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# SNAKE RIVER PLAIN AQUIFER MODEL SCENARIO:

# *HYDROLOGIC IMPLICATIONS OF CONTINUED DROUGHT AND POTENTIAL RECOVERY FROM DROUGHT*

## *"Drought Scenario"*

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## INTRODUCTION

This scenario, Hydrologic Implications of Continued Drought and Potential Recovery from Drought, (also know as the "Drought 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. The purpose of the Drought Scenario is to provide context for the other scenarios, which largely examine anthropogenic stresses to the aquifer, Snake River and springs. All the scenarios use the revised Snake River Plain aquifer model to predict hydrologic response to various hypothesized aquifer stresses.

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 scenario, Hydrologic Implications of Continued Drought and Potential Recovery from Drought, is intended to answer the questions: "What is the expected magnitude of impacts to the Snake River and springs if the drought continues?" and "How rapid might recovery be when the drought ceases?" The modeling results predict the spatial and temporal distribution of the hydrologic impacts to springs and rivers from three different synthetic drought and recovery regimes.

## BACKGROUND

The Eastern Snake Plain Aquifer has experienced large anthropogenic stresses over the last 110 to 120 years. Historical surface-water irrigation practices provided large quantities of recharge water incidental to irrigation, starting in the late 1800s. This was due both to leakage from canals and in-field percolation of applied irrigation water. This incidental recharge caused spring flows and river gains to increase. In the middle of the twentieth century, ground water pumping began withdrawing some of this water at the same time that surface-water diversions from the river began to decline. Superimposed upon this human-induced time series is a multi-year drought period that is also decreasing recharge to, and perhaps increasing extraction from, the aquifer. This scenario attempts to isolate the effects of the recent drought and estimate its effects on spring discharge and net river gains.

## SIMULATION AND MODELING APPROACH

Basic Approach. The basic modeling approach was to construct three different 100-year time series of synthetic recharge data for a transient, full-model (i.e. not superposition) rendition of the Snake Plain Aquifer model. The starting heads for the simulations were the ending heads from the calibration period simulation, representing water levels on April 30, 2002. This implicitly includes the cumulative effects of modeled stress in the periods leading up to May 2002. Three different drought periods were simulated, one ending April 30, 2005, another ending April 30, 2006 and a final drought ending April 30, 2007. Following the simulated droughts, a return to normal was simulated for the balance of each 100-year transient model run.

Representation of Drought. In order to produce a timely result without extensive data collection, processing and quality assurance, recharge data from May 2001 through April 2002 were used to simulate the drought years, for all stresses except surface-water diversions and returns and canal leakage. Because model-year 2001 diversions would have included deliveries from surface-water storage carryover, which would not have been available in subsequent years, new data were obtained and processed for diversions from the Snake River and the Big and Little Wood rivers. Return flows were estimated using end-of-calibration return flow coefficients or obtained directly from observations (for the Wood Rivers). For other basins, the drought was represented by using diversion volumes from a low-delivery year in the calibration data sequence. Most of these other irrigation entities were represented by diversion data from model-year 1983, 1992 or 1993.

In model calibration, adjustments were made for low surface-water delivery years to avoid calculating negative net recharge when the ET used in simulation exceeded surface-water deliveries. Only the Richfield Tract required this adjustment in calibration, but for the simulated drought years this adjustment was extended to other areas as required. The adjustment made was to increase diversions enough to avoid negative recharge,[1] though in reality what would occur is that actual ET would be reduced below the values used in simulation. No adjustment was made for ET on ground-water irrigated lands. This implies an assumption that ground-water users would continue to be able to pump a full supply. If aquifer water levels declined to the point of impeding ground-water pumping, this would reduce stress on the aquifer and partially mitigate the impacts shown here.

[1] In model calibration this adjustment was done using the "fixed point pumping" data set. This scenario retained that adjustment for Richfield since it was already represented in the data and was of appropriate magnitude.

Representation of Recovery. Recovery was represented by applying average aquifer recharge from the model calibration period. One adjustment was made, based on a documented change that occurred during the calibration period. Because of significant water-right transfers in the late 1980s that moved surface-water to irrigated lands inside the model domain in the Reno Ditch area (near Birch Creek), the recovery diversions for that irrigation entity were represented using the 1990-2001 average diversions.

It is acknowledged that practices and conditions in the future may not match the average of the calibration period, but additional adjustments would have required subjective decisions and would have potentially increased the opportunity for error.

Table 1 lists the data used for the simulated drought and recovery periods. Figures 1 through 3 illustrate the time series of stress for the four-year simulated drought, including the time series implicitly represented in the starting heads obtained from the end of the calibration model run. The five- and six-year time series would be identical except for a delay in the recovery portion of the time series. Design documents available at http://www.if.uidaho.edu/~johnson/ifiwrri/projects.html describe the components of aquifer recharge and the recharge calculations. Inspection of Figures 1 through 3 shows that the effects of the drought are primarily in reduced surface water diversions, reduced precipitation on irrigated lands, and reduced recharge from precipitation on rangeland. Other recharge impacts such as changes to evapotranspiration and tributary-valley underflow are minor in comparison.

