Coupled Reservoir Operation and Integrated Hydrologic Simulation Modeling of the SWP and CVP Systems in California with Dynamic Hydrology Adjustment

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Abstract

Mature water resources areas rely heavily on surface water and groundwater and supported by intertied storage, allocation, and routing infrastructure. In such areas computerized mathematical models are indispensable tools. They both inform and guide planners, policy makers, and stakeholders, on how best to balance supplies and demands while meeting complex regulatory requirements required ensuring safety, reliability, and sustainability of associated water resources. They are also increasingly impacted by the challenges of climate change. This research focuses on the integration of a reservoir operation system model for allocations, an integrated hydrological simulation model for physically routing surface water and groundwater, and the hydrology driving both models, together to address such needs. The models discussed are generic and therefore applicable to many areas. The models are the Integrated Water Flow Model IWFM, and the reservoir operation/allocation model WRIMS (Water Resources Integrated Modeling Suite). This research tests these models and their coupling in a complex example in California. The application of IWFM called California Central Valley Simulation model (C2VSIM) is linked to an application of WRIMS for the CVP/SWP systems in the Central Valley (developed as part of this research) to simulate key reservoirs for water allocation. Artificial Neural Network (ANN) techniques are also presented to improve hydrologic inputs to the models. The resulting tools and suggested approach for using these tools are applied to two examples: a proposed conjunctive use study in the Central Valley and a study to examine the impacts of global warming on upper watershed flows to downstream storage and allocations.

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Chapter 1 Introduction

The world today faces many challenges of meeting increasing water demands for agriculture, urban, and environmental needs. In many areas, there are significant spatial and temporal mismatches between availability of water supplies and demand needs. This is complicated by lacking, incomplete, or aging infrastructure required supporting the allocation, and a dynamically changing regulatory process required to ensure safety, reliability, and sustainability of associated water resources, the environment, and the public, and all increasingly impacted by the challenges of climate change. In areas with complex intertied water systems subject to many of the challenges stated above, computerized mathematical tools are needed to provide systematic solutions to address the technical issues of the complex physical/natural system, and to inform planners, managers, and policy makers

Models are important tools to both inform and to provide guidance for:

1. Real time operations: short term forecasting (days); medium term forecasting (weeks), and long-term forecasting (months).

2. Planning: long term horizons (tens of years) for purposes of evaluating resiliency of the system under differing hydrological regimes, or operational response of the system under proposed structural or non-structural alternatives.

Models are not perfect because of incomplete representation of the physical system (theoretical and hydrological), incomplete or unavailability of observations for many of the physical processes modeled, and technological limitations such as computer power availability and/or accessibility. While a perfect model may be elusive, decisions must be made, and therefore models must be developed and used with the goal of increasing reliability in the results and reduce the associated uncertainty.

There are several ways of improving simulation models to assist in the decision making process. The oldest and standard approach is through model calibration, verification, and validation (Hill and Tiederman 2007, Doherty 2016). These methods focus on improving parameters to minimize differences between simulated and observed variables such as streamflow at gaged locations and groundwater levels. Others look into the reliability of model results through sensitivity analyses (Saltelli et. al. 2000, Saltelli et. al. 2004, Saltelli et. al. 2008). More recent techniques rely on uncertainty analyses and using imperfect models by focusing on the objectives for which the models are being used for (Doherty et. al. 2010, Doherty and Welter, 2010, Doherty and Christensen 2011, White et al. 2014, Doherty 2015). This research is concerned with use of models where streamflows are of prime importance as they are not only calibration variables, but also determine allocations, exports, and meeting regulatory requirements. The research will propose and apply a methodology where the hydrology impacting streamflow is improved. The methodology will use a heuristic approach called Artificial Neural Network (ANN).

Artificial Neural Networks (ANN's) "…a form of artificial intelligence modelled after the human brain, are a class of 'data driven' models that 'learn' system behavior of interest from data" (Coppola Jr. et. al. 2014). Unlike analytical or numerical physical based-models, ANN's do not necessarily depend upon the physics of a simplified representation and assumptions of the real world, or the multitude of parameters required. They typically have simple mathematical structures for quick computations. As such ANN's are "black boxes" in a way. Among the disadvantages of using ANN's include:

- No fixed procedure for choosing the best ANN, though there are guidelines.
- If the data upon which the ANN was developed changes significantly, the ANN would require "retraining".

Some texts that describe the basic concepts of ANN in the field for hydrology and water resources in general include (Coppola Jr. et. al. 2014, Tayfur 2012, Abrahart et. al. 2004, Govindraju and Rao 2000, Minns and Hall 2005, Loucks and van Beek 2005, Jain & Singh 2003). Applications of ANN are varied in the different areas of water resources and hydrology, including: hydrology (ASCE 2000a, ASCE 2000b), rainfall-runoff modeling (Anmala et. al. 2000, Elshorbagy et. al. 2000, Anctil et. al. 2003, Rajurkar et. al. 2004, Jain and Srinivasulu 2004, Agarwal and Singh 2004, Chen and Adams 2006, Nilsson et. al., 2006, Aqil et. al. 2007, Nayak et. al. 2007, Parent et. al. 2008, Nourani et. al. 2009, Besaw et. al. 2010 and Zeoual et. al. 2016), hydrological forecasting (Thirumalaiah and Deo 2000), rainfall forecasting (Akrami et. al. 2013, Luk et. al. 2000, Wu et. al. 2010, and Ramirez et. al. 2005), reservoir inflow forecasting (Lohani et. al. 2012, Kumar et. al. 2015), flood forecasting (Latt 2013), river flow forecasting (Kumar et. al. 2004, Taormina et. al. 2015, Huo et. al. 2012, Wang et. al. 2009, and Zailin et. al. 2012), forecasting groundwater levels (Mohanty et. al. 2015), drought forecasting (Rezaeianzadeh et. al. 2016, Barua et. al. 2012, and Djerbouai and Souag-Gamane 2016), estimation of sediment transport (Chen and Chau 2016, Kumar et. al. 2011, and Katibi et. al. 2011), irrigation demand forecasting (Perea et. al. 2015), stream water temperature prediction (Piotrowski et. al. 2015), predicting water consumption (Firat et. al. 2011), reservoir operations (Neelakantan and Pundarikanthan 2000, Cancelliere et. al. 2002, Choong and El-Shafie 2015, Daiane and Karami 2014, Safavi et. al. 2013, Fayaed et. al. 2013, Senthil kumar et. al. 2013, Chaves and Chang, 2008, Deka and Chandramouli 2009, Chavez and Kojiri 2007, Chandramouli and Raman 2001, and Chandramouli and Deka 2005), impacts of climate change on water supplies (Elgaali and Garcia 2007), stream-aquifer modeling (Triana et. al. 2010), management of groundwater resources (Gaur et. al. 2013), conjunctive use of surface water and groundwater (Chen et. al. 2014), infilling missing daily weather records (Coulibaly and Evora 2007), and salinity estimation in estuaries (Sandhu and Finch 1995, and CDWR 2001).

Simulation and optimization techniques have been used extensively in planning, operating and managing water resources. Optimizing reservoir operations (storages, releases, and allocations) for planning studies or real time operations has been around the field of water resources for at least fifty years since the first applications of linear programming back in the 1960s (Labadie 2004). Many techniques have been developed over the years to address linear and non-linear situations including the more recent applications of evolutionary algorithms (Rosenberg and

Madani 2014, Brown et.al. 2015, McMahon 2009, Zagona et. al. 2001, Labadie 2004, Wurbs 2004, Rani 2009, Sechi and Sulis 2009, Haro et al 2012, Shabbir, 2013, and Ahmad et. al. 2014). They have also been applied to groundwater and conjunctive use studies (Safavi 2009, Singh 2013, and Singh 2014), and in hydro-economic modeling (McKinney et. al. 1999, Rosegrant et. al. 2000, Cai et. al. 2003, Pulido-Velazquez et. al. 2008, Brouwer and Hofkes 2008, Harou et. al. 2009).

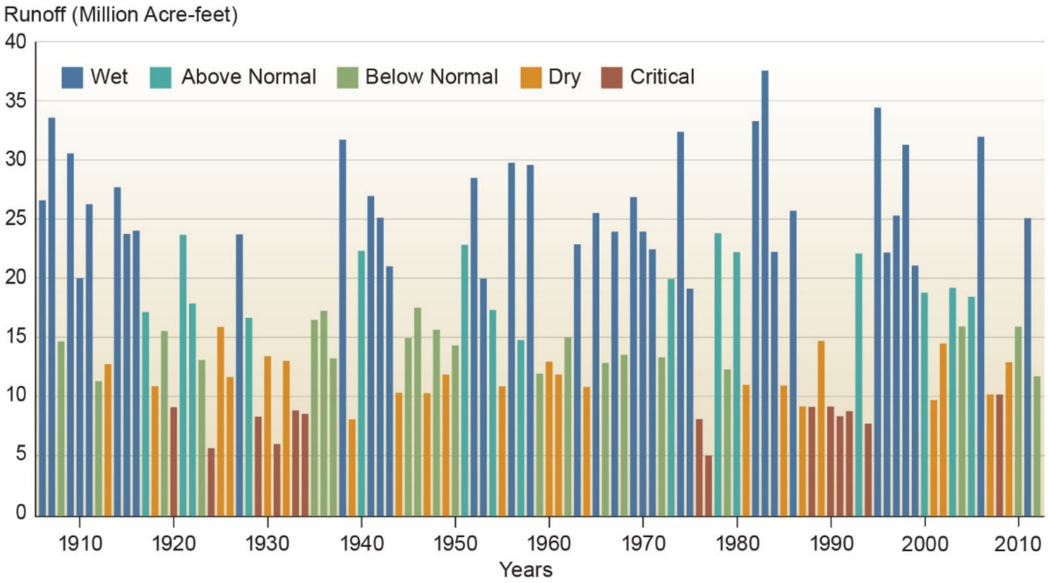
Integrated hydrological models are models that simulate physical processes surface water and groundwater flow and their interactions with each other. Examples include the Integrated Water Flow Model IWFM developed by California Department of Water Resources CDWR and U.S. Geological Survey's MODFLOW model with the Farm Process module (Dogrul et. al. 2006, Dogrul et. al. 2011b, Schmid et. al., 2011). Applications of such models are essential tools in planning and management of regional water management programs (Taghavi et. al. 2013, Dogrul et. al., 2016).

Climate change and global warming present significant challenges to the world today (IPCC 2014, Hay et. al. 2011), including impacts on surface water and groundwater resources (USBR 2016, USDA 2013, Rogers 2008, Earman and Dettinger 2011, Gleeson et. al. 2012, Mays 2013). Stationarity of hydrology, a key assumption in modeling, is questionable (Milly et. al. 2008, Milly et. al. 2015, Salas et. al. 2012, Matalas 2012, Read and Vogel 2015). In California climate change will impact water supply, the ecosystem, water and power operations, increased flooding and droughts, and sea level rise affecting the coastal areas and the Delta (CDWR 2014). The Delta is the hub for water aggregation and exports to meet State water needs, and will its agriculture, fisheries, habitats, ecosystems, and project operations (Lund 2016, Dettinger 2016). Climate change will also significantly impact a key source of water: the upper watersheds (Young et. al. 2009, Bales et. al. 2015, Trujillo and Molotoch 2014, Pupacko 1993). It also threatens the water resources of Central Valley (Brekke et. al. 2004, Yates et. al. 2009, Vicuna 2007, Gleick and Chalecki 1999). CDWR's mission to manage the water resources of California is taking the lead to address climate change in the State (CDWR 2015d, CDWR 2015e, CDWR 2006a). Another significant impact of climate change is on the regulatory process for managing water in California, specifically its impact on defining water year classifications (Null and Viers 2012, Null and Viers 2013, Rheinheimer et. al. 2016).

California is an excellent example where many of the challenges explained above are present. Figure 1-1 shows the major hydrologic regions in California including the Central Valley represented by the Sacramento, San Joaquin, and Tulare river basins. The range of hydrological variations and natural water supply availability is reflected in the runoff of the major streams in the Sacramento and San Joaquin river basins (Figure 1-2a and 1-2b). Over the last century California has developed major agricultural and urban sectors and associated water demands (Figure 1-3). These water demands were possible because of extensive surface water storage and delivery system exemplified by the state operated State Water Project (SWP) and the federally operated Central Valley Project (CV) as shown in Figure 1-4. The massive spatial movement of water between regions throughout the state is shown Figure 1-5a and 1-5b.

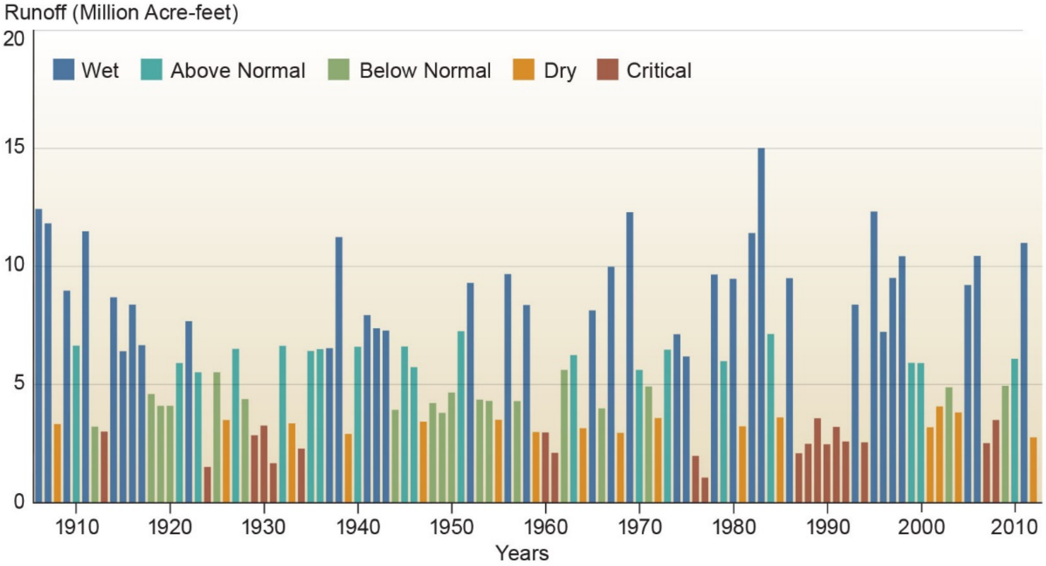
Original map and data points courtesy of University of California, Davis

Figure 1-1: California's Hydrologic Regions Including the Central Valley (CDWR 2014)



The Sacramento Four Rivers are: Sacramento River above Bend Bridge, near Red Bluff; Feather River inflow to Lake Oroville; Yuba River at Smartville; American River inflow to Folsom Lake.

Figure 1-2a: Runoff of the Sacramento Four Rivers (CDWR 2014)



The San Joaquin Four Rivers are: Stanislaus River inflow to New Melones Reservoir, Tuolumne River inflow to New Don Pedro Reservoir, Merced River inflow to New Exchequer Reservoir, San Joaquin River inflow to Millerton Reservoir.

Figure 1-2b: Runoff of the San Joaquin Four Rivers (CDWR 2014)

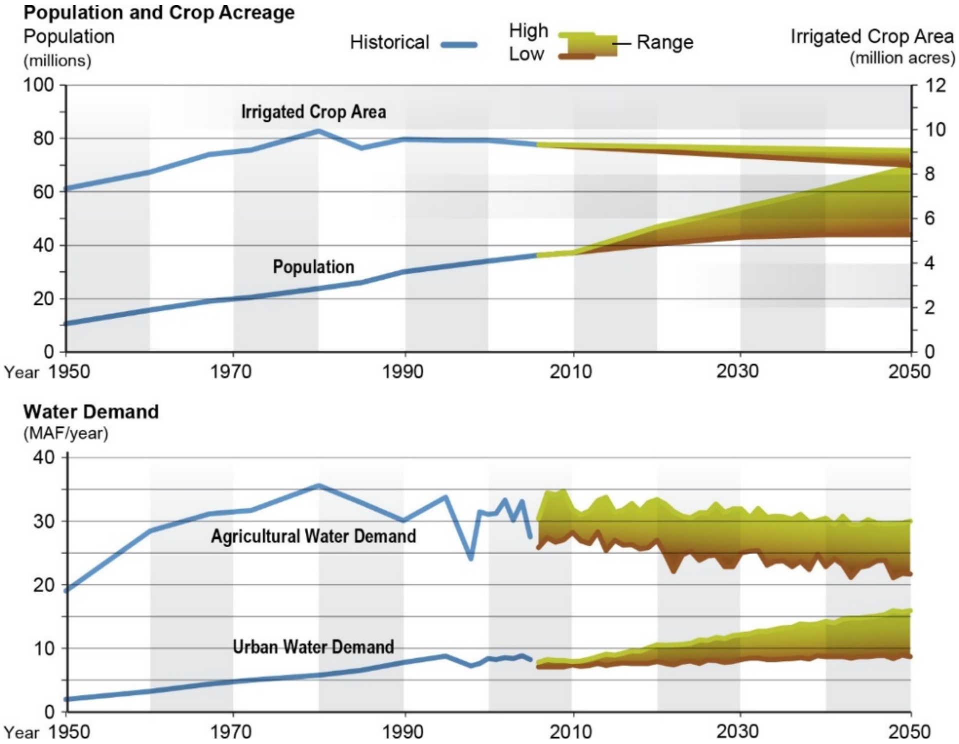


Figure 1-3: California Historical Irrigated Crop Area, Urban Population, and Associated Water Demands (CDWR 2014)

Figure 1-4: California's Major Rivers and Storage/Delivery Facilities (CDWR 2014)

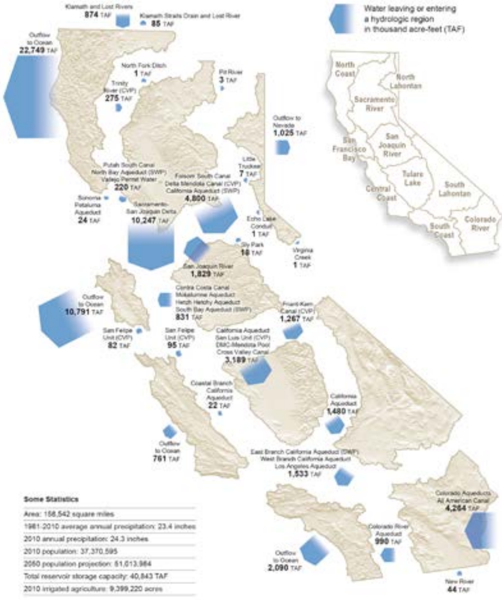


Figure 1-5a: California's Regional Inflows and Outflows for Water Year 2010 (CDWR 2014)

Figure 1-5b: California's Regional Imports and Exports at the 1995 Level of Development (CDWR 1998)

While surface water is the main supply to meet demands, groundwater contributes significantly to meeting the demands especially during dry and critical years (Figure 1-6). However, increased use of groundwater resources without adequate replenishment plans, especially in dry and critical years, has resulted in most of the Central Valley aquifers as being prioritized for modified management practices for long term sustainability (Figure 1-7).

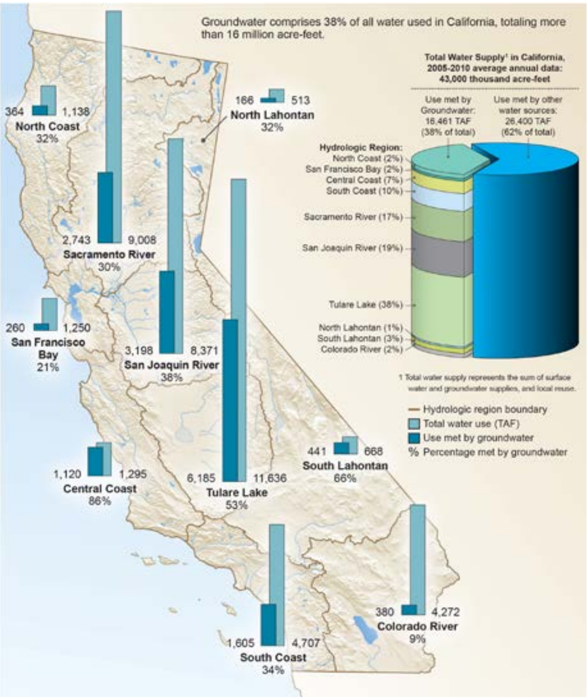
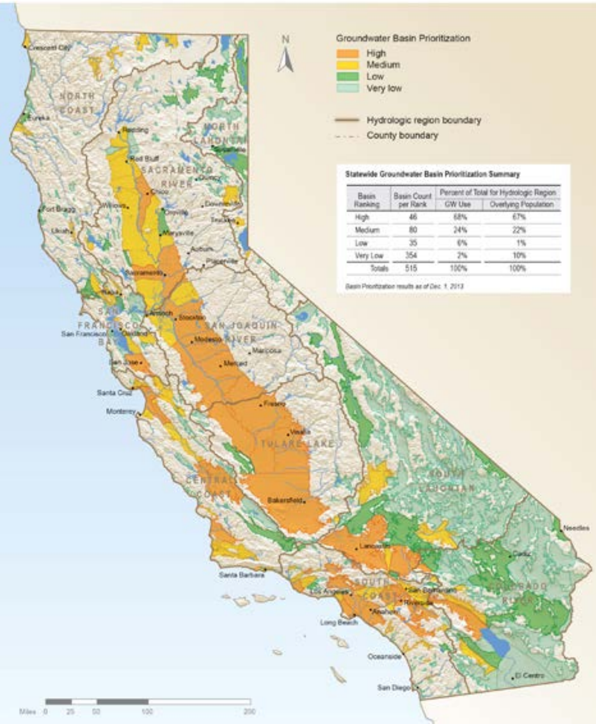


Figure 1-6: Contribution of Groundwater to Meeting California Water Use (CDWR 2014)



Statewide Groundwater Basin Prioritization Summary

Basin Ranking	Basin Count per Rank	Percent of Total for Hydrologic Region	
		GW Use	Overlying Population
High	46	68%	67%
Medium	80	24%	22%
Low	35	6%	1%
Very Low	354	2%	10%
Totals	515	100%	100%

Basin Prioritization results as of Dec. 1, 2013

Figure 1-7: CASGEM Draft Groundwater Basin Prioritization (CDWR 2014)

Three major and related programs are currently underway in California to address California's complicated water issues:

1. California Water Fix (CWF): The CWF is the State's plan to improve and upgrade the outdated water storage and delivery infrastructure in the Sacramento – San Joaquin Delta for securing water supplies to the 25 million people that depend on it, and improving the Delta's ecosystem. The CWF building on previous work by CalFED and BDCP, "…is a science-driven upgrade to our aging water system. It will provide clean, reliable water while protecting our environment…covering five main areas: water security, environmental protection, reduced risk from risk of earthquakes and climate change, system upgrades and new technology, and increased efficiency" (CRA 2017).

2. Sustainable Water Management Act (SGMA): Signed into law in September 2014, SGMA addresses California's groundwater resources, a significant supplement to the surface water supplies. Specifically, it requires local and regional agencies to develop Groundwater Sustainability Areas GSAs in areas overlying pre-identified high and medium priority groundwater basins, and to submit, and thereafter manage, Groundwater Sustainability Plans GSPs to ensure long term sustainability of the resource and limiting and/or mitigating previous negative impacts of chronic lowering of groundwater levels, reduction in groundwater storage, sea water intrusion, degradation of water quality, land subsidence, and surface water depletions (CDWR, 2017a).

3. State Water Resources Control Board (SWRCB) Water Quality Control Plan Hearings: A multi-phase public hearing process by the SWRCB to update and/or set new standards for water quality and flow and environmental protection for areas tributary to the Sacramento – San Joaquin Delta (SWRCB, 2017).

Two types of models used extensively in water resources planning are system or reservoir simulation models of storing, routing, and allocation of water for different uses, and integrated hydrologic simulation models that simulate many of the physical processes to estimate land use based water demands as well as routing surface and groundwater resources to meet those demands. This research unites both types of models along with the driving hydrology to provide guidance and alternatives for planners, policy and decision makers, and stakeholders to better manage the water resources. While the tools linked are generic, they are tested out in a complex real world example in California. The generic models are the Integrated Water Flow Model IWFM and the systems model WRIMS. The applications are the California Central Valley Simulation model C2VSIM (an application of IWFM) linked to a new simplified system model (developed as part of this research) to simulate key reservoirs for water allocation (application of WRIMS). In addition to computing the underlying hydrology dynamically in the linked system, Artificial Neural Network (ANN) techniques are also presented to improve reliability of the hydrological input to the models. The resulting unified approach is then tested out in two real world examples representing a proposed conjunctive use study, and a study to examine the impacts of global warming.

The chapters or this research are organized as follows:

Chapter 1 – Discusses the importance of modeling in complex water resources systems, the need to account for potential climate change, and use of Artificial Neural Networks in solving various hydrology and water resources related problems. The chapter also outlines how this research integrates hydrology, simulation, and system models together for solving complex water resources systems relying on both surface water and groundwater resources.

Chapter 2 – Presents the application of IWFM to California's Central Valley called C2VSIM (California Central Valley Simulation Model) for simulating the historical period WY1922-2003 using monthly time steps, and quantifies the "adjustments" to streamflows at selected locations. These adjustments represent the difference between simulation flows and observed or gaged flows, which when built back in as input in C2VSIM result in matching of simulated and observed flows (by construct). Results are discussed. The main contribution is a C2VSIM historical run (with balanced supplies and demands) with adjusted hydrology that can be used as a standalone model.

Chapter 3 – Presents an approach using Artificial Neural Networks to quantify the adjustments discussed in Chapter 2 as a function of many hydrological and water budget components computed within C2VSIM. The ANN based module is then built back into IWFM so that the adjustments are computed dynamically within C2VSIM. Results are discussed. The main contribution is a methodology of using ANN to quantify streamflow adjustments as a function of multiple hydrological inputs and computed parameters with insight on the relative importance of these parameters.

Chapter 4 – Presents the application of C2VSIM at a projected level of land use development for use in planning studies either as a stand-alone to tool or (next Chapter) linked to a system model. This includes dynamically computing the adjustments using the ANN approach of Chapter 3. Results are discussed.

Chapter 5 – Develops a simplified model of the CVP/SWP operation and allocation system SIM2, and then links it with the projected C2VSIM of Chapter 4 to get the combined CVSIM. A Base Case scenario is developed of the entire Central Valley intertied water resources system for use in planning studies. Results are discussed. The main contribution – the focus of this research – is a new model that integrates hydrology (with dynamic adjustments), simulation and system modeling for use in planning studies.

Chapter 6 – Applies CVSIM to two different studies: a global warming related study and a conjunctive use / water transfer study. Results are discussed. Key insights are drawn from the results quantifying impacts of climate change, and conjunctive use, which would not have been possible without the developed model.

Chapter 7 – Presents conclusions, major insights, and recommendations for future work.

Chapter 2 Development of C2VSIM Historical Run with Pre-Calculated Outflow Adjustments

This chapter begins with a historical background of the generic Integrated Water Flow Model (IWFM) and its application to the California's Central Valley called California Central Valley Simulation Model C2VSIM. A detailed C2VSIM schematic is presented along with the listing of all the code modules of IWFM. The concept of the "closure term" or "adjustment" is introduced to modify historical depletion area stream outflows. Finally the results of the C2VSIM historical run with the adjustments built in are presented and discussed. The focus of this research is on streamflow in C2VSIM because of their importance in meeting demands through surface water diversions and exports and their impact in meeting institutional flow requirements.

The IWFM code and C2VSIM application are both available in the public domain. The author's contributions to both in this research include:

1. Schematics for C2VSIM (Section 2.1) to better visualize the representation of the water system in the sub-regions and their spatial connectivity.

2. Modifications to the IWFM code, both existing code modules and development of new ones, to include the dynamic simulation of the adjustments, and weir flow spills in major streams (next Chapter).

3. Development of input data for C2VSIM to reflect projected levels of development (Chapter 4).

4. Developing a combined IWFM and Systems model that includes dynamic modification of the hydrology (Chapters 4 and 5).

2.1 C2VSIM Schematic and Versions of IWFM Code and C2VSIM Application

In the late 1980's the Bureau of Reclamation (BOR), State Water Resources Control Board (SWRCB), Department of Water Resources (CDWR), and Contra Costa Water District (CCWD) contracted for the development of what is today termed an "integrated hydrological model" called Integrated Groundwater – Surface Water Model IGSM (generic input-data driven), and its application to the Central Valley called Central Valley Groundwater – Surface water Model CVGSM (Montgomery-Watson 1990, Montgomery-Watson 1993). In the 1990's BOR used CVGSM as part of a suite of tools in its program to re-operate the Central Valley Project (CVP) reservoirs to re-allocate 800,000 acre-feet (800 TAF) of water for environmental needs in fulfillment of the Central Valley Project Improvement Act – Programmatic Environmental Impact Statement (CVPIA-PEIS) (USBR 1999). Following a peer review of IGSM by the California Water and Environmental Modeling Forum CWEMF (LaBolle et al. 2002), DWR (circa 2000) began developing its own version of IGSM and CVGSM. After revamping theory and code, DWR released its first versions in 2002, later renamed Integrated Water Flow Model IWFM, and California Central Valley Simulation Model C2VSIM, respectively (CDWR 2015a, CDWR 2015b, Dogrul et al. 2006, Ercan et al. 2016, Brush et al. 2006, CDWR 2010c, CDWR 2013a, CDWR 2013b, CDWR 2013c). DWR has been maintaining and enhancing both IWFM and C2VSIM. Enhancements include a mass-balanced approach for flow across finite-element boundaries (Dogrul and Kadir, 2006), enhanced solver (Dixon et al. 2010, Dixon et al. 2011, Nguyen et al. 2012), improved root zone accounting (Dogrul et al. 2011a), and GIS-based mesh-generator (Heinzer et al., 2012). Both DWR and U.S. Geological Survey (USGS) worked cooperatively to evaluate both IWFM and the USGS's equivalent of MODFLOW with the Farm Process (Dogrul et al. 2011b, Schmid et al. 2011). IWFM was also independently peer reviewed by the California Water and Environmental Modeling Forum CWEMF – along with MODFLOW/Farm Process, and HydroGeosphere (Harter and Morel-Seytoux 2013).

IWFM, at its core, is groundwater flow simulation model with modules to simulate associated hydrological components such as streamflow, runoff, infiltration, deep percolation, stream-aquifer interaction, tile drain flow, and subsidence (Figure 2-1 and 2-2). The extent of the C2VSIM model in the Central Valley and its finite element grid and the major steams simulated (red) appears in Figure 2-3a. The boundaries of the 21 sub-regions (SR) for C2VSIM, the major streams in the Central Valley modeled, the simulated small watersheds, and the hydrologic basins appear in the left-hand side of Figure 2-3b. The right hand of Figure 2-3b show the major hydrologic regions that will be used for reporting results later in this research: SR-1 through SR-7 represent the Sacramento Valley region, SR-8 represents the Eastside Streams region, SR-9 represents the Delta, SR-10 through SR-13 represent the San Joaquin Valley region, and SR-14 through SR-21 represents Tulare Lake region. The Depletion Study Areas developed by both CDWR and BOR with numbered Depletion Areas DA's appear in Figure 2-3c.

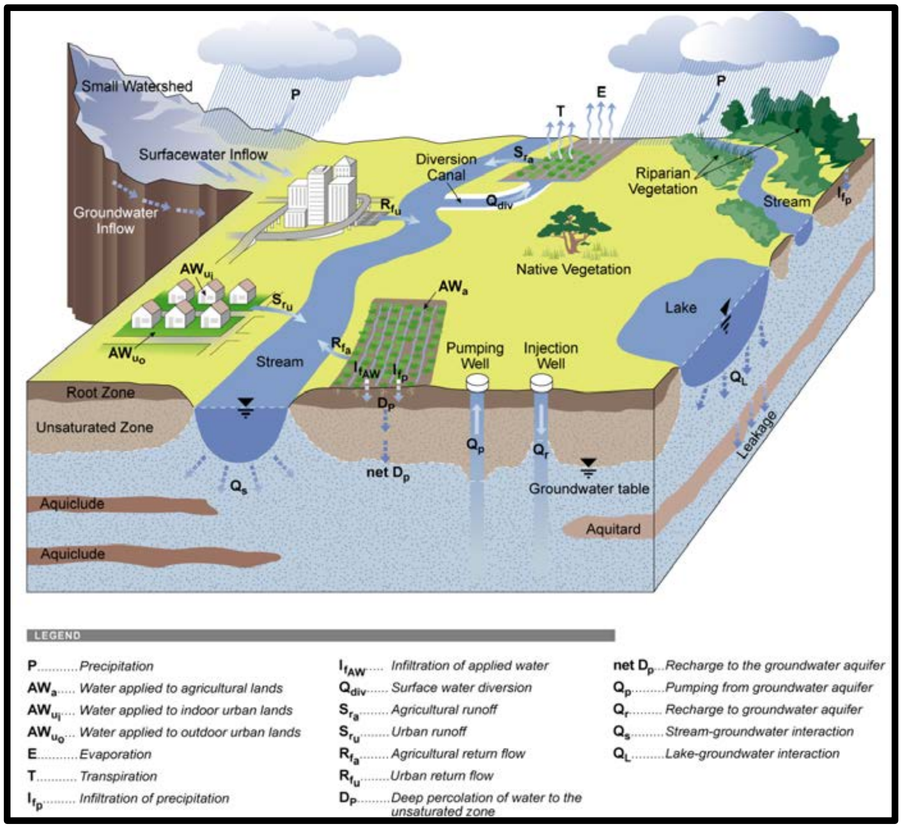


Figure 2-1: IWFM (DWR 2015a)

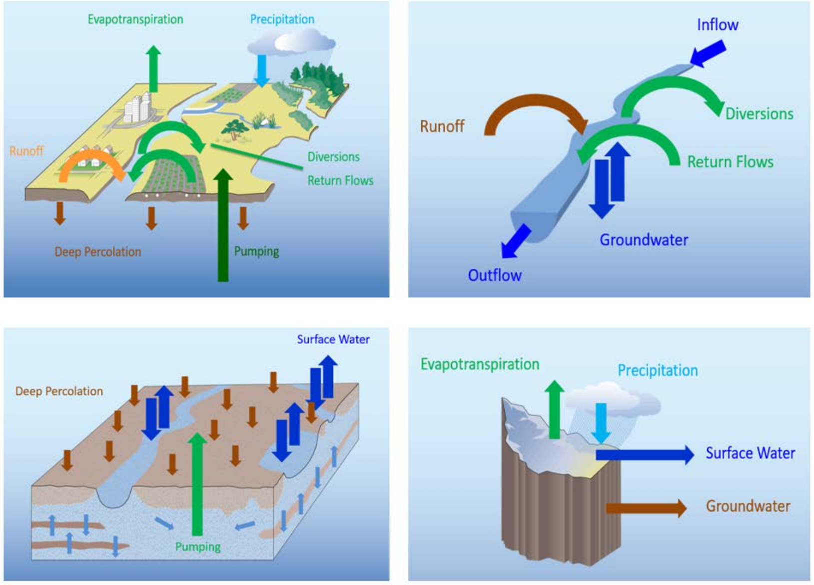


Figure 2-2: Major Hydrological Components Simulated in IWFM (CWEMF 2013)

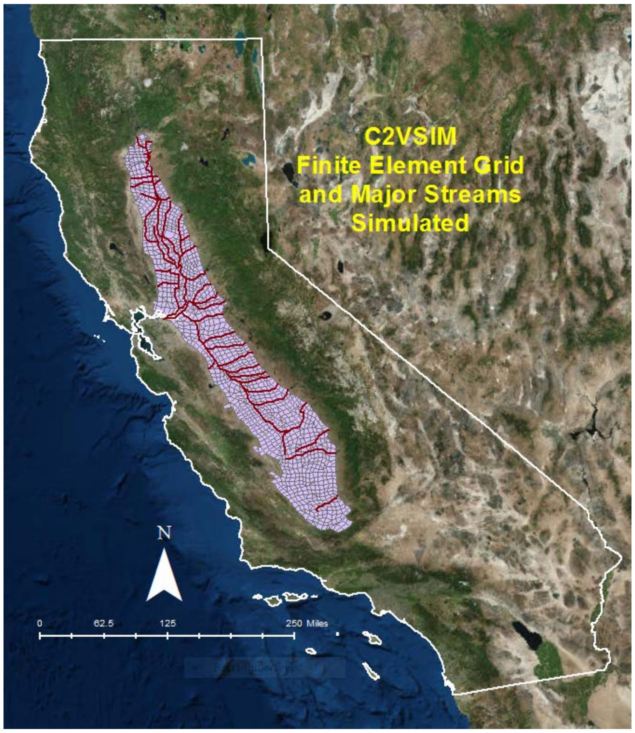


Figure 2-3a: C2VSIM Extent in the Central Valley

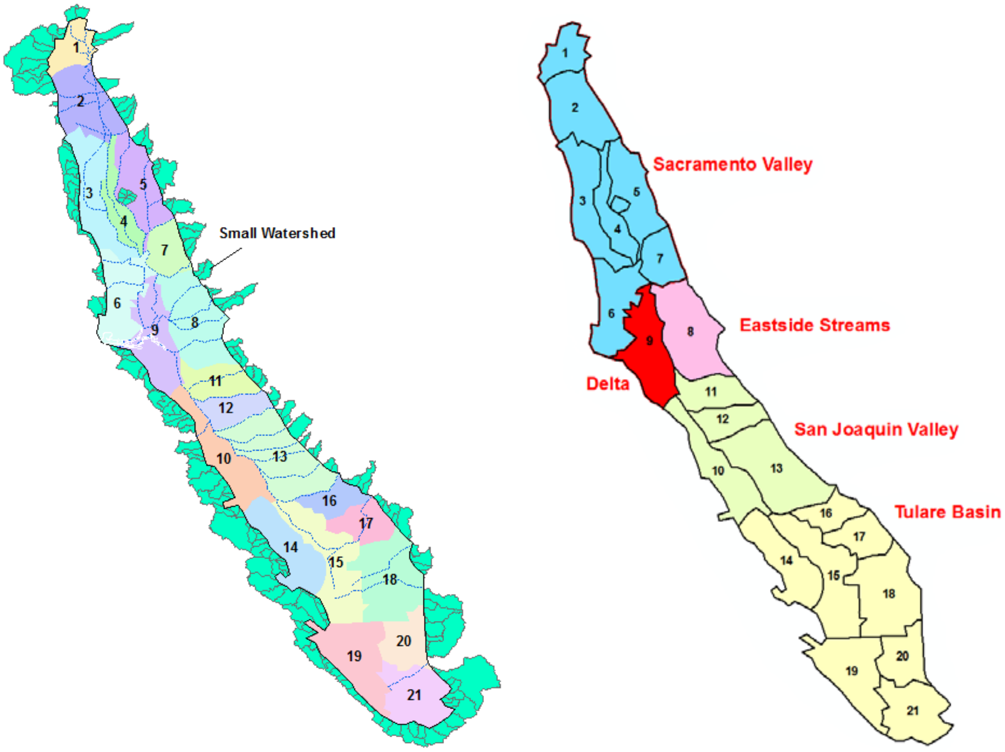


Figure 2-3b: C2VSIM Sub-regions –left- (black numbers), Major Streams, Small Watersheds, and Hydrologic Basins -right (red labels)

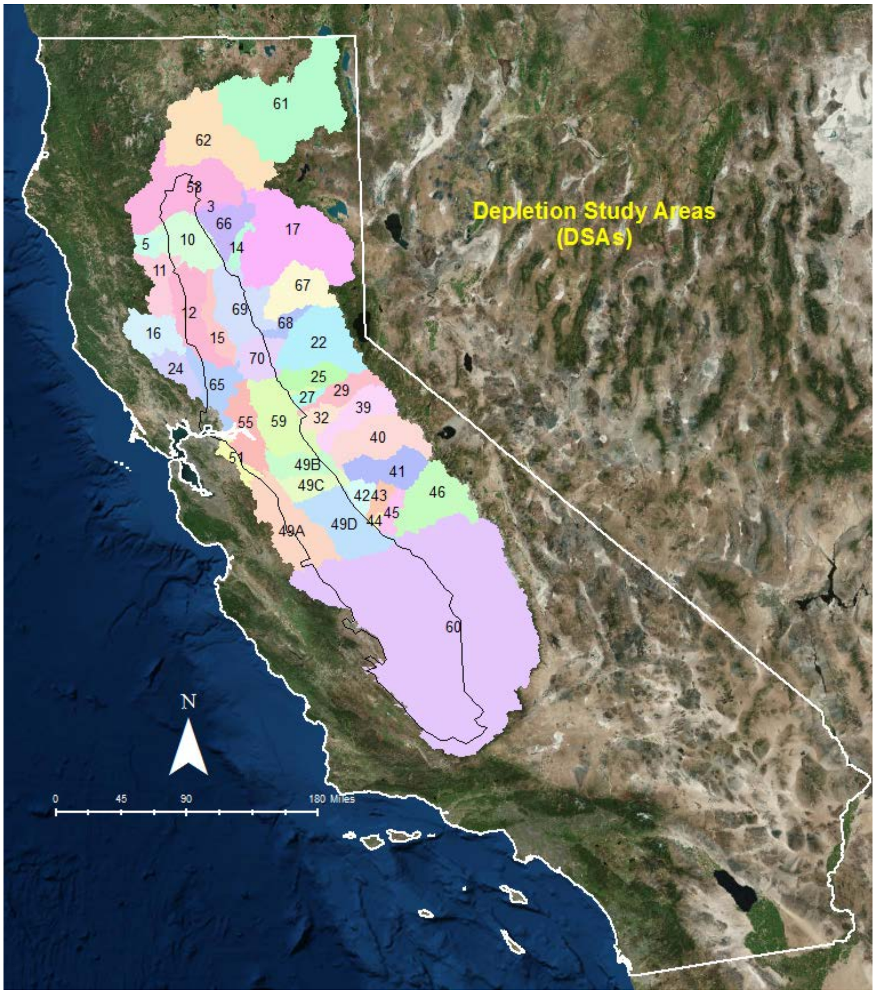


Figure 2-3c: Depletion Study Areas (black numbers) by CDWR

A global schematic of C2VSIM's twenty-one sub-regions appears in Figure 2-4. Each sub-region is identified three ways:

- By Depletion Area (e.g., DA58)
- By C2VSIM sub-region (e.g. SR-1)
- By common basin name used by CDWR (e.g., Sacramento River Above Red Bluff)

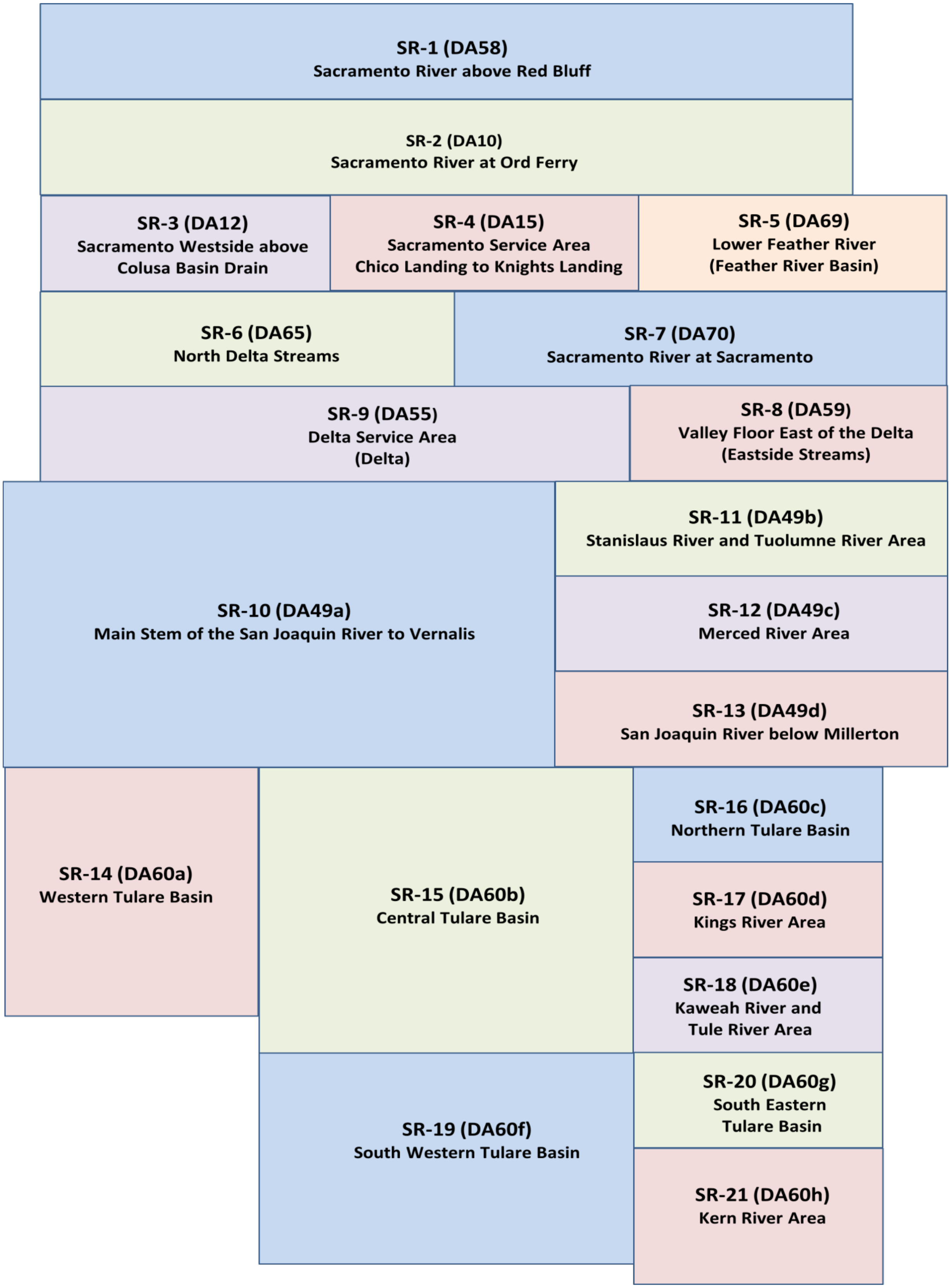


Figure 2-4: C2VSIM Sub-regions

Details of clusters of the C2VSIM sub-regions in Figure 2-4 are shown in Figure 2-5a through Figure 2-5f, with the legend in Figure 2-5g. Figure 2-5a through 2-5f were developed by this author using Microsoft Excel® from interpreting C2VSIM input files CVstrm.dat, CVdivspec.dat, and CVdiversion.dat. In SR-1 (DA58) of Figure 2-5a for example, the major streams simulated in C2VSIM are the Sacramento River (R-32, R-34, R-37, R-38, R-41, R-44, R-46, R-48) and “minor” streams Cow Creek (R-33), Battle Creek (R-36), Cottonwood Creek (R-35), and Payne’s Creek (R-38). Only the stream reaches (numbered) and terminal nodes (numbered) representing the inflow and outflow points of each stream reach are shown.

Some clarification is needed when two or more streams converge. For example, Cow Creek (R-33) flows into the Sacramento River (R-32), with the Sacramento River flowing downstream in R-34. The confluence is at the same point geographically. Similarly, for SR-2 (DA10) in Figure 2-3a, for example, the outflow of SR-10 is represented by nodes N-262, N-268 (Figure 2.5b) and N-272 which flow into N-273 of R-51, the inflow for SR-15 (Figure 2-5c).

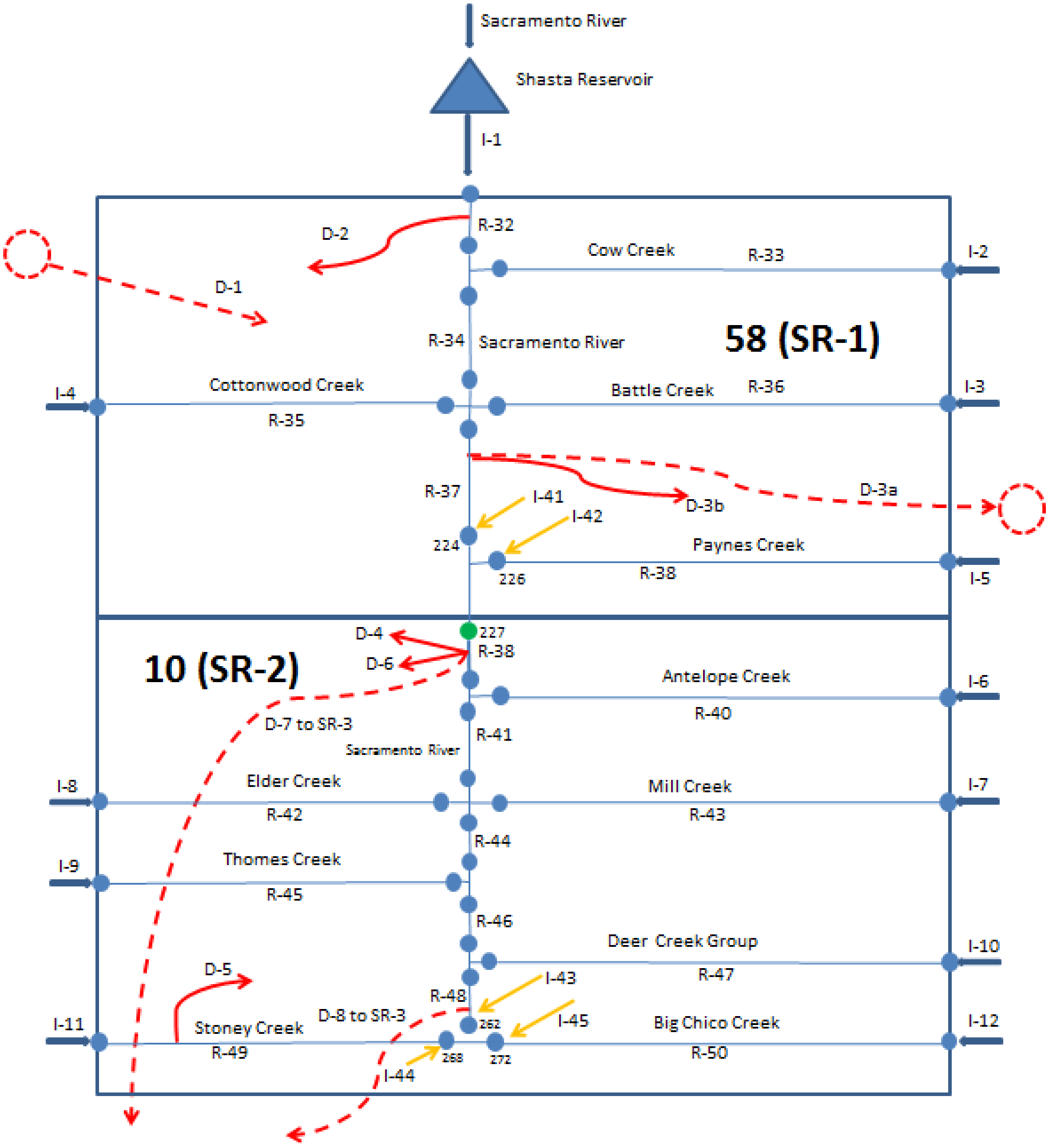


Figure 2-5a: C2VSIM SR-1 (DA58) and SR-2 (DA10)

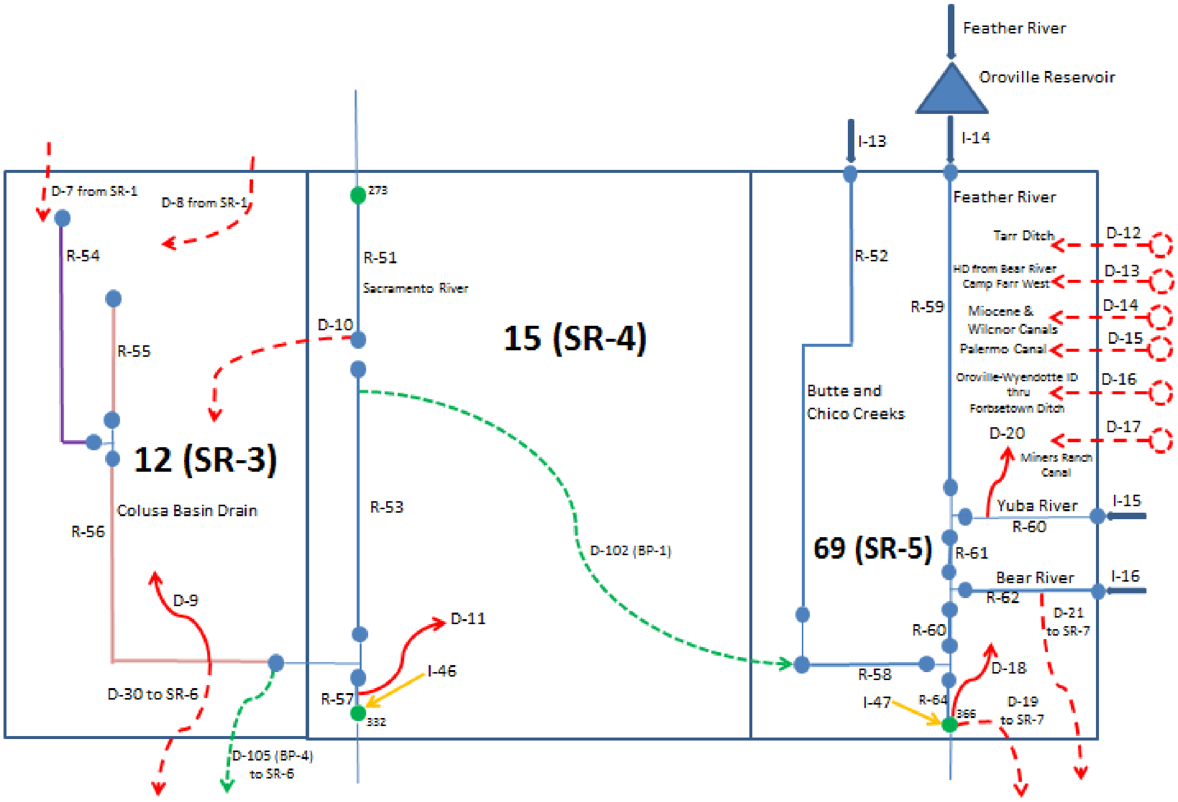


Figure 2-5b: C2VSIM SR-3 (DA12), SR-4 (DA15), and SR-5 (DA69)

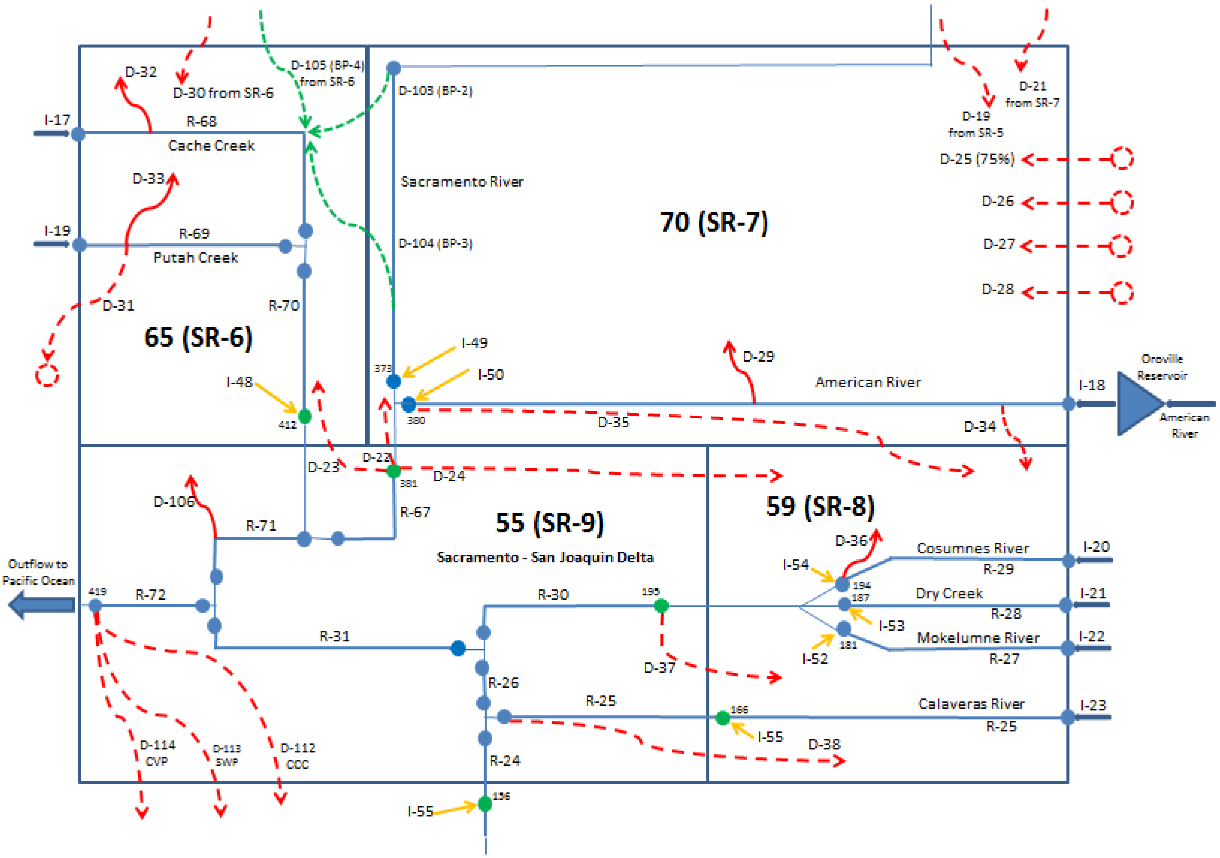


Figure 2-5c: C2VSIM SR-6 (DA65), SR-7 (DA70), SR-8 (DA59), and SR-9 (DA55)

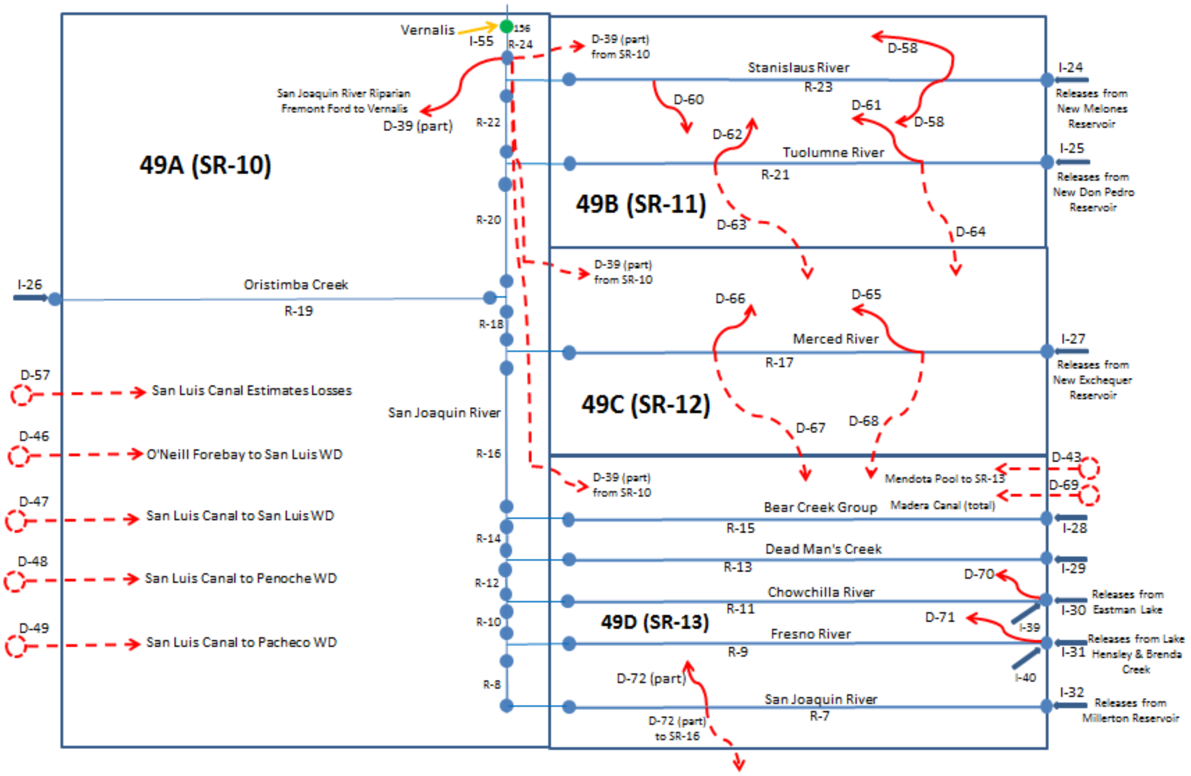


Figure 2-5d: C2VSIM SR-10 (DA49a), SR-11 (DA49b), SR-12 (DA49c), and SR-13 (DA49d)

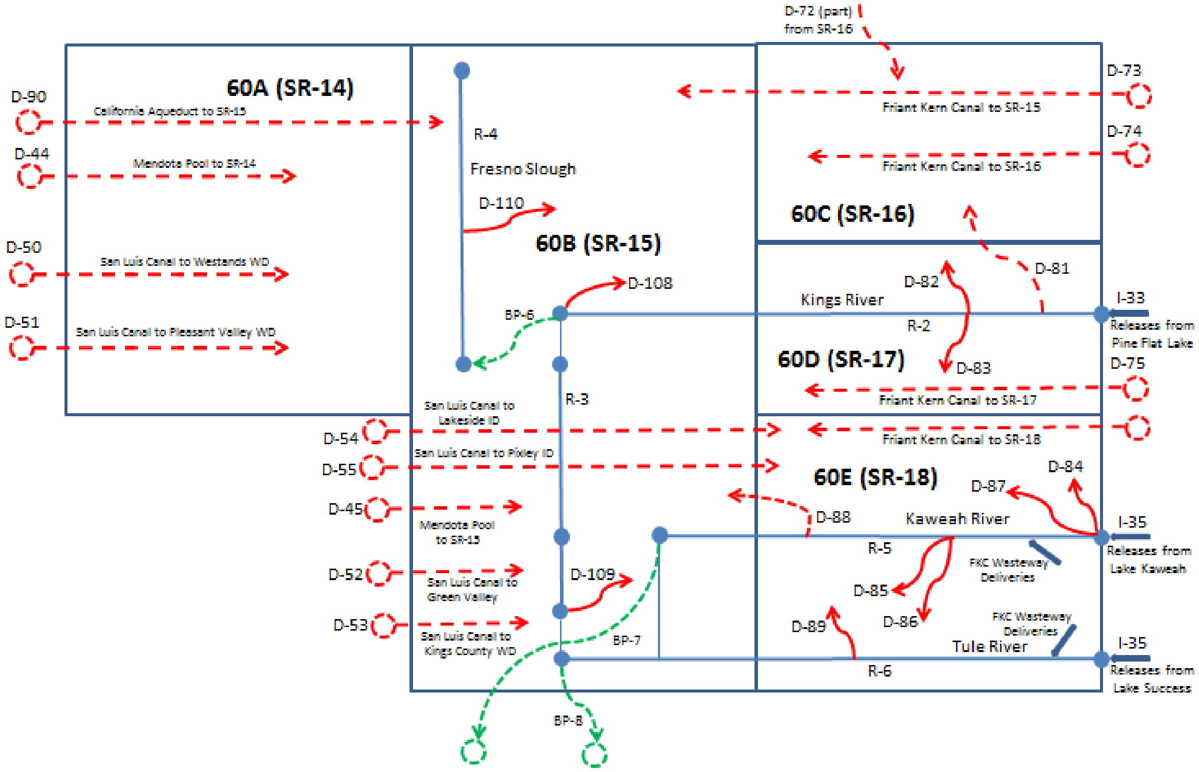


Figure 2-5e: C2VSIM SR-14 (DA60a), SR-15 (DA60b), SR-16 (DA60c), SR-17 (DA60d) and SR-18 (DA60e)

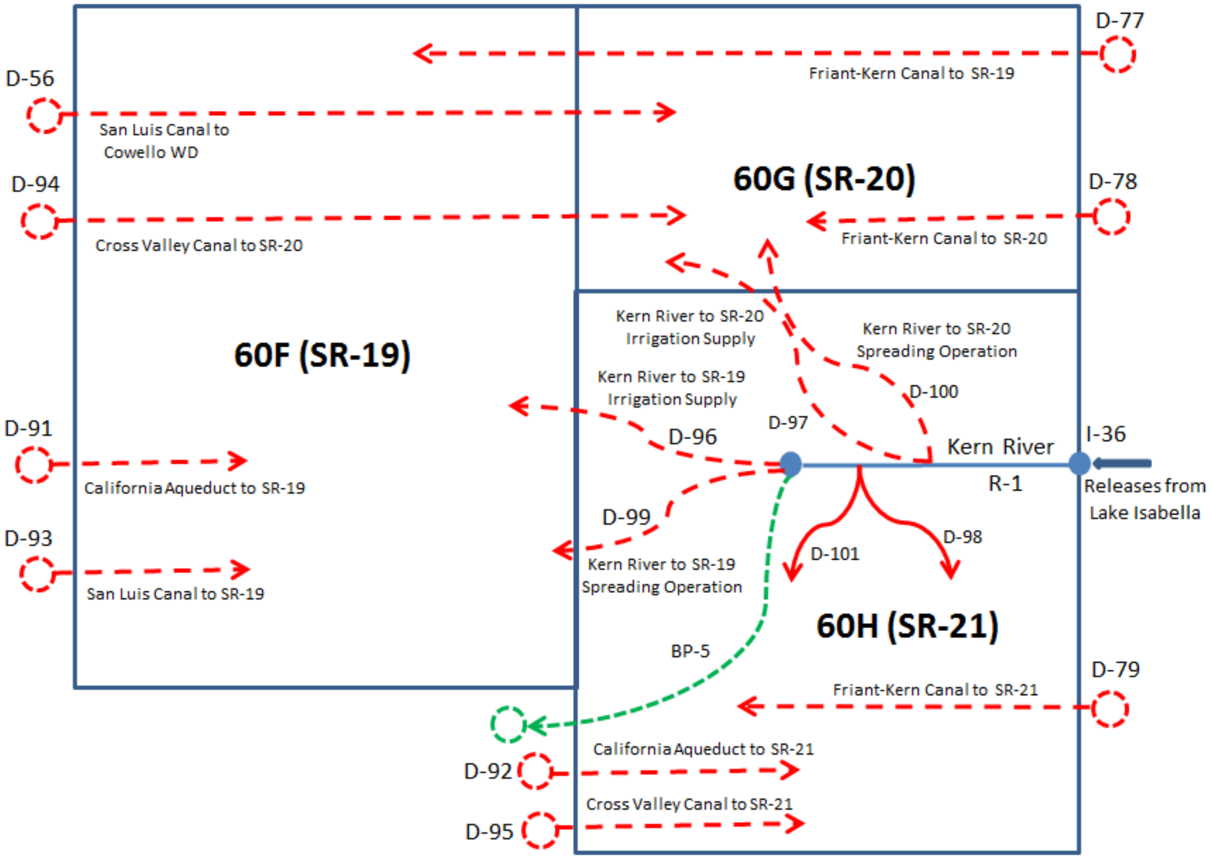


Figure 2-5f: C2VSIM SR-19 (DA60f), SR-20 (DA60g), and SR-21 (DA60h)

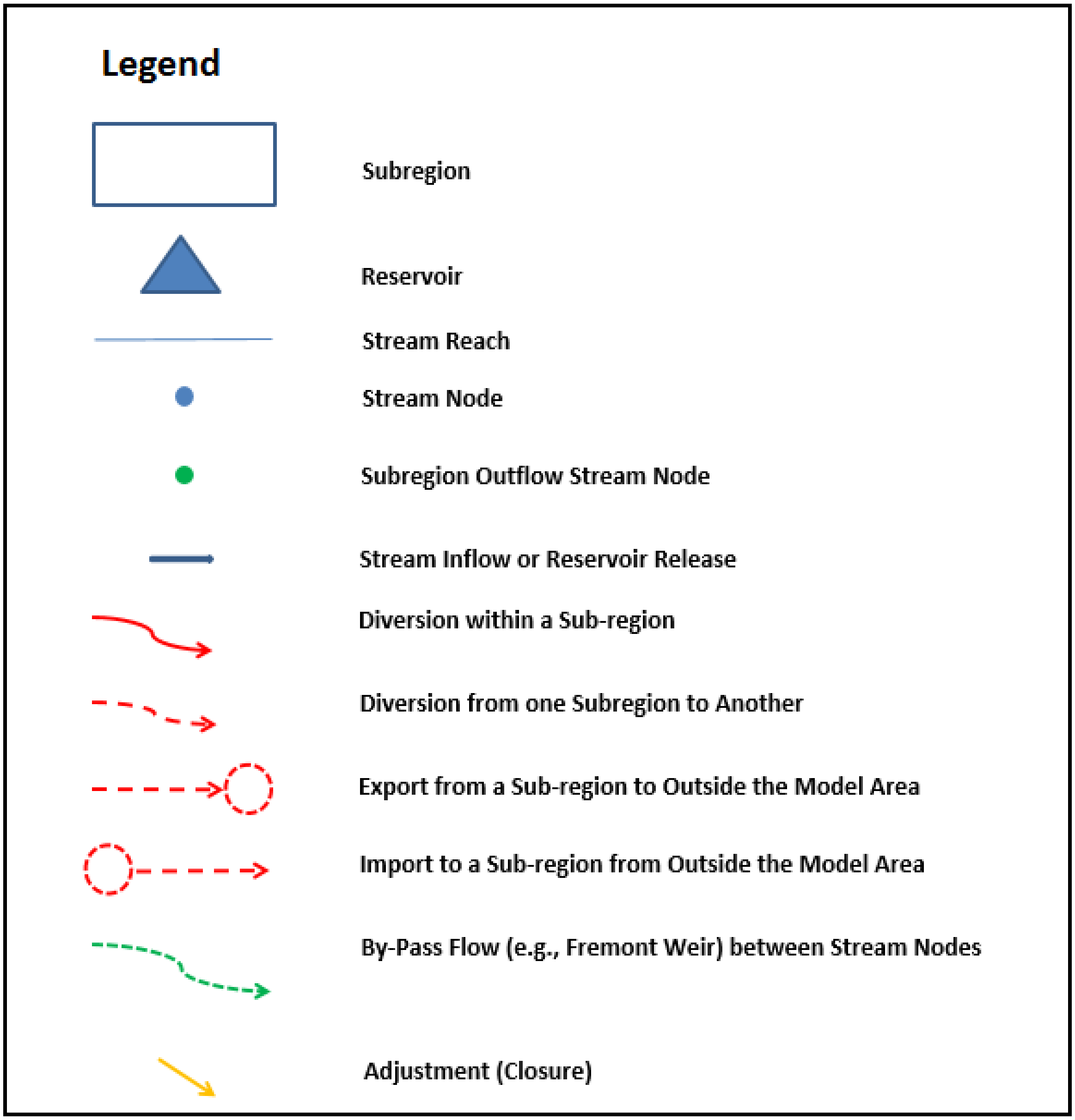


Figure 2-5g: Legend for C2VSIM Schematic

Reservoirs simulated (Chapter 5) are also shown. Only Shasta reservoir (Figure 2-5a), Oroville reservoir (Figure 2-5b), Folsom reservoir (Figure 2-5c), and the State and Federal storages of San Luis reservoir (see Chapter 5) are simulated in this research. There are four main types of inflows in C2VSIM:

1. Reservoir release (e.g., I-1 for Shasta reservoir release in Figure 2-5a)
2. Boundary stream inflows (e.g., I-2 for Cow Creek in Figure 2-5a)
3. Local accretions or known flows (e.g., I-39 and I-40 in Figure 2-5d)
4. Adjustments (e.g., I-43, I-44, I-45 in Figure 2-5a). These are the adjustments to the sub-regional outflows discussed later in this chapter and in Chapter 3.

There are five types of diversions in C2VSIM:

- Local diversions within a sub-region (e.g., D-2 in Figure 2-5a)
- Imports from outside the C2VSIM boundary (e.g., D-1 in Figure 2-5a)
- Exports from a sub-region to areas outside the C2VSIM boundary (e.g., D-3a in Figure 2-5a)
- Diversions from one sub-region to another (e.g., D-7 in Figure 2-5a)
- By-pass flows representing flows from one stream node to another. These are mainly weir spills, for example D-102 (BP-1) in Figure 2-5b

IWFM code v2.4.1 and the input of C2VSIM run R-321 were modified and used in this research. However, all research work is directly transferable to the latest versions of IWFM and C2VSIM. The IWFM code written in FORTRAN95 was compiled using the COMPAC FORTRAN compiler (today maintained by Intel® as Intel® FORTRAN compiler). Running C2VSIM using IWFM is a multi-step process:

1. Run Processor: Processes the geometrical configuration (time-invariant) and creates text output and binary files for input to Simulation.
2. Run Simulation: Processes the time series data and creates binary output for Budget and Z-Budget. This includes numerical solution of the groundwater equations, estimating land use based water demands, estimating runoff, computing stream-aquifer interaction, routing water through the stream network, and balancing supply and demand by adjusting surface water diversions and groundwater pumping.
3. Run Budget: Creates several water budgets by sub-region.
4. Run Z-Budget: Creates groundwater based water budgets for input-selected groups of elements.

A listing of the FORTRAN code files required for compilation for each executable (Processor, Simulation, Budget, and Z-Budget) are listed in Appendix A.

2.2 Develop C2VSIM Historical Run with Adjustments to Surface Water Diversions and Groundwater Pumping and with Delta Exports Built in

C2VSIM historical run simulates the period WY1922-WY2003 using monthly time steps. Agricultural and outdoor urban demands are calculated based on land use acreages and potential crop ET requirements. It is assumed that these demands are fully met (vs. for example actual ET). The demands are met at the regional level from three main sources, in order of priority:

1. Rainfall in that month or previously stored in the root zone.
2. Surface water diversions (including surface water imports).
3. Groundwater pumping

The input surface water diversions are either measured or estimated. There is little published information on groundwater pumping. In balancing supply and demand within C2VSIM there will be months where supplies exceed estimated demands, and other months less. The first step in preparing C2VSIM for this research is to balance the supplies and demands. C2VSIM has the option of adjusting either surface water diversions or groundwater pumping or both. The final results broken into deliveries to agricultural and urban areas are shown in Table 2-1. The final remaining shortages, total of 47 TAF average annual, are results of constraints on the deliveries at the sub-regional level.

C2VSIM v2.4.1 did not include exports from the Delta: State Water Project (SWP) at Banks, Central Valley Project (CV) at Tracy, and Contra Costa Water Canal. As a standalone model, building in the exports has no impact on the simulation since interest was in the Delta inflow. Since Delta exports are required for this research, they were built into this version of C2VSIM at node 419 in SR-9 (Delta) as shown in Figure 2-5c. The data was obtained from DAYFLOW (CDWR 2017c) and is summarized in Table 2-4.

Table 2-1: C2VSIM Historical Adjusted Surface Water Diversions and Groundwater Pumping

Final Diversions and Groundwater Pumping (TAF)									
	Agricultural Area			Urban Area			Agric + Urban Areas		
WY	GW	SW	Shortages	GW	SW	Shortages	GW	SW	Shortages
1922	4702	4248	99	55	228	-102	4757	4476	-2
1923	4000	3926	94	57	208	-83	4057	4134	10
1924	5833	3113	83	87	165	-61	5920	3278	22
1925	3969	3870	127	59	207	-79	4027	4077	49
1926	4801	3680	101	74	193	-72	4876	3872	30
1927	3697	4540	123	58	235	-93	3755	4776	29
1928	4908	3788	139	78	200	-71	4986	3988	68
1929	4684	4186	147	73	221	-80	4757	4408	68
1930	4626	4122	106	79	220	-75	4704	4341	31
1931	5604	3526	113	105	186	-63	5709	3712	50
1932	3680	4774	155	74	253	-92	3754	5027	63
1933	4343	4708	174	80	248	-84	4423	4955	90
1934	5242	3806	71	106	204	-60	5348	4010	12
1935	3285	4132	129	80	224	-63	3366	4356	66
1936	3338	4661	138	84	254	-70	3421	4915	68
1937	3307	4571	103	83	243	-66	3390	4814	37
1938	2962	4299	52	81	234	-52	3044	4533	0
1939	4279	4599	155	103	242	-67	4383	4841	88
1940	3794	4587	71	98	247	-61	3892	4834	10
1941	3280	4530	-9	97	242	-52	3377	4772	-61
1942	3830	5048	81	104	263	-64	3934	5310	17
1943	4295	5307	108	116	270	-61	4410	5577	48
1944	4732	5769	177	134	288	-78	4866	6058	99
1945	4496	6202	210	123	313	-83	4619	6514	127
1946	5355	6225	192	148	316	-78	5502	6540	114
1947	6902	5791	199	178	295	-69	7080	6086	131
1948	7198	5285	173	196	276	-69	7393	5561	104
1949	7367	6020	142	215	306	-84	7582	6326	59
1950	7212	6504	176	199	326	-69	7411	6830	107
1951	7576	6078	67	195	305	-36	7771	6383	31
1952	5598	7249	45	176	366	-76	5774	7615	-31
1953	7703	7332	98	204	358	-68	7907	7690	29
1954	7610	7714	219	205	384	-86	7815	8097	134
1955	8273	7066	117	239	348	-60	8511	7415	56
1956	7484	7866	-18	212	404	-73	7696	8269	-91
1957	8295	7689	133	243	391	-85	8539	8080	49
1958	6035	7213	-21	216	376	-56	6251	7589	-77
1959	10268	7399	176	276	379	-56	10544	7778	121
1960	10627	7220	87	309	365	-54	10936	7584	33
1961	11367	6168	110	360	310	-45	11727	6477	64
1962	8587	8541	158	290	433	-83	8877	8974	75
1963	7756	7888	24	274	417	-73	8030	8305	-49

Table 2-1 (cont.): C2VSIM Historical Adjusted Surface Water Diversions and Groundwater Pumping

Final Diversions and Groundwater Pumping (TAF)									
	Agricultural Area			Urban Area			Agric + Urban Areas		
WY	GW	SW	Shortages	GW	SW	Shortages	GW	SW	Shortages
1964	10678	7694	190	302	413	-47	10980	8107	143
1965	8604	8211	104	261	465	-62	8865	8676	42
1966	10974	7889	99	296	444	-31	11270	8333	68
1967	7729	8409	-116	262	479	-63	7991	8888	-179
1968	10824	8204	164	294	447	-17	11118	8651	147
1969	7730	8044	-135	274	460	-11	8003	8504	-146
1970	9600	8881	131	280	507	-32	9880	9387	99
1971	9817	8453	123	318	482	-30	10135	8935	93
1972	11743	9049	262	351	512	-52	12094	9561	210
1973	7756	8995	-28	312	516	-23	8068	9511	-51
1974	7558	10207	105	314	560	-52	7872	10767	53
1975	8367	10267	165	330	573	-43	8697	10840	122
1976	10766	9358	220	425	513	-37	11191	9871	183
1977	14853	5442	131	613	330	-3	15466	5772	128
1978	6892	8383	-47	418	485	14	7310	8868	-33
1979	7251	11022	175	389	614	-20	7640	11635	155
1980	7649	10039	60	399	573	19	8049	10611	79
1981	8486	10725	217	492	603	-40	8978	11328	176
1982	6207	9912	-32	465	548	11	6672	10460	-21
1983	5724	8216	-231	484	480	81	6209	8696	-150
1984	8068	11393	157	563	646	-11	8631	12040	145
1985	8479	10235	167	634	583	-14	9114	10819	153
1986	6324	9873	-52	597	576	36	6921	10449	-15
1987	8792	9978	159	733	578	-7	9525	10556	152
1988	9400	8442	47	814	509	-1	10214	8951	46
1989	9464	9031	169	831	519	-18	10295	9550	152
1990	11141	7880	147	916	470	-3	12057	8350	144
1991	10906	7001	71	963	435	33	11869	7435	104
1992	10710	6480	17	1002	442	30	11712	6922	47
1993	6910	8883	-302	806	529	72	7716	9412	-230
1994	10616	8444	81	1038	509	27	11653	8954	108
1995	6200	9650	-228	926	570	79	7126	10220	-149
1996	6374	10997	-76	945	654	75	7319	11652	0
1997	7877	10475	-150	1073	633	69	8950	11108	-81
1998	5486	8254	-383	999	511	131	6485	8765	-252
1999	8204	10190	63	1145	597	52	9349	10787	115
2000	7765	10235	131	1152	607	50	8917	10842	181
2001	8428	9166	94	1231	568	54	9659	9733	148
2002	8869	9389	10	1330	581	43	10199	9970	53
2003	8249	9466	-8	1318	584	52	9567	10050	44
Average	7200	7245	79	397	403	-32	7596	7648	47
Avg(-ve)			-115			-56			-90
Avg(+ve)			126			52			86

2.3 Streamflow Adjustment (Closure Term)

There are different types of water budgets that one can develop, depending on boundaries of that budget (i.e, the free-body diagram). For example a water budget of the streams for SR-1 in Figure 2-5a would consider all the stream inflows (I-1, I-2, I-3, etc.), diversions (D-2, D-3a, D-3b, etc.), accretions to the streams such as precipitation runoff and return flow from applied water, and losses/gains from streams due to stream – aquifer interaction, and the outflow of SR-1 at N-227, all part of the standard balance equation of Inflow – Outflow = Change in Storage. (Note- in this example the change in storage is zero if flow is instantaneous over the time step, i.e, no storage in streams). Typically the computed outflow would not be the same as the observed outflow due to many factors, including minor streams that are not accounted for, under or overestimation of stream flows and return flows, etc. The error between computed outflow and the observed outflow is the “adjustment” required to correct the computed outflow to get the observed outflow. This adjustment also applies to simulation models. In other words the simulated outflow does not match the observed historical outflow, even after calibrating the model. From the modeling perspective, if the adjustment term can be quantified in terms of parameters that can be computed dynamically within the model, it would increase reliability of simulated model outflows.

In the late 1950’s DWR and BOR issued a joint report summarizing the Central Valley’s hydrology for use in planning for both the CVP and the upcoming SWP facilities. The Central Valley was subdivided into 23 Depletion Areas or Depletion Study Areas (DAs or DSAs) as shown in Figure 2-3. (Note: the San Joaquin Valley, DA49, was considered one depletion area, as was the Tulare Basin DA60). When DWR began developing tools for operating the SWP and CVP reservoirs for planning studies, it developed a procedure known as the Hydrology Development Process HDP to estimate regional water supplies. The simulation period extended back to WY1922 using monthly time steps. The regional supplies were computed at both the historical level where land use changes annually, and at the projected level where the land use was fixed at given level. For example, the projected level for today would be called 2016 level or “current level” of development. The precipitation trace for both the historical and projected levels would be the same. The HDP uses what DWR termed the “Depletion Analysis Approach”, which can be summarized in three sequential steps:

1. Consumptive Use CU: Estimating demands using the Consumptive Use CU model (CDWR 1979 and WRMI-CDWR 1991). The CU model is a computerized program to estimate land use based consumptive water demand time series by DSA using a root zone approach for budgeting. These demands include agricultural, urban, and native vegetation demands.

2. Depletion Analysis DA: Estimating DSA projected outflows using the Depletion Model DA (CDWR 1977a and WRMI-CDWR 1991). Key output includes the projected outflow time series of each DSA. Depletion refers to water removed from the system (consumed) for budgeting purposes. The depletion model equates the water budget at a historical level

with the water budget at a projected land use level, using the common hydrological parameter, precipitation.

3. Accretions: Aggregating results from steps 1 and 2 to develop local was supplies within each DSA for use as input to the reservoir simulation models (CDWR 1977b and WRMI-CDWR 1991). Accretions refer to the computed terms from Steps 1 and 2 above affecting streams that can be input into the reservoir simulation model.

The approach described above applies to all depletion areas (Figure 2-3c). Further details can also be found in CDWR 1994 and CDWR 1995.

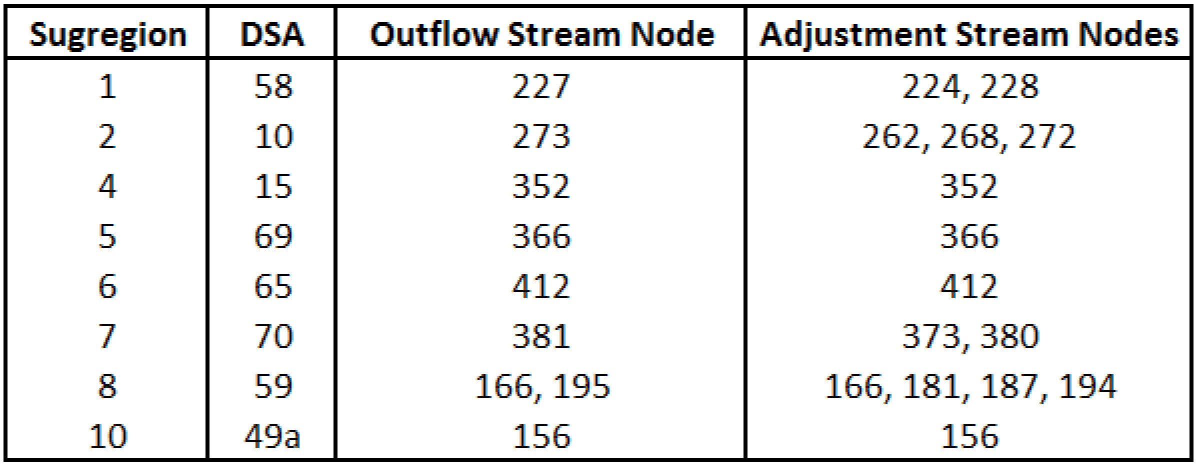
Looking at a typical water budget for an area (e.g., SR-1 in Figure 2-5a), a key feature of the HDP is equating monthly precipitation at both historical and projected levels. One can then develop a water budget of the form:

Precipitation = Known (or estimated) hydrological components + Closure term

The hydrological components in a DSA include inflows, outflows, diversions, return flows, stream-aquifer interaction, precipitation runoff, land use based demands, etc. At the historical level the inflows and outflows are observed (gaged) data (or estimated), and the other terms are derived from the CU and DA models. The closure term to the budget equation also can be computed for the future level of development, and is used as a supply term when developing inputs to the reservoir operation models of the SWP and CVP systems. The closure term ties in simulated flows to historical observed flow for DSA outflows. This research employs this novel idea in C2VSIM (i.e, extending the concept from an accounting approach of a water budget, to one simulated within a model). A note of clarification: When accounting for consumptive water demands in a water budget, one can look at it from the “water supply” point of view, or the “water demand” point of view. The “water supply” point of view implies looking at measured or estimated diversions. The “water demand” point of view implies looking at the land use based estimate (i.e, looking at crop acreages, unit ET’s, etc.), computed through the Consumptive Use model, described earlier. To eliminate biases, CDWR’s Depletion Analysis approach looks at it from the “water demand” viewpoint (i.e, using agricultural and urban historical and projected level acreages and associated crop unit ET’s to estimate demands).

When the original C2VSIM (CVGSM) was developed (Montgomery-Watson 1993) DSA boundaries were adopted for delineating the Sub-regions (Figure 2-3). The outflow locations for each Sub-region are shown in Figures 2-5a through 2-5f, and listed in Table 2-2. When running C2VSIM there will be differences between simulated streamflows and observed gaged flows at the same location. When applied at the C2VSIM Sub-regional level (i.e., at the outflow of each sub-region) the difference between the two is analogous to the closure term adopted by DWR.

Table 2-2: C2VSIM Sub-region Outflow and Adjustment Stream Nodes



Sugregion	DSA	Outflow Stream Node	Adjustment Stream Nodes
1	58	227	224, 228
2	10	273	262, 268, 272
4	15	352	352
5	69	366	366
6	65	412	412
7	70	381	373, 380
8	59	166, 195	166, 181, 187, 194
10	49a	156	156

In C2VSIM it reflects any structural deficiencies in modeling the different hydrological processes (e.g. runoff, stream aquifer interaction) and/or minor streams and accretions that are not known or modelled.

This research adopts the same concept for the closure term described above, and herein referred to as the “Adjustment” term, to represent the difference between simulated (unadjusted) outflow, and gaged (observed) outflow. When built back into C2VSIM as a supply, by construction, the result yields the observed outflow.

Note: Because of the way that sub-regional outflows are reported in C2VSIM, it is necessary to apply this adjustment to the stream nodes upstream of the outflow nodes. These appear in the last column in Table 2-2, and Figure 2-5a through 2-5d.

2.4 Historical (Observed) Sub-regional (DSA) Outflows for Use in C2VSIM

Three sources of data were used in this research to develop the monthly sub-regional (or DSA) observed historical outflows:

1. Historical outflows from DWR’s Hydrology Development Process (CDWR 1995). A historical outflow is typically gaged data. However, if the gage location is further away from the sub-region boundary, estimations are made for the accretions in between the two, to adjust the outflow.

2. Spreadsheets used by CH2M-Hill, Inc. consultants in developing CalSim hydrology as part of the Bay Delta Conservation Plan BDCP (CH2M-Hill 2011). CalSim is reservoir operations models using by CDWR for planning studies of the SWP and CVP systems.

The Bay Delta Conservation Plan (BDCP) is a multi-agency driven process initiated back in the 1990’s as CalFed, and currently as the Water Fix, to address the Sacramento – San Joaquin Delta's ecosystem and water management challenges.

3. DAYFLOW (CDWR 2017c). DAYFLOW is a database maintained by CDWR for historical observed or computed surface water budget components of the Sacramento – San Joaquin Delta.

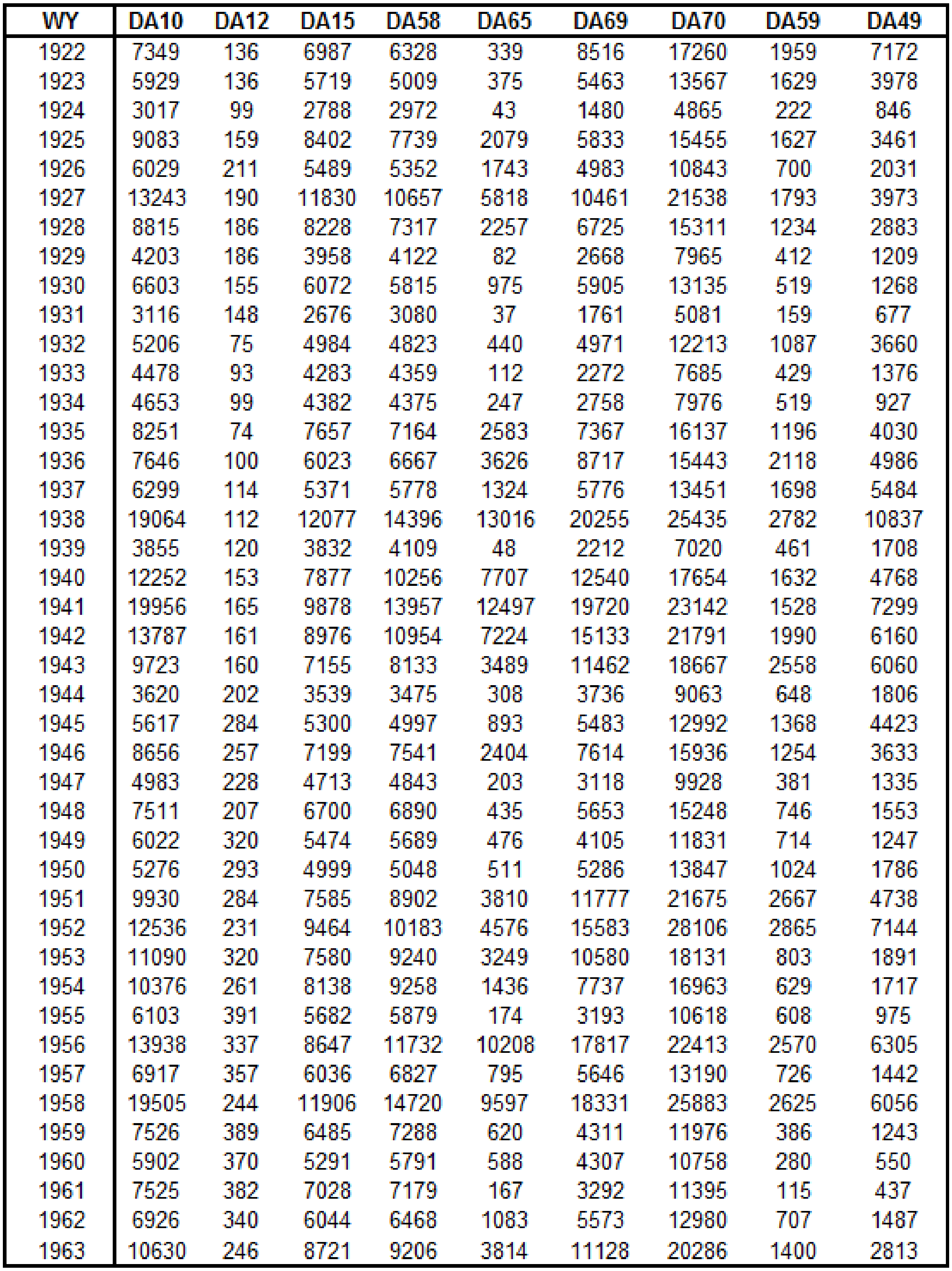
After comparing overlapping periods, and complementing others, the following dataset was assembled:

1. For SR-1 (DSA58), SR-2 (DSA10), SR-4 (DSA15), SR-5 (DSA69), SR-6 (DSA12), and SR-7 (DSA70): Use the values compiled for BDCP.

2. For SR-8 (DSA59) and SR-10 (DSA49a): Use DWR’s HDP values for WY 1922-1980 and use DAYFLOW values for WY 1981-2003.

Annual values are summarized in Table 2-3. The annual values for the SWP and CVP exports (discussed in Chapter 2-2) are summarized in Table 2-4.

Table 2-3: Sub-region (DSA) Historical (Observed) Outflows (TAF)



WY	DA10	DA12	DA15	DA58	DA65	DA69	DA70	DA59	DA49
1922	7349	136	6987	6328	339	8516	17260	1959	7172
1923	5929	136	5719	5009	375	5463	13567	1629	3978
1924	3017	99	2788	2972	43	1480	4865	222	846
1925	9083	159	8402	7739	2079	5833	15455	1627	3461
1926	6029	211	5489	5352	1743	4983	10843	700	2031
1927	13243	190	11830	10657	5818	10461	21538	1793	3973
1928	8815	186	8228	7317	2257	6725	15311	1234	2883
1929	4203	186	3958	4122	82	2668	7965	412	1209
1930	6603	155	6072	5815	975	5905	13135	519	1268
1931	3116	148	2676	3080	37	1761	5081	159	677
1932	5206	75	4984	4823	440	4971	12213	1087	3660
1933	4478	93	4283	4359	112	2272	7685	429	1376
1934	4653	99	4382	4375	247	2758	7976	519	927
1935	8251	74	7657	7164	2583	7367	16137	1196	4030
1936	7646	100	6023	6667	3626	8717	15443	2118	4986
1937	6299	114	5371	5778	1324	5776	13451	1698	5484
1938	19064	112	12077	14396	13016	20255	25435	2782	10837
1939	3855	120	3832	4109	48	2212	7020	461	1708
1940	12252	153	7877	10256	7707	12540	17654	1632	4768
1941	19956	165	9878	13957	12497	19720	23142	1528	7299
1942	13787	161	8976	10954	7224	15133	21791	1990	6160
1943	9723	160	7155	8133	3489	11462	18667	2558	6060
1944	3620	202	3539	3475	308	3736	9063	648	1806
1945	5617	284	5300	4997	893	5483	12992	1368	4423
1946	8656	257	7199	7541	2404	7614	15936	1254	3633
1947	4983	228	4713	4843	203	3118	9928	381	1335
1948	7511	207	6700	6890	435	5653	15248	746	1553
1949	6022	320	5474	5689	476	4105	11831	714	1247
1950	5276	293	4999	5048	511	5286	13847	1024	1786
1951	9930	284	7585	8902	3810	11777	21675	2667	4738
1952	12536	231	9464	10183	4576	15583	28106	2865	7144
1953	11090	320	7580	9240	3249	10580	18131	803	1891
1954	10376	261	8138	9258	1436	7737	16963	629	1717
1955	6103	391	5682	5879	174	3193	10618	608	975
1956	13938	337	8647	11732	10208	17817	22413	2570	6305
1957	6917	357	6036	6827	795	5646	13190	726	1442
1958	19505	244	11906	14720	9597	18331	25883	2625	6056
1959	7526	389	6485	7288	620	4311	11976	386	1243
1960	5902	370	5291	5791	588	4307	10758	280	550
1961	7525	382	7028	7179	167	3292	11395	115	437
1962	6926	340	6044	6468	1083	5573	12980	707	1487
1963	10630	246	8721	9206	3814	11128	20286	1400	2813

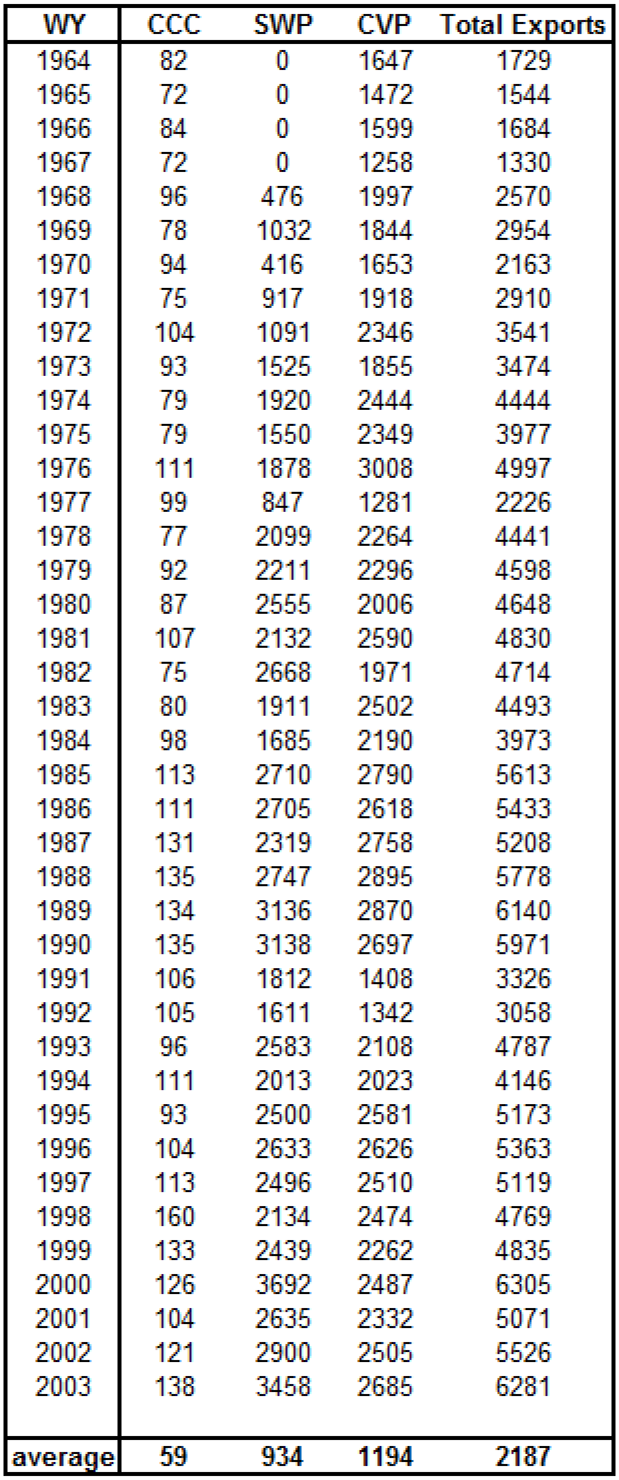
Table 2-3 (cont.): Sub-region (DSA) Historical (Observed) Outflows (TAF)

WY	DA10	DA12	DA15	DA58	DA65	DA69	DA70	DA59	DA49
1964	6686	320	6340	7103	81	3017	11627	325	1125
1965	11393	269	8330	9642	5505	13309	19929	1774	3795
1966	8806	285	8100	8452	393	3891	13383	656	1696
1967	12577	191	10783	11130	3649	11503	24164	1808	5560
1968	8792	302	8142	8778	650	3299	13388	525	1429
1969	14092	192	10475	11691	5763	12975	23212	2502	10073
1970	14150	230	9299	12767	8104	14126	20190	1428	3064
1971	12863	171	10556	11813	1350	9757	22869	953	1775
1972	6923	222	6831	7426	33	3627	12520	392	1114
1973	12087	263	9758	10466	3884	9708	20645	1531	2373
1974	19729	190	12740	17053	7555	19420	30656	1673	2770
1975	11487	277	9444	10117	993	7841	19871	1203	2815
1976	7112	249	6540	7782	15	2837	11022	192	1532
1977	4340	131	3796	5047	2	1320	5508	32	416
1978	11647	292	8475	9091	2918	8707	17637	1175	4480
1979	6665	315	6070	6433	163	4306	12998	1060	2615
1980	11994	366	10281	10028	5847	9348	19292	1990	5993
1981	7190	420	6407	7369	124	3373	11488	287	1765
1982	15267	334	11084	13146	6897	17137	30048	3017	5474
1983	23556	251	14088	18544	13785	24157	33952	4539	15406
1984	12123	438	9379	10971	4306	11677	22518	1809	6324
1985	6852	475	6241	7183	196	3893	12208	467	2125
1986	12012	590	7346	10414	8466	13678	17943	2065	5227
1987	6292	535	5842	6775	44	2679	10044	384	1816
1988	6474	528	5658	6642	130	2685	9712	143	1168
1989	6345	416	5958	6598	52	4539	12303	222	1059
1990	5201	299	4900	5562	15	3102	9883	169	916
1991	4450	223	4344	4725	113	2245	7573	223	657
1992	5067	108	4614	4854	96	2540	8046	262	700
1993	11271	200	10002	8784	1955	6751	19652	1025	1703
1994	5641	188	5356	5826	21	3165	9507	312	1220
1995	17607	197	11504	14663	10718	20087	27749	2226	6306
1996	12020	193	9185	10446	3828	11765	22754	1508	3945
1997	12518	217	8284	11636	8198	15322	21014	2618	6772
1998	19188	200	12217	15681	7505	19553	29015	2096	8456
1999	12111	284	9767	10621	1620	9545	21770	1399	3568
2000	11618	399	8363	10885	2808	9189	18360	1078	2846
2001	6768	572	5913	6882	200	2954	10379	372	1732
2002	7569	417	6796	7649	544	4666	13106	462	1396
2003	10991	285	9158	9861	1066	6920	18304	534	1365
average	**9422**	**256**	**7433**	**8354**	**2817**	**8071**	**16111**	**1185**	**3316**

Table 2-4: Historical SWP and CVP Exports from the Delta (TAF)

WY	CCC	SWP	CVP	Total Exports
1922	0	0	0	0
1923	0	0	0	0
1924	0	0	0	0
1925	0	0	0	0
1926	0	0	0	0
1927	0	0	0	0
1928	0	0	0	0
1929	0	0	0	0
1930	0	0	0	0
1931	0	0	0	0
1932	0	0	0	0
1933	0	0	0	0
1934	0	0	0	0
1935	0	0	0	0
1936	0	0	0	0
1937	0	0	0	0
1938	0	0	0	0
1939	0	0	0	0
1940	0	0	0	0
1941	0	0	0	0
1942	0	0	0	0
1943	0	0	0	0
1944	0	0	0	0
1945	0	0	0	0
1946	0	0	0	0
1947	0	0	0	0
1948	0	0	0	0
1949	0	0	0	0
1950	21	0	0	21
1951	30	0	0	30
1952	29	0	0	29
1953	35	0	0	35
1954	42	0	0	42
1955	48	0	0	48
1956	44	0	726	770
1957	54	0	1181	1235
1958	48	0	663	711
1959	69	0	1341	1409
1960	76	0	1390	1466
1961	78	0	1489	1567
1962	72	0	1357	1428
1963	63	0	1344	1406

Table 2-4 (cont.): Historical SWP and CVP Exports from the Delta (TAF)



WY	CCC	SWP	CVP	Total Exports
1964	82	0	1647	1729
1965	72	0	1472	1544
1966	84	0	1599	1684
1967	72	0	1258	1330
1968	96	476	1997	2570
1969	78	1032	1844	2954
1970	94	416	1653	2163
1971	75	917	1918	2910
1972	104	1091	2346	3541
1973	93	1525	1855	3474
1974	79	1920	2444	4444
1975	79	1550	2349	3977
1976	111	1878	3008	4997
1977	99	847	1281	2226
1978	77	2099	2264	4441
1979	92	2211	2296	4598
1980	87	2555	2006	4648
1981	107	2132	2590	4830
1982	75	2668	1971	4714
1983	80	1911	2502	4493
1984	98	1685	2190	3973
1985	113	2710	2790	5613
1986	111	2705	2618	5433
1987	131	2319	2758	5208
1988	135	2747	2895	5778
1989	134	3136	2870	6140
1990	135	3138	2697	5971
1991	106	1812	1408	3326
1992	105	1611	1342	3058
1993	96	2583	2108	4787
1994	111	2013	2023	4146
1995	93	2500	2581	5173
1996	104	2633	2626	5363
1997	113	2496	2510	5119
1998	160	2134	2474	4769
1999	133	2439	2262	4835
2000	126	3692	2487	6305
2001	104	2635	2332	5071
2002	121	2900	2505	5526
2003	138	3458	2685	6281
average	**59**	**934**	**1194**	**2187**

2.5 Seven Stages to Develop C2VSIM Historical Run with Pre-Specified Adjustments

As discussed previously, the monthly adjustment to the streamflow for a sub-region represents the predetermined amount of water that needs to be input at that stream node so that the simulated flow by C2VSIM will match historical outflow for that sub-region. Since upstream flows always get adjusted moving downstream (by for example stream-aquifer interaction), the process to get the final time series for each adjusted sub-region requires carrying it out in seven stages as follows:

Stage 1: Run the unadjusted C2VSIM historical run. Compute the monthly adjustments time series (WY1922-2003) as the difference between the simulated outflows and the historical outflows for SR-1 (DSA58), SR-8 (DSA59), and SR-10 (DSA49a). Proportion those flows to the upstream nodes, if necessary, as shown in the last column of Table 2-2. (Note: the proportion factors are based on the long-term average flows for those streams).

Stage 2: Build in the adjustment time series from Stage 1 as inflows at the adjustment nodes (or upstream nodes) and re-run C2VSIM. Compute the monthly adjustments time series for SR-2 (DSA10) in addition to those for SR-1 (note: during Stage 2 the “new” adjustment for SR-1 will be very small…a numerical artifact of the simulation process that diminishes to negligible numbers in subsequent stages).

Stage 3: Similar to Stage 2 but now for SR-4 (DSA15) and include any new adjustments for SR-1 and SR-2.

Stage 4: Similar to Stage 3 but now for SR-5 (DSA69) and include any new adjustments for SR-1, SR-2 and SR-4.

Stage 5: Similar to Stage 4 but now for SR-7 (DSA70) and include any new adjustments for SR-1, SR-2, SR-4, and SR-5.

Stage 6: Similar to Stage 5 but now for SR-6 (DSA65) and include any new adjustments for SR-1, SR-2, SR-4, SR-5, and SR-7.

Stage 7: Build in the adjustments for all previous stages. This final C2VSIM run results in simulated outflows that match historical outflows.

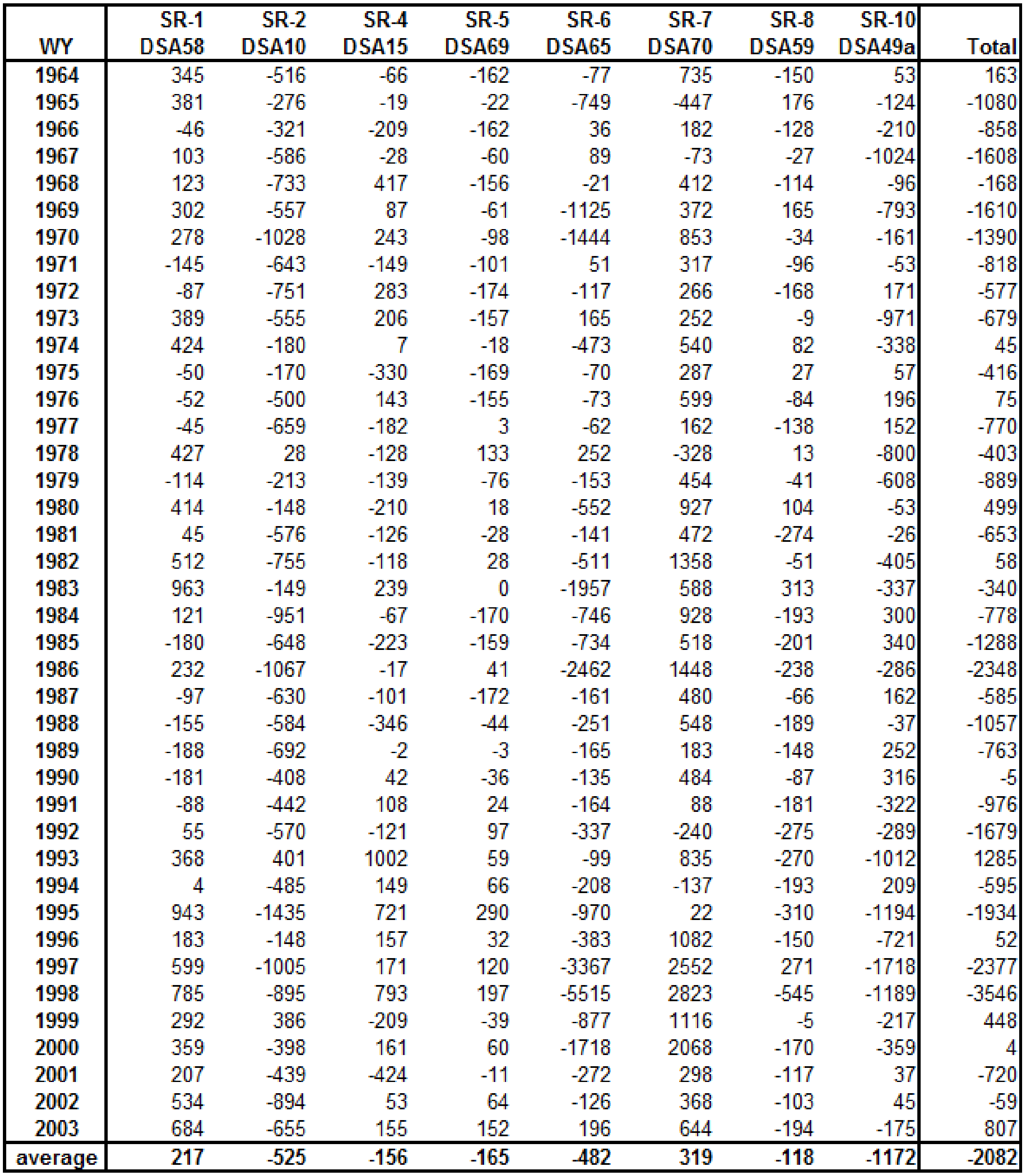
The results of Stage 7 are summarized in Tables 2-5 through 2-12 and Figures 2-6 through 2-15.

Note: In Tables 2-9 through 2-11, the row “Sac Valley (sum)” includes sum for all sub-regions where adjustments are computed (SR-1, SR-2, SR-4, SR-5, SR-6, and SR-7). The row “Sac Valley” represents the sub-regions inflow to the Delta from the Sacramento Valley: SR-6 and SR-7. This also applies to the legends in Figures 2-12 through 2-15.

