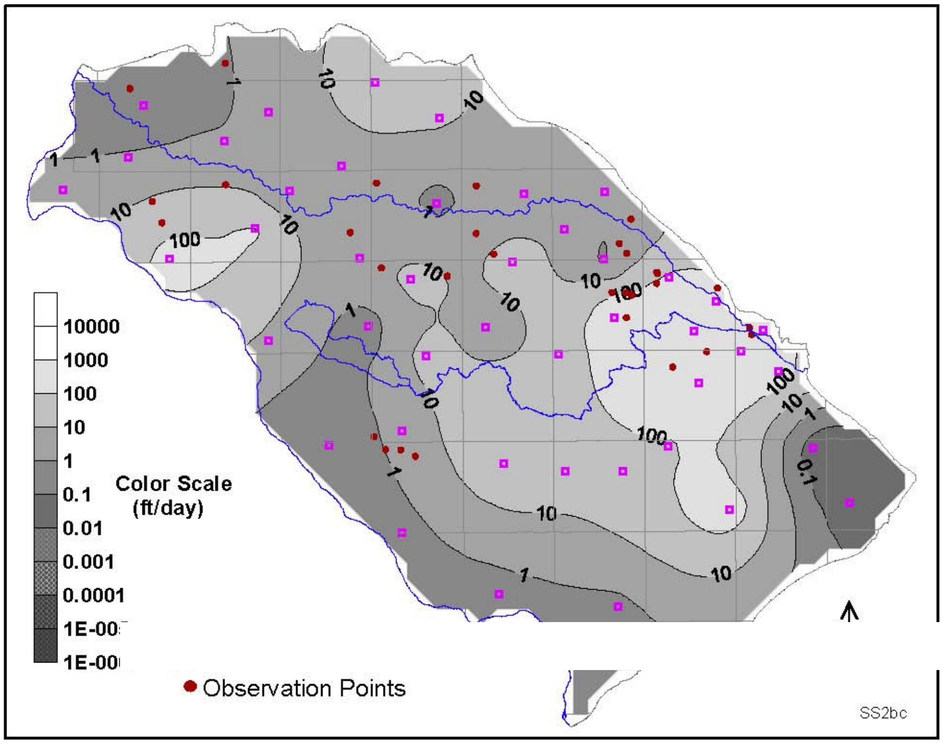

Figure 31. Estimated horizontal hydraulic conductivity distribution, layers 3 and 4 of TVHP model (from Petrich and Urban, 2004).

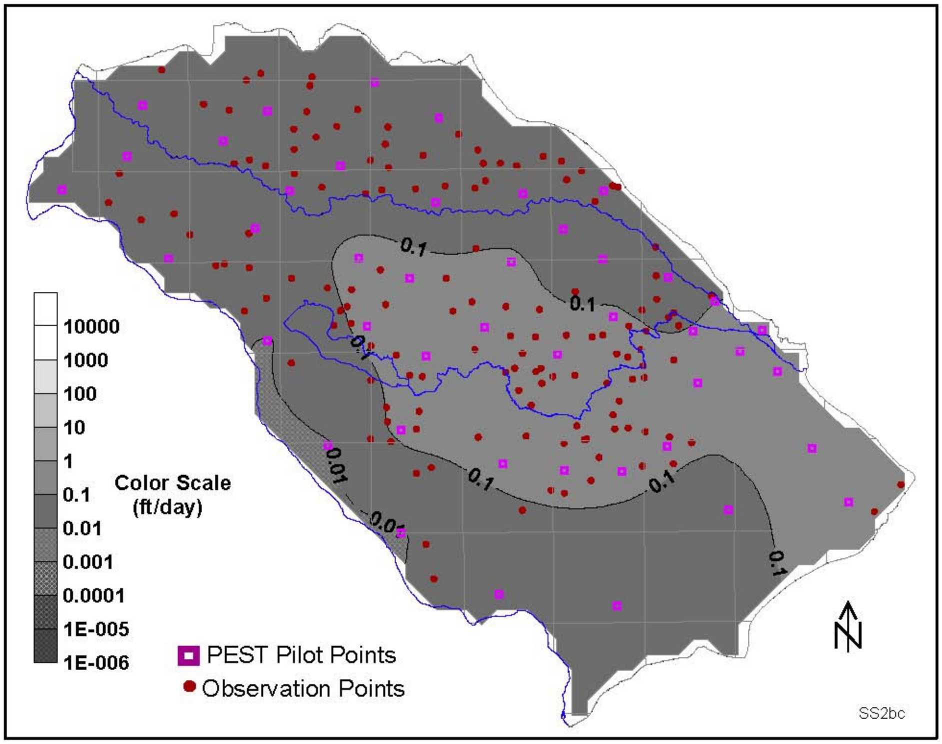

Figure 32. Estimated vertical hydraulic conductivity distribution, layer 1 of TVHP model (from Petrich and Urban, 2004).

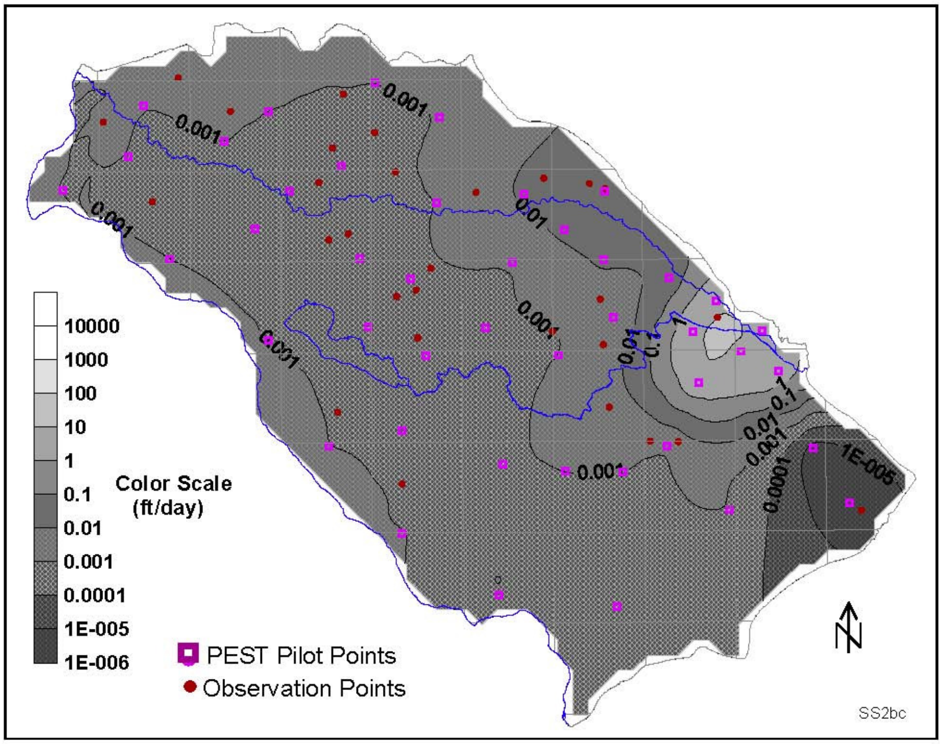

Figure 33. Estimated vertical hydraulic conductivity distribution, layer 2 of TVHP model (from Petrich and Urban, 2004).

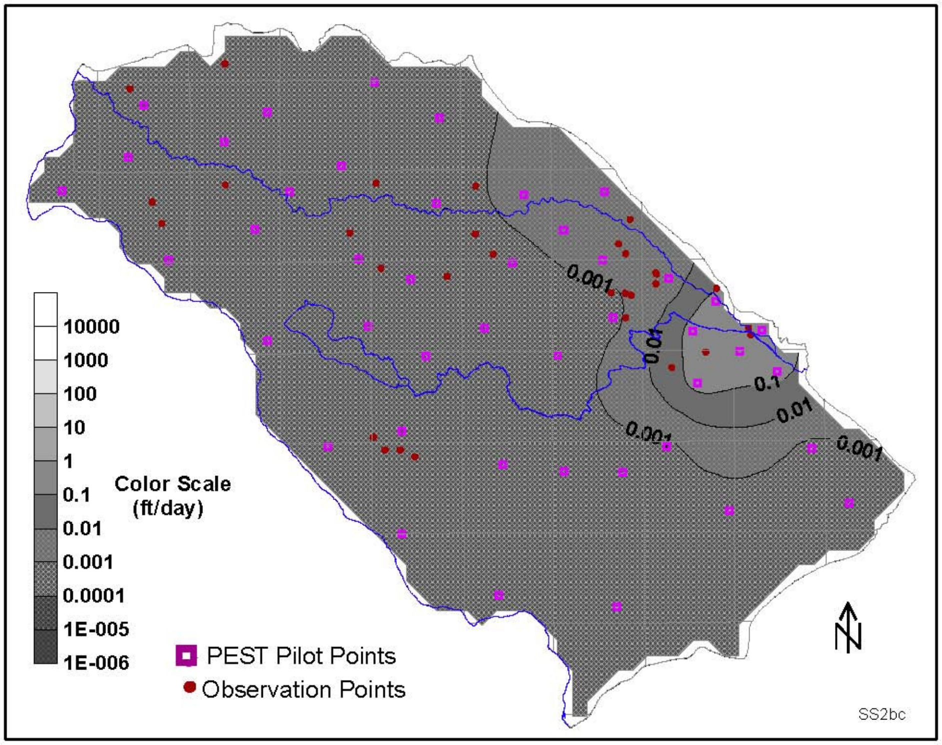

Figure 34. Estimated vertical hydraulic conductivity distribution, layers 3 and 4 of TVHP model (from Petrich and Urban, 2004).

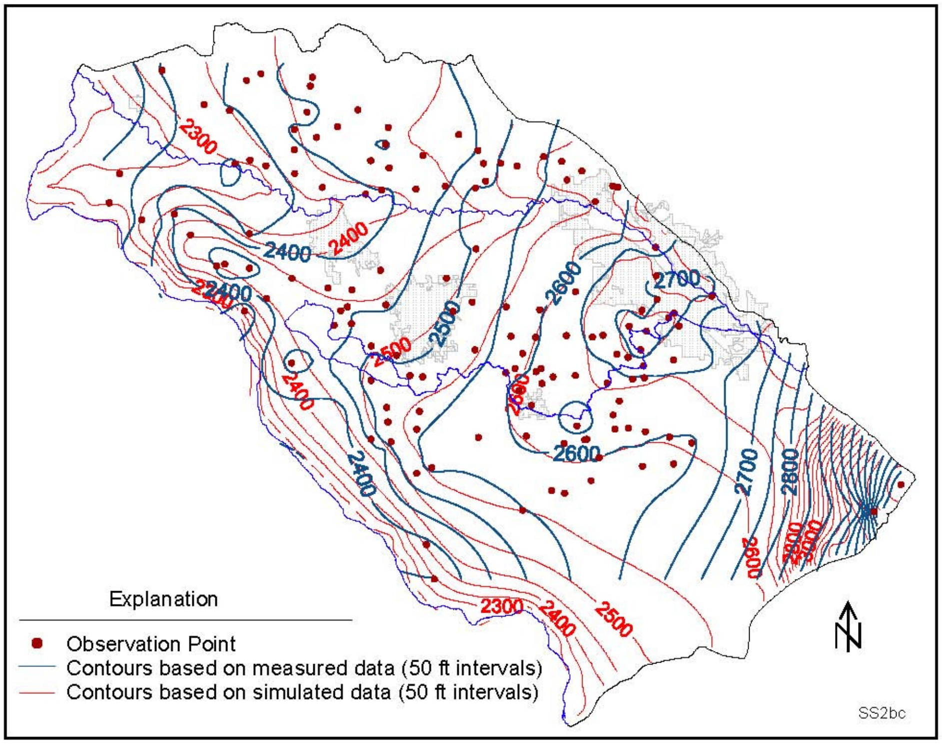

Figure 35. Simulated and observed potentiometric contours, layer 1 of TVHP model (from Petrich and Urban, 2004).

