PRELIMINARY DRAFT

Model River Representation

Above Milner Dam

Idaho Water Resources
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Eastern Snake Plain Aquifer Model Enhancement Project
Scenario Document Number DDM-010

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Eastern Snake Plain Model Aquifer Model Enhancement
Model Design and Calibration Document Number DDM-010

DESIGN DOCUMENTS

Design documents are a series of technical papers addressing specific design topics on the Eastern Snake Plain Aquifer Model Enhancement. 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 that 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 that 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

MODFLOW has the ability to simulate flux between surface water bodies such as the Snake River and aquifers such as the Eastern Snake Plain Aquifer. This flux recharges the aquifer when the head in the river exceeds the head in the aquifer or the aquifer discharges into the river when the head in the aquifer exceeds the head in the river. MODFLOW simulates these interactions using a series of mathematical equations. In order for these equations to describe the real world situation, the terms in the equations must be populated with appropriate values. These terms include river stage, river depth, and thickness of the river bottom sediments. This document focuses on estimating these terms for the portion of the Snake River above Milner Dam. The Snake River from Milner Dam to King Hill will be treated differently and addressed in another document. Target river gains and losses used in model calibration will also be discussed in another document.

The MODFLOW river package employs a term called C_{riv} that conceptually includes hydraulic conductivity of the riverbed sediments, width of the river and length of the river in the model cell. Other important terms include elevation of the river and thickness the material below the river kept saturated by river water (referred to as the thickness of the riverbed sediments). The bottom of the riverbed sediments represents the minimum elevation that aquifer water levels can fall to and still remain hydraulically connected to the river. Thus elevation of the bottom of the riverbed sediments describes the hydraulic river bottom. Figure 1 illustrates the relationship between river elevation (stage) and elevation of the bottom of the riverbed sediments.

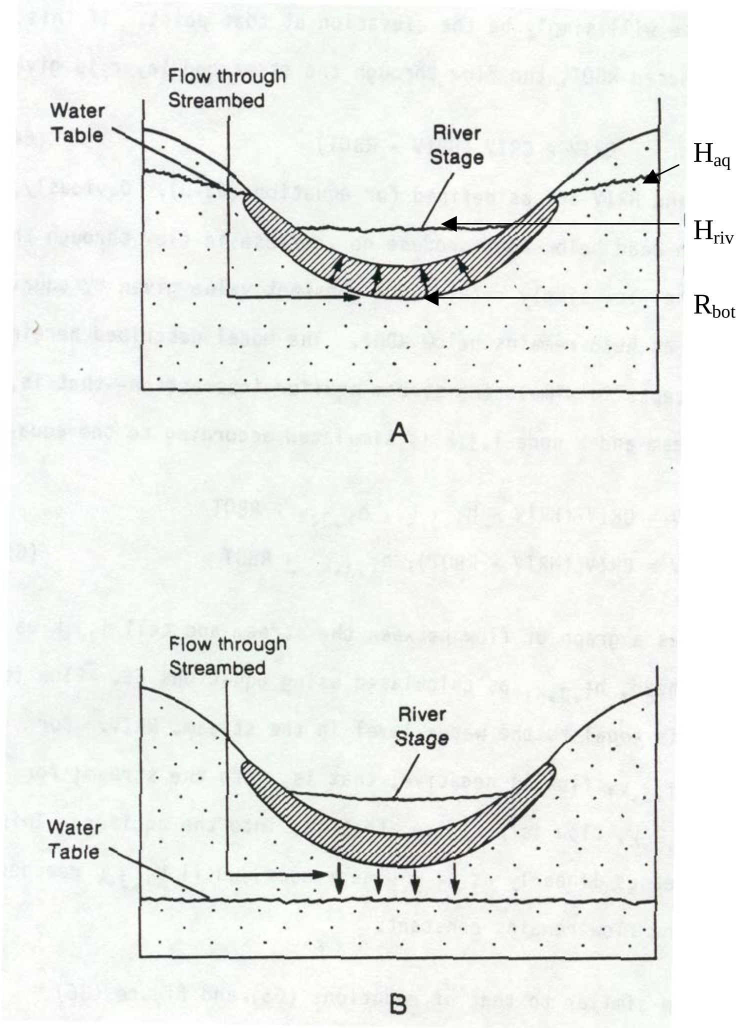

Figure 1. Illustrations showing the relationship between flux, head in the river and head in the aquifer (from McDonald and Harbaugh, 1988).