Table 2-5: Stage-7 Historical Adjustments by Sub-region (TAF)

WY	SR-1 DSA58	SR-2 DSA10	SR-4 DSA15	SR-5 DSA69	SR-6 DSA65	SR-7 DSA70	SR-8 DSA59	SR-10 DSA49a	Total
1922	-1283	-2209	-964	-1551	-1713	-1974	-2229	-7209	-19133
1923	-283	-1562	-592	-712	-774	-657	-1315	-3651	-9547
1924	-358	-1173	-299	-548	-451	-63	-1125	-2486	-6502
1925	306	-1026	-238	-436	-412	-389	-615	-3168	-5979
1926	67	-1107	-503	-449	-324	-107	-663	-2963	-6048
1927	594	-335	-285	-424	-682	81	-356	-3970	-5378
1928	222	-534	-274	-405	-1050	164	-341	-2717	-4935
1929	-109	-803	-523	-357	-255	199	-390	-2221	-4458
1930	94	-827	-520	-337	-159	-23	-330	-2230	-4331
1931	-255	-762	-703	-322	-168	76	-259	-1541	-3933
1932	18	-692	-458	-247	-188	-163	-112	-3425	-5267
1933	-20	-528	-483	-250	-121	-142	-182	-2931	-4657
1934	-32	-881	-559	-224	-55	-252	-152	-1888	-4042
1935	353	-683	-83	-195	-119	378	-29	-3128	-3507
1936	229	-644	-361	-246	-588	354	150	-2737	-3843
1937	163	-812	-370	-279	-194	500	98	-2584	-3479
1938	1019	544	-517	-184	-1559	204	203	-3033	-3323
1939	-145	-802	-312	-352	-135	-11	-60	-2013	-3829
1940	503	-679	-1154	-211	-925	673	-59	-2642	-4492
1941	740	1283	-1205	-206	378	-988	-128	-2580	-2707
1942	709	-297	-539	-353	-243	-953	136	-1938	-3478
1943	322	-521	-48	-358	-485	-1169	386	-2071	-3945
1944	-137	-586	-382	-394	-175	209	-67	-1877	-3410
1945	269	-530	-336	-304	-178	294	154	-2204	-2834
1946	233	-455	-197	-267	-162	230	87	-2045	-2575
1947	-78	-441	-377	-269	-72	810	-22	-1665	-2113
1948	390	-649	-273	-159	-374	1426	59	-1416	-995
1949	73	-737	-198	-214	-22	475	57	-1623	-2190
1950	77	-584	-193	-167	-17	1254	97	-1444	-977
1951	539	-500	-191	-189	-615	1040	380	-1753	-1288
1952	653	-213	-114	-188	-156	769	334	-1911	-826
1953	600	-18	-300	-214	121	-726	-42	-750	-1329
1954	471	-182	-217	-210	37	-62	25	-404	-542
1955	84	-346	-224	-239	-38	335	34	-574	-969
1956	1013	-652	469	-60	-99	-710	248	-1205	-997
1957	104	-517	-108	-178	-4	75	54	-207	-782
1958	1273	1185	-436	-85	-1363	-167	533	-1125	-182
1959	-154	-442	-202	-275	-283	217	-58	-334	-1531
1960	102	-456	-66	-183	-69	426	-67	-209	-521
1961	131	-395	-18	-191	-36	69	-147	-143	-730
1962	221	-381	-161	-141	-61	141	-104	-681	-1168
1963	401	-259	-211	-114	-328	286	-60	-168	-453

Table 2-5 (cont.): Stage-7 Historical Adjustments by Sub-region (TAF)



WY	SR-1 DSA58	SR-2 DSA10	SR-4 DSA15	SR-5 DSA69	SR-6 DSA65	SR-7 DSA70	SR-8 DSA59	SR-10 DSA49a	Total
1964	345	-516	-66	-162	-77	735	-150	53	163
1965	381	-276	-19	-22	-749	-447	176	-124	-1080
1966	-46	-321	-209	-162	36	182	-128	-210	-858
1967	103	-586	-28	-60	89	-73	-27	-1024	-1608
1968	123	-733	417	-156	-21	412	-114	-96	-168
1969	302	-557	87	-61	-1125	372	165	-793	-1610
1970	278	-1028	243	-98	-1444	853	-34	-161	-1390
1971	-145	-643	-149	-101	51	317	-96	-53	-818
1972	-87	-751	283	-174	-117	266	-168	171	-577
1973	389	-555	206	-157	165	252	-9	-971	-679
1974	424	-180	7	-18	-473	540	82	-338	45
1975	-50	-170	-330	-169	-70	287	27	57	-416
1976	-52	-500	143	-155	-73	599	-84	196	75
1977	-45	-659	-182	3	-62	162	-138	152	-770
1978	427	28	-128	133	252	-328	13	-800	-403
1979	-114	-213	-139	-76	-153	454	-41	-608	-889
1980	414	-148	-210	18	-552	927	104	-53	499
1981	45	-576	-126	-28	-141	472	-274	-26	-653
1982	512	-755	-118	28	-511	1358	-51	-405	58
1983	963	-149	239	0	-1957	588	313	-337	-340
1984	121	-951	-67	-170	-746	928	-193	300	-778
1985	-180	-648	-223	-159	-734	518	-201	340	-1288
1986	232	-1067	-17	41	-2462	1448	-238	-286	-2348
1987	-97	-630	-101	-172	-161	480	-66	162	-585
1988	-155	-584	-346	-44	-251	548	-189	-37	-1057
1989	-188	-692	-2	-3	-165	183	-148	252	-763
1990	-181	-408	42	-36	-135	484	-87	316	-5
1991	-88	-442	108	24	-164	88	-181	-322	-976
1992	55	-570	-121	97	-337	-240	-275	-289	-1679
1993	368	401	1002	59	-99	835	-270	-1012	1285
1994	4	-485	149	66	-208	-137	-193	209	-595
1995	943	-1435	721	290	-970	22	-310	-1194	-1934
1996	183	-148	157	32	-383	1082	-150	-721	52
1997	599	-1005	171	120	-3367	2552	271	-1718	-2377
1998	785	-895	793	197	-5515	2823	-545	-1189	-3546
1999	292	386	-209	-39	-877	1116	-5	-217	448
2000	359	-398	161	60	-1718	2068	-170	-359	4
2001	207	-439	-424	-11	-272	298	-117	37	-720
2002	534	-894	53	64	-126	368	-103	45	-59
2003	684	-655	155	152	196	644	-194	-175	807
average	**217**	**-525**	**-156**	**-165**	**-482**	**319**	**-118**	**-1172**	**-2082**

Table 2-6: WY1922-2003 Monthly Average Sub-regional Historical Outflow (TAF)

DSA	Subregion	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
DA58	**SR-1**	364	461	764	1028	1145	990	766	682	587	603	552	410	**8354**
DA10	**SR-2**	351	503	959	1372	1566	1315	916	673	505	473	431	358	**9422**
DA15	**SR-4**	358	465	739	940	1078	1032	761	570	416	365	349	361	**7433**
DA69	**SR-5**	213	350	873	1312	1485	1263	1014	686	340	189	166	180	**8071**
DA65	**SR-6**	12	35	295	678	859	590	295	42	7	1	1	2	**2817**
DA70	**SR-7**	643	864	1466	1987	2222	2267	1933	1612	1027	726	673	692	**16111**
DA59	**SR-8**	24	43	98	174	217	206	163	124	75	27	18	19	**1185**
DA49a	**SR-10**	136	136	219	307	399	450	429	488	401	163	86	102	**3316**
	Cumulative	**2101**	**2857**	**5414**	**7797**	**8970**	**8113**	**6277**	**4877**	**3357**	**2548**	**2277**	**2123**	**56711**

Table 2-7: WY1922-2003 Monthly Average Sub-regional Adjustments (TAF)

DSA	Subregion	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
DA58	**SR-1**	-20	-9	43	66	114	84	37	-10	-21	-24	-23	-20	**217**
DA10	**SR-2**	-77	-75	-36	-12	32	1	-47	-59	-49	-53	-63	-87	**-525**
DA15	**SR-4**	-42	-62	-43	15	26	21	-13	-17	-5	-5	-10	-22	**-156**
DA69	**SR-5**	-27	-8	27	22	10	-13	-4	-30	-47	-35	-29	-31	**-165**
DA65	**SR-6**	-14	-19	-30	-52	-99	-73	-53	-59	-33	-22	-16	-12	**-482**
DA70	**SR-7**	3	-46	-105	-12	43	81	38	47	57	47	83	83	**319**
DA59	**SR-8**	-13	-26	-26	-14	0	0	0	-10	-4	-9	-10	-7	**-118**
DA49a	**SR-10**	-39	-55	-70	-97	-124	-143	-173	-137	-84	-107	-83	-58	**-1172**
	Cumulative	**-230**	**-300**	**-240**	**-84**	**2**	**-43**	**-214**	**-275**	**-186**	**-208**	**-151**	**-154**	-2082

Table 2-8: WY1922-2003 Monthly Average Sub-regional Adjustment as Percent of Historical Outflow (TAF)

DSA	Subregion	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
DA58	**SR-1**	-6	-2	6	6	10	8	5	-1	-4	-4	-4	-5	**3**
DA10	**SR-2**	-22	-15	-4	-1	2	0	-5	-9	-10	-11	-15	-24	**-6**
DA15	**SR-4**	-12	-13	-6	2	2	2	-2	-3	-1	-1	-3	-6	**-2**
DA69	**SR-5**	-13	-2	3	2	1	-1	0	-4	-14	-18	-18	-17	**-2**
DA65	**SR-6**	-117	-53	-10	-8	-12	-12	-18	-138	-455	-1584	-1175	-679	**-17**
DA70	**SR-7**	0	-5	-7	-1	2	4	2	3	6	6	12	12	**2**
DA59	**SR-8**	-54	-61	-26	-8	0	0	0	-8	-6	-33	-55	-36	**-10**
DA49a	**SR-10**	-29	-40	-32	-32	-31	-32	-40	-28	-21	-66	-97	-57	**-35**
	Cumulative	**-11**	**-11**	**-4**	**-1**	**0**	**-1**	**-3**	**-6**	**-6**	**-8**	**-7**	**-7**	**-64**

Table 2-9: WY1922-2003 Monthly Average Regional Historical Outflow (TAF)

Region	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Sac Valley (sum)	1942	2678	5097	7316	8355	7457	5685	4265	2882	2358	2173	2002	**52209**
Eastside	24	43	98	174	217	206	163	124	75	27	18	19	**1185**
SJ Valley	136	136	219	307	399	450	429	488	401	163	86	102	**3316**
Sac Valley	655	899	1761	2665	3080	2856	2228	1654	1034	728	674	694	**18928**
Delta Inflow	815	1078	2078	3146	3696	3512	2820	2266	1509	918	778	815	**23430**

Table 2-10: WY1922-2003 Monthly Average Regional Adjustments (TAF)

Region	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Sac Valley (sum)	-178	-219	-144	27	126	100	-41	-127	-97	-92	-58	-89	**-793**
Eastside	-13	-26	-26	-14	0	0	0	-10	-4	-9	-10	-7	**-118**
SJ Valley	-39	-55	-70	-97	-124	-143	-173	-137	-84	-107	-83	-58	**-1172**
Sac Valley	-12	-65	-135	-64	-56	8	-14	-11	24	25	68	70	**-163**
Delta Inflow	-63	-146	-230	-175	-180	-135	-187	-159	-64	-91	-25	5	**-1453**

Table 2-11: WY1922-2003 Monthly Average Regional Adjustment as Percent of Historical Outflow (TAF)

Region	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Sac Valley (sum)	-9	-8	-3	0	2	1	-1	-3	-3	-4	-3	-4	**-2**
Eastside	-54	-61	-26	-8	0	0	0	-8	-6	-33	-55	-36	**-10**
SJ Valley	-29	-40	-32	-32	-31	-32	-40	-28	-21	-66	-97	-57	**-35**
Sac Valley	-2	-7	-8	-2	-2	0	-1	-1	2	3	10	10	**-1**
Delta Inflow	-8	-14	-11	-6	-5	-4	-7	-7	-4	-10	-3	1	**-6**

Table 2-12: WY1922-2003 Average Annual Historical Flows and Regional Adjustments by Water Year Type (TAF)

WY Type	HQ	Adjustment	%
W	89265	-1548	-1.7
AN	62177	-2472	-4.0
BN	44639	-2353	-5.3
D	35000	-1960	-5.6
C	31945	-2263	-7.1

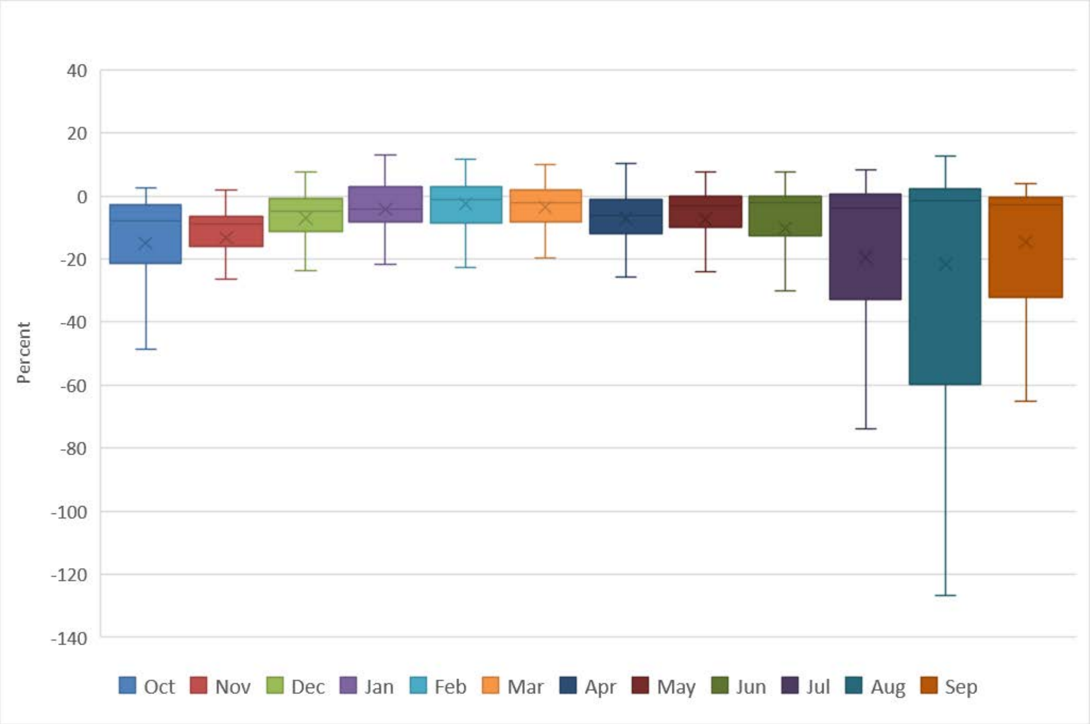


Figure 2-6: WY1922-2003 Monthly Average Cumulative Sub-regional Adjustment as Percent of Historical Outflow

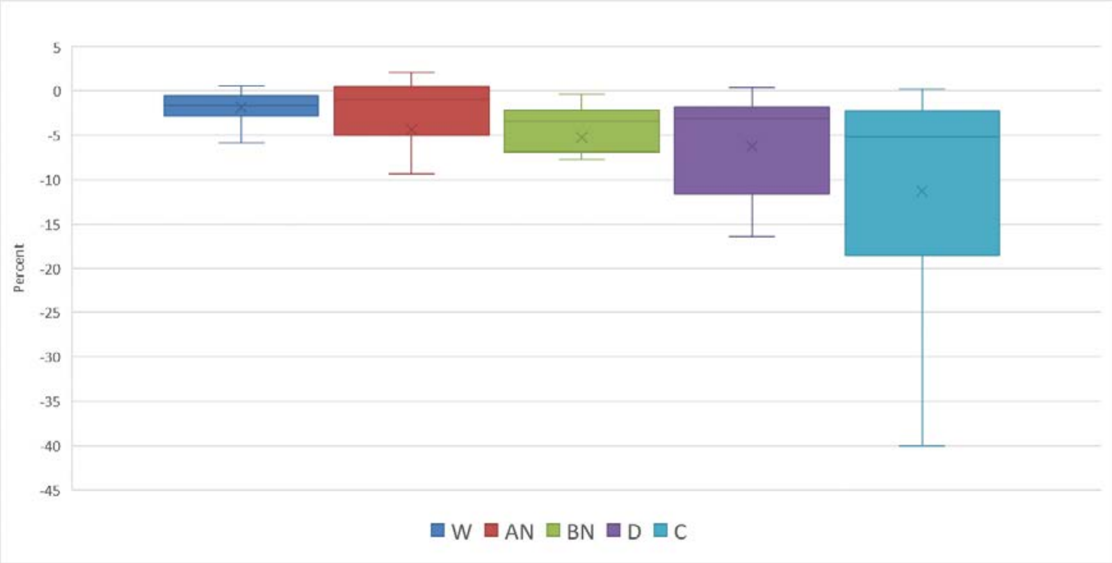


Figure 2-7: WY1922-2003 Cumulative Average Annual Adjustment as Percent of Historical Outflow by Water Year Type

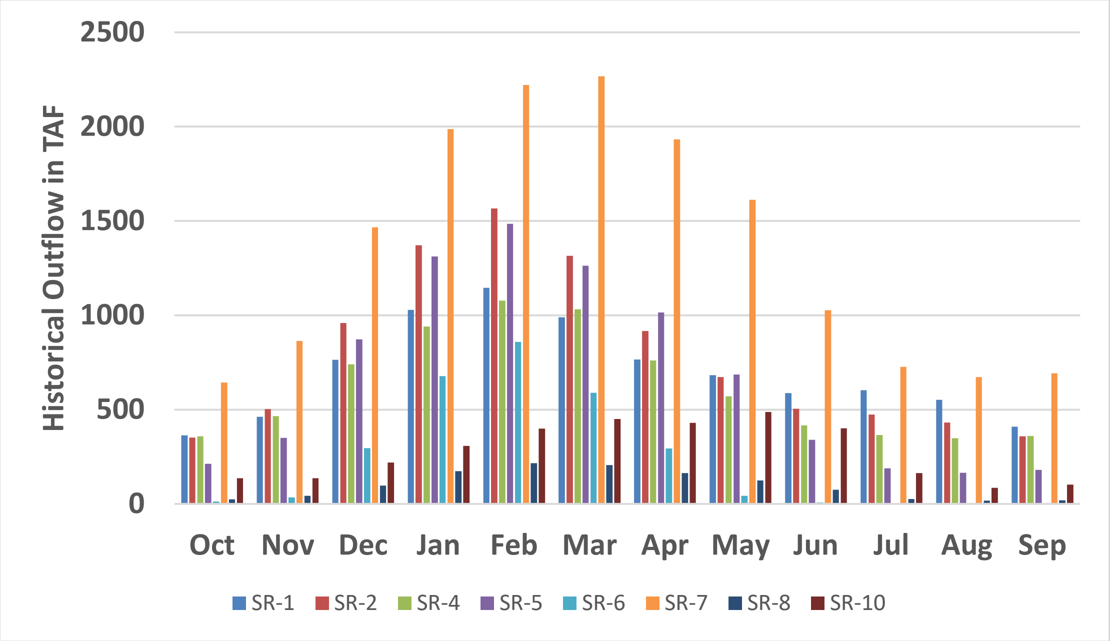


Figure 2-8: WY1922-2003 Monthly Average Sub-regional Historical Outflow

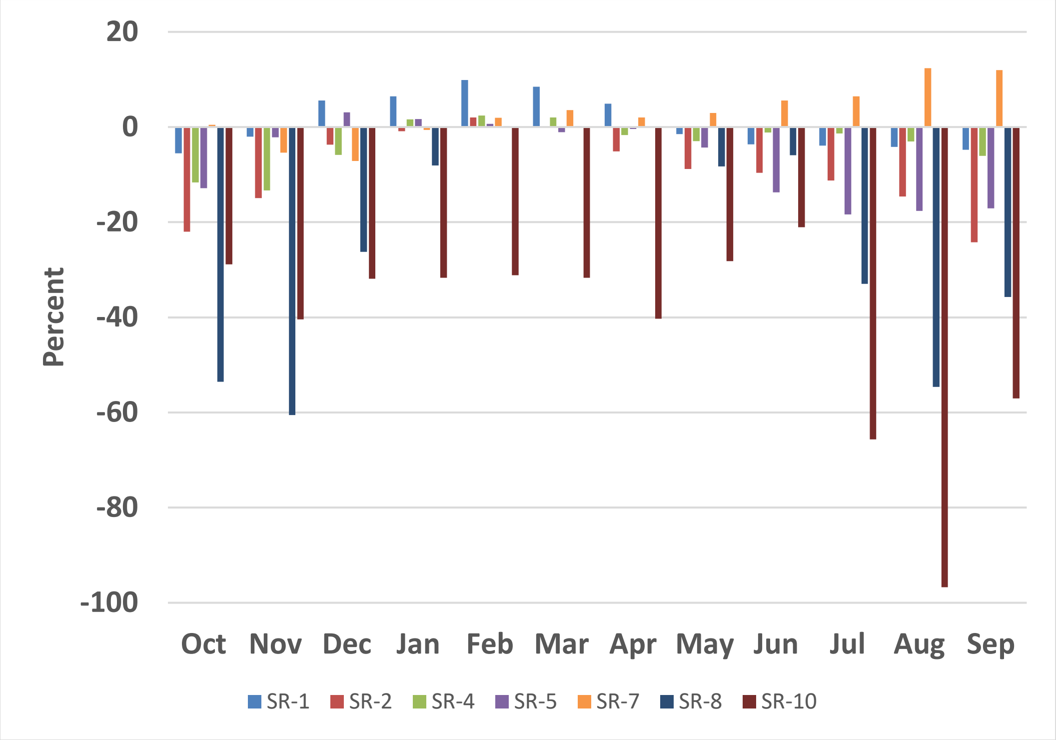


Figure 2-9: WY1922-2003 Monthly Average Sub-regional Outflow Adjustments

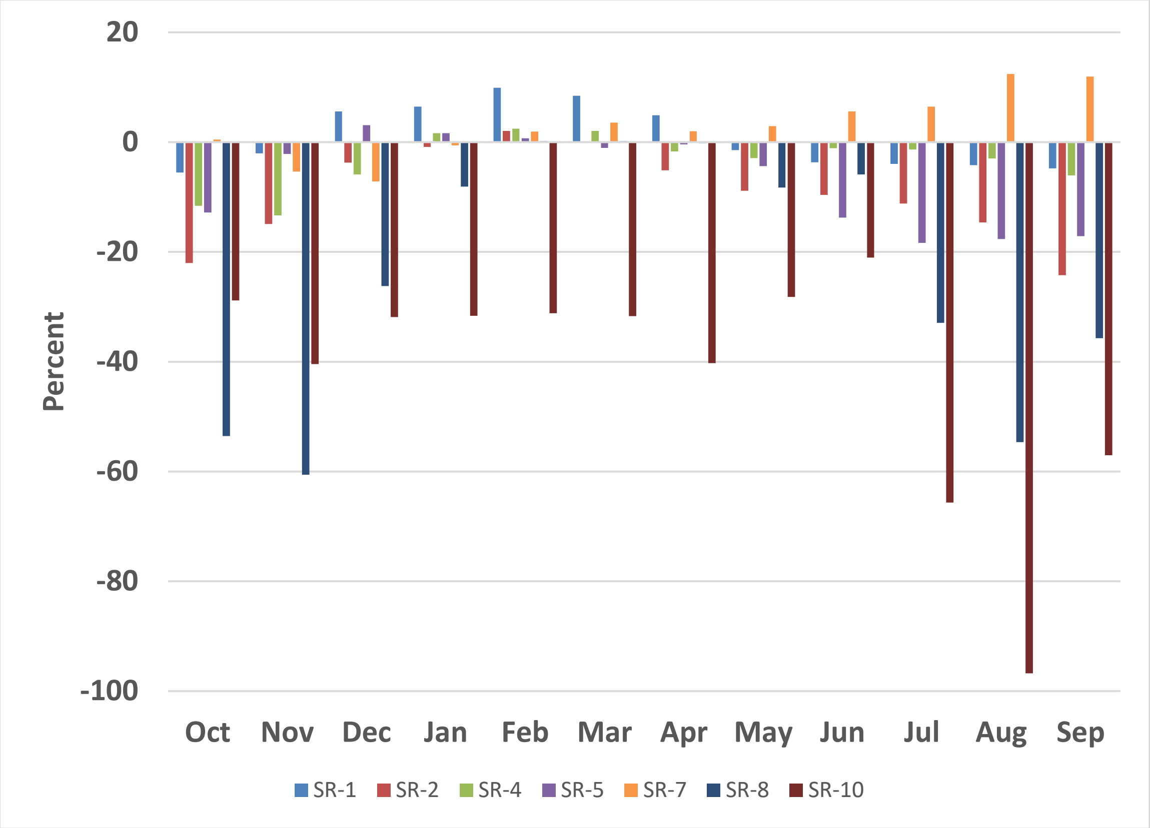


Figure 2-10: WY1922-2003 Monthly Average Sub-regional Adjustment as Percent of Historical Outflow

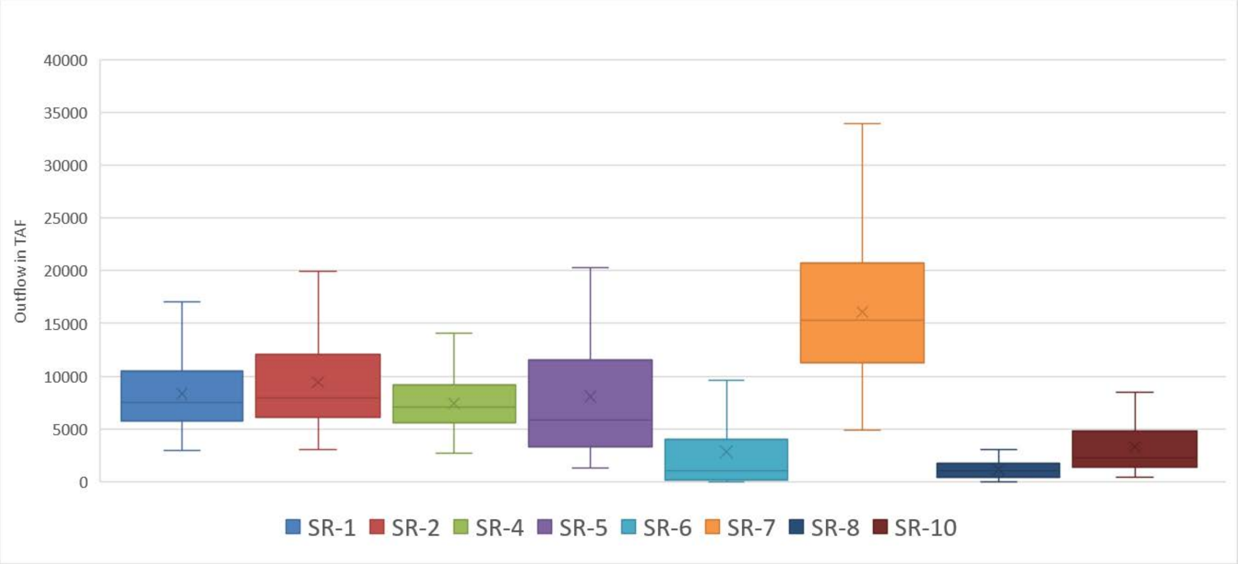


Figure 2-11: Average Annual WY1922-2003 Historical Outflows by Sub-region

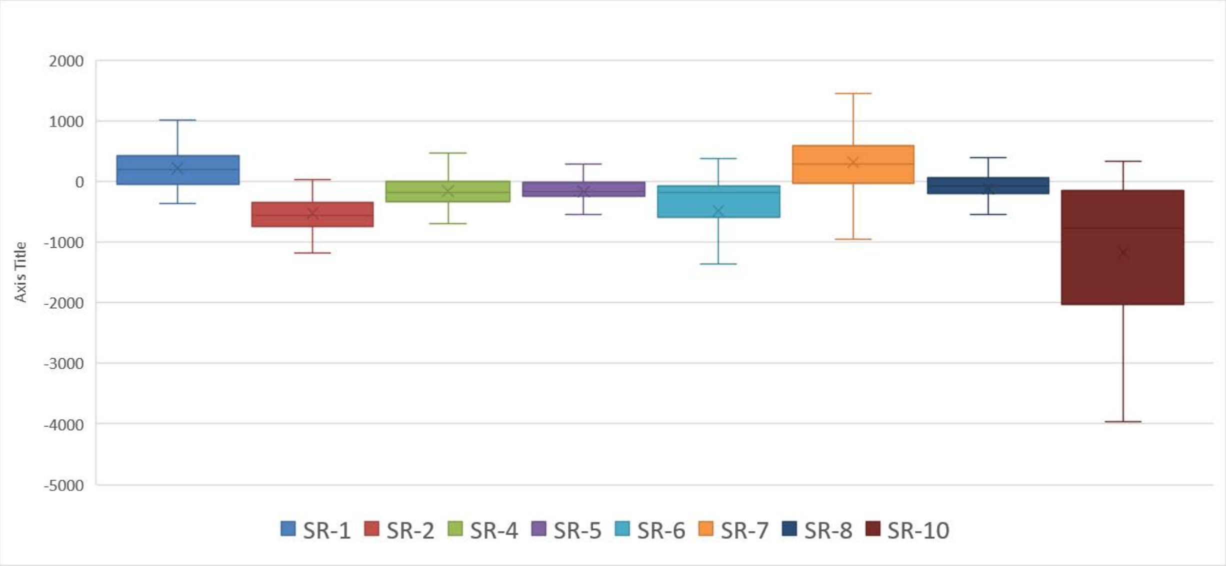


Figure 2-12: Average Annual WY1922-2003 Historical Adjustments by Sub-region

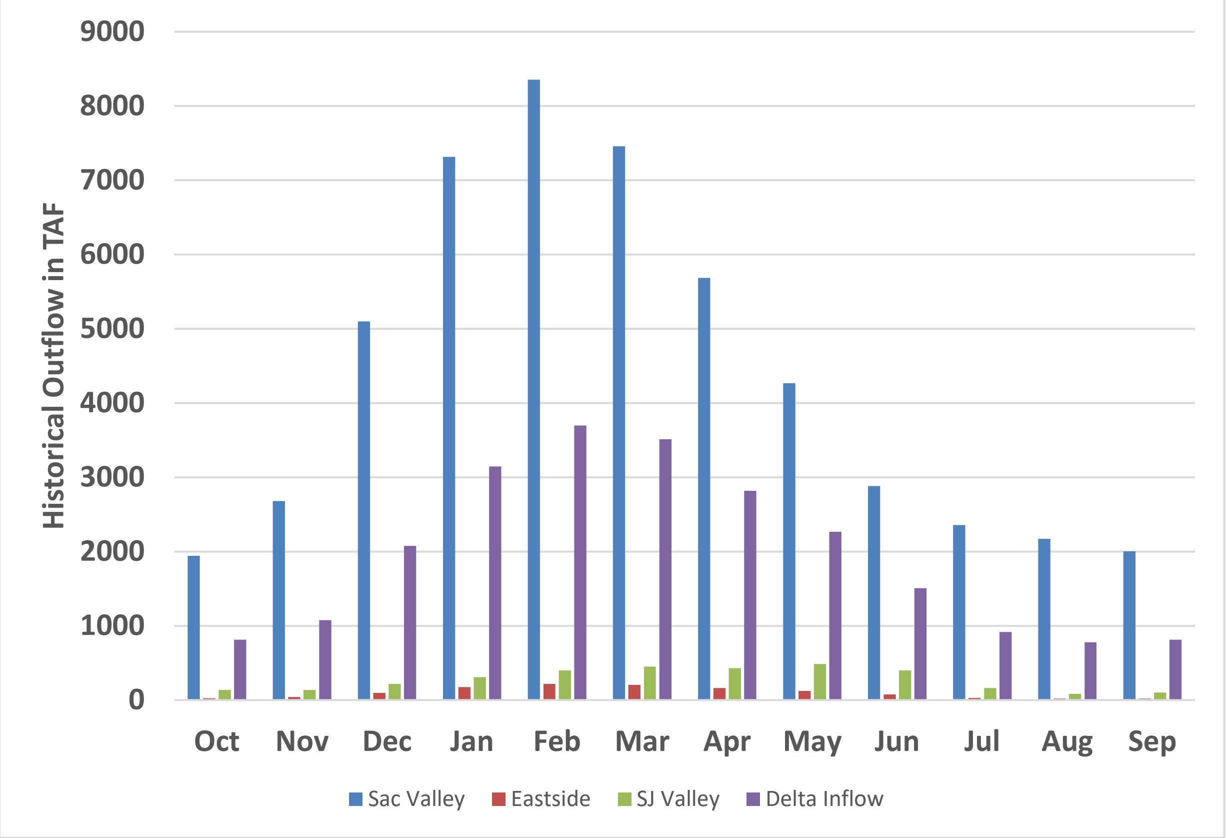


Figure 2-13: WY1922-2003 Monthly Average Regional Historical Outflow

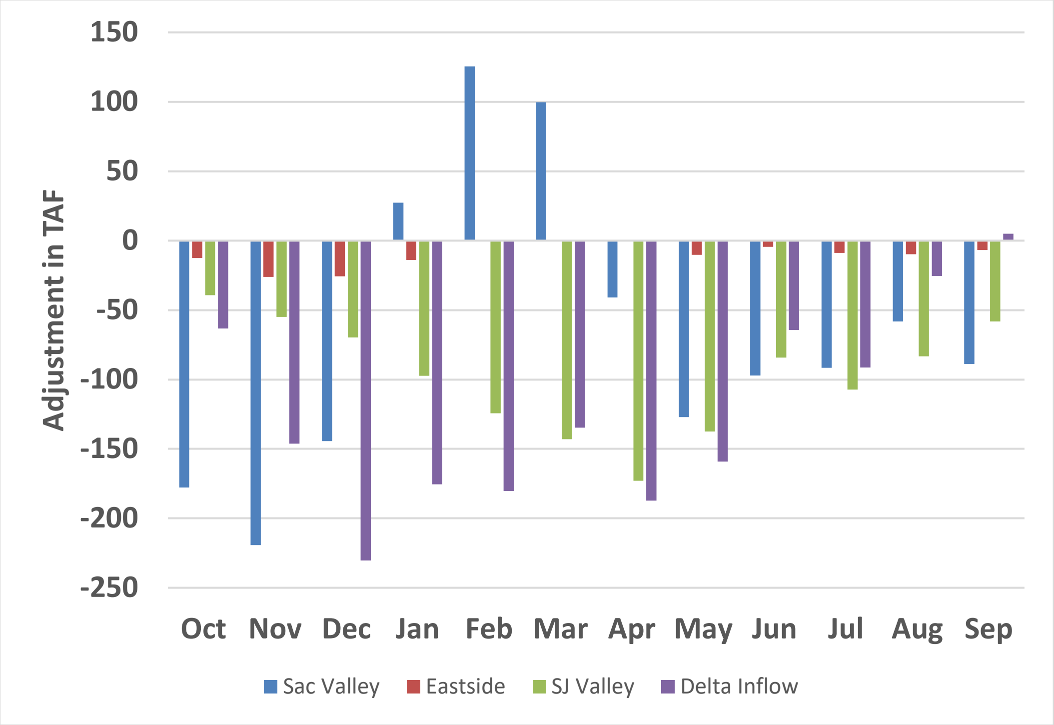


Figure 2-14: WY1922-2003 Monthly Average Regional Outflow Adjustments

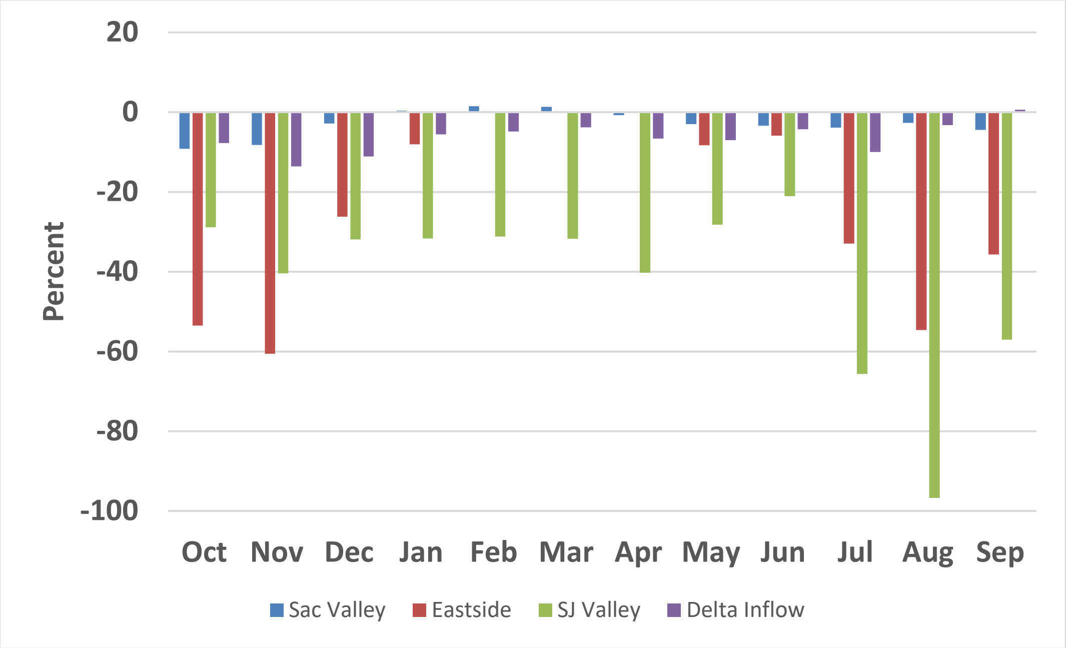


Figure 2-15: WY1922-2003 Monthly Average Regional Adjustment as Percent of Outflow

Figure 2-6 shows a Box-and-Whiskers (B&W) plot of the long term (WY1922-2003) monthly average cumulative sub-regional adjustments as a percent of the historical outflows with the largest percentages outside the high flow winter months, a reflection of the high activity (diversions, returns, etc) during the irrigation season. Figure 2-7 shows a B&W plot of the long term percentages by water year, increasing from wet to the dry years. Figures 2-8 through 2-10 show the long term monthly averages of the historical outflows, adjustments, and percentage of adjustments to the outflow, respectively, by sub-region. The largest percentages are for SR-8 (Eastside Streams) and SR-10 (San Joaquin Valley). The San Joaquin Valley was only adjusted at Vernalis, and the adjustments could be improved (reduced) if the upstream tributary areas were analyzed individually (SR-11 through SR-14). It also shows that C2VSIM could be better calibrated in those two sub-regions. Figure 2-11 and 2-12 shows B&W plots of the average annual historical outflows and adjustments, respectively, by sub-region. Figure 2-12 shows that the adjustments are negatively biased except of SR-2 and SR-10. The large magnitude for SR-10 may be largely due to incomplete or poor calibration for resulting flows at Vernalis. Similarly, Figures 2-13 through 2-15 show the values at the regional level, with the biggest adjustments to the outflows (as percentage) in the San Joaquin and Eastside Stream areas. Figure 2-14 shows that the long term monthly adjustments (cumulative by region) are negatively biased for all sub-regions, except for Feb and Mar, again mainly in SR-2.

Note: Eastside Streams = SR-8, San Joaquin Valley = SR-10 (but includes SR-11 through SR-14), Sacramento Valley = SR-1 through SR-7. The Delta Inflows include SR-6, SR-7, SR-8, and SR-10.

What the analysis shows is that simulation models like C2VSIM are not perfect in simulating observed flows (and groundwater elevations for that matter). The adjustments to the sub-regional outflows could be reduced through better calibration and more accurate simulation of the physical processes (e.g., precipitation runoff, stream-aquifer interaction, and deep percolation), and more reliable input data (e.g., land use acreages and estimates of actual ET). The average annual adjustment of nearly two-million acre-feet (Table 2-5) is a large amount of water to ignore for planning purposes, and that this approach of including adjustments would make C2VSIM a more reliable tool for planning studies. The focus of this research is improving simulation and accounting of flows in streams. Impacts from groundwater will be accounted for through processes such as stream – aquifer interaction, and deep percolation. Changes to groundwater elevations reacts much more slowly to stresses like seepage, pumping and recharge and stresses to streamflow such as diversions, seepage, runoff, and return flow, especially considering the monthly time step scale used in the research. Never the less, this research should be extended to include ground water elevations in working with the adjustments to greatly improve the overall integrated hydrological model C2VSIM.

2.6 Probabilistic Distributions of the Adjustments

For stochastic type modeling including Monte-Carlo simulations for example, it is helpful to know the probabilistic distributions of the adjustments. The software EasyFit ® (Mathwave 2017) was used to develop the probability density functions for the regional adjustments. EasyFit ® compares twenty nine different distributions and ranks the results for best fits according to three goodness-of-fit statistics: Kolmogorov Smirnov, Anderson Darling, and Chi-squared. The simplest and in the top three ranks among all goodness-of-fit statistics for all sub-regional adjustments was the Generalized Logistic Distribution. The generic functions and associated parameters are explained in Figure 2-16. The probability density functions for Sacramento Region (cumulative for all sub-regions), San Joaquin Region, Eastside Streams Region, and total of all are shown in Figures 2-17 through 2-20, respectively. The parameters for use in the distribution functions are summarized in Table 2-13.

Generalized Logistic Distribution

Parameters

K - Continuous shape parameter

σ – Continuous scale parameter (σ>0)

μ – Continuous location parameter

Domain

$1+k\dfrac{x-\mu}{\sigma}>0 \qquad k \neq 0$

$-\infty < x < +\infty \qquad k = 0$

Probability Density Function

$$f(x)=\frac{(1+kz)^{-1-1/k}}{\sigma(1+(1+kz)^{-1/k})^{2}} \qquad k \neq 0$$

$$f(x)=\frac{\exp(-z)}{\sigma(1+\exp(-z))^{2}} \qquad k = 0$$

Cumulative Distribution Function

$$F(x)=\frac{1}{1+(1+kz)^{-1/k}} \qquad k \neq 0$$

$$F(x)=\frac{1}{1+\exp(-z)} \qquad k = 0$$

Where

$$z \equiv \frac{x-\mu}{\sigma}$$

Figure 2-16: Generalized Logistic Distribution

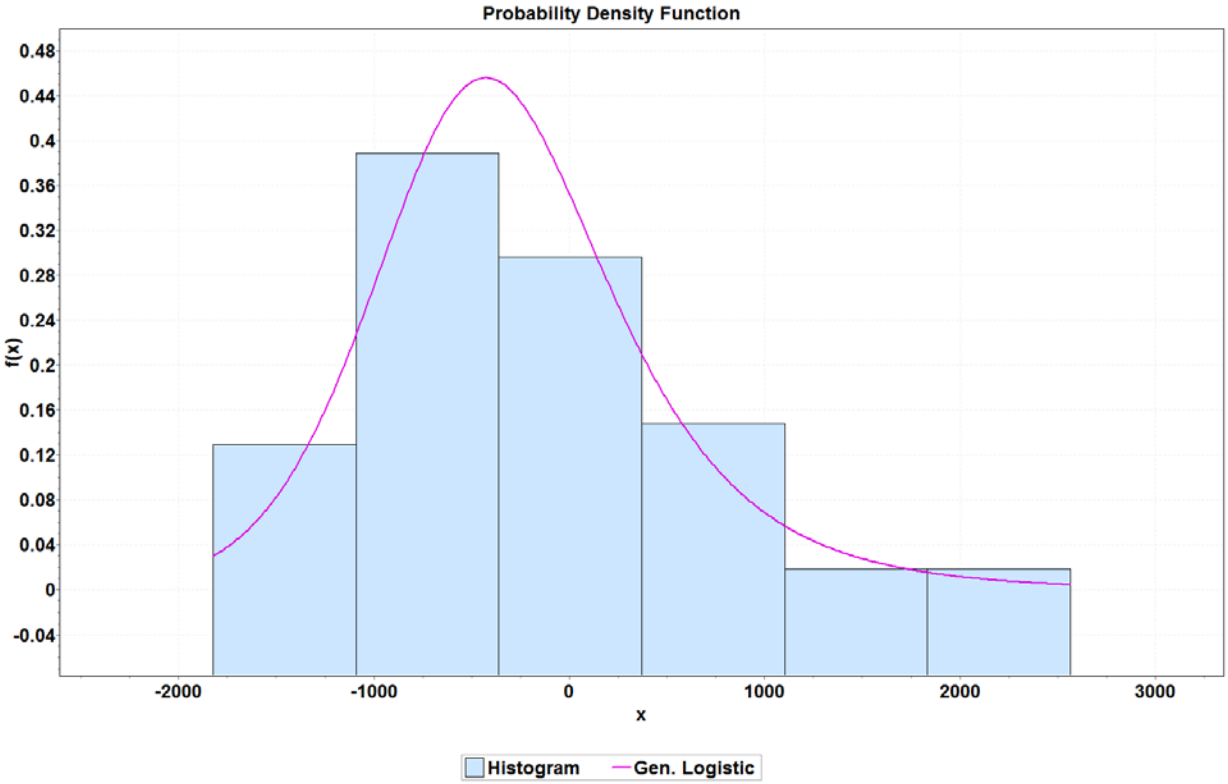


Figure 2-17: Probability Distribution Function for Annual (WY1950-2003) Historical Adjustments – Sac Region (sum for all sub-regions) in TAF

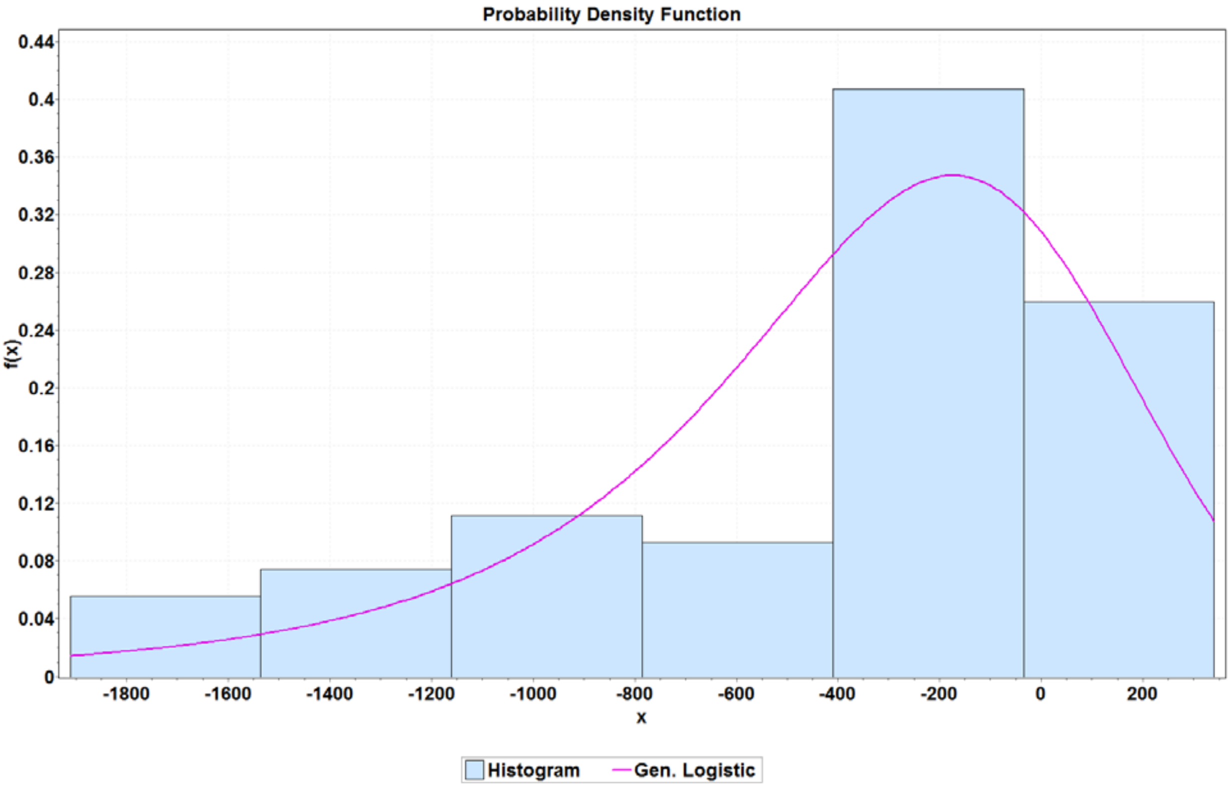


Figure 2-18: Probability Distribution Function for Annual (WY1950-2003) Historical Adjustments – SJ Region in TAF

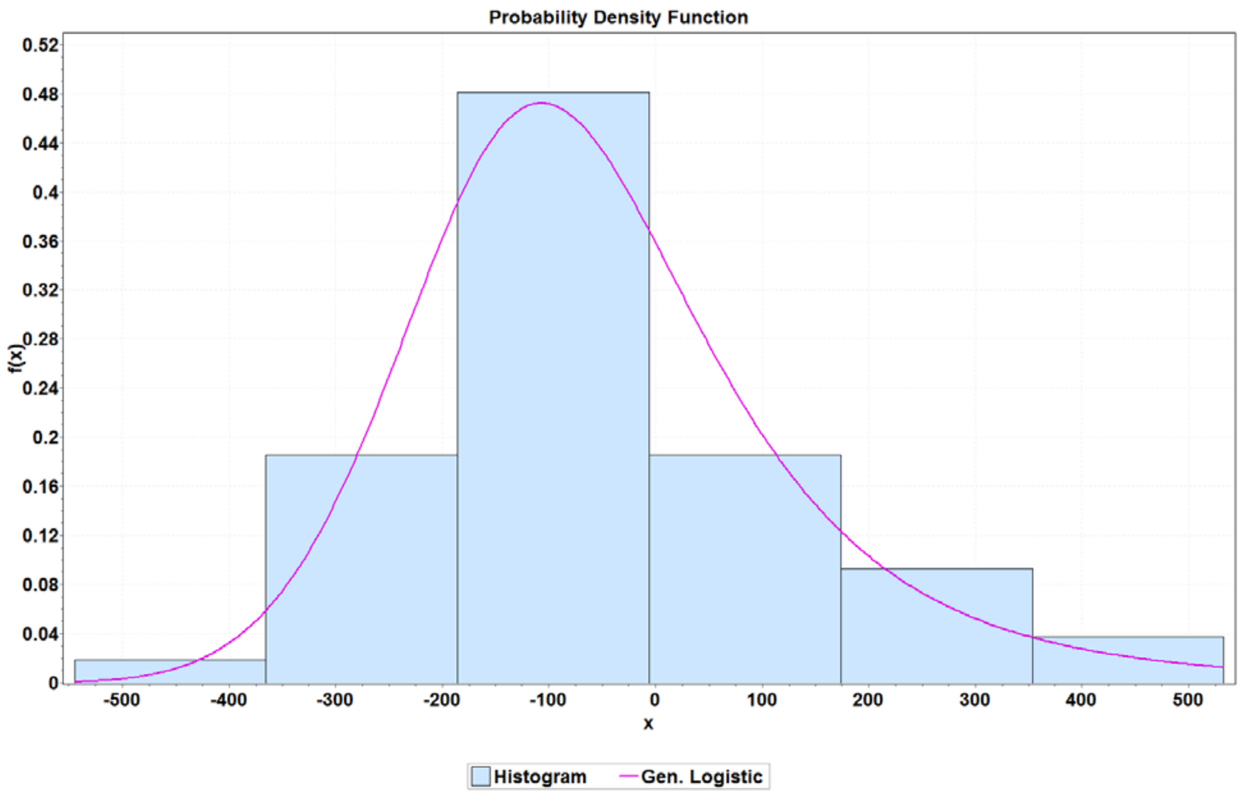


Figure 2-19: Probability Distribution Function for Annual (WY1950-2003) Historical Adjustments – ESS Region in TAF

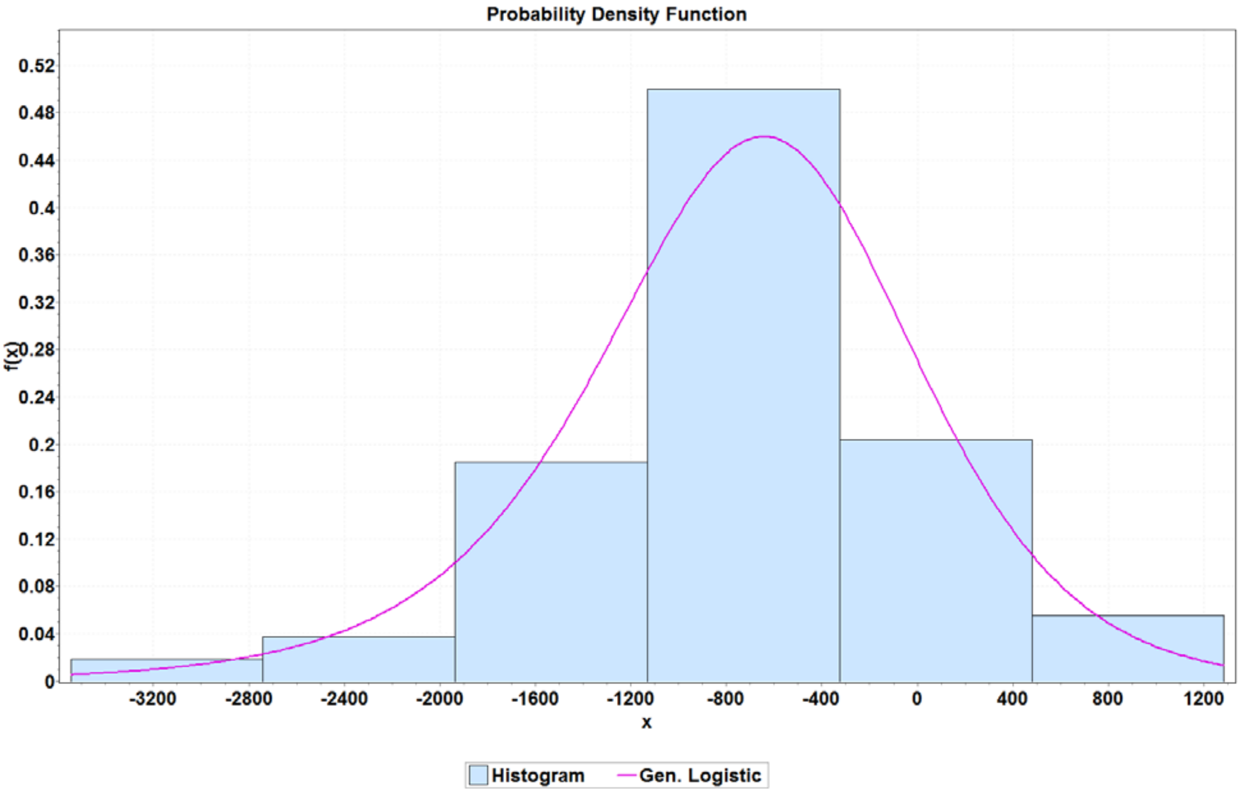
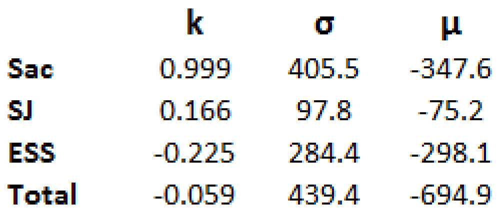


Figure 2-20: Probability Distribution Function for Annual (WY1950-2003) Historical Adjustments – All Regions in TAF

Table 2-13: Parameters for Probability Density Functions by Region



	k	σ	µ
Sac	0.999	405.5	-347.6
SJ	0.166	97.8	-75.2
ESS	-0.225	284.4	-298.1
Total	-0.059	439.4	-694.9

Chapter 3 Develop C2VSIM Historical Run with Adjustments to Outflows Simulated Dynamically Using ANN

In Chapter 2, adjustments (closure terms) to sub-region outflows for the historical simulation of C2VSIM were computed and made inputs into C2VSIM so that simulated sub-region outflows match observed outflows. This is of limited value for planning studies unless they can be adapted to changing historical and future conditions (e.g., streamflows, diversions, land use). This chapter develops a procedure to estimate such adjustment values, and builds it into C2VSIM to dynamically estimate adjustments, in preparation for the next phase of the research (Chapter 4) where C2VSIM is prepared to run planning studies with projected future levels of development.

3.1 Introduction

Chapters 2 introduced the concept of closure term or sub-regional adjustments developed by CDWR (CDWR 1977a, CDWR1977b, CDWR 1994, CDWR 1991) to tie in simulated streamflows at locations (sub-regional outflow points) to historical observed streamflows at the same locations; this concept was used by the CDWR over the last four decades in developing hydrologies for planning studies of the CVP/SWP systems.

For example, Delta inflow represented by the inflows from the major streams of the Sacramento River Basin, Eastside streams, and San Joaquin River Basin, is a key hydrological component that governs how the SWP/CVP projects are operated: to meet regulatory requirements (e.g., Delta outflows), operational agreements (e.g., COA), allocations, and exports from the Delta. This research modifies, and adapts the closure term concept to simulated surface water flows in IWFM and C2VSIM. Chapter 2 quantified the adjustments for the historical time trace of precipitation, land use, diversions, etc. They were computed for each sub-region by ensuring that the simulated outflow of the sub-region is equal to the observed, which then becomes the “perfect” inflow to the downstream sub-regions. For planning, quantifying the adjustments as a function of associated hydrological parameters provides the simulation model with more flexibility for developing alternative planning scenarios. This research uses the heuristic approach of Artificial Neural Networks (ANN’s) for estimating the adjustments to sub-region outflows for the simulation model.

3.2 Develop ANN’s to Compute Adjustments to Outflows

This research if focused on improving reliability in results of the integrated hydrological model (C2VSIM) by reducing the error between simulated and observed stream flow at the regional level (in this research the sub-region stream outflow) using ANN to quantify that error. What is different in this research from applications of ANN listed above is presenting an approach to address shortcomings of a simulation model in estimating streamflow compared to observed (imperfect or incomplete representation of the physical processes simulated) by attempting to quantify the difference between simulated streamflow and observed in terms of computed hydrological components (such as runoff, seepage, return flow, diversions), and to rank those components by importance. If the simulation model were perfect, observed would match simulated, and any adjustments to streamflow would not be necessary. Even under the best calibration efforts (and there is a point of diminishing returns on spending more time and effort on calibration) there would still be residual error and that is the purpose of using ANN to quantify the adjustment. An integrated hydrological model like IWFM (and its application Cb2VSIM) models many physical processes that interact in a non-linear way that makes it difficult if not impossible to address, in general, the underlying reasons for the errors in simulated streamflow. ANN is an approach that does not require an understanding of the underlying physical processes or how they interact. ANN itself will not eliminate the simulated streamflow error discussed, but ideally reduce it thus improving model performance.

Figure 3.1 shows the different types of flow affecting computation of stream node downstream flow in IWFM. These flows are affected by other physical processes simulated within C2VSIM, such as precipitation runoff, stream-aquifer interaction, and return flow.

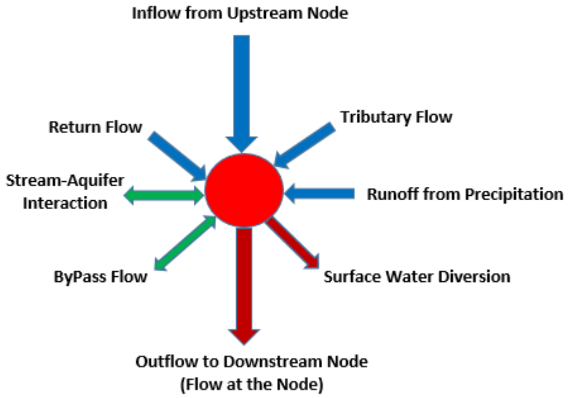


Figure 3-1: Components of Flow at a C2VSIM Stream Node

These physical processes and interactions among them are complex and non-linear and may not represent the real world perfectly, let alone impacted by any input data errors used in the model (e.g., estimation of unit evapotranspiration, errors in estimated diversions); otherwise there would be no need for adjustment. One approach to quantify the adjustment term is to examine the data associated with calculating the adjustment term, directly or indirectly, and develop a procedure to try to estimate it accordingly. One approach is using traditional “black box” statistical methods (e.g., regression). More recent methods patterned on evolutionary or biological principles (Loucks and van Beek, 2005) have been developed to improve correspondence between observed and “simulated” results, aside from the actual physical processes themselves. One of the more established methods patterned after human brain processes are Artificial Neural Networks (ANN’s), which technically are an extension of regression methods for emulating deterministic, process-oriented models (such us C2VSIM).

Types of ANN include Feed Forward networks (Figure 3-2, and used in this research), Recurrent Neural Networks (RNN), Self-Organizing Feature Maps (SOFMs), Hopfield Networks, Radial Basis Function Networks (RBF), Support Vector Machines (SVMs) (Loucks and van Beek 2005, Haykin 1999, Hertz et al. 1991).

Figure 3-2 is an example of the basic elements of neural network architecture which include an Input Layer, two Hidden Layers, and an Output Layer.

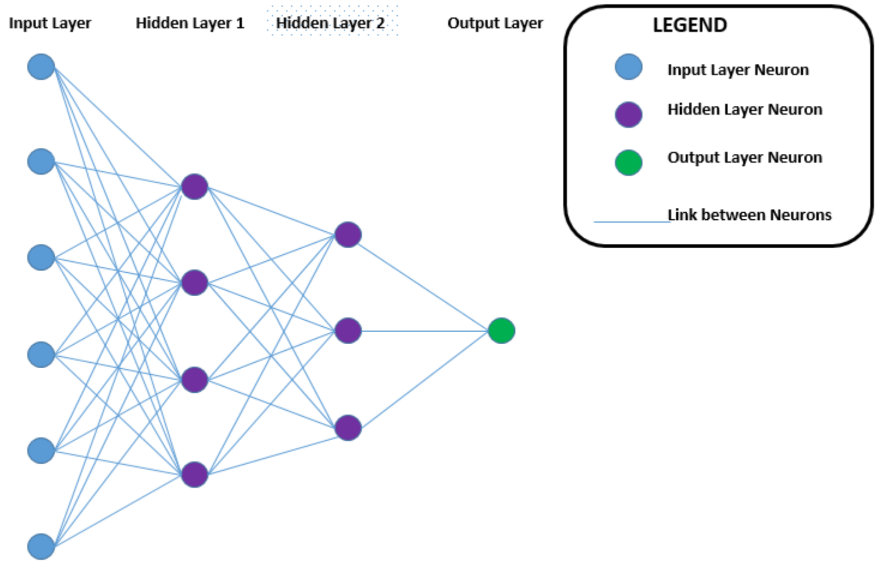


Figure 3-2: An Artificial Neural Network with Two Hidden Layers

Each layer is composed of neurons (or nodes) the number of which depend on the input data (for the Input Layer), the output data (for the Output Layer), and the computational process (for the Hidden Layers). In Figure 3-2 these numbers are 6, 4, 3, and 1, respectively. Neurons are connected by links having “weights” for passing the information from one layer to the next. The data passes through the neural network as follows:

For each neuron or node k in a layer connected to j neurons from the previous layer, the input I_k and output O_j are calculated using the equations:

$$I_k = \sum_j w_j O_j + \theta_k \quad \dots\dots\dots\dots\dots\dots \text{(3.1)}$$

$$O_j = \frac{1}{1 + e^{-I_k}} \quad \dots\dots\dots\dots\dots\dots \text{(3.2)}$$

Where θ_k is a “bias” term.

Note: This ANN approach uses a sigmoid transformation function (Eq. 3.2), though other types of functions are possible too.

The values w's and θ's shown in Eq 3.1 and Eq. 3.2 are set through a "training" or calibration process. Modern ANN software often automates the process of determining the number of hidden layers and the number of neurons in each hidden layer (but allowing for user intervention for modification). This research uses the EasyNN-plus ® software v14.0g (ENNplus 2017). The software utilizes the same equations above with the exception that the input data and all computations within are scaled internally as follows:

For each neural node value in the Input layer), the output value is scaled as:

$$O_{Scaled} = \frac{I_{unscaled} - I_{UnscaledMin}}{I_{UnscaledMax} - I_{UnscaledMin}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (3.3)$$

The final unscaled output is computed from the scaled output as:

$$O_{Unscaled} = +O_{Scaled}(O_{ScaledMax} - O_{ScaledMin}) \quad \ldots\ldots\ldots\ldots \; (3.4)$$

Note: Scaling is a normalization process to allow easy visualization of results from components that have different units (e.g., inches/month, TAF/yr) and differing ranges between minimum and maximum. Typical scaling is 0 to 1.

The first step in applying ANN to estimate sub-regional adjustments is to propose a list of variables within C2VSIM to include in the computations. This will then allow C2VSIM to dynamically calculate the adjustment. This research assumes that the adjustment is computed as a function of fourteen variables that encompass most physical processes used in C2VSIM. These variables are reported in C2VSIM output budget files, and listed in Table 3-1:

1. Water Year Type – Based on SWRCB 8-River Index as Wet (W), Above Normal (AN), Below Normal (BN), Dry (D) and Critical (C).

2. Season – Fall (F) for Oct-Dec, Winter (W) for Jan-Mar, Spring (S) for Apr-Jun, and Summer (S) for Jul-Sep, for the Water Year.

3. Inflow – The sub-regional total inflow consists of upstream inflows and tributary inflows to the sub-region, in TAF (1000's of acre-feet).

4. Runoff – Precipitation runoff for the sub-region, in TAF.

5. Return Flow – Return flow for the sub-region from surface water diversions, imports, and groundwater pumping in TAF.

6. Groundwater Gain – Net inflow to the stream from the stream-aquifer interaction, in TAF.

7. Surface Diversion – Surface water diversions within the sub-region plus any net bypass flows, in TAF.

8. Precipitation – Total precipitation within the sub-region, in TAF.

9. ETa – Total computed actual evapotranspiration within the sub-region from agricultural, urban, native vegetation, and riparian vegetation areas, in TAF.

10. Net Import – Total imports less exports into the sub-region from other sub-regions or outside C2VSIM boundaries, in TAF.

11. Deep Percolation – Net deep percolation (including recharge) from the unsaturated zone to groundwater, in TAF.

12. Groundwater Pumping – Total groundwater pumping within the sub-region, in TAF.

13. Agricultural and Urban Areas – Total agricultural and urban areas within a sub-region, in 1000’s acres.

14. Native and Riparian Vegetation Areas – Total native vegetation and riparian vegetation areas within a sub-region in acres in 1000’s acres.

A note of clarification: The terms “seepage”, “stream-aquifer interaction”, and “groundwater gain” are used interchangeably in this research. All three variables can have either positive or negative values. A positive seepage value implies flow from the stream to groundwater, and a negative seepage value is the opposite. Similarly, a positive groundwater gain value implies flow from the groundwater system to the stream, and a negative groundwater gain value is the opposite.

Another variable that could have been included is groundwater storage. Components affecting groundwater storage are: deep percolation (#11 above), recharge (included in #11), stream-aquifer interaction (#6), pumping (#12), and subsurface inflow from adjacent areas. In C2VSIM the net subsurface inflow is much smaller in magnitude than the other components. Therefore, groundwater storage was mostly accounted for implicitly through the other variables.

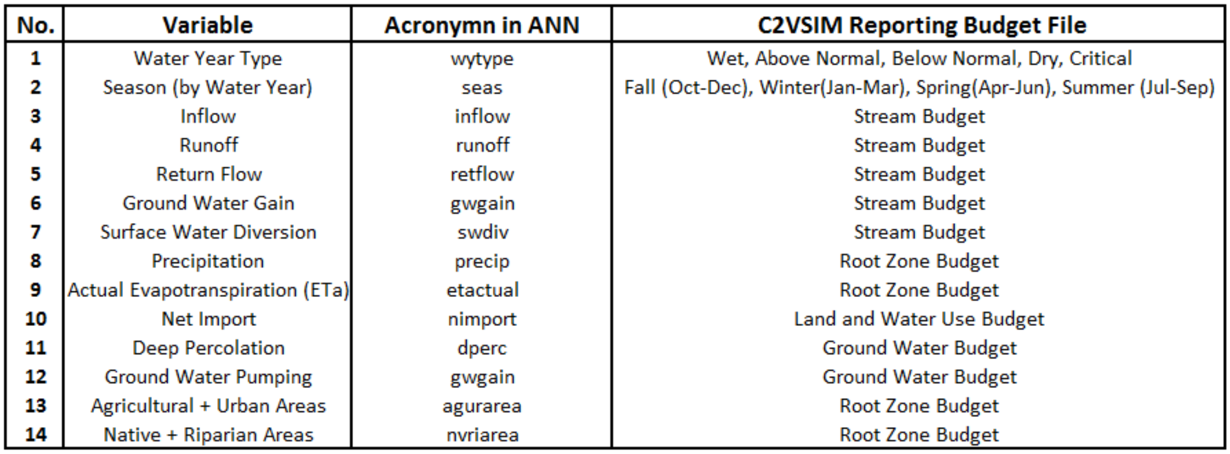
The input data to the ANN process are all monthly for the period (WY1950-2003); in TAF for volumetric and in acres for areas. For the Water Year Type and the Season (variables 1 and 2 above, respectively), the abbreviations are converted to numerical values using standard ASCII conversion numbers for computational purposes, as follows (letters are also weighted to ensure non-duplication of final values):

Water Year Type:
Wet (W): 87
Above Normal (AN): 2x65 + 1x78 = 208
Below Normal (BN): 2x66 + 1x78 = 210
Dry (D): 68
Critical (C): 67

Season:

Fall (FAL): 3x70 + 2x65 + 1x76 = 416
Winter (WIN): 3x87 + 2x73 + 1x78 = 485
Spring (SPR): 3x83 + 2x80 + 1x82 = 491
Summer (SUM): 3x83 + 2x85 + 1x77 = 496

Table 3-1: Variables for Computing C2VSIM Adjustment Using ANN



No.	Variable	Acronymn in ANN	C2VSIM Reporting Budget File
1	Water Year Type	wytype	Wet, Above Normal, Below Normal, Dry, Critical
2	Season (by Water Year)	seas	Fall (Oct-Dec), Winter(Jan-Mar), Spring(Apr-Jun), Summer (Jul-Sep)
3	Inflow	inflow	Stream Budget
4	Runoff	runoff	Stream Budget
5	Return Flow	retflow	Stream Budget
6	Ground Water Gain	gwgain	Stream Budget
7	Surface Water Diversion	swdiv	Stream Budget
8	Precipitation	precip	Root Zone Budget
9	Actual Evapotranspiration (ETa)	etactual	Root Zone Budget
10	Net Import	nimport	Land and Water Use Budget
11	Deep Percolation	dperc	Ground Water Budget
12	Ground Water Pumping	gwgain	Ground Water Budget
13	Agricultural + Urban Areas	agurarea	Root Zone Budget
14	Native + Riparian Areas	nvriarea	Root Zone Budget

The average annual values for the time series variables by sub-region are shown in Table 3-2 and Figure 3-3.

Table 3-2: Long Term WY1922-2003 Average Annual Values by Sub-region for the Variables Used in the ANN Process

Volumetric in TAF and Area in Acres

	Inflow (TAF)	Runoff (TAF)	RetFlow (TAF)	GWgain (TAF)	SWdiv (TAF)	Precip (TAF)	ETa (TAF)	Net Import (TAF)	DeepPerc (TAF)	Gwpump (TAF)	Ag+Ur Area (Acres)	NV+RV Area (Acres)
ANN Variable	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***	***13***	***14***
SR-1 (DA58)	7812	165	21	238	99	778	488	-1	205	19	40	289
SR-2 (DA10)	10100	259	12	295	692	1264	1098	-501	313	317	125	573
SR-4 (DA15)	10092	11	1	139	2303	526	814	-68	197	157	184	167
SR-5 (DA69)	6778	323	47	117	-971	1073	1475	-23	306	319	299	315
SR-6 (DA65)	847	134	21	-57	-2355	959	1046	33	196	285	184	474
SR-7 (DA70)	18256	132	40	-71	2375	518	662	223	56	127	161	189
SR-8 (DA59)	1218	158	22	-8	8	1279	1492	151	279	641	292	604
SR10 (DA49a)	4793	51	3	-243	116	491	1207	536	34	130	319	349

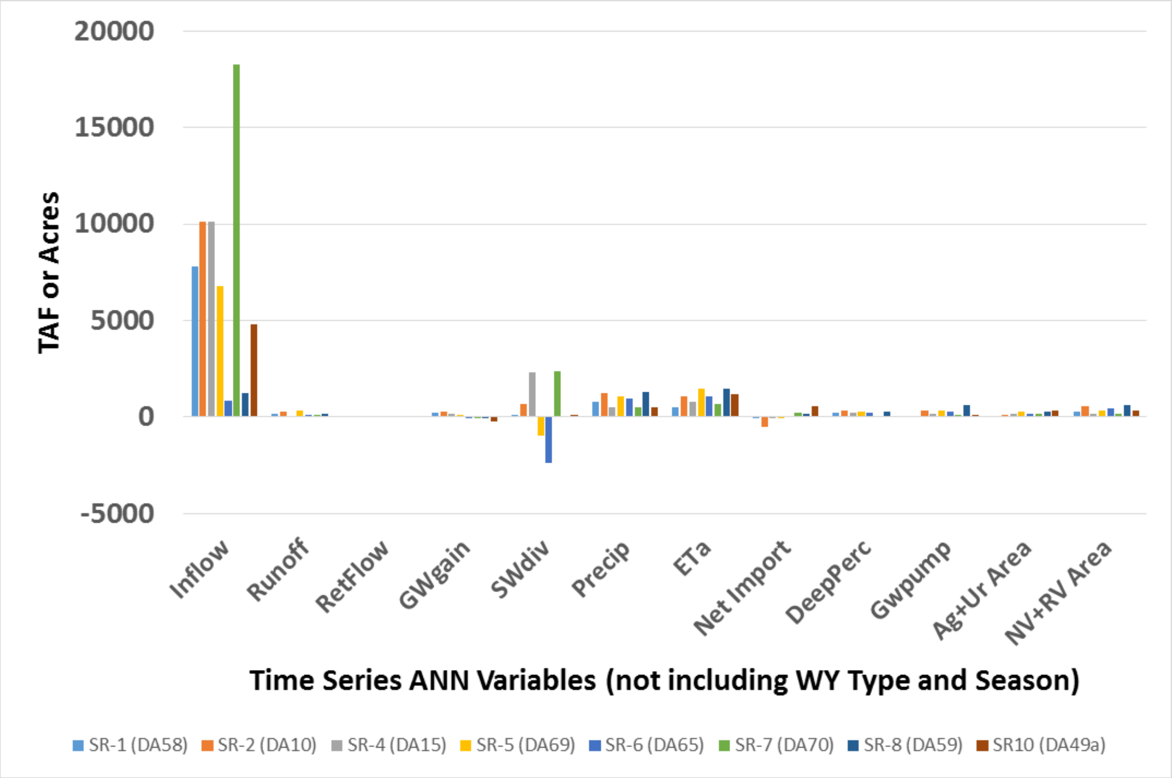


Figure 3-3: Average Annual Flow and Area Components Used in ANN for C2VSIM

The ANN parameters to compute the monthly adjustment values for each sub-region were obtained using the ANN software EasyNN-Plus ® (ENNplus 2017). Developing the neural network architecture for a sub-region (number of hidden layers and number of neurons within each hidden layer) is generally a trial and error process of choosing an optimum number of hidden layers and neurons within each layer. The objective is to minimize the error difference between the estimated values with ANN and the observed (input) values. Typically one starts with one hidden layer and keep adding a layer until the error begins to increase; an indication of "over training". Also taken into consideration is the computational time to achieve convergence, since more layers (and more neurons within) require longer run time. For training and testing of the ANN's only the data for the period WY1950-2003 was used. The ultimate objective of this research is developing a model for use in planning studies, which reflects reservoir operations for future levels of development of agricultural and urban areas during the entire simulation period. The historical earlier period (pre-WY1951) reflects pre-project times (e.g., Shasta came on line in 1945) when agricultural and urban areas were small (low demands for surface water diversions and groundwater pumping) and streamflows (at the reservoir release locations) reflect no reservoir operations for flood control, regulatory requirements (e.g., Delta Outflow), and Coordinated Operations Agreement between CVP and SWP projects (COA 1986).

An example of an ANN architecture is shown in Figure 3-4 for Sub-region 5. It consists of an input layer, three hidden layers (with 8, 5, 5 neurons, respectively), and an output layer where the result is the adjustment computed by ANN. The ANN architectures for the other sub-regions are shown in Appendix B. Table 3-3 summarizes the ANN architecture for the sub-regions.

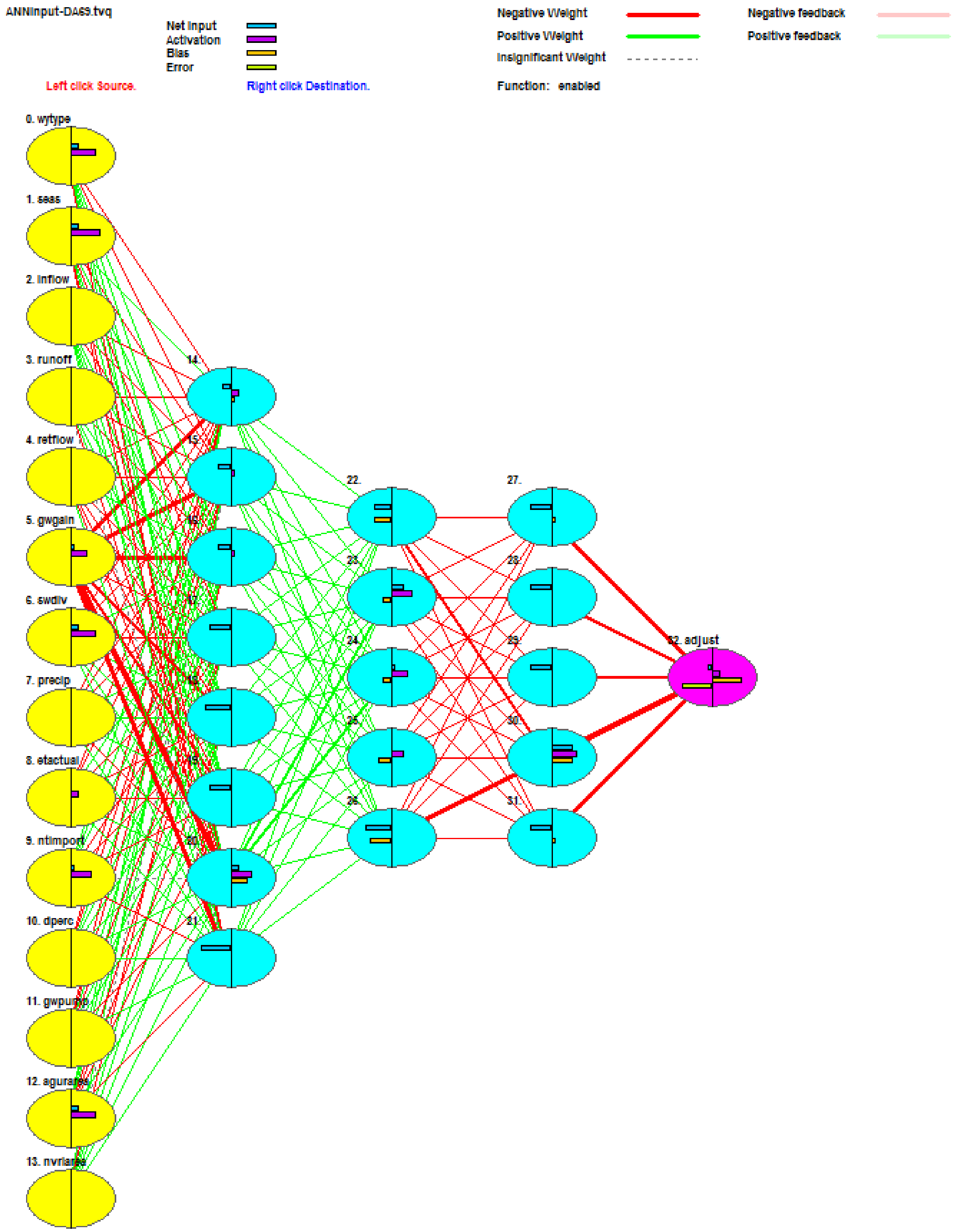
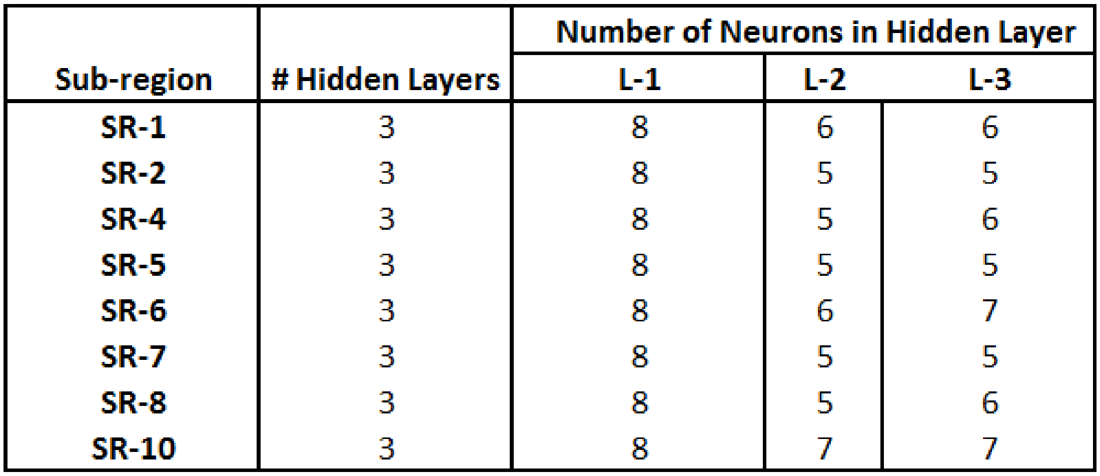


Figure 3-4: ANN Architecture for SR-5 (DA69)

Table 3-3: ANN Number of Hidden Layers and Neurons by Sub-region



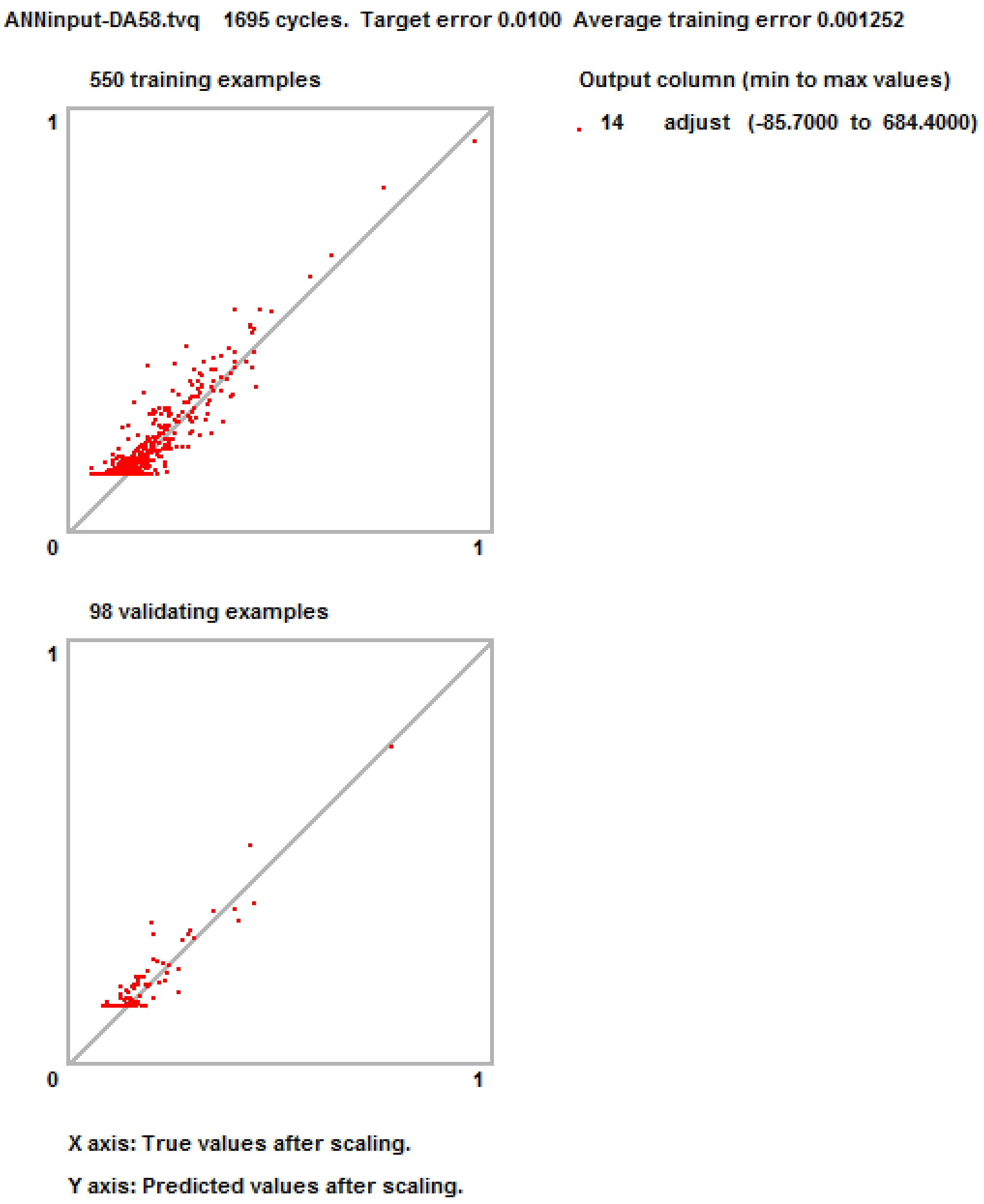
Sub-region	# Hidden Layers	Number of Neurons in Hidden Layer		
		L-1	L-2	L-3
SR-1	3	8	6	6
SR-2	3	8	5	5
SR-4	3	8	5	6
SR-5	3	8	5	5
SR-6	3	8	6	7
SR-7	3	8	5	5
SR-8	3	8	5	6
SR-10	3	8	7	7

The results of training and testing of the ANN process for all sub-regions are shown is Figure 3-5 through Figure 3-12 (extracted from the software output). Each figure shows two plots: the top plot is a scatter diagram of the monthly ANN adjustment vs. observed (scaled to between 0-1) used in training and the lower plot is a scatter diagram of the monthly ANN vs. observed for testing. The values used in the testing are randomly chosen by the software and excluded from the training process. All show relatively good correlations, with some better than others; for example SR-5 in Figure 3-8 (Feather River basin DA69) vs. SR-2 in Figure 3-6, respectively. As mentioned in Chapter 2, the IWFM and C2VSIM versions used in this research (available at that time) are v2.4.1 and R-321, respectively. Both IWFM and C2VSIM have undergone changes since then: the current versions are

IWFM 2015 (http://baydeltaoffice.water.ca.gov/modeling/hydrology/IWFM/), and

C2VSIM R-376 (http://baydeltaoffice.water.ca.gov/modeling/hydrology/C2VSim/index_C2VSIM.cfm).

The major change in IWFM included modifications to the root zone accounting method for computing demands. C2VSIM had undergone major recalibration efforts to improve to fix input data errors, and better simulation of streamflow and ground water elevations. Using a more recent version of C2VSIM should yield better ANN's for computing the adjustments (for future research). An example of the training convergence is shown in Figure 3-13 for SR-7 (American River basin DA70).



ANNinput-DA58.tvq   1695 cycles. Target error 0.0100 Average training error 0.001252

550 training examples

Output column (min to max values)

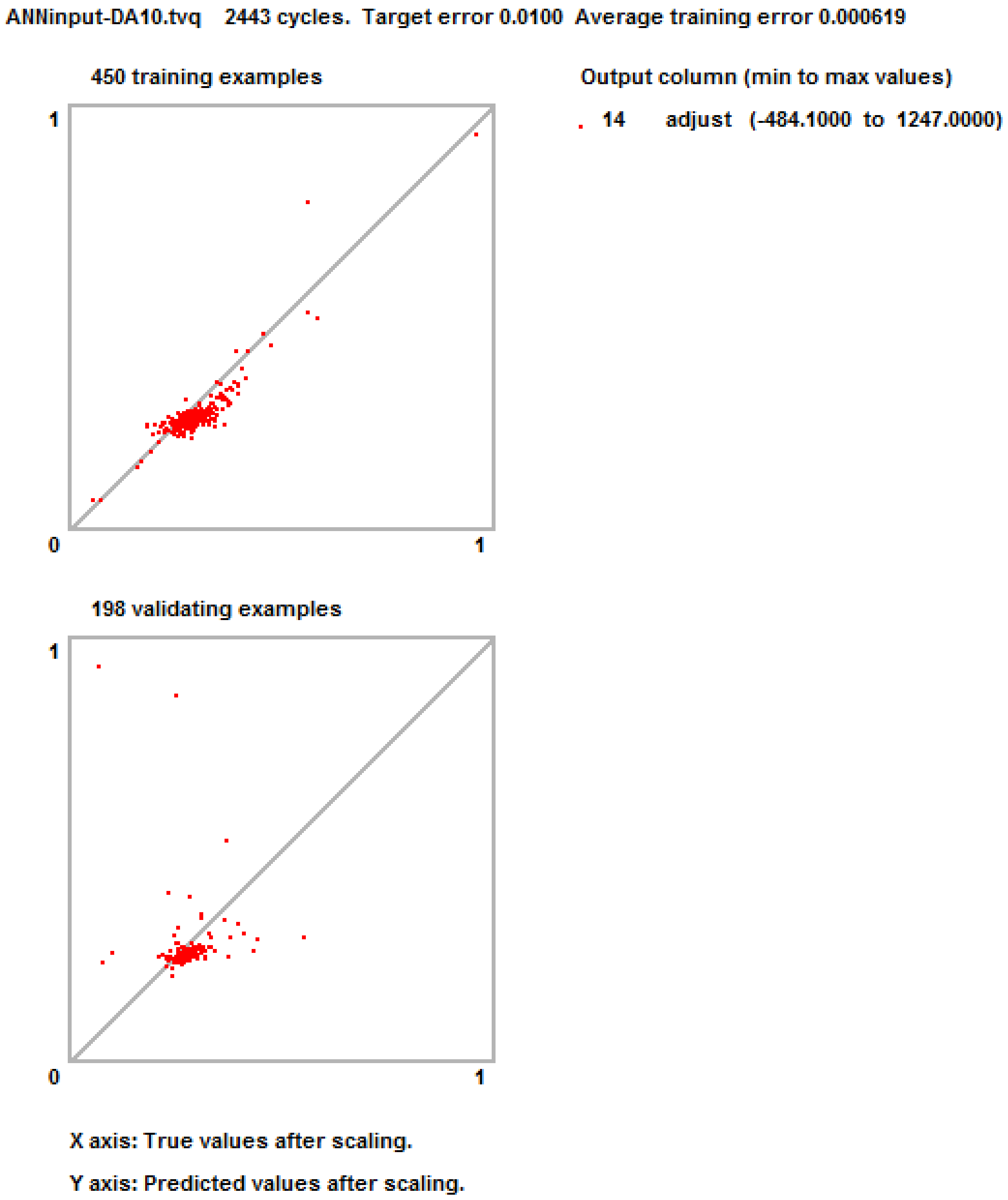
• 14   adjust (-85.7000 to 684.4000)

98 validating examples

X axis: True values after scaling.

Y axis: Predicted values after scaling.

Figure 3-5: ANN Adjustments vs. Observed SR-1 (DA58) Sacramento River above Red Bluff



ANNinput-DA10.tvq 2443 cycles. Target error 0.0100 Average training error 0.000619

450 training examples

Output column (min to max values)

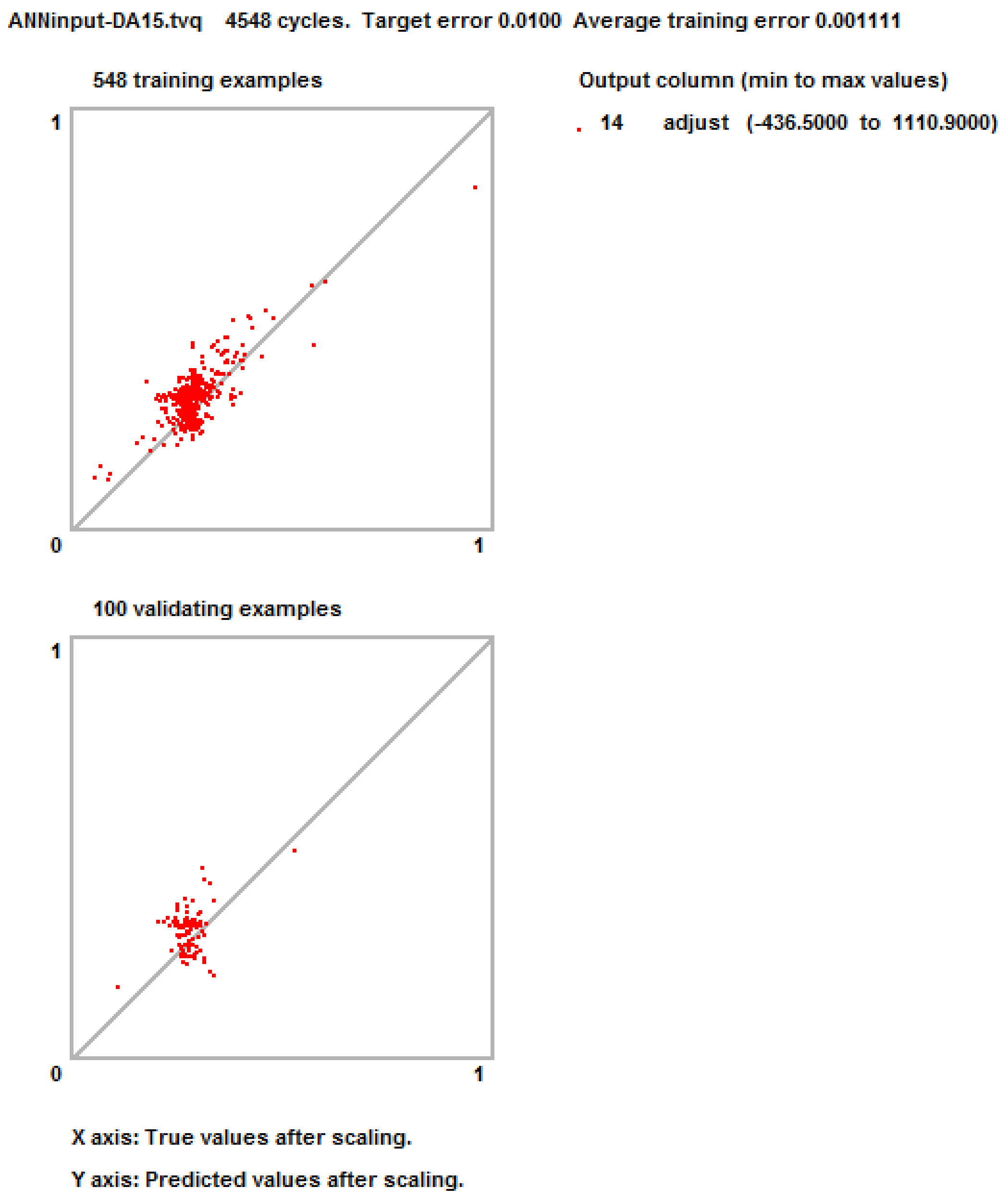
. 14 adjust (-484.1000 to 1247.0000)

198 validating examples

X axis: True values after scaling.

Y axis: Predicted values after scaling.

Figure 3-6: ANN Adjustments vs. Observed SR-2 (DA10) Sacramento River at Ord Ferry



ANNinput-DA15.tvq 4548 cycles. Target error 0.0100 Average training error 0.001111

Output column (min to max values)

14 adjust (-436.5000 to 1110.9000)

X axis: True values after scaling.

Y axis: Predicted values after scaling.

Figure 3-7: ANN Adjustments vs. Observed SR-4 (DA15) Sacramento Service Area Chico Landing to Knights Landing

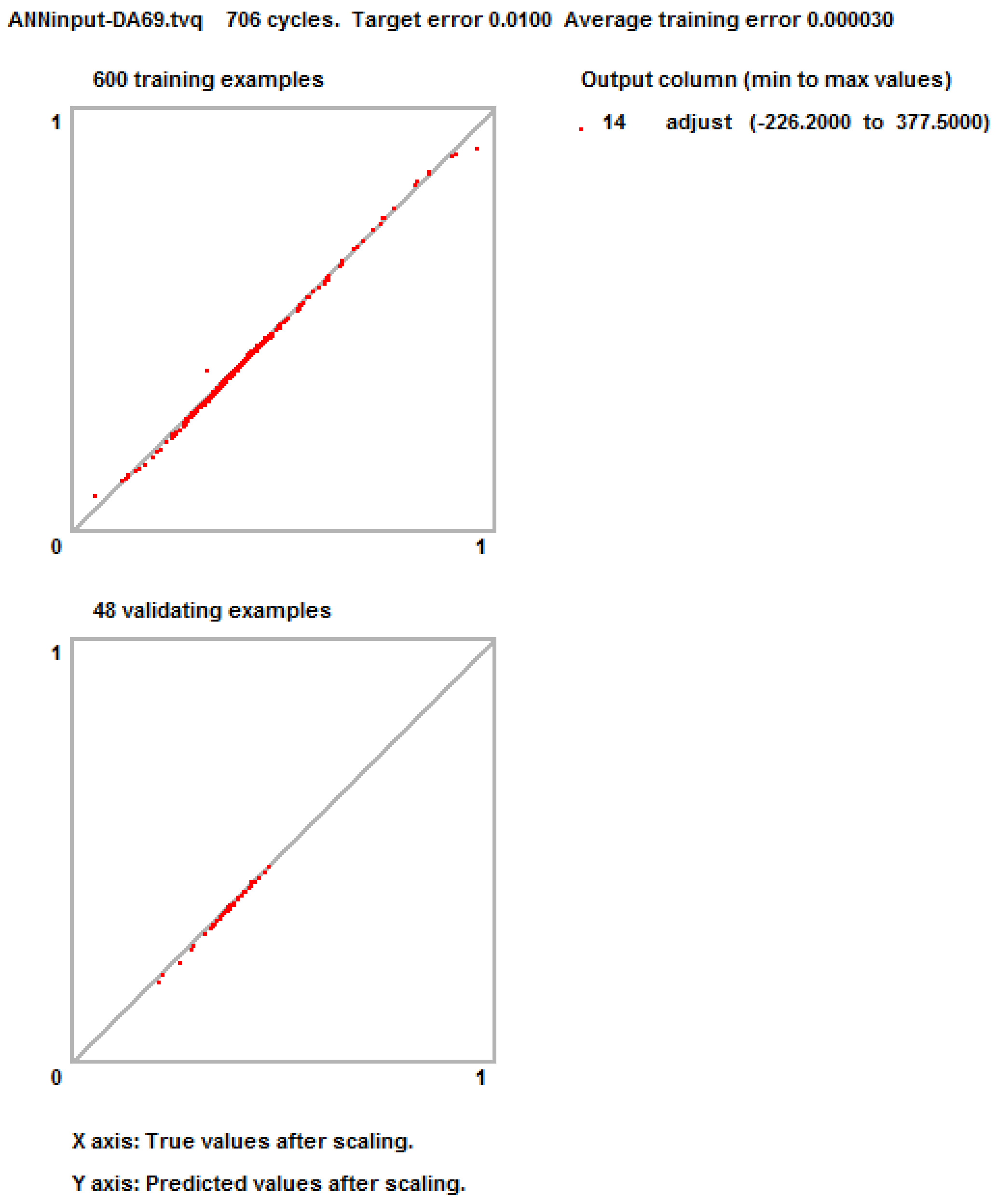
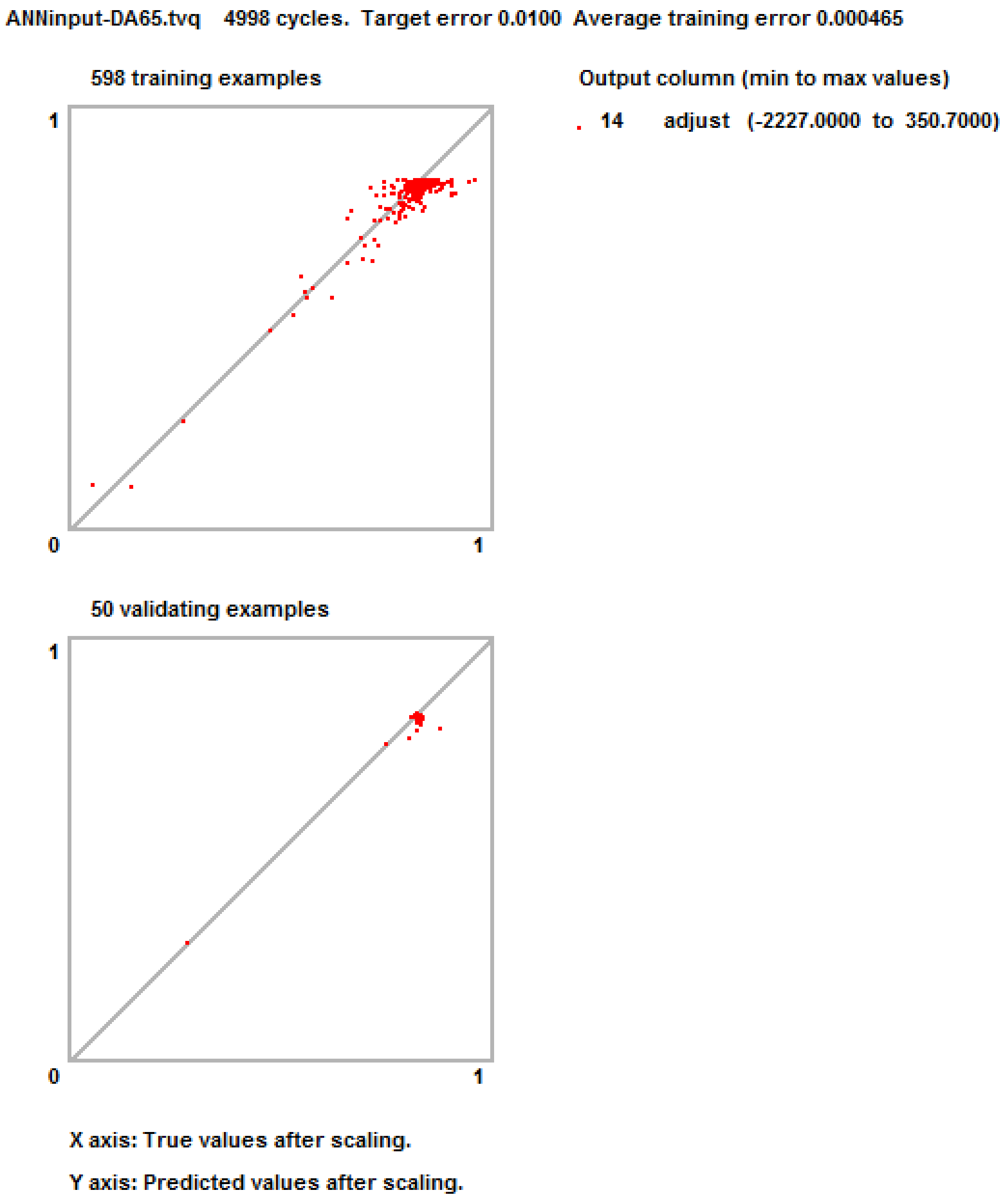


Figure 3-8: ANN Adjustments vs. Observed SR-5 (DA69) Lower Feather River



ANNinput-DA65.tvq 4998 cycles. Target error 0.0100 Average training error 0.000465

598 training examples

Output column (min to max values)

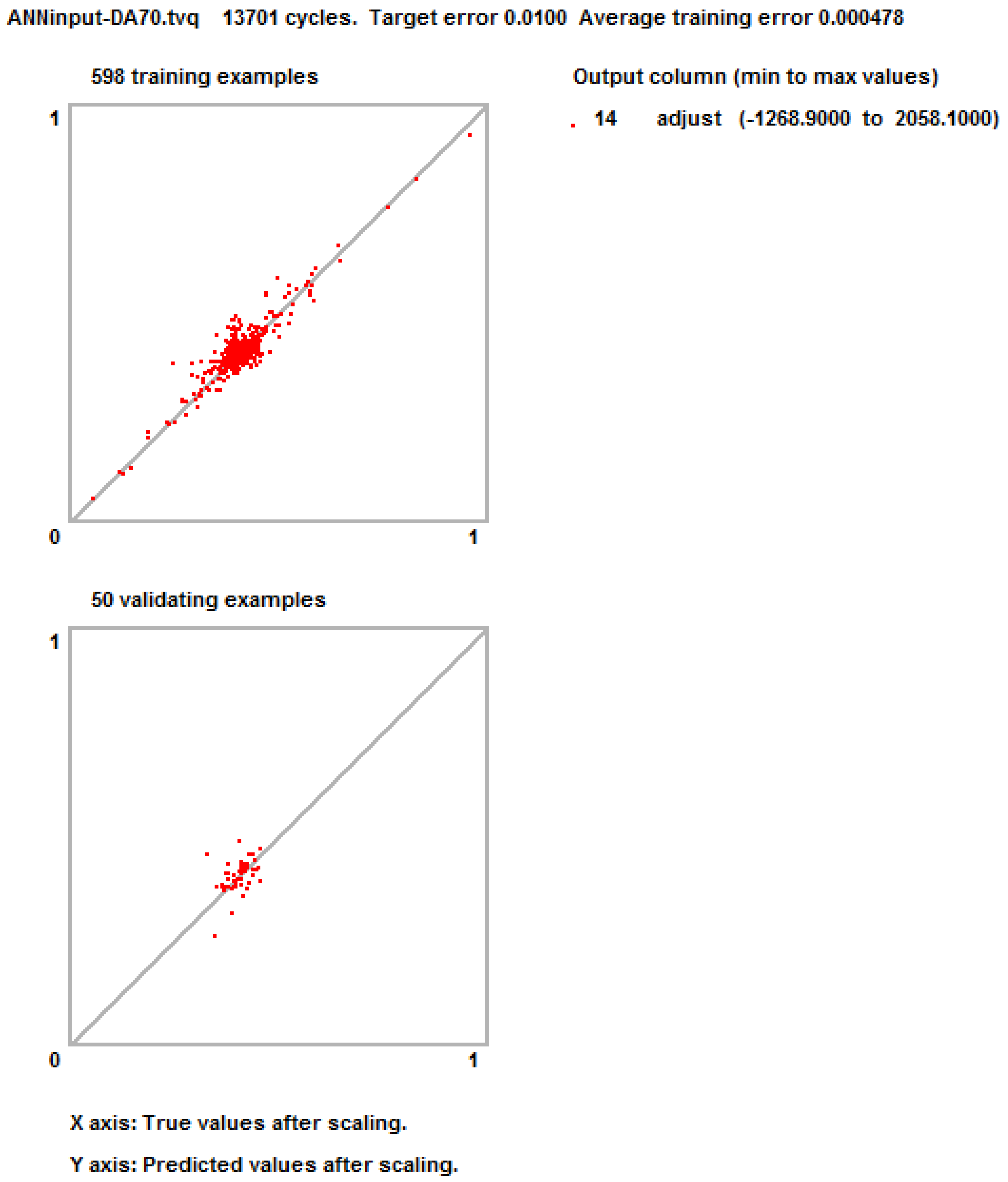
. 14 adjust (-2227.0000 to 350.7000)

50 validating examples

X axis: True values after scaling.

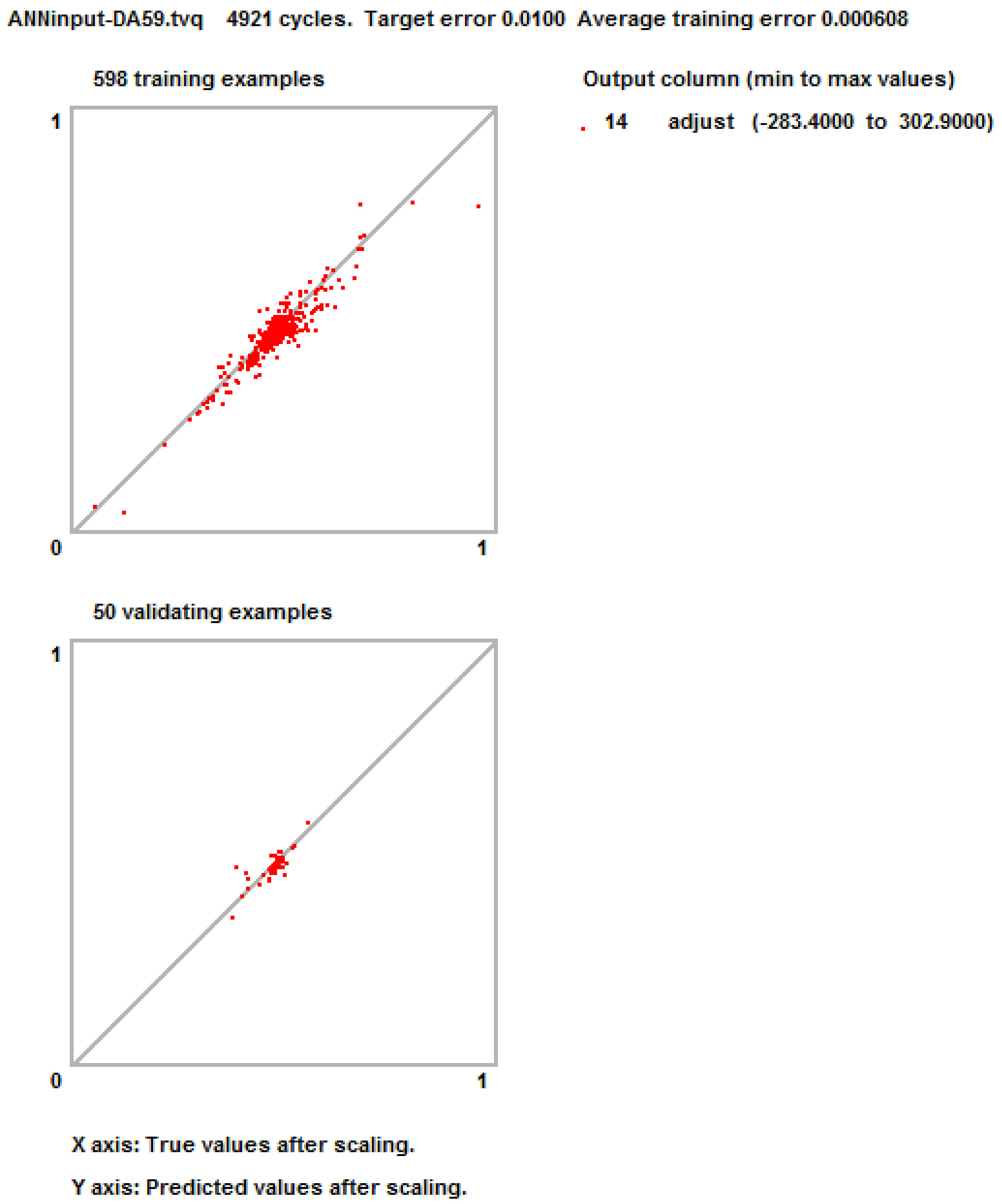
Y axis: Predicted values after scaling.