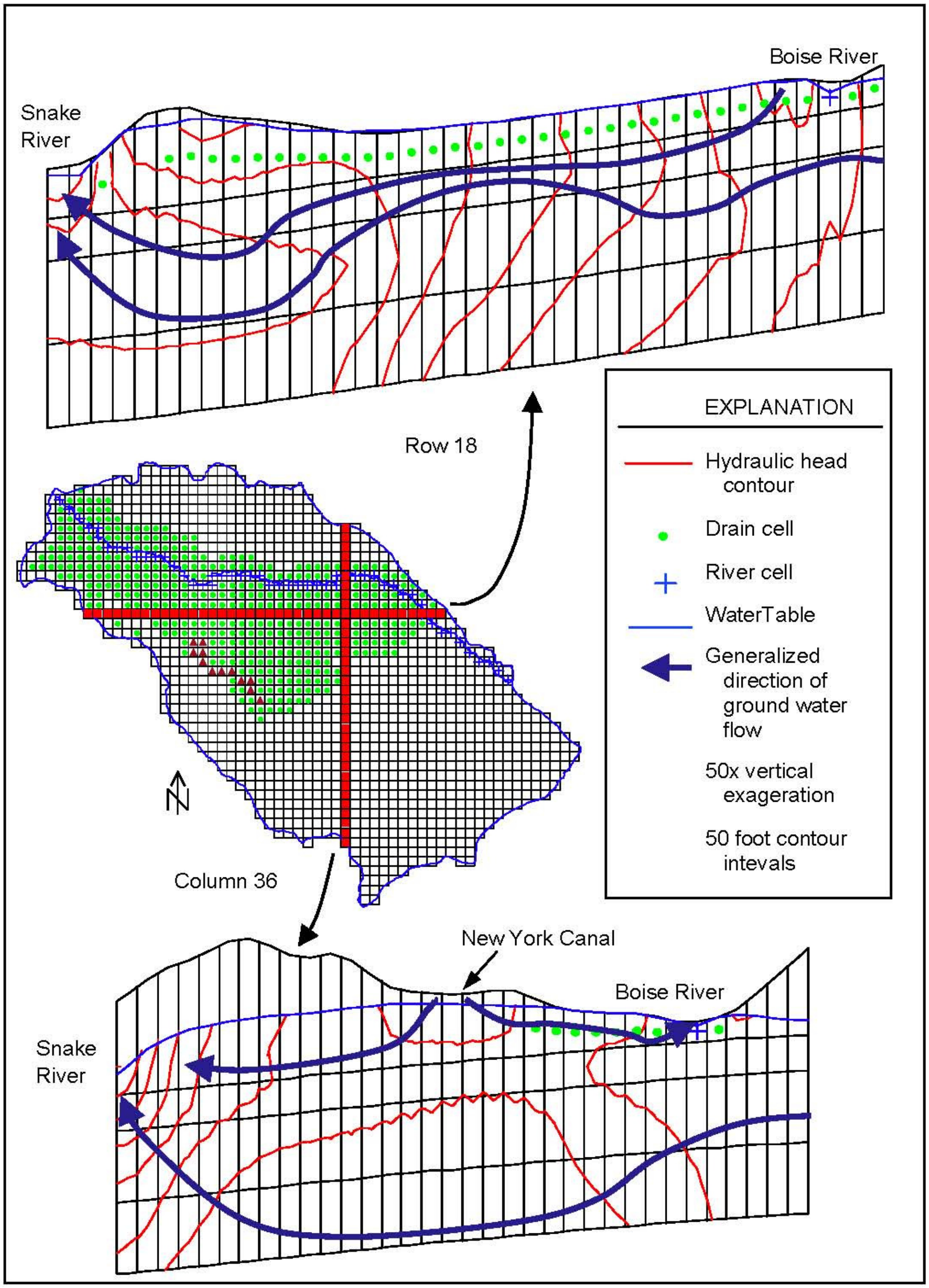

Figure 36. Potentiometric contours, row 18 and column 36 of TVHP model (from Petrich and Urban, 2004).

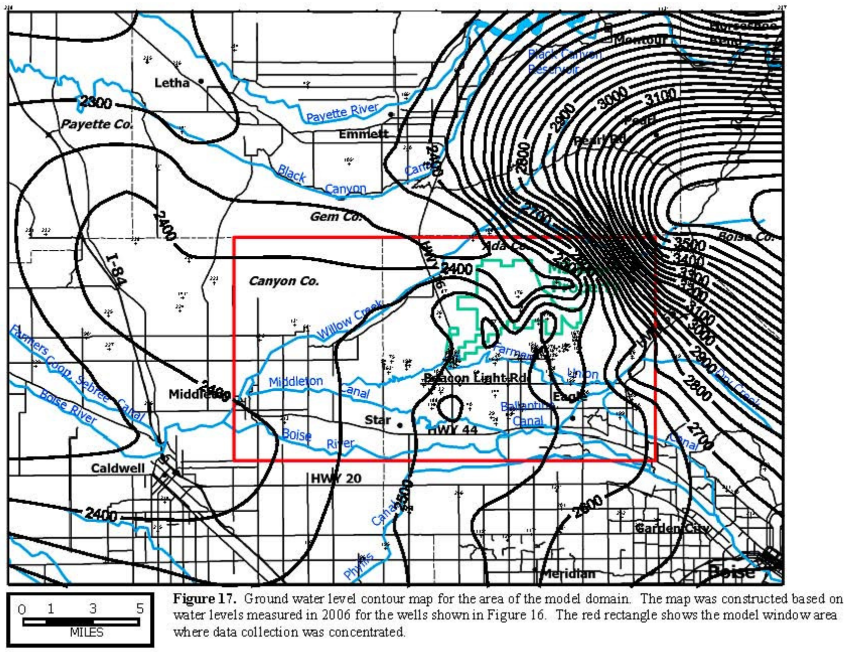

Figure 37. University of Idaho M3 Eagle Model study area outlined in red (from Douglas, 2007).

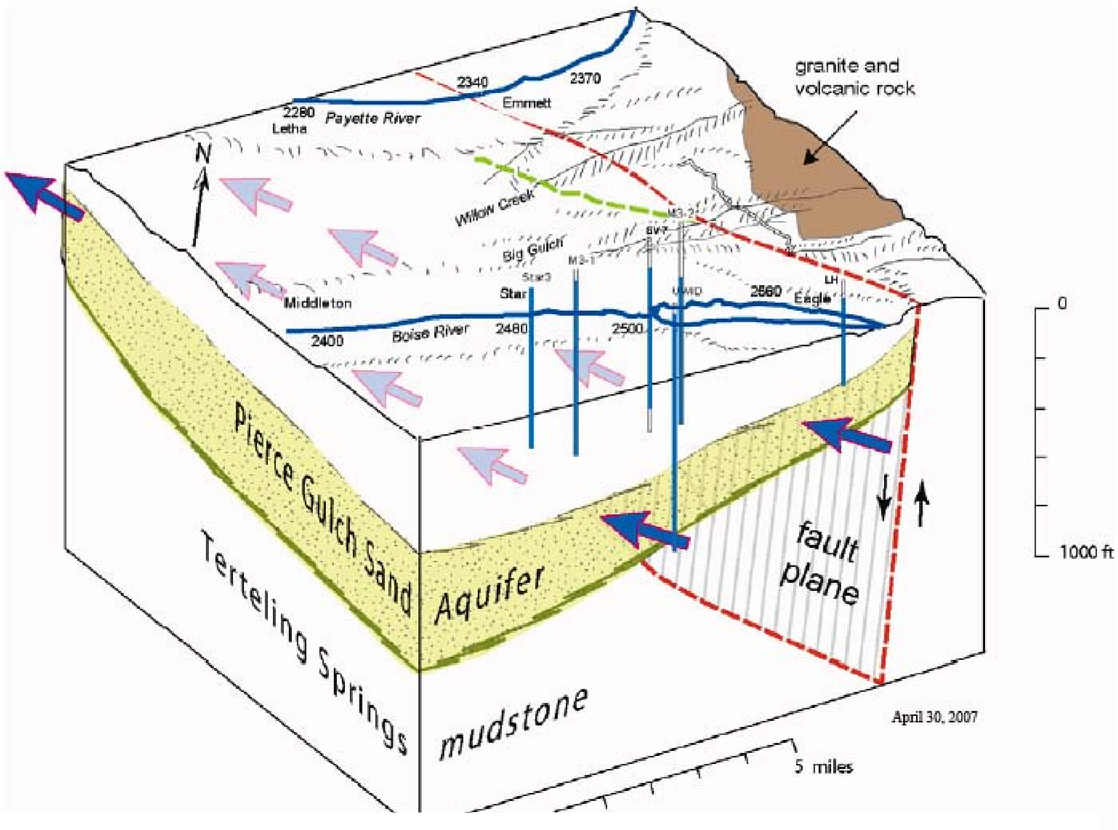

Figure 38. Conceptual model of Pierce Gulch Sands (from Squires and others, 2007).

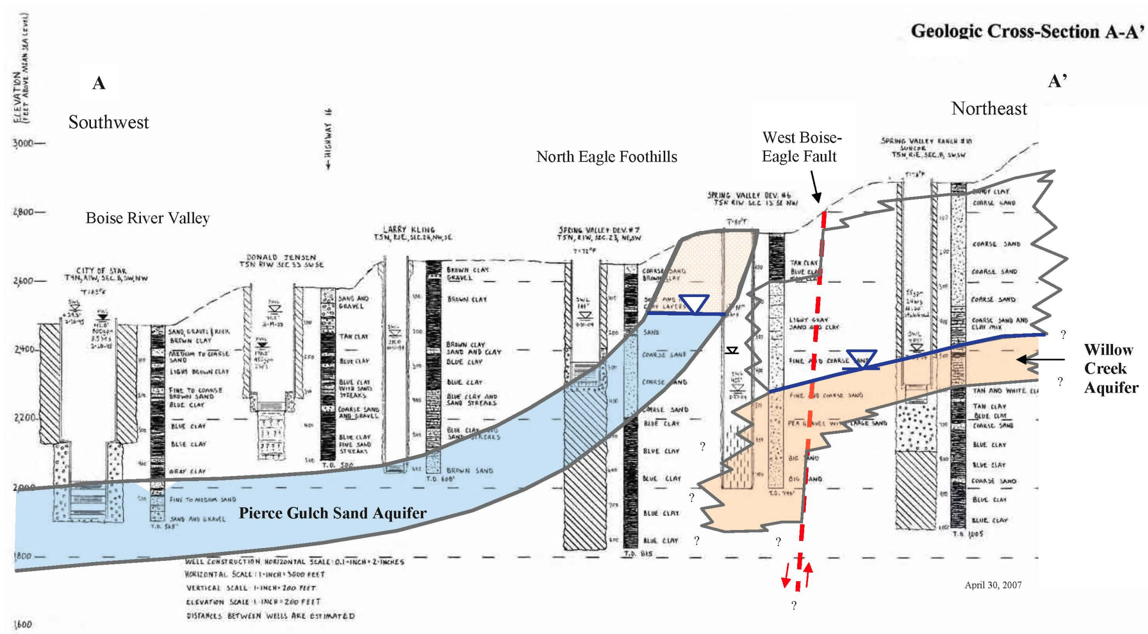

Figure 39. Cross-sectional conceptual drawing of Pierce Gulch Sand Aquifer (from Squires and others, 2007).

