Design Document: Tributary basin underflow into the Wood River Valley aquifer system; *DRAFT 4*

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Design document description and purpose

The U.S. Geological Survey (USGS), in collaboration with the Idaho Department of Water Resources (IDWR) is constructing a MODFLOW numerical groundwater-flow model of the Wood River Valley aquifer system in order to simulate potential anthropogenic and climatic effects on groundwater and surface-water resources. This model will serve as a tool for water-rights administration and water-resource management and planning. The study will be conducted over a 3-year period from late 2012 until model and report completion in 2015.

One of the goals of the modeling study is to develop the model in an open and transparent manner. To this end, a Technical Advisory Committee was formed to provide for transparency in model development and to serve as a vehicle for stakeholder input. Technical representation was solicited by the IDWR and includes such interested parties as water-user groups and current USGS cooperating organizations in the Wood River Valley.

The design, construction, and calibration of a groundwater-flow model requires a number of decisions such as the number of layers, model cell size, or methodologies used to represent processes such as evapotranspiration or pumpage. While these decisions will be documented in a final USGS report, intermediate decision documents will be prepared in order to facilitate technical discussion and ease preparation of the report. These decision documents should be considered preliminary status reports and not final products.

Background

One of the most difficult water-budget components to estimate is subsurface inflow or outflow from an aquifer because direct measurement is not possible and the data required for indirect estimates are often lacking. The groundwater-flow model of the Wood River Valley aquifer system requires estimates of the volumetric flux of groundwater through alluvium in tributary canyons into the main aquifer system. Following the usage of Garabedian (1992) for the groundwater-flow model of the Eastern Snake River Plain regional aquifer system, this flux is referred to as tributary basin underflow.

Smith (1960) inferred geologic sections at 27 streamgages in the Malad River basin in order to qualitatively estimate basin yield (estimated as “the sum of surface runoff and ground-water underflow from a basin.”). Ten of the streamgages evaluated were in the Wood River Valley, four of which are applicable to the estimate of tributary basin underflow: Big Wood River near Ketchum, Warm Springs Creek at Guyer Hot Springs near Ketchum, Warm Springs Creek near Ketchum, and Trail Creek at Ketchum. Smith’s estimates are:

1. Big Wood River near Ketchum: “The ground-water component probably is more than 10 percent of the water yield.”
2. Warm Springs Creek at Guyer Hot Springs near Ketchum: “Underflow probably is less than 1 percent of the water yield.”
3. Warm Springs Creek near Ketchum: “The …alluvium probably transmits a moderate amount of ground water past the gage site. The amount cannot be estimated.”
4. Trail Creek at Ketchum: “Underflow…is believed to be an appreciable percentage of the water yield of the…drainage area.”

The groundwater budget described in Bartolino (2009) identifies recharge from 28 tributary canyons as the largest component of recharge to the Wood River Valley aquifer system. This estimate was based on the USGS StreamStats tool (Ries and others, 2004) which uses regression equations from gaged streams to estimate flow in ungagged streams. For 23 of the tributaries Bartolino (2009) assumed that all of this estimated flow was recharged; the remaining five major tributaries were assumed to recharge 50 percent of the measured or estimated flow. Previous estimates of tributary recharge, such as Smith (1959) and Wetzstein and others (1989), were made with basin-yield calculations or model results: they are roughly comparable to those in Bartolino (2009).

Because Bartolino (2009) constructed a water budget for the entire aquifer system no effort was made to differentiate subsurface flux from recharged tributary streamflow. Thus, these estimates are not directly comparable to estimates of tributary basin underflow calculated for the groundwater-flow model.

Design decision

The process of tributary basin underflow begins with infiltration of precipitation or snowmelt that falls within tributary basins; this water eventually reaches the water table and flows down gradient. This infiltration may occur directly over the extent of the Wood River Valley aquifer system (as defined by previous work such as Bartolino and Adkins, 2012) or flow into the aquifer system in the subsurface. Because the boundaries of the groundwater-flow model of the Wood River Valley aquifer system currently under development does not include the entire mapped extent of the aquifer system, tributary basin underflow is defined as groundwater flow into the model domain that originates as precipitation in the tributary basins.

