Eastern Snake Plain Aquifer Modeling Scenario:

Hydrologic Implications of Current Water-use Practices and Historical Climate Conditions

"Current Practices" Scenario

August 2007

Idaho Water Resources Research Institute
Idaho Falls, Idaho
Bryce A. Contor
Research Hydrologist

IWRRI Technical Report 200702

IDAHO WATER RESOURCES RESEARCH INSTITUTE

Eastern Snake Plain Aquifer Modeling Scenario:

Hydrologic Implications of Current Water-use Practices and Historical Climate Conditions

INTRODUCTION

The Eastern Snake Plain Aquifer Model version 1.1 (ESPAM 1.1) is a numerical aquifer model of the Eastern Snake Plain Aquifer in southeastern Idaho. It is a fully-calibrated, transient model using the USGS MODFLOW computer code (McDonald and Harbaugh, 1988), developed to allow simulation of regional recharge and discharge stresses, in order to estimate flows in springs and river gains and losses (or changes in flows, gains, and losses). The model and documentation may be obtained from Idaho Water Resources Research Institute (IWRRI, 2007). Full model data are available from Idaho Department of Water Resources (IDWR, 2007 (1))

Modeling scenarios are applications of the model designed to answer hydrologic questions, to test hypotheses, or to explore possible administrative actions. Scenarios published by IWRRI and IDWR are developed in consultation with the Eastern Snake Hydrologic Modeling Committee (ESHMC).

This scenario, known as the "Current Practices Scenario," was developed by IWRRI and IDWR in consultation with the ESHMC. The ESHMC defined this scenario as the "simulation of aquifer conditions in response to current water use and management practices over a representative hydrologic sequence."

The storage capacity and large distances of the Eastern Snake Plain aquifer create a capacity for buffering that delays the impacts of hydrologic events upon hydraulically-connected surface-water bodies. If there were a fundamental imbalance between today's water-use practices and the current levels of spring discharges and river gains and losses, it might not be readily apparent by observation. For instance, it is possible that today's aquifer discharges to springs and rivers are still being sustained by accumulated storage in the aquifer that accrued from past events. Or, it is possible that today's discharges and gains are still depressed as a result of lingering effects of drought. In either case, the actual current gains and discharges would be different than the equilibrium gains and discharges that could be supported given current water use patterns. The purpose of this scenario is to determine the implied equilibrium levels of discharge and gains associated with current human water-use patterns and practices. These patterns and practices include ground-water and surface-water diversions, irrigation management and technology, canal maintenance practices, and crop rotation and cropping patterns. Determining the implied equilibrium condition has value in assessing the appropriateness of today's water use patterns, practices and allocations. It allows us to separate the implications of current human activity from the lingering effects of past events. Secondary purposes are to estimate the time that would be required to approach the hypothetical equilibrium condition and to describe the historical variability of river reach gains and spring discharges. Variability provides context in interpreting these results and in contemplating possible future conditions.

The scenario outcome is called an "implied" equilibrium because it is highly unlikely that either current practices or the historical hydrologic regime *will* actually prevail into the future. Therefore, the scenario is ***not a prediction***; it omits expected future changes. The ESHMC defined the scenario as an assessment of "current water use and management." It is not an assessment of current policy; use and management could conceivably change in the future, even without a change in policy. The scenario tests current use and water management. In a sense, the scenario is a snapshot of where we are today. It is neither a prediction nor an assessment of future trends.

There are three possible outcomes of the scenario, which represent three different potential snapshot descriptions of current water use and management:

1. The simulation could indicate equilibrium spring discharges and river gains that are higher than current levels. The snapshot would indicate that current practices could support higher long-term average spring discharges and river gains than current levels, given continued hydrologic conditions similar to the long-term record.
2. The simulation could produce equilibrium gains and discharges that are lower than today's levels. This would suggest a snapshot of practices that cannot support current levels of spring discharges and river gains.
3. The simulation could indicate that the expected equilibrium condition is similar to current levels of gains and spring discharges. This would indicate that net recharge associated with current practices is in balance with current gains and discharges.

The scenario makes no statement about whether today's gains, losses and spring discharge levels are desirable, nor whether the implied equilibrium gains, losses, and discharges would be desirable. Though the actual modeling procedure necessarily projected results out into future years, this does not imply any expectation about future gains, losses and discharges. The scenario *is not* and *cannot be considered* a prediction. Its fundamental construction is a representation of *current* practices and *historical* hydrologic conditions, which is counter to expectations for the future (as indicated by past observation). Human water-use patterns and practices will surely continue to change, and it is possible that hydrologic conditions will also change. It is acknowledged that assessments and forecasts of future conditions could be very useful and may appropriately be the subjects of future work, but they are not the subjects of this scenario[1].

Note that the simulations use a constant aquifer stress, which cannot represent the winter-to-summer, year-to-year and multi-year cyclical hydrologic variability that has been observed in the past and is expected in the future. The scenario does present a basic assessment of historical variability, which may be useful in contemplating potential future variability.

METHODS

The methods for this scenario were guided by the Eastern Snake Hydrologic Modeling Committee (ESHMC) and discussed extensively within the committee. The basic goal was to construct data sets representative of today's water use patterns and average hydrologic conditions, then apply these to the aquifer model to estimate Snake River gains and losses, and spring discharges. The data sets of themselves would have allowed direct assessment of the overall implied equilibrium, without aquifer modeling. Applying the data to transient aquifer model runs allowed discovery of the spatial distribution of gains and discharges, and the temporal pattern of progression from today's condition to the hypothetical conditions. Steps included:

1. Extend the calibration-period data (which ended 30 April 2002) through April 2007, in order to start the scenario with a representation of today's conditions.
2. Test the extended data by using them in a model run and comparing model outputs to observed water levels, spring discharges and river gains.
3. Select candidate pools of historic data from which to construct the representative data sets, in order to capture current human water-use practices.
4. Select hydrologic indices to guide extraction of data from the candidate pools, in order to represent average hydrologic conditions.
5. Use the hydrologic indices to construct representative data sets.
6. Use the data sets in transient model runs.
7. Explore the historical variability of reach gains and spring discharges, in order to provide some context for the differences between today's condition and the implied equilibrium conditions, and to illustrate the

[1] Some members of the ESHMC feel strongly that this scenario should have been an assessment of potential future changes.

future variability that should be expected even if practices and average hydrologic conditions were to remain constant.

8. Assess the time required to reach the implied equilibrium conditions, from today's condition.
9. Compare results of representative data sets, in order to understand the uncertainty introduced by different candidate pools and indices.

Extended Data Set

The ESHMC determined that it was important for the scenario to provide an indication of the period of time that would be required for the aquifer to meet the new equilibrium conditions implied by the scenario water budgets. To correctly represent the transition from today's condition to the hypothetical equilibrium condition, a model simulation must include a reasonable representation of today's aquifer heads. The ESHMC considered three options for representing starting heads:

1. Interpolate recently-measured heads across the study area. This option was rejected because scarcity of data would leave large areas represented only by interpolated values, which were judged to be unreliable for the required purposes.
2. Use recently-measured heads to adjust the modeled ending heads from the last calibration period (30 April 2002). This option was also rejected.
3. Apply an extended recharge and discharge data set in a short model run to bridge the period 1 May 2002 - 30 April 2007, and use ending heads from that model run as starting heads for the scenario simulation. The ESHMC selected this option because the model produces a head estimate for every model cell in the study area, based on the input water-budget data and controlled by the calibrated parameters of the aquifer model.

The extended recharge and discharge data set used actual precipitation and diversion data where possible, and used values from the calibration period as proxies for other components of the water budget. Based on natural flow at Heise (US BOR, 2007), the Palmer Drought Index (NOAA, 2007) and SNOTEL data (NRCS, 2007), model year 2000 was selected as a proxy for model years 2002 through 2005, and model year 1999 was selected as a proxy for model year 2006. Table 1 summarizes the components of the extended data set and the source of data or proxy used for each component:

Table 1
Inputs to short model run used to generate starting heads
for Current Water Use Practices Scenario

Component	**Representation in Extended Data Set**
Sprinkler percentage	Most recent calibration data (model-year 2001)
Irrigated Lands	Year-2000 LANDSAT data[2]
Starting Heads	Spring 2002 modeled heads, based upon final calibration data sets.
ET on irrigated lands, 2002-2005	Calibration data 2000
ET on irrigated lands, 2006	Calibration data 1999
Precipitation on irrigated lands	PRISM through February 2007. PRISM data corresponding to model-year 1999 for March and April 2007.
Surface-water diversions, Snake River and Wood Rivers, 2002-2005	IDWR diversion data
Surface-water diversions, Snake River and Wood Rivers, 2006	Calibration data 1999
Surface-water diversions, other sources, 2002-2005	Calibration data 2000
Surface-water diversions, other sources, 2006	Calibration data 1999
Return flows	Measured returns from IDWR data files for Big Wood and Little Wood Rivers. Other entities used measured fractions from the year of measurement if available, and used the most recent measured data otherwise. In most cases measured data extended through 2003 or 2004.
Offsite Pumping, 2002-2005	Calibration data 2000
Offsite Pumping, 2006	Calibration data 1999
Fixed-point pumping[3], 2002-2005	Calibration data 2000
Fixed-point pumping, 2006	Calibration data 1999

[2] Calibration used a 1992 landcover data set based on 1987 aerial photos and subsequent field inspection.
[3] Fixed-point pumping data include adjustments for deficit irrigation in the Richfield tract.

Component	Representation in Extended Data Set
Perched-river (non-Snake) seepage, 2002-2005	Calibration data 2000
Perched-river (non-Snake) seepage, 2006	Calibration data 1999
Tributary underflow, 2002-2005	Calibration data 2000
Tributary underflow, 2006	Calibration data 1999
Canal leakage, 2002-2005	Calculated from diversions, using 2001 leakage fractions
Canal leakage, 2006	Calculated from 1999 diversions using 2001 leakage fractions

<u>Test Extended Data</u>

The extended data were appended to model-calibration data, forming a 27-year data set. These data were then applied to a transient model run using the calibrated Eastern Snake Plain Aquifer Model 1.1 (ESPAM 1.1). Aquifer-level hydrographs were generated for selected locations, along with spring discharge and Snake River gain and loss hydrographs. These were visually compared with target data for a qualitative assessment of three factors:

1. Are head levels and discharge rates indicated by the extended data compatible with the results from calibration data?
2. Are the patterns (trend, seasonality, and amplitude) from the extended data compatible with the calibration data?
3. Are the post-2001 trends from the extended data compatible with the trends in the observed targets?

<u>Select Candidate Pools of Data</u>

After considerable discussion, the ESHMC selected two candidate pools from which to extract the representations of the current condition:

1. Ten-year pool: Calibration data for model years 1992 through 2001.
2. Fifteen-year pool: Calibration data for model years 1992 through 2001 and extended data for model years 2002 through 2006.

Years prior to 1992 were not used because it was felt that they would not be representative of today's application methods, allocation patterns, crop mix and practices.

The ESHMC could identify neither pool as preferable, because each has a unique advantage. The ten-year pool has the advantage of including no synthesized data, which greatly reduces concerns that a bias in estimates would propagate into the final result. The fifteen-year pool has the advantage of offering more options and a broader range of stress from which to select in constructing a representative data set. Because both pools had desirable characteristics, both were used in the scenario data sets.

Select Hydrologic Indices to Guide Extraction of Data

Both candidate pools are believed to represent current allocation patterns and water-use practices, but implicit within the candidate pools are also the hydrologic conditions that occurred during those years. In order to extract from the candidate pools data that are representative of the long-term average hydrologic condition, some kind of selection or weighting criterion is required. The method chosen was to use a hydrologic index to guide selection. As with the candidate pools, the ESHMC was not able to identify one clearly superior index, so three different indices were used:

1. Heise index; natural flow at Heise (US BOR, 2007), with consideration of antecedent condition. This index is identified in modeling data files with the prefix "H."
2. Dual index; natural flow at Heise with antecedent condition, combined with summer-time temperatures at Aberdeen (WRCC, 2007). The two indices are equally weighted in the selection process. This index is identified with the prefix "D."
3. Palmer Drought index (NOAA, 2007) identified with the prefix "P."

An index based on carryover storage was rejected because it was recognized that two different years of identical hydrologic character could have different index values. This is due to changes in total reservoir capacity, development of the rental pool, use of storage for flow augmentation and use of storage for hydropower generation[4].

