Model Grid and Grid Orientation

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Scenario Document Number DDM-015

DESIGN DOCUMENTS

Design documents are a series of technical papers addressing specific design topics on the eastern Snake River Plain Aquifer Model upgrade. Each design document will contain the following information: topic of the design document, how that topic fits into the whole project, which design alternatives were considered and which design alternative is proposed. In draft form, design documents are used to present proposed designs to reviewers. Reviewers are encouraged to submit suggested alternatives and comments to the design document. Reviewers include all members of the Eastern Snake Hydrologic Modeling (ESHM) Committee as well as selected experts outside of the committee. The design document author will consider all suggestions from reviewers, update the draft design document, and submit the design document to the SRPAM Model Upgrade Program Manager. The Program Manager will make a final decision regarding the technical design of the described component. The author will modify the design document and publish the document in its final form in .pdf format on the SRPAM Model Upgrade web site.

The goal of a draft design document is to allow all of the technical groups which are interested in the design of the SRPAM Model Upgrade to voice opinions on the upgrade design. The final design document serves the purpose of documenting the final design decision. Once the final design document has been published for a specific topic, that topic will no longer be open for reviewer comment. Many of the topics addressed in design documents are subjective in nature. It is acknowledged that some design decisions will be controversial. The goal of the Program Manager and the modeling team is to deliver a well-documented, defensible model which is as technically representative of the physical system as possible, given the practical constraints of time, funding and manpower. Through the mechanism of design documents, complicated design decisions will be finalized and documented.

Final model documentation will include all of the design documents, edited to ensure that the “as-built” condition is appropriately represented.

INTRODUCTION

Numerical models are discretized into a grid of cells. Ground water flow equations are then solved to describe ground water flow between adjacent model cells. Some of the decisions that must be made prior to numerically modeling an aquifer include how best to orient the grid, and the cell dimensions. These are the determinations addressed in this Design Document. In this document discussions will first focus on grid orientation and then cell size.

Orientation

Problem Statement

Generally, given the orientation of the aquifer, there is an optimal orientation of the model grid that will result in an alignment with the primary aquifer flow direction. This alignment minimizes water balance errors. Anderson and Woessner (1992) recommend aligning the grid parallel to the features that control flow within the aquifer. In the case of the Eastern Snake Plain aquifer these features are elevation differences forcing flow from the northeast to the southwest. Coincidentally a northeast to southwest orientation for the Snake Plain aquifer model minimizes the size of the model grid and aligns the model parallel with the features controlling flow, and aligns the principle axis of the model with the principle axis of aquifer flow (Figure 1).