Table 1
Data Used in Simulated Drought and Recovery Periods

| Component | Abbreviation | 2002 (1st year of simulation, 2nd year of drought) | Subsequent years of drought | Recovery |
|---|---|---|---|---|
| ET on irrigated lands | EIR | 2001 | 2001 | Average |
| Recharge on non-irrigated lands | RNI | 2001 | 2001 | Average |
| Precipitation on irrigated lands | PRI | 2001 | 2001 | Average |
| Surface-water diversions and returns[2] | SWV | 2002 | 2003 | Average |
| Offsite pumping | OFF | 2001 | 2001 | Average |
| Fixed-point | FPT | 2001 | 2001 | Average |

[2]Data for 2002 and 2003 were adjusted to prevent negative incidental recharge on surface-water-only lands. For sources other than the Snake River or Wood Rivers, a low-volume year from the calibration period was used to represent the drought periods. Average diversions were adjusted to represent the post-transfer condition in Reno Ditch area.

| Component | Abbreviation | 2002 (1st year of simulation, 2nd year of drought) | Subsequent years of drought | Recovery |
|---|---|---|---|---|
| pumping | | | | |
| Perched-river seepage | PCH | 2001 | 2001 | Average |
| Tributary underflow | TRB | 2001 | 2001 | Average |
| Canal leakage[3] | CNL | 2002 | 2003 | Average |

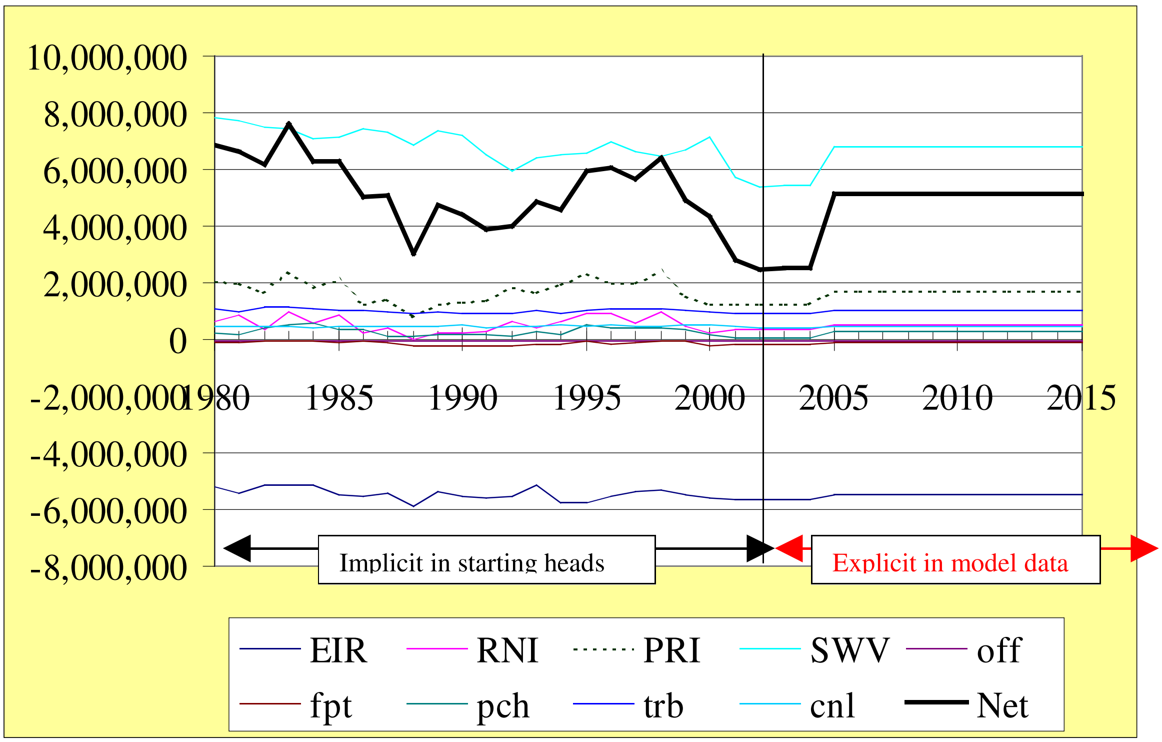


Figure 1. Components of aquifer recharge represented in drought and recovery simulation, acre-feet per year.

[3] Canal leakage is calculated from diversions and reflects the adjustments made to diversions.

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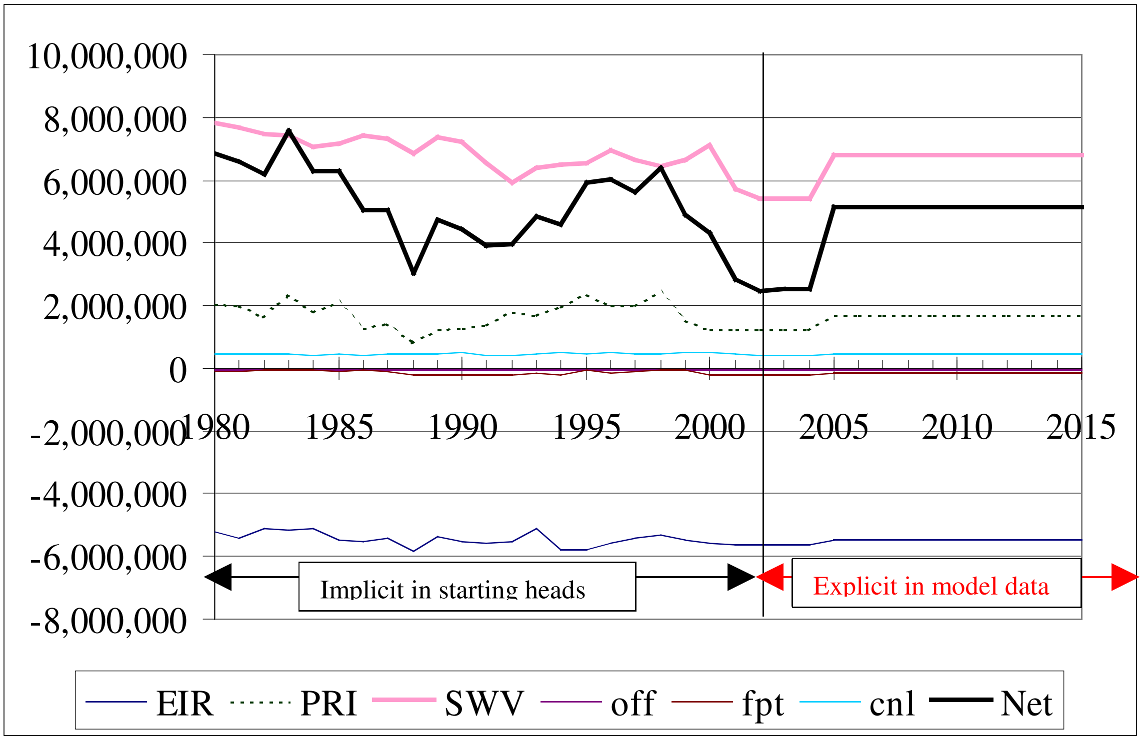


