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Unregulated Water Supply of the Upper Snake River Basin

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A database application was developed through research funding that allows the derivation of composite groundwater response functions. Response functions are used to segregate the influence of historical surface water and groundwater irrigation practice from a period of record water supply data set for the Snake River basin upstream of King Hill in Idaho. Response functions are used to adjust the historical "unregulated" streamflow to represent a more "natural" streamflow condition. These respond functions can be used to compute the influence on future streamflow from various alternative irrigation development and practice.

Summary of Process for Derivation of Local Water Supply Gains

The process used to compute the water supply gains can be described in the following equations.

Equation 1 Unregulated Local Gain = Downstream gage historic flow – Upstream gage historic flow + historical diversions – short term surface return flow [+ change in reservoir storage + reservoir evaporation if the reach has a reservoir]

Equation 2 Aquifer Recharge = Surface irrigation diversion – consumptive use – short term return flow

Equation 3 Aquifer Depletion = Groundwater irrigation consumptive use

Equation 4 "Naturalized Local River Gain" = Unregulated local gain – lagged Aquifer Recharge + lagged Aquifer Depletion

Lagging is completed using groundwater model generated response functions.

Equation 5 "Steady State Present Condition Local River Gain" = "Naturalized Local River Gain" + lagged influence from future surface irrigation diversions – lagged influence from future groundwater irrigation use

For the 2004 Snake River Biological Assessment analyses, the hydrograph of groundwater discharge influence experienced in 2001 (a hydrograph of 12 monthly values) from historical surface and groundwater irrigation practice is combined with the "naturalized local river gain" over the 1928-2000 period of record. This adjusted period of record water supply represents the water supply expected in the near future assuming historical climate conditions influenced by present groundwater discharge conditions.

Some Tools for Conjunctive Management Analyses

Reclamation has funded the Idaho Water Resources Research Institute (IWRRI) / University of Idaho (UofI) staff and participated with staff effort and technical review of developing the MODFLOW groundwater model application to the East Snake Plain Aquifer Basin [2] (ESPAB) and the Treasure Valley Hydrologic Modeling Program with Idaho Department of Water Resources (IDWR). One product of this funding, developed by UofI staff, is an MS-ACCESS™ database of response functions from the ESPAB groundwater model. This database is the basis for the research documented in this report. Figure 1 displays the geographic area modeled by IWRRI and Garabedian.[1]

