# Representation of MODFLOW-2000 River Cells for the Snake River above Milner Dam and American Falls Reservoir for Calibration of the Eastern Snake Plain Aquifer Model Version 2; As Built

Prepared by Idaho Water Resources Research Institute

In fulfillment of the Water-Budget Component – River Stage Elevation

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The Idaho Department of Water Resources


University of Idaho

Idaho Water Resources Research Institute

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## DESIGN DOCUMENT OVERVIEW

During calibration of the Eastern Snake Plain Aquifer Model Version 1.1 (ESPAM 1.1), a series of Design Documents were produced to document data sources, conceptual model decisions and calculation methods. These documents served two important purposes; they provided a vehicle to communicate decisions and solicit input from members of the Eastern Snake Hydrologic Modeling Committee (ESHMC) and other interested parties, and they provided far greater detail of particular aspects of the modeling process than would have been possible in a single final report. Many of the Design Documents were presented first in a draft form, then in revised form following input and discussion, and finally in an “as-built” form describing the actual implementation.

This report is a Design Document for the calibration of the Eastern Snake Plain Aquifer Model Version 2 (ESPAM 2). Its goals are similar to the goals of Design Documents for ESPAM 1.1: To provide full transparency of modeling data, decisions and calibration; and to seek input from representatives of various stakeholders so that the resulting product can be the best possible technical representation of the physical system (given constraints of time, funding and personnel). It is anticipated that for some topics, a single Design Document will serve these purposes prior to issuance of a final report. For other topics, a draft document will be followed by one or more revisions and a final “as-built” Design Document. Superseded Design Documents will be maintained in a “superseded” file folder on the project Website, and successive versions will be maintained in a “current” folder. This will provide additional documentation of project history and the development of ideas.

## INTRODUCTION

As described in ESPAM 1.1 Design Document DDM-010 (Wylie, 2004), the River package in MODFLOW is used to simulate flux between the Snake River and the Eastern Snake Plain Aquifer. The river recharges the aquifer when the head is above that of the aquifer or the aquifer discharges to the river when the head in the aquifer is above that of the river. In order to simulate these conditions, river water surface elevation (Stage), elevation of the bottom of riverbed sediments (Rbot), and river bed conductance (Cond) are necessary. These terms are thoroughly discussed in detail in DDM-10 (Wylie, 2004) and were estimated in ESPAM 1.1 for the portion of the Snake River above Milner Dam, which includes American Falls Reservoir. As a result of changing stress periods to monthly periods in ESPAM 2, the ESHMC has agreed to vary river elevation with time in the river cells representing the Snake River above Milner Dam.

In order to avoid confusion with the various terms used throughout this document, the list below describes each term. Figure 1 illustrates each term relative to when a river cell is used to represent a segment of the river and when a river cell is used to represent part of the reservoir in American Falls Reservoir. All terms referring to elevation will be values in feet above sea level.

List of terms used in this document:

(1) River stage elevation ($R_{stage}$) – water surface elevation of the river; same value as "Stage" in the MODFLOW River package.
(2) Reservoir stage elevation ($Res_{stage}$) – water surface elevation of the reservoir; same value as "Stage" in the MODFLOW River package.
(3) Riverbed elevation ($Riv_{bed}$) – surface elevation of the riverbed, which is 30 feet above the "Rbot" value in the MODFLOW River package.
(4) Reservoir bed elevation ($Res_{bed}$) – elevation at the top of the reservoir bed, which is the surface exposed when no water is in a specific cell in the reservoir; when the cell is not "wetted" by the reservoir this value is the same as "Stage" in the MODFLOW River package.
(5) Riverbed thickness – thickness of the material below the riverbed elevation kept saturated by the river water.
(6) River bottom elevation ($R_{bot}$) – elevation of the bottom depth of riverbed material and is the lowest extent of the riverbed thickness; represents the minimum elevation that the aquifer water levels can fall to and still remain hydraulically connected to the river.
(7) Aquifer head ($H_{aq}$) – elevation of the aquifer water levels.