Figure 2. Irrigation components of recharge for drought and recovery simulation.

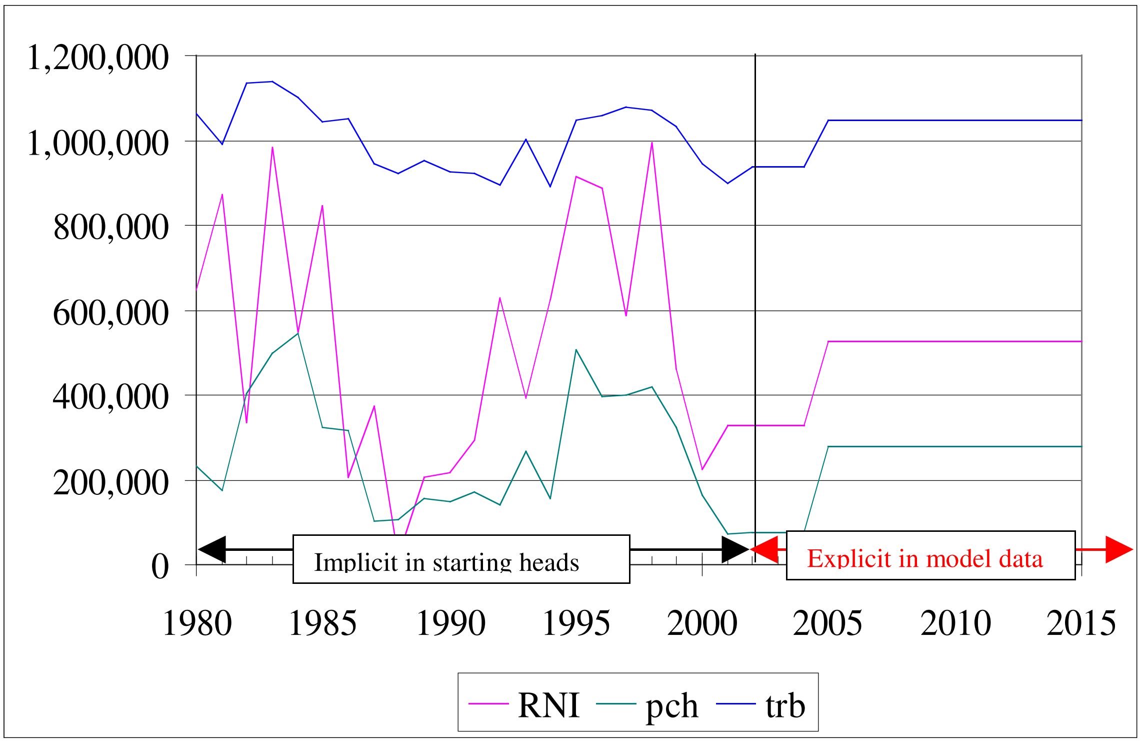


Figure 3. Natural components of recharge for drought and recovery simulation.

Surprisingly, some areas on the plain showed higher surface-water diversions in 2002 than in 2001. This resulted in some spatial variation in distribution of recharge that does not appear in Figures 1 through 3 but influences the reach-by-reach results shown in Figure 6 through Figure 16. The significance and magnitude of the drought are apparent in the net recharge line in Figure 1. Net recharge during the drought period is approximately half the recharge during the calibration period of May 1980 through May 2002. This is a reduction in recharge of almost 2,500,000 acre feet per year, or an annualized average rate of approximately 3,500 cfs.

Definition of Drought and Description of Return Frequency. The methods used for characterizing the intensity and duration of a drought are based on stream-discharge records (Ondrechen 2005). The unregulated flow record at the Snake River at Heise gauge offers a long history of flow largely unaffected by upstream irrigation. The unregulated flow record has been adjusted for the operation of Snake River dams and represents the natural flow that would have been available if the dams had not been in place.

Based on the period of record (1911 - 2004), an 80% exceedence level event (80% of the years in the record exceed the flow of the drought year) defines a population of events that would definitely be considered droughts. Some years in the historic sequence that fall in this category include 1931, 1934, 1961, 1977, 1987, 1988, 1992, 1994 and 2001-2004 (Ondrechen 2005). The synthetic drought for simulation was constructed to have a similar stress to the actual stress for the 2001 through 2004 period and can be defined as representative of an 80%-exceedence drought.