C_{riv}

Surface water bodies such as rivers and lakes contribute water to, or extract water from, ground water systems. The MODFLOW developers designed the river package to dynamically simulate this exchange. The explanation of the MODFLOW river package presented here follows the presentation by McDonald and Harbaugh (1988). Figure 1A shows a cross-section through a river. Note that a layer of streambed material separates the open water in the river from the ground water system. In such a system interconnection between the river and the ground water system can be represented by a one-dimensional flow system. The variables in this one-dimensional flow system include: head in the river, head in the aquifer, and conductance through the streambed material. The length (L) of the conductance block is the length of the river in the model cell, the width (W) is the width of the river, M represents the thickness of the streambed material and K represents the hydraulic conductivity of the riverbed sediments. Thus flow between the river and aquifer can be described by the equation:

$$Q_{riv} = \frac{K * L * W}{M}(H_{riv} - H_{aq})$$

Equation 1

where Q_{riv} is the flow between the stream and the aquifer; and H_{aq} is the head in the aquifer; and H_{riv} is the head in the river. If ($K*L*W/M$) is combined into one term C_{riv}, taken as the conductance of the river-aquifer interconnection, the equation becomes:

$$Q_{riv} = C_{riv}(H_{riv} - H_{aq})$$

Equation 2

Equation 2 normally provides an adequate approximation of river-aquifer interactions over a restricted range of aquifer head values. If aquifer head falls below a certain level, flux from the river ceases to depend on head in the aquifer. Figure 1B illustrates this concept. Water level in the aquifer falls below the bottom of the riverbed sediments, leaving an unsaturated interval between the riverbed sediments and the water table. McDonald and Harbaugh refer to the point in the riverbed sediments that remains saturated as the river bottom (R_{bot}). The flow through the riverbed sediments under these conditions is described by:

$$Q_{riv} = C_{riv}(H_{riv} - R_{bot})$$

Equation 3

As long as head in the aquifer remains below R_{bot}, flux through the streambed layer remains constant. Thus two equations describe flux between an aquifer and a river in MODFLOW:

$$Q_{riv} = C_{riv}(H_{riv} - H_{aq}); H_{aq} > R_{bot}$$

or

$$Q_{riv} = C_{riv}(H_{riv} - R_{bot}); H_{aq} \le R_{bot}$$

Equation 4

Type of River Cells in the Model

This portion of the document focuses on selecting the conceptual and mathematical representation for the Snake River. It consists of a problem statement, considered options, effects, and culminates with a design decision regarding the type of river cells. The following section discusses the method used to determine the elevation of the Snake River.

Problem Statement

Several types of hydraulically connected cells exist in MODFLOW, all developed for use in different situations. The user needs to evaluate the suitable options and select the most appropriate one.

Considered Options

We considered four options: 1) MODFLOW river package, 2) MODFLOW streamflow routing package, 3) using specified seepage rates for known perched reaches and the MODFLOW river package elsewhere, and 4) using the MODFLOW drain package where the river is always gaining and the MODFLOW river package elsewhere. The MODFLOW river package assumes an infinite supply of water, but it allows the river to gain water from the aquifer and to lose water from the river into the aquifer. The MODFLOW streamflow routing package allows the same aquifer-river interactions as the MODFLOW river package while also keeping track of flow in the river, while limiting the seepage from the river to the volume of water in the river. The MODFLOW drain package will only allow flow from the aquifer into the drain.

Effect

The MODFLOW river package allows representation of losing, gaining and perched river reaches. The gains and losses are a function of the relationship between the head in the river and the head in the aquifer as discussed previously. The user can also change the head in the river for each stress period to simulate observed changes in river stage. However, no internal constraint exists limiting the volume of water the river can gain or lose. Thus the river can lose more water than it carries. As a consequence, the modeler must be vigilant or the MODFLOW river package can generate unrealistic fluxes between the aquifer and the river.

The MODFLOW streamflow routing package allows representation of losing, gaining and perched river reaches and allows the user to change the river stage for each stress period. The difference between this package and the river package is that the streamflow routing package keeps track of the flow in the river. This adaptation limits the losses from the river to the aquifer to no more than the flow in the river. Although this constraint is based in reality, it can introduce a step function into the solution that complicates its use with parameter estimation software.

Conceptually using specified seepage rates for known perched reaches poses no problems. The variables required to calculate the seepage rates must be known anyway, and adding the seepage as recharge poses no difficulty. The difficulties reside in determining exactly where the perched reaches lie. The Snake River does not necessarily transition between perched and hydraulically connected at gauging stations. Thus, someone needs to determine where the transition les, how the transition point varies with time, and then estimate the seepage rate.

The MODFLOW drain package allows the aquifer to contribute water to the surface water system, but does not allow the surface water system to contribute water to the aquifer. Mathematically the MODFLOW drain package is similar to the MODFLOW river package when the head in the aquifer is above the head in the river. Equation 4 describes how the river package functions, while equation 5 describes how the drain package functions. Note the similarity between equation 4 for the case where the head in the aquifer (H_{aq}) is greater than the river bottom (R_{bot}) and equation 5 where head in the aquifer is greater than the drain elevation (D_{elev}).

$$Q_{drn} = C_{drn}(H_{aq} - D_{elev}); H_{aq} > D_{elev}$$

or

$$Q_{drn} = 0; H_{aq} \le D_{elev}$$

Equation 5

Where Q_{drn} is flux through the drain cell, C_{drn} is conductance of the drain, H_{aq} is head in the aquifer, and D_{elev} is drain elevation. The drain function is similar to the river package except flow into the aquifer is excluded.

