EXHIBIT 116

Walker River Decision Support Tool (version 2.0): Application and Analysis of National Fish & Wildlife Foundation Application No. 80700

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1. Introduction

Nevada's Walker Lake is one of the few desert terminal lakes in North America that has historically supported a diverse freshwater ecosystem. The lake's sole contributing perennial stream, the Walker River, provides a ready source of surface water for irrigation of crops and pastureland for several desert valleys upstream of the lake. Beginning in the 1880s, lake levels began a steady decline to present day, which has resulted in increased lake salinity.

In support of H.R. 2419 Energy and Water Development Appropriations Act, 2006, Section 208, we developed, tested, and implemented a computer-based Decision Support Tool (DST) to better inform decision makers of proposed water right acquisitions in the Walker River basin. The latest version of the DST (version 2.0) captures the spatial and temporal complexity of important relationships among climate, crop demand, river flows, groundwater-surface water exchange along the river, irrigation practices, groundwater pumping, and all known existing water rights (e.g., surface decree, storage, and flood) in the Walker River system above the USGS Wabuska gaging station (i.e., Mason Valley and Smith Valley). The development of the Walker Basin DST represents a major step forward in understanding the complex hydrologic relationships within the real system. The DST allows users to track water through the complicated deliveries and returns in the heavily irrigated Smith and Mason Valleys, down to the USGS gaging station at Wabuska. Since January 2010, the DST has been applied in scenarios that are strictly focused on assessing the impacts of potential water right acquisitions (and the associated change in place of use) on the efficiency of water deliveries throughout the system. These efforts have been in close collaboration with a broad group of stakeholders that comprise the Walker Water Group (WWG)[1].

The National Fish and Wildlife Foundation (NFWF) completed a purchase of water rights on the West Hyland ditch in December of 2010. In March of 2011, NFWF filed its first application (Application No. 80700) to the Nevada State Engineer to change these purchased water rights. The purchased rights include 7.745 cubic feet per second of Walker River Decree surface water rights with priority dates ranging from 1874 to 1906; the water is appurtenant to 646.16 acres of land. Application No. 80700, states that NFWF intends to “change the place, manner, and purpose of use of the subject water rights so that they can be administered and protected in stream to benefit the lower Walker River and Walker Lake.”

In this report, the DST is used to simulate, as closely as possible, the transfer of water rights as proposed in NFWF’s Application No. 80700 to better understand how this transfer may affect the system. Two DST modeling runs are made over calendar years 1996 through 2011: a baseline calibration run and a scenario run that simulates, as closely as possible, Application No. 80700. The results from the two model runs are presented in this report in a comparative scenario analysis format that is used to better understand the possible impacts of the transfer on the real system, within the assumptions and limitations associated with the DST, the observed data and other information that was incorporated into the DST.

[1] The Walker Water Group has met 9 times since January 2010. Stakeholders include: Walker Federal Water master, Walker River Irrigation District, Walker River Paiute Tribe, Walker Lake Working Group, USFWS, USGS, NDOW, Mason/Smith Valley Conservation District, etc.

2. Purpose and Scope

This document was developed in response to an order from the Nevada State Engineer (NSE) requiring NFWF to present the DST and its results as evidence during an administrative hearing related to the protested Application No. 80700. Specifically, the primary purpose of this report is to provide sufficient information to the NSE on the data, assumptions, and guidelines followed in the construction and testing, calibration and validation of the DST, and an expert report addressing the analysis of this specific Application.

3. Spatial Data and Other Information

Overview of Study Area and Model Domain

Figure 3.1 shows the entire Walker River Basin and the extent of the DST study area, from the headwaters in the Sierra Nevada Mountains on the southwest side of the basin to Walker Lake and its associated sub watersheds on the east. The headwaters for both the West and East Walker River stems are not modeled in this study[2]. The DST upstream boundary conditions are: observed flows at the USGS gaging station near Coleville, CA (southern end of Antelope Valley) on the West Walker River, and the Bridgeport Inflow on the East Walker River at Bridgeport Reservoir. The lower boundary condition is the USGS gaging station at Wabuska, NV at the north end of Mason Valley.

The DST is comprised of a set of models—MODSIM, MODFLOW, and HRU Water Balance (*see* Section 4)—applied in varying combinations throughout the study area. The level of hydrologic complexity of the DST varies by the type of information and data available in specific reaches of the study area (Figure 3.1). Reach 1, which contains Antelope Valley and Topaz Reservoir, extends from the southern end of Antelope Valley near Coleville, CA (USGS Gage 10296500) to Hoye Canyon on the west side of Smith Valley (USGS Gage 10297500). Reach 2 includes Smith Valley, which extends from Hoye Canyon to near Hudson, NV (USGS gage 10300000). Reach 3 extends from upstream of Bridgeport Reservoir to Strosnider Dam (USGS gage 10293500). Reach 4, which contains Mason Valley, extends from Hudson, NV and Strosnider Dam on the West Walker River and East Walker River, respectively, to near Wabuska, NV (USGS gage 10301500). Table 3.1 summarizes the available data and information as well as DST modeling components by reach.

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[2] Initial focus of the model was in the areas where the first transfers were expected to occur. Future model versions will likely expand up into the headwaters.

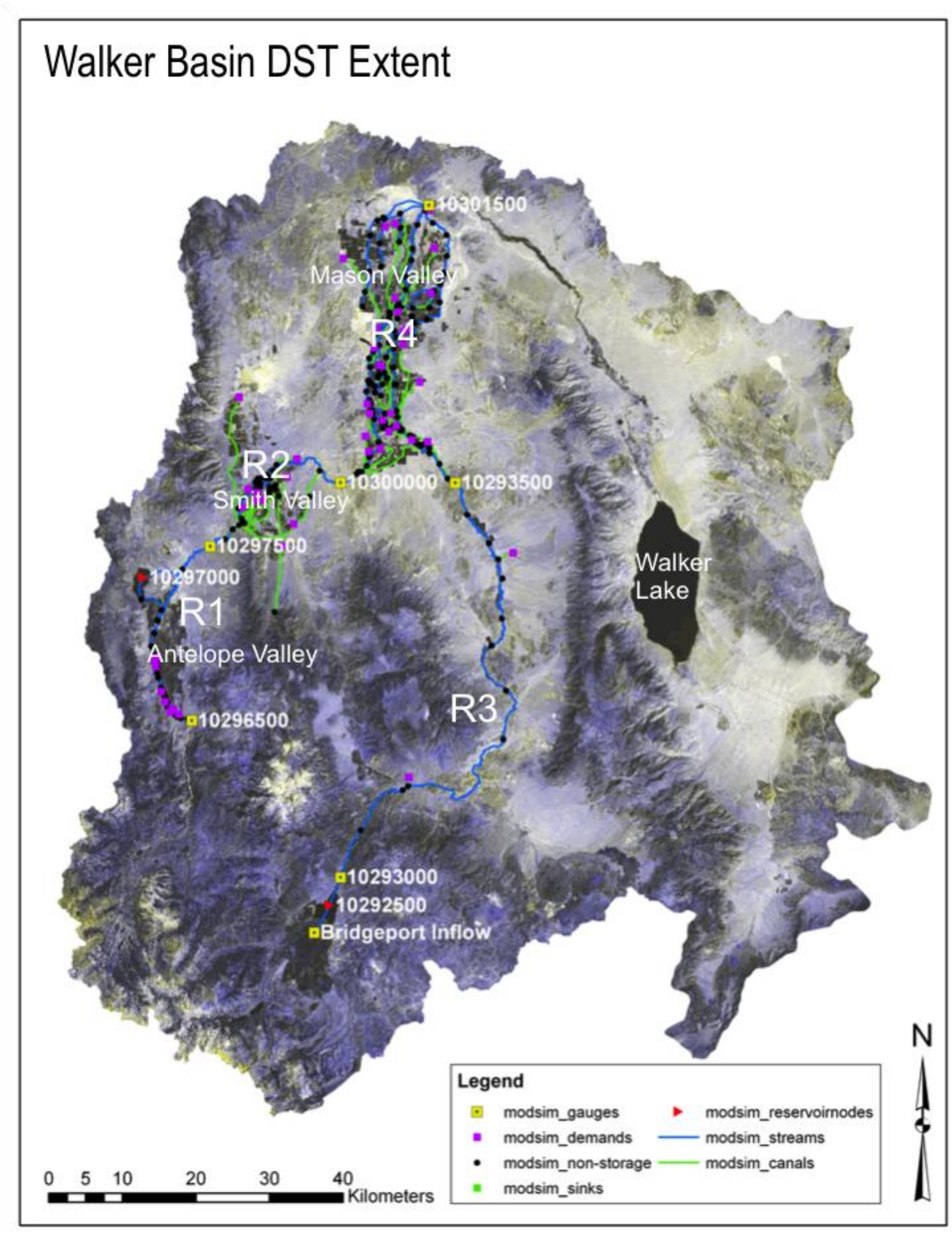

Figure 3.1 Walker River Basin DST extent

Table 3.1 Data, Information, and DST components by reach

Data/Information/DST Component	Reach 1 (10296500 to 10297500)	Reach 2 (10297500 to 10300000)	Reach 3 (Bridgeport_Inflow to 10293500)	Reach 4 (10300000&10293500 to 10301500)
Diversion Records	[3]Partial	Yes	Yes	Yes
Water Rights Info.	No	Yes	Yes	Yes
MODFLOW	No	Yes	No	Yes
HRU Water Balance	No	Yes	Yes	Yes
MODSIM	Yes	Yes	Yes	Yes

[3] Partial indicates a sporadic record of historical diversions

Basic GIS Information

Base layer information in the form of high resolution imagery, agricultural field boundaries, stream centerlines, and gaging stations were required to produce many of the derivative data sets required for the DST. A full description of all spatial and tabular data originally developed for the project can be found in the Walker Basin Project Final Report (Minor et al. 2010).

Aerial Photography

These data sets included high-resolution image files acquired from several different sources, including the United States Department of Agriculture (USDA) and private firms such as AirPhotoUSA. One-foot natural color aerial photography for Lyon County, collected by AirPhotoUSA, was utilized as the principle base layer. This high-resolution mosaic was acquired in the spring of 2007. To sufficiently cover the entire Walker Basin watershed, USDA National Agriculture Imagery Program (NAIP) one-meter natural color aerial photographic mosaics collected in 2005, 2006, and 2010 (collected in spring for all years) were used for all four counties in the basin (Douglas, Lyon, and Mineral counties on the Nevada side; Mono County on the California side).

Parcel, PLSS, and Administrative Data

Basic infrastructure data sets included updated parcel and road centerline data for all four counties in the Walker Basin. Other infrastructure data collected included the Public Land Survey System (PLSS), land ownership, and roads data sets from the Bureau of Land Management (BLM) geospatial data archive, as well as administrative boundaries for counties and the Walker River Irrigation District (WRID).

Agricultural Fields

Agricultural field boundaries for Mason, Smith, Antelope, and Bridgeport valleys, as well as the East Walker River corridor, were obtained from the USDA Farm Service Agency (FSA). These data consisted of field boundaries digitized from aerial photography flown in the mid-1990s. The USDA FSA field boundaries required updating based on current aerial photography from 2005, 2006, 2007 and 2010. The FSA fields were overlaid on the one-foot 2007 imagery for Mason, Smith, and East Walker Valleys and the one-meter 2005-2006 imagery for Antelope and Bridgeport Valleys, so that field boundaries could be edited, added, and/or deleted. Fields were digitized and/or edited based on the edges of irrigated vegetation, i.e., service roads, maintenance yards, and households were not included in the calculation of field areas. Once the field boundaries were updated, crop identification was performed for Mason and Smith Valleys based on analysis of the 2007 one-foot imagery, 2006 one-meter imagery, Google Earth, and field observations. Agricultural classes consisted of 17 types of forage and row crops, pastures, fallow fields, ponds and feed lots. Alfalfa accounted for approximately 58% of the crops being grown at the time of the survey (Table 3.2).

Table 3.2 Crop distribution in Mason and Smith Valleys (2007 Crop Survey)

Crop Key Code	Crop	% Of Total Crop Area
A	Alfalfa	58.87
P	Pasture	11.89
F	Fallow	9.97
G	Garlic	4.31
O	Oat	3.71
PO	Pond	3.58
C	Corn	2.93
Gr	Grass	1.64
FC	Forage Crop	1.26
B	Brush	0.41
T	Turf	0.40
L	Lettuce	0.39
Ga	Grain	0.27
DG	Dry Grass	0.17
Oa	Onion	0.16
FL	Feed Lot	0.04
Gp	Grapes	0.01

Hydrologic Response Unit (HRU) Concept

A minimum mapping or modeling unit for the primary irrigation areas in Mason and Smith Valleys was developed for the DST. A set of spatial data and associated database tables were compiled that identified sub-areas of irrigated lands by diversion source, the water rights that are appurtenant to the irrigated lands as a group, and the historic water diversion by ditch. Each set of fields serviced by a common diversion was defined and mapped as a Hydrologic Response Unit (HRU). Fields fed solely by primary groundwater were separated from other fields with access to surface water and setup as primary groundwater HRUs. The water right and historic water diversion data were compiled into associated attribute tables and applied to each HRU.

The base layer for the HRU polygons is the digitized agricultural fields described above. Agricultural field boundaries and diversion ditches were overlaid and the associations between fields and diversion ditches were established for sections of both Mason and Smith Valleys. A crop type (see description above in the Agricultural Fields section and Table 3.2) was assigned to each field in each HRU.

A total of 45 HRUs were developed for Mason and Smith Valleys. This included separate HRUs for fields served exclusively by primary groundwater pumping in Smith and Mason Valleys, five river pumps found in both valleys, Desert Creek drainage, and ponds and agricultural fields on the Mason Valley Wildlife Management Area (MVWMA), which is managed by the Nevada Department of Wildlife (NDOW). Figure 3.2 shows the spatial distribution of the DST HRUs in Mason and Smith Valleys, respectively, with each HRU color coded by diversion source.

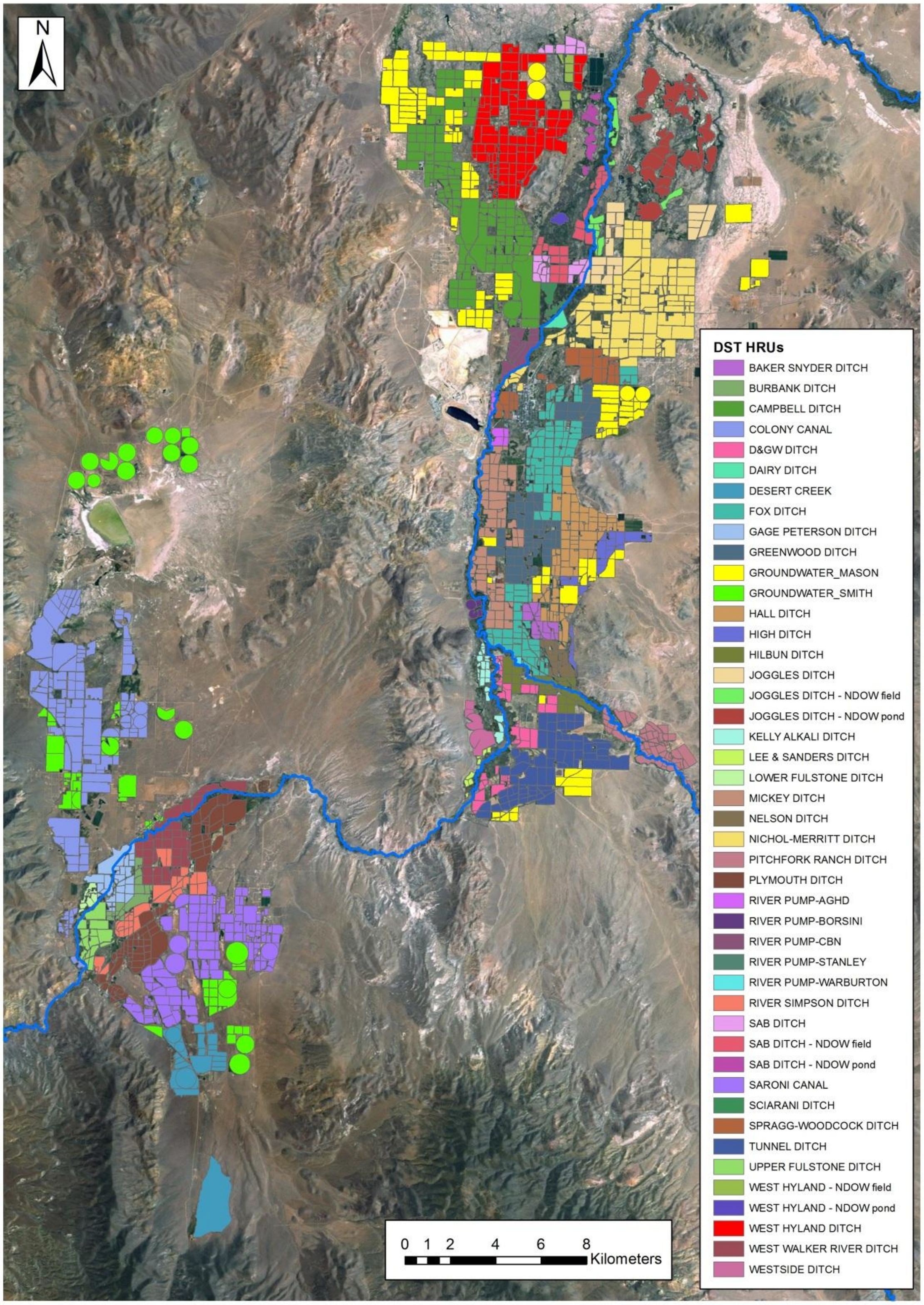

Figure 3.2 Spatial distribution of DST Hydrologic Response Units (HRUs) in Mason and Smith Valleys.

NDOW properties on the east and west side of the Walker River were not included as part of the model HRUs in the Phase I (Version 1.0) DST (Boyle, et. al 2009). These NDOW properties include fields for agriculture and ponds for recreation that are serviced by the Joggles, SAB, and West Hyland ditches (Figure 3.3). Given the proximity of the NDOW fields and ponds to the reach where Application No. 80700 is simulated, and the potential for the ponds to impact the stream-aquifer dynamics in that reach, they are now included as unique HRUs in the current DST (version 2.0) utilized for this report.

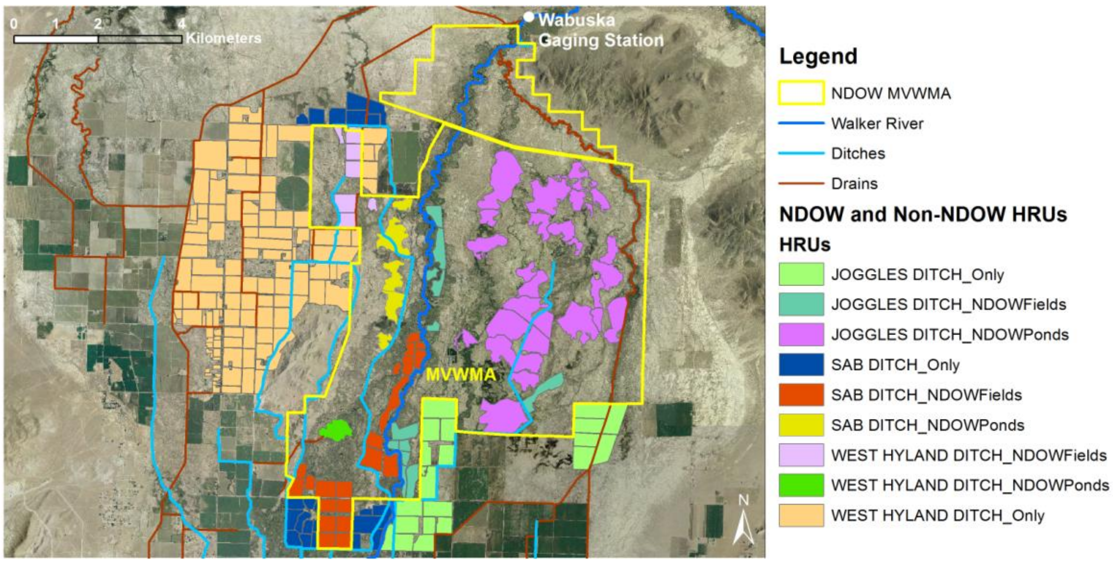

Figure 3.3 NDOW and Non-NDOW ("Only") HRUs.

Stream and Irrigation Network

The centerlines for the West, East, and main stems of the Walker River were digitized from one-meter NAIP aerial photography mosaics for the Walker Basin. NAIP county mosaics collected in 2005 and 2006 were used in a GIS framework to digitize the river centerlines from the Sierra Nevada headwaters to Walker Lake. WRID assisted with the location and identification of major diversions from the Walker River main stem, and west and east forks. Global positioning system (GPS) technology was used to locate the head gates and weirs for over 25 river diversions in Mason and Smith Valleys. These locations were input into the GIS database using the 2007 one-foot aerial imagery to correct for any GPS accuracy errors; most of the head gates and weirs were visible on the aerial photography. Additional points of diversion locations were added using the aerial photography and information from the Federal Water Master, WRID, and NFWF. A total of 36 diversions were used in the DST, including ditch diversions directly off the river stems, ditches off of other ditches, and river pumps (Figure 3.4).

Figure 3.4 DST Diversions – Main Stem, West Fork and East Fork of the Walker River in Mason and Smith Valleys.

The 2007 one-foot aerial photography was used to develop the delivery (ditches and river pumps) and drainage systems for irrigation in Mason and Smith Valleys. Primary ditches, river pumps, and drains were mapped for the two valleys using MANIFOLD SYSTEMS GIS software. From- and To-node topology was used to show flow direction for ditches, river pumps, and drains (Figure 3.5).

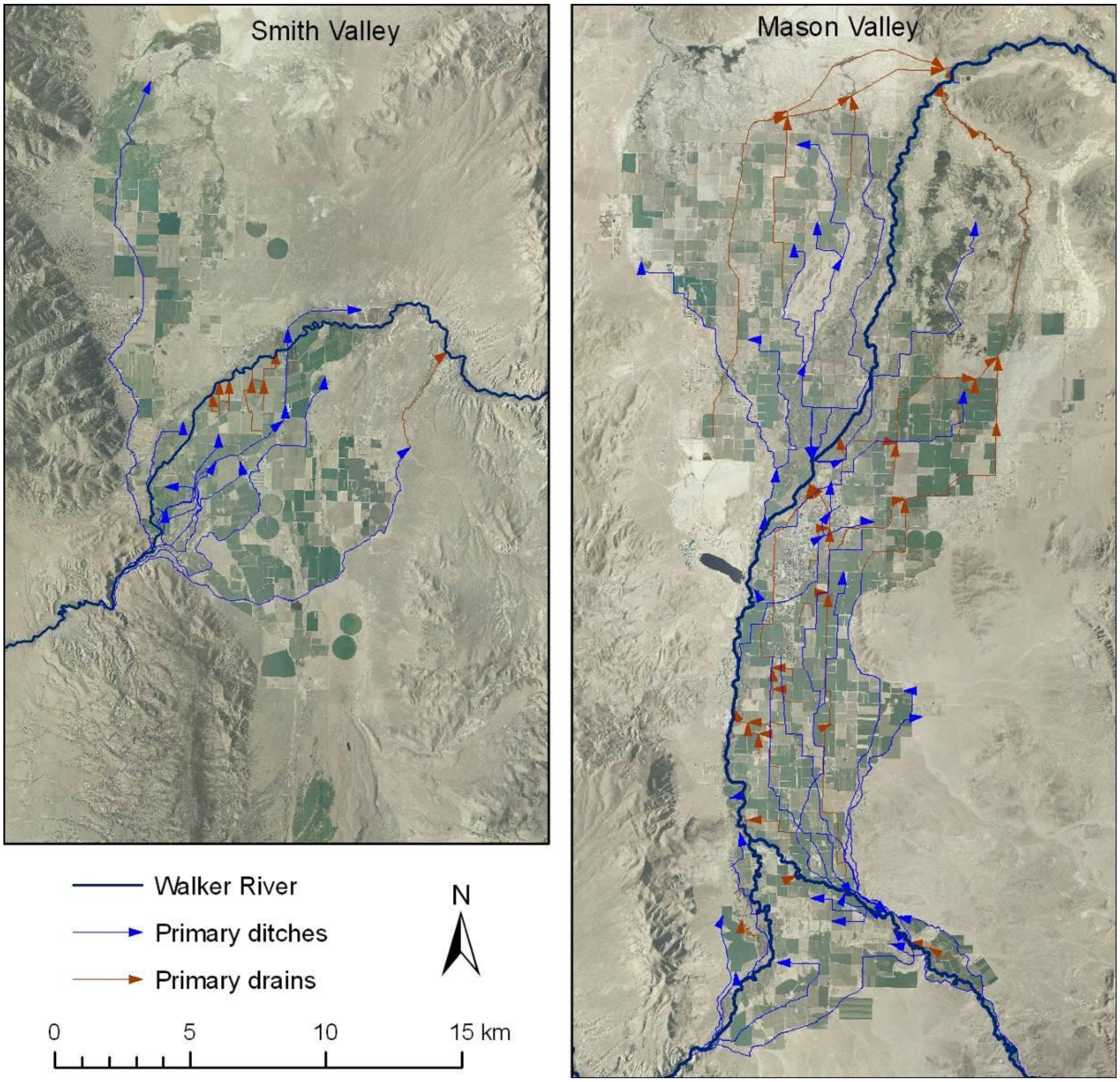

Figure 3.5 Diversion Ditches and Drains in Mason and Smith Valleys with flow directions identified.

Primary ditches and river pumps were assigned names based on the original points of diversion of the river system. In many cases, surface diversions could be directly traced to individual fields. One problem encountered was that many of the ditches had been diverted into underground pipes, leaving little evidence of their path visible on the high-resolution aerial photography. To correctly interpret these areas, multiple field inspections were conducted during the life of the project. Recorded subdivision and parcel maps from Lyon County were also used in some cases to identify both underground and aboveground pipe routes. Locations where ditches and drains were replaced with pipe and/or were routed underground were noted and appropriate adjustments to the line work were made. The ditch and drain line work was edited to ensure that all line segments representing ditches, river pumps, and drains properly connect to the river centerlines for the east and west forks, and main stem of the Walker River system. This was necessary to ensure proper network analysis of the delivery and drainage system in the DST. Coordinates for all USGS gaging stations in the Walker Basin were obtained from the USGS and converted to a spatial data layer that represented the locations of gaging stations.

Historical Surface Water Diversions

Monthly decree, storage and flood diversion data for ditches and river pumps on the Walker River system was obtained from WRID for the years 1996 to 2011. The data were provided by WRID in hardcopy format and then converted into a digital format (Excel) customized for input into the DST. An effort was made to reconcile the ditch and pump names; sometimes, when attempting to compare major diversions over the entire time series (1996–2011), the hardcopy data from WRID showed that diversion names changed and/or were omitted when a diversion was abandoned or was combined with another diversion.