Tributary basin underflow estimates are often made using the Darcy equation although such estimates are long-term averages that do not account for variability in precipitation and snowmelt timing. Depending on soil moisture, topographic gradients, and hydraulic conductivity, there is likely a lag time of some months between precipitation infiltration and movement of the tributary basin underflow into the model domain. Because of multiple recharge events and the time lag, recharge tends to be “smeared” or integrated over time rather than having distinct peaks (such as seen in graphs of stream-discharge or precipitation). Thus some form of seasonal indexing is needed to represent temporal variation in tributary basin underflow. One such technique to represent temporal variation in tributary basin underflow is to apply a seasonal scaling index (*SI* in equation 1) to convert the long-term average underflow into a monthly or quarterly value. The seasonally adjusted volumetric flux of tributary basin underflow can therefore be expressed as equation 1:

$$Q_{trib,i} = \bar{Q}_{trib} \times SI_{trib,i} \tag{1}$$

where:

$trib$ is an identifier for each of the 22 major tributary canyons,

i is an index for each month (or stress period) in the transient simulation,

$Q_{trib,i}$ is the estimated volumetric flux to the model from tributary *trib* during month *i*,

$\bar{Q}_{trib}$ is the estimated mean volumetric flux to the model from tributary *trib*, and

$SI_{trib,i}$ is the seasonal scaling index for tributary *trib* during month *i*.

Mean tributary basin underflow ($\bar{Q}_{trib}$)

Mean tributary basin underflow is commonly estimated with the Darcy equation whereby the water-table gradient is multiplied by the hydraulic conductivity and saturated cross-sectional area of the tributary basin. The mean volumetric flux in a tributary ($\bar{Q}_{trib}$ in equation 1) is expressed as:

$$\bar{Q}_{trib} = K \times A_{trib} \times \nabla h_{trib} \tag{2}$$

where:

$\bar{Q}_{trib}$ is the estimated mean volumetric flux to the model from tributary *trib*, in length^3/time units,

K is hydraulic conductivity in length/time units,

A_{trib} is the cross sectional area in length^2 units, and

∇h_{trib} is the hydraulic gradient, dimensionless.

Calculation of the gradient using water-level contours representing 2006 conditions (Skinner and others, 2007) proved to be problematic due to the incorporation of interpolation errors inherent in the contouring process as well as scarce data in many tributary canyons. While water levels from drillers' logs are more plentiful, the wide variability in measurement dates introduces noise in the interpolated water-table surface. It was therefore decided estimate a cross-sectional area of the saturated thickness in tributary canyons from well and geophysical data and apply a Darcian analysis for flux.

ArcMap GIS was used to manually draw a straight line across a given tributary canyon roughly perpendicular to the canyon axis to serve as the cross-sectional line. These lines were drawn in areas with existing data on depth to bedrock either from drillers' logs or geophysical data. A second line of equal length was drawn perpendicular to the first line and down the canyon axis to serve as the axial line. The ArcMap "Add surface information" tool and the "Field Calculator" and "Calculate Geometry" attribute table options were applied to 1/3 arc-second National Elevation Dataset (USGS, 2009) to determine the length of the cross-sectional line, the lowest elevation along the cross-sectional line, and the average gradient of the axial line.

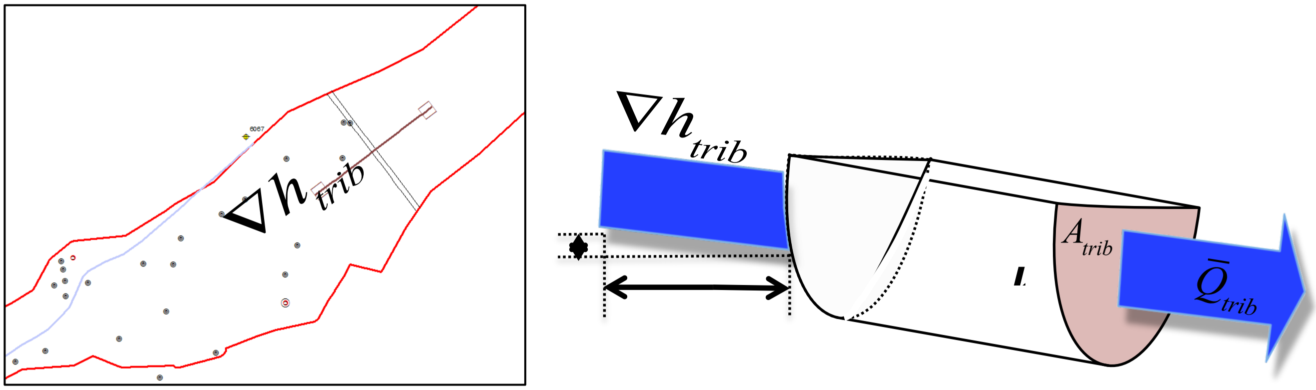

Figure 1. Illustration of tributary canyon and components of Darcian flux analysis.