Design Decision

The river above Milner Dam will be represented using MODFLOW river cells.

Snake River Stage

This portion of the document focuses on determining the elevation of the Snake River above Milner Dam, which is applied as river stage in MODFLOW. It consists of a problem statement, considered options, effects, and culminates with a design decision regarding estimating the elevation of the Snake River. The following section discusses estimating the depth of the Snake River.

Problem Statement

The flux between the aquifer and the river is a function of head in the aquifer and river elevation (see equation 4). Therefore, to correctly match both the head in the aquifer and the aquifer/river interactions, the river water surface elevations must be correct.

Considered Options

The considered options include: 1) surveying by professional surveyors; 2) surveying using a professional grade global positioning system (GPS); 3) interpolating elevations from topographic maps; and 4) using 10 meter digital elevation models (DEMs) to obtain elevation estimates.

Effect

A professional surveyor would be able to survey the river elevations to within 0.01 ft. Surveying with a professional grade global positioning system (GPS) can also yield accuracy within 0.01 ft., depending on time and availability of benchmarks for control. The accuracy of interpolating elevations from topographic maps depends on the contour interval of the map. Wylie (2003) determined that the 95% confidence interval for picking the well elevation from 10 meter DEMs is about 1.21 ft high $\pm$1.17 ft.

Considerations other than accuracy include time and money. Surveying the river using professional land surveyors will produce the most accurate and precise results at an unacceptable cost of time and money. Surveying using state-of-the art GPS technology still costs more in time and money than the project can afford. The bulk of the cost for both of these options resides in field time. The fourth option, projecting the river onto a 10 meter DEM, eliminates the field time and, therefore looks attractive.

Design Decision

Digitize the Snake River elevation above Milner Dam using 10 meter DEMs.

Depth of the Snake River

This portion of the document focuses on estimating Snake River depth above Milner Dam. This information is necessary to ultimately determine R_{bot} (when used with estimates of river sediment thickness) in equation 1. It consists of a problem statement, considered options, effects, and culminates with a design decision regarding a technique to estimate depth of the Snake River. The following section discusses estimating the effective river bottom.

Problem Statement

The point at which the river becomes perched (Figure 1B) is a function of the river elevation, the depth of the river, the thickness of the riverbed sediments beneath the river and head in the aquifer. In reality we do not know the depth of the river to the same level of accuracy that we know the elevation of the river surface. Therefore, some interpolation scheme must be used to infer the depth of the river between known points.

Considered Options

The considered options include: 1) apply an average fixed value; 2) apply the known values to adjacent reaches of the river; 3) linearly interpolate between known points.

Effect

None of the available options provide correct river depth values down the entire length of the river because we do not know river depth in sufficient detail. River depth is known only at discrete points, typically at gaging stations. However, some options make more efficient use of the available information than others.

Applying some kind of a fixed average value is the simplest option. This option does not effectively utilize the available river depth knowledge.

Applying known point values to adjacent reaches of the river utilizes the knowledge we have. Using this technique depth X, observed at station A, might be applied from gaging station A to half way between stations A and B where depth Y, observed at station

B, is applied. Depth Y, in turn is applied to half way between station B and C where depth Z, observed at station C, is applied. This technique imposes a step function on the depth of the river. The depth of the river is used to calculate the thickness of streambed sediments in equation 1, so a step in river depth translates to a step in riverbed conductances (C_{riv}) and could cause calibration problems. These problems would arise if neighboring cells possess radically different river depths and nearly identical river stage elevations.

Linearly interpolating river depth between known points utilizes the knowledge we have regarding the depth of the river and it avoids potential problems associated with step changes in riverbed conductance.

Design Decision

Linearly interpolate river depth between known points along the Snake River above Milner Dam.

Thickness of River Bottom Sediments

As mentioned in the introduction the river bottom is that point in the earth material below the river that remains saturated as the aquifer head drops low enough to lose hydraulic contact with the river. The condition is illustrated in Figure 1B.

Problem Statement

If aquifer head drops below a certain point due to gradient changes, pumping, or drought, flux between the aquifer and the river no longer depends on the difference between aquifer head and head in the river. It is a function of the parameter C_{riv} and the difference between head in the river and river bottom elevation (see Equation 4). Determining the river bottom sediment thickness is difficult because it is not defined by a stratigraphic change, yet it is used to compute the flux between the river and the aquifer.

Considered Options

The considered options include: 1) use the values Garabedian (1992) used (30 ft) and 2) evaluate the existing data and estimate the thickness of the river bottom sediments.