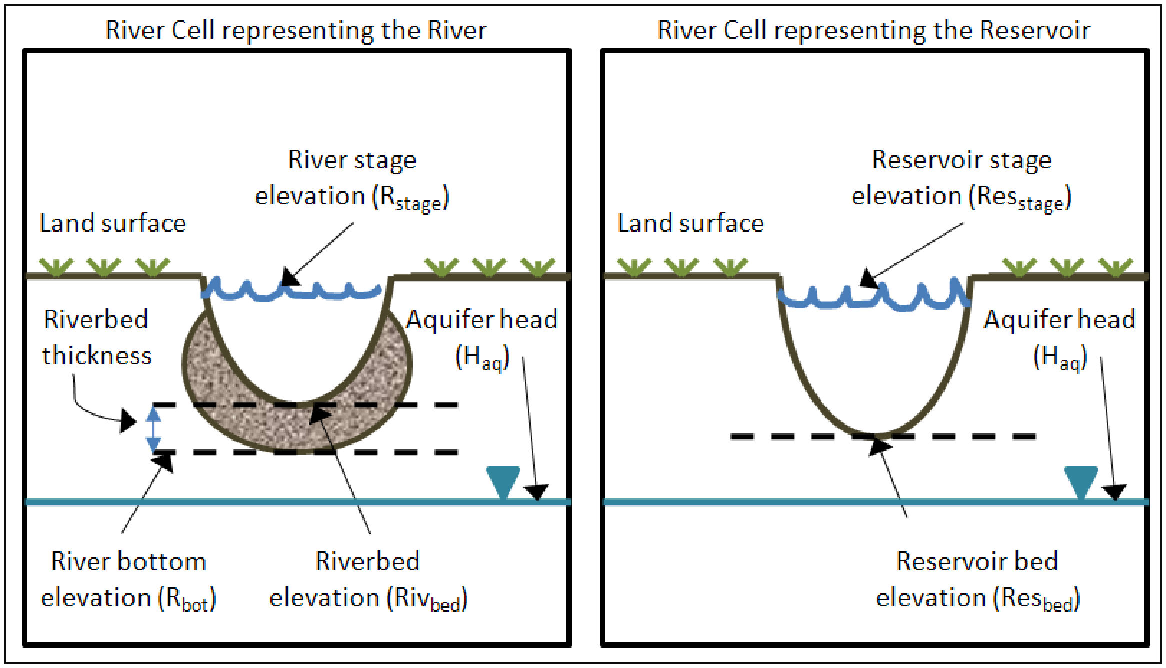



**Figure 1.** Illustration of the terms associated with the river cells used throughout this document.

This Design Document outlines a proposal for the treatment of the river cells above Milner Dam in ESPAM 2. It is based on discussions at ESHMC meetings during the spring of 2008. The Snake River from Milner Dam to King Hill will be addressed in another document. The process of introducing temporal variation in terms involved with the River package (river stage) to account for the change in stress period length will be discussed in this document. The values of river gains and losses used as calibration targets will not be discussed in this document.

**REVIEW OF ESPAM 1.1 APPROACH**

In ESPAM 1.1, the river stage elevation of the Snake River was estimated based on projecting the river onto a 10-meter DEM (Digital Elevation Model). The DEMs represented the Snake River and American Falls Reservoir as full and a constant value of head was assumed for each six-month stress period. The Snake River and American Falls Reservoir are heavily regulated and the average conditions for six-month stress periods are close to constant conditions. Since the stage varies so much over a six-month stress period, a constant value seemed to result in the least amount of error. Each river cell assigned to the Snake River was given a river stage elevation based on the DEM values intersecting that cell. The value for each individual cell was the same value for all of the six-month stress periods in ESPAM 1.1. River cells were also used to represent American Falls Reservoir. American Falls Reservoir fills and spills annually, so the same river stage was used for all stress periods in ESPAM 1.1. The river stage of these river cells was based on the DEMs and a slight gradient was imposed across the reservoir.

The river bottom elevation of the Snake River and reservoir was estimated by linear interpolation between known points along the Snake River above Milner Dam. These “known points” were gaging stations along the Snake River. The river bottom elevation is the 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. If the head in the aquifer remains above a defined river bottom elevation, the aquifer is in connection with the river. If the head in the aquifer drops below the river bottom elevation, the aquifer falls out of connection with the river. In ESPAM 1.1 the river bottom elevation was assumed to be 30 feet below the estimated elevation of the river bed elevation based on Garabedian’s (1992) values and Wylie’s (2004) evaluation of well hydrographs. This assumption was made because the riverbed thickness is difficult to determine since it is not defined by stratigraphic change.

**DISCUSSION TOPICS FOR ESPAM 2**

One-month stress periods are called for in ESPAM 2. Answers to the following questions were pursued in an attempt to update ESPAM 2 and will be discussed in sections to follow:

1.) How do we adjust for one-month stress periods?
2.) Will we adjust the river bottom elevations?
3.) Should we change the number of cells representing American Falls Reservoir, and if so how should it be changed?
4.) How should we change the stage elevation at American Falls Reservoir to account for the monthly stress periods?
5.) How will flux (Q) be calculated?

6.) Will conductance of the river cells change relative to ESPAM 1.1?

**Adjusting for One-Month Stress Periods**

Stage elevation of the Snake River requires more detail than DEMs provide. DEMs provide a single, average value. Actual river stage elevation varies with time as flows change. Several USGS gages exist in the Snake River to measure flow in which gage height measurements are also measured. Each gage has been surveyed by the USGS and a gage datum elevation is provided. By adding monthly gage height measurements to the gage datum measurement, a river stage elevation can be estimated at a given stage.