Several assumptions must be made to allow calculation of a Darcian flux. These assumptions include:

1. That the tributary contains a perennial stream the surface of which is represented by the lowest altitude of the cross-sectional line and that this altitude represents a flat, level water table across the cross-sectional line;
2. That the water table parallels the land surface along the canyon axis, that the water-table gradient is represented by the average gradient of the axial line, and that this represents the hydraulic gradient;
3. That the altitude of the aquifer base at the center of the cross-sectional line is taken as the altitude of bedrock in the nearest well or geophysical measurement; and
4. That the cross-sectional area of the saturated thickness is taken as half of an ellipse with width of the cross-sectional line length and height of the distance between the estimated water table and bedrock altitudes.

Values of hydraulic conductivity (*K*) were taken as 85 ft/d (26 m/d) which is the average of the two geometric means of hydraulic conductivity in the unconfined aquifer taken from table 2 in Bartolino and Adkins (2012). The cross-sectional area (*A* in equation 3) of the saturated thickness in a given tributary canyon is estimated as the lower-half of an ellipse, expressed as:

$$A = \left(\frac{aB}{4}\right)\left[\cos^{-1}\left(1-\frac{2H}{a}\right)-\left(1-\frac{2H}{a}\right)\sqrt{\frac{4H}{a}-\frac{4H^2}{a^2}}\right] \qquad (3)$$

where

A is the cross sectional area of the lower-half an ellipse representing the saturated thickness in length^2 units,

a is height of the ellipse in length units,

B is the width of the ellipse in length units,

H is the height of the segment in length units, and

Cos^{-1} is in radians.

Parameters and estimates of Darcian volumetric flux are shown in table 1.

Table 1. Initial and final estimates of average tributary basin underflow and selected tributary basin information.

[*, denotes a basin for which tributary basin underflow was calculated by multiplying basin yield by 0.05. --, not applicable]

Tributary	Saturated thickness (a) (ft)	Tributary width (B) (ft)	Cross-sectional area (A_{trib}) (ft²)	Land surface gradient (∇h_{trib})	Initial mean volumetric flux from Darcy equation ($\overline{Q}_{tribini}$) (acre-ft/yr)	Basin area (mi²)	Average annual precipitation (in)	Precipitation volume (P_{trib}) (acre-ft/yr)	Ratio of initial mean volumetric flux to precipitation volume ($R_{triblarge}$)	Final mean volumetric flux ($\overline{Q}_{trib}$) ($\overline{Q}_{triblarge}$ and $\overline{Q}_{tribsmall}$) (acre-ft/yr)
Adams Gulch (Adm)	48	650	24,694	0.0482	851	11	30	17,600	0.048	851
Chocolate Gulch (ChG) *	59	709	32,778	0.0727	1,703	0.75	21.6	864	--	43
Clear Creek (Clr) *	35	623	17,074	0.0795	971	2.2	19.5	2,288	--	114
Cold Springs Gulch (Cld) *	63	344	17,112	0.0576	705	2.9	21.6	3,341	--	167
Cove Canyon (Cov)	7	3,058	15,909	0.0127	145	14	15	11,200	0.013	145
Croy Creek (Cry)	40	1,391	43,660	0.0226	704	28	15.8	23,595	0.030	704
Deer Creek (DrC)	74	2,277	131,783	0.0155	1,462	55	25.3	74,213	0.020	1,462
Eagle Creek (Eag)	75	1,066	62,946	0.0226	1,015	11	29.4	17,248	0.059	1,015
East Fork (EstF)	43	1,414	48,259	0.0137	471	86	26.3	120,629	0.004	471
Elkhorn Gulch (Elk)	8	387	2,483	0.0289	51	13	18.4	12,757	0.004	51
Greenhorn Gulch (Grn)	78	860	52,395	0.0182	682	21	27.2	30,464	0.022	682
Indian Creek (InS)	83	1,070	69,452	0.0485	2,407	11	17.3	10,149	0.24	2,407
Lake Creek (Lak)	68	1,335	71,257	0.0472	2,406	12	27	17,280	0.14	2,406
Lees Gulch (Lee) *	57	827	37,328	0.0556	1,484	2.8	15	2,240	--	112
Ohio Gulch (OhG) *	85	1,243	83,032	0.0664	3,940	5.1	15.7	4,270	--	214
Quigley Creek (QgC)	60	1,325	62,378	0.0126	560	17	17.1	15,504	0.036	560
Seamans Creek (Sea)	156	1,391	170,357	0.0160	1,949	23	15.3	18,768	0.10	1,949
Slaughterhouse Gulch (Slh)	60	745	35,380	0.0200	506	13	16.6	11,509	0.044	506
Townsend Gulch (Twn) *	63	728	35,835	0.0476	1,218	1.2	15	960	--	48
Trail Creek (Trl)	125	2,152	212,020	0.0191	2,898	64	32.6	111,274	0.026	2,898
Upper Big Wood River (UBW)	118	940	87,037	0.0097	607	178	33	313,278	0.002	607
Warm Springs Creek (WmS)	46	1,617	58,006	0.0117	487	96	35.3	180,735	0.003	487
TOTAL:					**29,100**					
MEAN:									**0.05**	
STANDARD DEVIATION									**0.06**	