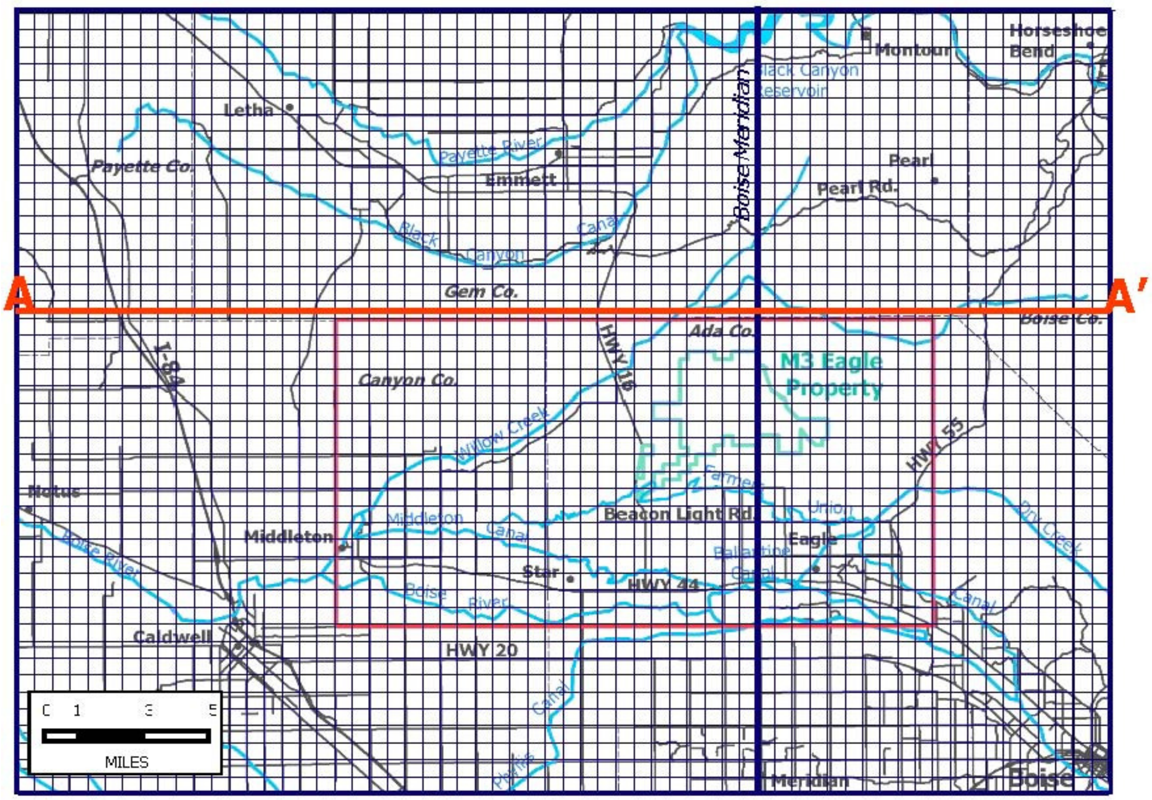

Figure 40. University of Idaho M3 Eagle model grid (from Douglas, 2007).

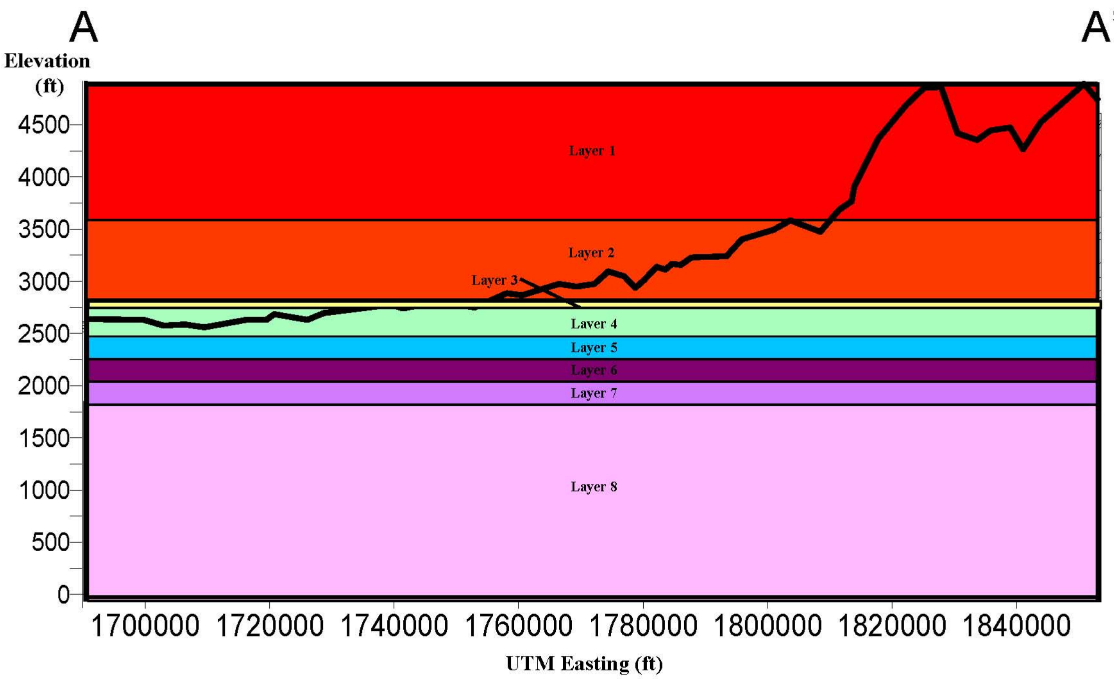

Figure 41. University of Idaho M3 Eagle model layers (from Douglas, 2007).

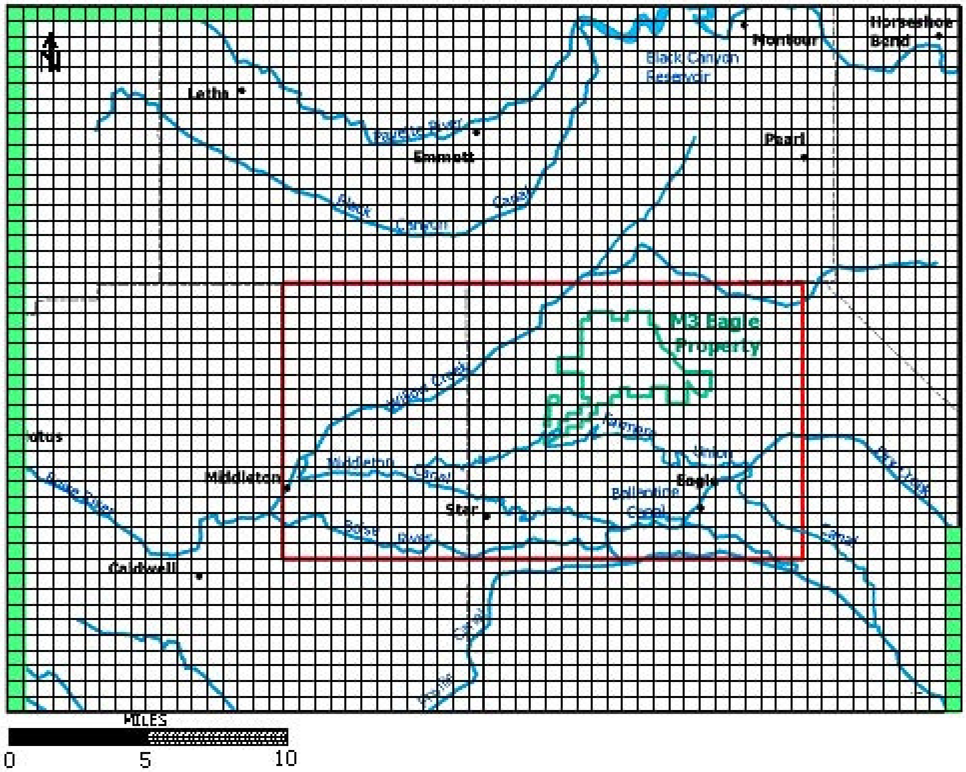

Figure 42. Location of general head boundaries, layer 8 of University of Idaho M3 Eagle model (from Douglas, 2007).

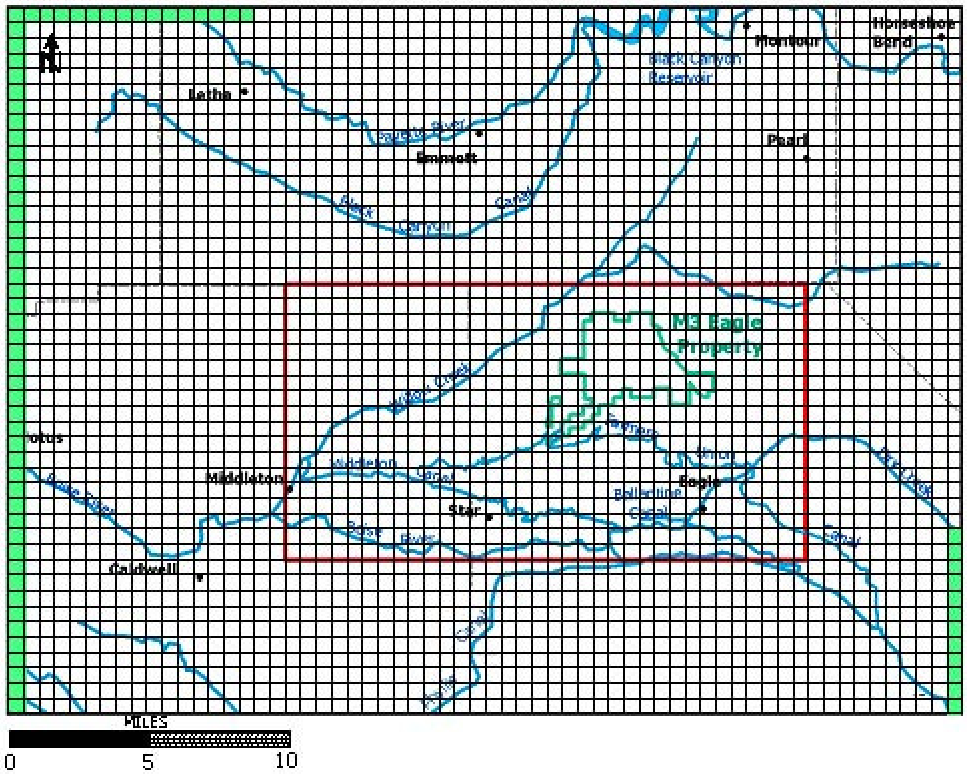

Figure 43. Location of general head boundaries, layer 6 of University of Idaho M3 Eagle model (from Douglas, 2007).

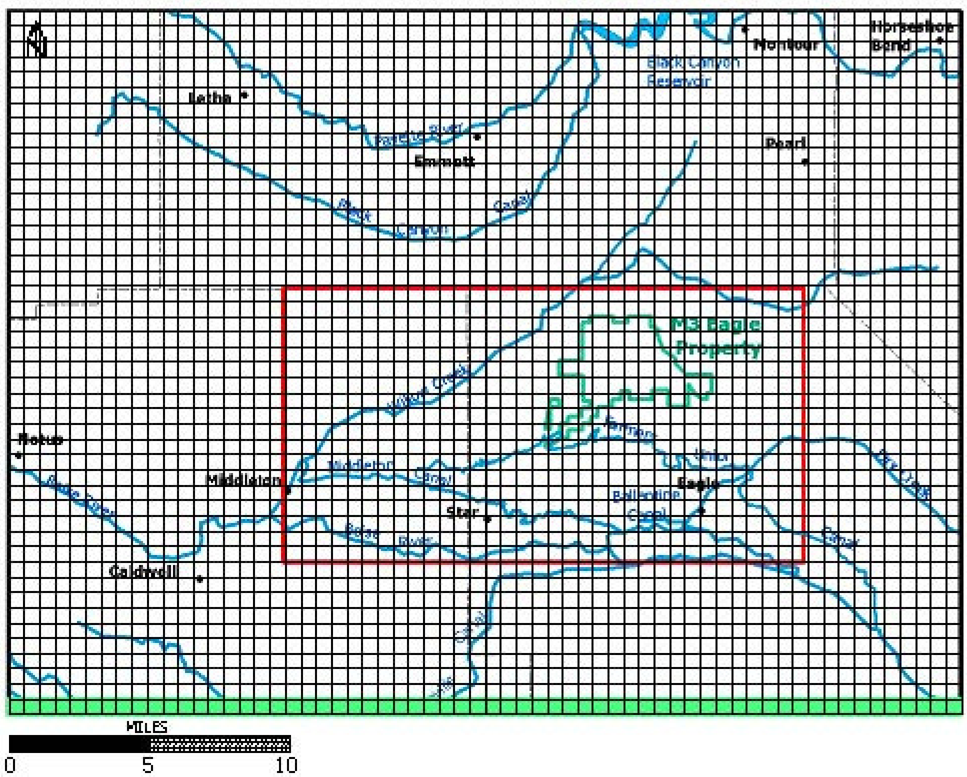

Figure 44. Location of general head boundaries, layer 7 of University of Idaho M3 Eagle model (from Douglas, 2007).

