SNAKE RIVER PLAIN AQUIFER MODEL SCENARIO:

HYDROLOGIC EFFECTS OF CURTAILMENT OF GROUND-WATER PUMPING USING SNAKE RIVER PLAIN AQUIFER MODEL VERSION 1.1

"Curtailment Scenario"

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INTRODUCTION

Hydrologic Effects of Curtailment of Ground-Water Pumping (also known as the Curtailment Scenario), was originally performed using version 1.0 of the Snake River Plain aquifer model [Idaho Water Resources Research Institute (IWRRI), 2004]. The Eastern Snake River Plain Aquifer Model (ESPAM) has been updated to version 1.1, and the results of re-running the Curtailment Scenario with the updated model are presented here. The Curtailment Scenario is one of many Snake River Plain aquifer model scenarios being developed to assist in resolution of conflicts among water users and guide future water management such as implementation of managed recharge. Water management should be guided by a collective perspective from many of the scenario evaluations rather than a single document.

The present version of the ESPAM 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 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, IWRRI and technical experts representing water user groups. The ESHMC has also served to guide and review the scenario evaluation process. Documentation of the model and related activities are available from the IDWR and the IWRRI at the University of Idaho.

This “Curtailment Scenario” is intended to answer the question “If all ground-water rights with priorities after a specified date were to be curtailed, what would the effect be on spring discharge and Snake River gains and losses?” This set of scenario simulations assesses this question for ground-water rights with priorities junior to the following dates:

a) the onset of ground-water irrigation (1870)
b) January 1, 1949
c) January 1, 1961
d) January 1, 1973
e) January 1, 1985

The underlying theory of this set of scenario simulations is that if all ground-water rights junior to a certain priority date were to be curtailed, benefits would be accrued to the river gains and spring discharges from the eastern Snake River Plain aquifer. These simulations illustrate the model-predicted increases in river gains and spring discharges over time. Benefit to river gains could be in the form of increased aquifer discharge to the river, decreased losses from the river to the aquifer or increased spring discharge from the aquifer. Future reference to increased river reach gains in this report will include all three of these cases.

It is important to recognize that even after curtailment of ground-water rights, there is a residual impact to river reaches due to previous years of ground-water pumping. The magnitude and timing of this residual impact can also be evaluated using these scenario simulations.

The Curtailment Scenario has been evaluated using numerical superposition. Using numerical superposition, the impacts of curtailment of ground-water pumping can be assessed in isolation of all other recharge and discharge.

The purpose of these scenario simulations is to determine and describe how spring discharges and river gains and losses would be affected by curtailment of ground-water pumping with priorities junior to some specified date. The specific objectives are to:

1) Determine the magnitude of increase in spring discharges and river gains over time for each sub-reach of the Snake River.
2) Determine the seasonal magnitude of the expected increases.
3) Determine the predicted impacts to aquifer water levels.

A related report exists which documents the Modflow files used for the Curtailment Scenario. This report is: Addendum A: CURTAILMENT SCENARIO: Modflow DATA AND PROGRAMS (DDS-004rev1–Addendum).

ESPAM Version 1.1

In May 2005, errors were discovered in v1.0 of the calibrated ESPAM, necessitating recalibration of the model. Correction of these errors and recalibration resulted in ESPAM v1.1, as documented in the ESPAM project final report. Most notable among the errors were: a) ESPAM v1.0 was inadvertently calibrated using the old irrigation return flow lag factors, and b) there was a discretization error in the Shelley to Near Blackfoot and Near Blackfoot to Neeley reaches. Each of these errors would cause a re-distribution of recharge and discharge among reaches of the Snake River and affect the final model parameters (transmissivity, storativity and riverbed conductance). The ESHMC decided that the Curtailment Scenario should be re-run using ESPAM v1.1.

BACKGROUND

Since the onset of ground-water irrigation on the eastern Snake River Plain, ground-water withdrawals have impacted aquifer water levels and river gains and losses. Initially, ground-water pumping removes water from aquifer storage, causing a localized cone of depression. As pumping continues, the effects propagate until a hydraulically connected boundary is reached. A recharge boundary will act as a source for the water being removed via ground-water pumping. Changes in aquifer water levels will impact the amount of water being recharged or discharged from a hydraulically connected recharge or discharge boundary. For example, in a hydraulically connected river reach, the relationship between river stage and aquifer water level will determine the amount of water moving between the aquifer and the river. For a gaining river reach, a decrease in aquifer water level will result in a decrease in the rate of ground-water discharge to the river.

Sources of recharge and discharge on the eastern Snake River Plain include precipitation, recharge incidental to surface water irrigation, ground-water withdrawals, evapotranspiration, tributary valley underflow, and river gains and losses. Of these sources of recharge and discharge, only the Snake River gains and losses are modeled as head-dependent.

As time passes and the collective impacts of ground-water pumping on the eastern Snake River Plain propagate throughout the aquifer system, less of the removed water is coming out of aquifer storage and more is coming from the river, either in the form of reduced spring discharges, decreased aquifer discharges to the river, or increased losses from the river. Ultimately, however, all of the ground water pumped and consumptively used for irrigation will come from the Snake River. It is difficult to quantify the volume and timing of these impacts to the river reaches. A numerical ground-water model is the best available tool for such an estimation.

Historically, the development of ground-water irrigation lagged the development of surface water irrigation by several decades. Figure 1 shows the increase in nominal diversion rate of ground-water rights versus time. The development of ground-water-irrigated land was tied to rural electrification and innovations in pump technology. This increase in ground-water development and other changes in water use caused a corresponding trend of decrease in river gains over time. The resultant decrease in surface water supplies has the potential for a senior surface water user to be damaged by a junior ground-water user. This is the motivation for investigating the potential hydrologic changes associated with curtailment of ground-water use by priority date. In presenting these scenario results, no implication is made of injury to surface water users. The results presented in this paper merely illustrate the potential impact to river gains and losses which could be attained via curtailment.