The WRID diversion data was modified to correspond to the HRUs as they are identified in the HRU Concept section above. Most of the HRUs have a one-to-one correspondence with the WRID diversion data. Where there was not a one-to-one correspondence, the WRID diversions and their respective data were assigned to the identified HRUs, as follows:

- East Walker data was partitioned into Pitchfork HRU (32%) and East Walker HRU (68%) based on irrigated area
- East Walker Pumps data was added into East Walker HRU data
- McLeod data was assigned to the River Pump CBN HRU
- Nordyke Quail was modeled as part of the D&GW HRU
- The Howard diversion was assigned to the Hilbun HRU
- Main River Pump data was partitioned into River Pump AGHD (62%) and River Pump Stanley (38%) based on irrigated area
- West Walker Pumps were modeled as River Pump Borsini

Hardcopy versions of the daily and monthly NDOW Mason Valley Wildlife Management Area (MVWMA) diversions from 1996 to 2011 were provided by NDOW; the decree, storage and flood data were subsequently converted to digital (Excel) format.

The WRID diversion data is combined such that the NDOW deliveries are included with the information for the HRUs that contain the NDOW properties. For example, Joggles diversions from WRID contain the diversions for the NDOW property in Joggles HRU. The WRID time series was adjusted to remove the NDOW diversions, but there were periods where the NDOW diversion data was actually larger than the lumped WRID diversion data. Additionally, the NDOW pond and field diversions are not broken out in the NDOW diversion data. To adjust the combined WRID diversion, create the NDOW diversion, and partition the NDOW diversion into pond and field deliveries, the data processing steps below were implemented.

First, the area ratio (*R*) of NDOW fields to Non-NDOW fields in the HRU is calculated as,

$$R = \mathbf{AreaNDOWFields/AreaNonNDOWFields} \qquad \textit{Eq. 1}$$

Next, the area ratio of NDOW fields (*RNF*) to the total agricultural field area in the HRU is calculated as,

$$RNF = \mathbf{AreaNDOWFields/(AreaNDOWFields + \ AreaNonNDOWFields)} \qquad \textit{Eq. 2}$$

The HRU areas and resulting ratios are shown in Table 3.3.

Table 3.3 HRUS with Sub-HRU areas

HRU	Area Non-NDOW Fields	Area NDOW Fields	Ratio (***R***)	NDOW Ratio Fields (***RNF***)
Joggles	1064.58	361.25	0.34	0.25
SAB	570.25	607	1.06	0.52
West Hyland	3691.8	223.13	0.06	0.057

Next the diversion to the Non-NDOW fields is calculated as,

$$\mathbf{NonNDOWDiv} = \mathbf{If}\ \ \mathbf{DL} < \mathbf{DivNDOW}, \mathbf{DL} * \ \ \mathbf{1} - \boldsymbol{RNF}\ \ , \mathbf{DL} - \mathbf{DivNDOW} \qquad \textit{Eq. 3}$$

Where DL is the lumped diversion. Based on the NonNDOWDiv calculation we calculate the diversion to the NDOW fields as,

$$\mathbf{NDOWFieldsDiv} = \mathbf{If}(\mathbf{DL} < \mathbf{DivNDOW}, \mathbf{DL} * \ \ \boldsymbol{RNF}\ \ , \mathbf{Max}\ \ \mathbf{NonNDOWDiv} * \boldsymbol{R}, \mathbf{DivNDOW}\ \ ) \qquad \textit{Eq. 4}$$

And finally, the NDOW ponds receive any remaining portion of the lumped diversion.

Groundwater Places of Use and Points of Diversion

The Nevada Division of Water Resources (NDWR) helped to develop the GIS data sets of groundwater usage Points of Diversion (PODs) and Places of Use (POUs) for irrigation purposes in Mason and Smith Valleys. Permitted and certificated POD and POU irrigation groundwater data were scanned from maps at NDWR based on the PLSS system. The following tasks were performed to create the data sets:

- A hydrographic abstract was performed for Mason and Smith Valleys to find all current, active groundwater rights used (restricted to permitted irrigation water rights only).
- Each groundwater right had a permit number and a map displaying the location/extent of the POU and POD.
- Each groundwater right map was geo-referenced to a PLSS data layer; the POU and POD data were manually digitized based on the referenced map. NDWR used the BLM Geographic Coordinate Database (GCDB) for a PLSS grid because it is the most comprehensive and non-proprietary grid available.
- Changes in location and amount of water allowed for each groundwater right were calculated; the base water rights were first identified, and then subsequent abrogation permits were applied.
- The permit (link) table was populated with each permit number as well as its corresponding POU IDs (Poly_ID) and POD IDs (Site_ID).
- The POU attribute table was populated with the amount of irrigated acres within a POU polygon, and supplemental information, including all associated polygons, and total supplemental acreage. Polygons and associated polygons represented groups of permits or Total Combined Duties for groundwater rights.
- The POD attribute table was populated with a Site ID (Basin Number, Township, Range, Section Number, and divisions of the section).
- The POD and POU data are stored in an Environmental Systems Research Institute (ESRI) personal geodatabase, with the permit table used to relate the POD attribute table

to the POU attribute table. Figure 3.6 shows the location of groundwater PODs and POUs in Mason and Smith Valleys.

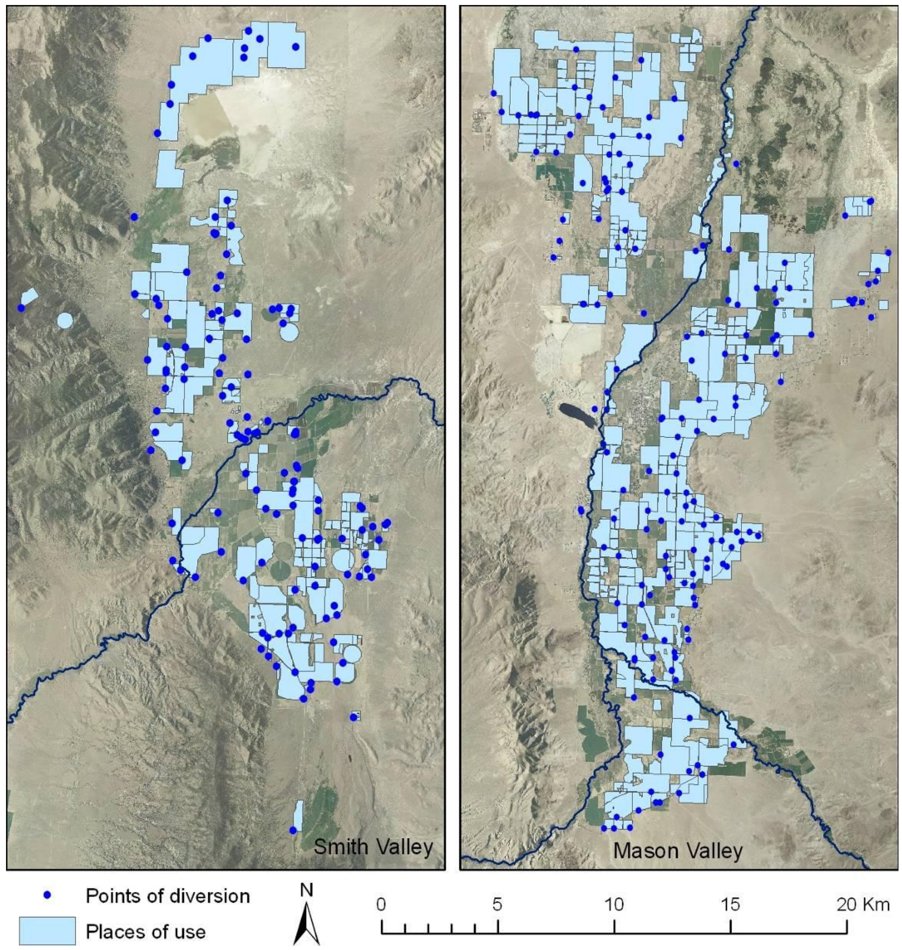

Figure 3.6 Groundwater Points of Diversion (POD) and Places of Use (POU) in Mason and Smith Valleys.

Other groundwater data acquired from NDWR included water level observations and pumping inventories for Mason and Smith Valleys. The water level data consisted of 112 wells in Mason and Smith Valleys and included well status, owner, well depth, and site names. Pumping data for the years 1994 to 2004 (Mason and Smith Valleys) was obtained from NDWR in hardcopy form (Gallagher, 2005), which was subsequently converted into digital format. Data fields included well locations, permit numbers, site use, and annual gross pumpage by site from 1994 to 2004.

Water Rights by HRU

The locations of the Decree C-125 surface water right claims by HRU were determined by using the data layer developed by HMS based on the BLM GCDB flat files PLSS base layer for the entire spatial extent of the C-125 decree Nevada. Figure 3.7 shows a subsection of the C-125 decree for Mason Valley.

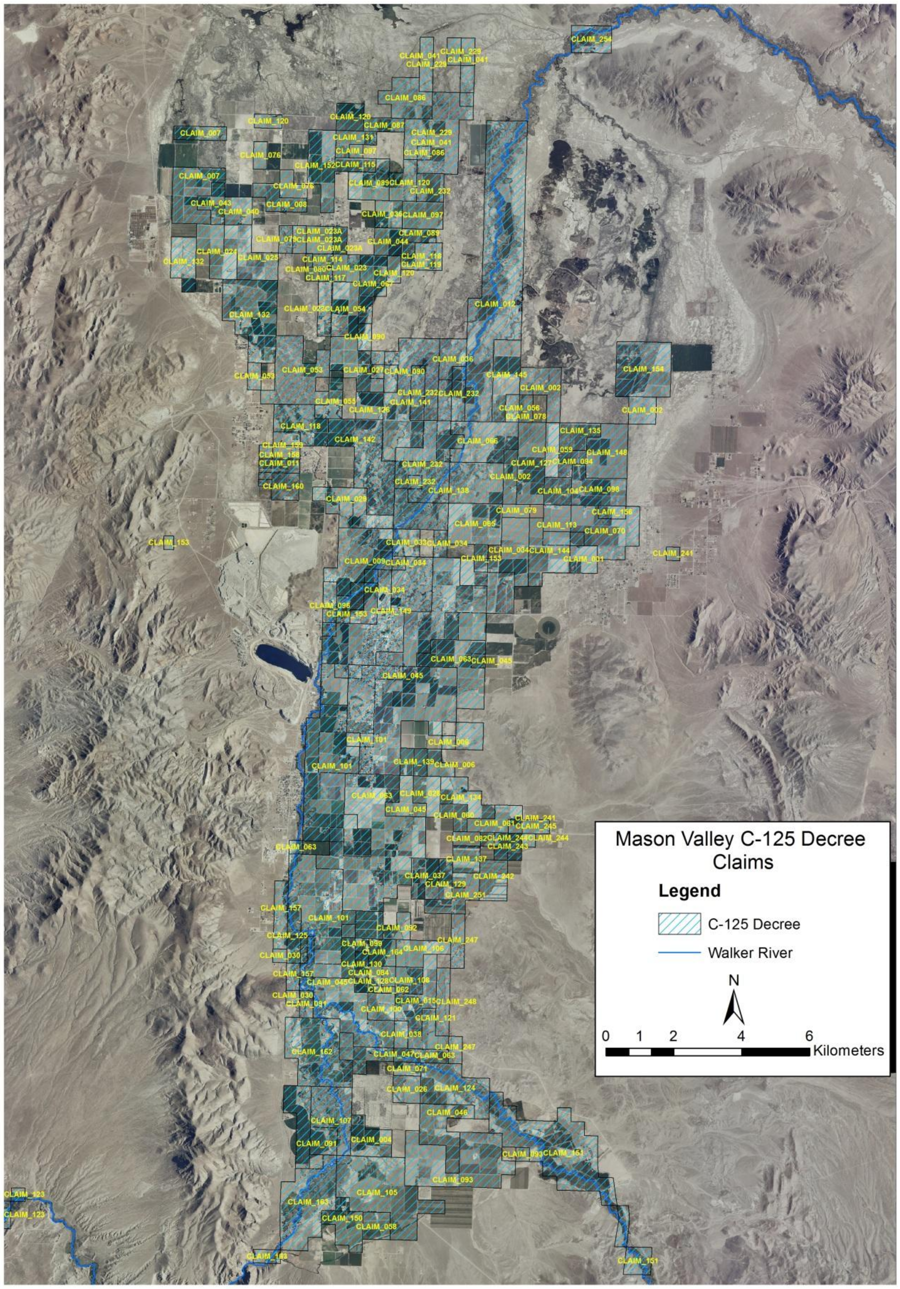

Figure 3.7 C-125 Decree surface water rights in Mason Valley.

There were often either extensive overlaps of claim areas, or much larger areas designated than actual irrigated acres. To attach each decree water right claim to a specific set of irrigated fields, a reasonable estimate was made by comparing the 1997 Nevada Division of Water Planning (NDWP) Abstract database with the C-125 data (Pahl, 1999) and the 2007 Lyon County parcel data set. The Abstract database provided information by claim number for individual owners; however, specific parcel numbers were not included. In most cases the parcels owned by the individual decree claim owners were identified, and the total water right was assigned to the existing irrigated fields on the property.

A series of data tables were developed to quantify the decree rights for the Mason and Smith Valley HRUs and the East Fork claims up to Bridgeport Reservoir. The most current data available were from the 1997 NDWP Abstract database compiled by NDWP from actual records at the Walker River Decree Federal Water Master's office (Pahl, 1999). The Abstract table was extracted from the 1997 NDWP water right database and converted into an Excel spreadsheet. In the Abstract table, there are individual entries by landowner for each priority date under each claim. Each priority date also has an acreage and assigned rate (in cfs). For the DST these entries were reduced to sums of acres by priority data for each HRU. The sum of the rate (cfs) for each entriy was converted into a flow rate (cfs/acre). These flow rates are equal to 0.016 CFS/AC or 0.012 CFS/AC for bench and bottom land assignments, respectively, or as 0.010 CFS/AC for permits with 1908 or junior priority dates (and see explanation of decreed diversion rates in Pahl, 1999). The decree data was updated as necessary with respect to subsequent water right transfers, particularly in relation to the various river pumps (for example, modifications were made to the Greenwood Ditch values to remove the Warburton Pump).

Table 3.4 contains the summarized irrigated acres and diversions for all priority dates and fields on the West Hyland ditch. The full table for all HRUs used in the DST is provided with the accompanying DST software.

Table 3.4 West Hyland Decree Water rights

Priority Date	Irrigated Acres	Diversions (CFS)
1873	250	3
1874	1761.19	21.13
1877	72	0.86
1880	867.54	10.41
1881	40	0.48
1887	65	0.78
1888	80	0.96
1891	138	1.656
1894	15	0.18
1896	92	1.10
1899	12	0.14
1900	140	1.68
1901	15	0.18
1904	26	0.31
1905	40	0.48
1906	20	0.24
Totals	3633.73	43.59

Net Irrigation Water Requirement (NIWR)

Net Irrigation Water Requirement (NIWR) data is required by the DST to establish a crop water requirement for each modeled field. NIWR data files for Mason and Smith Valley were obtained from the NDWR website, which correspond to a report entitled *Evapotranspiration and Net Irrigation Water Requirements for Nevada* (Huntington et al. 2010):

- Mason Valley – Yerington Location -'269229NIWR_stats.dat'
- Smith Valley – Wellington Location -'268977NIWR_stats.dat'.

The mean monthly NIWR in mm/day was obtained from each of the files for each crop type and converted to feet/month.

The NIWR represents the precipitation deficit or:

$$NIWR = ETact - Precipitation\ Retained\ in\ The\ Root\ Zone \quad \text{Eq. 5}$$

The crop types identified in the aforementioned crop survey did not always have an exact match to the crop types in the NIWR dataset. The two were reconciled by matching the most appropriate crop category in the survey to the NIWR dataset according to the following table:

Table 3.4 Relationship between 2007 crop survey types and NDWR NIWR crop categories

Crop Types from 2007 field mapping (Snyder/Minor)	Key Code	NDWR NIWR
Alfalfa	A	Alfalfa Hay
Brush	B	Bare Soil
Corn	C	Field Corn
Dry Grass	DG	Grass Pasture (Low)
Fallow	F	Bare Soil
Feed Lot	FL	Bare Soil
Flooded Field	FF	Open Water
Forage Crop	FC	Grass Hay
Garlic	Ga	Garlic
Grain	Gr	Spring Grain
Grapes	Gp	Fallon Grapes[4]
Grass	G	Grass Hay
Lettuce	L	Garden Vegetables
Oat	Oa	Spring Grain
Onion	O	Onion
Pasture	P	Grass Hay
Pond	PO	Open Water
Turf	T	TurfGrass Lawns

METRIC ET Data

Monthly and seasonal evapotranspiration (ET) were calculated for the Mason and Smith Valley HRUs using the Mapping Evapotranspiration with Internalized Calibration (METRIC) model (Allen et al. 2007), for the 2007 growing season. The 2007 METRIC results were compared to NIWR and DST consumptive use values to assess the accuracy of the water balance simulated consumptive use (see Section 5 below). METRIC estimates ET as the residual of the surface energy balance (SEB). The primary inputs for the model are satellite images from the Landsat Thematic Mapper (TM) platform, a digital elevation model (DEM), ground-based weather data measured within or near the area of interest, and land cover classification data for Mason and Smith Valleys. The local weather data is used to calibrate and interpolate ET estimates in time using an alfalfa reference ET (ETr) that is calculated hourly with the ASCE standardized Penman-Monteith equation (ASCE-EWRI 2005). Seasonal ET was calculated for March through October of 2007 and a seasonal ET raster was generated for 30-meter cells across the agricultural extent of Mason and Smith Valleys. To calculate ET zonal statistics by HRU and crop type, a 30-meter buffer was used on all HRU field boundaries to remove edge cells and retain the overall ET rate for each agricultural field in the HRUs. The statistics were used to generate monthly and seasonal ET summary tables by HRU and crop type.

[4] The NIWR value for grapes was sourced from the NDWR Fallon station

Change Application No. 80700 Areas

An Existing Place of Use map was developed for NFWF's Change Application No. 80700 using AutoCAD software. The AutoCAD data layer representing the areas of appurtenant water rights proposed to be transferred was converted into a GIS compatible format. The data layer's areal properties are not exact relative to the NFWF purchased water cards due to digitizing error inherent to the mapping process (less than 1%). Figure 3.9 shows the proposed area of water rights to be transferred in the West Hyland HRU at the north end of Mason Valley (overlaid on 2010 one-meter aerial photography). The fields shown in the figure reflect the total area of water rights proposed for transfer for all claims involved in Application No. 80700. The area shown represents the appurtenant water rights and not the actual areas of water usage.

Figure 3.9 Change Application No. 80700 proposed area of water rights to be transferred.

4. Methods

DST overview

The Walker Basin DST is a modeling system that captures the interactions between climate, evapotranspiration, surface water flows, groundwater-surface water exchange along the river, irrigation practices, and groundwater pumping. The modeling system consists of three components linked by a set of geospatial datasets and a controller module that facilitates the connectivity among the components. The three components are: the MODSIM component (Labadie et al. 2006) which simulates the surface water allocation, the MODFLOW component (Harbaugh et al. 2000) which simulates the groundwater system, and the HRU Water Balance component which performs a field-level water accounting of the agricultural activities.

A key feature of the DST Modeling system is the custom controller module that was developed to "loosely couple" the three software components together to provide an integrated approach to simulating the various hydrologic processes and manage information transfer between the components (Figure 4.1). The controller uses MODSIM to allocate different surface water sources (i.e., flood, storage, and decree water) to satisfy water right demands, determine diversion amounts at the ditch scale for input to the HRU Water Balance, and determine water routing information for input to MODFLOW. The controller then uses the HRU Water Balance component to determine supplemental pumping rates needed to satisfy crop demands and partition the available irrigation water into runoff, infiltration and evapotranspiration (ET). Finally, the controller uses MODFLOW to simulate groundwater response to pumping and infiltration in the agricultural areas and the stream-aquifer interaction in the river, ditches, and drains, throughout Smith and Mason Valleys (Figure 4.1). The controller then passes the simulated runoff and stream-aquifer interaction (in the form of accretions and depletions) back to the MODSIM component. The controller uses an iterative procedure based on the difference between the accretions and depletions at the end of a MODSIM run and those at the end of a MODFLOW run to determine when the three components are synchronized.

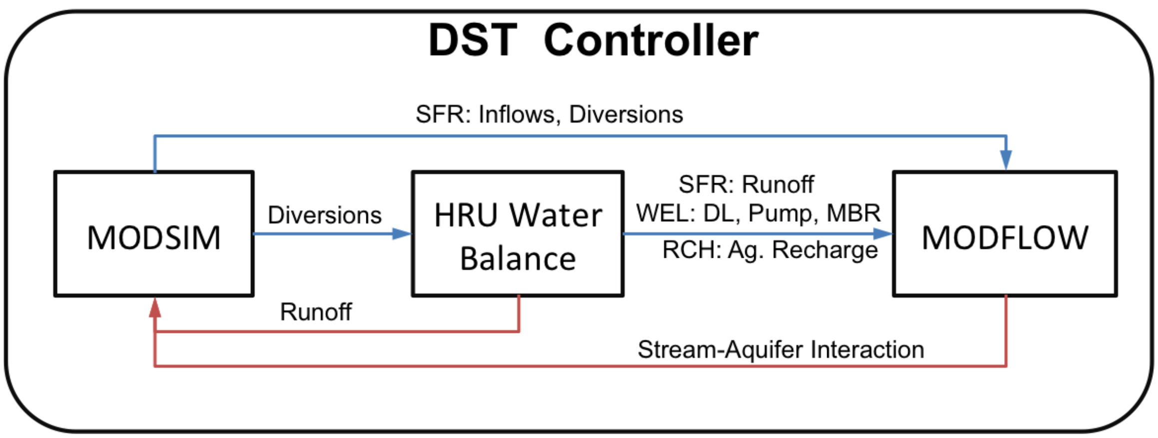

Figure 4.1 Walker Basin DST Modeling System Components Diagram

MODSIM Component

Overview

MODSIM is a generalized river basin management decision support system that is designed as a computer-aided tool for developing improved basin-wide and regional strategies, including long-term operational planning and water rights analysis. MODSIM was developed by Colorado State University (Labadie 2006), and has been used successfully by the U.S. Bureau of Reclamation, Colorado State University, MWH and many other groups on similar projects in the United States and internationally.

MODSIM uses a network flow approach that is comprised of interconnected nodes with unidirectional links to simulate river systems. Nodes can be classified as non-storage nodes, demand nodes, reservoir nodes, or network sinks. Non-storage nodes are inflow locations where water can flow into the system. Demand nodes represent consumptive uses, and sink nodes represent locations where flow exits the surface system. Reservoir nodes are storage nodes that simulate reservoir operations. Links convey flow from node to node. MODSIM optimizes the network flow-cost problem to distribute water among competing users in the system.

MODSIM Base Network

The MODSIM base network is a geospatial representation of the connectivity between the river, drains, ditches, demands, and reservoirs in the Walker River Basin as defined in Section 3 of this report. The base network was constructed by converting the shape files for these features into an ArcMap geometric network. The MODSIM base network begins upstream of Bridgeport Reservoir, CA at Bridgeport_Inflow on the East Walker River, and at Coleville, CA at USGS gage 10296500 on the West Walker River and continues downstream to Wabuska, NV at USGS gage 10301500 (Figure 3.1).

Demands and Water Rights

In MODSIM, agricultural demands correspond to the WRID time series of diversions for each ditch service area. Supply to the demands is dictated by decree, flood, and storage water right links. In the Walker River basin, users on different ditches distributed over a wide geographic area may have identical decree priority dates. Unique priority dates are necessary in MODSIM to avoid random water allocation among users with the same priority date. To achieve a unique priority scheme, demands were ranked in the downstream direction such that the most downstream owner of a commonly owned priority date would be assigned the lowest priority for that common date. Thus, if several demands have a priority date of 1880, the most upstream demand is assigned a priority data of January 1, 1880, the next January 2, 1880, and so on.

The usage of storage and floodwater is highly influenced by user preferences and operational decisions. Dynamic modeling of these decisions is difficult because the specific operational rules for these allocations have not been identified and, thus, were not implemented in the MODSIM component of the DST. The usage of storage and floodwater in the MODSIM component of the DST is therefore simulated to match historical records for each ditch diversion.

Water right priorities in MODSIM are simulated with the concept of cost. Cost is a way of preferentially driving flow to one place in the network over another. The more negative the cost, the more MODSIM will drive water to that point in the network. The design of cost structures in the MODSIM network allows simulation of the prior appropriation doctrine and other complex administrative rules. The model converts node priorities to costs, using the Equation 6. The node costs are then combined with the costs of the model links. The sum of all flows multiplied by the cost at each time step is minimized to solve the network flow-cost problem. Using this approach water distribution is optimized according to the supplied cost structure.

$$\mathbf{Cost} = -\mathbf{50,000} + (\mathbf{10} * \mathbf{Priority}) \qquad \textbf{\textit{Eq. 6}}$$

The MODSIM modeling approach for all the water rights is to use capacitated links with an upper bound and cost that pulls any righted water through the link up to the capacity. For the flood and storage links, a very senior cost is assigned so that the historical flood and storage diversion is forced to be delivered to each demand. For the decree rights, one link is created between the POD and the demand for each water right in that ditch service area. If MODSIM determines the right is in priority for a particular time step it will provide water up to the righted diversion rate.

Decree Buffer Links

A preliminary analysis of the decree water right capacity versus the historical diversion for each HRU showed that at times the combined decree water rights are not sufficient to supply the observed historical diversion. Figure 4.2 shows the total deficit for 1996 to 2011 for all demands where there was a deficit.

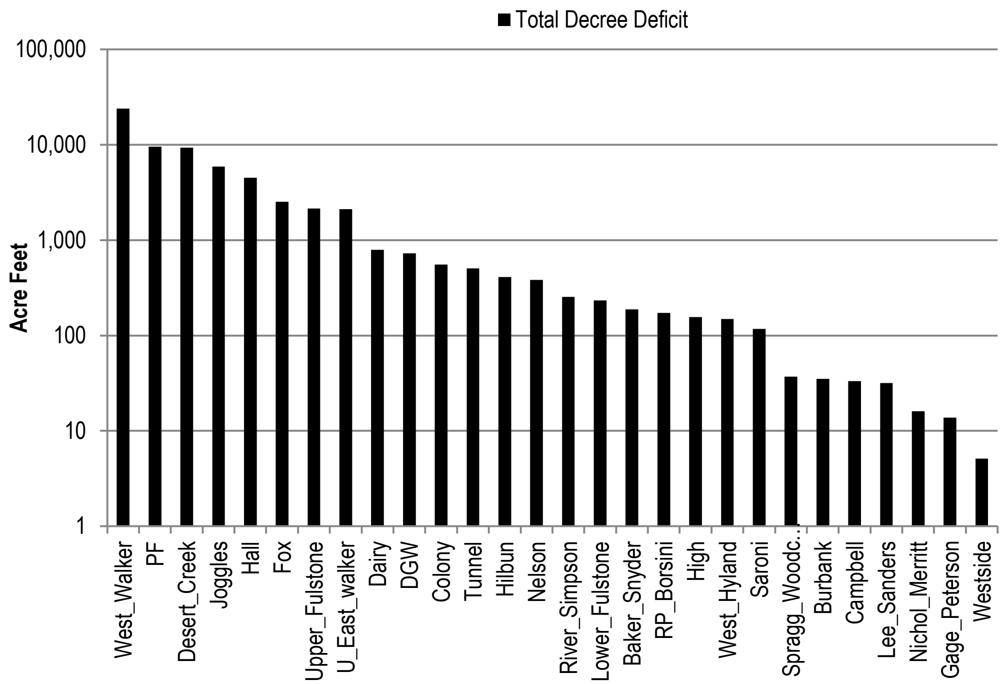

Figure 4.2 Total decree deficit for all demands over 1996-2011 (deficit >0).