Since the historical record is somewhat less than 100 years, the recurrence interval of any event less frequent than a 100-year event must be estimated using statistical methods. Using methods reported by Millan and Yevjevich (1971) for 80%-exceedence events, it is estimated that an event of four years duration would have a 500-year return period. Five-year-long and six-year-long droughts should have even longer return periods, but the Millan and Yevjevich methodology is only valid up to a 500-year return interval (Ondrechen 2005) so the exact return period is not quantified for the two longer simulated droughts.

## SIMULATION RESULTS

Model water balances at the end of 100 years of simulation showed that less than 0.5% of the modeled recharge was being represented as a contribution to storage, so the final results are virtually at steady state. Figures 4 and 5 show combined results for aggregated above-Milner and below-Milner reaches. Individual sub-reach results are shown in Figures 6 through 16.

The results in the figures are expressed as departures from the average (recovery) condition described above. They may be interpreted as the *impact* to actual discharge on any given date that may be attributed to the cumulative effects of these simulated droughts and recoveries. Total *actual* discharge on any date will reflect the value of cumulative effects from this simulation, plus the impact of any departures in actual stress from the stress used in simulation. These departures will include changes in human practices and natural variations in climate, precipitation and water supply.

In Figure 4, the simulation indicates that in the spring of 2002, discharges above Milner were reduced by about 1,390 (relative to discharges that would result from long-term average 1980 - 2002 conditions), due to the cumulative impacts of the years prior to 2002. Depending on when the drought ends, reach gains and spring discharges could decline another 200 to 400 cfs, based on the simulated drought stress. Recovery will be rapid once surface-water diversions and precipitation return to "average" levels or above.

Actual discharges in 2022 will be governed largely by what happens to human-caused stress and natural recharge to the aquifer, especially in the few years immediately preceding 2022. However, Figure 4 suggest that in year 2022, discharges above Milner will still be diminished by about 200 cfs (from what they would have been otherwise) due to lingering residual impact of the current drought. Similarly, Figure 5 suggests that total impact of the drought on the greater Thousand Springs reach may be 300 to 350 cfs by the end of the drought, and that by year 2022 there will still be a residual impact of about 50 cfs.

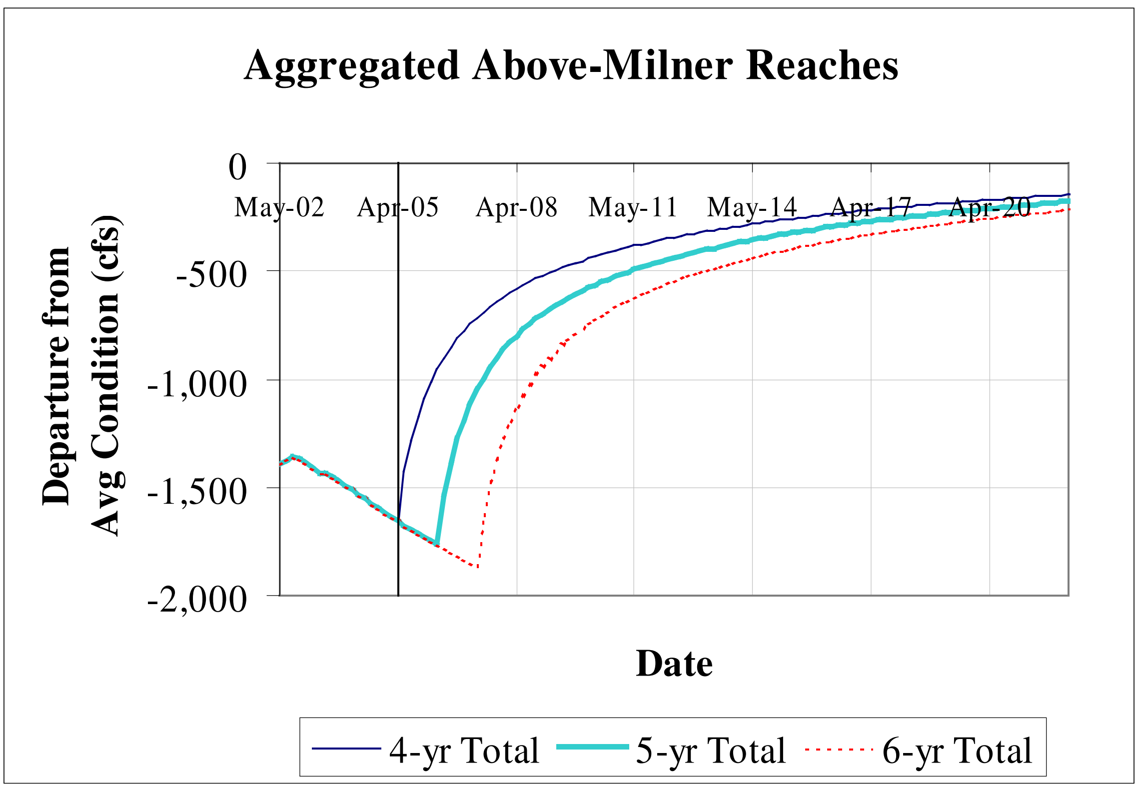


Figure 4. Aggregated transient response of above-Milner reaches to simulated drought of four-year, five-year or six-year total duration. Values are

departures from the 100-year average-condition value (1390 cfs), which approaches steady-state.