An implicit assumption in the volumetric flux estimated by the Darcy equation is that the saturated thickness and hydraulic gradient remain constant, implying an unlimited supply of water. While this assumption may be valid for larger tributary canyons with perennial streamflow, it is likely violated when estimating the volumetric flux in smaller tributary canyons with ephemeral streamflow. In either case, the maximum possible yearly flux cannot be more than the yearly precipitation that falls in the basin, and probably much less when evapotranspiration and sublimation are considered. This assumption, in combination with ambiguity due the lack of well or geophysical data (typical of the smaller tributaries), results in more uncertainty in the volumetric fluxes estimated using Darcy's law in smaller tributary canyons (Chocolate, Cold Springs, Ohio, Lees, and Townsend Gulches and Clear Creek Canyon) (table 1).

To account for the overestimation of volumetric fluxes in the smaller tributary canyons the USGS StreamStats tool (Ries and others, 2004) was used to delineate a basin area above the cross-sectional line described above. This basin area was then multiplied by the mean annual precipitation in the basin (in inches), as provided by StreamStats, to estimate mean annual precipitation volume (in acre-ft/yr) (table 1). The areas of the tributary basins were then plotted on an exponential scale and a natural break was found between 5.1 and 11 mi^2 (fig. 2). For each of the 16 tributary basins of 11 mi^2 or greater, the ratio of mean annual precipitation volume to estimated mean volumetric flux was calculated using equation 4:

$$R_{triblarge} = \bar{Q}_{triblarge} / P_{triblarge} \tag{4}$$

where:

$R_{triblarge}$ is the ratio of volumetric flux to annual precipitation volume for tributary $_{trib}$, larger than 11 mi^2, dimensionless,

$\bar{Q}_{triblarge}$ is the estimated mean volumetric flux to the model for tributary $_{trib}$, larger than 11 mi^2 in $length^3$/time units, and

$P_{triblarge}$ is mean annual precipitation volume for tributary $_{trib}$ in $length^3$/time units.

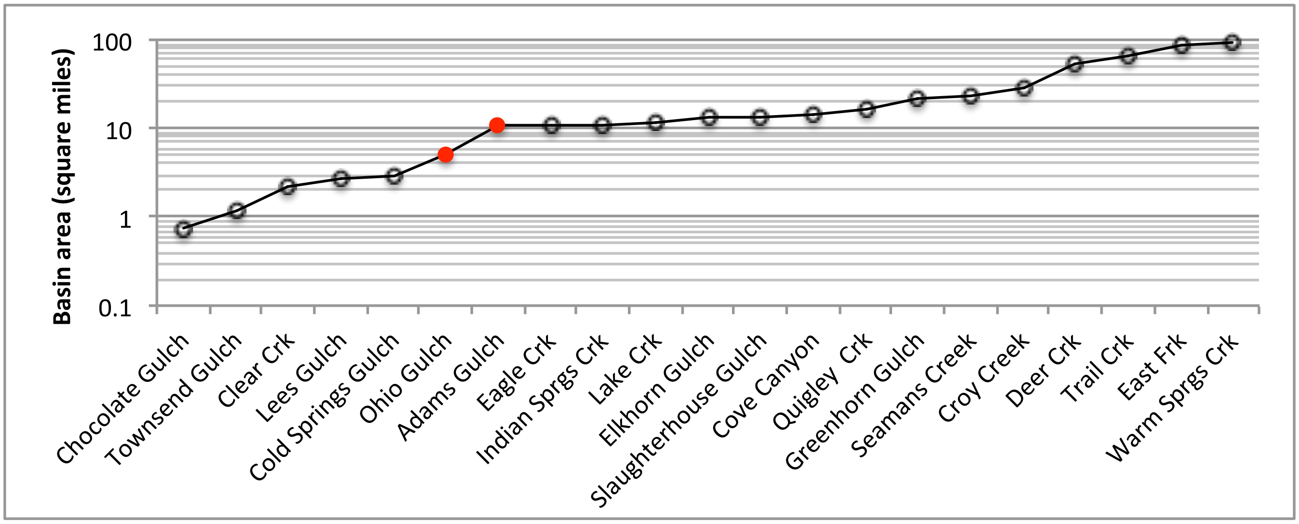

Figure 2. Basin area (square miles) in ascending order plotted on an exponential Y-axis. Note the break in slope between Ohio Gulch (5.1 mi^2) and Adams Gulch (11 mi^2).