An index based on snow-pack observations was rejected because of surprisingly low correlation with the aquifer water budget, for years when both data sets were available.

Use Indices to Select Data and Construct Data Sets

The goal of using the indices was to select from the candidate pools data which were representative of the "average" hydrologic condition. This was done by assigning an index value to each year in the candidate pool, based on the full period of record (back to the early 1900s for natural flow and temperatures, to the late 1800s for the drought index). For each year in the record, the index value was that year's value divided by the mean value for the period of record. To use the data in the constructed data sets, each year in the candidate pool was assigned a weight, so that (*weight x index*) for all candidate years summed to

[4] There may not have been full consensus on this point within the ESHMC.

approximately 1.0. The resultant "representative data set" was the sum of (*weight x net recharge*) for all the years in the candidate pool.

With ten or fifteen candidate years in each pool, there would be an infinite number of combinations that could satisfy the criterion that the weighted index be approximately 1.0. For instance, Table 2 illustrates two different weighting schemes for hypothetical years "A," "B" and "C, both of which satisfy the criterion:

Table 2
Hypothetical Application of Weights to Candidate Years

Candidate Year	Index	Scheme 1 Weight	Scheme 1 Weight x Index	Scheme 2 Weight	Scheme 2 Weight x Index
A (dry)	0.5	0.5	0.25	0	0
B (average)	1.0	0	0	1.0	1.0
C (wet)	1.5	0.5	0.75	0	0
Sum		1.0	1.0	1.0	1.0

Intuitively, we reject both of these schemes. Scheme 1 ignores the mid-range condition, which occurs frequently and should be included in a representation of expected conditions. Scheme 2 ignores the extreme events, which also should have some representation in the final data set. Table 3 shows an allocation that matches our intuitive expectations of the relative frequencies of wet, dry, and average years and also gives a weighted index of 1.0:

Table 3
Alternate Hypothetical Application of Weights to Candidate Years

Candidate Year	Index	Scheme 3 Weight	Scheme 3 Weight x Index
A	0.5	0.25	0.125
B	1.0	0.50	0.500
C	1.5	0.25	0.375
Sum		1.0	1.0

In order to apply weights objectively, a frequency histogram of index values was constructed from the period of record for each index, and candidate years were assigned to histogram bins according to their individual index values. Bins were combined into categories based on the available years in the candidate pools. The relative frequencies of the categories that the years represented were used to assign target frequencies for consideration in applying weights.

The drought index and temperature index considered only the individual index value of candidate years, while the natural flow index also considered the antecedent condition.[5] For instance, 1998 was a moderately wet year with a wet antecedent condition. During the period of record, years in that category occurred with a frequency of 0.105; hence, the desired frequency for candidate year 1998 was 0.105. Candidate years 1993 and 2000 both fell in the same category (dry, with average antecedent condition), whose historical frequency was 0.252. Each of those candidate years was assigned a desired frequency of half that amount, or 0.126. Candidate year 1996 was a very wet year, with a wet antecedent condition. This category represents a very rare occurrence in the record; consequently, candidate year 1996 has a very low desired frequency with this index.

In constructing the weighting scheme, three criteria were applied: a) The weights will sum to 1.0; b) The weighted average index of the candidate years will be very near 1.0; c) The weight for each individual candidate year will be near its desired frequency (as described above). The optimization of these criteria was performed using the Solver tool in Microsoft Excel. In all six cases, the criteria were reasonably satisfied. Figure 1 illustrates a typical result.

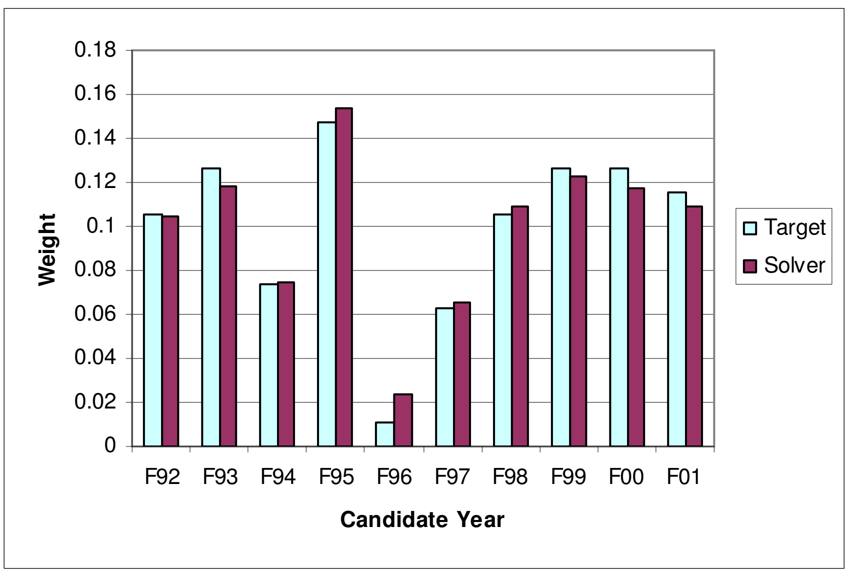


Figure 1. Comparison of target frequencies (from frequency histogram) and solver-assigned weights for a representative data set. The weighted average index is 0.996 and the sum of weights is 1.0001, both very near the target of 1.0

[5] Antecedent condition is already included in the drought index, and the processes intended to be captured by the temperature index (changes in irrigation demand associated with higher or lower summertime ET) are believed to be acute effects with little residual to following years.

Once the weights were obtained for each year in the candidate pools, the representative data sets were constructed by multiplying the MODFLOW well file[6] for each candidate year by the solver weights, and summing across candidate years.

The combination of two candidate pools and three hydrologic indices produced six representative data sets. All are considered equally valid estimates of the representation of current practices and average hydrologic conditions, and none can be preferred above the others. The current practices scenario used all six data sets, as described below.

<u>Use Constructed Data Sets in Model Runs</u>

A stress period is a period of time during which the MODFLOW well file, representing net recharge and discharge to the aquifer, is held constant. Model calibration and some previous scenarios used six-month stress periods in order to represent the seasonality of aquifer stress, spring discharges and river gains. This is appropriate when a representation of seasonal variability is important to the modeling purpose. In the Current Practices scenario, however, the primary purpose was to establish implied equilibrium average discharges, and a secondary purpose was to describe the expected change from today's condition to this hypothetical equilibrium. If the scenario were to use seasonally-variable stress periods, one could produce the situation illustrated in Figure 2, where an apparent "improvement" from today's situation to the final equilibrium condition is simply the difference between seasonal and average representations, rather than a difference between current and equilibrium conditions.

[6] In this application the MODFLOW well contains all water-budget recharge and discharge data except spring discharges and Snake River gains and losses. There is one entry for each model cell, for each stress period of a modeling simulation.

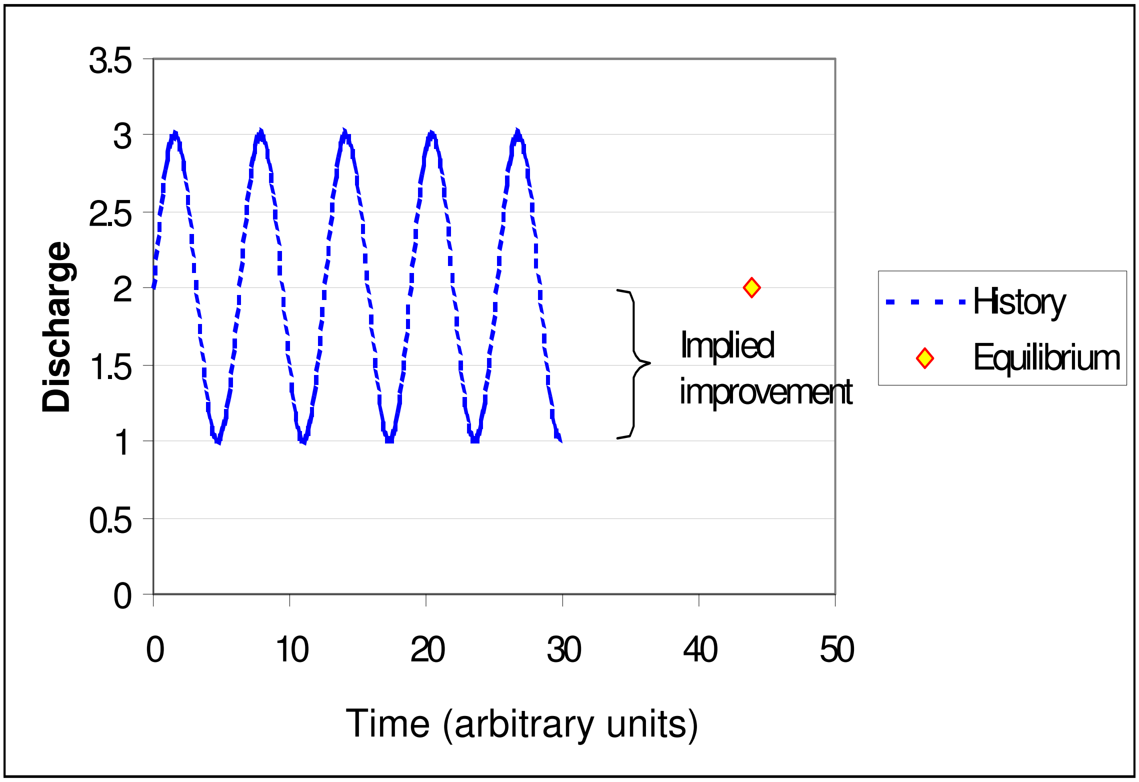


Figure 2. Hypothetical simulation showing how seasonal effects could be mistaken for a difference between the current condition and an eventual equilibrium average condition.

In order to avoid this potential of a false indication of trend, the scenarios were run with average annual stress. To achieve the equivalent annual average starting heads that would be representative of spring 2007, the entire 27-year series was recombined into a data set with annual stress periods. The six representative data sets described above were also constructed as annual-stress data sets. From these, six 327-year data sets were constructed. Each included 22 years of calibration data, five years of extended data, and 300 years of representative average stress. Each of these data sets were processed with ESPAM 1.1, using the calibration starting heads for the simulation start date of 1 May 1980. Each year was 365.25 days long, compatible with the assumptions used in construction of the original recharge data. Discharge and reach-gain data were extracted at the end of each year. Head data were extracted at less-frequent intervals.

Explore Historical Variability of Spring Discharges and Reach Gains

It is important in considering the implications of current practices to understand not only the implied average condition, but to understand how much variability could be expected about the implied average. In a transient MODFLOW aquifer model, a time-variable input data set can produce a time-variable output series. After considerable discussion with the ESHMC, IWRRI rejected extracting variability data from scenario modeling results because neither candidate pool contains a full complement of years of various hydrologic character. In such a case, IWRRI believes the output could not fully represent the potential variability that would be expected[7,8].

Instead of constructing data sets with synthetic variability, the process described above was used to produce six constant-stress transient model runs. These generated results that could be considered traces of mean spring discharges and reach gains. If current water-use practices were to continue in an environment of typical historical water-supply variability and cyclical behavior, one would never expect actual spring discharges and gains to match the simulation results. However, one would expect them to range within an envelope surrounding the simulated traces (assuming no underlying long-term trend in hydrologic regime). The representation of potential future variability was extracted from the historical data (for Snake River reach gains, IDWR 2007 (2)) or from the 27-year data set of calibration and extended data (for spring discharges). Variability was extracted by generating trend lines using ordinary least squares regression[9], and subtracting the trend from the data set. When the character of the historical trace appeared to change, separate trend regressions were constructed for each period of the record. Separation into periods was based on visual inspection of the data. All of the trend lines are illustrated later in the report.

The historical data include some extreme values, so the representation of variability for Snake River reach gains was based on the 5th and 95th percentiles of de-trended monthly observed data. Because the spring variability was based on modeling results, which cannot show response to individual short-term recharge and discharge events, the full range of observed variability in 18-day model results was used to represent variability in spring reaches.

<u>Assess Time Required to Reach Hypothetical Equilibrium</u>

This assessment was approached by determining how soon (in years) the simulated discharge or reach gain was within 10% of the final value, for each reach and simulation data set.

Note that the "time to reach equilibrium" describes the *modeling representation* of the hypothetical trace of simulated average discharge. As described above, at

[7] There was not consensus on this opinion within the ESHMC.

