SNAKE RIVER PLAIN AQUIFER MODEL SCENARIO:

HYDROLOGIC EFFECTS OF CHANGES IN SURFACE-WATER IRRIGATION

"No Surface-water Changes Scenario"

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INTRODUCTION

This scenario, *Hydrologic Effects of Changes in Surface-water Irrigation Practices* (also known as the No Changes in Surface-water Practices Scenario), is one of many simulations using the Snake River Plain aquifer model to provide information and assist in resolution of conflicts among water right holders and guide future water management such as implementation of managed recharge. Water management should be guided by a collective perspective, using many of the scenario evaluations rather than a single document.

The present version of the Snake River Plain aquifer model was developed with funding provided by the State of Idaho, Idaho Power Company, the U.S. Geological Survey, and the U.S. Bureau of Reclamation. The model was designed with the intent of evaluating the effects of land and water use on the exchange of water between the Snake River Plain aquifer and the Snake River. This evaluation is part of the application of the model towards this purpose.

The model was developed by the Idaho Water Resources Research Institute (IWRRI) under the guidance, and with the participation of, the Eastern Snake Hydrologic Modeling Committee (ESHMC). The effort was led by the Idaho Department of Water Resources (IDWR) and active participants in the Committee included Idaho Power Company, the U.S. Geological Survey, the U.S. Bureau of Reclamation, and IWRRI. The ESHMC has also served to guide and review the scenario evaluation process. Documentation of the model and related activities are available from the Idaho Department of Water Resources and the Idaho Water Resources Research Institute at the University of Idaho.

This “No Changes in Surface-water Practices Scenario” is intended to answer the question: “If surface-water irrigation practices had remained as they were in the 1950s, how much higher would spring discharges be today?”. This scenario is presented to *provide context* for other scenarios and allow comparison of relative magnitudes of other scenarios. Because this “No Changes in Surface-water Practices Scenario” incorporates changes in diversions that may be the direct result of ground-water development, it is not additive to other scenarios. In particular, this scenario is not additive to the Curtailment Scenario. Goals of the “No Changes in Surface-water Practices” analysis are:

1. Describe changes in surface-water diversions and consumptive use on surface-water-irrigated lands.
2. Quantify the propagation of these changes through the aquifer to the springs and river reaches.
3. Describe the uncertainty associated with estimates and assumptions used in the analysis.
4. Identify potential causes for observed changes in diversions and partition the total amount of change to these possible causes.
5. Compare the results of this scenario with other scenarios and other hydrologic studies.

Objective 5 will address the relationship of the results of this scenario to the results of the Curtailment Scenario, which deals with ground-water irrigation. Additionally, Objective 5 will compare results from this scenario with results from the Upper Snake Basin Study (IDWR, 1997). Readers are cautioned that this "No Changes in Surface-water Practices" scenario is not additive to the Curtailment Scenario because some of the changes in diversions in this scenario may be directly attributed to development of supplemental ground-water sources.

This scenario explores the hypothesis that declines in spring discharges and river gains are due, in part, to changes in irrigation practices across the eastern Snake River Plain. At the onset of surface water irrigation, incidental recharge from the gravity irrigation caused increases in aquifer water levels. The aquifer water levels reached a peak in the 1950s, at which time several practices began to change. Rural electrification and improved pump and drilling technology caused an increase in the use of ground water for irrigation, including supplemental ground-water rights on land already irrigated from surface water. At the same time (and perhaps partly as a result), total diversions of surface water decreased across the plain. This decline is also partly attributed to practices such as the lining of canals and migration from flood irrigation to sprinkler irrigation. Many irrigators enlarged their irrigated areas to make use of the increased water availability due to the increased efficiency of sprinklers. Each of these phenomena created an impact to the aquifer either in the form of increased ground-water withdrawal or decreased recharge incidental to irrigation. This scenario attempts to discern the declines in spring levels due to changes in surface water irrigation practices such as reduced diversions, conversion to sprinklers and enlargement of irrigated area.

This analysis was performed by evaluating effects from two periods: 1) a "historical period" representing the 1950s and 2) a "current period" representing the practices of the 1980 - 2002 period. Hydrologic effects at land surface were explored using historical diversion data where available, maps of irrigated lands at various points in time, estimates of current and historical evapotranspiration, and calibration-period estimates of current sprinkler percentages and return flow fractions. An assumption was made that during the historical analysis period all surface water irrigation used gravity application methods. These effects were mapped to the model grid using the GIS and Fortran recharge tools developed for use with the aquifer model.

The modeling approach was to represent current surface-water irrigation using numerical superposition, then represent historical irrigation using superposition, and, finally, to difference the model outputs of the two model runs. Representing these simulation conditions using numerical superposition means that only the recharge associated with surface water irrigation is imposed on a no-initial-gradient starting condition. The result is an estimate of the difference between today's spring discharges and the level of spring discharges that would exist today if surface-water practices had not changed (assuming today's condition can be represented as a steady-state condition).

SURFACE HYDROLOGIC EFFECTS (Objective 1)

Changes in surface irrigation practices are thought to have had various hydrologic effects on the hydrology of the eastern Snake River Plain. These changes in practices would include changes in irrigated lands, diversions, irrigation returns, canal leakage and consumptive use. To accomplish this scenario, for each of these key components, current practices and historical practices were evaluated and estimated. This section discusses the effects these changes caused to the surface hydrology. Additionally, changes in precipitation patterns would cause a change to the hydrology of the Snake River system; however, it is assumed that anthropogenic water use on the plain has had no impact on precipitation on irrigated lands.

Determination of Irrigated Lands

From inspection of USGS maps of irrigated lands for 1945 and 1966 (Goodell 1988), in conjunction with model calibration-period (1980-2001) maps of irrigated lands and aerial photographs, it appears that the calibration-period maps had finer resolution and used more accurate representation of small areas of non-irrigated inclusions within irrigated lands. It also appears that on a broad scale, very little surface-water irrigation has been developed since 1966.[1] Due to the similarity of present surface-water irrigated land to 1966 conditions, this scenario used an irrigated-lands map based on the calibration-period map (with a few deletions) to represent both the historical and current periods. The original map is available from the IDWR web site as SNAKLC92.shp and was based on 1987 aerial photos which were land-truthed by Idaho Department of Water Resources and U.S. Bureau of Reclamation. The irrigated lands are subdivided into "irrigation entities," which are groups of one to several canal companies and nearby lands irrigated with private water rights. An irrigation entity is the smallest geographic region that can be associated with a unique combination of diversions and return flow conditions.

Based on the difference between the 1945, 1966 and 1987 maps, and confirmed by diversion records, the upland areas of IESW012 (rolling hills east of Newdale) were removed from the map of irrigated lands because they appear to not have been irrigated in the 1950s. Description of the irrigation entities used for the Enhanced Snake Plain Aquifer Model calibration can be found in Gilliland (2003).