The shortcomings in decree water right capacity were addressed by adding a link, identified with a name ending in “DecreeBuffer”, that provides the mechanism to supply the historical diversion to the HRUs. This was necessary because the DST calibration run requires a zero shortage run.

Reservoir Modeling

The accrual and releases from Bridgeport and Topaz reservoirs is simulated to match the historical storage time series for each reservoir. The usable, dead, and total storage used in the MODSIM DST component for each reservoir is shown in Table 4.1. The average monthly observed free water evaporation estimates for Topaz Reservoir (Western Regional Climate Center WRCC 1957-2006) were also used for Bridgeport Reservoir (Figure 4.3). Two rating curves were implemented, Bridgeport and Topaz, to relate the reservoir surface area to volume. The Topaz curve was digitized from *Bathymetric Reconnaissance of Topaz Lake, Nevada and California* (Rush et al. 1972), and the Bridgeport curve was adapted from several sources, including tables obtained from the Federal Water Master and a 1998 USGS California Hydrologic Data Report for Bridgeport Reservoir (Figure 4.4 and Figure 4.5) respectively.

Table 4.1 Bridgeport and Topaz Reservoir Capacity (Acre-Feet.)

	Topaz	Bridgeport
Usable Storage	59439	42460
Dead Storage	65000	0
Total Storage	124439	42460

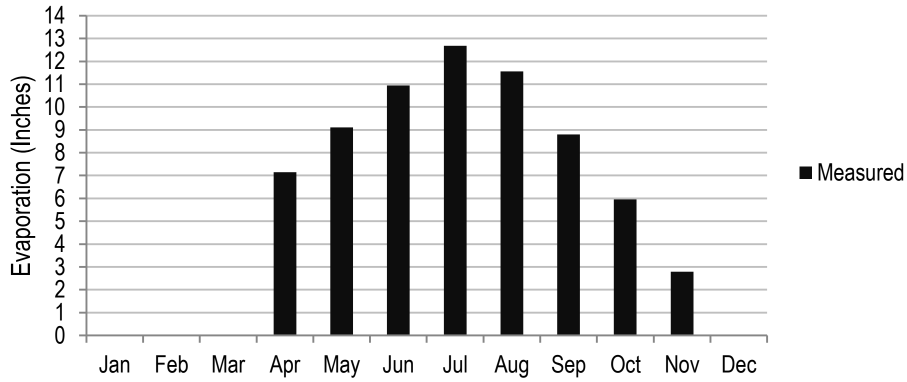

Figure 4.3 Average monthly measured reservoir pan evaporation depth (.in)

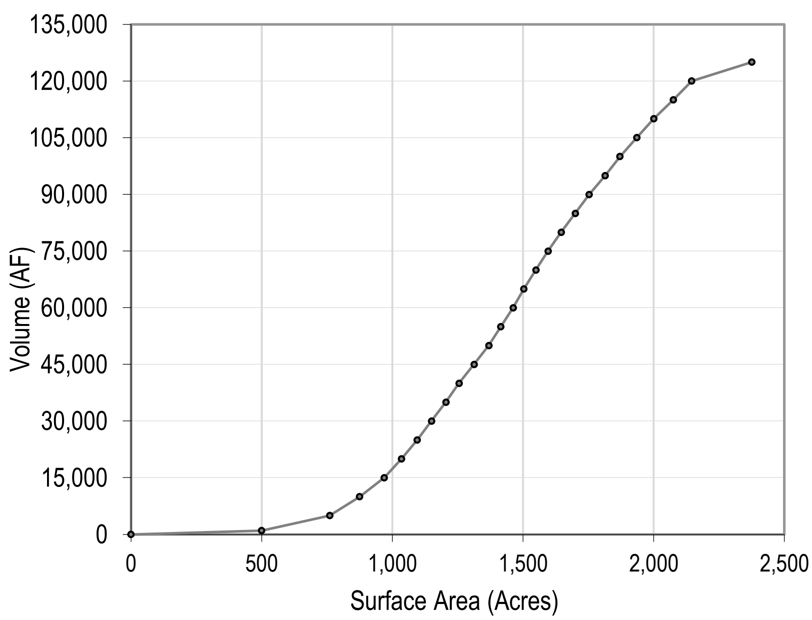

Figure 4.4 Topaz Reservoir Area-Volume rating curve

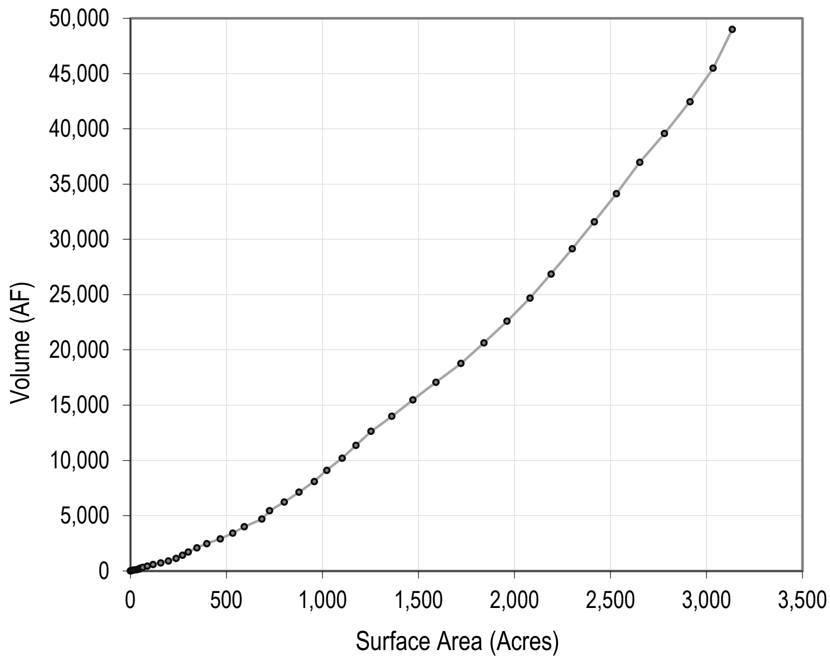

Figure 4.5 Bridgeport Reservoir Area-Volume rating curve

Accretions and Depletions

The MODSIM base network includes stream and drain line segments where information on surface water distribution (i.e., boundary condition stream flow and diversions), simulated within MODSIM, and stream-aquifer interaction (i.e., accretions and depletions), simulated with MODFLOW SFR segments (i.e., groups of river cells or reaches in the Stream Flow Routing SFR package), can be exchanged between the components. The MODSIM component implemented within the DST does not simulate the accretions and depletions directly; rather it relies completely on the simulation of these from MODFLOW.

The MODFLOW accretions are implemented as inflows using standard MODSIM non-storage nodes with an associated time series. The monthly net accretions to the river from an SFR segment are simulated at the corresponding downstream non-storage node. Non-storage nodes used for accretion modeling contain the prefix "34_" in the node name. Nodes with multiple segments upstream will contain the sum of the individual accretions in the time series. For example, in Figure 4.6, non-storage node "34_73" will contain accretions for segment 12 (i.e. pink MODFLOW cells) and for segment 22 (i.e. pink MODFLOW cells) in non-storage node "34_73". Both segments have accretions for the yellow cell.

Depletions modeled by MODFLOW from the river and ditch systems are simulated in MODSIM using a set of capacitated links and a sink node. The links upper bound is proscribed as a monthly net depletion of the corresponding SFR segment and low negative cost (i.e. -120,000) to guarantee that the flow at capacity through these links. The end result of this construct is that the model forces the calculated depletions out of the network at the downstream end of the segment. These links are identified with the prefix "ANN_Deplet_From_". For example, in Figure 4.6 the link between the sink node "GW_Sink" and non-storage node "34_73" will contain a time series of depletions for segment 12 and segment 22.

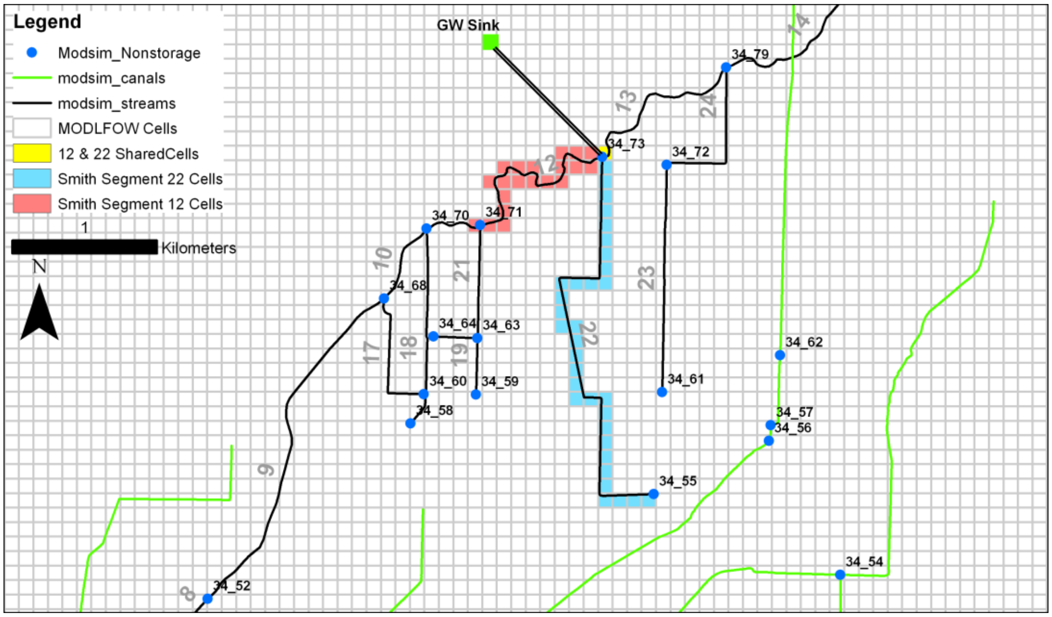

Figure 4.6 Accretions and depletions illustration

Runoff

The runoff simulated from the different HRUs is transferred to non-storage nodes identified with the prefix "FR_" and the name of the HRU from which they originate. HRUs may have multiple points of returns to the surface water system. The spatial distribution of the HRUs with respect to the river and ditch systems was used to define these return locations and their corresponding return fractions.

NDOW Properties and Combined Water Rights

The DST water right information is an aggregate of water rights for all lands served on each ditch. The water rights for the NDOW properties are therefore included in the water rights for the ditches that contain NDOW fields or ponds. For example, West Hyland's water rights contain the water rights for the NDOW property on West Hyland ditch. For the ditches where NDOW property is present (West Hyland, Joggles, and SAB), the following approach was used.

The approach delivers the total diversion through the aggregate water rights for all entities (West Hyland Non-NDOW, NDOW fields and ponds, and a node for Application No. 80700) to a FlowThru node (i.e. West Hyland Total). The FlowThru node passes 100% of the total delivery to the FlowThru Destination node in Figure 4.7. A priority structure is setup for the Non-NDOW, NDOW fields, NDOW ponds, and Application No. 80700 nodes such that the Application No. 80700 demand is met first, followed by the Non-NDOW and the NDOW fields, with the ponds receiving any remaining water. In the baseline run, when there is no Application No. 80700 water, the Application No. 80700 demand is served on the West_Hyland Non-NDOW demand and the demand for the Application No. 80700 node is zero. In the scenario, the demand for the Application No. 80700 node will be greater than zero, and the total volume of surface water inflow to the node is returned back to the POD node.

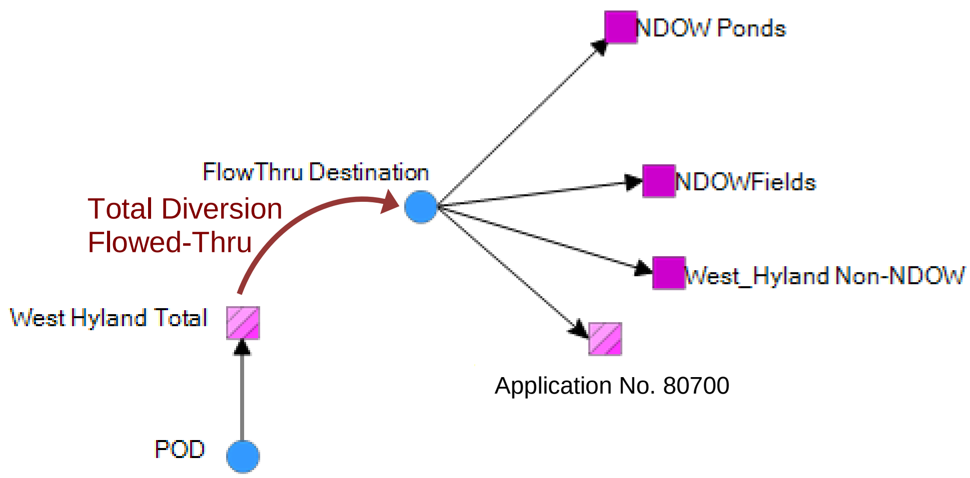

Figure 4.7 NDOW, Non-NDOW ("Only"), and App. No. 80700 MODIM demands.

Calibration Structures

The MODSIM network is set up with "Calibration Structures", which are artificial constructs of MODSIM nodes and links, that allow the model to automatically simulate unmeasured (Unknown) gains and losses in reaches of the system between gaging stations where the surface water flow is measured (Known). The Calibration Structure consists of a sink and a source. The sink of the Calibration Structure is connected to the upstream reach and disposes of excess water. Excess water at the calibration structure represents river system losses that are not explicitly simulated in the reach. The source of the Calibration Structure provides water shortfall to the downstream reach. Water shortfall is generated by inflows to the system that are not explicitly simulated in the network.

The Calibration Structures implemented in the DST use standard MODSIM nodes and links so they are included in the Base Network. Figure 4.8 shows the schematic of the Calibration Structure parts.

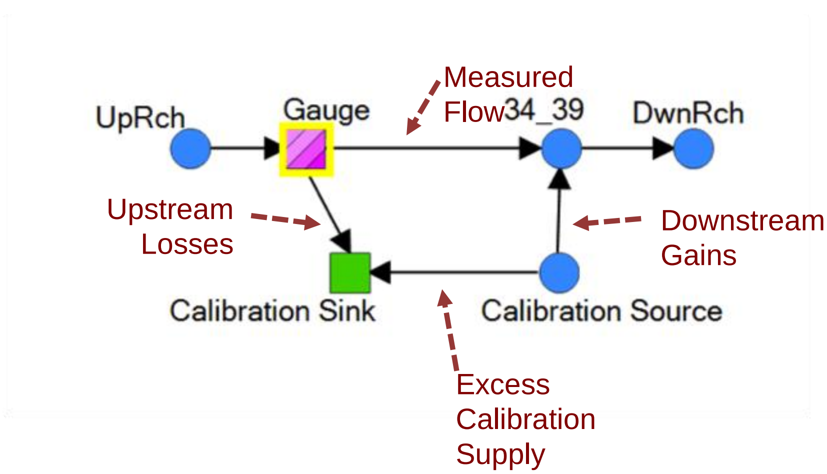

Figure 4.8 Components of the MODSIM Calibration Structure

Calibration Structures are implemented for each gaging station in the study area. The most upstream gaging stations in the network will have a Calibration Structure that is only a source, for both the associated gaging station and the next downstream station. Alternatively, the most downstream station will have a Calibration Structure that has only the sink feature. Table 4.2 shows the gaging stations with calibration structures implemented in the Walker model Base Network and the type of Calibration Structure functionality.

Table 4.2 Gaging Stations With Calibration Structures

Station Name	MODSIM Node Name	Station ID	Calibration Structure Source	Calibration Structure Sink
West Walker at Coleville	WF_Coleville	10296500	♦	
Bridgeport Res. Inflow	BP_Inflow	Calculated[5]	♦	♦
West Walker at Hoye	WF_Hoye	10297500	♦	♦
West Walker at Hudson	WF_Hudson	10300000	♦	♦
East Walker at Strosnider	EF_Strosnider	10293500	♦	♦
Walker River at Wabuska	MSW_Wabuska	10301500		♦

Simulation vs. Calibration Usage

Calibration Structures are implemented differently in calibration and simulation modes. In calibration mode, the Calibration Structures dynamically operate as a sink for the associated gaging station and as a source for the downstream gaging station. The gains and losses computed in the calibration step are historical components of the reach mass balance that are not explicitly represented in the MODSIM network, but based on the mass balance between measured points, should be added/removed from the reaches to match the measured flows at those control points. In simulation mode, the Calibration Structures are locked, with upper bounds on the inflow and outflow links, to remove and/or supply only the losses and/or gains computed in the calibration step. Figure 4.9 shows a schematic of the Calibration structure in calibration and simulation modes.

[5] Inflow to Bridgeport Reservoir was calculated as the change in reservoir storage plus the outflow plus the average monthly Topaz WRCC evaporation applied to the reservoir surface area.

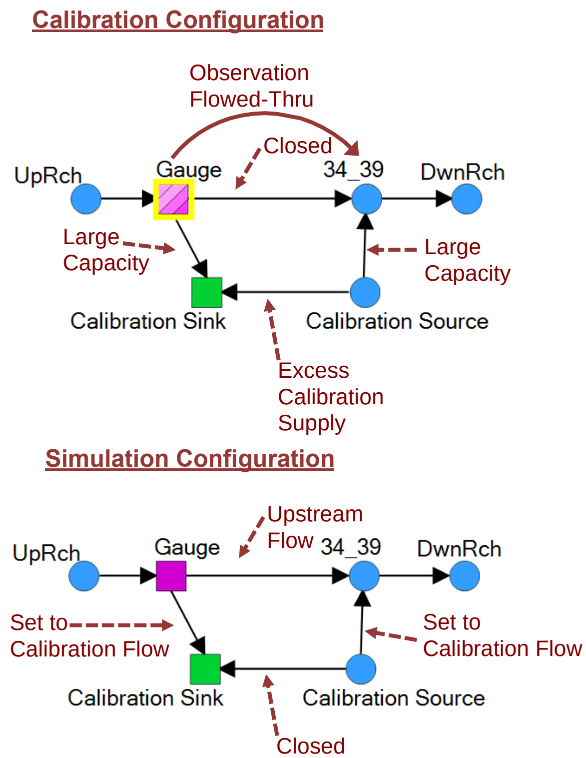

Figure 4.9 Schematic of the Calibration Structure in Calibration and Simulation

In the current version of the DST, customization of the MODSIM model was avoided, so that all the modeling features are available directly in the MODSIM *Network*, which uses standard nodes, links and functionality, facilitating its use and review. The current DST MODSIM model accounts for historical reservoir storage and flood operations as part of the calibration process, and focuses on simulation of natural flow allocation based on the water rights. This setting is ideal to evaluate water rights transfer scenarios without adding the additional complexity of changes in storage or floodwater operations.

Linkage to Other Components

Once MODSIM has achieved its solution for the optimal water allocation, information for the run is passed to the HRU Water Balance and the MODFLOW SFR input file. Specifically, a table of the surface inflow to each MODSIM demand is passed to the HRU Water Balance component. The observed inflow plus the calibration supply is written into the boundary condition inflow positions of the MODFLOW SFR files for Hoye gage in the Smith Valley portion of the model and for Hudson and Strosnider gages in the Mason Valley portion of the model. The same table of diversions, which is passed to the HRU Water Balance component, is also written into the appropriate locations of the SFR file for the MODFLOW component.

HRU Water Balance Component

Overview

The HRU Water Balance component simulates field-level water accounting of the agricultural activities to estimate supplemental pumping rates needed to satisfy crop demands and partition the available irrigation water into runoff, infiltration and ET. The software for the component was developed in Microsoft VB.NET specifically for application in the DST modeling system. It relies on geospatial datasets and the MODSIM simulated water allocation to perform a detailed accounting of all water entering and leaving each HRU. In this study, because water right information was aggregated to the HRU scale, the surface water deliveries are applied uniformly over each HRU area and supplemental groundwater pumping is only applied to areas within an HRU that are known to have supplemental pumping rights and have a demand remaining in a time step after the surface deliveries are made.

Two parameters are used to account for farm and conveyance inefficiencies while a third is used to partition excess irrigation water into runoff and recharge. The water balance parameters were estimated during the DST development process using a manual approach to match historical streamflow observations and basin wide pumping estimates obtained from the NDWR office as closely as possible. Results from the HRU Water Balance component are processed using a geo-referenced grid to compute cell-by-cell groundwater recharge, pumping and ditch leakage for use in the MODFLOW component and the localized inputs that represent irrigation runoff to the surface system network in the MODSIM component and the MODFLOW SFR network.

Water Balance Modeling Grid

At the coarsest level, the water balance represents agricultural demand areas at the HRU scale. The HRUs have a one to one relationship with the MODSIM demands. The modeling grid for the water balance incorporates the MODFLOW modeling grids, the HRU map, and the NDWR place of use spatial dataset for groundwater pumping. The grid is developed by intersecting these map elements as shown in Figure 4.10. The intersection of these features defines a “sub-poly” unit. A sub-poly has an HRU attribute, MODFLOW row column information, and a Poly ID, which defines its pumping capabilities (i.e. permits, well(s), place of use, etc.).

In cases where groundwater places of use overlap or there are digitizing errors, there are overlapping Sub-Polys. The effective production area of the overlapping Sub-Polys is reduced by the count of the sub-polys to handle for these situations. The effective area reductions ensure that the HRU Water Balance component simulate the correct irrigated area. For a sub-poly with access to two groundwater places of use, the water balance uses two sub-polys and treat each as having half of the area, so half the area will use supplemental pumping from one permit and the other half will use supplemental pumping from the other permit.

Where sub-polys within the same HRU have common access to pumping, they are treated as one modeling unit called a HRU group. The grouping approach was selected primarily to improve the water balance runtime performance. It was possible to use this approach because the surface water application and demand are uniform over the HRU, therefore the groups have similar characteristics per unit area in terms of surface supply, demand, efficiencies and access to supplemental pumping. The computation of the water balance is performed in units of water depth for each HRU group.

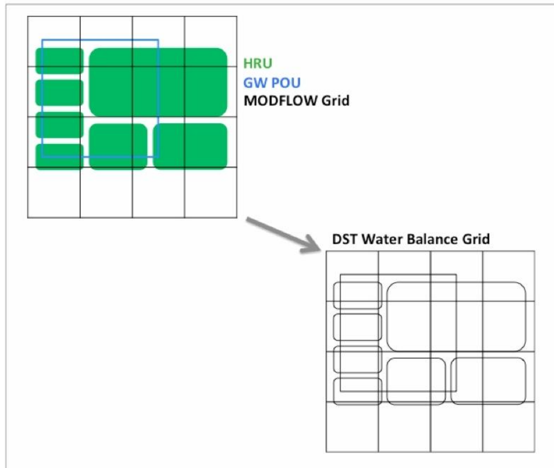

Figure 4.10 Schematic of the generation of the DST Water Balance Grid

HRU Water Balance Parameters

The irrigation system efficiency in the HRU Water Balance component consists of two different sources; one associated with the ditch conveyance losses and the other associated with irrigation application losses. The *Encyclopedia of Water Science* has defined these terms as: 1) the ratio of the water reaching a farm to the amount diverted from the irrigation source, and 2) the ratio of the crop water requirement to the water applied to the field (Howell, T. A., 2003). The terms imply only a portion of the available water sources are used to satisfy the crop demand, and that a quantity of water greater than the crop demand is required to meet the crop demand.

Two parameters are specified in the DST to simulate the irrigation system efficiency within each HRU. The Ditch Conveyance Loss (DCL) parameter determines conveyance losses as a fraction of the monthly diversion for each ditch. In this study, the value of the DCL parameter is the same across all ditches and does not vary according to ditch length or other ditch features. The Farm Efficiency (FEF) parameter determines the fraction of the irrigation application that is used to meet the crop water requirement. Conversely, it also determines the “excess” portion of the application that is modeled as recharge and runoff.

Storage efficiency is often considered in the context of irrigation efficiency since the root zone may not need to be fully replenished during each subsequent application, however, the HRU Water Balance component does not incorporate this concept explicitly into its logic in this version. As a result, within a model time step all irrigation water applied is consumed by crops, recharged to the groundwater system, or routed as runoff from the HRU and back to the stream or drain network.

A third parameter, Rfactor, is used within the HRU Water Balance component to partition excess water on the HRU into runoff and recharge.

Water Balance Computations

The HRU Water Balance component computations begin with the simulated diversions from the MODSIM output file. The DCL parameter specifies the fraction of water lost in transport between the point of diversion and the application area of the HRU. Surface water available at the HRU is estimated as the diversion minus the ditch leakage and is evenly spread over the entire irrigated area of the HRU. The active irrigated area and the surface water diversion are used to estimate the equivalent depth of surface water (SW_{HRU}) to be applied over each HRU.

$$SW_{HRU} = \frac{SW_{Div} - \quad SW_{Div} * DCL}{A} \qquad \textbf{Eq. 7}$$

where SW_{Div} is the HRU diverted water as simulated in MODSIM; *DCL* is the Ditch Conveyance Loss and *A* corresponds to the active irrigated area in the HRU.

The Net Irrigation Water Requirement (NIWR) is the depth of irrigation water that is required for the crop to grow without water stress. After accounting for farm efficiency (FEF), the total water requirement for a water balance HRU group is calculated as the NIWRE.

$$NIWRE = \frac{NIWR}{FEF} \qquad \textbf{Eq. 8}$$

Pumping Calculation

For each HRU group, the depth of available surface water (*SW*) is compared with the NIWRE. If there is more surface water provided to the HRU than the NIWRE, the excess water (SW_{Excess}) will be used to estimate aquifer recharge and runoff and computation of the supplemental pumping will not be performed. If there is less surface water provided to the HRU than the NIWRE, computation of the required depth of pumping is triggered and SW_{Excess} is set to zero.

Seasonal maximum pumping is the maximum depth of pumping allowed for each place of use. The amount of monthly pumping by HRU group is not restricted unless the accumulated pumping in the year exceeds the annual authorized amount. The HRU Water Balance component assumes that the maximum annual pumping (P_{Max}) allowed for each HRU group, from all the associated pumping wells is 4 ft. Accounting of the pumping is reset for all the HRU groups in January of every year.