Evaluating the existing data involves looking at hydrographs for wells above Milner Dam along the Snake River and preparing river profiles. We will then check to see if the assumed thickness of the bottom sediments of 30 ft is reasonable. Producing the river profiles involves digitizing the Snake River to obtain easting, northing and river stage elevations along the length of the Snake River, then kriging the water table to obtain easting, northing and elevations for the water table. One then plots the data together. Figure 2 is a river profile for March 1980. This profile indicates that the only extensive perched reach is between Blackfoot, Idaho and the confluence of the Henry's Fork and the South Fork where river stage is consistently above aquifer level.

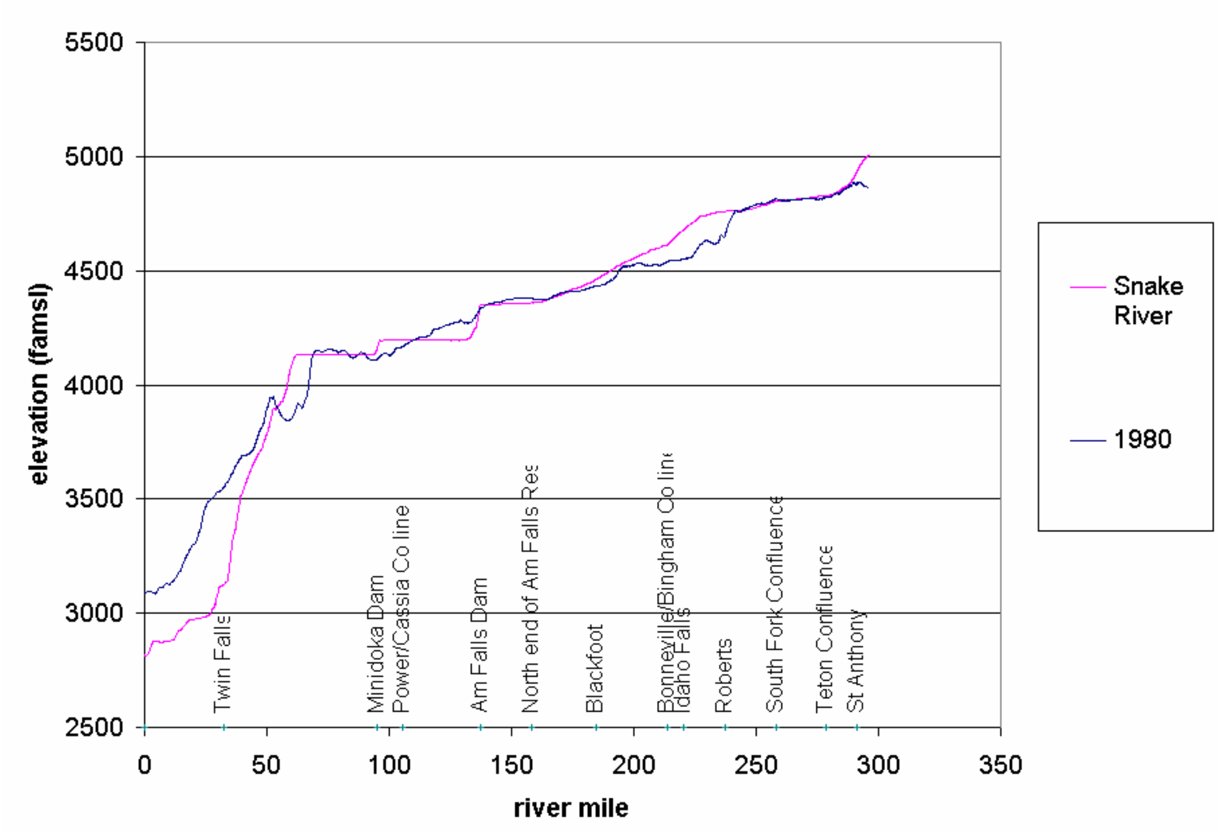

Figure 2. Snake River profile for March 1980.

Hydrographs along the perched reach between the confluence of the Henry's Fork and the South Fork and Blackfoot Idaho should be different than hydrographs of wells along hydraulically connected reaches. Wells in portions of the aquifer not hydraulically connected to the river should have more significant annual fluctuations than wells in hydraulically connected river reaches because the river will not act as a source or sink to dampen the fluctuations. Figure 3 shows the locations of wells selected with significant time series below the confluence of the Henry's Fork and the South Fork and above Minidoka, Idaho. Nearby hydraulic connection with the Snake River is only one factor affecting the variation in the hydrographs. Consequently much uncertainty exists in the following analysis.