Additional lands were removed because of data concerns. These include:

1. Entities IESW031 (part of Fremont-Madison Irrigation District near Ashton) and IESW041 (Twin Falls Southside Canal Company). Nearly all the lands of these entities lie outside the model boundary, and our knowledge of historical and current practices in the portions outside the model is limited.
2. Dewey Canal (IESW015), west of the Henrys Fork near Ashton. These lands were irrigated historically, but are currently a wildlife refuge. Changes on these lands are not representative of the changes in practice that this scenario seeks to evaluate.

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[1] This is in contrast to ground-water development, which continued through the 1980s.

3. Entities IESW020 and IESW035 in the Rigby Fan area. In the 1950s these entities were in the Willow Creek water district and their historical volumes are omitted in the historical data from IDWR. Because current diversions include storage releases from Ririe Dam, historical diversions cannot be extrapolated from current diversions. These two entities represent about 6% of the surface-water-irrigated lands in the study area. However, there has been relatively little conversion to sprinklers in this area, so the effect of this omission will be less than 6%.

Table 1 summarizes these exclusions and compares the excluded acreage to the total surface-water irrigated acreage within the study area. Excluded lands are illustrated in Figure 1.

Table 1
Lands Excluded from No Changes in Surface-water Practices Scenario
(gross acreage)

Entity	**Reason**	**Acres Excluded**	**Approximate Percent of Total**
IESW012 (upland portion)	Not irrigated in 1950s	2200	< 1%
IESW015	Data concern	1200	< 1%
IESW020	Data concern	33000	3%
IESW031	Data concern	1200	< 1%
IESW035	Data concern	30000	3%
IESW041	Data concern	3900	< 1%
Subtotal	Data concern	69300	7%
Total		**71500**	**7%**

Because the focus of this scenario is to examine the effect of changes in practice, the same irrigated lands map was used for the historical analysis and for the current analysis. It is acknowledged that there may be additional effects at the springs from surface-water irrigation that has been developed since the 1950s, but this analysis focuses on changes to the practices that were already in place during the late 1950s.

Land leveling and conversion to sprinklers allow for irrigation of more net acres within individual farm fields. This suggests that the historical simulation should use a smaller irrigated area than the current. This effect is represented in the analysis by setting the reduction for non irrigated inclusions at 17% for the historical model run and at 12% (the value used in model calibration) for the current model run, representing a net increase in surface-water irrigated lands of 5%. This adjustment is a source of uncertainty in the results. After subtracting the lands listed in Table 1, the scenario represents 816,000 net acres of surface-water irrigation in the current period and 770,000 net acres in the historic period.

Current Surface-water Diversions for Irrigation

The total volume used in the scenario for current-period diversions was 7,530,000 acre feet per year. This volume was based on the average of calibration-period diversions. Diversion data were obtained from IDWR electronic records and other sources. The diversion data for the calibration period are documented in Gilliland (2003). Diversions were omitted for the lands that were removed from the irrigated-lands data set.

Historical Surface-water Diversions for Irrigation

Under the guidance of the ESHMC, the average of 1957 through 1960 diversions was chosen to represent the historical condition. The total volume (again omitting diversions for omitted lands) was 9,370,000 acre feet per year. For the Snake River, the Big Wood River, and the Little Wood River, diversion volumes were obtained from IDWR electronic records. This automatically incorporated changes associated with the winter water savings agreement and the additional storage provided by Palisades reservoir, since those influences were not operating in the 1957 - 1960 period but were operating in the later period. The diversion files used in the calibration data set were compared entity-by-entity with diversion files available for the historical period. There were three classes of files that showed values for the current period but not the historical:

1. Small files for miscellaneous pump diversions. These do not generally represent new water rights or diversions, but transfers in point of diversion. The diversion volume for the associated lands will appear in the historical period within the diversion file representing the pre-transfer condition (Swank 2004, Swensen 2004 and Lutz 2004).
2. Diversions associated with Willow Creek. As discussed above, these are associated with omitted entities IESW020 and IESW035. Because current diversions include storage releases from Ririe Dam, they cannot be used to estimate historical diversions (Swank 2004).
3. Burgess Canal. This is a diversion that would have been operational in the 1950s, but it has a small enough diversion rate that apparently records were not kept at that time (Swensen 2004). Because there has been no change in upstream conditions, the historical diversion for that canal was estimated from current diversions and added to the historical diversions from electronic data.

A selection of individual diversion records was examined more carefully to understand historical changes in diversion volume. Figure 2 illustrates a typical pattern. Figure 3 illustrates the pattern for Osgood (IESW033, northwest of Idaho Falls). Diversion data for this entity support a hypothesis that in some cases, additional ground-water supplies were developed along with conversion to sprinklers. No data exist to prove this hypothesis; however the dramatic reduction in surface water diversions with no apparent reduction in irrigated area implies that additional ground-water supplies may have been developed.[2] The historical diversion data were used in this analysis without adjustment

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[2] The observed change is too great to be explained solely by conversion to sprinklers.

because they reflect changes that actually occurred in connection with changes in surface-water practice.

Historical data were not readily available for entities supplied by streams other than the Big and Little Wood Rivers or the Snake River. Since none of these entities have had significant changes in upstream storage or conditions, average calibration-period diversions were used. Figure 4 shows the ratio of historical to current diversions used for all entities.

Irrigation Returns

Irrigation return data have not historically been measured or recorded. Some isolated attempts at estimating irrigation returns have been made, however neither the current nor historical levels of irrigation returns are well known. For the Enhanced Snake Plain Aquifer Model project, 44 sites were instrumented to collect two years of return flow data. Additionally, some irrigation returns were measured in the mid 1980s by IDWR. Few data exist prior to the 1980s, however.

Rational arguments can be made for the hypothesis that return flow fractions should have increased and for the hypothesis that they should have decreased with changes in practice. Data are inadequate to provide guidance as to which hypothesis may be correct. Under the guidance of the ESHMC, the decision was made to use the average return flow fractions from the calibration period to calculate returns for both the current and historical period. For the two entities where return flow data exist, the data were used. The total volume of returns used for the current period was 1,070,000 acre feet per year and for the historical period 1,250,000 acre feet per year was used.

Canal Leakage

Changing the representation of canal leakage would change the spatial distribution of recharge to the aquifer but not the total volume of recharge. Because of this fact and the fact that only limited historical data on canal leakage are available, the average canal leakage percentages from the calibration period were applied both to current and historical simulations. In the modeling data sets, only large canals distant from irrigated lands have an explicit representation of canal leakage. For other canals, the calculation methods apply the canal leakage as part of general irrigation recharge, uniformly across the irrigated lands. For estimates of the actual volume and change in canal leakage, see the uncertainty discussion below.

Evapotranspiration

The three components of evapotranspiration (ET) calculation within the recharge tools are reference ET, crop coefficient, and ET adjustment factor (Contor, 2003b). Reference ET and crop coefficient are combined in the ET rasters in the recharge data. The crop coefficient is a function of the crop mix in each county and the basic coefficients for individual crops. The basic crop coefficient is a function of physiological properties and cultural practices. Unique ET adjustment factors can be applied to sprinkler lands and gravity lands within each irrigation entity.