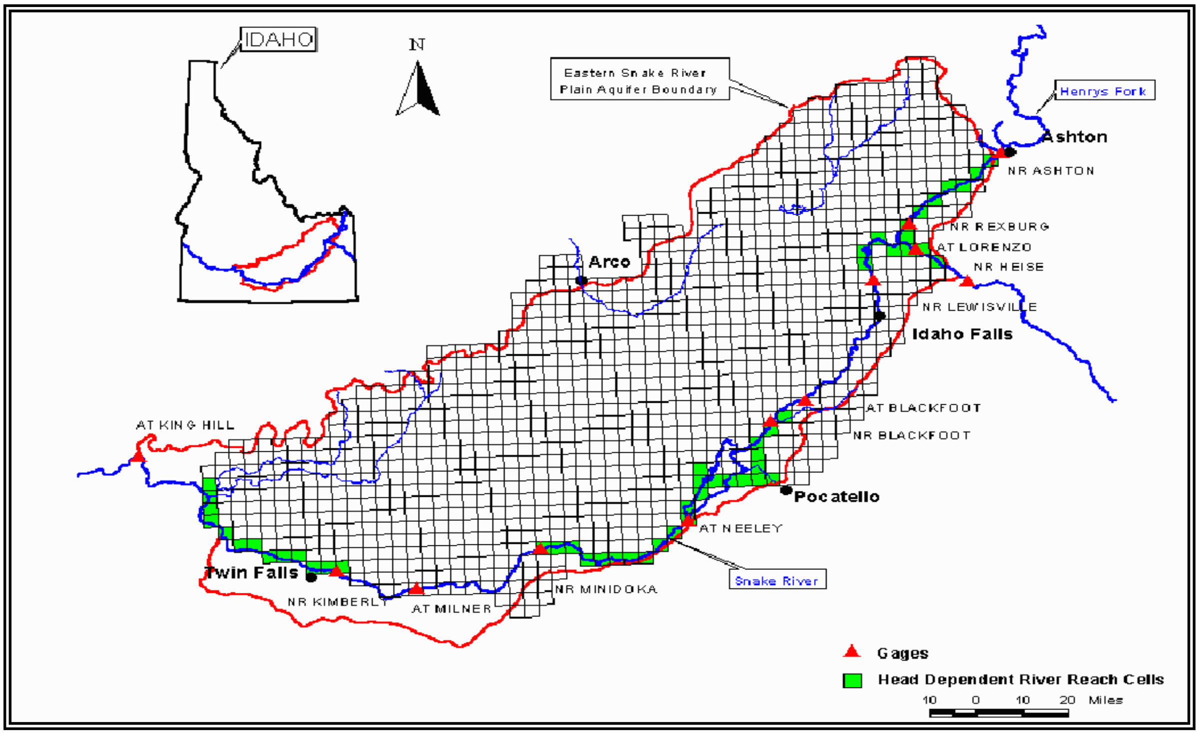

Figure 1 Map of East Snake Plain Aquifer groundwater model area with model grid cells

GIS layers of the irrigation areas and groundwater model grid cells were used to define the relationship between irrigation areas and the groundwater model database of response functions. The developed database application allows the user to derive the response function from a group of groundwater model grid cells representing a groundwater aquifer stress (change in pumping or recharge from irrigation practice) location to a group of cells representing a groundwater aquifer discharge (spring) location along the river. The group of cells representing a discharge location is related to a surface water model node that in turn represents the downstream end of a river reach.

River and Reservoir Operation Simulation of the Snake River

Until recently, long term river and reservoir operation simulation of the Snake River Basin has been completed with monthly time step models specifically coded by USBR and IDWR for the

Snake River.   With the completion of the 1MAF study (February 1999) and other studies since, Reclamation has adopted MODSIM, a generic network flow model developed by CSU, for operation simulation of the Snake River and other river basins throughout the western United States. Reclamation and CSU have jointly enhanced MODSIM to model complex physical and institutional constraints that allow model users to simulate a wide variety of water rights, storage contract agreements, water exchange conditions, and forecasted river and reservoir target operation objectives. Figure 2 MODSIM interface displaying minimum flow parameters below Jackson Dam and graphs of a scenario's output