[8] The 27 years of calibration and extended data were used to describe variability of spring reaches, since no data exist for all the springs in all the reaches. This limits us to understanding of only the variability during those 27 years but does not subject us to the additional potential errors of the nature of variability in a synthetic, hypothetical data set.

[9] When trend regressions were not statistically significant, the mean value for the period was used to represent trend.

any point in time the actual discharge will be a combination of the smooth-curve transition from current conditions to the equilibrium, plus cyclical (multi-year) and annual variations, plus seasonal variations, plus any changes associated with changes in practice, allocations, and climate. The mean trace is the representation of the implications of current practices, and this assessment will tell us how quickly the *mean trace* approaches the equilibrium condition. The assessment will tell us very little about the progression of actual spring discharges and reach gains into the future.

Comparison of Results of Representative Data Sets

The flow results of the six data sets were compared by tabulating the final simulated equilibrium gains, losses and discharges with the simulated year-2007 average values. Head results were compared by visual inspection of 300-year water-level change maps (simulation year 327 minus year 27).

RESULTS

Test of Extended Data Set

Extended data results were compared to calibration results and targets for many locations upon the plain (head data) and all river reaches. No targets exist for entire spring reaches, but several comparisons were made of individual springs within reaches. Figures 3 and 4 show sample results. Since spring-discharge model results are for entire reaches, while targets represent discharge of individual springs within reaches, absolute magnitudes cannot be directly compared. Model results are posted every 18 days, based upon input data held constant for six-month periods. This causes each simulated cycle to have a very regular shape. Target data generally respond similarly to annual variations in stress, but shorter-term individual events are also apparent in the data.

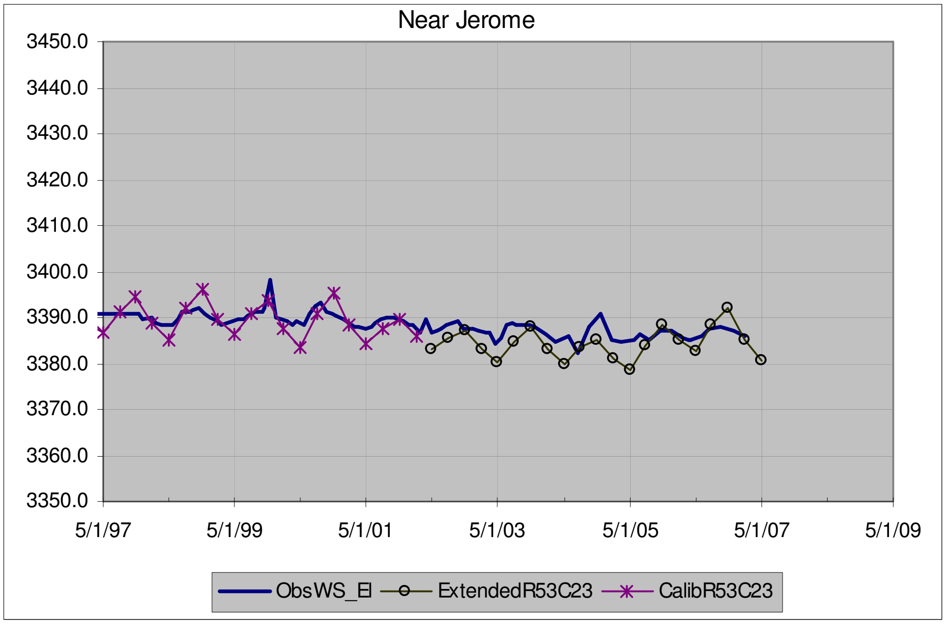


Figure 3. Sample aquifer head comparison. The solid heavy line is the observed aquifer head (water level) and the lines with symbols are simulation results.

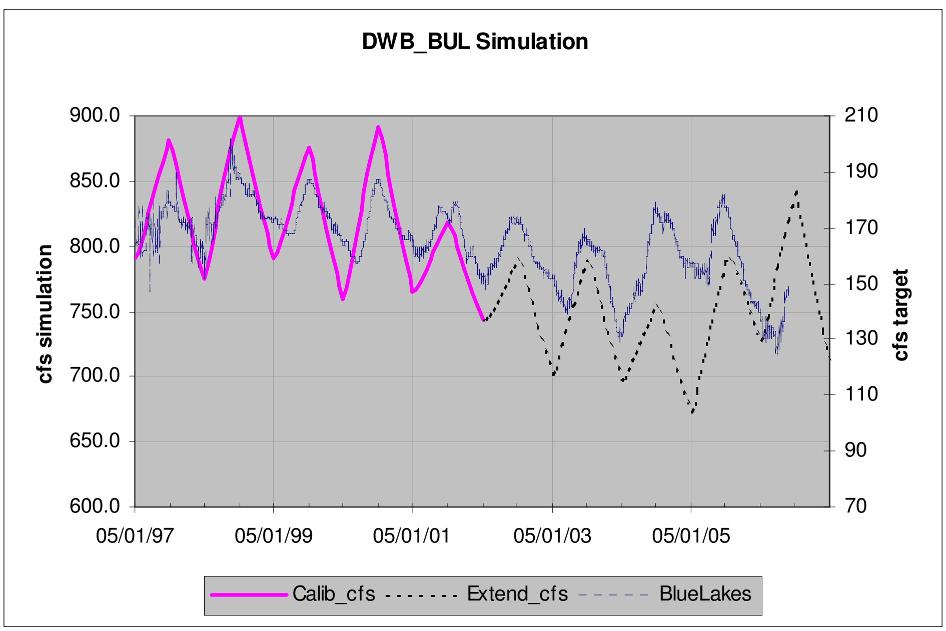


Figure 4. Sample spring-discharge comparison. Note that simulations use the left vertical axis and the target (Blue Lakes Spring) uses the right axis.

The result of comparing multiple water level, reach gain and spring discharge targets is that, based on the criteria listed earlier, the extended data set cannot be rejected. The general head levels and discharges are compatible with the calibration data, its trend and variability characteristics are consistent with calibration data, and its post-2002 trend is not grossly inconsistent with the trend observed in target time series.

Equilibrium Hydrologic Conditions Implied by Current Practices

Aquifer water levels are buffered by the river or spring elevations near the river and springs, so simulated equilibrium levels in those areas are not too different from current levels. However, in areas distant from the river, equilibrium water levels differ from current water levels by as much as one hundred feet or more. Further, the six simulations differ substantially from one another. Figures 5 and 6 illustrate the difference between the implied equilibrium water levels (heads) and the modeled year-2007 average water levels for the two simulations that differed the most. Note that both figures use the same color scale; neither figure will contain the full range of values.

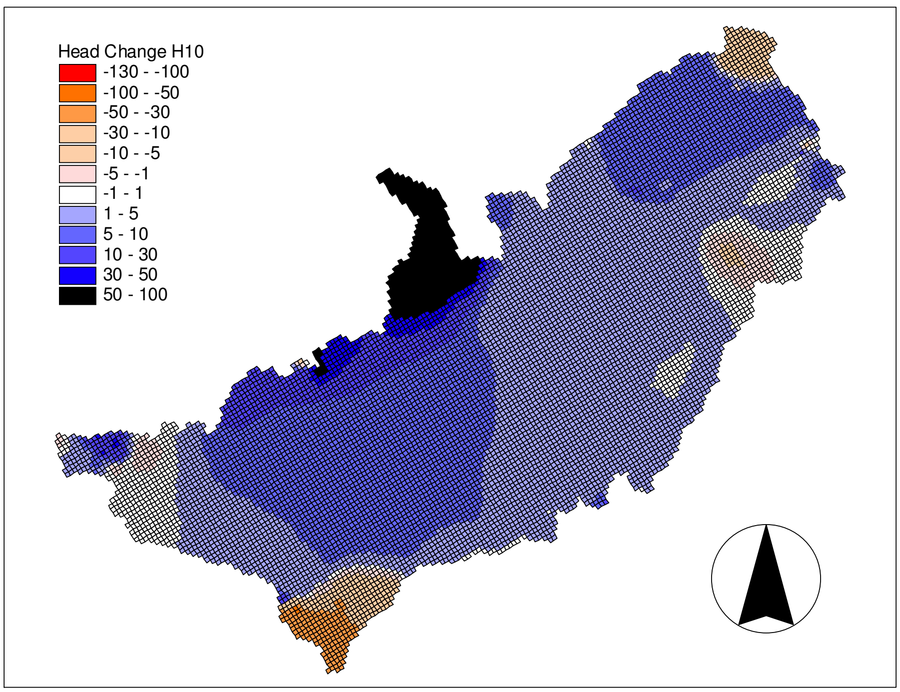


Figure 5. Head difference map from ten-year candidate pool, Heise-index selection method (Final implied equilibrium heads minus modeled 2007 heads).

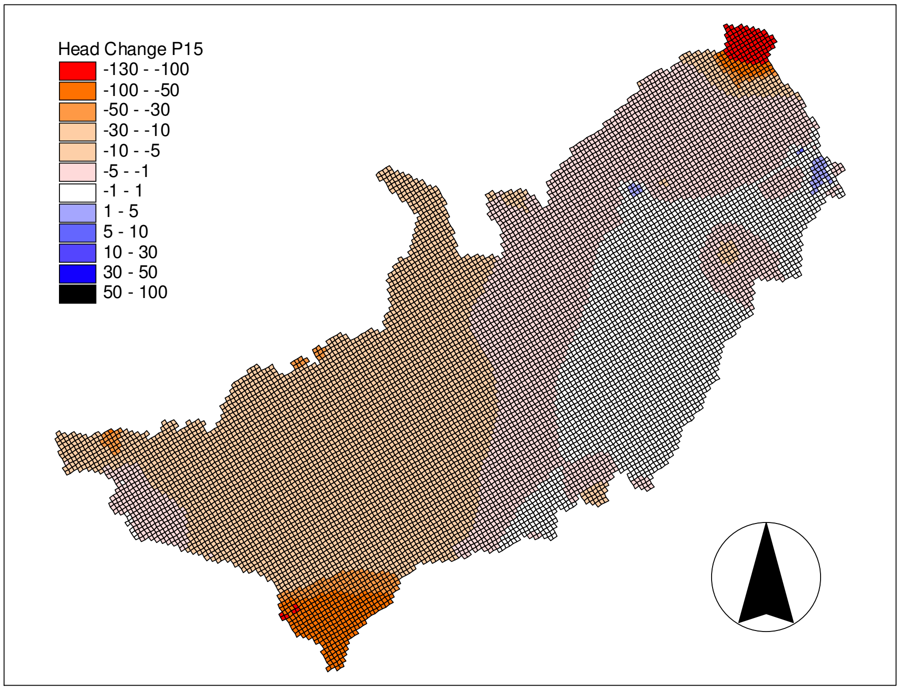


Figure 6. Head-difference map from fifteen-year candidate pool, drought-index selection method (Final implied equilibrium heads minus modeled 2007 heads).

Equilibrium spring discharges and river gains are very similar to current levels. Table 4 summarizes the reach gain results and Table 5 summarizes the spring discharge results. Figures 7 and 8 present the same information graphically.

Table 4
Simulated 2007 and Equilibrium Reach Gains,
Six Representative Simulations
(Simulated season-average flow in cfs. Positive numbers
are reach gains and negative numbers are losses to the aquifer.)

Reach	**D10**	**D15**	**H10**	**H15**	**P10**	**P15**	**Median Equ.**	**2007**
Ashton-Rexburg	114	82	163	160	180	-8	137	60
Heise-Shelley	-755	-755	-730	-719	-728	-776	-742	-744
Shelley-Near Blackfoot	-859	-875	-837	-848	-847	-892	-853	-879
Near Blackfoot-Neeley	2459	2392	2508	2455	2443	2287	2449	2373
Neeley-Minidoka	61	48	68	55	47	29	51	53

Reach	D10	D15	H10	H15	P10	P15	Median Equ.	2007
Sum Above Milner[10]	1021	892	1172	1104	1095	639	1058	864

Table 5
Simulated 2007 and Equilibrium Spring Discharges,
Six Representative Simulations
(Simulated average discharge in cfs)

Reach	D10	D15	H10	H15	P10	P15	Median Equ.	2007
Devils Washbowl-Buhl	689	663	701	681	701	610	685	679
Buhl-Thousand Springs	1511	1500	1516	1508	1516	1473	1509	1510
Thousand Springs	1953	1945	1957	1951	1957	1922	1952	1955
Thousand Springs-Malad	61	61	61	61	61	60	61	62
Malad	1203	1201	1206	1204	1206	1183	1204	1212
Malad-Bancroft	128	125	128	127	128	121	127	127
Sum Below Milner	5544	5494	5569	5532	5569	5368	5538	5546

[10] Note that the sum of medians will not necessarily equal the median of the sums.