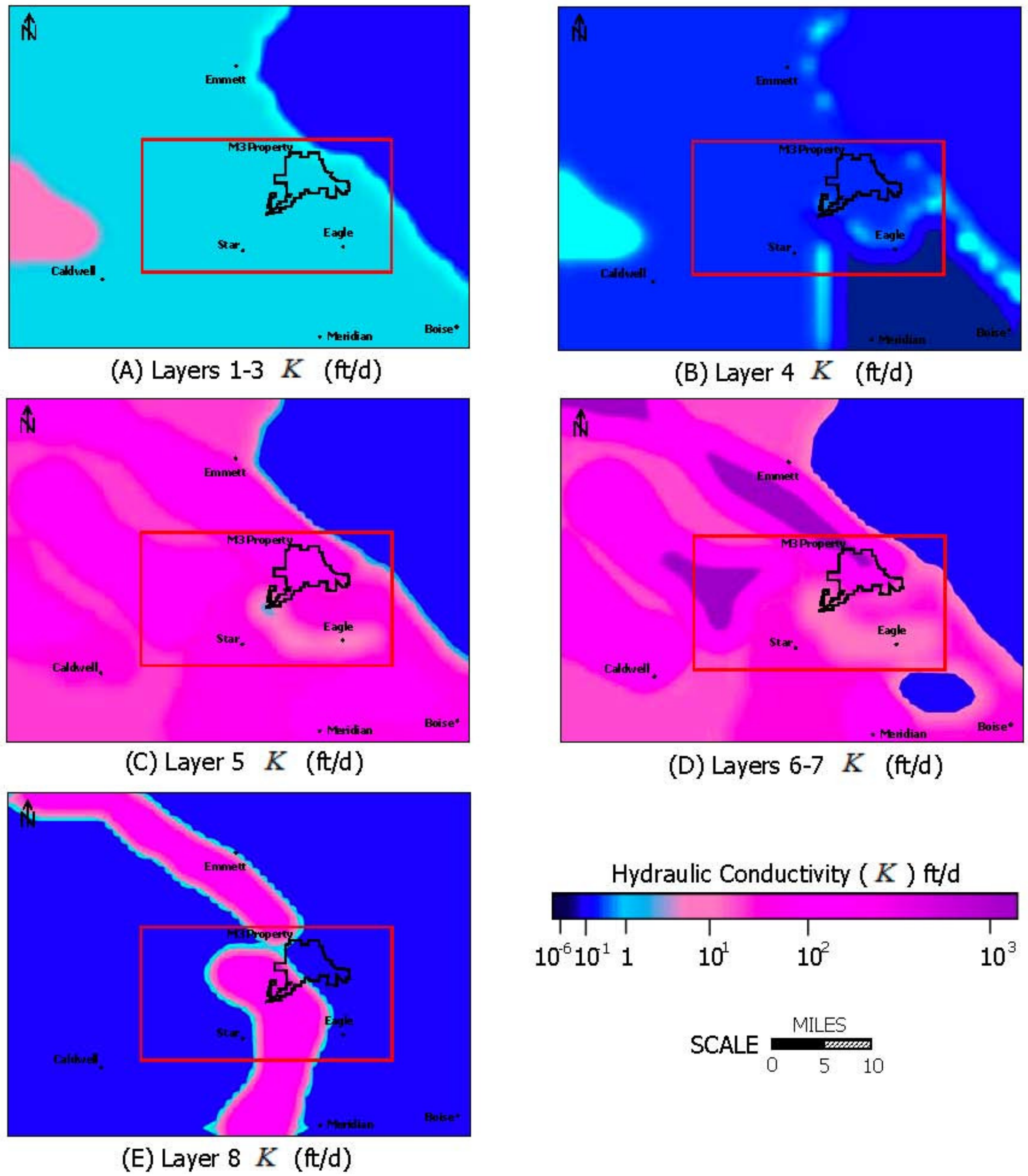

Figure 45. Hydraulic conductivity distribution for the Pierce Gulch Sand aquifer system, layers 1-7 of University of Idaho M3 Eagle model (from Douglas, 2007).

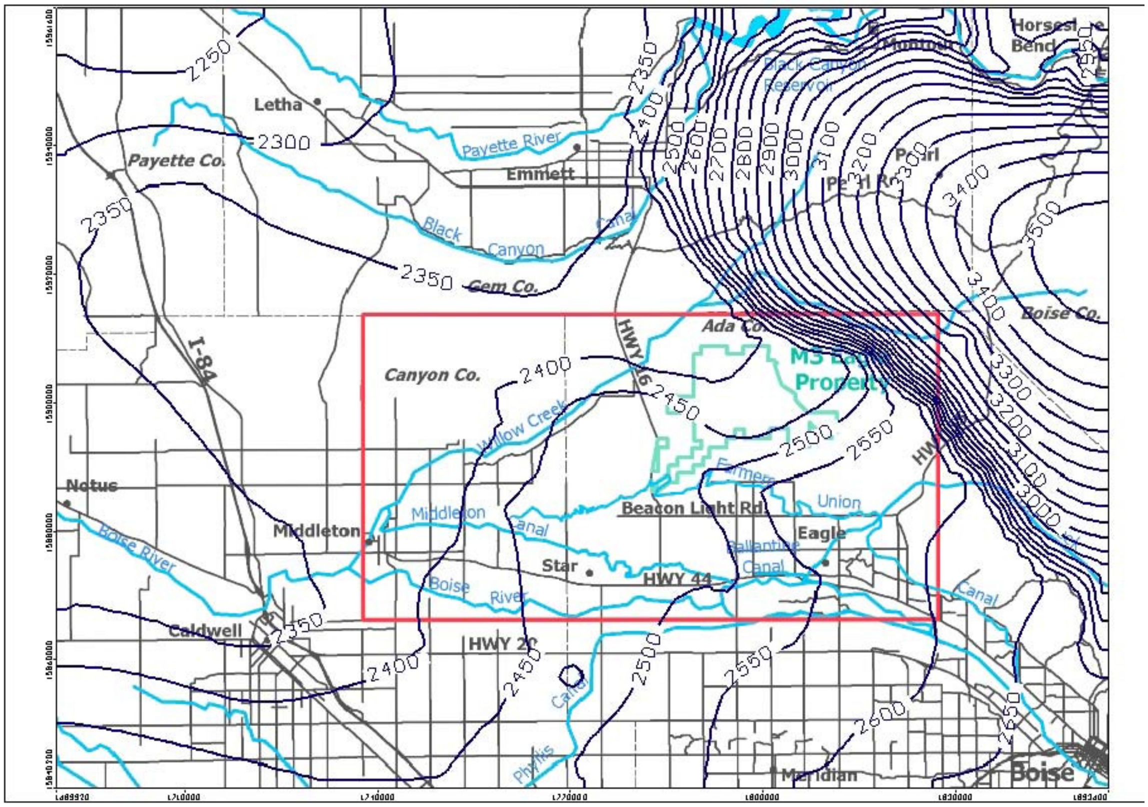

Figure 46. Model-predicted potentiometric surface map for layer 6 of quasi-steady state model 6 of University of Idaho M3 Eagle model (from Douglas, 2007).

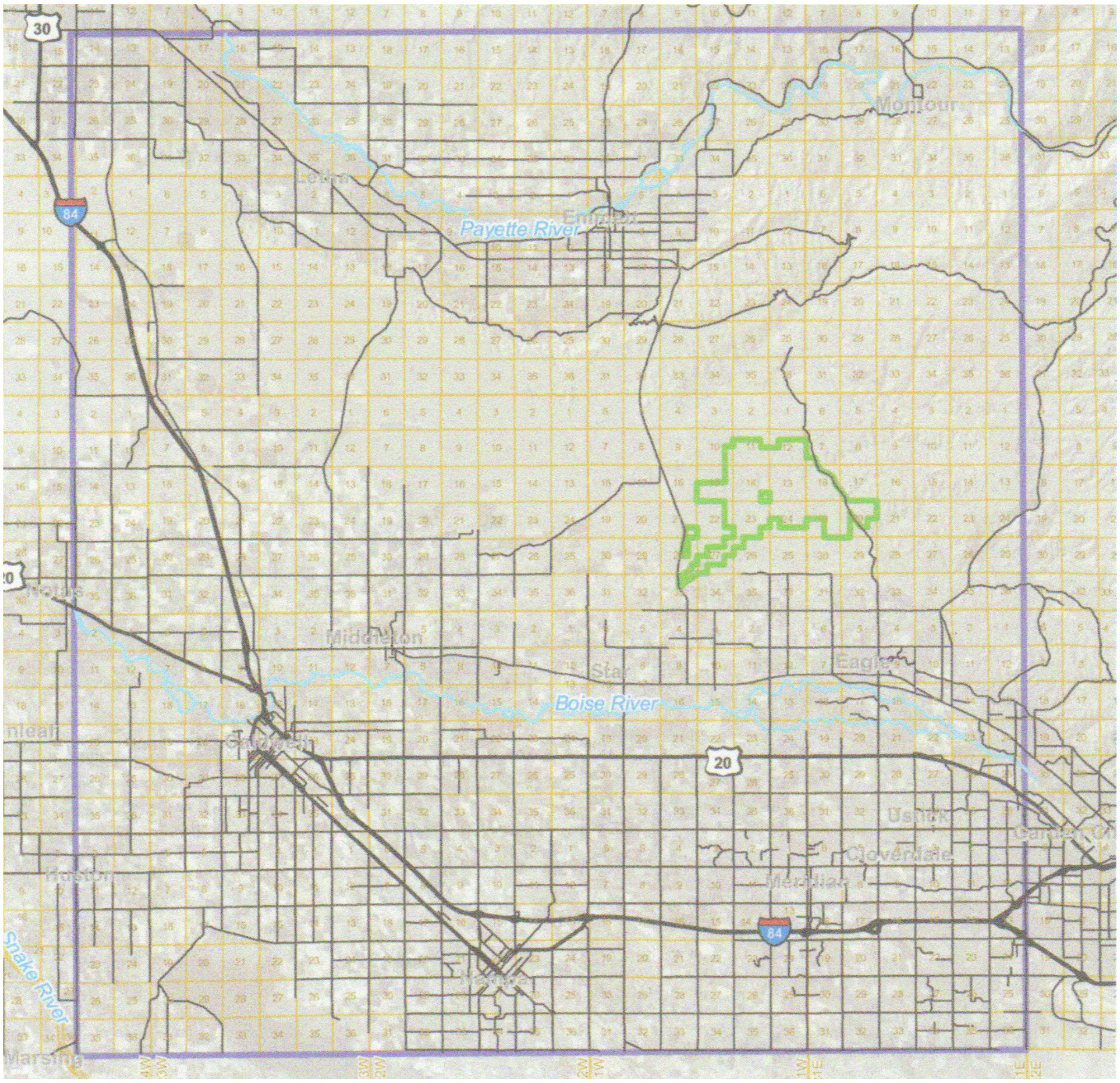

Figure 47. Areal extent of Pacific Groundwater Group M3 Eagle model (from Pacific Groundwater Group, 2008).

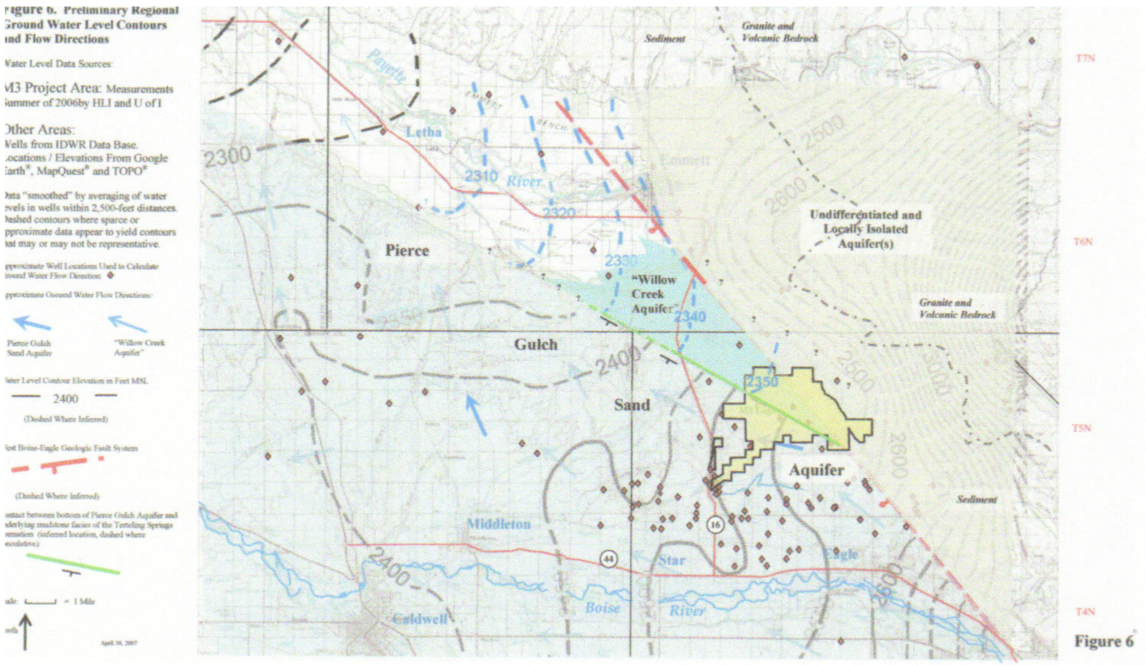

Figure 48. Regional water level contours in area of Pacific Groundwater Group M3 Eagle model (from Pacific Groundwater Group, 2008).