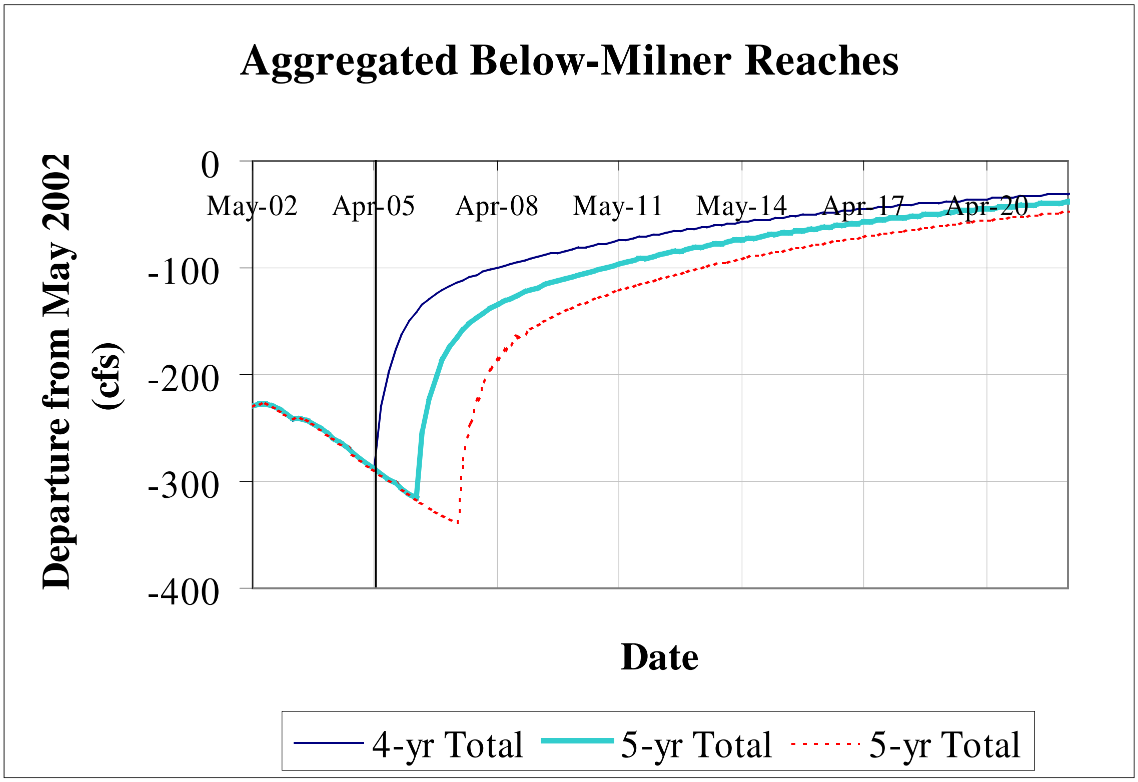


Figure 5. Aggregated transient response of the greater-Thousand Springs reach to simulated drought of four-year, five-year or six-year total duration. Values are departures from the 100-year average-condition value (230 cfs), which approaches steady state.

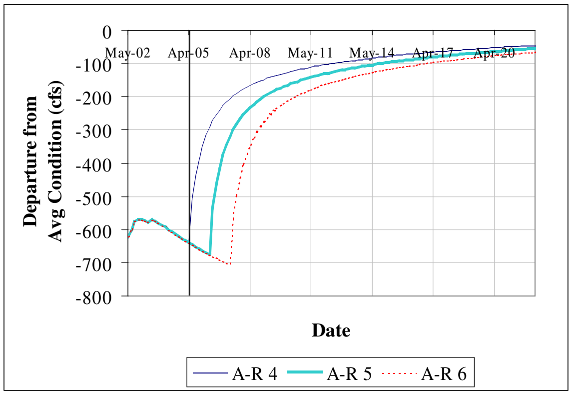


Figure 6. Ashton to Rexburg simulated drought impacts.

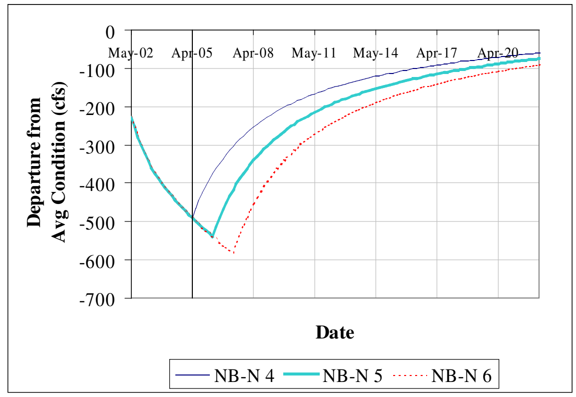


Figure 9. Near-Blackfoot to Neeley simulated drought impacts.

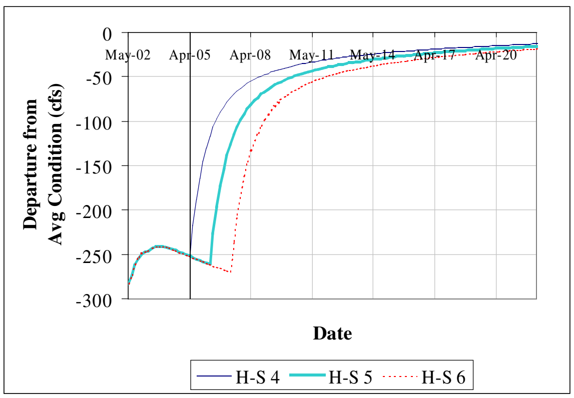


Figure 7. Heise to Shelley simulated drought impacts.

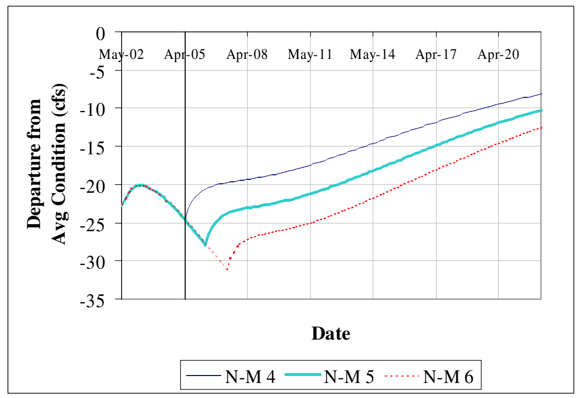


Figure 10. Neeley to Minidoka simulated drought impacts.