Figure 2 displays the location of the gages along the Snake River and Henrys Fork. The blue cells represent the MODFLOW river cells used in ESPAM 1.1. These gages will be used to linearly interpolate river stage elevations for all river cells between known sites. Data are available at all gages during the entire calibration period (May 1980-October 2008) except for the gages at Minidoka, near Blackfoot, Eagle Rock, and Menan. At Minidoka, data are missing between May 1980 and August 1980. The "near Blackfoot" gage is missing data between May 1980 and July 1982. At Eagle Rock, data are missing between May 1980 and January 1988. At Minidoka, data are missing between May 1980 and September 1980. At Menan, data are missing between May 1980 and March 2000. In most cases, gage

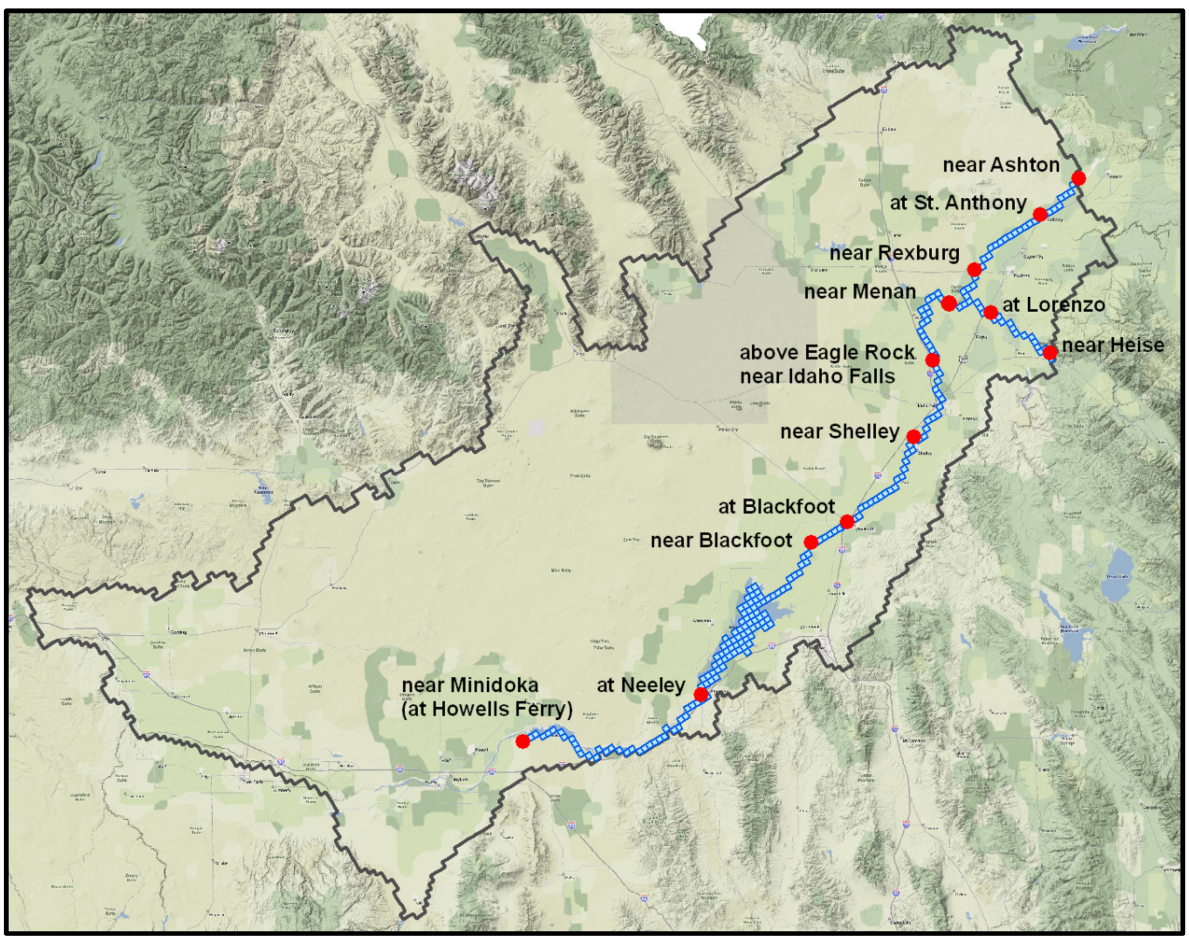



**Figure 2.** USGS gages on the Snake River and Henrys Fork.

height measurements are available for about every other month (in some cases, as many as four months may have been skipped). In this case, monthly measurements were estimated by taking an average of the preceding and following month. In a situation where some gages are missing several years of data, the river stage elevation will be estimated based on years that have data at that gage. For example, similar water years were compared to gage measurements at same gage site in order to estimate missing values of river stage elevation. The possibility of ignoring the gage with missing data and interpolating between two gages with known data was explored; however, this proved to be a poor interpolation of the river stage elevation. Table 1 shows the gages and USGS-assigned station number in the Henrys Fork and Snake River that will be used to estimate river stage elevation in the Snake River. The "Snake River at Blackfoot" gage is a USGS gage, but the gage height data is provided by the U.S. Bureau of Reclamation telemetry.