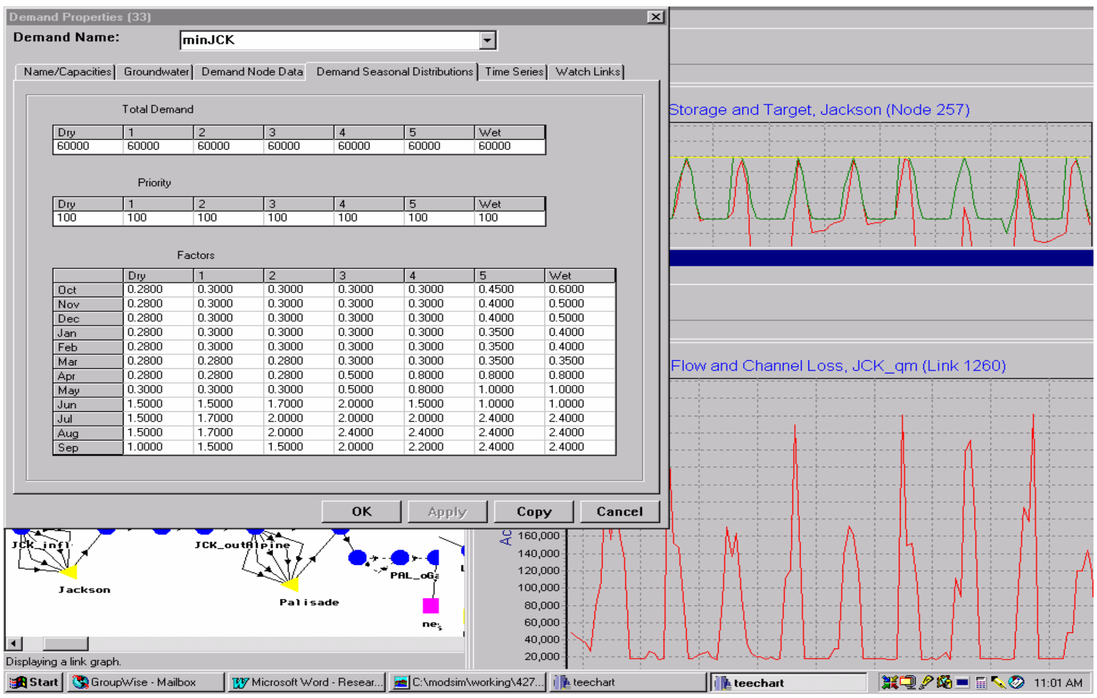

Figure 2 Example of using MODSIM GUI interface

Data sets for these models include 1) a period of record water supply or river gains, 2) "present level" irrigation diversion demands, and 3) physical river system features' parameters. The irrigation diversion demands are usually based on recent diversion records (in this case 1991-2000) and past years are either adjusted (if a long record indicates that demands are significantly different than the present) or estimated (where the diversion or record did not exist). The physical river system parameters primarily define the river system topology, operational targets or constraints such as "minimum" flows and reservoir content levels, and other feature dimensions such as reservoir size. The gains data is (in most analyses) a static representation of historical water supply through a period of record. Usually, this gains data set is derived as the "unregulated / natural" local runoff at gauged river locations. Using historical streamflow, diversion, and reservoir content data, and typical estimates of return flow factors, one could "unregulate" the river system with simple mass balance equations on monthly time steps. Most all of these data are typical and available in the Snake River basin except for one: return flow factors.

Importance of Groundwater in Surface Water Simulation in the Snake River Basin

What makes the Snake River system unique and challenging to model is the significant magnitude and long term persistence that the groundwater aquifer discharge has on river flows. Changes in irrigation practice have taken decades to implement and the impacts have taken as long to materialize. Garabedian [1] states "Average annual groundwater discharge to the Snake River between Milner and King Hill increased from about 3,800,000 acre-feet during 1912-15 to a maximum of about 5,300,000 acre-feet during 1951-55 in response to increased diversions of surface water for irrigation. Since 1955, groundwater discharge to the reach has declined to about 4,800,000 acre-feet."

To accurately use the true lags that represent the physical processes from irrigation diversion to groundwater discharge, we need to lag portions of diversions for more than 40 or 50 years in some cases. Unless we make some assumption that describes the groundwater discharge for a particular scenario as a steady state change from the existing condition, we could not simulate the impact from a proposed change in the time frame of the simulation analyses. We would attempt to simulate a change that would not show an impact until the last part of the period of record in the analyses. This is not, in many cases, the impact information we need to describe the long term merits of a given proposal.

In the past the long term impact from assumed past and future changes in groundwater interaction on surface water operations has been ignored or given narrow specific consideration on a case by case basis. Depending on the estimated impacts to groundwater recharge / depletion, adjustments to the gains would be needed for accurate simulation for each proposed action scenario. These adjustments are difficult to derive even for the experienced and knowledgeable modeler.

Response Functions -What are they?

From a surface water modeler's point of view, response functions can be thought of as a series of lag coefficients that describe the result (groundwater discharge) over time and space from aquifer stress (recharge from water application or aquifer withdrawal). Use of response functions (as defined and outlined in this report) assume the laws of super position are not violated. In other words, changes in head / groundwater discharge from a proposed change in aquifer stress do not result in changes in aquifer properties. If the change in aquifer stress is significant enough to change the assumed aquifer properties, the scenario would have to be run in stages to generate new response functions between stages of the aquifer stress.