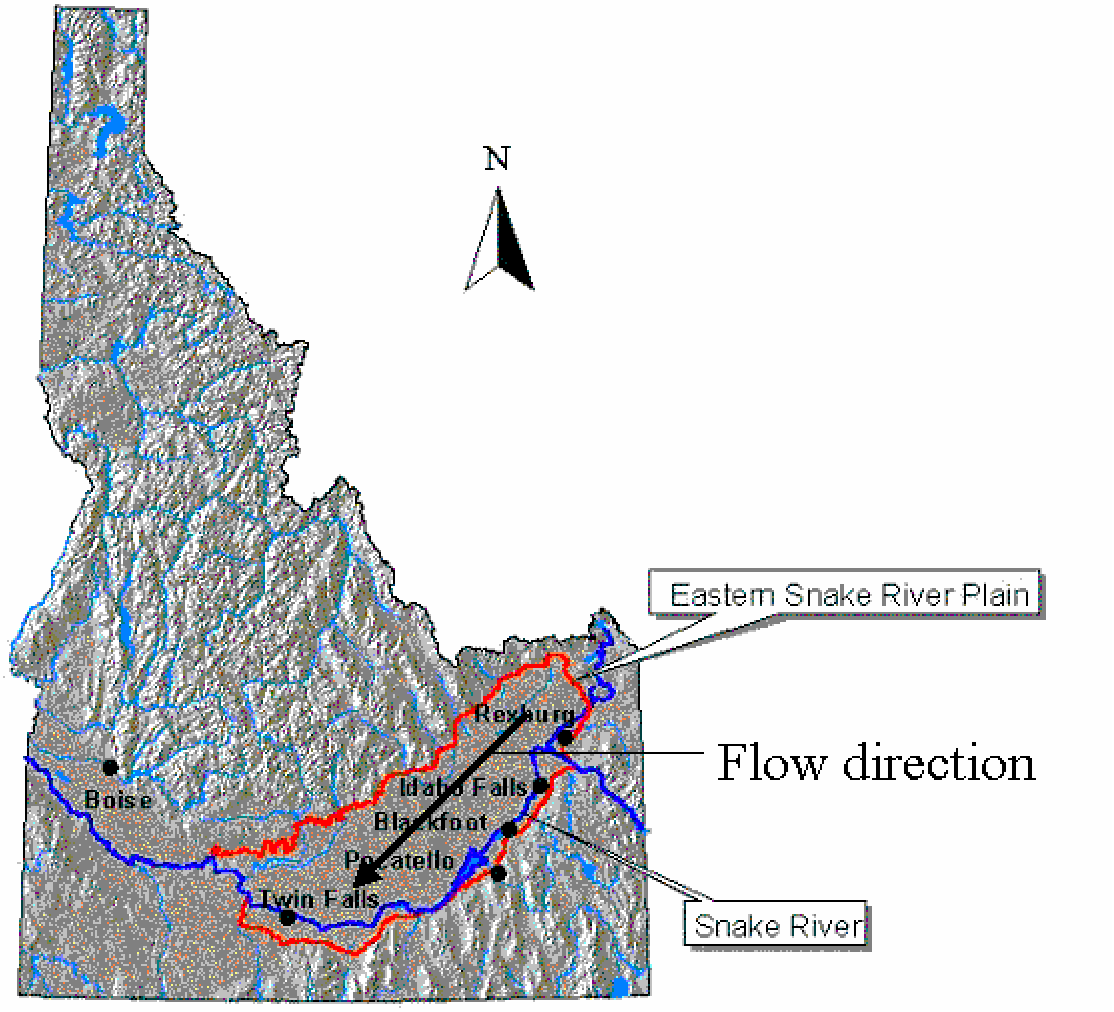

Figure 1. Location and orientation of the Eastern Snake Plain.

Considered Options

The grid could be oriented north-south, parallel with the Idaho Transverse Mercator (IDTM) grid system, thus the cells would align with most political boundaries. However, the aquifer is aligned northeast to southwest, and a north-south orientation results in a large number of inactive model cells in the northwest and southeast portion of the grid.

The orientation of the Eastern Snake Plain suggests an orientation for the model grid. Rotating the grid 31.4° counter clock-wise aligns the model with the principal direction of flow in the aquifer and results in a grid using fewer cells (Figure 2).