Figure 3-9: ANN Adjustments vs. Observed SR-6 (DA65) North Delta Streams



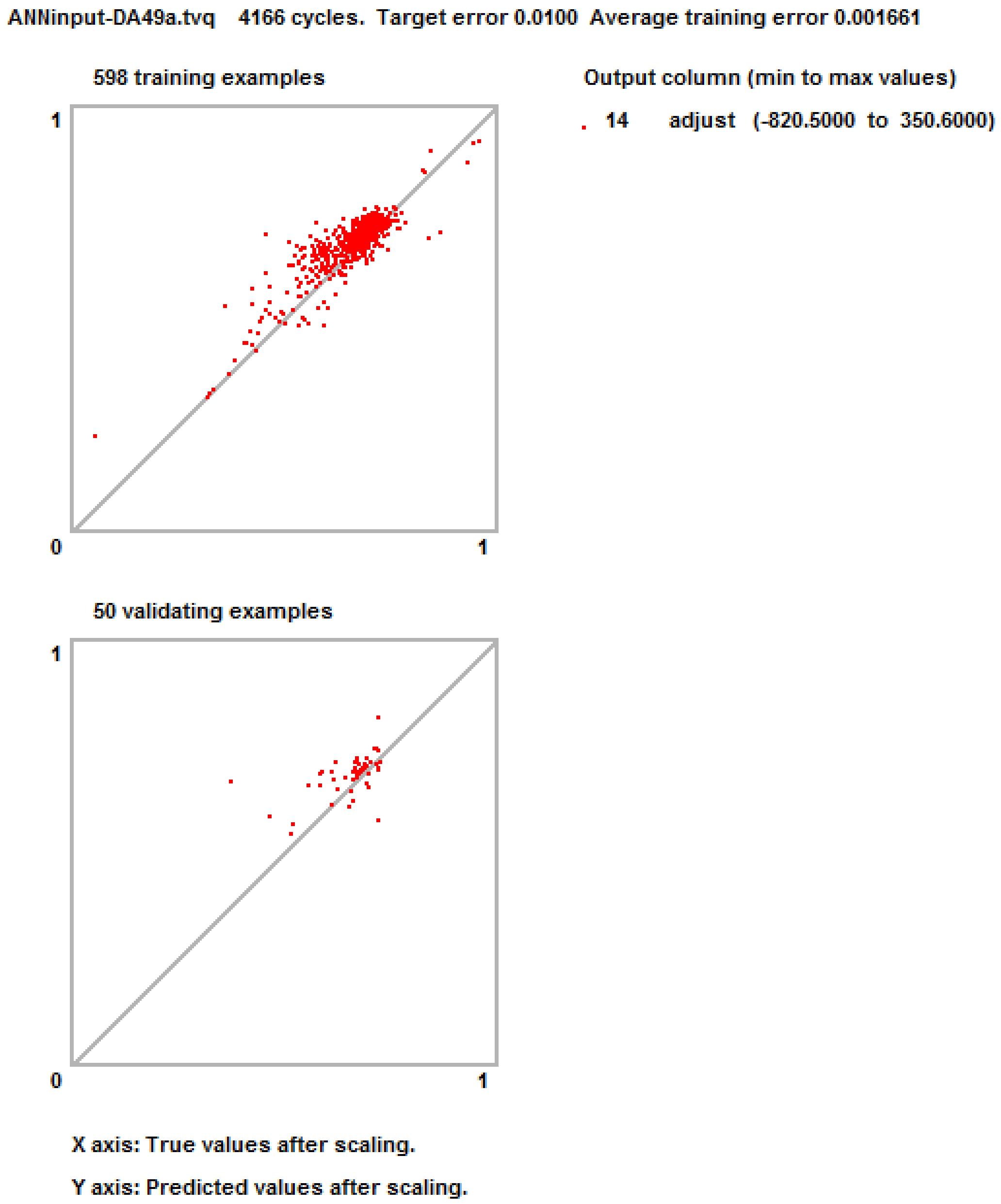
```
ANNinput-DA70.tvq   13701 cycles.  Target error 0.0100  Average training error 0.000478

Output column (min to max values)
.  14     adjust  (-1268.9000  to  2058.1000)

X axis: True values after scaling.
Y axis: Predicted values after scaling.
```

Figure 3-10: ANN Adjustments vs. Observed SR-7 (DA70) Sacramento River at Sacramento (American River Basin)



```
ANNinput-DA59.tvq    4921 cycles.  Target error 0.0100  Average training error 0.000608

598 training examples                    Output column (min to max values)

                                         14      adjust   (-283.4000  to  302.9000)

50 validating examples

X axis: True values after scaling.

Y axis: Predicted values after scaling.
```

Figure 3-11: ANN Adjustments vs. Observed SR-8 (DA59) Valley Floor East of the Delta (Eastside Streams)



ANNinput-DA49a.tvq 4166 cycles. Target error 0.0100 Average training error 0.001661

598 training examples

Output column (min to max values)

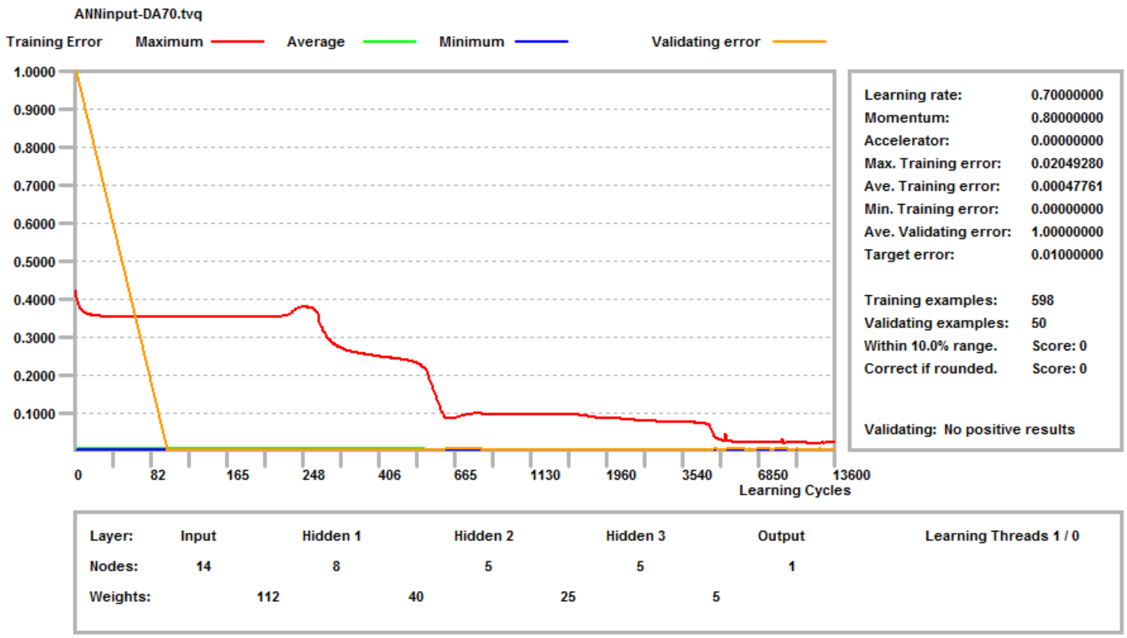
14 adjust (-820.5000 to 350.6000)

50 validating examples

X axis: True values after scaling.

Y axis: Predicted values after scaling.

Figure 3-12: ANN Adjustments vs. Observed SR-10 (DA49a) San Joaquin River at Vernalis (San Joaquin Valley)

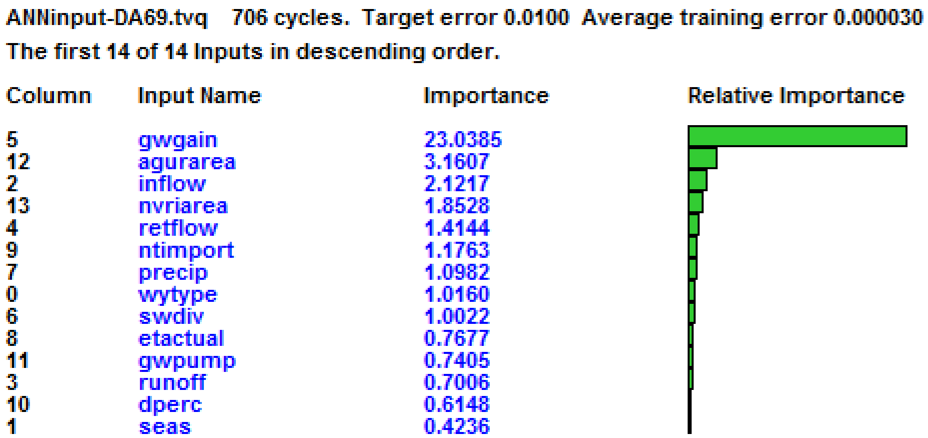


```
Learning rate:          0.70000000
Momentum:               0.80000000
Accelerator:            0.00000000
Max. Training error:    0.02049280
Ave. Training error:    0.00047761
Min. Training error:    0.00000000
Ave. Validating error:  1.00000000
Target error:           0.01000000

Training examples:      598
Validating examples:    50
Within 10.0% range.     Score: 0
Correct if rounded.     Score: 0

Validating:  No positive results
```

```
Layer:     Input       Hidden 1      Hidden 2      Hidden 3      Output        Learning Threads 1 / 0
Nodes:     14          8             5             5             1
Weights:          112           40            25            5
```

Figure 3-13: ANN Training Process for SR-7 (DA70) American River Basin

Another bi-product of the ANN process is a listing of which input variables play larger roles in computing the adjustment values. Figure 3-14 shows the importance and relative importance of input variables in impacting the adjustment value for SR-5. The importance is computed as *"…the sum of the absolute weights of the connections from the input neuron to all the other neurons in the first hidden layer*" (ENNplus 2017). As shown in Figure 3-14 for the Feather River Basin (SR-5 or DA69) – and area dominated by highly permeable volcanic rocks) the stream-aquifer interaction (groundwater gain or "gwgain") is by far the dominant variable for that sub-region.

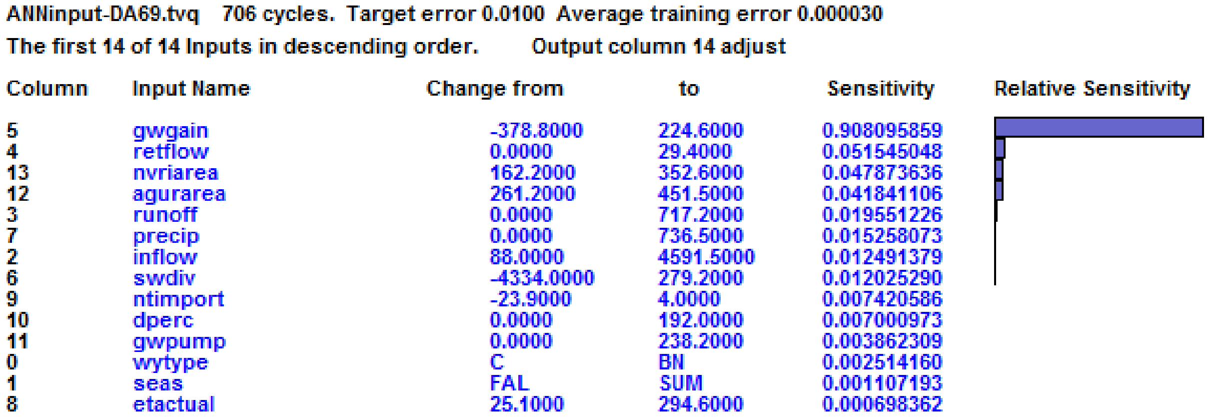

ANNinput-DA69.tvq 706 cycles. Target error 0.0100 Average training error 0.000030

The first 14 of 14 Inputs in descending order.

Column	Input Name	Importance
5	gwgain	23.0385
12	agurarea	3.1607
2	inflow	2.1217
13	nvriarea	1.8528
4	retflow	1.4144
9	ntimport	1.1763
7	precip	1.0982
0	wytype	1.0160
6	swdiv	1.0022
8	etactual	0.7677
11	gwpump	0.7405
3	runoff	0.7006
10	dperc	0.6148
1	seas	0.4236

Figure 3-14: Relative Importance of the Input Variables in ANN for SR-5 (DA69) Feather River Basin

Figure 3-15 shows sensitivity and the relative sensitivity of the input variables (how much the adjustment changes when the inputs are changed). "*The inputs are all set to the median values and then each in turn is increased from the lowest value to the highest value. The change in the output is measured as each input is increased from lowest to highest to establish the sensitivity to change*" (ENNplus 2017). Again, for SR-5 the adjustment is most sensitive to the stream-aquifer interaction. Appendix B includes the results for "importance" and "sensitivity" for all the other sub-regions. As a summary, Table 3-4 and Table 3-5 list the top three variables for each sub-region for both "importance" and "sensitivity", as described for SR-5 earlier. Both tables show that the dominant variables impacting an adjustment for most sub-regions are inflow to the sub-region, stream-aquifer interaction (or groundwater gain), and surface water diversions (which include bypass flows into, or out of the sub-region).



```
ANNinput-DA69.tvq    706 cycles.  Target error 0.0100  Average training error 0.000030
The first 14 of 14 Inputs in descending order.        Output column 14 adjust

Column      Input Name                 Change from          to          Sensitivity       Relative Sensitivity

5           gwgain                          -378.8000       224.6000      0.908095859
4           retflow                         0.0000          29.4000       0.051545048
13          nvriarea                        162.2000        352.6000      0.047873636
12          agurarea                        261.2000        451.5000      0.041841106
3           runoff                          0.0000          717.2000      0.019551226
7           precip                          0.0000          736.5000      0.015258073
2           inflow                          88.0000         4591.5000     0.012491379
6           swdiv                           -4334.0000      279.2000      0.012025290
9           ntimport                        -23.9000        4.0000        0.007420586
10          dperc                           0.0000          192.0000      0.007000973
11          gwpump                          0.0000          238.2000      0.003862309
0           wytype                          C               BN            0.002514160
1           seas                            FAL             SUM           0.001107193
8           etactual                        25.1000         294.6000      0.000698362
```

Figure 3-15: Relative Sensitivity of the Input Variables in ANN for SR-5 (DA69) Feather River Basin

Table 3-4: Top Three Variables Affecting Value of Adjustment

Sub-region	Top Three Variables Impacting Adjustment for Sub-region		
	Rank 1	Rank 2	Rank 3
SR-1	swdiv	inflow	dperc
SR-2	inflow	dperc	gwgain
SR-4	gwgain	inflow	runoff
SR-5	gwgain	agurarea	inflow
SR-6	swdiv	gwgain	dperc
SR-7	inflow	runoff	dperc
SR-8	retflow	gwgain	runoff
SR-10	gwgain	inflow	seas

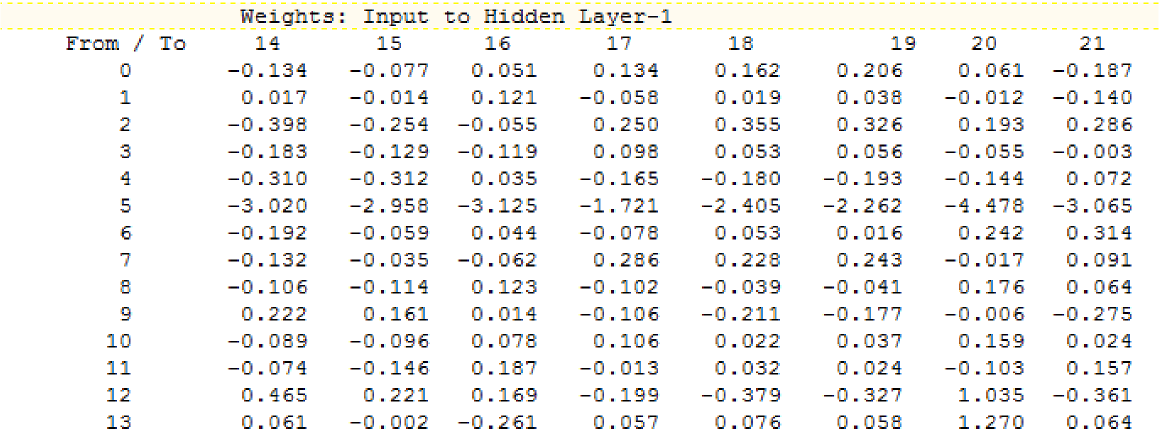
Table 3-5: Top Three Variables Affecting Sensitivity of Adjustment

Sub-region	Top Three Variables Impacting Sensitivity for Sub-region		
	Rank 1	**Rank 2**	**Rank 3**
SR-1	swdiv	inflow	runoff
SR-2	runoff	inflow	gwpump
SR-4	gwgain	swdiv	runoff
SR-5	gwgain	retflow	nvriarea
SR-6	swdiv	retflow	wytype
SR-7	swdiv	dperc	inflow
SR-8	gwgain	runoff	precip
SR-10	precip	nvriarea	ntimport

3.3 ANN Stand Alone Module to Compute Adjustments to Outflows

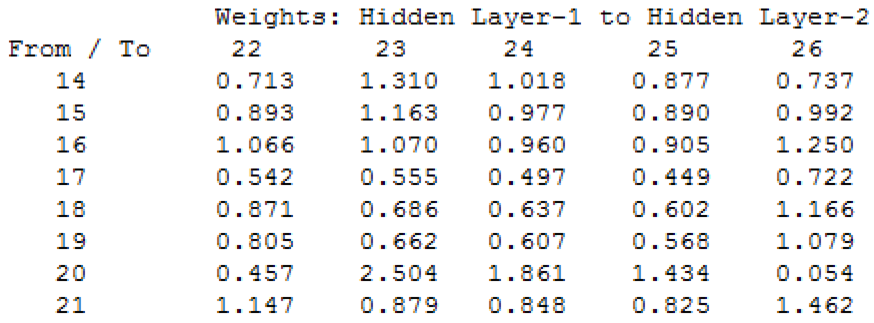
Output from the ANN procedure described in Section 3.1 include the "weights" and "biases" that can be used to compute the adjustments using Eq 3-1 through Eq 3-4.

It is a straightforward procedure to develop a FORTAN code that uses as input the values of variables listed in Table 3-1, and use Eq 3-1 through Eq 3-4 to compute the monthly adjustment for each sub-region. An example of the weights and biases for SR-5 is shown in Figure 3-16a through Figure 3-16e. The node numbering used in the figures can be found in Figure3-4. The FORTAN code is listed in Appendix C.



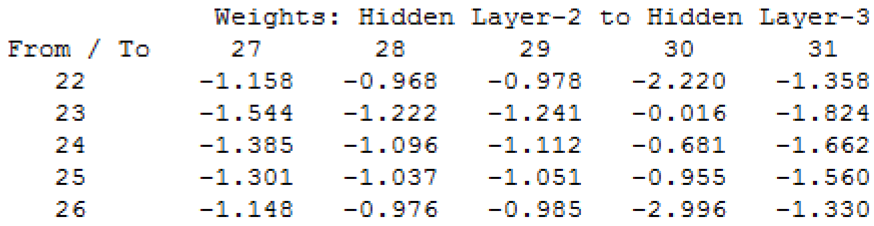
```
                    Weights: Input to Hidden Layer-1
     From / To       14         15        16         17         18            19       20        21
         0         -0.134     -0.077     0.051      0.134      0.162      0.206      0.061    -0.187
         1          0.017     -0.014     0.121     -0.058      0.019      0.038     -0.012    -0.140
         2         -0.398     -0.254    -0.055      0.250      0.355      0.326      0.193     0.286
         3         -0.183     -0.129    -0.119      0.098      0.053      0.056     -0.055    -0.003
         4         -0.310     -0.312     0.035     -0.165     -0.180     -0.193     -0.144     0.072
         5         -3.020     -2.958    -3.125     -1.721     -2.405     -2.262     -4.478    -3.065
         6         -0.192     -0.059     0.044     -0.078      0.053      0.016      0.242     0.314
         7         -0.132     -0.035    -0.062      0.286      0.228      0.243     -0.017     0.091
         8         -0.106     -0.114     0.123     -0.102     -0.039     -0.041      0.176     0.064
         9          0.222      0.161     0.014     -0.106     -0.211     -0.177     -0.006    -0.275
        10         -0.089     -0.096     0.078      0.106      0.022      0.037      0.159     0.024
        11         -0.074     -0.146     0.187     -0.013      0.032      0.024     -0.103     0.157
        12          0.465      0.221     0.169     -0.199     -0.379     -0.327      1.035    -0.361
        13          0.061     -0.002    -0.261      0.057      0.076      0.058      1.270     0.064
```

Figure 3-16a: SR-5 Feather River Basin ANN Weights: Input Layer to Hidden Layer-1



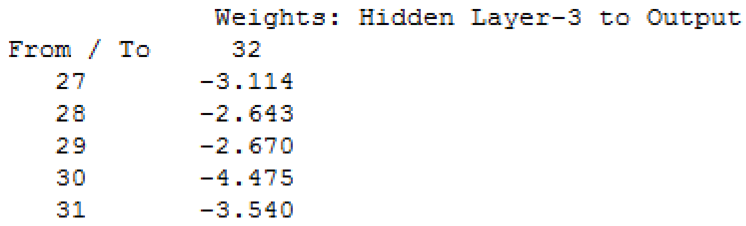
```
                  Weights: Hidden Layer-1 to Hidden Layer-2
From / To          22        23        24        25        26
    14           0.713     1.310     1.018     0.877     0.737
    15           0.893     1.163     0.977     0.890     0.992
    16           1.066     1.070     0.960     0.905     1.250
    17           0.542     0.555     0.497     0.449     0.722
    18           0.871     0.686     0.637     0.602     1.166
    19           0.805     0.662     0.607     0.568     1.079
    20           0.457     2.504     1.861     1.434     0.054
    21           1.147     0.879     0.848     0.825     1.462
```

Figure 3-16b: SR-5 Feather River Basin ANN Weights: Hidden Layer-1 to Hidden Layer-2



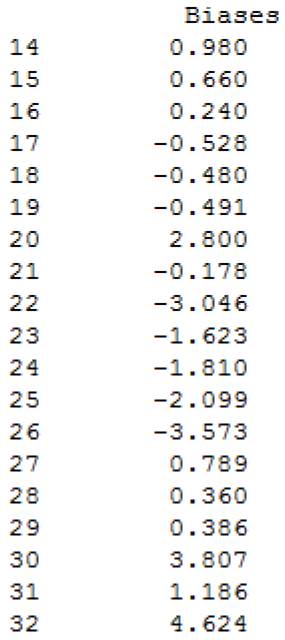
```
                  Weights: Hidden Layer-2 to Hidden Layer-3
From / To          27        28        29        30        31
    22          -1.158    -0.968    -0.978    -2.220    -1.358
    23          -1.544    -1.222    -1.241    -0.016    -1.824
    24          -1.385    -1.096    -1.112    -0.681    -1.662
    25          -1.301    -1.037    -1.051    -0.955    -1.560
    26          -1.148    -0.976    -0.985    -2.996    -1.330
```

Figure 3-16c: SR-5 Feather River Basin ANN Weights: Hidden Layer-2 to Hidden Layer-3



```
                  Weights: Hidden Layer-3 to Output
From / To          32
    27          -3.114
    28          -2.643
    29          -2.670
    30          -4.475
    31          -3.540
```

Figure 3-16d: SR-5 Feather River Basin ANN Weights: Hidden Layer-3 to Output Layer



```
             Biases
  14          0.980
  15          0.660
  16          0.240
  17         -0.528
  18         -0.480
  19         -0.491
  20          2.800
  21         -0.178
  22         -3.046
  23         -1.623
  24         -1.810
  25         -2.099
  26         -3.573
  27          0.789
  28          0.360
  29          0.386
  30          3.807
  31          1.186
  32          4.624
```

Figure 3-16e: SR-5 Feather River Basin ANN Biases

3.4 Regression Equations for Weirs on the Sacramento River

C2VSIM models three relief structures (weirs) on the Sacramento River as bypasses (Figure 2-4 and 2-5): Sutter Bypass, Fremont weir, and Sacramento weir. The Sutter bypass is the aggregation of Moulton, Colusa, and Tisdale weirs (Figure 3-17). In the historical run C2VSIM inputs the weir spills as a pre-defined time series. However, for planning purposes it is important to define a relationship between the upstreamflow of the weir location, and the weir spill itself so as to compute the spills dynamically within the simulation model. Using regression analysis it is possible to determine these relationships as described below.

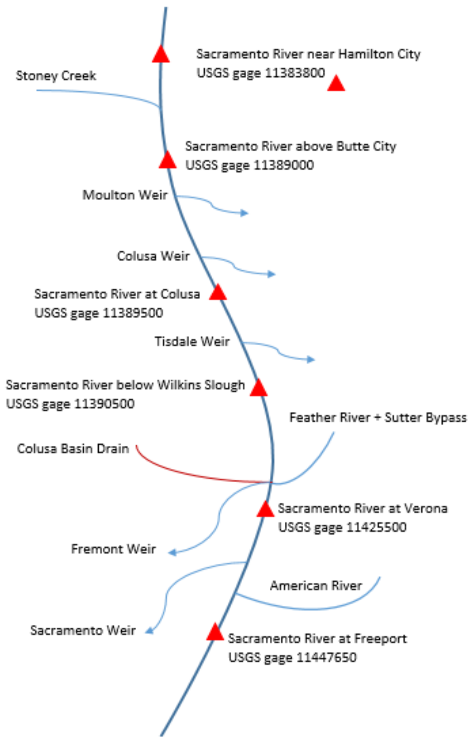


Figure 3-17: Weirs on the Sacramento River Modeled in C2VSIM

Using historical measurements at gaged locations (aggregated to monthly), and the quantities of spills (aggregated to monthly), a piecewise linear regression curve was developed for each of the three weirs (Moulton, Colusa, and Tisdale combined into one) using Minitab ®. The historical data for Sacramento River flow above the weirs and the associated weir spills are shown in Figure 3-18 through 3-20. Using Minitab ® the following piecewise linear regression equations were derived:

$$\text{Spill}_{\text{MCT}} = 5.90 + 0.0035 * \text{Flow}_{\text{MCT}} + 0.829 * (\text{Flow}_{\text{MCT}} - 1100) * \text{X2}_{\text{MCT}} \quad \ldots\ldots\ldots\ldots \quad (3.5)$$

$$\text{Spill}_{\text{F}} = 2.60 + 0.0006 * \text{Flow}_{\text{F}} + 0.741 * (\text{Flow}_{\text{F}} - 2460) * \text{X2}_{\text{F}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.6)$$

$$\text{Spill}_{\text{S}} = 21.1 + 0.0003 * \text{Flow}_{\text{S}} + 0.359 * (\text{Flow}_{\text{S}} - 3000) * \text{X2}_{\text{S}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.7)$$

With R^2 = 93.7%, 95.9%, and 24.1%, respectively.

The X2 parameters shown in the above equations are binary variables.

Where (all flows are monthly):

$\text{Spill}_{\text{MCT}}$ = Spill at Moulton + Colusa + Tisdale weirs in TAF

Spill_{F} = Spill at Fremont weir in TAF

Spill_{S} = Spill at Sacramento weir in TAF

Flow_{MCT} = Sacramento River flow upstream of MCT weirs in TAF

Flow_{F} = Sacramento River flow upstream of Fremont weir in TAF

Flow_{S} = Sacramento River flow upstream of Sacramento weir in TAF

X2_{MCT}: = 0 if Flow_{MCT} <= 1100 TAF/mon, = 1 if Flow_{MCT} > 1100 TAF

X2_{F}: = 0 if Flow_{MCT} <= 2460 TAF/mon, = 1 if Flow_{MCT} > 2460 TAF

X2_{S}: = 0 if Flow_{MCT} <= 3000 TAF/mon, = 1 if Flow_{MCT} > 3000 TAF

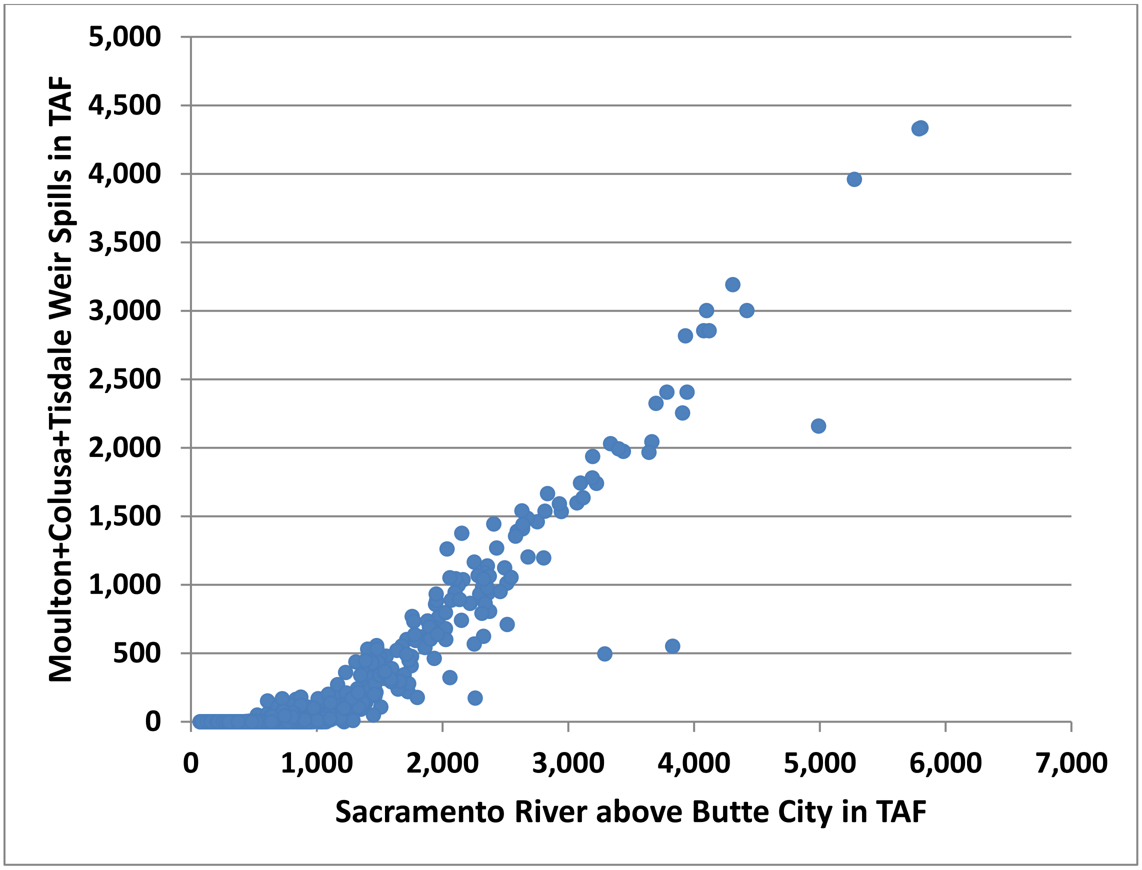


Figure 3-18: Historical Sacramento River above Butte City and MCT Weirs Spills

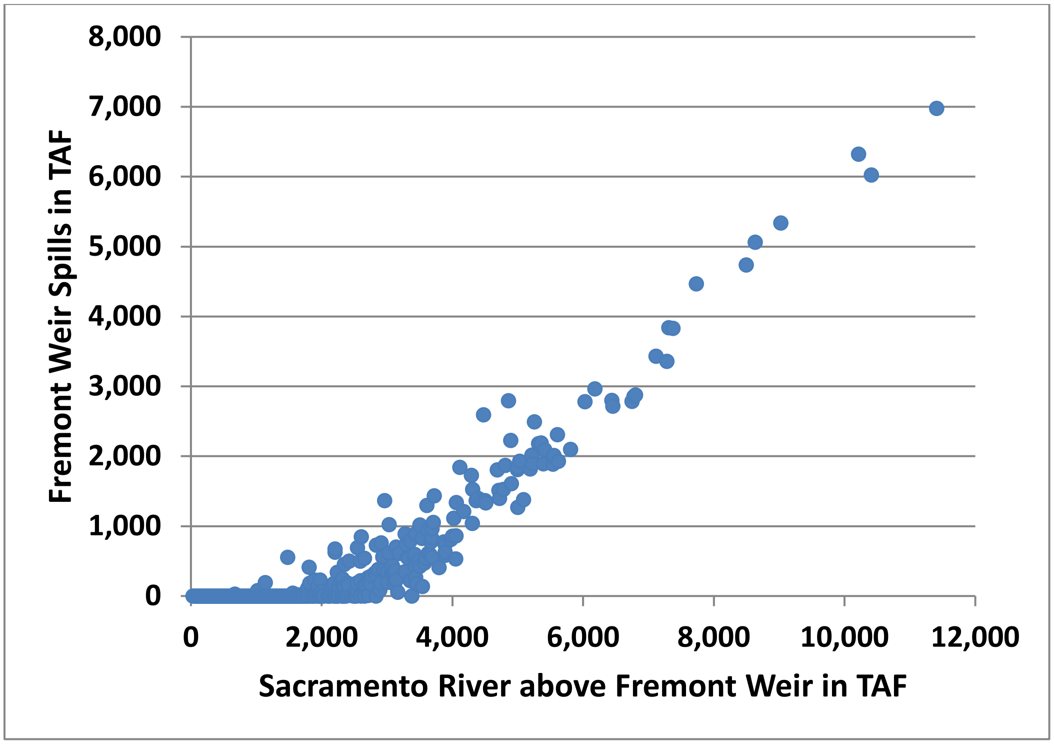


Figure 3-19: Historical Sacramento River above Fremont Weir and Fremont Weir Spills

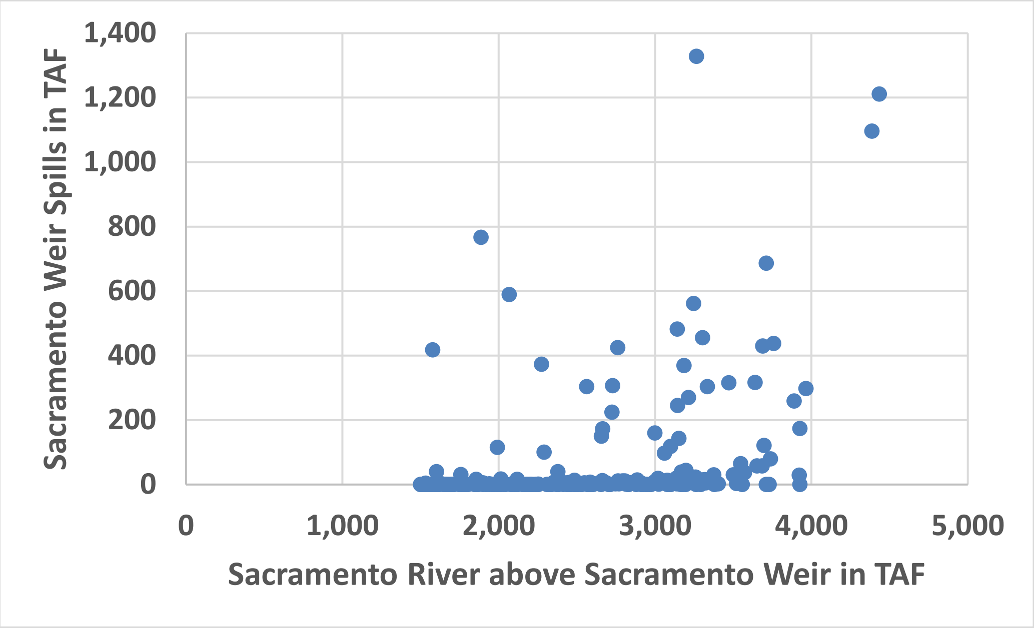


Figure 3-20: Historical Sacramento River above Sacramento Weir and Sacramento Weir Spills

Fgures 3-21 through 3-23 show scatter diagrams between the “observed” and predicted spills using Equations 3-5 through 3-7. The regression equations for both MCT and Fremont weirs show good correlations (> 93%) whereas for the Sacramento weir the correlation is very poor (24%). The main reason is that the “observed” estimates for the Sacramento weir are poorly estimated with no pattern (Figure 3-20) and difficult to simulate. Fortunately most of the weir flows upstream of the Delta take place at the MCT and Fremont weirs before reaching the Sacramento weir.

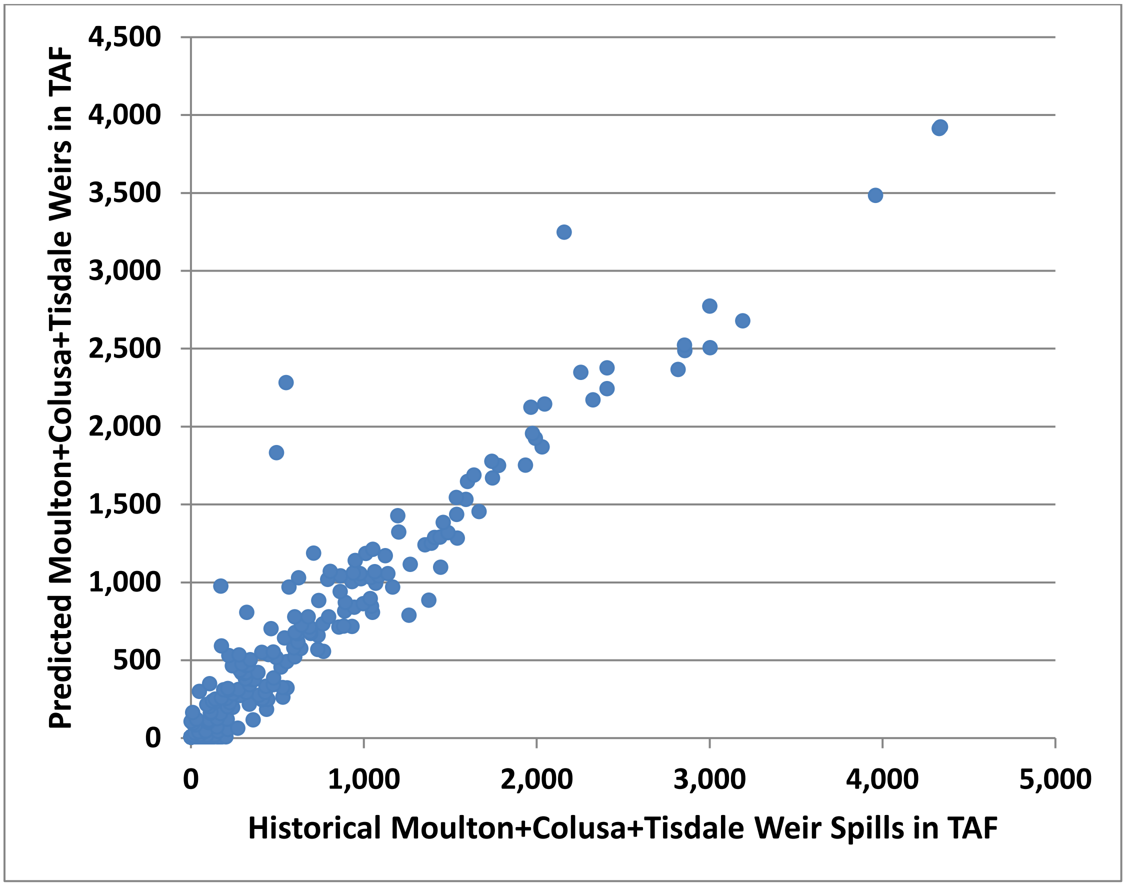


Figure 3-21: Historical vs. Predicted MCT Weirs Flows

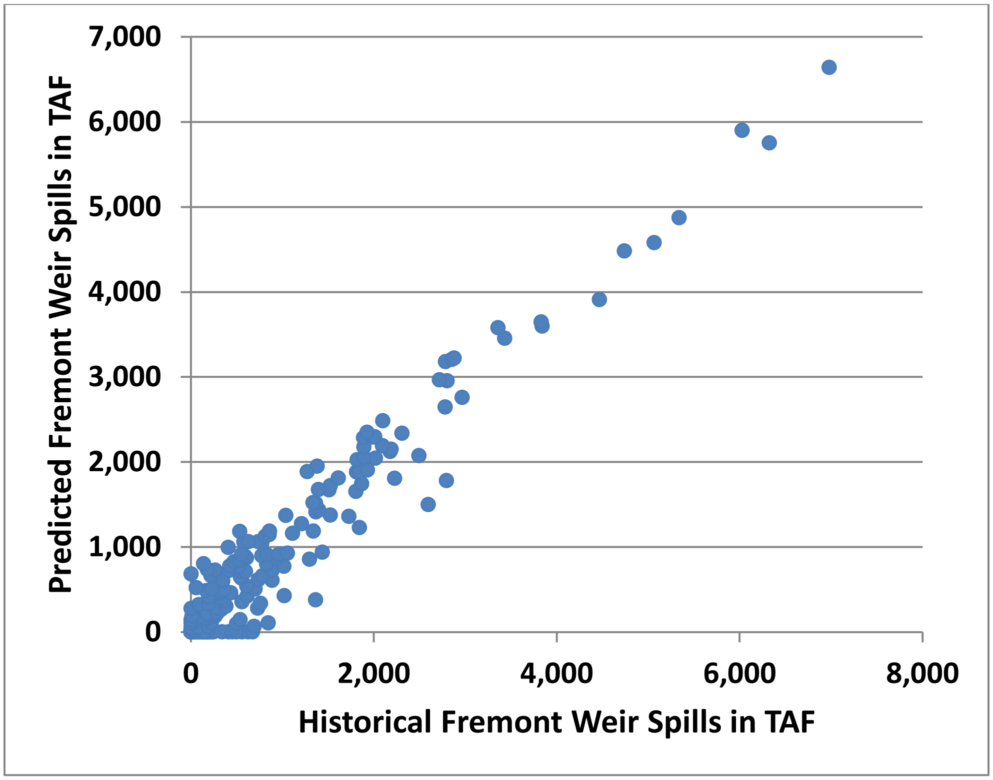


Figure 3-22: Historical vs. Predicted Fremont Weir Flows

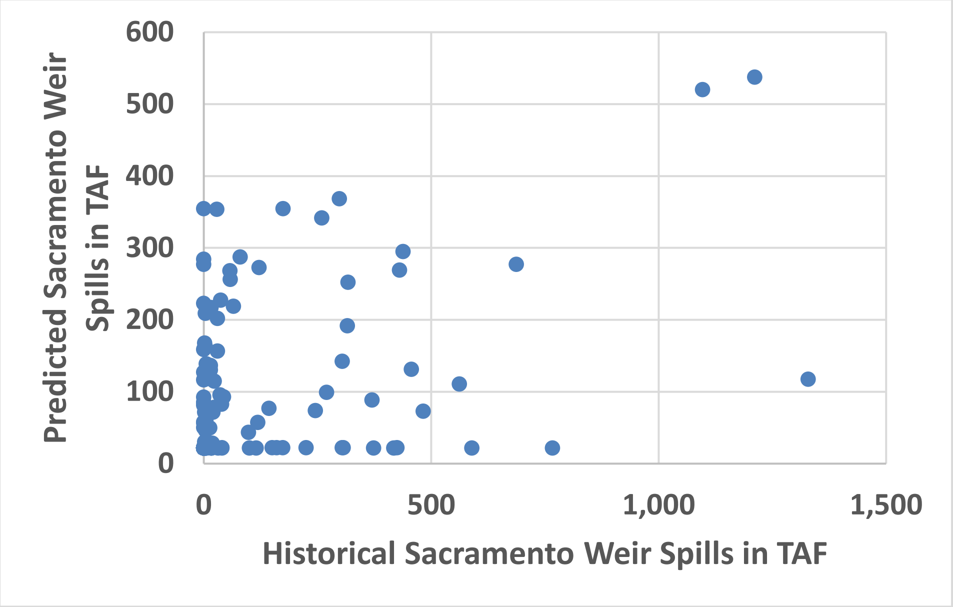
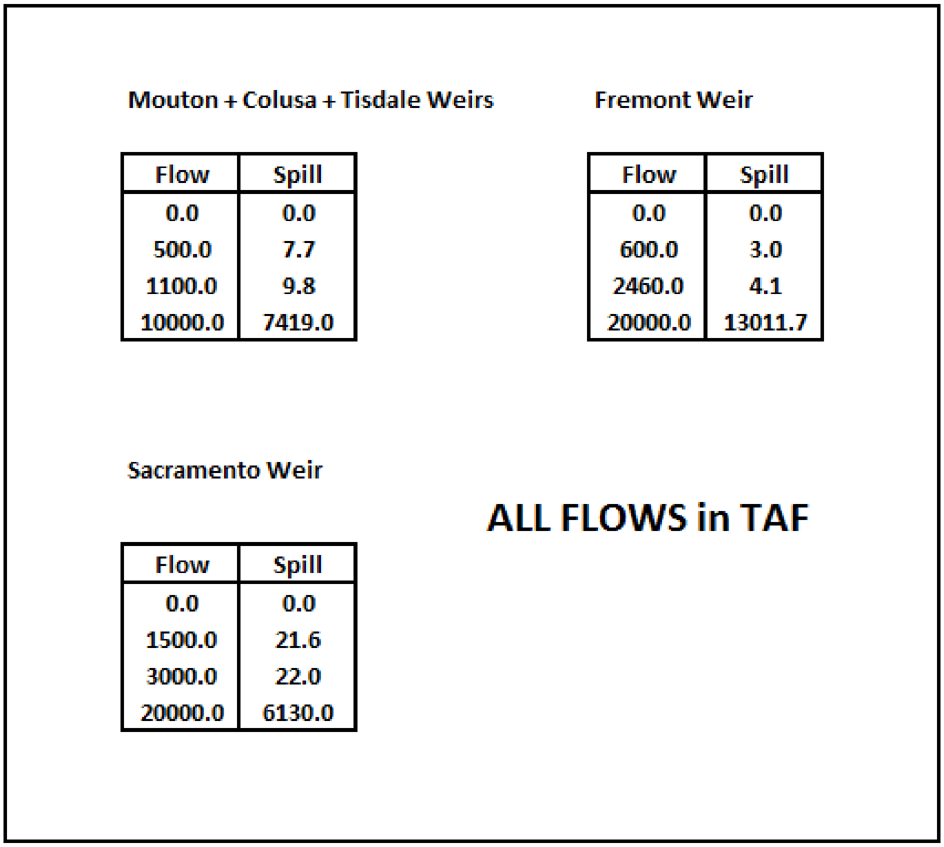


Figure 3-23: Historical vs. Predicted Sacramento Weir Flows

The break points shown in Equations 3-5 through 3-7 (1100, 2460, and 3000 respectively) were chosen by visual inspection of the data (Figures 3-18 through 3-20) and to ensure that slope coefficients in Equations 3-5 through 3-7 are all positive. The main reason is that C2VSIM models bypasses only using convex rating curves as input, to avoid convergence issues when using the iterative Newton-Raphson procedure for solving C2VSIM non-linear equations internally. Based on Equations 3-5 through 3-7 the rating curves (piecewise linear) derived for use in C2VSIM are summarized in Figure 3-24.



Mouton + Colusa + Tisdale Weirs

Flow	Spill
0.0	0.0
500.0	7.7
1100.0	9.8
10000.0	7419.0

Fremont Weir

Flow	Spill
0.0	0.0
600.0	3.0
2460.0	4.1
20000.0	13011.7

Sacramento Weir

Flow	Spill
0.0	0.0
1500.0	21.6
3000.0	22.0
20000.0	6130.0

ALL FLOWS in TAF

Figure 3-24: Weir Rating Table Coefficients for Use in C2VSIM

3.5 C2VSIM Historical Run with ANN Adjustments and Weirs Built-in

The final step in developing the new historical C2VSIM model is to integrate the ANN parameters developed in Section 3-1, the code to implement ANN presented in Section 3-2, include bypass (weir) curves developed in Section 3-3, into the IWFM code to simulate the adjustments and weir spills dynamically. This required extensive modifications to the FORTRAN code for IWFM and developing new modules for implementing the new procedures. The code also underwent extensive testing to ensure that the ANN's were implemented correctly. The

ANN’s were built in to dynamically estimate the monthly adjustments but applied only for the period WY1950-2003 for the reason explained previously that the model is to be used for planning (future levels of development). The historical simulation itself, however, is still WY1922-2003. The ANN module was built into IWFM with the flexibility of input-based instructions to either turn on or turn off individual sub-region computations. The main reason is that if ANN results were unreasonable they could be turned off (de-activated).

Table 3-6 and Figure 3-25 show the long term WY1950-2003 month average Delta inflows for both historical observed and simulated (both with and without ANN adjustments activated). In Table 3-6 the top row “HQ” is monthly historical observed (gaged) flows. The “No Adjust” row is the simulation with all ANN adjustments turned off. The “With ANN (inc ANN70)” row is the historical simulation Delta inflow with all sub-region ANN’s activated. The last row “With ANNs (No ANN70) is Delta inflow with all sub-regions ANN’s activated except for SR-7 (DA70), the American River Basin.

Table 3-6: Average Monthly WY1922-2003 Delta Inflow for Historical C2VSIM with ANN Simulated Dynamically in TAF

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
HQ	1023	961	1204	2297	3583	3804	3534	2531	2075	1474	1134	1031	24652
No Adjust	1068	1456	2458	3615	3757	3508	2685	2153	1490	1159	1004	1046	25399
With ANN (inc ANN70)	961	1280	2282	3595	3860	3489	2578	2088	1504	1201	1002	1031	24871
With ANNs (No ANN70)	980	1357	2432	3659	3799	3430	2546	2027	1454	1123	902	927	24635

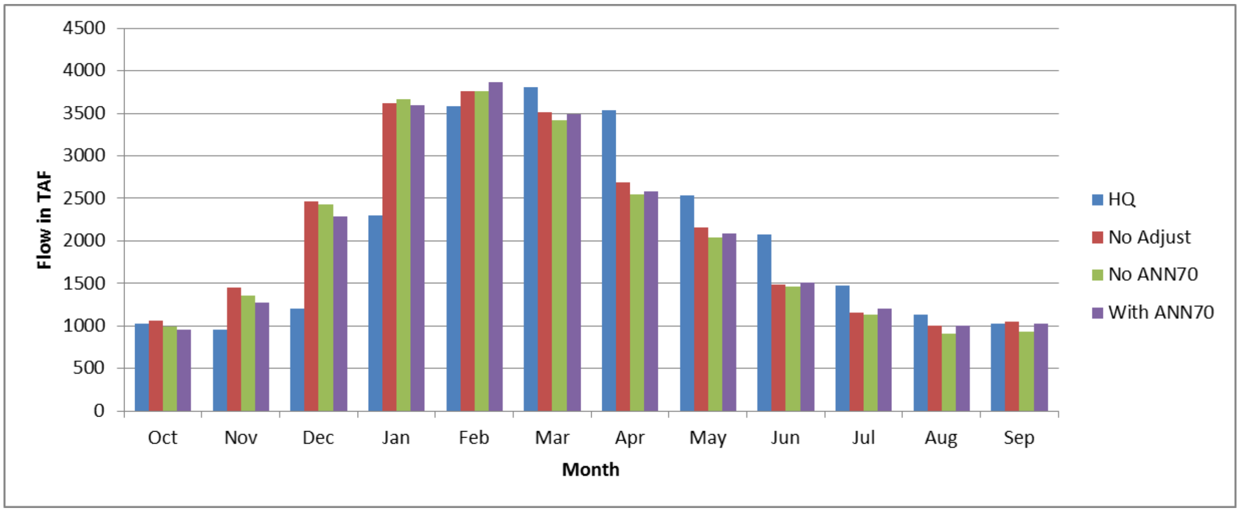


Figure 3-25: Monthly Average Historical and Simulated Delta Inflow

Figures 3-26 through 3-29 are the box and whisker plots of the monthly averages shown in Table 3-6. Figure 3-30 shows long term (1950-2003) monthly averages for simulated Delta inflow (without ANN’s) and the difference between the simulated and observed. Figure 3-30 shows that simulated Delta inflow are overestimated for the Fall/Winter months, and underestimated for the Spring/Summer months. Figure 3-31 shows long term WY1950-2003 simulated Delta inflows with and without including DA70. By not including ANN70 the error - compared to observed values - is an overestimation of 87TAF, whereas by including ANN70 the overestimation is about 220 TAF annually. By not including any ANN's (no adjustments) the long term overestimation of simulated Delta Inflow is 732TAF. Figure 3-32 shows the cumulative difference between simulated and observed annual inflow to the Delta for the long term WY1950-2003 period for the three cases listed in Table 3-6: No ANN's, All ANN's activated, All but SR-7 ANN activated. As Figure 3-30 shows turning off the ANN for SR-7 gave better results than with the ANN for that sub-region turned on. While the ANN formulation for SR—7 is very good (Figure 3-10) including it actually gave worse results. This is explainable by the fact that the stand alone ANN developed earlier in this chapter assumes that the inflow (an ANN input variable) is "perfect". However once the ANN modules are activated in C2VSIM they operated on any simulated upstream inflow. Therefore any accumulated errors from upstream sub-regions (since the model is not perfect) will be reflected in the inflow to SR-7 (the most downstream sub-region, see also Table 3-4 for ranked variables affecting adjustment calculations by sub-region). At this point there are three options: turn off the ANN for SR-70, keep the ANN for SR-70 activated, or develop a whole new ANN for SR-70 that accounts for the new sub-region simulated inflows. The second option is inferior to the first as shown in Figure 3-30. The third option requires further study since now it requires developing cascading ANN formulations (compared the procedure described earlier in this chapter). Therefore for subsequent runs discussed in this research it is implied that "with ANNs" implies with all sub-region ANN's except SR-7.

Figure 3-29 shows the clear bias built up by not including ANN adjustments. With the ANN's (except SR-7) built in the cumulative error by the end of the simulation is near zero. One observation, however, is that while the adjustments reduce the error of simulated compared to observed it does not eliminate the inter-annual bias shown in Figure 3-30. This has significant impacts on project operations (Delta exports and Delta outflow) which are a limitation of using simulation models. However, there are ways to improve the situation:

- Improved ways to emulate the physical process affecting variables listed in Tables 3-3 and 3-4.

- Improved calibration of the simulation model by considering the dominant variables as shown in Tables 3-3 and 3-4.

- Improving the ANN applications by using two ANN representations for each subregion, one for the Fall/Winter season and one for the Spring/Summer season.

- Using the model in a comparative mode for evaluating results.

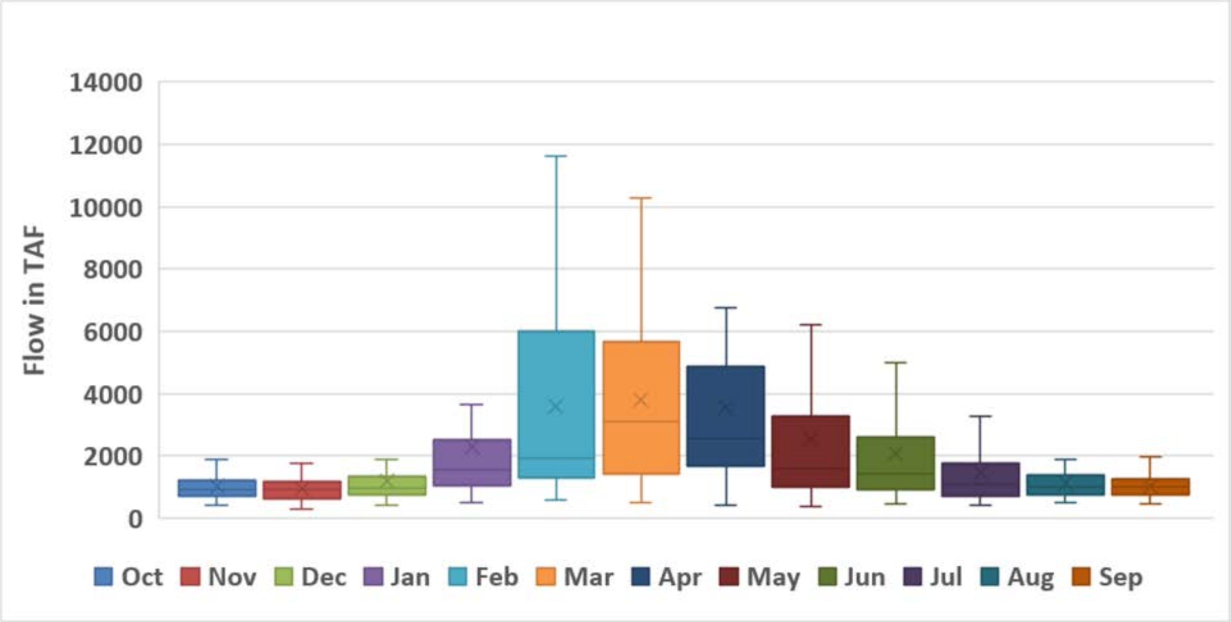


Figure 3-26: Monthly Average WY1950-2003 Historical Observed Delta Inflow

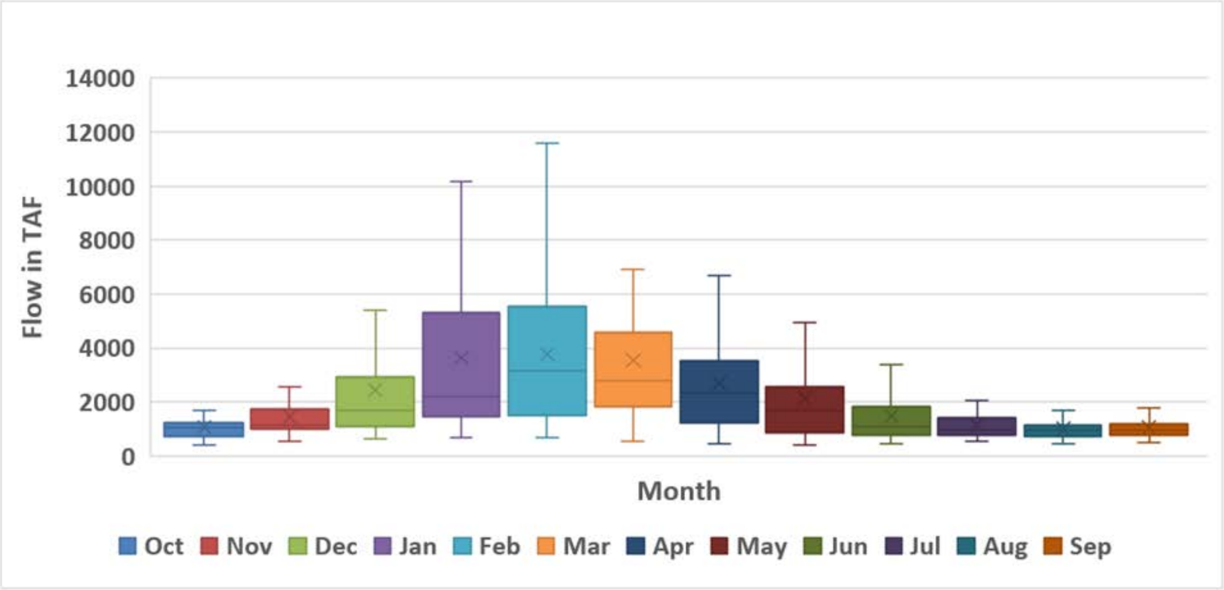


Figure 3-27: Monthly Average WY1950-2003 Simulated Historical Delta Inflow without ANN’s

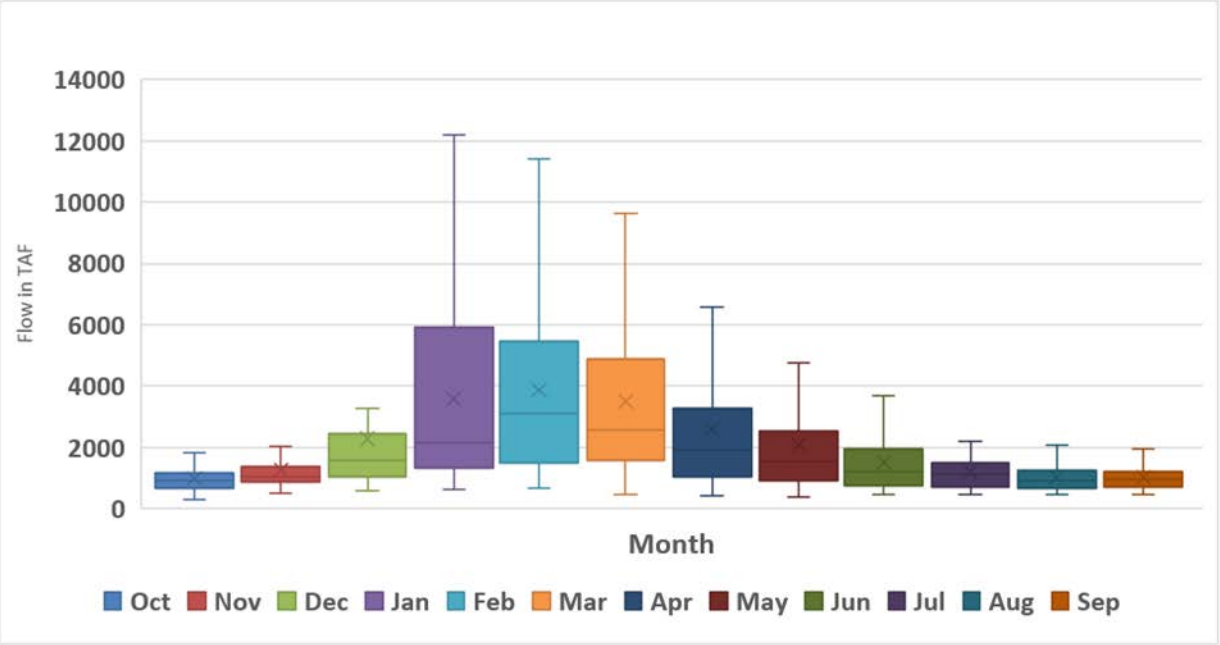


Figure 3-28: Monthly Average Simulated Historical Delta Inflow with all ANN's (including ANN70)

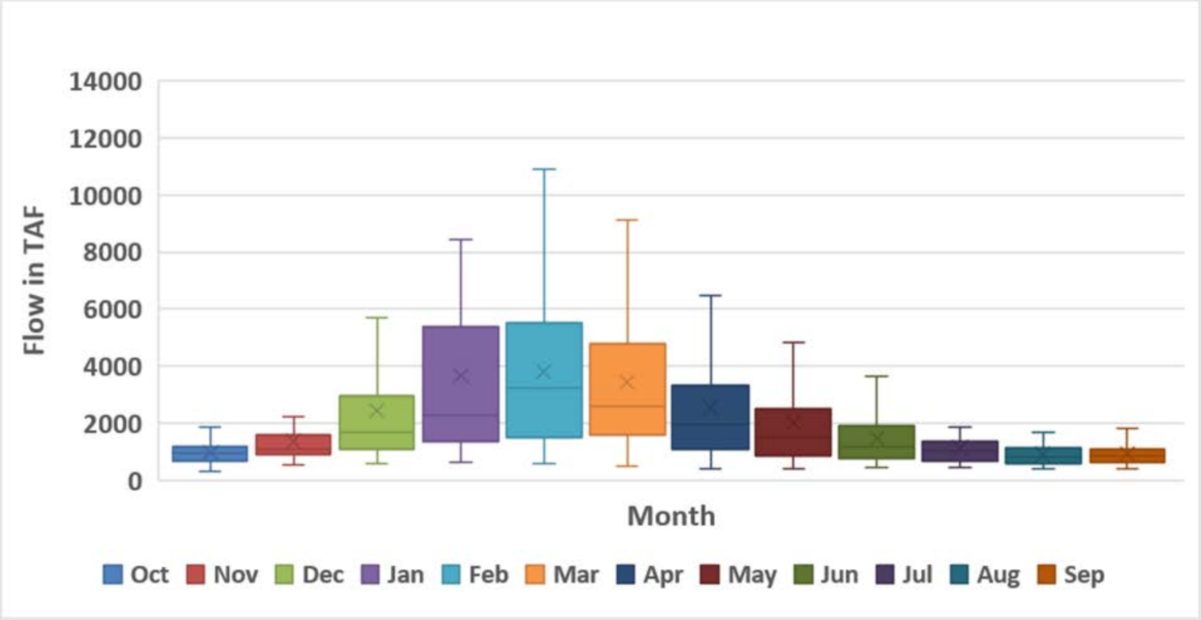


Figure 3-29: Monthly Average Simulated Historical Delta Inflow with all ANN's (excluding ANN70)

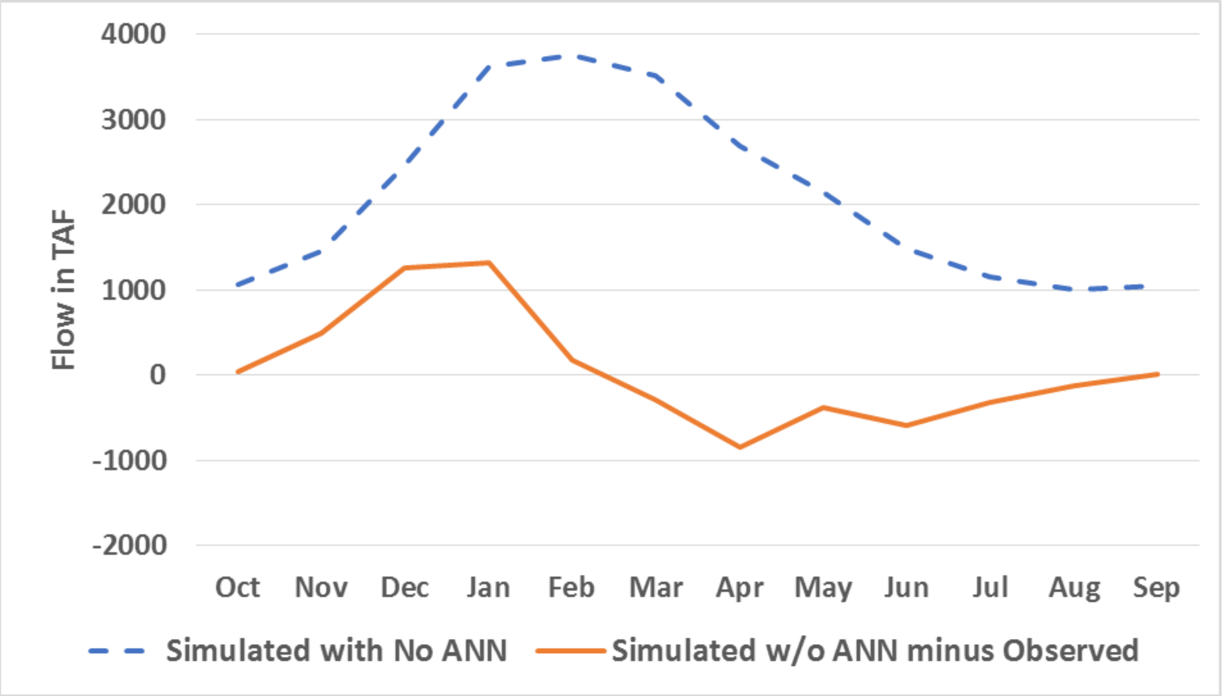


Figure 3-30: Monthly Average WY1950-2003 Observed Delta Inflow and Difference (Simulated w/o ANN's minus Observed)

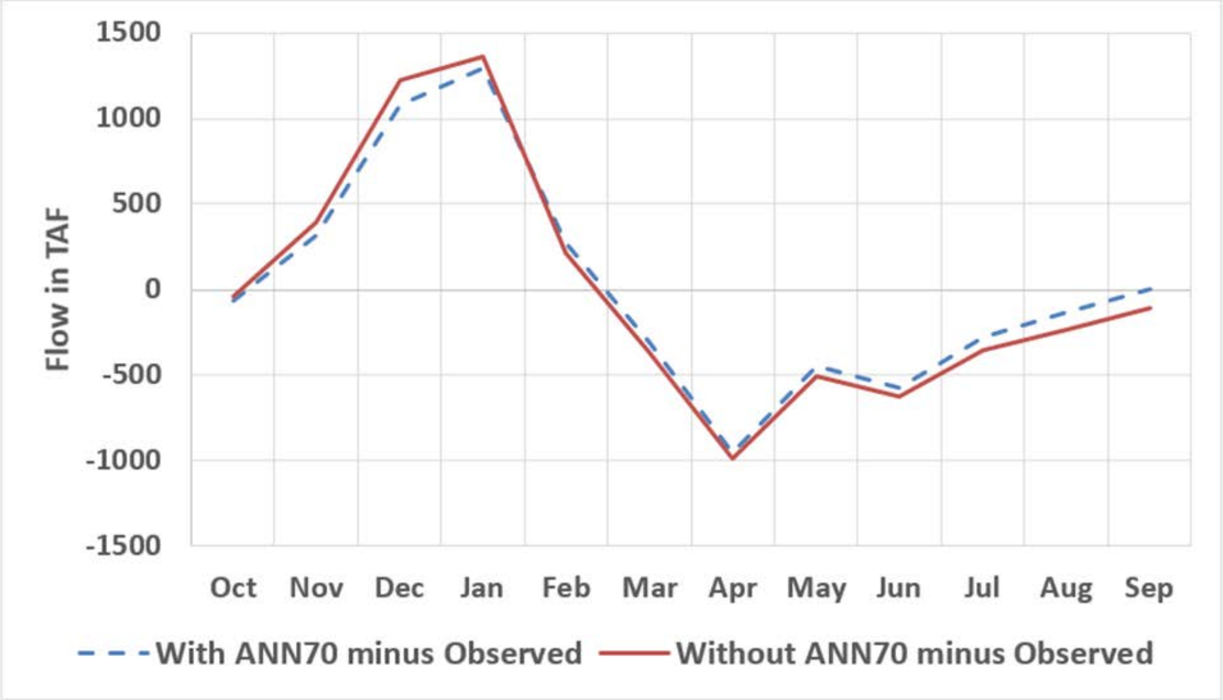


Figure 3-31: Monthly Average WY1950-2003 Simulated Delta Inflows using ANN's Minus Observed: With and Without ANN70

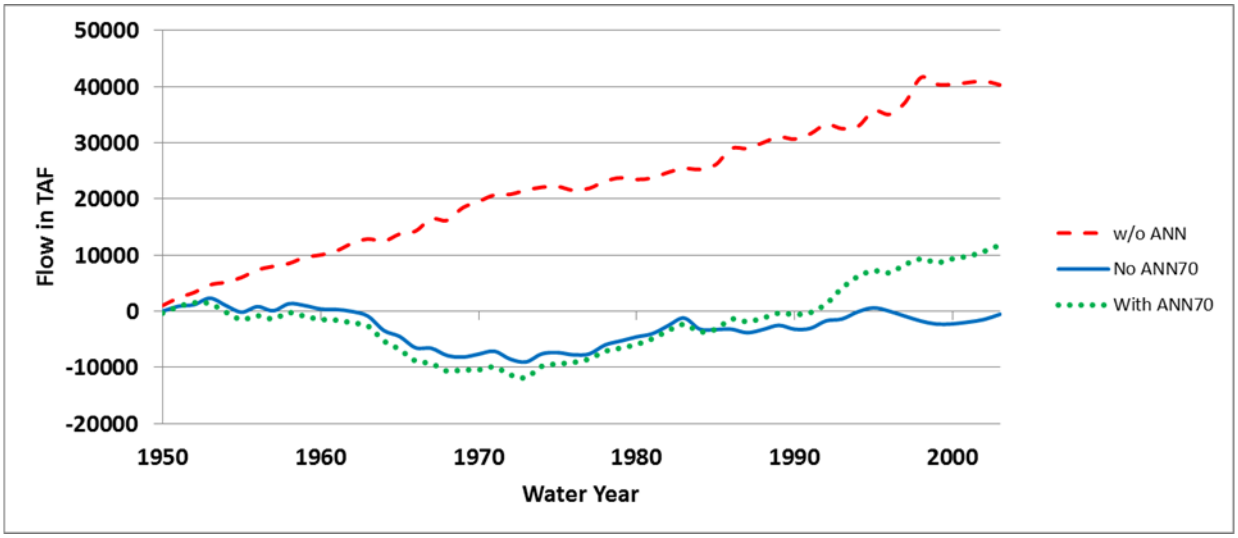


Figure 3-32: Cumulative Error of Inflow to the Delta Using C2VSIM With ANN vs. Without ANN

3.6 Discussion

It is first important to distinguish between the results presented in Chapter 2 compared to those presented in this chapter, even though both relied on a simulation of C2VSIM using historical hydrology. In Chapter 2 the adjustments were computed for each sub-region independently and built back into C2VSIM, thus ensuring that the simulated sub-regional outflows match the historical observed (gaged) outflows. In this chapter the adjustments were estimated using ANN for each sub-region, and any errors between simulated outflows with the ANN adjustments built in, and the actual observed flow cascades downstream through the system. In other words, the computed adjustment for a sub-region includes inflow from the upstream sub-region which itself includes the error between the observed and adjustment for the upstream sub-region.

The advantage of including ANN-based adjustments in the simulation versus not including them is exemplified by the Delta inflow as shown in Figure 3-29. This figure shows the difference between simulated inflow to the Delta and the observed inflow to the Delta for both with and without ANN's. The cumulative error over the simulation period by including ANN is near zero, whereas the cumulative error by not including the ANN's is nearly 40,000TAF with a clear increasing bias. This implies that without ANN's the Delta inflow is overestimated by 40,000 TAF, or nearly 1 million acre-feet a year. That considerable amount of water has significant impacts on reliability of planning studies, since Delta inflow impacts how projects are operated to meeting regulatory requirements (e.g., Delta outflow), and also the amount of exports from the Delta. For example, CDWR currently publishes every two years a report on the delivery capability of the State Water Project for use by planners and decision makers (CDWR 2015).

Obviously a large error in simulating inflow to the Delta decreases the simulation's reliability. Since exports from the Delta in the historical run of C2VSIM are fixed to actual historical, in this case the simulation substantially overestimates the Delta outflow. In the next three Chapters where exports are computed the issue becomes more relevant.

This chapter introduces the use of adjustments to modify simulated sub-regional stream outflow. Two important questions are:

1. Are the adjustments important and why?
2. Do the adjustments represent "real" water or "numerical" water?

In answer to the first question the adjustments have helped identify deficiencies in the simulation models, whether they are related to the underlying theoretical basis for the simulation, or data related, and impact results. Consequentially, the reliability of the simulation results by not including them is greater. Ideally zero adjustments would represent "perfect" models. However, improving models through calibration of parameters can only go so far, and even then may be inadequate for the modeling (Doherty 2015). Adjustments also serve another purpose, shown in this research, in that they can point to the dominating factors causing the need for adjustments. As shown in Tables 3-4 and 3-5 the top three factors affecting adjustments were inflows, surface water diversions, and stream-aquifer interaction. Stream-aquifer interaction can have a significant impact on sub-regions outflows. Models can be improved not only through additional calibration, but also by better theoretical representation in the simulation model (Morel-Seytoux et. al. 2014 and 2017, Mehl and Hill 2010). In other applications of IWFM, the adjustments may result from other dominating factors. By improving either modeling of physical processes or the data associated with the dominant factors, adjustment values would decrease, and reliability in model results increase. Including adjustments with a feedback to the dominant causes serve an important purpose in simulation models.

The second question stated is more difficult to answer. Technically one can create a "perfectly" calibrated model by creating unrealistic hydrological time series to ensure simulated and observed match. For example adding numerical water at a node so simulated results match observed streamflows, or numerical net recharge to groundwater to simulated groundwater elevations match observed. This is an unacceptable practice and certainly violates "true" mass balance. When CDWR introduced the concept of the closure term in developing hydrologies for planning studies, the implications were that it represented water unaccounted for. For example many minor streams flowing into the Central Valley are not explicitly accounted for and therefore underestimate true inflows. Also, groundwater in CDWR's original work was not explicitly accounted for, thus affecting stream-aquifer interactions. Another example is estimated runoff from precipitation which must be approximated or rely on some physical simulation. If the system is more "integrated" hydrologically, care should be taken to ensure that there is minimal numerical water created. This research focused only on adjustments related to streamflows. Further research can be done to include groundwater elevations as adjustment inputs. Figure 3-29 shows a consistent bias in overestimating Delta inflow without adjustments. This may point to underestimating of land use based demands in the model, thus overestimating surface water diversions which get routed back to the streams. Minor streams from outside C2VSIM boundaries modeled in C2VSIM through the small watershed module could have overestimated inflows to the valley floor, and thus inflows to the Delta. Hopefully this research would develop further interest and future research in improving on the closure term or adjustments concept inclusion in simulation models. The findings of this research can also be applied to other models, and also to applications other than the Central Valley inside and outside California.

Chapter 4 C2VSIM Projected Level with ANN Adjustments Simulated Dynamically

In Chapter 3 adjustments to sub-region historical (observed) outflows were emulated using ANN. The developed ANN equations were then built back into the IWFM code, resulting in a stand-alone historical C2VSIM run with adjustments simulated dynamically. For planning purposes the WY1922-2003 historical simulation is of limited value since the Central Valley water resources system have evolved considerably. This chapter focuses on developing a base case planning level or projected level C2VSIM model with the ANN adjustments simulated dynamically.

4.1 Projected Level Studies

Since 1922 water resources infrastructure and development have evolved considerably, especially the building of the SWP and CVP systems. Figure 4-1 shows cumulative surface reservoir storage capacity built over time (MBK 2017). Construction of the federally operated CVP system began in the 1930's, with the largest reservoir Shasta coming on line around 1945. Construction for the State operated SWP began in the 1960's with the largest reservoir Oroville coming on line in the late 1960's. The CVP and SWP projects supported for increased development of agricultural and urban areas. Figure 4-2 shows increasing agricultural and urban acreages in the Central Valley (solid lines) compiled from the C2VSIM historical run input data.

For planning studies of the SWP and CVP systems, DWR developed procedures for estimating "projected land use level" water supplies (CDWR 1994 and CDWR 1995). In short, agricultural and urban land use is held at fixed values for every year while the historical precipitation trace

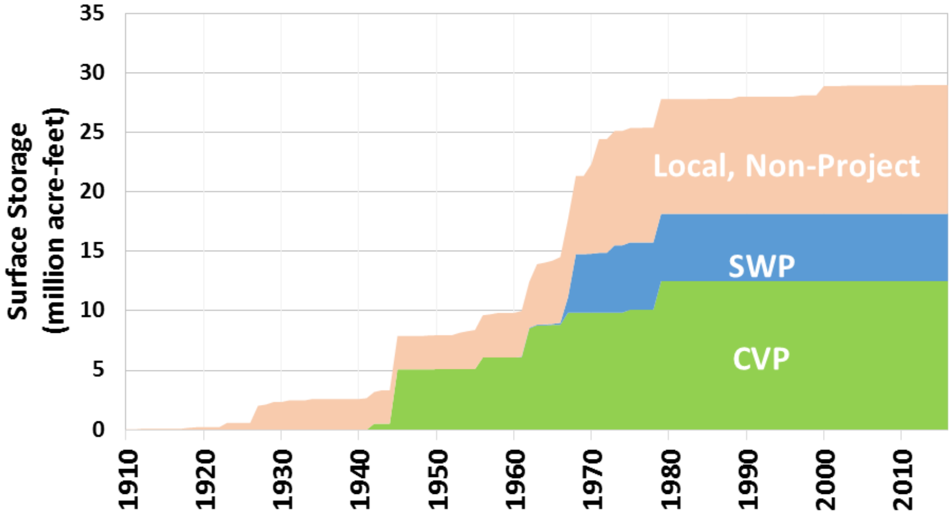


Figure 4-1: Timeline of Major CVP, SWP, and Local Surface Storage Projects in the Central Valley (MBK 2017)

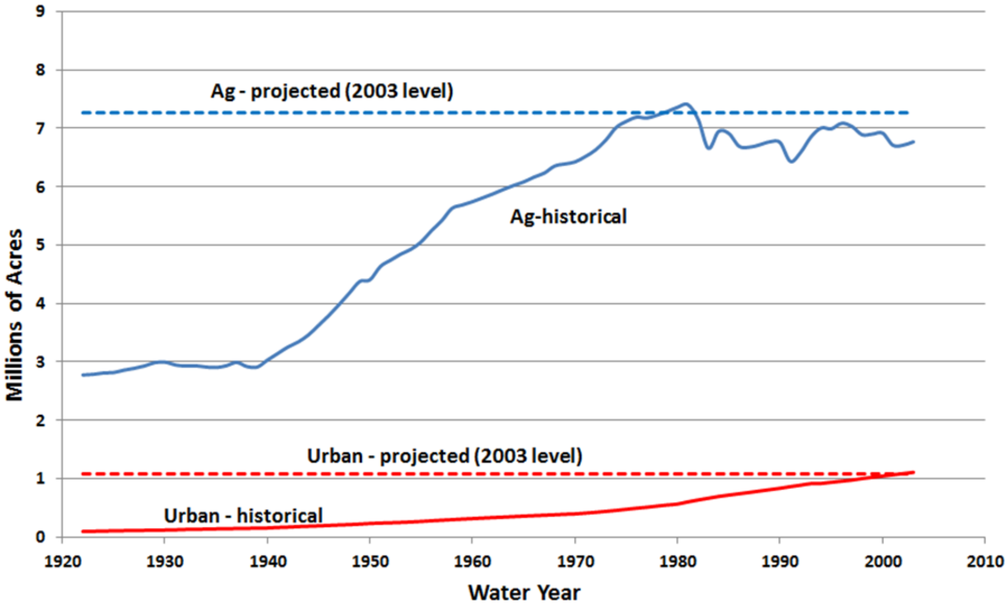


Figure 4-2: C2VSIM Historical and Projected Level Land Use in the Central Valley

is used to estimate the water supplies that would be available at the projected level to operate the reservoir systems. Projected levels can mean current level land use, or some future level (e.g. 2020 or 2050 as estimated by DWR's Water Plan Update). For this research, since data available only extended through WY2003, current level of development (i.e. circa 2003) is used as the projected level of development. Figure 4-2 shows both the agricultural and urban projected area acreages. Section 4.3 describes how those projections are estimated.

The major types of input data for a projected level C2VSIM are:

a. Land Use acreages (agricultural and urban) at projected levels.
b. Boundary stream inflows (including reservoir releases) at projected levels.
c. Surface water diversions and exports at projected levels.
d. Groundwater pumping at projected levels.

The following sections describe how each of these time series was estimated.

4.2 Estimating Projected Level Land Use

DWR has been conducting ground-based land use surveys in California every five to seven years by County dating back to the early 1960s. These surveys are staggered in time, so there does not exist a "snapshot" of the agricultural and urban areas for any single year. The survey results were tabular until the early 1990's when Geographic Information System (GIS) technology was used to report the spatially distributed data. C2VSIM historical run input data includes annual crop/urban/native vegetation acreages by sub-region for WY1922-2003. That data set was put together by DWR land and water use analysts who linearly interpolated between surveys, and then adjusted to annual values using published County Agricultural Commissioner reports. Approximately ten years ago advances in satellite technology allowed for remote sensing of land use. For example the U.S. Department of Agriculture (USDA) publishes annual GIS-based data on land use for the United States (including the Central Valley of California) generally referred to as National Agricultural Statistics Service NASS (https://www.nass.usda.gov/Data_and_Statistics/) or Crop Data Library CDL. However, the remote sensed data collected is mostly "unsupervised", meaning there is minimal ground truthing of the data. This results in many misclassifications of crops. Over time the USDA has improved the analysis algorithms, resulting in fewer misclassifications, though still not mature enough for reliability: NASS or CDL was developed primarily with the eastern United States in mind, with more supervision for those areas. For example, in recent work for DWR comparing NASS data to Kern County published GIS data (CDWR 2017d), it was found that " *the total cotton acreage is more than 50,000 acres less in the Kern County GIS data in 1997. Similarly, orchard acreage is 30,000 acres higher in the Kern County GIS data in 2014, and truck crops are more than triple the NASS county acreage in the Kern County GIS data.*" This author had similar experiences comparing 2007 NASS crop acreages to DWR's 2007 land use survey of the Sacramento San Joaquin Delta. The misclassification, unfortunately are not uniform, nor the bias consistent throughout the Central Valley.

For this research the approach used to calculate the projected level land use is to download the most recent GIS-based land use from DWR's website (by County) available at the time and mosaic all the counties covering the Central Valley, and then carry out (by the author) GIS-based spatial analysis to develop the crop and urban footprint acreages by sub-region. The GIS data posted by DWR required extensive filtering and corrections prior to analysis. Details are given in Appendix D. The steps used to develop the C2VSIM projected level land use using ArcMap are:

a. Download from DWR's website the most recent publicly available (http://www.water.ca.gov/landwateruse/lusrvymain.cfm) GIS-based County surveys for the areas overlapping with the C2VSIM boundary (Table 4-1).

b. Merge all areas within the C2VSIM boundaries and eliminate all overlapping areas.

c. Filter and correct the data (details appear in Appendix D).

d. Intersect the data with the C2VSIM elements.

e. Aggregate element data to the sub-regional level using both the Class1 and sub-Class1 attributes to match standard C2VSIM nomenclature and group categories. Final results are shown in Tables 4-2a and 4-2b and Figure 4-2a.

Table 4-1: DWR Land Use Surveys Used to Develop Projected Level 2003 Land Use for C2VSIM

	County	Sub-regions	Survey Year
1	Alameda	9*	1993
2	Amador	8	1997
3	Butte	2,3,4,5	1994
4	Calaveras	8	2000
5	Colusa	3,4,5	1998
6	Contra Costa	8,9	1995
7	Fresno	10,13,14,16,17	1994
8	Glenn	2,3,4,5	1998
9	Kern	15,18,19,20,21	1998
10	Kings	14,15,17,18,19	1996
11	Madera	13,15,16	1995
12	Mariposa	13	1998
13	Merced	10,12,13	1995
14	Placer	7	1994
15	Sacramento	6, 7,8,9	2000
16	San Joaquin	8,9,10,11	1996
17	Shasta	1	1995
18	Solano	10,11	1994
19	Stanislaus	8,10,11,12,13	1996
20	Sutter	3,4,5,6,7	1998
21	Tehama	1,2	1994
22	Tulare	15,17,18,20	1999
23	Tuolumne	11	1997
24	Yolo	3,4,5,6,7,8,9	1997
25	Yuba	5,7	1995

Table 4-2a: Projected Level 2003 Land Use Acreages for C2VSIM by Sub-region (acres)

Sub-region	PA	AL	SB	FI	RI	TR	TO	OR	GR	VI	CO	SO	UR	NV	Total
1	16377	1279	0	1161	42	406	0	3341	1770	7	0	1017	41701	261189	**328288**
2	36855	7786	0	7137	3705	1499	11	87137	18106	73	0	22473	45515	467740	**698035**
3	12040	20774	229	35673	172090	11518	26961	66872	55079	6083	8721	1634	21445	249996	**689116**
4	6158	7680	0	47910	128230	12103	20083	26742	28922	9	1183	37	5648	66870	**351574**
5	20020	3704	29	6167	190764	3196	748	134835	7310	132	741	3862	51299	190957	**613763**
6	13781	40323	11045	71529	14376	6323	47456	25837	99218	1931	1233	233	55437	269151	**657873**
7	12132	3014	490	4157	79426	404	361	10344	11357	53	0	238	106627	121260	**349862**
8	44602	14080	2921	37434	2787	9486	15142	51768	34436	82784	0	639	125534	473930	**895541**
9	33090	61743	9525	174471	1275	37097	38252	20435	73510	21309	0	100	73106	181543	**725456**
10	14344	78248	8658	34605	7762	34840	45682	57934	48427	2542	98898	879	21957	213311	**668086**
11	53434	9889	7	9811	5920	5397	1379	99893	31556	11203	0	227	60443	123391	**412549**
12	18580	19104	0	11744	25	5655	22	105547	55790	11740	0	184	28167	83783	**340341**
13	42012	80495	3067	51692	3712	12748	20120	176609	85296	115992	44012	7081	59629	335211	**1037676**
14	979	24655	7936	66668	0	55639	96159	50569	50675	10749	207861	846	11631	85889	**670256**
15	5873	108160	6000	119834	0	3067	11484	83000	85035	73602	153924	702	28956	224865	**904502**
16	5839	6855	0	14076	14	9069	12	29629	833	77613	3604	14061	100152	40711	**302467**
17	6145	7883	15	20641	0	2454	668	94245	5825	118012	3227	38125	24354	51316	**372910**
18	5406	103281	4296	151325	0	5734	1891	90753	61928	67761	81585	106984	56758	159435	**897135**
19	1787	31914	419	25469	0	8294	841	124718	55516	7927	43420	3573	38144	459430	**801450**
20	311	13364	0	13192	0	8511	350	93351	19022	42871	7077	29365	30914	165402	**423730**
21	3499	43255	156	46200	0	39253	4552	39714	41104	51178	40325	29757	93565	220304	**652861**
Total	**353261**	**687486**	**54791**	**950896**	**610129**	**272693**	**332174**	**1473270**	**870714**	**703569**	**695811**	**262016**	**1080981**	**4445680**	**12793472**

PA=pasture, AL-alfalfa, SB-sugar beets, FI-field crops, RI-rice, TR-truck crops, OR-orchards, GR-grains, VI-vineyards, CO=Cotton, SO=citrus & olivers, UR=urban, NV=native and riparian vegetation

Table 4-2b: Projected Level 2003 Land Use Acreages for C2VSIM Aggregated (acres)

	Ag	Ur	NV	Total
	25,398	41,701	261,189	**328,288**
	184,781	45,515	467,740	**698,035**
	417,674	21,445	249,996	**689,116**
	279,056	5,648	66,870	**351,574**
	371,508	51,299	190,957	**613,763**
	333,285	55,437	269,151	**657,873**
	121,975	106,627	121,260	**349,862**
	296,077	125,534	473,930	**895,541**
	470,807	73,106	181,543	**725,456**
	432,818	21,957	213,311	**668,086**
	228,716	60,443	123,391	**412,549**
	228,392	28,167	83,783	**340,341**
	642,837	59,629	335,211	**1,037,676**
	572,736	11,631	85,889	**670,256**
	650,681	28,956	224,865	**904,502**
	161,605	100,152	40,711	**302,467**
	297,240	24,354	51,316	**372,910**
	680,943	56,758	159,435	**897,135**
	303,877	38,144	459,430	**801,450**
	227,414	30,914	165,402	**423,730**
	338,992	93,565	220,304	**652,861**
Total	**7,266,811**	**1,080,981**	**4,445,680**	**12,793,472**

AL : Alfalfa
CO : Cotton
FI : Field Crops
GR : Grains
NV : Native Vegetation
OR : Orchards
PA : Pasture
RI : Rice
SB : Sugar Beets
SO : Citrus and Olives
TO : Tomatoes
TR : Truck Crops
UR : Urban
VI : Vineyards

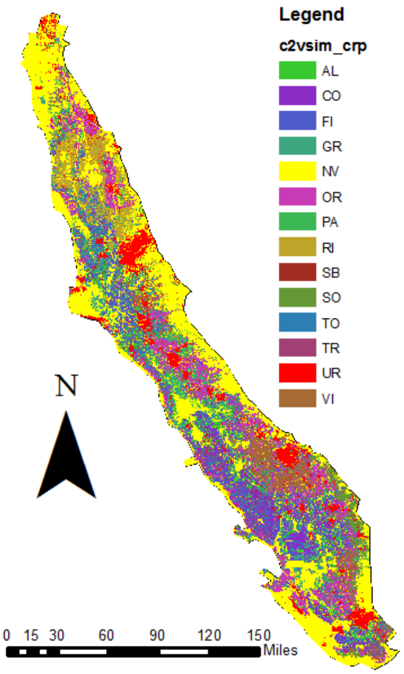


Figure 4-2a: C2VSIM Projected Level 2003 Crops in the Central Valley

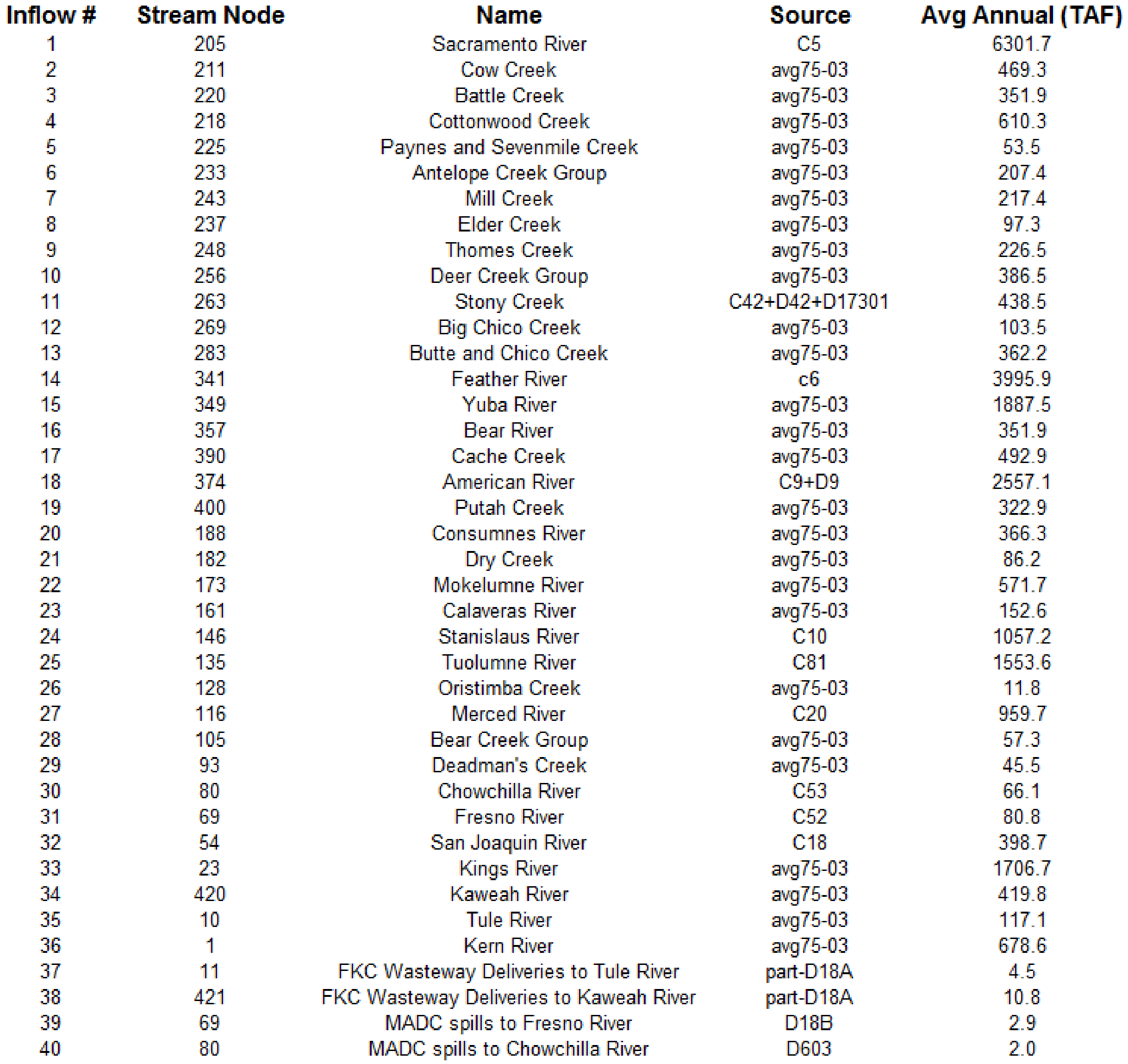
4.3 Estimating Projected Level Inflows

The boundary inflows at stream nodes used in C2VSIM (Figure 2-5) are listed in Table 4-3. Three sources of data were used to develop the time series for C2VSIM surface water inflows and diversions for the projected C2VSIM run (current level of land use development):

a. Historical C2VSIM run (Chapter 2) for the period WY1975-2003, sorted and averaged by water year type.

b. DWR's "2009 State Water Project Delivery Reliability Report" DRR2009 (CDWR 2010a). This report is related to the using the CalSim-II model used by DWR (Figure 4-3) to summarize reliability of the SWP to meet contractual deliveries. Data related to DRR2009 report were in two HEC-DSS files: DRR_TXFR_2005A01ADV.DSS and DRR_CONV_2005A01DV.DSS. The first DSS file includes the time series for the Sacramento Valley and Delta (Sub-regions 1 through 9), and the second DSS file includes the time series for the San Joaquin and Tulare Valleys (Sub-regions 10 through 21). The full schematic for CalSim-II can be found at: http://baydeltaoffice.water.ca.gov/modeling/hydrology/CalSim/Downloads/CalSimDownloads/index.cfm

Table 4-3: Source of Data and Annual Averages WY1922-2003 for C2VSIM Projected Level 2003 Surface Water Inflows in TAF (CDWR)



Inflow #	Stream Node	Name	Source	Avg Annual (TAF)
1	205	Sacramento River	C5	6301.7
2	211	Cow Creek	avg75-03	469.3
3	220	Battle Creek	avg75-03	351.9
4	218	Cottonwood Creek	avg75-03	610.3
5	225	Paynes and Sevenmile Creek	avg75-03	53.5
6	233	Antelope Creek Group	avg75-03	207.4
7	243	Mill Creek	avg75-03	217.4
8	237	Elder Creek	avg75-03	97.3
9	248	Thomes Creek	avg75-03	226.5
10	256	Deer Creek Group	avg75-03	386.5
11	263	Stony Creek	C42+D42+D17301	438.5
12	269	Big Chico Creek	avg75-03	103.5
13	283	Butte and Chico Creek	avg75-03	362.2
14	341	Feather River	c6	3995.9
15	349	Yuba River	avg75-03	1887.5
16	357	Bear River	avg75-03	351.9
17	390	Cache Creek	avg75-03	492.9
18	374	American River	C9+D9	2557.1
19	400	Putah Creek	avg75-03	322.9
20	188	Consumnes River	avg75-03	366.3
21	182	Dry Creek	avg75-03	86.2
22	173	Mokelumne River	avg75-03	571.7
23	161	Calaveras River	avg75-03	152.6
24	146	Stanislaus River	C10	1057.2
25	135	Tuolumne River	C81	1553.6
26	128	Oristimba Creek	avg75-03	11.8
27	116	Merced River	C20	959.7
28	105	Bear Creek Group	avg75-03	57.3
29	93	Deadman's Creek	avg75-03	45.5
30	80	Chowchilla River	C53	66.1
31	69	Fresno River	C52	80.8
32	54	San Joaquin River	C18	398.7
33	23	Kings River	avg75-03	1706.7
34	420	Kaweah River	avg75-03	419.8
35	10	Tule River	avg75-03	117.1
36	1	Kern River	avg75-03	678.6
37	11	FKC Wasteway Deliveries to Tule River	part-D18A	4.5
38	421	FKC Wasteway Deliveries to Kaweah River	part-D18A	10.8
39	69	MADC spills to Fresno River	D18B	2.9
40	80	MADC spills to Chowchilla River	D603	2.0

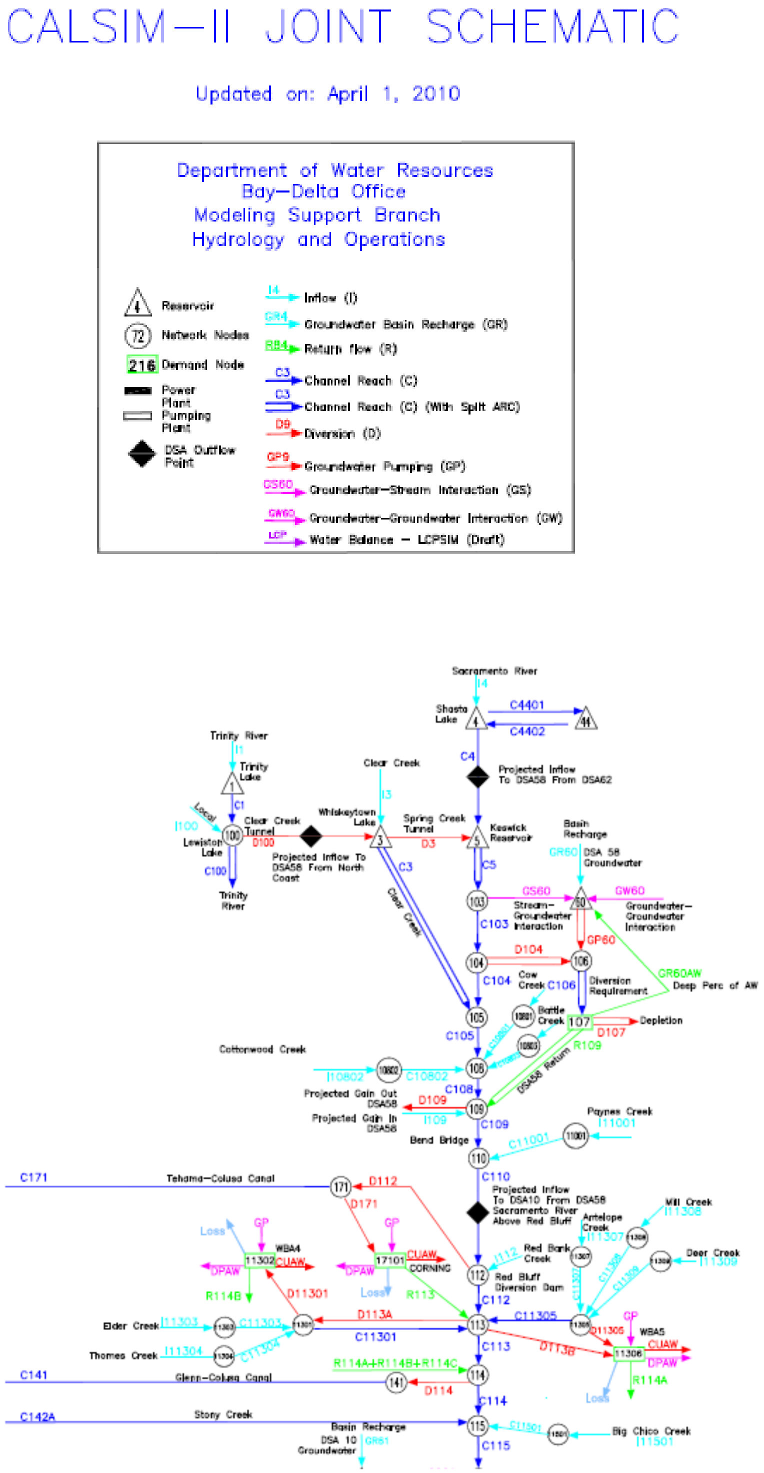


Figure 4-3: CalSim-II Schematic Northern Region

In Table 4-3 the fourth column represents the source of data used to compile the projected level inflows: Historical C2VSIM average for WY1975-2003 C2VSIM (averaged by water year type by sub-region), or DRR2009. If data from the DRR2009 was not available (i.e. the inflow were not explicitly modeled in C2VSIM but imbedded in the hydrology of CalSim-II) then the C2VSIM source was used. For the C2VSIM historical data source, the year classifications for WY1975-03 are shown in Table 4-4. Note: The Water Year index was used to average the data described earlier to reflect hydrological variation. The index is runoff based but also a good reflection of the precipitation.

Table 4-4: CDWR Water Year Classification for WY1975-2003

WY	Classification
1975	W
1976	C
1977	C
1978	AN
1979	BN
1980	AN
1981	D
1982	W
1983	W
1984	W
1985	D
1986	W
1987	D
1988	C
1989	D
1990	C
1991	C
1992	C
1993	AN
1994	C
1995	W
1996	W
1997	W
1998	W
1999	W
2000	AN
2001	D
2002	D
2003	AN

AN = Above Normal
BN = Below Normal
C = Critical Dry
D = Dry
W = Wet

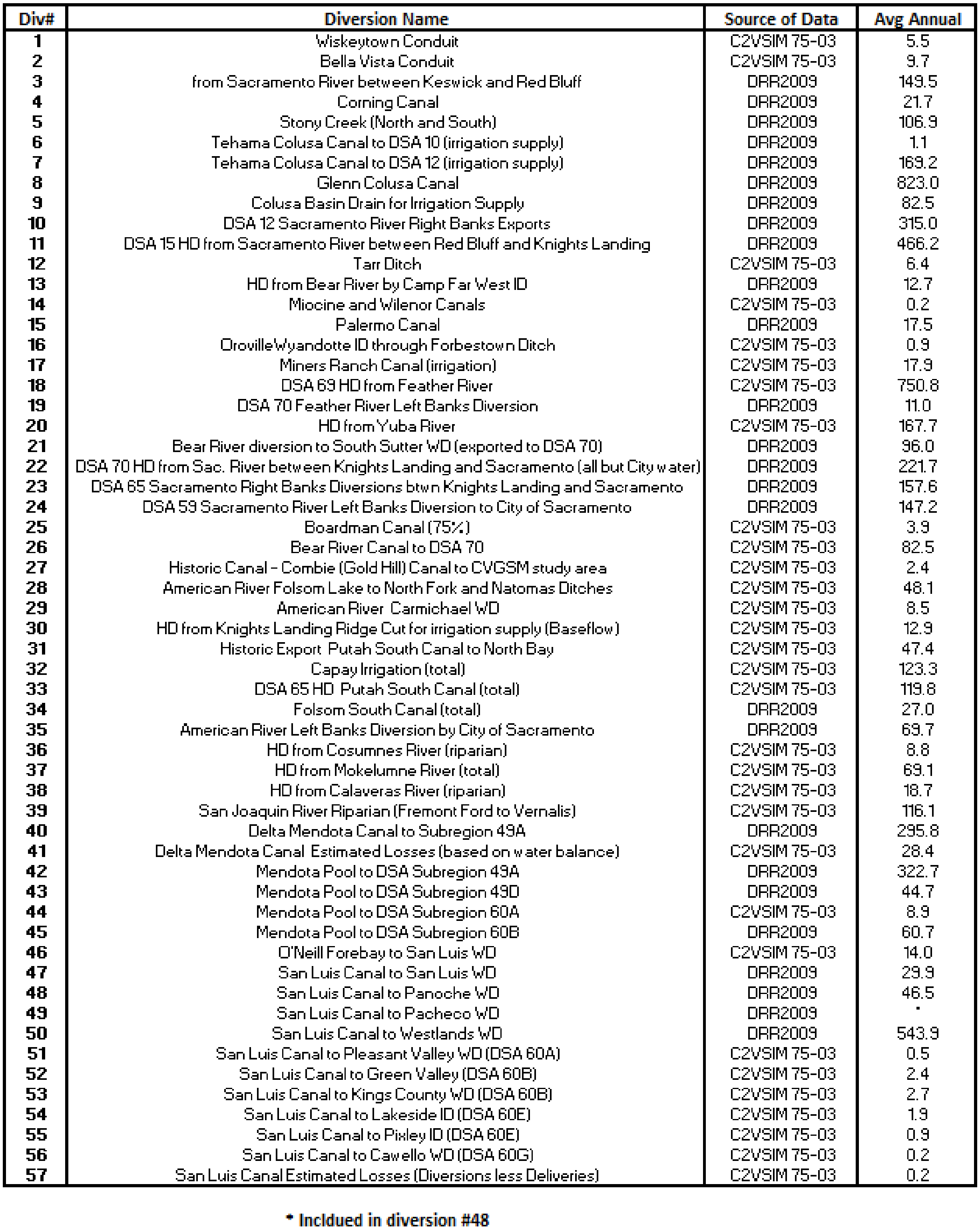
The C2VSIM historical monthly inflows for WY1975-2003 were sorted and averaged by water year type, and the monthly average for that water year type was used. The fourth column in Table 4-3 lists the CalSim-II node that corresponds to the C2VSIM node (first column). The long term average annual projected inflows for C2VSIM are shown in the last column of Table 4-3.

4.4 Estimating Projected Level Surface Water Diversions

The diversions from stream nodes used in C2VSIM are listed in Table 4-5. In addition to the two sources listed in Section 4.3, a third source used is an Excel ® Spreadsheet mapping CalSim-II diversions to the Central Valley Production Model CVPM developed as part of the Common Assumptions for the CALFED Surface Storage Investigations program (CWEMF 2007, CDWR 2010b, CH2M-Hill 2011). CVPM is currently called the California Statewide Agricultural Production Model SWAP; a multi-region economic optimization model of the agricultural economy in California (Howitt et al 2012 and http://swap.ucdavis.edu) with sub-regional boundaries very similar to C2VSIM (CVPM's sub-regional boundaries are nested within C2VSIM's 21 sub-regions). Appendix E lists the diversions mapped from CalSim-II to C2VSIM.

The projected level time series is assembled similar to the procedure used for inflows described in Section 4.3. In Table 4-5 the last column lists the WY1922-2003 average annual values of the diversions. Figure 4-4 shows the WY1922-2003 monthly average values. Figure 4-5 shows the statistics for annual projected surface water diversions. Table 4-6 shows the statistics for the monthly average diversions. Histograms for the monthly averages appear in Appendix F.