The required pumping (P_{Req}) is computed based on the NIWRE shortage and water available for irrigation from diversion (SW) as:

$$P_{Req} = NIWRE - SW \qquad \textbf{Eq. 9}$$

For any particular month, the actual pumping (P_{Act}) equals the required pumping unless the accumulated pumping for a given year exceeds the annual limit, in which case the actual pumping for that month (m) is given by:

$$P_{Act_m} = P_{Max} - \sum_{i=1}^{m} P_i \qquad \textbf{Eq. 10}$$

Where *m* is the current month index and P_i is the pumping for month *i*.

Runoff and Recharge Calculation

The total water applied to the group (App) includes the surface water and the actual pumping.

$$App = SW + P_{Act} \qquad \textbf{Eq. 11}$$

Water that cannot be used by the crop or on farm loss (OFL) is calculated using the minimum of the application and the NIWRE, the farm efficiency factor (FEF), and the surface water excess (SW_{Excess}).

$$OFL = [\min\ App, NIWRE\ *\ 1 - FEF\ ] + SW_{Excess}$$ **Eq. 12**

The OFL is partitioned into aquifer recharge and surface runoff using the runoff factor (Rfactor). Runoff is computed as:

$$RO = OFL * Rfactor$$ **Eq. 13**

While the aquifer recharge is computed as: the remaining portion of the OFL.

$$RCH = OFL *\ 1 - Rfactor$$ **Eq. 14**

Linkage to Other Components

Once the HRU Water Balance component has calculated this sequence for every time step, the MODFLOW input files are written to include the water balance output for actual pumping, agricultural recharge, and runoff. The HRU groups actual pumping, computed per PolyID, is used to compute the pumping per permit. The number of permits per PolyID is used to compute the individual pumping per permit (P_{Permit}) assuming an even contribution of each permit to the PolyID actual pumping. The total pumping per permit (P_{Permit}) is calculated as:

$$P_{Permit} = PIDP_{Act}/(Count\ of\ Permits\ Per\ Poly\ ID)$$ **Eq. 15**

Next the pumping per well site ID is calculated using the relationship between the permits and well site ID, by summing the pumping per permit for each site. Still this must be related to the proper location in the MODFLOW grids. A spatial join between the MODFLOW grids and the wells contained in the NDWR place of use dataset is performed to relate the groundwater pumping wells to their respective MODFLOW row and column ID. Using this relationship, the pumping per well in cubic meters per day is written into the MODFLOW WEL file as a negative specified flux condition.

Using the spatial relationship between the ditches and the underlying MODFLOW cells, ditch leakage is divided among the cells based on the ditch length that lies above each cell. The fraction calculated for each cell in cubic meters per day is written as specified flux boundary condition in MODFLOW's WEL package file.

Mountain-block recharge (MBR) in cubic meters per day is also written into to the WEL file as a specified flux boundary condition. It is a static flux in the MODFLOW component (i.e. it is constant for all runs and time steps). Smith Valley MBR averages 17,000 acre-feet annually, whereas Mason Valley MBR averages 2,000 acre-feet annually. Refer to the Version 1.0 DST (Boyle et al. 2010) report for more information.

The monthly recharge (RCH) for each HRU group, in water depth equivalent, is assigned to the corresponding sub-polys and converted to a volume, using the sub-poly equivalent area while considering overlapping areas. Since each sub-poly has an associated MODLFOW row and column ID, the sub-poly recharge is then summed per MODFLOW cell, divided by the cell area (10,000 square meters) and written in meters per day into the recharge file.

The surface runoff (RO) is written in cubic meters per day into the appropriate SFR file location based on a common indexing in the stream and drain network between MODSIM and MODFLOW. Runoff is also imported into the MODSIM network as additional non-storage inflows to the surface network.

MODFLOW Component

Overview

MODFLOW is a three-dimensional finite-difference groundwater flow model developed by the U.S. Geological Survey (Harbaugh et al. 2000). It has been used extensively in a wide range of studies, and is now considered as the de facto standard for groundwater flow modeling. The role of MODFLOW in the DST is to provide physically-based feedback from natural and anthropogenic processes acting on the surface and groundwater hydrology, such as the river's response to pumping and agricultural recharge. The MODFLOW models use input files generated based on output from the other DST components. Stream and drain routing in MODFLOW is defined such that it duplicates the water distribution computed by the MODSIM component, and consequently the flows and stages simulated by MODSIM in the surface system for detailed simulation of the stream-aquifer interaction.

The Mason Valley Groundwater Model (MVGM) and Smith Valley Groundwater Model (SVGM) were developed in phase 1 (DST version 1.0) of the project. A detailed description of these models is provided in the Walker Basin Project 2010 Final Report (Boyle et al. 2010) and in a peer-reviewed journal article (Carroll et al. 2010). Both of the models were developed in two steps. Steady-state models were initially developed to test the validity of the conceptual model in producing appropriate basin-wide water balances and to establish initial values of hydraulic conductivity. After validation of the conceptual approach with steady-state models, transient models were constructed.

The Smith and Mason Valley MODFLOW models in version 2.0 of the DST have remained mostly unchanged from the phase 1 versions. However, there were some noteworthy changes in both models. The NDOW MVWMA properties, located on the east and west side of the Walker River, are now included in the Mason Valley MODFLOW model. The NDOW fields are implemented as standard DST agricultural areas. Due to time and modeling constraints, a detailed water budget scheme for the ponds could not be implemented, so it is assumed that the ponds are maintained full throughout the simulation. Since stage in the ponds is assumed constant, each NDOW pond is modeled as a General Head Boundary (GHB) in MODFLOW with a constant stage of 1 m above land surface as defined by a USGS 10m Digital Elevation Model (DEM) and the stage remains constant throughout the entire simulation. Recharge from the ponds is calculated internally by MODFLOW using Darcy's Law. The recharge is therefore controlled by the head gradient between the aquifer and the pond and the conductance of the pond bed material. A conductance of 1 m^2/day was used for all NDOW ponds, which represents a low permeability unit that is consistent with fine-grained sediments that settle in low energy ponds.

In the Smith Valley model, the starting head values were adjusted to yield better agreement between simulated and observed water table elevations. These water level data were obtained from the NDWR office.

The version 1.0 MODFLOW models relied on a Surface Water Linking (SWL) program to generate and write the input files for the WEL, RCH, and SFR packages. In this version of the DST, the MODFLOW files are populated by output from MODSIM and the HRU Water Balance as described above. The HRU Water Balance calculates agricultural recharge, ditch leakage, and groundwater pumping for the WEL and RCH package input files, while the SFR file is populated with runoff from the HRU Water Balance and inflows and diversions from MODSIM. Using the relationship between the water balance grid and the MODFLOW cells, results from the HRU water balance are processed to compute cell-by-cell-recharge and are written into the MODFLOW recharge file. Ditch leakage is simulated as a specified flux boundary condition (using the MODFLOW Well Package) so that it can be constrained to a percentage of the diversion. The MODISM canals feature is geo-referenced to the MODFLOW cells that intersect each ditch, such that ditch leakage from the HRU Water Balance is translated to an amount of aquifer recharge based on the ditch length that lies above each cell. Groundwater pumping is translated to a pumping rate, which is associated with specific wells using the geo-referenced relationship between the permits associated with each HRU group and the wells tied to those permits. The MODSIM water allocation along with runoff from the HRU Water Balance is written into specific locations in the SFR file, which correspond to the locations of gaging stations and points of diversion. The modsim_streams feature class was indexed to the version 1 MODFLOW SFR segment numbers to ensure synchronous routing between MODSIM and MODFLOW. Using the updated WEL, RCH, and SFR files, which are written as a function of the water balance and MODSIM output, the MODFLOW models are run to completion. This is the endpoint for a single model run of the DST modeling system.

Controller Module

Overview

The controller module is custom software developed in Visual Basic.Net to integrate the components of the DST together. It manages DST runs, iterations and convergence of the components, sequential execution of the components, reads outputs and generates required inputs, and oversees the workspace and general preferences. The controller has two modes, single and iterative. If single run is selected the controller performs one complete DST run and stops.

Iterative Process

When iterative mode is selected the controller performs the first DST run exactly as it does in the single run mode, but instead of stopping at this point, the controller performs a series of successive DST runs, with each set of runs being a single iteration.

The controller determines if additional iterations are required after each iteration is complete based on a convergence tolerance stopping criteria. The tolerance (t) is calculated as the maximum absolute difference in accretions and depletions for all stream and drain links in the DST for the previous (i-1) and current (i) DST runs as shown in Eq. 16.

$$\mathbf{t} = \mathbf{MaxOfAllLinks}(\mathbf{Abs}\ \ \boldsymbol{Acc_{i-1} - Dep_{i-1}}\ \ -\ \ \boldsymbol{Acc_{i} - Dep_{i}}\ \ ) \qquad \textbf{\textit{Eq. 16}}$$

The user specifies in the controller what value of t should indicate that the DST components are converged. For example, if the user specifies 0.2 AF/Month, the controller will stop the iteration process when the calculated value of t is less than the 0.2. Otherwise, the iteration process will continue and results from the current MODFLOW and water balance runs will be transferred to MODSIM as indicated in the DST Overview in Section 4 of this report.

5. Calibration of all components – Baseline Model Run

In the baseline run, the surface water system is calibrated to historical flows while also representing the physical and legal availability of water at the different points of the system. The main limitation of modeling natural surface water systems is the inability to accurately represent all the components of the water balance in the model, especially unmeasured contributions. The DST explicitly accounts for stream-aquifer interaction and surface returns from irrigation activities; however, there are other contributions to the surface water budget that are not measured or explicitly simulated. The main calibration objectives are to:

- Quantify the unmeasured gains and losses for each reach, defined between control points.
- Provide base system hydrologic conditions for comparative scenario analysis of the NFWF water rights transfer requested by Application No. 80700.
- Optimize the model pumping and simulated streamflow to observations.

To achieve these objectives, a set of manual calibration runs was performed to understand the sensitivity of the DST output to variations in the FEF, DCL, and Rfactor parameters. For each run, the parameters were manually adjusted and the DST was executed to a convergence tolerance of 0.2. For each run, the Root Mean Squared Error (RMSE) of the total basin-wide simulated pumping versus the NDWR measured and the lowest value of net unknown calibrated MODSIM gains and losses (Gains-Losses) were computed. Table 5.1 shows the parameter sets that were tested and their associated objective measures. The parameter values associated with model run No. 5 were selected for use in the remainder of this study because they resulted in a reasonably good compromise fit to the basin wide NDWR measured pumping and the net unknown calibrated MODSIM gains and losses. The run No. 5 parameters were also used in the scenario application (described in the next section of this report). Note that the parameter values associated with the remaining model runs (i.e., run Nos. 1-4 & 6-7) were made with the version of the DST that existed on 25 November 2012. The current version of the DST (included with this report) has since undergone minor modifications and, due to time and resource constraints, the parameter values associated with these model runs (i.e., run Nos. 1-4 & 6-7) have not been verified with the current DST. This should probably be done as part of a much more extensive sensitivity analysis of the DST results with respect to the calibration parameters.

Table 5.1 Manual parameter sets tested in calibration

Run No.	FEF	DCL	Rfactor	RMSE Total Mason & Smith pumping	Net Calibration Gain and loss
1	0.55	0.15	0.3	53.2	-38,397
2	0.6	0.2	0.3	71.45	-38301
3	0.55	0.13	0.38	55.85	-47,327
4	0.55	0.18	0.32	49.82	-59,065
5	0.53	0.15	0.35	43.78	-62,172
6	0.45	0.15	0.3	66.79	135,285
7	0.55	0.25	0.3	46.61	-96,535

Calibration Results (Baseline Run)

MODSIM

The expected result in the MODSIM calibration run is to have a supply that equals the demand (i.e., historical diversion). Failure to meet all demand in this run will prevent a valid comparative analysis between the baseline and scenario runs. A zero shortage calibration run is achieved by supplying additional water when required as outlined in the calibration structures approach in section 4. Calibration structures quantify the upstream losses and downstream gains for each of the control points in the network. Table 5.2 shows the total demand, supply, and shortage for the

MODSIM agricultural demands and the USGS stream flow gaging stations over the entire calibration period.

Table 5.2 Simulated water supply & demand in the Baseline MODSIM model

MODSIM Demand Type	Total Supply (AF)	Total Demand (AF)	Total Shortage (AF)
Agricultural Demands (i.e. Historical Diversions)	3,493,154.58	3,493,154.58	0
USGS Streamflow Gages	9,457,917	9,457,917	0

Calibration Gains and Losses

The calibration gains and losses are dynamically calculated by MODSIM based on available water supply and demand. Strosnider, Hudson, and Hoye can both provide and withhold flow, whereas BP_Inflow and WF_Hoye can only provide flow, and MSW_Wabuska can only withhold flow. When the DST components are properly synchronized, the calibration losses at gaging locations (WF_Hudson and MSW_Wabuska) are equal to the MODFLOW over prediction. Table 5.3 shows the average calibration gain and loss for each month at each MODSIM calibration structure.

Table 5.3 Average Calibration Unmeasured Gains and Losses by Control Point (AF)

MODSIM Name	Type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
WF_Coleville	Gain	2731	2906	369	657	2552	0	0	666	3495	4091	2872	3066
	Loss	0	0	0	0	0	0	0	0	0	0	0	0
WF_Hoye	Gain	1031	546	707	759	2190	1127	220	101	188	356	24	29
	Loss	0	61	1918	4024	6866	19997	11362	2340	0	0	0	25
WF_Hudson	Gain	0	0	0	0	0	0	0	0	0	0	0	0
	Loss	263	122	55	250	1230	1073	1582	1620	1211	181	527	445
EF_Strosnider	Gain	308	529	1540	817	360	365	59	0	68	147	18	18
	Loss	794	667	1358	0	0	1225	544	0	0	0	14	291
MSW_Wabuska	Gain	0	0	0	0	0	0	0	0	0	0	0	0
	Loss	1274	409	134	694	2528	3000	1892	1446	958	568	1043	1437
BP_Inflow	Gain	821	1512	383	4305	8978	3039	1551	2679	5155	5188	1591	1428
	Loss	0	0	0	0	0	0	0	0	0	0	0	0

Streamflow Fit at Wabuska Gage

Streamflow observed at the Wabuska gage is the most downstream boundary condition for the DST. It is a measured quantity representing the downstream Tribal water rights and the upstream operational excess. A high priority is placed on meeting the observed flow at Wabuska because it indicates that the simulated water allocation complies with the historical water allocation and system operations.

Figure 5.1 shows the simulated and observed flow at Wabuska gage for the calibration period (RMSE = 2635 AF/Month). Note that the simulated flow over-predicts the observed but never under-predicts. The type of fit occurs because the Wabuska historical flow is setup as a demand, and flow is supplied at the EF_Strosnider location such that all demands are met. The over-prediction is the equivalent of the average loss seen in Table 5.3 for the MSW_Wabuska MODSIM location. The over prediction collects in a MODSIM sink that accepts any surface water in excess of the system's demands, including the measured Tribal right and operational excess. The general calibration behavior described above for the Wabuska gage is present for all calibration structure locations in Table 5.3.

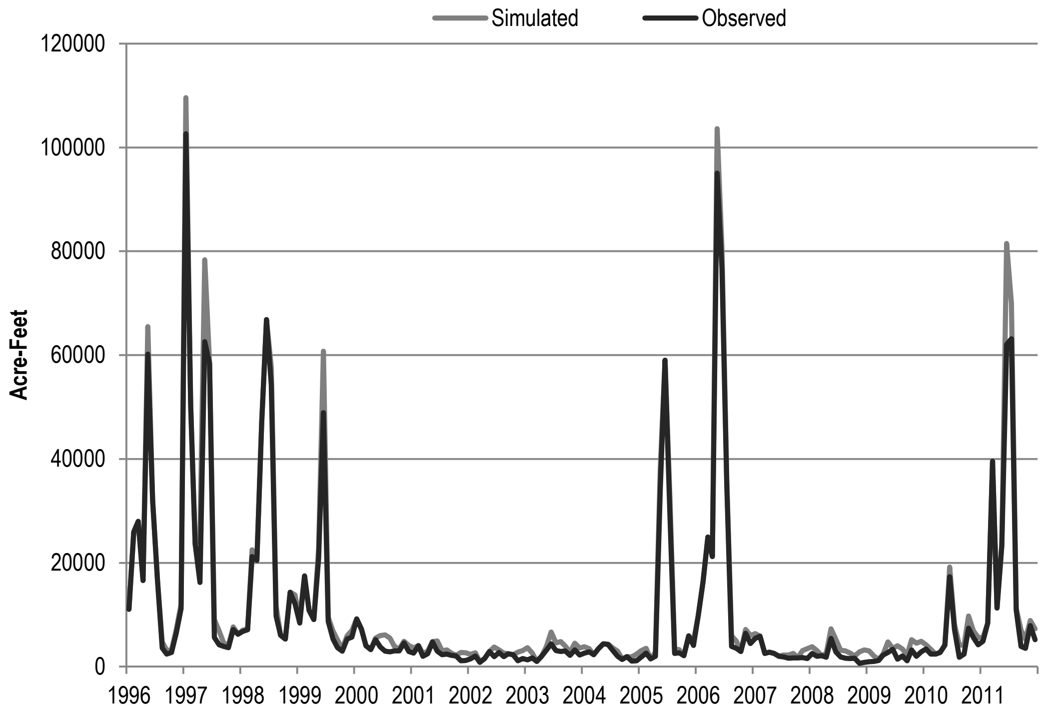

Figure 5.1 Simulated MODSIM flows at Wabuska compared with the USGS observations.

MODSIM Deliveries

MODSIM allocates available surface water to each agricultural demand in a specific order, which is a function of the supplied cost structure for the calibration run. First, storage is delivered and MODSIM checks to see if there is additional demand. If so, flood is delivered. Next MODSIM will allocate any available surface water based on the decree water rights for that particular demand, and finally, any remaining unfilled demand will be met with the Decree Buffer link. Figure 5.2, shows the total delivery for each of the aforementioned delivery components. In all cases, the total supply through these four types of links equals the WRID historical diversion.

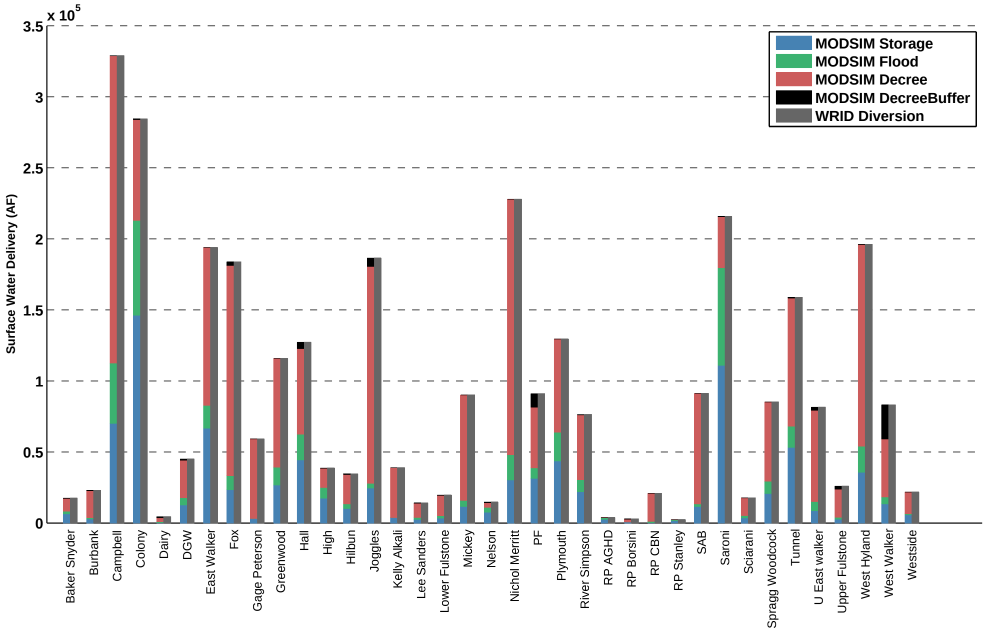

Figure 5.2 MODSIM simulated deliveries by color compared to the total WRID historical diversion

Reservoir Operations and Evaporation

Reservoir storage for both Topaz and Bridgeport Reservoirs was simulated to be an exact match to the historical accrual and releases. Using the area-volume rating curve for each reservoir, and the WRCC pan evaporation measurements, the reservoir evaporation is calculated by MODSIM during the calibration run (Figure 5.3).

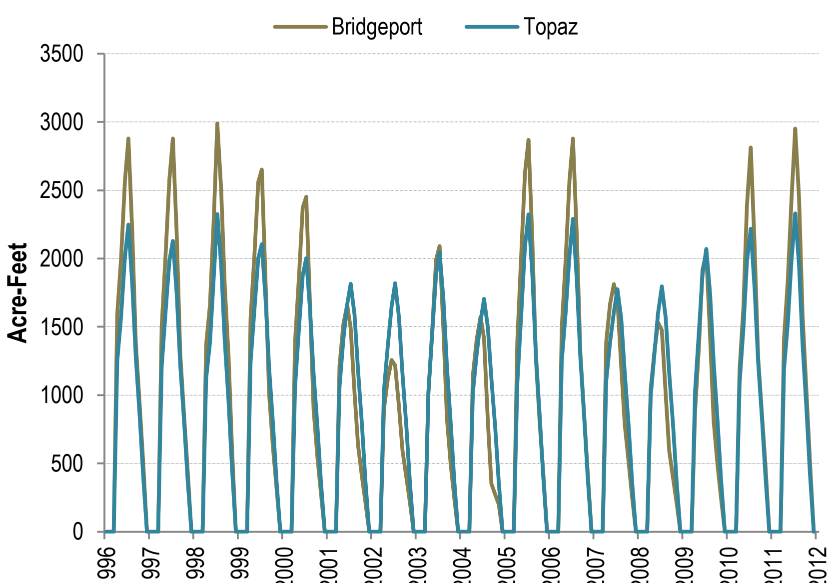

Figure 5.3 Simulated Reservoir Evaporation in Acre-feet

HRU Water Balance

The HRU water balance results are generated by HRU group based on the available water for irrigation. The HRU water balance results will be presented for the non-NDOW portion of the West

Hyland ditch for the year 2007. Results for all of the HRUs and years can be found in the Water_balance_Debug.mdb file in the .\Walker Files\DST\Baseline directory on the DVD that accompanies this report.

The available surface water for all groups in the HRU is equal to (1 - 0.15) of the diversion, and therefore the ditch leakage is (0.15) of the diversion. The surface water diversion, ditch leakage, and surface water at the HRU are shown in Figure 5.4.

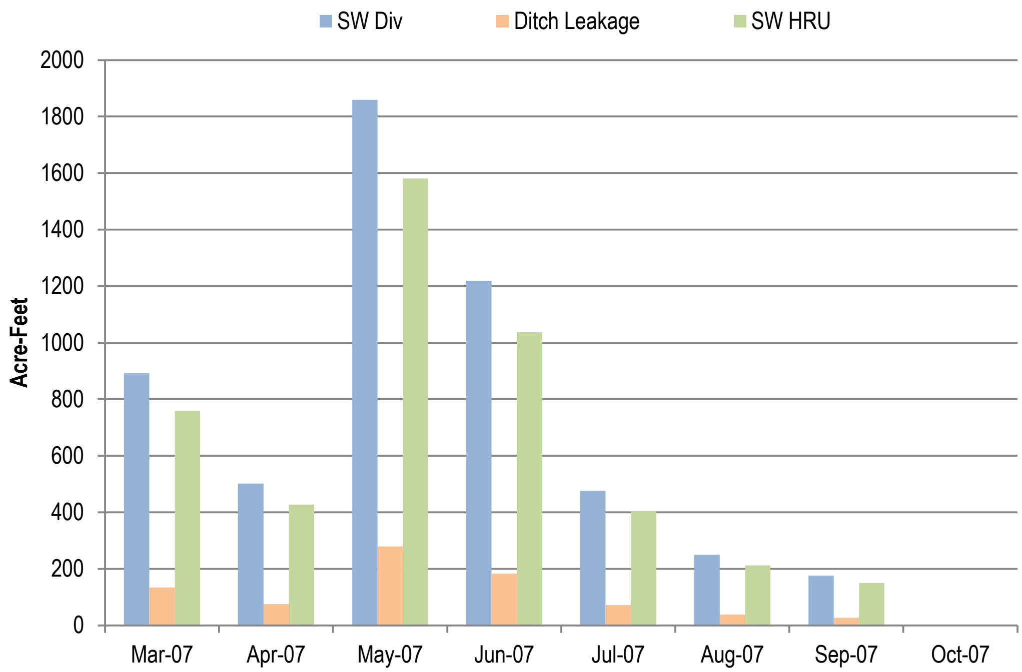

Figure 5.4 2007 monthly West Hyland Non-NDOW diversion, ditch leakage, and surface water at HRU.

Each modeling unit within the HRU is delivered an area-weighted volume of surface water at the HRU (SW HRU). The calculation of the HRU water balance is performed in units of depth of water so the water balance results from here forward are presented in units of feet. The HRU Water Balance represents the NIWR as an average crop water requirement for the entire HRU. Applying a farm efficiency of (0.53) yields the HRU water requirement or NIWRE. Figure 5.5 shows the total annual NIWR and NIWRE for the West Hyland Non-NDOW HRU. The total annual simulated NIWR depth for 2007 is 2.76 ft., which is less than the 3.08 ft. NDWR requirement of alfalfa, because 10% of the area was surveyed as fallow and another 11% of the crop distribution was surveyed to be crops with a lower NIWR than alfalfa.

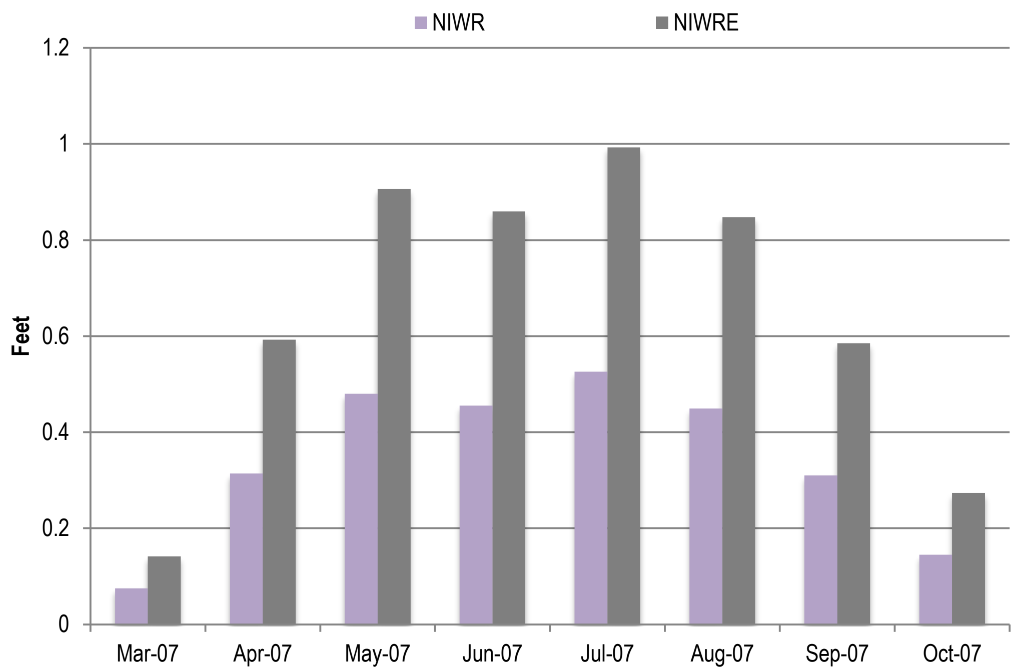

Figure 5.5 Average NIWR and NIWRE by month for 2007 West Hyland Non-NDOW HRU

Figure 5.6 shows the surface water at the HRU relative to the NIWRE. For the month of March, no supplemental pumping is required because there is more surface water delivered to the farms than required. This is surface water excess. For the remainder of the months, the HRU will require additional water to meet the NIWRE, which will come from supplemental pumping where permitted. The pumping required is calculated only where the NDWR groundwater place of use dataset indicates it is permitted. If the entire HRU had access to supplemental pumping the total required pumping would equal the NIWRE-SW HRU, this never happens, indicating that a fraction of the HRU does not have access to supplemental pumping (yellow area in Figure 5.7). Actual pumping should equal required pumping, the only month this does not occur is October, which indicates that the seasonal maximum pumping was met (i.e. all permitted pumping was used for the season).