The notion of a series of lag factors to simulate return flows expected from irrigation diversion is featured in most river and reservoir operation simulation models as a portion of diversion distributed in time and space as percentages of the amount diverted (or pumped). These lag factors / coefficients represent the temporal and spatial distribution of water that is diverted, not consumptively used, and can be accounted for as surface runoff or interflow in the soil or subsoil. These flows are part of the downstream river gage's gain in one or more locations over typically a number of months after the diversion takes place.

The lag coefficient parameters are often derived through a process of segregation of known / observed streamflow records and water budget analysis. Factors are selected and used to derive local gains at river gage locations. These derived local gains are usually thought to represent the "natural" or "unregulated" inflow to the river reach. If 1) the amount of computed return flow can be supported by observed drain data, and 2) the derived gains hydrographs can be supported by the water budget analyses, correlation with streamflow data, and reason, then the return flow lag factors are thought to represent the physical process where the soil / subsoil lags water application from irrigation back to the river in time and space.

What we call response functions are derived from a numerical groundwater model. The water budget analyses used to develop the data set for the groundwater model and the calibration process in selecting parameters for the groundwater model replace the trial – error and more suggestive processes in the streamflow segregation analyses described above. Once one is satisfied that a groundwater model is calibrated, response functions can be derived by introducing a unit stress (increase in recharge or withdrawal) at a given location, running the groundwater model, and summarizing the result in terms of change in water levels and/or groundwater discharge to springs. The result (change in discharge at various locations and over time) can be divided by the unit stress to derive the response functions. For a unit stress at a given location, a response function is a series of coefficients that define the location and time of change in discharge as a percent of the unit stress.

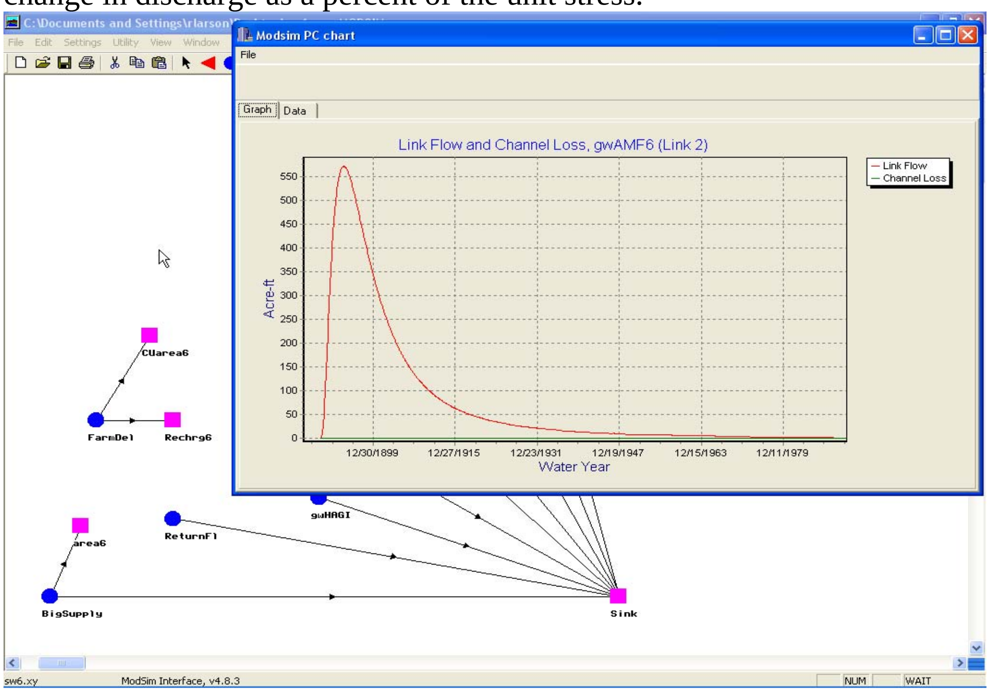

Figure 3 MODSIM network showing response function for area 6 to the American Falls river reach

Response Functions -What are they good for?