Table 4-5: Source of Data and Annual Averages WY1922-2003 for C2VSIM Projected Level 2003 Surface Water Diversions in TAF



Div#	Diversion Name	Source of Data	Avg Annual
1	Wiskeytown Conduit	C2VSIM 75-03	5.5
2	Bella Vista Conduit	C2VSIM 75-03	9.7
3	from Sacramento River between Keswick and Red Bluff	DRR2009	149.5
4	Corning Canal	DRR2009	21.7
5	Stony Creek (North and South)	DRR2009	106.9
6	Tehama Colusa Canal to DSA 10 (irrigation supply)	DRR2009	1.1
7	Tehama Colusa Canal to DSA 12 (irrigation supply)	DRR2009	169.2
8	Glenn Colusa Canal	DRR2009	823.0
9	Colusa Basin Drain for Irrigation Supply	DRR2009	82.5
10	DSA 12 Sacramento River Right Banks Exports	DRR2009	315.0
11	DSA 15 HD from Sacramento River between Red Bluff and Knights Landing	DRR2009	466.2
12	Tarr Ditch	C2VSIM 75-03	6.4
13	HD from Bear River by Camp Far West ID	DRR2009	12.7
14	Miocine and Wilenor Canals	C2VSIM 75-03	0.2
15	Palermo Canal	DRR2009	17.5
16	OrovilleWyandotte ID through Forbestown Ditch	C2VSIM 75-03	0.9
17	Miners Ranch Canal (irrigation)	C2VSIM 75-03	17.9
18	DSA 69 HD from Feather River	C2VSIM 75-03	750.8
19	DSA 70 Feather River Left Banks Diversion	DRR2009	11.0
20	HD from Yuba River	C2VSIM 75-03	167.7
21	Bear River diversion to South Sutter WD (exported to DSA 70)	DRR2009	96.0
22	DSA 70 HD from Sac. River between Knights Landing and Sacramento (all but City water)	DRR2009	221.7
23	DSA 65 Sacramento Right Banks Diversions btwn Knights Landing and Sacramento	DRR2009	157.6
24	DSA 59 Sacramento River Left Banks Diversion to City of Sacramento	DRR2009	147.2
25	Boardman Canal (75%)	C2VSIM 75-03	3.9
26	Bear River Canal to DSA 70	C2VSIM 75-03	82.5
27	Historic Canal - Combie (Gold Hill) Canal to CVGSM study area	C2VSIM 75-03	2.4
28	American River Folsom Lake to North Fork and Natomas Ditches	C2VSIM 75-03	48.1
29	American River Carmichael WD	C2VSIM 75-03	8.5
30	HD from Knights Landing Ridge Cut for irrigation supply (Baseflow)	C2VSIM 75-03	12.9
31	Historic Export Putah South Canal to North Bay	C2VSIM 75-03	47.4
32	Capay Irrigation (total)	C2VSIM 75-03	123.3
33	DSA 65 HD Putah South Canal (total)	C2VSIM 75-03	119.8
34	Folsom South Canal (total)	DRR2009	27.0
35	American River Left Banks Diversion by City of Sacramento	DRR2009	69.7
36	HD from Cosumnes River (riparian)	C2VSIM 75-03	8.8
37	HD from Mokelumne River (total)	C2VSIM 75-03	69.1
38	HD from Calaveras River (riparian)	C2VSIM 75-03	18.7
39	San Joaquin River Riparian (Fremont Ford to Vernalis)	C2VSIM 75-03	116.1
40	Delta Mendota Canal to Subregion 49A	DRR2009	295.8
41	Delta Mendota Canal Estimated Losses (based on water balance)	C2VSIM 75-03	28.4
42	Mendota Pool to DSA Subregion 49A	DRR2009	322.7
43	Mendota Pool to DSA Subregion 49D	DRR2009	44.7
44	Mendota Pool to DSA Subregion 60A	C2VSIM 75-03	8.9
45	Mendota Pool to DSA Subregion 60B	DRR2009	60.7
46	O'Neill Forebay to San Luis WD	C2VSIM 75-03	14.0
47	San Luis Canal to San Luis WD	DRR2009	29.9
48	San Luis Canal to Panoche WD	DRR2009	46.5
49	San Luis Canal to Pacheco WD	DRR2009	*
50	San Luis Canal to Westlands WD	DRR2009	543.9
51	San Luis Canal to Pleasant Valley WD (DSA 60A)	C2VSIM 75-03	0.5
52	San Luis Canal to Green Valley (DSA 60B)	C2VSIM 75-03	2.4
53	San Luis Canal to Kings County WD (DSA 60B)	C2VSIM 75-03	2.7
54	San Luis Canal to Lakeside ID (DSA 60E)	C2VSIM 75-03	1.9
55	San Luis Canal to Pixley ID (DSA 60E)	C2VSIM 75-03	0.9
56	San Luis Canal to Cawello WD (DSA 60G)	C2VSIM 75-03	0.2
57	San Luis Canal Estimated Losses (Diversions less Deliveries)	C2VSIM 75-03	0.2

* Incldued in diversion #48

Table 4-5 (cont.): Source of Data and Annual Averages WY1922-2003 for C2VSIM Projected Level 2003 Surface Water Diversions in TAF

Div#	Diversion Name	Source of Data	Avg Annual
58	South San Joaquin Canal near Knights Landing	DRR2009	347.8
59	Oakdale Canal near Knights Ferry (Total)	DRR2009	147.7
60	Stanislaus River Riparian	DRR2009	20.0
61	Modesto Canal Diversion from Tuolumne River (Total)	DRR2009	305.3
62	Tuolumne River Riparian (Right Bank)	DRR2009	7.6
63	Tuolumne River Riparian (Left Bank)	DRR2009	7.6
64	Turlock Canal Diversion from Tuolumne River (Total)	DRR2009	572.2
65	Merced Irrigation District Northside Canal Diverison from Merced River	DRR2009	26.2
66	Merced River Riparian (Right Bank)	DRR2009	41.4
67	Merced River Riparian (Left Bank)	DRR2009	25.4
68	Merced Irrigation District Main Canal Diversions from Merced River	DRR2009	459.6
69	Madera Canal (Total)	DRR2009	253.7
70	Chowchilla River Riparian	C2VSIM 75-03	24.2
71	Fresno River Riparian	DRR2009	22.8
72	San Joaquin River Riparian (Friant to Gravelly Ford)	C2VSIM 75-03	17.3
73	FKC to DSA 60B	C2VSIM 75-03	2.9
74	FKC to DSA 60C	DRR2009	25.7
75	FKC to DSA 60D	DRR2009	39.6
76	FKC to DSA 60E	DRR2009	538.9
77	FKC to DSA 60F	C2VSIM 75-03	4.8
78	FKC to DSA 60G	DRR2009	169.7
79	FKC to DSA 60H	DRR2009	177.3
80	FKC Estimated Losses	C2VSIM 75-03	26.7
81	Kings River to Fresno Irrigation District (Does not include CVP)	C2VSIM 75-03	403.5
82	Kings River to Consolidated Irrigation District (Does not include CVP)	C2VSIM 75-03	226.1
83	Kings River to Alta Irrigation District (Does not include CVP)	C2VSIM 75-03	150.9
84	Kaweah River Partition A	C2VSIM 75-03	82.0
85	Kaweah River Partition B	C2VSIM 75-03	130.5
86	Kaweah River Partition C	C2VSIM 75-03	21.4
87	Kaweah River Partition D	C2VSIM 75-03	51.1
88	Kaweah River to Corcoran Irrigation District	C2VSIM 75-03	5.9
89	Tule River Riparian	C2VSIM 75-03	5.9
90	California Aqueduct to DSA 60B	DRR2009	76.1
91	California Aqueduct to DSA 60F	DRR2009	340.9
92	California Aqueduct to DSA 60H	DRR2009	114.9
93	Cross Valley Canal to DSA 60F	C2VSIM 75-03	1.4
94	Cross Valley Canal to DSA 60G	DRR2009	27.0
95	Cross Valley Canal to DSA 60H	DRR2009	55.0
96	Kern River to DSA 60F (Irrigation Supply)		41.1
97	Kern River to DSA 60G (Irrigation Supply)	C2VSIM 75-03	193.9
98	Kern River to DSA 60H (Irrigation Supply)	C2VSIM 75-03	198.4
99	Kern River to DSA 60F (Spreading Operation)	C2VSIM 75-03	0.3
100	Kern River to DSA 60G (Spreading Operation)	C2VSIM 75-03	0.1
101	Kern River to DSA 60H (Spreading Operation)	C2VSIM 75-03	1.6
102	Sutter Weir Flow	**	1794.4
103	Fremont Weir Flow	**	924.7
104	Sacramento Weir Flow	**	241.9
105	Knights Landing Ridge Cut Flood Flow	DRR2009	319.5
106	DSA 55 SW Diversion Estimated	DRR2009	983.6
107	Madera Canal Estimated Seepage Losses	C2VSIM 75-03	7.7
108	Kings River Diversion to Main Stem, Section A of DSA 60B	C2VSIM 75-03	274.0
109	Kings River Diversion to South Fork, Section B of DSA 60B	C2VSIM 75-03	14.9
110	Kings River Diversion to North Fork, Section C of DSA 60B	C2VSIM 75-03	21.5
111	Not Used but Must Keep!!!	Not Used	------
112	CCC Export from the Delta	DRR2009	128.0
113	SWP Export from the Delta	DRR2009	2713.3
114	CVP Export from the Delta	DRR2009	2199.2

** weirs simulated dynamically

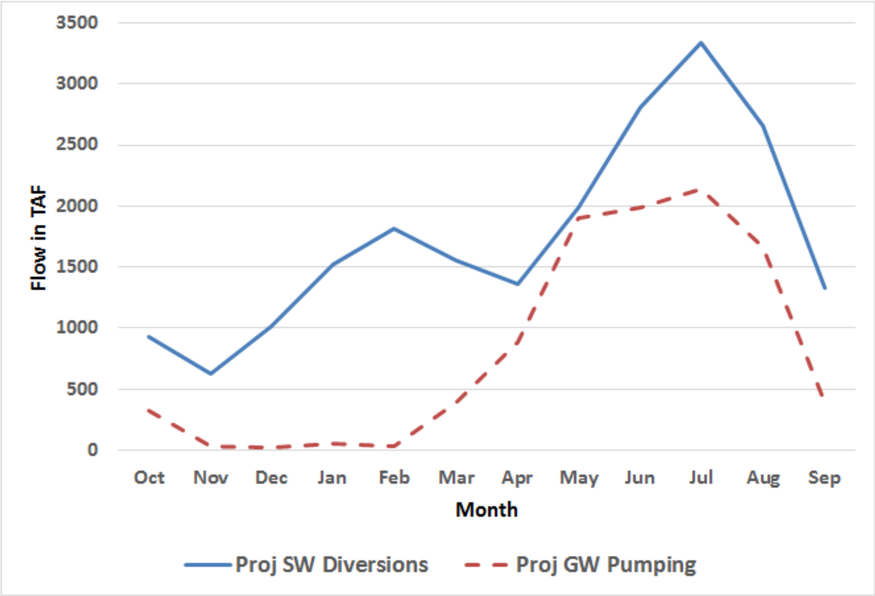
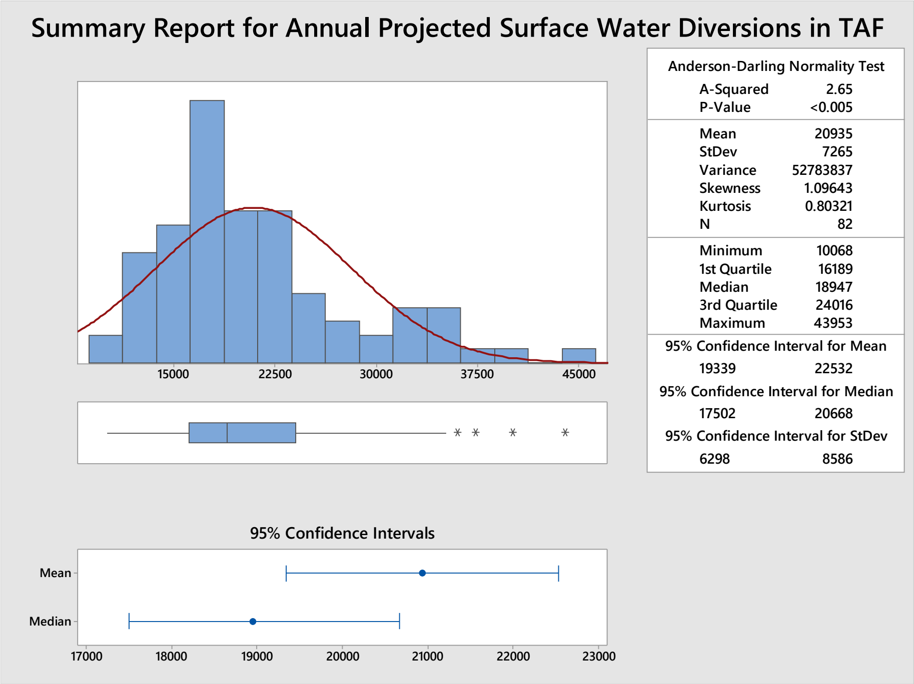


Figure 4-4: C2VSIM Projected Level 2003 Surface Water Diversions and Groundwater Pumping WY1922-2003



Anderson-Darling Normality Test

A-Squared	2.65
P-Value	<0.005
Mean	20935
StDev	7265
Variance	52783837
Skewness	1.09643
Kurtosis	0.80321
N	82
Minimum	10068
1st Quartile	16189
Median	18947
3rd Quartile	24016
Maximum	43953

95% Confidence Interval for Mean

19339 22532

95% Confidence Interval for Median

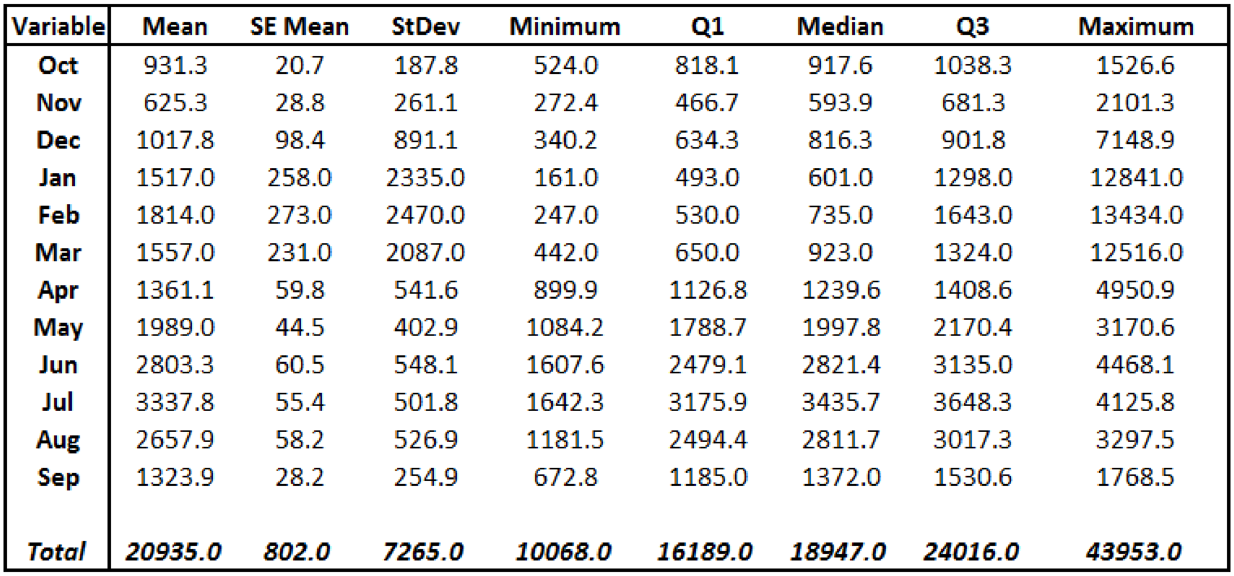
17502 20668

95% Confidence Interval for StDev

6298 8586

Figure 4-5: Summary Report for C2VSIM Projected Level 2003 Surface Water Diversions

Table 4-6: Summary Statistics for WY1922-2003 Monthly Average Projected Level 2003 Surface Water Diversions TAF

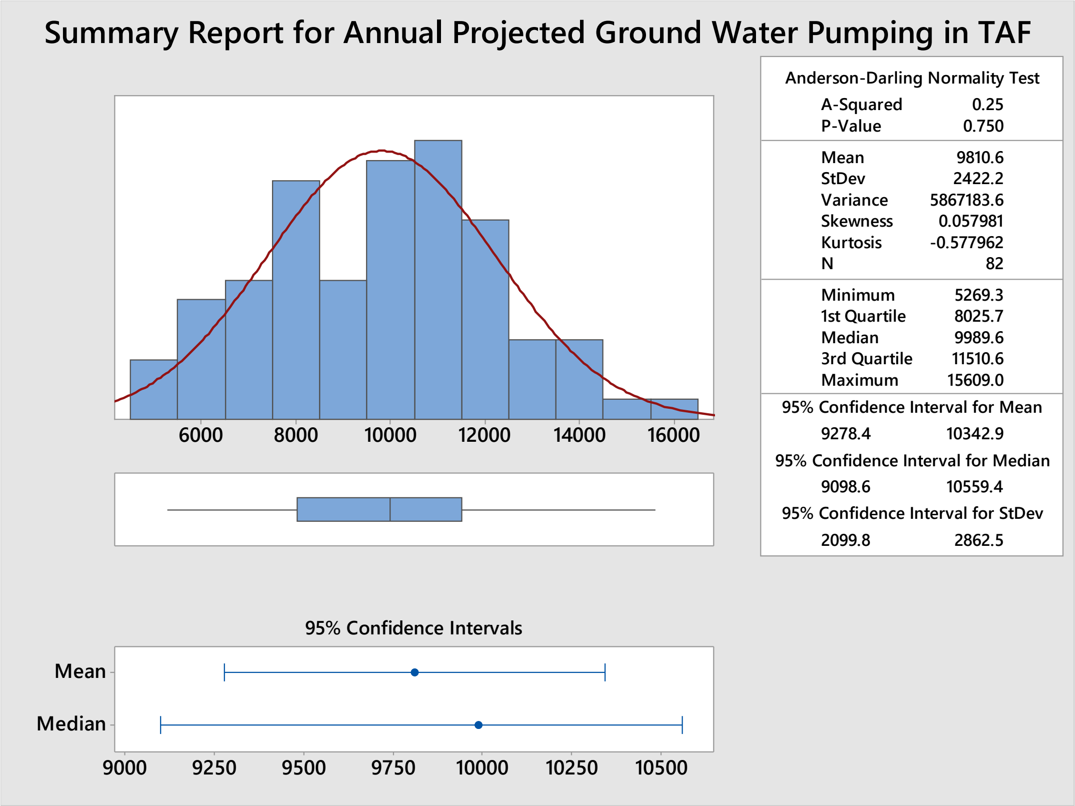


Variable	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Oct	931.3	20.7	187.8	524.0	818.1	917.6	1038.3	1526.6
Nov	625.3	28.8	261.1	272.4	466.7	593.9	681.3	2101.3
Dec	1017.8	98.4	891.1	340.2	634.3	816.3	901.8	7148.9
Jan	1517.0	258.0	2335.0	161.0	493.0	601.0	1298.0	12841.0
Feb	1814.0	273.0	2470.0	247.0	530.0	735.0	1643.0	13434.0
Mar	1557.0	231.0	2087.0	442.0	650.0	923.0	1324.0	12516.0
Apr	1361.1	59.8	541.6	899.9	1126.8	1239.6	1408.6	4950.9
May	1989.0	44.5	402.9	1084.2	1788.7	1997.8	2170.4	3170.6
Jun	2803.3	60.5	548.1	1607.6	2479.1	2821.4	3135.0	4468.1
Jul	3337.8	55.4	501.8	1642.3	3175.9	3435.7	3648.3	4125.8
Aug	2657.9	58.2	526.9	1181.5	2494.4	2811.7	3017.3	3297.5
Sep	1323.9	28.2	254.9	672.8	1185.0	1372.0	1530.6	1768.5
Total	***20935.0***	***802.0***	***7265.0***	***10068.0***	***16189.0***	***18947.0***	***24016.0***	***43953.0***

4.5 Estimating Projected Level Groundwater Pumping

The final time series needed for a projected level C2VSIM is groundwater pumping. Groundwater pumping is estimated by building into the input the projected level land use (Chapter 4-2), projected level inflows (Chapter 4-3), and the projected level surface water diversions (Chapter 4-4), and simulate C2VSIM with the groundwater pumping adjustment option built in. C2VSIM will internally balance the supply side (consumptive water demands) and the demand side (surface water diversions and groundwater pumping) and supplement any groundwater pumping required. The resulting groundwater pumping time series for each sub-region is then re-built into the input data for C2VSIM.

Figure 4-6 shows the statistics for annual projected groundwater pumping. Table 4-7 shows the statistics for the monthly average groundwater pumping. Histograms for the monthly averages for groundwater pumping are given in Appendix F.



Anderson-Darling Normality Test

A-Squared	0.25
P-Value	0.750
Mean	9810.6
StDev	2422.2
Variance	5867183.6
Skewness	0.057981
Kurtosis	-0.577962
N	82
Minimum	5269.3
1st Quartile	8025.7
Median	9989.6
3rd Quartile	11510.6
Maximum	15609.0

95% Confidence Interval for Mean

9278.4 10342.9

95% Confidence Interval for Median

9098.6 10559.4

95% Confidence Interval for StDev

2099.8 2862.5

Figure 4-6: Summary Report for C2VSIM Projected Level 2003 Groundwater Pumping

Figures 4-5 and 4-6 show the statistics for long term WY1922-2003 historical annual surface water diversions and groundwater pumping in C2VSIM, respectively. Using the definitions of Standard Error of the Mean (SEM) and 95% Confidence Intervals (C.I.) as:

$$SEM = \frac{\sigma}{\sqrt{n}} \quad \text{(4.1)}$$

$$95\%\ C.I. = \bar{x} \pm 1.96\frac{\sigma}{\sqrt{n}} \quad \text{(4.2)}$$

The mean and 95% C.I. are:

	Mean	SEM	95% CI Range
Surface Water Diversions	20935 TAF	802 TAF	19339-22532 TAF
Groundwater Pumping	9810 TAF	268 TAF	9278-10343 TAF

The first observation is that the above numbers show that projected level water demands are met by nearly 50% from groundwater pumping. The second observation is the variability about the mean, of nearly 800 TAF/yr and 270 TAF/yr, respectively, which impact simulated streamflows, should be considered carefully when evaluating model results for regulatory purposes.

Table 4-7: Summary Statistics for WY1922-2003 Projected Level 2003 Monthly Average Groundwater Pumping TAF

Variable	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Oct	321.9	18.2	164.7	34.2	186.1	328.2	455.3	646.5
Nov	34.2	2.8	25.5	3.9	12.7	28.6	50.5	121.5
Dec	26.2	2.2	20.0	3.8	7.4	21.3	39.2	74.2
Jan	54.0	8.1	73.5	3.6	14.2	30.1	59.6	410.9
Feb	35.2	5.1	46.4	2.2	9.2	22.8	45.2	335.4
Mar	386.6	36.0	325.6	4.1	96.5	331.8	615.2	1299.4
Apr	882.0	59.3	536.6	52.0	407.8	874.4	1263.5	2248.2
May	1900.2	58.1	525.8	376.0	1622.5	1985.8	2259.1	2787.2
Jun	1988.9	40.9	370.3	1150.5	1706.4	2020.6	2247.2	2900.2
Jul	2135.3	42.8	387.5	1414.2	1849.7	2135.9	2364.7	3099.4
Aug	1659.7	35.0	316.6	1027.9	1419.6	1646.0	1847.6	2472.1
Sep	386.5	13.0	118.1	81.1	317.9	383.1	454.5	659.3
Total	***9811.0***	***267.0***	***2422.0***	***5269.0***	***8026.0***	***9990.0***	***11511.0***	***15609.0***

4.6 Simulating C2VSIM with ANN at Projected 2003 Level of Development: Results and Discussion

The results of projected level inflows, projected level surface water diversions, and projected groundwater pumping described in previous sections of this chapter are used for the final projected level runs of C2VSIM: without and with ANN outflow adjustments activated for the entire WY1922-2003 period. Table 4-8 shows the long term average monthly sub-region outflows, and Delta inflows. Table 4-8 results also show that differences in sub-regional outflows vary in magnitude and direction (positive or negative) as one progress downstream from the uppermost sub-region. In Table 4-8 for example the outflow of SR-1 is underestimated by an average annual of 284 TAF (relative to run with ANN activated), whereas the outflow of SR-2 (which receives inflow from SR-1) is overestimated by 333 TAF. That difference for SR-2 reflects both any adjustment due to what is happening in SR-2 itself, plus impacts from SR-1 (since outflow from SR-1 is a component as inflow to SR-2). Figure 4-4 shows the long term monthly averages for SR-1, and Figure 4-8 shows the cumulative difference in outflows for SR-1 for the entire simulation period, with a cumulative difference of nearly 23 million acre-feet. Results for the other sub-regions appear in Figure 4-9 through Figure 4-22. Figures 4-23 and 4-24 show the long term monthly averages Delta inflow, and the cumulative differences with and without ANN, respectively. The long term underestimation of inflow to the Delta is approximately 217 TAF annually (Table 4-8). By water year type the values are (number in parenthesis are the number of years of that classification in the 19299-2003 period): +913 TAF for Wet (26), -669 TAF for Above Normal (12), -1136 TAF for Below Normal (14), -647 TAF for

Dry (18), and -496 TAF for Critical (12). As percentages of the inflow the values are: W=1.3%, AN=1.7%, BN=4.6%, D=3.2% and C=3.7%. The cumulative difference over the simulation period is nearly 17 million acre-feet (Figure 4-24). Figure 4-25 is a Box-and-Whiskers plot of the annual Delta inflows, where the statistics look very similar.

Table 4-8: Projected Level 2003 C2VSIM Sub-region Monthly Average Sub-region Outflows and Delta Inflows WY1922-2003

SR-1 (DA58) Outflow: WY(1922-2003) in TAF

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Without ANN	438	507	651	850	938	808	590	604	695	833	662	511	8087
With ANN	440	520	691	928	1023	876	601	600	687	825	655	505	8352
Difference	-1	-12	-40	-78	-85	-69	-11	3	8	8	8	6	-264

SR-2 (DA10) Outflow: WY(1922-2003) in TAF

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Without ANN	456	600	876	1207	1317	1105	677	610	566	667	550	535	9166
With ANN	374	544	816	1272	1448	1111	746	551	492	591	461	428	8834
Difference	83	56	60	-65	-131	-6	-69	59	74	76	89	107	333

SR-4 (DA15) Outflow: WY(1922-2003) in TAF

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Without ANN	478	620	763	896	917	870	558	495	394	472	427	530	7419
With ANN	427	601	810	1069	1081	921	627	566	573	705	429	502	8312
Difference	51	19	-48	-172	-165	-51	-70	-71	-179	-233	-2	29	-892

SR-5 (DA69) Outflow: WY(1922-2003) in TAF

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Without ANN	286	318	662	1067	1253	1099	710	507	379	480	326	414	7501
With ANN	261	310	664	1144	1364	1116	776	521	383	505	314	405	7762
Difference	25	8	-2	-77	-110	-18	-67	-13	-3	-25	12	9	-261

SR-6 (DA65) Outflow: WY(1922-2003) in TAF

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Without ANN	34	54	234	577	709	534	207	92	41	30	26	27	2564
With ANN	11	31	178	542	631	460	204	78	26	14	11	6	2193
Difference	23	23	56	34	78	74	3	14	15	15	15	21	371

SR-7 (DA70) Outflow: WY(1922-2003) In TAF

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Without ANN	841	1087	1486	1850	2027	1870	1348	1135	905	1078	843	1067	15538
With ANN	769	1062	1523	1999	2169	1905	1438	1208	1078	1328	839	1035	16352
Difference	72	25	-37	-149	-143	-34	-90	-72	-173	-250	4	33	-814

SR8 (DA59) Outflow: WY(1922-2003) in TAF

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Without ANN	39	71	127	192	220	208	168	141	85	39	31	29	1350
With ANN	33	49	97	166	202	204	182	180	128	59	51	26	1377
Difference	6	22	30	26	19	4	-14	-39	-43	-20	-20	2	-27

SR-10 (DA49a) Outflow: WY(1922-2003) in TAF

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Without ANN	157	161	224	335	447	474	446	415	330	229	150	139	3508
With ANN	239	209	239	190	314	390	377	342	292	288	203	173	3256
Difference	-81	-49	-15	145	134	84	69	73	38	-59	-53	-34	253

Delta Inflow WY(1922-2003) in TAF

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Without ANN	1071	1372	2071	2954	3403	3087	2170	1783	1361	1376	1050	1263	22960
With ANN	1051	1352	2037	2897	3316	2958	2201	1808	1524	1689	1104	1240	23177
Difference	19	20	34	57	87	128	-31	-25	-163	-313	-54	22	-217

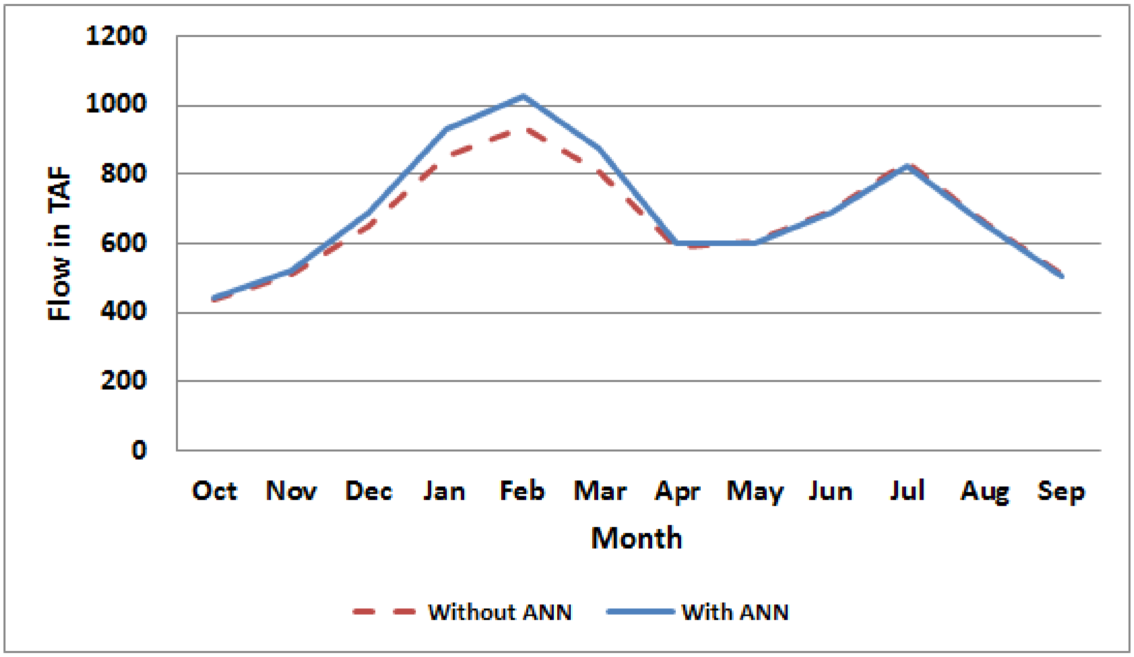


Figure 4-7: Average Monthly SR-1 Outflow WY1922-2003

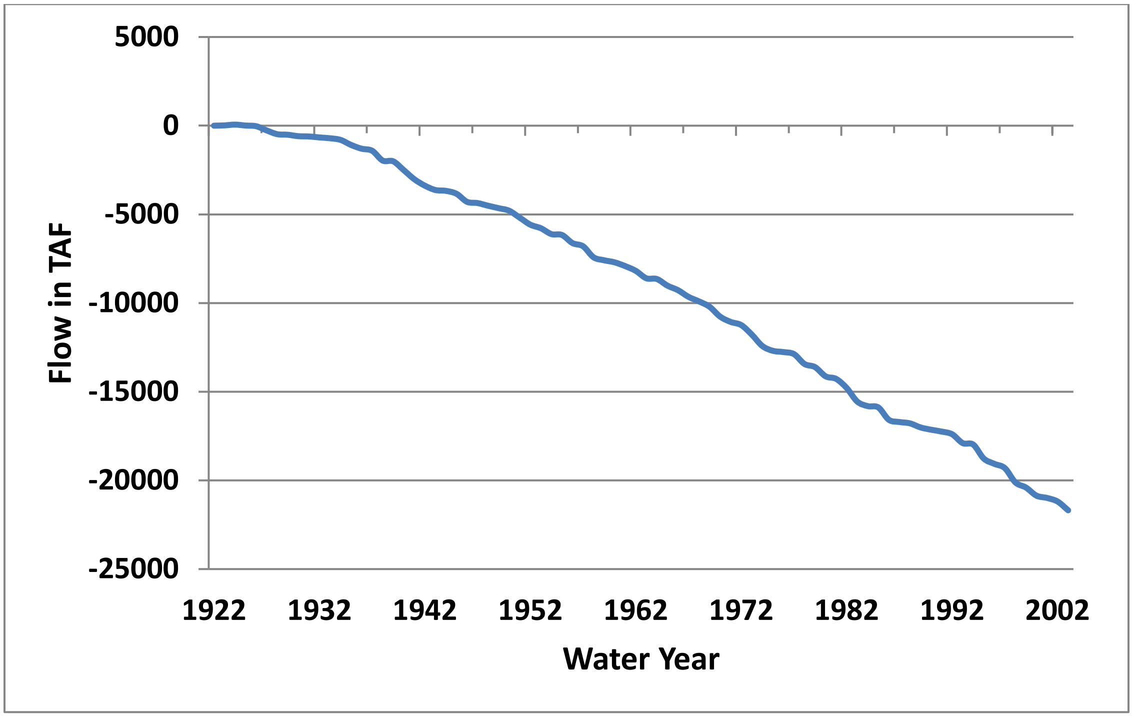


Figure 4-8: WY1922-2003 Projected Annual SR-1 Outflow Cumulative Difference (w/o ANN minus w/ANN)

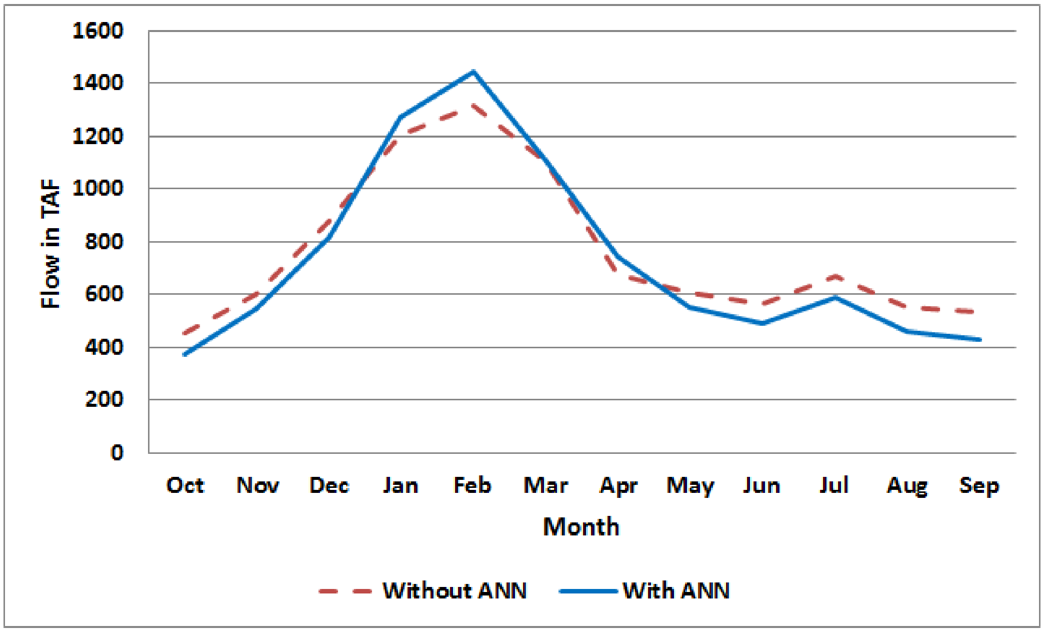


Figure 4-9: Average Monthly SR-2 Outflow WY1922-2003

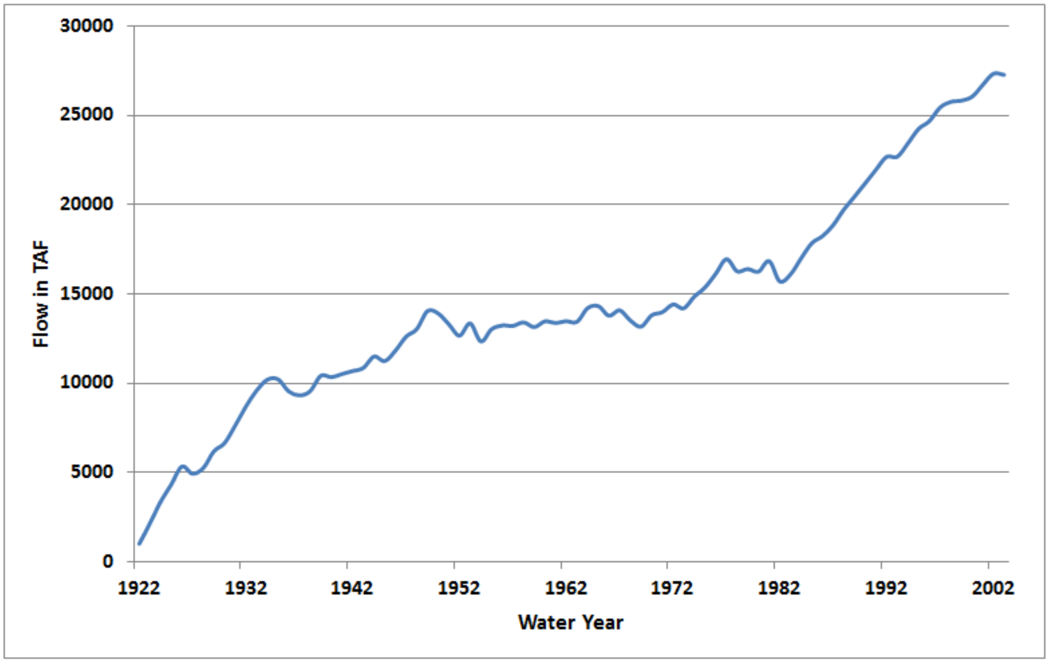


Figure 4-10: WY1922-2003 Projected Annual SR-2 Outflow Cumulative Difference (w/o ANN minus w/ANN)

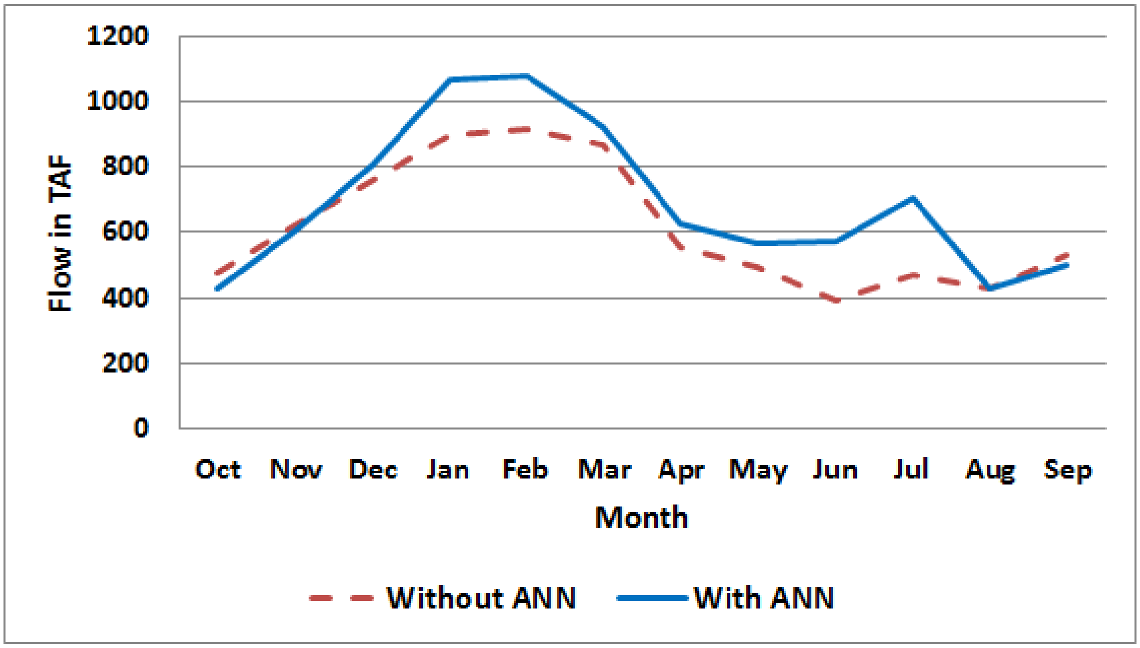


Figure 4-11: Average Monthly SR-4 Outflow WY1922-2003

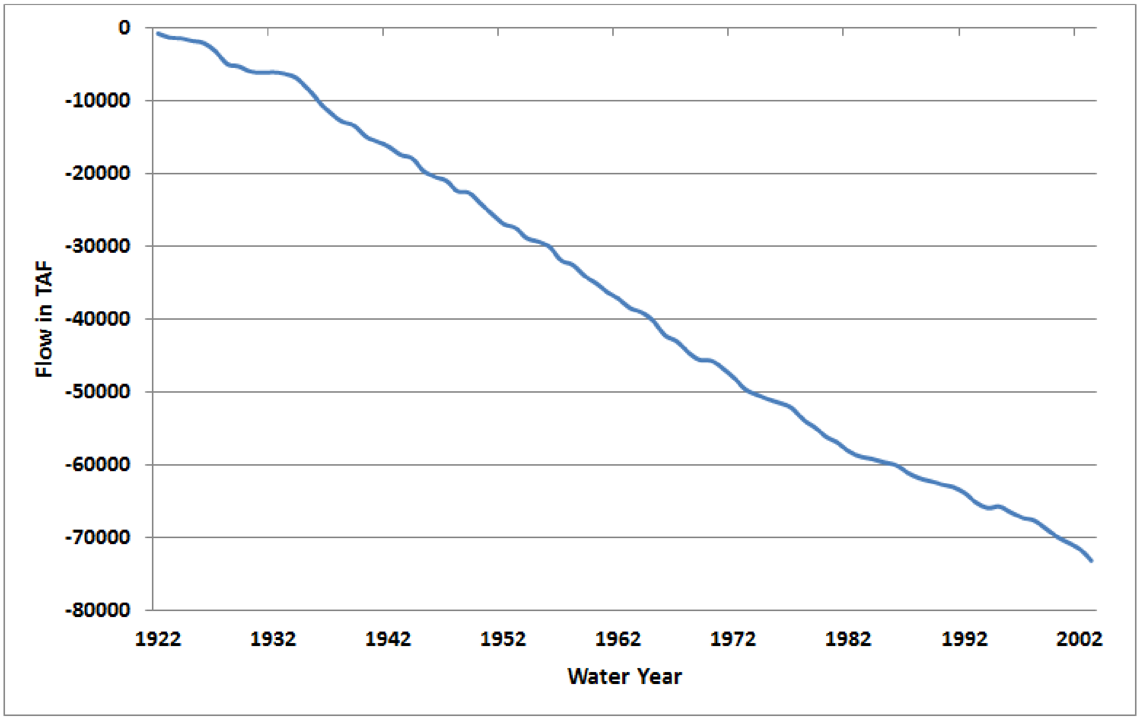


Figure 4-12: WY1922-2003 Projected Annual SR-4 Outflow Cumulative Difference (w/o ANN minus w/ANN)

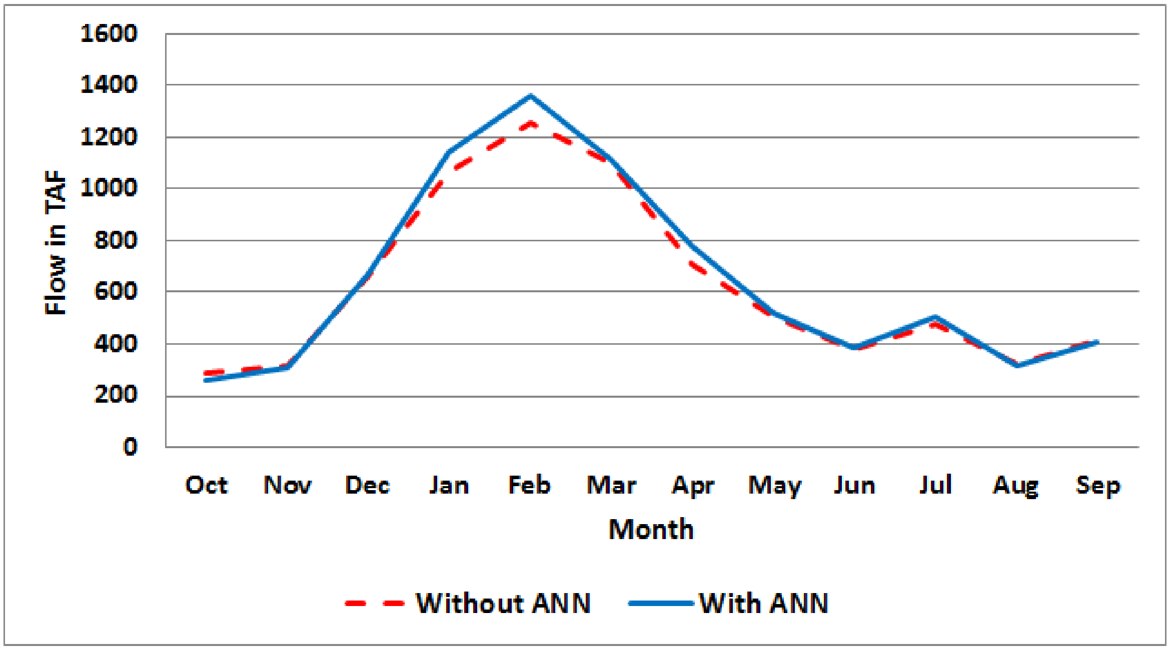


Figure 4-13: Average Monthly SR-5 Outflow WY1922-2003

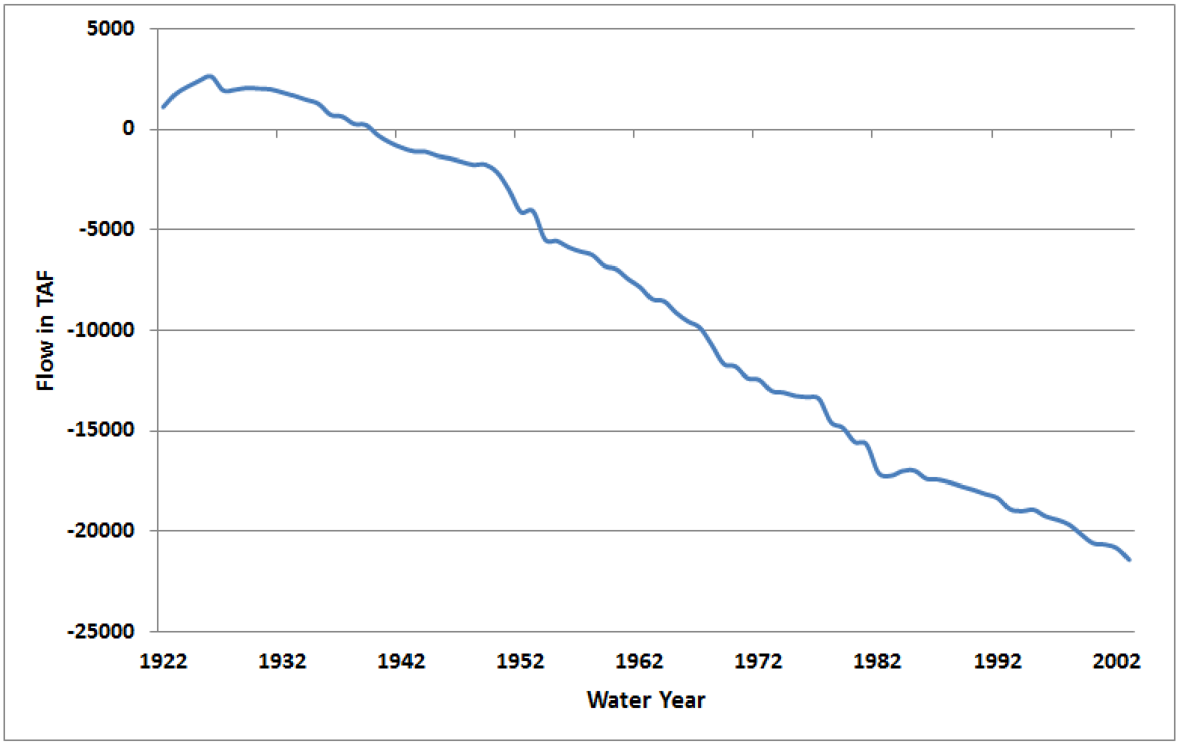


Figure 4-14: WY1922-2003 Projected Annual SR-5 Outflow Cumulative Difference (w/o ANN minus w/ANN)

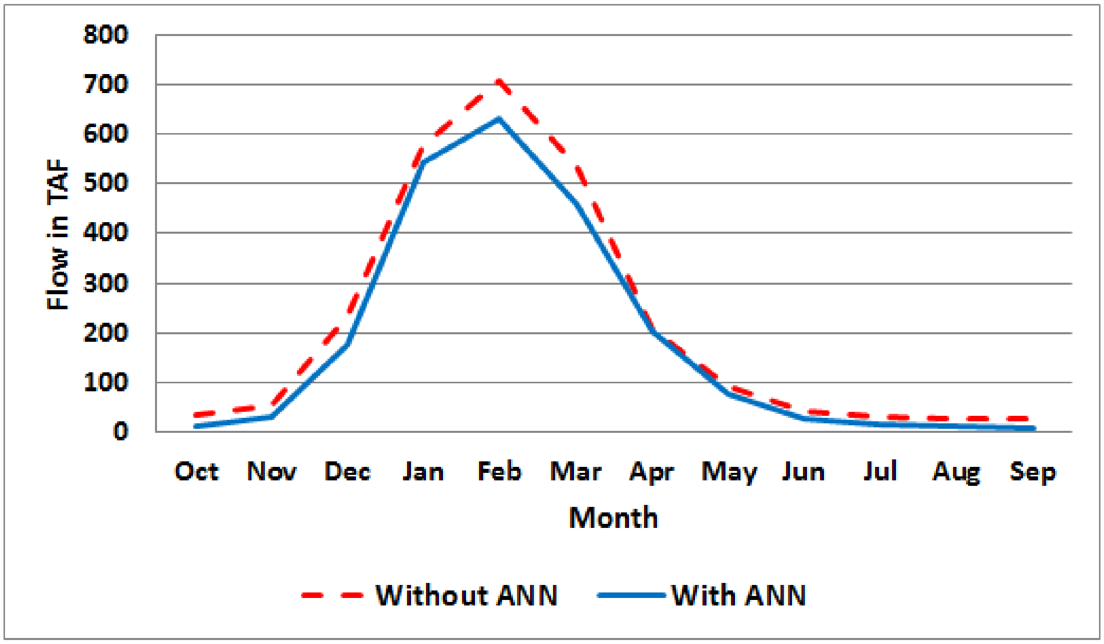


Figure 4-15: Average Monthly SR-6 Outflow WY1922-2003

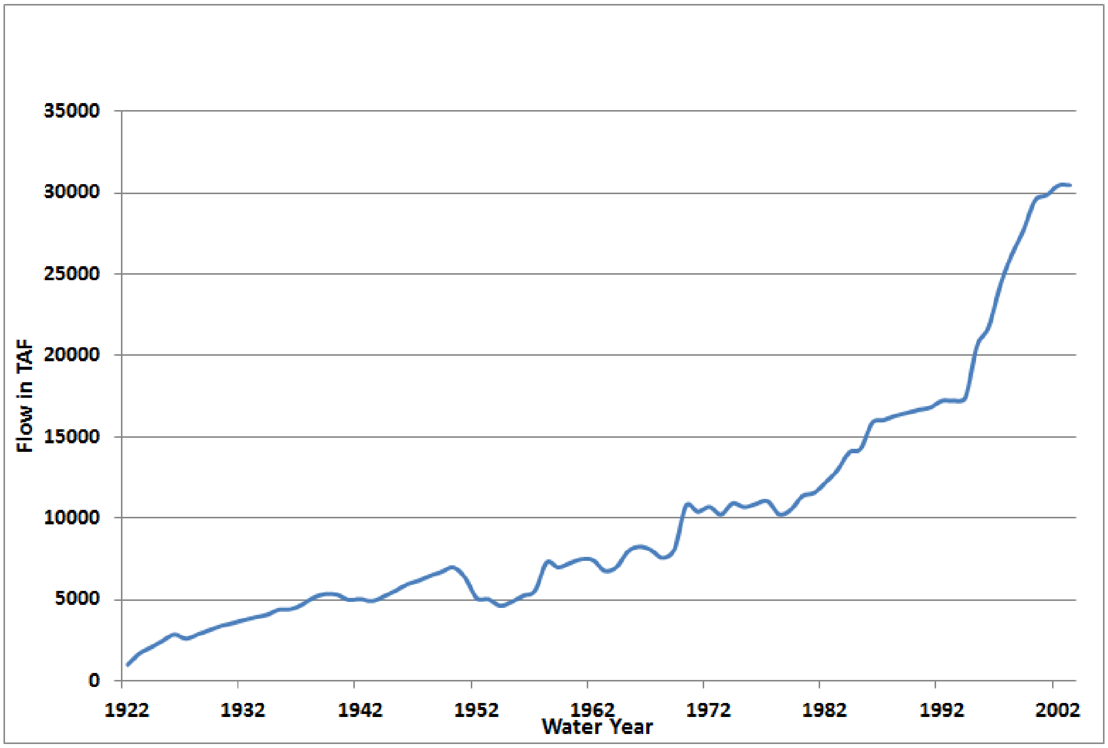


Figure 4-16: WY1922-2003 Projected Annual SR-6 Outflow Cumulative Difference (w/o ANN minus w/ANN)

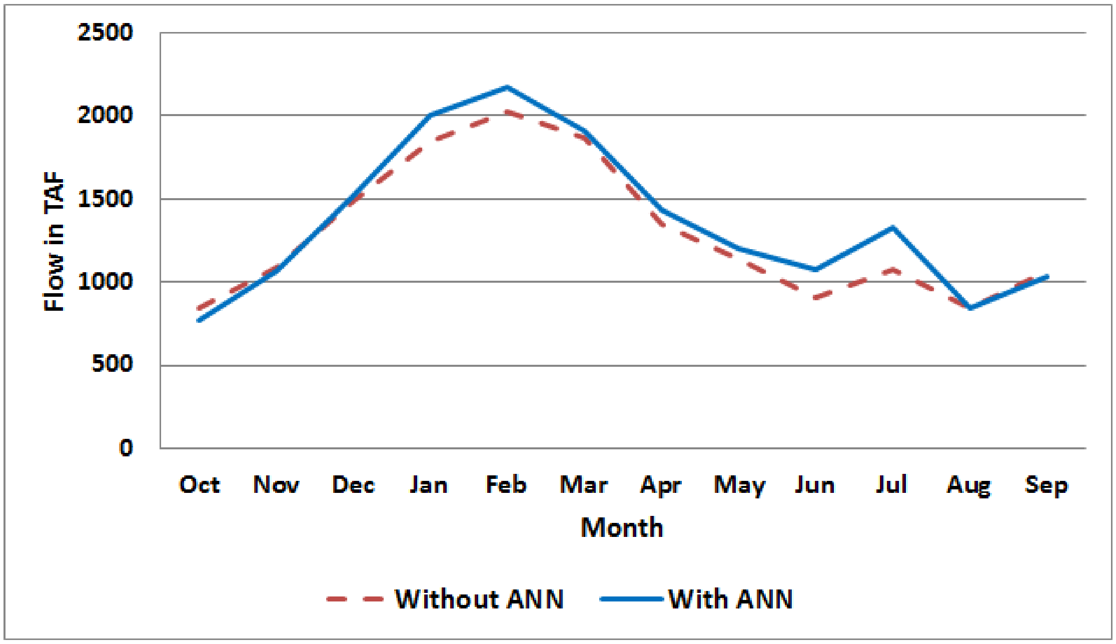


Figure 4-17: Average Monthly SR-7 Outflow WY1922-2003

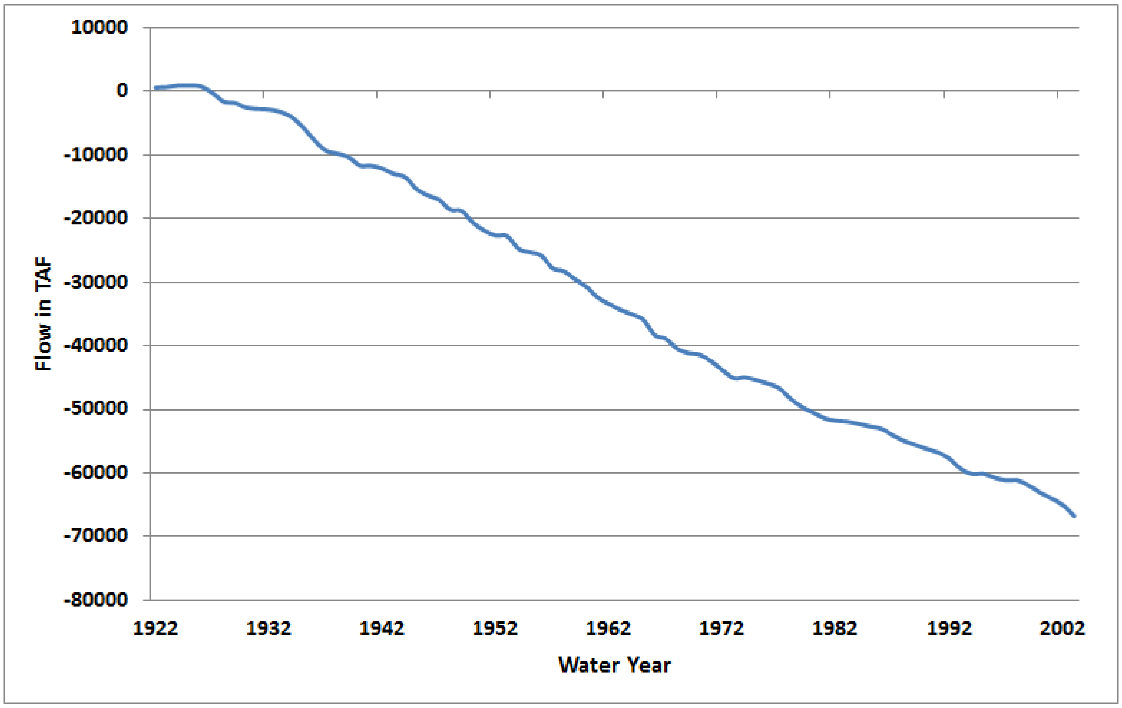


Figure 4-18: WY1922-2003 Projected Annual SR-7 Outflow Cumulative Difference (w/o ANN minus w/ANN)

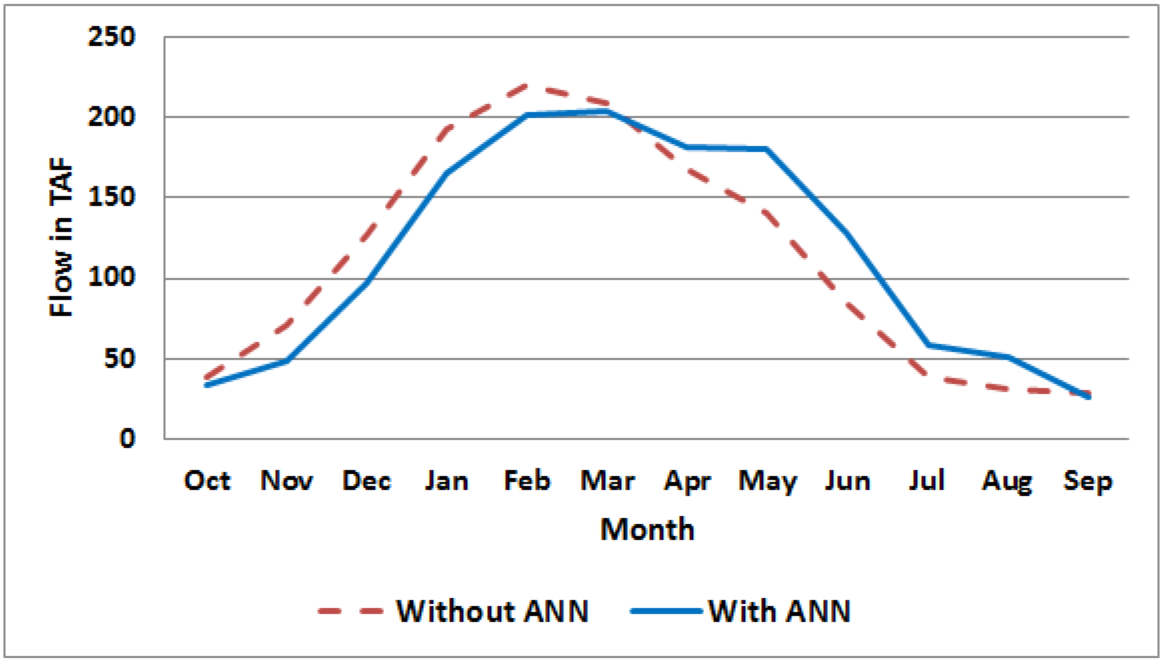


Figure 4-19: Average Monthly SR-8 Outflow WY1922-2003

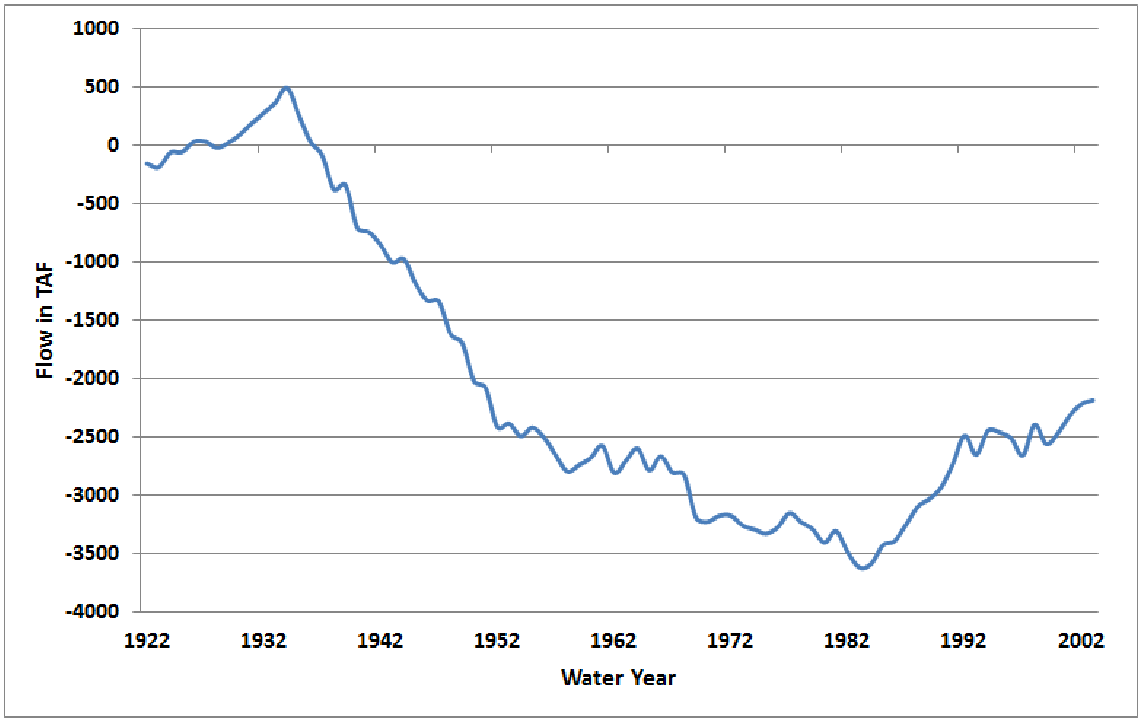


Figure 4-20: WY1922-2003 Projected Annual SR-8 Outflow Cumulative Difference (w/o ANN minus w/ANN)

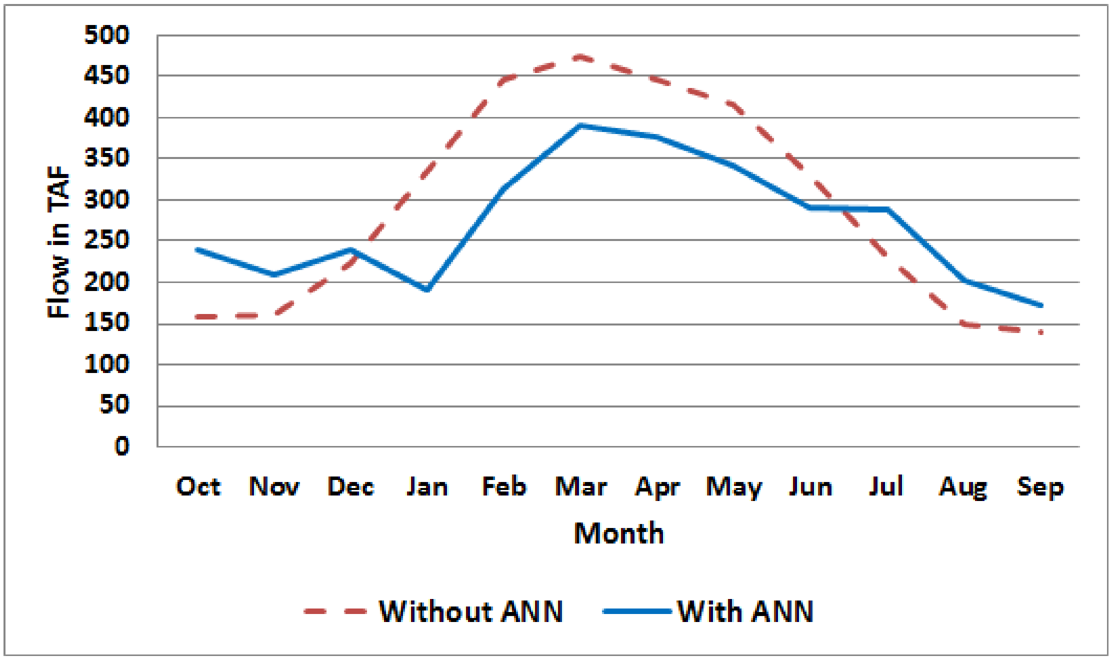


Figure 4-21: Average Monthly SR-10 Outflow WY1922-2003

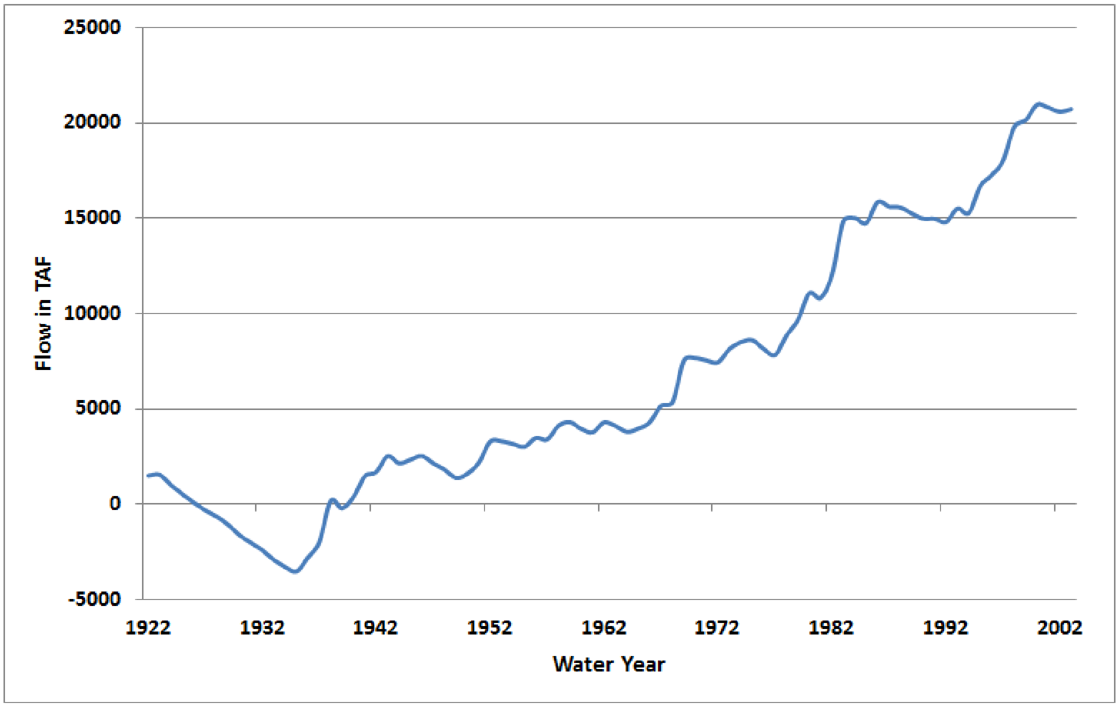


Figure 4-22: WY1922-2003 Projected Annual SR-10 Outflow Cumulative Difference (w/o ANN minus w/ANN)

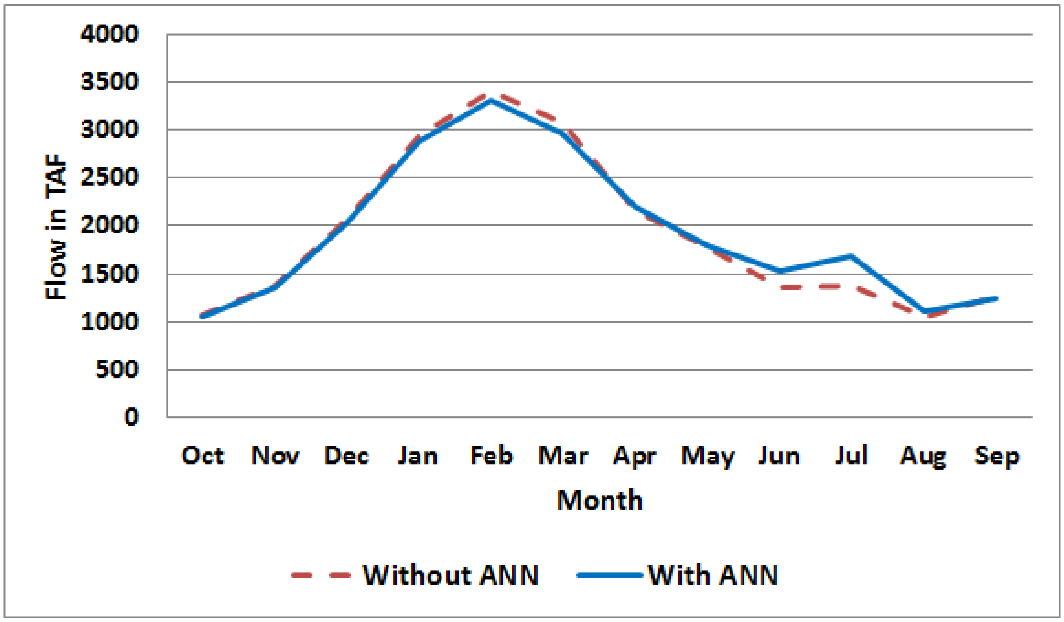


Figure 4-23: C2VSIM Projected Level 2003 Monthly Delta Inflow WY1922-2003

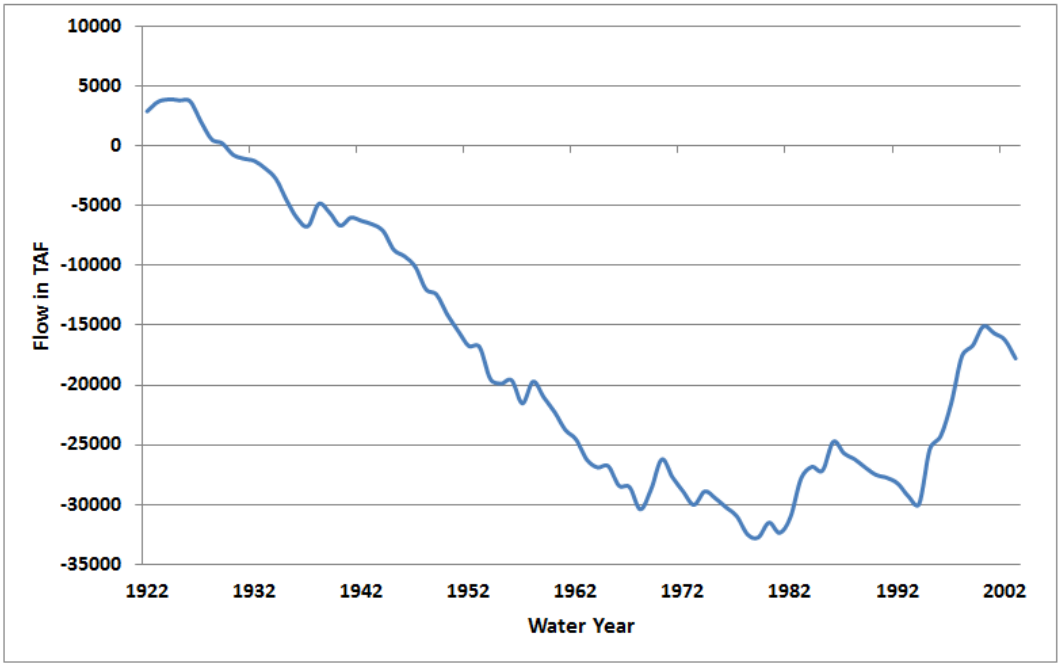


Figure 4-24: WY1922-2003 C2VSIM Projected Level 2003 Cumulative Adjustment to Delta Inflow (w/o ANN minus with ANN)

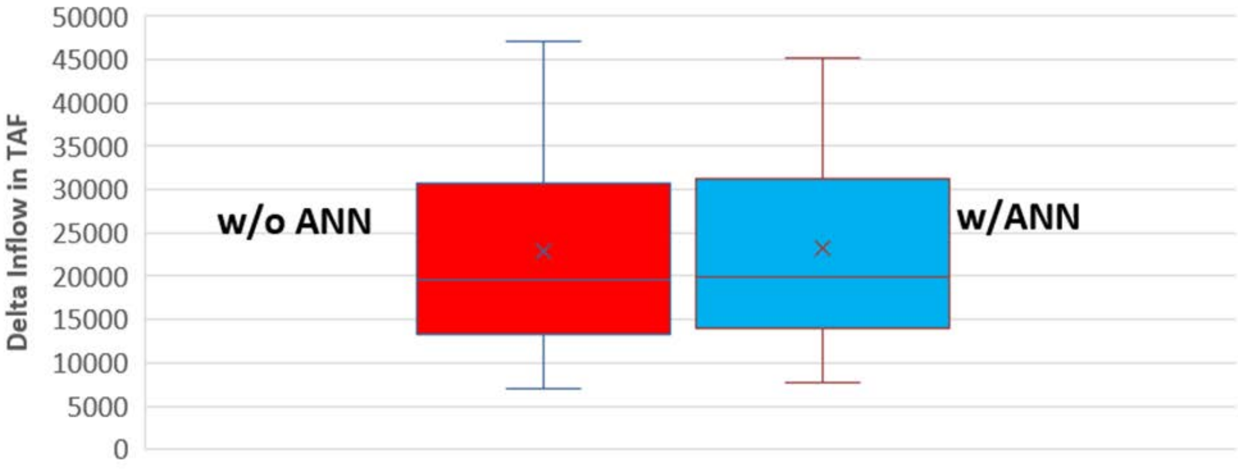


Figure 4-25: C2VSIM Average Annual Delta Inflow for Projected 2003 WY1922-2003

To determine the impact of the adjustments on Delta inflow, Figure 4-26 shows the difference in Delta inflow (with ANN minus without ANN) and the associated cumulative adjustments for all sub-regions. For the spring and summer months, April through August, Figure 4-26 shows that the adjustments can explain the difference in Delta inflow to a large degree. For the other months however they are actually larger. A important point of clarification here, however, is that a negative "computed" adjustment, which in the simulation model implies water is "removed" from the stream, similar to a diversion, does not always occur if there is not sufficient water in the stream. As such the negative adjustments are actually less than what they appear in Figure 4-26.

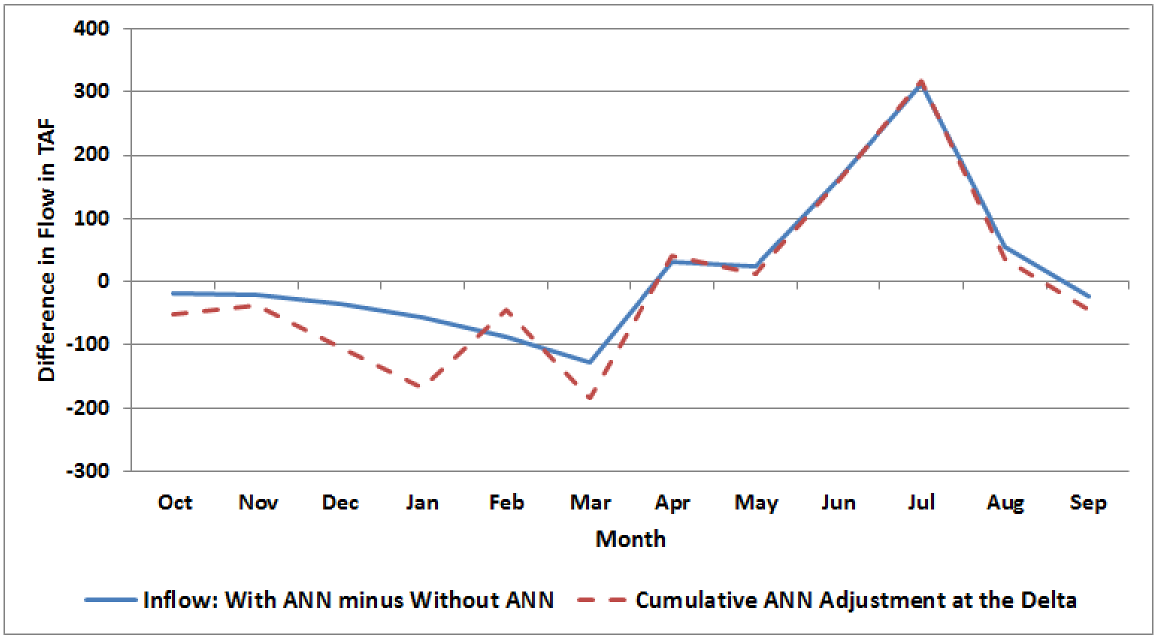


Figure 4-26: C2VSIM Average Monthly Delta Inflow for Projected 2003 WY1922-2003

Figure 4-27 shows the adjustments (total) are a percentage of the difference in Delta inflow.

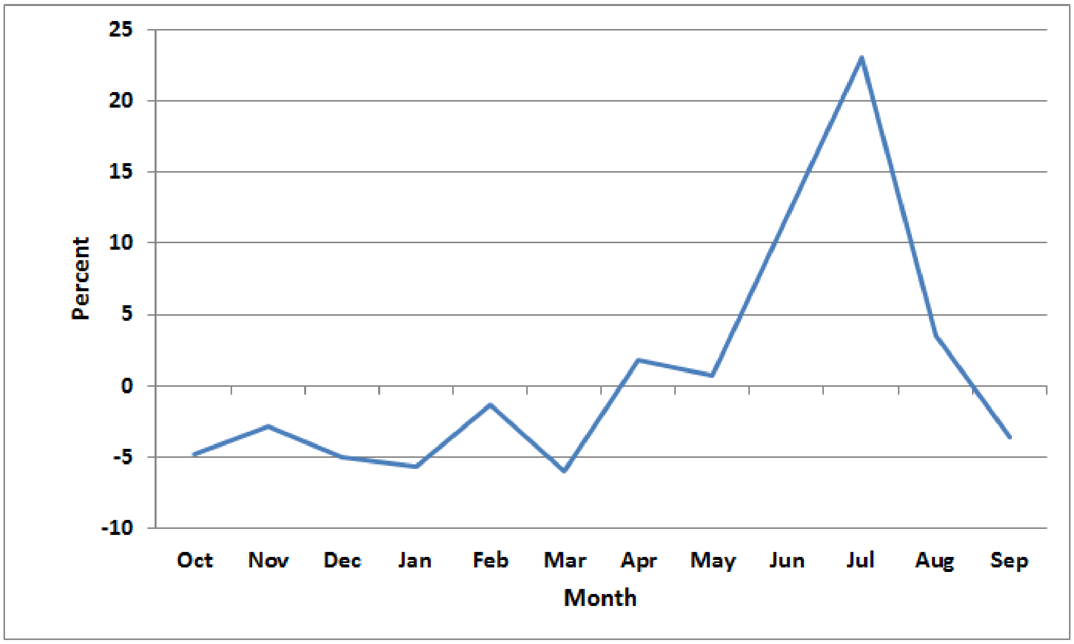


Figure 4-27: C2VSIM Average Monthly Adjustments as Percent of Delta Inflow for Projected 2003 WY1922-2003

Finally, Figure 4-28 shows annual Delta inflows from the both the C2VSIM runs with and without ANN, along with the historical (observed) Delta inflows, and the Delta inflows from the CalSim-II run for DWR’s 2009 State Water Project Delivery Reliability report DRR2009 (CDWR 2010a) mentioned in Section 4-3. The inflows to the Delta are represented in the CalSim-II schematic by arcs C157, C169, C504, and C514. The link to the CalSim-II schematic is:

http://baydeltaoffice.water.ca.gov/modeling/hydrology/CalSim/Downloads/CalSimDownloads/BST_CALSIMII_schematic_040110.pdf

For comparisons to historical observed, only the results for the period 1975 through 2003 were used since it represents the recent historical period where both CVP and SWP projects are fully operational. Figure 4-28 clearly shows that the C2VSIM run with ANN’s closely tracks the CalSim-II run in general.

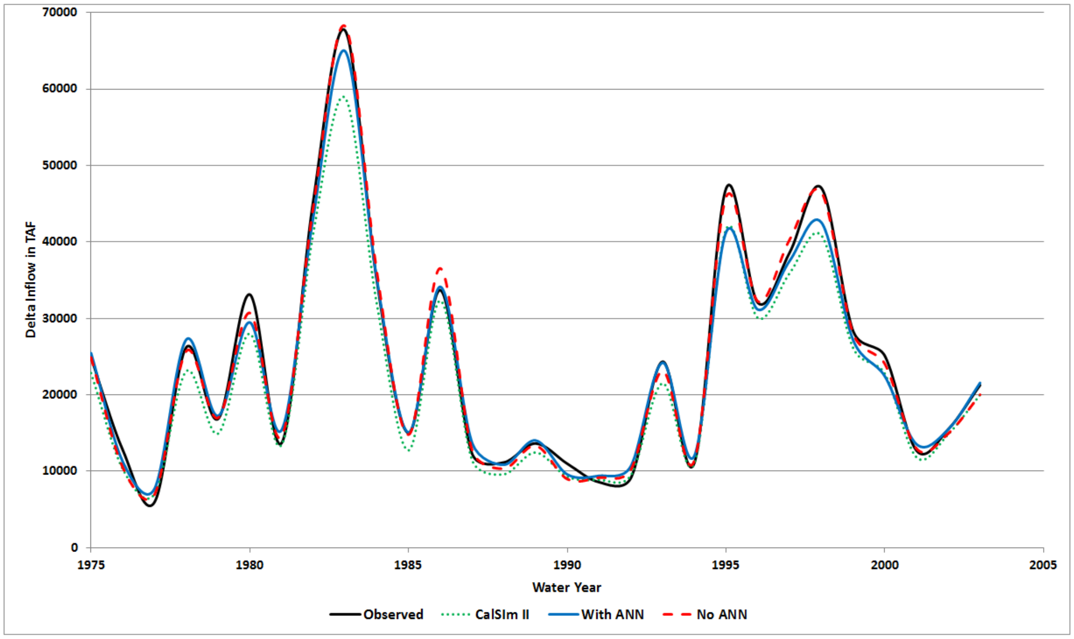


Figure 4-28: Comparison of Annual Delta Inflow: Historical (Observed), CalSim-II Projected, C2VSIM Projected with ANN, and C2VSIM Projected without ANN

Figure 4-29 shows the differences between simulated and observed flows for CalSim II, C2VSIM with ANN, and C2VSIM without ANN. When comparing C2VSIM to CalSim II, the differences for mean and standard deviation are:

- With ANN: Mean=1699 TAF/year, SDEV=1280 TAF/year
- Without ANN: Mean=2082 TAF/year, SDEV=2072 TAF/year

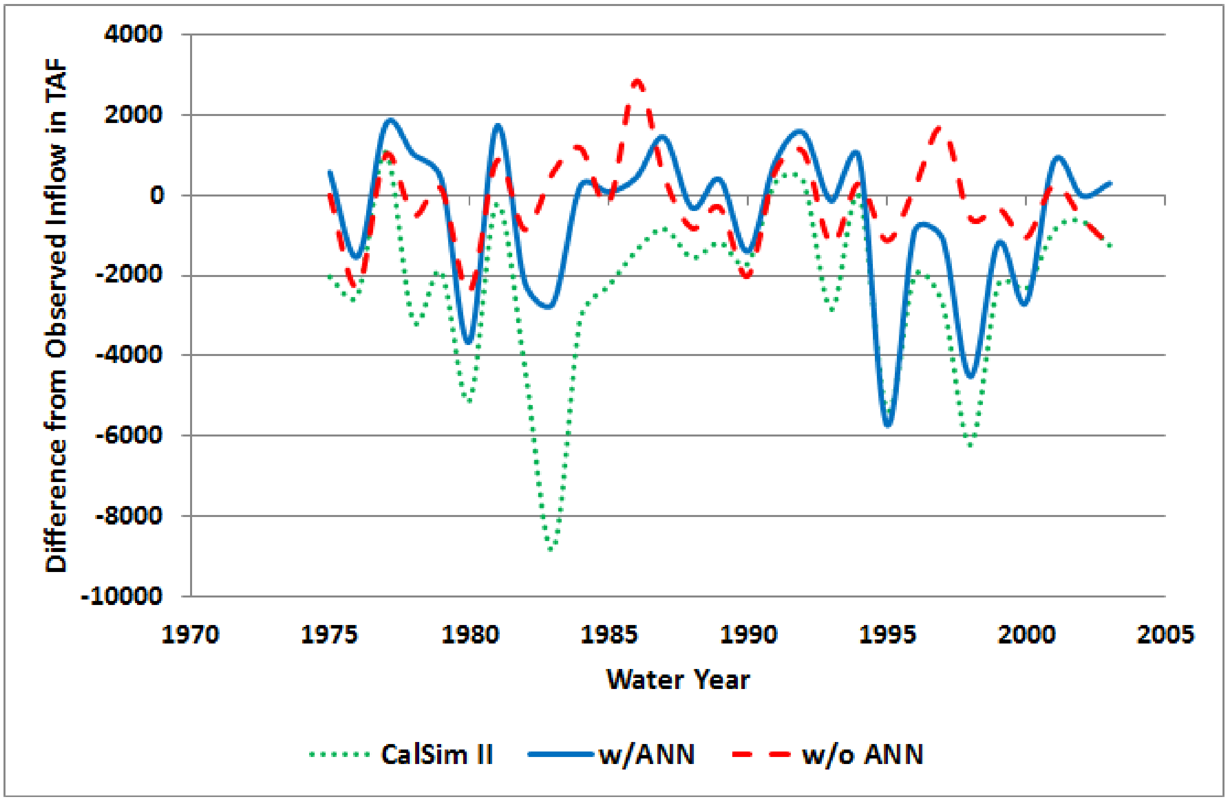


Figure 4-29: Difference in Annual Delta Inflow (Simulated minus Observed) for CalSim-II Projected, C2VSIM Projected with ANN, and C2VSIM Projected without ANN

This Chapter focused on building a Base Case 2003 projected level simulation run for C2VSIM with the ANN adjustments built in. Results were compared to the C2VSIM run without the adjustments activated, and showed by and large that the impact on inflows to the Delta are approximately 217 TAF per year (underestimation without ANN). Although a small percent of total flows, this value is quite significant, especially to project operations for meeting regulatory requirements and contractual deliveries and exports. Delta inflows were also compared to recent historical and to a similar projected level CalSim-II run with very good results.

Chapter 5 CVSIM: A New System Model SIM2 Linked to C2VSIM

This chapter builds on Chapter 4. First, a stand-alone systems (reservoir simulation and water allocation) model SIM2 is developed for the Central Valley system compatible with the C2VSIM representation. SIM2 is then linked with the C2VSIM model (with dynamic ANN's) Projected Level 2003 developed in Chapter 4 to create the Central Valley Simulation Model CVSIM. This integration of the simulation, system, and hydrology represents a unique contribution to water resources planning. A Base Case 2003 projected level scenario for CVSIM is developed and results compared to CalSim-II.

5.1 Background

California faces many water related challenges (Chung et. al. 2002). In modeling California's complex water resources for storing and allocating water through the State Water Project, Central Valley Project, and other local projects, several models have been developed over the years. The two current widely used models are CalSim by the DWR and BOR (Draper et. al. 2004) and CALVIN by UCD (Draper et al 2003, Jenkins et al 2004, Zhu et al 2015). A simplified version of CalSim called CalLite was developed by DWR in recent years (Islam et. al. 2011, Islam et. al. 2015).

CalSim-II (the current public version available) is set up as Mixed Integer Linear Programming MILP problem, computes the hydrology externally (pre-defined in simulation), and uses a simplified groundwater representation, namely modeling only the Sacramento River Basin as seven regions, with the model for groundwater flow and surface water interaction embedded as linear constraints within the Linear Programming LP setup. CalLite, a screening tool, is a much simpler representation of the system, with both the hydrology and groundwater aggregated from the CalSim-II run. CALVIN is an economics based model, more refined spatially and extended geographically representation of California's intertied water resources. The model is set up as an LP problem and solved using network flow algorithm with limitations on representing the physical system and operational constraints. The hydrology for CALVIN is also predefined and groundwater representation is limited.

In the examples cited above, the models are "simulation" in the sense that water is routed in the system (mass balance), and the "optimization" attempts to define the "what best" alternative to operate and allocate the water subject to hydro-economic-institutional constraints. A more preferred approach is to rely on simulation models that simulate the physics and non-linearity of flow of the hydrological components such as runoff, deep percolation, and groundwater flow. Recent examples for linking a groundwater model and LP based optimization include: WEAP and MODFlOW (Hadded et. al., 2013, Nouiri et. al., 2015), WEAP and Parflow (Condon and Maxwell, 2013), IWFM (groundwater only) and CalSim (Dogrul et. al. 2015). In the last example cited, CDWR developed a new version of CalSim called CalSim 3 that improves on the groundwater simulation by including the groundwater module of C2VSIM (Dogrul et al 2016). The hydrology (land use based demands, runoff, return flow, etc), however, is still pre-computed as input. CalSim 3 is still not in the public domain. This research goes a step further by linking the full functional IWFM to a systems model. This allows for integrating the hydrology dynamically into the simulation-optimization process. The resulting tool CVSIM allows for optimizing storage and operations in surface and groundwater reservoirs and allowing for planning studies under various hydrologic (including climate change) and water demand scenarios.

5.2 Development of the Systems Model SIM2

In developing the systems model SIM2 for this research the following guiding principles were followed:

a. SIM2 would simulate the operations of the reservoirs to calculate reservoir releases and the water allocations (surface water diversions and groundwater pumping). Hydrological time series such runoff, return flow, stream-aquifer interaction (seepage), by-pass flows, and sub-regional adjustments would be transferred from C2VSIM to SIM2, for routing the water in the systems model.

b. Only Shasta, Oroville, Folsom, and San Luis (both CVP and SWP portions) are simulated in SIM2. Remaining reservoir releases in the San Joaquin and Tulare basins are transferred from the C2VSIM projected level run (Chapter 4).

c. Only selected operational and institutional constraints are incorporated in SIM2, including flood control, minimum instreamflow requirements, COA (Coordinated Operating Agreement), and Delta Export/Inflow (E/I) ratio.

d. The SIM2 representation would map the major routing components of C2VSIM schematic (Chapter 2) as simple as possible by aggregating hydrological components without compromising model integrity at this research level.

The schematic for SIM2 is shown in Figures 5-1 through 5-3. Due to page size limitations for visualization, the schematic is broken up into separate regions as shown in Figure 5-1. Figures 5-2a through 5-2e show the different regions mapped, and the connectors for stitching together the entire schematic. The legend is shown in Figure 5-3.

The schematic for SIM2 is composed of nodes and arcs. The nodes are numbered as shown and the arcs connecting nodes are implicitly defined by the upstream node since the flow is unidirectional. For example in Figure 5-2a the arc connecting Node 1 (Shasta Reservoir) and Node 100 is named Arc 1, and the arc representing flow below Node 100 is named Arc 100.

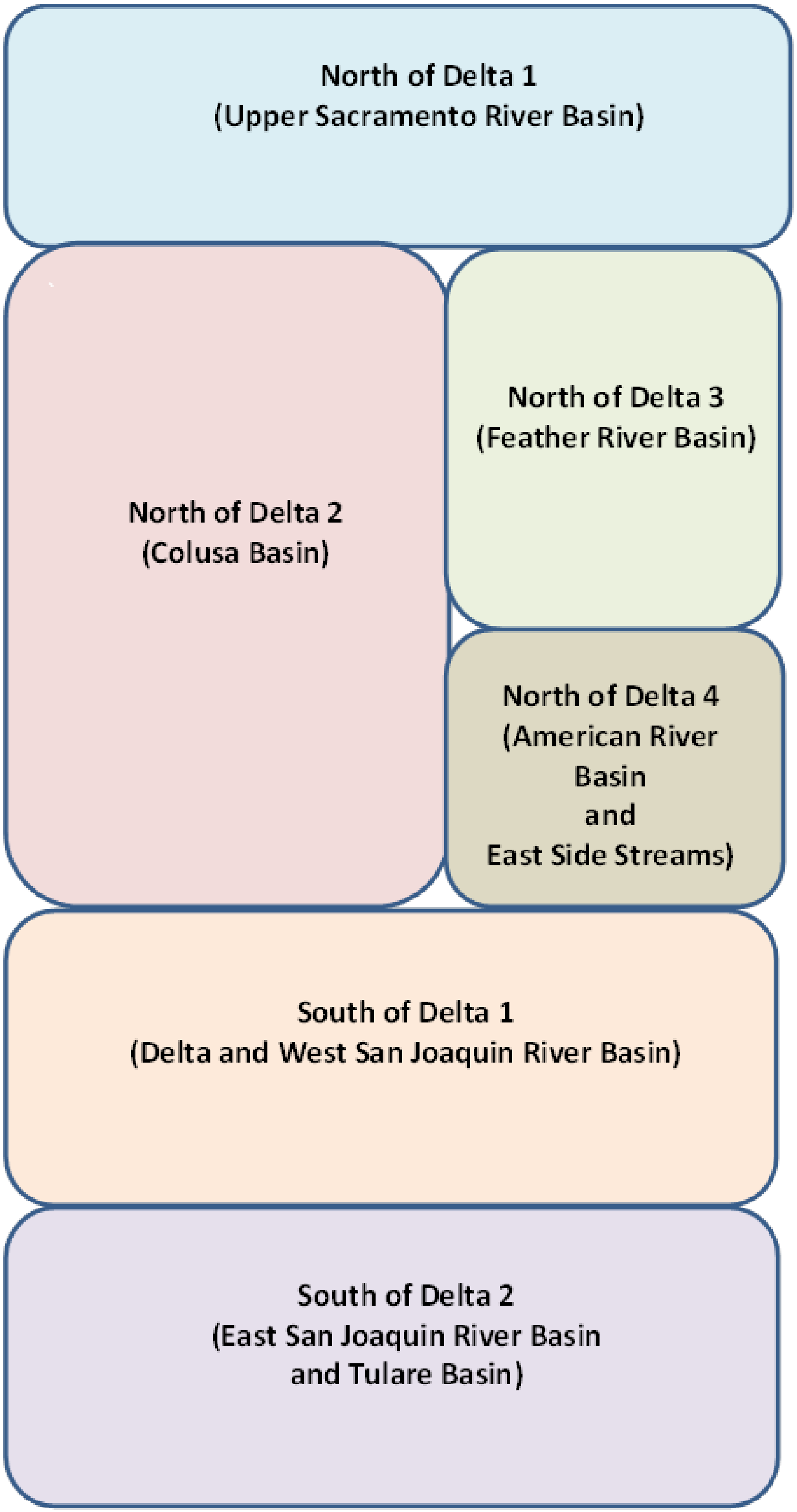


Figure 5-1: Systems Model SIM2 Regional Components

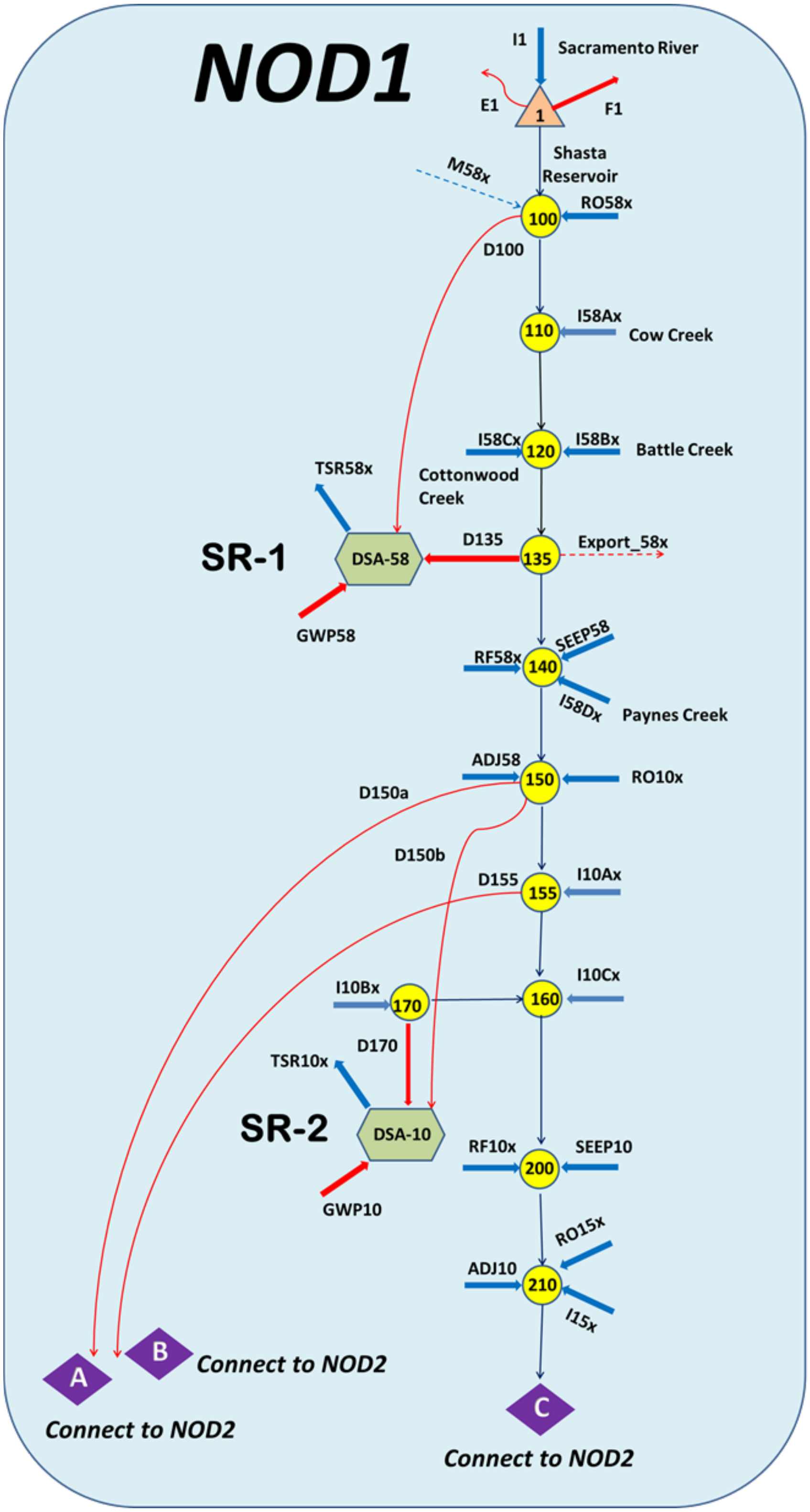


Figure 5-2(a): North of Delta 1 (NOD1) Schematic of SIM2

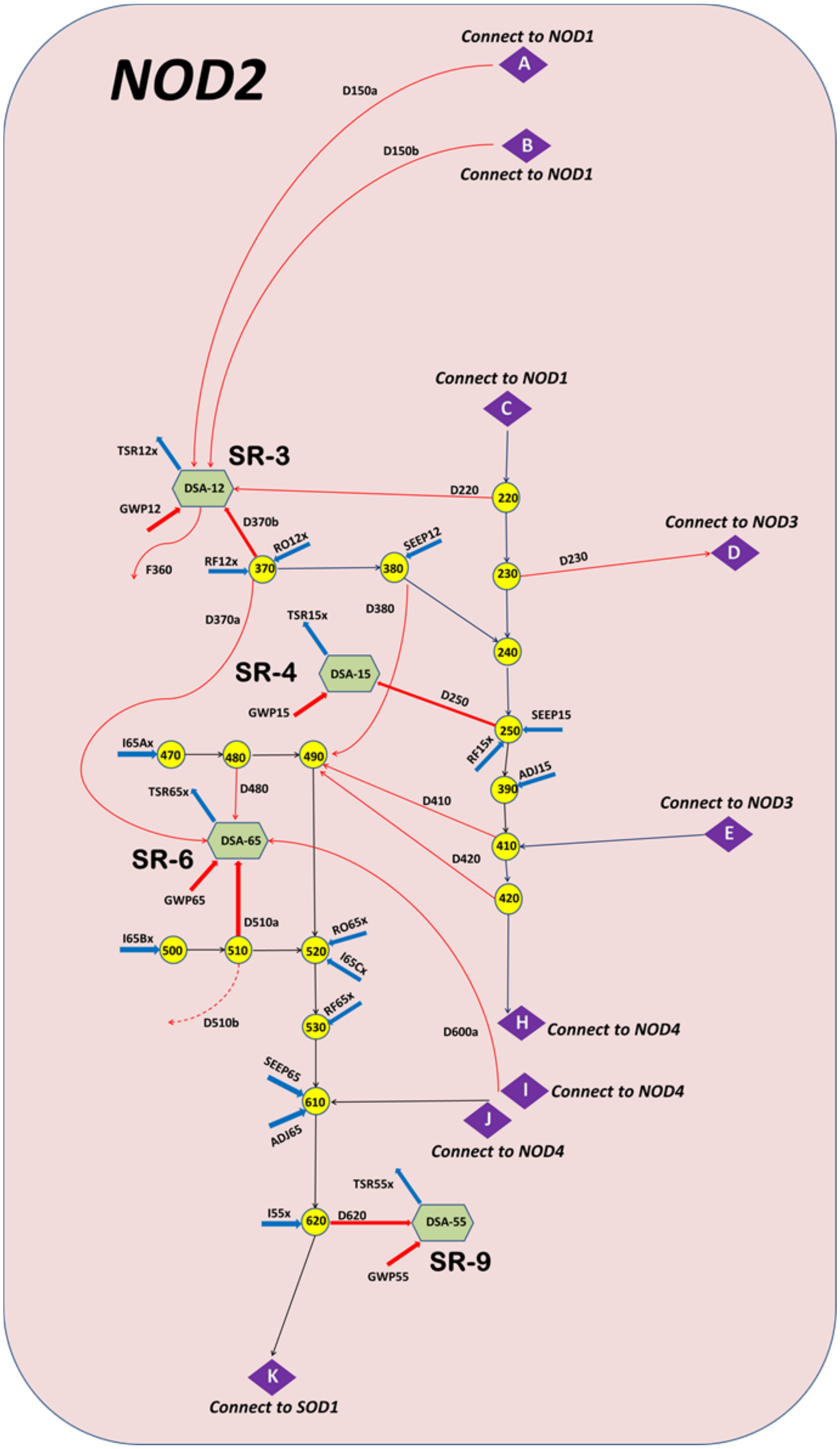


Figure 5-2(b): North of Delta 2 (NOD2) Schematic of SIM2

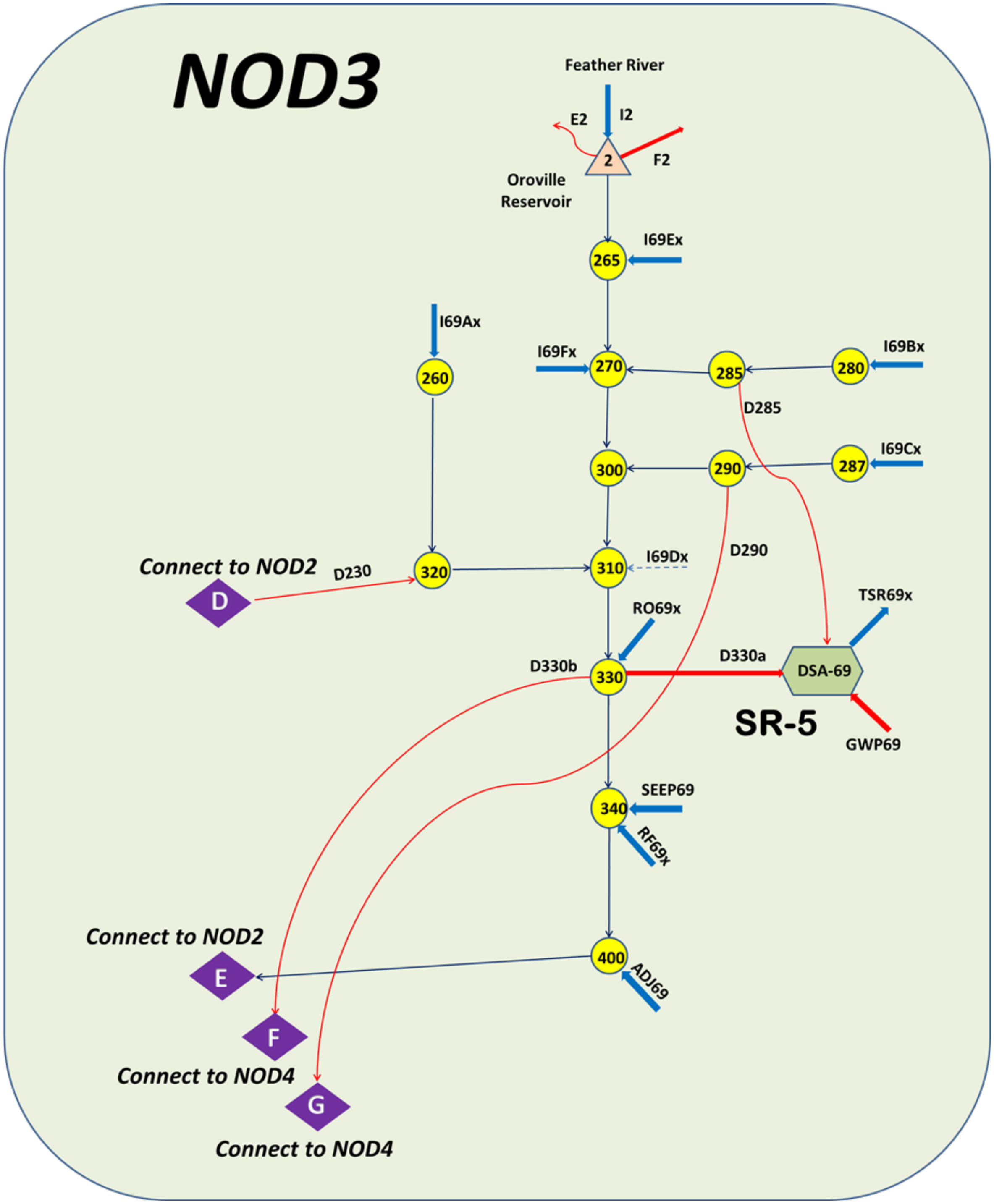


Figure 5-2(c): North of Delta 3 (NOD3) Schematic of SIM2

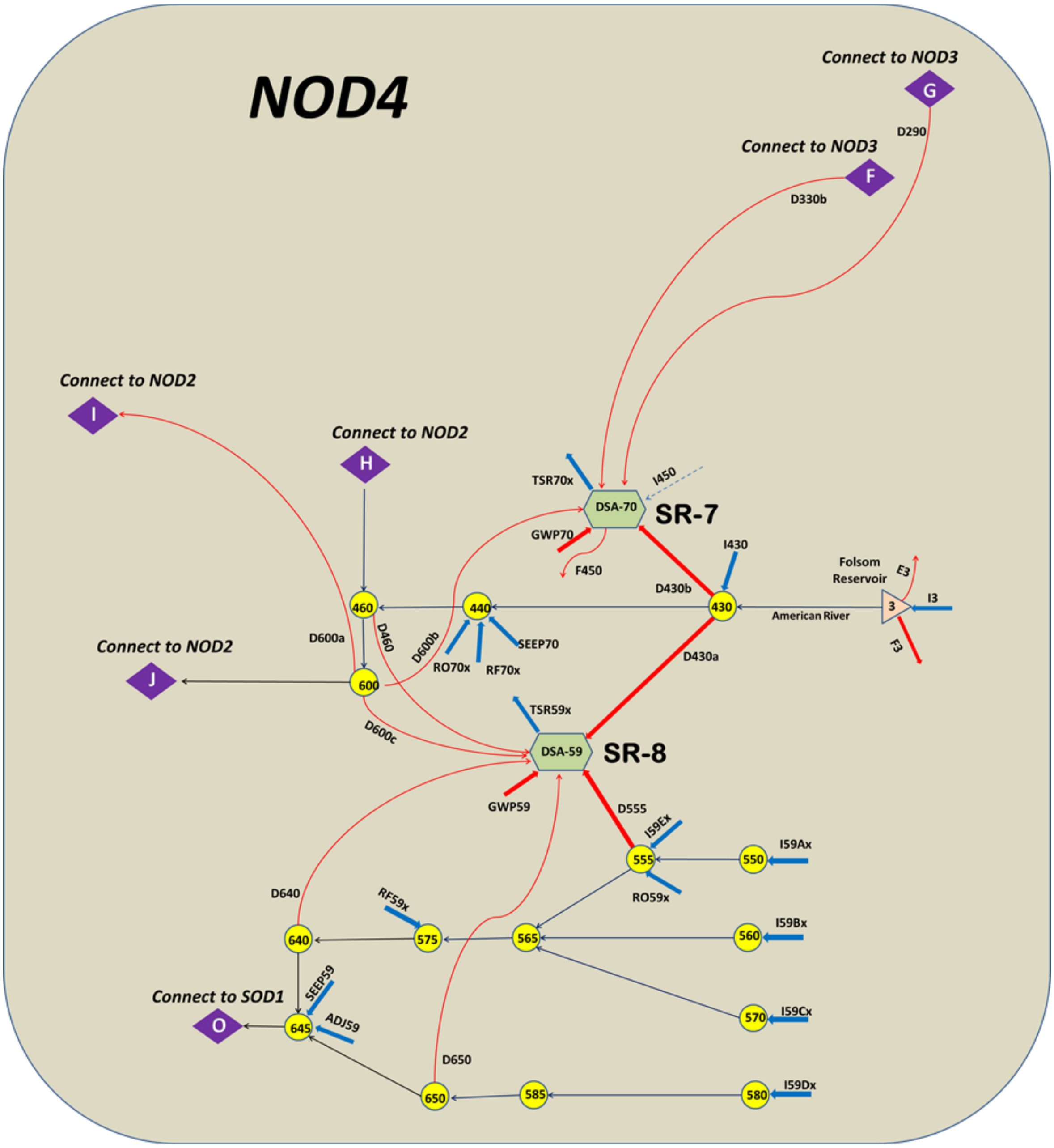


Figure 5-2(d): North of Delta 4 (NOD4) Schematic of SIM2

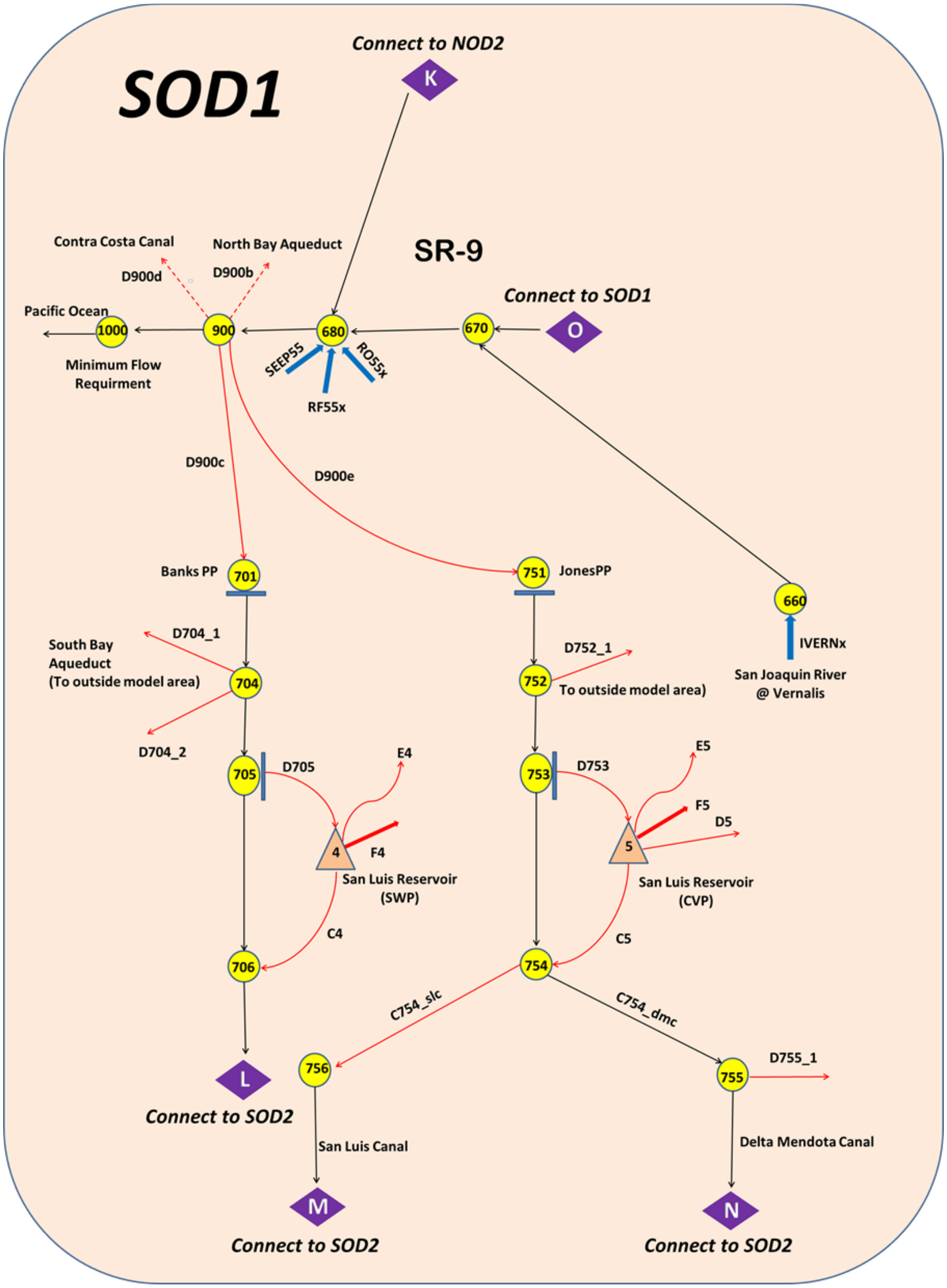


Figure 5-2(e): South of Delta 1 (SOD1) Schematic of SIM2

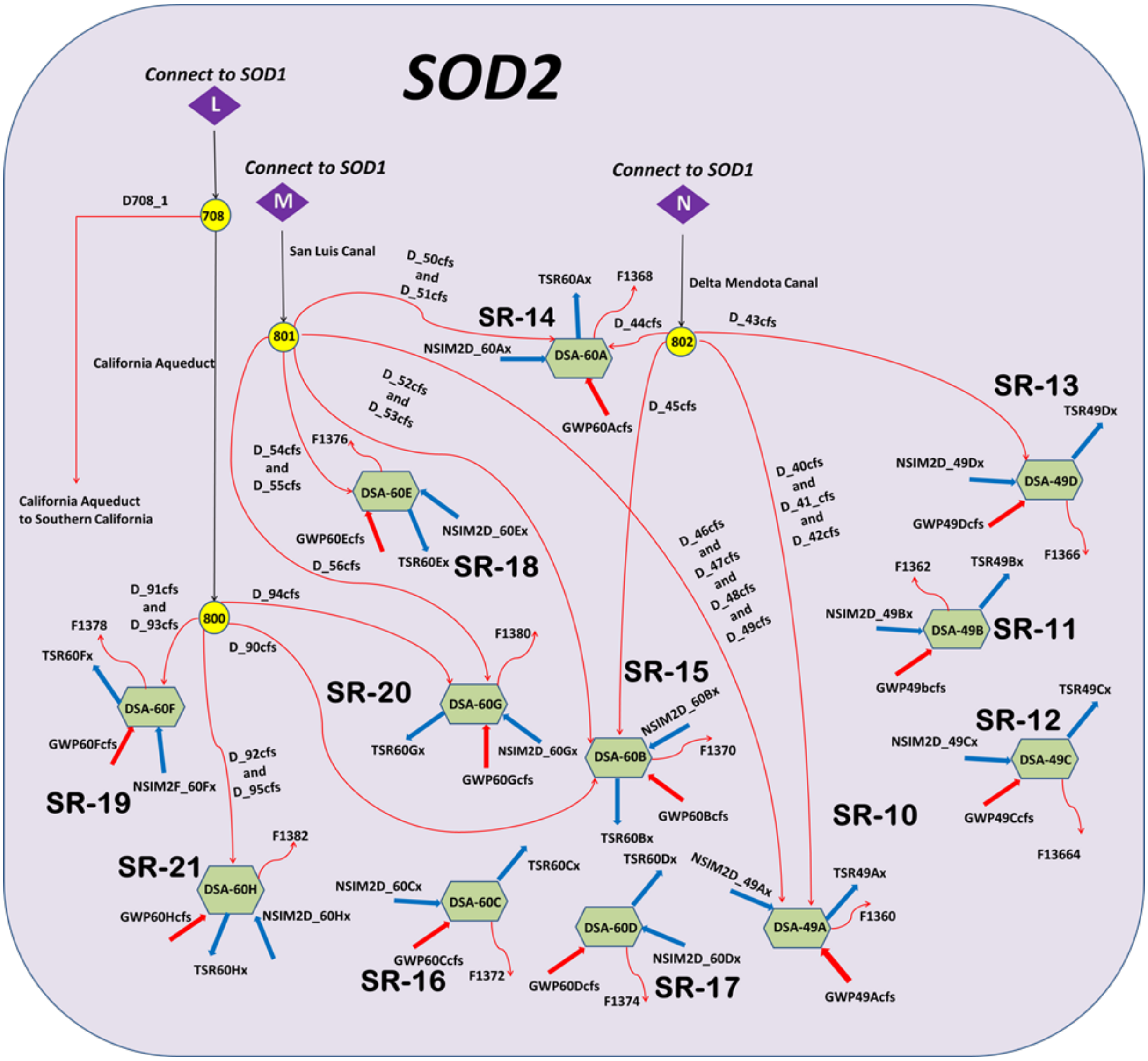


Figure 5-2(f): South of Delta 2 (SOD2) Schematic of SIM2

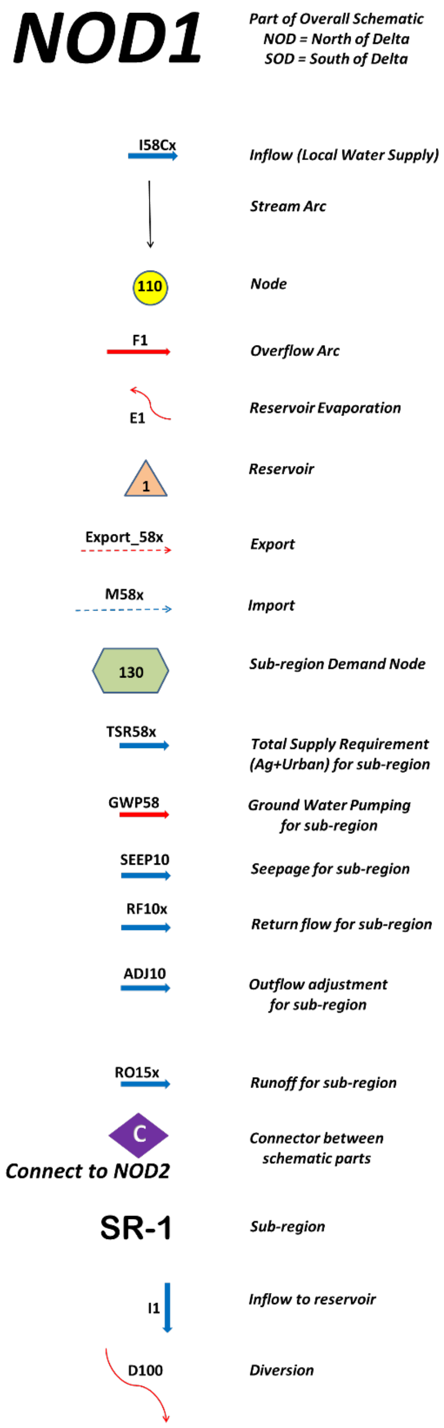


Figure 5-3: Legend for SIM2 Schematics

The clipped arrows in the schematic represent time series either input to the model or transferred from C2VSIM during simulation.