Current Evapotranspiration. The current-period simulation was represented using an average of the calibration-period ET raster (which combines the influences of reference ET, crop mix and crop coefficient). Calibration-period ET adjustment factors (1.05 for sprinklers, 1.00 for gravity, for all entities) and the 2002 sprinkler percentages were used. The resulting estimate of ET was 2,410,000 acre feet per year on surface-water irrigated lands.

Historical Evapotranspiration. It was assumed that average reference ET, which is a function solely of climate, would be the same for the historical period as for the current period. An attempt was made to use historical crop data and knowledge of changes in cultural practices to set an appropriate average historical crop coefficient, but available data were not adequate (Allen 2004). Instead, the historical simulation used an ET raster that was 95% of the average raster used for the current-period simulation. All sprinkler percentages were set to zero, so in the historical simulation all ET multipliers used for individual irrigated parcels were 1.0. The contribution of these assumptions to uncertainty in results is discussed below. The combined estimate for historical ET was 2,080,000 acre feet per year on surface-water irrigated lands.

Precipitation on Irrigated Lands

For both current and historical simulations, the 1961-1990 PRISM average precipitation was used (Daly and Taylor 2001). It is acknowledged that long-term trends and cycles may exist in the climate, but the purpose of this scenario was to assess anthropogenic changes. While the same precipitation map was used, precipitation was represented on a different total irrigated acreage because of different reductions for non-irrigated inclusions. The scenario used 762,000 acre feet of precipitation on irrigated lands for the current period and 718,000 acre feet of precipitation on irrigated lands for the historical period.

Comparison of Net Recharge

The net recharge in the historical period is 6,730,000 acre feet per year. The current-period net recharge is 4,810,000 acre feet per year. The relative magnitudes of the components of recharge are illustrated in Figure 5. Figure 6 shows the spatial distribution of net recharge to the aquifer for the historic surface water irrigation represented in this scenario. Figure 7 shows the distribution of net recharge to the aquifer for the current surface water irrigation and Figure 8 shows the difference in net recharge between historic and current surface water practices. Inspection of Figure 8 shows that, for the most part, incidental recharge to the aquifer has been reduced due to changes in surface water irrigation. However, red-colored areas in Figure 8 indicate that some areas of the eastern Snake River plain actually have experienced increases in net recharge. These are areas where surface-water diversions in the current period are significantly greater than in the historic period. The current-period net recharge is 1,910,000 acre feet per year less than the historic-period recharge. This is equivalent to an annualized rate of 2,639 cfs. This estimate is rounded to 2,600 for reporting purposes.

PROPAGATION OF EFFECTS TO SPRINGS AND RIVER REACHES (Objective 2)

Modeling Approach

The surface hydrology impacts described above were applied as a repeating annual stress (with two stress periods per year) in a transient numerical superposition model run, and as an average stress in a steady-state numerical superposition run. The numerical superposition model is described in the Curtailment Scenario report (Contor and others, 2004). The steady-state results show the final impact to the springs after all changes in aquifer storage have stabilized. The transient numerical superposition model that was used to calculate the seasonal effects for this scenario represented 300 stress periods of six months, each with 3 time steps. The transient model was only used to predict the seasonal variation in spring and river impacts in late time. Because recharge data do not represent the evolution over time of changes to surface water practices, the transient results from this scenario are meaningless except to show how the seasonal effects oscillate around steady state in late time.

This modeling approach involved differencing of results from two numerical superposition model runs. A steady state and transient run were completed for the current-period data and for the historical-period data. For each river or spring reach, the difference between the current simulation and historical simulation was calculated, for transient and steady state. Figure 9 shows the location of the modeled reaches.

Modeling Results

There are two primary sets of scenario modeling results: a) steady state results which show the effects of changes in surface water practices after a long period of time, and b) transient results which predict seasonality of these impacts to river and spring gains and losses. As previously stated, the recharge data include no representation of the timing of changes to surface water practices, so display of transient impacts due to these changes would be meaningless and perhaps prone to misinterpretation.

<u>Steady State Results.</u> Table 2 summarizes the steady state results. Negative values in the first column suggest a decrease in net gains or discharge, or an increase in net losses. Negative values in the second column suggest a losing reach and positive values suggest a gaining reach. For example, looking at the Thousand Springs sub-reach in Table 2, the modeled discharge is 1,760 cfs and changes in surface water practices are predicted to have caused a 134 cfs decline. The 134 cfs represents the difference between the theoretical flows that would be associated with steady-state realization of the 1957-1960 conditions and the steady-state realization of the 1980-2002 conditions. In reality, both simulations are “snapshots” taken during periods of dynamic change, so it is possible that neither data set represents a stress that was fully expressed at the springs. Further, the reader should keep in mind that data do not exist to fully describe the timing of these changes in surface water practices, so it is possible that impacts from recent changes in surface water irrigation practices have not yet been fully expressed in the river gains.

Table 2.
Steady-state Results
for No Changes in Surface-water Practices Scenario.

Location	**Modeled Impact of changes in Surface Water Practices (cfs)**[3]	**Modeled Average Reach Gain (calibration period) (cfs)**	**Magnitude of changes as a percentage of discharge magnitude**
Ashton to Rexburg	-392	205	190%
Heise to Shelley	-213	-490	44%
Sum of Reaches Above Shelley	**-605**	**-285**	**210%**
Shelley to Near Blackfoot	-294	-360	82%
Near Blackfoot to Neeley	-645	2222	29%
Neeley to Minidoka	-76	28	270%
Sum of Reaches Shelley to Minidoka	**-1015**	**1890**	**54%**
Sum of Reaches above Milner	**-1620**	**1645**	**98%**
Devil's Washbowl to Buhl	-465	969	47%
Buhl to Thousand Springs	-212	1578	13%
Thousand Springs	-134	1760	8%
Thousand Springs to Malad	-18	77	23%
Malad	-157	1191	13%
Malad to Bancroft	-34	100	34%
Sum of Milner to King Hill Reaches	**-1019**	**5676**	**18%**
Sum of All Reaches	**-2639**	**7281**	**37%**

Gains (or losses) in the second column are based on the average of the gains predicted by the ground water model for the 22-year calibration period. The average modeled gains were used because measured data are not available for all comparable reaches in the Thousand Springs area. The third data column of Table 2 shows the magnitude of predicted changes as a percentage of the magnitude of average reach gains.

The reader will note that, particularly in some of the upper Snake River reaches, the change in gains associated with changes in surface-water practices are large relative to the magnitude of current gains. This implies that surface irrigation is an important driver of the hydrology of the eastern Snake River plain and that current hydrology is significantly altered from the pre-development condition.

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[3] Values may not sum exactly, due to rounding.

Also apparent in Table 2 is the fact that the impacts in the Thousand Springs area tend to be higher in the eastern portion of the reach and lower in the western portion of the reach. Further, impacts to the eastern reaches of the Snake River are generally greater than to the reaches in the Thousand Springs area. Looking at Figure 8, it is clear that the center of mass of the applied stress is located to the east of the Thousand Springs area, which makes this outcome reasonable.