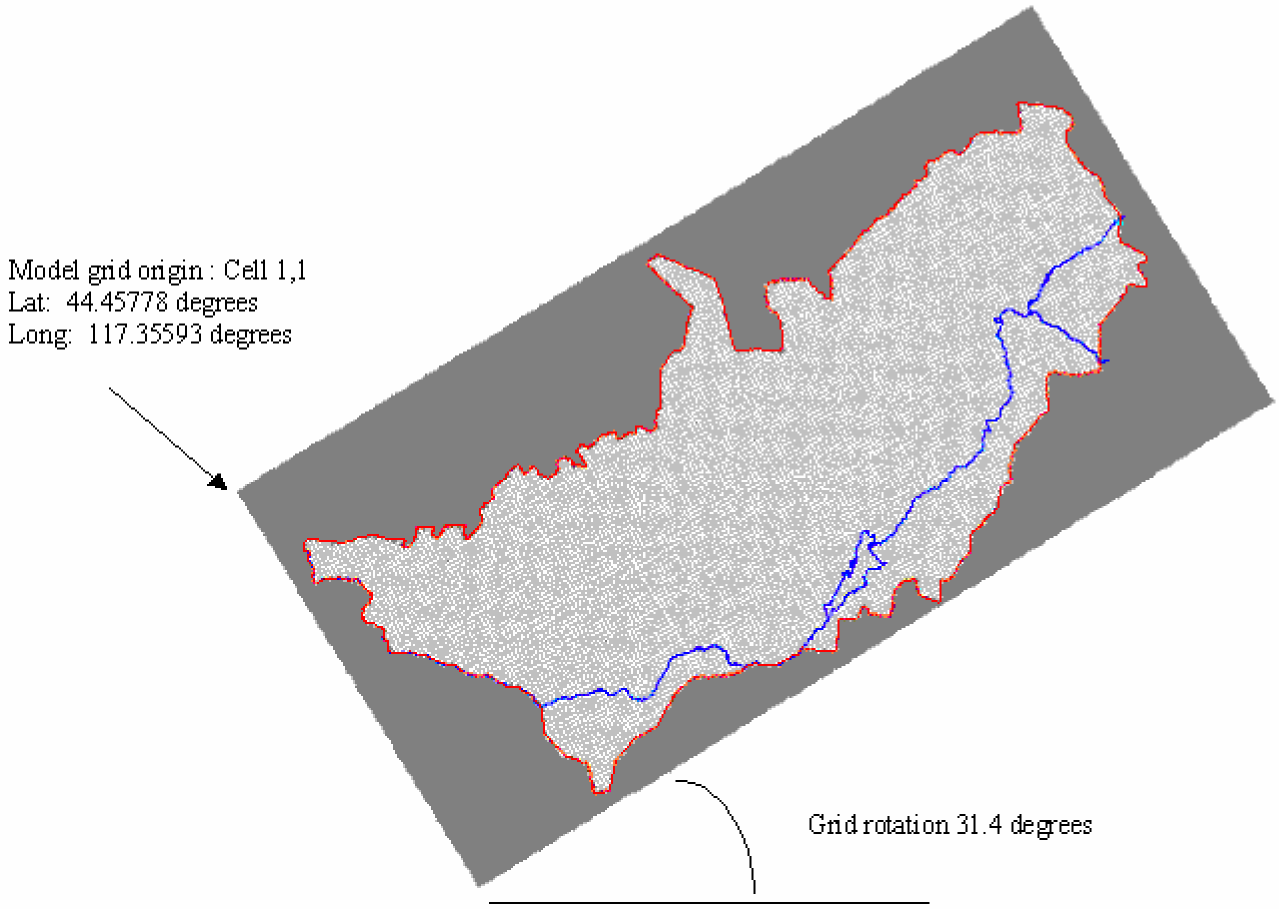

Figure 2. Outline of the Snake Plain Aquifer Model superimposed on a rotated grid.

Effect

Grid orientation can affect the functioning of a finite difference model. The finite difference calculations can result in water balance errors when flow is diagonally across grid cells. It also affects the number of model cells and consequently model run time. Anderson and Woessner (1992) state that for a finite difference model such as MODFLOW (1988), the grid should be oriented to minimize the number of cells that fall outside the model boundary. Even though these cells are outside the active grid, they occupy space in arrays and tie up computer memory. An unintended side effect of an orientation other than north-south will be that most cells are not aligned with political boundaries. However, with the Geographical Information System (GIS) tools available, model output can be easily mapped to geopolitical systems with any grid orientation.