Figure 5-2a (NOD1) shows areas for SR-1 (DA58) and SR-2 (DA10) areas mapped from C2VSIM. Shasta reservoir (Node 1) on the Sacramento River has three components: inflow (I1), Evaporation (E1), and the “F” arc F1 whose purpose is to bypass excess flows to prevent the simulation from aborting (to be explained in further detail later in the chapter). The sub-regional runoff, return flow, seepage (stream-aquifer interaction), groundwater pumping, and adjustments are shows for SR-1 (DA58) as RO58x, RF58x, SEEP58, GWP58, and ADJ58, respectively. The sub-region net demands for SR-1 (DA58) and SR-2 (DA10) are shown at nodes DSA-58 and DSA-10, as TSR58x, and TSR10x, respectively. Diversions and inflows are mapped directly or aggregated from C2VSIM.

Figure 5-2b (NOD2) shows mapped areas for SR-3 (DA12), SR-4 (DA15), SR-6 (DA65), and the Delta SR-9 (DA55). Figure 5-2c (NOD3) shows the mapped area for Feather River basin SR-5 (DA69), with Oroville reservoir and Node 2. Figure 5-2d (NOD4) shows the mapped areas for the American River basin SR-7 (DA70), and the Eastside Streams SR-8 (DA59) including Folsom reservoir at Node 3. Figure 5-2e (SOD1) shows the Delta area SR-9 (DA55), including the San Luis reservoir: SWP portion at Node 4, and CVP portion at Node 5. Figure 5-2f shows the remaining San Joaquin and Tulare basins SR-10 through SR-21.

The variables for SIM2 shown Figures 5-2a through 5-2f are defined in Tables 5-1 through 5-4, and are grouped as follows:

- Table 5-1 lists the SIM2 variables which are transferred from SIM2 to C2VSIM along with the corresponding C2VSIM variable name.
- Table 5-2 lists the SIM2 variables which are transferred from C2VSIM to SIM2, and the corresponding C2VSIM variable name.
- Table 5-3 lists the SIM2 variables whose values are input to the model directly or shared with C2VSIM during simulation, and the corresponding C2VSIM variable name.
- Table 5-4 lists the SIM2 variables which are local to the systems model simulation.
- Note: The variables NSIM2D-xxxx shown in Figures 5-2e and 5-2f represent local diversions in C2VSIM to meet demands. They are fixed to the C2VSIM values and not modeled dynamically in SIM2

5.3 Building SIM2 using DWR’s WRIMS GUI and WRESL Code

SIM2 is a simplified planning tool for simulating and operating the SWP and CVP reservoirs and related facilities in the Central Valley. SIM2 simulates available water resources to meet competing demands including water allocations (surface water diversions, exports from the Delta, and groundwater pumping) for meeting consumptive land use based demands at fixed levels of development. The simulation uses monthly time steps and a precipitation trace for the period WY1922-2003. The geographic coverage includes the entire Central Valley as described by the C2VSIM model in Chapters 2 and 4. The model accounts for system operational objectives, physical constraints on storage, conveyance, and delivery, and selected institutional agreements such as reservoir flood control guidelines, minimum flows for navigation or SWRCB decisions, Coordinated Operating Agreement between CDWR and USBR for operating the CVP/SWP systems. Water is also used in the Delta to meet in basin demands, and exported south of the Delta to meet demands within the Central Valley, or exported to Southern California.

Table 5-1: Variables Transferred from SIM2 to C2VSIM

No.	SIM2 Variable	Definition	Corresponding Variable in C2VSIM
1	M58x	Trinity Import (Input)	I-1 (part 2 of 2)
2	C1	Release from Shasta Reservoir	I-1 (part 1 of 2)
3	C2	Release from Oroville Reservoir	I-14
4	C3	Release from Folsom Reservoir	I-18
5	D_40cfs	Delta Mendota Canal to Subregion 49A	D-40
6	D_41cfs	Delta Mendota Canal Estimated Losses (based on water balance)	D-41
7	D_42cfs	Mendota Pool to DSA Subregion 49A	D-42
8	D_43cfs	Mendota Pool to DSA Subregion 49D	D-43
9	D_44cfs	Mendota Pool to DSA Subregion 60A	D-44
10	D_45cfs	Mendota Pool to DSA Subregion 60B	D-45
11	D_46cfs	O'Neill Forebay to San Luis WD	D-46
12	D_47cfs	San Luis Canal to San Luis WD	D-47
13	D_48cfs	San Luis Canal to Panoche WD	D-48
14	D_49cfs	San Luis Canal to Pacheco WD	D-49
15	D_50cfs	San Luis Canal to Westlands WD	D-50
16	D_51cfs	San Luis Canal to Pleasant Valley WD (DSA 60A)	D-51
17	D_52cfs	San Luis Canal to Green Valley (DSA 60B)	D-52
18	D_53cfs	San Luis Canal to Kings County WD (DSA 60B)	D-53
19	D_54cfs	San Luis Canal to Lakeside ID (DSA 60E)	D-54
20	D_55cfs	San Luis Canal to Pixley ID (DSA 60E)	D-55
21	D_56cfs	San Luis Canal to Cawello WD (DSA 60G)	D-56
22	D_90cfs	California Aqueduct to DSA 60B	D-90
23	D_91cfs	California Aqueduct to DSA 60F	D-91
24	D_92cfs	California Aqueduct to DSA 60H	D-92
25	D_93cfs	Cross Valley Canal to DSA 60F	D-93
26	D_94cfs	Cross Valley Canal to DSA 60G	D-94
27	D_95cfs	Cross Valley Canal to DSA 60H	D-95
28	D100	Bella Vista Conduit	D-2
29	D135	Diversions from Sacramento River between Keswick and Red Bluff	D-3
30	D150a	Tehama Colusa Canal to DSA 12 (irrigation supply)	D-7
31	D150b	Corning Canal	D-4
32	D155	Glenn Colusa Canal	D-8
33	D170	Stony Creek (North and South)	D-5
34	D220	DSA 12 Sacramento River Right Banks Exports	D-10
35	D250	DSA 15 from Sacramento River between Red Bluff and Knights Landing	D-11
36	D285	Diversions from Yuba River	D-20
37	D290	Bear River diversion to South Sutter WD (exported to DSA 70)	D-21
38	D330a	DSA 69 Diversions from Feather River	D-18
39	D330b	DSA 70 Feather River Left Banks Diversion	D-19
40	D370a	Diversions from Knights Landing Ridge Cut for irrigation supply	D-30
41	D370b	Colusa Basin Drain for Irrigation Supply	D-9

Table 5-1 (cont.): Variables Transferred from SIM2 to C2VSIM

No.	SIM2 Variable	Definition	Corresponding Variable in C2VSIM
42	D430a	Folsom South Canal (total)	D-34
43	D430b	American River Carmichael WD	D-29
44	D460	American River Left Banks Diversion by City of Sacramento	D-35
45	D480	Capay Irrigation (total)	D-32
46	D510a	DSA 65 Diversions Putah South Canal (total)	D-33
47	D510b	Export Putah South Canal to North Bay	D-31
48	D555	Diversions from Cosumnes River (riparian)	D-36
49	D600a	DSA 65 Sacramento Right Banks Diversions btwn Knights Landing and Sacramento	D-23
50	D600b	DSA 70 Diversions from Sac. River between Knights Landing and Sacramento (all but City water)	D-22
51	D600c	DSA 59 Sacramento River Left Banks Diversion to City of Sacramento	D-24
52	D620	DSA 55 Surface Water Diversions	D-106
53	D640	Diversions from Mokelumne River (total)	D-37
54	D650	Diversions from Calaveras River (riparian)	D-38
55	D900b	SWP Export from the Delta- North Bay Aqueduct (part 1 of 2)	D-113
56	D900c	SWP Export from the Delta - Banks PP (Part 2 of 2)	D-113
57	D900d	Contra Costa Canal Export from the Delta	D-112
58	D900e	CVP Export from the Delta	D-114
59	Export_58x	Diversions from Sacramento River between Keswick and Red Bluff	D-3
60	GWP10	Ground Water Pumping SR-2 (DA10)	calculated internally
61	GWP12	Ground Water Pumping SR-3 (DA12)	calculated internally
62	GWP15	Ground Water Pumping SR-4 (DA15)	calculated internally
63	GWP49Acfs	Ground Water Pumping SR-10 (DA49a)	calculated internally
64	GWP49Bcfs	Ground Water Pumping SR-11 (DA49b)	calculated internally
65	GWP49Ccfs	Ground Water Pumping SR-12 (DA49c)	calculated internally
66	GWP49Dcfs	Ground Water Pumping SR-13 (DA49d)	calculated internally
67	GWP55	Ground Water Pumping SR-9 (DA55)	calculated internally
68	GWP58	Ground Water Pumping SR-1 (DA58)	calculated internally
69	GWP59	Ground Water Pumping SR-8 (DA59)	calculated internally
70	GWP60Acfs	Ground Water Pumping SR-14 (DA60a)	calculated internally
71	GWP60Bcfs	Ground Water Pumping SR-15 (DA60b)	calculated internally
72	GWP60Ccfs	Ground Water Pumping SR-16 (DA60c)	calculated internally
73	GWP60Dcfs	Ground Water Pumping SR-217 (DA60d)	calculated internally
74	GWP60Ecfs	Ground Water Pumping SR-18 (DA60e)	calculated internally
75	GWP60Fcfs	Ground Water Pumping SR-19 (DA60f)	calculated internally
76	GWP60Gcfs	Ground Water Pumping SR-20 (DA60g)	calculated internally
77	GWP60Hcfs	Ground Water Pumping SR-21 (DA60h)	calculated internally
78	GWP65	Ground Water Pumping SR-6 (DA65)	calculated internally
79	GWP69	Ground Water Pumping SR-5 (DA69)	calculated internally
80	GWP70	Ground Water Pumping SR-7 (DA70)	calculated internally

Table 5-2: Variables Transferred from C2VSIM to SIM2

No.	SIM2 Variable	Definition	Corresponding Variable in C2VSIM
1	ADJ10	Adjustment Term SR-2 (DA10)	I-43 & I-44 & I-45
2	ADJ15	Adjustment Term SR-4 (DA15)	I-46
3	ADJ58	Adjustment Term SR-1 (DA58)	I-41 & I-42
4	ADJ59	Adjustment Term SR-8 (DA59)	I-52 & I-53 & I-54
5	ADJ65	Adjustment Term SR-6 (DA65)	I-48
6	ADJ69	Adjustment Term SR-5 (DA69)	I-47
7	D230	Sutter Weir Flow	D-102
8	D380	Knights Landing Ridge Cut Flood Flow	D-105
9	D410	Fremont Weir Flow	D-103
10	D420	Sacramento Weir Flow	D-104
11	I15x	Tributary Flows SR-3 (DA15)	calculated internally
12	I430	Tributary Flows SR-37 (DA70)	calculated internally
13	I55x	Tributary Flows SR-9 (DA55)	calculated internally
14	I59Ex	Tributary Flows SR-8 (DA59)	calculated internally
15	I65Cx	Tributary Flows SR-6 (DA65)	calculated internally
16	I69Fx	Tributary Flows SR-5 (DA69)	calculated internally
17	IVERNx	Vernalis Flow	Streamflow Node 156
18	RF10x	Return Flow SR-2 (DA10)	calculated internally
19	RF12x	Return Flow SR-3 (DA12)	calculated internally
20	RF15x	Return Flow SR-4 (DA15)	calculated internally
21	RF55x	Return Flow SR-9 (DA55)	calculated internally
22	RF58x	Return Flow SR-1 (DA58)	calculated internally
23	RF59x	Return Flow SR-8 (DA59)	calculated internally
24	RF65x	Return Flow SR-6 (DA65)	calculated internally
25	RF69x	Return Flow SR-5 (DA69)	calculated internally
26	RF70x	Return Flow SR-7 (DA70)	calculated internally
27	RO10x	Runoff SR-2 (DA10)	calculated internally
28	RO12x	Runoff SR-3 (DA12)	calculated internally
29	RO15x	Runoff SR-4 (DA15)	calculated internally
30	RO55x	Runoff SR-9 (DA55)	calculated internally
31	RO58x	Runoff SR-1 (DA58)	calculated internally
32	RO59x	Runoff SR-8 (DA59)	calculated internally
33	RO65x	Runoff SR-6 (DA65)	calculated internally
34	RO69x	Runoff SR-5 (DA69)	calculated internally
35	RO70x	Runoff SR-7 (DA70)	calculated internally
36	SEEP10	Seepage SR-2 (DA10)	calculated internally
37	SEEP12	Seepage SR-3 (DA12)	calculated internally
38	SEEP15	Seepage SR-4 (DA15)	calculated internally
39	SEEP55	Seepage SR-9 (DA55)	calculated internally
40	SEEP58	Seepage SR-1 (DA58)	calculated internally
41	SEEP59	Seepage SR-8 (DA59)	calculated internally
42	SEEP65	Seepage SR-6 (DA65)	calculated internally
43	SEEP69	Seepage SR-5 (DA69)	calculated internally
44	SEEP70	Seepage SR-7 (DA70)	calculated internally

Table 5-2 (cont.): Variables Transferred from C2VSIM to SIM2

No.	SIM2 Variable	Definition	Corresponding Variable in C2VSIM
45	TSR10x	Total Supply Requirement SR-2 (DA10)	calculated internally
46	TSR12x	Total Supply Requirement SR-3 (DA12)	calculated internally
47	TSR15x	Total Supply Requirement SR-4 (DA15)	calculated internally
48	TSR49Ax	Total Supply Requirement SR-10 (DA49a)	calculated internally
49	TSR49Bx	Total Supply Requirement SR-11 (DA49b)	calculated internally
50	TSR49Cx	Total Supply Requirement SR-12 (DA49c)	calculated internally
51	TSR49Dx	Total Supply Requirement SR-13 (DA49d)	calculated internally
52	TSR55x	Total Supply Requirement SR-9 (DA55)	calculated internally
53	TSR58x	Total Supply Requirement SR-1 (DA58)	calculated internally
54	TSR59x	Total Supply Requirement SR-8 (DA59)	calculated internally
55	TSR60Ax	Total Supply Requirement SR-14 (DA60a)	calculated internally
56	TSR60Bx	Total Supply Requirement SR-15 (DA60b)	calculated internally
57	TSR60Cx	Total Supply Requirement SR-216 (DA60c)	calculated internally
58	TSR60Dx	Total Supply Requirement SR-17 (DA60d)	calculated internally
59	TSR60Ex	Total Supply Requirement SR-18 (DA60e)	calculated internally
60	TSR60Fx	Total Supply Requirement SR-192 (DA60f)	calculated internally
61	TSR60Gx	Total Supply Requirement SR-20 (DA60g)	calculated internally
62	TSR60Hx	Total Supply Requirement SR-21 (DA60h)	calculated internally
63	TSR65x	Total Supply Requirement SR-6 (DA65)	calculated internally
64	TSR69x	Total Supply Requirement SR-5 (DA69)	calculated internally
65	TSR70x	Total Supply Requirement SR-7 (DA70)	calculated internally
66	TSR15x	Total Supply Requirement SR-4 (DA15)	calculated internally
67	TSR49Ax	Total Supply Requirement SR-10 (DA49a)	calculated internally
68	TSR49Bx	Total Supply Requirement SR-11 (DA49b)	calculated internally
69	TSR49Cx	Total Supply Requirement SR-12 (DA49c)	calculated internally
70	TSR49Dx	Total Supply Requirement SR-13 (DA49d)	calculated internally
71	TSR55x	Total Supply Requirement SR-9 (DA55)	calculated internally
72	TSR58x	Total Supply Requirement SR-1 (DA58)	calculated internally
73	TSR59x	Total Supply Requirement SR-8 (DA59)	calculated internally
74	TSR60Ax	Total Supply Requirement SR-14 (DA60a)	calculated internally
75	TSR60Bx	Total Supply Requirement SR-15 (DA60b)	calculated internally
76	TSR60Cx	Total Supply Requirement SR-216 (DA60c)	calculated internally
77	TSR60Dx	Total Supply Requirement SR-17 (DA60d)	calculated internally
78	TSR60Ex	Total Supply Requirement SR-18 (DA60e)	calculated internally
79	TSR60Fx	Total Supply Requirement SR-192 (DA60f)	calculated internally
80	TSR60Gx	Total Supply Requirement SR-20 (DA60g)	calculated internally
81	TSR60Hx	Total Supply Requirement SR-21 (DA60h)	calculated internally
82	TSR65x	Total Supply Requirement SR-6 (DA65)	calculated internally
83	TSR69x	Total Supply Requirement SR-5 (DA69)	calculated internally
84	TSR70x	Total Supply Requirement SR-7 (DA70)	calculated internally

Table 5-3: Variables Input Directly to SIM2

No.	SIM2 Variable	Definition	Corresponding Variable in C2VSIM
1	I69Dx	Imports to SR-5 (DA69)	D12 through D17
2	I1	Inflow to Shasta Reservoir	
3	I10Ax	Antelope+Mill+Elder+Thomes+Deer Creeks + Trib Flow SR-2 (DA10)	I6 +I7 + I8 + I9 + I10 + Tributary Flows SR-2 (DA10)
4	I10Bx	Stony Creek	I-11
5	I10Cx	Big Chico Creek	I-12
6	I2	Inflow to Oroville Reservoir	not applicable
7	I3	Inflow to Folsom Reservoir	not applicable
8	I450	Imports to SR-7 (DA70): Boardman Canal, Bear River Canal, etc	I35 + I26 + I27 + I28
9	I58Ax	Cow Creek	I-2
10	I58Bx	Butte Creek	I-3
11	I58Cx	Cottonwood Creek	I-4
12	I58Dx	Paynes Creek	I-5
13	I59Ax	Cosumnes River	I-20
14	I59Bx	Dry Creek	I-21
15	I59Cx	Mokelumne River	I-22
16	I59Dx	Calaveras River	I-23
17	I65Ax	Cache Creek	I-17
18	I65Bx	Putah Creek	I-19
19	I69Ax	Butte and Chico Creeks	I-13
20	I69Bx	Yuba River	I-15
21	I69Cx	Bear River	I-16
22	I69Ex	Kelly Ridge	not applicable

Table 5-4: Variables Local to SIM2

No.	SIM2 Variable	Definition
1	C4	Release from San Luis Reservoir (SWP)
2	C5	Release from San Luis Reservoir (CVP)
3	C754_dmc	Diversion to Delta Mendota Canal
4	C754_slc	Diversion to San Luis Canal
5	D5	San Benito County & Santa Clara Valley WD and Pajaro Valley WD
6	D704-1	South Bay Aqueduct Export
7	D704-2	Local Diversion
8	D705	Diversion to San Luis Reservoir (SWP)
9	D708-1	California Aqueduct to South California
10	D752-1	Upper DMC Export
11	D753	Division to San Luis Reservoir (CVP)
12	D755-1	Local Diversion
13	E1	Evaporation from Shasta Reservoir
14	E2	Evaporation from Oroville Reservoir
15	E3	Evaporation from Folsom Reservoir
16	E4	Evaporation from San Luis Reservoir (SWP)
17	E5	Evaporation from San Luis Reservoir (CVP)
18	NSIM2D_49Ax	Local Diversions to SR-10 (DSA49a)
19	NSIM2D_49Bx	Local Diversions to SR-11 (DSA49b)
20	NSIM2D_49Cx	Local Diversions to SR-12 (DSA49c)
21	NSIM2D_49Dx	Local Diversions to SR-13 (DSA49d)
22	NSIM2D_60Ax	Local Diversions to SR-14 (DSA60a)
23	NSIM2D_60Bx	Local Diversions to SR-15 (DSA60b)
24	NSIM2D_60Cx	Local Diversions to SR-16 (DSA60c)
25	NSIM2D_60Dx	Local Diversions to SR-17 (DSA60d)
26	NSIM2D_60Ex	Local Diversions to SR-18 (DSA60e)
27	NSIM2D_60Fx	Local Diversions to SR-19 (DSA60f)
28	NSIM2D_60Gx	Local Diversions to SR-20 (DSA60g)
29	NSIM2D_60Hx	Local Diversions to SR-21 (DSA60h)

The SIM2 model is set up as a Mixed Integer Linear Programming (MILP) problem composed of an objective function and a set of linear constraints with non-negative value variables:

$$\max Z = \sum_i c_i X_i \quad \text{...} \quad (5.1)$$

Subject to:

$$\sum_{j=1}^{m} a_{ij} X_j \leq b_i \quad \text{..} \quad (5.2)$$

$$X_i \geq 0 \quad \text{...} \quad (5.3)$$

Where:

X_j are the decision variables

c_i are the cost coefficients or weights to reflect priorities

a_{ij} and b_i are known constants

The decision variables X_i in Equation 5.1 and 5.2 represent flows through the arcs during a time step or reservoir storages at the end of a time step. The set of constraints in Equation 5.2 represent mass balances at the nodes, upper bound constraints (e.g., channel capacities), lower bound constraints for minimum flow requirements in arcs, or relational constraints in emulating operational criteria, or regulatory limits. The cost coefficients c_i represent “weights” that reflect priorities for storing and allocating water. They cost coefficients no physical meaning (compared to economic costs for example), and the absolute magnitudes themselves are not important, but the relative values to each other and in combination to reflect appropriate priorities are. The MILP setup is an optimization for water allocation over a time step. Typically in CalSim and CalLite some of the decision variables X_i take on integer binary values of 0 and 1, for example in estimating flow through flood weirs on the major rivers. In SIM2 weir flood flows are simulated in C2VSIM (Chapter 3), thus greatly reducing the runtime of the LP problem. The constraints in Equation 5.2 are specified using the higher level language WRESL (Water Resources Engineering Simulation Language) that allows for more intuitive set up and interpretation. There are two types of constraints in Equation 5.2: hard constraints which are strict equality constraints, and soft constraints of the form “≤”. Hard constraints are used for mass balance of flow at nodes. Soft constraints are used in situations where there are targets to achieve (e.g., minimum flows in streams) with penalties if targets are not achieved; this allows simulation runs to continue without aborting.

SIM2 was set up as a mixed integer linear programming (MILP) problem using the Water Resource Integrated Modeling System (WRIMS) v1.5. WRIMS is a generalized water resources modeling platform for evaluating operational alternatives of large and complex water resources systems, specifically to operate surface water reservoirs and determine water allocation while meeting physical and institutional constraints. WRIMS integrates a simulation language called WRESL (Water Resources Engineering Simulation Language) for specifying flexible operational criteria, an MILP solver called XA for efficient water allocation decisions, and has built in graphics capabilities for displaying time series data. The MILP objective function and specification of constraints written in WRESL are then interpreted internally using a JAVA based parser that translates them into standard LP formats for the solver XA. (Note: while WRIMS includes a GUI driven wrapper for running the MILP problem, for purposes of this research the "command line" option was used which allows for batch running WRIMS with C2VSIM and associate programs explained later in this chapter). The SIM2 code written using WRIMS' WRESL language is listed in Appendix G.

SIM2 was set up to simulate the period WY1922-2003 using monthly time steps using hydrology representing a projected level of land used development; specifically, "current conditions" similar to the C2VSIM projected level run discussed in Chapter 4. The constraints are set up in separate WRESL codes (different pieces associated with addressing different criteria) and stored in separate folders that WRIMS identifies with. The folders and associated files for storing the WRESL codes and input/output files (in HEC-DSS) files are as follows (Appendix G):

SIM2 – This is the main folder and contains the file ***ex2.sty*** which stores basic data identifying the run, simulation period, etc. SIM2 folder has two subfolders:

DSS - contains three HEC-DSS files
- ***ExampleINIT2.dss:*** stores initial reservoir elevations, etc.
- ***Ex2_sv.dss*** ***:*** stores input time series data
- ***Ex2_dv.dss*** ***:*** stores output time series data

RUN – contains the main control WRESL code ***Ex2.wresl*** and has six subfolders:
- **COA** - includes WRESL code for the Coordinated Operating Agreement
- **Export-Ops** - includes WRESL code for the Delta E/I ratios governing exports
- **Lookup** - includes tabular text files:
  - ***Demand.table*** (empty..data stored elsewhere)
  - ***EIration.table*** (monthly ratio factors)
  - ***FebEIratio.table*** (February EI ratio factors by water year)
  - ***Inflow.table*** (empty..data stored elsewhere)
  - ***Minflow.table*** (empty..data stored elsewhere)
  - ***Res_Info.table*** (storage/area/discharge capacity/elevation data for simulated reservoirs)
  - ***Res_level.table*** (empty…data stored elsewhere)
  - ***WytypeSAC.table*** (water year and type)

- **Misc** - includes the two WRESL codes:
  - ***Pumping_cap.wresl*** (limits on SWP and CVP exports)
  - ***SODstor.wresl*** (rule curves for south of Delta reservoirs)

System - includes ten WRESL codes:

Adjustment-table.wresl (for specifying the “adjustments”)

Channel-table.wresl (identifying channels, capacities, and minimum flow requirements)

Connectivity-table.wresl (specifying equality “hard” constraints for continuity at nodes - Figure 5-2)

Delivery-table.wresl (specifying “soft” constraints for surface water diversions/exports)

Inflow-table.wresl (defines many simulated variables shown in Figure 5-2)

Report.wresl (defines simulated variables for output)

Reservoir-table.wresl (specifies the reservoir storage zones and evaporation algorithms)

Seepage-table.wresl (specifies stream-aquifer variables and penalties)

System.wresl (contains pointers to other WRESL codes)

Weight-table.wresl (specifies weights for reservoir storages, diversions, groundwater pumping, exports, etc)

WYtypes - includes ***wytype.wresl*** for specifying water year types.

5.4 Linking SIM2 and C2VSIM: CVSIM

CVSIM (Central Valley Simulation Model) links both SIM2 of Section 5.3 and C2VSIM model of Chapter 4. This in effect combines the hydrology development (demands, outflow adjustments), the simulation of the integrated surface water and groundwater routing (runoff, return flow, groundwater elevation simulation, and stream-aquifer interactions), and the systems priority based optimization (water allocation – diversions, reservoir operation, groundwater pumping, exports) into one consistent platform for carrying planning studies of

the CVP/SWP and Central Valley water resources systems. The approach used was to link SIM2 and C2VSIM sequentially in an iterative process that terminates when convergence of variables passed between the two converge to within a tolerance level. Fortran codes to transfer output variables from the SIM2 model to the C2VSIM input files and vise a versa were developed noting that the input/output (I/O) files for C2VSIM are text files, whereas the I/O files for SIM2 are HEC-DSS (binary format). The entire process can be run manually, or automated with a simple batch file for execution.
The algorithm for running CVSIM for the Base Case (Section 5.5) and the two studies in Chapter 6 is listed in Appendix H.

5.5 Base Case for CVSIM

The CVSIM simulation discussed in Section 5.4 results in output that are too varied and extensive to list all. To highlight some key results, however, and for comparative purposes, several output variables will be compared to the CalSim-II DRR study mentioned in Chapter 3 (CDWR 2010a). Since CVSIM is a screening tool not fully optimized at this stage compared to the mature and much higher resolution (for reservoir operations) CalSim-II, differences would be expected. At the same time where results are closer to each other may be by construction, e.g. some CalSim-II results were used as targets for CVSIM - a good example are the exports to southern California via the California Aqueduct.

Comparisons between CVSIM and CalSim-II results will focus on the following six variables:

1. End-of-Year storages for Shasta, Oroville, Folsom, and San Luis reservoirs.
2. Total Delta inflows.
3. Delta outflow (to the Pacific Ocean).
4. Exports from Banks and Jones pumping plants.
5. Exports to southern California via the California Aqueduct.
6. Total groundwater pumping the Sacramento Valley.

End-of-Year storages for Shasta, Oroville, Folsom, and San Luis reservoirs:

The annual end-of-September storages for the four reservoirs simulated in CVSIM are shown in Figure 5-4 through Figure 5-7. Shasta, Oroville, and Folsom reservoirs exhibit the same patterns in that more water is held in the reservoirs (rather than released) in CVSIM compared to CalSim-II. This can be attributed to several factors:

a. The variable flood control diagrams are not the same: this is a minor factor since by and large the monthly time series target storage zones in both models are very close to each other. The flood diagrams in CalSim-II are subject to more hydrological and regulatory related constraints.

b. The land use based demands and the limits on surface water diversions are different between the two models. The hydrology in CalSim-II uses a different root zone accounting system than C2VSIM. Also the maximum amounts for surface water diversions in CalSim-II are tied in to project/non-project contractual entitlements.

c. CalSim-II has many more physical and institutional constraints built in.

d. The weights for storing and allocating water between the two models differ.

The last factor (weights) listed above is probably the most significant. Weights in CalSim-II were developed by trial and error with nearly thirty years of experience in the model application. Even today, however, these weights –aside from many being dynamic during the simulation- can vary by planning study application to fit the needs. CVSIM weights by comparison were developed to preserve relative priority, but not investigated thoroughly for best optimized values. This particular point has been addressed in recent years for CalSim-II and similar LP-based problems, and warrants further investigation (Israel and Lund 1999, Ferreira 2007, Ferreira 2013).

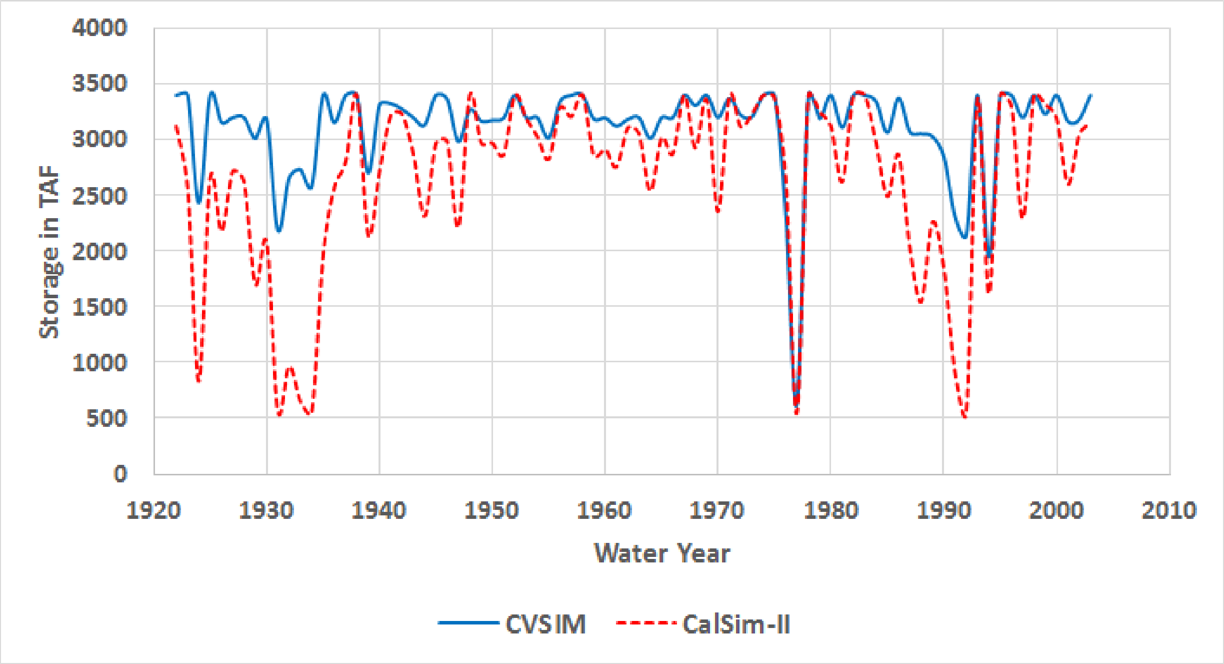


Figure 5-4: Comparing CVSIM and CalSim-II: Shasta Reservoir Storage

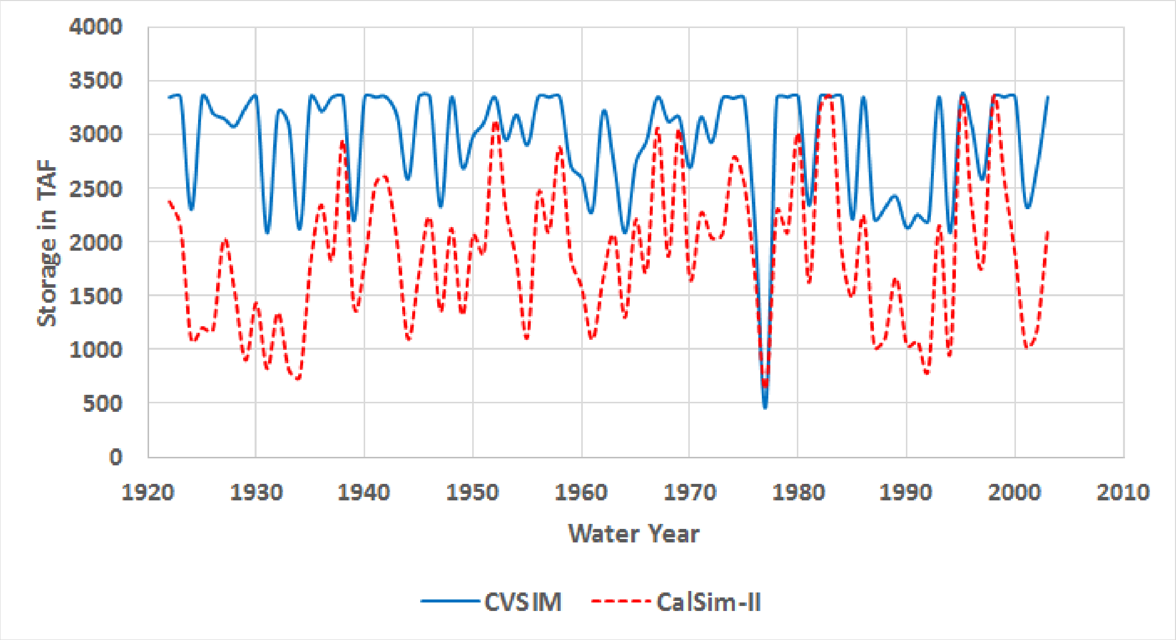


Figure 5-5: Comparing CVSIM and CalSim-II: Oroville Reservoir Storage

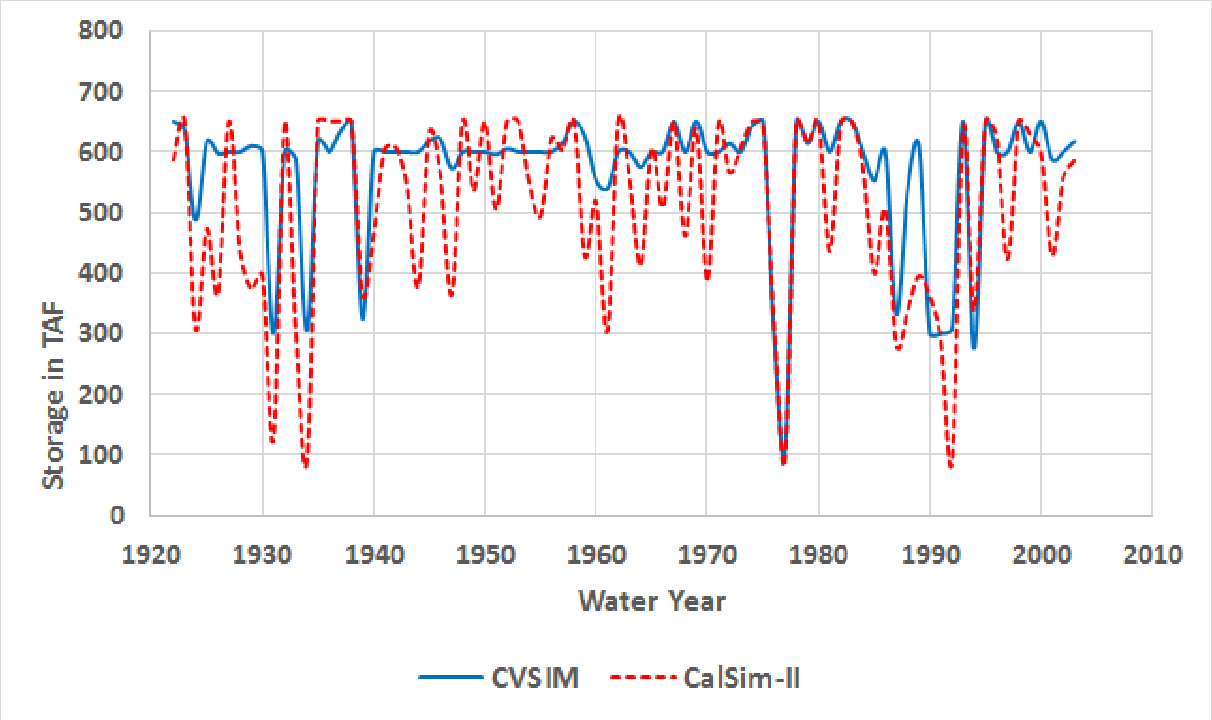


Figure 5-6: Comparing CVSIM and CalSim-II: Folsom Reservoir Storage

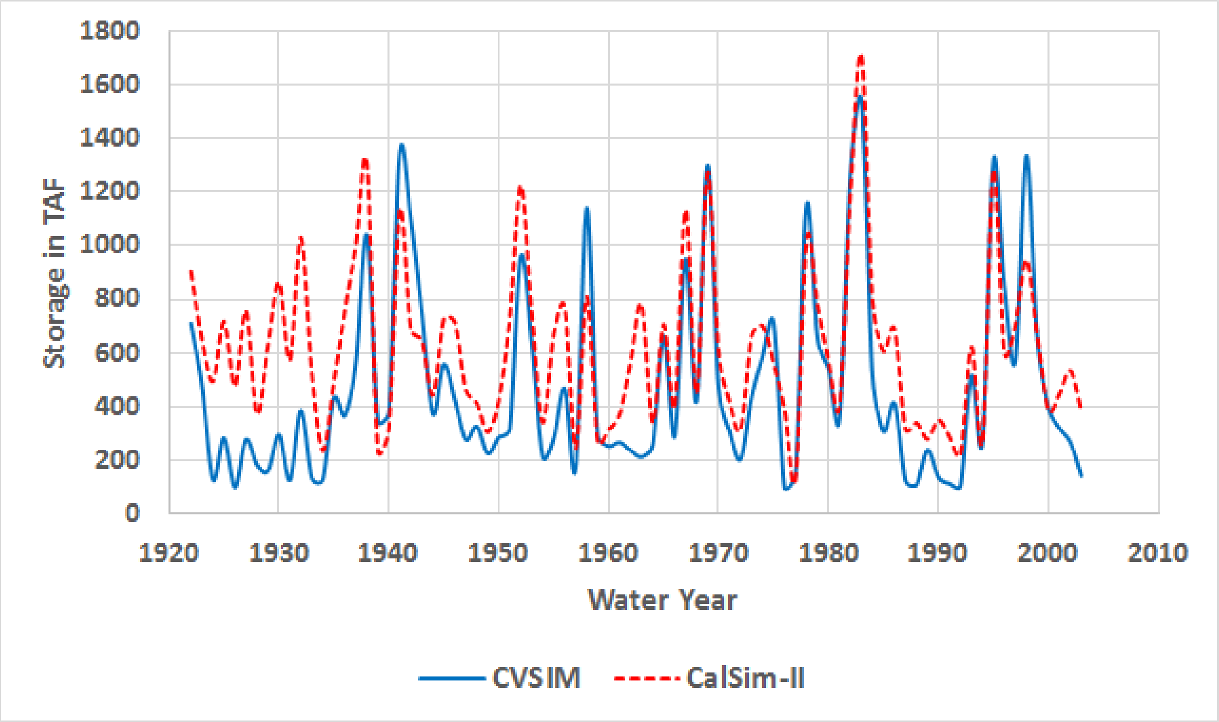


Figure 5-7: Comparing CVSIM and CalSim-II: San Luis Reservoir Storage

Total Delta Inflows:

Figures 5-8 and 5-9 show the annual inflows to the Delta and the corresponding long term (WY1922-2003) monthly averages, respectively. The annual values track very well and the monthly averages show slightly higher inflows in CVSIM compared to CalSim-II, possibly a reflection of what was observed in the reservoir operations (above), i.e, more reservoir releases were for surface water diversions in the Sacramento Valley in CalSIm-II compared to CVSIM.

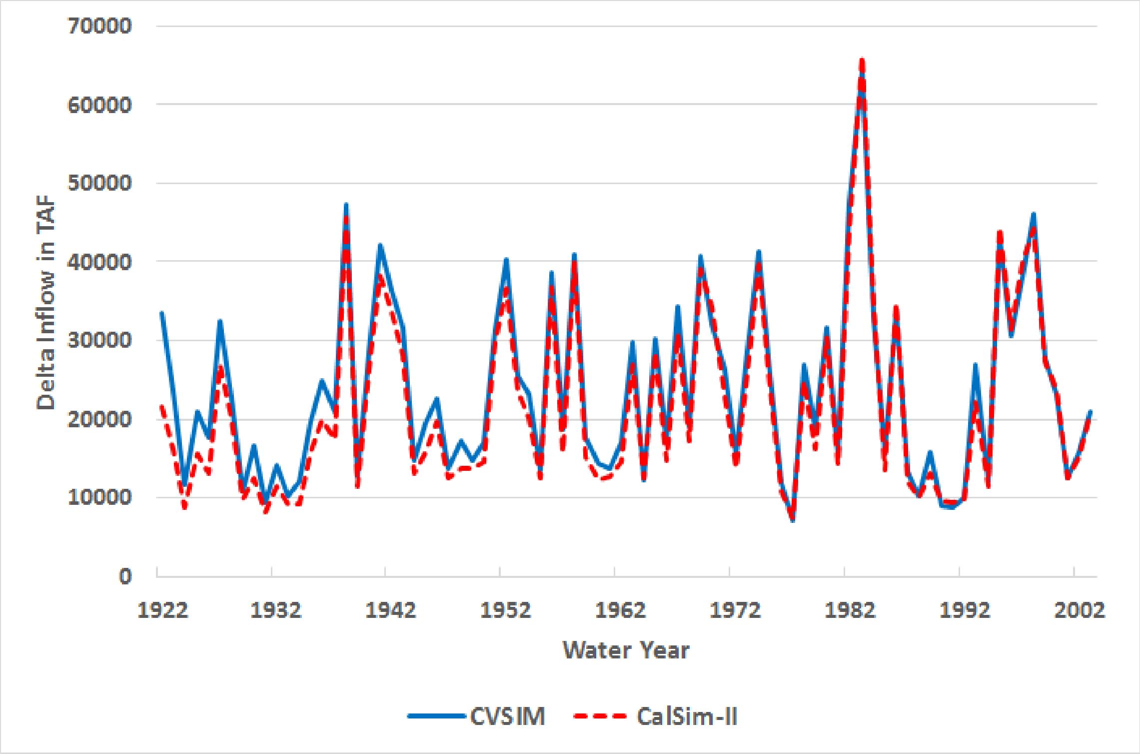


Figure 5-8: Comparing CVSIM and CalSim-II: Annual Inflow to the Delta

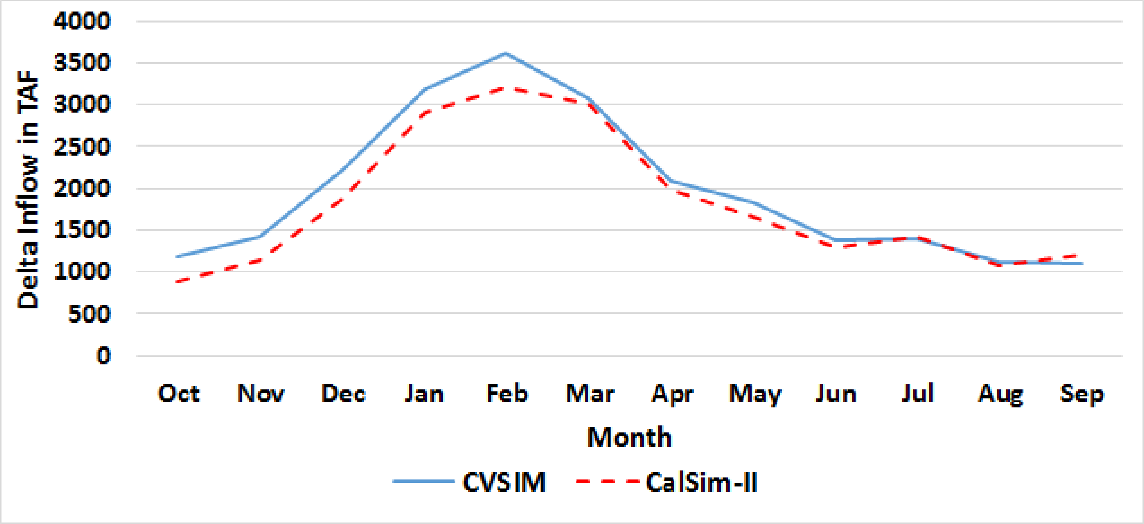


Figure 5-9: Comparing CVSIM and CalSim-II: WY1922-2003 Monthly Average Inflow to the Delta

Delta Outflow (to the Pacific Ocean):

Figures 5-10 and 5-11 show the annual outflows to the Delta and the corresponding long term (WY1922-2003) monthly averages, respectively. The pattern is very similar to the Delta inflows described above, tracking well overall, with slightly higher outflows in CVSIM.

Exports from Banks and Jones Pumping Plants:

The annual and long term (WY1922-2003) monthly averages for the Delta exports from the SWP Banks Pumping Plant, and the CVP Jones Pumping Plant are shown in Figures 5-12 through 5-15. They all show the higher exports in CalSim-II compared to CVSIM (and confirms the Delta inflow/outflow patterns described above). This is quite possibly again due to the weights/priorities set in the model as well as additional and more complicated regulatory related constraints set in CalSim-II.

Exports to southern California via the California Aqueduct:

The results for exports to southern California through the SWP California Aqueduct are shown in Figures 5-16 and 5-17. CVSIM shows higher exports in the October through December and July through September, while CalSim-II show higher exports in the months January through June months. One factor – in addition to constraints and weights described earlier – could be the Kern intertie simulated in CalSim-II but not CVSIM. Overall the annual values track well.

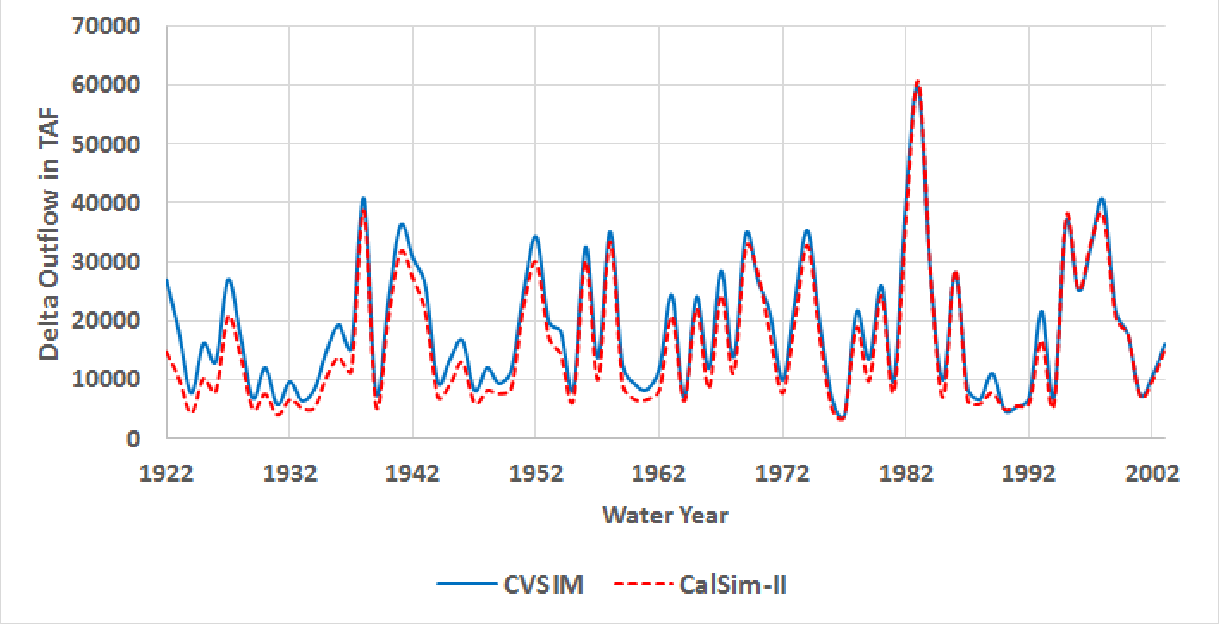


Figure 5-10: Comparing CVSIM and CalSim-II: Annual Delta Outflow

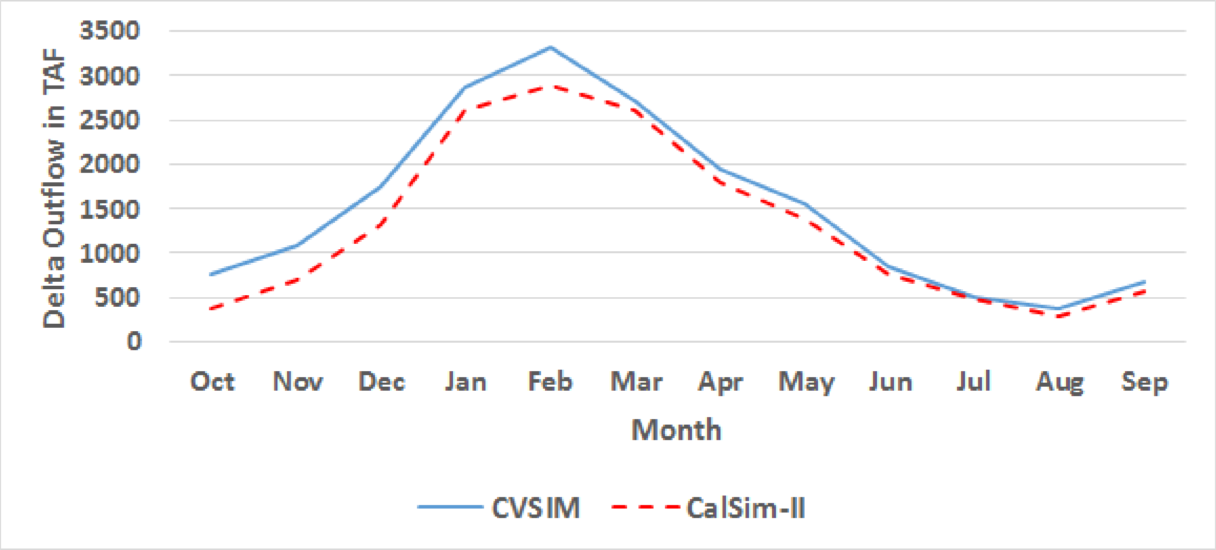


Figure 5-11: Comparing CVSIM and CalSim-II: WY1922-2003 Monthly Average Delta Outflow

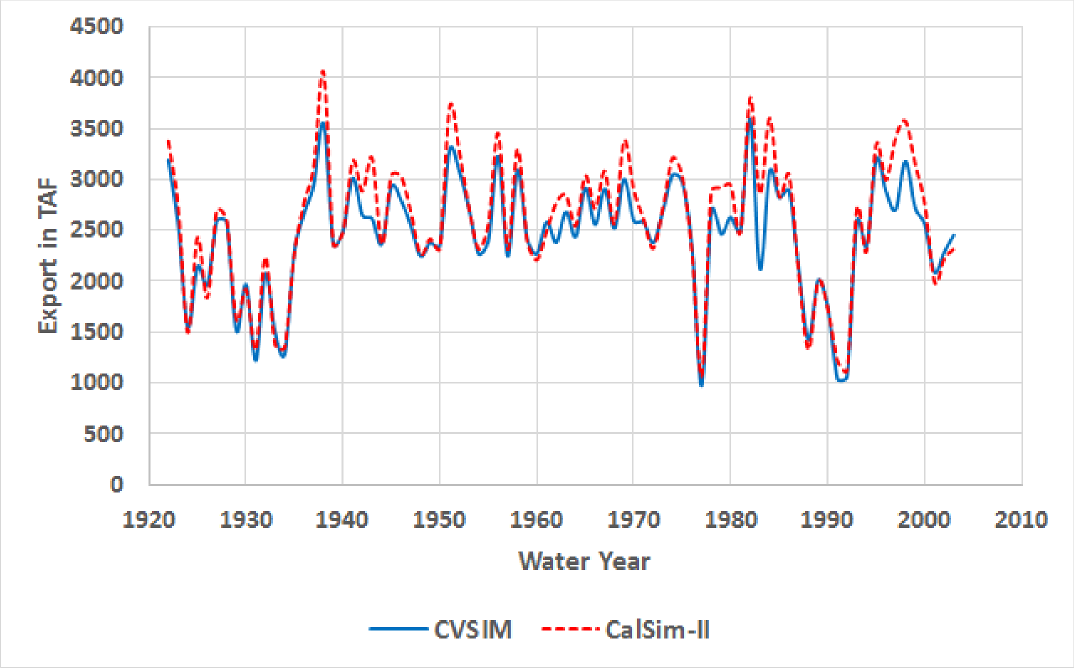


Figure 5-12: Comparing CVSIM and CalSim-II: Annual Banks Pumping Plant Exports

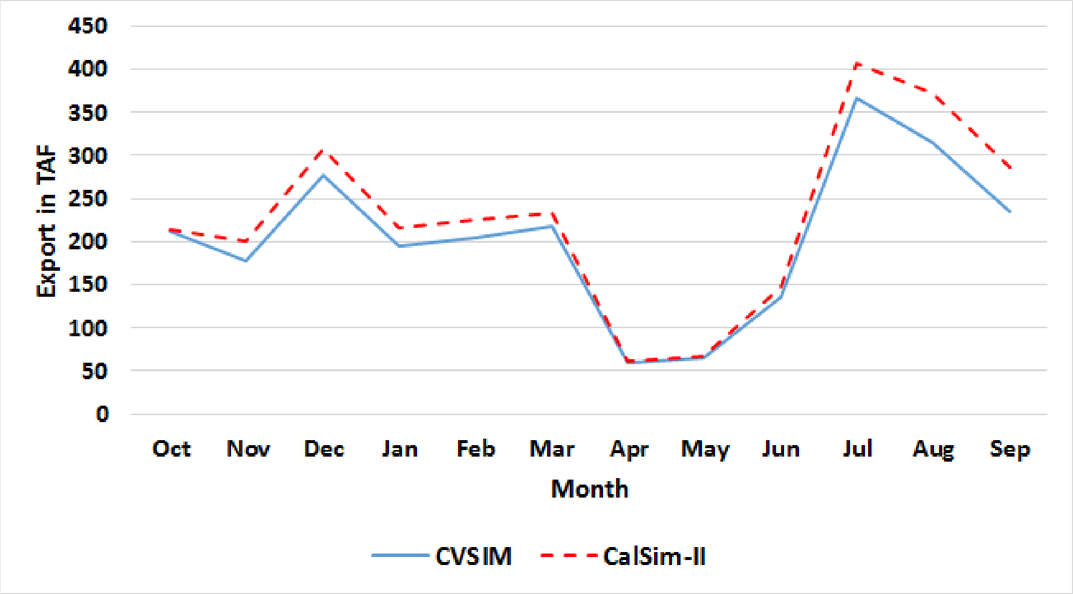


Figure 5-13: Comparing CVSIM and CalSim-II: WY1922-2003 Monthly Average Banks Pumping Plant Exports

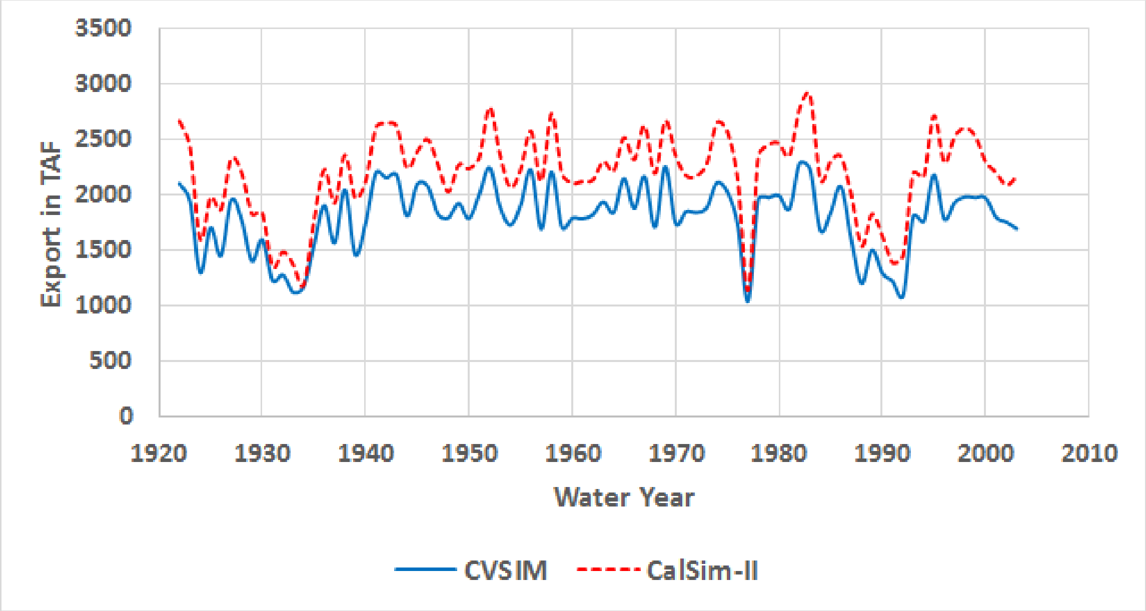


Figure 5-14: Comparing CVSIM and CalSim-II: Annual Jones Pumping Plant Exports

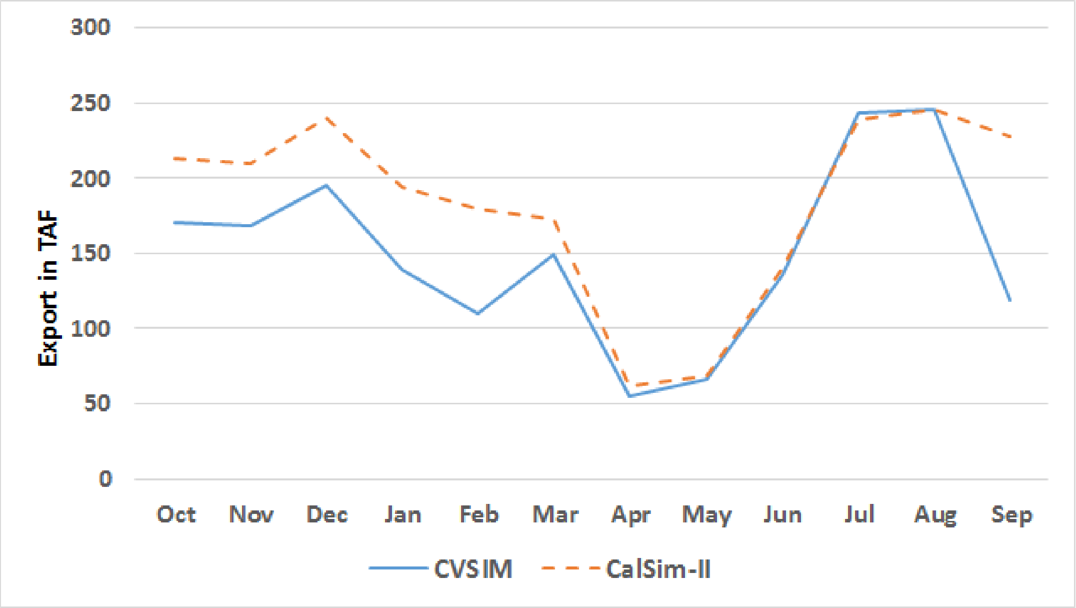


Figure 5-15: Comparing CVSIM and CalSim-II: WY1922-2003 Monthly Average Jones Pumping Plant Exports

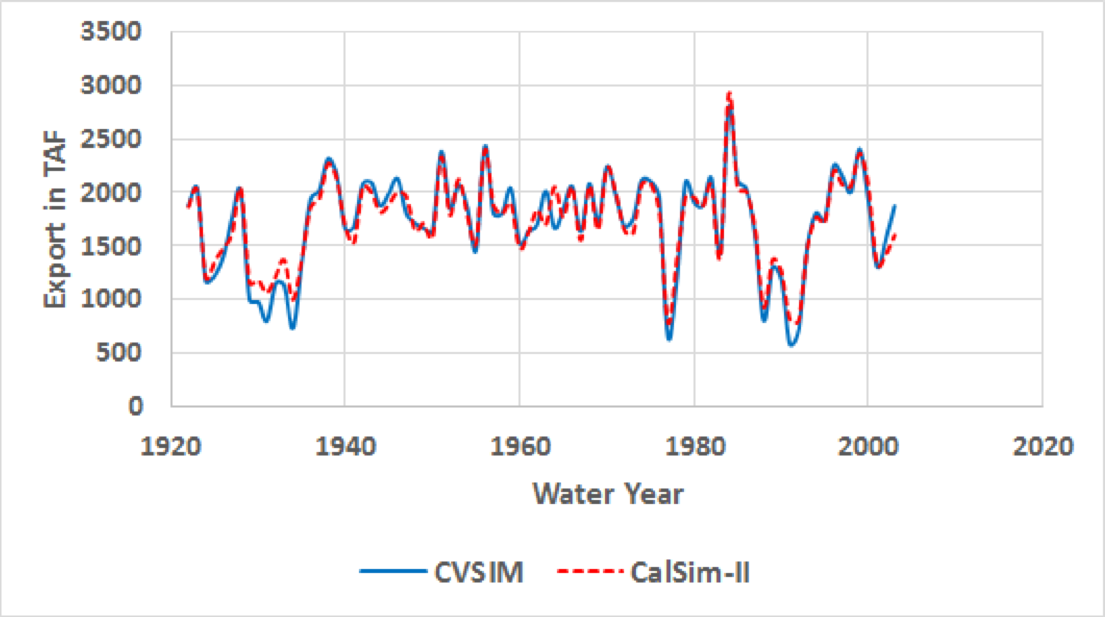


Figure 5-16: Comparing CVSIM and CalSim-II: Annual California Aqueduct Exports to Southern California

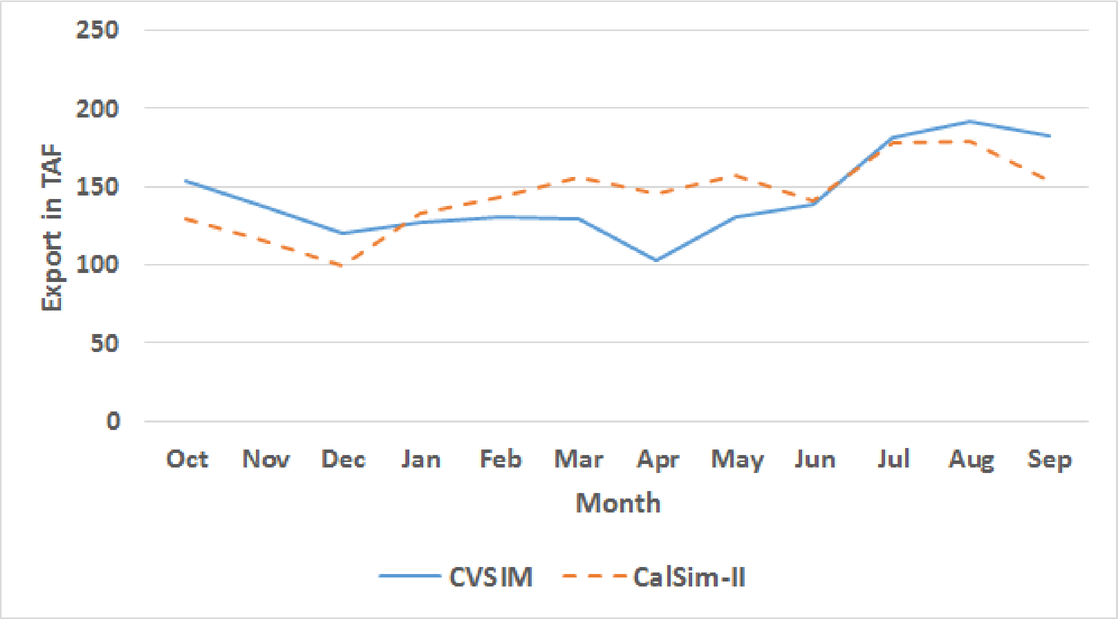


Figure 5-17: Comparing CVSIM and CalSim-II: WY1922-2003 Monthly Average California Aqueduct Exports to Southern California

Total Groundwater Pumping the Sacramento Valley:

Results for the aggregate groundwater pumping in the Sacramento Valley region (SR-1, SR-2, SR-3, SR-4, SR-5, SR-6, and SR-7) are shown in in Figures 5-18 and 5-19. The higher groundwater pumping in CVSIM during the irrigation months of March through August would seem to confirm the higher surface water diversions in CalSim-II because of higher assigned weights/priority values. It is not possible to compare the San Joaquin since groundwater is not modeled in CalSim-II. Tulare Lake basin could not be compared since it is not modeled in CalSim-II.

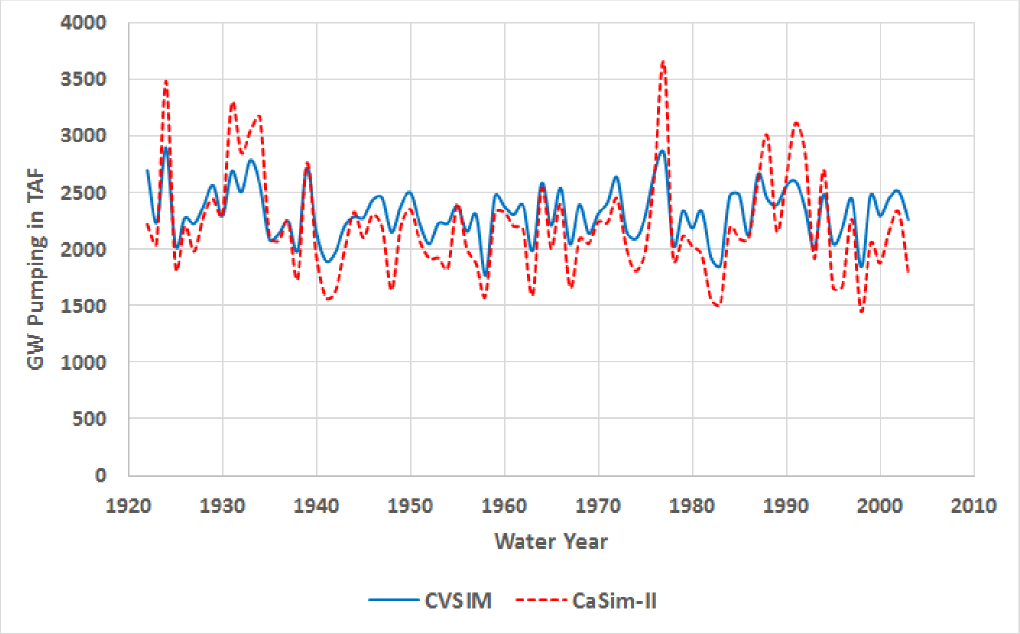


Figure 5-18: Comparing CVSIM and CalSim-II: Annual Groundwater Pumping (Sacramento Valley not including Delta and Eastside Streams)

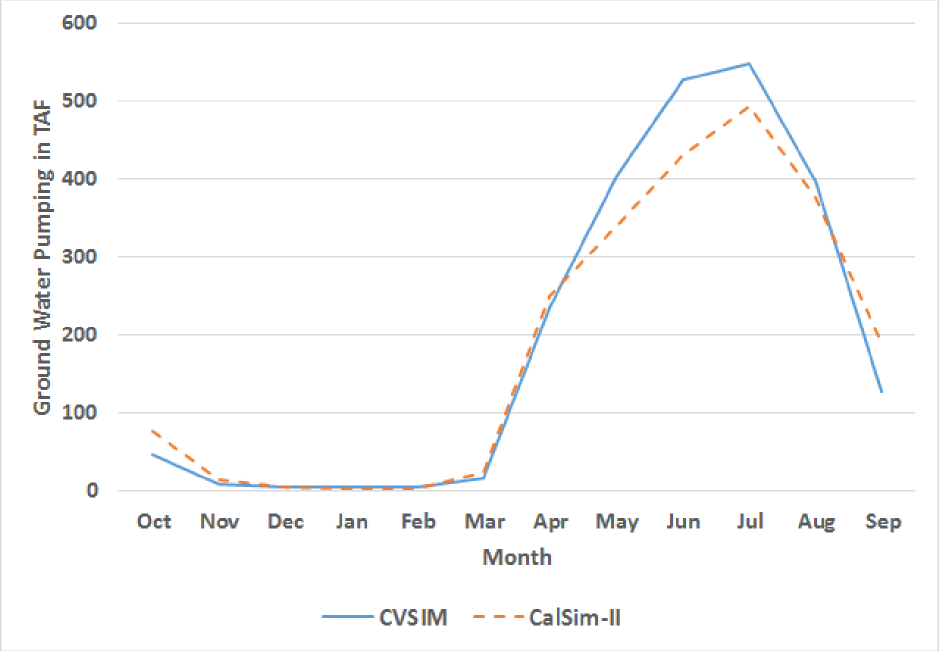


Figure 5-19: Comparing CVSIM and CalSim-II: WY1922-2003 Monthly Average Groundwater Pumping (Sacramento Valley not including Delta and Eastside Streams)

Finally of interest are the adjustments computed in CVSIM and overall impacts on the Delta inflows. Figure 5-20 shows the annual sum of all adjustments. Figure 5-21 shows the corresponding long term monthly averages for WY1922-2003. The higher values in CVSIM for the irrigation months of May through August would explain the slightly higher inflows to the Delta observed in Figure 5-9 as a result of higher groundwater pumping shown in Figure 5-19 (i.e, lower surface water diversions in CVSIM compared to CalSim-II) though balanced by the higher reservoir releases in CalSim-II (Figures 5-4 through 5-6). Similarly the higher adjustments in the winter months balance the extra reservoir (Figures 5-4 through 5-6) releases in CalSim-II. Finally, the cumulative total annual adjustments over the simulation period are shown in Figure 5-22, with an average annual value of 221TAF.

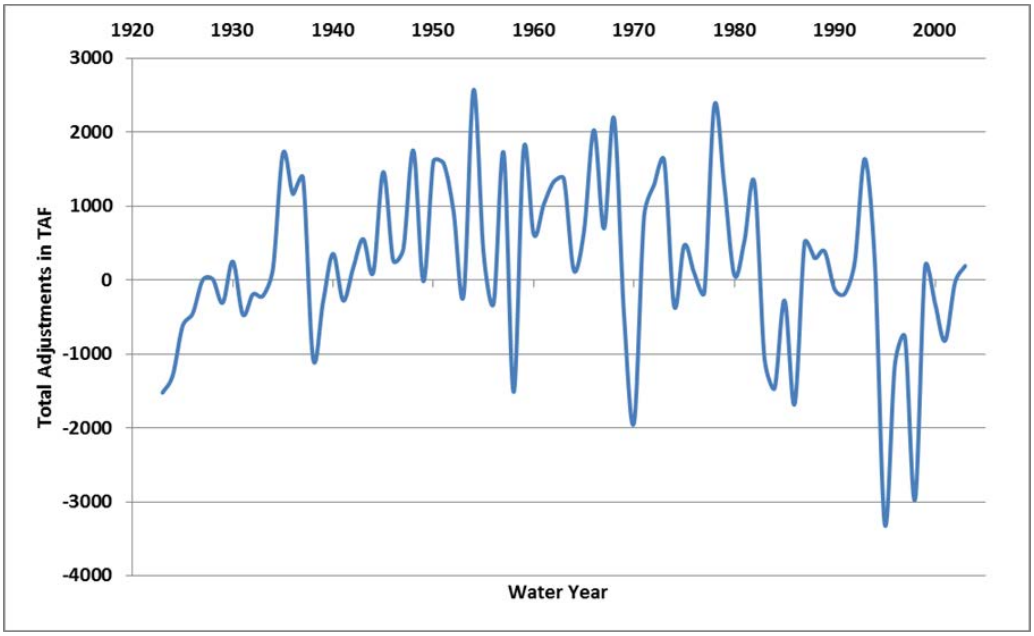


Figure 5-20: CVSIM Annual Adjustments WY1922-2003

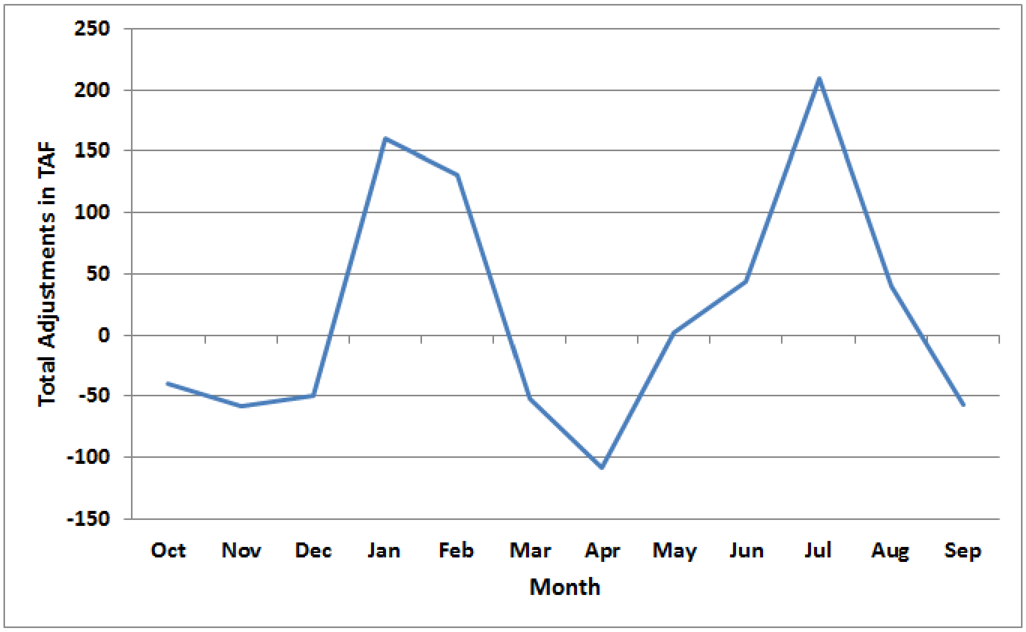


Figure 5-21: CVSIM Monthly Average WY192202003 Total Adjustments

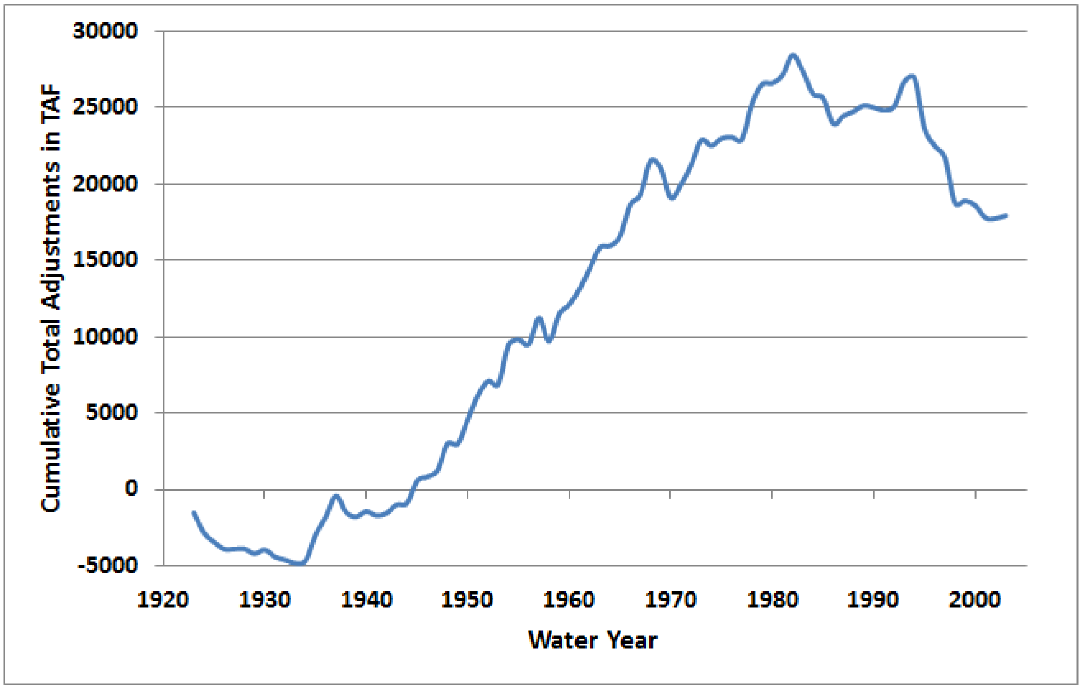


Figure 5-22: CVSIM Cumulative Annual Total Adjustments WY1922-2003

5.6 Summary

This chapter focused on building a system reservoir operation and allocation model SIM2 and linking it to the simulation model C2VSIM (with built in hydrology computation and adjustment) resulting in an integrated CVSIM model. The demands and hydrological components such as adjustments, surface runoff, return flows, deep percolation, and stream aquifer interaction are computed in C2VSIM and passed on during the iterative process to SIM2 to determine the reservoir releases and allocations (surface water diversions and groundwater pumping). This integrated model is an important contribution to the state of the art of modeling complex water resources. It allows for increased reliability of model results (adjustments), flexibility for varied model applications requiring dynamic adjustments of demands such as economic-based forecasting of optimal following year cropping patterns based on status of available surface water supplies (carry over reservoir storages) and groundwater storages in forecasted droughts (Miller et. al. 2009, Dale et. al. 2013, Medelin-Azuara et. al. 2015). The built in hydrology also allows for dynamically modifying components (e.g., land use which modifies water demands) to control management of the water resources – for example modifying cropping patterns (dynamically) to reduce pumping if target ground water levels or storages affect SGMA based thresholds.

Chapter 6 CVSIM Applications

This chapter applies CVSIM of Chapter 5 (2003 Projected Level) to two different studies: a global warming study and a conjunctive use / water transfer study. The global warming study is a sensitivity analysis of impacts to incremental increases of ambient temperatures of up to 4°C by the end of the 21st Century. Temperature increases modify land use based consumptive water demands that drives CVSIM, and affect upstream watershed outflows on the SWP and CVP reservoir operations to meet downstream demands and constraints. While the global warming study is focused on surface water as the driving force (impact on streamflow, diversions, and reservoir operations), using CVSIM (which includes both reservoir operations and surface water – groundwater modeling) also allows for studying the impact on groundwater throughout the Central Valley. The conjunctive use study determines the impact of implementing the Sacramento Valley Water Management Program whereby stakeholders forgo entitled surface water diversions during non-wet years (above normal, below normal, dry, and critical) and supplement the demand with increased groundwater pumping, with the expectations that natural recharge from subsequent wet years would recover decreased groundwater storage due to the program of groundwater pumping. Similar to the global warming study, CVSIM allows for studying the impacts on both surface water and groundwater. Using a model like CalSim alone (for the reservoir operations), or C2VSIM as a standalone (for the impacts on groundwater) is insufficient, unless both used together. CVSIM integrates both types of models in one tool.

6.1 Study 1: Global Warming Sensitivity

There is consensus among scientists on global warming (Cook et. al. 2013), and that ambient earth temperatures would increase by up to (or more) 4°C by the end of the 21st century (IPCC 2015). For California's Central Valley water resources, this study will focus on two major factors:

1. Increased land use based demands: As temperatures increase, so do evapotranspiration requirements for agricultural and outdoor urban use (golf courses, parks, swimming pools, gardens, lakes, etc). For this study temperature increases were used to estimate the increase in ETo (potential evapotranspiration) and thereby increase in crop ETc (assuming crop coefficients are constant). These increases in ETc are input to the C2VSIM module of CVSIM, which then impact the computed total supply requirements (demands) that need to be met either by increased surface water diversions or groundwater pumping.

2. Modifications of inflows to reservoirs: Increases in ambient temperatures also impact snow-dominated upper watersheds resulting in earlier snowmelt, and thus a shift in watershed outflows to the reservoirs which in turn will affect reservoir operations for storage and meeting downstream project demands and institutional constraints.

One major assumption in this study is that vegetation type is fixed under the warming scenarios. In reality, the upper watershed natural vegetation will modify to more arid types, modifying the unit evapotranspiration values. Similarly, for agricultural crops, farmers may modify both the crops they grow and the irrigations practices. All of these changes can introduce non-linearities that are not within the scope of this research.

6.1.1 Developing Additional Input Data: Modified Reservoir Inflows and Crop ETc's

In addition to the input data sets from Chapter 5, two modified data sets are required for the Global Warming study: Potential Evapotranspiration crop coefficients ETc's for input to C2VSIM, and the inflows to Shasta, Oroville, and Folsom reservoirs for SIM2.

1. Modified Crop Potential Evapotranspiration ETc's

The procedure used to modify the Base Case C2VSIM unit crop coefficients ETc's to account for increased temperatures. To begin use results of potential evapotranspiration ETo's from a model developed for the Sacramento –San Joaquin Delta, compute modified ETo's due to temperature increases in the Delta, and then scale the ETc's for the crops for all sub-regions in C2VSIM accordingly. The steps are:

a. Start with data from the DETAW model: The Delta Evapotranspiration of Applied Water DETAW is a daily model developed for CDWR for the Sacramento – San Joaquin Delta sub-region 9 (CDWR 2006). DETAW estimates the daily consumptive water demands for each of 168 subareas that are nested within boundaries of the Delta Service Area, for period WY1922-2003. The unit ETc for each crop category by subarea is computed by multiplying the potential ETo of each subarea with a crop coefficient that varies by month, but does not vary year to year. The ETo computation is dynamic temporally because is it affected by the daily variations in ambient temperatures. The ETo is computed using the temperature-based Hargreaves-Samani equation (Hargreaves and Samani 1982, and Hargreaves and Samani 1985), and then adjusted within DETAW by a factor to reflect the more accurate computation of the Pennman-Montieth Equation used to calculate ETo at CIMIS stations located near the Delta (http://www.cimis.water.ca.gov/). A copy of the DETAW package and results was obtained from CDWR (CDWR 2013d).

b. From DETAW daily values, aggregate to calculate the Delta monthly total unit ETo (weighted by crop areas) for every year for the period WY1922-2003.

c. From Step 2 calculate the 12 monthly averages unit ETo over the period WY1922-2003. This is the “Base Case”ETo's.

d. Increase the daily minimum, maximum, and average daily temperatures equally in DETAW input by one degree centigrade (1^{o}C) to compute modified ETo's using the Hargreaves-Samani Equation to calculate ETo for every day for the period WY1922-2003. Repeat step 3. Call this "Base + 1^{o}C" Case, or more simply as "+ 1^{o}C" Case, or Plus One Case.

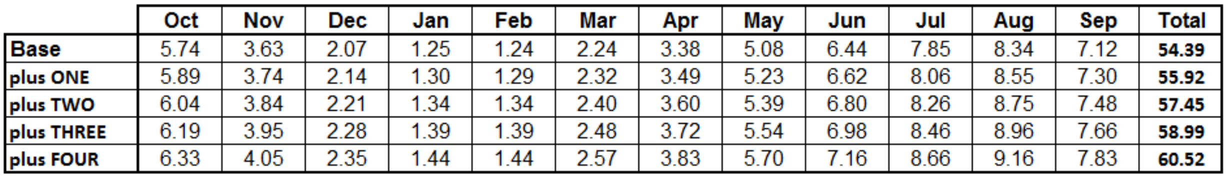
e. Repeat Step 4 to get "+ 2^{o}C", "+ 3^{o}C", and "+ 4^{o}C" Cases. Results are shown in Table 6-1 and Figure 6-1.

f. Use the ETo's for Base and other 4 Cases to compute the increase in percent of each scenario relative to the Base Case. Results are shown in Table 6-2.

g. Use the % increases of Step 6 to compute ETc's for C2VSIM by scaling the base ETc by these percentages. The C2VSIM ETc's are by month by sub-region by crop. The monthly pattern is repeated for every year. Note: The reason for not using the monthly ETc's time series directly from DETAW is that there are several crops grown in the Central Valley that are not grown in the Delta (e.g., cotton); using ETo's would provide consistency for modifying all crops .

h. Run C2VSIM for all sensitivity scenarios to get the Total Supply Requirements TSR (water demand) for each sub-region (note: TSR's don't change in the CVSIM iterative process within CVSIM for a simulation, and can be input in the SV-DSS file for SIM2 when running CVSIM).

Table 6-1: WY1922-2003 Monthly Average Delta ETo (inches)



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Base	5.74	3.63	2.07	1.25	1.24	2.24	3.38	5.08	6.44	7.85	8.34	7.12	**54.39**
plus ONE	5.89	3.74	2.14	1.30	1.29	2.32	3.49	5.23	6.62	8.06	8.55	7.30	**55.92**
plus TWO	6.04	3.84	2.21	1.34	1.34	2.40	3.60	5.39	6.80	8.26	8.75	7.48	**57.45**
plus THREE	6.19	3.95	2.28	1.39	1.39	2.48	3.72	5.54	6.98	8.46	8.96	7.66	**58.99**
plus FOUR	6.33	4.05	2.35	1.44	1.44	2.57	3.83	5.70	7.16	8.66	9.16	7.83	**60.52**

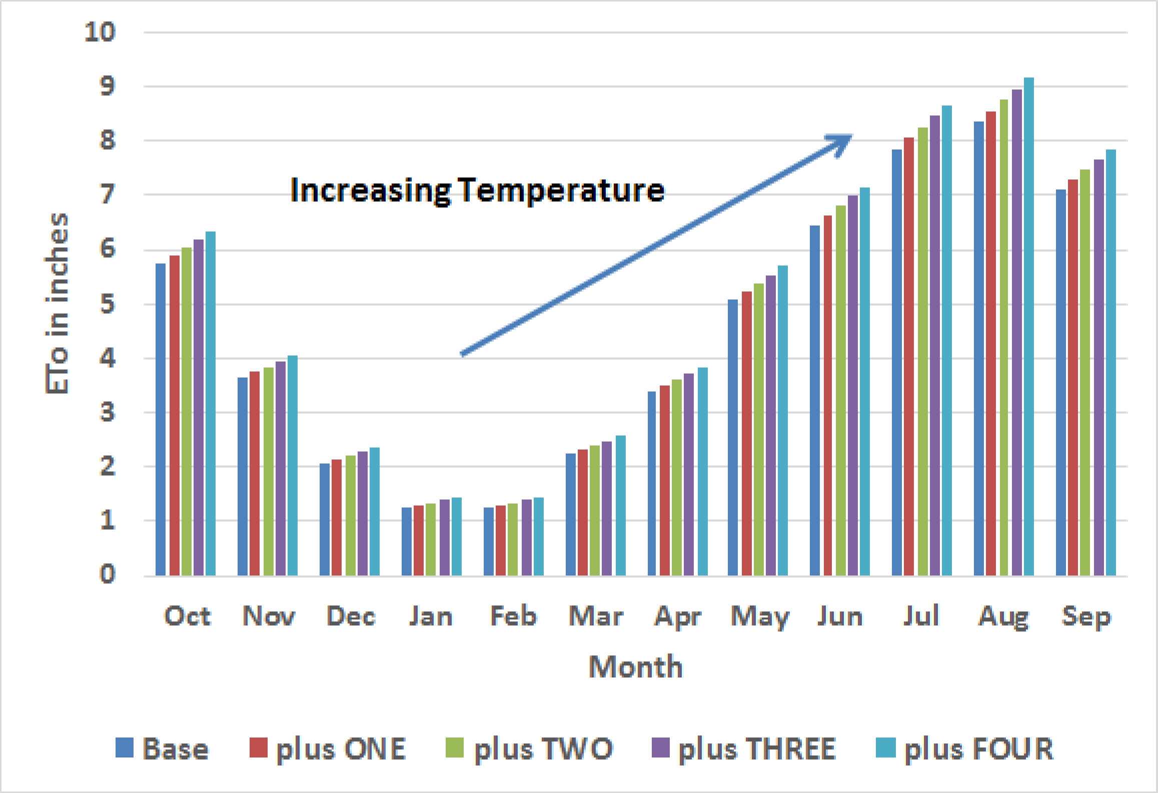


Figure 6-1: Delta Monthly Average ETo for Base, +1°c, +2°C, +3°C, +4°C

Table 6-2: WY1922-2003 Monthly Average Increase in ETo (%)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
plus ONE	2.59	2.88	3.44	3.97	4.01	3.61	3.34	3.05	2.78	2.57	2.45	2.49
plus TWO	5.17	5.75	6.87	7.93	8.02	7.21	6.67	6.10	5.56	5.13	4.90	4.98
plus THREE	7.76	8.63	10.31	11.90	12.02	10.82	10.01	9.16	8.34	7.70	7.35	7.46
plus FOUR	10.35	11.51	13.74	15.87	16.03	14.42	13.34	12.21	11.12	10.26	9.79	9.95

2. ***Modified Inflows to Shasta, Oroville, and Folsom Reservoirs***

The outflows of the upper watersheds are inflows to SWP and CVP reservoirs, and can generally be considered “unimpaired” (i.e., no major diversions to meet consumptive water demands affecting the observed/measured outflows). However there may be re-allocations upstream of the outflow points due mainly to power operations, though generally this does not affect monthly outflows. Any impacts due to urban developments for example are minor relative to basin runoff. This is true for both Shasta and Oroville reservoirs, though there is increasing urbanization on the upper American river basin upstream of Folsom. Estimates of the unimpaired flows for the upper Sierra Nevada watersheds are computed by CDWR's Division of Flood Management.

In 2005 the U.S. Geological Survey USGS completed development of a model for CDWR to estimate daily outflows of the Upper Feather River Watershed at Oroville (Koczot et al 2005). The study used the USGS' model Precipitation Runoff Modeling System PRMS (USGS 2015). CDWR extended the simulation period of 1971-1997 through 2003 and improved the calibration. CDWR used the enhanced version of PRMS for a sensitivity analysis of impacts of increasing temperatures in the watershed on outflows (Huang et. al. 2012). The sensitivity analysis included increasing ambient temperatures (daily minimum, maximum, and average) equally by +1^{o}C, + 2^{o}C, + 3^{o}C, and + 4^{o}C. The results showed the significant impact on the outflow by shifting the center of mass several weeks earlier due mainly to earlier snowmelt and increased fraction of precipitation as rainfall (Huang et. al. 2012).

Building on the PRMS work for the Feather River Basin, CDWR moved to a more recently developed generic model SWAT (Soil and Water Assessment Tool) supported by the U.S. Department of Agriculture USDA, for estimating daily natural outflows. SWAT is a public domain river basin scale model developed to quantify the impact of land management practices in large, complex watersheds (SWAT 2017). Approximately twenty SWAT models have been developed and calibrated by CDWR to date, and cover all the major upper watersheds of the Central Valley. The latest draft report summarizing both the unimpaired outflows and natural outflows can be found in (CDWR 2016). The SWAT models developed by CDWR are daily precipitation/snowmelt runoff models for the period WY1922-2015. (Note: for all practical purposes "unimpaired flows" and "natural flows" are very similar in magnitude for upper watersheds). The advantage of the SWAT model (over using the retroactively computed unimpaired outflows) is that the algorithms for snowmelt and evapotranspiraton computation are temperature based which allows for modifications of these temperatures for studies related to global warming and climate change.

The SWAT models for the upper watersheds of Shasta, Oroville, and Folsom reservoirs were used to carry out a sensitivity analysis of increasing temperatures of +1^{o}C, + 2^{o}C, + 3^{o}C, and + 4^{o}C and estimate the associated daily outflows (CDWR 2013e). These outflows become the inflows to the associated reservoirs for this research.
Results of the average annual inflows to Shasta, Oroville, and Folsom reservoirs (outflows of the respective upper watersheds from SWAT) along with the increases due to increase in temperature over the Base Case are shown in Figures 6-2 through 6-4. Annual inflow values do not differ much from the Base Case, though interestingly Shasta inflows decrease with increasing temperatures whereas both Oroville and Folsom show increases (Figure 6-5). Increasing temperatures will increase potential ETc's. However, actual ETc' are also expected to increase. However increasing ETc will decrease outflows only if the water is available to meet the potential ETc. Shasta is a lower elevation mountain range with a higher fraction of the precipitation being rainfall compared to snowfall during the year. Oroville and Folsom are snow dominated, and increasing temperatures will decrease snowpack (to meet spring/summer

vegetative demands). Also decreasing snowpacks decrease sublimation (snow evaporation). These explain the increase in simulated SWAT outflows.

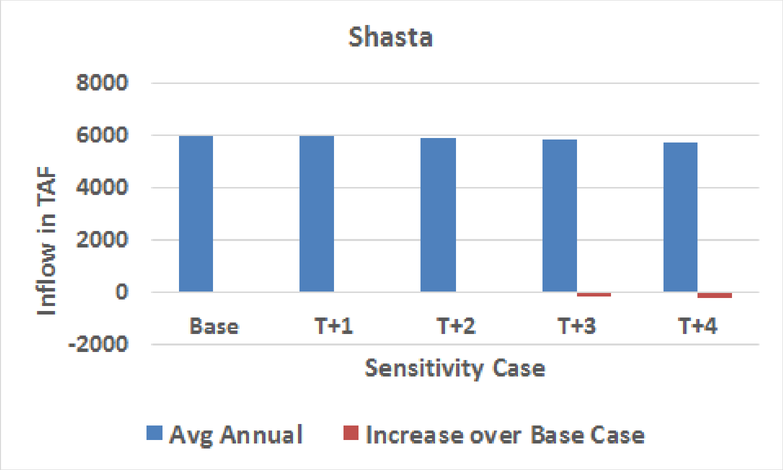


Figure 6-2: Average Annual Inflow to Shasta Reservoir for Base and Sensitivity Cases (WY1922-2003)

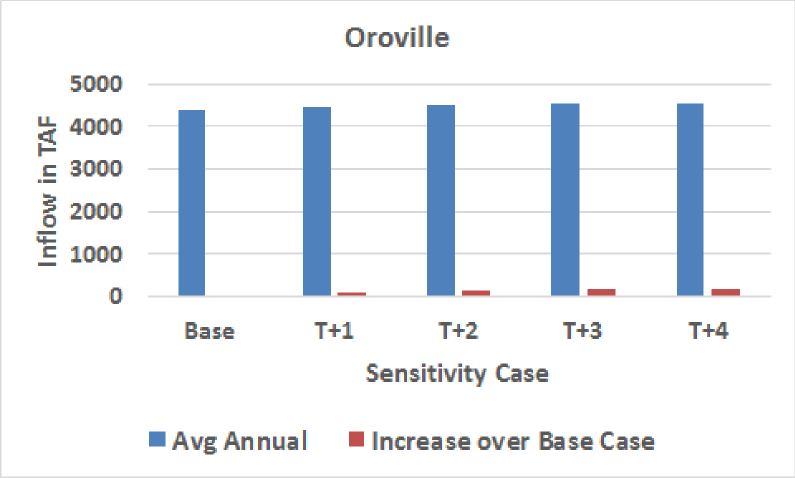


Figure 6-3: Average Annual Inflow to Oroville Reservoir for Base and Sensitivity Cases (WY1922-2003)

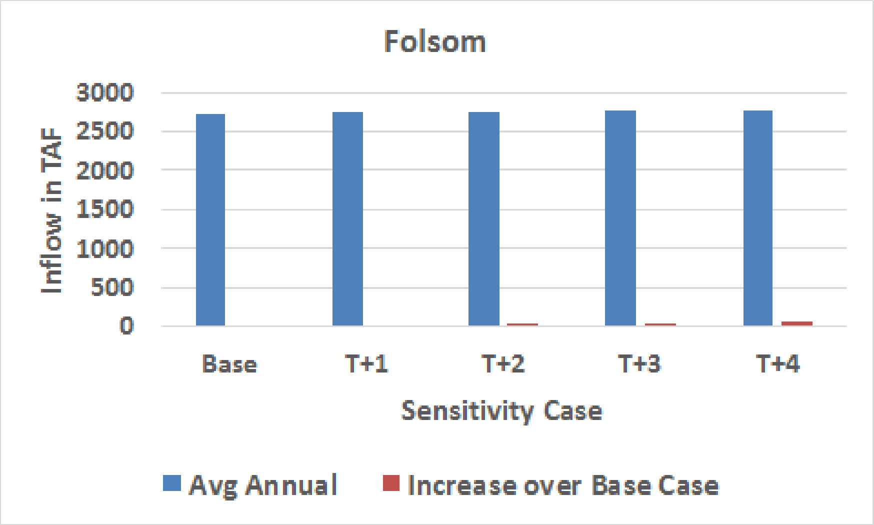


Figure 6-4: Average Annual Inflow to Folsom Reservoir for Base and Sensitivity Cases (WY1922-2003)

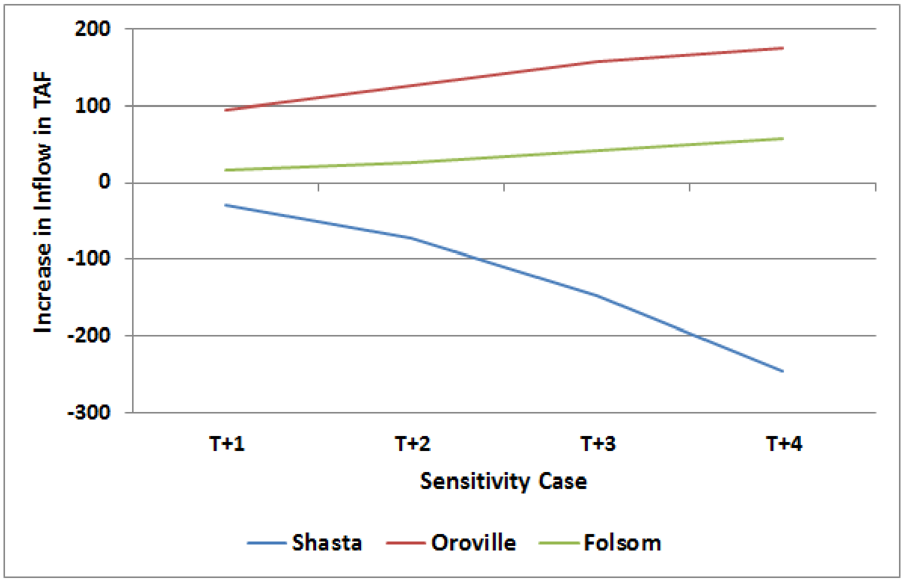


Figure 6-5: Average Annual Reservoir Increase in Inflow over Base Case (WY1922-2003)

Figures 6-6 through 6-8 show the long term monthly average inflow increases over the base for Shasta, Folsom, and Oroville reservoirs, respectively. The increased inflows to the reservoirs occur in the Fall/Winter seasons, and decrease in the Spring/Summer seasons due to earlier snowmelt. This can significantly influence reservoir operations since flood diagrams may require revisiting to avoid downstream flood damages (Willis et. al. 2011). Also the Spring/Summer reduction in inflows can impact meeting project and institutional requirements.

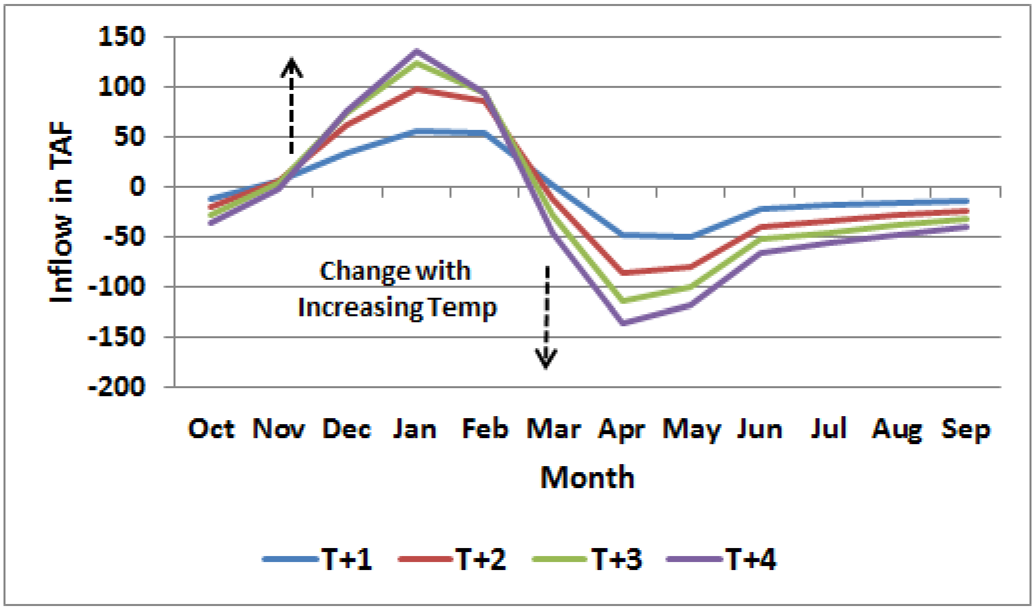


Figure 6-6: Average Monthly Increase in Inflow to Shasta Reservoir over Base Case (WY1922-2003)

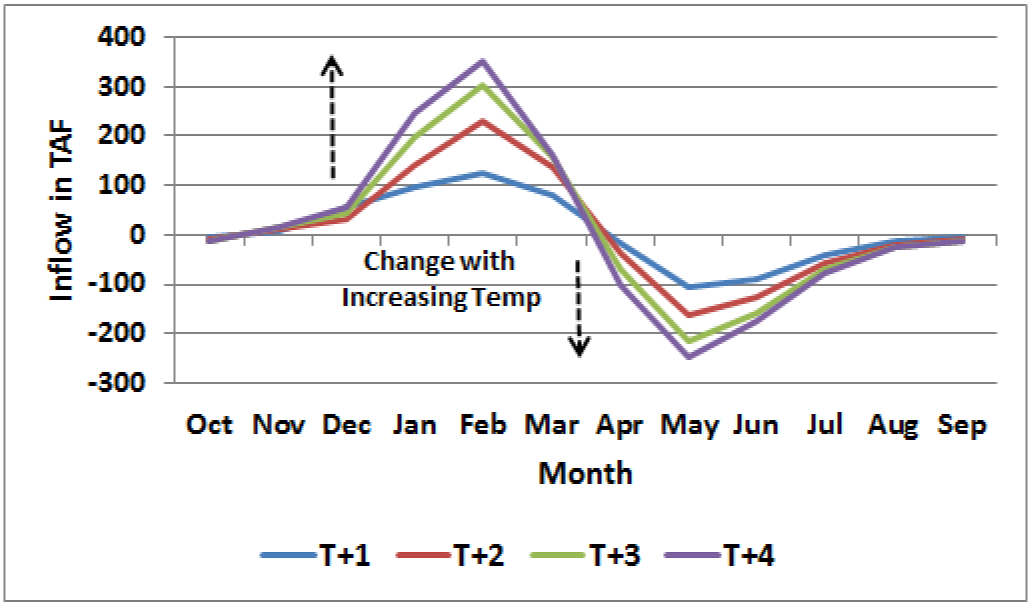


Figure 6-7: Average Monthly Increase in Inflow to Oroville Reservoir over Base Case (WY1922-2003)

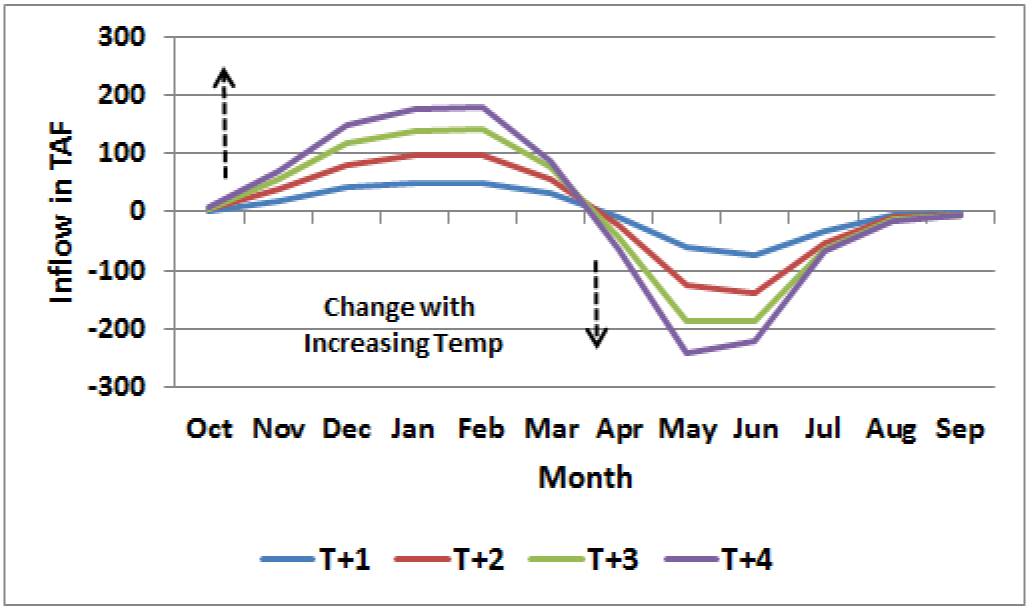


Figure 6-8: Average Monthly Increase in Inflow to Folsom Reservoir over Base Case (WY1922-2003)

6.1.2 Results from CVSIM

CVSIM was run iteratively using the algorithm described in Chapter 5. Results presented will focus on the impacts of increasing temperatures on: water demands, reservoir operations (releases), exports from the Delta, Delta outflow, surface water diversions, groundwater pumping, and groundwater storage.

1. ***Impact on Total Supply Requirements (Water Demand)***

The results of increasing temperatures on the total supply requirement TSR relative to the Base Case are shown in Figures 6-9 through 6-13. Figure 6-9 shows WY1922-2003 annual average total supply requirement for the Base Case and the four sensitivity cases +1°C, + 2°C, + 3°C, and + 4°C, aggregated to the Sacramento (including the Delta and Eastside Streams), San Joaquin, and Tulare River Basins. The increase is uniform at about 2.5% per increase of 1°C. Figures 6-10 through 6-12 show the long term WY1922-2003 monthly averages increase in TSR over the Base Case for the Sacramento Valley, San Joaquin Valley, and Tulare Basins, respectively. The monthly values shown reflect an agricultural demand pattern during the irrigation season, and increasing with increasing temperatures. Figure 6-13 shows the increase in the TSR over the Base Case for the entire Central Valley. The values are summarized in Table 6-3 and show that with increasing temperatures, average annual water demands or TSR increase from 18,700 TAF/year for the Base Case to 21,435 TAF/year for the +4°C Case.