The mean of the ratio for the 16 large tributaries (larger than 11 mi^2) was then calculated yielding a value of 0.05. This mean ratio was then multiplied by to the StreamStats derived precipitation volume for each of the 6 small tributaries (less than 11 mi^2) to determine the volumetric flux for each, expressed by equation 5:

$$\bar{Q}_{tribsmall} = \bar{R}_{triblarge} \times P_{tribsmall} \tag{5}$$

$\bar{Q}_{tribsmall}$ is the estimated mean volumetric flux to the model from tributary *trib*, smaller than 11 mi^2 in length^3/time units,

$\bar{R}_{triblarge}$ is the mean ratio of volumetric flux to annual precipitation volume for tributaries larger than 11 mi^2, dimensionless, and

$P_{tribsmall}$ is the estimated mean volumetric flux to the model from for tributary *trib*, smaller than 11 mi^2 in length^3/time units.

Henceforth, the nonadjusted values for $\bar{Q}_{triblarge}$ and adjusted values for $\bar{Q}_{tribsmall}$ will be referred to as $\bar{Q}_{trib}$.

As an alternative to the Darcian approach the specification of tributary basin underflow of flux by a constant head boundary in the groundwater-flow model was considered. Heads could be specified using groundwater levels measured in 2006 or 2012, however this approach was judged to be a poor representation of volumetric flux from tributaries.

Temporal variation of tributary basin underflow with the seasonal scaling index ($SI_{trib,i}$)

The seasonal index is typically the ratio between short and long-term means of a proxy such as precipitation or stream discharge. Hsieh and others (2007) applied a similar “scaling index” to apportion tributary basin underflow for the Spokane Valley-Rathdrum Prairie groundwater-flow model.

The most obvious basis for a seasonal scaling index are groundwater-levels in wells in each of the tributary canyons. However, pumping effects and the dearth of wells with continuous water-level measurements during the model period make this approach impracticable. Precipitation data were also considered as a basis for calculating a seasonal index but were rejected for three reasons: (1) only two weather stations in the Wood River Valley have sufficient data to make such an estimate, (2) these stations likely do not represent conditions in the higher elevations of the tributary valleys, and (3) snowmelt and infiltration may occurs several months after the precipitation falls as snow thus requiring another adjustment. Weather data were used to adjust the timing of precipitation and snowmelt for areal recharge in the WRV groundwater-flow model (McVay, 2014), but surface elevations range over only1,400 ft within the model domain. Because elevations in tributary canyons may range over 6,400 ft, with large variability between tributaries, existing weather data is not likely to adequately represent conditions in the tributaries.

Stream discharge integrates the various components of streamflow for all of the tributary basins above the streamgage and thus captures the timing of both precipitation and snowmelt (although detailed spatial and temporal resolution is sacrificed). Because discharge data provide a reasonable representation of the timing and amount of precipitation and snowmelt above the streamgage it can serve as a basis for the calculation of a seasonal scaling index. Additionally, streamgages often provide a long-term continuous record often lacking in meteorological data from small weather stations.

The Big Wood River at Hailey (13139510) streamgage was chosen as a basis for temporal variation because it has continuously recorded discharge data for the entire model period. The record at Hailey goes back to 1915 making it the oldest continuously operated streamgage in the Wood River Valley. Of the 22 tributary basins for which tributary basin underflow were calculated, 15 are up-valley from the streamgage including the five largest. The only upstream irrigation diversion large enough to significantly affect the flow is the Hiawatha Canal.

Monthly mean discharge at the Hailey streamgage from January 1994 to December 2010 was retrieved from the USGS NWIS (USGS, 2014) (Fig. 3). (Data for 1994 were retrieved for use in calculation of a moving average, described below.) This record shows extreme variability, sometimes with large month-to-month fluctuations. Because the conceptual model of tributary basin underflow described above suggests that the processes of infiltration and groundwater movement both integrate and lag specific recharge events, a process is needed to incorporate this before the scaling seasonal index can be calculated.