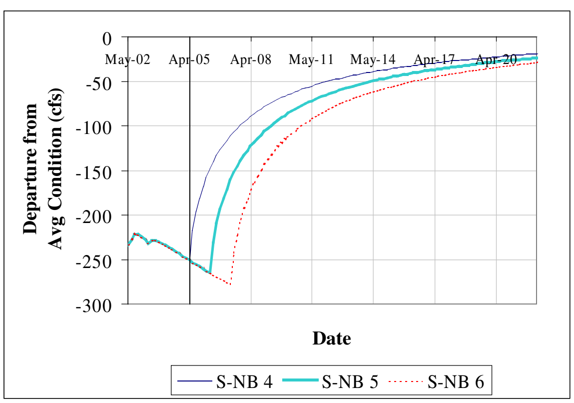


Figure 8. Shelley to Near-Blackfoot simulated drought impacts.

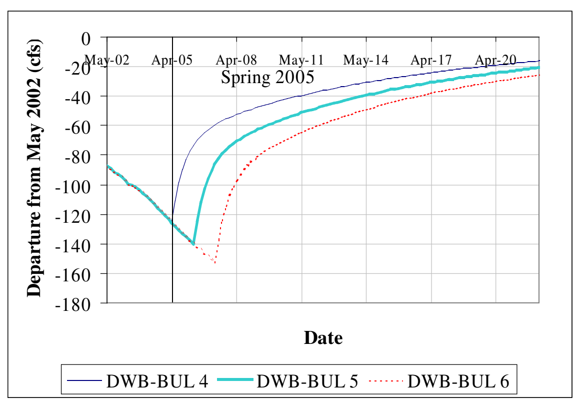


Figure 11. Devils Washbowl to Buhl simulated drought impacts.

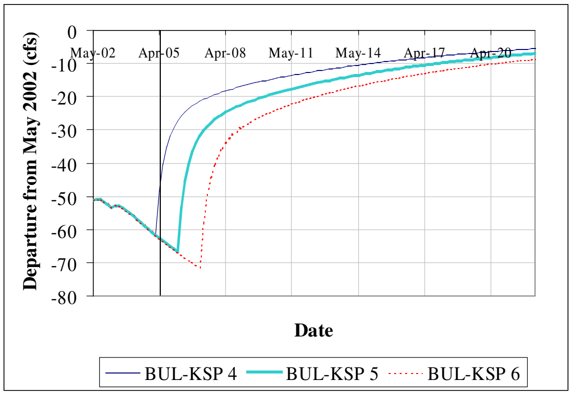


Figure 12. Buhl to Thousand Springs simulated drought impacts.

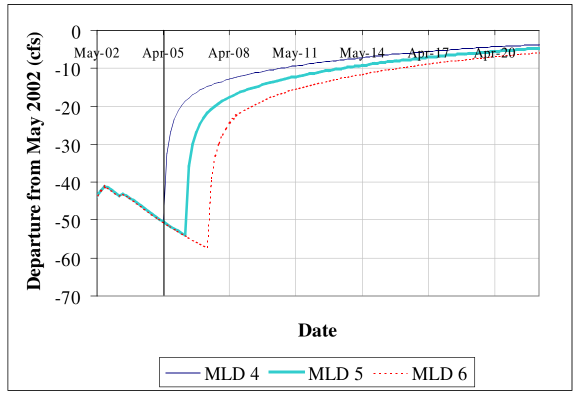


Figure 15. Malad simulated drought impacts.

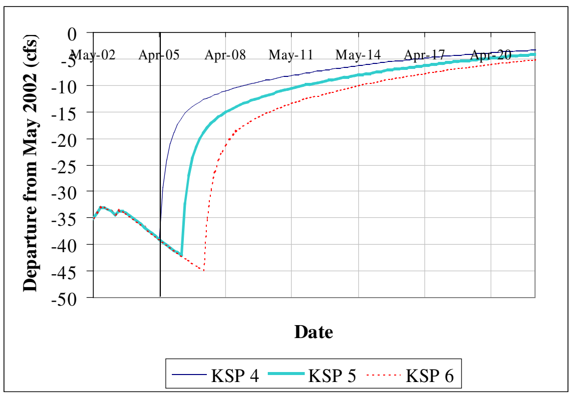


Figure 13. Thousand Springs proper simulated drought impacts.

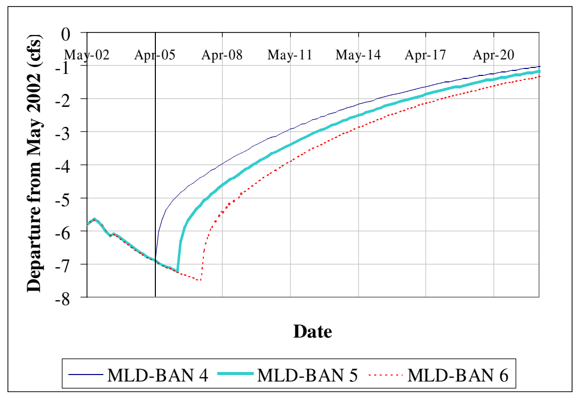


Figure 16. Malad to Bancroft simulated drought impacts.