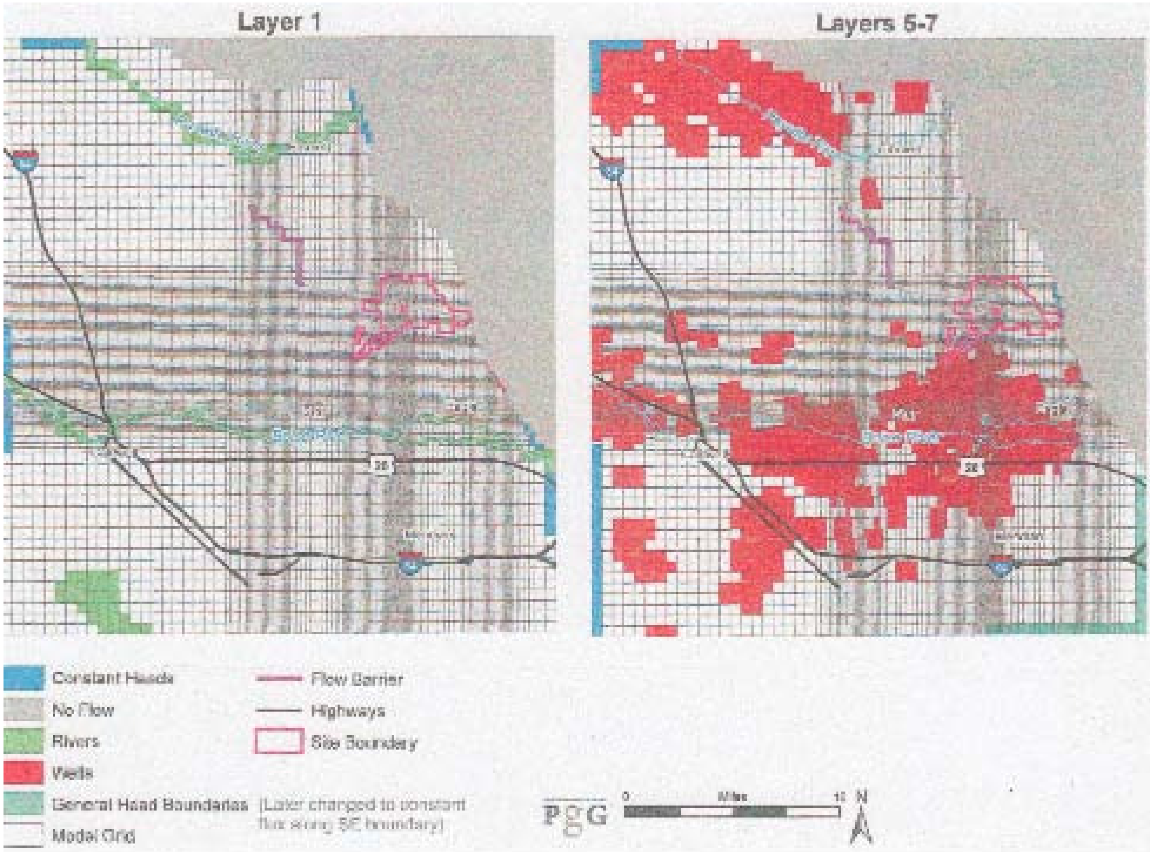

Figure 49. Model grid and model boundaries for layer 1 and layers 5-7, Pacific Groundwater Group M3 Eagle model (from Pacific Groundwater Group, 2008).

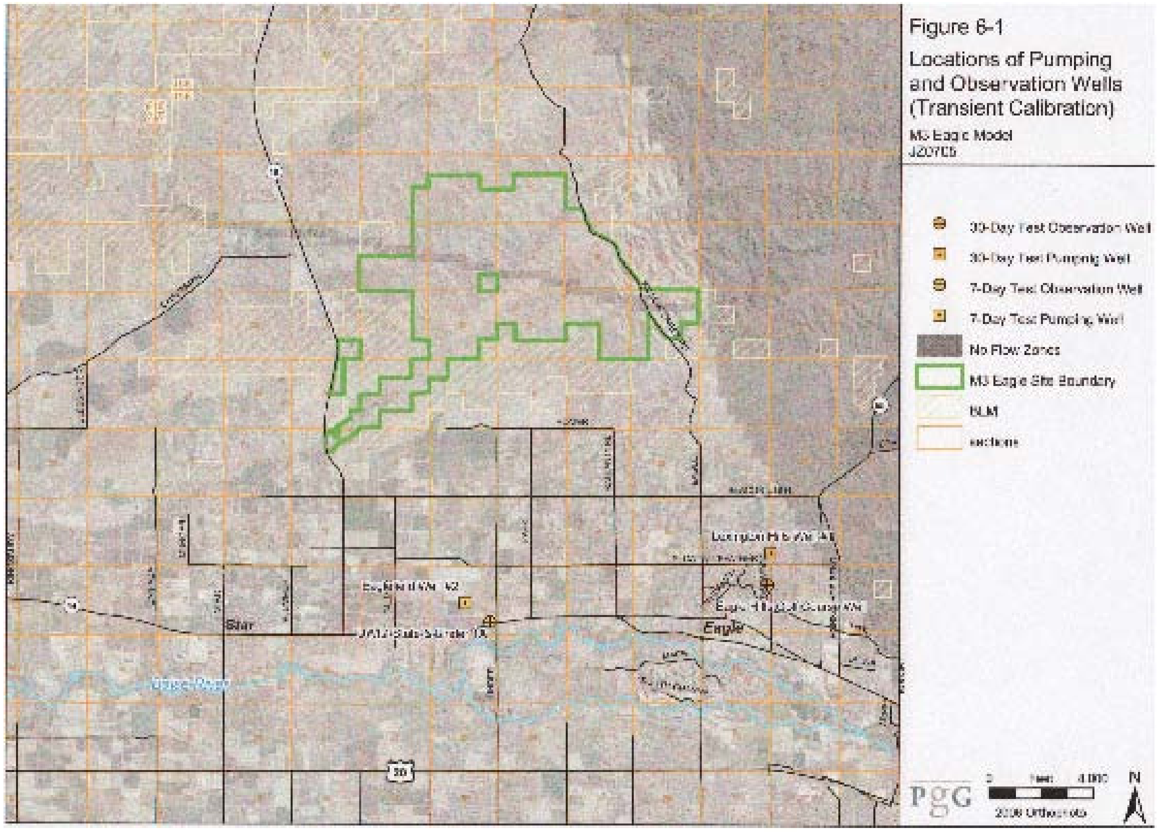

Figure 50. Location of pumping and observation wells used for transient calibration, Pacific Groundwater Group M3 Eagle model (from Pacific Groundwater Group, 2008).

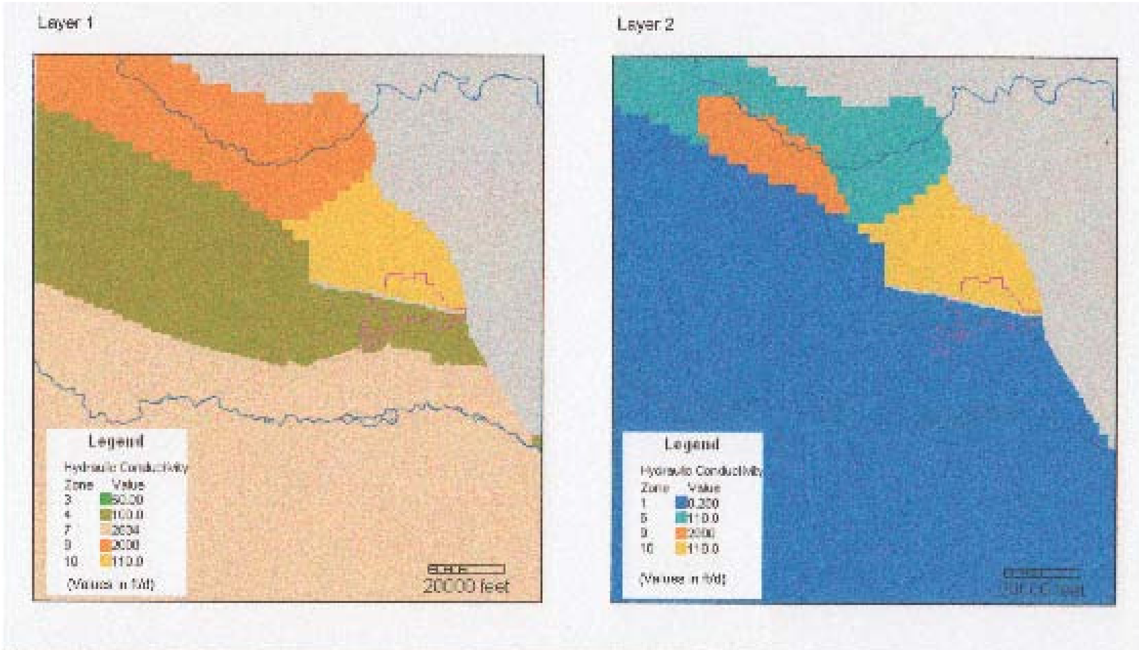

Figure 51. Hydraulic conductivity for layers 1 and 2, Pacific Groundwater Group M3 Eagle model (from Pacific Groundwater Group, 2008).

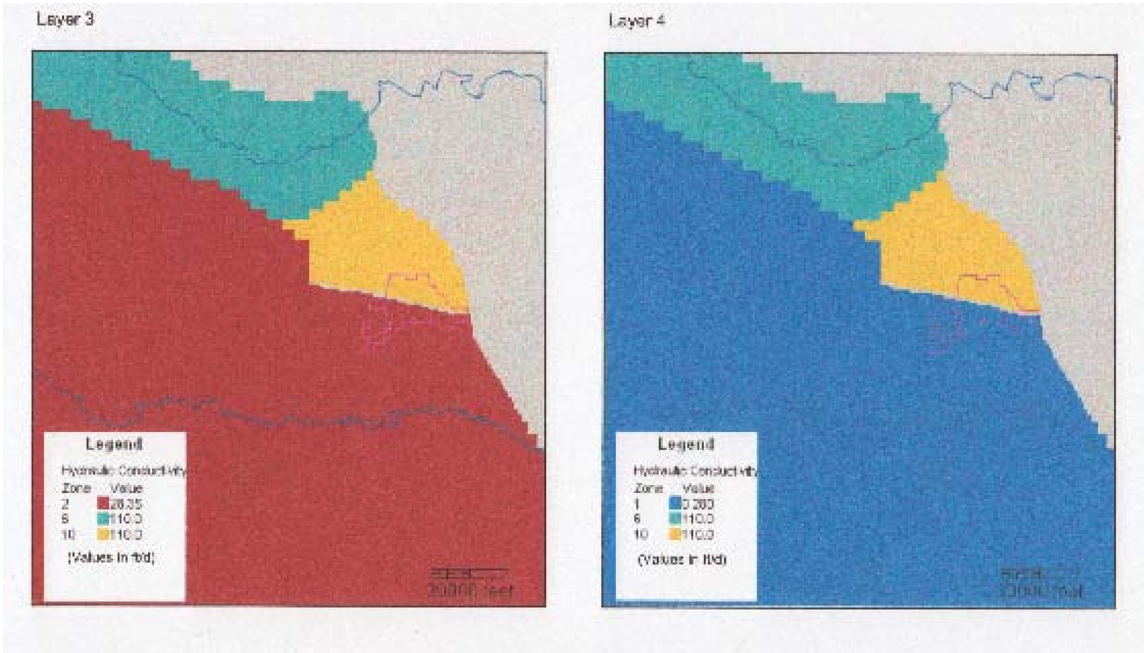

Figure 52. Hydraulic conductivity for layers 3 and 4, Pacific Groundwater Group M3 Eagle model (from Pacific Groundwater Group, 2008).