Response functions are used as groundwater recharge /depletion lag factors. The influence from surface water diversion that ends up in the groundwater aquifer or the influence from groundwater irrigation in the Upper Snake River basin takes a very long time to be realized. The influence from each year's irrigation activity has an accumulated effect on the river gains for decades after the irrigation activity takes place. The location of influence from irrigation activity will depend on the location of the irrigation activity. Response functions derived from a numerical groundwater model are used to derive the influence from past irrigation activity and predict the influence from future irrigation practice.

Figure 4 shows the response to the American Falls reach from historical diversions in surface water irrigation Area 6 from 1890 through 2000 plus 100 years of 1996-2000 average diversions thereafter.

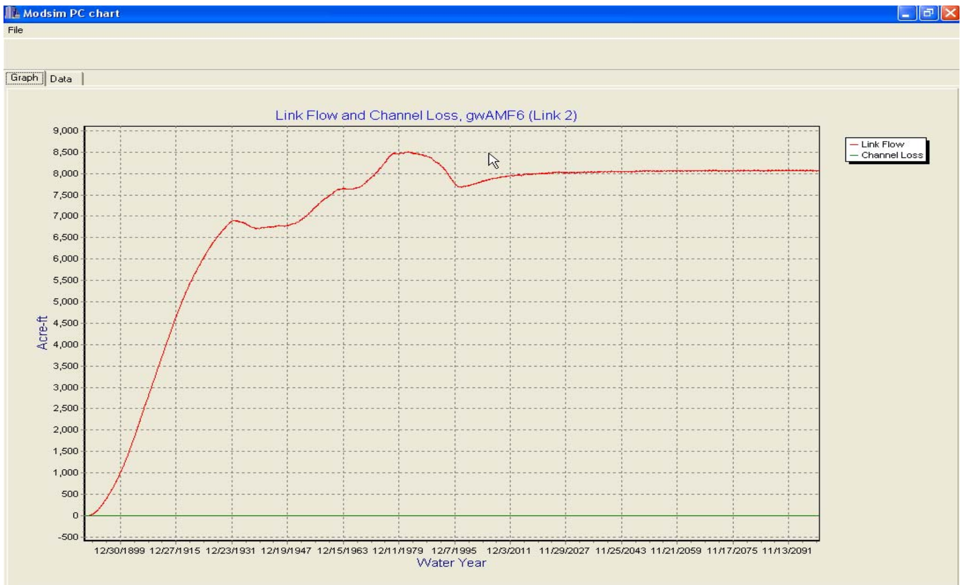

Figure 4

Using the response functions with historical / estimated surface and groundwater irrigation use, provides the ability to use three adjustments to the historical water supply data set:

1. Influence from past irrigation (surface and ground water) can be removed from the historical unregulated river gains; the local gains can be "naturalized".
2. A combination of present state of groundwater influence and future influence from a continuation of present irrigation use (or some other defined use) can be included in the river gains data set.
3. The naturalized state of the river gains from number one has allowed the generation of stochastic data that can be used in place of or in combination with the historical water supply trace.

The response function application along with the data sets derived to accomplish the first two adjustments can be used to quite easily derive adjustments to the water supply data set in order to simulate proposed actions that include significant changes in surface and ground water use. The third adjustment (use of stochastic generated traces) allows us to complete analyses that address very long term impacts and / or deriving the probability of an impact within a certain time period.

Groundwater Response Functions

Response functions were obtained from the Idaho Water Resources Research Institute (IWRRI) in the form of an ACCESS database. The database has 1200 monthly lag coefficients for each groundwater model grid cell to each other model grid cell. A developed database application allows the modeler to derive specific composite response functions for a group of grid cells representing a recharge or withdrawal area to a group of grid cells representing a river reach.

Unregulated Local Gains

Historical unregulated flows for reaches in the Snake River were derived using historical streamflow and diversion data obtained from IDWR, USGS, and USBR Hydromet databases. Monthly unregulated local gains between river gages were computed from mass balance equations. Correlation was used to extend records of duration shorter than the 1928 through 2000 period used.