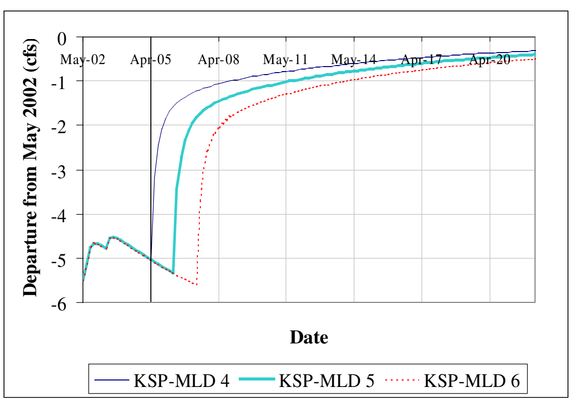


Figure 14. Thousand Springs to Malad simulated drought impacts.

## DISCUSSION OF RESULTS

Spatial Differences in Drought Stress. Several individual reaches (see Figures 6, 7, 10 and 14) show an increase in spring discharge or reach gain from 2002 to 2003, followed by a decline until the end of the drought. This is a result of the fact that while diversions overall were lower for 2002 that for prior years, some entities actually had higher diversions in 2002, temporarily improving nearby reach gains.

Spatial Distribution of Impact. At first glance, below-Milner response appears to be unexpectedly low relative to above-Milner response. This is caused by two characteristics of the simulation data that actually do reflect reality. Most of the drought stress is in the form of decreased surface-water diversions. Figure 17 shows that most of the surface-water irrigated lands affected are east of Milner Dam. Further, the surface-water lands nearest the six below-Milner spring reaches are lands within the Northside Canal Company. While across the plain drought-period recharge is about 50% of average, for the Northside Canal Company, drought-period Snake River diversions are over 90% of average. The surprisingly low drought impact below Milner, then, is a combination of the spatial distribution of affected lands and the smaller magnitude of impact to the lands closest to the springs.

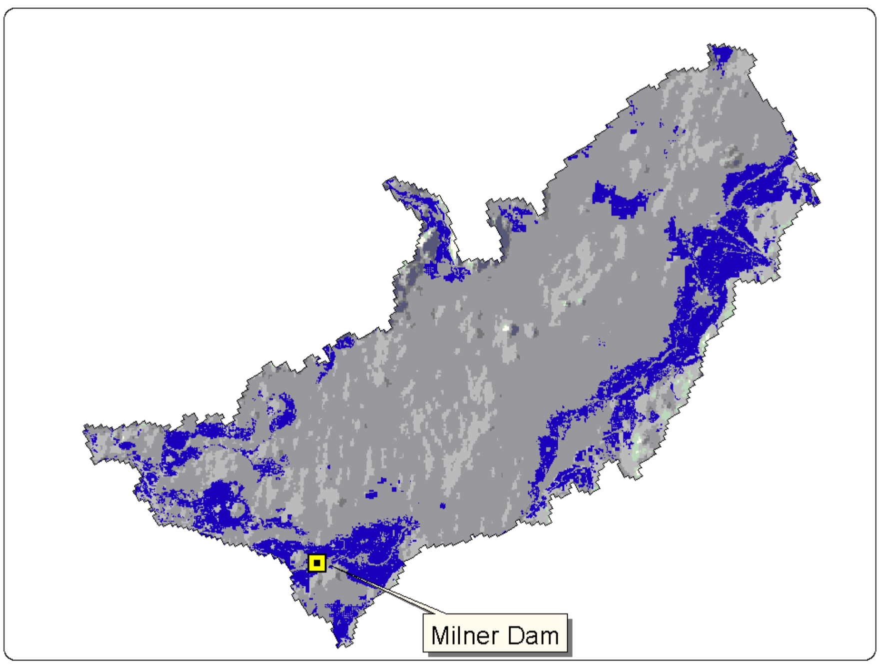


Figure 17. Irrigated lands with full or partial supply from surface water, and location of Milner Dam.

Impacts in the Shelley to Near-Blackfoot and Near-Blackfoot to Neeley reaches. These reaches are of interest because gains in these reaches are important to water users who have storage in American Falls Reservoir and who divert between Shelley and Milner. They are also of interest because Figure 8 and Figure 9 at first glance may appear to be in conflict with the historical lack of change in gains in this area (Garabedian 1992).

The large impact predicted to these reaches by the drought simulations is consistent with the location of lands affected by drought, and consistent with the fact that these two reaches together command a large part of overall aquifer discharge. Preliminary data from IDWR (Ondrechen 2005) illustrated in Figure 18 show that the drought scenario predictions are also consistent with recent observed changes in net gains in these two reaches, even though the drought simulation used estimated rather than actual recharge. The observed changes are calculated using river gauge records and diversion records. The Shelley to Near-Blackfoot reach is typically a loosing reach, and Near-Blackfoot to Neeley is typically a gaining reach. Figure 18 illustrates observed results of approximately 200 cfs increase in the losses in the Shelley to Near-Blackfoot reach and approximately 500 cfs decline in gains in the Near-Blackfoot to Neeley reach. These may be compared with simulated results in Figure 8 and Figure 9.