**Table 1.** USGS gages and corresponding station number.

| USGS Station Name | USGS Station Number |
|---|---|
| Snake River near Heise | 13037500 |
| Snake River at Lorenzo | 13038500 |
| Henrys Fork near Ashton | 13046000 |
| Henrys Fork at St. Anthony | 13050500 |
| Henrys Fork near Rexburg | 13056500 |
| Snake River near Menan | 13057000 |
| Snake River above Eagle Rock near Idaho Falls | 13057155 |
| Snake River near Shelley | 13060000 |
| Snake River at Blackfoot | 13062500 |
| Snake River near Blackfoot | 13069500 |
| Snake River at Neeley | 13075000 |
| Snake River near Minidoka (at Howells Ferry) | 13081500 |

### River Bottom Elevations ($R_{bot}$)

At the ESHMC meeting in May 2008, it was agreed upon to use the river bottom elevations ($R_{bot}$) from ESPAM 1.1, which were based on linear interpolation between cross-sections at gages along the Snake River and Henrys Fork since this is currently the best information we have available. The $R_{bot}$ values will continue to be assumed to be 30 feet below the actual riverbed elevation, which was based on Garabedian values and checked using river profiles produced by Wylie (2004).

### Number of Cells Simulating American Falls Reservoir

The level and extent in American Falls varies from month to month. In Figure 3, the reservoir level is near maximum extent and highest level. In Figure 4, the reservoir is at one of its smallest extents and lowest levels. In ESPAM 1.1, the same number of cells was used to represent the reservoir for each six-month stress period. The MODFLOW river cells in ESPAM 2 will need to be changed to account for varying extent and varying stage elevation.

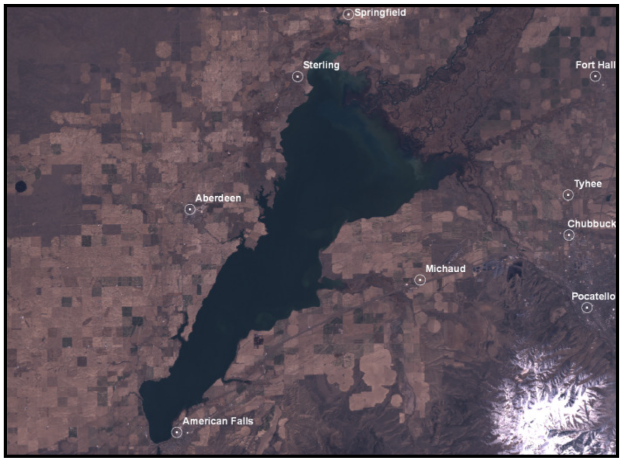



Figure 3. Extent of American Falls Reservoir in March 2000.

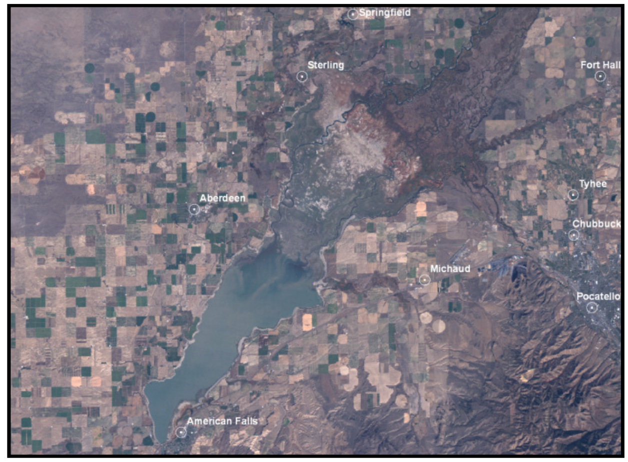



**Figure 4.** Extent of American Falls Reservoir in October 2000.

Figure 5 shows the distribution of river cells simulating American Falls Reservoir in ESPAM 1.1. Figure 6 shows the new cells in green that will be added to the existing river cells in blue to accurately portray the flux in the American Falls Reservoir in each one-month stress period in ESPAM 2. For each stress period, the same distribution of river cells will be used in the simulation. However, in instances when the reservoir does not wet a particular cell, the river stage elevation in that cell will be based on either (1) head in the reservoir at American Falls Reservoir or (2) land surface elevation in the non-wetted cell, whichever is larger. Setting a zero conductance in the non-wetted cells was considered, but this would prevent spring discharge in exposed cells so this idea was eliminated. Discussion on the river stage elevation in non-wetted or "exposed" cells will be discussed in the next section on "Stage Elevation at American Falls Reservoir" and an equation as to how flux is calculated in the vicinity of the reservoir is discussed in the section "Flux in the River Cells Representing the Reservoir". Several aerial