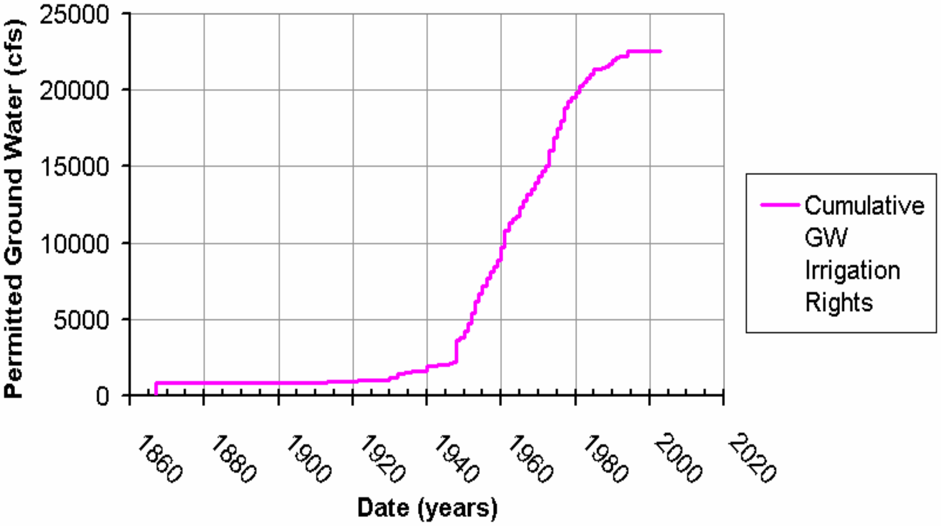

Figure 1. Ground water priorities on the eastern Snake River Plain.

DESCRIPTION OF THE NUMERICAL SUPERPOSITION MODEL

The numerical superposition version of the ESPA model is very similar to the fully populated ESPA model with all recharge and discharge terms removed and with a zero initial gradient. The numerical superposition model uses the concepts of superposition as detailed in Reilly and others (1987). The fundamental basis of superposition theory is that, for a strictly linear system, a complex problem can be decomposed into more simple sub-problems. The sum of the solutions of the sub-problems will be the same as the solution to the whole, more complex problem.

The ESPA model is a confined representation of a generally unconfined aquifer system. Confined aquifer model representations are strictly linear; unconfined aquifer model representations are non-linear due to the fact that aquifer transmissivity changes as aquifer water levels change. In the eastern Snake River Plain aquifer, the changes in water levels are very small relative to the total saturated thickness, so these non-linearities are considered negligible. A comparison of the confined version of the ESPA model versus the unconfined version has been done by IWRRI and is published in ESPAM Design Document DDM-019, Comparison of Unconfined and Confined Aquifer Representation. Similarly, a comparison of model results using the fully populated model versus the numerical superposition model has been done by IWRRI and will also be documented in a report. The results of these evaluations support the conclusion that the non-linearities of the ESPAM are negligible. These results have been presented to the ESHMC.

Model parameters, which represent physical traits of the aquifer system, are the same for the numerical superposition model and the fully populated model. These parameters include aquifer transmissivity and storativity and river and drain conductance. The numerical superposition model requires a zero initial hydraulic gradient, so the initial aquifer head is uniformly set to zero. The Modflow (McDonald and Harbaugh, 1988) representation of drains (springs) only allows water to leave the aquifer. The Modflow representation of rivers allows water to leave or enter the aquifer. Otherwise, drain and river representations in Modflow are identical. For the numerical superposition model, all drain cells (which were used to represent spring discharge between Milner and King Hill) are converted to river cells. The initial elevation of the river cells is set to zero. This creates an initial condition where there is no flux between the aquifer and surface water features. All recharge and discharge terms are removed in the numerical superposition model except for the aquifer stress being evaluated. For example, simulation of an aquifer stress will induce flux from represented surface water features in an amount that is equal to the depletion of rivers and springs for the same stress in the fully populated model. The results from this simulation represent the impacts from the particular aquifer stress being evaluated in isolation of all other recharge and discharge.

A simple example of an evaluation using numerical superposition would be an evaluation of the impacts to river reaches due to pumping at a single well. Pumping at the well does not affect any of the sources of recharge or discharge which are not hydraulically connected. For example, pumping will have no effect on precipitation or evapotranspiration from shallow-rooted plants in an area where the water table is deep, such as in the eastern Snake River Plain aquifer. The cone of depression from the pumping well will propagate radially from the well until the resultant drawdown affects water levels near a river reach. At that time, the pumping will result in a reduction of the river gain or increase in river loss. By analyzing this stress using the numerical superposition model, all exchanges between the river and aquifer will be due to the ground-water pumping being evaluated. Evaluation of the same pumping well using the fully populated model would require running the fully populated model with and without the pumping well and differencing results of the two model runs. The latter analysis is more cumbersome and more prone to analysis and numerical error.

Evaluation of the impacts of curtailment of ground-water pumping was greatly facilitated by using the numerical superposition model. The numerical superposition model is not restricted to the 22-year period of the fully populated model and the effects of curtailment can be evaluated in isolation of all other recharge and discharge, yielding an estimate of expected *changes* in river gains and spring discharges due to curtailment. Evaluations of the results of these scenarios using numerical superposition can be used to estimate expected future impacts to river gains due to curtailment and the residual impacts to river gains from ground-water pumping after ground-water curtailment. Using superposition allows analysis of the future impacts of a specified stress (in this case, ground-water pumping) without requiring knowledge of other future conditions such as weather.