Design Decision

The grid will be rotated 31.4^{o} counter clock-wise relative to the IDTM central meridian to align the grid system with the primary flow direction in the aquifer. Coincidentally this alignment also minimizes the number of model cells and the number of inactive cells that occupy space in model arrays. The rotation point, and origin, shown in Figure 2, is the top left corner of the grid; the top left corner of model cell whose row and column numbers are each 1. The coordinates of this point in IDTM is x= 378416.2 m and y=233007.2 m (in ft 1241523, 764459.2, latitude 43.118806^{o}, longitude $–115.49619^{o}$). This information is contained in file esp1x1.dxf in the CD accompanying this document.

Cell size

Problem Statement

The appropriate cell size depends on the size of the aquifer, computer memory limitations and run times, data density, and the nature of the problem being addressed with the model. In general, sub-regional models cover smaller areas and have smaller cells than regional models addressing larger, more general issues. Computer technology continues to improve, resulting in shorter run times and increased memory. However, most of the physical parameters used in the equations to describe ground water flow in each cell are unknown. In other words the physical parameters used to calculate water levels in each cell within the model are estimates. More model cells may allow more accurate representation of the areal distribution of aquifer and river characteristics including aquifer head. However, a refined model grid will not help resolve heterogeneity of aquifer properties. Resolution of aquifer heterogeneity is controlled by the number and distribution of model zones or pilot points and data density (Watermark Numerical Computing, 2000)

Considered Options

The cell sizes considered were 1mi x 1mi with refinement of 1mi x 0.5mi along the river, 2mi x 2mi with refinement of 2mi x 1mi along the river and a uniform 1mi x 1mi grid. Figures 3, 4 and 5 illustrate the three grid options.