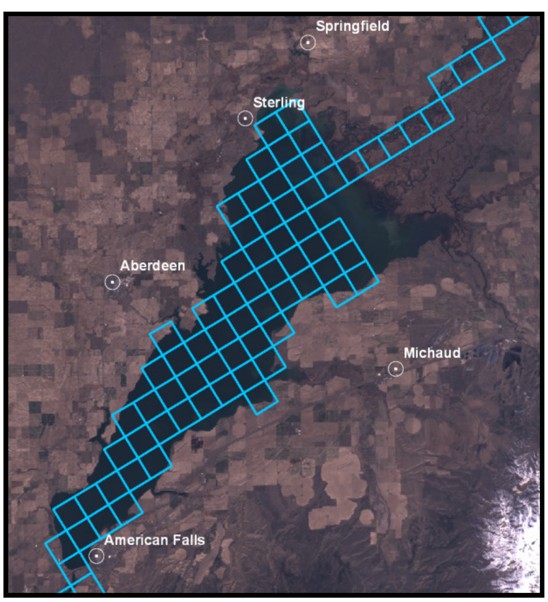



**Figure 5.** River cells simulating American Falls Reservoir in ESPAM1.

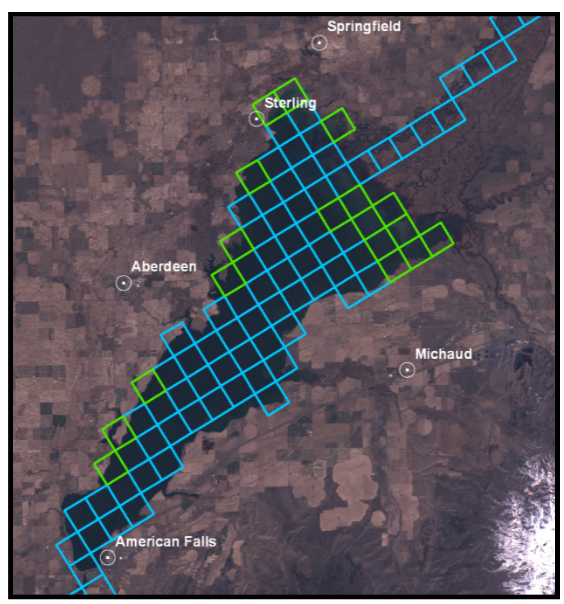



**Figure 6.** Proposed river cells to be used in ESPAM2 to simulate American Falls Reservoir.

photos will be used to approximate the extent of the reservoir corresponding to various stage elevations. Aerial photography is not available for every year and month; therefore, assumptions will need to be made from one stress period to the next based on the stage elevation. These assumptions will be further discussed on the following section on stage elevation.

### Stage Elevation at American Falls Reservoir

Table 2 is a list of months and years in which aerial images of the American Falls Reservoir are available. Images are not available for the entire calibration period (May 1980-October 2008) of ESPAM 2; however, daily stage elevation at American Falls is available from the Bureau of Reclamation's Hydromet Historical website. Based on the available images and stage height data at American Falls, correlations can be made between the images and actual stage elevations.

**Table 2.** Aerial images available for American Falls Reservoir used for estimating extent of reservoir and stage elevation.

| Date of Image | Image Source | Stage Elevation (ft) at American Falls on date of image capture |
|---|---|---|
| August 9, 1986 | LANDSAT image for P39R30 | 4350 |
| June 30, 1989 | LANDSAT image for P39R30 | 4345 |
| July 29, 1992 | DOQ images for Springfield SW, Schiller NW, Schiller NE, and Aberdeen NE (6-1-1992) | 4323 |
| March 16, 2000 | LANDSAT image for P39R30 | 4353 |
| April 1, 2000 | LANDSAT image for P39R30 | 4354 |
| May 3, 2000 | LANDSAT image for P39R30 | 4354 |
| June 20, 2000 | LANDSAT image for P39R30 | 4350 |
| July 6, 2000 | LANDSAT image for P39R30 | 4345 |
| August 7, 2000 | LANDSAT image for P39R30 | 4333 |
| September 8, 2000 | LANDSAT image for P39R30 | 4318 |
| October 18, 2000 | LANDSAT image for P39R30 | 4312 |
| July 22, 2002 | LANDSAT image for P39R30 | 4326 |
| July 12, 2004 | 2004 NAIP for Blackfoot and Pocatello | 4330 |
| September 2006 (mosaic – several dates) | 2006 NAIP for Bingham, Bannock, and Power counties | varies |
| July 18, 2007 | LANDSAT image for P39R30 | 4329 |

During the ESPAM 2 calibration period, a minimum and maximum elevation in American Falls Reservoir (based on monthly averages) is calculated as 4303 ft and 4355 ft. Given the maximum and minimum elevations based on the dates of the images available (4312 ft and 4354 ft), the images provide a good estimate of varying extents and elevations of the reservoir stage. For September 2006, several small mosaics (DOQs) composing the American Falls Reservoir were acquired; however, each one represented a different date. The reservoir stage elevation widely varied over these dates and therefore the mosaics were not used to configure a variation in reservoir extent.

Based on the images available, certain cells were selected to represent the reservoir extent on the specific date. If a model cell was approximately 50% or more covered (wetted) by the reservoir, it was selected to represent the reservoir for a given stage elevation on the given date. Figure 7 shows how cells were chosen to represent a specific stage elevation. The image is a Landsat image of American Falls Reservoir captured on March 16, 2000. The elevation of the reservoir on this date was 4353 ft. All stress periods having a reservoir stage elevation at this elevation (4353 ft) will have the same cell distribution representing reservoir extent in ESPAM 2.