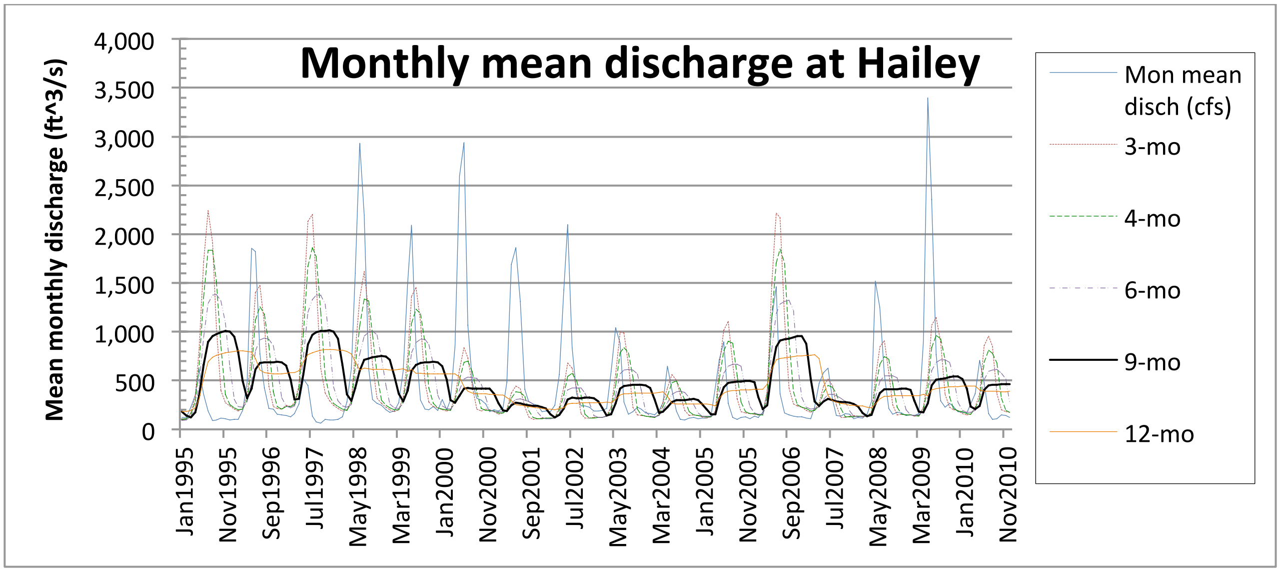

Figure 3. Monthly mean discharge at the Big Wood River at Hailey (13139510) streamgage and moving averages of discharge with windows of selected lengths, 1995-2010.

Initially, monthly mean discharge was averaged into quarterly (or seasonal) mean discharge to avoid large month-to-month changes and to integrate and lag specific recharge events (as described in the previous paragraph). This quarterly mean discharge still displayed quarterly variability greater than that suggested by the conceptual model. Therefore, a simple moving (or running) average of the monthly mean discharge was investigated. The moving average was calculated using monthly mean discharge for different periods (of a specified number of months preceding and including a given month). Windows (or periods) of 3, 4, 6, 9, and 12 months were calculated; results are shown in figure 3. A 9-month window was chosen as the best compromise between timing and magnitude of monthly mean discharge. Because the window was chosen to incorporate discharge for a given month and preceding eight months, it has the effect of integrating recharge events in accordance with the conceptual model of tributary basin underflow described above. After the monthly mean discharge was calculated using a 9-month window, monthly mean discharge was aggregated into quarterly (or seasonal) mean discharge for each of the 64 quarters encompassing the 1995-2010 model period.

Because the moving average is considered a type of data smoothing or filtering, monthly mean discharge calculated with the 9-month moving average will henceforth be referred to as smoothed mean discharge.

Seasonal Scaling Index

Once the moving average was applied to discharge at the Hailey streamgage and aggregated into quarters the seasonal scaling index was calculated. The seasonal scaling index was calculated by dividing the smoothed quarterly mean discharge by the smoothed mean discharge of all 64 quarters in the model simulation period. The calculation of the seasonal scaling index is presented in Equation 6:

$$SI = \frac{D_{sqm}}{D_{spm}} \tag{6}$$

where

SI is the seasonal scaling index, dimensionless,

D_{sqm} is smoothed quarterly mean discharge at the Hailey streamgage in length^3/time units, and

D_{spm} is smoothed mean discharge at the Hailey streamgage for the model simulation period, in length^3/time units.

Figure 4 and Table 2 show the seasonal scaling index for each quarter of the model simulation period. Seasonal scaling index values range from 0.32 to 2.2 and represent 32 to 220 percent of the smoothed mean discharge for the model simulation period.