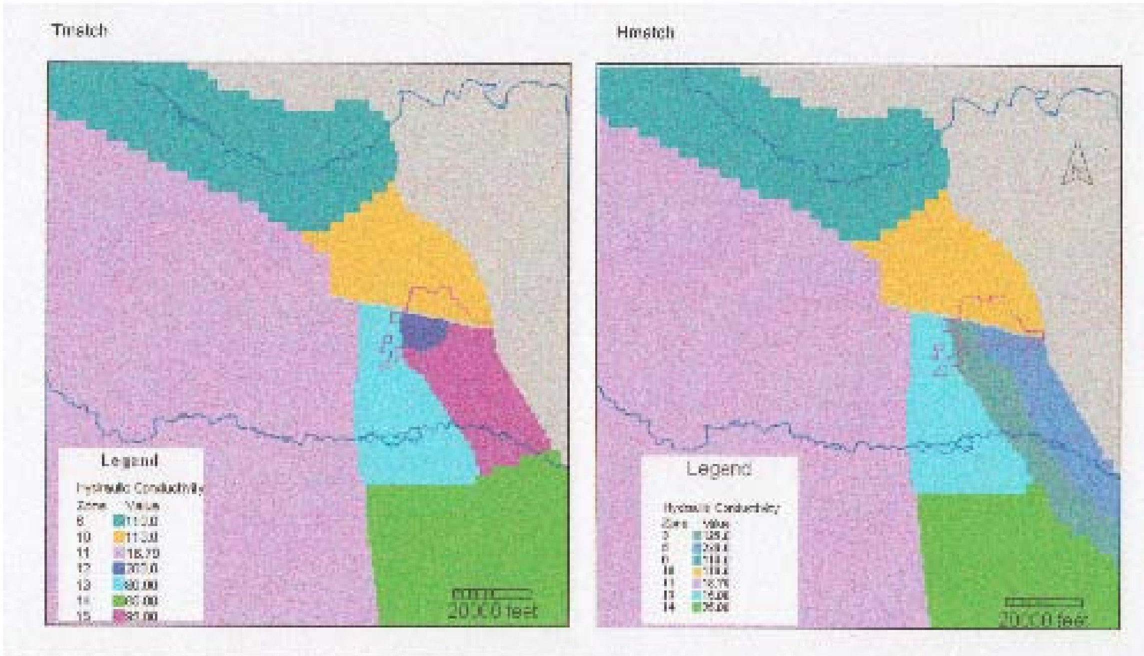

Figure 53. Hydraulic conductivity for layers 5, 6 and 7, Pacific Groundwater Group M3 Eagle model (from Pacific Groundwater Group, 2008).

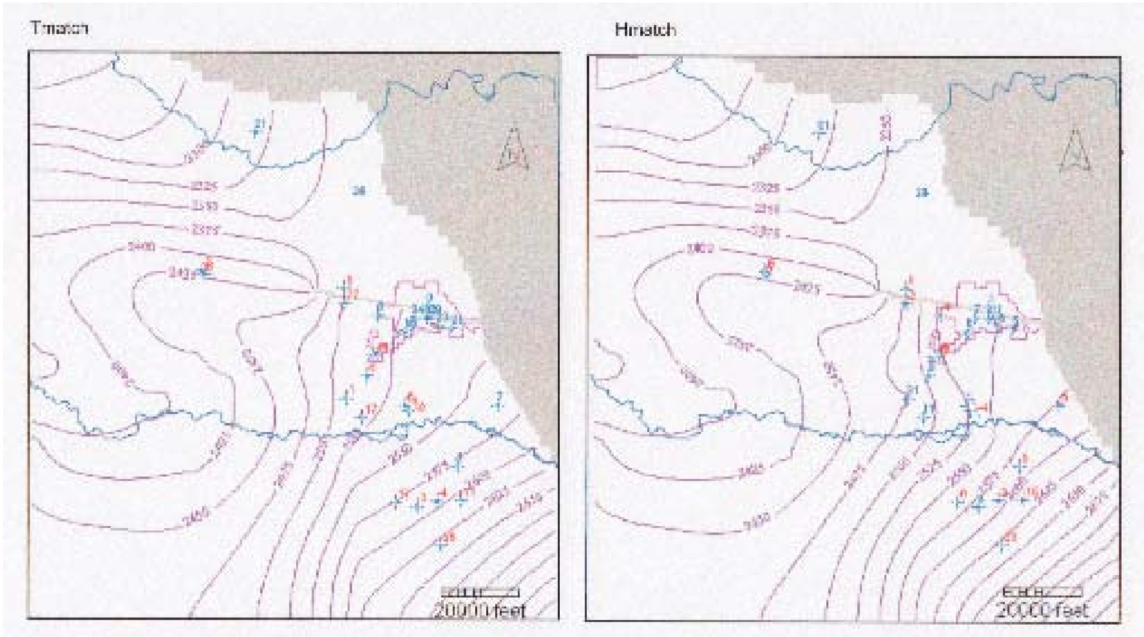

Figure 54. Model-generated water level contours for Tmatch and Hmatch models, Pacific Groundwater Group M3 Eagle model (from Pacific Groundwater Group, 2008).

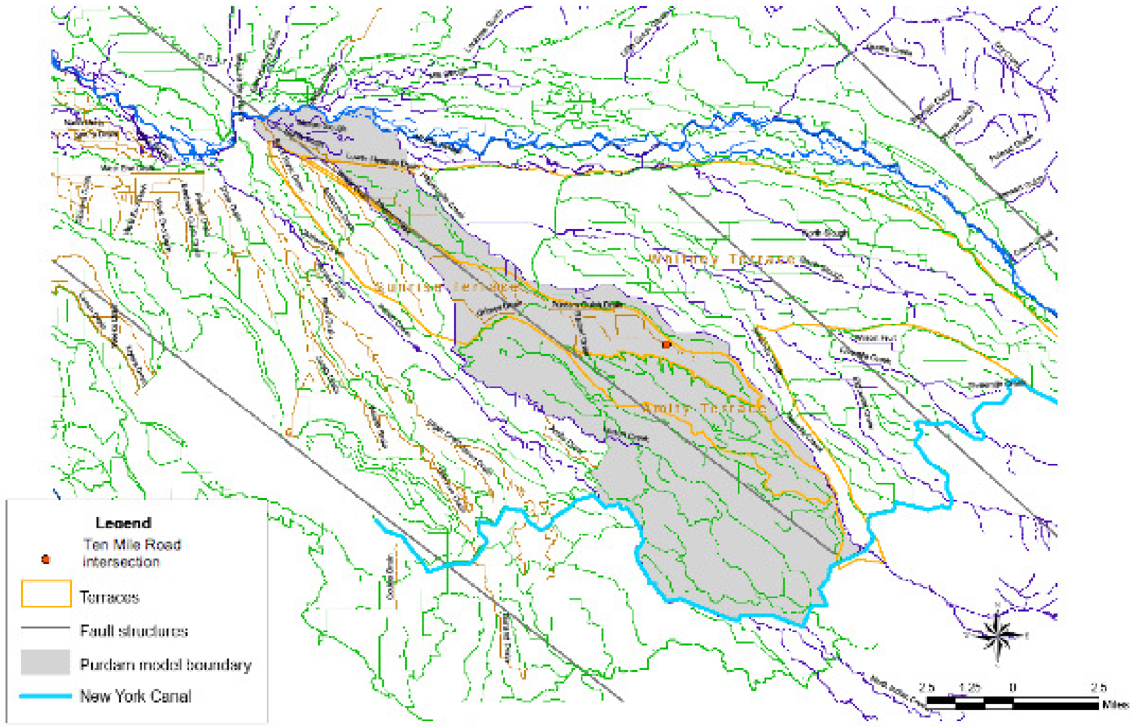

Figure 55. Model boundary, Bureau of Reclamation Purdam Drain Model, (from Schmidt, 2008).

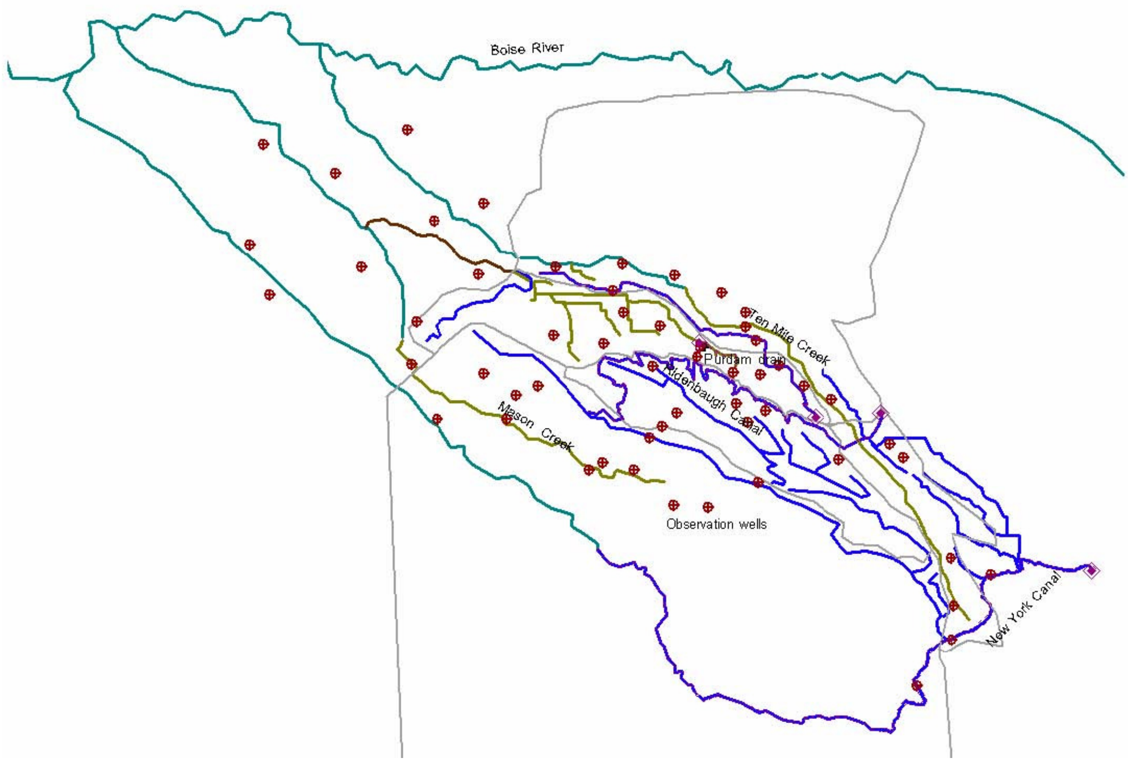

Figure 56. Location of analytic elements, Bureau of Reclamation Purdam Drain Model, (from Schmidt, 2008).