In order to segregate the influence from historical irrigation on streamflows in the Snake River, the incremental change in ground water discharge to the river at seven locations was estimated by using response functions. The response functions for 26 surface water areas and 21 groundwater zones were derived using the response function application.

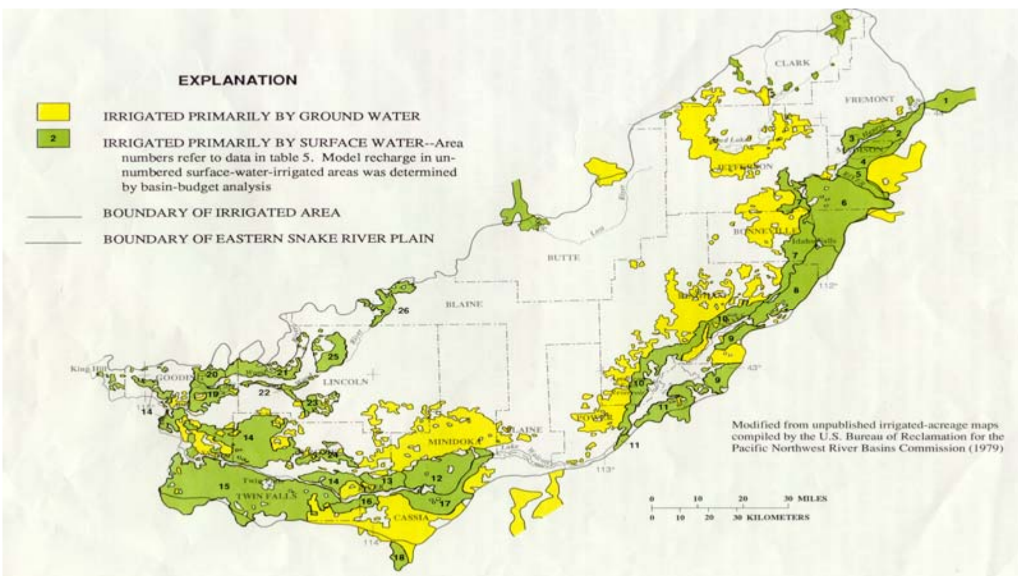

FIGURE 7.—Irrigated lands, 1979, and numbered surface-water-irrigated areas.

Figure A-2 – From USGS Professional Paper 1408-F Designating 26 surface water irrigated areas