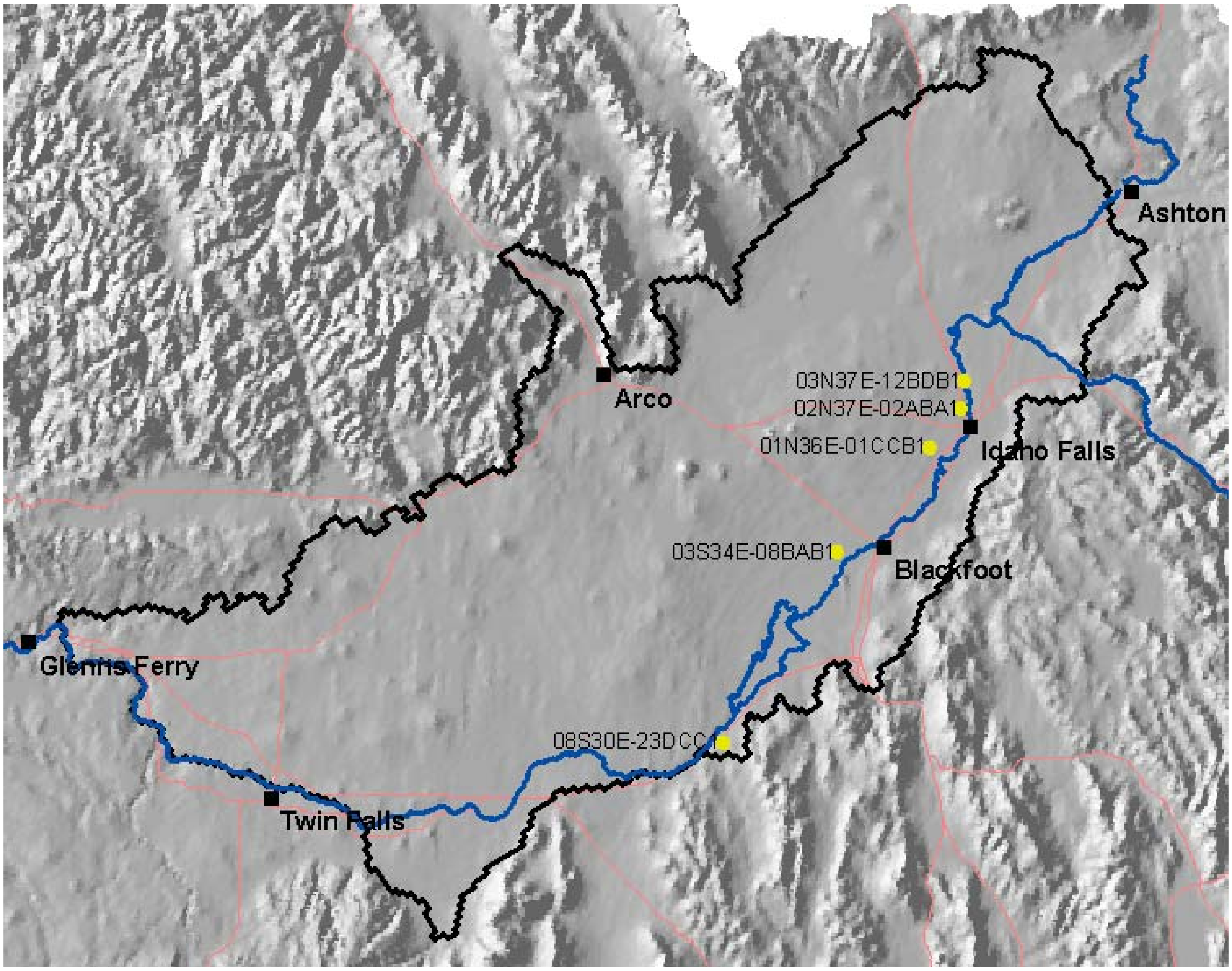

Figure 3. Wells with significant time series along the Snake River.

Figures 4 through 8 contain hydrographs for wells identified in Figure 3. The profile inset shows the location of the well. Note that the wells near the perched reach, wells 03N37E-12BDB1, 02N37E-02ABA1 and 01N36E-01CCB1 (figures 4-6) exhibit more annual fluctuation than the wells near hydraulically connected reaches. This suggests the transition between the hydraulically connected reach and the perched reach is between wells 01N36E-01CCB1 and 03S34E-08BAB1. Although this does not provide any direct information regarding thickness of the river bottom, it suggests that R_{obt} is sufficient to cause a transition from hydraulically connected to perched in the identified reach.