GROUND-WATER PUMPING CURTAILMENT ANALYSIS METHOD

The Curtailment Scenario has been evaluated using the following general steps:

a) Retrieve data from the IDWR water rights database which describes point of diversion, purpose of use, priority date, diversion rate and place of use for all ground-water rights. The results of this one-time query were intersected with the model grid and stored in a database.

b) Query the database created in step a) for ground-water irrigation rights with a priority date junior to the date of interest. The percentage of ground-water use in each model cell that is junior to the specified priority date is calculated. The results are applied to the current GIS layer of irrigated lands and multiplied by the ground-water irrigated area within the model cell, creating a new GIS layer containing the lands irrigated under water rights that are junior to a specific priority date.

c) Apply average (1961-1990) values of precipitation and average (1980-2001) evapotranspiration to this new irrigated lands coverage to estimate net consumptive use for the lands identified in the query. For the long-term curtailment assessment, the annual averages of precipitation and evapotranspiration were used. For the seasonal curtailment assessment, summer and winter (corresponding to irrigation season and non-irrigation season) averages were used. These data were used as input to the GIS-Fortran Recharge Program to create the Modflow Well File for the numerical superposition version of the ESPA ground-water model, representing only the consumptive use associated with ground-water development across the eastern Snake River Plain under water rights that are junior to the specified priority date.

d) Run the numerical superposition version of the ESPA ground-water model using the Modflow Well File created in step c). Both the steady state and transient numerical superposition versions of the ESPA ground-water model were run for this step.

e) Determine the impacts to each river reach due to the ground-water pumping.

Step a) was only done one time. Steps b) through e) were done once for each of the five selected priority dates and for both the average and seasonal cases. Each of these steps is described in more detail in Appendix A.

For the ESPAM v1.1 version of the Curtailment Scenario, no changes were made to the GIS processing used to produce the Modflow well file. Therefore, the only changes were to the Modflow files representing storativity, transmissivity and river and drain conductance.

DISTRIBUTION OF CURTAILED AREAS

How river reaches are affected over time by curtailment depends on the distribution of the area being curtailed and the consumptive use associated with the curtailed area. Figure 2 shows the proportion of the ground-water irrigated area junior to 1870 (nearly all ground-water irrigated lands) for each model cell. The irrigated areas are color-coded, with dark cells being 80-100% irrigated by ground water junior to 1870, lighter colors being less. Figures 3 through 6 show the proportion junior to January 1, 1949, January 1, 1961, January 1, 1973 and January 1, 1985, respectively. Figures 2 through 6 show the spatial distribution of ground-water use relative to river and spring reaches as well as the location of new ground-water development for each time period.

Close inspection of Figures 2 through 6 shows where ground-water development was most common during various time periods. For example, looking at the difference between Figures 3 and 4, it is clear that much of the development with priority dates between 1949 and 1961 was in the area of the A&B Irrigation District, the Oakley Fan and north of American Falls.

The analysis of curtailed areas excluded ground-water rights in the Ft. Hall area that were senior to 1870. These are tribal rights and are not subject to curtailment. Appendix B contains a summary of the number of curtailed acres and the associated amount of consumptive use by ground-water district.

MODELING ANALYSES

Determine the Magnitude of Expected Spring and River Accruals Due to Long-Term Curtailment of Ground-Water Pumping (Objective 1)

Curtailment of ground-water pumping will result in increases in river gains (or decreases in river losses) either due to a) increased spring discharge in the Thousand Springs and American Falls area or b) higher aquifer water levels near other hydraulically connected reaches of the river, causing more water to discharge to the river reach (or, in the case of a losing reach, causing less water to be lost from the river reach). River gains were evaluated for each of the five cutoff dates for ground-water pumping as detailed in the Introduction. The gains were evaluated for both the steady state case (infinitely long time) and for the transient case (predicting impacts over time).

Steady State Results

Steady state simulations were performed to predict the accruals to river reaches after the full impact of the curtailment has been realized. The steady state analysis presumes the unlikely case that pumping has been permanently curtailed. Table 1 lists the predicted steady state gains by river reach for each modeled cutoff period. Additionally, Table 1 lists the time for each reach to come within 10% of the steady state value. For example, in Table 1, curtailment of all ground water is predicted to cause a 298 cfs accrual in the Devil’s Washbowl to Buhl reach. Transient simulation results indicate that it would take approximately 59 years for the recovery to reach 90% of the steady state value. Similarly, curtailment of ground water junior to January 1, 1973 is predicted to cause an 88 cfs recovery in the same reach. Ninety percent of this recovery would be realized in 51 years.

Comparison of Table 1 with Figures 2 through 6 shows that the magnitude of the predicted accrual for each reach is dependent upon proximity of the area being curtailed to the specific reach and the volume of ground water pumped within that area. For example, although the Devil’s Washbowl to Buhl reach has significantly less spring discharge than the Malad reach, the predicted steady state gain in the Devil's Washbowl to Buhl reach due to curtailment of all ground-water pumping is 298 cfs versus 77 cfs for the Malad reach. Figure 2 shows that most of the ground-water irrigated acres are east of the Malad reach, so curtailment will have the greatest impact in the eastern and northern areas of the eastern Snake River plain. Table 1 provides some indication of the spatial distribution of predicted impacts due to curtailment of ground-water irrigation.

Transient Results

Figures 7 through 17 show the predicted reach accruals over a long period of time for each modeled reach, for each cutoff date. For example, Figure 17 shows predicted accruals for the Malad to Bancroft reach in the Thousand Springs area. The yellow line in Figure 17 represents the expected reach accrual (which, in this case, equates to an expected increase in spring discharge for this reach) if ground-water pumping junior to January 1, 1985 were to be curtailed. Similarly, the orange line shows expected accruals if pumping junior to January 1, 1973 were curtailed, etc. Each figure also shows the steady state value for predicted accruals for each of the cutoff dates.

Also apparent in Figures 7 through 17 is the fact that some of the river reaches approach steady state more rapidly than others. This is due to how proximal the curtailed ground-water pumping is to the river reach and the magnitude of the change in stress. If the pumping is distant from the reach or the change in stress is very large, the effects take longer to propagate through the aquifer, causing a longer time until steady state is reached.