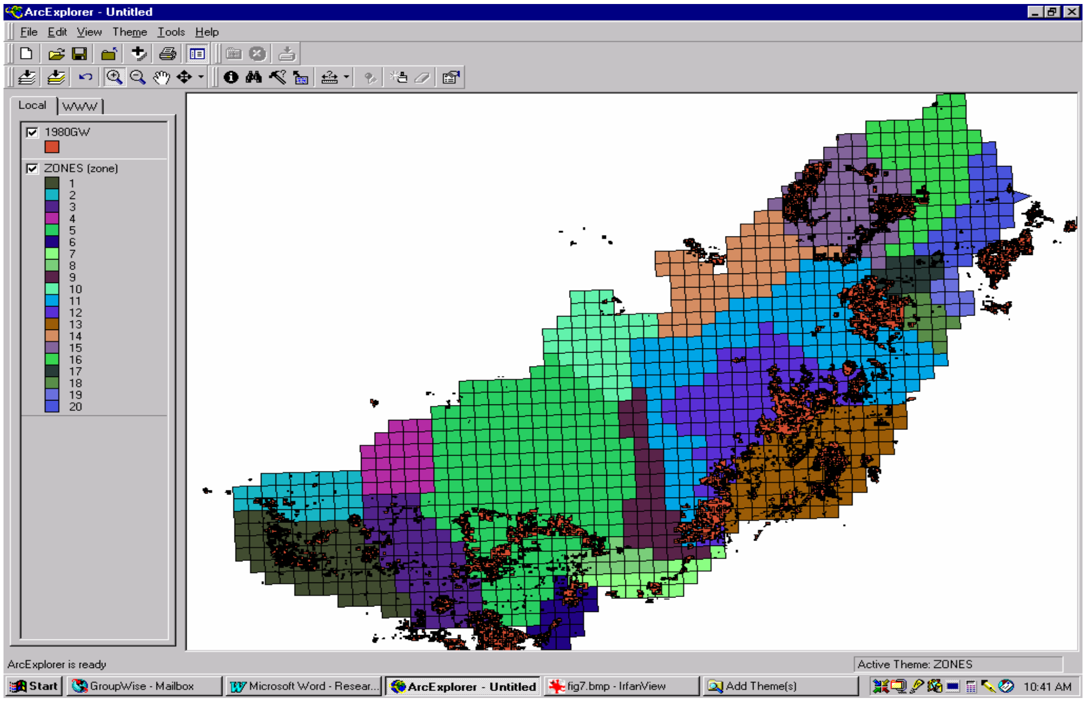

Figure A-3 GIS layer showing groundwater zones and 1980 groundwater irrigated acreage

Historical surface water diversions were summarized for each of the surface water diversion areas. Diversion data from 1928-2000 are from IDWR records; diversions before 1928 are estimated as ratios of acreage estimates before 1928 and acreage estimates for 1928 multiplied by diversions in 1928. Ground water use was estimated as consumptive use based on acreage served by groundwater. Groundwater irrigated acreage is taken from Garabedian. Table 1 shows irrigated acreage estimates from Garabedian (USGS Paper 1408-F).

Table 1 ←------------------ Thousands of Acres --→

Year	Snake Neeley	Henrys Fork	Blw Neeley	SW	GW	Total
1890	47	2	195	244	0	244
1900	221	30	233	484	0	484
1905	299	49	394	742	0	742
1910	372	58	459	889	0	889
1915	423	62	814	1299	0	1299
1920	451	65	834	1350	0	1350
1930	471	68	1001	1540	0	1540
1935	462	56	1082	1600	0	1600
1940	483	70	1127	1680	0	1680
1945	497	71	1202	1770	0	1770
1960	497	71	862	1430	400	1830
1966	497	71	992	1560	640	2200
1980	497	71	772	1340	930	2270

Short term surface water diversion return flow factors were used from Garabedian with some adjustments. Irrigated acreage for computing consumptive use before 1980 was also taken from Garabedian.

	Surface Water Irrigated Area																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
%Return	35	17	7	22	26	13	17	20	20	20	20	12	3	7	34	1	18

Table 2 - Percent of diversion estimated as short term surface return flow –Garabedian USGS Paper 1408-F with adjustments

GIS layers were obtained from Idaho Water Resources Research Institute staff to summarize acreage after 1980.

Consumptive use was estimated for three areas 1) Henry's Fork , using St Anthony weather station, 2) Snake River above Neeley, using Aberdeen weather station, and 3) Snake River below Neeley, using Twin Falls weather station. Blaney_Criddle procedures were used with the weather station temperature and precipitation data and crop patterns from the 1999 1MAF study. Average annual consumptive use for the assumed cropping patterns and period of record climate data are 1) 1.84 feet at St Anthony, 2.13 feet at Aberdeen, and 2.10 feet at Twin Falls.

Each of the 26 surface water diversion areas and 21 ground water pumping zones was assigned one, or an average of two, consumptive use pattern(s). MODSIM networks were developed for each surface water area and each ground water zone to compute the incremental influence from irrigation to the seven Snake River reaches: Henry's Fork at Rexburg, Snake River at Shelly, Snake River at Neeley, Snake River at Minidoka, Snake River at Kimberly, Snake River at Buhl, Snake River at Hagerman.

The influence from surface water irrigation recharge is estimated as recharge (historical diversion minus short term return flow minus consumptive use) lagged through the response functions. The lagged ground water discharge is subtracted from computed historical unregulated flows.