Transient Seasonality. The seasonal nature of surface water irrigation would imply that impacts due to changes would also have an associated seasonality. Figures 10-20 show the seasonality of modeled effects on each of the reaches. The steady state results are also noted on Figures 10-20, shown as an 'X'. The reader will note that in all cases the seasonal swings oscillate around the steady state impact. For example, in Figure 10, the impacts due to changes in surface water practice ranges between -300 cfs and -475 cfs, oscillating around the steady state solution of -392 cfs. Values are "surface-water centric;" a negative value indicates a *decrease* in spring discharge or reach gain (or an increase in reach loss). The water years of the simulation start in May in each case. For most of the reaches, Figures 10-20 show the magnitude of the impact increasing between May and October, then diminishing from November through April, in concert with the irrigation season. The original surface-water irrigation provided most of its benefits during the summer, and a decrease in these benefits also manifests itself mostly in the summer. Figure 21 shows the response at the Thousand Springs sub-reach of a single-year stress. Most of the response is early in the first year. Superimposing a repeated series of subsequent stresses dampens some of the amplitude seen in Figure 21, but the seasonal pattern is still apparent. Varying amplitudes of seasonality in Figures10 through 20 reflect the shapes of the single-year responses. A lower peak and more pronounced residual tail result in a more dampened response. This corresponds to reaches more hydraulically distant from locations of aquifer stress.

The reader is cautioned that the seasonal shape is influenced by stress-period length and time-step selection in the modeling runs. The general result of higher summertime and lower wintertime impact of change is valid, but the exact timing of the peak and the shape of the hydrograph may be artifacts of model structure.

There is almost no seasonality in Figure 14 (Neeley to Minidoka reach). This appears to be due to the dampening effects of low river-bed conductance and the distance of the reach from modeled stresses. Figure 22 shows the response at the Neeley to Minidoka reach of a single year stress. In comparison with Figure 21 (Thousand Springs sub-reach), the peak impact is delayed by three or four years and the residual impact in later years is more pronounced (note the difference in horizontal time-series scale). Figure 22 also shows a small, immediate positive response from the area of increased recharge shown in Figure 8, which is very near to the Neeley to Minidoka reach. When multiple years are superimposed, however, this small immediate positive impact is overcome by the residual negative impact from earlier years' stresses.

UNCERTAINTY (Objective 3)

The resulting steady-state reach gains of this scenario are the difference between two steady-state numerical superposition runs, one for the historical condition and one for the current condition. Overall uncertainty of a sum or difference may be estimated by considering the uncertainty of its components. When components are combined, the uncertainty of the combination depends on the variance of the individual components and the covariance between components.

Water budget components

The water budget for each run includes the following components:

1. Net diversion volume
    a) Gross diversion volumes.
    b) Return flow fractions.
2. Net consumptive use

Because the scenario is evaluated using the difference of two model runs, the net change in recharge is calculated as:

$$\text{Change} = (\text{Div}_{\text{historic}} - \text{CU}_{\text{historic}}) - (\text{Div}_{\text{current}} - \text{CU}_{\text{current}}) \qquad \text{(eq. 1)}$$

where $\text{Div}_{\text{historic}}$ and $\text{Div}_{\text{current}}$ are net diversion volumes for the respective periods, and $\text{CU}_{\text{historic}}$ and $\text{CU}_{\text{current}}$ are net consumptive use volumes.

The model runs do not change the water-budget calculation, but simply distribute the net recharge spatially among the reaches. By expressing net diversions as the difference between gross diversions and total return flows, and re-ordering terms, equation (1) may be rearranged as:

$$\begin{aligned}\text{Change} = {} & (\text{GrossDiv}_{\text{historic}} - \text{GrossDiv}_{\text{current}}) \\ & - (\text{Ret}_{\text{historic}} - \text{Ret}_{\text{current}}) + (\text{CU}_{\text{historic}} - \text{CU}_{\text{current}}) \qquad \text{(eq. 2)}\end{aligned}$$

This does not change the calculation, but makes consideration of uncertainty more straightforward.

Estimation of uncertainty

The variance of a sum (or difference) may be calculated using the following formula (Clemens and Burt 1997):[4]

$$s_0^2 = s_1^2 + s_2^2 + 2\, s_{12} \qquad \text{(eq. 3)}$$

where s_0 = standard deviation of the sum
s_0^2 = variance of the sum
s_1 = standard deviation of the first component
s_2 = standard deviation of the second component

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[4] Notation altered

s_{12} = covariance between the two components

Using the definitions of covariance (Ott 1993) and correlation coefficient (Snedecor and Cochrane 1980), this may be expressed as:

$$s_0^2 = s_1^2 + s_2^2 + 2\, r\, s_1\, s_2 \qquad \text{(eq. 4)}$$

where r = correlation coefficient between the two components

Possible values for the correlation coefficient range between -1 (perfect negative correlation) and + 1 (perfect positive correlation). The correlation coefficient may be estimated subjectively using understanding of physical relationships. Standard deviations of components may be estimated as 1/4 of the range of expected observations. The range of interest is the range based on uncertainty in the measurement methods. Random uncertainties are reduced by averaging many observations during the four-year historical period or the twenty-two-year current period, but systematic under- or over-estimation is not reduced by averaging multiple observations.

Based on the measurement and estimation methods used and the possibility of systematic disturbances, the uncertainty of the change in gross diversions is assumed to be plus or minus ten percent, giving a range of 360,000 acre feet per year and a standard deviation estimate of 90,000 acre feet.

Because returns are based on estimated return-flow fractions as well as diversion measurements, the uncertainty will be higher than for diversions. Uncertainty is assumed to be plus or minus fifty percent. This gives a range of about 200,000 acre feet per year and a standard deviation of 50,000 acre feet per year. An estimated correlation coefficient of 0.50 between gross diversions and returns recognizes that returns are calculated from diversions, but that a large part of the uncertainty in returns is in the return flow fractions, which were estimated independently of the methods used to measure diversions.

The change in consumptive use is driven by estimated changes in overall evapotranspiration (ET) rates and the estimated adjustment factor for sprinkler ET in the current period. The estimated uncertainty of the change in ET is plus or minus 100%, or 280,000 acre feet per year. This gives an estimated standard deviation of 70,000 acre feet per year. Because ET is estimated using completely different methods than diversions or returns, the correlation coefficient between consumptive use and the other components is assumed to be zero.

Additional uncertainty is introduced by the assumption that 5% enlargement of irrigated area occurred between the historical and current periods.

Calculation of estimated standard deviation
Applying equation (4), the variance of change in net diversions may be estimated as:

$$(90{,}000)^2 + (50{,}000)^2 + (2)\,(0.5)\,(90{,}000)\,(50{,}000) = 1.5\text{ E }10 \qquad \text{(eq. 5)}$$

The standard deviation is the square root of 1.5 E 10, or 120,000 acre feet per year (170 cfs).