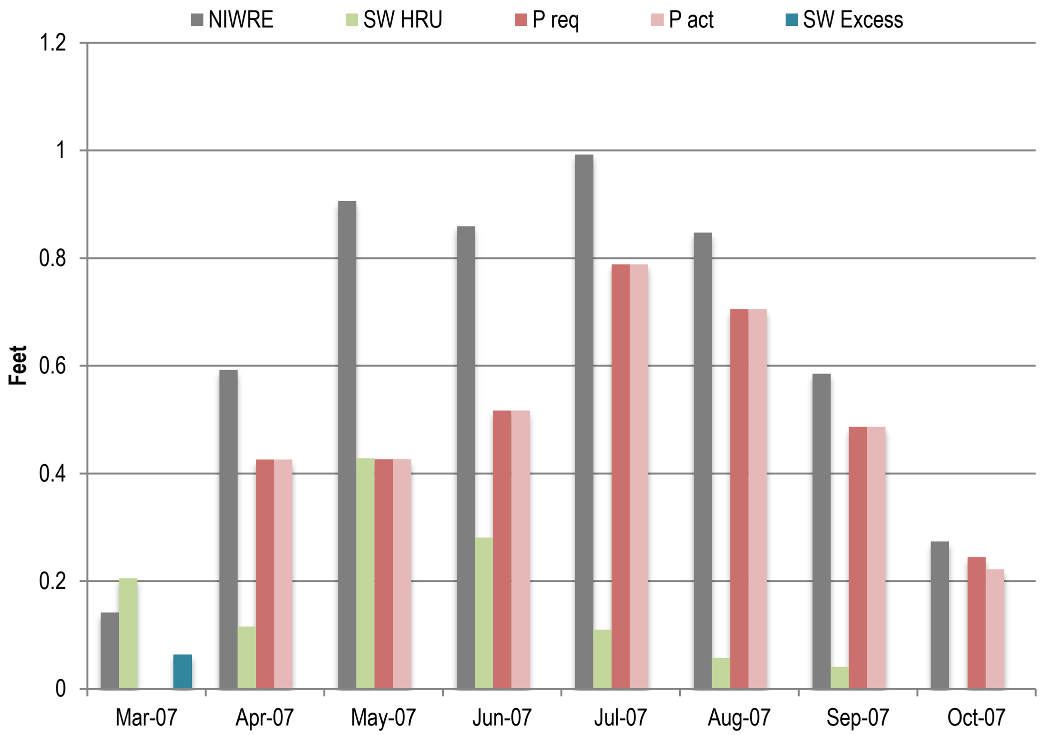

Figure 5.6 West Hyland Non-NDOW total demand and supply components

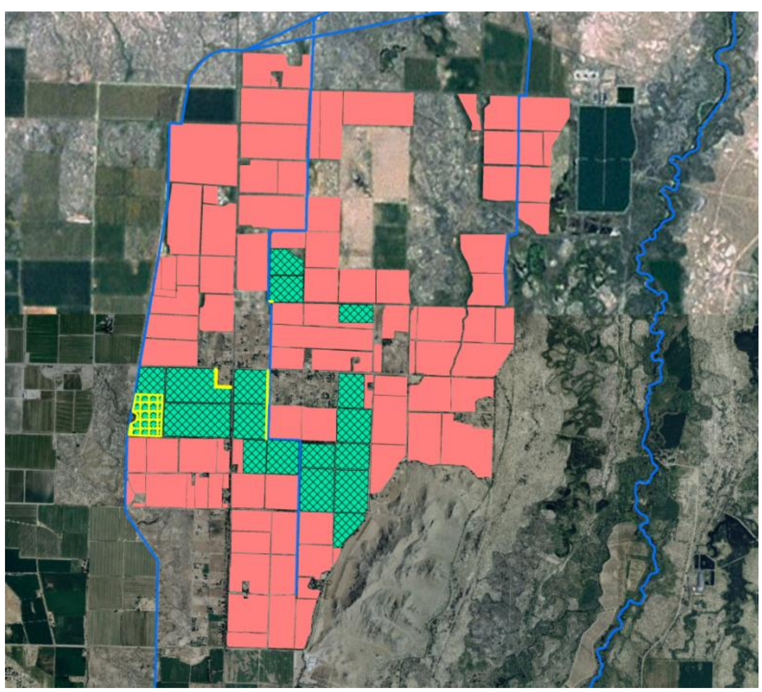

Figure 5.7 DST West Hyland Non-NDOW modeling units without supplemental pumping access (yellow)

The application, or water that is applied to the HRU, is the sum of the surface water at the HRU and the actual pumping. The non-consumptive use (NCU) is calculated by applying the FEF (0.53) to the application up to the NIWRE. The total non-consumptive is the sum of the NCU and the SW Excess, such that the portion of the application above the NIWRE is not hit with the FEF. The total non-consumptive use is then partitioned into runoff and recharge. Runoff is generated as the Rfactor (0.35) fraction of the total non-consumptive use, and the recharge is (1-0.35) of the total non-consumptive use (Figure 5.8)

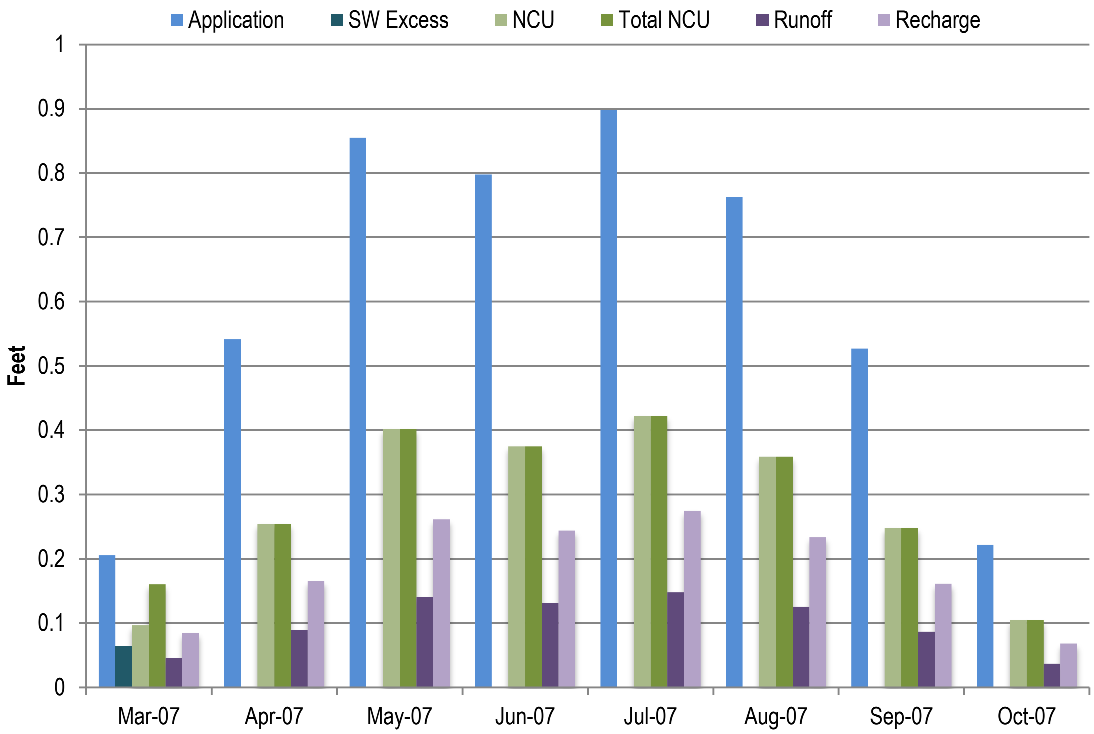

Figure 5.8 West Hyland Non-NDOW application and Non-consumptive use components

Mass is conserved in the water balance such that, SW Div – DL + Pact – CU – RO – RCH is equal to zero indicating there is no change in storage. Table 5.4 shows the annual terms for the non-NDOW portion of the West Hyland Ditch in the baseline run.

Table 5.4 Annual mass balance check on HRU Water balance

Year	SW Div (ft)	DL (ft)	P act (ft)	CU (ft)	RO (ft)	RCH (ft)	Error (ft)
1996	3.17	0.48	2.24	2.61	0.81	1.51	0.00
1997	3.07	0.46	2.31	2.61	0.81	1.50	0.00
1998	5.00	0.75	0.99	2.69	0.89	1.66	0.00
1999	3.82	0.57	1.74	2.64	0.82	1.52	0.00
2000	2.99	0.45	2.40	2.60	0.82	1.52	0.00
2001	1.98	0.30	3.16	2.56	0.80	1.48	0.00
2002	1.59	0.24	3.43	2.54	0.79	1.46	0.00
2003	1.90	0.29	3.20	2.55	0.79	1.47	0.00
2004	1.95	0.29	3.27	2.55	0.83	1.55	0.00
2005	4.33	0.65	1.36	2.67	0.83	1.54	0.00
2006	4.81	0.72	1.09	2.69	0.87	1.62	0.00
2007	1.46	0.22	3.57	2.52	0.80	1.49	0.00
2008	1.51	0.23	3.57	2.52	0.82	1.52	0.00
2009	1.70	0.26	3.35	2.54	0.79	1.47	0.00

2010	2.85	0.43	2.54	2.59	0.83	1.54	0.00
2011	3.90	0.59	1.69	2.65	0.82	1.53	0.00

In the water balance, the crop requirement is not always met, so at times there is a NIWR deficit, primarily because some of the HRU does not have access to supplemental pumping (Figure 5.9).

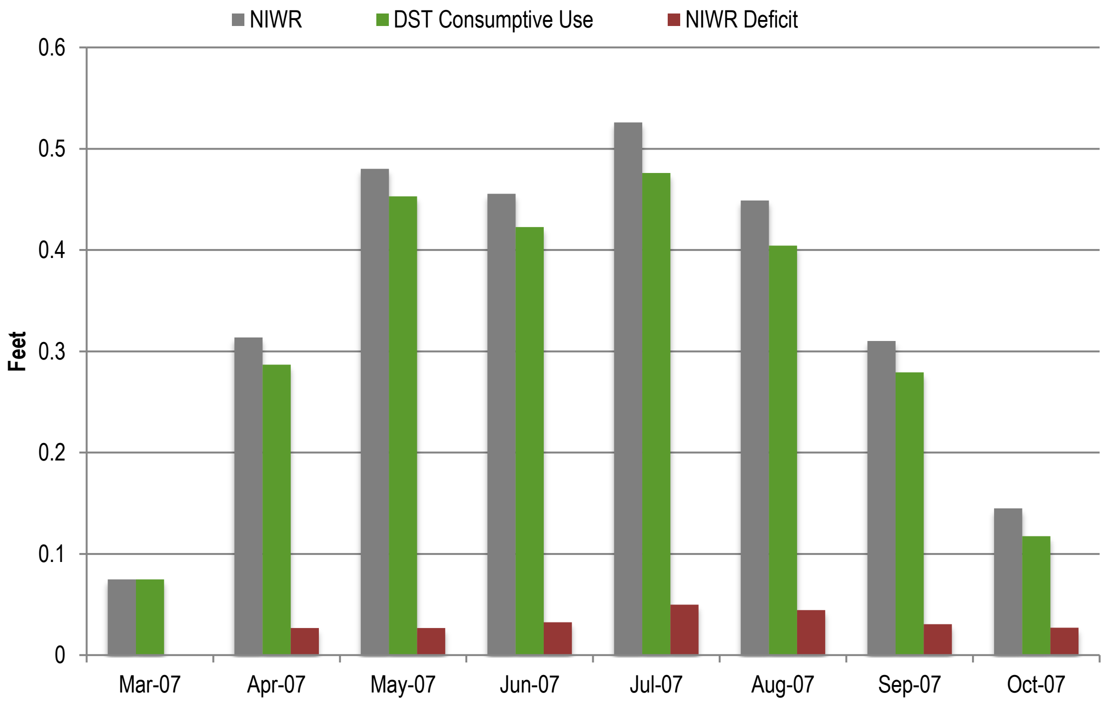

Figure 5.9 NIWR compared to DST consumptive use and the NIWR deficit

METRIC Comparison

The HRU Water balance results were also compared with the 2007 METRIC dataset introduced in Section 3. The crop survey used in the DST was performed in 2007 so this is an opportunity for assessment of the water balance simulated consumptive use. Figure 5.10 shows the METRIC ET, NIWR, and DST consumptive use for the non-NDOW portion of the West Hyland ditch in 2007. Except for April of 2007, the METRIC ET is greater than the NIWR, and in all months except March, the NIWR is greater than the DST consumptive use.

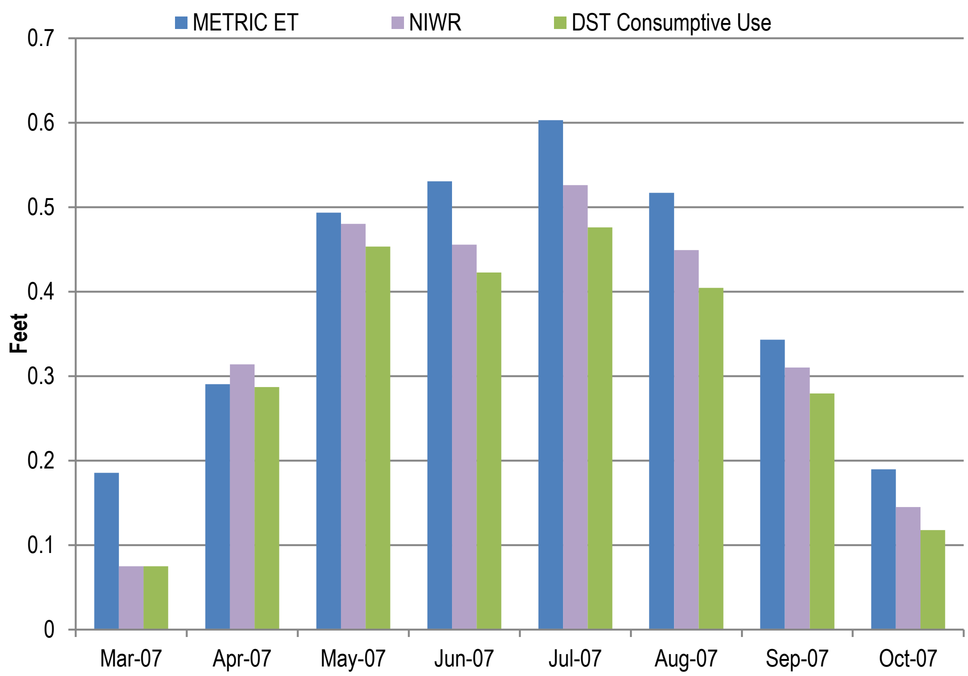

Figure 5.10 METRIC comparison for 2007 West Hyland Non-NDOW

Figure 5.11 shows the same variables for each of the HRUs in 2007. The same trend is apparent, where the NIWR is most often less than the METRIC ET and the DST consumptive use is less than the NIWR, although for some ditches the NIWR is greater that the METRIC ET.

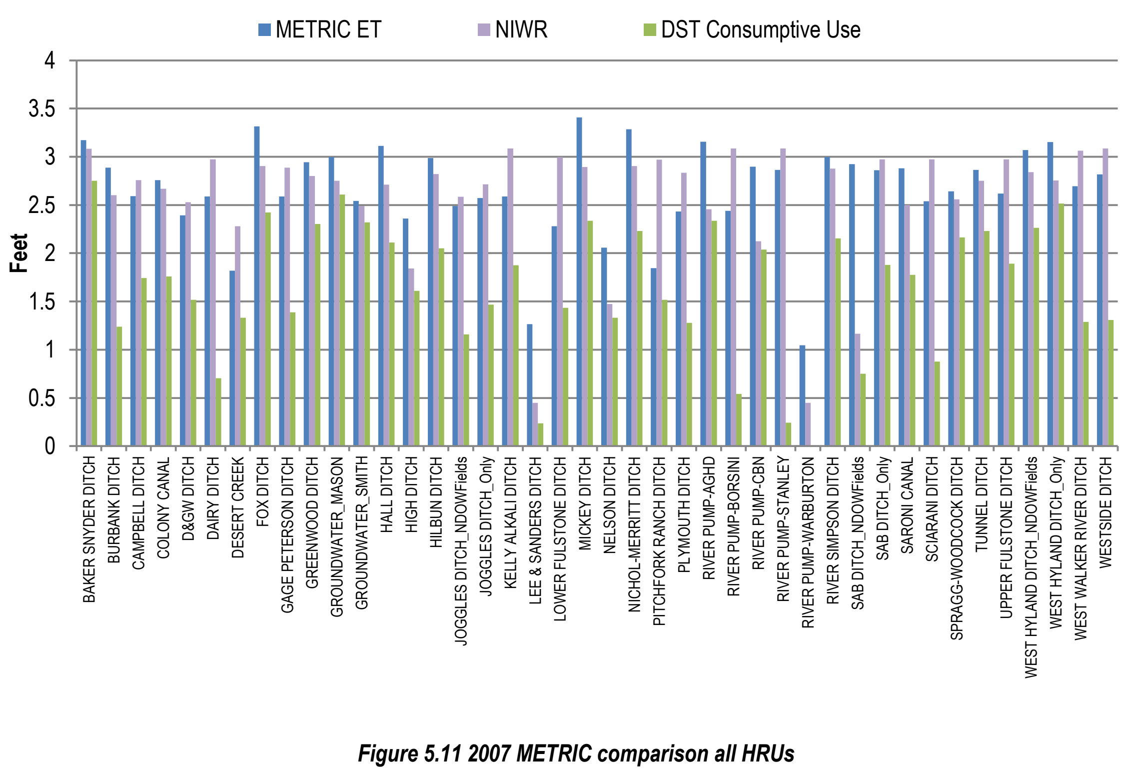

Figure 5.11 2007 METRIC comparison all HRUs

The bulk of the deficit in Figure 5.10 and 5.11 between the NIWR and the DST consumptive use is attributed to the uniform spreading of surface water on the HRUs and the fact that some portion of most of the HRUs does not have access to supplemental pumping.

Basin-wide Groundwater Pumping

The total annual HRU Water Balance simulated groundwater pumping in Mason and Smith Valley corresponding to the final parameter set (FEF = .53,DCL = .15, Rfactor = .35) selected in calibration, is compared to the NDWR basin wide pumpage (Gallagher, 2005) in Figure 5.12. The simulated pumping tends to over predict in wet years (1996 – 1998), and under predict in dry years (2000 – 2004).

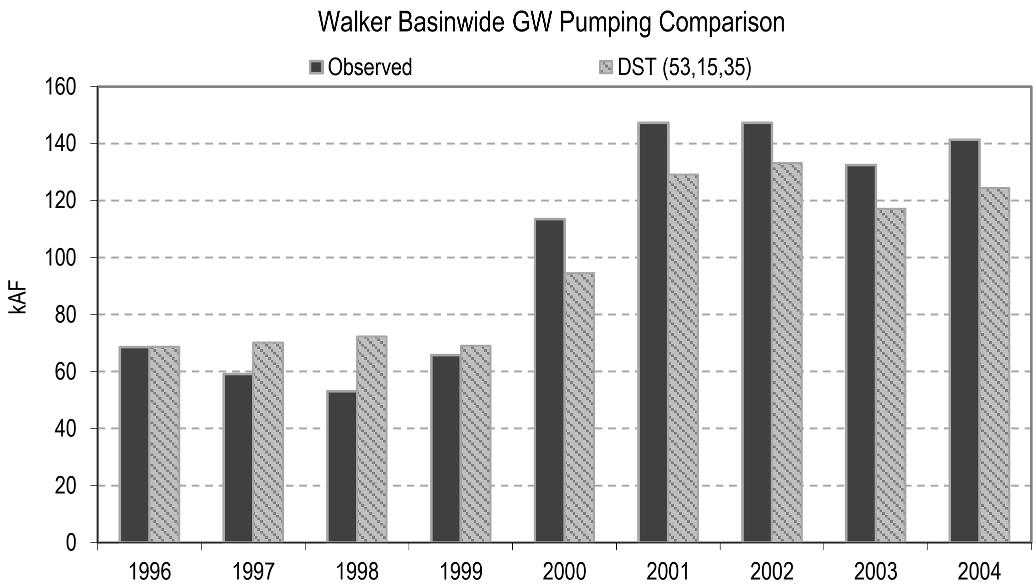

Figure 5.12 Baseline basin-wide simulated and observed pumping

<u>*MODFLOW*</u>

Head Levels

Final baseline simulations produced (RMSE) values equal to 3.64m, and 8.85m, for Mason and Smith Valley head levels, respectively. An expanded water level dataset (obtained from the Nevada State Engineer's Office) was used to calculate these calibration metrics. Specifically, a total of 972 and 524 water level measurements were used in Mason and Smith Valley, respectively. The relative error (root mean squared error divided by the total head drop in the system) was 1.93 and 5.04 percent for Mason and Smith Valleys, respectively. Figure 5.13 and 5.14 show observed and simulated water levels for the Mason and Smith Valley, respectively. Locations of observation wells are shown in Figure 5.15.

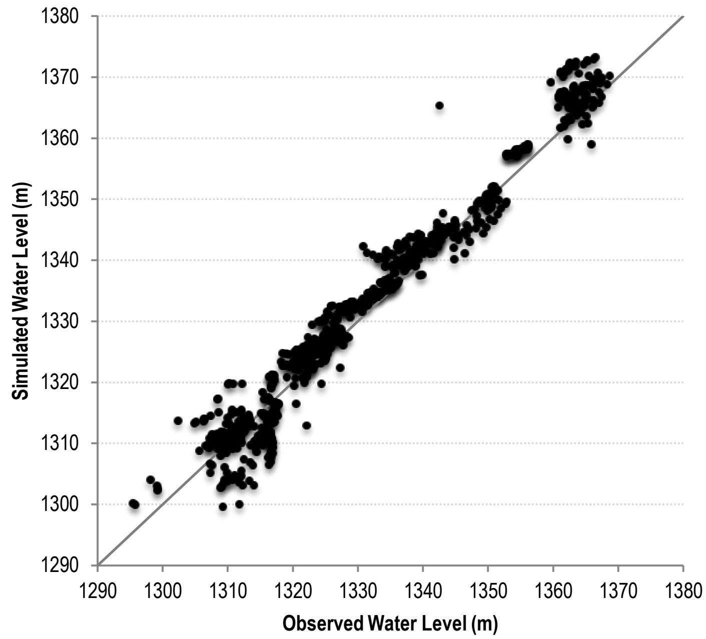

Figure 5.13 Simulated and observed water levels 1996-2011 for the Mason Valley MODFLOW model

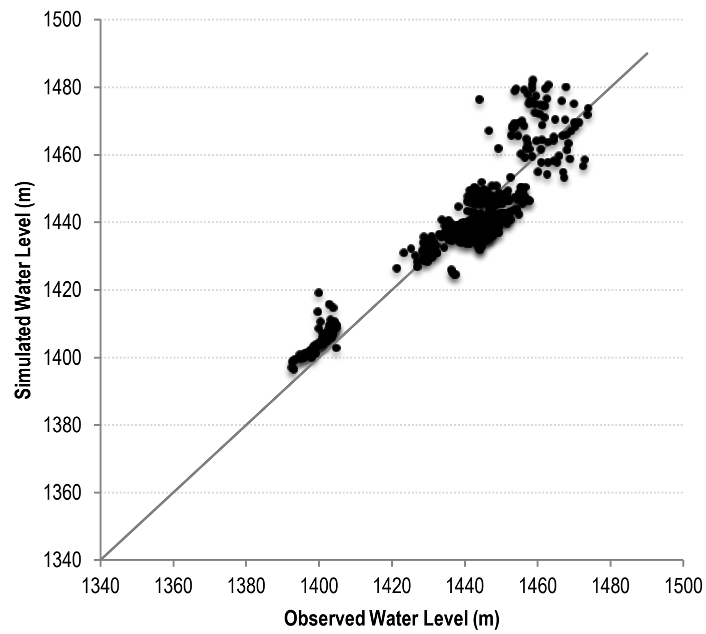

Figure 5.14 Simulated and observed water levels 1996-2011 for the Smith Valley MODFLOW model

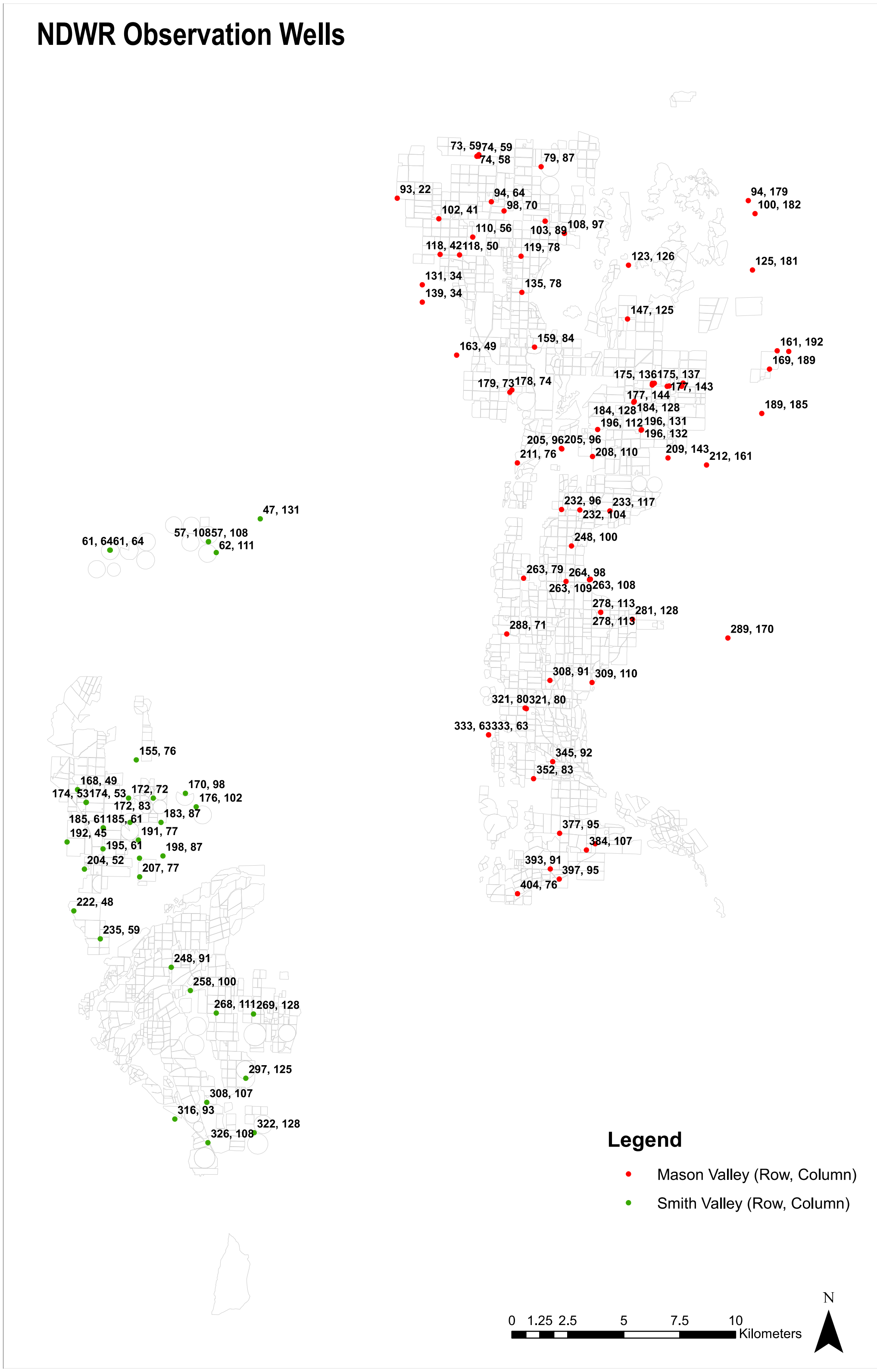

Figure 5.15 NDWR observation wells

Calibration results for hydraulic head are provided in Figures 5.16 and 5.17 for two selected wells in Mason Valley. In general the model is able to match the measured water levels trends throughout the simulation period. Since a certain degree of error is imposed by the uncertainty in the steady-state model, some of this error is transferred to the transient model. Therefore, there is likely to be a “shift” required to ensure a one-to-one correspondence between the simulated and measured head values. Figure 5.16 is an example of the simulated heads being nearly identical to the measured values. Figure 5.17 is an example where the model is able to capture the trend but the simulated heads are consistently 1.0 – 1.5 m above the observed heads. At other locations the simulated heads may be less than observed. As seen in Figures 5.13 and 5.14 the offset or shift between simulated and observed head values alternates between positive and negative which eliminates an overall model bias. Based on the RMSE the average shift is approximately +/- 4 m for Mason Valley, and +/- 9 m for Smith Valley. Calibration results for hydraulic head are provided in Figure 5.18 for a selected well in Smith Valley. Again, the model is able to reproduce the temporal trend, but a larger difference between the simulated and observed head values is evident.