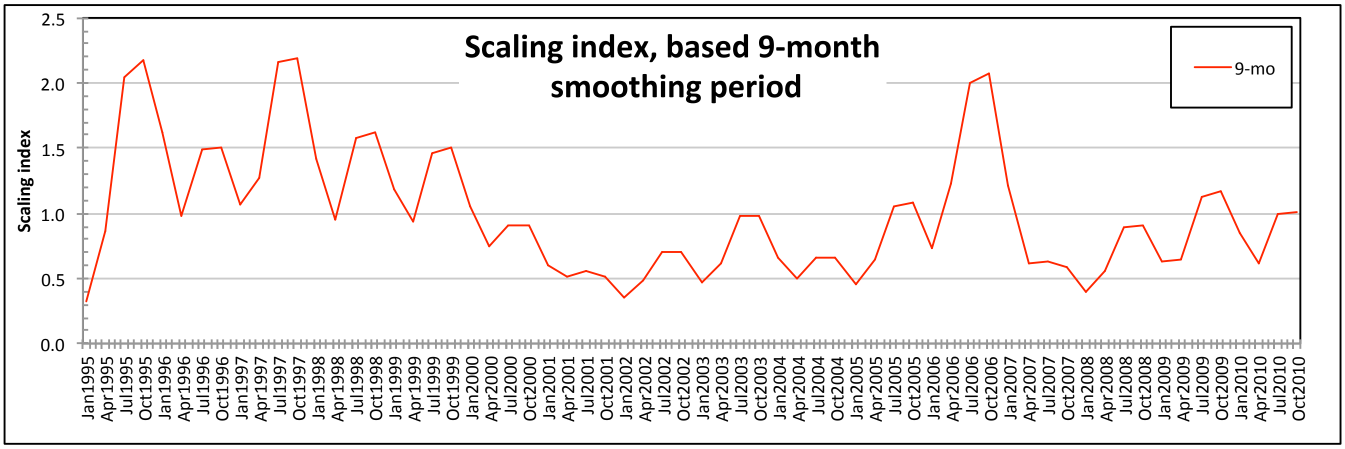

Figure 4. Seasonal index by quarter, 1995-2010.

Table 2. Seasonal scaling index by quarter, 1995-2010.

Quarter	Seasonal index	Quarter	Seasonal index	Quarter	Seasonal index	Quarter	Seasonal index
Jan1995	0.32	Jan1999	1.2	Jan2003	0.47	Jan2007	1.2
Apr1995	0.86	Apr1999	0.93	Apr2003	0.61	Apr2007	0.61
Jul1995	2.0	Jul1999	1.5	Jul2003	0.98	Jul2007	0.63
Oct1995	2.2	Oct1999	1.5	Oct2003	0.99	Oct2007	0.59
Jan1996	1.6	Jan2000	1.1	Jan2004	0.65	Jan2008	0.39
Apr1996	0.98	Apr2000	0.75	Apr2004	0.50	Apr2008	0.56
Jul1996	1.5	Jul2000	0.91	Jul2004	0.65	Jul2008	0.89
Oct1996	1.5	Oct2000	0.91	Oct2004	0.66	Oct2008	0.90
Jan1997	1.1	Jan2001	0.60	Jan2005	0.45	Jan2009	0.63
Apr1997	1.3	Apr2001	0.51	Apr2005	0.64	Apr2009	0.65
Jul1997	2.2	Jul2001	0.56	Jul2005	1.0	Jul2009	1.1
Oct1997	2.2	Oct2001	0.51	Oct2005	1.1	Oct2009	1.2
Jan1998	1.4	Jan2002	0.35	Jan2006	0.74	Jan2010	0.84
Apr1998	0.96	Apr2002	0.49	Apr2006	1.2	Apr2010	0.62
Jul1998	1.6	Jul2002	0.70	Jul2006	2.0	Jul2010	0.99
Oct1998	1.6	Oct2002	0.70	Oct2006	2.1	Oct2010	1.0

Parameterization for PEST calibration

Given the uncertainty in tributary basin underflow estimates, they will be evaluated during model calibration using the parameter estimation program PEST (Doherty, 2004). For calibration, 23 estimation parameters will be defined in PEST: estimated mean tributary basin underflow for 22 tributaries and a single reduction factor to vary the amplitude of the seasonal scaling seasonal index through the model simulation period.

A stream hydrograph is a type of digital signal in the time domain because it consists of discrete measurements of discharge (the dependent variable) over time (the independent variable). A low-pass filter reduces the amplitude of the hydrograph (bringing high and low values closer to the mean) but leaves the mean the same. Thus the application of a low-pass filter for signal amplitude reduction allows tributary recharge to be varied with a single parameter.