Using the results of calculation (eq. 5) and the estimated standard deviation for change in consumptive use, the next incremental calculation of variance is:

$$(120{,}000)^2 + (70{,}000)^2 + (2)\,(0)\,(120{,}000)\,(70{,}000) = 1.9\text{ E }10 \qquad \text{(eq. 6)}$$

The standard deviation is the square root of 1.9 E 10, or 140,000 acre feet per year.

The 5% adjustment for enlargement of irrigated area is roughly equivalent to the change suggested by the scaling applied to ET, and is probably as uncertain. The enlargement adjustment is not additive in the calculations, so equation (4) does not strictly apply. However, equation (4) does compensate for the fact that it is highly unlikely that all factors would simultaneously be at extreme values. Acknowledging that it is not strictly in accordance with theory, an additional uncertainty of 70,000 acre feet per year is combined with the previous estimate of 140,000 acre feet per year from calculation (eq. 6):

$$(140{,}000)^2 + (70{,}000)^2 + (2)\,(0)\,(140{,}000)\,(70{,}000) = 2.5\text{ E }10 \qquad \text{(eq. 7)}$$

The resulting standard deviation is 160,000 acre feet per year, equivalent to 220 cfs. The 90 percent confidence interval from the standard normal distribution may be obtained by calculating plus or minus 1.65 standard deviations. Therefore, the estimated 90 percent confidence interval for the changes represented in this scenario is 2,600 cfs plus or minus 400 cfs. Table 3 summarizes the partition of the 2,600 cfs to the components of the recharge calculation.

Table 3
Partitioning of Change in Recharge
From 1957-1960 Period to 1980-2001 Period.

Component	**Estimate of effect (cfs)**	**Estimate of standard deviation**	**Estimate as percentage of total change (estimate/-2,600 cfs)**
Change in net diversions	-2,250	170	86%
Change in consumptive use	-390	165	14%
Combined	**-2,640 (rounded to -2,600)**	**220**	**100%**

PARTITIONING OF CHANGES IN DIVERSIONS (Objective 4)

Of the 2,600 cfs of impact represented by this scenario, 2,250 cfs is associated with a decrease in net diversions. Possible reasons for change in diversions include:

1. Reduction in winter diversions.
2. Changes in canal leakage.
3. Additional reliance on ground water on mixed source lands.
4. Storage water released for flow augmentation.
5. Change in percolation on lands converted to sprinkler.

A range and best approximation for each of these components may be estimated, as discussed below.

Winter Diversions

Diversions for November through March in water years 1957 through 1960 average 500,000 acre feet per year for entities that had winter-time diversions in 1957 through 1960 but not in the 1980 through 2001 period. This is an annualized rate of 690 cfs. The data appear to be estimated rather than measured; for each diversion file, the volume for a given month is identical from year to year. It is assumed that the actual rate may have differed by +/- 50% or more. Further, a change in winter diversion is not necessarily a change in total annual diversions. The water that was diverted in the winter during the historical period became water stored in Palisades reservoir during the current period. If this water is released from storage and delivered to irrigation in the summer, it is not a change in diversions, but simply a change in timing. Winter-savings water that is released past Milner (perhaps to create flood-control space) becomes a change in diversions. The lower limit is therefore zero (all of the winter-savings water is diverted for irrigation) and the upper limit is 1,000 cfs (690 cfs x 150%, none of the winter-savings water is diverted for irrigation). The actual effect is subjectively estimated at 300 cfs.

Canal Leakage

Canal-company interviews conducted during model calibration suggest no general reduction in canal leakage. This provides a lower limit of zero effect on net diversions. An upper limit is estimated by assuming that current leakage is 15% of 8,000,000 acre feet of diversions, or about 1,200,000 acre feet. If the historical leakage volume was 25% higher, the change in diversions due to reduced canal leakage could be 300,000 acre feet per year, or an annualized rate of 420 cfs. The best estimate of 100 cfs is set low to correspond with canal-company interviews and higher than zero to correspond to ESHMC guidance.

Additional Reliance on Ground Water on Mixed-source Lands

Calibration data suggest that about 350,000 acres on the plain have both surface-water and ground-water supplies. The presence of a surface-water right indicates that originally the lands had enough supply to at least establish a water right. The presence of a ground-water right suggests that the surface-water supply was inadequate. Calibration data indicate that, in current practice, the mix ratio is the equivalent of 220,000 acres of ground-water irrigation and 130,000 acres of surface-water irrigation.

A lower estimate of zero assumes that providing supplemental ground water simply allows better delivery to all irrigated lands, and that there is no net effect on diversions. An upper estimate of 1,050,000 acre feet assumes that in reality all mixed-source lands are supplied by ground water, and the equivalent surface-water field-headgate delivery volume (3 feet x 350,000 acres) is left in the river.[5] This is an upper limit of 1,500 cfs.

The best estimate is derived by assuming that the presence of wells indicates that the supply was not adequate, but the presence of a perfected surface-water right suggests the supply was nearly adequate. The original field headgate deliveries for these lands may have been 1,050,000 acre feet (3 feet x 350,000 acres). Assuming that the current condition allows adequate deliveries to the surface-water equivalent acres, current field headgate deliveries may be 520,000 acre feet (4 feet x 130,000 acres)[6]. The difference of 530,000 acre feet per year represents an annualized estimate of 730 cfs reduction in diversions due to development of supplemental ground-water supplies.

Storage Released for Flow Augmentation

IDWR data (2004) show that flow augmentation from the Upper Snake for water years 1987 through 2001 averaged 163,000 acre feet per year, or an annualized rate of 230 cfs. If this represents a shift in timing of water that would have otherwise been released for flood control (perhaps in a later year), the lower limit impact on diversions would be zero. The upper limit of 230 cfs assumes that all flow augmentation water would otherwise have been diverted to irrigation. The best estimate of 120 cfs assumes that about half the time, flow augmentation reduces subsequent irrigation diversions.

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[5] The three-foot rate (instead of the standard IDWR rate) assumes that short surface-water supplies were the driving factor for providing supplemental ground-water sources.

[6] Idaho Department of Water Resources water-right field headgate requirement for much of the study area is four feet per acre per year (2002).

Change in percolation

About 620,000 acres of surface-water supplied lands have been converted to sprinkler irrigation. Using the Farm Irrigation Rating Index Method (Klamm and Brenner 1995), the lower limit of change in percolation is a spatially-averaged reduction of 0.65 feet. Applied to the converted lands, this is 400,000 acre feet per year or an annualized rate of 560 cfs. An extreme upper limit may be calculated by assuming that sprinklers require 2.7 feet of field headgate delivery (2.1 feet of ET divided by 77% efficiency) and that gravity irrigation across the plain requires an average of 5.7 feet (2 feet of ET divided by 35% efficiency). This gives a reduction in diversion depth of 3 feet, equivalent to 1,850,000 acre feet per year or 2,600 cfs.