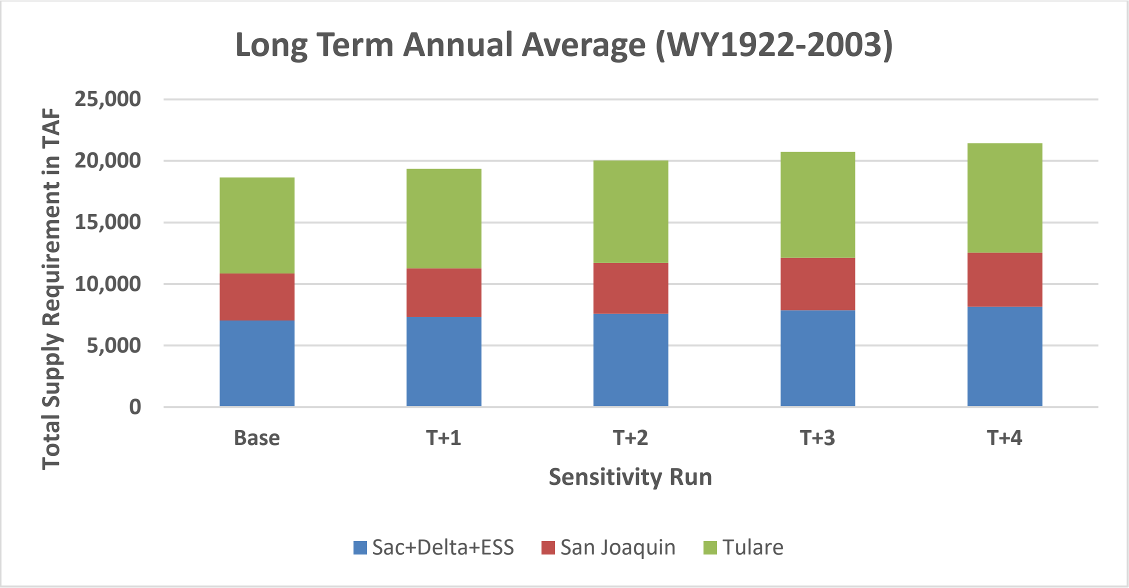


Figure 6-9: Central Valley Average Annual Total Supply Requirement (WY1922-2003)

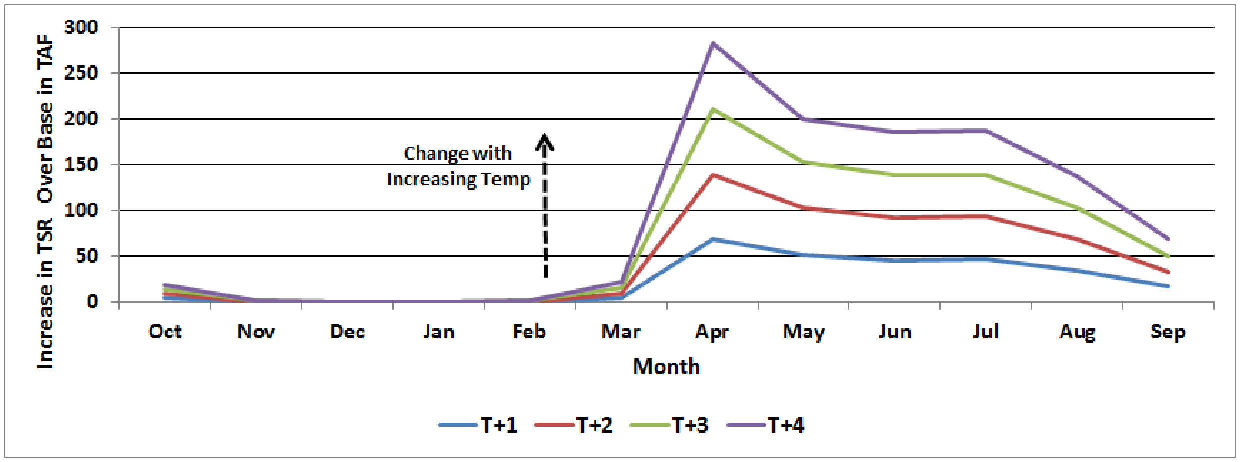


Figure 6-10: Increase Over Base Case in Long Term Monthly Average (WY1922-2003) Total Supply Requirement (Sacramento + Delta + ESS)

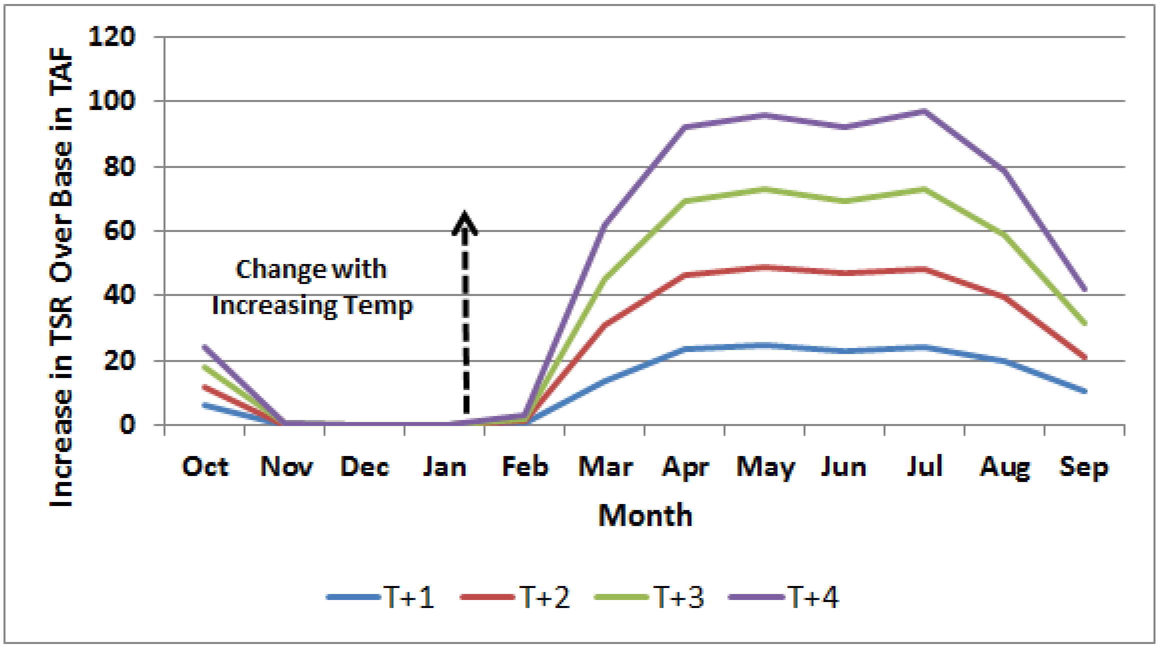


Figure 6-11: Increase Over Base Case in Long Term Monthly Average (WY1922-2003) Total Supply Requirement: San Joaquin River Basin

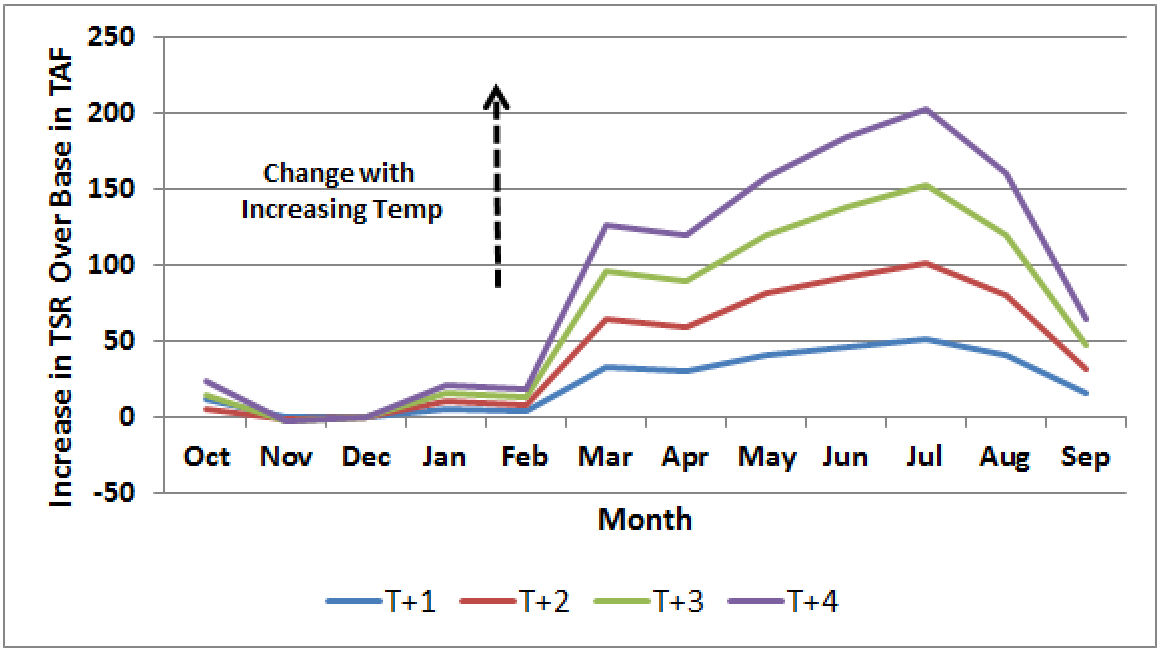


Figure 6-12: Increase Over Base Case in Long Term Monthly Average (WY1922-2003) Total Supply Requirement: Tulare River Basin

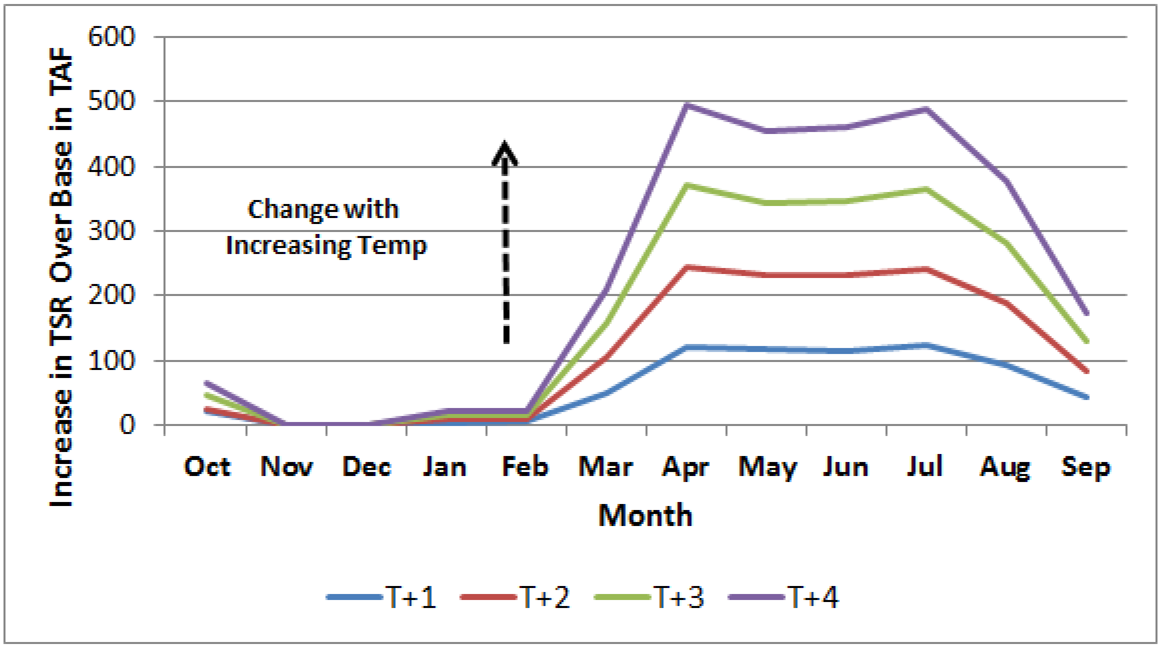


Figure 6-13: Increase Over Base Case in Long Term Monthly Average (WY1922-2003) Total Supply Requirement: Central Valley

Table 6-3: Average Annual Total Supply Requirement WY1922-2003 in TAF

	Base	T+1	T+2	T+3	T+4
Sacramento + Delta + Eastside Streams River Basin	7,040	7,314	7,591	7,869	8,146
San Joaquin River Basin	3,817	3,964	4,112	4,257	4,405
Tulare River Basin	7,811	8,087	8,341	8,613	8,884
Total for Central Valley	18,669	19,365	20,044	20,740	21,435

2. ***Impact on Reservoir Releases:***

The long term monthly averages WY1922-2003for Shasta, Oroville, and Folsom reservoir increase in releases over the Base Case from CVSIM are shown in Figures 6-14 through 6-16. In general increased releases during the summer months coinciding with increased water demands. The patterns for Shasta and Oroville are very similar with less releases during the winter months (storing the increased inflows from upper watersheds for later use) and increased in outflows during the high demand agricultural months (June through August) to meet the additional increases in the total supply requirement and exports. The pattern for Folsom reservoir is similar for the summer months though also increased during the winter months due to additional exports from the Delta.

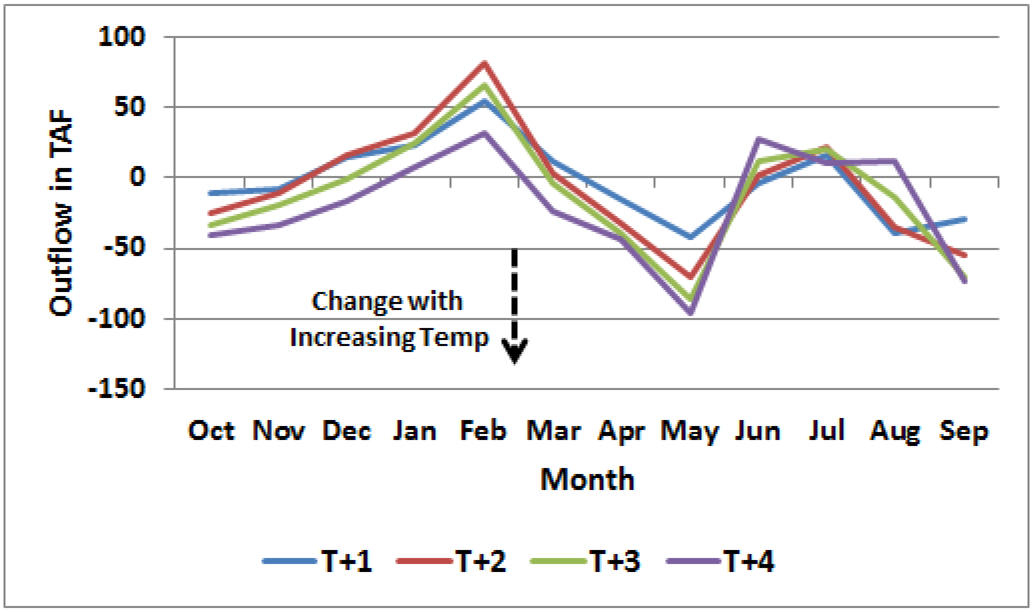


Figure 6-14: Average Monthly Increase in Releases from Shasta Reservoir over Base Case (WY1922-2003)

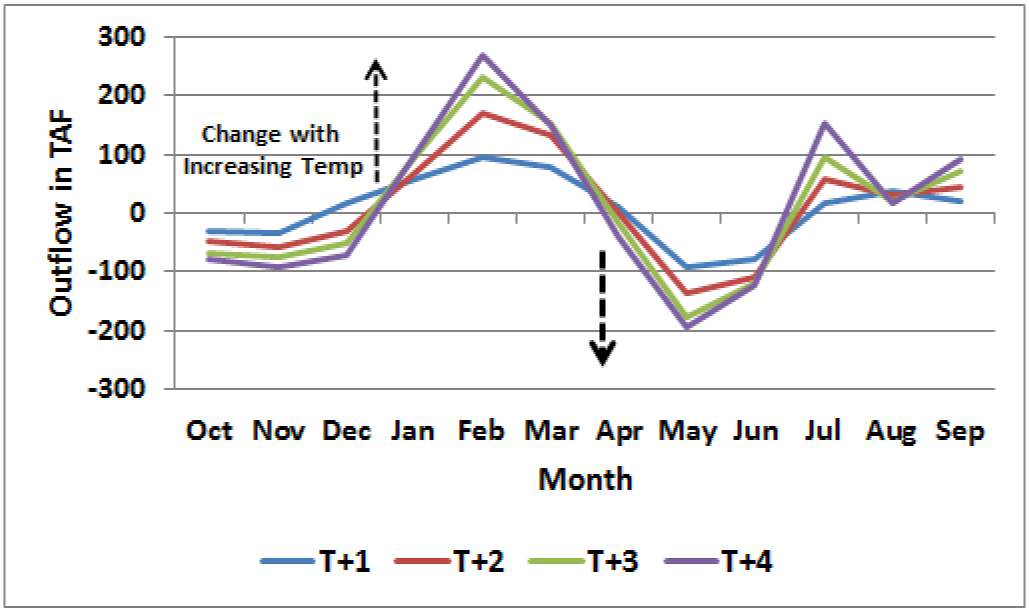


Figure 6-15: Average Monthly Increase in Releases from Oroville Reservoir over Base Case (WY1922-2003)

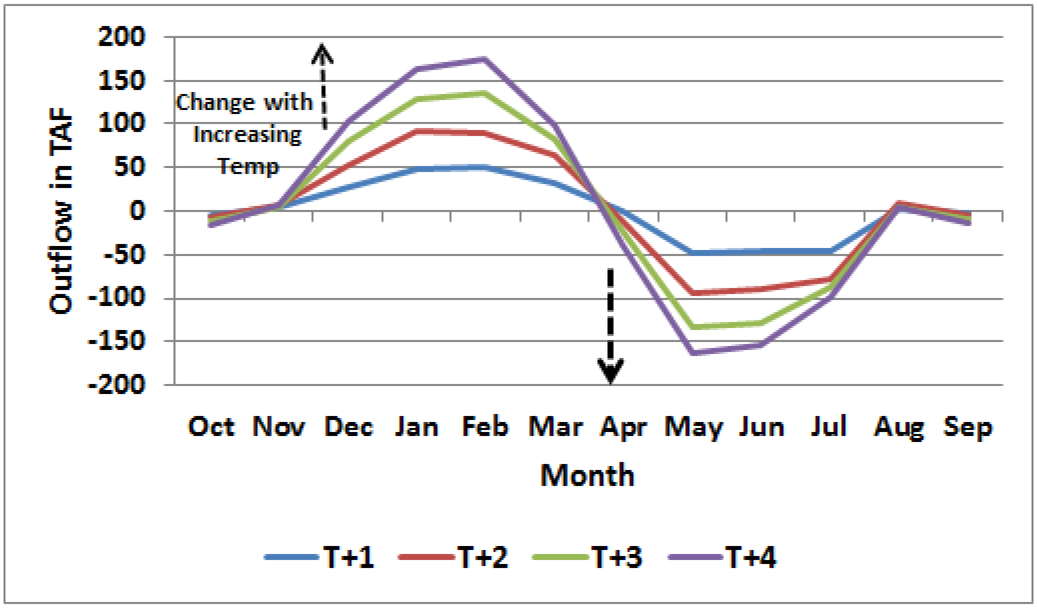


Figure 6-16: Average Monthly Increase in Releases in from Folsom Reservoir over Base Case (WY1922-2003)

3. ***Impact on Exports from the Delta:***

Results for exports from SWP's Banks Pumping Plant (BPP) and CVP's Jones Pumping Plant in the Delta are shown in Figures 6-17 and 6-18. The magnitudes are not large mainly because most of the target for exports was met in the Base Case (targets were not changed for the Sensitivity Cases).

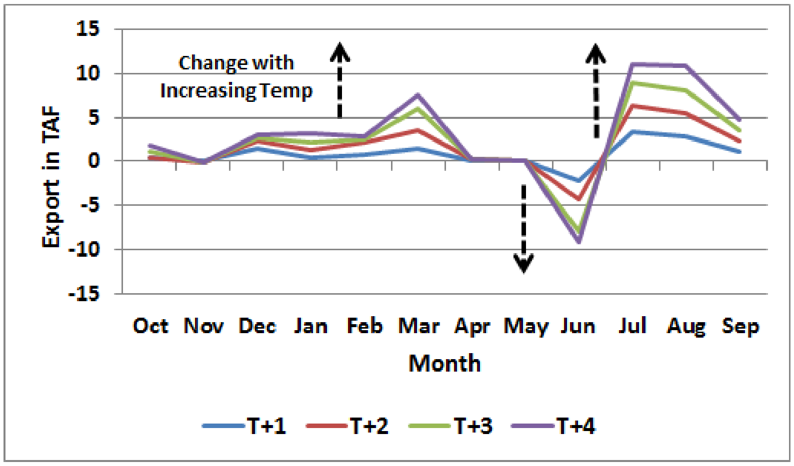


Figure 6-17: Average Monthly Increase in Exports from Banks Pumping Plant over Base Case (WY1922-2003)

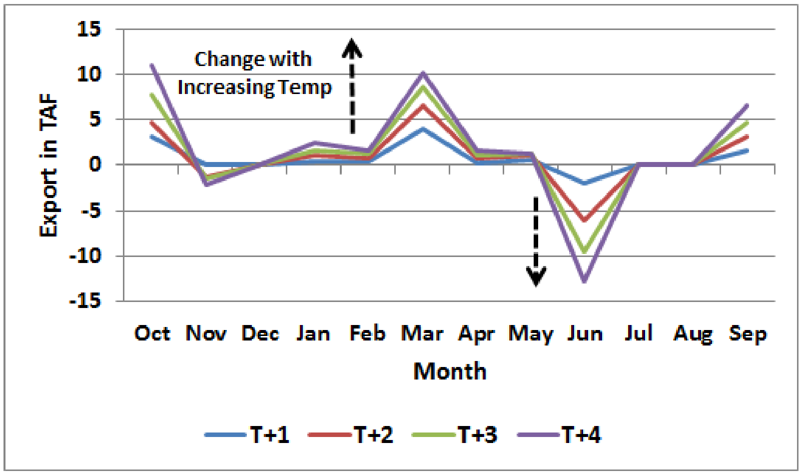


Figure 6-18: Average Monthly Increase in Exports from Jones Pumping Plant over Base Case (WY1922-2003)

4. *Impact on Exports from the Delta:*

Figure 6-19 shows the sensitivity values (increase over Base Case) for Delta Outflow (to the Pacific Ocean). The increases in the Fall/Winter months reflect increase in upstream reservoir releases, and which could not be utilized for exports through BPP and JPP.

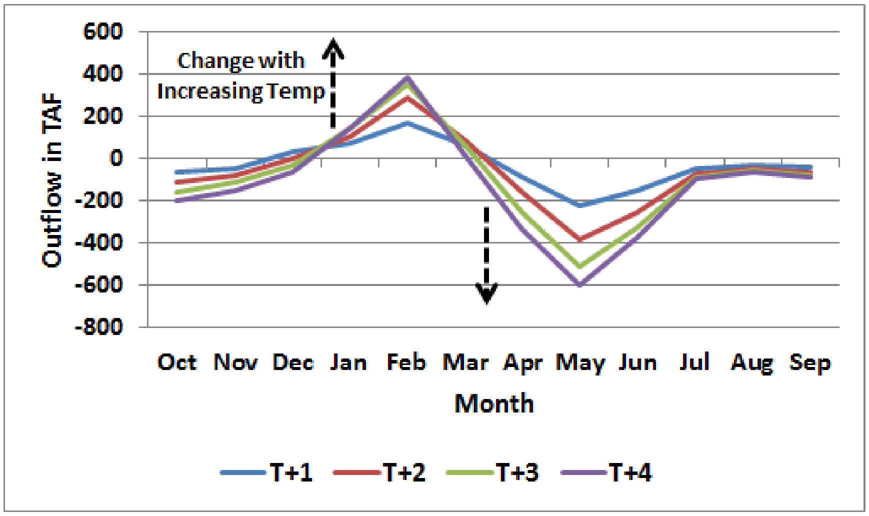


Figure 6-19: Average Monthly Increase in Delta Outflow over Base Case (WY1922-2003)

5. *Impact on Surface Water Diversions:*

Figure 6-20 through 6-23 show the long term WY1922-2003 monthly average Central Valley total increases in surface water diversions over Base case aggregated to the hydrologic regions. The pattern reflects increases in the total supply requirements (Figures 6-10 through 6-13), except for the month of June, most likely because of limits in surface water availability. This may also an issue with the weights assigned for allocation between surface water and groundwater, discussed in Chapter 5. The increase in surface water diversions for the Central Valley also appears in Figure 6-24 combined with the increases in groundwater pumping. Figure 6-24 can be compared to Figure 6-13 to show the near match with the increases in Total Supply Requirements (balancing water supplies and demands).

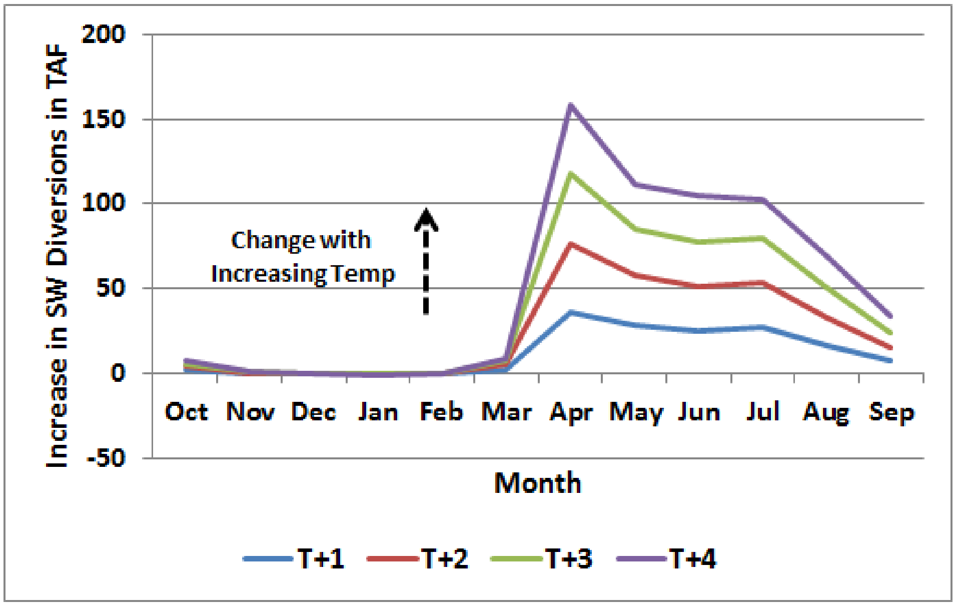


Figure 6-20: Average Monthly Increase in Surface Water Diversions in the Sacramento Valley over Base Case (WY1922-2003)

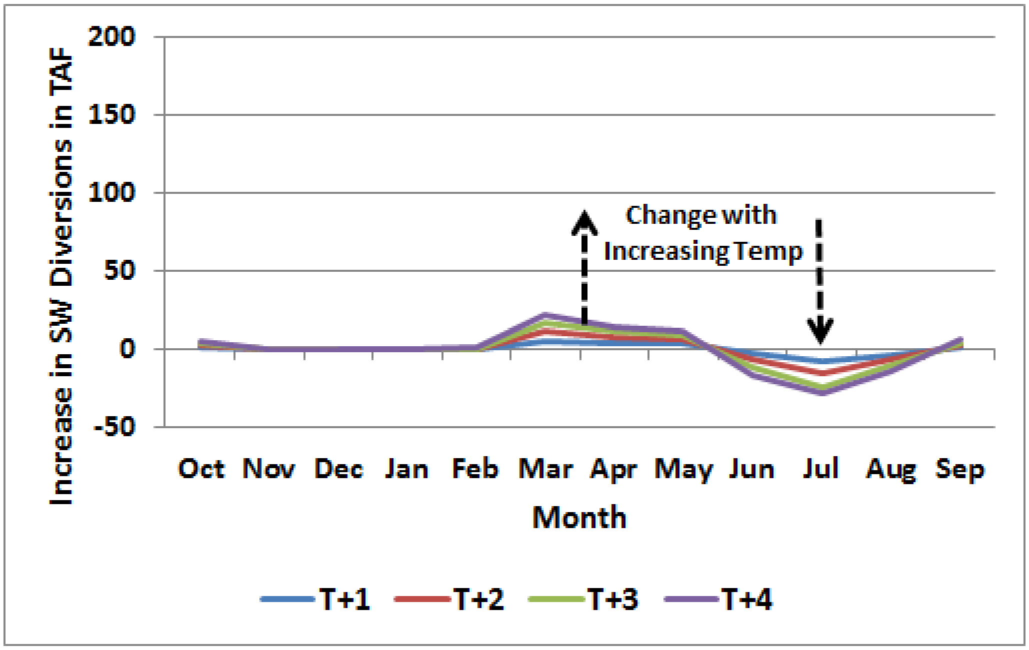


Figure 6-21: Average Monthly Increase in Surface Water Diversions in the San Joaquin Valley over Base Case (WY1922-2003)

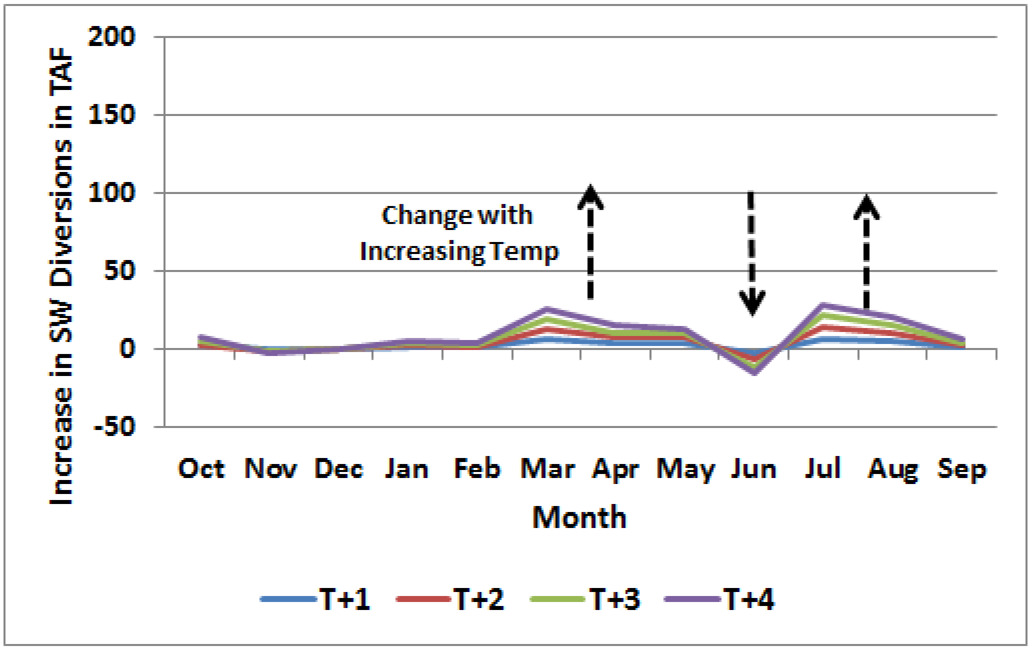


Figure 6-22: Average Monthly Increase in Surface Water Diversions in the Tulare Basin over Base Case (WY1922-2003)

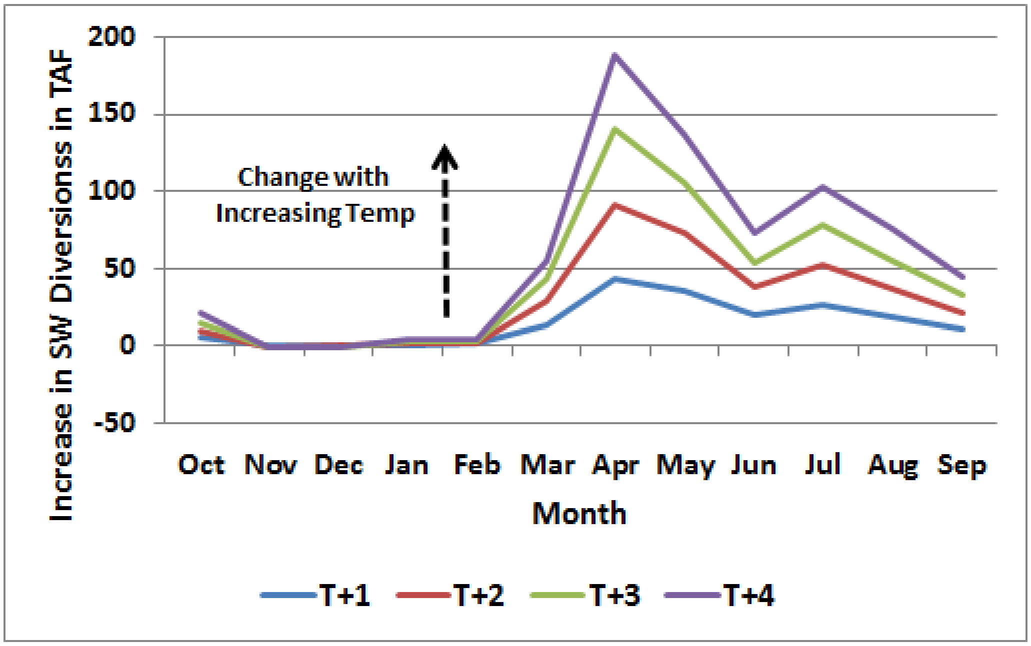


Figure 6-23: Average Monthly Increase in Surface Water Diversions in the Central Valley over Base Case (WY1922-2003)

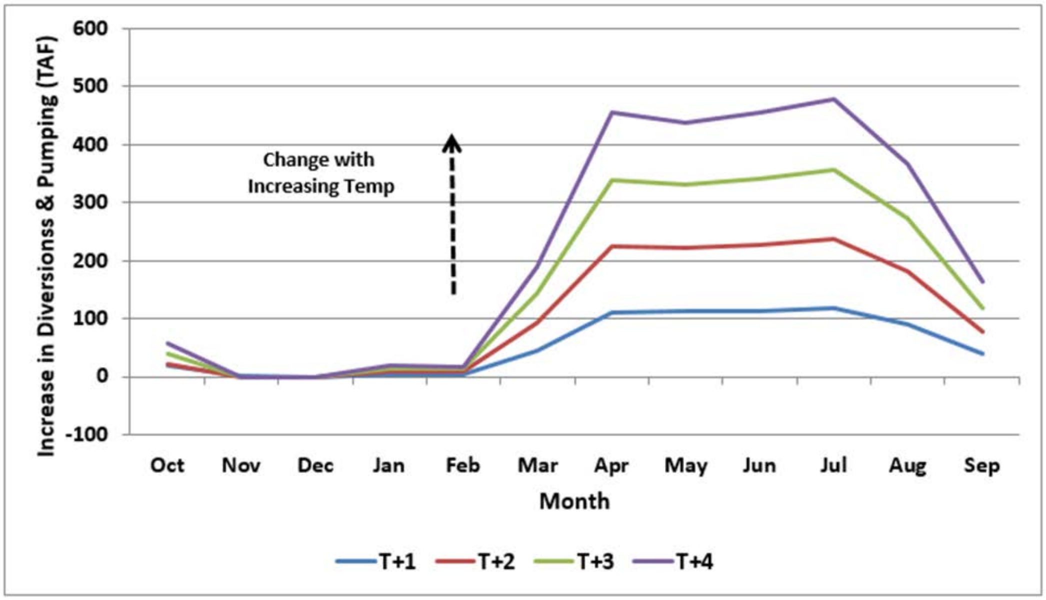


Figure 6-24: Average Monthly Increase in Surface Water Diversions and Groundwater Pumping in the Central Valley over Base Case (WY1922-2003)

6. *Impact on Grounwater Pumping:*

The increase in groundwater pumping for the Sacramento, San Joaquin, and Tulare basins, and the total for the Central Valley due to increases in TSR because of increasing temperatures are shown in Figures 6-25 through 6-28. The patterns are as expected coinciding mainly with the large agricultural water demands. Any shortages not met by surface water diversions are met by the groundwater pumping according the allocation priorities set. The increase in groundwater pumping for the Central Valley also appears in Figure 6-24 combined with the increase in surface water diversions for comparison the increase in Total Supply Requirements (agricultural and urban water demands) shown in Figure 6-13.

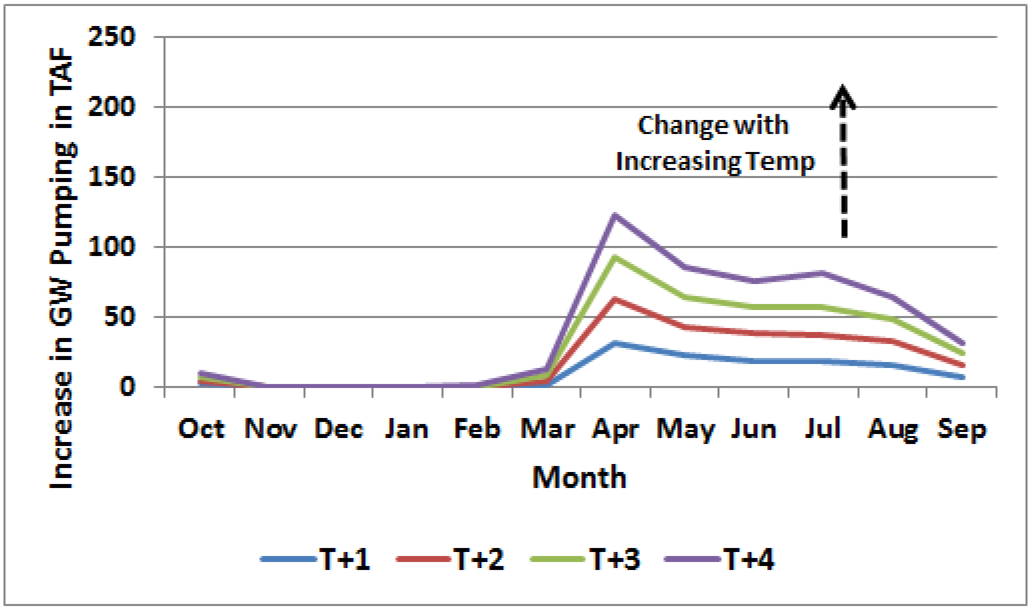


Figure 6-25: Average Monthly Increase in Groundwater Pumping in the Sacramento Valley over Base Case (WY1922-2003)

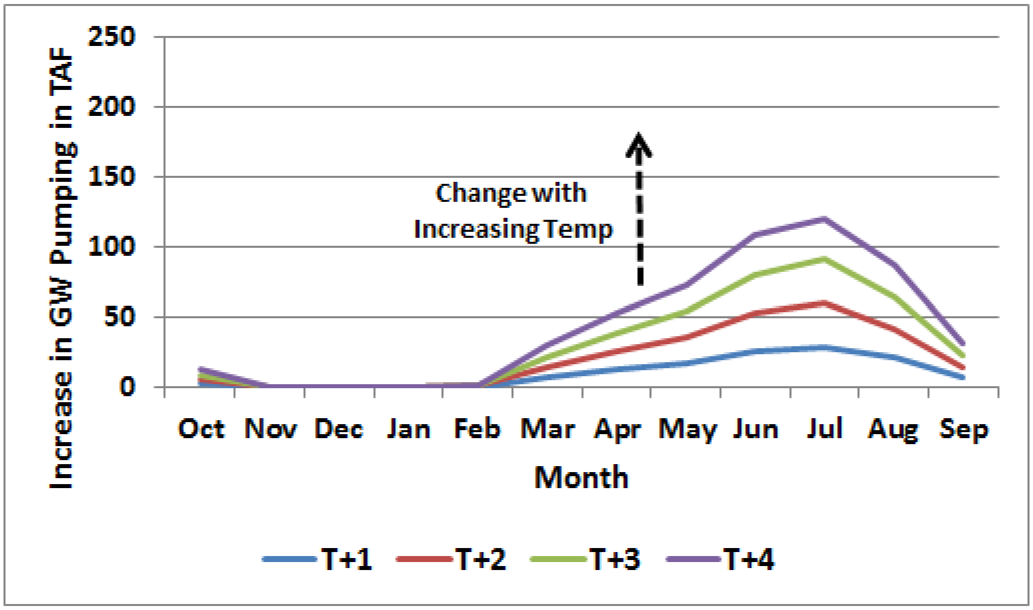


Figure 6-26: Average Monthly Increase in Groundwater Pumping in the San Joaquin Valley over Base Case (WY1922-2003)

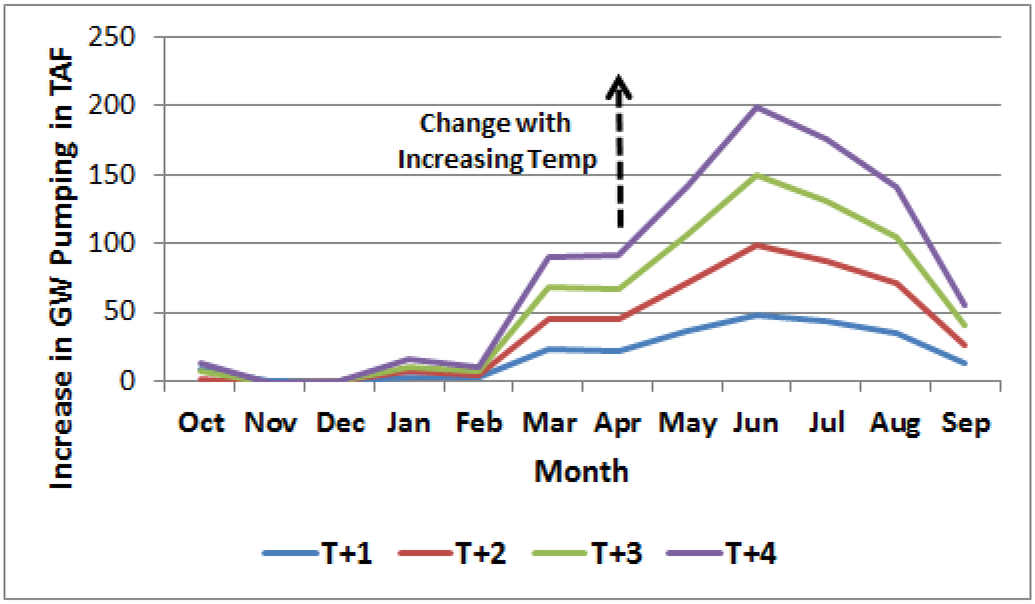


Figure 6-27: Average Monthly Increase in Groundwater Pumping in the Tulare River Basin over Base Case (WY1922-2003)

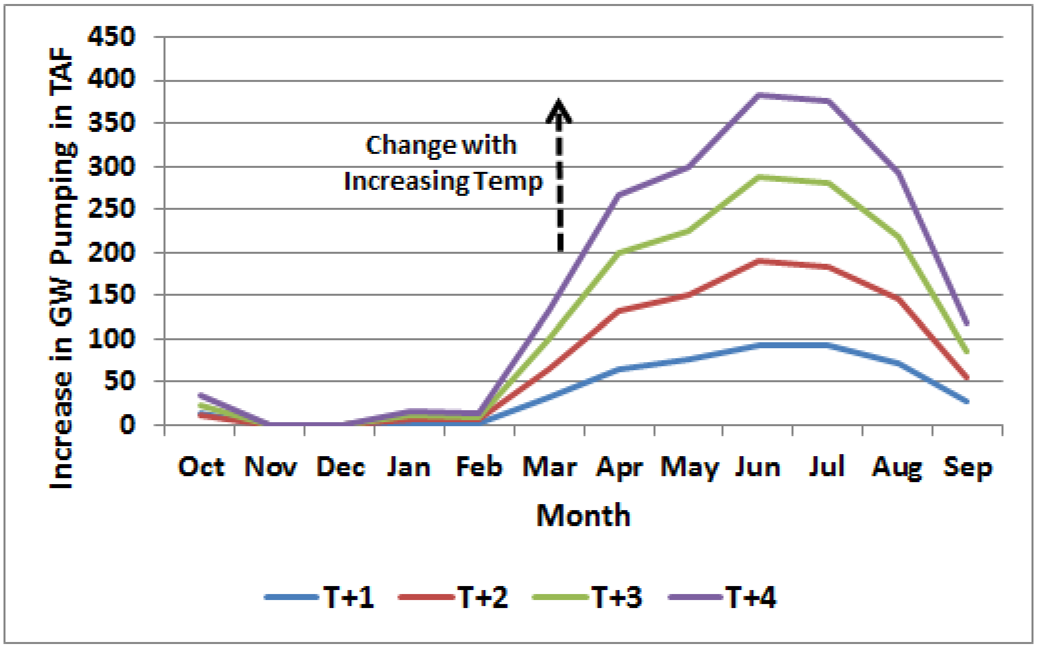


Figure 6-28: Average Monthly Increase Groundwater Pumping in Central Valley over Base Case (WY1922-2003)

7. Impact on Groundwater Storage:

Figures 6-29 through 6-32 show the impact of the increased pumping on the groundwater storages for the Sacramento, San Joaquin, Tulare Basins and the total for the Central Valley, respectively. Again the patterns follow the agricultural demand pattern over the irrigation season. There ae relatively small increases in storages during the Fall/Winter months, whereas large decreases in storages during Spring/Summer months mainly due to increased groundwater pumping.

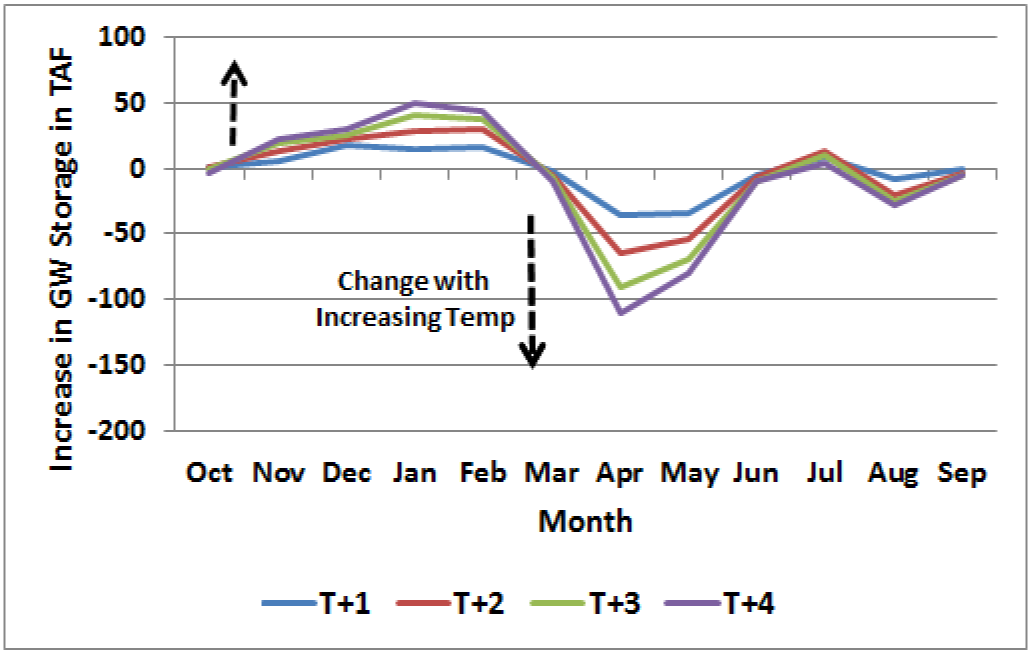


Figure 6-29: Average Monthly Increase in Groundwater Storage in the Sacramento Valley over Base Case (WY1922-2003)

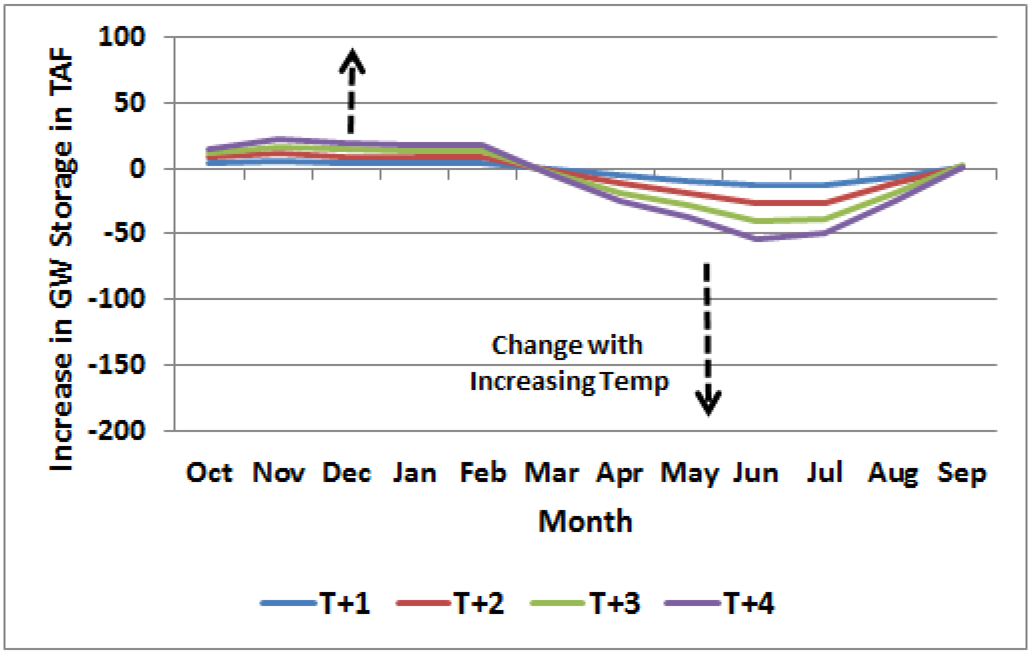


Figure 6-30: Average Monthly Increase in Groundwater Storage in the San Joaquin Valley over Base Case (WY1922-2003)

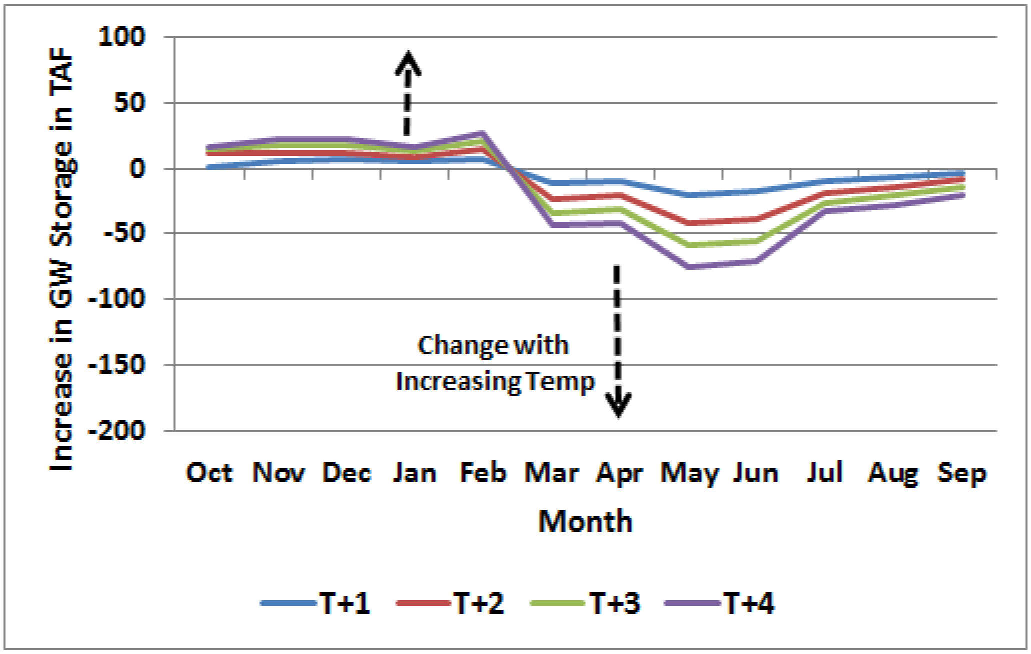


Figure 6-31: Average Monthly Increase in Groundwater Storage in Tulare River Basin over Base Case (WY1922-2003)

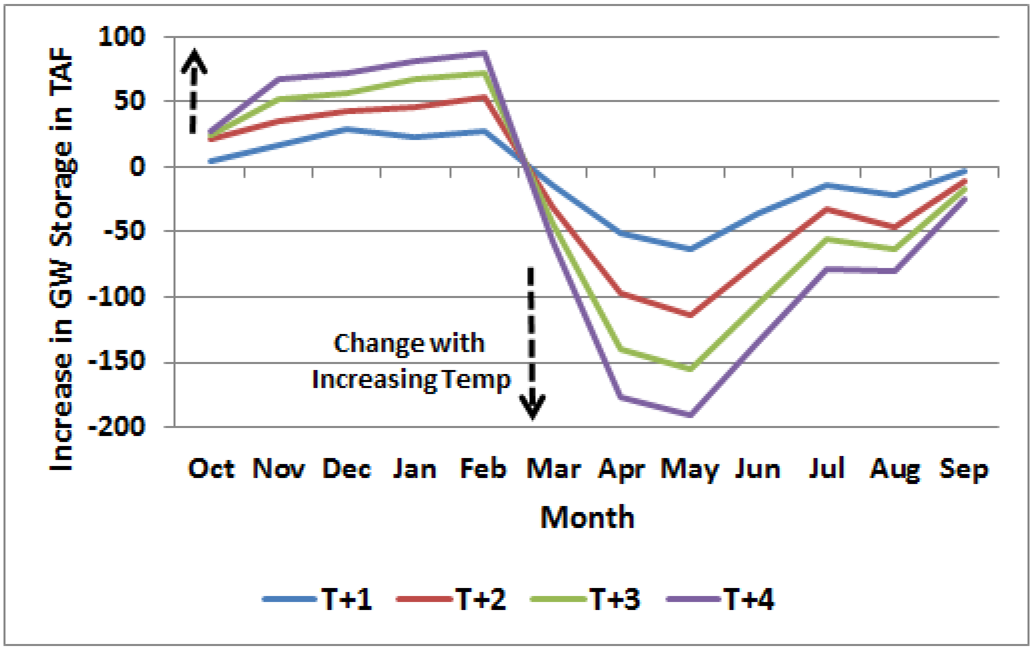


Figure 6-32: Average Monthly Increase in Groundwater Storage in the Central Valley over Base Case (WY1922-2003)

Finally, Figure 6-33 shows the cumulative impact on the groundwater storage for the Central Valley over the simulation period. The consistent bias of continued decline reflects increased total water use requirements and correspondingly increased groundwater pumping. This clearly shows the dramatic impact of maintaining status quo operations (reliance on groundwater pumping) in the face of increased demands due to global warming, and would definitely go against SGMA efforts for long term sustainability of groundwater resources. Alternatives to address this include increased and more efficient coordination of surface water and groundwater resources (optimal conjunctive use), shifting to lower water demand crops, or fallowing altogether, and limiting exports to Southern California.

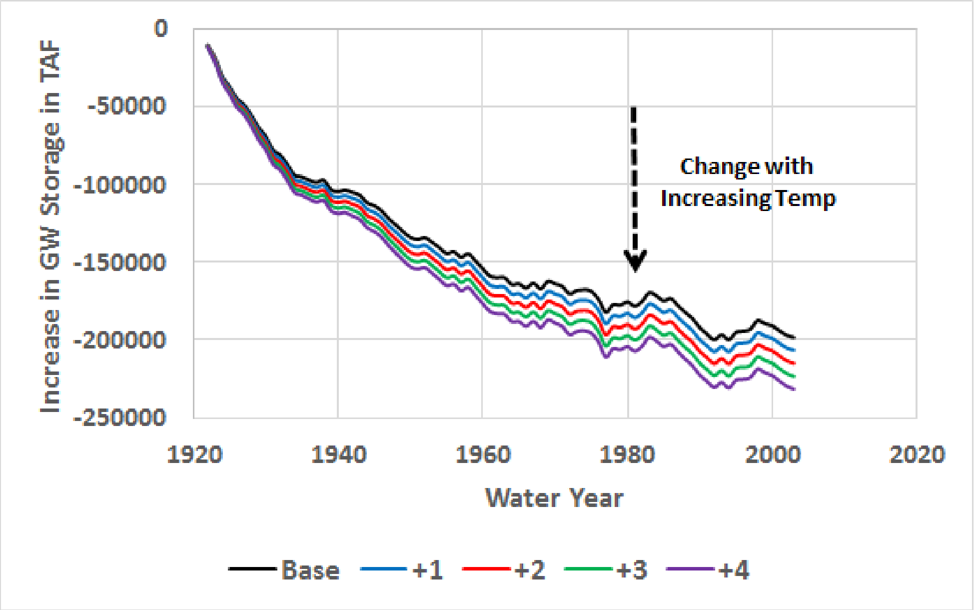


Figure 6-33: Cumulative Increase in Groundwater Storage in the Central Valley for Base and Sensitivity Cases (WY1922-2003)

6.2 Study 2: Conjunctive Use / Water Transfer Study in the Sacramento Valley

Water transfers are an important option for California to meet its water needs (Johns 2003, Newlin et. al. 2002, and USBR 2015). In this study, CVSIM is used to evaluate a proposed in lieu groundwater pumping conjunctive use / water transfer project in California. In this project surface water right holders (stakeholders) reduce their surface water diversions in selected months of drier classified year types, and increase by an equal amount their groundwater pumping to meet consumptive water demands. The increase in stream flows due to cutbacks in surface water diversions will presumably reach the Delta (for exports). It is also assumed that the hydrology of the wetter classified year types would allow groundwater storages to recover without any long term impacts due to project operations. The stakeholders would be compensated for the cutback in the surface water diversions. Two key questions are:

1. As a water transfer contract, what are the stakeholders entitled to be compensated for? Should they get compensated for the entire cutback in surface diversions or a portion of it because of losses in streamflows before reaching the Delta?

2. As a conjunctive use study, what are the short term (during years the project is in operation), and the long term (over the entire WY1922-2003 simulation) impacts on groundwater storage?

6.2.1 Background

In April of 2002 a partnership of CDWR, USBR, over 40 water suppliers in the Sacramento Valley and Downstream Water Users entered into the Sacramento Valley Water Management Agreement to avoid resolving issues with the Phase 8 of the CSWRCB's 1997 water right hearings related to meeting the water quality and flow objectives of the 1995 Delta Water Quality Control Plan D-1641 objectives and led to the Short-Term Settlement Agreement of December 2002. Projects developed would help meet water supply, water quality, and environmental needs in the Sacramento Valley, Bay-Delta, and throughout California. Four categories identified are planning and assessment, system improvements, institutional actions, and conjunctive water management projects (CDWR 2007). The Sacramento Valley Water Management Program (http://www.svwmp.water.ca.gov/) was subsequently developed to meet surface water flow requirements to the Delta through conjunctive use reservoir re-operation and water transfers. The conjunctive use/water transfers proposal would include nearly 30 Sacramento Valley stakeholders forgoing their surface water rights of diverting nearly 187 TAF/year in non-wet years (as defined by the Sacramento River Index) and instead pump groundwater from nearly 230 wells (Figure 6-34) to supplement local water needs. The expectations are that the decrease in diversions compensated by groundwater pumping would result in increased streamflows that would reach the Delta. A key question is whether all of the forgone surface water diversion actually reaches the Delta because of stream-aquifer interaction, and what would be the long term impacts of the project operations

In the early-mid 2000's, work by consultants to the SVWMP -as part of the EIS/EIR process- used the MicroFEM ® (http://www.microfem.com/) groundwater model in a steady-state simulation with a superposition approach to determine that 10-15% of the expected streamflow increases due to reductions in surface water diversions would be lost to stream-aquifer interaction (seepage) before the water reached the Delta. The results were later codified in reports and a White Paper for use in water transfer negotiations (SVWMP 2002, CDWR-USBR 2015, and USBR 2015).

In 2007 CDWR carried out a similar internal study where 187 TAF (a little higher than the SVWMP value of 173 TAF) of water is pumped in May through October during non-wet years, and in lieu of that surface water diversions would be reduced by an equal amount. The period of study was WY1972-2003. Based on the water year classifications, the project was in operation in 20 of the 31 years. Results showed that the increase in streamflows and increased pumping resulted in approximately 32% losses due to stream aquifer interaction (seepage). In other words only 68% of the expected increase in flow into the Delta actually occurred in model simulations. One key finding was that continual operation of the program in the long term reduces the expected benefits (increased streamflows to the Delta and recovery of groundwater elevations), mainly because of the long term memory of groundwater response to recovery.

This research uses the same data in the CDWR study discussed above (with minor changes) in a CVSIM study to determine the impacts both during the years when the project is in operation, and long term impacts.

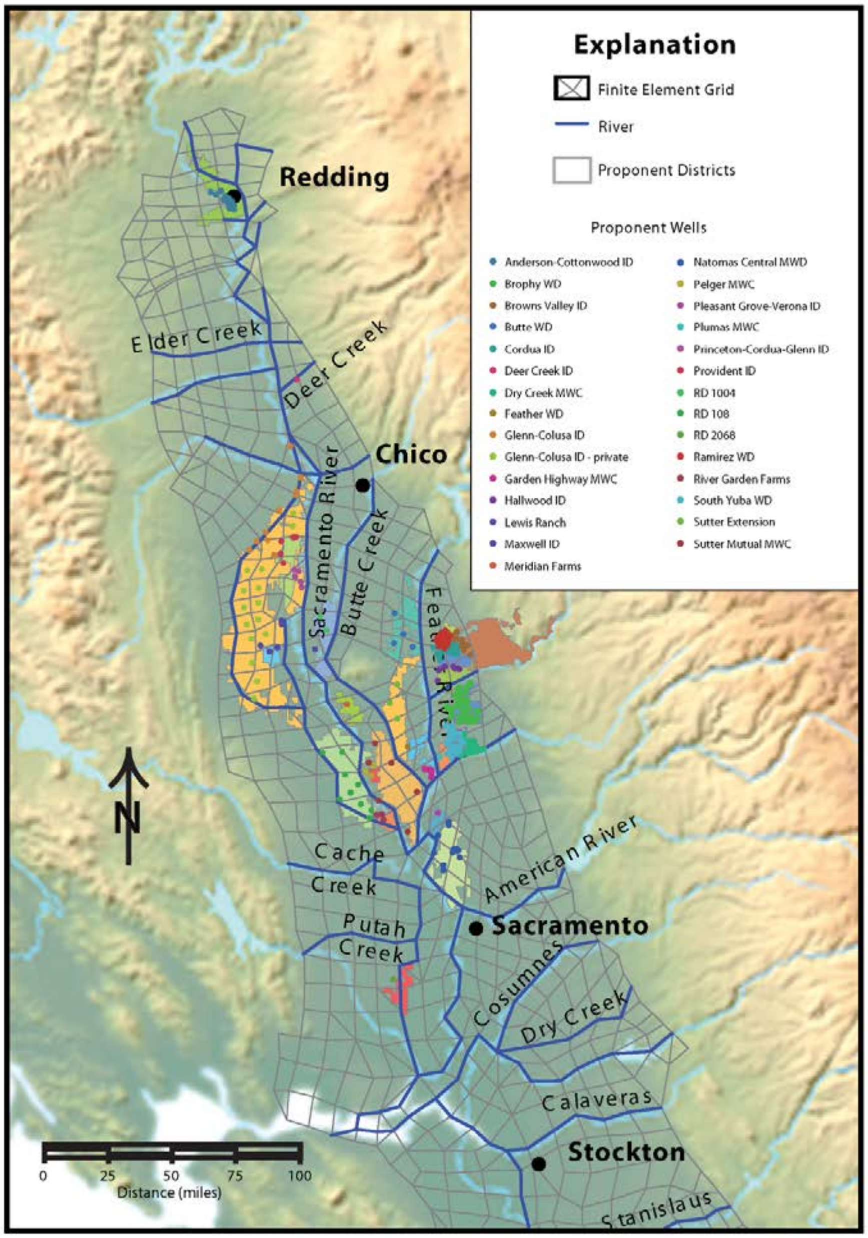


Figure 6-34: Water Districts Participating in the Sacramento Valley Water Management Plan Conjunctive Use Program SVWMP and the Groundwater Wells

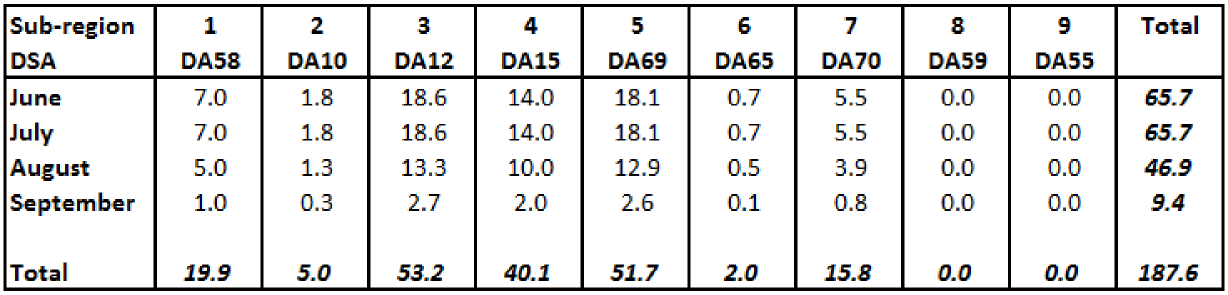
6.2.2 CVSIM Application and Results

Some modifications to the CDWR study discussed in the previous section were made to simplify the application in this research, as follows:

1. In the CDWR study 230 wells in 7 sub-regions in the Sacramento Valley (Sub-regions 1 through 7) were simulated in C2VSIM. In this study the pumping was reflected in the regional groundwater pumping for same sub-region.

2. In the CDWR study ~188TAF per year were distributed equally from June through October in every year the project was in operation (20 non-wet years between WY1973-2003). In this research the 188TAF were distributed by proportioning it to the average Total Supply Requirement (i.e, on an agricultural demand pattern) from June through October: 35%, 35%, 25%, and 5%, respectively. This is probably a more realistic assumption. The final values appear in Table 6-4.

Table 6-4: Increase in Groundwater Pumping and Reduction in Surface Water Diversions SVWMP in Non-Wet Years of Operation in TAF



Sub-region **DSA**	**1** **DA58**	**2** **DA10**	**3** **DA12**	**4** **DA15**	**5** **DA69**	**6** **DA65**	**7** **DA70**	**8** **DA59**	**9** **DA55**	**Total**
June	7.0	1.8	18.6	14.0	18.1	0.7	5.5	0.0	0.0	***65.7***
July	7.0	1.8	18.6	14.0	18.1	0.7	5.5	0.0	0.0	***65.7***
August	5.0	1.3	13.3	10.0	12.9	0.5	3.9	0.0	0.0	***46.9***
September	1.0	0.3	2.7	2.0	2.6	0.1	0.8	0.0	0.0	***9.4***
Total	***19.9***	***5.0***	***53.2***	***40.1***	***51.7***	***2.0***	***15.8***	***0.0***	***0.0***	***187.6***

3. The CDWR study cut back the 188TAF at 23 surface water diversion points in C2VSIM. In this study only one major surface water diversion per sub-region was identified to adjust the diversions, as shown in Table 6-5.

4. The simulation period in the CDWR study was 31 years (WY1973-2003), 20 of which the project was operational. In this research the simulation period is WY1922-2003 (83 years) with project operational in 56 years.

Table 6-5: Identified SVWMP Surface Water Diversion in CVSIM

Sub-region	DSA	Diversion
1	8	D135
2	10	D170
3	12	D155
4	15	D250
5	69	D330a
6	65	D480
7	70	D600b

The approach adopted to analyze the conjunctive use program is to create a Base Case followed by the Alternative Case where the modifications to surface water diversions and groundwater pumping are built in, and then to analyze the incremental differences in the results. The initial Base Case scenario is similar as the Base Case for CVSIM used in the previous section of this Chapter (i.e, the Base Case in the Global Warming sensitivity analysis). In addition two alternative cases were initially considered. The following is a summary of the three cases:

1. ***Base Case***: Fix the diversions to the Base Case diversions as targets in SIM2 and verify that C2VSIM and SIM2 in CVSIM give the identical results as in Section 5.2. Here there is no SVWMP and the ANN adjustments are dynamic in C2VSIM.

2. ***SVWMP Alternative A:*** Similar to the Base Case, except that SVWMP surface diversions are decreased with an expected increase in groundwater pumping. The ANN adjustments are still dynamic. In this case the dynamic adjustments also affect (during the iterative process) the implemented SVWMP diversions, groundwater pumping, and seepage above the “No SVWMP” case. This case is not recommended for analyzing SVWMP and was discarded. The reason is that the purpose of the adjustments for this study is to create a base hydrology from which alternatives can be compared. The adjustments themselves should not impact the simulation process by creating/removing water, thus confusing the impacts on actual streamflows from the project operation. Instead the next alternative is chosen.

3. ***SVWMP Alternative B (preferred):*** Similar to case 2 above, except that the dynamic adjustments calculations are turned off in C2VSIM, and instead the adjustments from the Base Case are used as input in both C2VSIM and SIM2 (i.e., pre-defined and fixed for the duration of the simulation). This allows determining what happens to the SVWMP implementation (e.g., how much of the extra water in reducing diversions actually reaches the Delta, and what is the effect on groundwater storage net recovery comparing Base and alternative cases).

For purposes of this research only the results of the Base Case and SVWMP Alternative B will be presented.

The mechanics for developing the additional input data for the Base Case are as follows:

1. Build the diversions from the Base Case (previous Section) and include in the DSS-SV file as targets to be reached in SIM2.

2. Modify appropriate WRESL codes:
    a. *Delivery Table WRESL Code*: set groundwater pumping now to zero and set diversions to those in SV file.
    b. *Inflow Table WRESL Code*: read in fixed upper limit diversions.

3. Run iterations for CVSIM using the algorithm described in Chapter 5.

The mechanics for developing the input and implementing the Alternative B Case are as follows:

1. Start with Base Case.

2. Modify the diversions per Tables 6-4 and 6-5, and prepare a new DSS-SV file for SIM2.

3. Fix the ANN adjustments time series to the Base Case values.

4. Modify the WRESL codes:
    a. Modify *Inflow Table* WRESL code to read in all the xD…. Diversions and xI450 Import.

    b. Modify the *Delivery Table* WRESL code to set limits (i.e, targets) to the Diversions and I450 to those in the DSS-SV file.

    c. Modify the *Table* WRESL code to include the fixed time series adjustments in the DSS-SV file, and read in a new *Inflow Table* WRESL code.

    d. Modify the *Report* WRESL code, to report additional results.

    e. Use the nnexclude .in file in C2VSIM to turn off all dynamic ANN adjustment computations.

5. Run iterations for CVSIM using the algorithm described in Chapter 5.

Results of applying CVSIM for Alternative B will be presented and discussed from two perspectives:

- From the surface water point of view; specifically impacts on inflow to the Delta.
- From the groundwater pumping point of view; specifically the groundwater budgets to determine the sources of the increased groundwater pumping.

1. Results from the surface water (Delta inflow) point of view:

Analysis of the Base case (without SVWMP) and Alternative Case (with SVWMP) will focus on two time windows:

a. The period June through September (when cutback in surface water diversions and increased groundwater pumping occur) of every year the project is in operation.

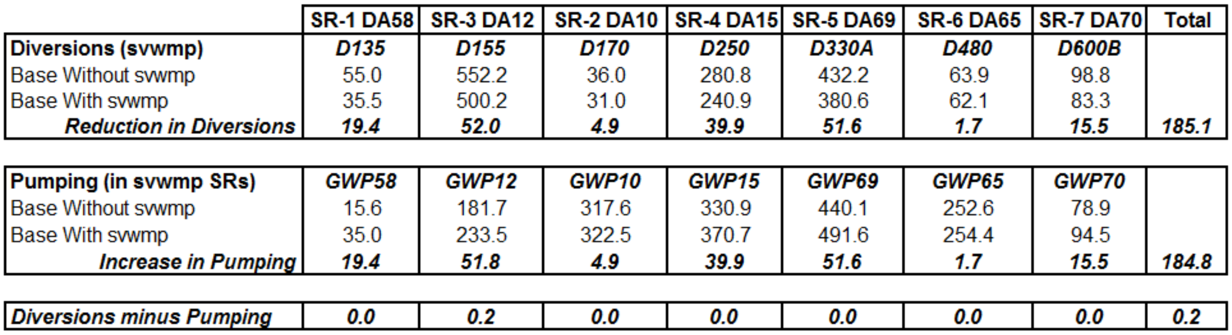
b. The entire 12 months for all years with and without project operations.

To determine impacts of the project, results will be presented in a comparative mode relative to the Base Case.

a. <u>Results for Years of Operation (June-September Period)</u>

Table 6-6 summarizes the cumulative June through September sub-regional surface water diversion cutbacks and the associated increase in groundwater pumping (~ 185 TAF).

Table 6-6: Average Annual WY1922-2003 Cumulative June-Sep Diversion Cutbacks and Groundwater Pumping in TAF



	SR-1 DA58	SR-3 DA12	SR-2 DA10	SR-4 DA15	SR-5 DA69	SR-6 DA65	SR-7 DA70	Total
Diversions (svwmp)	***D135***	***D155***	***D170***	***D250***	***D330A***	***D480***	***D600B***	
Base Without svwmp	55.0	552.2	36.0	280.8	432.2	63.9	98.8	
Base With svwmp	35.5	500.2	31.0	240.9	380.6	62.1	83.3	
Reduction in Diversions	***19.4***	***52.0***	***4.9***	***39.9***	***51.6***	***1.7***	***15.5***	***185.1***
Pumping (in svwmp SRs)	***GWP58***	***GWP12***	***GWP10***	***GWP15***	***GWP69***	***GWP65***	***GWP70***	
Base Without svwmp	15.6	181.7	317.6	330.9	440.1	252.6	78.9	
Base With svwmp	35.0	233.5	322.5	370.7	491.6	254.4	94.5	
Increase in Pumping	***19.4***	***51.8***	***4.9***	***39.9***	***51.6***	***1.7***	***15.5***	***184.8***
Diversions minus Pumping	***0.0***	***0.2***	***0.0***	***0.0***	***0.0***	***0.0***	***0.0***	***0.2***

Table 6-7 summarizes in the inflow to the Delta from the Sacramento Valley (Sacramento River), Eastside Streams, and San Joaquin Valley (San Joaquin River at Vernalis) with an average annual increase (over Base Case) of about 38.8 TAF for the Sacramento Valley, and minimal impacts on the ESS and San Joaquin Valley increases. The key observation is that only about 21% of the cutback in surface water diversions shows up as increased inflow to the Delta. Of interest, next, are what the contributing factors are.

Table 6-7: Average Annual WY1922-2003 Cumulative June-Sep Inflow to the Delta in TAF

	Sac *C610*	*ESS* *C645*	*SJ* *C660*
Base Without svwmp	3298.2	197.3	719.2
Base With svwmp	3337.0	197.2	719.4
Increase	***38.8***	***-0.1***	***0.2***

Table 6-8 summarizes the sub-regional ANN adjustments to outflows, with minimal differences; not surprising since the ANN adjustments was fixed in both scenarios.

Table 6-8: Average Annual WY1922-2003 Cumulative June-Sep Sub-region Outflow Adjustments in TAF

	DA10 **A10XCFS**	*DA15* **A15XCFS**	*DA58* **A58XCFS**	*DA59* **A59XCFS**	*DA65* **A65XCFS**	*DA69* **A69XCFS**	*Total*
Base Without svwmp	-334.3	721.3	-14.9	7.3	-115.4	49.2	***313.3***
Base With svwmp	-334.3	721.3	-14.9	7.3	-115.4	49.2	***313.3***
Increase	***0.0***	***0.0***	***0.0***	***0.0***	***0.0***	***0.0***	***0.0***

Tables 6-9 and 6-10 summarize the Shasta, Oroville, and Folsom reservoir evaporations and releases, respectively. The difference is a ***reduction*** in releases of nearly 82.4 TAF due to changes in reservoir operations.

Table 6-9: Average Annual WY1922-2003 Cumulative June-Sep Reservoir Evaporation in TAF

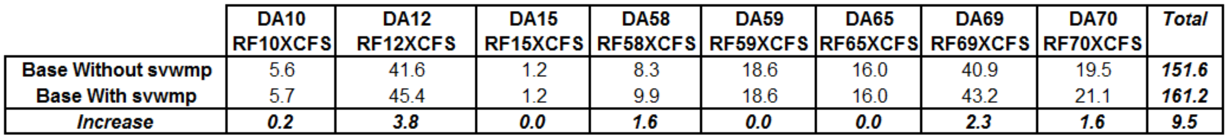
	Shasta **E1**	**Oroville** **E2**	**Folsom** **E3**	***Total***
Base Without svwmp	60.5	38.1	28.2	***126.8***
Base With svwmp	61.0	38.3	28.4	***127.6***
Increase	***0.5***	***0.3***	***0.2***	***0.9***

Table 6-10: Average Annual WY1922-2003 Cumulative June-Sep Reservoir Releases in TAF

	Shasta **C1**	**Oroville** **C2**	**Folsom** **C3**	***Total***
Base Without svwmp	2025.8	938.0	748.7	***3712.6***
Base With svwmp	2009.1	881.0	740.1	***3630.2***
Increase	***-16.7***	***-57.0***	***-8.6***	***-82.4***

Table 6-11 summarizes the sub-regional return flows, with differences contributing about 9.5 TAF to expected increased Delta inflow.

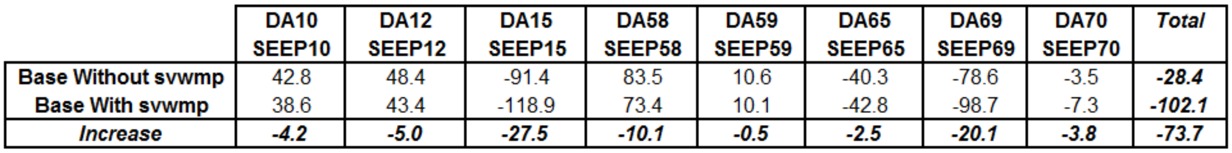
Table 6-11: Average Annual WY1922-2003 Cumulative June-Sep Sub-region Return Flows in TAF



	DA10 RF10XCFS	DA12 RF12XCFS	DA15 RF15XCFS	DA58 RF58XCFS	DA59 RF59XCFS	DA65 RF65XCFS	DA69 RF69XCFS	DA70 RF70XCFS	*Total*
Base Without svwmp	5.6	41.6	1.2	8.3	18.6	16.0	40.9	19.5	***151.6***
Base With svwmp	5.7	45.4	1.2	9.9	18.6	16.0	43.2	21.1	***161.2***
Increase	***0.2***	***3.8***	***0.0***	***1.6***	***0.0***	***0.0***	***2.3***	***1.6***	***9.5***

Table 6-12 summarizes the increase (over Base Case) of stream-aquifer interaction, with a ***reduction*** of nearly 73.7 TAF.

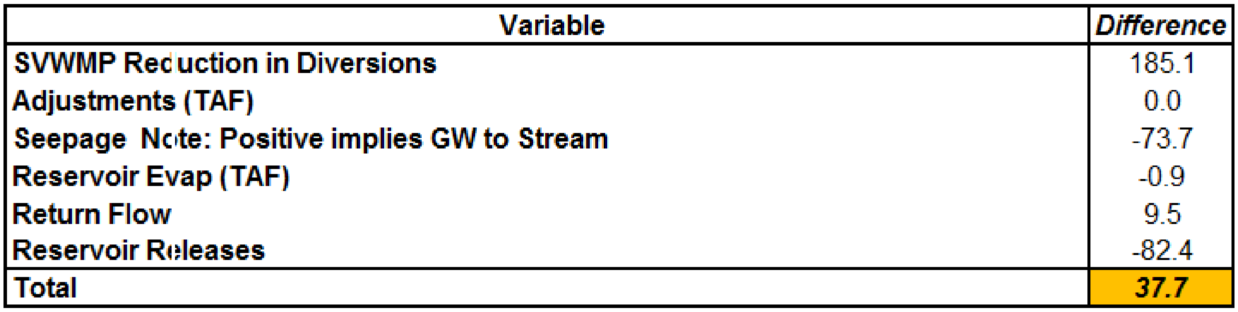
Table 6-12: Average Annual WY1922-2003 Cumulative June-Sep Sub-region Stream –Aquifer Interaction (positive GW to stream) in TAF



	DA10 SEEP10	DA12 SEEP12	DA15 SEEP15	DA58 SEEP58	DA59 SEEP59	DA65 SEEP65	DA69 SEEP69	DA70 SEEP70	*Total*
Base Without svwmp	42.8	48.4	-91.4	83.5	10.6	-40.3	-78.6	-3.5	***-28.4***
Base With svwmp	38.6	43.4	-118.9	73.4	10.1	-42.8	-98.7	-7.3	***-102.1***
Increase	***-4.2***	***-5.0***	***-27.5***	***-10.1***	***-0.5***	***-2.5***	***-20.1***	***-3.8***	***-73.7***

A summary of all the variables discussed above appears in Table 6-13.

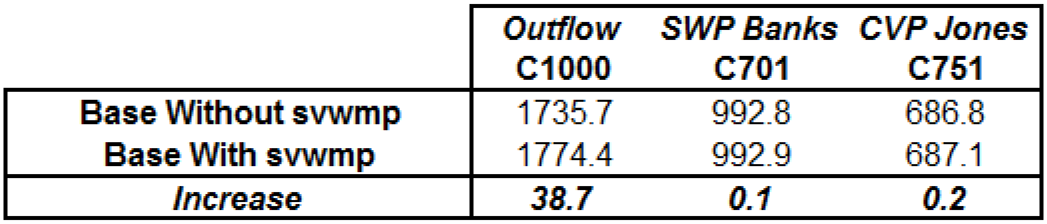
Table 6-13 – Average Annual WY1922-2003 Cumulative June-Sep Key Components Contributing to Inflow to the Delta from Sacramento Valley in TAF



Variable	*Difference*
SVWMP Reduction in Diversions	185.1
Adjustments (TAF)	0.0
Seepage Note: Positive implies GW to Stream	-73.7
Reservoir Evap (TAF)	-0.9
Return Flow	9.5
Reservoir Releases	-82.4
Total	***37.7***

The conclusion is that the reduction in the expected increases to Delta inflow is due mainly to increased seepage to groundwater (surface water – groundwater interaction) and reduction in reservoir operations over the June through September period (with possible increased releases in other months due to pre-set priorities). The increased seepage can be explained as follows. Reductions in surface water diversions imply increased local streamflow. Also increased groundwater pumping implies lower groundwater elevations. Both factors increase the flow gradient between stream and aquifer, thus increasing seepage. Table 6-14 summarizes the Delta Outflow and the CVP/SWP exports at Banks and Jones Pumping Plants.

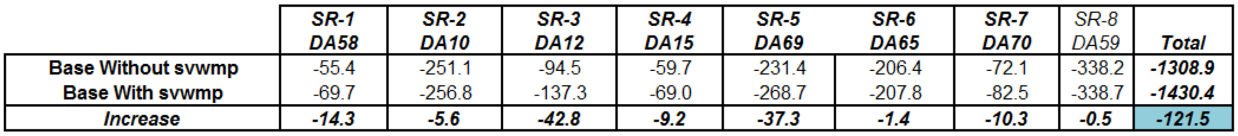
Table 6-14 – Average Annual WY1922-2003 Cumulative June-Sep Delta Outflow and SWP/CVP Exports in TAF



	Outflow C1000	*SWP Banks* C701	*CVP Jones* C751
Base Without svwmp	1735.7	992.8	686.8
Base With svwmp	1774.4	992.9	687.1
Increase	***38.7***	***0.1***	***0.2***

Minimal differences are expected since the Base Case already maximizes use of export capacity at the pumps. Therefore any increased inflow to the Delta becomes Delta outflow. Table 6-15 summarizes the sub-regional change in groundwater storage; there is a ***decrease*** in storage of approximately 121.5 TAF/year over the June through September period.

Table 6-15 – Average Annual WY1922-2003 Cumulative June-Sep Sub-region change in Groundwater Storage in TAF



	SR-1 *DA58*	*SR-2* *DA10*	*SR-3* *DA12*	*SR-4* *DA15*	*SR-5* *DA69*	*SR-6* *DA65*	*SR-7* *DA70*	*SR-8* *DA59*	***Total***
Base Without svwmp	-55.4	-251.1	-94.5	-59.7	-231.4	-206.4	-72.1	-338.2	***-1308.9***
Base With svwmp	-69.7	-256.8	-137.3	-69.0	-268.7	-207.8	-82.5	-338.7	***-1430.4***
Increase	***-14.3***	***-5.6***	***-42.8***	***-9.2***	***-37.3***	***-1.4***	***-10.3***	***-0.5***	***-121.5***

Figure 6-35 summarizes the increased inflows to the Delta over the simulation period. If the project is implemented for every non-wet year, the trend is a decrease in Delta inflow over time from the target.

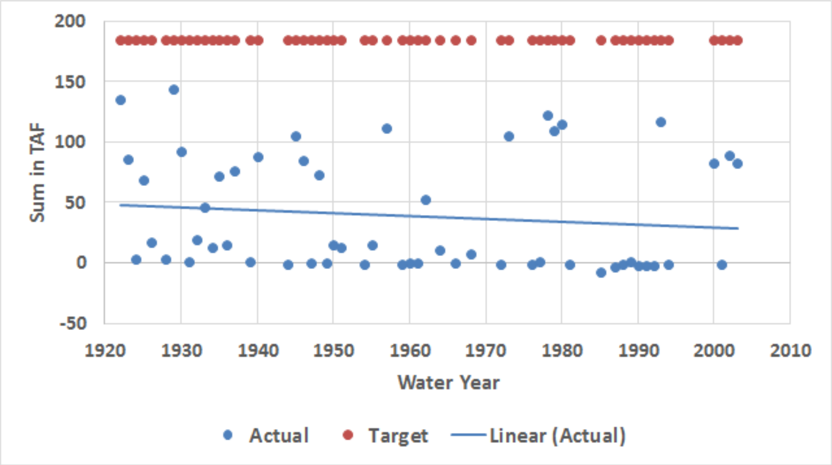


Figure 6-35: Operational Years Target and Actual Increases in Delta Inflow June-Sep

b. *Results for All Years WY 1922-2003 (all months)*

Tables 6-16 through Table 6-25 summarize the results similar to the above, but the average annual values now reflect the entire year, not only the months of project operation. Table 6-16 shows the balance between diversion cutbacks and groundwater pumping increases of nearly 122 TAF/year (now averaged over the 12 months of the year).

Table 6-16: Average Annual WY1922-2003 Diversion Cutbacks and Groundwater Pumping in TAF

	SR-1 DA58	SR-3 DA12	SR-2 DA10	SR-4 DA15	SR-5 DA69	SR-6 DA65	SR-7 DA70	*Total*
Diversions (svwmp)	***D135***	***D155***	***D170***	***D250***	***D330A***	***D480***	***D600B***	
Base Without svwmp	74.6	819.1	50.3	400.1	628.6	96.5	189.6	
Base With svwmp	61.3	783.5	47.0	372.9	593.4	95.3	179.0	
Reduction in Diversions	13.3	35.5	3.4	27.2	35.2	1.2	10.6	***126.39***

Pumping (in svwmp SRs)	***GWP58***	***GWP12***	***GWP10***	***GWP15***	***GWP69***	***GWP65***	***GWP70***	
Base Without svwmp	20.6	258.4	441.5	470.6	649.1	355.7	132.2	
Base With svwmp	33.8	293.8	444.8	497.8	684.3	356.9	142.8	
Increase in Pumping	13.3	35.4	3.4	27.2	35.2	1.2	10.6	***126.2***

Diversions minus Pumping	***0.0***	***0.1***	***0.0***	***0.0***	***0.0***	***0.0***	***0.0***	***0.1***

The average annual increase for inflow from the Sacramento Valley of 17.7 TAF/year, approximately 14% of the expected 122 TAF/year, is shown in Table 6-17.

Table 6-17: Average Annual WY1922-2003 Inflow to the Delta TAF

	Sac *C610*	*ESS* *C645*	*SJ* *C660*
Base Without svwmp	19417.5	1357.5	3601.8
Base With svwmp	19435.2	1357.0	3601.9
Increase	***17.7***	***-0.5***	***0.1***

The impact of the ANN adjustments, which are none by design since they are fixed to the Base Case is shown in Table 6-18.

Table 6-18 – Average Annual WY1922-2003 Sub-region Outflow Adjustments in TAF

	DA10 **A10XCFS**	*DA15* **A15XCFS**	*DA58* **A58XCFS**	*DA59* **A59XCFS**	*DA65* **A65XCFS**	*DA69* **A69XCFS**	*Total*
Base Without svwmp	-739.8	1309.8	297.2	-22.3	-870.0	223.8	***198.7***
Base With svwmp	-739.8	1309.8	297.2	-22.3	-870.0	223.8	***198.7***
Increase	***0.0***	***0.0***	***0.0***	***0.0***	***0.0***	***0.0***	***0.0***

Table 6-19 and Table 6-20 show the reservoir evaporation and reservoir releases, respectively. Unlike the June through September analysis, the long term difference in reservoir releases is minimal, as expected since long term WY1922-2003 inflows to the reservoirs do not change.

Table 6-19 – Average Annual WY1922-2003 Reservoir Evaporation in TAF

	Shasta **E1**	**Oroville** **E2**	**Folsom** **E3**	*Total*
Base Without svwmp	94.7	33.5	48.3	***176.5***
Base With svwmp	95.1	33.6	48.4	***177.1***
Increase	***0.4***	***0.1***	***0.1***	***0.6***

Table 6-20 – Average Annual WY1922-2003 Reservoir Releases in TAF

	Shasta C1	Oroville C2	Folsom C3	*Total*
Base Without svwmp	5863.8	4324.4	2676.2	***12864.5***
Base With svwmp	5863.5	4324.3	2675.5	***12863.3***
Increase	***-0.4***	***-0.1***	***-0.7***	***-1.2***

The minimal impacts of the return flows are shown in Table 6-21.

Table 6-21 – Average Annual WY1922-2003 Sub-region Return Flows in TAF

	DA10 RF10XCFS	DA12 RF12XCFS	DA15 RF15XCFS	DA58 RF58XCFS	DA59 RF59XCFS	DA65 RF65XCFS	DA69 RF69XCFS	DA70 RF70XCFS	*Total*
Base Without svwmp	13.11	57.50	1.68	14.64	35.07	32.30	58.68	38.47	***251.44***
Base With svwmp	13.23	60.07	1.70	15.80	34.95	32.29	60.23	39.53	***257.79***
Increase	***0.12***	***2.56***	***0.03***	***1.16***	***-0.12***	***-0.01***	***1.55***	***1.06***	**6.35**

The average annual increase in stream seepage of approximately 113 TAF/year is shown in Table 6-22.

Table 6-22 – Average Annual WY1922-2003 Sub-region Stream –Aquifer Interaction (positive GW to stream) in TAF

	DA10 SEEP10	DA12 SEEP12	DA15 SEEP15	DA58 SEEP58	DA59 SEEP59	DA65 SEEP65	DA69 SEEP69	DA70 SEEP70	*Total*
Base Without svwmp	95.5	167.1	-86.3	202.7	-37.9	-221.6	-252.9	-54.7	***-187.9***
Base With svwmp	84.9	157.5	-116.3	187.6	-37.3	-225.6	-291.8	-60.2	***-301.1***
Increase	***-10.6***	***-9.6***	***-30.0***	***-15.1***	***0.6***	***-4.0***	***-38.9***	***-5.5***	**-113.2**

Table 6-23 summarizes all major components discussed above affecting inflow to the Delta. It shows that the expected increase in inflow because of the surface water diversions cutbacks is only 17.7 TAF/year (10% of the 126.4 TAF/year), due mainly to increased seepage upstream of the Delta.

Table 6-23: Average Annual WY1922-2003 Key Components Contributing to Inflow to the Delta from Sacramento Valley in TAF

Variable	*Difference*
SVWMP Reduction in Diversions	***126.4***
Adjustments	***0.0***
Seepage Note: Positive implies GW to Stream	***-113.2***
Reservoir Evap	***-0.6***
Return Flow	***6.4***
Reservoir Releases	***-1.2***
Total	***17.7***

Results confirming that nearly all increased inflow to the Delta shows up as Delta outflow appears in Table 6-24.

Table 6-24: Average Annual WY1922-2003 Delta Outflow and SWP/CVP Exports in TAF

	Outflow **C1000**	*SWP Banks* **C701**	*CVP Jones* **C751**
Base Without svwmp	19141.7	2464.2	1800.5
Base With svwmp	19158.7	2464.3	1800.7
Increase	***17.0***	***0.1***	***0.1***

Table 6-25 shows the impact on groundwater storage. The cumulative decrease in groundwater storage over the WY1922-2003 period is nearly 1.3 million acre-feet.

Table 6-25 – WY1922-2003 Cumulative Sub-region Change in Groundwater Storage in TAF

	SR-1 DA58	*SR-2 DA10*	*SR-3 DA12*	*SR-4 DA15*	*SR-5 DA69*	*SR-6 DA65*	*SR-7 DA70*	*SR-8 DA59*	*Total*
Base Without svwmp	-7363.2	-15879.0	-11583.0	-980.3	-6328.9	-9034.7	-3840.5	-22712.2	***-77721.8***
Base With svwmp	-7457.6	-15961.1	-12275.5	-1020.7	-6506.5	-9046.2	-3975.4	-22773.8	***-79016.8***
Increase	***-94.4***	***-82.1***	***-692.5***	***-40.4***	***-177.6***	***-11.5***	***-134.9***	***-61.6***	***-1295.0***

The time series of the decrease in storage is shown in Figure 6-36. Since there 56 years of operation (non-Wet years) and 26 years of non-operation (Wet years), the conclusion is that the system never recovers (increasing overdraft) since replenishment to the system is insufficient.

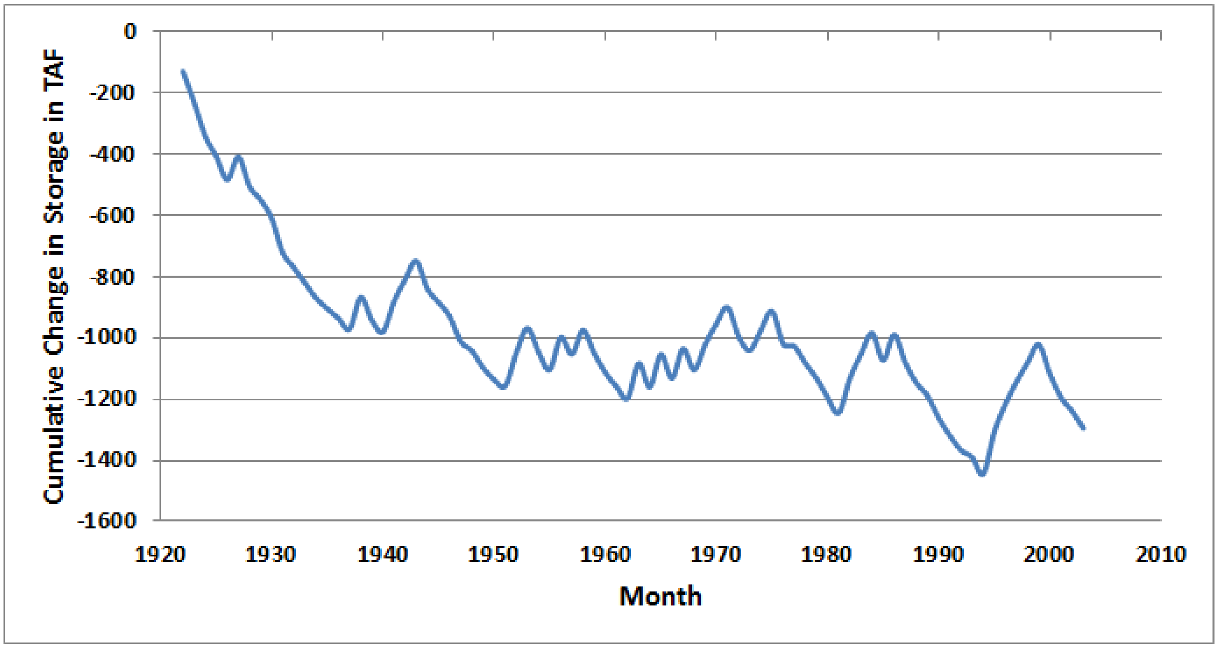


Figure 6-36: Impact of Project on Cumulative Groundwater Storage

2. Results from the groundwater pumping point of view:

An interesting question to ask is what is the source of water for the increased groundwater pumping due to the operation of the conjunctive use program? The results for the average annual WY1922-2003 groundwater budget components from the CVSIM run for each sub-regions in the Sacramento Valley for the Base Case (no conjunctive use) appears in Tables 6-26.

The components for the water budget are:

Change in storage: change in groundwater storage (decrease of ~ 948 TAF).
Net deep percolation: deep percolation below the unsaturated zone (~1346 TAF).
Gain from stream: loss from stream to groundwater through seepage (~202 TAF).
Recharge: Losses from By-passes and recoverable losses from delivery canals (~264 TAF).
Boundary inflow: subsurface inflow from boundary small watersheds/ mountain face (~53 TAF).
Subsidence: simulated subsidence due to groundwater pumping (~3 TAF).
Pumping: groundwater pumping (~2878 TAF).
Net subsurface inflow: subsurface inflow from the San Joaquin Valley (~61 TAF).

Table 6-26: Average Annual WY1922-2003 Groundwater Budget Components for the Base Case (No Conjunctive Use) in TAF

Sub-region	Change in Storage	Net Deep Percolation	Gain from Stream	Recharge	Boundary Inflow	Subsidence	Pumping	Net Subsurface Inflow
SR-1 DA58	-89.8	161.2	-192.2	21.0	0.0	0.0	20.5	-59.4
SR-2 DA10	-193.6	243.2	-99.4	19.9	42.1	0.3	441.4	41.7
SR-3 DA12	-141.3	152.0	-84.4	150.7	4.8	0.7	258.3	-106.6
SR-4 DA15	-12.0	193.3	1.7	20.0	0.0	0.0	470.8	243.8
SR-5 DA69	-77.2	281.4	268.6	37.7	19.2	0.2	654.6	-29.6
SR-6 DA65	-110.2	101.2	235.9	5.7	-46.6	1.3	355.7	-52.0
SR-7 DA70	-46.8	69.1	33.5	6.5	23.6	0.0	126.7	-52.8
SR-8 DA59	-277.0	145.0	38.6	2.3	10.2	0.3	549.7	76.2
Total	***-947.8***	***1346.4***	***202.3***	***263.7***	***53.3***	***2.9***	***2877.7***	***61.3***

The results are also shown schematically in Figure 6-37.

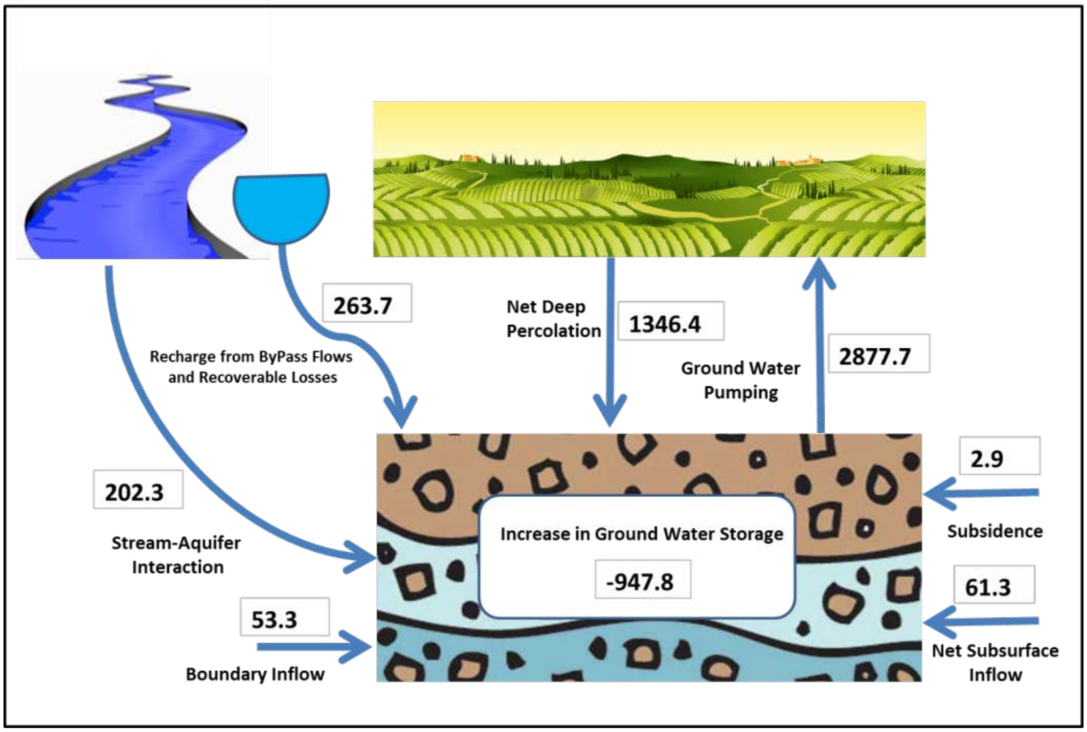


Figure 6-37: Average Annual WY1922-2003 Groundwater Budget for the Base Case (no Conjunctive Use) in TAF

Results for the groundwater budgets with the conjunctive use (Alternative B) are summarized in Table 6-27, and shown schematically in Figure 6-38.

Table 6-27 – Average Annual WY1922-2003 Groundwater Budget Components for Alternative B (With Conjunctive Use) in TAF

Sub-region	Change in Storage	Net Deep Percolation	Gain from Stream	Recharge	Boundary Inflow	Subsidence	Pumping	Net Subsurface Inflow
SR-1 DA58	-90.9	161.5	-177.1	17.3	0.0	0.0	33.6	-59.2
SR-2 DA10	-194.6	244.8	-88.2	18.7	42.1	0.3	444.8	32.5
SR-3 DA12	-149.9	155.2	-72.0	144.6	4.8	0.8	293.9	-89.2
SR-4 DA15	-12.5	196.4	32.3	18.6	0.0	0.0	498.0	238.2
SR-5 DA69	-79.3	285.5	300.6	35.6	19.2	0.2	690.3	-30.1
SR-6 DA65	-110.3	101.2	241.1	5.7	-46.6	1.3	356.9	-56.3
SR-7 DA70	-48.5	68.2	39.8	6.4	23.6	0.1	136.8	-49.6
SR-8 DA59	-277.7	143.2	40.0	2.3	10.2	0.3	549.7	75.8
Total	***-963.8***	***1356.0***	***316.6***	***249.2***	***53.3***	***3.0***	***3004.0***	***62.1***

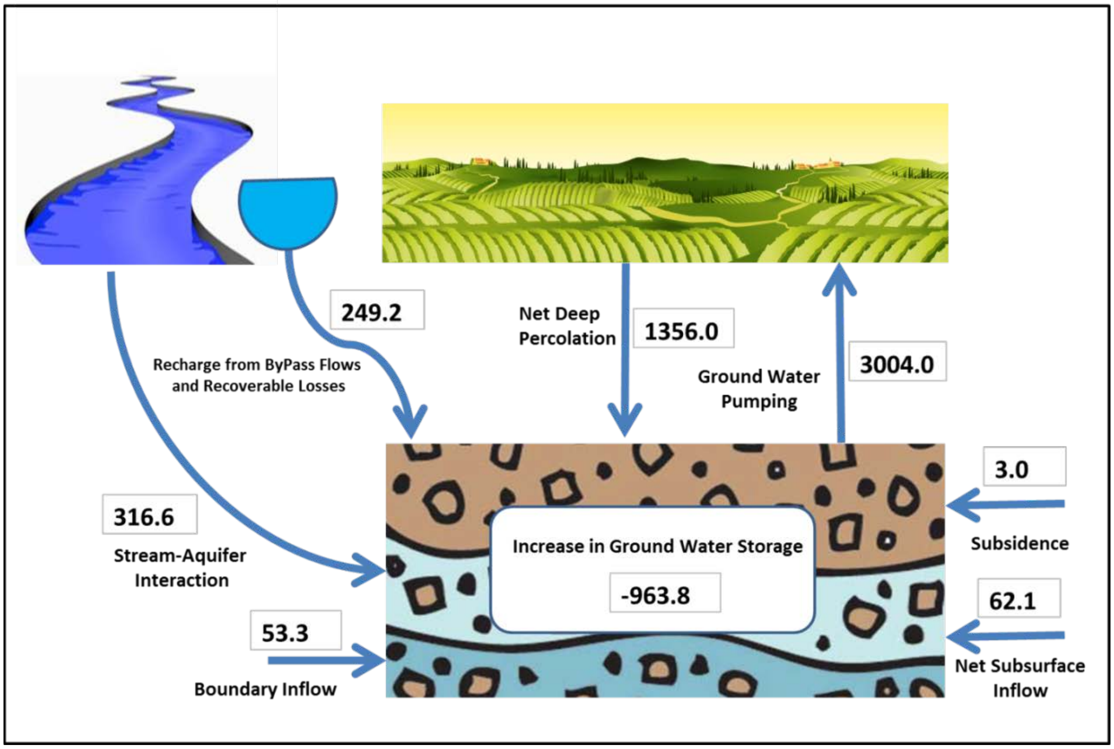


Figure 6-38: Average Annual WY1922-2003 Groundwater Budget for the Base Case (with Conjunctive Use) in TAF

The differences to show the impacts of the conjunctive use project are summarized in Table 6-28 and shown schematically in Figure 6-39.

Table 6-28 – Average Annual WY1922-2003 Difference Groundwater Budget Components (With Conjunctive Use minus Base Case) in TAF

Sub-region	Change in Storage	Net Deep Percolation	Gain from Stream	Recharge	Boundary Inflow	Subsidence	Pumping	Net Subsurface Inflow
SR-1 DA58	-1.2	0.3	15.1	-3.7	0.0	0.0	13.1	0.2
SR-2 DA10	-1.0	1.6	11.2	-1.1	0.0	0.0	3.4	-9.2
SR-3 DA12	-8.6	3.2	12.4	-6.1	0.0	0.1	35.6	17.5
SR-4 DA15	-0.5	3.1	30.6	-1.4	0.0	0.0	27.2	-5.7
SR-5 DA69	-2.2	4.1	32.0	-2.1	0.0	0.0	35.7	-0.5
SR-6 DA65	-0.1	0.0	5.2	0.0	0.0	0.0	1.2	-4.3
SR-7 DA70	-1.6	-0.9	6.3	-0.1	0.0	0.0	10.1	3.3
SR-8 DA59	-0.8	-1.7	1.4	0.0	0.0	0.0	0.0	-0.4
Total	***-16.0***	***9.5***	***114.3***	***-14.5***	***0.0***	***0.1***	***126.3***	***0.8***

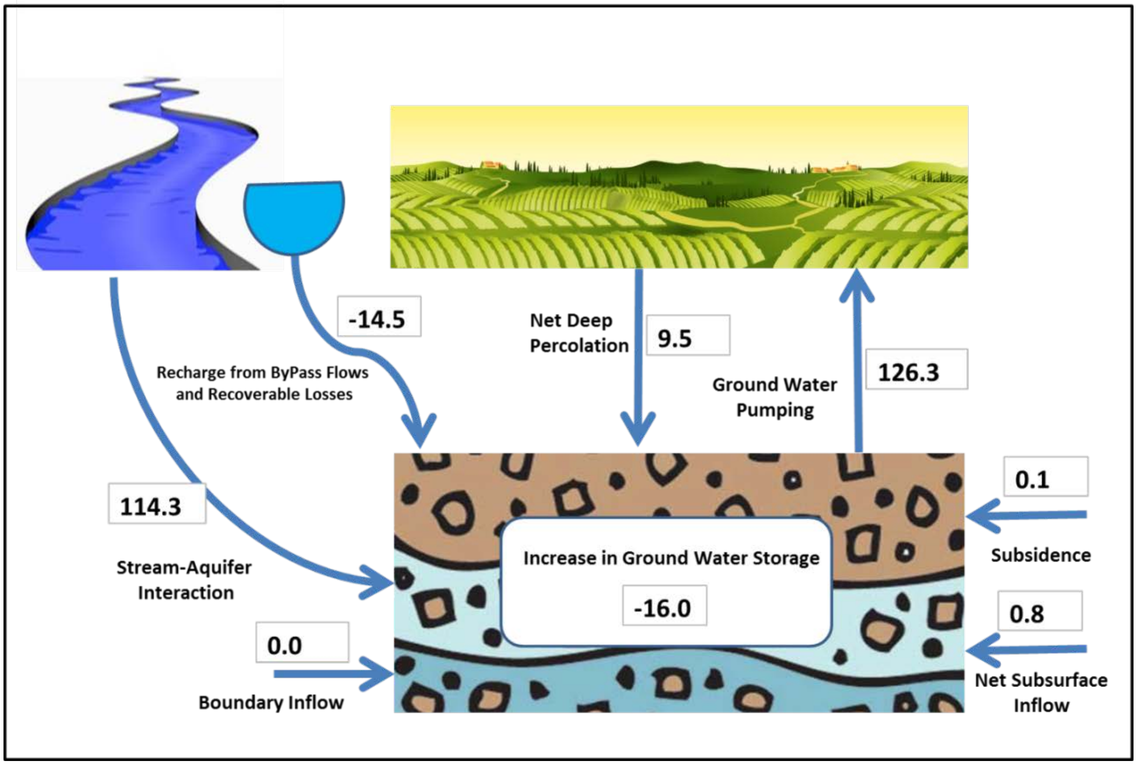


Figure 6-39: Difference in Average Annual WY1922-2003 Groundwater Budget Components (with Conjunctive Use minus Without Conjunctive Use) in TAF

What Table 6-28 and Figure 6-35 show are that the average annual groundwater pumping sources are mainly from increased seepage (114 TAF) and increased net deep percolation (10 TAF). The reduction in groundwater storage by 16 TAF is balanced out by the decrease in recharge and minor increases in net subsurface inflow and water release due to subsidence.

The analysis presented in this Section highlights the importance of using a model like CVSIM to analyze not only the intra-annual impacts of the project operation, but also the long term impacts including years when the conjunctive use project in not in operation (Wet years). Groundwater and surface water have long term and short term memory, respectively. This is a very important consideration in evaluating conjunctive use projects. In this case, if the project is implemented as planned it is unsustainable. Since typically transfer projects occur on a year by year basis, one approach is to apply the project one year at a time for every non-wet year of WY1922-2003, and use CVSIM to determine statistically from all the simulation runs what the expected project benefit would be.

6.3 Conclusions

This chapter applied the CVSIM model developed in Chapter 5 to two separate studies:

- a global warming study to determine impacts of changes in reservoir inflows (due to changes in outflow patterns from the upstream watersheds) and increases in water demands due to increases in temperature

- a conjunctive study to determine the impacts on Delta inflow due to cutbacks in surface water diversions and corresponding increases in groundwater pumping upstream of the Delta

The main conclusions drawn from the results of the global warming study are:

1. Increasing ambient temperatures increase the Total Supply Requirement (water demand for agricultural and urban needs to be supplies with surface water diversions or groundwater pumping) significantly throughout the Central Valley, and especially for heavily agricultural areas during the irrigation season (March through September). The marginal difference in increase for water between the Base Case and increase of 1^oC is reflected with each additional 1^oC increase.

2. Reservoir inflows increase in the fall and winter months and decrease in the spring and summer months. This reflects the chance in pattern for outflow from the upper watersheds flowing into the reservoirs. Marginal changes decrease with increasing temperature after 2^oC mainly due to the reduction in snowpack in the upper watersheds, leaving vegetative consumptive demands shorted.

3. Reservoir releases increase in winter months and decrease in summer months, reflecting the respective inflows patterns. The marginal changes decrease with increasing temperature similar to the inflows.

4. Exports from Banks and Jones pumping plants in the Delta decrease significantly during critical summer months, impacting deliveries south of the Delta

5. Delta outflow increases during winter months and decreases significantly during spring and summer months. This impacts reservoir operations to meet the higher priority Delta outflow regulatory standards rather than meeting the increase in water demands.

6. Surface water diversions increase, especially during the irrigation season. The marginal increase in diversions due to temperature rise is similar to that reflected in the Total Supply Requirement discussed in (1) above. The main increases are in the Sacramento Valley mainly because there is less water to export south of the Delta to both the San Joaquin and Tulare Basins.

7. Groundwater pumping increase significantly especially in the irrigation season. The marginal increase pattern is similar to that for the surface water diversions.

8. Groundwater storage increases in fall and winter months but decreases significantly in the spring and summer time. However, on an annual basis these is a net decrease, and the cumulative annual effect is continuous decline in storage reflecting the mining of the Central Valley groundwater storage; already a chronic problem in California historically.

The main conclusions from the conjunctive use study are:

1. For the operation months of June through September and operational years (non-Wet) when the conjunctive use project is in operation:

    a. The reduction in surface water diversions - equaled by an equal increase in groundwater pumping to meet the resulting shortage in supply - does not result in an equal increase in Delta inflow, which was the main objective of the project. Instead only 21% of the reduction in surface diversions reaches the Delta.

    b. The reduction in Delta inflows observed in (a) is caused mainly by increased seepage from the channels to the ground water system upstream of the Delta, and modification of reservoir operations resulting in increases in Delta outflow. The Delta outflow regulatory standard for Delta outflow is already met, so the additional outflow is unused water (spills) that the projects cannot make use of under the assumptions of this study where target exports from the Delta were same.

2. Since the project is operating in 56 (non-Wet) of the 82 simulated years, there isn’t sufficient precipitation in the Wet years to recover the groundwater system. This leads to increased overdraft conditions complicating an already long-term overdraft condition in the Central Valley (mainly San Joaquin and Tulare Basins).

3. The source for increased ground water pumping for the conjunctive use project is mainly from stream seepage and increase in net deep percolation. In other words the increase in pumping can be interpreted as not “prime” water but rather “recycled” water within the system during the same time step.

4. The decrease in ground water storage is equal in magnitude to the decrease in recharge (this represents the seepage from by-pass flows and recoverable losses from delivery canals), and to a smaller extent from net subsurface inflow (to the Sacramento Valley) and increased subsidence (due to increased pumping).

Both studies highlight the importance of using CVSIM to determine impacts on reservoir operations, Delta inflow, Delta outflow, Delta exports, and changes to streamflow regimes and groundwater storage.

CVSIM is an important contribution to the science of modeling complex water resources systems. CVSIM combines the hydrology development and enhancement (through ANN adjustments), a physically based simulation model (C2VSIM) for routing the water and simulating both surface water and groundwater, and a systems model to compute surface water diversions and groundwater pumping while meeting water demand and meeting operational and institutional constraints for protecting the environment.

Chapter 7 Conclusions, Insights, and Recommendations For Future Work

This dissertation examined the integration of an integrated hydrological simulation model IWFM, and systems or reservoir operation and allocation model WRIMS and associated hydrology for solving complex water resources systems. In Chapter 2 the integrated hydrological model IWFM as applied to California's complex Central Valley C2VSIM was used as an example. Chapter 2 introduced the idea of the "Adjustments" to sub-regional stream outflows, which represent the difference between the simulation sub-regional outflows and observed or gaged outflows. The historical run of C2VSIM for WY1922-2003 was used to compute the sub-regional stream adjustments in seven stages to ensure that the adjustments were a reflection of the sub-region hydrology only, and not outside factors (e.g., inflows to the sub-region). The long term WY1922-2003 cumulative impact of not including the adjustments affects inflows by nearly two million acre-feet. In Chapter 3 the concept of estimating the sub-regional "Adjustments" by relating it to water budget components within the sub-region was introduced. A methodology was presented and applied to estimate the sub-regional adjustments as a function of 14 different hydrological components computed within the model using Artificial Neural Networks. Modifications to the IWFM code included both integration of the ANN module to compute the adjustments dynamically, and also the dynamic simulation of the By-Pass spills on the Sacramento River (Moulton-Tisdale-Colusa, Fremont, and Sacramento). Chapter 4 developed the projected land use development level run of C2VSIM using the modified IWFM of Chapter 3 showing the long term WY1922-2003 average annual impact of not including the adjustments at nearly 217 TAF to Delta inflow. Chapter 5 presented the development of a simplified representation of the complex SWP/CVP systems (SIM2) using the generic WRIMS tool. Chapter 5 also presented how both SIM2 and C2VSIM (projected level) are combined into CVSIM such that all the routing of water is done by C2VSIM, and the reservoir operations and estimation of surface water diversions and groundwater pumping are done by SIM2. The iterative algorithm of CVSIM was used to prepare a base case scenario for the next chapter. Chapter 6 concluded this research by using the CVSIM model developed in Chapter 5 to analyze two different applications in California; a global warming sensitivity analysis, and conjunctive use / water transfer study. The global warming sensitivity analysis focused on impacts increased temperatures in the upper watersheds on inflows to Shasta, Oroville, and Folsom reservoirs and increased land use based water demands due to increased ETc values, on system results including reservoir releases, exports, Delta outflow, surface water diversions, groundwater pumping, and groundwater storage.

The main insights from this research are:

1. ANNs: In addition to improving simulated sub-region outflows at projected levels of development, the ANN's also identified and ranked the important hydrological components affecting computing those adjustments. These components such as surface water diversions, stream-aquifer interaction, sub-region inflows, and runoff, which vary

by type and ranked importance by sub-region, can be the focus of additional work to improve both the simulation of the physical processes and calibration in C2VSIM.

2. CVSIM: The combined system model (SIM2) and simulation model (C2VSIM) as one tool (CVSIM) produced results for a projected level run that were very comparable to the more complicated (system representation and operating rules) CalSim-II model used by CDWR. The comparisons with CalSim-II included inflow and outflow from the Delta, exports from the Delta, California Aqueduct exports to Southern California, and groundwater pumping.

3. Global Warming Study: Increasing ambient temperatures have significant impacts on both increasing water demands and the availability and timing of water supplies to meet these demands. Demands increase with increasing temperature at a rate of approximately 4% per 1^{o}C rise relative to the Base Case. Also, available surface water supplies are less because of the shift from spring and summer to fall and winter in outflows from the upper watersheds. There is less water to divert from streams and to export from the Delta, and increased reliance on groundwater pumping which compounds the already declining groundwater storage conditions in the Central Valley. Surface reservoirs will need to modify their operations (including flood diagrams) to better capture the fall and winter additional flows and modify storage operations to meet downstream demands, exports, and Delta standards. Other mitigating alternatives include increased re-use of water in agriculture, improved irrigation practices, shift to crops requiring less water to grow, reduction in urban demands, and increased use of conjunctive projects.