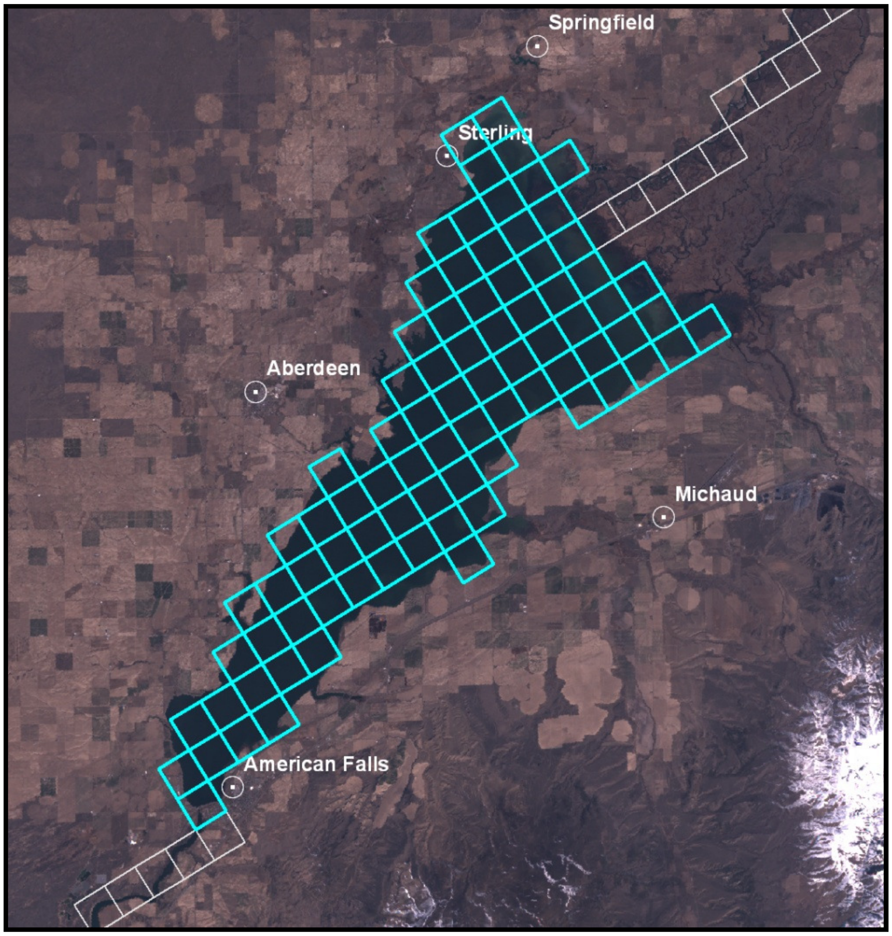


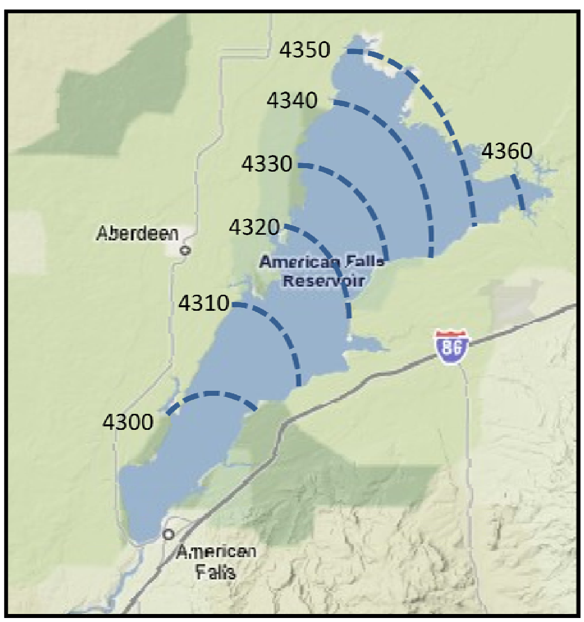

**Figure 7.** Cells highlighted in blue represent the American Falls Reservoir extent on March 16, 2000 with a stage elevation of 4353 ft.

Given the images available, some of the cells chosen to represent the reservoir for a known reservoir elevation were the same as those for another elevation. For example, the extent of the reservoir (distribution of cells "wetted" by the reservoir) was the same for the images on August 1986 (reservoir stage elevation of 4350 ft) and March 2000 (stage elevation of 4354 ft); therefore, months with similar monthly average reservoir stage elevations (4351 ft or 4355 ft, for example) were assumed to include the same distribution of wetted cells. Known monthly reservoir stage elevations were assigned to a given cell distribution based on which one most appropriately represented the reservoir at that time.

A gap in elevation values provided by the images is found at 4300 ft and 4340 ft, given the range of monthly average values of the stage height in the reservoir. Since no aerial images were found to match these stage heights, the river cells associated with these elevations were estimated based on images with similar elevations or topographic maps. For example, for reservoir stage elevations near 4300 ft, the cells chosen to represent the reservoir were based on the cells chosen to represent 4312 ft as shown in the image for October 2000 and land surface elevations from topographic maps. For reservoir elevations near 4340 ft, cells representing the elevations in the August 2000 (4333 ft) and June 1989 (4345 ft) were compared to select cells and were also compared to topographic maps.