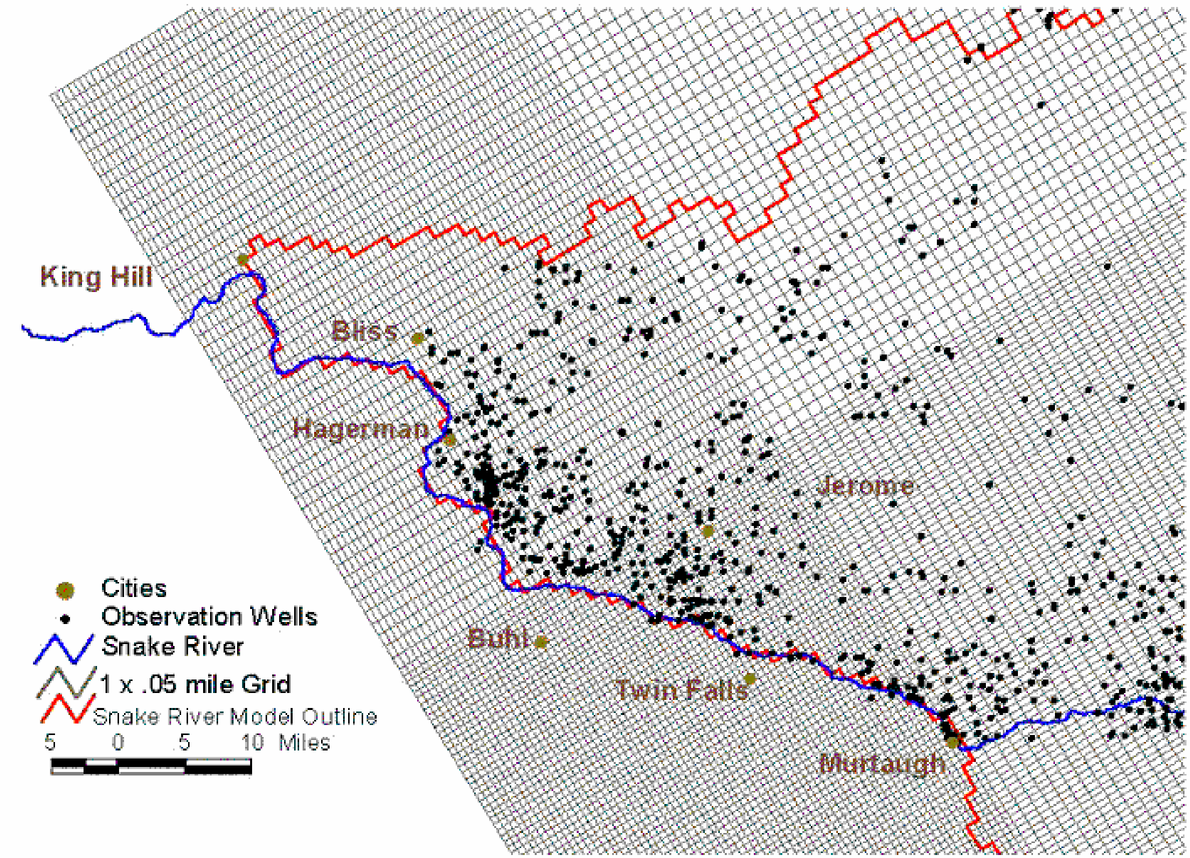

Figure 3. 1mi x 0.5mi grid refinement in the Thousand Springs reach.