Similarly, within a given reach, curtailment related to each cutoff date approaches steady state at a different rate. Again, using Figure 17 as an example, in the Malad to Bancroft reach, the impacts associated with a cutoff date of January 1, 1985 approach steady state after approximately 50 years. However, the impacts associated with a cutoff date of January 1, 1949 do not approach steady state until approximately 90 years. This is due to the spatial distribution of the ground-water pumping being curtailed as well as the spatial distribution of storativity and transmissivity. The response to curtailment will also vary reach by reach. Figures 7 through 17 were generated using an average annual net consumptive use and, therefore, show no seasonality.

Table 2 summarizes the predicted reach accrual after one year of curtailment for each reach for each cutoff date. These results can be used to estimate impacts of curtailment of ground-water pumping on a year-by-year basis. Looking at the Buhl to Thousand Springs reach, a 1-year curtailment of all ground-water pumping junior to January 1, 1870 would result in a 34,000 acre-foot accrual. Similarly, in the Buhl to Thousand Springs reach, a 1-year curtailment of all ground water junior to January 1, 1973 would result in a 16,000 acre-foot accrual by the end of that year.

Determine the Seasonality of River Accruals Due to Curtailment of Ground-Water Pumping (Objective 2)

The seasonal nature of ground-water pumping will cause the impacts of curtailment to have seasonal swings. These seasonal swings will be most prominent in reaches very close to curtailed areas and more dampened in reaches that are affected more by distant ground-water pumping. The seasonal swings are important, however, in that the reach accruals due to curtailment will vary seasonally and not be a continuous smooth curve as those shown in Figures 7 through 17. This means that the peak of the accrual due to curtailment may come at a time other than when the water is most needed in the reach.

Since curtailment represents the cessation of an activity, it is conceptually difficult to understand why the predicted accruals will have a seasonal component. These simulations are intended to predict the changes in river reach accruals due to curtailment. Under normal operation, the river reaches would be seasonally impacted due to ground-water pumping, with depletions occurring during the irrigation season and recovery during the non-irrigation season. The numerical superposition model is used for estimating *changes* in river reach gains. When these changes are superimposed on measured reach gains, the model predicts what the measured reach gains would have been, had the change already occurred. Figures 18 through 28 show curtailment effects during the irrigation season with an estimated attendant reach accrual, and less accrual during the non-irrigation season because there is no pumping to curtail at that time.

Figures 18 through 28 show the seasonal predictions of reach accruals for the 11 reaches of the Snake River for each of the five cutoff priority dates. Each of these figures shows the characteristic increase in reach accruals during the irrigation season with a diminished accrual during the non-irrigation season. The reader should note that the scale on the y-axis varies for each of the graphs in Figures 18 through 28, indicating a variation in magnitude of the accrual and the seasonal variation. The magnitude of the seasonal variation depends upon how close the reach is to the areas being curtailed and the overall magnitude of the predicted reach accruals. For example, the Malad-Bancroft reach, shown in Figure 28, has a seasonal variation in spring discharge of only about 3 cfs due to curtailment of all ground-water pumping. In contrast, the Buhl to Thousand Springs reach, shown in Figure 24, has an almost 80 cfs seasonal swing between spring and fall.

Many of the reaches depicted in Figures 18 through 28 show a winter decline almost back to the river reach gain levels of the previous year. Some of the reaches, however, show a smaller decline relative to the predicted accruals. This would indicate that the curtailed areas are more distant from the reach and that the accruals are taking longer to get to the reach. Figure 18 shows this dampened seasonal effect for the Ashton to Rexburg reach. Inspection of Figures 2 through 6 show that relatively little of the curtailed area is close to this reach, so the impacts are traveling further and are attenuated before impacting the Ashton to Rexburg reach.

Figures 18 through 28 also show the predicted 10-year accrual for a 1-year curtailment of pumping junior to 1985 and pumping junior to 1870, for each reach. As can be seen in

Figures 18 through 28, even after the 1-year curtailment is lifted, there would be residual accruals at the river reach from the 1-year curtailment.

Determine the Predicted Impacts to Aquifer Water Levels After Curtailment of Ground-Water Pumping (Objective 3)

Just as curtailment of ground-water pumping will cause increases in river gains, curtailment will also cause a recovery of aquifer water levels. Figures 29 through 34 show predicted changes in aquifer water levels at six locations throughout the plain due to curtailment of all ground-water pumping. In each case, the aquifer water levels are predicted to rise. The magnitude of the rise is driven by how proximal the curtailed ground-water irrigated lands are to the river reach under evaluation.

SUMMARY

Curtailment of ground-water pumping by specified priority date will have varied impacts on reaches of the Snake River, depending upon the location and size of the curtailed areas. Even with permanent curtailment of ground-water pumping, there would be residual impacts to the river for decades into the future. The magnitude of predicted accruals at each river reach is dependent upon how close the curtailed area is to each reach and the magnitude of the curtailment.

There will be a seasonal aspect to the actual accruals to river reaches as a result of curtailment. Curtailment will result in peak increases in the fall, at the end of the irrigation season, declining over winter to a low in the spring. This seasonal aspect to the recovery of the modeled reaches could be important depending upon what the water is being used for.

For the temporary, 1-year simulation, maximum realizable accruals are relatively small but the benefits last for several years. Most of the ground-water pumping occurs in the eastern and northern portions of the eastern Snake River plain, creating a natural limit on the benefit that can be realized at the most western reaches of the Snake River.

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Appendix A. Detailed Procedures Used for Curtailment Scenario.

Data Retrieval from IDWR Water Rights Database

The point-of-diversion water right table described in the main body of the report is based on the IDWR water rights and adjudication databases, and processed specifically for this application. IDWR personnel extracted point-of-diversion data for all ground-water rights within all the Administrative Basins that intersect the plain. Because of the ongoing Snake River Basin Adjudication, each right may be represented in multiple locations within the databases. The query was structured to avoid duplicate retrievals and extract only current data. Where available, adjudication partial decrees were used.

The result was two data tables. The first was a point-of-diversion table that contained an entry for every unique combination of point of diversion and water right. The table contained many data fields, including geographic location (X and Y coordinates), a water-right identifier, a priority date and an enlargement flag. The second table was a water-right table that contained an entry for every unique combination of water right and water use. This table included the water-right identifier, water use, and diversion rate specific to the water use.