Eleven different variations of the reservoir extent are possible in ESPAM 2. One of the 11 will be assigned to each stress period based on the average monthly reservoir elevation calculated for that stress period. Since the reservoir stage elevation in the reservoir varies, some of the cells are not covered or "wetted" by the reservoir at some stages. For cells that are not continuously submerged, the minimum elevation value will be reservoir bed elevation. This is in contrast to the Snake River reaches where $R_{bot}$ is riverbed elevation minus the 30 feet riverbed thickness. Assuming there is no gradient in the reservoir surface, it is unlikely for the reservoir stage elevation to be higher than land surface elevation. In other words, cells in the reservoir that are intermittently dry or not "wetted" by the reservoir will be assigned a stage that is the higher elevation between (1) reservoir bed elevation or (2) reservoir stage elevation at American Falls, for a given stress period.

The maximum stage elevation in the reservoir is 4355 ft. The minimum stage elevation is 4303 ft, in which some cells are exposed or "dry". Figure 8 shows contour lines representing the lowest possible values of reservoir stage elevation ("Stage" in the MODFLOW River package). The elevation of 4360 ft is approximately the highest elevation the reservoir could reach; however, this reservoir stage height is an average monthly value calculated within the calibration period and is therefore not reached.




3. Contour lines showing the approximate values
rvoir stage elevation in American Falls Reservoir.

In summary, the reservoir stage elevation of American Falls Reservoir will be represented as the elevation of the water surface or the reservoir bed elevation, depending on which is greater. The reservoir bed elevation will only be greater than the reservoir stage elevation when a given cell is not submerged.

**Flux in the River Cells Representing the Reservoir**

Discharge (flux) to or from the river in an individual model cell is calculated as follows in the reservoir:

$$Q = C_{riv}\,[\max(Res_{stage}, Res_{bed}) - \max(Res_{bed}, H_{aq})]$$

Where: Q is the flux to or from a cell ($L^3/T$), $C_{riv}$ is the conductance ($L^2/T$), $Res_{stage}$ is the elevation of the water in the reservoir (L), $Res_{bed}$ is the actual bed elevation of the reservoir (L), and $H_{aq}$ is the head in the aquifer in a model cell (L). Q is a product of the river conductance and a driving head (difference in elevations). The driving head is expressed in MODFLOW as the difference between a "reservoir head" term and an "aquifer head" term. In ESPAM 2, representation of the reservoir head term is the greater of the reservoir stage or elevation of the reservoir bed, for a given cell. The "aquifer head" term is the greater of the aquifer head elevation or reservoir bed elevation, for a given cell. A positive value of flux implies the aquifer is gaining water from the reservoir whereas a negative value of flux implies that the aquifer is losing water to the reservoir. Figure 9 displays different scenarios that apply to calculating flux in cells in American Falls Reservoir. The brown "X" marks the reservoir bed in 9(a) through 9(d) and is the focus point for calculation purposes. In Figure 9(a), the flux is a function of the reservoir stage elevation minus the aquifer head (Head difference: 4300 ft – 4200 ft = 100 ft). Figure 9(b) shows a reservoir stage that is less than the aquifer stage (Head difference: 4200 ft – 4250 ft = -50 ft). Figure 9(c) shows the reservoir bed is greater than the elevation of the reservoir and less than the elevation of the aquifer head. Flux is a function of reservoir bed elevation minus the aquifer head elevation in Figure 9(c) (Head difference = 4100 ft – 4200 ft = -100 ft). Figure 9(d) shows the reservoir bed located above the reservoir stage and an aquifer head. This implies there is no flux since the flux is a product of conductance and a head difference of zero (Head difference: $Res_{bed} - Res_{bed} = 0$).

**River Cell Conductance**

The river cell conductance will be assigned to the river cells by Allan Wylie of the Idaho Department of Water Resources (IDWR). In ESPAM 1.1, the conductance ranged from 35,100 $ft^2$/day – 1,010,000 $ft^2$/day for the river cells not included in the reservoir. As discussed by the ESHMC, the river will be divided into reaches and the model independent parameter estimation program, PEST, will be allowed to adjust the conductance of these reaches. The American Falls Reservoir was represented with a conductance of 99,000 $ft^2$/day in ESPAM 1.1. The conductance in American Falls Reservoir will be held at a low conductance as decided by the ESHMC; however, the extreme southwestern end of the reservoir will be within the Neeley-Minidoka reach of the river cells and will be adjusted by PEST.