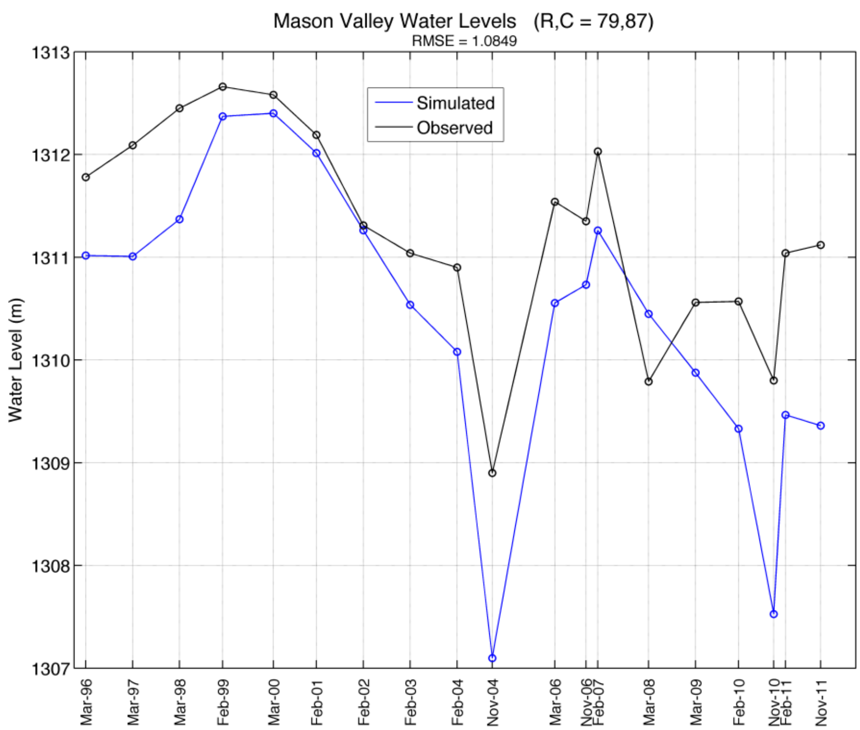

Figure 5.16 Simulated and observed hydraulic head for row 79, column 87 in the Mason Valley model.

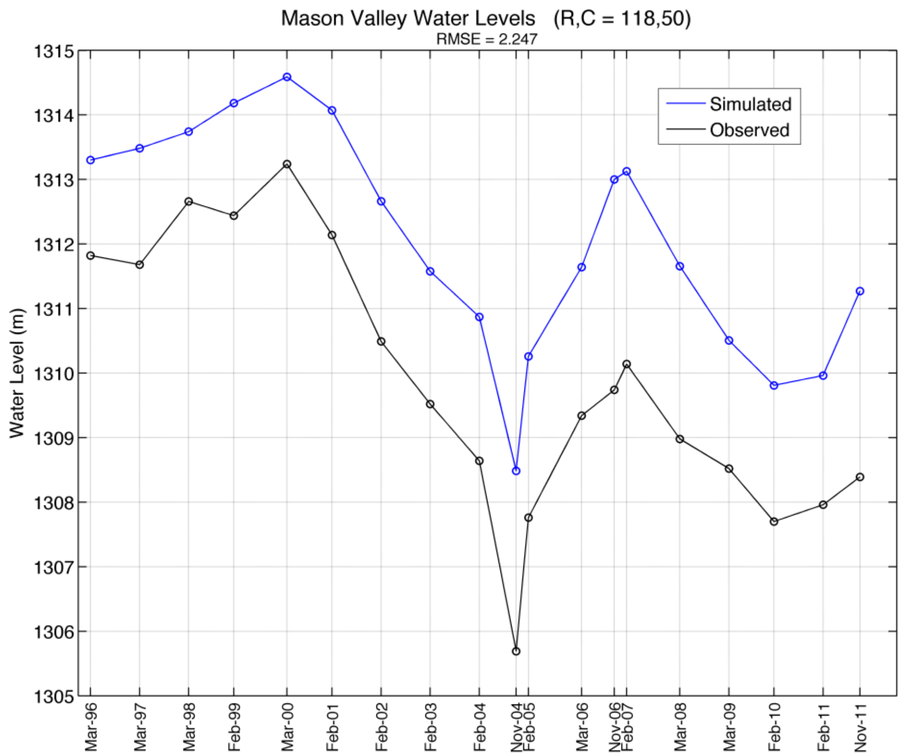

Figure 5.17 Simulated and observed hydraulic head for row 118, column 50 in the Mason Valley model.

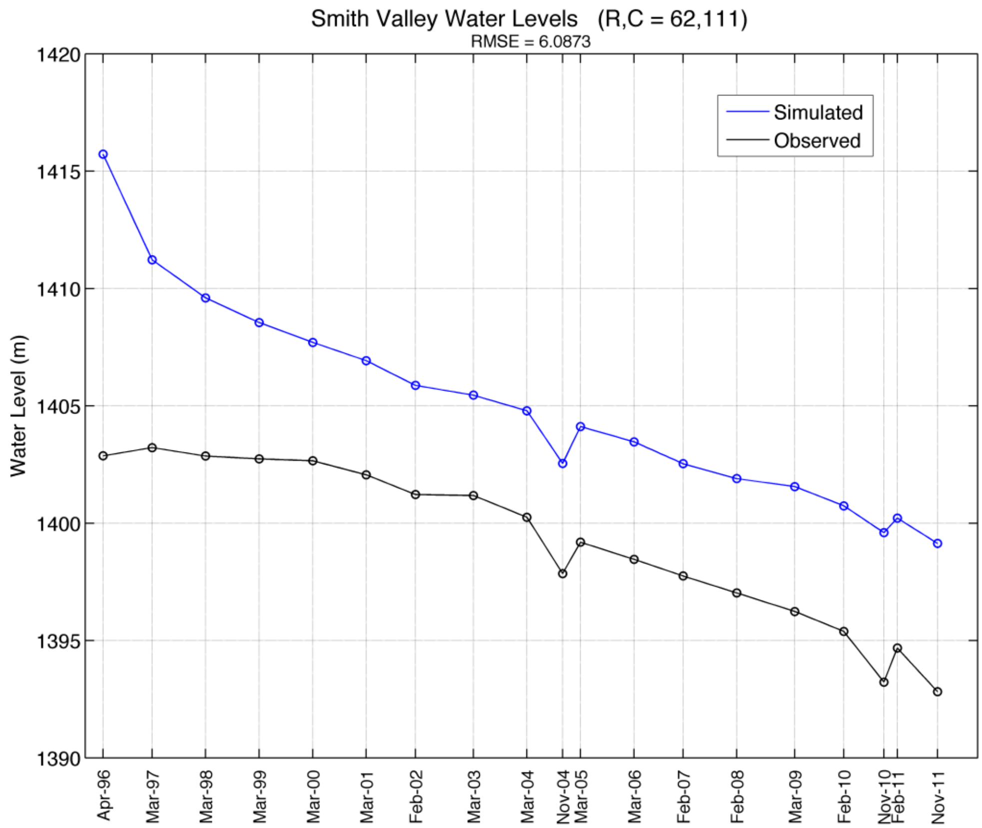

Figure 5.18 Simulated and observed hydraulic head for row 62, column 111 in the Smith Valley model.

Streamflow

Simulated flows at Wabuska are in general agreement with measured discharge except that peak discharge during several years is over-predicted (RMSE = 2635 AF/Month) (Figure 5.19). Simulated stream flow at the Hudson gage corresponds very well to the observations (RMSE = 1229 AF/Month)(Figure 5.20).

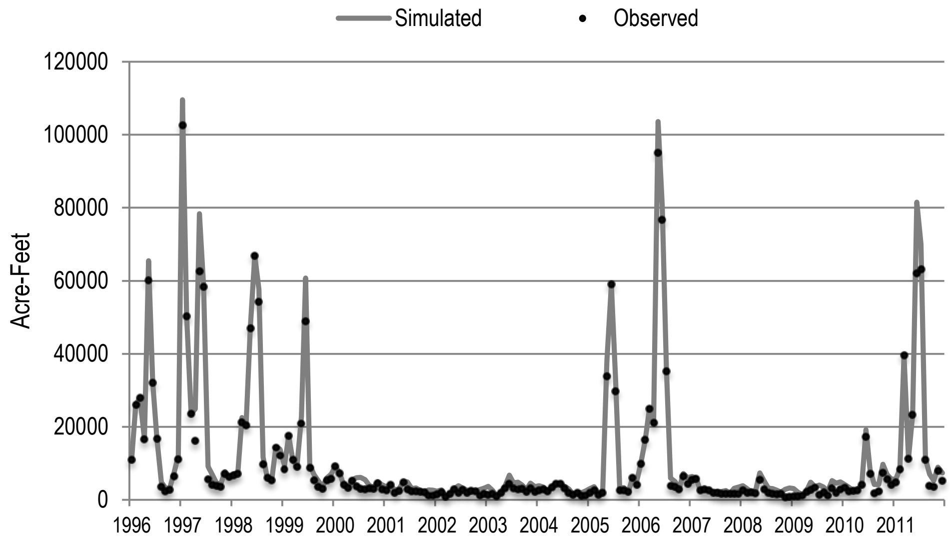

Figure 5.19 MODFLOW simulated stream flow at Wabuska gage

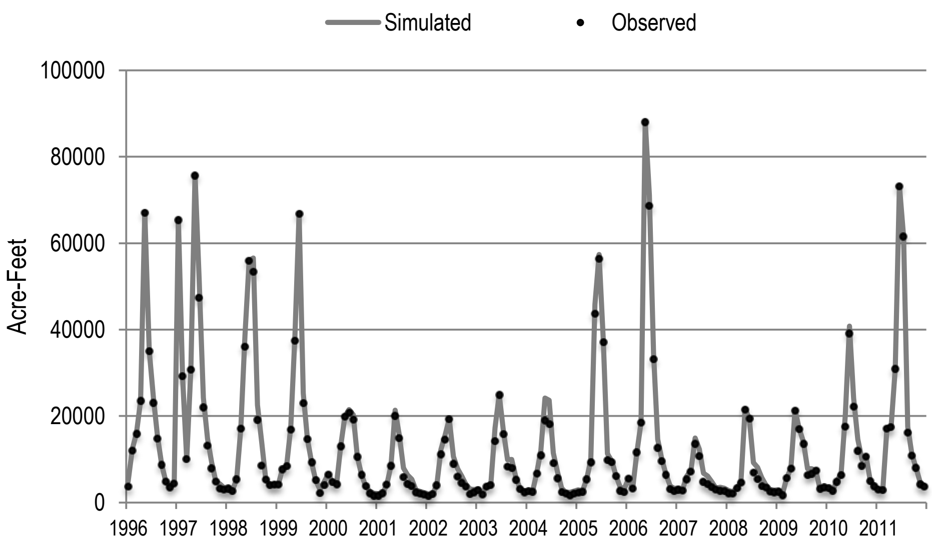

Figure 5.20 MODFLOW simulated stream flow at Hudson gage.

The inclusion of the NDOW agricultural properties as a unique HRU and the incorporation of the wildlife ponds using the GHB package was an important modification to ensure that the groundwater model properly simulates all known sources and sinks within the system. Following these modifications, the Mason and Smith Valley MODFLOW models are still in general agreement to the measured water levels. Both models have a relative error below 10 percent, which is a common threshold used to declare a model as effectively calibrated, and the one-to-one plots do not show any significant model bias.

Accretions and Depletions

MODFLOW provides important feedback to the DST modeling system in the form of stream accretions and depletions. The pattern and magnitude of these fluxes reflects the impact of natural and anthropogenic process occurring over the historical period. Stream depletions and accretions for Mason Valley model are provided in Figures 5.21 and 5.22 for the West and East forks, respectively. The modeling results indicate that the West Walker River reach is primarily gaining, with fluxes typically ranging between 0 and 1,000 acre-feet per month. The aquifer tends to provide the highest flux to the river during the summer months, which is most likely due to lower river flows and increased agricultural recharge. There are short periods, during late spring, when the West Walker River switches from a gaining reach to a losing reach. This flux reversal is most likely during periods of high flow causing increased stage and therefore a reversal in the hydraulic gradient but localized along the river corridor. Some may call this process “bank storage.”

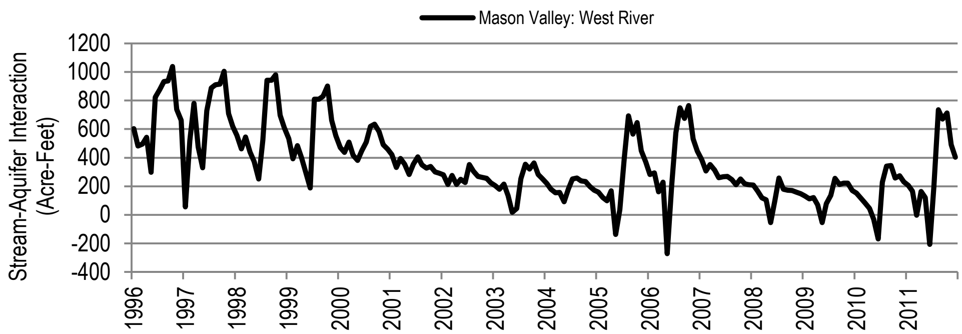

Figure 5.21 Mason Valley West River stream-aquifer interaction. Negative values denote a losing stream, and positive values denote a gaining stream.

The East Walker Reach in Mason Valley is similar to the West Walker Reach, except losses are more pronounced. With dry conditions, the East Walker Reach becomes a continually losing system from the end of 2000 until the end of the irrigation season in 2005 and in the period 2007 to 2009. It returns to more gaining conditions in 2005 and 2006, losing again in the later part of that decade and gaining in the last year simulated (Figure 5.22).

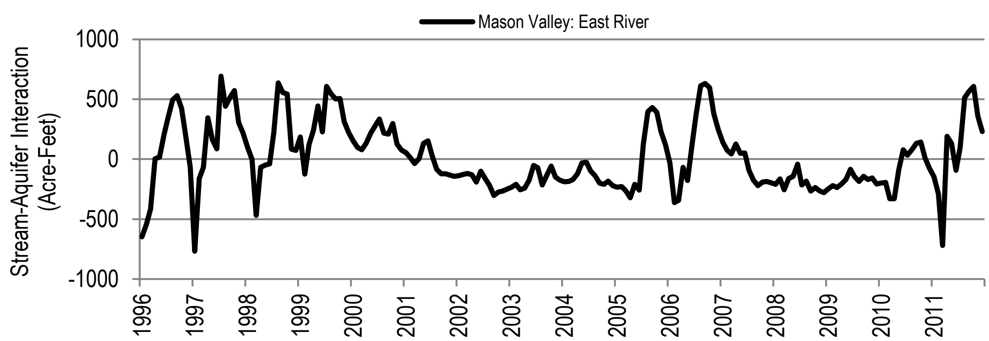

Figure 5.22 Mason Valley East River stream-aquifer interaction. Negative values denote a losing stream, and positive values denote a gaining stream.

Stream depletions and accretions for the main stem of the Walker River in Mason Valley are shown in Figure 5.23. The Main Walker River is almost always a losing system, with short gaining periods in August and September. Again, the gaining periods are likely due to irrigation recharge. During the drought years of 2000 to 2004, the Main Walker River shows a trend of increased loss. Large losses in 2006 show a system still recovering from the drought despite relatively large stream flows and surface diversions in 2005 and 2006. Annual variations in the magnitude of stream loss are likely due to a complex interplay between stream discharge, groundwater pumping, and diversions, which ultimately result in groundwater recharge.

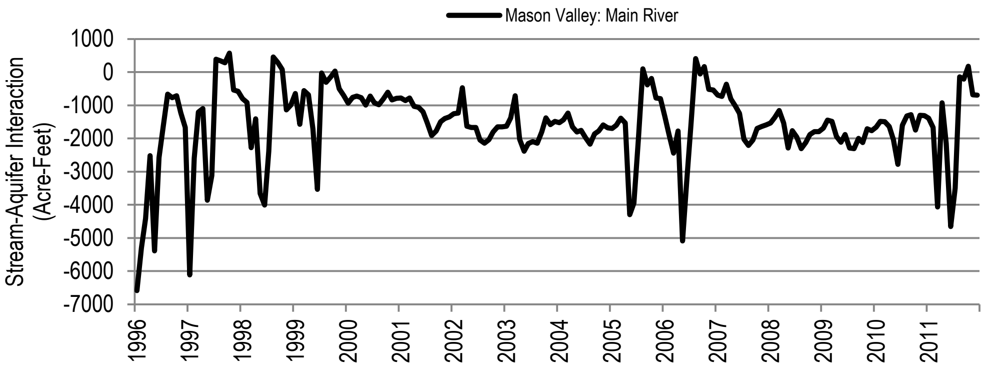

Figure 5.23 Mason Valley Main River stream-aquifer interaction.
Negative values denote a losing stream, and positive values denote a gaining stream.

Figure 5.24 shows the stream depletions and accretions for the agricultural drains within Mason Valley. Mason Valley drains are a losing system during the irrigation season and neutral to slightly gaining during the winter months.

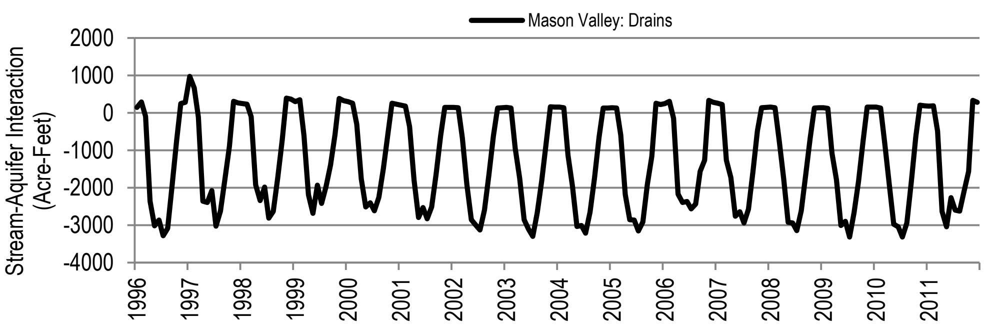

Figure 5.24 Mason Valley drain-aquifer interaction.
Negative values denote a losing stream, and positive values denote a gaining stream.

Figure 5.25 shows the stream depletions and accretions for the Walker River in Smith Valley. With the exception of the first year of simulation (1996), the river is largely gaining. The larger losses exhibited during 1996 are a result of the model coming into equilibrium with the starting heads. The annual cycle of larger gains during the summer months switching to near neutral or losing during the peak runoff in the spring is consistent throughout the simulation. Drought periods (2000 – 2004) cause the annual variation to decrease, but in general the behavior is similar to wet years. The flux reversal from gain to loss is during peak runoff and high river stage. It is important to note that while the stream is losing water to the aquifer, simulated surface return flows during the early irrigation season prevent a net computed loss in the river between the Hoye and Hudson gages.

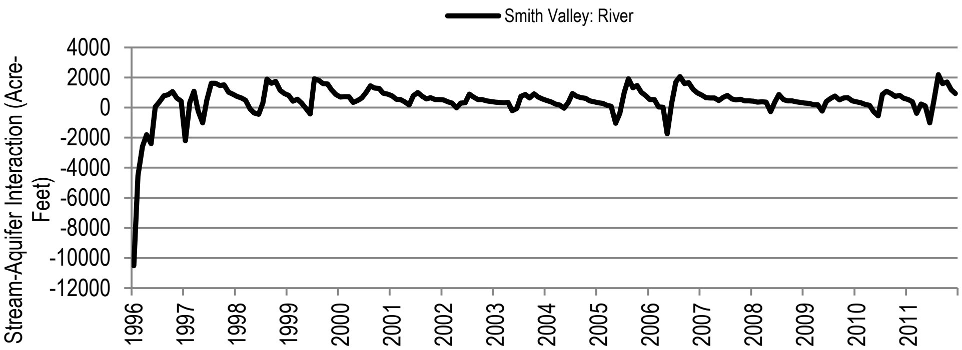

Figure 5.25 Smith Valley River stream-aquifer interaction.
Negative values denote a losing stream, and positive values denote a gaining stream.

Figure 5.26 shows the stream depletions and accretions for the agricultural drains within Smith Valley. With the exception of the first few months of simulation where the model is coming into equilibrium, the Smith Valley drains are always gaining.

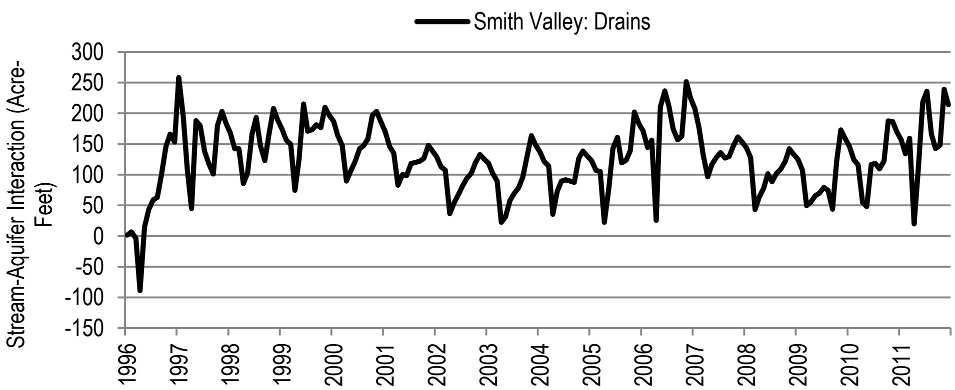

Figure 5.26 Smith Valley drain-aquifer interaction.
Negative values denote a losing stream, and positive values denote a gaining stream.

The figures above show the temporal variation in depletions and accretions over a reach to basin scale. Figure 5.27 shows the spatial variation in flux between the Walker River and agricultural drains over the entire simulation period. Positive flux values (cooler colors) represent gaining conditions and negative values (warmer colors) represent losing conditions. Similar to the results shown in Figure 5.25, the Walker River in Smith Valley is largely gaining. There are small sections up river of Smith Valley in which the River is losing, most likely because of increased depth to groundwater. After the Hudson gage, there is a small losing reach, followed by a longer gaining section up to the confluence with the East Walker River. The East Walker River is near neutral with sections both gaining and losing throughout the simulation period. North of the confluence the Walker River is on average a losing stream. These results are consistent with the results of Lopes and Allander, 2009 who noted that the Walker River is mostly gaining in Smith Valley and losing in Mason Valley. These results are also in agreement with the results of Tyler et al. 2010, who used thermal methods to estimate seepage just above the Wabuska gage. Their results indicated that this reach of the Walker River is generally losing with short intermittent reversals in which the river is gaining.