A GIS program was used to assign model-cell identifiers to each point of diversion, and perform a many-to-many data-table join. This generated a data table with an entry for every unique combination of point of diversion, water right, and water use. For each use, the associated diversion rate was apportioned to all points of diversion for that use, for that right. The priority dates were retained in calendar date format, but were also recorded in new data fields representing the priority dates as integer numbers. One of these represented the nominal water-right priority date and the other represented the effective date, considering that enlargement water rights are subordinated to April 12, 1994. IWRRI and IDWR performed careful quality-assurance checks on the joined data table (Ciscell, 2004).

Determination of Net Consumptive Use Associated With Ground-Water Irrigated Areas Junior to Specified Priority Date

Irrigated areas were identified using the GIS polygons used in model calibration. Water-right place-of-use descriptions were not used to determine irrigated areas because of the effects of overlapping water rights. Irrigation water source (i.e. surface water or ground water) was identified using data from the model calibration.

In the recharge tool, the irrigated area for each model cell was calculated using GIS-derived area multiplied by a source fraction. In these simulations, the source fraction was set to zero on surface-water-irrigated areas (including the surface-water member of each mixed-source pair). On ground-water-irrigated areas (including mixed-source members), the source fraction was set equal to the calibration-period source fraction (indicating the fraction of irrigation water supplied by surface or ground water) multiplied by a consumptive use fraction. The consumptive use fraction was based on priority dates and derived from water right point-of-diversion data.

Scenario consumptive use was based on the average of 22 years of calibration data (May, 1980-April, 2001). In the recharge calculations, consumptive use is applied only to irrigated areas. By scaling the irrigated area according to priority-date consumptive fraction, only the consumptive use represented by the selected priorities was applied to the model.

The consumptive use associated with a given priority date was determined by the fraction of total diversion rate that is junior to the given priority for water-right points of diversion within each model cell. Face-value diversion rates were used, without considering combined use limitations, because only the face-value rate is readily extracted by a database query. This process of scaling the calibration-data consumptive use allows direct comparison to other model runs and avoids the difficult problem of establishing a linkage between water-right diversion rate and consumptive use. It relies on an assumption that the progression of nominal diversion rate over time paralleled the progression of consumptive use.

To test this key assumption, a statistical sampling of 20 quarter-quarter sections was evaluated. All irrigation rights within each tract were examined manually, considering all combined use limitations on acreage. The actual progression of irrigated acreage over time was calculated, assuming that consumptive use would correspond to irrigated acreage. This was compared with the progression of nominal diversion rate that could be automatically extracted from the data. Some individual tracts showed considerable over- or under-estimation at some priority dates. Figure A-1 shows the combined results for the entire sample. Across the range of priority dates, the difference between the two methods was not statistically significant.

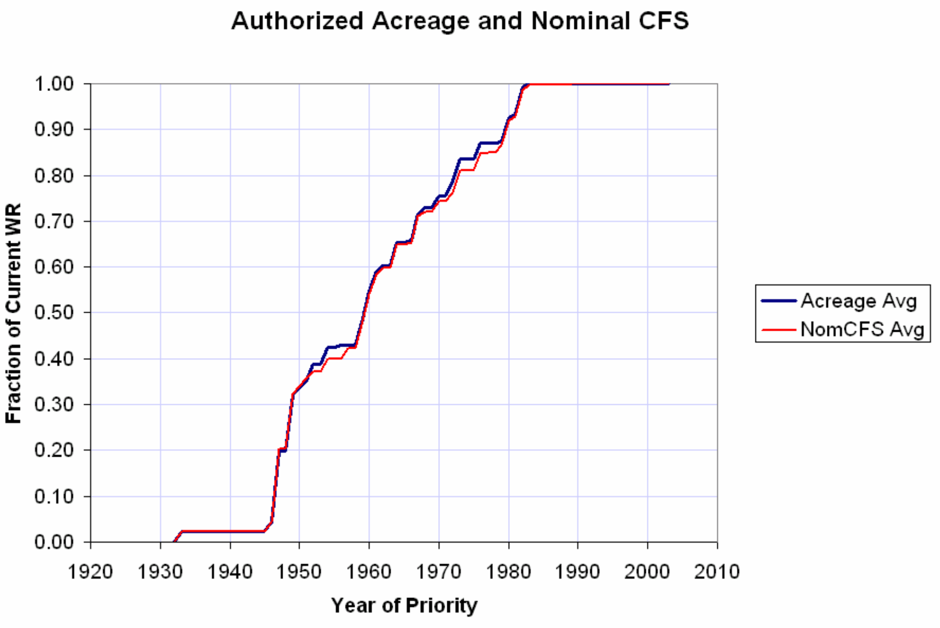

Figure A-1. Results of diversion-rate method test for statistical sample

To move from a data table of diversion rates to a consumptive use fraction by model cell, a Visual Basic program (P_DIV_FRAC.EXE) was utilized to manipulate the point-of-diversion water-right file. The water-right file can be queried for specific water uses before calculating the diversion fractions; in this case only irrigation rights were selected.[1] This assumed that minor omissions would not affect the illustrative nature of these simulations. For a simulation evaluating an actual contemplated administrative action, other assumptions could be made.

The program P_DIV_FRAC.exe uses the selected records to produce a new data table listing the fraction of diversion rate within each model cell that is junior to a user-specified priority date. The process was repeated for each of the sample curtailment dates, but any desired date may be analyzed when an actual situation is to be evaluated.

Once consumptive use and ground-water irrigated areas were determined, the data were processed using the Fortran component of the GIS-Recharge Tool, resulting in Modflow Well files, the input files for the ground water model which represents the ground water pumping. The Well files for the long-term curtailment simulations represent the rate of average daily ground water pumping, spread out over a year, for each model cell. The Well files for the seasonal curtailment simulations represent the average net consumptive use alternating for the irrigation season and for the non-irrigation season. One Well file was generated for each of the five desired time periods, for each type of simulation.