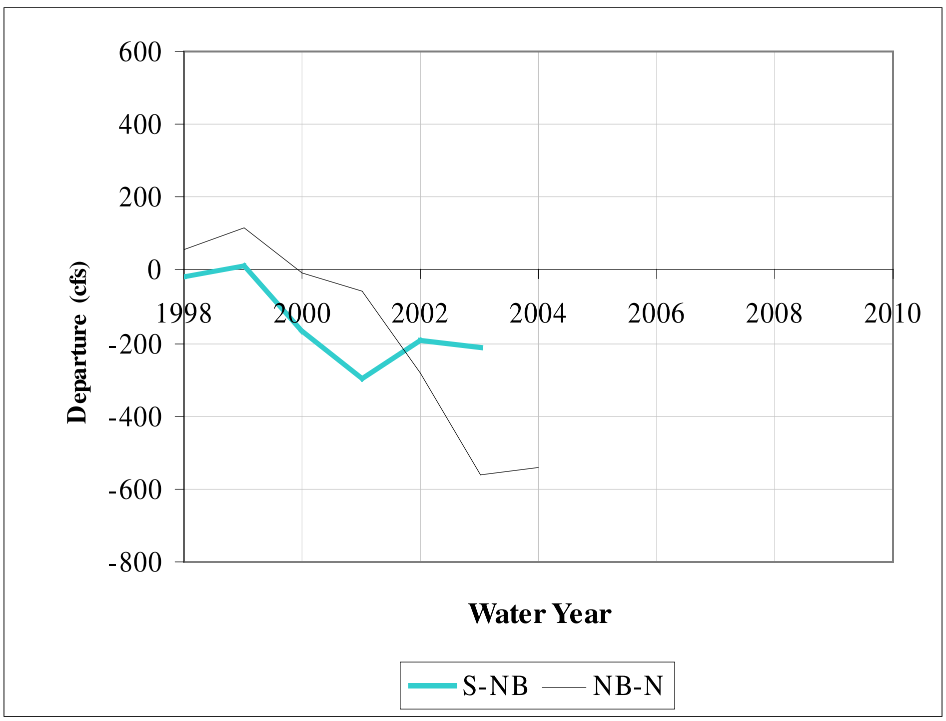


Figure 18. Reach gains departure from calibration period average, Shelley to Near-Blackfoot reach and Near-Blackfoot to Neeley reach. The base period for calculations was water years 1980 through 2001.

Comparison of Drought Impacts to Other Impacts. The total springtime of 2005 simulated impact of the drought is 1,900 cfs, compared to a 3,500 cfs reduction in average recharge during the drought. This suggests that the impact of the drought to springs and rivers has been greatly mitigated by the dampening effect of aquifer storage. If the drought were to continue to steady state without recovery, the magnitude of its effects to springs and rivers would eventually equal the change in recharge, or about 3,500 cfs.

The simulated impact on springs and rivers of 1,900 cfs (with recovery) to 3,500 cfs (without recovery) may be compared to the steady-state results of approximately 2,900 cfs from the Curtailment Scenario (1870 priority cutoff) and approximately 2,600 cfs from the No Surface-water Changes Scenario. Drought effects, then, are in the same range of magnitude as other impacts to the aquifer.

The Curtailment Scenario and No Surface-Water Changes Scenario are not additive, because some changes (such as the impact of supplemental ground-water supplies on mixed-source lands) are common to both scenarios. The combined effect of curtailment and changes to surface-water irrigation is less than the sum of the two effects. Data are insufficient to precisely identify how much overlap there is between the two estimates, though some partition of the contribution of supplemental ground-water development to changes in surface-water diversions is attempted in the No Surface-Water Changes Scenario.

Drought effects are independent of these other effects *in the analysis procedure*, but in reality the current and previous droughts are likely to have influenced both ground-water development and changes in surface-water practices. While the three influences are similar in magnitude, they are not independent and not additive.

The transient impacts of ground-water pumping, surface-water changes and drought may have intercepted impacts of surface-water irrigation that *had not yet been expressed* at the river and springs. Therefore, none of these results can be interpreted as an amount of decline that has occurred from some historical rate of flow. Instead, they represent how much lower today's flows are than they would have been, absent the modeled change (ground-water development, surface-water changes, drought). They also represent the amount of recovery that could be expected if the simulated effect were reversed. The recovery, however, would be superimposed on whatever additional time series of future precipitation, river flows, and human activities were to occur.

## SUMMARY AND CONCLUSIONS

Using a full-model transient representation of the Snake River Plain Aquifer Model, three simulated drought and recovery cycles were represented. All three model runs begin on May 1, 2002, using ending heads from model calibration. This implicitly incorporates 2001, the first year of drought by the criterion that Snake River natural flow at Heise is exceeded by 80% or more of historical observations. An additional three, four, or five years of drought were represented, for total drought length of four, five, or six years. The four-year drought corresponds to a 500-year event. The five-year and six-year droughts correspond to longer recurrence intervals, but the exact recurrence is not identified.

The primary drivers of reduced recharge are surface water diversions, precipitation on irrigated lands, and recharge from precipitation on non-irrigated lands. Following the simulated droughts, return to normal was represented by applying an average calibration-period stress for enough years to complete a 100-year model run. At year 100, results closely approach steady-state values for all three simulations.

Simulation results suggest that current discharges from the aquifer to springs and the Snake River are about 1,900 cfs lower that they would have been without the drought. If the drought continues another two years, an additional 300 cfs of decline may be expected. Most of the declines appear above Milner.

Once precipitation and surface-water diversions return to normal, recovery is predicted to be rapid. Within 15 years of the end of the drought, residual effects should be approximately 250 cfs. The simulations used estimated average recharge conditions to represent recovery, producing very smooth recovery curves. The actual recovery that occurs will be governed by how much human activity and natural conditions depart from the average conditions applied to the model simulation.

The drought has had a very significant impact on river gains and spring discharges, similar in magnitude to the impacts of ground-water pumping and changes in surface water practices. Recovery of springs and river gains should be rapid, once surface-water diversions and precipitation return to average levels.

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