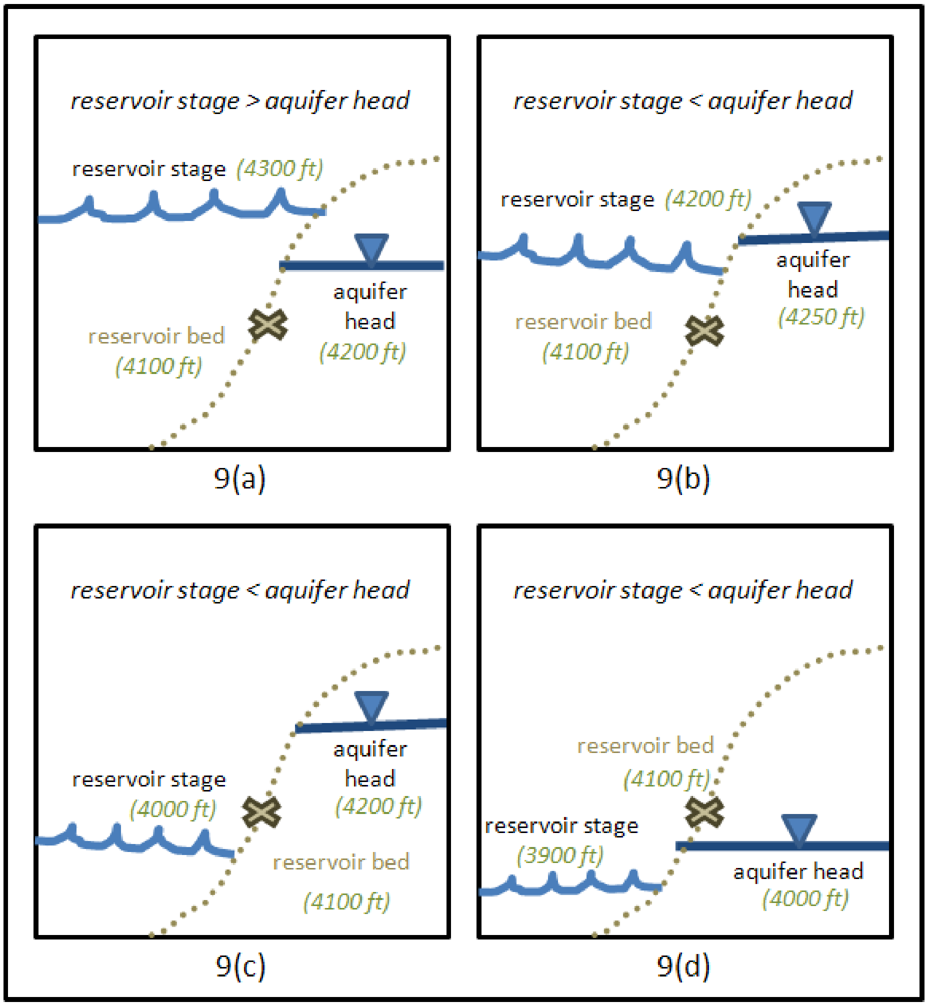



**Figure 9.** Scenarios showing different possibilities for flux American Falls Reservoir. "X" is the reservoir bed elevation, which is the focus of the calculations of flux.

**Final Product**

The final Excel spreadsheet will consist of the following information:

1. Layer (1)
2. Row
3. Column
4. Stage (ft)
5. Conductance ($ft^2$/day)
6. River bottom (ft)

The same number of river cells will exist from one stress period to the next and information on each stress period will be placed in one Excel spreadsheet.

## Additional Changes Made to the River Cells File after Completion of this Document

This design document was completed prior to the final completion of the river cells spreadsheet. Due to unforeseen circumstances discovered during completion of the river cells spreadsheet, the river bottom elevation ($R_{bot}$) for river cells simulating American Falls Reservoir needed to be updated from ESPAM 1.1 since some of the values were higher than the actual reservoir stage elevation. Figure 10 shows the river bottom elevation (approximated reservoir bed elevation ($Res_{bed}$) minus 30 ft) applied to those cells simulating the reservoir. These elevations were estimated from shorelines in the reservoir shown in aerial photographs. Notice that one cell in the southwestern end of American Falls Reservoir is about 30 ft higher in elevation relative to the surrounding cells. This cell was more than 50% "wetted" only when the reservoir stage elevation was greater than 4350 ft. In order to prevent this cell from having a lower river bottom elevation relative to the actual reservoir stage, a higher river bottom elevation needed to be applied.

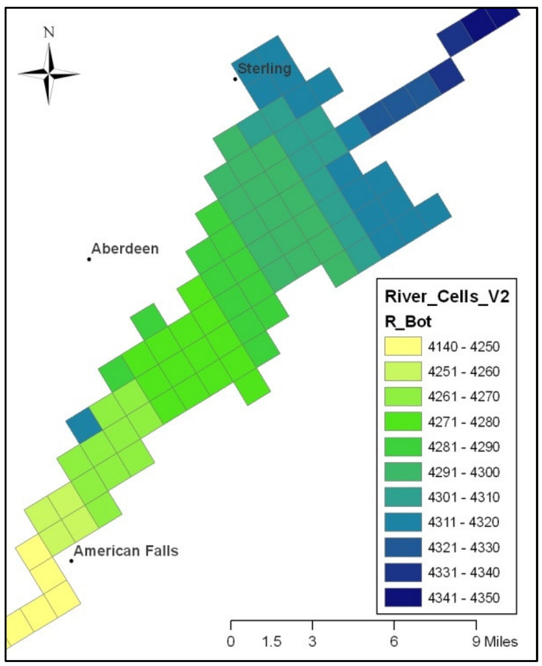



**Figure 10.** Updates made to the river bottom elevations ($R_{bot}$) for cells in American Falls Reservoir.

## References

Garabedian, S.P., 1992. Hydrology and Digital Simulation of the Regional Aquifer System, Eastern Snake River Plain, Idaho. U.S. Geological Survey Professional Paper 1408-F.

Wylie, A., 2004. Model River Representation above Milner Dam. Idaho Water Resources Research Institute Technical Report 04-017.