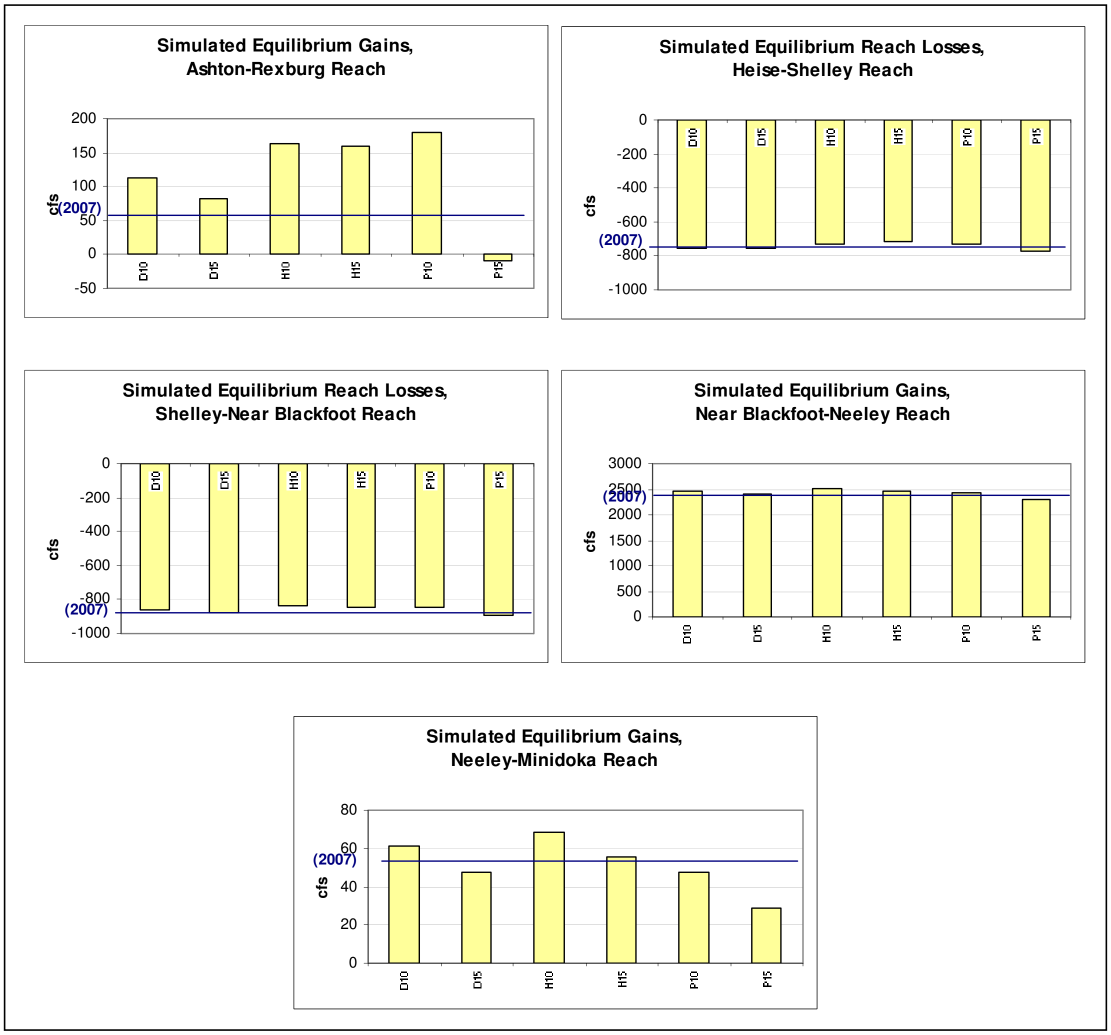


Figure 7. Implied equilibrium reach gains and losses above Milner.

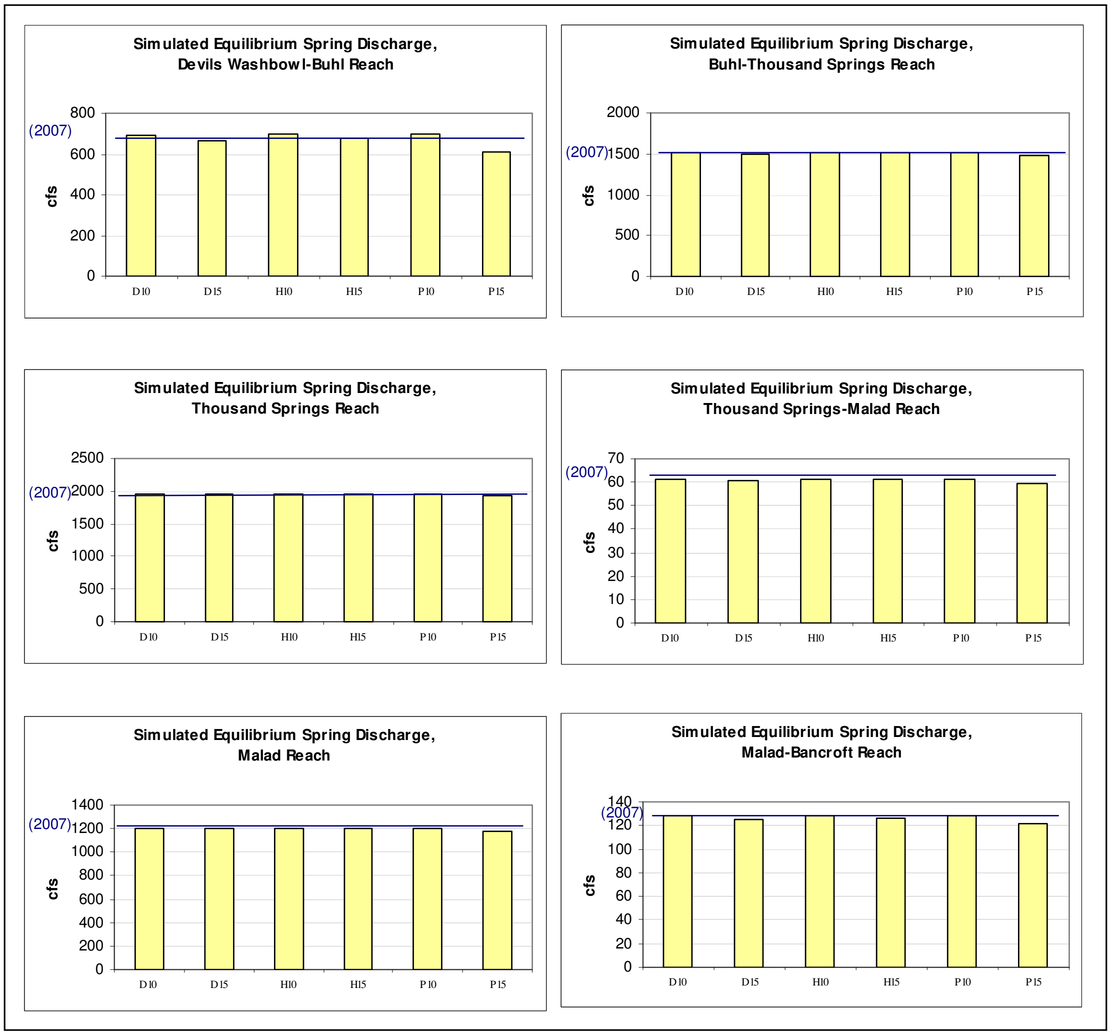


Figure 8. Implied equilibrium spring-reach discharge below Milner.

Overall, results are ambiguous for the Snake River reaches; for each reach, at least one of the six representations suggests an improvement and at least one suggests a decline. Two spring reaches unambiguously show equilibrium results lower than the current condition, though the differences are small. The other spring reaches are ambiguous. Figures 20 and 21 illustrate the range of differences by reach. *All differences are small relative to measurement precision and data uncertainty*.

Explore Historical Variability - Snake River Gains

As described in the "methods" section, the data were de-trended and a simple moving average was applied to explore cyclical (inter-year) behavior. Figures 9 through 13 illustrate the variability of historical monthly river gains. Monthly gains data were obtained from IDWR (2007 (2)). The "de-trended" line is the monthly gain (loss) minus the trend line and represents the total variability around the long-term trend. The "moving average" line is a centered 13-month moving average and represents the year-to-year and multi-year variability (cyclical behavior) in the de-trended data. The "seasonal" line is the de-trended monthly gains minus the 13-month moving average and represents the seasonal (intra-year) variability of gains. The reader must be aware that the gains are calculated using upstream and downstream Snake River gage data, measured diversions, and calculated irrigation surface-water returns to the river. The measurement uncertainty in these data is sometimes very large relative to the gains that must be estimated.

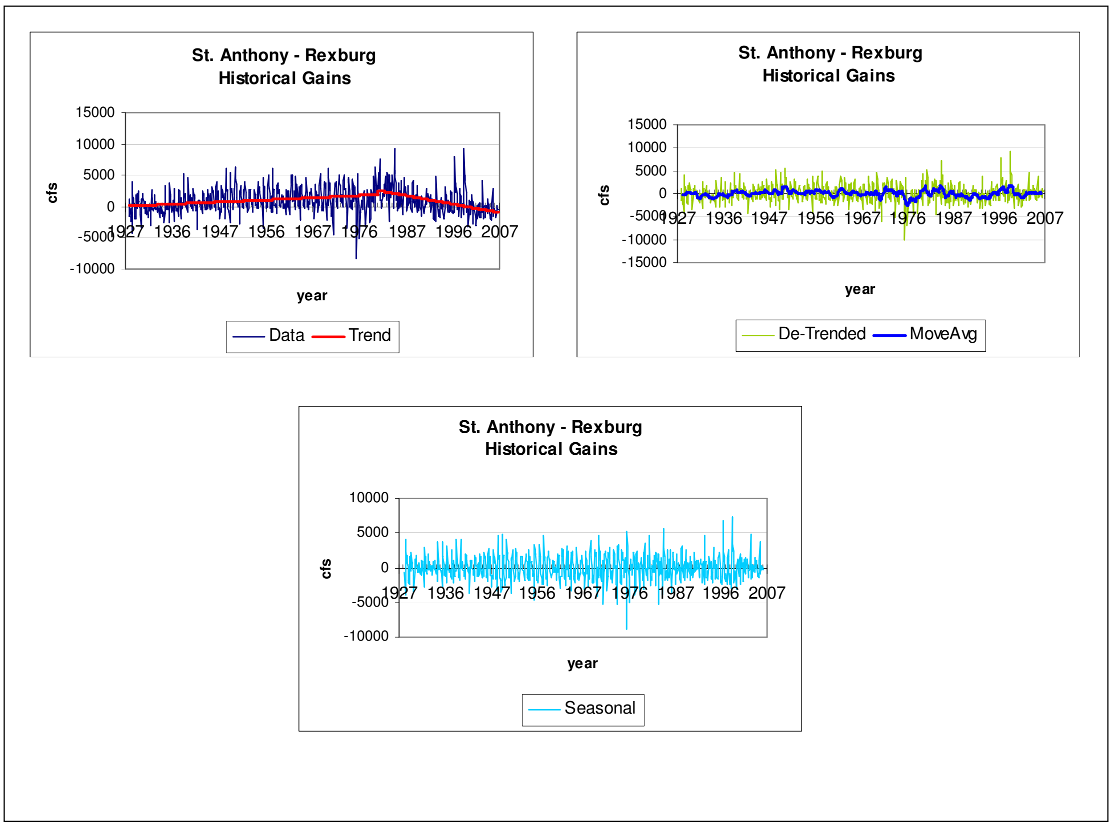


Figure 9. St. Anthony to Rexburg reach gains gains. Note that the scenario modeled Ashton to Rexburg gains, while the gains were calculated using the St. Anthony gage, downstream of Ashton.