4. Conjunctive Use Study: The conjunctive use study under the proposed operating criteria is neither effective (decreasing surface water diversions results in not equal increases to Delta inflow) nor sustainable (continuous decrease in groundwater storage over time). The first concern can be addressed with more refined modeling to address the seepage issue discussed earlier. The second concern can be improved with modifying the operational criteria of the project; for example, operate only in Dry and Critical years to allow recovery during Wet, Above Normal, Below Normal classified years. It is important for the success of the project that the natural recharge during non-operating periods allows for recovery of the groundwater system.

The following are recommendations for future work:

1. Modify the stream adjustments module using ANN by including other sub-regional parameters such as deep percolation / recharge to groundwater, sub-region average groundwater elevation or groundwater storage. Note: Use of ANN assumes that a comprehensive calibration of C2VSIM has been completed. As this research showed, stream-aquifer interaction is a key factor in modeling streamflow, and more effort should be spent on better simulating it, and understanding the associated flow driving forces such as vertical and horizontal gradients.

2. Integrate economics with IWFM to dynamically estimate the upcoming water year land use based on the current year's status of the surface water and groundwater systems. In California for example with the precipitation season being October through March, a good estimate of the future surface water supply is usually known with a reliable degree by January of that water year (prior to the irrigation season). Coupling that with current status of groundwater elevations at the beginning of the water year one can either link an economics driven model like SWAP, or imbed SWAP's emulation using Logit Functions (Dale et. al. 2013) in IWFM to estimate next year's crop mix.

3. Researching use of CVSIM for a variety of applications, including:

    a. SGMA planning studies by include triggers within C2VSIM to mitigate a combination of the negative impacts identified to ensure sustainability.

    b. CVP/SWP planning studies at the screening level similar to CalLite, where use of stochastic hydrologies (e.g, for climate change studies) are feasible with current computer technology.

    c. Enhance CVSIM representation and operating rules and criteria for use in planning studies similar to CalSim.

    d. Using the daily version of IWFM - including the newly developed stream routing module to use for short term or medium term forecasting for real time operations of the CVP/SWP systems.

4. Use the research of this dissertation as a basis for emulating C2VSIM entirely and embed the developed modules in other systems models including CalSim, CALVIN, and WEAP applications.

5. Integrate CVSIM with upper watershed models like SWAT which would allow for estimating impacts on watershed outflows due to changes like global warming or upstream development, which affect surface inflows to reservoirs and simulated streams without reservoirs, and subsurface inflow at the C2VSIM boundary.

Computerized mathematical modeling is on the path integrating different disciplines to provide more sophisticated and reliable tools including hydrology, simulation, systems, and environmental. A new dimension that is being considered is including sociological and societal as well, generally termed socio-hydrology (Davies and Simonovic 2011, Sivapalan et. al. 2012, Lund 2015, Loucks 2015, Montanari 2015, and Troy et. al. 2015). With better understanding of human factors, and more powerful computing technologies, this may lead to a more holistic approach to modeling in the future.

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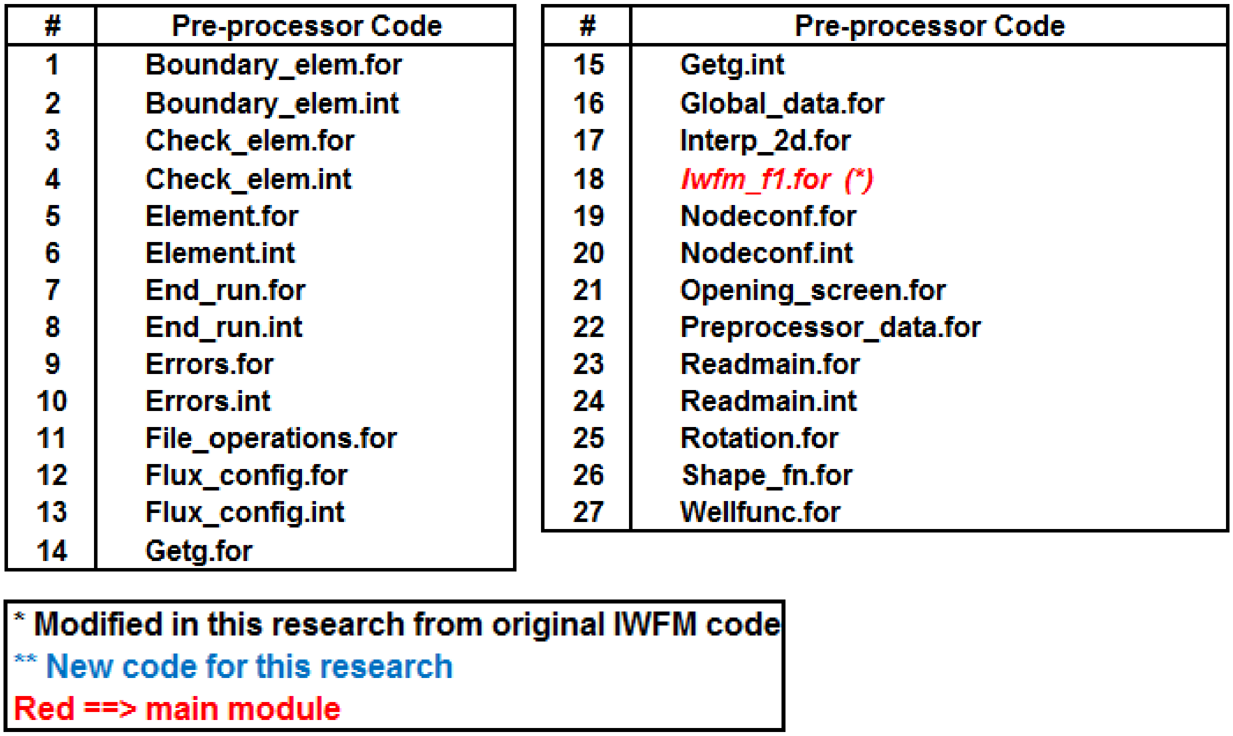
Appendix A. IWFM v2.4.1 FORTRAN Source Code File Names

There are three IWFM executables used in this research:

1. Pre-processor: Processes the non-time series data including geometry (grid) and stratigraphy. The associated Fortran code file names appear in Table A-1. The main file for compilation “Iwfm_f1.for” was modified for this research. Total lines of code are approximately 4,450.

Table A-1. IWFM "Preprocessor" Fortran Code Files



#	Pre-processor Code
1	Boundary_elem.for
2	Boundary_elem.int
3	Check_elem.for
4	Check_elem.int
5	Element.for
6	Element.int
7	End_run.for
8	End_run.int
9	Errors.for
10	Errors.int
11	File_operations.for
12	Flux_config.for
13	Flux_config.int
14	Getg.for
15	Getg.int
16	Global_data.for
17	Interp_2d.for
18	*Iwfm_f1.for (*)*
19	Nodeconf.for
20	Nodeconf.int
21	Opening_screen.for
22	Preprocessor_data.for
23	Readmain.for
24	Readmain.int
25	Rotation.for
26	Shape_fn.for
27	Wellfunc.for

* Modified in this research from original IWFM code
** New code for this research
Red ==> main module

2. Simulation: Processes the time series data. The associated Fortran codes file names appear in Table A-2. The main file for compilation “Iwfm_f2_ExtraOutput” (renamed from the original “Iwfm_f2.for” , and “Gettsd.for” were modified for this research. Also three new code modules were programmed for this research to simulate ANN: “ANNadd.for”, “ANNcompute.for”, and “ANNtoNodes.for”. Total lines of code are approximately 17,600.

Table A-2. IWFM "Simulation" Fortran CodeFiles

#	Simulation Code	#	Simulation Code	#	Simulation Code
1	Adjland.for	36	Flow_ids.for	71	Nodal_diversion.int
2	Adjland.int	37	Flow_ids.int	72	Opening_screen.for
3	Adjust_supply.for	38	Fpe_check.for	73	Outbud.for
4	Adjust_supply.int	39	Fpe_check.int	74	Outbud.int
5	ANNadd.for (**)	40	Gener.for	75	Outfile.for
6	ANNcompute.for (**)	41	Gener.int	76	Outfile.int
7	ANNsubtract.for (**)	42	Getgd.for	77	Output.for
8	ANNtoNodes.for (**)	43	Getgd.int	78	Output.int
9	Aquifer.for	44	Getpar.for	79	Pump_dist.for
10	Aquifer.int	45	Getpar.int	80	Pump_dist.int
11	Array_allocate.for	46	Gettsd.for (*)	81	Readcd.for
12	Array_allocate.int	47	Gettsd.int	82	Readcd.int
13	Bound.for	48	Global_data.for	83	Report_arrays.for
14	Bound.int	49	Gw_depth.for	84	Report_arrays.int
15	Boundary_flow.for	50	Gw_depth.int	85	Rotation.for
16	Boundary_flow.int	51	Gw_source.for	86	RunoffInfiltration_SCSMethod.f90
17	Check_elem.for	52	Gw_source.int	87	Shape_fn.for
18	Check_elem.int	53	Gwstorage.for	88	Simresult.for
19	Confile.for	54	Gwstorage.int	89	Simresult.int
20	Confile.int	55	Initial.for	90	Simulation_data.for
21	Convergence.for	56	Initial.int	91	Soilmag.f90
22	Convergence.int	57	Initialize.for	92	Solve.for
23	CUAW.for	58	Initialize.int	93	Solve.int
24	CUAW.int	59	Interface_f2.int	94	SOR.for
25	Delivery_rank.for	60	Interp_1d.for	95	SOR.int
26	Delivery_rank.int	61	Interp_1d.int	96	Spcfile.for
27	Demand.for	62	Interp_2d.for	97	Spcfile.int
28	Demand.int	63	*Iwfm_f2_ExtraOutput.for (*)*	98	Stream.for
29	End_run.for	64	Lake.for	99	Stream.int
30	End_run.int	65	Lake.int	100	Supply.for
31	Errors.for	66	Lubksb.for	101	Supply.int
32	Errors.int	67	Ludcmp.for	102	Surface.for
33	Face_flow.for	68	Nflow.for	103	Surface.int
34	Face_flow.int	69	Nflow.int	104	Tsdfile.for
35	File_operations.for	70	Nodal_diversion.for	105	Tsdfile.int

3. Budget: A post-processor to report all the different types of water budgets from the simulation process. The associated Fortran code file names appear in Table A-3. The main file for compilation "Budget.for" was modified for this research. Total lines of code are approximately 1,280.

Table A-3. IWFM "Budget" Fortran Code Files

#	Code component
1	*Budget.for (*)*
2	Budget_data.for

Appendix B. ANN Results for C2VSIM Sub-regions

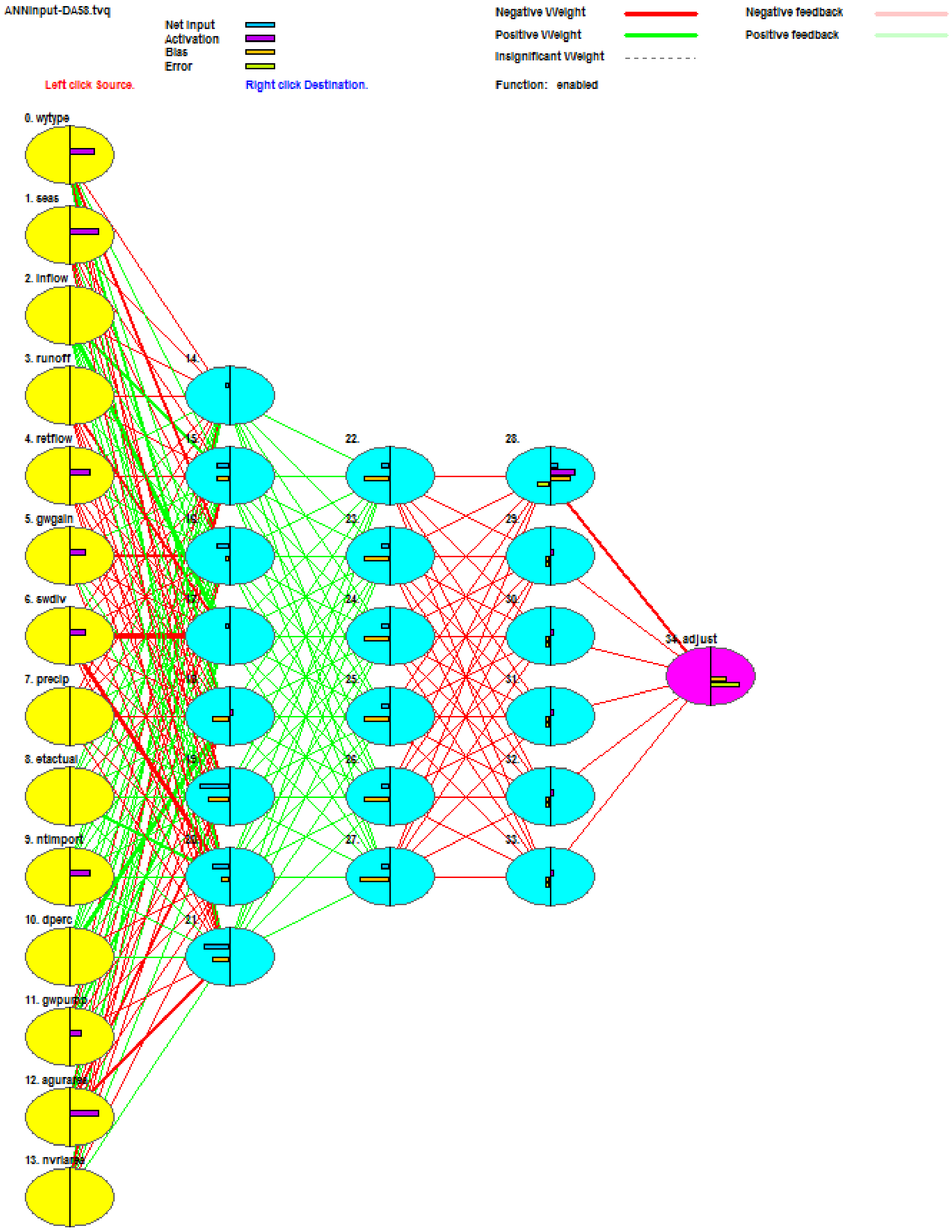
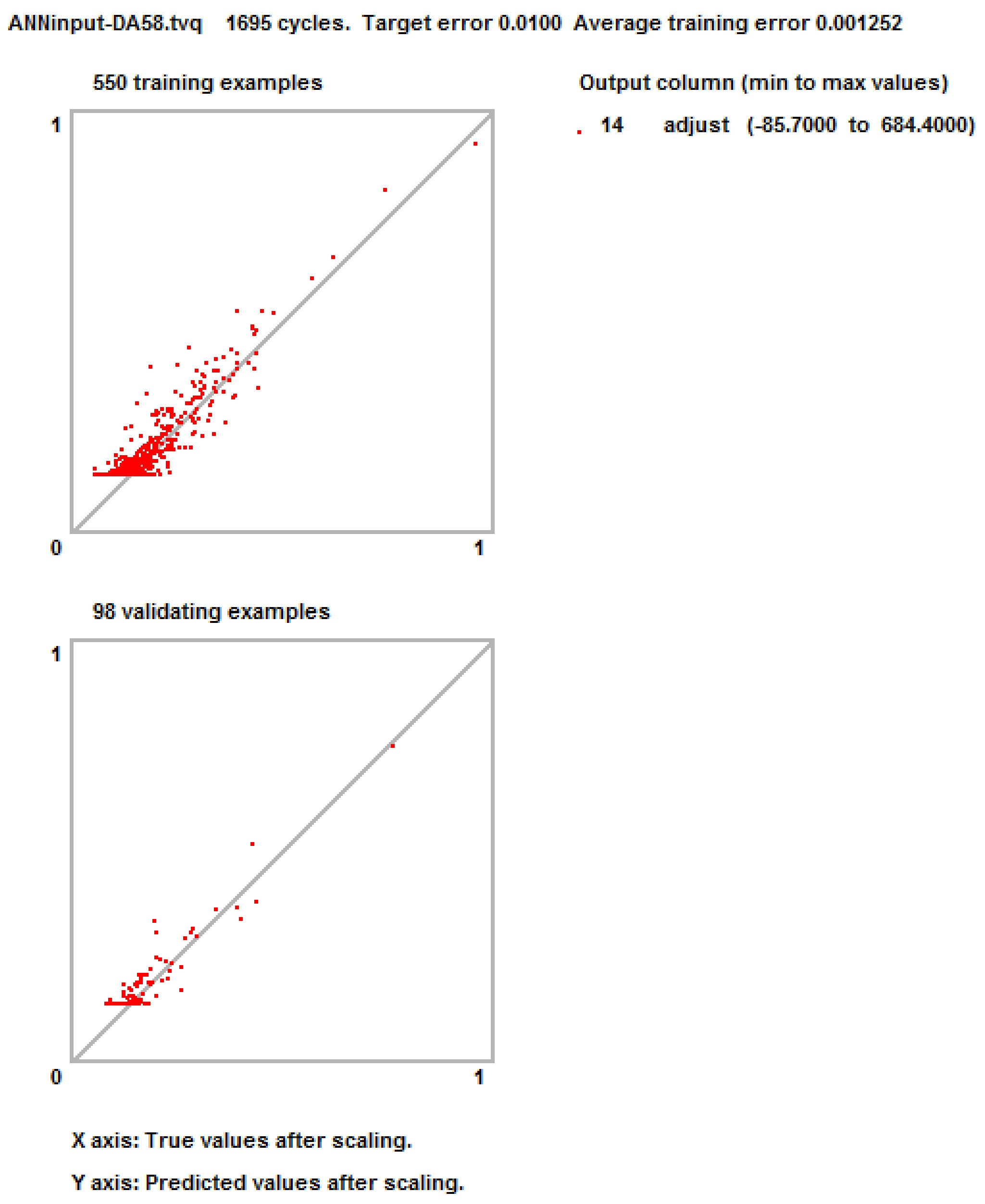


Figure A-1: ANN Architecture for SR-1 (DA58)



ANNinput-DA58.tvq 1695 cycles. Target error 0.0100 Average training error 0.001252

550 training examples

Output column (min to max values)

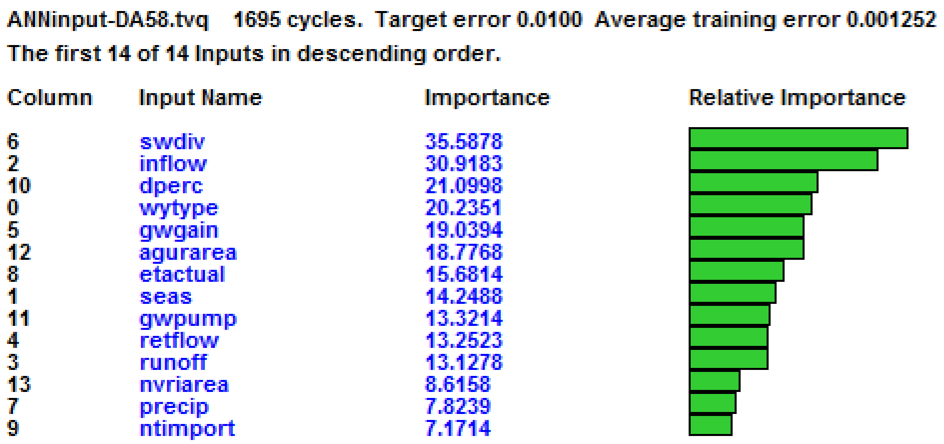
. 14 adjust (-85.7000 to 684.4000)

98 validating examples

X axis: True values after scaling.

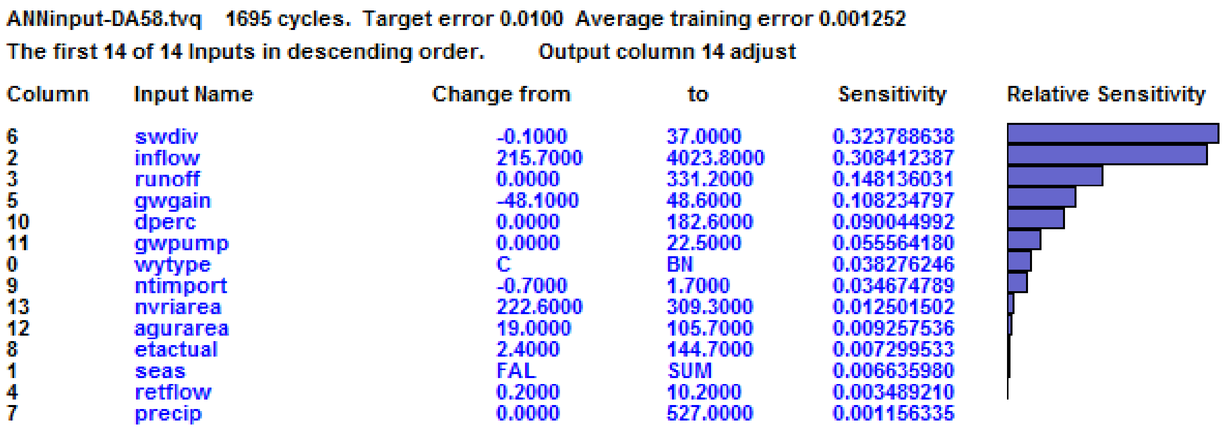
Y axis: Predicted values after scaling.

Figure A-2: Scatter Diagrams of the ANN Results for SR-1 (DA58)



```
ANNinput-DA58.tvq    1695 cycles.  Target error 0.0100  Average training error 0.001252
The first 14 of 14 Inputs in descending order.

Column        Input Name              Importance           Relative Importance

6             swdiv                   35.5878
2             inflow                  30.9183
10            dperc                   21.0998
0             wytype                  20.2351
5             gwgain                  19.0394
12            agurarea                18.7768
8             etactual                15.6814
1             seas                    14.2488
11            gwpump                  13.3214
4             retflow                 13.2523
3             runoff                  13.1278
13            nvriarea                8.6158
7             precip                  7.8239
9             ntimport                7.1714
```

Figure A-3: Relative Importance of the Input Variables in ANN for SR-1 (DA58)



```
ANNinput-DA58.tvq    1695 cycles.  Target error 0.0100  Average training error 0.001252
The first 14 of 14 Inputs in descending order.       Output column 14 adjust

Column       Input Name             Change from        to           Sensitivity        Relative Sensitivity

6            swdiv                     -0.1000         37.0000      0.323788638
2            inflow                    215.7000        4023.8000    0.308412387
3            runoff                    0.0000          331.2000     0.148136031
5            gwgain                    -48.1000        48.6000      0.108234797
10           dperc                     0.0000          182.6000     0.090044992
11           gwpump                    0.0000          22.5000      0.055564180
0            wytype                    C               BN           0.038276246
9            ntimport                  -0.7000         1.7000       0.034674789
13           nvriarea                  222.6000        309.3000     0.012501502
12           agurarea                  19.0000         105.7000     0.009257536
8            etactual                  2.4000          144.7000     0.007299533
1            seas                      FAL             SUM          0.006635980
4            retflow                   0.2000          10.2000      0.003489210
7            precip                    0.0000          527.0000     0.001156335
```

Figure A-4: Relative Sensitivity of the Input Variables in ANN for SR-1 (DA58)

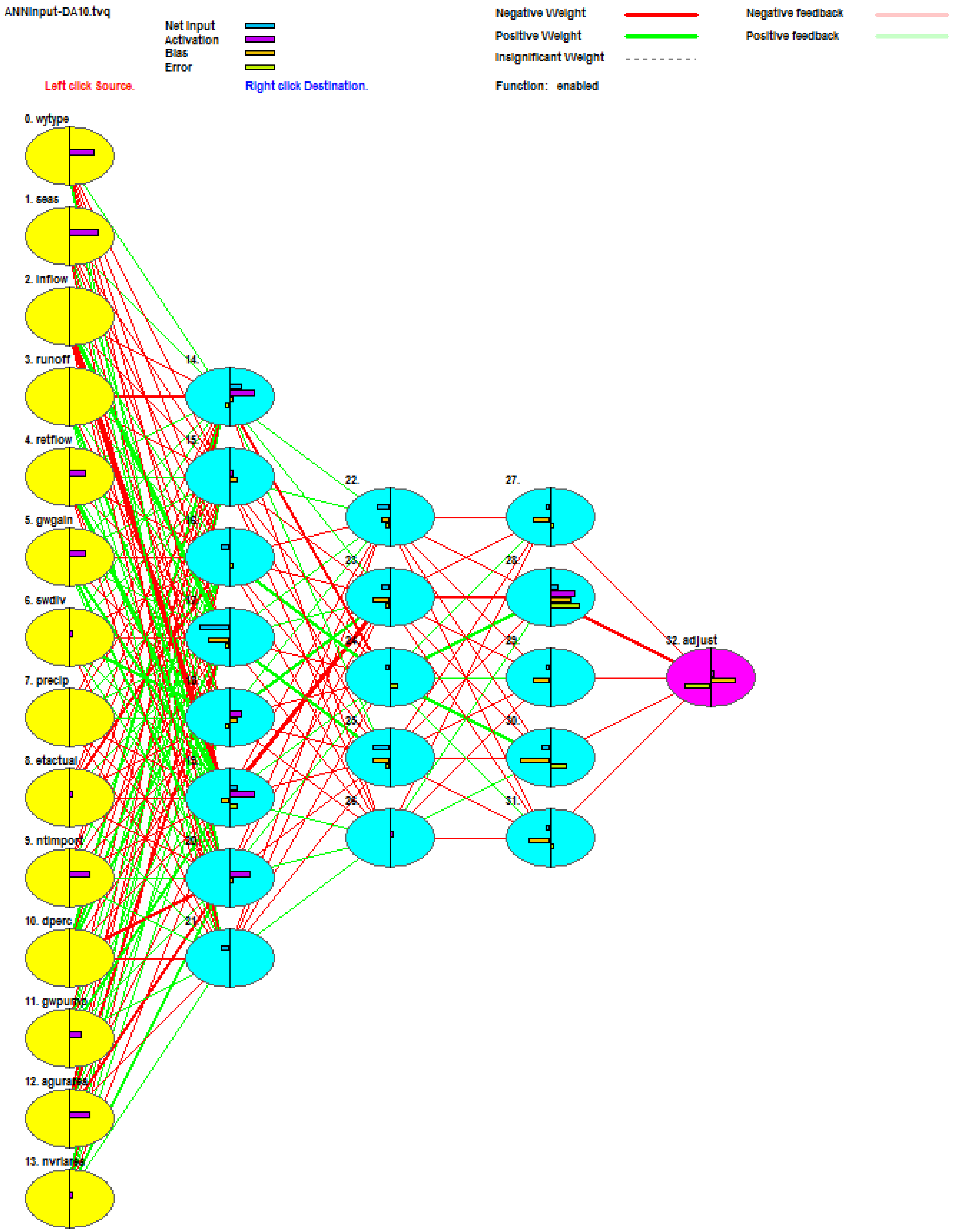
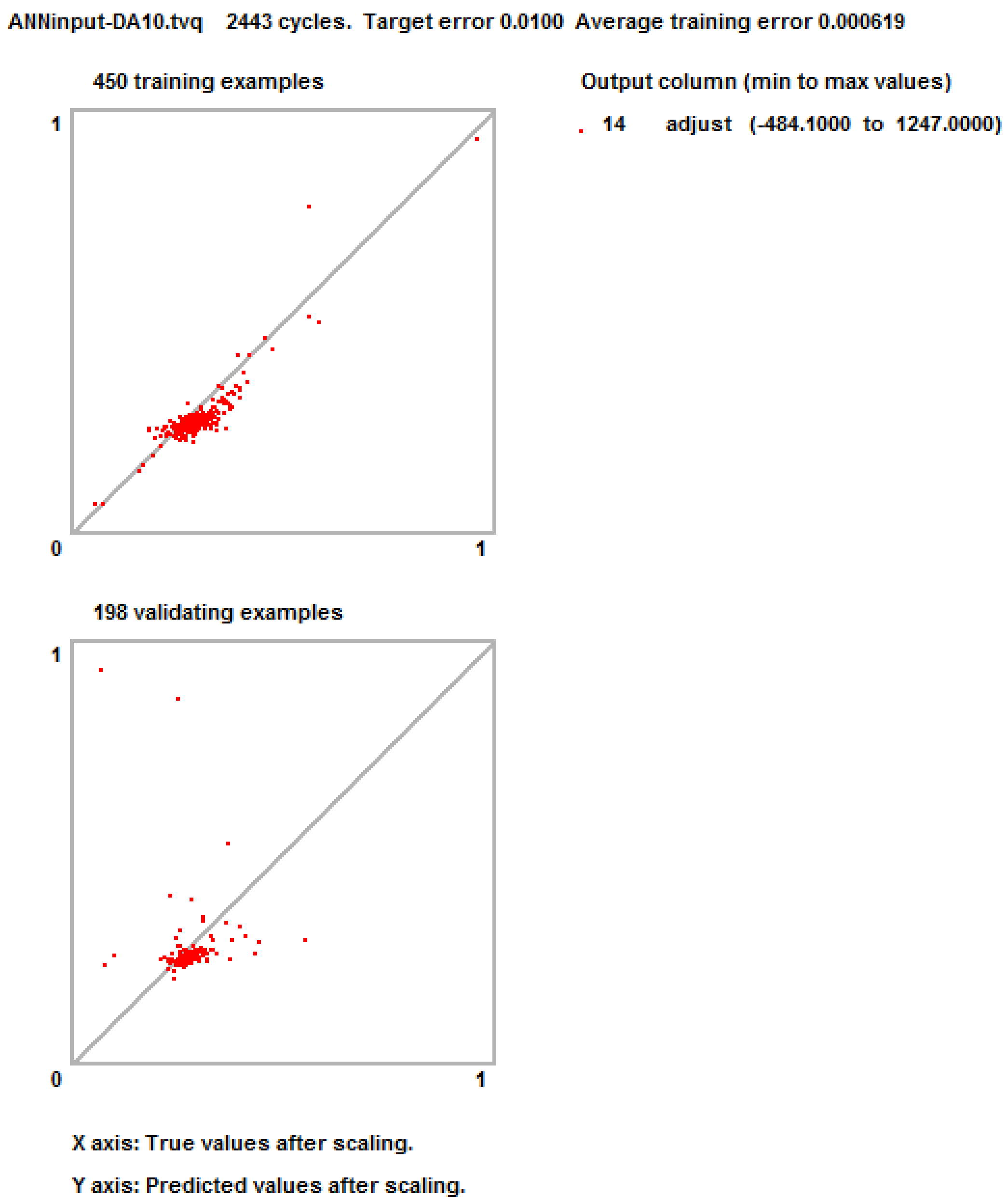


Figure A-5: ANN Architecture for SR-2 (DA10)



ANNinput-DA10.tvq   2443 cycles. Target error 0.0100 Average training error 0.000619

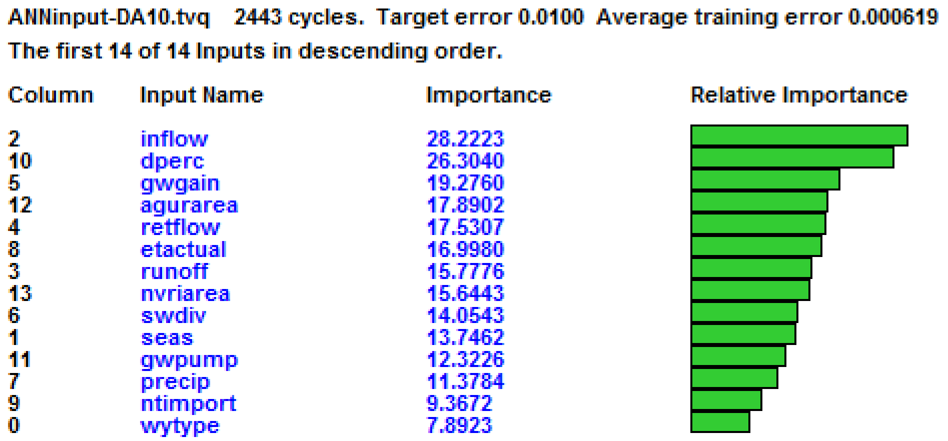
Output column (min to max values)

. 14   adjust (-484.1000 to 1247.0000)

X axis: True values after scaling.

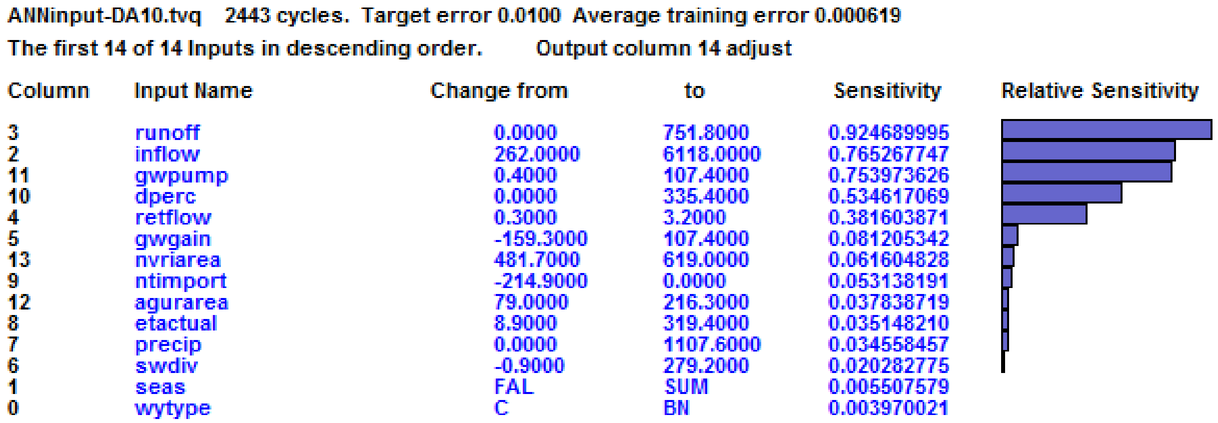
Y axis: Predicted values after scaling.

Figure A-6: Scatter Diagrams of the ANN Results for SR-2 (DA10)



```
ANNinput-DA10.tvq    2443 cycles.  Target error 0.0100  Average training error 0.000619
The first 14 of 14 Inputs in descending order.

Column     Input Name            Importance          Relative Importance

2          inflow                28.2223
10         dperc                 26.3040
5          gwgain                19.2760
12         agurarea              17.8902
4          retflow               17.5307
8          etactual              16.9980
3          runoff                15.7776
13         nvriarea              15.6443
6          swdiv                 14.0543
1          seas                  13.7462
11         gwpump                12.3226
7          precip                11.3784
9          ntimport              9.3672
0          wytype                7.8923
```

Figure A-7: Relative Importance of the Input Variables in ANN for SR-2 (DA10)



```
ANNinput-DA10.tvq    2443 cycles.  Target error 0.0100  Average training error 0.000619
The first 14 of 14 Inputs in descending order.        Output column 14 adjust

Column     Input Name            Change from       to            Sensitivity      Relative Sensitivity

3          runoff                     0.0000       751.8000      0.924689995
2          inflow                     262.0000     6118.0000     0.765267747
11         gwpump                     0.4000       107.4000      0.753973626
10         dperc                      0.0000       335.4000      0.534617069
4          retflow                    0.3000       3.2000        0.381603871
5          gwgain                     -159.3000    107.4000      0.081205342
13         nvriarea                   481.7000     619.0000      0.061604828
9          ntimport                   -214.9000    0.0000        0.053138191
12         agurarea                   79.0000      216.3000      0.037838719
8          etactual                   8.9000       319.4000      0.035148210
7          precip                     0.0000       1107.6000     0.034558457
6          swdiv                      -0.9000      279.2000      0.020282775
1          seas                       FAL          SUM           0.005507579
0          wytype                     C            BN            0.003970021
```

Figure A-8: Relative Sensitivity of the Input Variables in ANN for SR-2 (DA10)

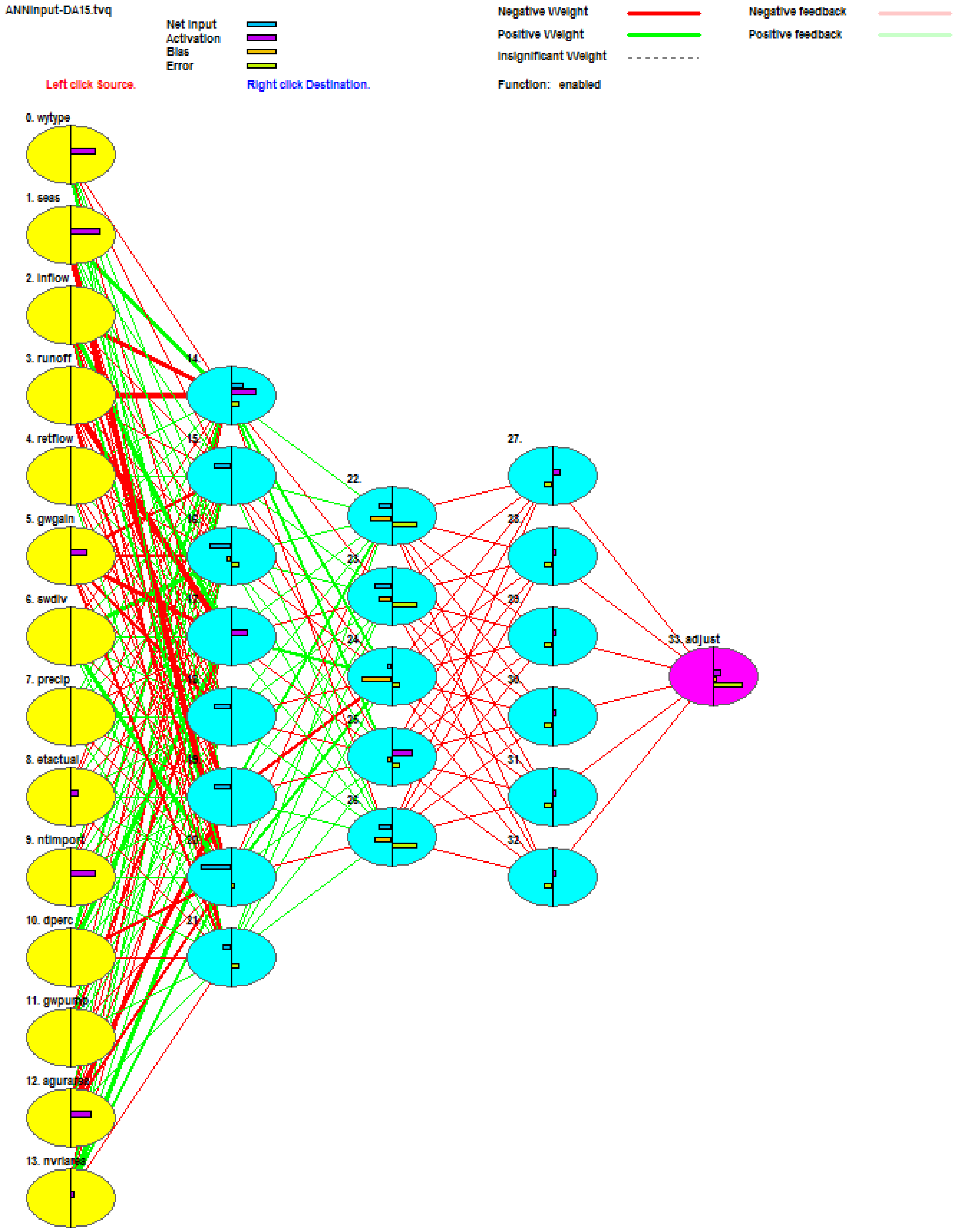
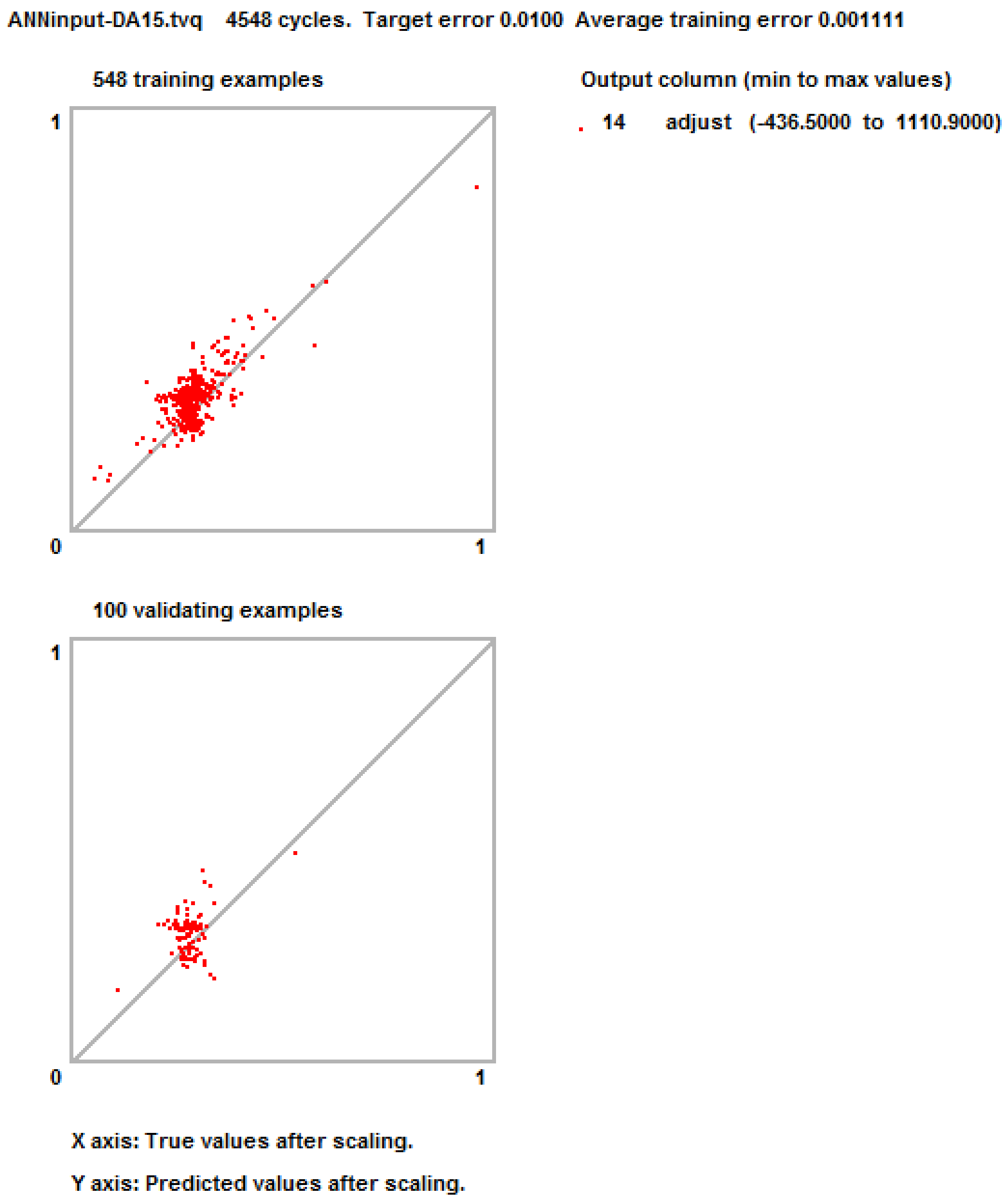


Figure A-9: ANN Architecture for SR-4 (DA15)


ANNinput-DA15.tvq 4548 cycles. Target error 0.0100 Average training error 0.001111

548 training examples

Output column (min to max values)

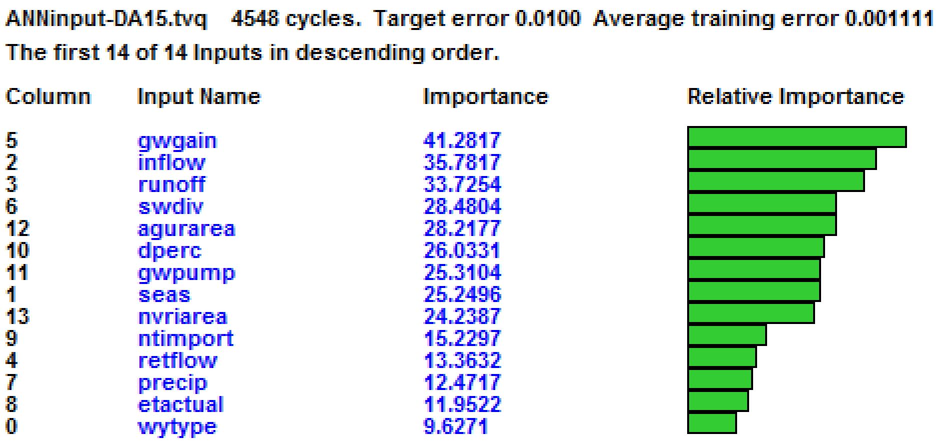
■ 14 adjust (-436.5000 to 1110.9000)

100 validating examples

X axis: True values after scaling.

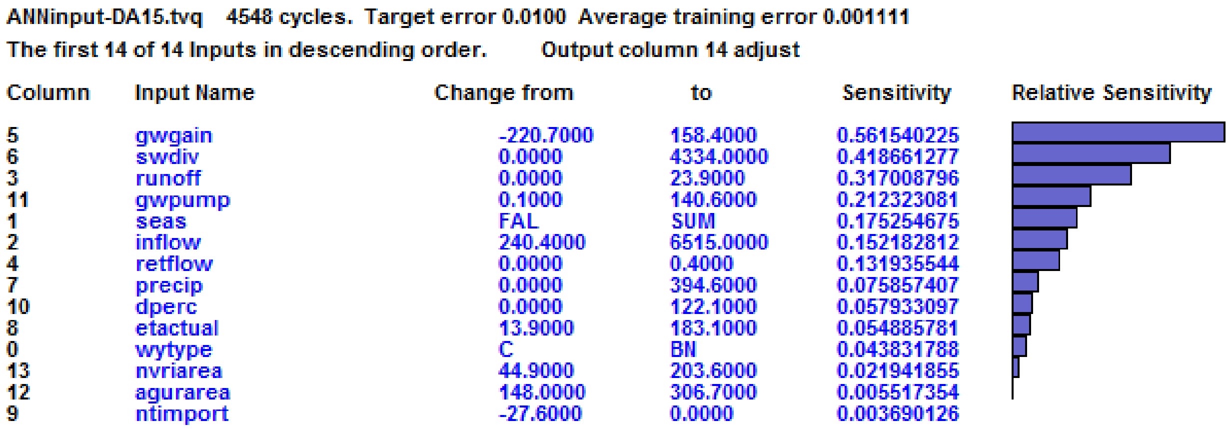
Y axis: Predicted values after scaling.

Figure A-10: Scatter Diagrams of the ANN Results for SR-4 (DA15)



```
ANNinput-DA15.tvq   4548 cycles.  Target error 0.0100  Average training error 0.001111
The first 14 of 14 Inputs in descending order.

Column      Input Name              Importance          Relative Importance

5           gwgain                  41.2817
2           inflow                  35.7817
3           runoff                  33.7254
6           swdiv                   28.4804
12          agurarea                28.2177
10          dperc                   26.0331
11          gwpump                  25.3104
1           seas                    25.2496
13          nvriarea                24.2387
9           ntimport                15.2297
4           retflow                 13.3632
7           precip                  12.4717
8           etactual                11.9522
0           wytype                  9.6271
```

Figure A-11: Relative Importance of the Input Variables in ANN for SR-4



```
ANNinput-DA15.tvq   4548 cycles.  Target error 0.0100  Average training error 0.001111
The first 14 of 14 Inputs in descending order.      Output column 14 adjust

Column      Input Name          Change from         to          Sensitivity     Relative Sensitivity

5           gwgain              -220.7000       158.4000        0.561540225
6           swdiv               0.0000          4334.0000       0.418661277
3           runoff              0.0000          23.9000         0.317008796
11          gwpump              0.1000          140.6000        0.212323081
1           seas                FAL             SUM             0.175254675
2           inflow              240.4000        6515.0000       0.152182812
4           retflow             0.0000          0.4000          0.131935544
7           precip              0.0000          394.6000        0.075857407
10          dperc               0.0000          122.1000        0.057933097
8           etactual            13.9000         183.1000        0.054885781
0           wytype              C               BN              0.043831788
13          nvriarea            44.9000         203.6000        0.021941855
12          agurarea            148.0000        306.7000        0.005517354
9           ntimport            -27.6000        0.0000          0.003690126
```

Figure A-12: Relative Sensitivity of the Input Variables in ANN for SR-4 (DA15)

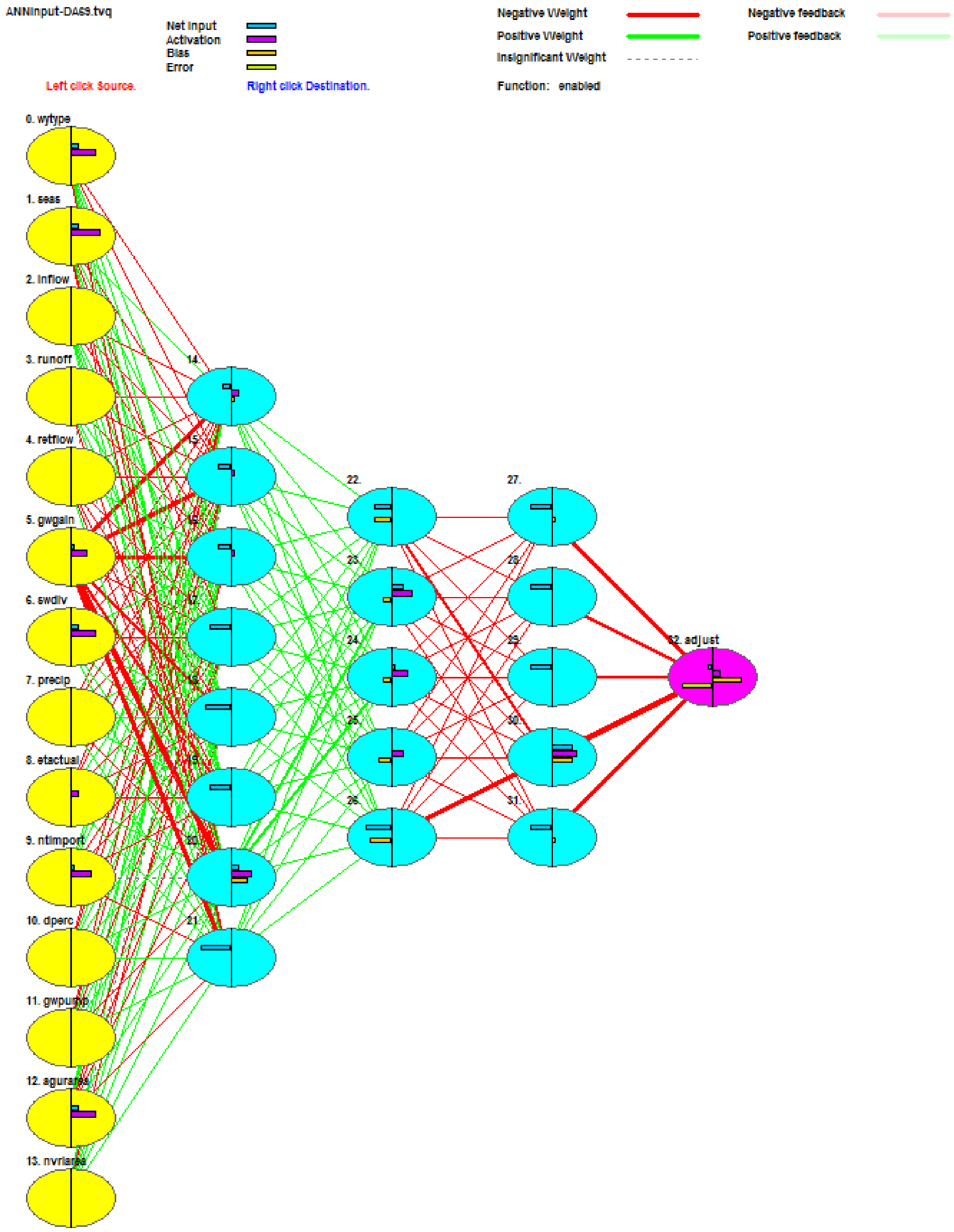
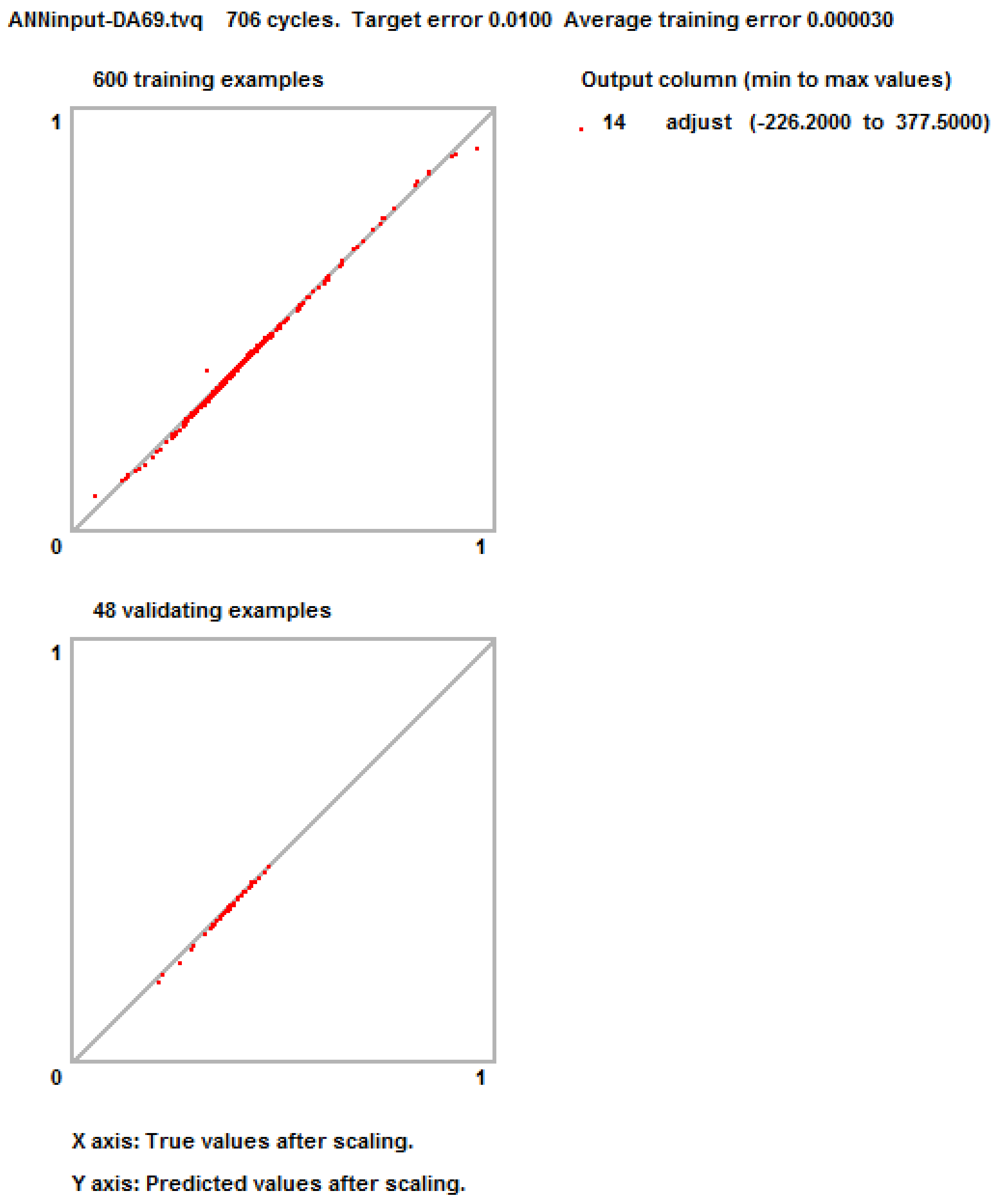
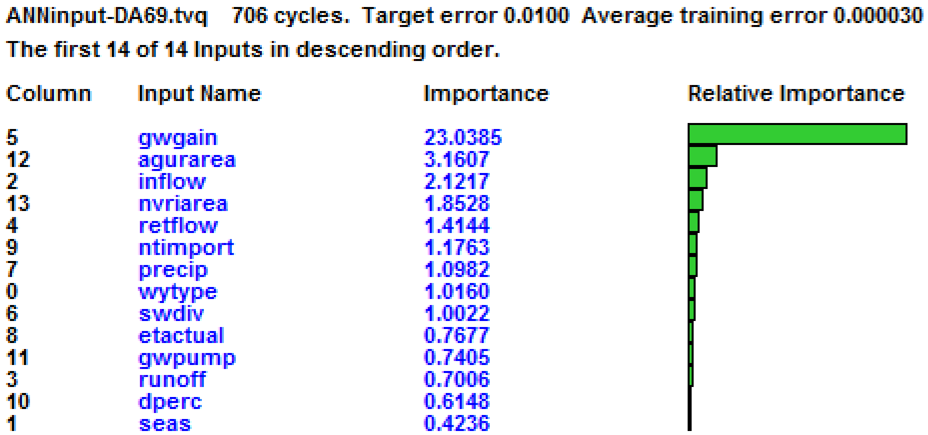


Figure A-13: ANN Architecture for SR-5 (DA69)



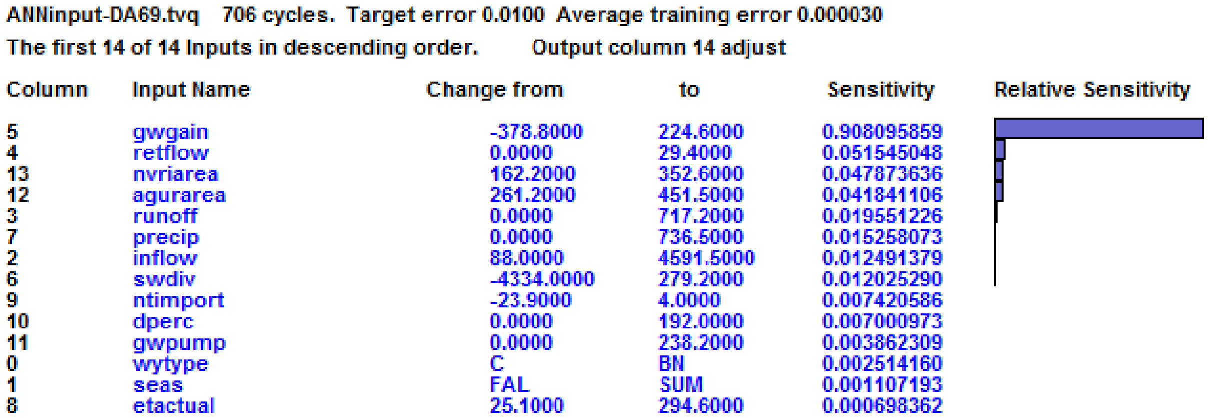
```
ANNinput-DA69.tvq    706 cycles.  Target error 0.0100  Average training error 0.000030

Output column (min to max values)
•  14      adjust   (-226.2000  to  377.5000)

X axis: True values after scaling.
Y axis: Predicted values after scaling.
```

Figure A-14: Scatter Diagrams of the ANN Results for SR-5 (DA69)



```
ANNinput-DA69.tvq    706 cycles.  Target error 0.0100  Average training error 0.000030
The first 14 of 14 Inputs in descending order.

Column      Input Name              Importance          Relative Importance

5           gwgain                  23.0385
12          agurarea                3.1607
2           inflow                  2.1217
13          nvriarea                1.8528
4           retflow                 1.4144
9           ntimport                1.1763
7           precip                  1.0982
0           wytype                  1.0160
6           swdiv                   1.0022
8           etactual                0.7677
11          gwpump                  0.7405
3           runoff                  0.7006
10          dperc                   0.6148
1           seas                    0.4236
```

Figure A-15: Relative Importance of the Input Variables in ANN for SR-5



```
ANNinput-DA69.tvq    706 cycles.  Target error 0.0100  Average training error 0.000030
The first 14 of 14 Inputs in descending order.      Output column 14 adjust

Column      Input Name              Change from      to           Sensitivity      Relative Sensitivity

5           gwgain                  -378.8000        224.6000     0.908095859
4           retflow                 0.0000           29.4000      0.051545048
13          nvriarea                162.2000         352.6000     0.047873636
12          agurarea                261.2000         451.5000     0.041841106
3           runoff                  0.0000           717.2000     0.019551226
7           precip                  0.0000           736.5000     0.015258073
2           inflow                  88.0000          4591.5000    0.012491379
6           swdiv                   -4334.0000       279.2000     0.012025290
9           ntimport                -23.9000         4.0000       0.007420586
10          dperc                   0.0000           192.0000     0.007000973
11          gwpump                  0.0000           238.2000     0.003862309
0           wytype                  C                BN           0.002514160
1           seas                    FAL              SUM          0.001107193
8           etactual                25.1000          294.6000     0.000698362
```

Figure A-16: Relative Sensitivity of the Input Variables in ANN for SR-5 (DA69)

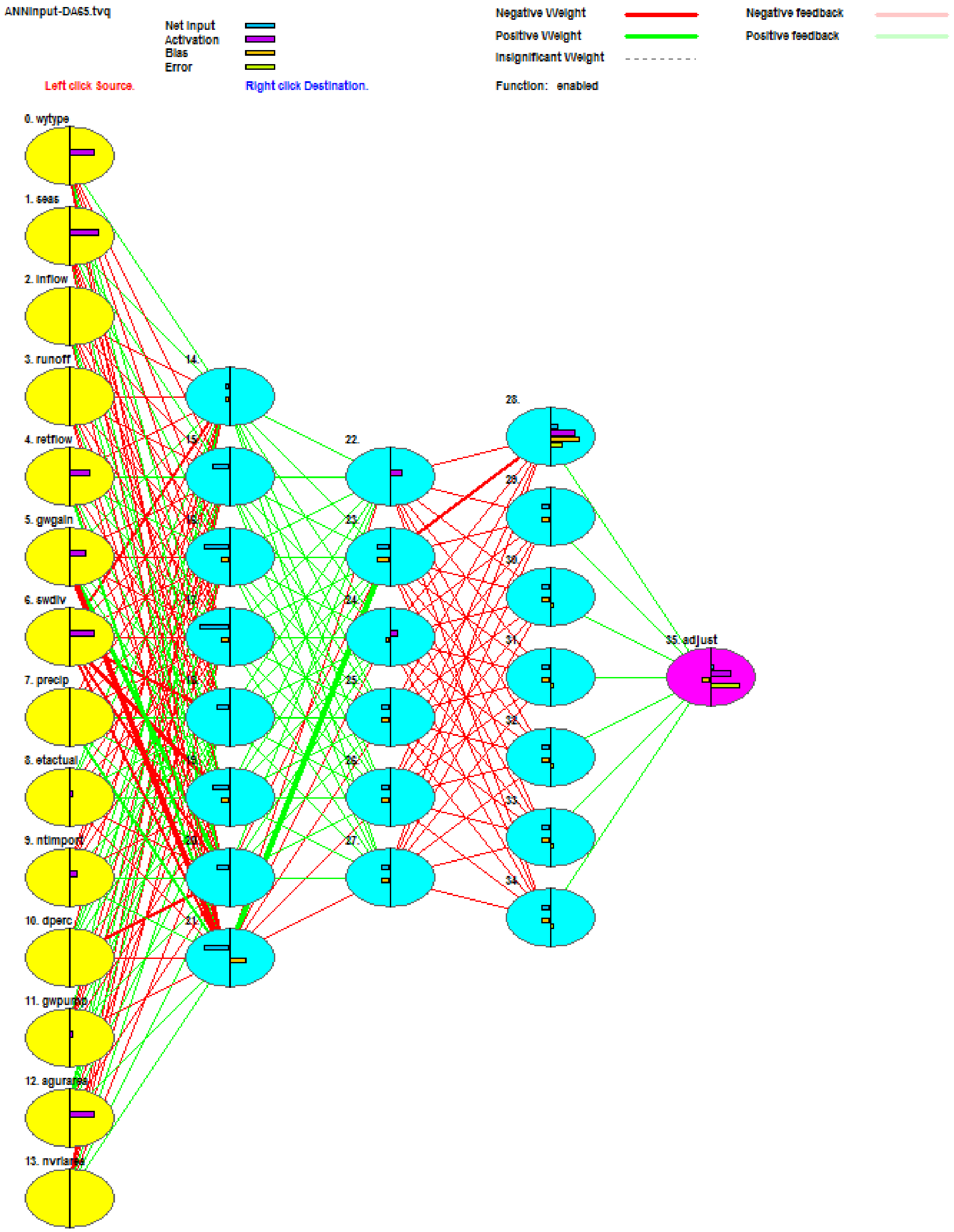
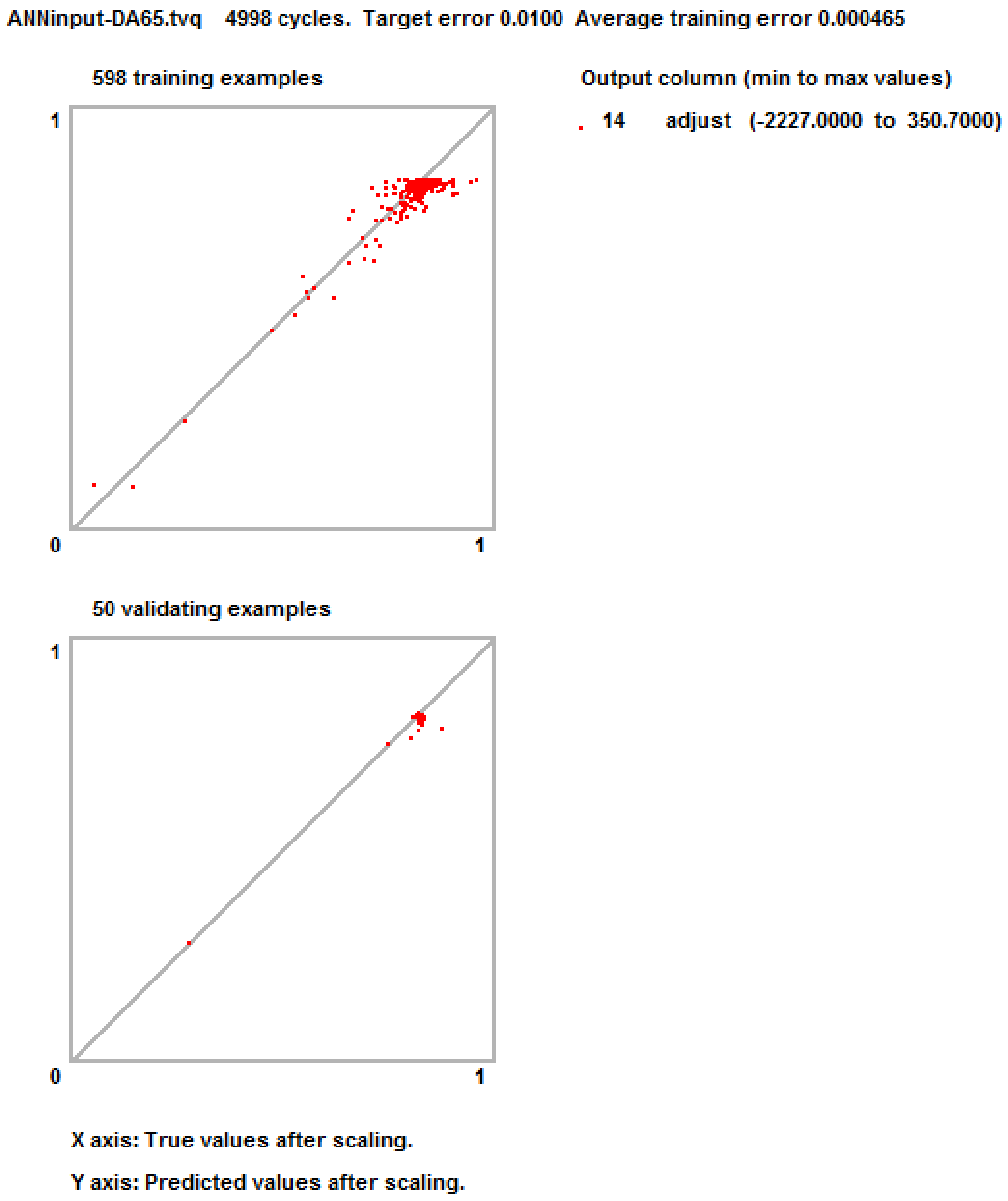


Figure A-17: ANN Architecture for SR-6 (DA65)



ANNinput-DA65.tvq 4998 cycles. Target error 0.0100 Average training error 0.000465

598 training examples

Output column (min to max values)

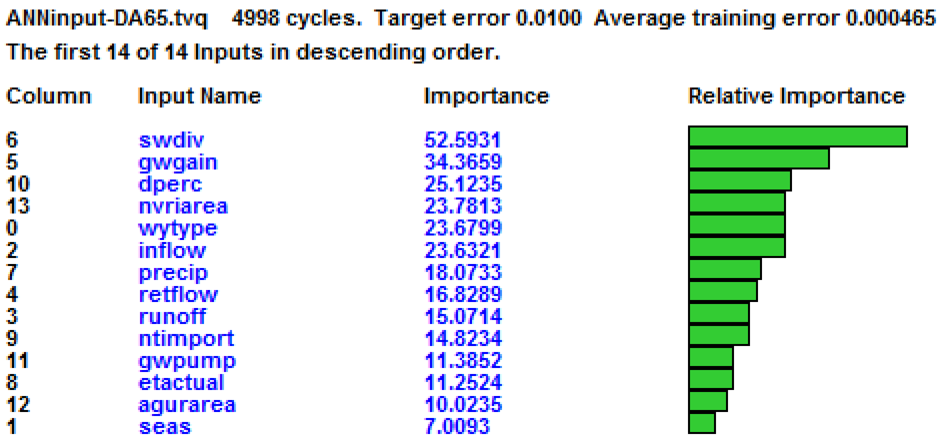
14 adjust (-2227.0000 to 350.7000)

50 validating examples

X axis: True values after scaling.

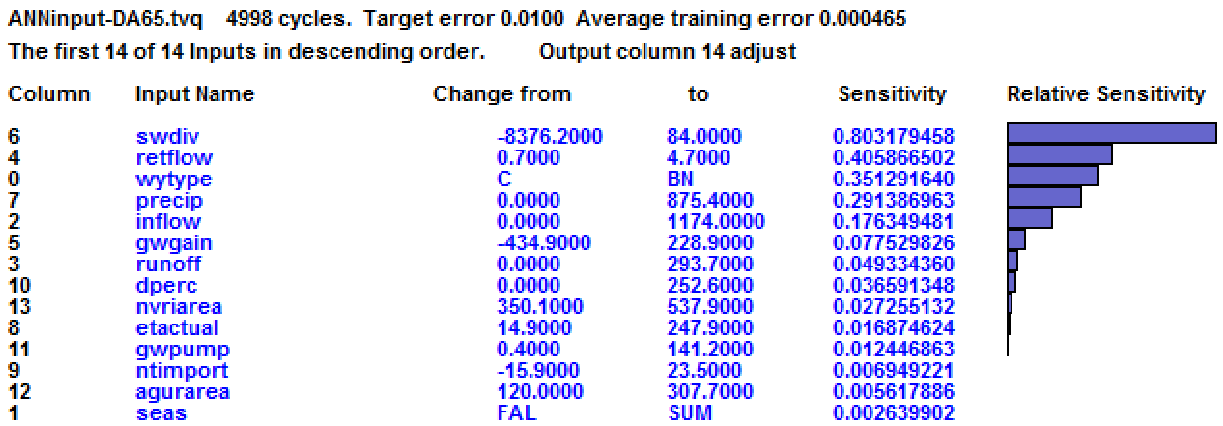
Y axis: Predicted values after scaling.

Figure A-18: Scatter Diagrams of the ANN Results for SR-6 (DA65)



```
ANNinput-DA65.tvq    4998 cycles.  Target error 0.0100  Average training error 0.000465
The first 14 of 14 Inputs in descending order.

Column     Input Name            Importance          Relative Importance

6          swdiv                 52.5931
5          gwgain                34.3659
10         dperc                 25.1235
13         nvriarea              23.7813
0          wytype                23.6799
2          inflow                23.6321
7          precip                18.0733
4          retflow               16.8289
3          runoff                15.0714
9          ntimport              14.8234
11         gwpump                11.3852
8          etactual              11.2524
12         agurarea              10.0235
1          seas                  7.0093
```

Figure A-19: Relative Importance of the Input Variables in ANN for SR-6 (DA65)



```
ANNinput-DA65.tvq    4998 cycles.  Target error 0.0100  Average training error 0.000465
The first 14 of 14 Inputs in descending order.       Output column 14 adjust

Column     Input Name            Change from          to          Sensitivity      Relative Sensitivity

6          swdiv                    -8376.2000   84.0000      0.803179458
4          retflow                  0.7000       4.7000       0.405866502
0          wytype                   C            BN           0.351291640
7          precip                   0.0000       875.4000     0.291386963
2          inflow                   0.0000       1174.0000    0.176349481
5          gwgain                   -434.9000    228.9000     0.077529826
3          runoff                   0.0000       293.7000     0.049334360
10         dperc                    0.0000       252.6000     0.036591348
13         nvriarea                 350.1000     537.9000     0.027255132
8          etactual                 14.9000      247.9000     0.016874624
11         gwpump                   0.4000       141.2000     0.012446863
9          ntimport                 -15.9000     23.5000      0.006949221
12         agurarea                 120.0000     307.7000     0.005617886
1          seas                     FAL          SUM          0.002639902
```

Figure A-20: Relative Sensitivity of the Input Variables in ANN for SR-6 (DA65)

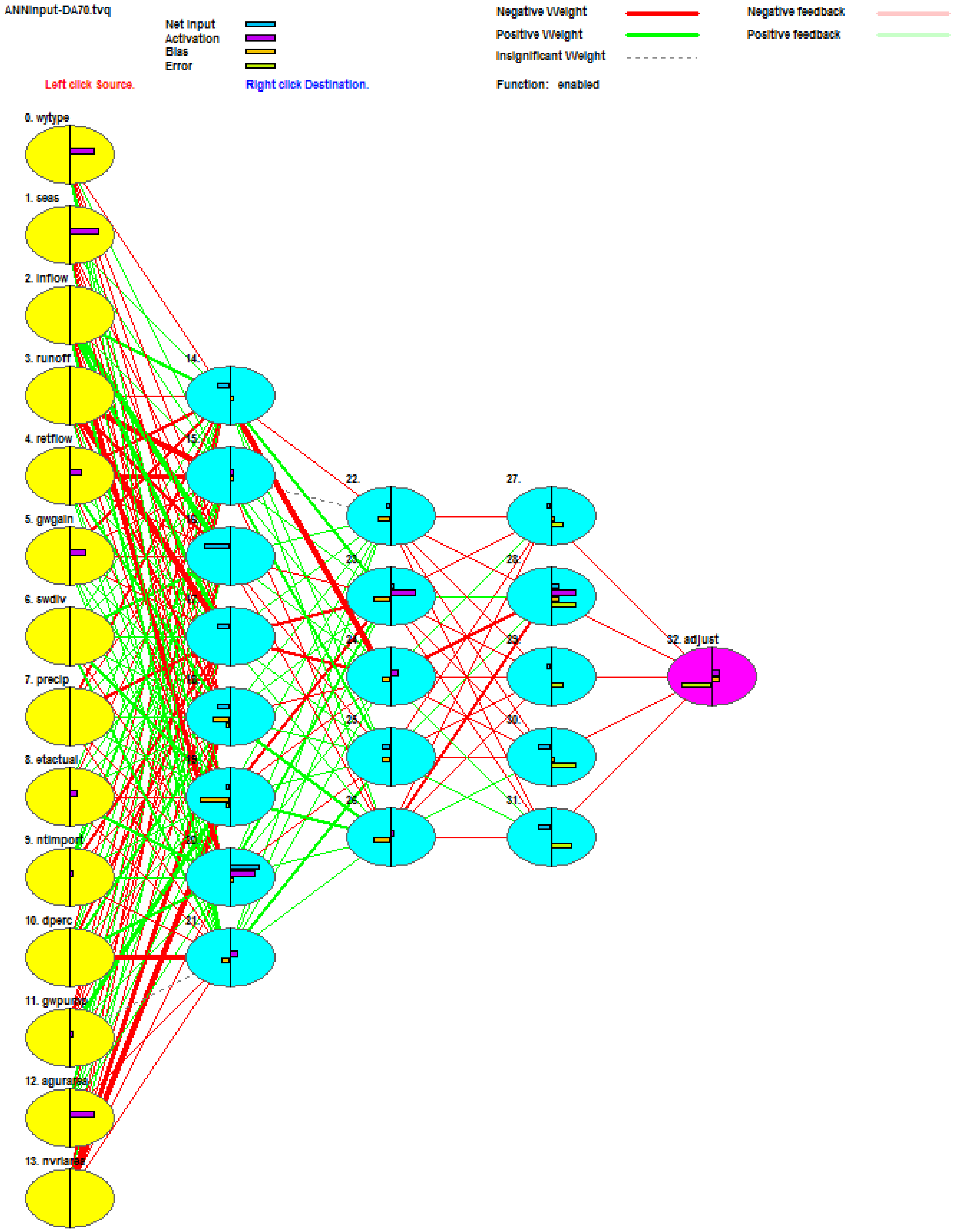
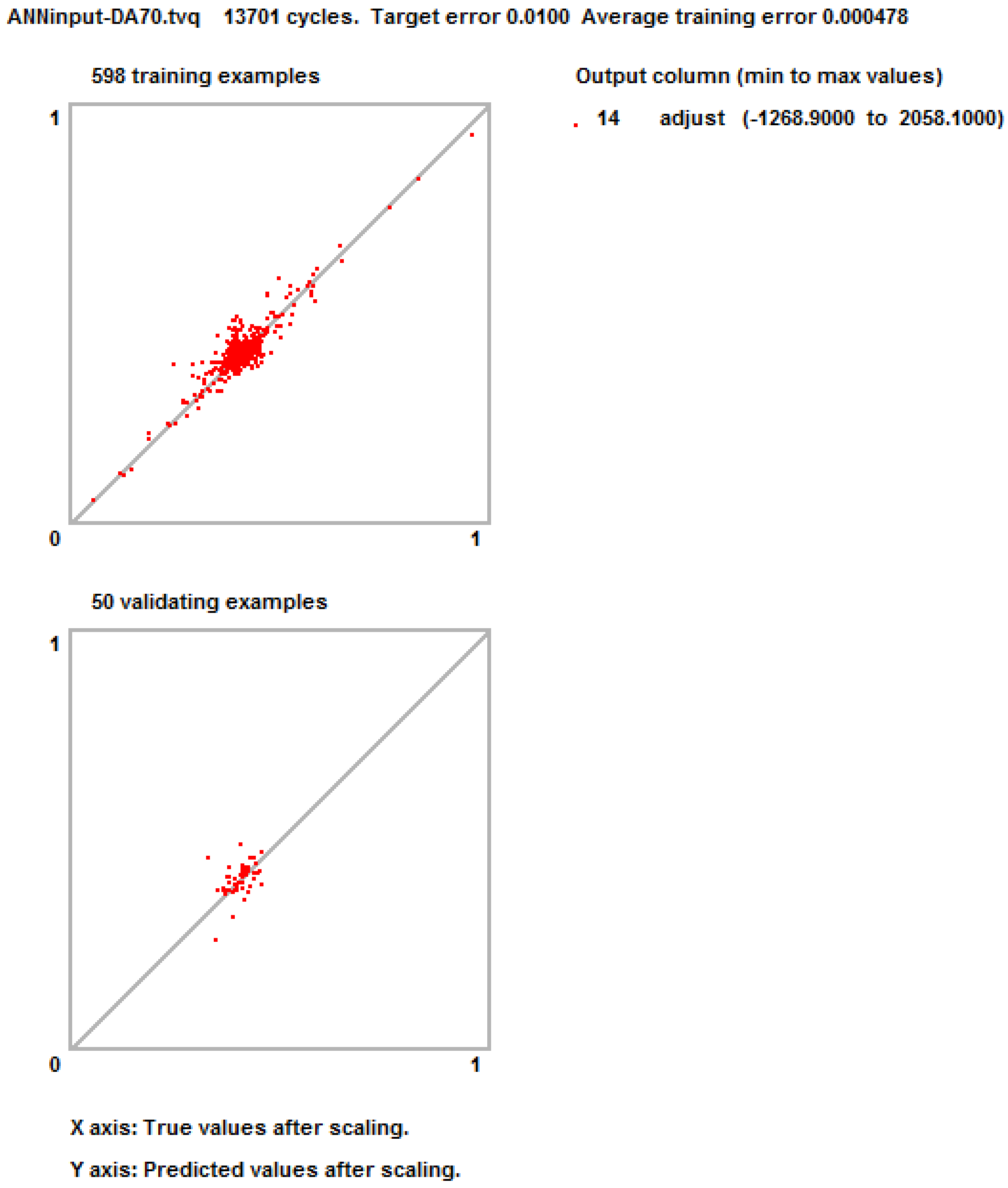


Figure A-21: ANN Architecture for SR-7 (DA70)



ANNinput-DA70.tvq   13701 cycles. Target error 0.0100 Average training error 0.000478

598 training examples

Output column (min to max values)

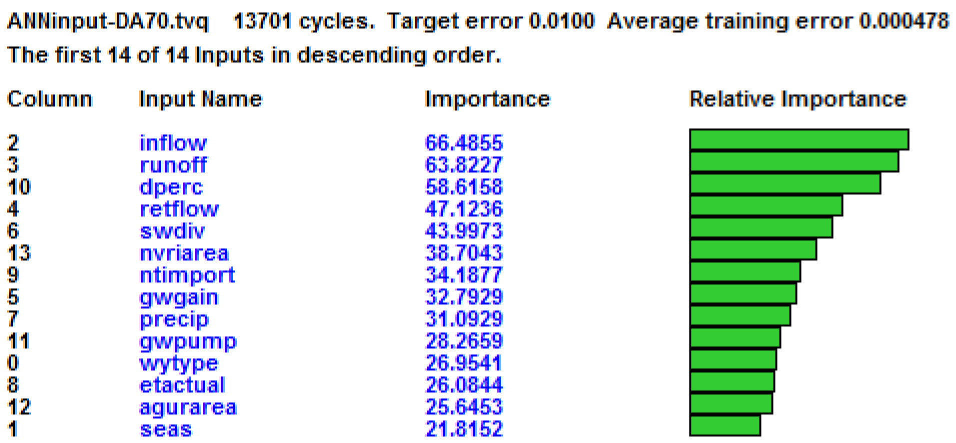
14   adjust   (-1268.9000 to 2058.1000)

50 validating examples

X axis: True values after scaling.

Y axis: Predicted values after scaling.

Figure A-22: Scatter Diagrams of the ANN Results for SR-7 (DA70)

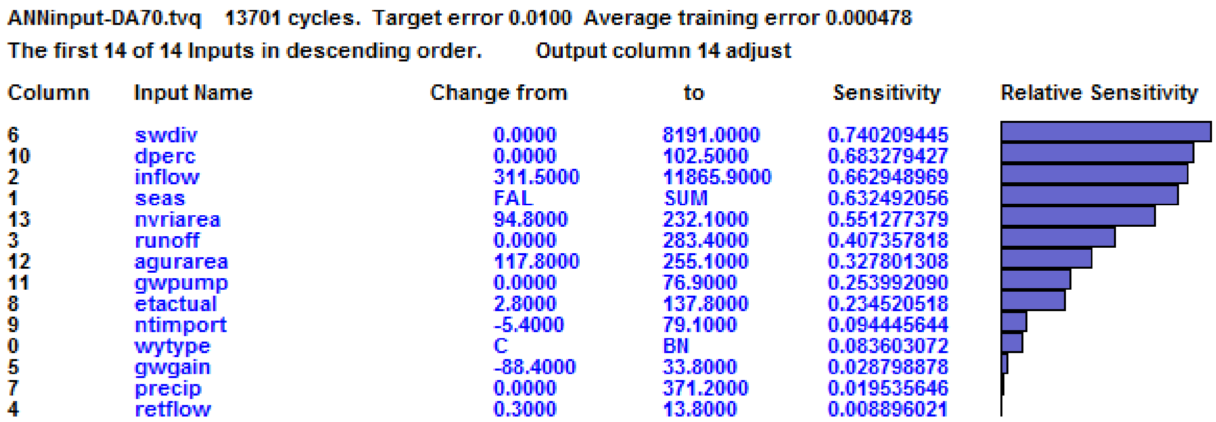


ANNinput-DA70.tvq 13701 cycles. Target error 0.0100 Average training error 0.000478

The first 14 of 14 Inputs in descending order.

Column	Input Name	Importance
2	inflow	66.4855
3	runoff	63.8227
10	dperc	58.6158
4	retflow	47.1236
6	swdiv	43.9973
13	nvriarea	38.7043
9	ntimport	34.1877
5	gwgain	32.7929
7	precip	31.0929
11	gwpump	28.2659
0	wytype	26.9541
8	etactual	26.0844
12	agurarea	25.6453
1	seas	21.8152

Figure A-23: Relative Importance of the Input Variables in ANN for SR-7 (DA70)



ANNinput-DA70.tvq 13701 cycles. Target error 0.0100 Average training error 0.000478

The first 14 of 14 Inputs in descending order. Output column 14 adjust

Column	Input Name	Change from	to	Sensitivity
6	swdiv	0.0000	8191.0000	0.740209445
10	dperc	0.0000	102.5000	0.683279427
2	inflow	311.5000	11865.9000	0.662948969
1	seas	FAL	SUM	0.632492056
13	nvriarea	94.8000	232.1000	0.551277379
3	runoff	0.0000	283.4000	0.407357818
12	agurarea	117.8000	255.1000	0.327801308
11	gwpump	0.0000	76.9000	0.253992090
8	etactual	2.8000	137.8000	0.234520518
9	ntimport	-5.4000	79.1000	0.094445644
0	wytype	C	BN	0.083603072
5	gwgain	-88.4000	33.8000	0.028798878
7	precip	0.0000	371.2000	0.019535646
4	retflow	0.3000	13.8000	0.008896021

Figure A-24: Relative Sensitivity of the Input Variables in ANN for SR-7 (DA70)

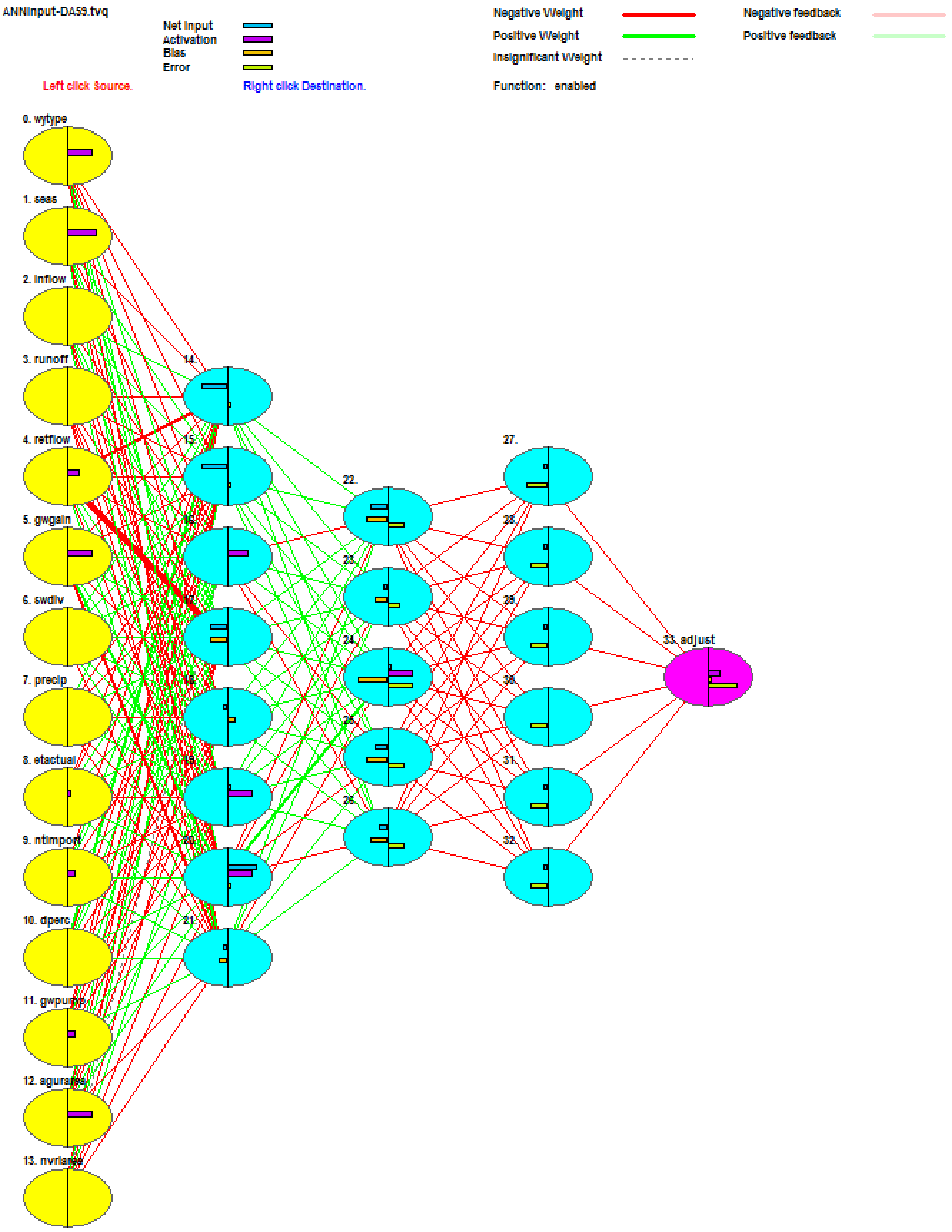
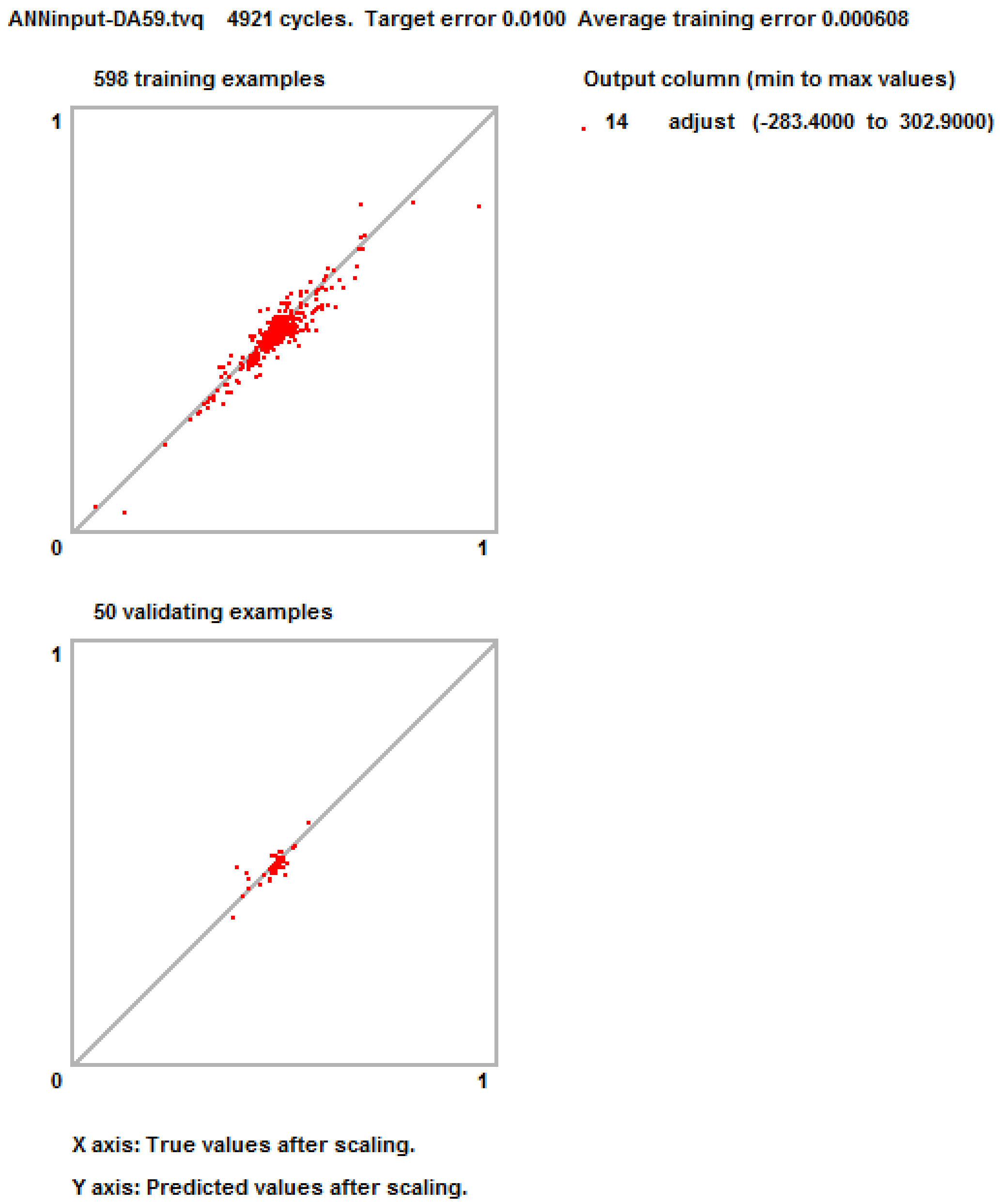


Figure A-25: ANN Architecture for SR-8 (DA59)

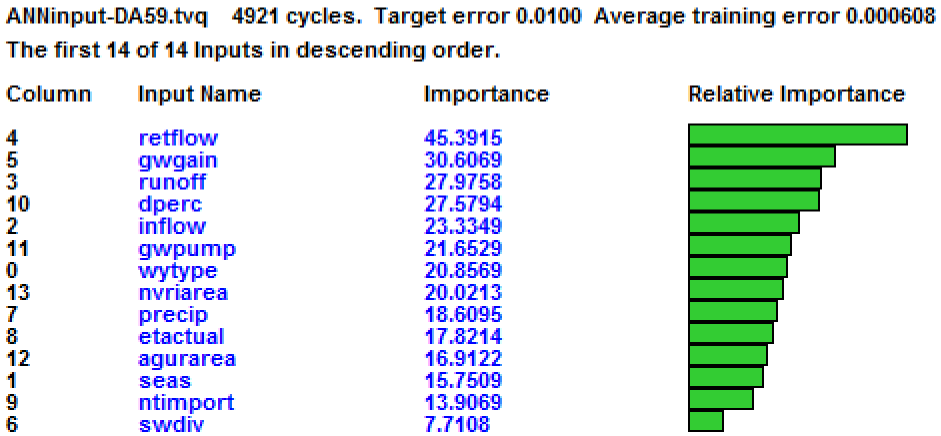


```
ANNinput-DA59.tvq    4921 cycles.  Target error 0.0100  Average training error 0.000608

Output column (min to max values)
.  14      adjust   (-283.4000  to  302.9000)
```

X axis: True values after scaling.

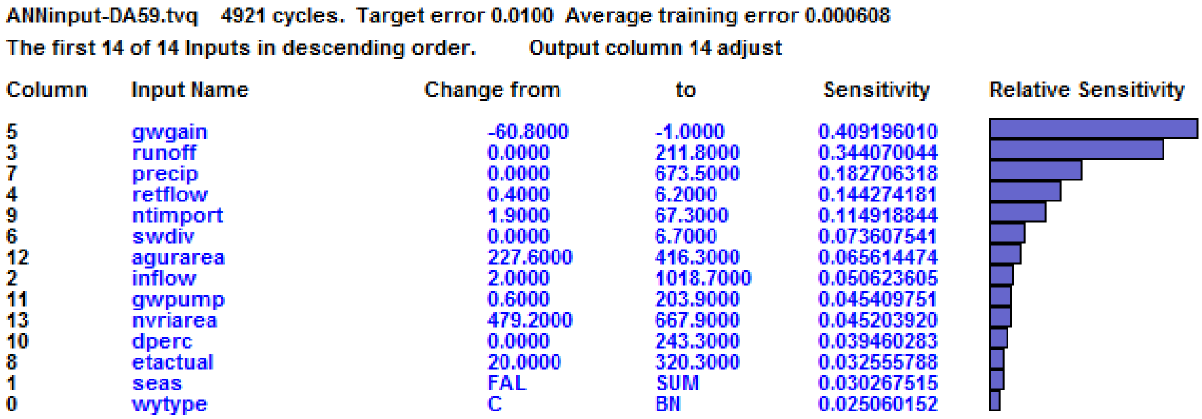
Y axis: Predicted values after scaling.

Figure A-26: Scatter Diagrams of the ANN Results for SR-8 (DA59)



```
ANNinput-DA59.tvq    4921 cycles.  Target error 0.0100  Average training error 0.000608
The first 14 of 14 Inputs in descending order.

Column      Input Name          Importance          Relative Importance

4           retflow             45.3915
5           gwgain              30.6069
3           runoff              27.9758
10          dperc               27.5794
2           inflow              23.3349
11          gwpump              21.6529
0           wytype              20.8569
13          nvriarea            20.0213
7           precip              18.6095
8           etactual            17.8214
12          agurarea            16.9122
1           seas                15.7509
9           ntimport            13.9069
6           swdiv               7.7108
```

Figure A-27: Relative Importance of the Input Variables in ANN for SR-8 (DA59)



```
ANNinput-DA59.tvq    4921 cycles.  Target error 0.0100  Average training error 0.000608
The first 14 of 14 Inputs in descending order.       Output column 14 adjust

Column      Input Name          Change from      to            Sensitivity     Relative Sensitivity

5           gwgain                 -60.8000      -1.0000       0.409196010
3           runoff                 0.0000        211.8000      0.344070044
7           precip                 0.0000        673.5000      0.182706318
4           retflow                0.4000        6.2000        0.144274181
9           ntimport               1.9000        67.3000       0.114918844
6           swdiv                  0.0000        6.7000        0.073607541
12          agurarea               227.6000      416.3000      0.065614474
2           inflow                 2.0000        1018.7000     0.050623605
11          gwpump                 0.6000        203.9000      0.045409751
13          nvriarea               479.2000      667.9000      0.045203920
10          dperc                  0.0000        243.3000      0.039460283
8           etactual               20.0000       320.3000      0.032555788
1           seas                   FAL           SUM           0.030267515
0           wytype                 C             BN            0.025060152
```

Figure A-28: Relative Sensitivity of the Input Variables in ANN for SR-8 (DA59)

DA49a

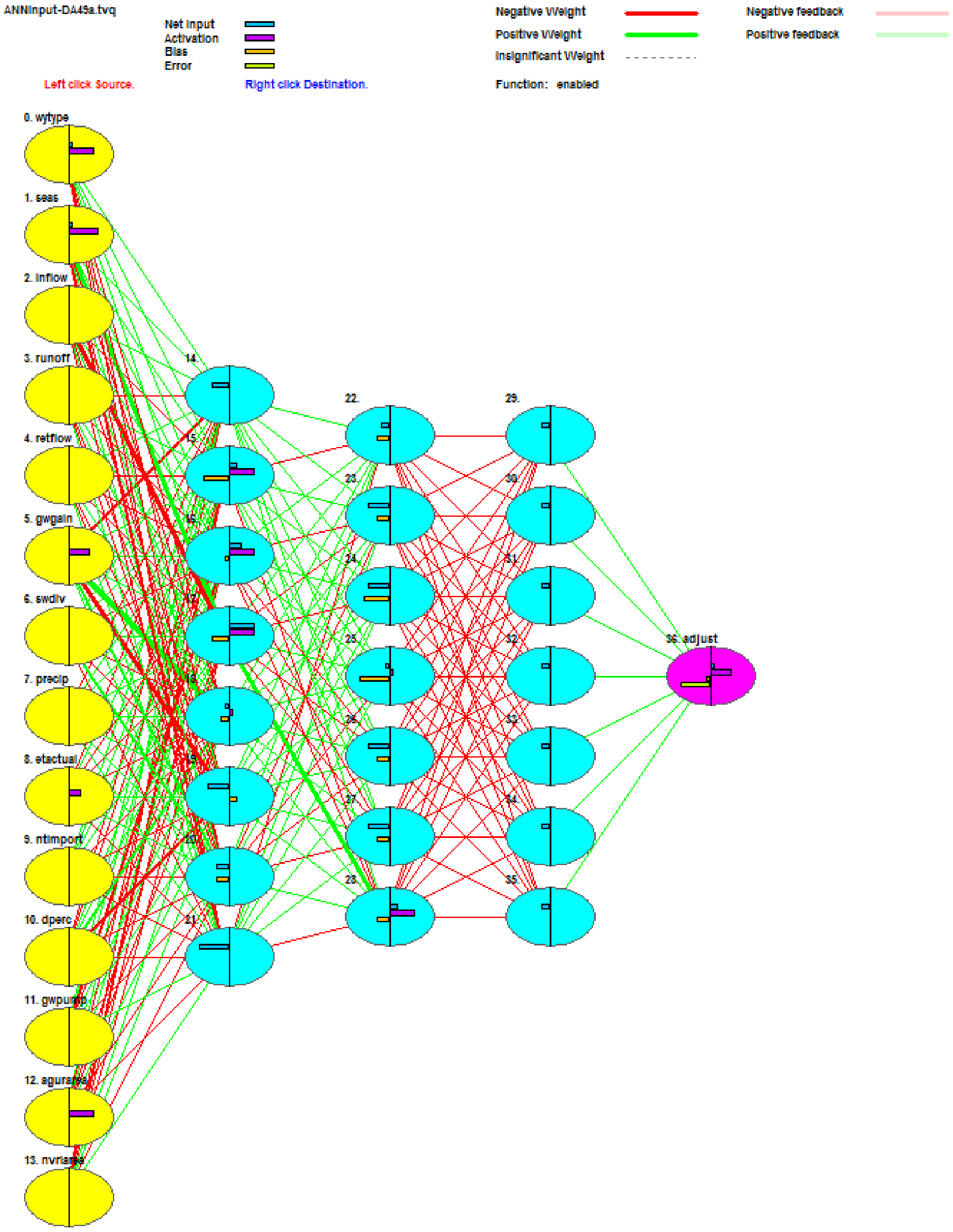
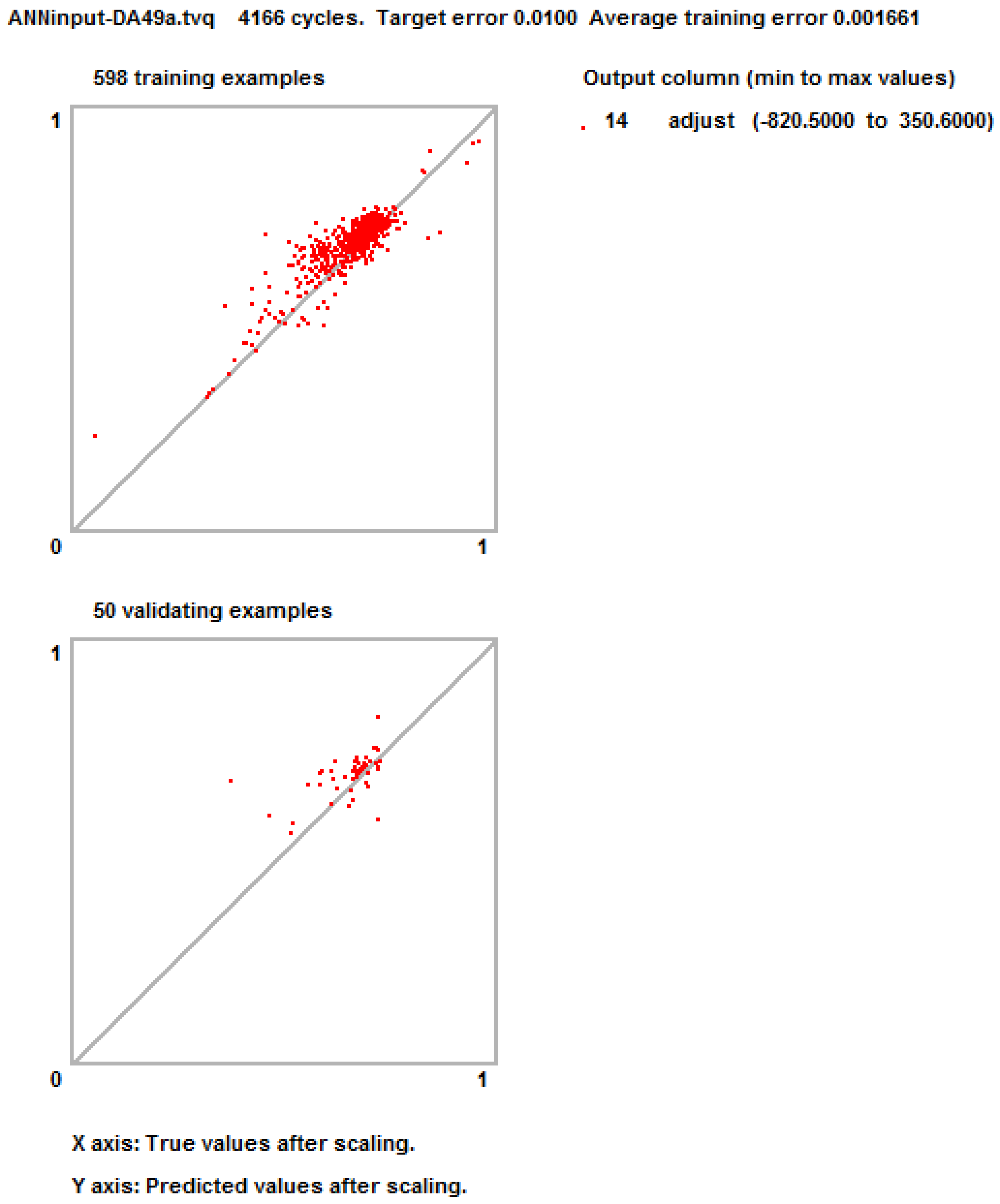


Figure A-29: ANN Architecture for SR-10 (DA49a)



ANNinput-DA49a.tvq 4166 cycles. Target error 0.0100 Average training error 0.001661

598 training examples

Output column (min to max values)

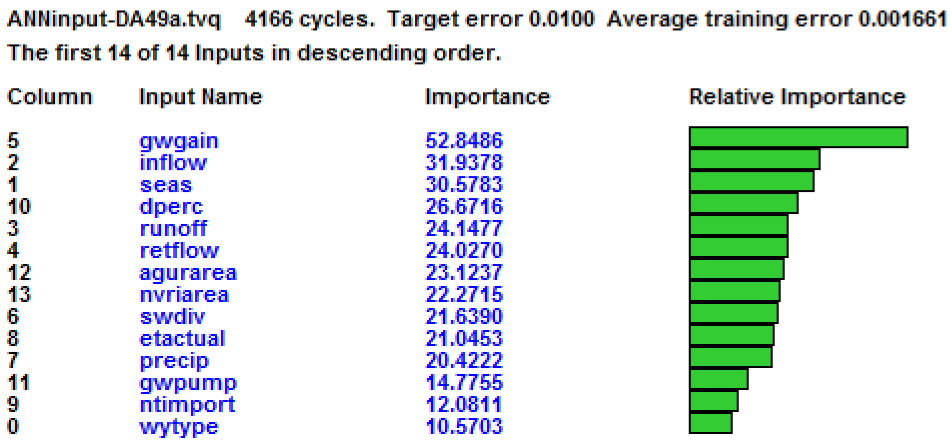
● 14 adjust (-820.5000 to 350.6000)

50 validating examples

X axis: True values after scaling.

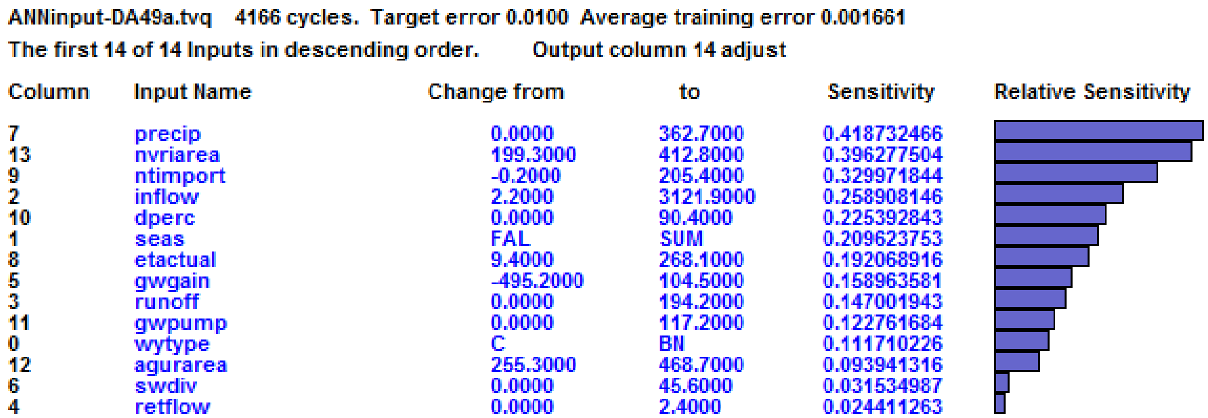
Y axis: Predicted values after scaling.