Handling of Mixed Source Lands

Mixed source lands, where the same acreage is permitted for both ground water and surface water use, present a particular challenge in this analysis. Acreage has been authorized with both surface water and ground water supplies for multiple reasons. In some cases, the original diversion structures have been replaced by wells but the nominal surface water rights are still recorded, resulting in mixed source authorizations. In other cases, ground water rights have been issued to supplement surface water use during water shortages, but in fact are seldom if ever used.

The amount of benefit gained by curtailing ground water-irrigated areas which are assigned to mixed source lands will be driven by what happens after the curtailment. If the curtailment results in the land not being irrigated, then using consumptive use as an estimate of the benefit of curtailment is reasonable. However, if curtailment of ground water pumping results in an increased use of surface water on the same acreage, then no benefit is seen from curtailment.

In the model calibration, the fraction of supply on mixed-source parcels was partitioned between ground-water and surface-water using a diversion-depth analysis. The fraction of supply is represented in the GIS data by a “source fraction” value. The curtailment of

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[1] IWRRI calculations and independent USGS data (Goodell 1988, Maupin 2004) indicate that 95% to 97% of all consumptive use from ground water is associated with irrigation.

ground-water pumping is represented by reducing the source fraction of all ground-water irrigated parcels within a model cell according to the fraction of ground water rights junior to the date of interest, within that model cell. Three methods were tested, as outlined in Appendix C. The method selected was to proportionally reduce the source fraction according to the priority fraction, without consideration of the total amount of supply coming from ground water. This is a simplification of the conceptual model of what actually may occur, but the test shows that results obtained using this method are within 1% of more sophisticated methods that increase opportunities for error and require estimation of additional parameters. Appendix C documents this test.

Running of ESPA Model

Both the steady state and transient versions of the numerical superposition ESPA model were run using the Modflow well files described in the previous section. The steady state model predicts impacts to river reaches after the full effect of the aquifer stress has been realized (essentially after infinite time). The transient model predicts the impacts as they occur over time. The transient ESPA model for the long-term curtailment simulations was set up using 150 1-year stress periods, with each stress period having 5 time steps. The transient ESPA model for the long-term curtailment simulations was set up using 20 6-month stress periods, with each stress period having 3 time steps. A stress period is the period of time during which the representation of aquifer pumping is held constant. A time step is an intermediate calculation point.

As discussed in the previous section, the Modflow well files for the long-term curtailment simulations represent average daily ground-water pumping, applied as continuous pumping for the duration of the model scenario, for each model cell. For the seasonal curtailment scenarios, the Modflow well files represent the net recharge due to precipitation and evapotranspiration for 6-month periods, representing irrigation and non-irrigation seasons, for each model cell.

Determination of Impacts to River Reaches Due to Modeled Ground-Water Pumping

Once the ESPA model is run, a post-processing utility is run to sum river reach impacts for each of the eleven modeled reaches of the Snake River. These results are available for each of the modeled cutoff dates for both steady state and transient simulations. The results are then imported into a Microsoft EXCEL workbook for preparation of resulting graphs and tables.

Appendix B. Irrigated Land and Consumptive Use by Ground-Water District

A request was made for a summary by ground-water district of how many acres and how much consumptive use would be curtailed for each priority date cutoff. No statement is being made in this appendix of plans for curtailment of any particular group of ground-water pumpers. These data are merely being supplied as a courtesy. Figure B-1 shows the map of water districts used for this analysis.

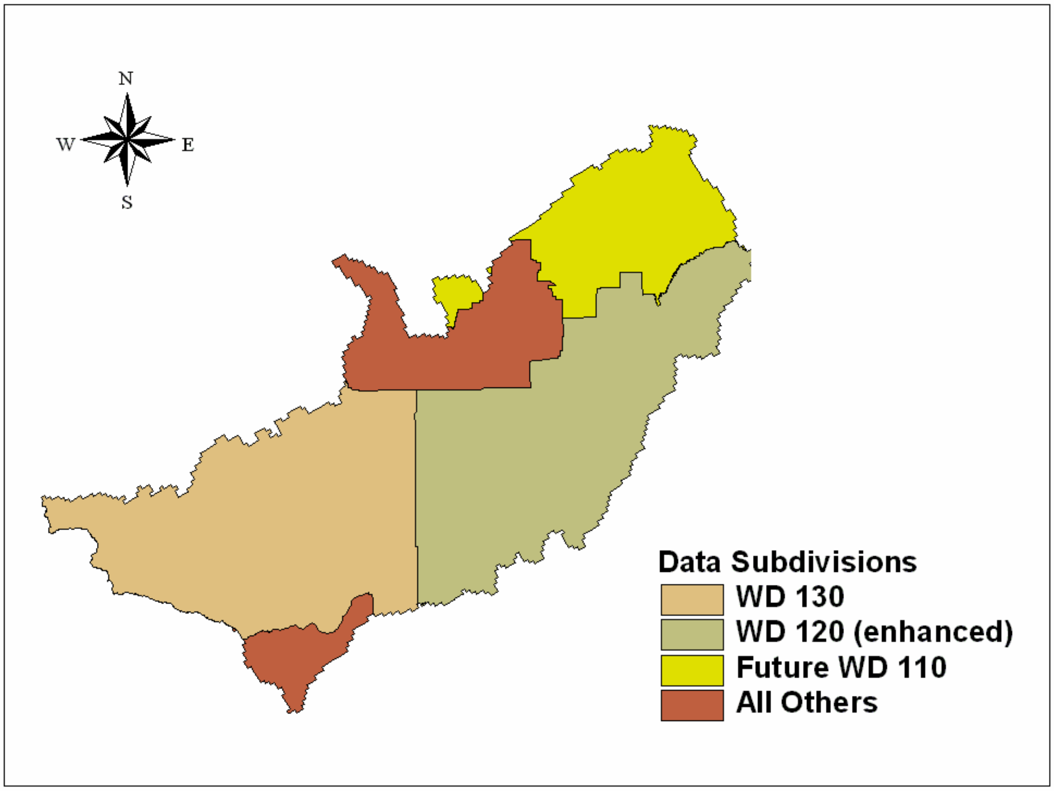

Figure B-1. Ground-water district boundaries used for summary of curtailed acres and consumptive use.