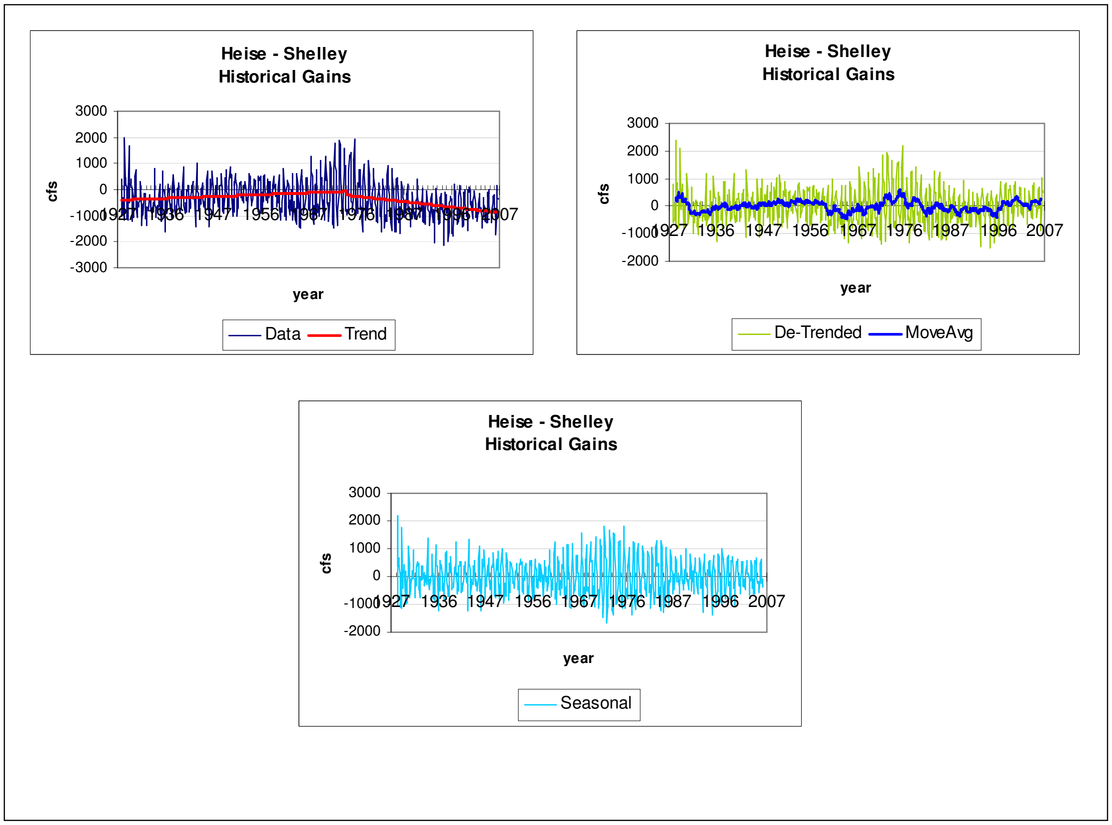


Figure 10. Heise to Shelley reach gains

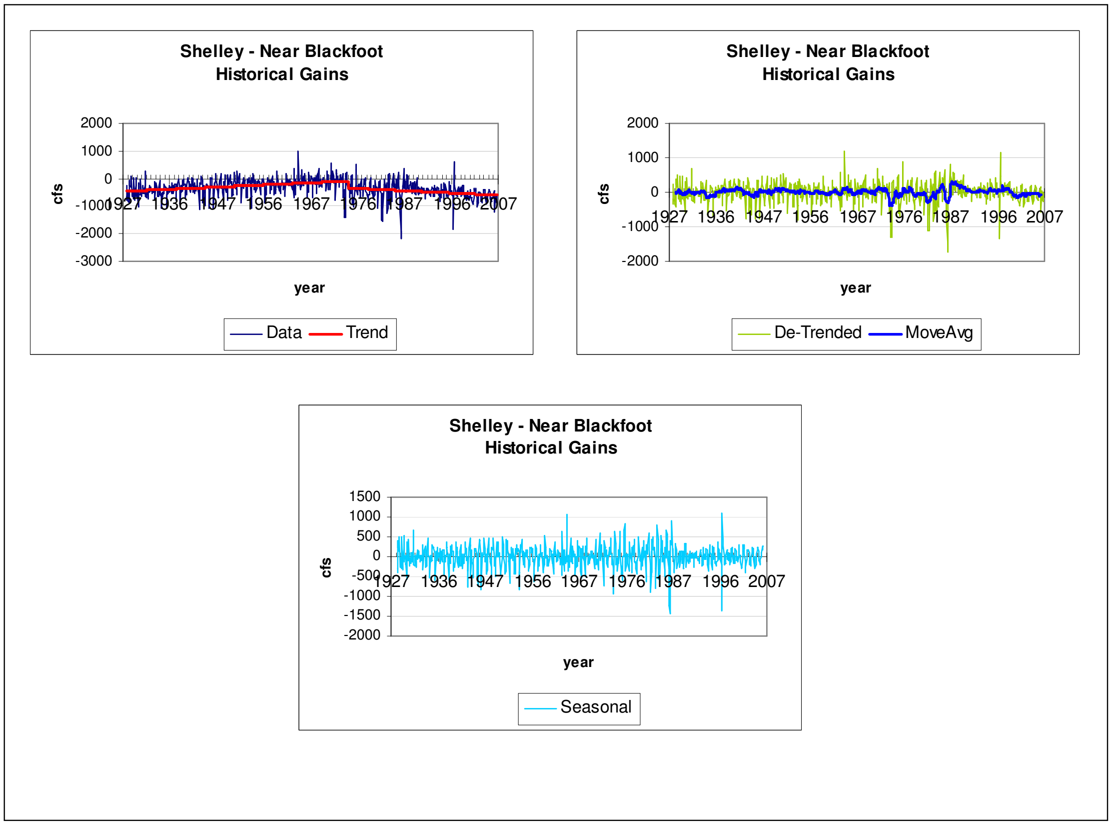


Figure 11. Shelley to Near Blackfoot reach gains.

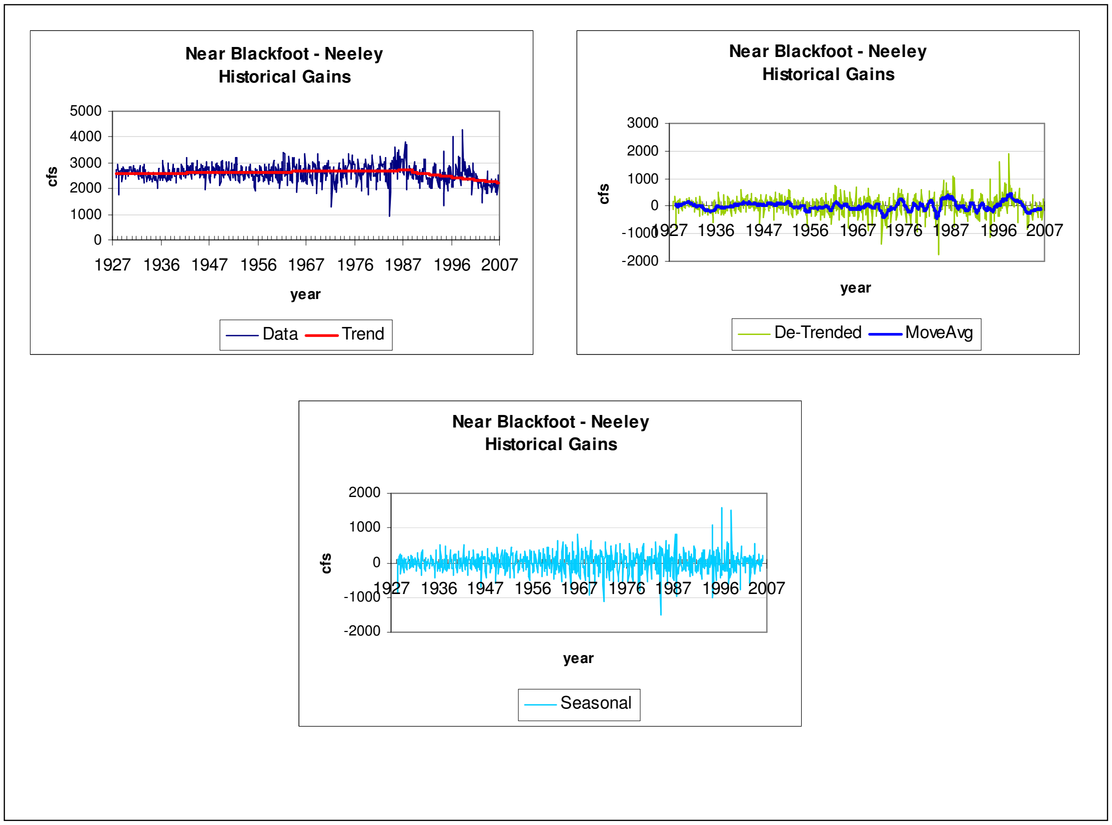


Figure 12. Near Blackfoot to Neeley reach gains.

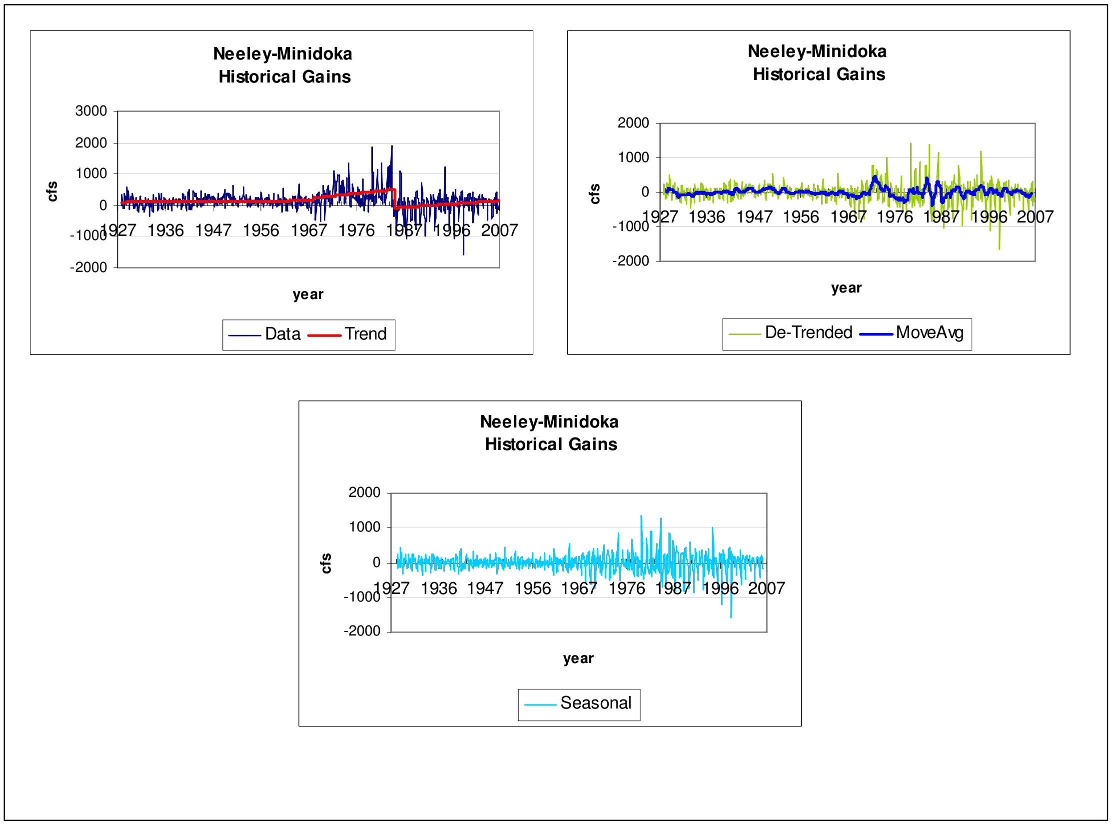


Figure 13. Neeley to Minidoka reach gains.

Some reaches appear to show periodic changes in variability. In contemplating the implications of the results of this scenario, the reader should consider the possibility that future changes may include changes in hydrologic variability.

Explore Historical Variability - Spring Discharges

As described in the "methods" section, spring discharge variability was assessed based on model calibration and extended-data results, due to lack of appropriate target data. There were no full-reach data available for spring reaches, so that actual gains and variability by reach are unknown. However, during calibration, model outputs were compared to available partial-reach target values. Cosgrove and others (2006) point out that modeled variability was sometimes less than target variability for parts of reaches; therefore, it is possible that the actual variability in full-reach discharge exceeds the representations in Figures 14 through 19. The charted values are output from the model approximately every 18 days, based upon input data held constant for six-month stress periods.

These figures show the simulated spring-reach discharges with an exaggerated scale on the right chart so that the reader may see the character of the variability, as well a full-scale axis on the left chart to show the changes in context.