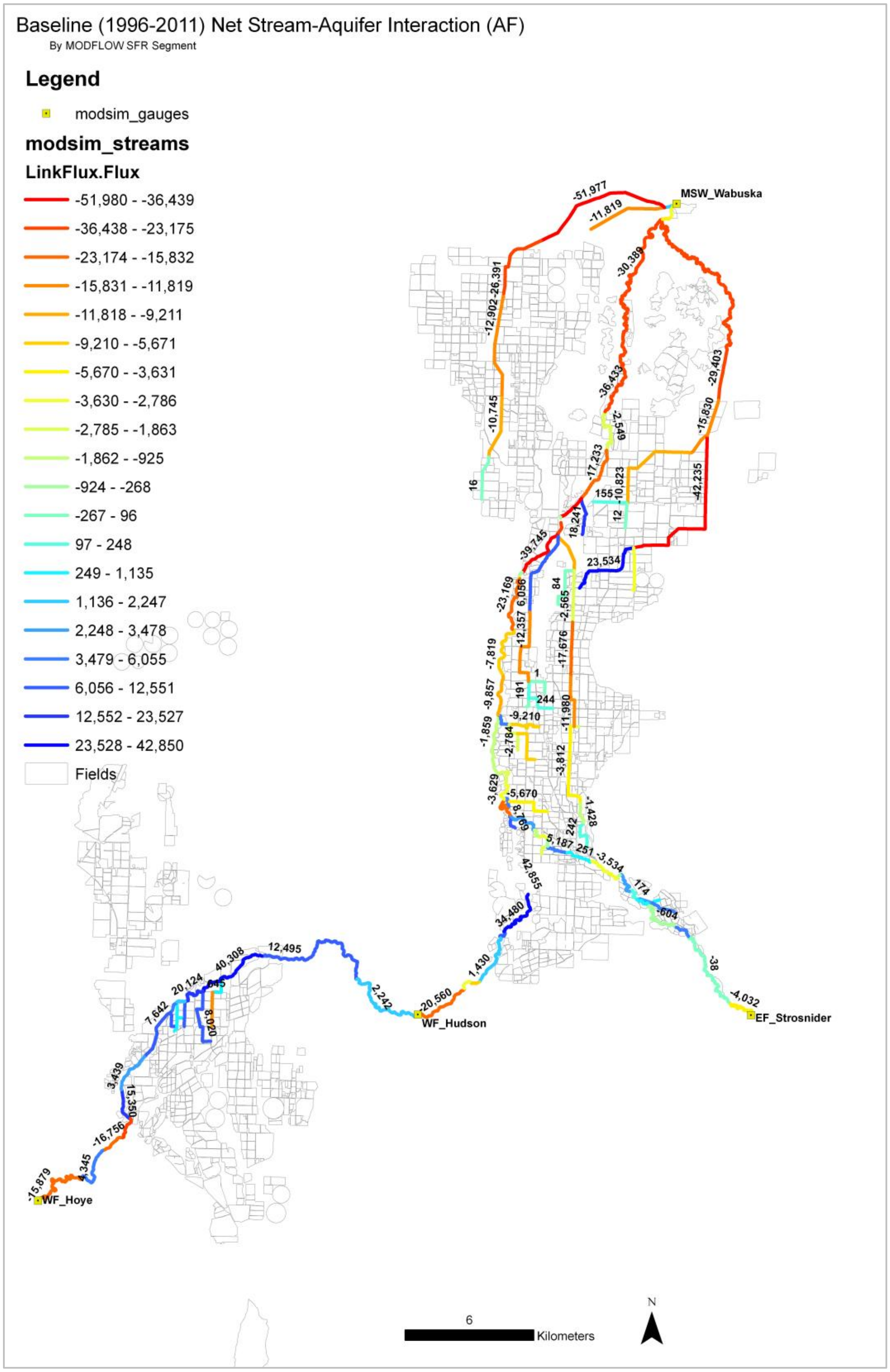

Figure 5.27 Simulated net flux into or out of streams and agricultural drains for Smith and Mason Valley for the modeled time period (Acre-Feet). Negative values denote a losing stream, and a positive value indicates a gaining stream.

Convergence

Although the DST uses the accretions and depletions to determine when the components are converged, the true assessment of convergence is a comparison of the difference in simulated flow in MODSIM and MODFLOW. The percent error in flow between MODSIM and MODFLOW was calculated for each time step for the converged baseline run (Figure 5.28). The plot shows a maximum percent error of 0.0064 in March of 2003 and an average percent error of 0.0006.

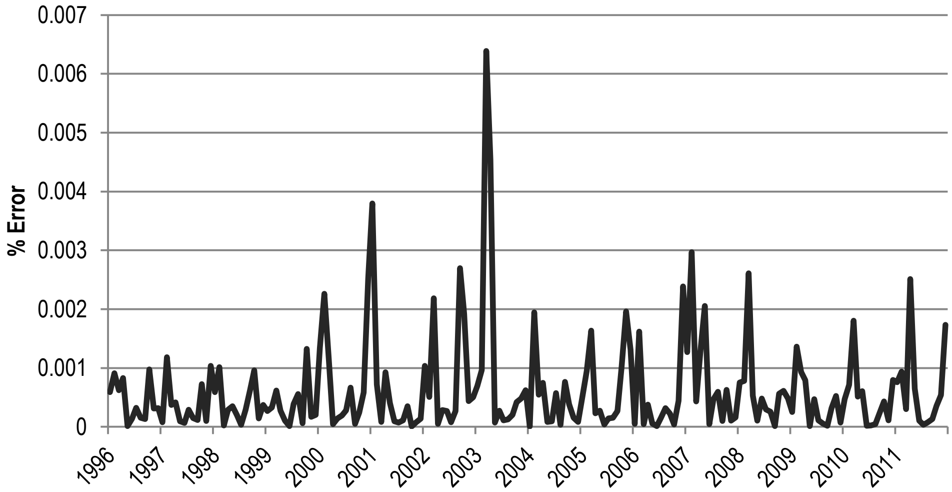

Figure 5.28 Percent error in flow between MODSIM and MODFLOW

A global water budget for all DST components is presented Appendix A - Table A.1. There are two modeling issues that need to be included in the HRU Water Balance for the comparison between components to be made. In particular, (1) the Colony Canal and Smith Primary Groundwater HRUs do not return all of their runoff to the surface network. This was a concept implemented in the phase 1 Smith Valley MODFLOW model, which assumes 18% of the Smith Primary GW HRU, and 15% of Colony's runoff are transported to Artesia Lake and lost from the system to evaporation, and (2) there is a portion of the Stanley Ranch, which lies outside of the active MODFLOW boundary. The HRU water balance generates recharge for this area, but it is not written into the MODFLOW recharge file because there are no active cells for the area.

In Table A.1, there is a mass balance for each component of the DST. The table illustrates that the DST components are simulating the hydrologic behaviors of the system nearly identically (i.e. +/- 1AF). The MODSIM model simulates water budget variables that should be identical to equivalent variables in the HRU Water Balance and MODFLOW. For example, in MODSIM the simulated runoff and diversions are identical to those in the HRU Water Balance. Additionally, the accretions and depletions in MODSIM match the MODFLOW simulated accretions and depletions. Furthermore, the recharge, ditch leakage, and pumping in the HRU Water Balance are identical to the equivalent simulated variables in MODFLOW. After accounting for (1) and (2) in Table A.1, all three DST components are shown to conserve mass and common variables between the components are different by 1 Acre-foot or less. The low percent error in the flow distribution between the MODSIM and MODFLOW models and the uniformity between DST component variables in the Global Water Budget prove convergence of the DST modeling system for the baseline run.

6. *Scenario Application (80700)*

The National Fish and Wildlife Foundation (NFWF) acquired water rights on the West Hyland ditch (Table 6.1) in May of 2010. These rights include Walker River decree rights appurtenant to 646.16 acres of land and total 7.745 cubic feet per second of Walker River decree rights with priority dates ranging from 1874 to 1906. The decree rights also have appurtenant supplemental groundwater rights. In March of 2011, NFWF filed Application No. 80700 with the Nevada State Engineer to change the place, manner, and purpose of use of the acquired decree rights. NFWF proposes that these rights be administered instream from the point of non-diversion to Walker Lake in order to benefit the lower Walker River and Walker Lake. In Application No. 80700 NFWF also states that the appurtenant supplemental groundwater rights will be retired upon finalization of the new instream permit. This section discusses how the DST is applied in a "scenario" mode to simulate, as closely as possible, the surface water rights transfer and groundwater rights retirement proposed in Application No. 80700.

Table 6.1 NFWF App. 80700 Water Rights at West Hyland Ditch

Priority Date	App. 80700 Area [Acres]	App. 80700 Water Right [cfs]
1874	33.36	0.400
1877	72.00	0.860
1880	145.83	1.745
1881	20.00	0.240
1887	32.50	0.390
1888	80.00	0.960
1891	8.93	0.110
1894	7.50	0.090
1896	92.00	1.100
1900	125.04	1.500
1901	15.00	0.180
1904	4.00	0.050
1906	10.00	0.120
Total	**646.16**	**7.745**

Scenario Methods

To simulate the Application No. 80700 water rights transfer scenario, the DST was modified from the baseline model run (described in Section 5) to reflect, as closely as possible, the effects of the proposed change over calendar years 1996 through 2011. The results from the scenario model run are then compared to the results from the baseline model run.

As described in Section 5, limitations in the availability of detailed water right information throughout Smith and Mason Valleys resulted in a ditch-scale HRU approach to calling, diverting, and applying surface water in the current version of the DST. As a result, these limitations precluded the simulation of the movement of the "exact" water rights proposed for transfer in Application No. 80700, rather the scenario model run was designed to simulate the movement of the water that was applied in the baseline model run to the irrigated area associated directly with the water rights in Application No. 80700. In addition, since the current version of the DST does not include detailed logic for delivering flood and supplemental storage water to the HRU, any flood and storage water delivered in the baseline run to the irrigated area associated directly with the water rights in Application No. 80700 was included with the movement of the decree water in the scenario.

The scenario was implemented by disabling the DST modeling units for the irrigated areas associated with Application No. 80700, which automatically disables supplemental groundwater pumping for those areas (i.e., the supplemental groundwater pumping for the areas is "retired").

The volume of surface water that is not applied in the scenario run is calculated based on the fraction of the areas taken out of production relative to the total non-NDOW HRU area. It is equal to the sum of the decree, flood and storage water delivered to the same areas in the baseline run. The volume of the demand remaining in the non-NDOW portion of the HRU is calculated by subtracting the volume proposed for transfer from the original volume. Using a MODSIM flow-thru node, the time series of Application No. 80700 water is returned back to the river at the point of diversion in the scenario. In essence, the water is "protected" because it is diverted through the same rights as in the baseline, but the volume of Application No. 80700 water is returned to the river as if it were never diverted. This water is hereafter referred to as the "Application 80700 water" and the amount of the Application 80700 water that reaches the Wabuska Gage downstream of the point of non-diversion is referred to as the "80700 Wabuska water".

Figure 6.1 shows the Baseline DST fields, and two spatial representations of the areas associated with Application No. 80700. The WRID water cards associated with Application No. 80700 included 646.16 acres of decreed water rights. Unlike the original map filed with Application No. 80700, the DST spatial representation includes the area of water usage so the map submitted as part of Application No. 80700 was edited to produce areas that reflect the actual historical crop irrigated areas (cross hatched "DST App. No 80700 Map" in Figure 6.1). Table 6.2 summarizes the Application No. 80700 area from these sources.

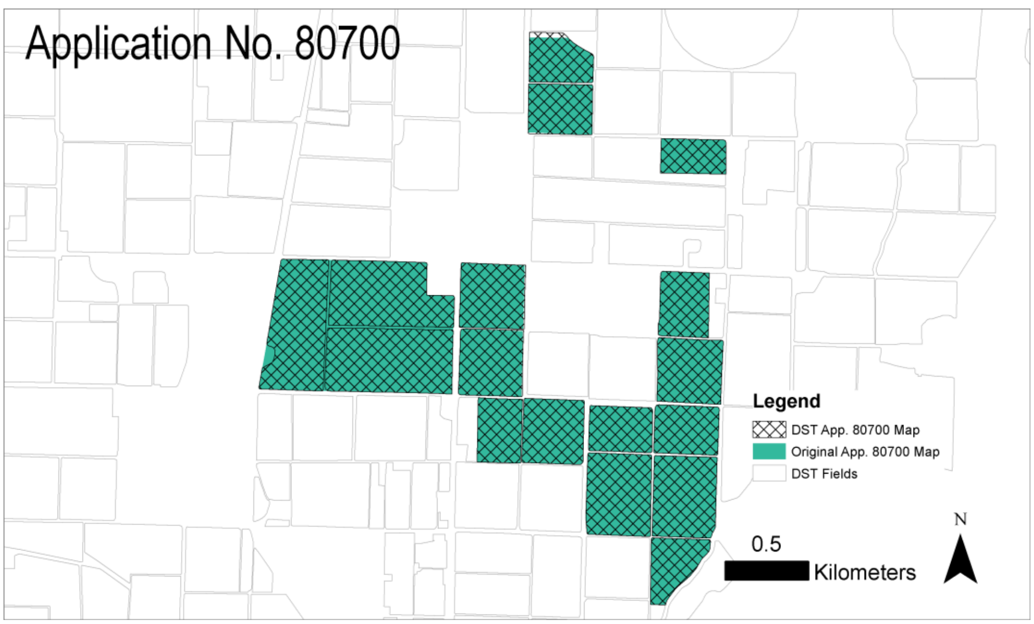

Figure 6.1. Map of West Hyland HRU and App. 80700 fields

Table 6.2 Summary of App. 80700 areas by source.

Source	Acres
App. 80700 Water Cards	646.16
Original App. 80700 Map Spatial Representation	644.37
DST App. 80700 Spatial Representation	640.62

To calculate the volume of Application 80700 water, an area-based factor is computed as the ratio of the DST Application No. 80700 areas to the non-NDOW West Hyland Ditch area. Table 6.3 shows the summary of the DST spatial representation of Application No. 80700 areas, the original total irrigated Non-NDOW area and the computed area-based factor.

Table 6.3 Area-based Factor Summary

Owner	DST App. 80700 Area [Acres]	Non-NDOW Total Area [Acres]	Area-based Factor
West_Hyland	640.62	3691.79	0.1735

The area-based factor is used to reduce the water demand of the West Hyland Ditch Non-NDOW node and create the water demand for Application No. 80700 node. This is possible because the DST evenly distributes surface water over an HRU and therefore, water demand reduction is proportional to the area-based factor.

The Application 80700 scenario was run in the DST to a convergence tolerance of 0.2 AF/Month over the same time period as the baseline (1996–2011). The calibration parameter values were held constant for the scenario run and the calibration gains and losses simulated in the baseline run are forced to occur in the scenario run because they represent unmeasured natural and/or human activities in the historical operation that would not have changed in the scenario. This means that inflows to the system are held constant between the two runs and the scenario will therefore simulate the net change in surface water availability, including changes in flows at key points, in aquifer response, and in water right calls.

The global water budget for the Application 80700 scenario run is shown in Appendix A - Table A.2. The scenario global water budget table demonstrates that mass is conserved in the Application 80700 scenario run in each of the DST components. Simulated values for diversions and runoff are within +/- 1 AF between MODSIM and the HRU Water Balance. The river and drain depletions and accretions are simulated within +/- 1 AF between MODSIM and MODFLOW, and the recharge, ditch leakage, and pumping in the HRU Water Balance are also within +/- 1 AF of the equivalent simulated variables in MODFLOW.

Scenario Results

The Application No. 80700 water over the entire sixteen-year period (1996-2011) was 29,500 AF; this is the volume of water protected to the West Hyland diversion and allowed to flow downstream to Wabuska (Figure 6.2). Note that the cumulative "type" of Application 80700 water (i.e., Storage, Flood, and Decree) is also indicated in the figure. Figure 6.2 also shows the 26,834 AF of supplemental groundwater pumping that occurred in the baseline run over the sixteen-year period but was "retired" in the scenario. The amount of the Application No. 80700 water that makes it to Wabuska (i.e., the 80700 Wabuska water) over the entire sixteen-year period (1996-2011) was 25,344 AF (86% of the Application 80700 water) and is shown as the maroon bar in the figure. Note that the 80700 Wabuska water and the difference between the Application No. 80700 water and the 80700 Wabuska water cannot easily be broken down into the Storage, Decree, and Flood water types since it is a result of the entire system responding to the change in delivery at the West Highland ditch, including changes in stream accretions and depletions, changes in return flows from the West Highland HRU, changes in losses and uses on the West Hyland HRU, and impacts (shortages and surpluses) to other surface water demands (ditches and boundary conditions) in the system. Over the entire sixteen-year period, the shortages and surpluses in the scenario were 221 AF and 92 AF, respectively, and are described in more detail in the Scenario Impacts section below.

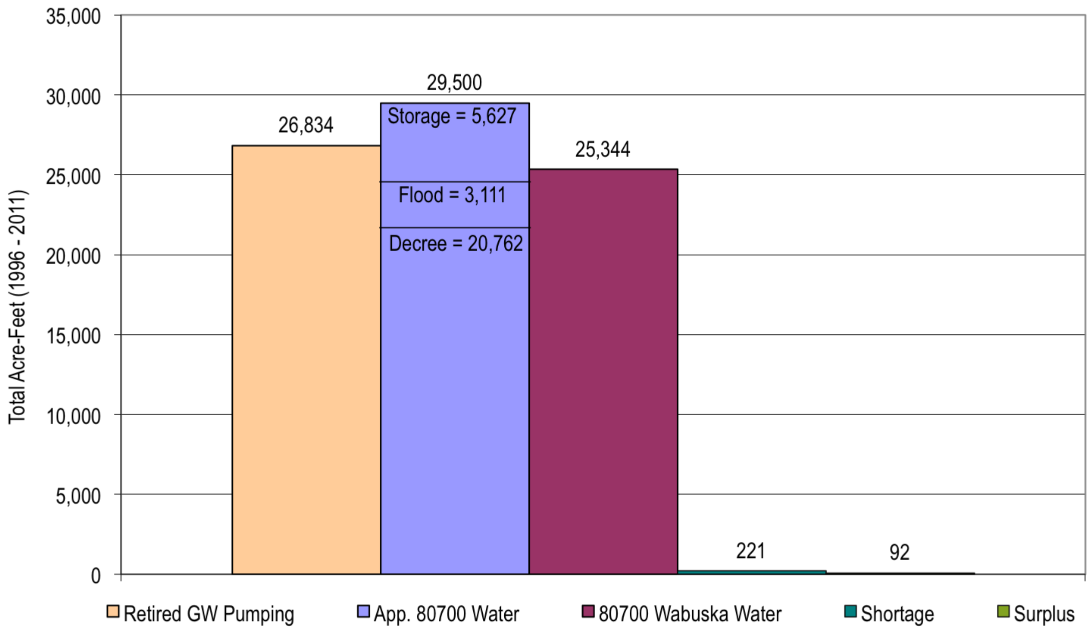

Figure 6.2 Comparison of output from the baseline and scenario run for App. No. 80700

The annual variation in each of the quantities shown in Figure 6.2 is shown in Figure 6.3. The retired groundwater pumping is greatest in the dry years and smallest in the wet years, whereas the Application 80700 water is largest in wet years and smallest in dry years. The ratio of the 80700 Wabuska water to the Application 80700 water varies from year to year with 1996 (92.9%) being the largest and 2000 (77.3%) being the smallest. The shortage is relatively small for all years, with 2006 (0 AF) being the smallest and 2007 (44.24 AF) the largest. The surplus ranges from 0 AF to a maximum of 25.5 AF in 2011.

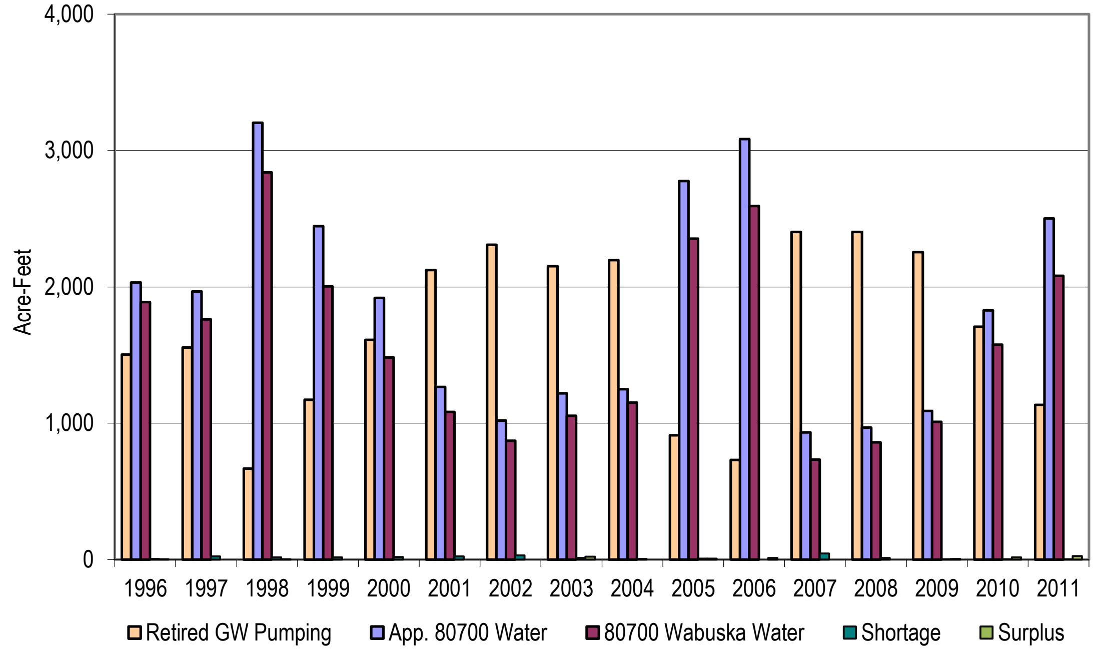

Figure 6.3 Annual comparison of output from the baseline and scenario run for App. No. 80700

The monthly variation in the Application 80700 water and 80700 Wabuska water is shown in Figure 6.4. Note that, as stated above in the Scenario Methods, the Application 80700 water includes Storage, Flood, and Decree Water whereas the dark blue line shown in Figure 6.4 shows the actual Application 80700 Water Right rate.

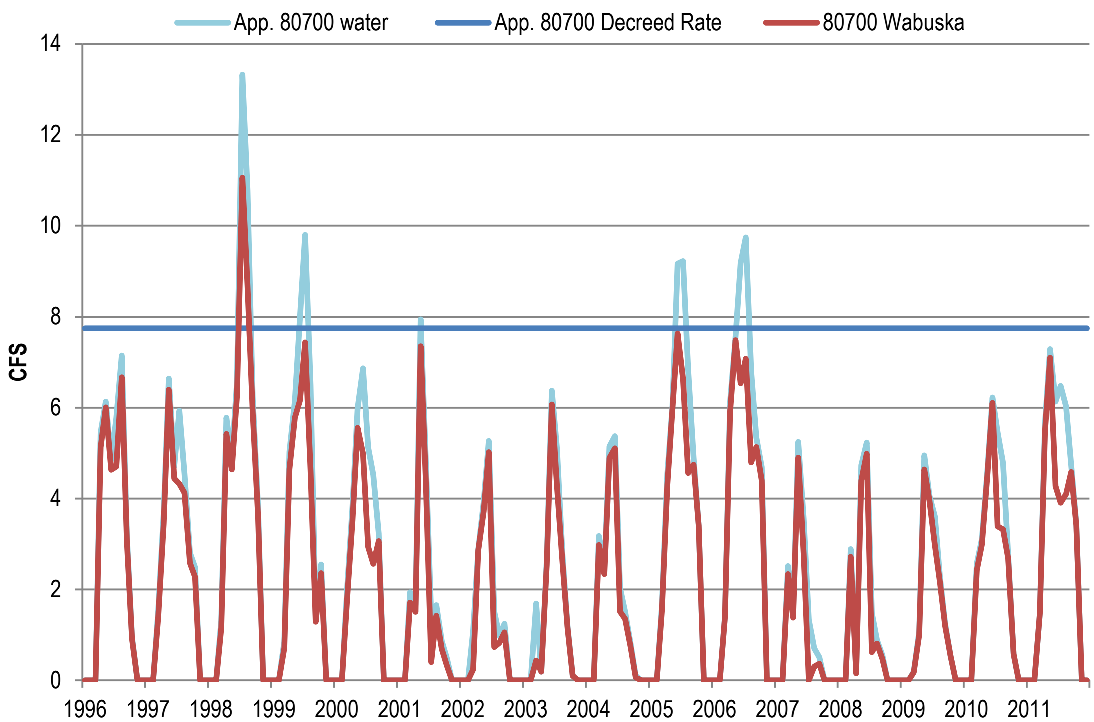

Figure 6.4 Monthly variation in the Application 80700 water and 80700 Wabuska water.

Tracking the Lost Application 80700 Water

The majority of the "Lost Application 80700 water" (the difference between the Application 80700 water and 80700 Wabuska water) occurs during the higher delivery rate periods of the irrigation season. In order to explain the source of this Lost Application 80700 water a worked example is provided. The example disaggregates the Lost Application 80700 water for a specific time step (June 2005) of the DST Scenario run. This time step was selected because there were no shortages or surpluses and all demands in the system were met. For June 2005 the Application 80700 water was 545 AF called on but not diverted at the West Hyland point of diversion. The additional amount of water reaching Wabuska, or the 80700 Wabuska water, was 454 AF. In other words there is a difference between the App. 80700 water and the 80700 Wabuska water of 91 AF (a 20% loss) for the June 2005 time step. This difference is a function of:

- The change in flow at the West Hyland POD
- The Application 80700 water
- The change in stream-aquifer interaction between the POD and Wabuska
- The change in drain return flows
- The change in diversions
- The change in direct runoff to the river

Figure 6.5 shows the aforementioned reach and the values for the items above. With the exception of the Application 80700 water and the 80700 Wabuska water, the values for each reach are presented as the *Scenario* minus the *Baseline* value. Positive values represent additional flows or accretions into the reach and negative values indicate decreases in flow or additional depletions. There is a small amount of additional flow above the point of diversion that is attributed to a rise in water table elevation adjacent to the river. Starting with the gain above the point of diversion, adding in the Application 80700 water and stepping through the downstream reaches and summing the terms in Table 6.4 yields a calculated 80700 Wabuska volume of 454.01 AF. This is the exact volume of water simulated with the DST in the Scenario run. All of the sources of the Lost Application 80700 water are therefore documented in the figure and table.

The primary variable influencing the 80700 Wabuska water is the reduction in return flows in the Wabuska Drain, which is the source of 81 AF of loss. This indicates that 89% of the Lost Application 80700 water is attributed directly to a reduction in return flows in the Wabuska drain. In this example, changes in accretions and depletions, the additional flow at the West Hyland POD, and the other changes in return flows account for the remainder of the outcome. Direct runoff to the river did not factor into this example but it could play an important role in other time steps when demands are short and runoff is different from the baseline values.