Not all of the changes discussed above could occur at the maximum rate; diversion data indicate that they must sum to about 2,250 cfs. Because of the wide range of uncertainty in the change in percolation value, the best estimate of 1,000 cfs for change in percolation is calculated as a residual using the 2,250 total change in net diversions and the best estimates for the other components.

For the change in percolation component, this 1,000 cfs impact implies a volume change of 724,000 acre feet per year, or a depth change of 1.15 feet.[7] Adding 1.15 feet to the sprinkler estimate of 2.7 feet gives a field headgate delivery for gravity irrigation of 3.85 feet, which compares well to the IDWR standard field headgate requirement of four feet (IDWR 2002).

Results

Table 3 (above) partitions the total change in recharge to changes in net diversions and other changes. Table 4 (below) partitions the change in net diversions to the contributing factors discussed above. The sum of components in Table 4 has a wider confidence interval than does the change in net diversions reported in Table 3. There is more confidence in the magnitude of the change in diversions (based on measurements) than there is in the partition of this change to potential causes (based on estimates). Because the calculations above were used only to *partition* the changes in diversions and not *derive* them, uncertainty in the partitioning methods does not propagate into the scenario simulation.

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[7] Assuming 620,000 acres converting to sprinklers.

Table 4
Partitioning of Observed Reduction in Diversions
From 1957-1960 Period to 1980-2001 Period.

Component	**Low estimate of effect on diversions (cfs)**	**High estimate of effect on diversions (cfs)**	**Estimated standard deviation (cfs, range/4)**	**Best estimate of effect on diversions (cfs)**	**Best estimate as percentage of total change (estimate/-2,600 cfs)**
Winter diversions	zero	-1000	250	-300	11%
Canal leakage	zero	-420	105	-100	4%
Mixed-source lands[8]	zero	-1500	375	-730	28%
Flow augmentation	zero	-230	60	-120	5%
Change in percolation due to sprinkler conversion[9]	-560	-2600	510	-1000	38%
Partition of impacts to net diversions [10]	**-1100**	**-3400**	**690[11]**	**-2250**	**86%**

Because observed changes in diversions are a result of many components, including a) changes in ground-water practice that may have influenced surface water practice and b) the probable fact that the full positive impacts of surface water irrigation had likely not been realized before the negative impacts of ground-water irrigation commenced, this scenario is not additive to the results of other scenarios. The results of Table 4 provide some guidance for partitioning the modeled changes to various possible contributing factors.

Combining the results in Table 3 with the results in Table 4, the partition of changes represented in the No Changes in Surface-water Practices Scenario is illustrated in Figure 23. While this figure gives an indication of relative magnitude, there is enough uncertainty in the partitioning that the impact of ground water on mixed-source lands, for instance, could actually be larger than the impact of changes in percolation, or smaller

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[8] This may be considered an effect of ground-water development and not an effect of surface-water-practices; had ground-water supplies not been developed, this change could not have occurred.

[9] Best estimate calculated as a residual to balance observed change in diversions.

[10] See uncertainty discussion. High and low estimates are the best estimate calculated value +/- 1.65 standard deviation.

[11] Square root of the sum of squared standard deviations, assuming independent estimation methods (equivalent to applying equation (4) with r = zero).

than the impact of changes in consumptive use. But, impacts of changes in canal leakage re most likely smaller than the effect of changes in percolation.

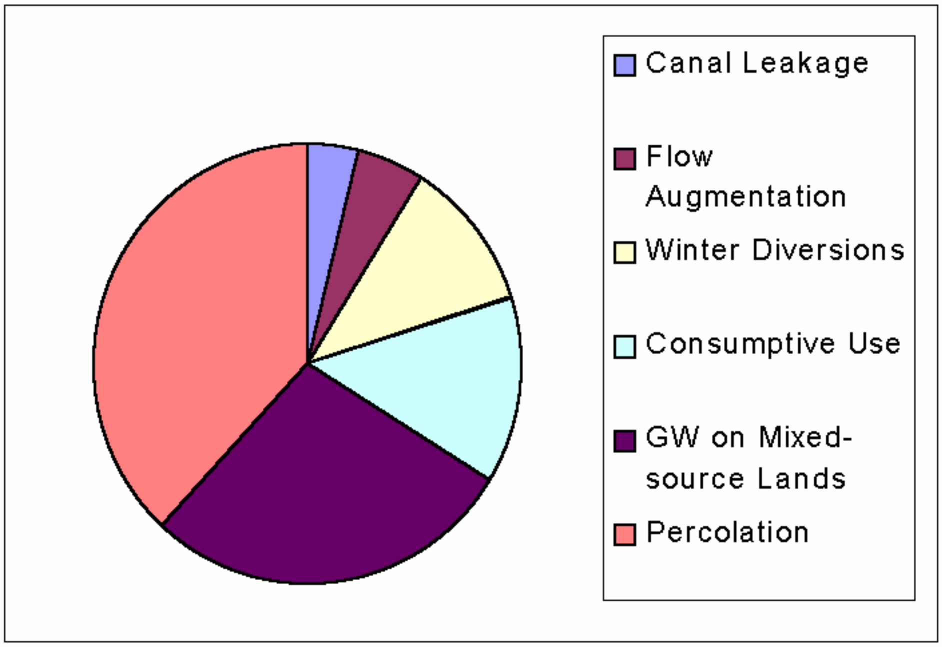

Figure 23. Partition of changes in recharge in the No Changes in Surface-water Practices Scenario.

RELATIONSHIP TO CURTAILMENT SCENARIO AND PREVIOUS STUDIES (Objective 5)

This section addresses three comparisons:

1. Comparison of the combined results of the Curtailment Scenario and the No Changes to Surface Water Practices Scenario with measured declines in the Thousand Springs area
2. Comparison of results of the Curtailment Scenario with results of a similar study published in the Upper Snake Basin Study (IDWR 1997)
3. Comparison of the total predicted impacts to reach gains from surface water irrigation and ground water irrigation with measured historical reach gains since pre-development.

The comparisons were primarily done to sense-check the results from the Curtailment Scenario and the No Changes in Surface-water Practices Scenario. Additionally, the comparisons allow for some analysis of the current hydrologic conditions in the eastern Snake River aquifer. Because the No Changes in Surface-water Practices scenario incorporates changes in diversions that may be a direct result of ground-water development, this scenario is NOT additive to the Curtailment Scenario. This scenario is presented to provide context for other scenarios and allow comparison of relative magnitudes of other scenarios. The reader is also reminded that the Curtailment Scenario discusses the possibility that curtailment of ground water may result in spreading of surface water, which could offset some of the benefits predicted by the Curtailment Scenario.

Scenario Results Compared with Measured Declines

With the assumption that most of the declines which have been experienced in aquifer discharges to the Snake River are caused by a) the increased use of ground water for irrigation, b) changes in surface water irrigation practices and c) drought, the surface-water component of results of the Curtailment Scenario and the No Changes in Surface-water Practices Scenario should account for most of the measured declines in spring flows in the Thousand Springs area. This discussion is centered on the Milner to King Hill (aggregate Thousand Springs) reach because that reach has experienced measurable declines in the past 40 or 50 years. The American Falls area, although experiencing more dramatic seasonal swings in reach gains, has not experienced comparable declines since data collection began.