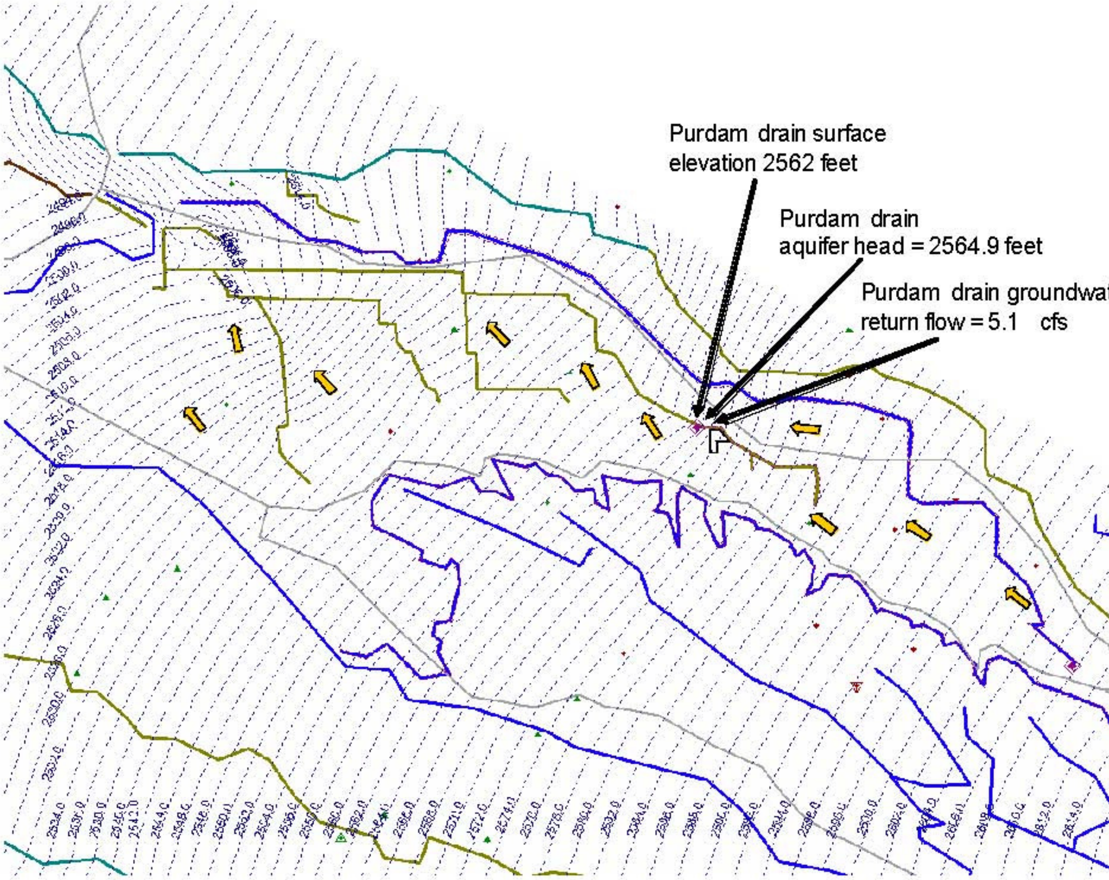

Figure 57. Model-generated water level contours, Bureau of Reclamation Purdam Drain Model, (from Schmidt, 2008).

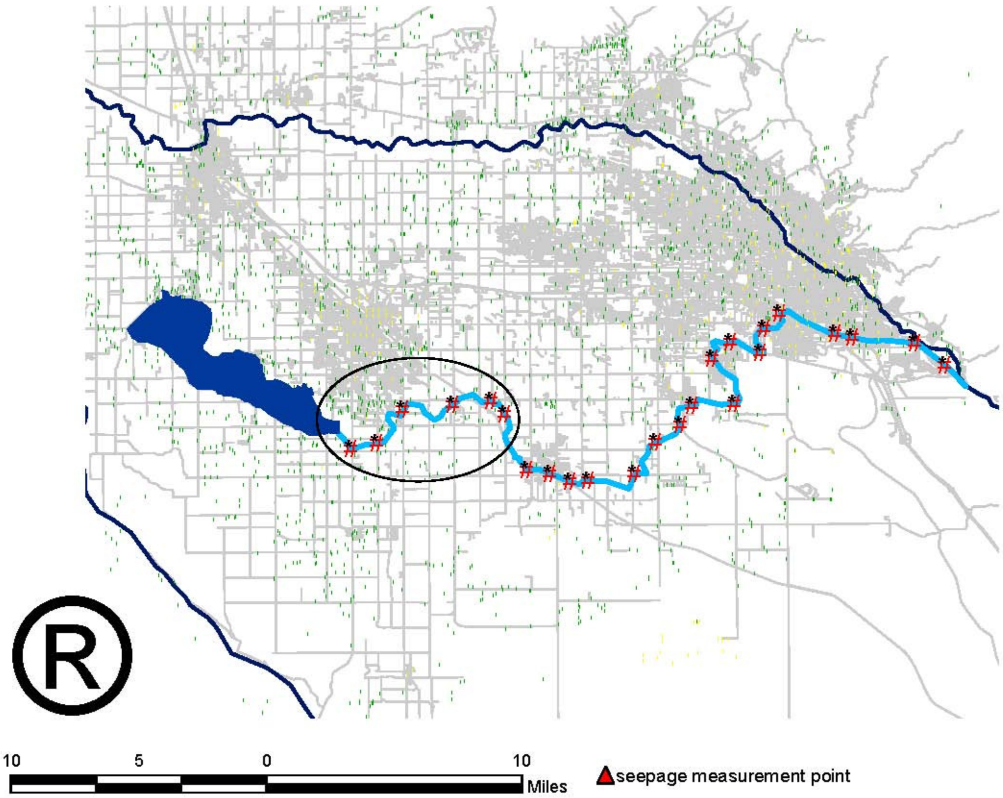

Figure 58. Model areal extent and location of seepage measurements, Bureau of Reclamation New York Canal Model, (from Schmidt, 2009).

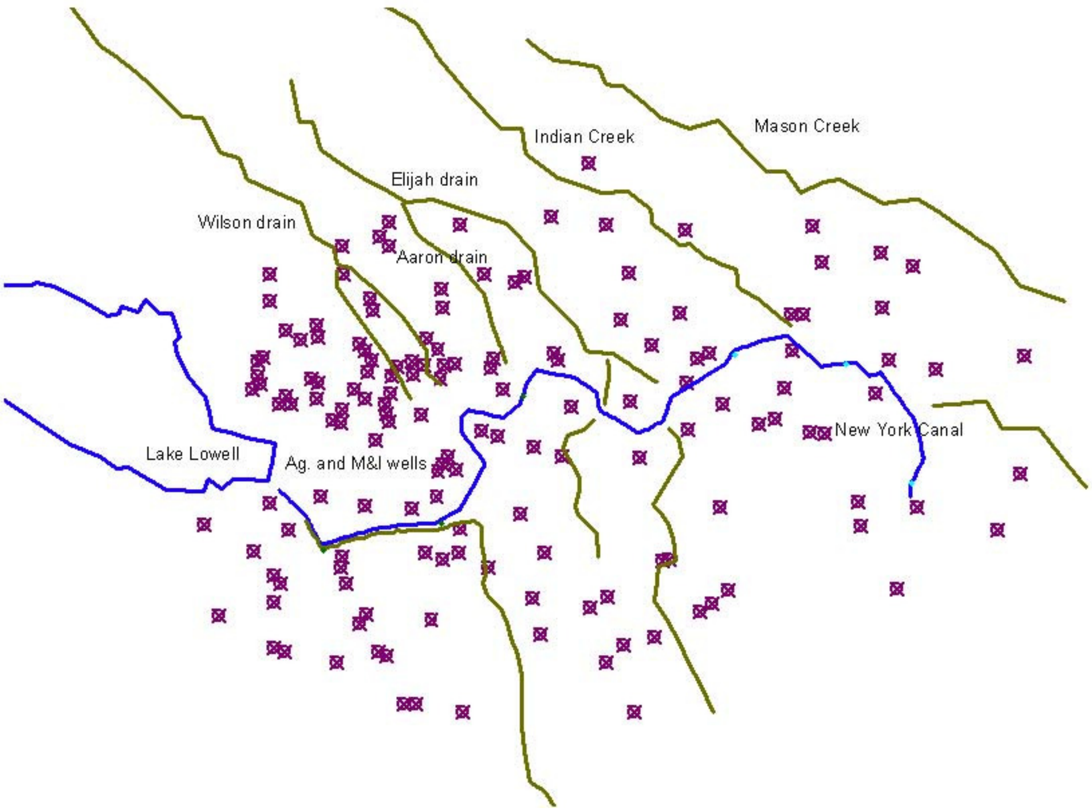

Figure 59. Location of analytic elements, Bureau of Reclamation New York Canal Model, (from Schmidt, 2009).

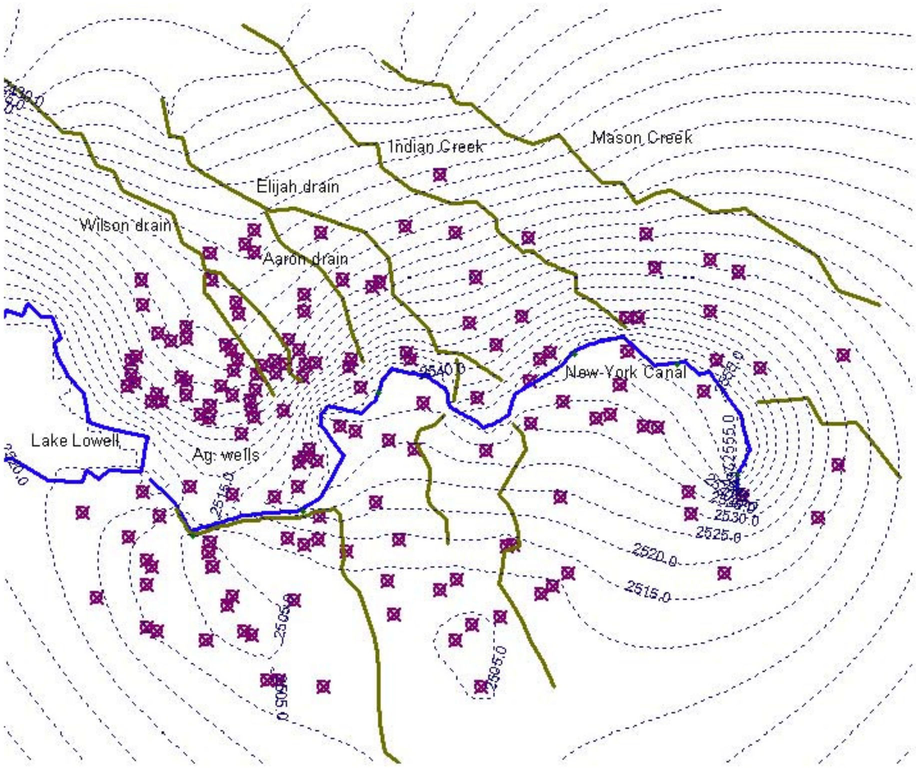

Figure 60. Model-generated water level contours, Bureau of Reclamation New York Canal Model, (from Schmidt, 2009).

Appendix

Model	Model Type	Model Code Used	Purpose
Lindgren (1982)	Finite Difference	De Sonneville (1972)	Explore Regional Hydrology
USGS (1991)	Finite Difference	Modflow	Explore Regional Hydrology
TVHP (2004)	Finite Difference	Modflow	Explore Regional Hydrology, Create Management Model
Univ of Idaho M3 Eagle (2007)	Finite Difference	Modflow	Demonstrate Pierce Gulch Sands Hydrology, Evaluate impacts from M3 Project
PGG M3 Eagle (2008)	Finite Difference	Modflow	Demonstrate Pierce Gulch Sands Hydrology, Evaluate impacts from M3 Project
BOR Purdam Drain (2008)	Analytic Element	Gflow	Explore shallow drain hydrology
BOR New York Canal (2009)	Analytic Element	Gflow	Demonstration model to explore New York Canal hydrology/ economics

Model	Description of Area Covered	Area Covered (mi^2)	Hydrologic Conceptual Model
Lindgren (1982)	N-North of Nyssa, Idaho NE-Boise Foothills SW,W-Snake River SE-Boise River Diversion Dam	2,000 mi^2	Developed regional hydrology concept based on previous investigations, ground-water divide between Payette and Boise drainages
USGS (1991)	N-South of Weiser, Idaho NE-Boise Foothills SW-Owyhee Foothills S-West of Twin Falls, Idaho	7,250 mi^2	Developed regional hydrology concept based on previous investigations
TVHP (2004)	N-Payette County, south of Payette River NE-Boise Foothills SW-Snake River S-Boise River Diversion Dam	3,000 mi^2	Developed regional hydrology concept based on previous investigations, ground-water divide between Payette and Boise drainages
Univ of Idaho M3 Eagle (2007)	N-Payette County, north of Payette River E-Horseshoe Bend SE-Just south of Boise, Idaho SW-Just southwest of Caldwell, Idaho	700 mi^2	Pierce Gulch Sands conceptual hydrology from HLI, Inc
PGG M3 Eagle (2008)	NE-Montour, Idaho NW-Letha, Idaho SW-Marsing, Idaho SE-Boise, Idaho	520 mi^2	Pierce Gulch Sands conceptual hydrology from HLI, Inc
BOR Purdam Drain (2008)	E-Tenmile Creek W-Mason Creek N-Boise River S-New York Canal	~100 mi^2	Exploring drain interaction with shallow, unconfined gravel deposits. Flow is NW towards Boise River
BOR New York Canal (2009)	8 mile section of New York Canal, just up-gradient from Lake Lowell	~12 mi^2	Investigating interaction between canal seepage and shallow, unconfined aquifer and area pumping.