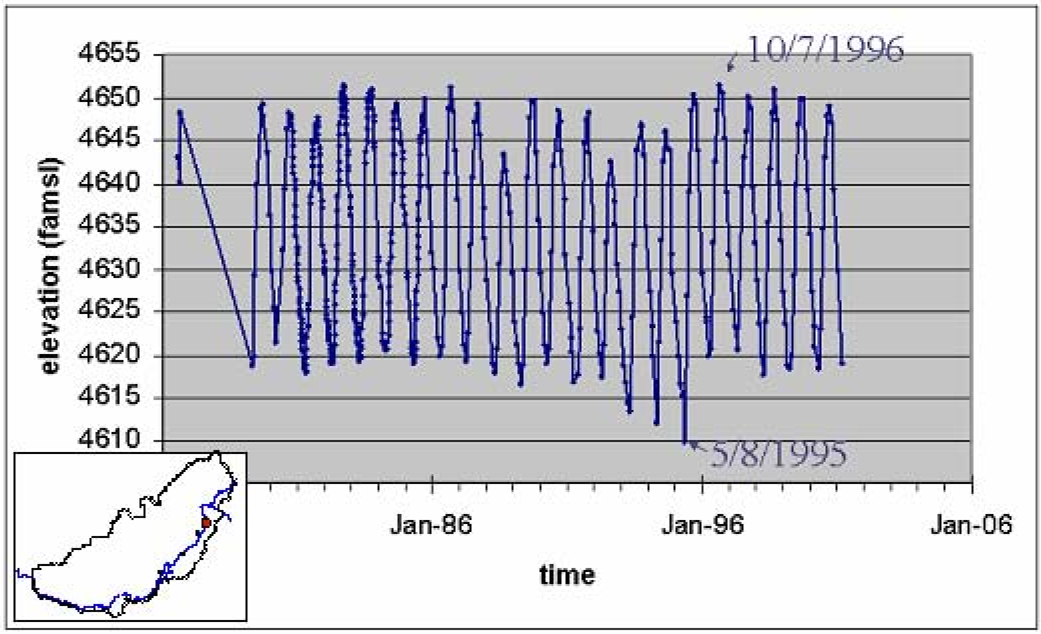

Figure 4. Hydrograph for well 03N37E-12BDB1.

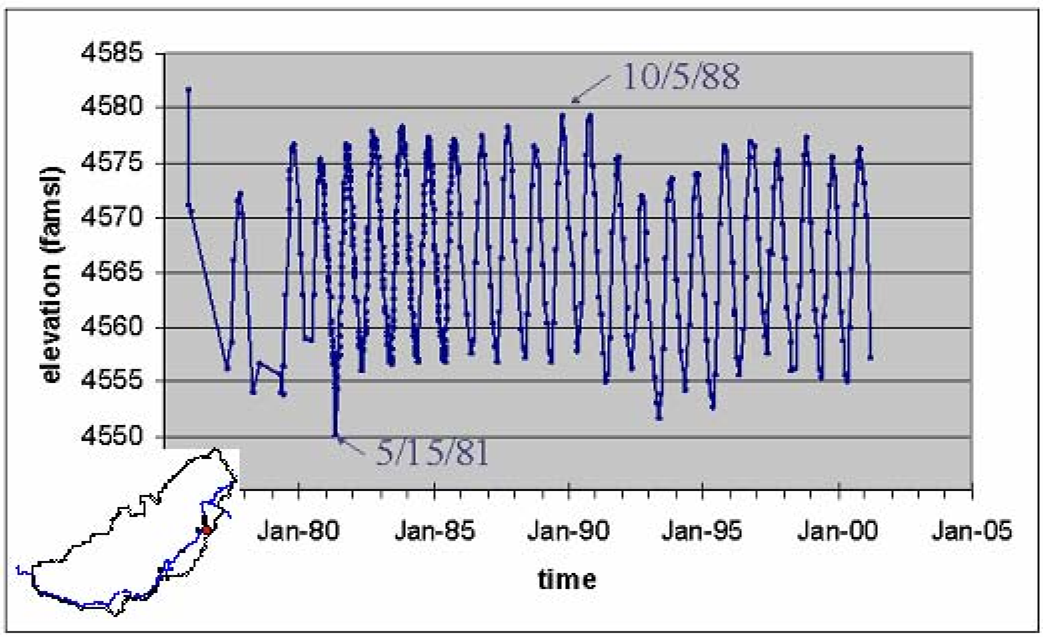

Figure 5. Hydrograph for well 03N37E-02ABA1.

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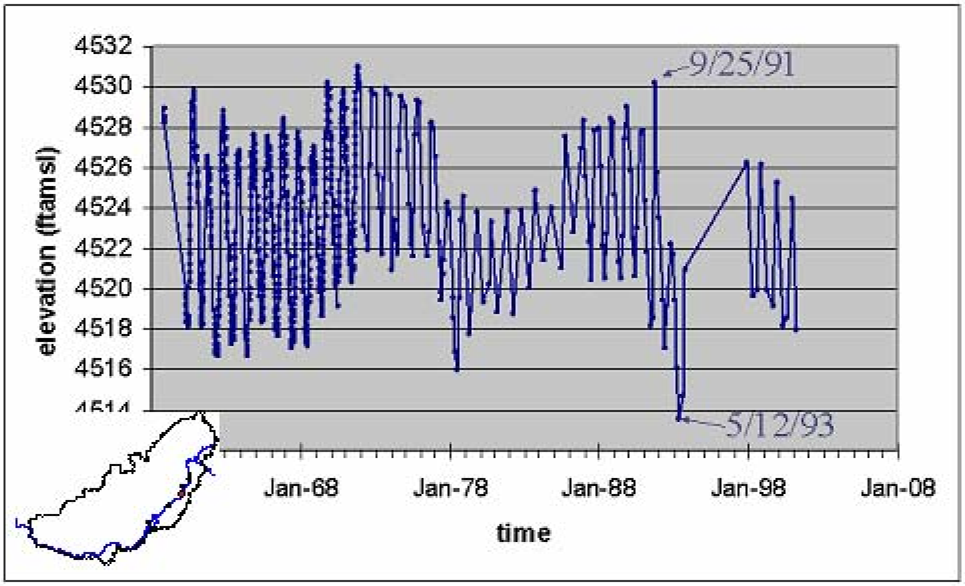

Figure 6. Hydrograph for well 01N36E - 01CCB1.