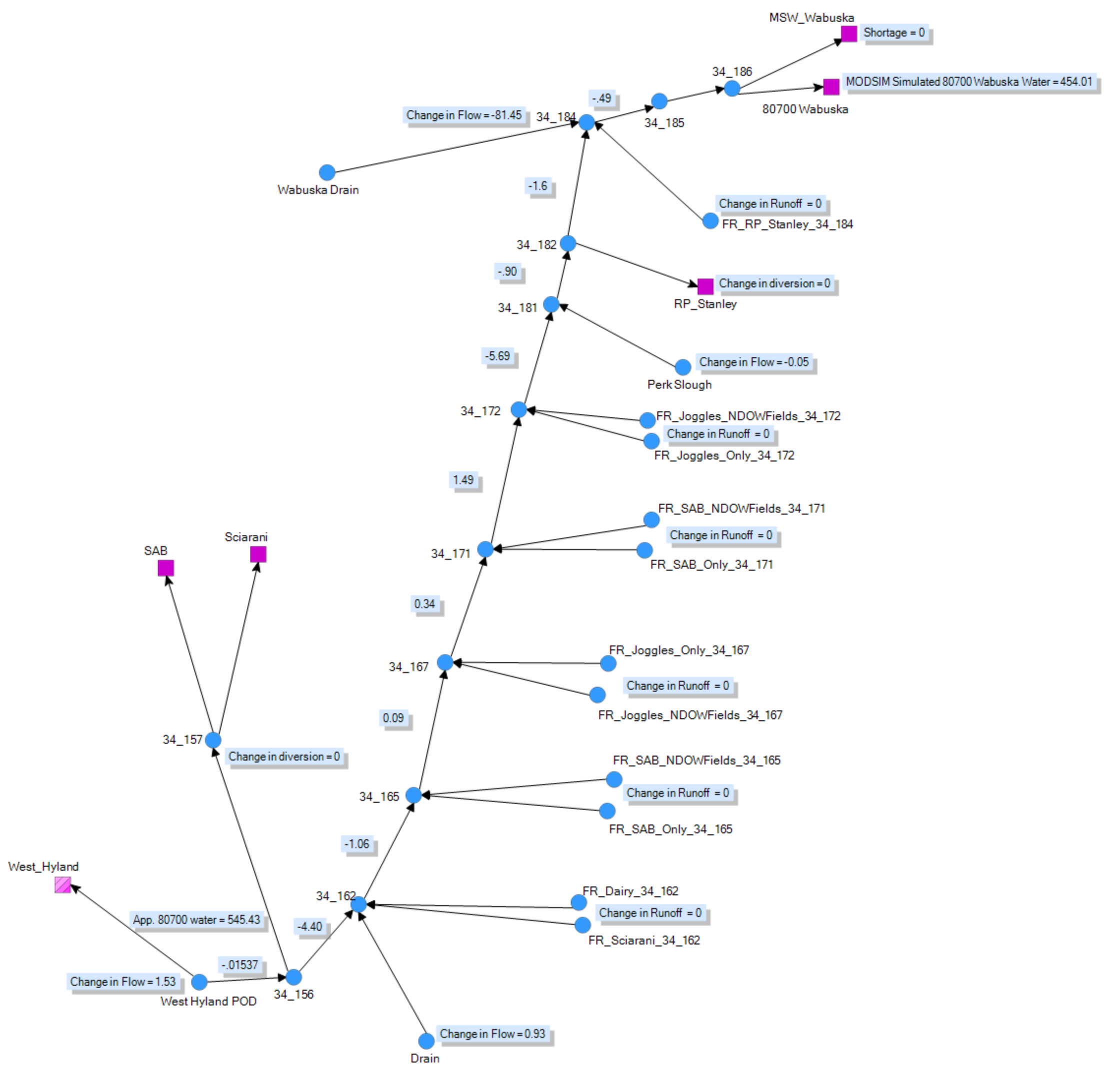

Figure 6.5 Schematic illustrating components of the Lost Application 80700 water for the reach between the West Hyland POD and the Wabuska gage (June 2005)

Table 6.4 Reach components which sum to total Lost Application 80700 water (June 2005)

System Feature	Inflow/Outflow
Change In Flow at West Hyland POD	1.53
Application 80700 water	545.43
Increased Depletion	-0.1537
Change in SAB Diversion	0
Change in Sciarani Diversion	0
Increased Depletion	-4.4
Change Drain Return Flow	0.93
Change in Runoff	0
Increased Depletion	-1.06
Change in Runoff	0
Decreased Depletion	0.09
Change in Runoff	0
Decreased Depletion	0.34
Change in Runoff	0
Decreased Depletion	1.49
Change in Runoff	0
Increased Depletion	-5.69
Change In Perk slough flow	-0.05
Increased Depletion	-0.9
Change in Stanley Diversion	0
Increased Depletion	-1.6
Change in Runoff	0
Change in Wabuska Drain Flow	-81.45
Increased Depletion	-0.49
Calculated 80700 Wabuska water	**454.01**

Scenario Impacts

Throughout the entire sixteen-year period of the scenario, there were no surface water delivery shortages to the West Hyland Ditch (i.e., the West Hyland areas not included in Application No. 80700 received the exact same delivery of surface water as in the baseline). There were changes to the runoff, groundwater recharge, and return flows from the West Hyland ditch HRU because of the non delivery of the Application 80700 water and the associated retirement of the supplemental groundwater on the Application 80700 areas. As a result, there were minor changes to the stream accretions and depletions in the stream system. These changes resulted in occasional minor shortages (Figure 6.6) and surpluses (Figure 6.7) within the system that are directly related to the system responding to stream accretions and depletions in the stream system and the changes in return flow from the West Highland HRU. The shortages occur at the Pitchfork ditch (PF), the Wabuska gage, and the Stanley River Pump when these demands did not have access to streamflow that was available in the baseline. The surplus occurs at the Wabuska gage in time steps when there is water available at the Wabuska gage that is not needed to satisfy a demand for the time step.

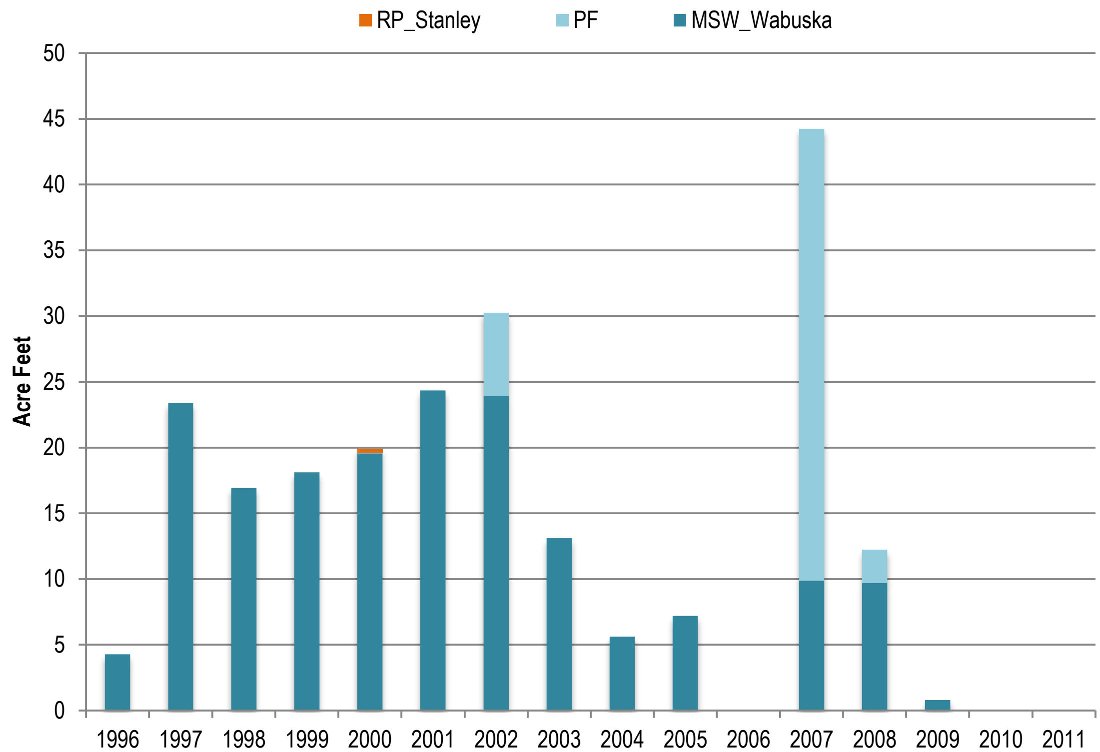

Figure 6.6 Shortage by demand for all years

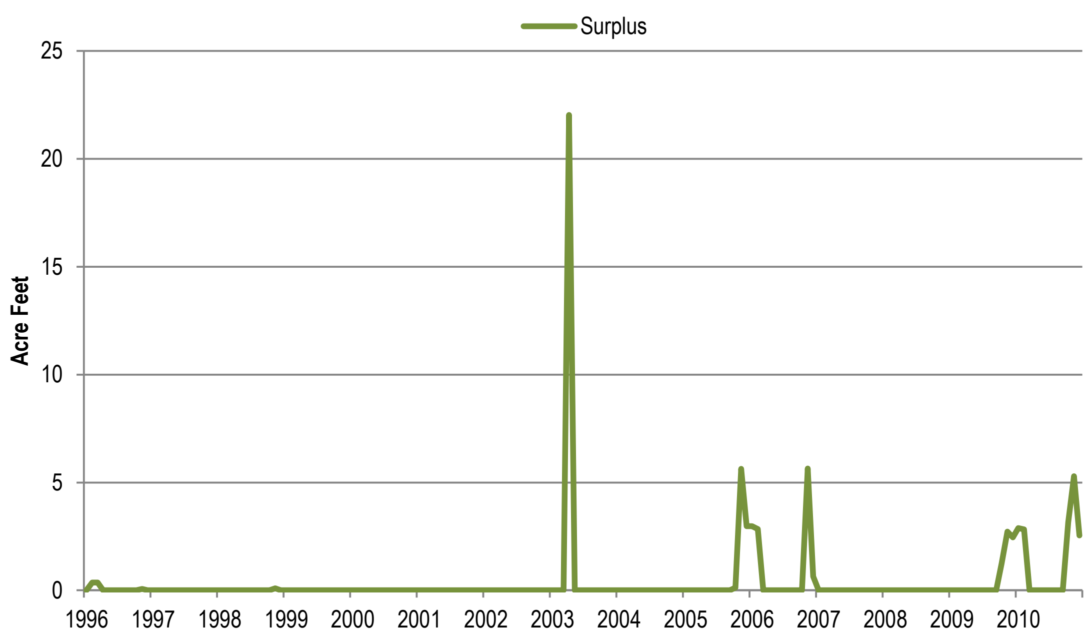

Figure 6.7 Simulated surplus water at the Wabuska gage

Summary of Scenario Results and Recommendations for Future Work

In this section, the DST was modified from the baseline model run to simulate, as closely as possible, the proposed Application No. 80700 water rights transfer scenario over calendar years 1996 through 2011. The results from the scenario model run were then compared to the results from the baseline model run. An analysis of the results indicates that, within the assumptions and limitations of the DST and the scenario method, 86% of the Application 80700 water reaches the Wabuska Gage (80700 Wabuska water) over the sixteen-year time period with an annual range between 77.3% and 92.9%. The analysis also indicates that there were no shortages in surface water delivered to the remaining areas of the West Hyland HRU but that there are occasional minor shortages and surpluses within the system that are directly related to the system responding to the changes in losses and uses of surface water and supplemental pumping on the 80700 Application area of the West Hyland HRU, changes in return flows from the West Highland HRU, and changes in stream accretions and depletions in the stream system.

We recommend a comprehensive sensitivity analysis of the relationship between the DST output variables and the three calibration parameters. In addition, further development of the operational rules for the storage and flood waters within the DST would allow for a more realistic scenario design (i.e., storage and flood water would not need to be included in the Application 80700 water). Finally, we recommend moving from the ditch level delivery priority-demand system we have used in this version to a priority-demand system that is based, to the extent possible, on actual water rights associated with specific areas. This last recommendation will be difficult to achieve without cooperation to ensure that the most accurate estimates of water rights are identified and used in the DST.

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7. References

Allen, R.G., Tasumi, M., Trezza, R. *Satellite-based Energy Balance for Mapping Evapotranspiration with Internalized Calibration (METRIC) – Model.* Journal of Irrigation and Drainage Engineering, ASCE 133(4), 2007a.

ASCE-EWRI. *The ASCE Standardized Reference Evapotranspiration Equation. ASCE-EWRI Standardization of Reference Evapotranspiration Task Committee Report.* American Society of Civil Engineers, 2005.

Boyle, D., Pohll G., Bassett, S., Minor, T., Garner, C., Carroll, R., McGraw, D., Knust, A., Barth, C.,. "Project F:F.1 - Development of a Decision Support Tool in Support of Water Right Aquisitions in the Walker River Basin, In Restoration of a Desert Lake in an Agriculturally Dominated Watershed: The Walker Lake Basin. M.W. Collopy and J.M. Thomas (eds.)." 2010.

Carroll, R., G. Pohll, D. McGraw, C. Garner, A. Knust, D. Boyle, T. Minor, S. Bassett, K. Pohlmann. *Mason Valley Groundwater Model: Linking Surface Water and Groundwater in the Walker River Basin, Nevada.* Vol. 46. 3 vols. Journal of the American Water Resources Association, 2010.

Gallagher, T.K. *Estimated Annual Ground-water Pumpage 1994-2004 Smith Valley and Mason Valley Lyon County, Nevada.* Department of Conservation and Natural Resources, Division of Water Resources, 2005.

Harbaugh, A.W., E.R. Banta, M.C. Hill, and M.G. McDonald. "MODFLOW-2000, the U.S. Geological Survey Modular Ground-water Model – User Guide to Modularization Concepts and the Ground-water Flow Process." U.S. Geological Survey, 2000.

Howell, T. A. *Irrigation Efficiency, In: Encyclopedia of Water Science, B. A. Stewart and T. A Howell (eds.) .* Marcel-Dekker, Inc., 2003.

Huntington J.L., Allen, R.G. *Evapotranspiration and Net Irrigation Water Requirements for Nevada.* Nevada Division of Water Resources, 2010.

Labadie, John W. "MODSIM: River Basin Management Decision Support System." In *Watershed Models*, by V P Singh and D K Frevert, Chapter 23 . Boca Raton, FL: CRC/Taylor & Francis, 2006.

Lopes, T.J., and K.K. Allander. *Hydrologic Setting and Conceptual Hydrologic Model of the Walker River Basin, West-Central Nevada.* U.S. Geological Survey, Scientific Investigations Report 2009-5155., 2009.

Minor, T.B., A. Stroud, S. Bassett, M. Rincon, J. Saltenberger, D.P. Boyle, G. Pohll, C. Garner, R.W.H. Carroll, D. McGraw, and A. Knust. "Project I: Development of a Water Distribution and Water Rights GIS Database for Integration with a Water Flow Model in the Walker Basin, In Restoration of a Desert Lake in an Agriculturally Dominated Watershed: The Walker Lake Basin. M.W. Collopy and J.M. Thomas (eds.)." 2010.

Pahl, R. *Walker River basin water rights, Volume 1: An introduction to natural flow diversion rights defined in Decree C-125. Nevada Water Basin Information and Chronology Series.* Division of Water Planning, Department of Conservation and Natural Resources, 2009.

Rush, E.F., Hill, V.R. *Bathymetric Reconnaissance of Topaz Lake, Nevada and California.* Nevada Division of Water Resources, 1972.

Tyler, S.W., C.M. Hatch, and B. Rawat. *Project F:F.2 Development of a Decision Support tool iin Support of Water Right Acquisitions in the Walker River Basin – Use of Fiber Optic Temperature Sensing for Water Resource Management in the Walker Basin, In Restoration of a Desert Lake in an Agriculturally Dominated Watershed: The Walker Lake Basin. M.W. Collopy and J.M. Thomas (eds.).* 2010.

8. *Appendix A - DST Global Water Budget Tables*

Table A.1 Global Calibration Water Budget in Acre Feet. Note that components conserve mass and variables between components match (+/- 1 AF). There are two modeling issues that need to be included in the HRU Water Balance for the comparison between components to be made. In particular, (1) the Colony Canal and Smith Primary Groundwater HRUs do not return all of their runoff to the surface network. This was a concept implemented in the phase 1 Smith Valley MODFLOW model, which assumes 18% of the Smith Primary GW HRU, and 15% of Colony's runoff are transported to Artesia Lake and lost from the system to evaporation, and (2) there is a portion of the Stanley Ranch, which lies outside of the active MODFLOW boundary. The HRU water balance generates recharge for this area, but it is not written into the MODFLOW recharge file because there are no active cells for the area. Grey rows account for these discrepancies the water balance and other components.

			1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
MODSIM	Inflows	River Inflow	507,531	626,458	507,613	397,041	235,025	156,808	157,336	206,474	186,936	422,256	585,105	136,617	162,266	198,762	283,575	547,174
		Runoff	41,549	43,935	41,584	42,369	36,668	31,706	31,639	34,194	33,615	41,779	44,828	30,980	31,422	33,928	37,213	46,253
		Stream Accretions	45,775	59,517	55,182	58,808	50,246	38,495	32,803	32,731	32,548	43,302	53,908	37,382	30,855	30,968	35,278	48,969
	Ouflows	Stream Depletions	103,593	71,240	65,536	58,322	52,438	55,330	60,601	62,802	62,663	66,533	67,826	56,909	62,950	65,091	63,764	70,150
		Diversions	263,229	264,545	242,997	266,351	203,255	122,734	120,600	157,227	136,229	272,002	288,586	99,071	111,016	153,091	206,773	290,389
		River Outflow	228,033	394,125	295,847	173,545	66,246	48,945	40,577	53,370	54,206	168,801	327,428	48,998	50,577	45,477	85,529	281,857
		Volumetric Error (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HRU Water Balance	Inflows	Diversions	263,229	264,545	242,997	266,351	203,255	122,734	120,600	157,227	136,229	272,002	288,586	99,071	111,016	153,091	206,773	290,389
		GW Pumping	68,643	70,101	72,252	68,998	94,530	129,089	133,081	117,016	125,032	65,384	58,954	141,215	136,529	120,624	95,314	61,378
	Outflows	Ditch Leakage	39,484	39,682	36,450	39,953	30,488	18,410	18,090	23,584	20,434	40,800	43,288	14,861	16,652	22,964	31,016	43,558
		Crop ET	162,274	158,513	148,932	163,141	152,494	134,015	136,384	143,360	135,904	165,783	164,453	128,441	132,678	144,492	154,560	163,976
		Runoff	*41,549*	*43,935*	*41,584*	*42,369*	*36,668*	*31,705*	*31,639*	*34,194*	*33,615*	*41,779*	*44,828*	*30,980*	*31,422*	*33,928*	*37,213*	*46,253*
		Runoff Colony & Smith PGW	*3,859*	*3,691*	*3,737*	*3,787*	*3,381*	*2,952*	*2,951*	*3,228*	*2,976*	*3,870*	*3,970*	*2,832*	*2,821*	*3,130*	*3,434*	*4,097*
		Total WB Runoff	45,407	47,625	45,321	46,157	40,049	34,657	34,590	37,422	36,591	45,649	48,797	33,812	34,243	37,058	40,646	50,349
		Ag. Recharge	*84,669*	*88,796*	*84,507*	*86,058*	*74,729*	*64,726*	*64,604*	*69,858*	*68,310*	*85,118*	*90,983*	*63,163*	*63,961*	*69,191*	*75,833*	*93,875*
		Ag. Recharge - Stanley Ranch Zeroed	*37*	*30*	*39*	*40*	*25*	*15*	*13*	*19*	*22*	*36*	*19*	*9*	*10*	*9*	*31*	*9*
		Total WB Ag. Recharge	84,706	88,825	84,546	86,098	74,754	64,741	64,617	69,876	68,332	85,154	91,002	63,172	63,972	69,200	75,864	93,884
		Volumetric Error (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MODFLOW (Smith & Mason)	Inflows	Storage	156,734	95,926	85,759	78,990	91,307	122,753	117,921	93,959	103,617	63,084	63,068	131,107	113,864	89,227	69,701	56,242
		Mtn. Block Recharge	19,050	18,998	18,998	18,998	19,050	18,998	18,998	18,998	19,050	18,998	18,998	18,998	19,050	18,998	18,998	18,998
		Ponds Recharge	2,168	1,701	1,438	1,252	1,150	1,120	1,135	1,142	1,140	1,084	997	981	1,041	1,073	1,068	1,011
		GW Interbasin Flow	760	688	734	760	803	824	824	812	815	767	738	810	804	788	767	721
		Ag. Recharge	84,669	88,796	84,507	86,058	74,729	64,726	64,604	69,858	68,310	85,118	90,983	63,163	63,961	69,191	75,833	93,875
		Ditch Leakage	39,484	39,682	36,449	39,953	30,488	18,410	18,090	23,584	20,434	40,800	43,288	14,861	16,652	22,964	31,016	43,558
		Stream Depletions	103,593	71,240	65,537	58,322	52,438	55,330	60,601	62,802	62,663	66,533	67,825	56,909	62,951	65,091	63,764	70,150
	Outflows	Stream Accretions	45,774	59,517	55,183	58,808	50,246	38,496	32,803	32,731	32,548	43,302	53,909	37,382	30,855	30,967	35,278	48,969
		Storage	241,361	132,203	108,524	96,915	65,710	56,607	60,015	66,025	63,071	110,154	112,274	49,641	54,858	60,992	75,321	115,951
		GW Interbasin Flow	575	716	786	848	893	937	961	982	999	1,037	1,079	1,062	1,077	1,066	1,073	1,102
		GW Pumping	68,643	70,101	72,252	68,998	94,530	129,089	133,081	117,016	125,032	65,384	58,954	141,215	136,529	120,624	95,314	61,378
		Non-Ag. ET	50,095	54,472	56,654	58,741	58,578	57,009	55,286	54,374	54,363	56,479	59,660	57,505	54,986	53,654	54,134	57,129
		Volumetric Error (%)	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Table A.2 Global Scenario Water Budget in Acre Feet. Note that components conserve mass and variables between components match (=/- 1 AF). There are two modeling issues that need to be included in the HRU Water Balance for the comparison between components to be made. In particular, (1) the Colony Canal and Smith Primary Groundwater HRUs do not return all of their runoff to the surface network. This was a concept implemented in the phase 1 Smith Valley MODFLOW model, which assumes 18% of the Smith Primary GW HRU, and 15% of Colony's runoff are transported to Artesia Lake and lost from the system to evaporation, and (2) there is a portion of the Stanley Ranch, which lies outside of the active MODFLOW boundary. The HRU water balance generates recharge for this area, but it is not written into the MODFLOW recharge file because there are no active cells for the area. Grey rows account for these discrepancies the water balance and other components.

			1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
MODSIM	Inflows	River Inflow	507,531	626,458	507,613	397,041	235,025	156,808	157,336	206,474	186,936	422,256	585,105	136,617	162,266	198,762	283,575	547,174
		Runoff	41,005	43,391	40,982	41,822	36,120	31,166	31,104	33,658	33,053	41,225	44,248	30,442	30,872	33,393	36,657	45,700
		Stream Accretions	45,774	59,486	55,143	58,768	50,225	38,478	32,784	32,713	32,553	43,317	53,917	37,374	30,852	30,972	35,295	48,980
	Ouflows	Stream Depletions	103,196	70,893	65,275	58,194	52,324	54,980	60,224	62,404	62,210	66,417	67,735	56,608	62,517	64,633	63,459	70,002
		Diversions	261,197	262,578	239,794	263,905	201,337	121,467	119,574	156,008	134,979	269,226	285,502	98,104	110,045	152,001	204,946	287,888
		River Outflow	229,917	395,863	298,669	175,532	67,709	50,005	41,425	54,433	55,352	171,155	330,033	49,722	51,427	46,493	87,121	283,964
		Volumetric Error (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HRU Water Balance	Inflows	Diversions	261,197	262,578	239,794	263,905	201,337	121,467	119,574	156,008	134,979	269,226	285,502	98,105	110,045	152,001	204,946	287,888
		GW Pumping	67,064	68,470	71,475	67,749	92,846	126,894	130,697	114,789	122,762	64,389	58,141	138,811	134,073	118,294	93,533	60,161
	Outflows	Ditch Leakage	39,180	39,387	35,969	39,586	30,200	18,220	17,936	23,401	20,247	40,384	42,825	14,716	16,507	22,800	30,742	43,183
		Crop ET	160,522	156,763	147,153	161,377	150,745	132,284	134,658	141,631	134,176	164,011	162,674	126,752	130,969	142,767	152,815	162,211
		Runoff	*41,005*	*43,391*	*40,982*	*41,822*	*36,120*	*31,166*	*31,104*	*33,658*	*33,053*	*41,225*	*44,248*	*30,442*	*30,872*	*33,393*	*36,657*	*45,700*
		Runoff Colony & Smith PGW	*3859*	*3691*	*3737*	*3788*	*3381*	*2951*	*2951*	*3228*	*2976*	*3870*	*3970*	*2832*	*2821*	*3130*	*3434*	*4096*
		Total WB Runoff	44,864	47,082	44,719	45,609	39,500	34,117	34,055	36,885	36,029	45,095	48,218	33,275	33,692	36,522	40,091	49,797
		Ag. Recharge	*83,659*	*87,787*	*83,389*	*85,041*	*73,711*	*63,723*	*63,609*	*68,861*	*67,267*	*84,089*	*89,906*	*62,165*	*62,939*	*68,196*	*74,801*	*92,848*
		Ag. Recharge - Stanley Ranch Zeroed	*37*	*30*	*39*	*40*	*25*	*15*	*13*	*19*	*22*	*36*	*19*	*9*	*10*	*9*	*32*	*9*
		Total WB Ag. Recharge	83,696	87,816	83,428	85,081	73,736	63,739	63,622	68,880	67,289	84,125	89,925	62,174	62,950	68,206	74,832	92,857
		Volumetric Error (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MODFLOW (Smith & Mason)	Inflows	Storage	156,115	95,259	85,463	78,577	90,565	121,364	116,351	92,598	102,241	62,753	62,928	129,625	112,349	87,963	68,991	55,861
		Mtn. Block Recharge	19,050	18,998	18,998	18,998	19,050	18,998	18,998	18,998	19,050	18,998	18,998	18,998	19,050	18,998	18,998	18,998
		Ponds Recharge	2,168	1,701	1,438	1,252	1,151	1,120	1,134	1,141	1,138	1,082	996	980	1,039	1,071	1,066	1,008
		GW Interbasin Flow	760	688	734	760	803	824	824	812	815	767	738	810	804	788	767	721
		Ag. Recharge	83,659	87,787	83,389	85,041	73,711	63,723	63,610	68,861	67,267	84,089	89,906	62,165	62,939	68,196	74,801	92,848
		Ditch Leakage	39,179	39,387	35,969	39,586	30,200	18,220	17,936	23,401	20,247	40,384	42,825	14,716	16,507	22,800	30,742	43,183
		Stream Depletions	103,196	70,893	65,275	58,194	52,324	54,980	60,225	62,404	62,210	66,417	67,735	56,608	62,517	64,634	63,459	70,002
	Outflows	Stream Accretions	45,774	59,486	55,143	58,768	50,225	38,478	32,784	32,713	32,553	43,317	53,917	37,374	30,852	30,972	35,294	48,980
		Storage	240,668	131,692	107,387	96,532	65,492	56,108	59,521	65,500	62,440	109,351	111,370	49,204	54,293	60,524	74,825	115,216
		GW Interbasin Flow	573	712	783	846	891	933	956	977	993	1,034	1,077	1,057	1,071	1,060	1,068	1,099
		GW Pumping	67,064	68,470	71,475	67,749	92,846	126,894	130,697	114,789	122,762	64,389	58,141	138,811	134,073	118,294	93,533	60,161
		Non-Ag. ET	50,038	54,330	56,454	58,490	58,341	56,794	55,093	54,209	54,204	56,371	59,601	57,432	54,899	53,571	54,075	57,141
		Volumetric Error (%)	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01