Table B-1 summarizes the number of acres curtailed and the associated consumptive use for each ground-water district for each of the cutoff periods.

Table B-1. Curtailed acres and consumptive use by district.

Cutoff Date	Post January 1, 1870		Post January 1, 1949		Post January 1, 1961		Post January 1, 1973		Post January 1, 1985	
Basin Name	Acres Curtailed	Curtailed CU (ac-ft)	Acres Curtailed	Curtailed CU (ac-ft)	Acres Curtailed	Curtailed CU (ac-ft)	Acres Curtailed	Curtailed CU (ac-ft)	Acres Curtailed	Curtailed CU (ac-ft)
WD130—North Snake	274,600	561,900	215,500	440,600	140,100	289,300	80,400	167,200	15,800	32,000
WD120—American Falls	484,300	876,900	457,700	827,900	309,200	558,000	171,600	309,700	38,900	70,100
Future WD110—Upper Snake	185,200	350,400	167,900	317,100	129,700	242,000	78,400	145,600	9,900	18,700
Other	158,000	307,900	148,500	289,300	854,00	165,200	41,700	80,500	9.600	18,900
Total	1,102,000	2,097,000	989,700	1,874,900	664,300	1,245,500	372,000	702,900	74,200	139,600

Appendix C. Analysis of Impact of Mixed Source Lands on Curtailment Scenarios.

When ground-water rights are curtailed, there is an effect on mixed-source lands. Preliminary calculations assumed that the reduction in consumptive use with curtailment is proportional to the fraction of supply from ground water for the area being evaluated. However, it is possible that actual responses will depend on the adequacy of the surface-water supply and the reliance on ground water. To determine the significance of this possibility on curtailment scenarios, three alternate methods of treating mixed-source lands were considered.

The fine black line in Figure C-1 illustrates the conceptual model that the reduction in consumptive use from curtailment is dependent on the fraction of supply from ground water. When ground water is a high fraction of supply, a unit reduction in supply may reduce consumptive use by more than one unit, but when ground water is a low fraction of supply, curtailment may not reduce consumptive use at all.

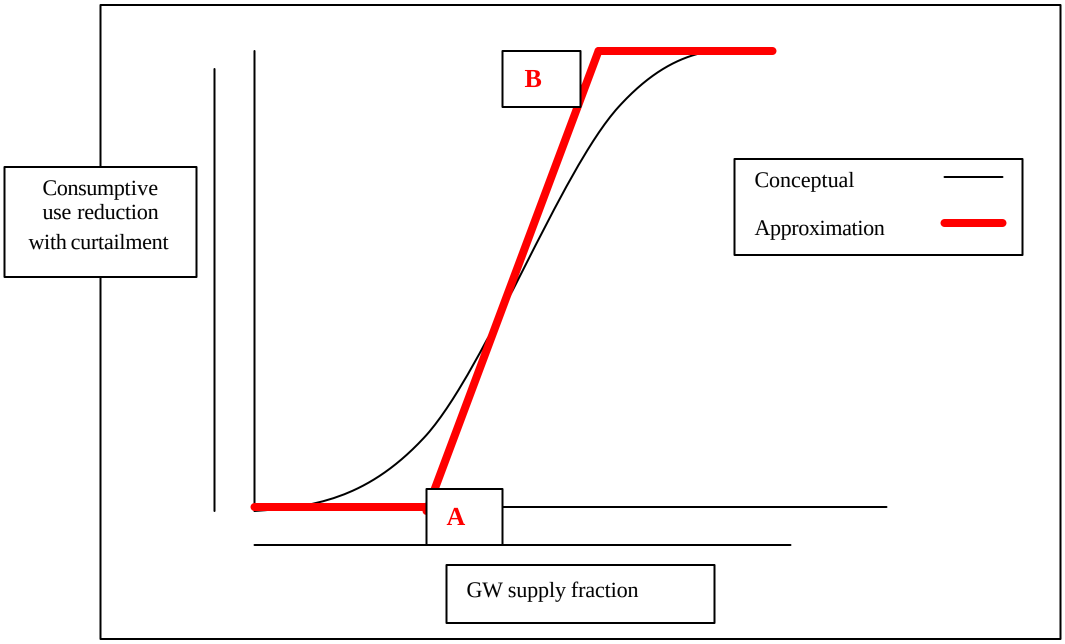

Figure C-1. Conceptual Model

An approximation of the unknown non-linear relationship could be the stepwise-linear relationship illustrated with the heavy red line. The shape of the approximation line is governed by placing of breakpoints A and B. Three pairs of breakpoints “A” and “B” were tested: 1) 0% and 100%, 2) 10% and 90%, 3) 20% and 80%. Option 1 is a straight diagonal line, corresponding to preliminary analyses.

Using GIS analysis of the ground-water-irrigated polygons from model calibration, the three breakpoint pairs were applied to all the ground-water polygons within the study area. Polygons that were ground water only were left with a source fraction of 100%, and mixed-source polygons were scaled according to the following rules:

1. If ground-water fraction is less than breakpoint A, set source fraction to zero. This implies that for parcels with only a small supply of ground water, the response to curtailment will be more careful management of surface water with no reduction in acreage or consumptive use.

2. If ground-water fraction is greater than breakpoint B, set source fraction to 100%. This implies that for parcels almost totally dependent on ground water, curtailment will result in fallowing the entire farm. All consumptive use, even that formerly associated with the small surface-water supply, will cease.

3. If ground-water fraction is between A and B, set the source fraction equal to:

   (GW fraction - A) / (B - A)

   This sets the transition line on a diagonal between the breakpoints.