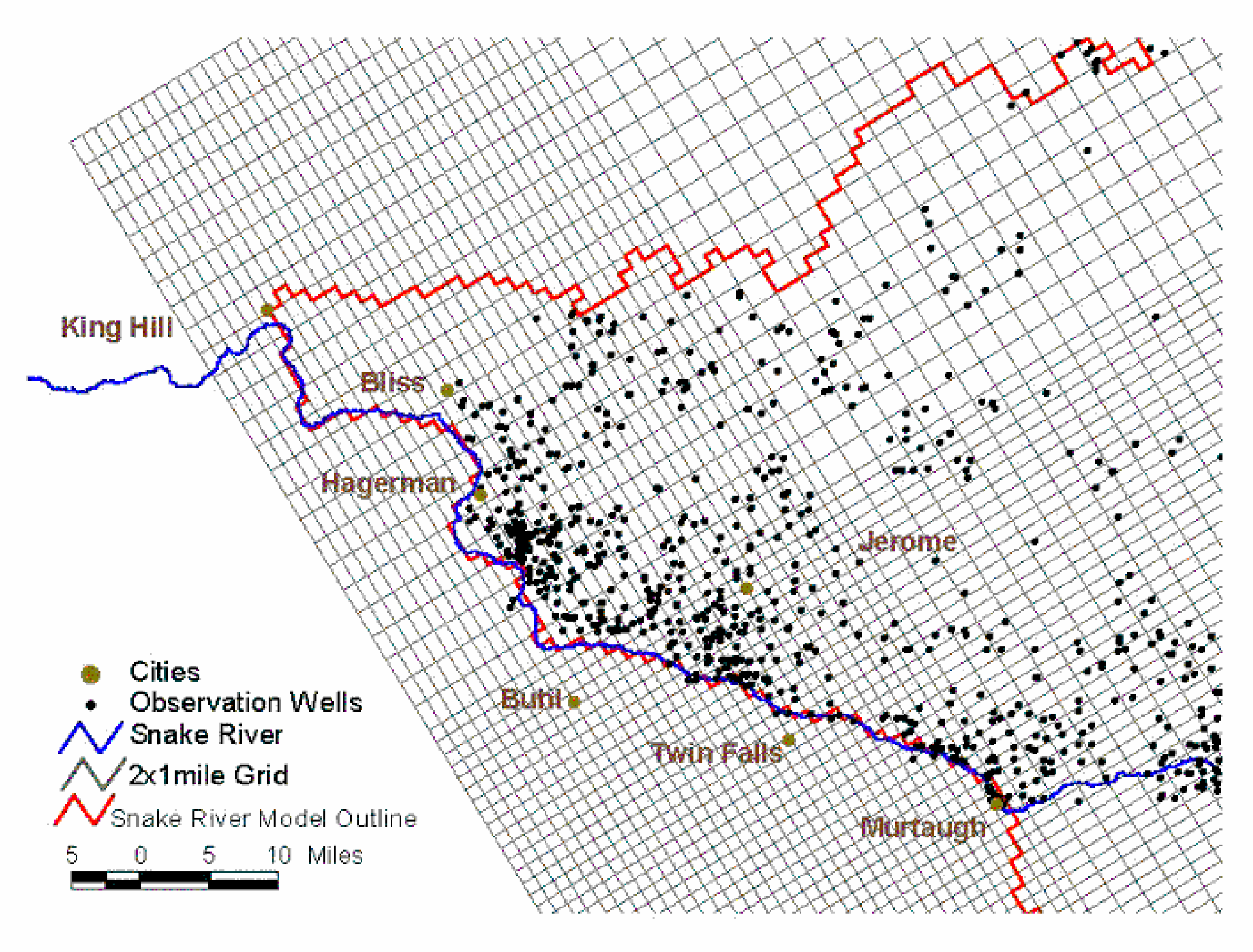

Figure 4. 2mi x 1mi grid refinement in the Thousand Springs reach

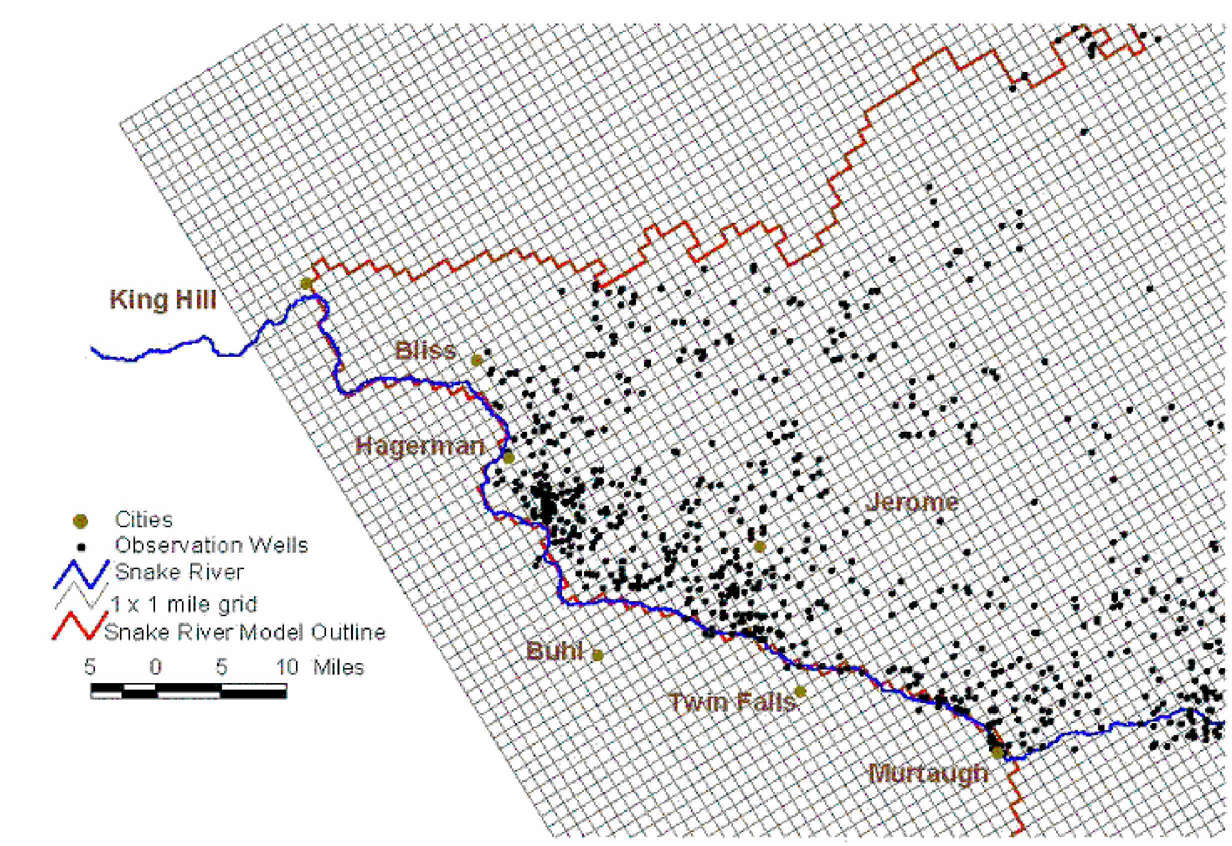

Figure 5. 1mi x 1mi grid showing observation wells in the Thousand Springs reach

Effect

The finer grid will result in better estimates of head near the Snake River. Heads within MODFLOW (1988) river and drain cells are strongly controlled by the river or drain elevation, thus, observations from wells within river or drain cells must be used with care during the head matching process in model calibration or as viable results in a predictive run. The 1mi x 0.5mi grid will maximize the number of observations that can be used during calibration near the Snake River. However, this results in an irregular grid spacing and Anderson and Woessner (1992) claim that in a finite difference grid, irregular grid spacing can result in numerical errors. These errors arise because the finite difference expression for the second derivative has a large error when derived for irregularly spaced grids. Thus the variable spaced grids (i.e. the 1mi x 0.5mi and the 2mi x 1mi grids) should be avoided, if possible.

A finer grid will result in a more stable representation of the Snake River. As the area of the river cell increases and the riverbed conductance parameter increases and water balance errors become more likely. This is because the flux between the river and the aquifer becomes very large. Decreasing the cell size minimizes this problem. Thus, a grid fine enough to yield a stable river representation should be chosen.

One limit on grid size is model run times. Average model run times were less than 1 second on a series of steady state runs conducted using the LINK-AMG (LMG) solver, standard with MODFLOW 2000, on a Micron computer with a 1.5GHz Intel Pentium processor and a uniform 1 mi x 1 mi test grid. On the same computer a sample transient run over a 23-year time span, with 2 stress periods per year for the first 22 years and 12 stress periods for