The influence from ground water irrigation is estimated as the consumptive use of area served lagged through the response functions. The effect from groundwater use needs to be added to the computed historical unregulated flows.

Once the influence on ground water discharge from both surface and ground water irrigation is segregated from the unregulated flows, the result is a more naturalized flow.

GIS Data

GIS layers for the ground water model cell grids, irrigation district boundaries, and ground water zones were used with the response function application to derive the area specific response functions. These layers were obtained from IDWR and University of Idaho. The irrigation district boundary layer was modified to include a surface water area number per Garabedian (Figure A-2).

The ground water zones were delineated by IWRRI as being representing areas of like aquifer characteristics or at least like response from aquifer stress.

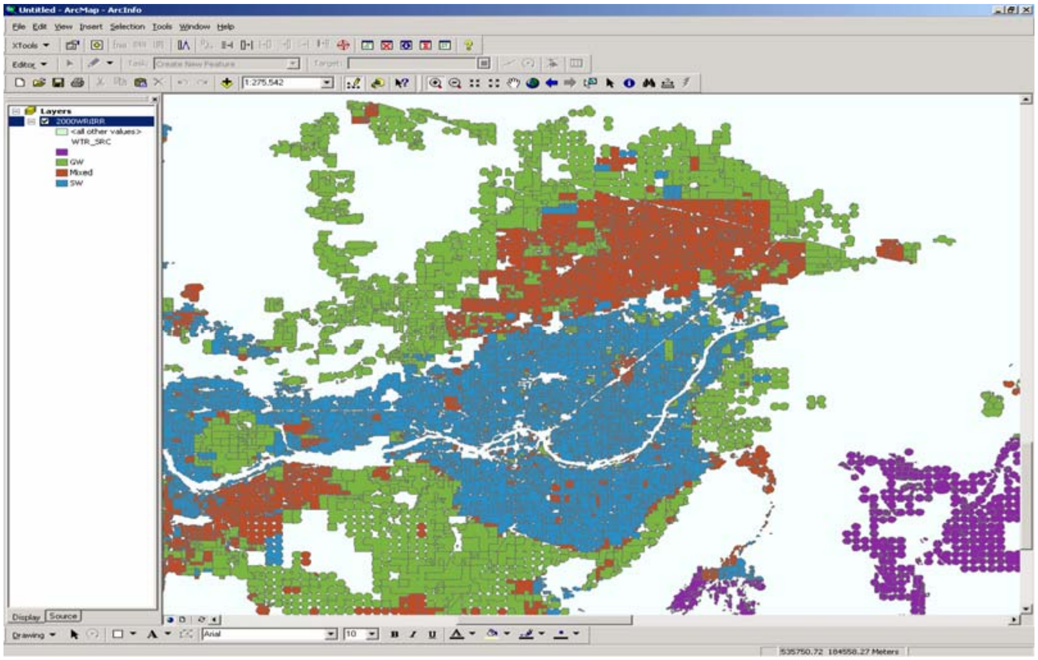

Figure A-4 Map layer showing year 2000 irrigated acreage by water source.

MODSIM Networks

MODSIM networks were derived from a common template for each of the surface water areas and groundwater zones using the response functions from the database application. These networks include the response functions for the area / zone to each of the seven defined river reaches. Historical diversion, historical consumptive use and short term return flow factors are used with the MODSIM model to derive the lagged influence from irrigation on each of the 7 river reaches for each area / zone.

The networks for each surface water area and groundwater zone were run for the 111 years of historical irrigation practice (1890-2000) plus an extra 100 years of present average (1996-2000) irrigation use. The output from each area / zone run is used to segregate the influence of historical irrigation (1928-2000) and to use the “future” 100 years as an incremental adjustment to the naturalized historic local gains and / or stochastic traces that were derived from the naturalized streamflows. The networks for each area / zone can be used for future analyses requests to derive adjustments that include proposals that would include significant deviations from the present average irrigation use.

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5. Amended Biological Assessment for USBR Operations and Maintenance in the Snake River Basin Above Brownlee Reservoir 2001

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