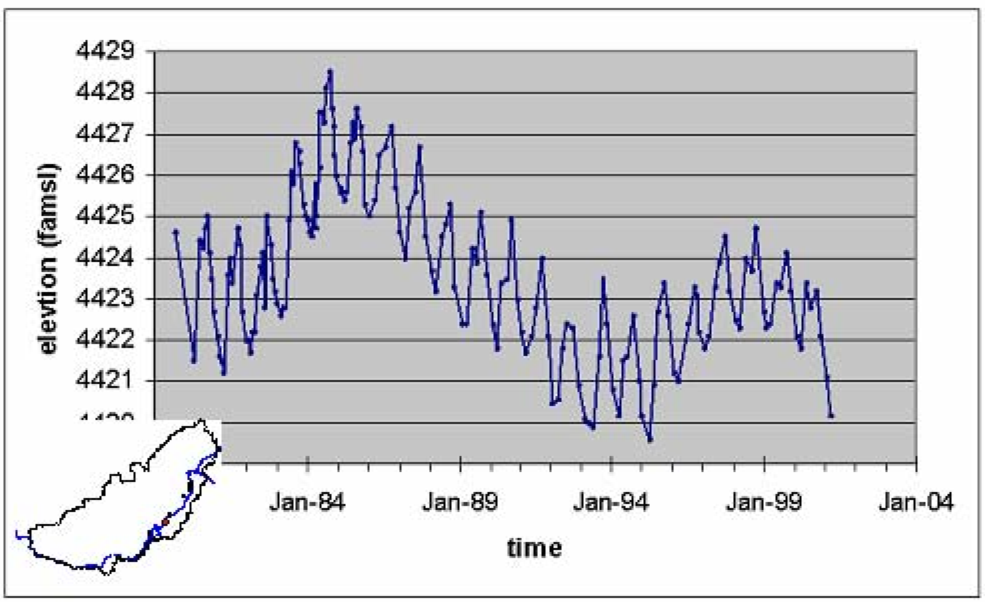

Figure 7. Hydrograph for well 03S34E-08BAB1.

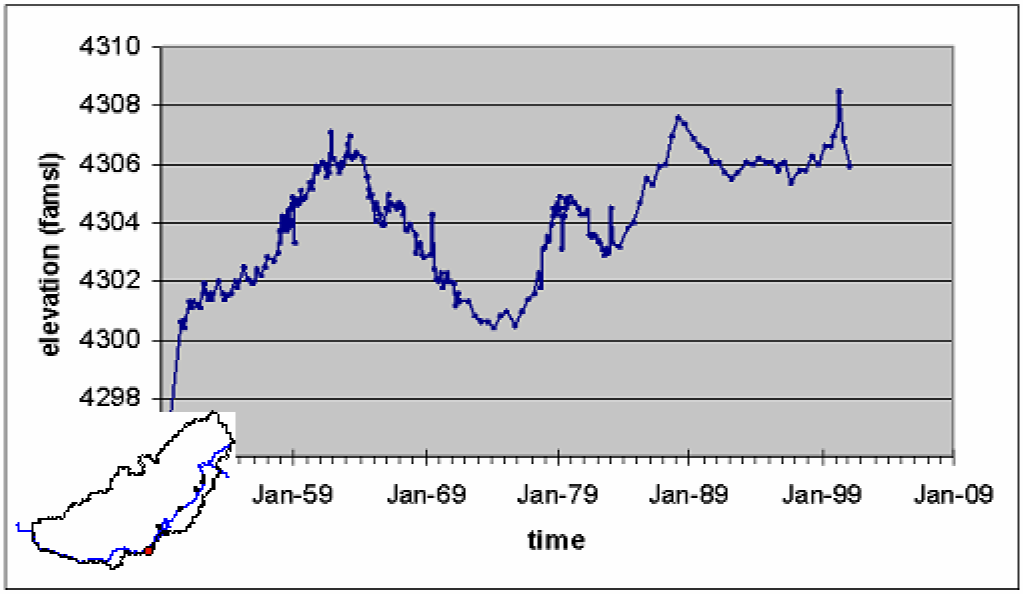

Figure 8. Hydrograph for well 08S30E-23CDD1.