the last year, with 10 time steps per stress period took 1.5 minutes. This appears to be significantly faster than the MODFLOW PCG solver and does not appear to present any numerical instability problems. During model calibration simulations are repeated many times to determine optimum parameter values. Thus a 1.5 minute run time may equate to calibration times in the range of 0.5 to 1 days. Thus, model run time does not appear to present a problem with the 1mi x 1mi grid.

Use of a refined grid, such as the 1mi x 1mi grid, may cause future misuse of the model to help resolve local single water right-to-water right issues. Although a finer grid does provide better resolution of model heads, this is still a regional model. The observations the model is calibrated against are regionally distributed and hence the resulting residuals (difference between observed and model values) are regionally distributed. Although the average residual may be low, the residuals in any one area may be unacceptable. It is also important to note that aquifer properties, such as hydraulic conductivity are greatly smoothed among many model cells and values do not represent the true value in any specific cell.

Design Decision

The selected alternative is for a 1mi x 1mi grid with no refinement along the Snake River. Although this option may result in future misuse of the model, it results in a stable representation of the Snake River. The square grid also eliminates the risk of numerical difficulties possible with variably spaced grids. The resulting grid contains 21736 total model cells, 10447 of them active with 279 river cells.

References

Anderson, M.P, W.W. Woessner, 1992. Applied Groundwater Modeling. Academic Press.

McDonald M.G., and A.W. Harbaugh, 1988. A Modualr Three-Dimensional Finite-Difference Ground-Water flow Model. U.S. Geological Survey Open-File Report 83-875.

Watermark Numerical Computing, 2000, PEST: Model-Independent Parameter Estimation. Watermark numerical Computing. Corinda Australia.