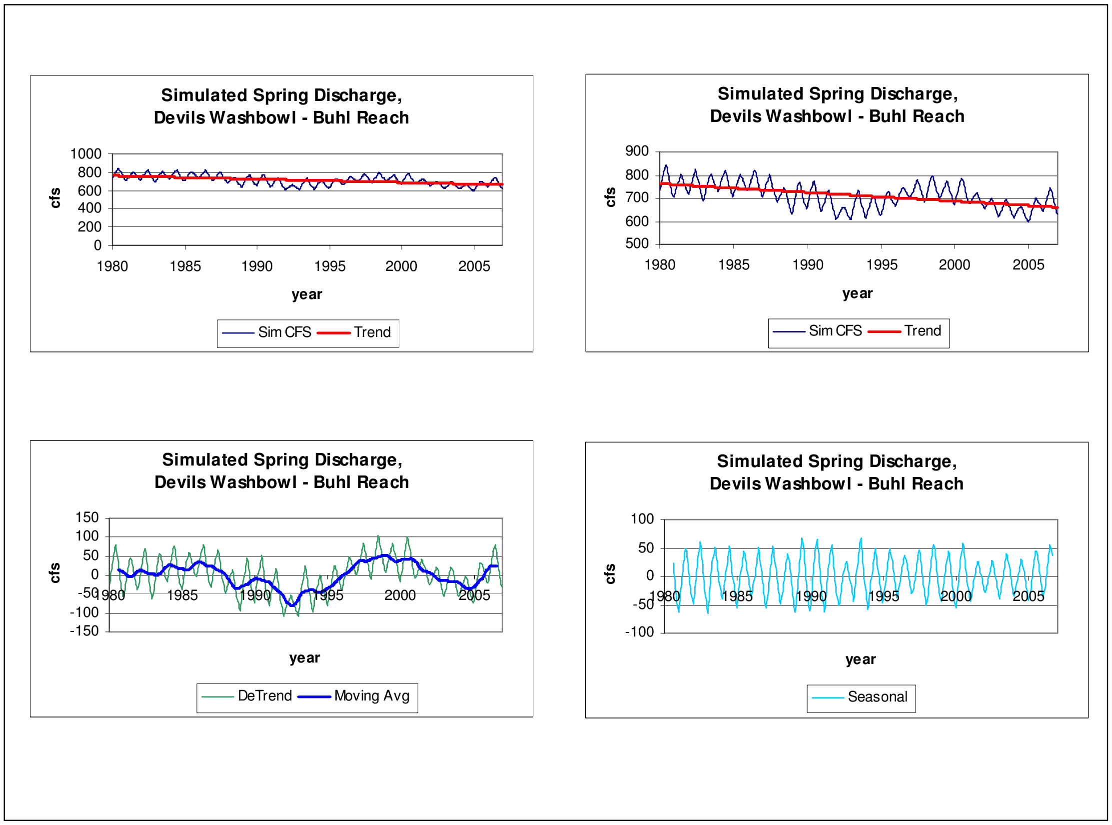


Figure 14. Devils Washbowl to Buhl simulated spring discharge.

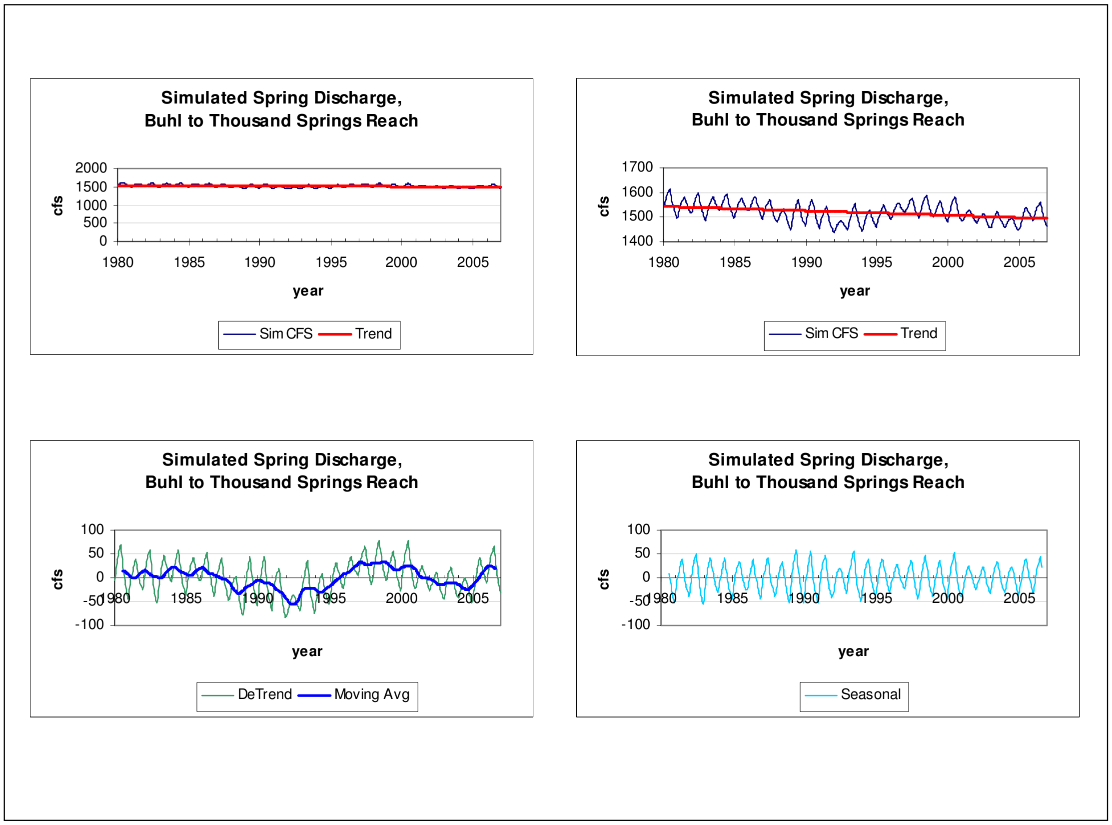


Figure 15. Buhl to Thousand Springs simulated spring discharge.

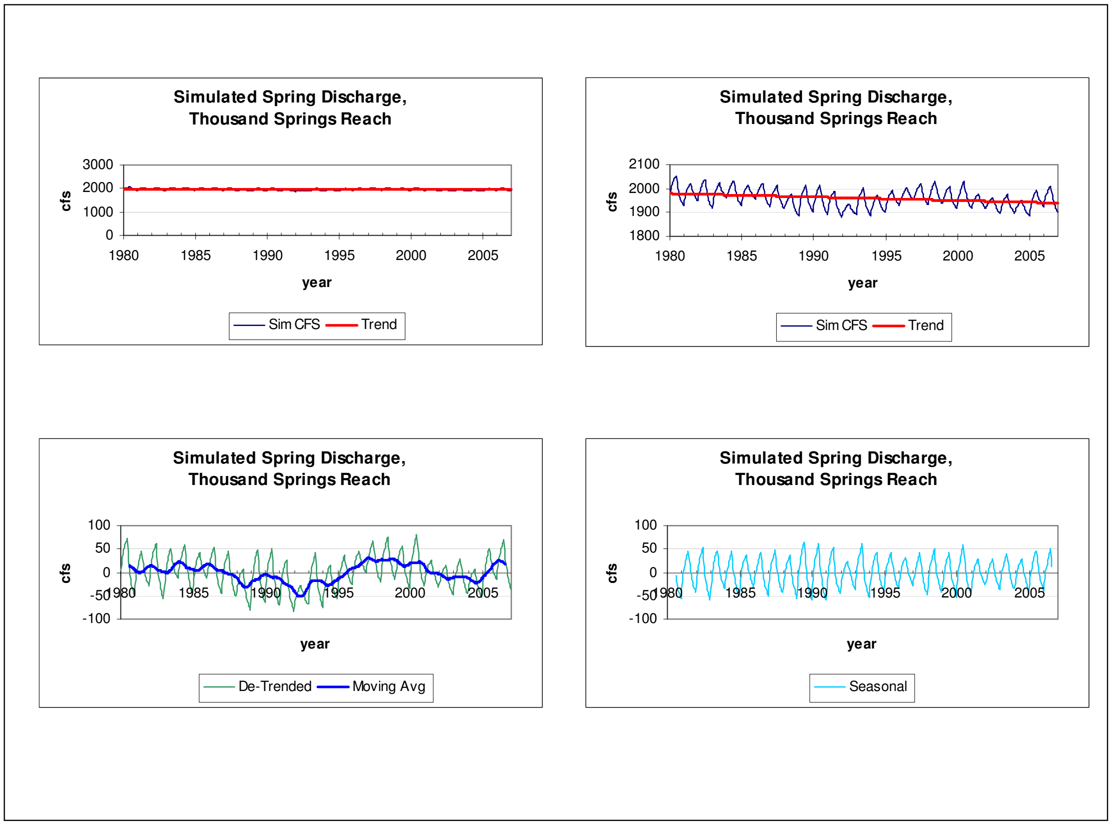


Figure 16. Thousand Springs reach simulated spring discharge.

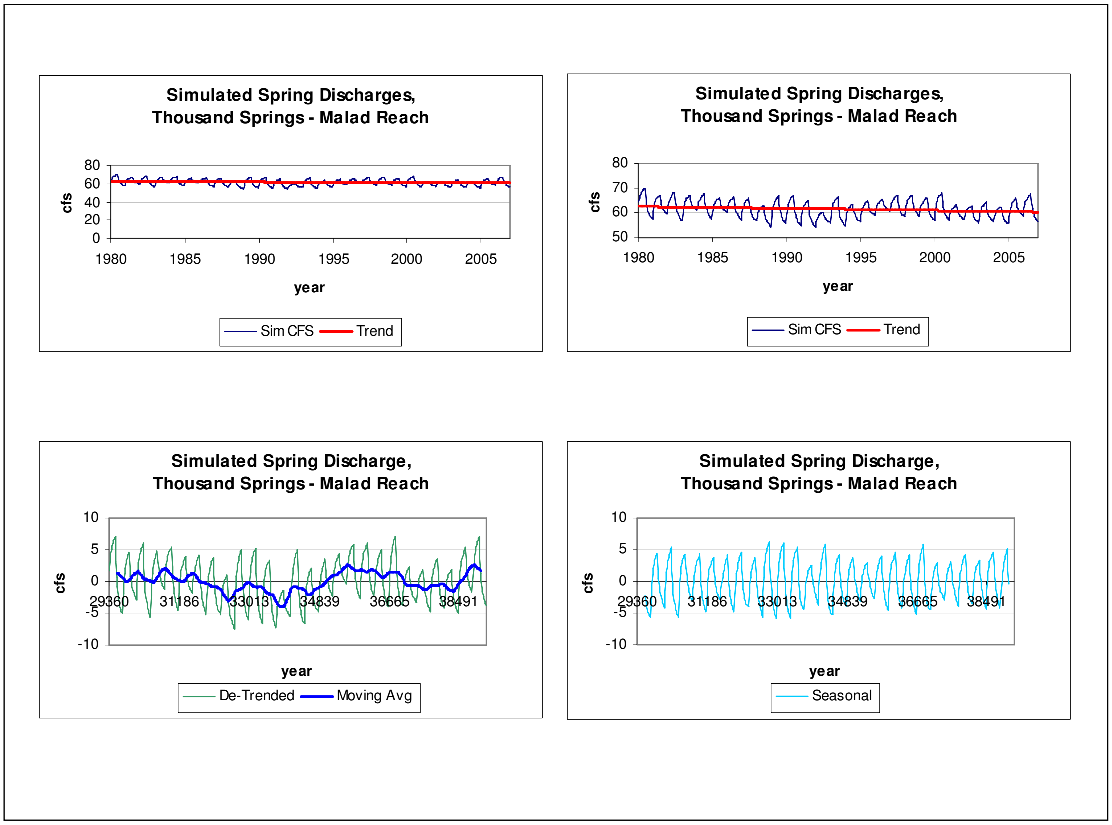
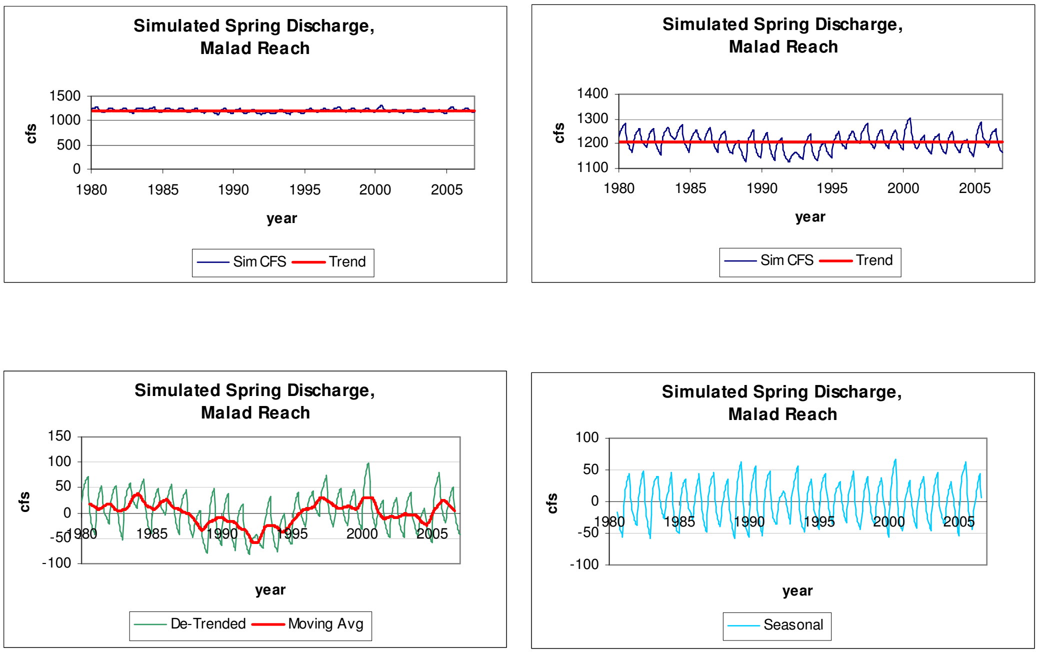