Figure 9 contains a river profile of this region. This figure indicates the elevation of the bottom of the river (Snake depth in Figure 9), and the elevation of the base of the river sediments (river bottom in Figure 9), assuming a uniform 30 ft thickness of riverbed sediments. Note how on the up river edge of the Figure (right side) the water table elevations remain below the assumed bottom of the riverbed sediments. At river mile 205 occasionally the aquifer levels become hydraulically connected with the river. Near river mile 185 all the water table level lines cross the assumed riverbed bottom indicating that, at this point, the river and aquifer are always hydraulically connected.

Because the transition between hydraulically connected and perched is similar in Figure 9 as that implied by the hydragraphs of Figures 4-8, a riverbed sediment thickness of 30 ft appears reasonable. Figure 9 appears to offer some circumstantial evidence that the riverbed sediments are about 30 ft thick. Note that between river mile 205 and 190 the aquifer levels that cross the assumed river bottom tend to stay across and those that do not cross, tend to stay below the river bottom. Perhaps, once the aquifer achieves hydraulic connection, the river tends to maintain that connection or perhaps the water table is coincidentally parallel with the river bottom.

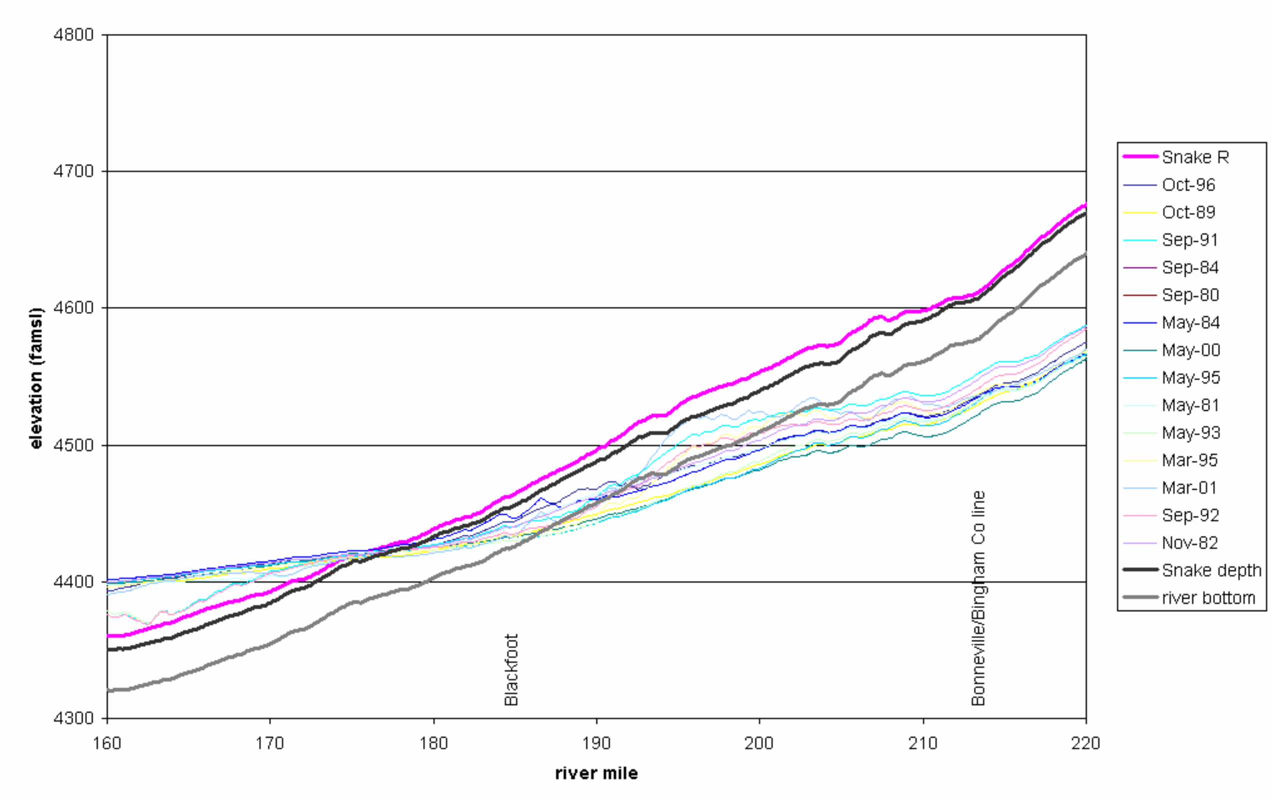

Figure 9. River profile showing assumed river bottom.

Effect

An incorrect estimate of the thickness of the river bottom sediments would result in incorrectly simulating the point at which the Snake River becomes perched. Since targets for gains and losses would be unaffected and errors in R_{bot} would be partially offset by adjustments in C_{riv}, this would introduce an error in distribution of flux and not much error in the collective magnitude.

Design Decision

Assume a uniform 30 ft thickness for the river bottom sediments for the portion of the Snake River above Milner Dam.

References

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