For the 0%/100% pair, this rule simply set the source fraction equal to the original ground-water fraction from the calibration data. Figure C-2 illustrates the results graphically.

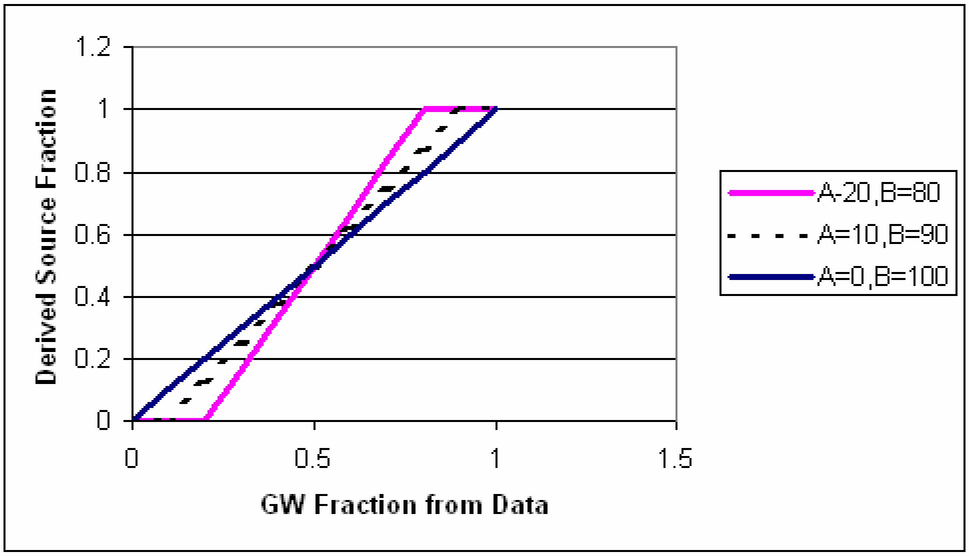

Figure C-2. Results of Calculations.

To test the impact of these three options, acreage was calculated for each polygon. For each polygon, the acreage was multiplied times the three different rule-derived source fractions to obtain the equivalent acreage suggested by the three different rules. To compare results, the effective acreage for all polygons was summed for each option. Table C-1 shows the results:

Table C-1
Results of Test

Breakpoint A	**Breakpoint B**	**Effective Acres**	**Acres, % of Calibration-period acres**
0%	100%	1,111,000	100%
10%	90%	1,120,000	101%
20%	80%	1,125,000	101%

Because the percentages were so similar, the original method was retained. When considering the effect of curtailment on mixed-source lands, the impact on consumptive use is represented as proportional to the fraction of supply from ground water.

Table 1. Predicted steady state reach accruals for each curtailment period (using ESPAM v1.1).

Cutoff Date	All Pumping		Post January 1, 1949		Post January 1, 1961		Post January 1, 1973		Post January 1, 1985	
Reach Name	Steady State Gain (cfs)	Time (yrs) to realize 90% of gain	Steady State Gain (cfs)	Time (yrs) to realize 90% of gain	Steady State Gain (cfs)	Time (yrs) to realize 90% of gain	Steady State Gain (cfs)	Time (yrs) to realize 90% of gain	Steady State Gain (cfs)	Time (yrs) to realize 90% of gain
Ashton to Rexburg	316	20	290	20	222	19	128	19	22	19
Heise to Shelley	211	18	195	18	141	17	78	17	15	17
Sum of Reaches Above Shelley	**526**		**484**		**363**		**206**		**37**	
Shelley to Near Blackfoot	406	30	368	30	240	28	132	25	26	28
Near Blackfoot to Neeley	1035	35	925	36	593	33	331	29	69	32
Neeley to Minidoka	158	62	134	65	84	61	46	55	10	60
Sum of Reaches Shelley to Milner	**1598**		**1427**		**917**		**509**		**105**	
Devil’s Washbowl to Buhl	298	59	257	61	160	57	88	51	18	60
Buhl to Thousand Springs	137	49	122	50	81	43	47	37	8.0	51
Thousand Springs	89	48	79	48	54	42	31	35	5.6	47
Thousand Springs to Malad	10	45	9	46	6.4	38	3.7	32	0.74	42
Malad	77	50	68	51	47	43	29	35	5.5	44
Malad to Bancroft	5.8	38	5.2	38	3.8	34	2.4	31	0.59	36
Sum of Thousand Springs Reaches	**617**		**541**		**352**		**201**		**38**	
Total (cfs)	**2741**		**2453**		**1633**		**916**		**180**	
Total (acre-feet/year)	**1,984,659**		**1,775,637**		**1,182,086**		**663,362**		**130,506**	

Table 2. Predicted reach gains during first year of curtailment (ESPAM v1.1).

Cutoff Date	January 1, 1870	January 1, 1949	January 1, 1961	January 1, 1973	January 1, 1985
Reach Name	Predicted Gain During First Year of Curtailment (ac-ft)	Predicted Gain During First Year of Curtailment (ac-ft)	Predicted Gain During First Year of Curtailment (ac-ft)	Predicted Gain During First Year of Curtailment (ac-ft)	Predicted Gain During First Year of Curtailment (ac-ft)
Ashton to Rexburg	34,000	32,000	25,000	14,000	2,500
Heise to Shelley	39,000	37,000	26,000	13,000	3,100
Shelley to Near Blackfoot	83,000	78,000	50,000	28,000	6,000
Near Blackfoot to Neeley	240,000	220,000	140,000	82,000	18,000
Neeley to Minidoka	11,000	10,000	7,000	4,700	1,100
Devil’s Washbowl to Buhl	37,000	36,000	26,000	16,000	2,100
Buhl to Thousand Springs	34,000	33,000	26,000	16,000	1,900
Thousand Springs	23,000	23,000	18,000	11,000	1,600
Thousand Springs to Malad	3,000	2,900	2,400	1,500	270
Malad	18,000	18,000	15,000	11,000	1,700
Malad to Bancroft	1,300	1,200	1000	760	120