Figure 17. Thousand Springs to Malad simulated spring discharge.



*Note that the regression was not statistically significant, so the mean value was used to represent the trend.

Figure 18. Malad reach simulated spring discharge.

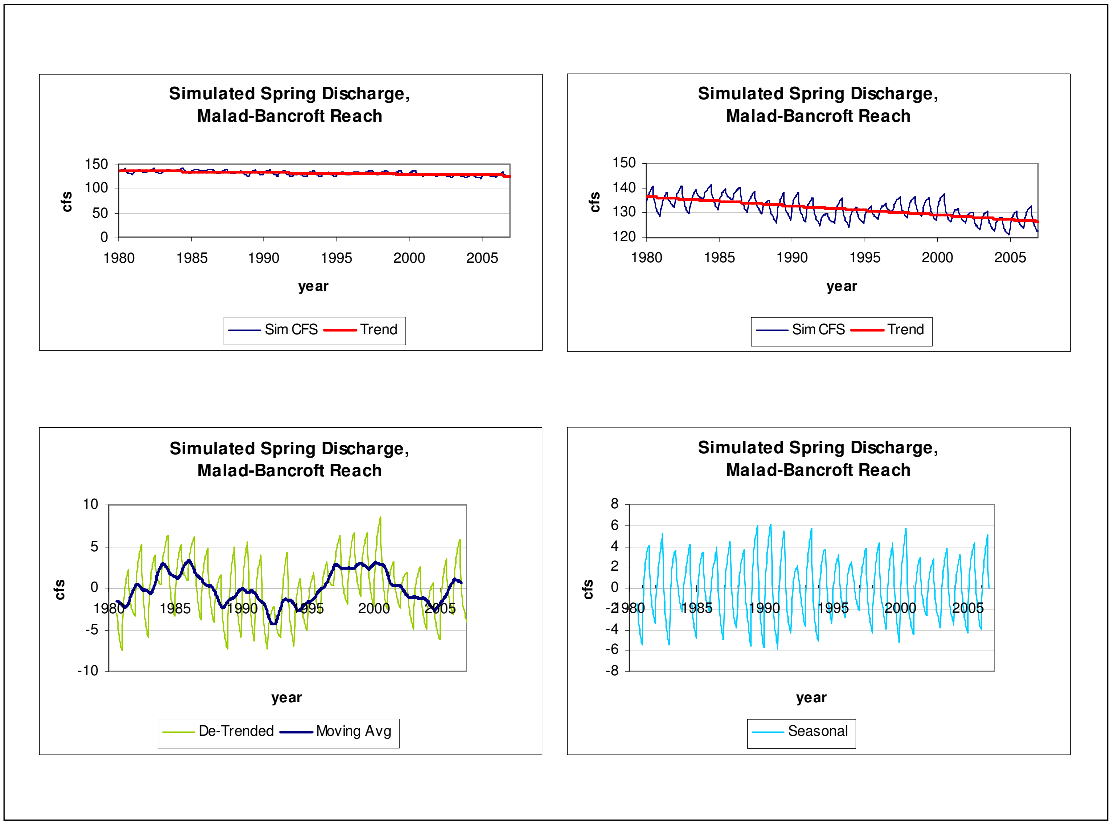


Figure 19. Malad to Bancroft simulated spring discharge.

Time to Reach Hypothetical Equilibrium

Most simulations showed such small changes that the simulated values were within ten percent of the equilibrium value within the first year. The exception was the Ashton to Rexburg reach, where the median time (among the six methods) was ten years for the simulation value to come within ten percent of the final equilibrium value.

Comparison of Representative Data Sets

Table 4, Table 5 and Figures 7 and 8 show that discharge and gains results are very similar across the six representative data sets, except for the Ashton to Rexburg and Neeley to Minidoka reaches. Even in those reaches the differences are small on a practical basis, relative to total flow in the river and relative to the precision of flow measurement and other data. It appears that little uncertainty is introduced into flow results by the differences between the six best-estimate data sets.

In contrast, Figure 5 and Figure 6 show that the different data sets produce markedly different equilibrium aquifer heads in locations distant from the springs and river. The differences are primarily in spatial distribution of water stored in the aquifer; average heads across the aquifer are similar for the six simulations. All six are deemed equally valid; the ESHMC was not able to find a rational basis to prefer any of the methods above the others. The large spatial differences between methods cast doubt on these distant-from-the-river head estimates. It appears that significant water-level uncertainty is introduced by differences between the best-estimate data sets and that indications of water-level differences far from the river are unreliable. [11]

Combining Hydrologic Variability Results with Results from Different Data Sets

The most important results of the scenario are the comparisons of the six equally-valid data sets with the current levels of gains, losses and spring discharges, illustrated in Figures 20 and 21.

The range of values represented in the implied equilibria may be set in context, and expectations for the future may be tempered, by comparing the six data sets with the range of observed hydrologic variability in the historical data.

Cyclical variability was assessed by finding percentiles of the variation in the 13-month moving averages obtained from de-trended monthly (river gains) or 18-day (spring discharge) values. Seasonal traces were obtained by subtracting the moving average from the de-trended monthly or 18-day data, and seasonal variability was obtained by finding percentiles of the variation in these seasonal series.

Figures 22 and 23 apply indications of historical variability to the river-gains differences. Figures 24 and 25 apply variability estimates to the spring-discharge differences.

[11] Not all members of the ESHMC agree with the assessment that distant-from-the-river head results should be characterized as unreliable.

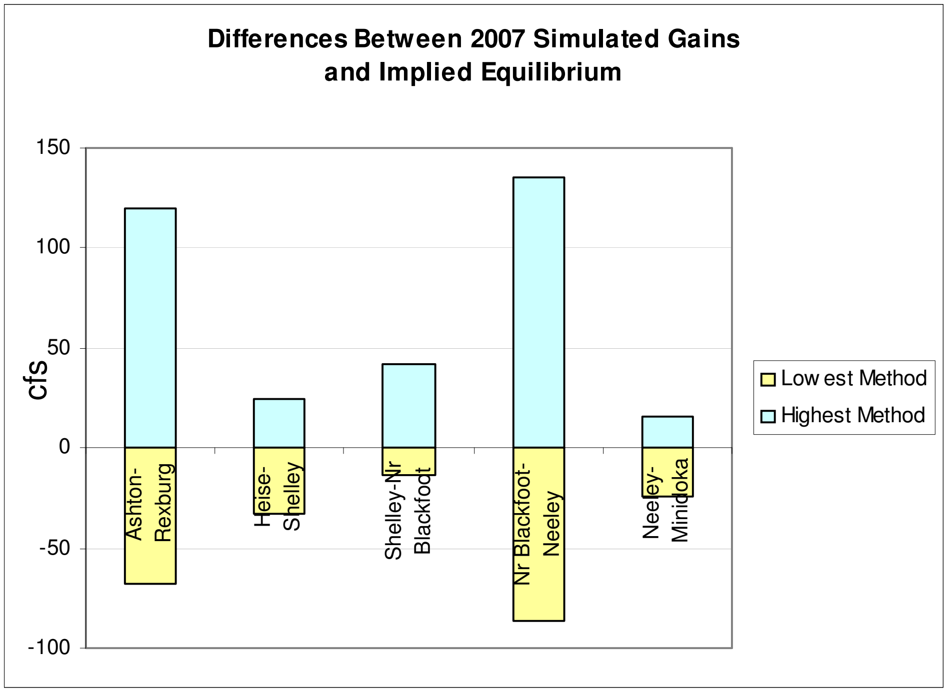


Figure 20. Differences between implied equilibrium reach gains and year-2007 simulated reach gains.

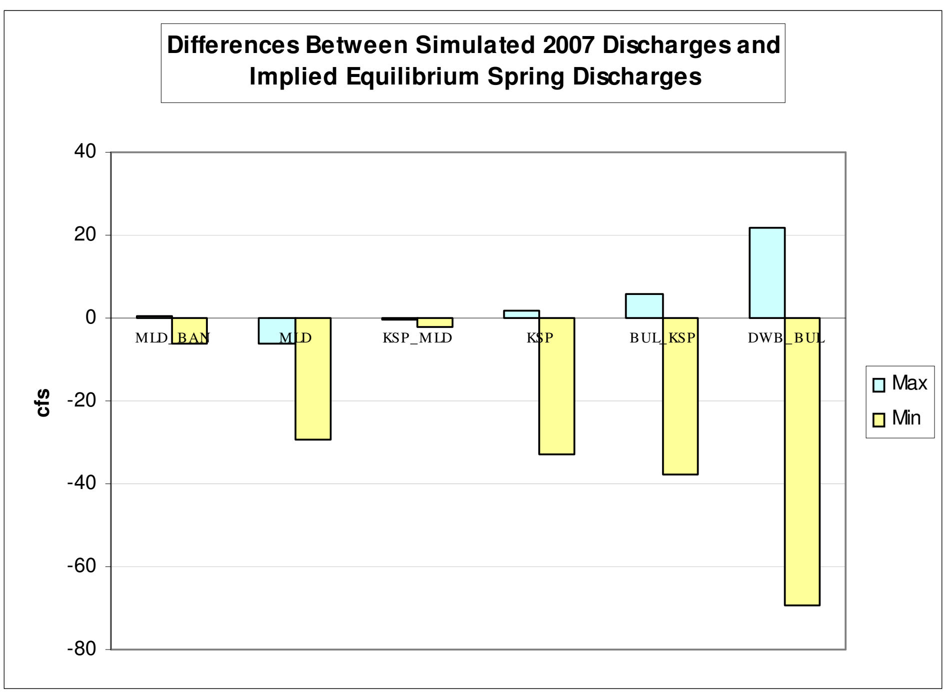


Figure 21. Differences between implied equilibrium spring-reach discharge and year-2007 simulated discharge.