The single amplitude reduction algorithm chosen (McCoy, 2011) dampens the quarterly mean discharge before it is used to calculate the seasonal index. The amount of amplitude reduction/damping is controlled by a reduction factor which must be greater than or equal to 1. A reduction factor of 1 does not change the quarterly mean discharge; thus damping is applied when the reduction factor is greater than 1 and the amount of damping increases with the reduction factor.

The single amplitude reduction algorithm is implemented in two steps. The first, shown in equation 7, calculates a temporary signal:

$$TS = \frac{D_{sqm}}{RF} \tag{7}$$

where

TS is the temporary signal, in length^3/time units,

D_{sqm} is smoothed quarterly mean discharge at the Hailey streamgage in length^3/time units, and

RF is the reduction factor, dimensionless.

The single amplitude reduction is then calculated with the temporary signal (equation 8):

$$SAR = D_{spm} - TS_m + TS \tag{8}$$

where

SAR is the single amplitude reduction, in length^3/time units,

D_{spm} is smoothed mean discharge at the Hailey streamgage for the model simulation period, in length^3/time units,

TS is the temporary signal, in length^3/time units, and

TS_m is the mean temporary signal for the model simulation period, in length^3/time units.

Once the damped quarterly discharge has been calculated, the seasonal scaling index is calculated as described in the previous section. Figure 5 shows the seasonal scaling index with selected values of the reduction factor.

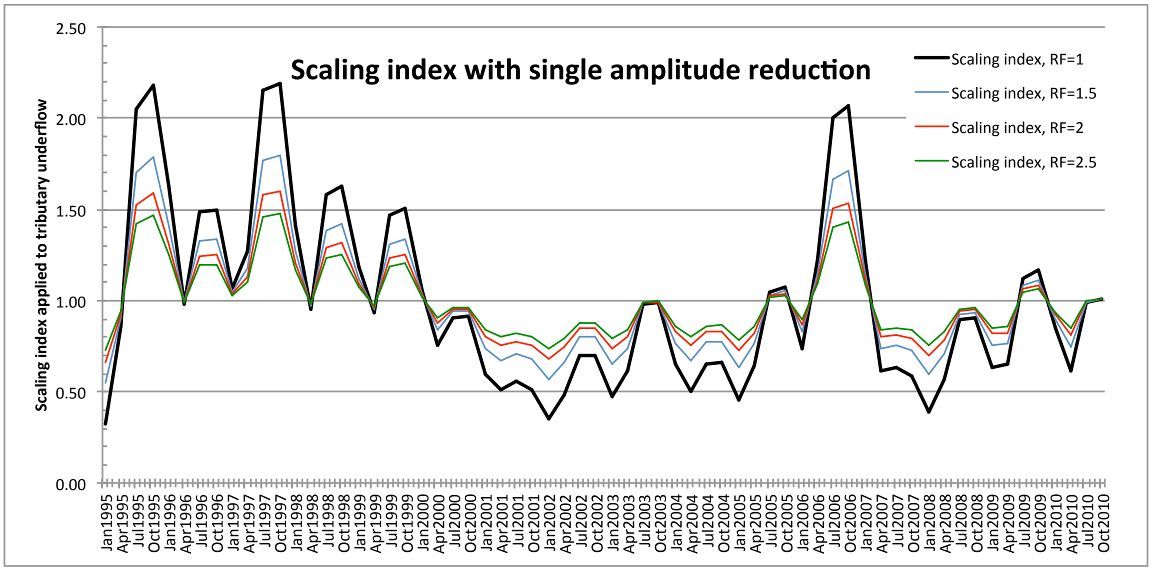

Figure 5. The seasonal index with single amplitude reduction at selected values of the reduction factor.

During steady-state calibration PEST will be allowed to adjust the estimated mean tributary basin underflow for 22 tributaries. During the transient calibration the 22 mean tributary basin underflow values and the reduction factor will be allowed to vary. In addition, PEST will be allowed to adjust the length of the moving average window.

Summary

Mean underflow into the Wood River Valley aquifer system from 22 tributary valleys is estimated with the Darcy equation and estimates of saturated cross-sectional area and water-table gradients. Underflow from the smallest tributary valleys is estimated as a fraction of basin yield determined from an analysis of the ratio of estimated flux to basin yield in larger tributaries. These estimates of tributary basin underflow are then adjusted to represent seasonal variation on the basis of the monthly mean discharge at the Big Wood River at Hailey streamgage. A 9-month moving average is applied to the mean monthly discharge values from which a seasonal scaling index is calculated. During steady-state calibration PEST will be allowed to vary the estimated mean tributary basin underflow for 22 tributaries. During the transient calibration the 22 mean tributary basin underflow values and the reduction factor will be allowed to vary.

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