An estimate of peak spring discharge from Milner to King Hill is 6,800 cfs and an estimate of 2002 average discharge is 5,500 cfs (with uncertainty in both of these estimates). These estimates were made using the Kjelstrom (1992) method. These estimates suggest a long-term decline of approximately 1,300 cfs as of 2002. It should also be recognized that spring discharges might have climbed above 6,800 cfs had practices of the 1950s continued and ground-water development not proceeded as it did. It should be further noted that significant spring declines have been experienced since 2002, largely due to drought. This analysis focuses on 2002 discharge because that is the end date of the calibration period, so mare data are available for that period.

Table 5 summarizes results of the Curtailment Scenario and the No Changes in Surface-water Practices Scenario. The Curtailment Scenario suggests that the steady-state impact of all ground water pumping is approximately 2,780 cfs, with 650 cfs in the Milner to King Hill (aggregate Thousand Springs) reach. From values in Table 4, it appears that approximately 72% of the change in recharge may be attributed to pure surface-water effects (with considerable uncertainty in this partition). Applying this ratio to No Changes in Surface-water Practices Scenario impacts in the aggregated Thousand Springs reach suggests that pure surface-water impacts in that reach are about 730 cfs. This gives a combined estimate from the two ESPAM scenarios of 1,380 cfs, which compares very well with the estimate of 1,300 cfs for observed declines.

Table 5.
Comparison of Scenario Results
(absolute values of changes in net reach gains, cfs)

Reach	**Curtailment Scenario (earliest priority)**	**No Changes Scenario**	**Observed Changes**	**Upper Snake Basin Study (no-groundwater evaluation)**
Ashton/Heise to Shelley	570	605	Unknown	Not Available (estimate in report of 175 cfs for Henrys Fork)
Shelley to Neeley	1550	1015	Minimal[12]	850
Milner to King Hill	650	1019	1300	620
Totals	**2770**	**2639**	**Unknown**	**1470** **(1645 including estimate for Henrys Fork)**

Also of interest is the fact that both the Curtailment Scenario and the No Changes in Surface-water Practices Scenario predict that the distribution of the impact has been weighted toward the eastern portion of the aggregated Thousand Springs reach, with the Devil's Washbowl to Buhl sub-reach showing the largest impact. This conclusion is supported by maps showing the spatial distribution of lands which would be affected by either curtailment or by changes in surface water irrigation practices. This conclusion suggests that targeting mitigation to specific springs via curtailment would be very difficult.

Comparison of Curtailment Scenario with Upper Snake Basin Study

The Upper Snake Basin Study (IDWR, 1997) contains results of the 'No Groundwater' Scenario, a scenario with goals very similar to the Curtailment Scenario. Table 5 contains summary results for both the Curtailment Scenario and the 'No Groundwater' scenario from the Upper Snake Basin Study. Each study attempts to isolate the impacts of ground water pumping to the river reaches. As can be seen in Table 5, the Curtailment Scenario predicts a total impact to the river of 2770 cfs compared with the 'No Groundwater' prediction of 1470 cfs —a difference of 1300 cfs. The possible reasons for this difference are explored below.

Further inspection of Table 5 shows that the Curtailment Scenario predicts 650 cfs of impact to the aggregated Thousand Springs reach and the Upper Snake Basin Study predicts 620 cfs of impact to the same reach. These numbers are effectively the same given the amount of uncertainty in both studies. This indicates that the 1300 cfs difference between the two studies is all above Milner.

It is important to understand what drives model results in order to understand the differences between these two studies. The model results will be driven, in part, by the

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[12] Estimates of spring discharges and reach gains to the American Falls area suggest no long-term decline but an increase in seasonal swings in discharge.

physical properties represented in the model (transmissivity, storativity, river conductance, etc.). In steady state, however, the inputs to the model must equal the outputs. The outputs, in each case, are the river gains. The inputs in these two scenarios are the representation of consumptive use of ground water. In steady state, the physical properties will serve to distribute the water among the various river reaches but will not change the total amount of water gained by the river. That must equal the model input.

The Upper Snake Basin Model study was completed using the original IDWR ground water model. The study used a version of the model created prior to the extension of the model to include the Henrys Fork area. Model boundaries of the Enhanced Snake Plain Aquifer Model (ESPAM), the model used for the Curtailment Scenario includes additional acreage in the Henrys Fork, the Big Lost River valley, the Rexburg Bench and the Oakley Fan. The Curtailment Scenario omitted consumptive use and pumping in the Fort Hall area based on Tribal ownership of water rights. The Upper Snake Basin geographically excluded acreage based on Tribal boundaries. As a result of different methods, the Upper Snake Basin Study omitted more acres than did the Curtailment Scenario.

The areas included in ESPAM which were not represented in the Upper Snake Basin Study (Rexburg Bench, Big Lost drainage, Henrys Fork, Oakley Fan and parts of Ft. Hall) comprise 252,000 acres irrigated from ground water. These are reduced for non-irrigated inclusions using a factor of 0.88, giving an effective 222,000 acres in the Curtailment Scenario for these areas.[13] The total number of acres represented in the Curtailment Scenario was 1.11 million acres from ground water, or 978,000 net acres after reduction. This means that the number of acres represented in the Curtailment Scenario that were within the boundaries of the original State ground water model was 683,000 (excluding Ft. Hall), or about 62,000 fewer ground-water irrigated acres than the Upper Snake Basin Study. Both the ESPAM and Upper Snake Basin Study analyses used the same irrigated lands GIS data, but relied on different methods to assign irrigated lands to ground-water or surface-water sources and different adjustments for non-irrigated inclusions.

To summarize, the total number of ground-water irrigated acres represented in the Curtailment Scenario was 233,000 acres more than in the Upper Snake Basin Study. This represents 222,000 acres of irrigation in areas of extended boundaries plus 73,000 acres in the Ft. Hall area, less 62,000 acres difference due to methods of assigning water source and adjusting for non-irrigated inclusions.

The Curtailment Scenario used a spatial distribution for precipitation which ranged from 0.73 to 1.92 ft, with an area-weighted average of 0.91 ft. The evapotranspiration on irrigated parcels ranged from 2.48 to 3.39 ft with a weighted average of 2.81 ft. However, most ground-water irrigated lands use sprinkler application. In the scenario, ET on sprinkler-irrigated lands was multiplied by 1.05, giving an effective average ET of almost 2.95 feet. Subtracting ET supplied by precipitation, the net depth represented as a

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[13] The Upper Snake Basin Study also reduced for non-irrigated inclusions, but using a factor of 0.95 for ground-water irrigated lands.

stress on irrigated parcels was approximately 2.04 ft, 0.3 ft for winter-time ET and 1.74 ft for growing-season ET. This compares to a net depth of 1.83 feet used in the Upper Snake Basin Study. Considering only the equivalent model areas and adjusting for Ft. Hall, the ESPAM values would have indicated 1.39 million acre feet of consumptive use on the lands for which the Upper Snake Basin Study indicated 1.36 million acre feet.