Model	**Grid Size**	**Cell Size**	**Variable or Uniform Grid**	**Number of Active Cells**	**Grid Orientation**
Lindgren (1982)	43 Rows 50 Columns 1 Layer	1 mi x 1 mi (640 acres)	Uniform	~1,500	N-S
USGS (1991)	25 Rows 72 Columns 3 Layers	2 mi x 2 mi (2560 acres)	Uniform	~8,000	45° from north
TVHP (2004)	61 Rows 49 Columns 4 Layers	1 mi x 1 mi (640 acres)	Uniform	5,448	N-S
Univ of Idaho M3 Eagle (2007)	46 Rows 62 Columns 8 Layers	0.5 mi x 0.5 mi (135 acres)	Uniform	22,816	N-S
PGG M3 Eagle (2008)	Not reported: approx 120x120 rows/cols 7 Layers	330 ft to 2,460 ft (2.5 acres to 139 acres)	Variable	~18,200	N-S
BOR Purdam Drain (2008)	58 analytic elements	N/A	N/A	N/A	N/A
BOR New York Canal (2009)	864 analytic elements 709-head dependent line sources, 155-specified flux sources	N/A	N/A	N/A	N/A

Model	Boundary Conditions Used	Number of Layers	Layer Types	Layer Thicknesses
Lindgren (1982)	Hydraulically connected No-flow Specified Gradient	1		? – 1,000 ft’
USGS (1991)	Specified flux No-flow Head-dependent	3	1-Unconfined 2-Confined 3-Confined	1-500’ seds and volcanics 2-4,000’ fine grained seds 3-7,000’ volcanics
TVHP (2004)	Specified flux No-flow Head-dependent	4	1-Unconfined 2-Confined 3-Confined 4-Confined	1-200’ coarse seds 2-200’ intermed seds 3-400’ deep Id group seds 4-400’ deep Id group seds
Univ of Idaho M3 Eagle (2007)	Specified flux No-flow Head-dependent	8	1-8 allowed to be confined/ unconfined	1-1 to 1,400’ 2-1 to 900’ 3-1 to 197’ 4-3’ 5-150’ 6-250’ 7-250’ 8-1,850’ table provided with compositiona
PGG M3 Eagle (2008)	Specified flux No-flow Head-dependent Specified head	7	1-5 allowed to be confined/ unconfined 6-7 Confined	1-50’ 2 through 4, evenly distributed layers above Pierce Gulch Sands 5 through 7, evenly distributed layers of Pierce Gulch Sands Thicknesses not reported
BOR Purdam Drain (2008)	Head-dependent line source analytic elements Specified flux point source analytic elements	1	Unconfined representation	N/A
BOR New York Canal (2009)	Head-dependent line source analytic elements Specified flux point source analytic elements	1	Unconfined representation	N/A

Model	**Number of Boise River Cells**	**Number of Snake River Cells**	**Number of Salmon Falls Creek Cells**	**Number of Payette River Cells**
Lindgren (1982)	6 reaches 46 river cells	52 river cells	N/A	N/A
USGS (1991)	9 river cells 16 drain cells	65 river cells	22 river cells	20 river cells
TVHP (2004)	53 river cells	61 specified head cells	N/A	N/A
Univ of Idaho M3 Eagle (2007)	Not reported	No river cells, used General Head Boundary in Layer 8	N/A	Not reported
PGG M3 Eagle (2008)	~150 river cells	N/A	N/A	~80 river cells
BOR Purdam Drain (2008)	Not reported	N/A	N/A	N/A
BOR New York Canal (2009)	N/A	N/A	N/A	N/A

Model	Lake Lowell Representation	Representation of Area Drains
Lindgren (1982)	20 river cells	None
USGS (1991)	3 river cells	65 drain cells, Caldwell/Nampa area 12 cells, Emmet area
TVHP (2004)	12 general head boundary cells	~420 drain cells
Univ of Idaho M3 Eagle (2007)	N/A	None
PGG M3 Eagle (2008)	31 river cells	None
BOR Purdam Drain (2008)	N/A	N/A
BOR New York Canal (2009)	N/A	Local drains represented

Model	Transient or Steady State	Number of Stress Periods	Number of Time Steps	Transient Model Period
Lindgren (1982)	Both	21, 17 15.2 day periods, 4 30.1 day periods	N/A	1 year
USGS (1991)	Both	10	Not reported	100 years
TVHP (2004)	Steady State	N/A	N/A	N/A
Univ of Idaho M3 Eagle (2007)	Steady State	N/A	N/A	N/A
PGG M3 Eagle (2008)	Both	2 transient models 2 Stress Periods in each 100 days, 7 days 100 days, 30 days	30 time steps in each SP	30 day pump test, 7 day pump test
BOR Purdam Drain (2008)	Steady State	N/A	N/A	N/A
BOR New York Canal (2009)	Steady State	N/A	N/A	N/A

Model	Water Budget Source	Calibration Method	Zones or Pilot Points	Number of Water Level Observations
Lindgren (1982)	Developed to 1970 conditions, April 1, 1970 to Mar 31, 1971	Automated calibration routine	N/A	420 wells, interpolated to ~1,500 model cells
USGS (1991)	Developed to 1980 conditions, transient 1880-1980, 10 year increments	Not reported, probably hand calibrated	11 geohydrologic zones in each layer	305 wells, very few wells in layers 2,3
TVHP (2004)	Developed comprehensive water budget to 1996 conditions	Automated calibration using PEST	44 pilot points in each layer	200 wells, Lay 1 ~140 Lay 2 ~30 Lay 3 ~30
Univ of Idaho M3 Eagle (2007)	Used hybrid of estimated and reported TVHP recharge	Automated calibration using PEST	~440 pilot points	137 measured water levels, 540 interpolated water levels
PGG M3 Eagle (2008)	Used hybrid of estimated and reported TVHP recharge	Not reported, probably hand calibrated	Each layer divided into 3 to 7 geohydrologic zones	37 wells, 13 in Pierce Gulch Sands
BOR Purdam Drain (2008)	Developed comprehensive water budget to 2001 conditions	Hand calibrated	N/A	55 wells
BOR New York Canal (2009)	Developed comprehensive water budget to 2001 conditions	Hand calibrated	N/A	Not reported

Model	**Number of River/Lake Seepage Observations**	**Calibration Metrics**	**Calibration Comments**
Lindgren (1982)	6	11'/cell residual on average, 1.9' average at stress period 11, 2.1' average at stress period 21	Interpolated heads from water contour map to model cells, automated routine calibrated K at each model cell. Some problems calibrating near Lake Lowell
USGS (1991)	4	50% of modeled cells within 10' 70% within 40'	Calibrated K, T and Kv. Compared model results to measured water levels and river gains. Best fit near Boise, worst at margins of plain.
TVHP (2004)	2	Median residual 8-19' depending on model layer Regression fit: Y=.9721x-69 R^2=.9819	Comprehensive PEST calibration of Kh and Kv. Layers 3 and 4 calibrated identically. Some problems with cells drying.
Univ of Idaho M3 Eagle (2007)	Not reported	Regression fit: Y=.95x+120 R^2=.93	Evolved model through calibration. Selected final model which did not provide the best fit but which "incorporated the best available data to date". Modified Kh and Kv. Compared results with observed water levels.
PGG M3 Eagle (2008)	Not reported	Residual mean =2.82 Absolute residual mean=9.75 Std. Dev = 12.83	Generated two calibrated models, one to match measured T and one to match measured water levels. No comparisons of reach gains. Transient calibration to 30 and 7 day pump tests.
BOR Purdam Drain (2008)	1-Riedenbaugh Canal	Residual mean = 3.8 Redisual median = 6.2 Absolute resid mean = 10.8	Calibrated K and canal bed conductance. Compared with observed aquifer water levels and canal seepage measurements.
BOR New York Canal (2009)	Not reported	Not reported	Calibrated K and canal bed conductance. Compared with observed aquifer water levels, drain returns and canal seepage measurements.

Model	Layer 1 Perimeter Boundary	Layer 2 Perimeter Boundary
Lindgren (1982)	Impermeable to north, Constant gradient and impermeable to east, hydraulically connected along Snake in west	N/A
USGS (1991)	Rivers cells southeast for Salmon Falls, NW for Snake River, North for Payette River, part of NE for Boise River. All other specified flux.	Specified flux and no flow
TVHP (2004)	No flow NE and SE, GW Flow divide between Payette and Boise drainages, specified flux for underflow along north edge, No flow below bottom layer (no upwelling from geothermal), Head-dependent Boise River reaches and drains in much of central area, Lake Lowell general head boundary, Snake River specified head boundary.	Same as layer 1?
Univ of Idaho M3 Eagle (2007)	Not reported, assumed no-flow	Not reported, assumed no-flow
PGG M3 Eagle (2008)	Constant head cells SE, W and N (controlled by river levels), river cells for Lake Lowell	No flow
BOR Purdam Drain (2008)	N/A	N/A
BOR New York Canal (2009)	N/A	N/A

Model	**Layer 3 Perimeter Boundary**	**Layer 4 Perimeter Boundary**
Lindgren (1982)	N/A	N/A
USGS (1991)	All specified flux and no flow	N/A
TVHP (2004)	Same as layer 1?	Same as layer 1?
Univ of Idaho M3 Eagle (2007)	Not reported, assumed no-flow	Not reported, assumed no-flow
PGG M3 Eagle (2008)	No flow	No flow
BOR Purdam Drain (2008)	N/A	N/A
BOR New York Canal (2009)	N/A	N/A

Model	**Layer 5 Perimeter Boundary**	**Layer 6 Perimeter Boundary**
Lindgren (1982)	N/A	N/A
USGS (1991)	N/A	N/A
TVHP (2004)	N/A	N/A
Univ of Idaho M3 Eagle (2007)	Not reported, assumed no flow	W and NW general head boundary representing Snake River, SE GHB representing underflow from south
PGG M3 Eagle (2008)	SW and NW specified head representing Snake River SE general head boundary representing inflow from New York Canal leakage E small number of specified head	Same as Layer 5
BOR Purdam Drain (2008)	N/A	N/A
BOR New York Canal (2009)	N/A	N/A

Model	Layer 7 Perimeter Boundary	Layer 8 Perimeter Boundary
Lindgren (1982)	N/A	N/A
USGS (1991)	N/A	N/A
TVHP (2004)	N/A	N/A
Univ of Idaho M3 Eagle (2007)	S-General head boundary	S and W- general web boundary in 108 cells, representing Snake River
PGG M3 Eagle (2008)	Same as Layer 5	N/A
BOR Purdam Drain (2008)	N/A	N/A
BOR New York Canal (2009)	N/A	N/A

Model	**Snake River Riverbed Conductance**	**Boise River Riverbed Conductance**	**Payette River Riverbed Conductance**
Lindgren (1982)	Not reported?	Not reported?	N/A
USGS (1991)	1.2×10^6 ft^2/d	1.2×10^6 ft^2/d	1.2×10^6 ft^2/d
TVHP (2004)	N/A	2×10^5 ft^2/d	N/A
Univ of Idaho M3 Eagle (2007)	N/A	31 ft^2/d	60-60,000 ft^2/d
PGG M3 Eagle (2008)	N/A	50-1125 ft^2/d	50-1125 ft^2/d
BOR Purdam Drain (2008)	N/A	Not reported	N/A
BOR New York Canal (2009)	N/A	N/A	N/A

Model	**Range of Horizontal Hydraulic Conductivity or Transmissivity**	**Range of Vertical Hydraulic Conductivity or Transmissivity**	**Range of Specific Yield**	**Range of Storativity**
Lindgren (1982)	$1x10^3$ to $3x10^6$ ft^2/d	N/A	.01 to .2	N/A
USGS (1991)	4-43 ft/d	9-900 ft/d lay 2 22 ft/d lay 3	.1	4 to 7 2 x 10^{-3}
TVHP (2004)	.0001 to 1000 ft/d	.0001 to 1 ft/d	N/A	N/A
Univ of Idaho M3 Eagle (2007)	.1 to 10 ft/d	Not reported	N/A	N/A
PGG M3 Eagle (2008)	20-200 ft/d Pierce Gulch 30 to 3000 ft/d elsewhere	8-20 ft/d Pierce Gulch 3-300 ft/d elsewhere	.1	.00035
BOR Purdam Drain (2008)	Not reported	N/A	N/A	N/A
BOR New York Canal (2009)	Not reported	N/A	N/A	N/A