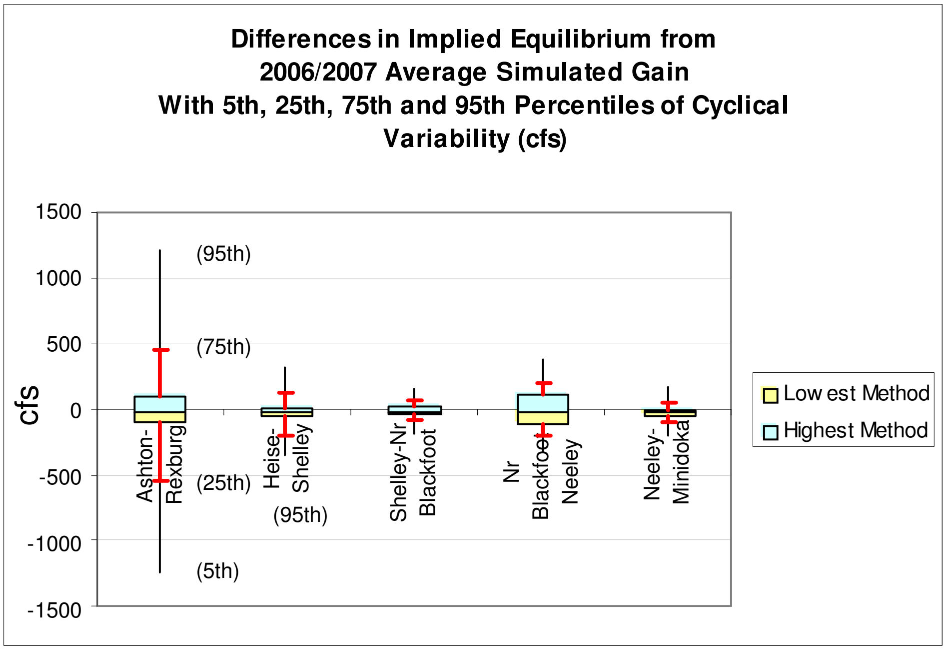


Figure 22. Cyclical (inter-year and multi-year) variability applied to reach-gains differences. If the hypothetical equilibrium were reached, 90% of the time the annual mean gains would be expected to fall between the 5th and 95th percentiles, and 50% of the time to fall between the 25th and 75th.[12]

[12] Differences in equilibrium are from modeled Ashton-Rexburg gains. Variability is from St. Anthony-Rexburg data.

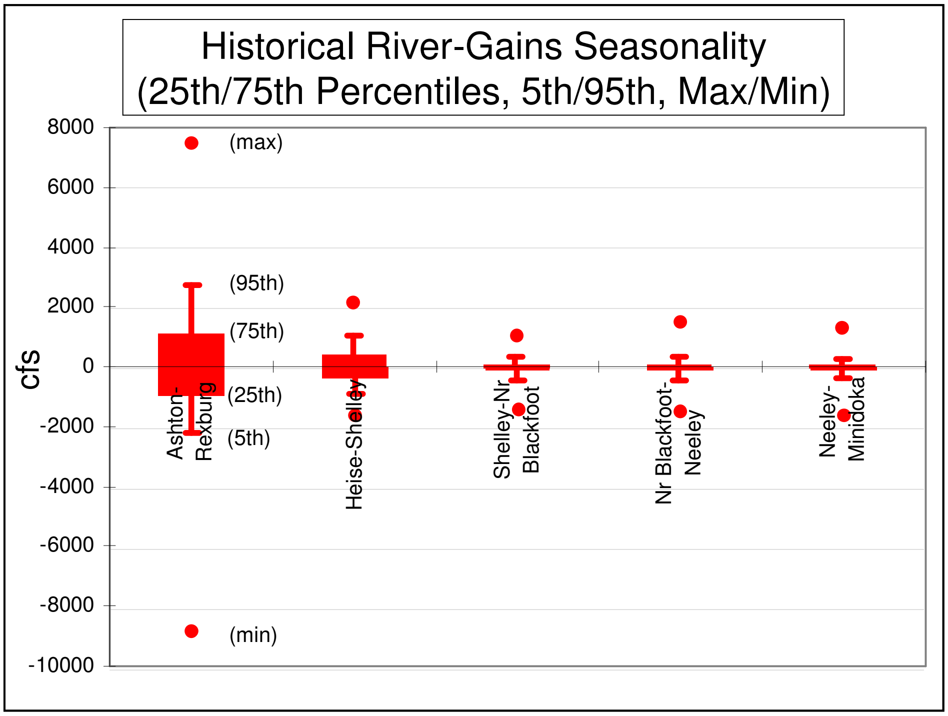


Figure 23. Seasonal (intra-year) variability in historical reach gains.[13]

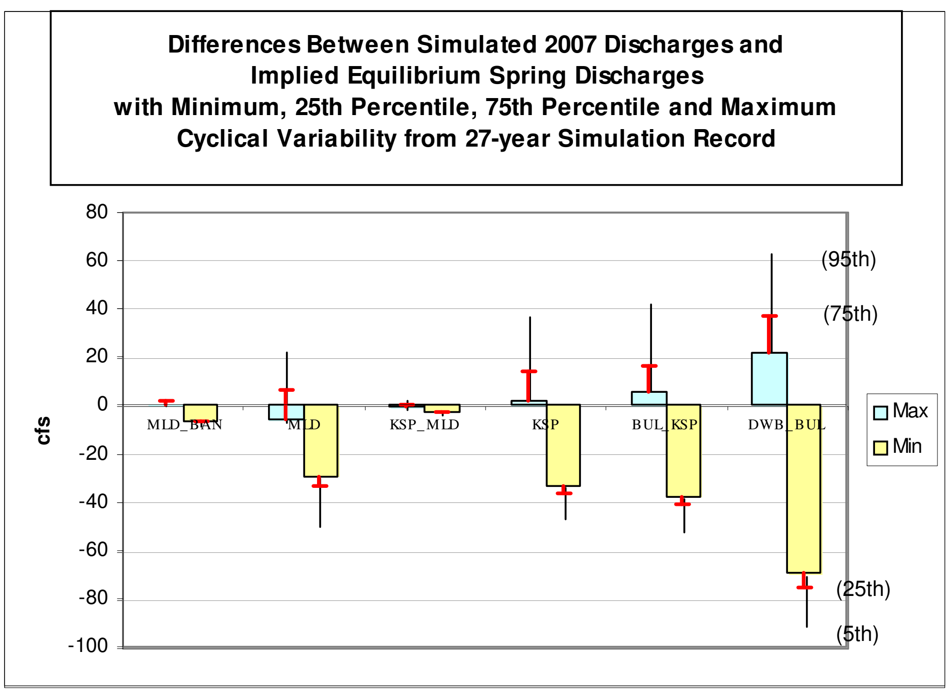


Figure 24. Cyclical (inter-year and multi-year) variability applied to spring-discharge differences.

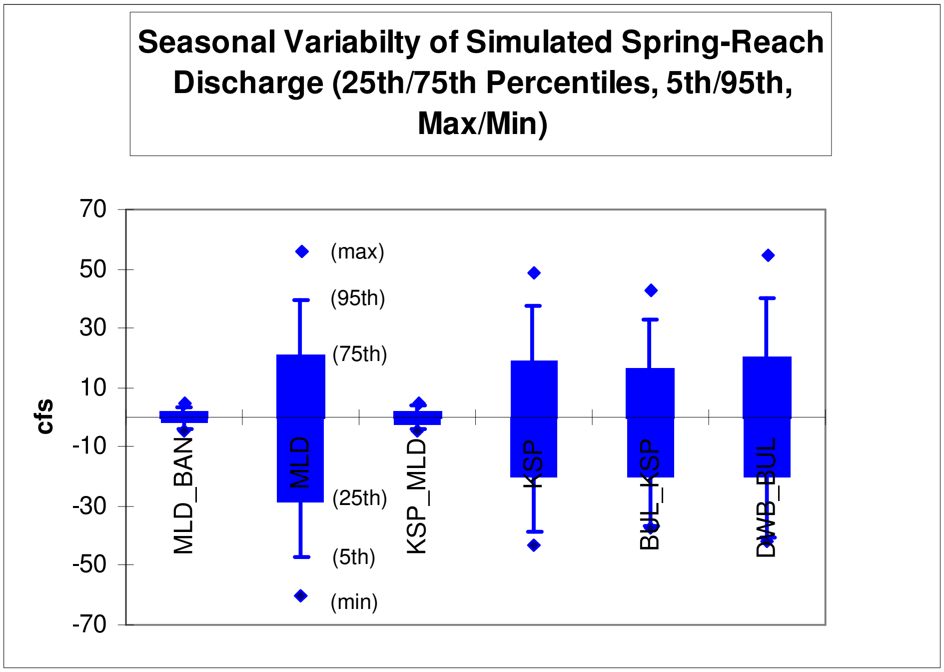


Figure 25. Seasonal (intra-year) variability in simulated spring-reach discharges.

Examination of Figures 20 through 25 suggests that historical cyclical and seasonal variability are large relative to the differences between the implied equilibrium discharges and today's discharges. Comparison of these figures with Figures 7 and 8 shows that, except for the Ashton-Rexburg reach, the differences between the implied equilibria and today's condition are very small compared to total reach gains/losses or spring discharges. On a practical basis, all the differences are small relative to total flow in the river and relative to the precision of available water-measurement methods

CONCLUSIONS

Results from the six representative data sets all indicate that equilibrium spring discharges and reach gains implied by today's practices and historical hydrologic conditions are not too different from today's discharges and gains. Small differences (relative to total gains, and relative to total flow in the river) between the flow estimates suggest that the methods for estimating current practices do not introduce significant uncertainty into flow results. However, aquifer-head results distant from the river contain considerable uncertainty associated with the different best-estimate data sets.

Hydrologic implications of the simulations and comparisons include:

1. no expectation of significant future recovery of gains and spring discharges, unless a future event were to cause such a recovery;

2. no indication that residual effects of past conditions artificially support current gains and discharges;
3. typical variability in gains and discharges is far greater than the differences between the six best-estimate equilibrium average results, and greater than the difference between any of them and current discharges; and
4. variability should be expected to continue into the future.

The Current Practices Scenario *is not* and *cannot be considered* a prediction. In the future, we may experience changes associated with future changes in practice, allocation, or hydrologic regime. The scenario does not address these possibilities.

The scenario *does* address the implications of current practices, allocations and hydrologic regime. It indicates that today's water use (as applied to historic water supply conditions) is more or less in balance with today's general levels of spring discharge and river gains. The implied equilibrium gains and discharges associated with current practices are near today's levels. However, given this implied equilibrium, one would still expect significant seasonal, year-to-year and multi-year variability. If current practices and historical hydrology were to continue into the future, we would expect *neither* rebound nor decline associated with the current water use practices, but we would expect *either* rebound or decline associated with normal hydrologic variability. These variations would oscillate about a mean condition very similar to today's levels of gains and discharges.

REFERENCES

Cosgrove, D.M., B.A. Contor and G.S. Johnson. 2006. Enhanced Snake Plain Aquifer Model Final Report. Idaho Water Resources Research Institute Technical Report 06-002. Available at **http://www.if.uidaho.edu/~johnson/ifiwrri/projects.html**. Most recently accessed August 2007.

IDWR, 2007. Idaho Department of Water Resources. Electronic files with modeling data, parameters and software. Available at **ftp://ftp.state.id.us.gov/idwr/outgoing/**. Most recently accessed August 2007.

IDWR, 2007. Idaho Department of Water Resources. Electronic files with reach-gains calculations adjusted for return flows. Available at **ftp://ftp.state.id.us.gov/idwr/outgoing/** as "Hfsarx.gai.xls" and "Heise_to_Milner_Reach_Gains_Upto_2006_final_RS.xls."

IWRRI, 2007. Idaho Water Resources Research Institute Research and Education Reports. **http://www.if.uidaho.edu/~johnson/ifiwrri/projects.html**. Most recently accessed August 2007.

McDonald, M.G. and A.W. Harbaugh, 1988. A modular three-dimensional finite-difference ground-water flow model. US Geological Survey Techniques of Water-Resource Investigation, Book 6, Chapter A1.

NOAA, 2007. National Oceanographic and Atmospheric Administration. Palmer Drought Severity Index data, eastern Idaho and western Wyoming. **http://lwf.ncdc.noaa.gov/oa/climate/research/prelim/drought/palmer.html**. Most recently accessed August 2007.

NRCS, 2007. Natural Resources Conservation Service. Idaho SNOTEL data, eastern Idaho and western Wyoming. **http://www.wcc.nrcs.usda.gov/snotel/Idaho/idaho.html**. Most recently accessed August 2007.

US BOR, 2007. US Bureau of Reclamation. Historical natural flow data for Heise, Idaho. **http://www.usbr.gov/pn-bin/arcread.pl?station=HEII**. Most recently accessed August 2007.

WRCC, 2007. Western Regional Climate Center, Desert Research Institute and National Oceanographic and Atmospheric Administration. Historical precipitation data, Aberdeen Idaho. **http://www.wrcc.dri.edu/cgi-bin/cliMONtmxt.pl?idaber.** Most recently accessed August 2007.