So, in the Curtailment Scenario, 978,000 million net acres of ground-water irrigated area was represented using 2.04 ft of consumptive use, for a total of 2.0 MAF per year, or 2760 cfs. Most of the increased acreage represented in the Curtailment Scenario was in the northern part of the plain, so most of the impact was shown in the upper reaches of the Snake River.

Comparison of Curtailment Scenario, No Changes in Surface-water Practices Scenario and Post-Development Increases in Spring Discharges

Garabedian (1992) published pre-development reach gains of 700 cfs in the American Falls area and 4000 cfs in the Thousand Springs area, for a total of 4700 cfs.[14] Current discharges in those areas, as of 2002, were 2600 cfs and 5500 cfs, respectively, for a total of 8100 cfs. The estimated net increase in spring discharge since the onset of irrigation is 3400 cfs (8100 minus 4700).

From Table 1 in the Curtailment Scenario report, the predicted impact from all of ground water pumping is 2770 cfs. The impact of the No Changes in Surface-water Practices Scenario is 2600 cfs. Subtracting the 730 cfs of ground-water-contribution estimated in Table 4, the best estimate of the pure surface-water impact from the No Changes in Surface-water Practices Scenario is about 1870 cfs. The sum, then, of ground-water effects and pure surface-water effects is estimated to be 3870 cfs. This is larger than the estimated historical increases of 3,400 cfs, though the discrepancy is only 470 cfs. This is a relatively small difference, given the uncertainty of both estimates. Possible explanations for the discrepancy include:

1. Imprecision in pre-development estimates.
2. Imprecision in Curtailment Scenario water budgets.
3. Imprecision in No Changes in Surface-water Practices water budgets.
4. Imprecision is partitioning No Changes in Surface-water Practices impacts to ground-water and pure surface-water effects.
5. Declines that otherwise would have occurred in the American Falls reach may have been buffered by increased leakage from the Aberdeen-Springfield canal, which is not represented as hydraulically connected in the model (though presented as a possibility, this potential effect has not been investigated and is neither promoted nor discounted).
6. Effects of reduced diversions may have not yet fully propagated to river and spring reaches.

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[14] These are modeling and water-budget results; pre-development measurement data do not exist.

CONCLUSIONS

An overwhelming conclusion that can be drawn from the No Changes in Surface Water Practices Scenario is that surface irrigation dominates the modern hydrology of the eastern Snake River Plain. In the northeast, changes predicted by the scenario are large relative to current reach gains or losses. In the Thousand Springs area, the western springs are less affected by changes in surface water irrigation practices than the eastern springs. The maps showing the spatial distribution of areas most affected by the changes in surface water practices support this conclusion. All reaches have experienced declines due to changes in surface water practices.

This scenario is presented to provide context for other scenarios. Because observed changes in diversions may reflect the impact of many factors, this No Changes in Surface-water Practices Scenario is not additive to other scenarios, particularly to the Curtailment Scenario. Results from this scenario, in combination with results from the Curtailment Scenario, were assessed for overall sense and magnitude. Though not additive, the two scenarios appear reasonably consistent with changes from pre-development conditions as well as changes since the 1950s. The results of the Curtailment Scenario were also compared with the results from the Upper Snake Basin Study. The Curtailment Scenario used different assumptions for number of ground water irrigated acres and had different boundary conditions, which explained differences in the results of the two studies.

The No Changes in Surface-water Practices Scenario contains many assumptions about the evolution of practices, most notably assumptions about evapotranspiration and irrigation returns. The reader should bear in mind that these assumptions introduce uncertainty into the results, which was addressed in Objective 3. Additionally, no effort was made to predict the transient nature of these changes as no information was available regarding the timeframe over which the changes occurred. An estimate was made of the partition of changes in diversions to various potential causes, but this partition has considerable uncertainty.

In conclusion, the combined effects of increases in ground water pumping (illustrated by the Curtailment Scenario) and changes in surface water practices (illustrated by the No Changes in Surface-water Practices Scenario) have caused much of the decline in spring discharges to the Snake River from the eastern Snake River Plain aquifer. Additionally, it is anticipated that declines have been realized due to natural drought conditions. Restoring the springs to previous peak levels would be an unrealistic goal, given that surface water irrigation dominates the hydrology and most of the changes in surface irrigation practices are irreversible.

REFERENCES

Allen, R, 2004, University of Idaho, Kimberly Research and Extension Center. Personal communication.

Clemens, A.I. and C.M. Burt, 1997, *Accuracy of Irrigation Efficiency Estimates,* Journal of Irrigation and Drainage Engineering, November/December 1997.

Contor, B.A., 2003, Enhanced Snake River Aquifer Model Design Document DDW008, Aggregation of Surface Water Canal Companies into Surface Water Irrigation Entities, Idaho Water Resources Research Institute, University of Idaho, Moscow, ID.

Contor, B.A., 2003, Enhanced Snake River Aquifer Model Design Document DDW010, Traditional Evapotranspiration Calculation, Idaho Water Resources Research Institute, University of Idaho, Moscow, ID.

Contor, B.A., D. M. Cosgrove, N. Rinehart, A. Wylie and G. S. Johnson, 2004, Enhanced Snake River Aquifer Model Scenario Document DDS-002, Hydrologic Effects of Curtailment of Ground Water Pumping “Curtailment Scenario”, University of Idaho, Moscow, ID.

Dakins, M.E., 2003, University of Idaho, Associate Professor of Environmental Science. Personal communication.

Daly, C. and G. Taylor, 2001, PRISM Precipitation Maps. Oregon State University, http://www.ocs.orst.edu/prism/prism_new.html

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, 102 p.

Gilliland, B., 2003, Snake River Aquifer Model Design Document DDW012, Estimating Irrigation Entity Diversions: Snake River, Idaho Water Resources Research Institute, University of Idaho, Moscow, ID.

Goodell, S.A., 1988, Water use on the Snake River Plain, Idaho and Eastern Oregon: U.S. Geological Survey Professional Paper 1408-E, 51 p.

Idaho Department of Water Resources, 1997, Upper Snake River Basin Study: Idaho Department of Water Resources, Boise, ID, 85 p.

Idaho Department of Water Resources, 2004, Unpublished electronic data of releases for flow augmentation.

Idaho Department of Water Resources, 2002, Paper map of standard field headgate requirement, consumptive use, and season of use.

Klamm, D.D. and J.S. Brenner, 1995, Farm Irrigation Rating Index - FIRI. 1995 ET and Irrigation Efficiency Seminar.

Lutz, D., 2004, Idaho Department of Water Resources. Personal communication.

Ott, R.L., 1993, An Introduction to Statistical Methods and Data Analysis.

Snedecor, G.W. and W. G. Cochran, 1980, Statistical Methods, Seventh Edition.

Swank, L., 2004, Water District 01, Personal communication.

Swensen, D., 2004, Fremont-Madison Irrigation District. Personal communication.