Figure A-30: Scatter Diagrams of the ANN Results for SR-10 (DA49a)



```
ANNinput-DA49a.tvq    4166 cycles.  Target error 0.0100  Average training error 0.001661
The first 14 of 14 Inputs in descending order.

Column      Input Name           Importance      Relative Importance

5           gwgain               52.8486
2           inflow               31.9378
1           seas                 30.5783
10          dperc                26.6716
3           runoff               24.1477
4           retflow              24.0270
12          agurarea             23.1237
13          nvriarea             22.2715
6           swdiv                21.6390
8           etactual             21.0453
7           precip               20.4222
11          gwpump               14.7755
9           ntimport             12.0811
0           wytype               10.5703
```

Figure A-31: Relative Importance of the Input Variables in ANN for SR-10



```
ANNinput-DA49a.tvq    4166 cycles.  Target error 0.0100  Average training error 0.001661
The first 14 of 14 Inputs in descending order.      Output column 14 adjust

Column    Input Name          Change from       to           Sensitivity      Relative Sensitivity

7         precip                  0.0000        362.7000     0.418732466
13        nvriarea                199.3000      412.8000     0.396277504
9         ntimport                -0.2000       205.4000     0.329971844
2         inflow                  2.2000        3121.9000    0.258908146
10        dperc                   0.0000        90.4000      0.225392843
1         seas                    FAL           SUM          0.209623753
8         etactual                9.4000        268.1000     0.192068916
5         gwgain                  -495.2000     104.5000     0.158963581
3         runoff                  0.0000        194.2000     0.147001943
11        gwpump                  0.0000        117.2000     0.122761684
0         wytype                  C             BN           0.111710226
12        agurarea                255.3000      468.7000     0.093941316
6         swdiv                   0.0000        45.6000      0.031534987
4         retflow                 0.0000        2.4000       0.024411263
```

Figure A-32: Relative Sensitivity of the Input Variables in ANN for SR-10 (DA49a)

Appendix C. FORTAN Source Code to Compute Adjustments with ANN

```
      program CombANN

c     FORTAN code to compute adjustments using ANN weights
c     and biases (with scaling).
c
c        By: Tariq Kadir
c            PhD Dissertation
c            UC Davis

      implicit real*8 (a-h,o-z)
      implicit integer*4 (i-n)

      character*1 skip
      character*7 id(8,984)
      character*2 wytype(8,984)
      character*3 season(8,984)
      character*8 var(8,15)

      dimension bias(8,4,25), weight(8,4,25,25), xinmin(8,14),
     1       xinmax(8,14),xin(8,984,14),xout(8,984),
     1       xinput(8,20),activation(8,20),zoutput(8,984),
     1       xoutmin(8),xoutmax(8)

      dimension ninput(8), nl1(8), nl2(8), nl3(8)

      open(801, file="DA58-nodes.in" , status="old")
      open(802, file="DA10-nodes.in" , status="old")
      open(803, file="DA15-nodes.in" , status="old")
      open(804, file="DA69-nodes.in" , status="old")
      open(805, file="DA70-nodes.in" , status="old")
      open(806, file="DA65-nodes.in" , status="old")
      open(807, file="DA59-nodes.in" , status="old")
      open(808, file="DA49a-nodes.in", status="old")

      open(811, file="DA58-parameters.in" , status="old")
      open(812, file="DA10-parameters.in" , status="old")
      open(813, file="DA15-parameters.in" , status="old")
      open(814, file="DA69-parameters.in" , status="old")
      open(815, file="DA70-parameters.in" , status="old")
      open(816, file="DA65-parameters.in" , status="old")
```

```
      open(817, file="DA59-parameters.in" , status="old")
      open(818, file="DA49a-parameters.in", status="old")

      open(821, file="DA58-hydrology.in" , status="old")
      open(822, file="DA10-hydrology.in" , status="old")
      open(823, file="DA15-hydrology.in" , status="old")
      open(824, file="DA69-hydrology.in" , status="old")
      open(825, file="DA70-hydrology.in" , status="old")
      open(826, file="DA65-hydrology.in" , status="old")
      open(827, file="DA59-hydrology.in" , status="old")
      open(828, file="DA49a-hydrology.in", status="old")

      open(831, file="DA58-output.out", status="new")
      open(832, file="DA10-output.out", status="new")
      open(833, file="DA15-output.out", status="new")
      open(834, file="DA69-output.out", status="new")
      open(835, file="DA70-output.out", status="new")
      open(836, file="DA65-output.out", status="new")
      open(837, file="DA59-output.out", status="new")
      open(838, file="DA49a-output.out", status="new")

      do m=1,8

       iunit1=800+m
           iunit2=810+m
           iunit4=830+m

c....initialize biases and weights arrays
       do i=1,4
          do j=1,25
           bias(m,i,j)=888.8
          end do
       end do

         do i=1,4
           do j=1,25
             do k=1,25
               weight(m,i,j,k)=9999.9
            end do
          end do
       end do


c....read input data
```

```
        read(iunit1,100)skip
 100   format(a1)

       read(iunit1,105)ninput(m),nl1(m),nl2(m),nl3(m)
       write(iunit4,200)ninput(m),nl1(m),nl2(m),nl3(m)
 105   format(i5/i5/i5/i5)
 200   format(3x,i5/3x,i5/3x,i5/3x,i5)


c.....weights for Input to layer-1

       write(iunit4,205)
 205    format(/3x,'Weights for Input Layer to Layer-1:')

       do i=1,6
         read(iunit2,100)skip
       end do

       do i=1,ninput(m)
          read(iunit2,110)(weight(m,1,i,j),j=1,nl1(m))
          write(iunit4,110)(weight(m,1,i,j),j=1,nl1(m))
 110        format(17x,20f12.6)
       end do

c.....weights for Layer-1 to Layer-2

       write(iunit4,220)
 220    format(/3x,'Weights for Layer-1 to Layer-2:')

       do i=1,4
         read(iunit2,100)skip
       end do

       do i=1,nl1(m)
          read(iunit2,110)(weight(m,2,i,j),j=1,nl2(m))
          write(iunit4,110)(weight(m,2,i,j),j=1,nl2(m))
       end do

c.....weights for Layer-2 to Layer-3

       write(iunit4,230)
 230    format(/3x,'Weights for Layer-2 to Layer-3:')
       do i=1,4+(10-nl1(m))
```

```
        read(iunit2,100)skip
 555      format(1x,a1)
       end do

       do i=1,nl2(m)
         read(iunit2,110)(weight(m,3,i,j),j=1,nl3(m))
         write(iunit4,110)(weight(m,3,i,j),j=1,nl3(m))
       end do

c.....weights for Layer-3 to Output layer

       write(iunit4,234)
 234     format(/3x,'Weights for Layer-3 to Output Layer:')

       do i=1,4+(10-nl2(m))
        read(iunit2,100)skip
       end do

       do i=1,nl3(m)
         read(iunit2,110)(weight(m,4,i,j),j=1,1)
         write(iunit4,110)(weight(m,4,i,j),j=1,1)
       end do

c.....biases

       write(iunit4,239)
 239     format(/3x,'Biases:')

       do i=1,3+(10-nl3(m))
        read(iunit2,100)skip
       end do

       write(iunit4,241)
 241     format(/3x,'Biases for Layer-1:')

       do i=1,nl1(m)
         read(iunit2,160)bias(m,1,i)
         write(iunit4,160)bias(m,1,i)
 160       format(18x,f12.6)
       end do

       write(iunit4,243)
 243     format(/3x,'Biases for Layer-2:')
```

```
        do i=1,nl2(m)
          read(iunit2,160)bias(m,2,i)
          write(iunit4,160)bias(m,2,i)
        end do

        write(iunit4,245)
  245     format(/3x,'Biases for Layer-3:')

        do i=1,nl3(m)
           read(iunit2,160)bias(m,3,i)
           write(iunit4,160)bias(m,3,i)
        end do

        write(iunit4,247)
  247     format(/3x,'Biases for Output Layer:')

        do i=1,1
           read(iunit2,160)bias(m,4,i)
           write(iunit4,160)bias(m,4,i)
        end do

c....mix and max values

        write(iunit4,276)
  276     format(/3x,'Min and Max Values of Variables:')

        do i=1,3+30-(nl1(m)+nl2(m)+nl3(m))
           read(iunit2,100)skip
        end do


        do i=1,ninput(m)
          read(iunit2,130)var(m,i),xinmin(m,i),xinmax(m,i)
  130       format(17x,a8,4x,2f12.1)
          write(iunit4,130)var(m,i),xinmin(m,i),xinmax(m,i)
        end do
        read(iunit2,130)var(m,ninput(m)+1),xoutmin(m),xoutmax(m)
        write(iunit4,130)var(m,ninput(m)+1),xoutmin(m),xoutmax(m)

              close(iunit1)
              close(iunit2)

      end do
```

```
c---------------------------------------------------------------------------
c....begin calculations

     do m=1,8

           iunit3=820+m
     iunit4=830+m

        write(iunit4,283)
  283   format(//3x,'Results:',/5x,'wy',3x,'wytype',1x,'seas',3x,
       1          'ascii',4x,'ascii',3x,'inflow',4x,'runoff',3x,
       1          'retflow',2x,'gwgain',4x,'swdiv',3x,
       1          'precip',3x,'etactual',1x,'ntimport',2x,
       1          'dperc',4x,'gwpump',2x,'agurarea',1x,
       1          'nvriarea',1x,'adjust',2x,'zoutput')

        read(iunit3,100)skip

        do it=1,984

          read(iunit3,120)id(m,it),wytype(m,it),season(m,it),
       1               (xin(m,it,j),j=3,14),xout(m, it)
120     format(1x,a7,3x,a2,3x,a3,5x,13f8.1)

c....convert ASCII to numbers
          if(wytype(m,it).eq."W ")xin(m,it,1)= 87.0
          if(wytype(m,it).eq."AN")xin(m,it,1)=208.0
          if(wytype(m,it).eq."BN")xin(m,it,1)=210.0
          if(wytype(m,it).eq."D ")xin(m,it,1)= 68.0
          if(wytype(m,it).eq."C ")xin(m,it,1)= 67.0

          if(season(m,it).eq."FAL")xin(m,it,2)=416.0
          if(season(m,it).eq."WIN")xin(m,it,2)=485.0
          if(season(m,it).eq."SPR")xin(m,it,2)=491.0
          if(season(m,it).eq."SUM")xin(m,it,2)=496.0

c....Input Layer
c          write(iunit4,400)
c  400      format(//3x,'Input Layer:')
          do i=1,ninput(m)
             activation(m,i)=(xin(m,it,i)-xinmin(m,i))/(xinmax(m,i)
    1                               -xinmin(m,i))
c            write(iunit4,402) i,activation(m,i)
c  402         format(8x,'node=',i4,2x,'activation=',3x,f12.6)
```

```
          end do

c....Hidden Layer-1
c          write(iunit4,404)
c  404      format(//3x,'Hidden Layer-1:')
          do j=1,nl1(m)
            sum=0.
            do i=1,ninput(m)
              sum=sum+weight(m,1,i,j)*activation(m,i)
            end do

            xinput(m,j)=sum+bias(m,1,j)
           end do

           do j=1,nl1(m)
                   activation(m,j)=1./(1. + exp(-xinput(m,j)))
c               write(iunit4,406)j,xinput(m,j),activation(m,j)
c  406            format(8x,'node=',i4,3x,'input=',f12.6,3x,
c    1             'activation=',f12.6)
           end do

c....Hidden Layer-2
c          write(iunit4,408)
c  408      format(//3x,'Hidden Layer-2:')
           do j=1,nl2(m)
            sum=0.
            do i=1,nl1(m)
              sum=sum+weight(m,2,i,j)*activation(m,i)
            end do
            xinput(m,j)=sum+bias(m,2,j)
           end do

           do j=1,nl2(m)
                   activation(m,j)=1./(1. + exp(-xinput(m,j)))
c               write(iunit4,406)j,xinput(m,j),activation(m,j)
           end do

c....Hidden Layer-3
c          write(iunit4,410)
c  410      format(//3x,'Hidden Layer-3:')
          do j=1,nl3(m)
            sum=0.
            do i=1,nl2(m)
              sum=sum+weight(m,3,i,j)*activation(m,i)
```

```
        end do
        xinput(m,j)=sum+bias(m,3,j)
      end do

      do j=1,nl3(m)
         activation(m,j)=1./(1. + exp(-xinput(m,j)))
c         write(iunit4,406)j,xinput(m,j),activation(m,j)
      end do

c....Output Layer
c      write(iunit4,412)
c  412   format(//3x,'Output Layer:')
      do j=1,1
        sum=0.

        do i=1,nl3(m)
          sum=sum+weight(m,4,i,j)*activation(m,i)
       end do
        xinput(m,j)=sum+bias(m,4,j)
      end do
      do j=1,1
            activation(m,j)=1./(1. + exp(-xinput(m,j)))
c          write(iunit4,406)j,xinput(m,j),activation(m,j)
      end do

      zoutput(m,it)=activation(m,1)*(xoutmax(m)
   1              -xoutmin(m))+xoutmin(m)
c      write(iunit4,420)zoutput(m,it)
c  420   format(8x,'scaled output=',f12.6/)

      write(iunit4,280)id(m,it),wytype(m,it),season(m,it),
   1               (xin(m,it,j),j=1,14),xout(m,it),
   1               zoutput(m,it)
280     format(3x,a7,2x,a2,3x,a3,16f9.1)

    end do
    close(iunit3)
        close(iunit4)
   end do

   stop
   end
```

Appendix D. Using GIS to Estimate Projected Level 2003 Land Use and Crop Acreages for C2VSIM

Two important input files necessary to run C2VSIM at a projected level of development are the Land Use file (CVLandUse.dat) and Crop Acreages file (CVcropacres.dat). The Land Use file lists for each element in C2VSIM the percent of area that is agricultural (crops), urban, native vegetation, and riparian vegetation. With the exception of the Delta all other sub-regions currently do not simulate the riparian vegetation, and instead lump those areas with native vegetation. For this research the same was applied to the Delta. The Crop Acreages file lists by sub-region the crop acreage for eight categories (aggregating some crops together into one category) and those for urban areas, native vegetation.

There are two types of projected levels of land use development used by the Department of Water Resources for planning simulations: current levels of development (CLD) and future level of development (FLD). CLD, as implied, represents current land use and crop acreages, while FLD represent land use and crop acreage at a more distant future (e.g. 2020, 2035, 2050). CLD estimates are simpler to assemble (quantitatively and spatially), especially given GIS technology. FLD estimates rely on a combination of extending current trends and future market projections, and normally are not available at current GIS spatial resolutions. For example it may be possible to project future urban expansions based on current urban footprints, but it is much more difficult to predict future crops needs (nationally and internationally) and associated spatial resolution.

This work is concerned with running C2VSIM at a current level of resolution taken to mean around year 2000. Land use surveys carried out by DWR every 5-7 years by Detailed Analysis Unit (DAU) by County. Since the early 1990s that data has been put into GIS format which simplifies the retrieval and analysis of that data. Therefore a mosaic land use of all the counties within the C2VSIM boundary is stitched together from recent land use surveys to represent CLD.

For this work both ArcGIS version 8.3 and later 9.3.1 was used to compile and process the data. The steps used to prepare the Land Use and Crop Acreages files for C2VSIM are as follows:

1. Load the layers Counties, C2VSIM sub-regions, C2VSIM elements, DAU's, and – for visualization, the California hillshade SID file (from the ESRI website).

2. Intersect the California Counties layer with the C2VSIM sub-regions layer, the following counties were located within C2VSIM boundaries(a total of 25): Alameda (very small area), Amador, Butte, Calaveras, Colusa, Contra Costa, Fresno, Glenn, Kern, Kings, Madera, Mariposa, Merced, Placer, Sacramento, San Joaquin, Shasta, Solano, Stanislaus, Sutter, Tehama, Tulare, Yolo, and Yuba.

3. Surveys for all counties listed in Step 2 were download from the DWR website (raw format) except for Alameda, and Calaveras which were not available. All data were in NAD27 UTM Zone 10.

4. Data for the Delta was downloaded from the DWR website which includes only portions of Alameda County. The portion of Alameda County within C2VSIM is small. The Delta file had to be projected to Zone 10.5 and then re-projected to Zone 10.

5. Calaveras County lies within Sub-region 8 in C2VSIM (SR-8), and is part of Depletion Study Area 59 (Eastside Streams). In the mid 2000's, DWR's Central District completed digitizing the wedge of Calaveras County within the C2VSIM boundary and the data provided (data obtained through private communication).

6. The Kern County survey does not have all quads covered for areas within sub-regions SR-19, SR-20, SR-21. A new layer was formed and the blank areas given a native vegetation designation NX.

7. A separate layer for each County was created, by selection from the Counties layer.

8. Clip the County crop (called crop but actually includes urban and NV) to the respective County layer.

9. A merged crop layer for all Counties was then created.

10. An outer boundary for the C2VSIM sub-regions was created by dissolving the sub-region layer.

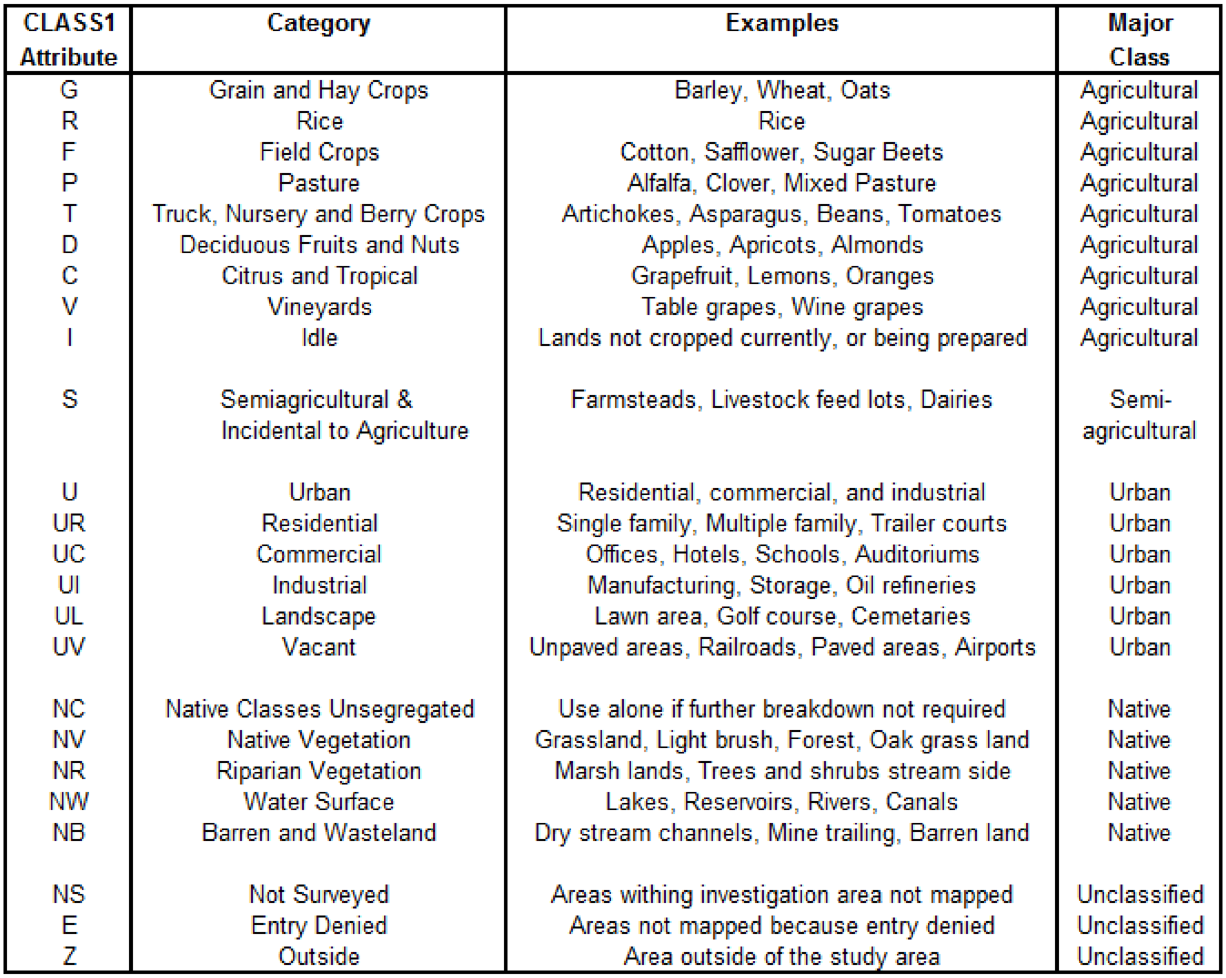
11. The counties crops merged layer (step 10) was clipped with the C2VSIM outer boundary layer (step 11), to get all crop polygons within the C2VSIM boundary.

12. The attribute table of the layer in step 12 was edited by deleting unnecessary fields (to reduce process time requirements for subsequent computations).

13. A new field called "zArea" was created using an ArcScript macro in Visual Basic called "calcarea.bas" to calculate all polygon areas. The "Area" field that came with the original crop shapefiles were not reliable because of the all the re-projections made as explained earlier. The units of zArea are in meters squared.

14. According to the DWR "Standard Land Use Legend" (July 1993 and March 1999, ref?), the "CLASS1" field in the attribute table of the crops layer (step 12) contains the different types of attributes as shown in Table D-1.

Table D-1. CLASS1 Attributes from DWR's Standard Land Use Legend



CLASS1 Attribute	Category	Examples	Major Class
G	Grain and Hay Crops	Barley, Wheat, Oats	Agricultural
R	Rice	Rice	Agricultural
F	Field Crops	Cotton, Safflower, Sugar Beets	Agricultural
P	Pasture	Alfalfa, Clover, Mixed Pasture	Agricultural
T	Truck, Nursery and Berry Crops	Artichokes, Asparagus, Beans, Tomatoes	Agricultural
D	Deciduous Fruits and Nuts	Apples, Apricots, Almonds	Agricultural
C	Citrus and Tropical	Grapefruit, Lemons, Oranges	Agricultural
V	Vineyards	Table grapes, Wine grapes	Agricultural
I	Idle	Lands not cropped currently, or being prepared	Agricultural
S	Semiagricultural & Incidental to Agriculture	Farmsteads, Livestock feed lots, Dairies	Semi-agricultural
U	Urban	Residential, commercial, and industrial	Urban
UR	Residential	Single family, Multiple family, Trailer courts	Urban
UC	Commercial	Offices, Hotels, Schools, Auditoriums	Urban
UI	Industrial	Manufacturing, Storage, Oil refineries	Urban
UL	Landscape	Lawn area, Golf course, Cemetaries	Urban
UV	Vacant	Unpaved areas, Railroads, Paved areas, Airports	Urban
NC	Native Classes Unsegregated	Use alone if further breakdown not required	Native
NV	Native Vegetation	Grassland, Light brush, Forest, Oak grass land	Native
NR	Riparian Vegetation	Marsh lands, Trees and shrubs stream side	Native
NW	Water Surface	Lakes, Reservoirs, Rivers, Canals	Native
NB	Barren and Wasteland	Dry stream channels, Mine trailing, Barren land	Native
NS	Not Surveyed	Areas withing investigation area not mapped	Unclassified
E	Entry Denied	Areas not mapped because entry denied	Unclassified
Z	Outside	Area outside of the study area	Unclassified

15. The contents of the "CLASS1" field of step 15 was not consistent. The main problem was that many of the attributes listed in the above table had a "space" in front (e.g, " C" instead of "C"). Since subsequent computations require exact identification of the field attribute, a new field called "class1x" was created. First the records in the field were put as exact duplicates of the "CLASS1" field. Next, by selecting by attributes (e.g, " C" and "C" and then right click on the "class1x" field and calculate to change all selected records in that field to "C". This was done for all the following attributes:
    - " C" and "C" → "C"
    - " D" and "D" → "D"
    - " F" and "F" → "F"
    - " G" and "G" → "G"
    - " I" and "I" → "I"
    - " P" and "P" → "P"
    - " R" and "R" → "R"
    - " T" and "T" → "T"

- “ V” and “V” → “V”
- “~~D”~~ → “D”

Also, the following sub-classes were aggregated for the Urban and Native classifications:

- “NB” & “NC” & “NR” & “NV” & “NW” & “NX” → “N”
- “U” & “UC” & “UI” & “UL” & “UR” & “UV” → “U”
- “AC” & “AF” → “N” Note: These are “abandoned” fields surveyed. They are minimal in number and only in Alameda County
- “ “ → “N” Note: Very minimal in number, and only in Calaveras County

Finally, the sub-categories were refined further by aggregating” :

- “N” & “Z” & “E” & “I” & “S” → “N” Note: A summary statistics was carried out in ArcMap to check the Areas of the Z, E, I, and S categories; they were very small comparatively.

Note: When County crop surveys are carried out, the final shapefile is a union of the different topographic maps covering the County boundary. Areas outside the County boundary are designated as “Z”. In evaluating the data for this report, it was discovered that there were three Counties where not the entire County was surveyed. They are usually areas too distant from agricultural and urban areas. Therefore, a “Z” attribute was given to those polygons which explain why the attribute shows up after merging all the Counties together. Also when merging the Counties together, a thin sliver of “Z”s will also exist because the shapefiles do not fit perfectly at the boundaries.

16. The sub-Class1 field in the GIS data was used to break out some crops from the Class1 field.

17. Another field was created in the attribute table for crop layer called “class1y” which aggregated all the crop categories shown in Table D-1 into one attribute:

“C” & “D” & “F” & “G” & “P” & “R” & “T” & “V” → “L” for agricultural

Therefore the “class1y” field contains the following attributes:

“L” for agricultural crop areas
“U” for urban areas
“N” for native vegetation areas

18. The merged crop layer is then intersected with the elements layer. Data is then aggregated to the sub-regional level (see Table 4-2).

19. It is also possible to process the intersection of elements and crop layers to obtain the percentages of Ag, Urban and Native Vegetation percentages of element area required for the Land Use data file in C2VSIM.

Appendix E. Mapping CalSim-II Diversions to C2VSIM

For C2VSIM projected diversions not based on WY1975-2003 averages, the following are the formulae to aggregate CalSim-II diversions (arcs) to C2VSIM stream diversions, sorted by Sub-region:

SR-1

D-3 = 0.852*D104_PSC + D104_PAG

SR-2

D-4 = D171
D-5 = D42 + D17301
D-6 = D172
D-7 = D112 - D171 - D172
D-8 = D114

SR-3

D-9 = D180 + D182A + D182B + D183 + D18302
D105 = C184B

SR-4

D-10 = 0.783*D122B-PSC + D129A_PSC + D124A
D-11 = D128_PSC + D183_PSC

SR-5

D-13 = D285
D-15 = D6
D-19 = D223
D-21 = D283

SR-6

(None)

SR-7

D-34 = D9
D-35 = D302
D-103 = D160
D-104 = D166A

SR-8

(None)

SR-9

D-22 = D168
D-23 = D163

D-24 = D162
D-106 = D400B + D404 + D406 + D410 + D412 + D409B
D-112 = D408RS + D408OR + D408VC
D-113 = D419
D-114 = D418

SR-10

D-40 = D706 + D707 + D701 + D836_PAG
D-42 = C605A + D607C + D608C
D-47 = D833
D-48 = D835
D-49 = (included in D-48)

SR-11

D-58 = D520B
D-59 = D520C
D-60 = D528
D-61 = D540A
D-62 = D630A
D-63 = D545
D-64 = D540B

SR-12

D-65 = D562
D-66 = D566
D-67 = D620C
D-68 = D561

SR-13

D-43 = C608C
D-69 = D18B
D-71 = D588 + D595

SR-14

D50 = D837 + D839 + D841 + D843

SR-15

D-90 = D846_PAG + D846_PCO + D846_PIN + D847_PAG +D847_PCO + D848_PAG +D848_PCO + D848_PIN
D-45 = D607A_PAG + 0.059*D607B_PEX

SR-16

D-74 = 0.023*D855_PAG + 0.007*D18A_C1 + 0.072*D18A_C2 + 0.023*D18A_215

SR-17

D-75 = 0.035*D55_PG + 0.059*D18A_C1 + 0.022*D18A-215

SR-18

D-76 = 0.425*D18A_215 + 0.553*D18A_C1 + 0.543*D18A_C2

SR-19

D-91 = 0.697*D851_PCO + D867_PCO + D867_PAG + 0.697*D851_PAG + 0.61*D859_PIN

SR-20

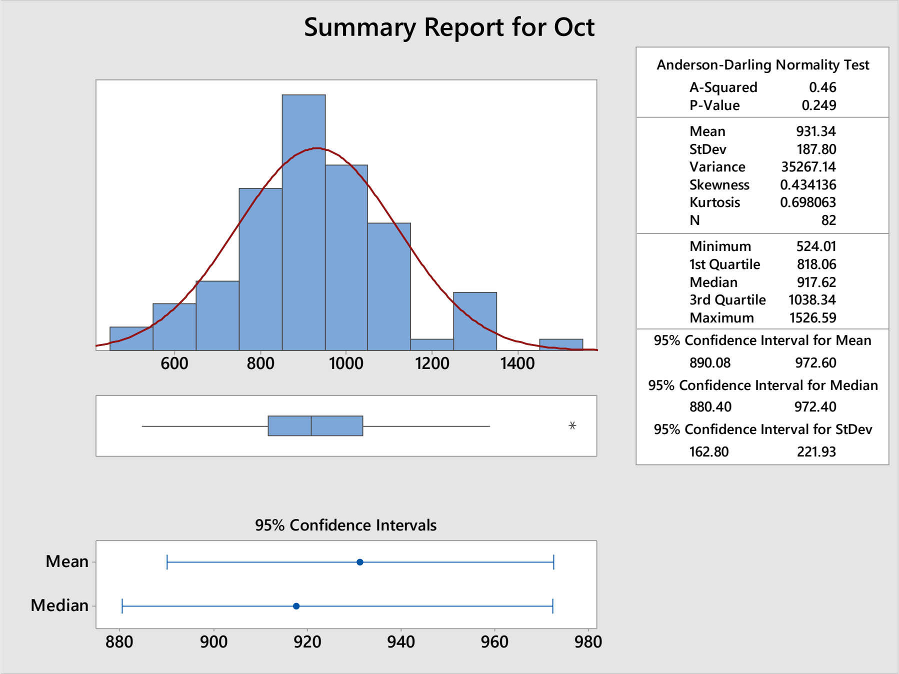
D-94 = 0.07*D851_PCO + 0.07*D851_PAG
D78 = 0.223*D18A_C1 + 0.086*D18A_C2 + 0.07*D18A_215

SR-21

D-79 = 0.46*D18A_215 + 0.299*D18A_C2 + 0.061*D18A_C1
D-92 = 0.39*D859PIN + D859_PCO + D859_PAG + D863*PCO + D863_PAG
D-95 = 0.233*D851_PCO + 0.139*D851_PAG

Appendix F. Histograms for C2VSIM Monthly Projected Level 2003 Surface Water Diversions and Groundwater Pumping

Figures F-1 and F-2 show the histograms for the WY1922-2003 average monthly projected surface water diversions and groundwater pumping for C2VSIM projected level run, respectively.



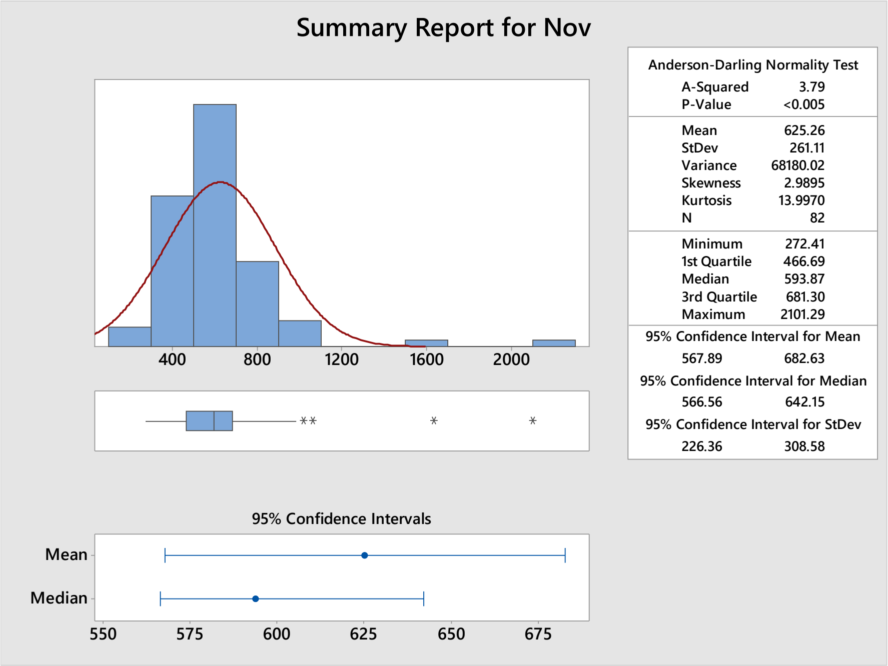
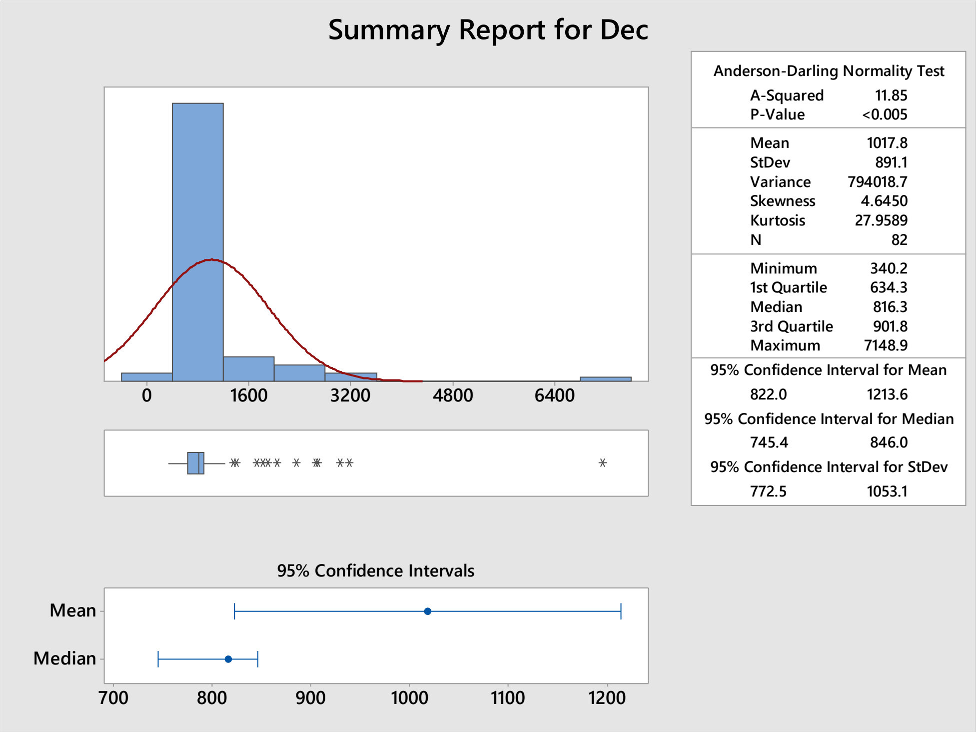


Figure F-1 – Histograms for C2VSIM Monthly Projected 2003 WY1922-2003 Surface Water Diversions in TAF



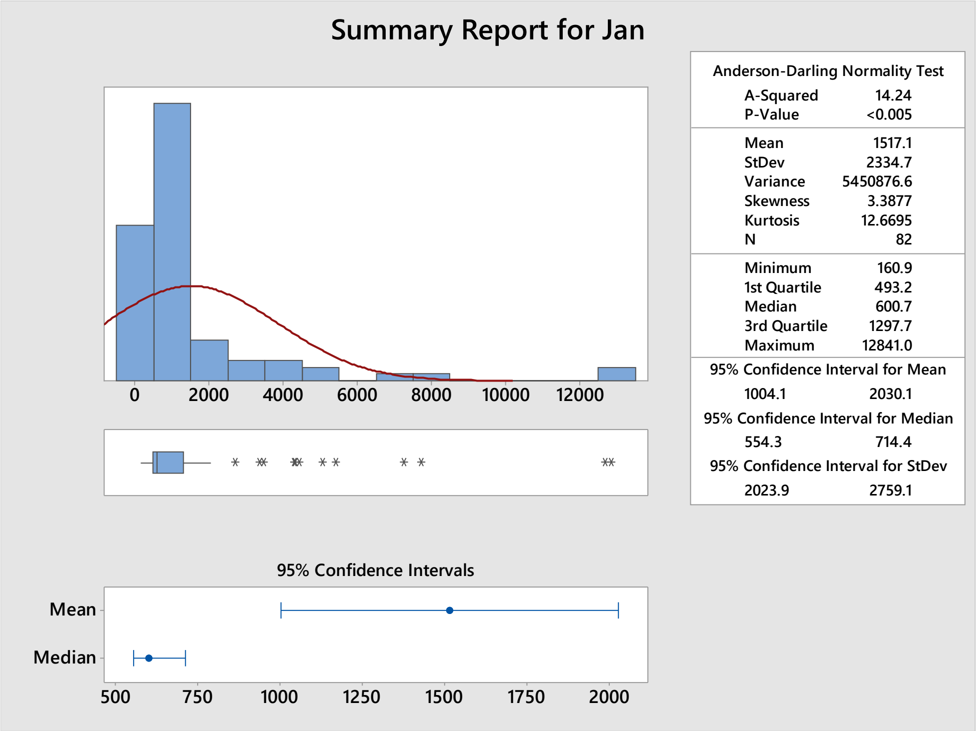
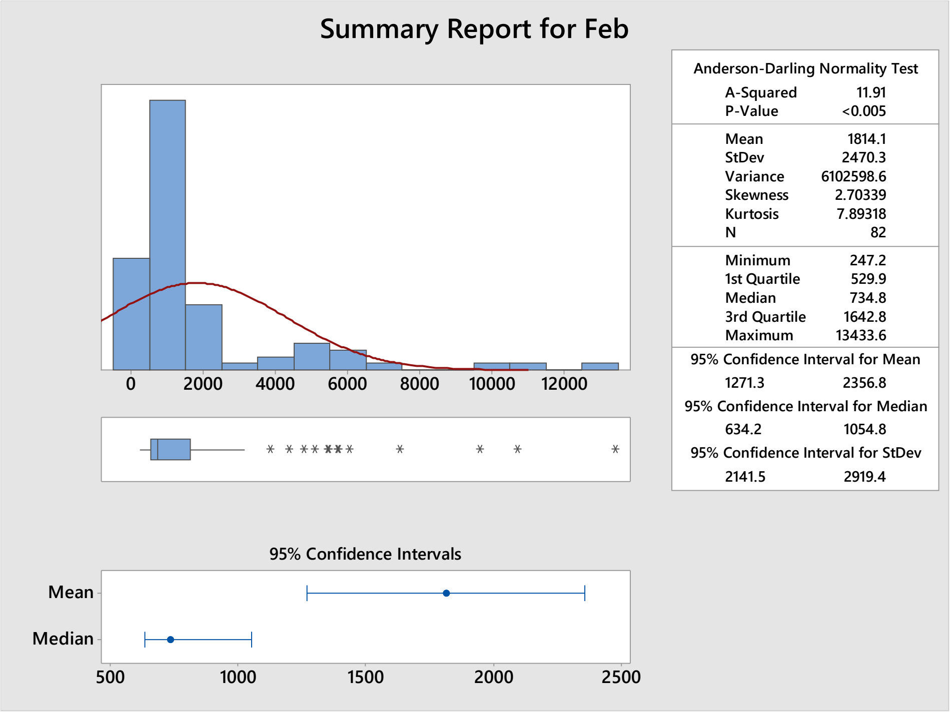
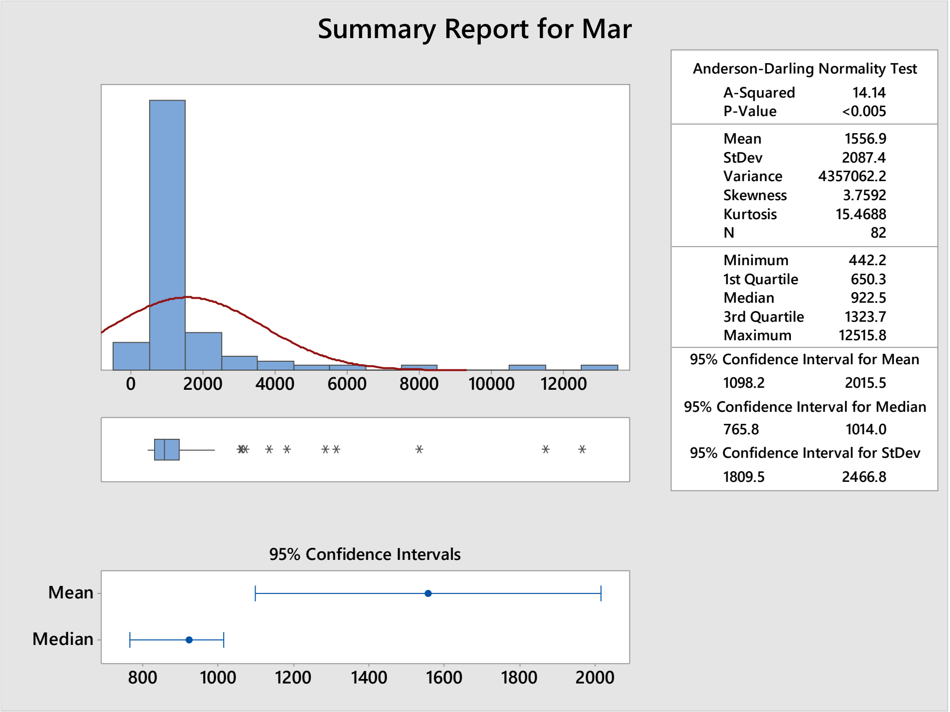


Figure F-1 (cont.) – Histograms for C2VSIM Monthly Projected 2003 WY1922-2003 Surface Water Diversions in TAF

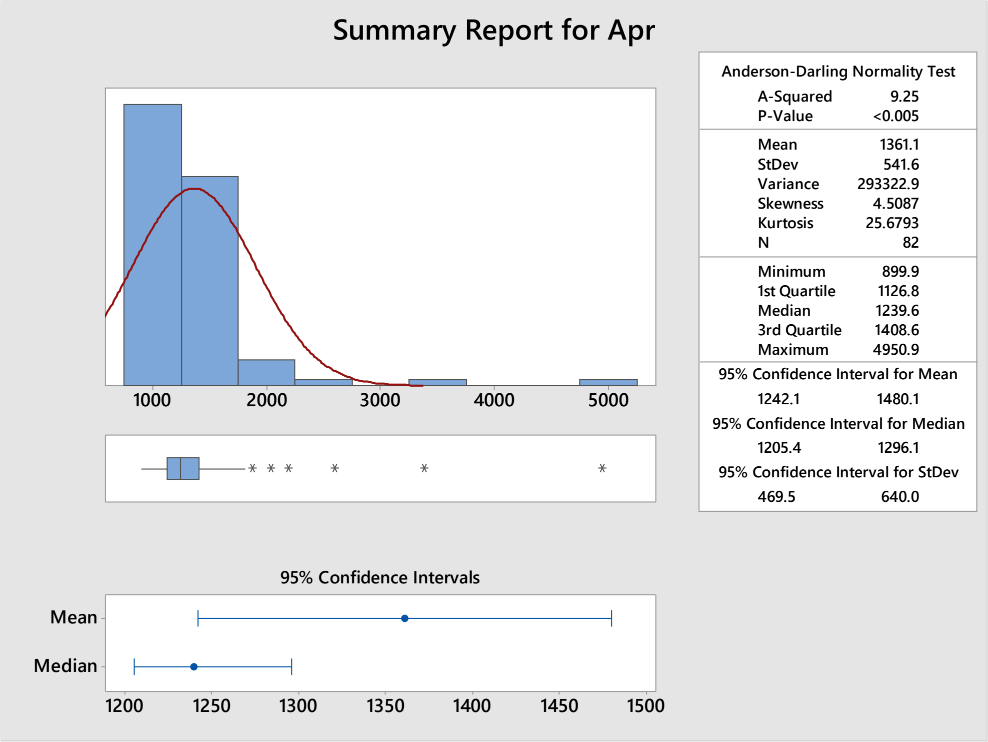


Anderson-Darling Normality Test	
A-Squared	11.91
P-Value	<0.005
Mean	1814.1
StDev	2470.3
Variance	6102598.6
Skewness	2.70339
Kurtosis	7.89318
N	82
Minimum	247.2
1st Quartile	529.9
Median	734.8
3rd Quartile	1642.8
Maximum	13433.6
95% Confidence Interval for Mean	
1271.3	2356.8
95% Confidence Interval for Median	
634.2	1054.8
95% Confidence Interval for StDev	
2141.5	2919.4

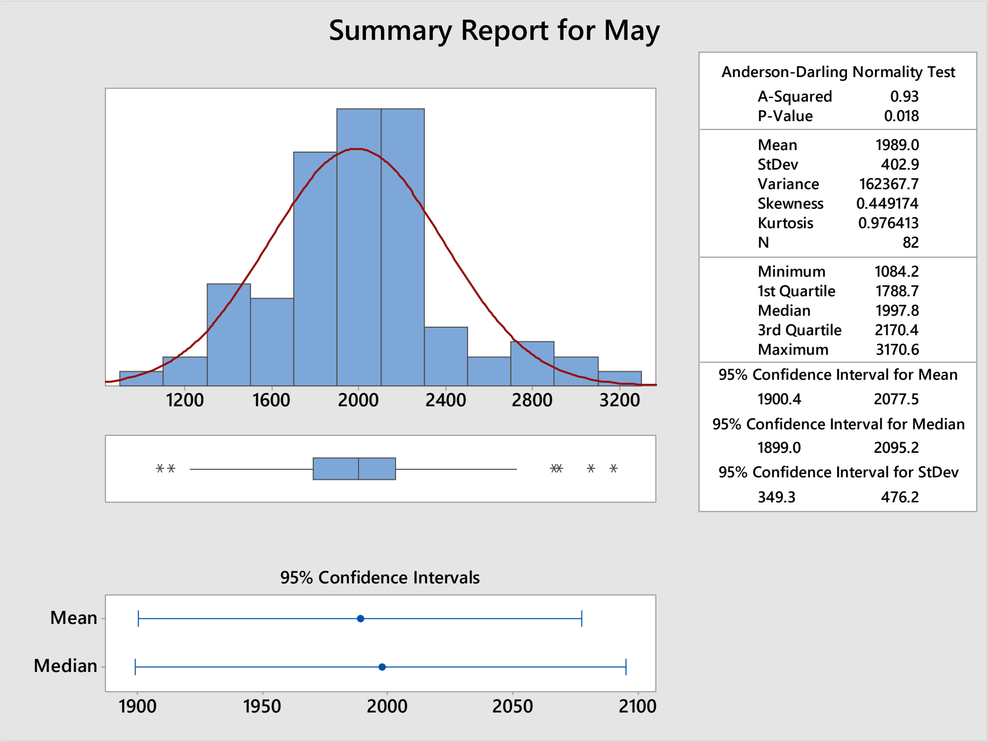


Anderson-Darling Normality Test	
A-Squared	14.14
P-Value	<0.005
Mean	1556.9
StDev	2087.4
Variance	4357062.2
Skewness	3.7592
Kurtosis	15.4688
N	82
Minimum	442.2
1st Quartile	650.3
Median	922.5
3rd Quartile	1323.7
Maximum	12515.8
95% Confidence Interval for Mean	
1098.2	2015.5
95% Confidence Interval for Median	
765.8	1014.0
95% Confidence Interval for StDev	
1809.5	2466.8

Figure F-1 (cont.) – Histograms for C2VSIM Monthly Projected 2003 WY1922-2003 Surface Water Diversions in TAF

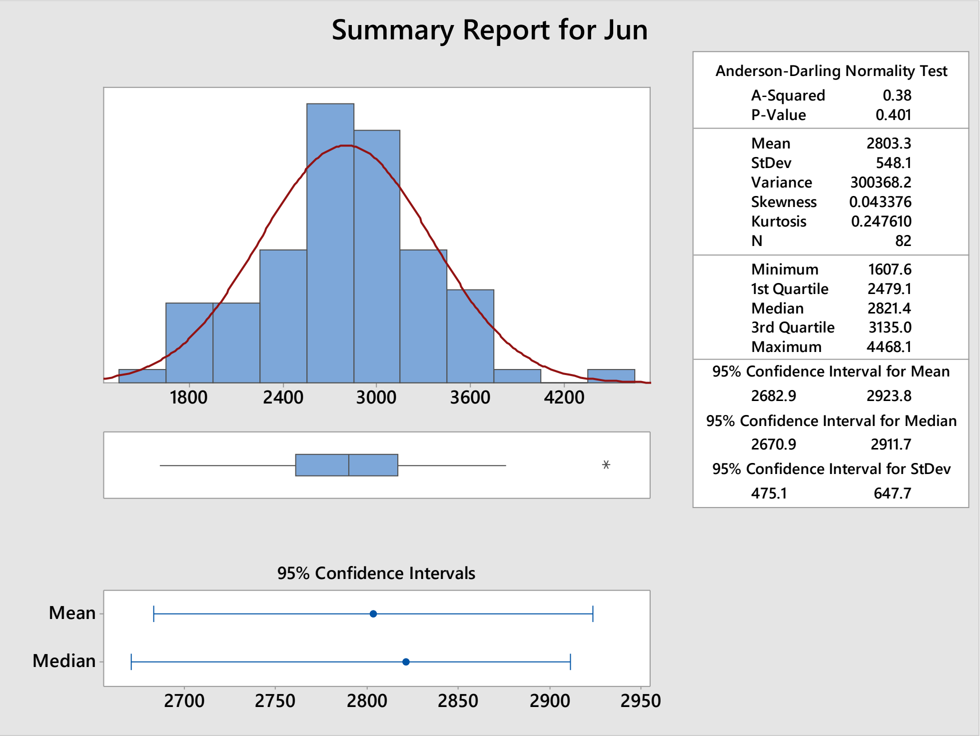


Anderson-Darling Normality Test	
A-Squared	9.25
P-Value	<0.005
Mean	1361.1
StDev	541.6
Variance	293322.9
Skewness	4.5087
Kurtosis	25.6793
N	82
Minimum	899.9
1st Quartile	1126.8
Median	1239.6
3rd Quartile	1408.6
Maximum	4950.9
95% Confidence Interval for Mean	
1242.1	1480.1
95% Confidence Interval for Median	
1205.4	1296.1
95% Confidence Interval for StDev	
469.5	640.0



Anderson-Darling Normality Test	
A-Squared	0.93
P-Value	0.018
Mean	1989.0
StDev	402.9
Variance	162367.7
Skewness	0.449174
Kurtosis	0.976413
N	82
Minimum	1084.2
1st Quartile	1788.7
Median	1997.8
3rd Quartile	2170.4
Maximum	3170.6
95% Confidence Interval for Mean	
1900.4	2077.5
95% Confidence Interval for Median	
1899.0	2095.2
95% Confidence Interval for StDev	
349.3	476.2

Figure F-1 (cont.) – Histograms for C2VSIM Monthly Projected 2003 WY1922-2003 Surface Water Diversions in TAF



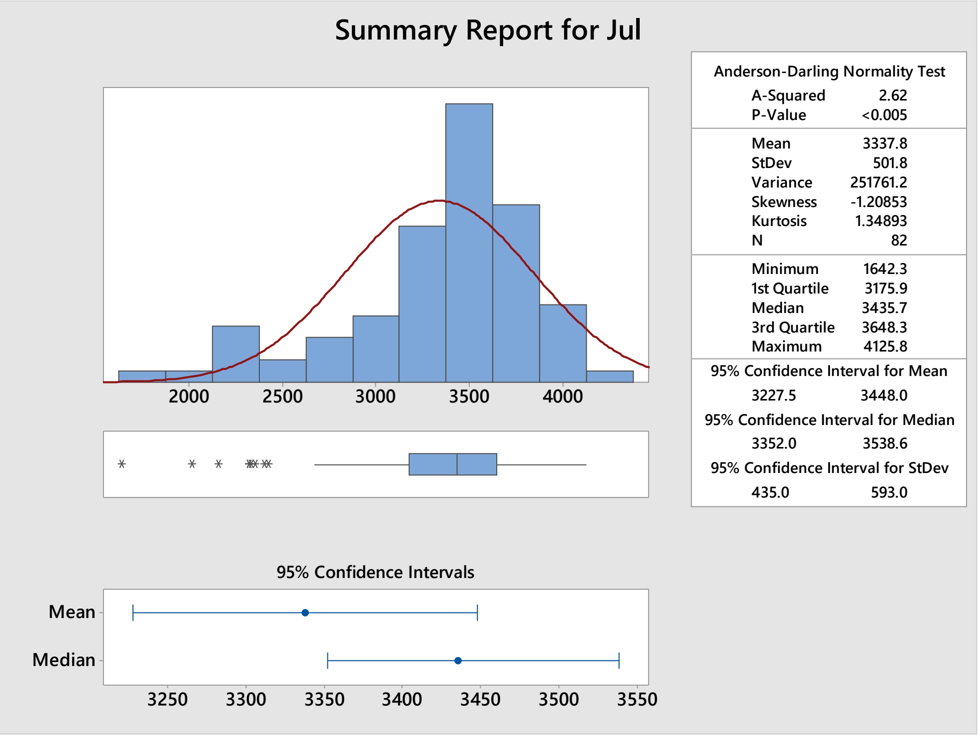
Anderson-Darling Normality Test
A-Squared 0.38
P-Value 0.401

Mean	2803.3
StDev	548.1
Variance	300368.2
Skewness	0.043376
Kurtosis	0.247610
N	82
Minimum	1607.6
1st Quartile	2479.1
Median	2821.4
3rd Quartile	3135.0
Maximum	4468.1

95% Confidence Interval for Mean
2682.9 2923.8

95% Confidence Interval for Median
2670.9 2911.7

95% Confidence Interval for StDev
475.1 647.7



Anderson-Darling Normality Test
A-Squared 2.62
P-Value <0.005

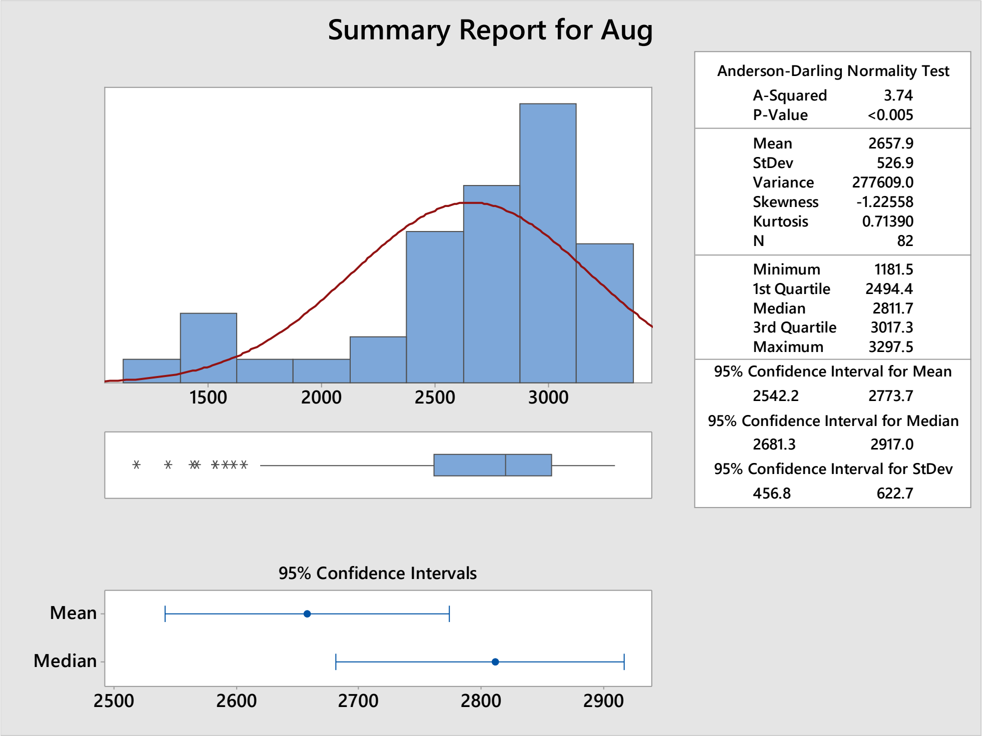
Mean	3337.8
StDev	501.8
Variance	251761.2
Skewness	-1.20853
Kurtosis	1.34893
N	82
Minimum	1642.3
1st Quartile	3175.9
Median	3435.7
3rd Quartile	3648.3
Maximum	4125.8

95% Confidence Interval for Mean
3227.5 3448.0

95% Confidence Interval for Median
3352.0 3538.6

95% Confidence Interval for StDev
435.0 593.0

Figure F-1 (cont.) – Histograms for C2VSIM Monthly Projected 2003 WY1922-2003 Surface Water Diversions in TAF



Anderson-Darling Normality Test
A-Squared 3.74
P-Value <0.005

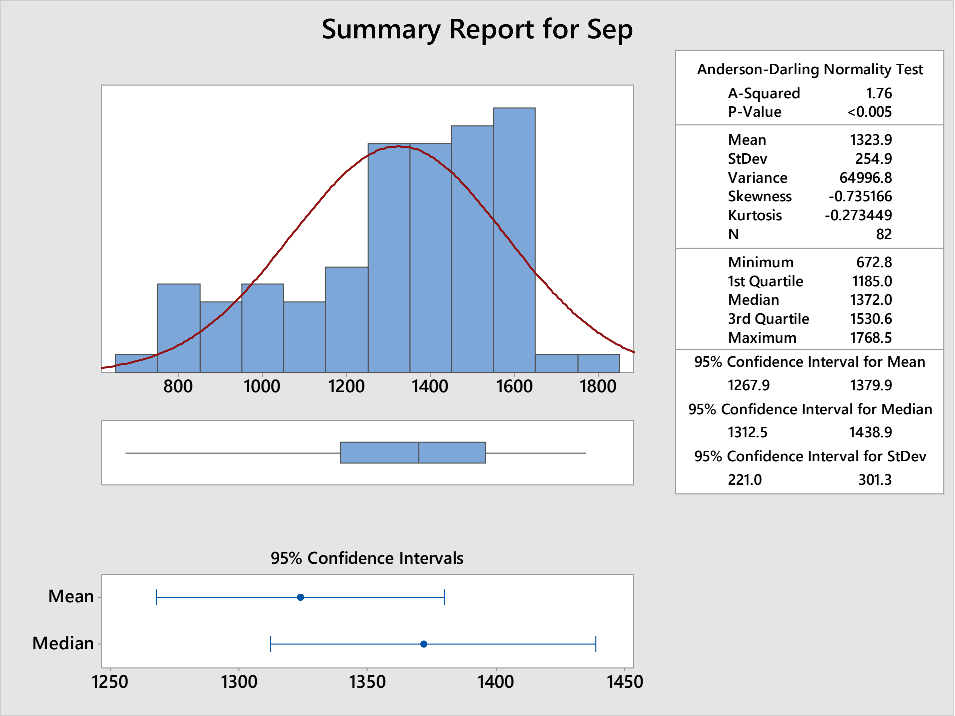
Mean 2657.9
StDev 526.9
Variance 277609.0
Skewness -1.22558
Kurtosis 0.71390
N 82

Minimum 1181.5
1st Quartile 2494.4
Median 2811.7
3rd Quartile 3017.3
Maximum 3297.5

95% Confidence Interval for Mean
2542.2 2773.7

95% Confidence Interval for Median
2681.3 2917.0

95% Confidence Interval for StDev
456.8 622.7



Anderson-Darling Normality Test
A-Squared 1.76
P-Value <0.005

Mean 1323.9
StDev 254.9
Variance 64996.8
Skewness -0.735166
Kurtosis -0.273449
N 82

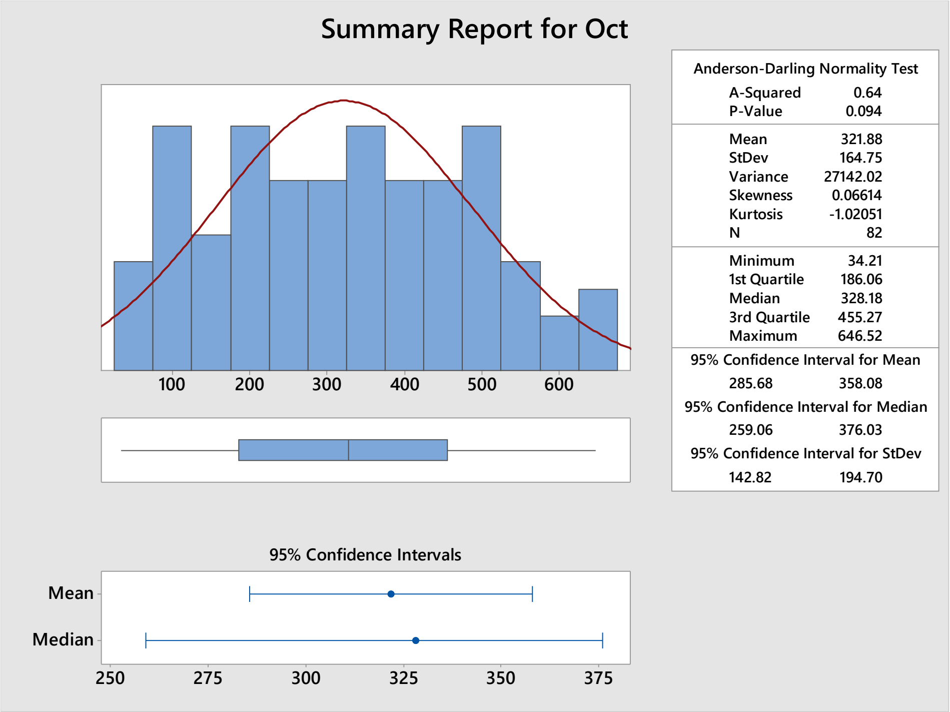
Minimum 672.8
1st Quartile 1185.0
Median 1372.0
3rd Quartile 1530.6
Maximum 1768.5

95% Confidence Interval for Mean
1267.9 1379.9

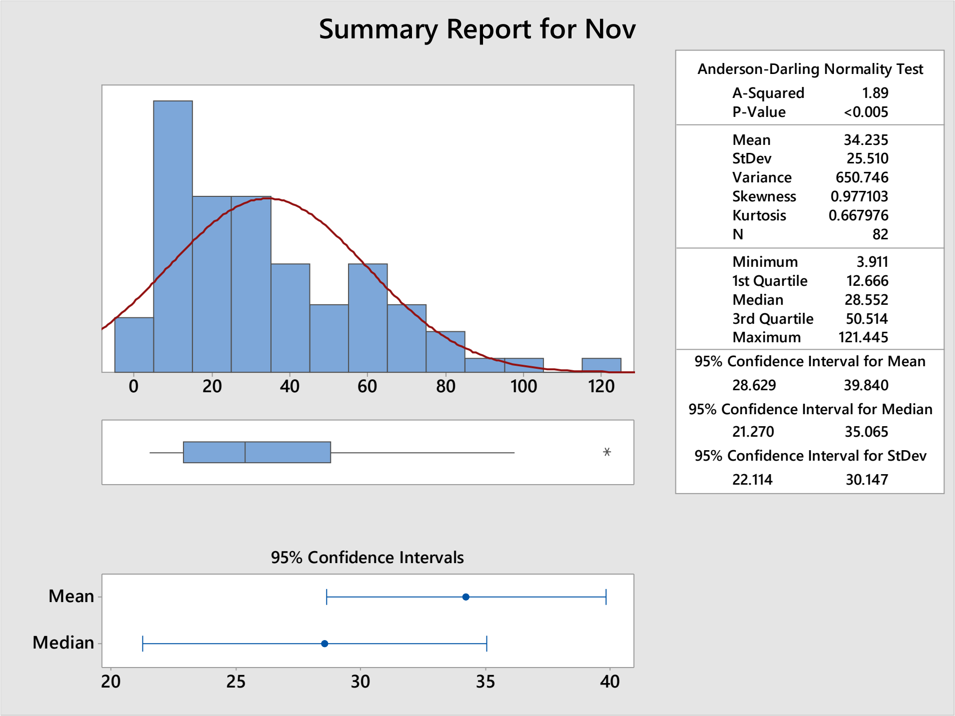
95% Confidence Interval for Median
1312.5 1438.9

95% Confidence Interval for StDev
221.0 301.3

Figure F-1 (cont.) – Histograms for C2VSIM Monthly Projected 2003 WY1922-2003 Surface Water Diversions in TAF

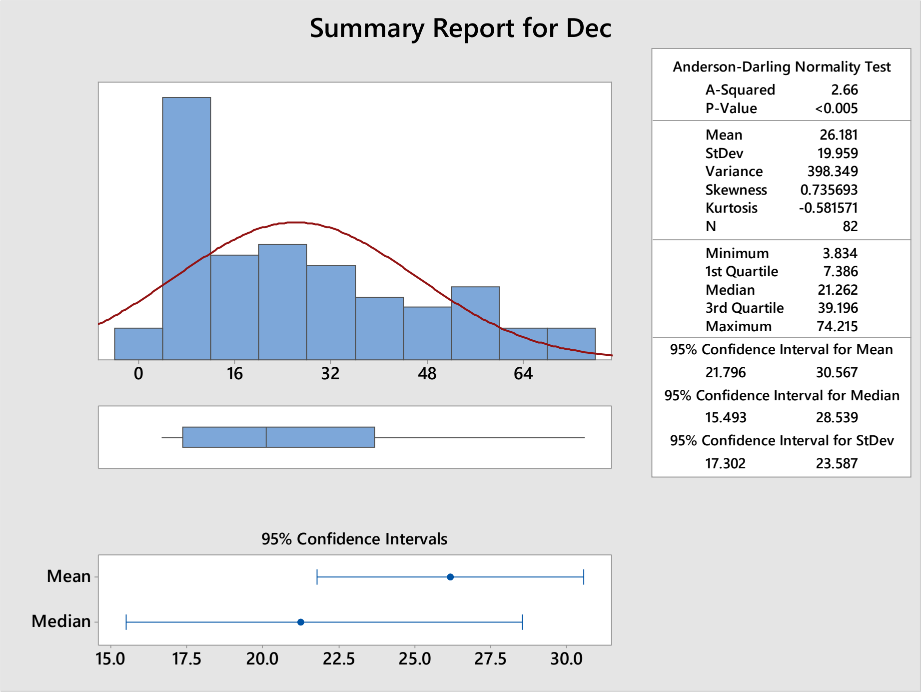


Anderson-Darling Normality Test	
A-Squared	0.64
P-Value	0.094
Mean	321.88
StDev	164.75
Variance	27142.02
Skewness	0.06614
Kurtosis	-1.02051
N	82
Minimum	34.21
1st Quartile	186.06
Median	328.18
3rd Quartile	455.27
Maximum	646.52
95% Confidence Interval for Mean	
285.68	358.08
95% Confidence Interval for Median	
259.06	376.03
95% Confidence Interval for StDev	
142.82	194.70

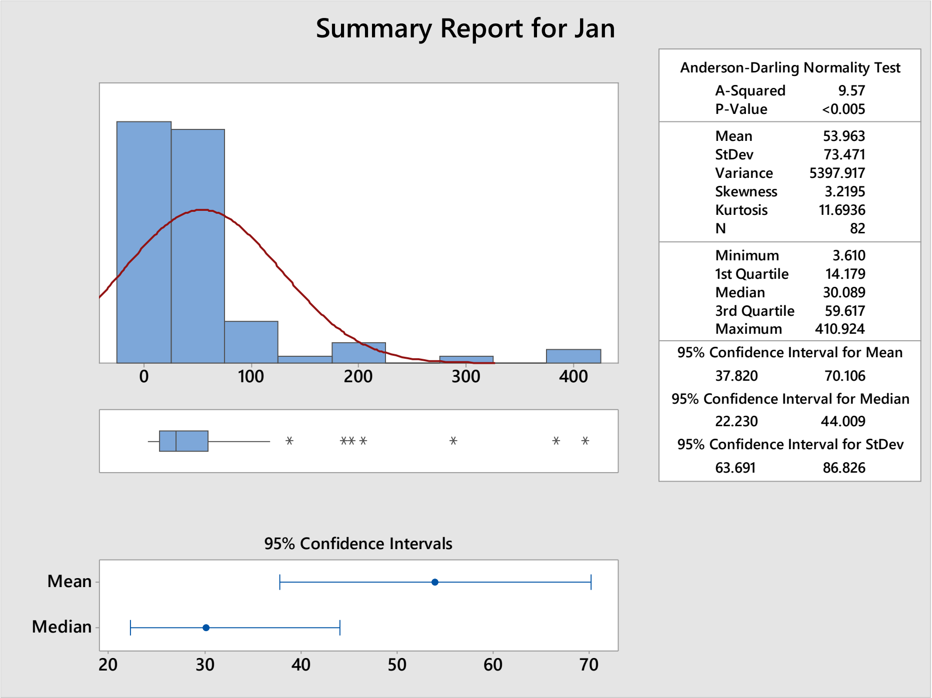


Anderson-Darling Normality Test	
A-Squared	1.89
P-Value	<0.005
Mean	34.235
StDev	25.510
Variance	650.746
Skewness	0.977103
Kurtosis	0.667976
N	82
Minimum	3.911
1st Quartile	12.666
Median	28.552
3rd Quartile	50.514
Maximum	121.445
95% Confidence Interval for Mean	
28.629	39.840
95% Confidence Interval for Median	
21.270	35.065
95% Confidence Interval for StDev	
22.114	30.147

Figure F-2 – Histograms for C2VSIM Monthly Projected 2003 WY1922-2003 Groundwater Pumping in TAF

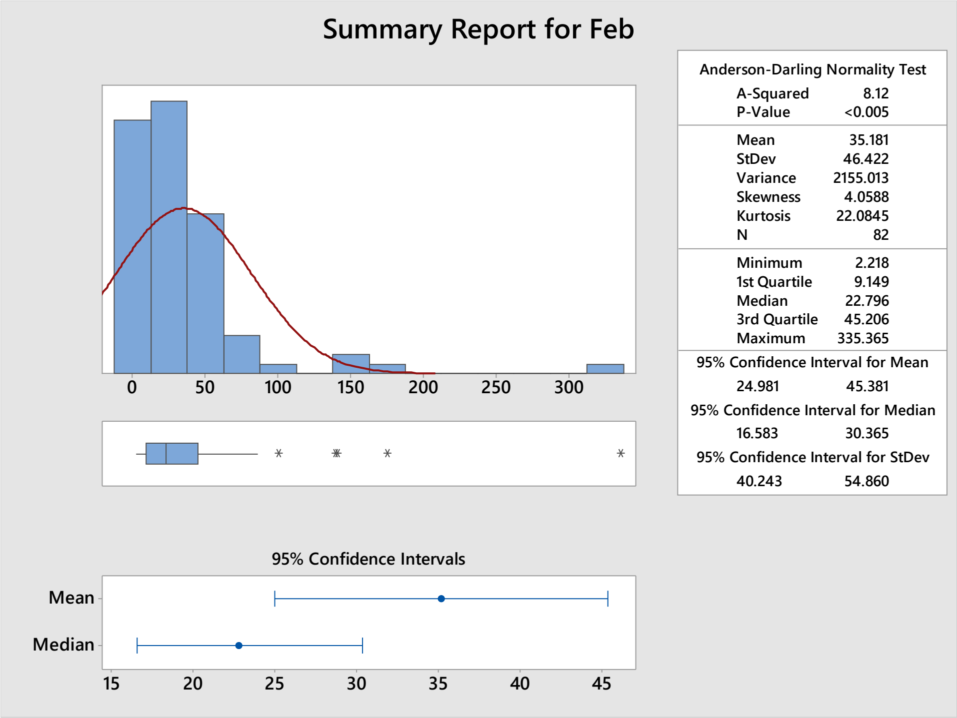

Summary Report for Dec

```
Anderson-Darling Normality Test
   A-Squared           2.66
   P-Value           <0.005

   Mean              26.181
   StDev             19.959
   Variance         398.349
   Skewness        0.735693
   Kurtosis       -0.581571
   N                     82

   Minimum            3.834
   1st Quartile       7.386
   Median            21.262
   3rd Quartile      39.196
   Maximum           74.215
95% Confidence Interval for Mean
   21.796            30.567
95% Confidence Interval for Median
   15.493            28.539
95% Confidence Interval for StDev
   17.302            23.587
```

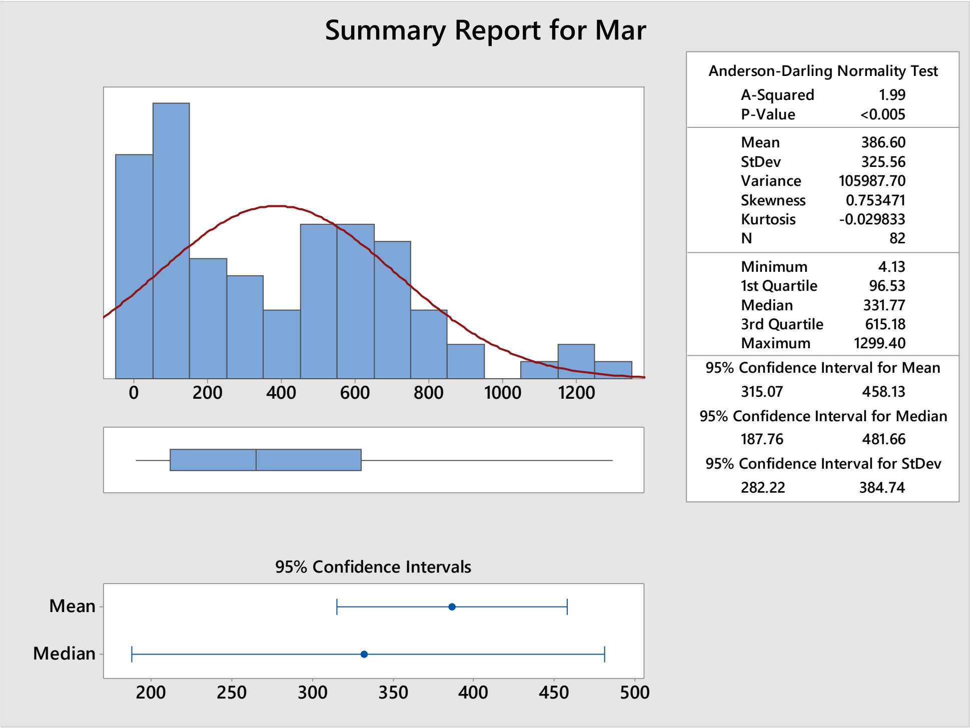

Summary Report for Jan

```
Anderson-Darling Normality Test
   A-Squared           9.57
   P-Value           <0.005

   Mean              53.963
   StDev             73.471
   Variance        5397.917
   Skewness          3.2195
   Kurtosis         11.6936
   N                     82

   Minimum            3.610
   1st Quartile      14.179
   Median            30.089
   3rd Quartile      59.617
   Maximum          410.924
95% Confidence Interval for Mean
   37.820            70.106
95% Confidence Interval for Median
   22.230            44.009
95% Confidence Interval for StDev
   63.691            86.826
```

Figure F-2 (cont.) – Histograms for C2VSIM Monthly Projected 2003 WY1922-2003 Groundwater Pumping in TAF

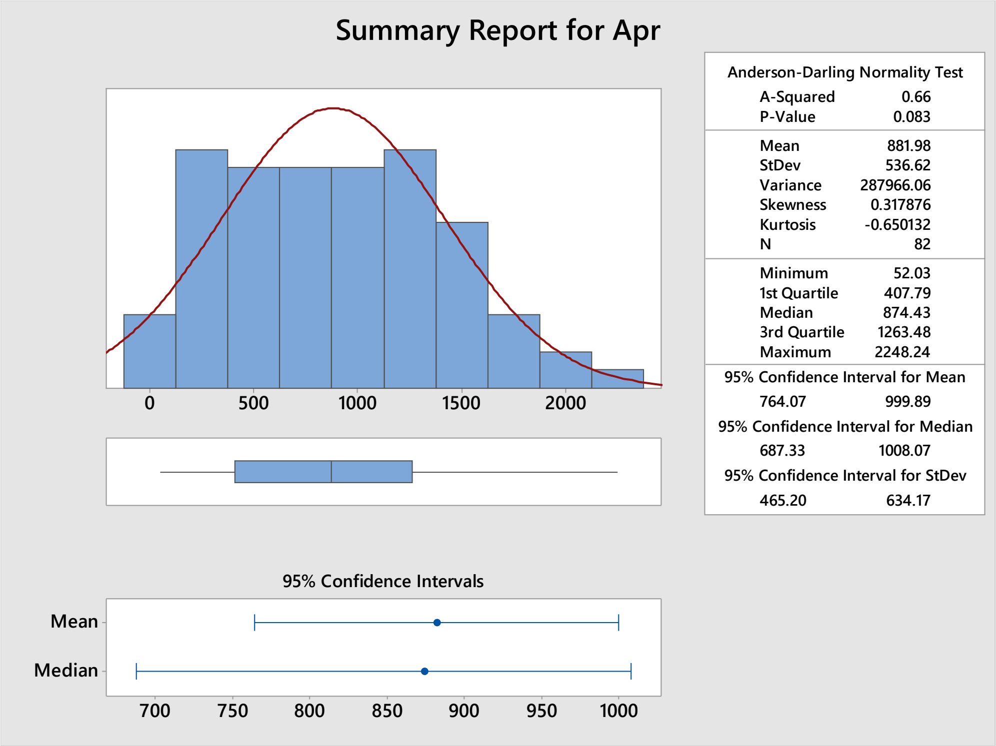


Anderson-Darling Normality Test	
A-Squared	8.12
P-Value	<0.005
Mean	35.181
StDev	46.422
Variance	2155.013
Skewness	4.0588
Kurtosis	22.0845
N	82
Minimum	2.218
1st Quartile	9.149
Median	22.796
3rd Quartile	45.206
Maximum	335.365
95% Confidence Interval for Mean	
24.981	45.381
95% Confidence Interval for Median	
16.583	30.365
95% Confidence Interval for StDev	
40.243	54.860

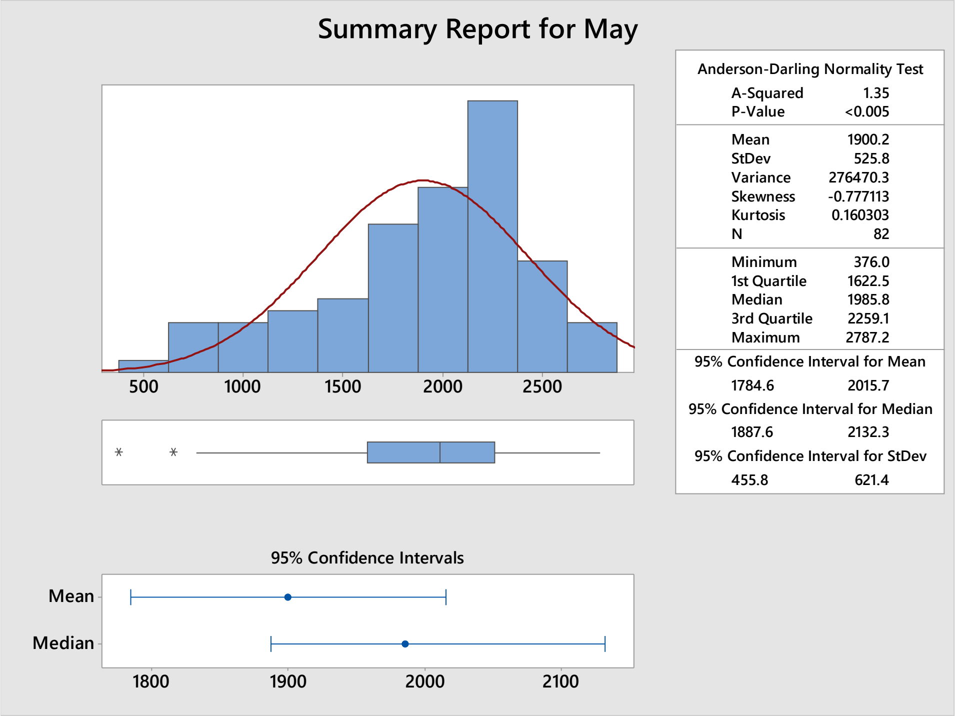


Anderson-Darling Normality Test	
A-Squared	1.99
P-Value	<0.005
Mean	386.60
StDev	325.56
Variance	105987.70
Skewness	0.753471
Kurtosis	-0.029833
N	82
Minimum	4.13
1st Quartile	96.53
Median	331.77
3rd Quartile	615.18
Maximum	1299.40
95% Confidence Interval for Mean	
315.07	458.13
95% Confidence Interval for Median	
187.76	481.66
95% Confidence Interval for StDev	
282.22	384.74

Figure F-2 – Histograms for C2VSIM Monthly Projected 2003 WY1922-2003 Groundwater Pumping in TAF

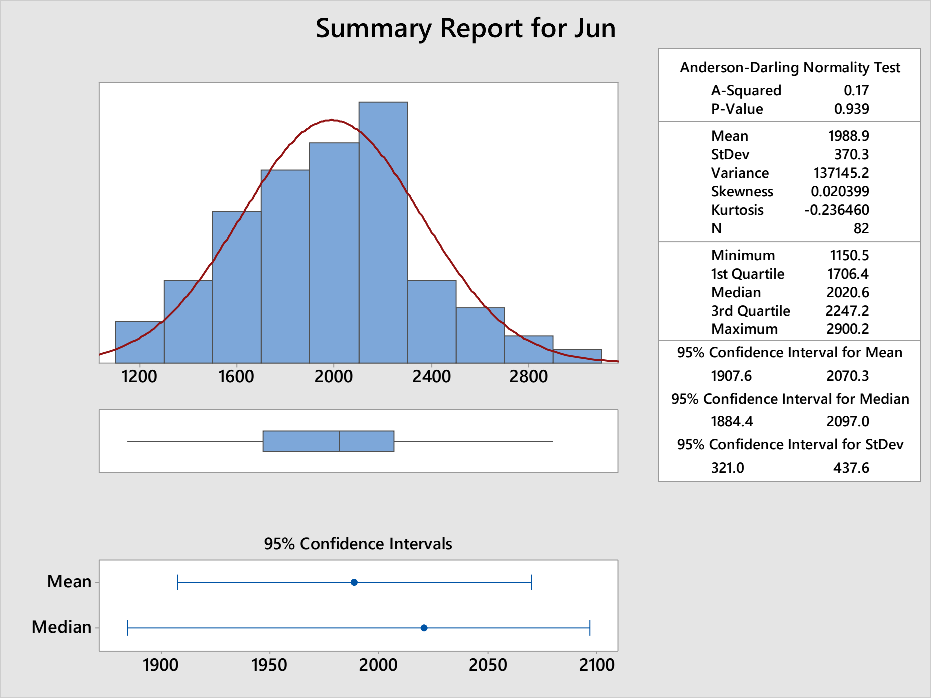

Summary Report for Apr

Anderson-Darling Normality Test	
A-Squared	0.66
P-Value	0.083
Mean	881.98
StDev	536.62
Variance	287966.06
Skewness	0.317876
Kurtosis	-0.650132
N	82
Minimum	52.03
1st Quartile	407.79
Median	874.43
3rd Quartile	1263.48
Maximum	2248.24
95% Confidence Interval for Mean	
764.07	999.89
95% Confidence Interval for Median	
687.33	1008.07
95% Confidence Interval for StDev	
465.20	634.17

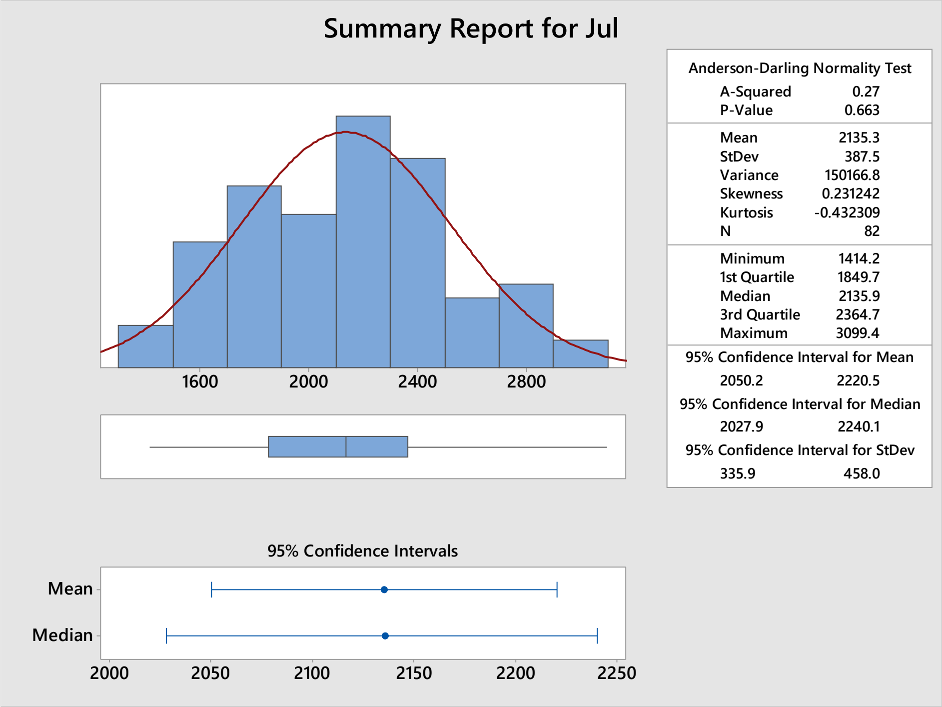

Summary Report for May

Anderson-Darling Normality Test	
A-Squared	1.35
P-Value	<0.005
Mean	1900.2
StDev	525.8
Variance	276470.3
Skewness	-0.777113
Kurtosis	0.160303
N	82
Minimum	376.0
1st Quartile	1622.5
Median	1985.8
3rd Quartile	2259.1
Maximum	2787.2
95% Confidence Interval for Mean	
1784.6	2015.7
95% Confidence Interval for Median	
1887.6	2132.3
95% Confidence Interval for StDev	
455.8	621.4

Figure F-2 – Histograms for C2VSIM Monthly Projected 2003 WY1922-2003 Groundwater Pumping in TAF

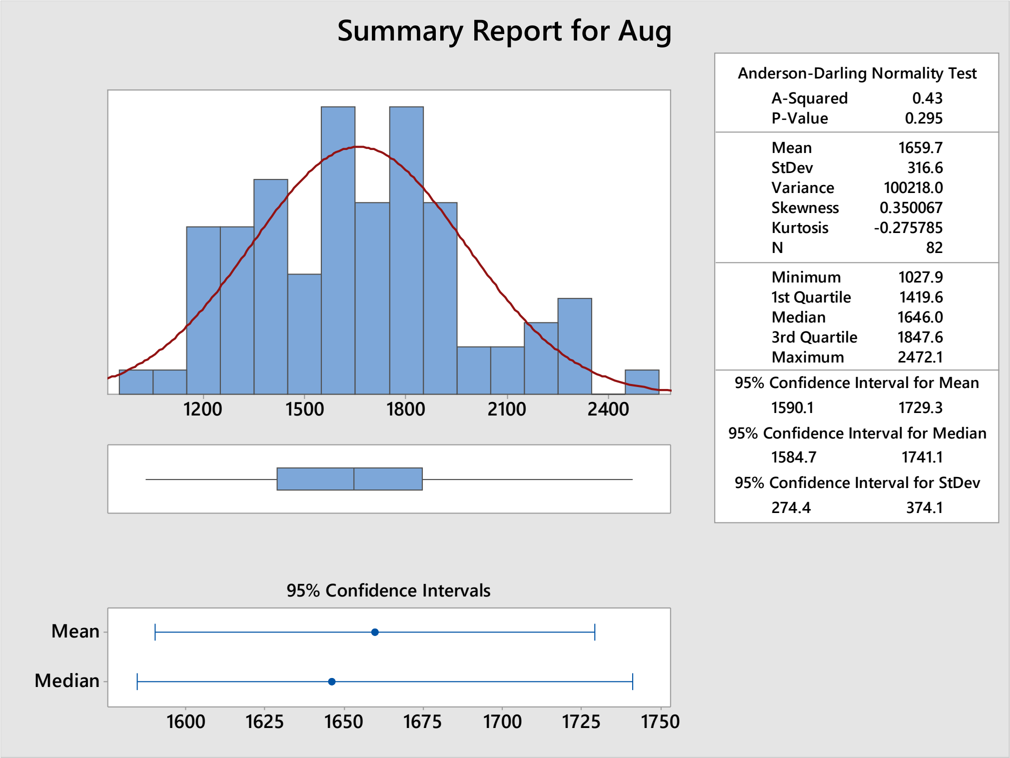


Anderson-Darling Normality Test	
A-Squared	0.17
P-Value	0.939
Mean	1988.9
StDev	370.3
Variance	137145.2
Skewness	0.020399
Kurtosis	-0.236460
N	82
Minimum	1150.5
1st Quartile	1706.4
Median	2020.6
3rd Quartile	2247.2
Maximum	2900.2
95% Confidence Interval for Mean	
1907.6	2070.3
95% Confidence Interval for Median	
1884.4	2097.0
95% Confidence Interval for StDev	
321.0	437.6



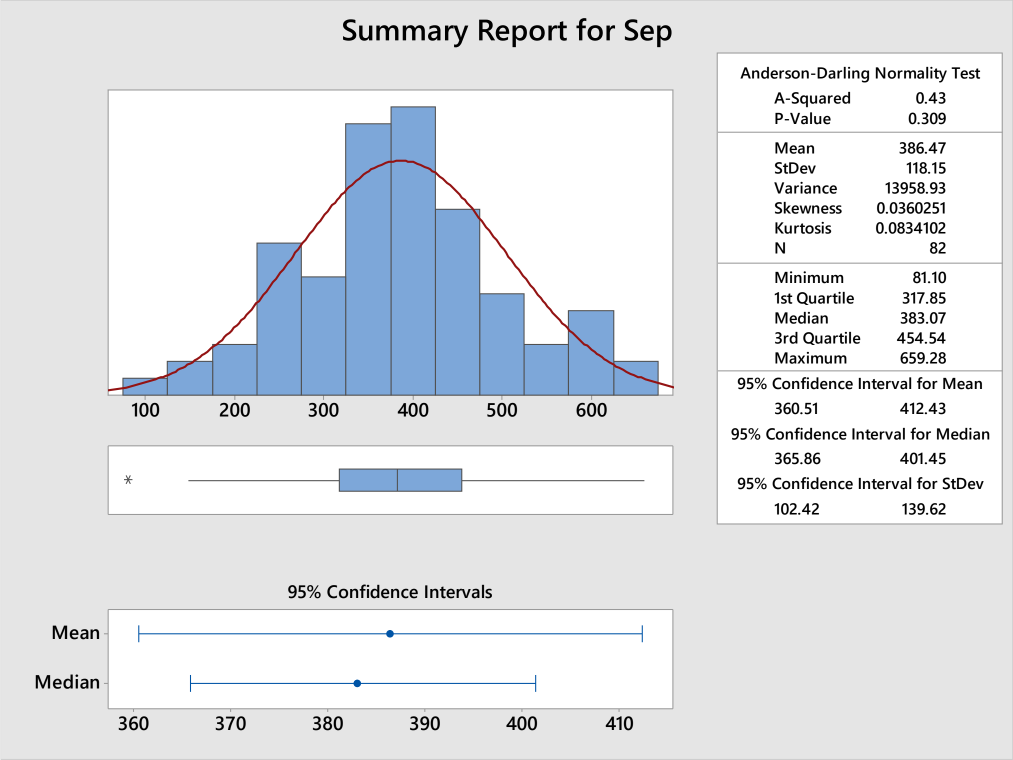
Anderson-Darling Normality Test	
A-Squared	0.27
P-Value	0.663
Mean	2135.3
StDev	387.5
Variance	150166.8
Skewness	0.231242
Kurtosis	-0.432309
N	82
Minimum	1414.2
1st Quartile	1849.7
Median	2135.9
3rd Quartile	2364.7
Maximum	3099.4
95% Confidence Interval for Mean	
2050.2	2220.5
95% Confidence Interval for Median	
2027.9	2240.1
95% Confidence Interval for StDev	
335.9	458.0

Figure F-2 – Histograms for C2VSIM Monthly Projected 2003 WY1922-2003 Groundwater Pumping in TAF



Summary Report for Aug

Anderson-Darling Normality Test	
A-Squared	0.43
P-Value	0.295
Mean	1659.7
StDev	316.6
Variance	100218.0
Skewness	0.350067
Kurtosis	-0.275785
N	82
Minimum	1027.9
1st Quartile	1419.6
Median	1646.0
3rd Quartile	1847.6
Maximum	2472.1
95% Confidence Interval for Mean	
1590.1	1729.3
95% Confidence Interval for Median	
1584.7	1741.1
95% Confidence Interval for StDev	
274.4	374.1



Summary Report for Sep

Anderson-Darling Normality Test	
A-Squared	0.43
P-Value	0.309
Mean	386.47
StDev	118.15
Variance	13958.93
Skewness	0.0360251
Kurtosis	0.0834102
N	82
Minimum	81.10
1st Quartile	317.85
Median	383.07
3rd Quartile	454.54
Maximum	659.28
95% Confidence Interval for Mean	
360.51	412.43
95% Confidence Interval for Median	
365.86	401.45
95% Confidence Interval for StDev	
102.42	139.62

Figure F-2 – Histograms for C2VSIM Monthly Projected 2003 WY1922-2003 Groundwater Pumping in TAF

Appendix G. WRESL Code for SIM2

This appendix lists the WRESL code developed by the author for running SIM2 through WRIMS. All the folders and files are shown, but only about a third of the code is listed for space saving.

RUN Folder

Ex2.wresl

```
/*
 EXAMPLE 1 (SimOP)
 Main WRESL File
*/

! SEQUENCE block defines the model solution sequence
SEQUENCE One {
   MODEL   Mod1
   ORDER   1
}

! MODEL block defines files included in model "MOD1"
MODEL Mod1 {
            INCLUDE 'system\system.wresl'
      INCLUDE 'Export_ops\exportratio.wresl'
            INCLUDE 'misc\pumping_cap.wresl'
      INCLUDE 'coa\coa.wresl'
      INCLUDE 'misc\sodstor.wresl'
            INCLUDE 'wytypes\wytypes.wresl'
            INCLUDE 'system\weight-table.wresl'
            INCLUDE 'system\report.wresl'
```

COA Folder

coa.wresl

```
!coa.wresl

!****************** DEFINES  ***********************************

! define decision variables to be used in the COA statements
define SWPDS {lower -1000000. upper 1000000. kind 'STORAGE-CHANGE' UNITS 'CFS'} !  SWP change in storage
define CVPDS {lower -1000000. upper 1000000. kind 'STORAGE-CHANGE' UNITS 'CFS'} !  CVP change in storage
define IBU   {std kind 'IBU' UNITS 'CFS'}                        !  Total In-Basin-Uses met with storage withdrawals
define UWFE  {std kind 'UWFE' UNITS 'CFS'}                        !  Total Unstored-Water-For-Export
define CVP_SHARE {std kind 'PERCENT-COA' UNITS 'NONE'}            !  CVP COA Share
define SWP_SHARE {std kind 'PERCENT-COA' UNITS 'NONE'}            !  SWP COA Share
define UNUSED_FS {std kind 'UNUSED-FS' UNITS 'CFS' }              !  Unused Federal Share of surplus
define UNUSED_SS {std kind 'UNUSED-SS' UNITS 'CFS' }              !  Unused State Share of surplus
:
:
:
goal swp_storage_change {SWPDS = C2 - I2}!Define SWP Storage Change
goal cvp_storage_change {CVPDS = C1 - I1 + C3 - I3} !Define CVP Storage Change
```

```
! ********************* COA BALANCE CONSTRAINTS ******************************************
define D900e_EXP1 {std kind 'FLOW-DELIVERY' units 'CFS'}
define D900e_EXP2 {std kind 'FLOW-DELIVERY' units 'CFS'}
:
:
:
goal COA_balance {UWFE - IBU = C1000_MIFcvp  + C1000_MIFswp + D900e_EXP1 + D900d + D900c_EXP1 + D900b
- CVPDS - SWPDS + UNUSED_FS + UNUSED_SS}

goal UWFE_force {UWFE < int_IBU_UWFE * IBU_UWFE_max}                    ! if int=0, UWFE=0, IBU=pos
goal IBU_force  {IBU < IBU_UWFE_max - int_IBU_UWFE * IBU_UWFE_max}        ! if int=1, UWFE=pos, IBU=0

define CVP_UWFE {value 0.55}                        ! CVP COA Share of unstored water for export
define CVP_IBU  {value 0.75}                        ! CVP COA Share of storage withdrawals
:
:
:
goal setUNUSED_FS { D900c_EXP2 < UNUSED_FS }
goal setUNUSED_SS { D900e_EXP2 < UNUSED_SS }

! Attempt to split export even during EI control situations

goal EI_split_swp {
    lhs     D900c_EXP1
    rhs       0.5*EiExpCtrl
    lhs>rhs    penalty 100
    lhs<rhs    penalty 0
}
goal EI_split_cvp {
    lhs     D900e_EXP1
    rhs       0.5*EiExpCtrl
    lhs>rhs    penalty 100
    lhs<rhs    penalty 0
}
```

EXPORT_OPS Folder

exportratio.wresl

```
! Export-Inflow Ratio restriction on exports

! Delta Export defined as in DWRSIM Algorithm Description for Export Ratio
define ExportActual {alias D900c+D900e KIND 'EXPORT-PRJ' units 'CFS'  }

! Delta Inflow defined as in DWRSIM Algorithm Description for Export Ratio
define Inflow {alias C680 kind 'INFLOW-DELTA' UNITS 'CFS'   }

! EI allowable export variable - MAXIMUM ALLOWABLE EXPORT due to EXPORT RATIO
define EiExpCtrl {std kind 'EXPORT-CTRL-EI' units 'CFS'}
! EI Ratio dependent on month
define ExpRatio {
   case feb    {
```

```
:
:
:
! Compute exports allowable by the EI ratio
goal find_max_export {EiExpCtrl = ExpRatio*Inflow}

! Restrict exports to be less than that allowable by EI ratio
goal export_comply { ExportActual < EiExpCtrl }
```

LOOKUP Folder

demand.table

```
demand
D_arc     month    demand
```

EiRatio.table

```
! Export-Inflow Ratio (WQCP 1995)
! Feb Ratio is determined by 8-river-index (see FebEiRatio.table)
EiRatio
month   ratio
1      0.65
2      0.65
3      0.65
4      0.65
5      0.00
6      0.35
7      0.35
8      0.35
9      0.35
10      0.65
11      0.65
12      0.65
```

FebEiRatio.table

```
febeiratio
wateryear   ratio
1922       0.44
1923       0.35
1924       0.45
1925       0.45
1926       0.45
:
:
:
1995       0.35
1996       0.35
1997       0.35
1998       0.35
1999       0.35
2000       0.35
2001       0.45
```

```
2002     0.35
2003     0.35
```

inflow.table

```
inflow
I_arc   month   inflow
```

minflow.table

```
minflow
C_arc   month   minflow
```

res_info.table

```
res_info
res_num     storage     area      discharge     elevation
1           0           0         0             0
1           100000      2400      0             738
1           150000      2800      4000          750
:
:
1           3713000     26400     80000         1037
1           4552100     30000     271000        1067
2           0           0         50000         340
2           29638       594       50000         340
2           120000      1553      50000         440
2           480000      3950      50000         570
2           846367      5810      50000         639
:
:
2           3553405     15855     280000        901
2           3864497     16899     750000        920
3           0           0         0             0
3           10          2         0             210
3           47723       1311      16800         305
3           93313       2152      28090         332
:
:
3           677845      9406      132770        437
3           976955      11183     466690        466
4           0           0         0             0
4           42000       1864      14376         326.2
4           157500      3369      14376         369.2
:
:
4           997500      6518      14376         532.8
4           1102000     6745      14376         548.7
5           0           0         0             0
5           37980       1686      14376         326.2
:
:
5           902500      5897      14376         532.8
5           998000      6103      14376         548.7
```

res_level.table

```
res_level
res_numlevel     month    target
```

wytypeSAC.table

```
wytypeSAC
wateryear     index
1922         2
1923         3
1924         5
1925         4
1926         4
1927         1
:
:
:
1998         1
1999         1
2000         2
2001         4
2002         4
2003         2
```

MISC Folder

pumping_cap.wresl

```
!pumping_cap.wresl

!set maximum pumping limits for CVP and SWP
goal maxLimitCVP {D900e < 4600.}
goal maxLimitSWP {D900c < 10300.}

!set minimum pumping limits for CVP and SWP
goal minLimitCVP {
        lhs D900e
        rhs 800.
        lhs>rhs penalty 0
        lhs<rhs penalty 2000 }

goal minLimitSWP {
        lhs D900c
        rhs 300. !150.
        lhs>rhs penalty 0
        lhs<rhs penalty 2000 }

define totalpumping {std kind 'Total-Pumping' units 'cfs'}
goal set_total {totalpumping = D900c + D900e}
```

sodstor.wresl

```
!sodstor
```

```
define CVPRuleCV {timeseries kind 'Rulecurve' units 'taf'}
define SWPRuleCV {timeseries kind 'Rulecurve' units 'taf'}

define S5level3 {value CVPRuleCV}

goal S5Zone3 {S5_3 < max(0.0,S5level3 - S5level2)}
goal S5Zone4 {S5_4 < S5level4 - S5level3}
goal S5Zone5 {S5_5 < S5level5 - S5level4}

define S4level3 {value SWPRuleCV}

goal S4Zone3 {S4_3 < max(0.0,S4level3 - S4level2)}
goal S4Zone4 {S4_4 < S4level4 - S4level3}
goal S4Zone5 {S4_5 < S4level5 - S4level4}
```

SYSTEM Folder

Adjustment_table.wresl

```
define adj58 {lower unbounded kind 'adjustment' units 'CFS'}
goal adjust58 {
  lhs Adj58
  rhs A58x
  lhs>rhs penalty 9000
  lhs<rhs constrain }

define adj10 {lower unbounded kind 'adjustment' units 'CFS'}
goal adjust10 {
  lhs Adj10
  rhs A10x
  lhs>rhs penalty 9000
  lhs<rhs constrain }
:
:
:
define adj65 {lower unbounded kind 'adjustment' units 'CFS'}
goal adjust65 {
  lhs Adj65
  rhs A65x
  lhs>rhs penalty 9000
  lhs<rhs constrain }

define adj59 {lower unbounded kind 'adjustment' units 'CFS'}
goal adjust59 {
  lhs Adj59
  rhs A59x
  lhs>rhs penalty 9000
  lhs<rhs constrain }
```

Channel-table.wresl

```
define C1    {lower 0 upper 200000 kind 'FLOW-CHANNEL' units 'CFS'} !Shasta Release
define C5_MIF {timeseries kind 'FLOW-MinRequired' units 'CFS'}
```

```
define C1_MIF {std kind 'FLOW-MIN-INSTREAM' units 'CFS'}
define C1_EXC {std kind 'FLOW-EXCESS-INSTREAM' units 'CFS'}
goal C1total {C1=C1_MIF+C1_EXC}
goal C1minflow {C1_MIF < C5_MIF}

define C100  {lower 0 upper 200000 kind 'FLOW-CHANNEL' units 'CFS'}
define C110  {lower 0 upper 200000 kind 'FLOW-CHANNEL' units 'CFS'}
define C120  {lower 0 upper 200000 kind 'FLOW-CHANNEL' units 'CFS'}
define C130  {lower 0 upper 200000 kind 'FLOW-CHANNEL' units 'CFS'}
define C135  {lower 0 upper 200000 kind 'FLOW-CHANNEL' units 'CFS'}
define C140  {lower 0 upper 200000 kind 'FLOW-CHANNEL' units 'CFS'}
:
:
:
define C5  {lower 0 upper 8000 kind 'FLOW-CHANNEL' units 'CFS'}
define C751  {lower 0 upper 13100 kind 'FLOW-CHANNEL' units 'CFS'}
define C752  {lower 0 upper 13100 kind 'FLOW-CHANNEL' units 'CFS'}
define C753  {lower 0 upper 11000 kind 'FLOW-CHANNEL' units 'CFS'}
define C754_slc  {lower 0 upper 11000 kind 'FLOW-CHANNEL' units 'CFS'}
define C754_dmc  {lower 0 upper 11000 kind 'FLOW-CHANNEL' units 'CFS'}
define C755  {lower 0 upper 10000 kind 'FLOW-CHANNEL' units 'CFS'}
define C756  {lower 0 upper 4635 kind 'FLOW-CHANNEL' units 'CFS'}

define C800 {lower 0 upper 10000 kind 'FLOW-CHANNEL' units 'CFS'}
define C801 {lower 0 upper 10000 kind 'FLOW-CHANNEL' units 'CFS'}
define C802 {lower 0 upper 10000 kind 'FLOW-CHANNEL' units 'CFS'}
```

Connectivity-table.wresl

```
goal continuity1 {I1-C1-F1-E1=S1*taf_cfs-S1(-1)*taf_cfs} !Shasta Reservoir
goal continuity2 {C1+M58x+RO58x-D100-C100=0}
goal continuity3 {C100+I58Ax-C110=0}
goal continuity4 {C110+I58Bx+I58Cx-C120=0}
goal continuity5 {C120-D135-Export_58x-C135=0}
goal continuity6 {D100+D135+GWP58-TSR58x=0}
goal conitnuity6a {C135+SEEP58+RF58x-C140+I58Dx=0}

goal continuity9 {C140+RO10x+Adj58-D150a-D150b-C150=0}
goal continuity10 {C150+I10Ax-D155-C155=0}
goal continuity11 {C155+I10Cx+C170-C160=0}
goal continuity12 {I10Bx-D170-C170=0}
goal continuity13 {D170+D150b+GWP10-TSR10x=0}
goal continuity14 {C160+RF10x+SEEP10-C200=0}

goal continuity15 {C200+Adj10+RO15x+I15x-C210=0}
goal continuity16 {C210-D220-C220=0}
goal continuity17 {C220-D230-C230=0}
goal continuity18 {D250+GWP15-TSR15x=0}
goal continuity19 {C230+C380-C240=0}
goal continuity20 {C240+RF15x-D250+SEEP15-C250=0}
:
:
:
```

```
goal continuity618 {TSR49ax + F1360 - gwp49Acfs - NSIM2D_49ax - D_40cfs - D_42cfs - D_46cfs - D_47cfs - D_48cfs
- D_49cfs - D_41cfs=0}
goal continuity619 {TSR49bx + F1362 - gwp49bcfs - NSIM2D_49bx                                   =0}
goal continuity620 {TSR49cx + F1364 - gwp49ccfs - NSIM2D_49cx                                   =0}
goal continuity621 {TSR49dx + F1366 - gwp49dcfs - NSIM2D_49dx - D_43cfs                                    =0}
goal continuity622 {TSR60ax + F1368 - gwp60acfs - NSIM2D_60ax - D_44cfs - D_50cfs - D_51cfs
=0}
goal continuity623 {TSR60bx + F1370 - gwp60bcfs - NSIM2D_60bx - D_90cfs - D_45cfs - D_52cfs - D_53cfs
=0}
goal continuity624 {TSR60cx + F1372 - gwp60ccfs - NSIM2D_60cx                                   =0}
goal continuity625 {TSR60dx + F1374 - gwp60dcfs - NSIM2D_60dx                                   =0}
goal continuity626 {TSR60ex + F1376 - gwp60ecfs - NSIM2D_60ex - D_54cfs - D_55cfs
=0}
goal continuity627 {TSR60fx + F1378 - gwp60fcfs - NSIM2D_60fx - D_91cfs - D_93cfs                          =0}
goal continuity628 {TSR60gx + F1380 - gwp60gcfs - NSIM2D_60gx - D_56cfs - D_94cfs
=0}
goal continuity629 {TSR60hx + F1382 - gwp60hcfs - NSIM2D_60hx - D_92cfs - D_95cfs
=0}

goal continuity630 {C708-D_90cfs-D_91cfs-D_92cfs-D_93cfs-D_94cfs-D_95cfs                     -C800  =0}
goal continuity632 {C755-D_40cfs-D_41cfs-D_42cfs-D_43cfs-D_44cfs-D_45cfs                     -C802  =0}
goal continuity631 {C756-D_46cfs-D_47cfs-D_48cfs-D_49cfs-D_50cfs-D_51cfs-D_52cfs-D_53cfs-D_54cfs-D_55cfs-
D_56cfs  -C801  =0}
```

Delivery-table.wresl

```
define D100 {std kind 'diversion' units 'CFS'}
goal SWD58a {D100 < 0.09*TSR58x}
define D135 {std kind 'diversion' units 'CFS'}
goal SWD58b {D135 < 0.9*TSR58x}
define GWP58 {lower 0.19*TSR58x kind 'pumping' units 'CFS'}
goal Pump58 {GWP58 < TSR58x}

define GWP10 {lower 0.86*TSR10x kind 'pumping' units 'CFS'}
goal Pump10{GWP10 < TSR10x}
define D150b {lower 0.0 upper 170.0 kind 'diversion' units 'CFS'}
goal SWD10a {D150b < 0.04*TSR10x}
define D170 {lower 0.0 upper 420.0 kind 'diversion' units 'CFS'}
goal SWD10b {D170 < 0.21*TSR10x}
:
:
:
define GWP60fcfs {lower 0.0 kind 'pumping' units 'cfs'}
define F1378 {std kind 'SPILL-NON-RECOV' units 'cfs'}

define GWP60gcfs {lower 0.0 kind 'pumping' units 'cfs'}
define F1380 {std kind 'SPILL-NON-RECOV' units 'cfs'}

define GWP60hcfs {lower 0.0 kind 'pumping' units 'cfs'}
define F1382 {std kind 'SPILL-NON-RECOV' units 'cfs'}
```

Inflow-table.wresl

```
define I1 {timeseries kind 'inflow' units 'TAF' convert 'CFS'} !Inflow to Shasta
```

```
define M58x {timeseries kind 'import' units 'TAF' convert 'CFS'}
define I58Ax {timeseries kind 'MinorStreams' units 'TAF' convert 'CFS'}
define I58Bx {timeseries kind 'MinorStreams' units 'TAF' convert 'CFS'}
define I58Cx {timeseries kind 'MinorStreams' units 'TAF' convert 'CFS'}
define I58Dx {timeseries kind 'MinorStreams' units 'TAF' convert 'CFS'}
define Export_58x {timeseries kind 'DEMAND-export' units 'TAF' convert 'CFS'}
define RO58x {timeseries kind 'runoff' units 'TAF' convert 'CFS'}
define TSR58x {timeseries kind 'DEMAND-TotalSupReq' units 'TAF' convert 'CFS'}
define RF58x {timeseries kind 'ReturnFlow' units 'TAF' convert 'CFS'}
define S58x {timeseries kind 'seepage' units 'TAF' convert 'CFS'}

define Export_NBA {timeseries kind 'DEMAND-export' units 'CFS'} !exports from Delta for NBA
define Export_CCWD {timeseries kind 'DEMAND-export' units 'CFS'} !exports from Delta for CCWD
:
:
:
define NSIM2D_60fx {timeseries kind 'DEMAND-Nonsim2div' units 'TAF' convert 'CFS'}
define NSIM2D_60gx {timeseries kind 'DEMAND-Nonsim2div' units 'TAF' convert 'CFS'}
define NSIM2D_60hx {timeseries kind 'DEMAND-Nonsim2div' units 'TAF' convert 'CFS'}
```

report.wresl

```
define [local] I1CFS     {alias I1     kind 'inflow'       units 'CFS'}
define [local] M58xCFS   {alias M58x   kind 'import'       units 'CFS'}
define [local] Export_58xCFS   {alias Export_58x   kind 'export'       units 'CFS'}
define [local] I58AxCFS  {alias I58Ax  kind 'MinorStreams'  units 'CFS'}
define [local] I58BxCFS  {alias I58Bx  kind 'MinorStreams'  units 'CFS'}
define [local] I58CxCFS  {alias I58Cx  kind 'MinorStreams'  units 'CFS'}
define [local] I58DxCFS  {alias I58Dx  kind 'MinorStreams'  units 'CFS'}
define [local] RO58xCFS  {alias RO58x  kind 'runoff'       units 'CFS'}
define [local] RF58xCFS  {alias RF58x  kind 'ReturnFlow'    units 'CFS'}
define [local] S58xCFS   {alias S58x   kind 'seepage'      units 'CFS'}
define [local] TSR58xCFS {alias TSR58x kind 'DEMAND-TotalSupReq' units 'CFS'}
define [local] M58xtaf {alias M58x*cfs_taf kind 'import' units 'TAF'}
define [local] Export_58xtaf {alias Export_58x*cfs_taf kind 'export' units 'TAF'}
define [local] C1taf {alias C1*cfs_taf kind 'release' units 'TAF'}
define [local] C1000taf {alias C1000*cfs_taf kind 'release' units 'TAF'}
define [local] D100taf {alias D100*cfs_taf kind 'diversion' units 'TAF'}
define [local] D135taf {alias D135*cfs_taf kind 'diversion' units 'TAF'}
define [local] TSR58xTAF {alias TSR58x*cfs_taf kind 'DEMAND-TotalSupReq' units 'TAF'}
define [local] GWP58taf {alias GWP58*cfs_taf kind 'pumping' units 'TAF'}
:
:
:
define [local] D600Ataf {alias D600A*cfs_taf kind 'diversion' units 'TAF'}
define [local] D600Btaf {alias D600B*cfs_taf kind 'diversion' units 'TAF'}
define [local] D600Ctaf {alias D600C*cfs_taf kind 'diversion' units 'TAF'}
define [local] D620taf {alias D620*cfs_taf kind 'diversion' units 'TAF'}
define [local] D640taf {alias D640*cfs_taf kind 'diversion' units 'TAF'}
define [local] D650taf {alias D650*cfs_taf kind 'diversion' units 'TAF'}
define [local] GWP55taf {alias GWP55*cfs_taf kind 'pumping' units 'TAF'}

define seepshort58 {lower unbounded upper 200000 kind 'shortages' units 'CFS'}
```

```
goal shortages1 {seepshort58=s58x-seep58}
define seepshort58taf {alias seepshort58*cfs_taf kind 'shortages' units 'TAF'}

define seepshort10 {lower unbounded upper 200000 kind 'shortages' units 'CFS'}
goal shortages2 {seepshort10=s10x-seep10}
define seepshort10taf {alias seepshort10*cfs_taf kind 'shortages' units 'TAF'}

define seepshort12 {lower unbounded upper 200000 kind 'shortages' units 'CFS'}
goal shortages3 {seepshort12=s12x-seep12}
define seepshort12taf {alias seepshort12*cfs_taf kind 'shortages' units 'TAF'}
:
:
:
define [local] D900Dtaf {alias D900D*cfs_taf kind 'export' units 'TAF'}
define [local] D900Etaf {alias D900E*cfs_taf kind 'export' units 'TAF'}

define [local] GWP49aTAF {alias GWP49aCFS*cfs_taf kind 'pumping' units 'TAF'}
define [local] GWP49bTAF {alias GWP49bCFS*cfs_taf kind 'pumping' units 'TAF'}
define [local] GWP49cTAF {alias GWP49cCFS*cfs_taf kind 'pumping' units 'TAF'}
define [local] GWP49dTAF {alias GWP49dCFS*cfs_taf kind 'pumping' units 'TAF'}


define [local] GWP60aTAF {alias GWP60aCFS*cfs_taf kind 'pumping' units 'TAF'}
define [local] GWP60bTAF {alias GWP60bCFS*cfs_taf kind 'pumping' units 'TAF'}
define [local] GWP60cTAF {alias GWP60cCFS*cfs_taf kind 'pumping' units 'TAF'}
define [local] GWP60dTAF {alias GWP60dCFS*cfs_taf kind 'pumping' units 'TAF'}
define [local] GWP60eTAF {alias GWP60eCFS*cfs_taf kind 'pumping' units 'TAF'}
:
:
:
define [local] NSIM2D_60gxTAF {alias NSIM2D_60gx*cfs_taf kind 'DEMAND-Nonsim2div' units 'TAF'}
define [local] NSIM2D_60hxTAF {alias NSIM2D_60hx*cfs_taf kind 'DEMAND-Nonsim2div' units 'TAF'}
```

Reservoir-table.wresl

```
define Shsta_Level1 {timeseries kind 'STORAGE-LEVEL' units 'TAF'}
define S1_1 {std kind 'STORAGE-ZONE' units 'TAF'}
goal S1Zone1 {S1_1 < Shsta_Level1}

define Shsta_Level2 {timeseries kind 'STORAGE-LEVEL' units 'TAF'}
define S1_2 {std kind 'STORAGE-ZONE' units 'TAF'}
goal S1Zone2 {S1_2 < Shsta_Level2-Shsta_Level1}

define Shsta_Level3 {timeseries kind 'STORAGE-LEVEL' units 'TAF'}
define S1_3 {std kind 'STORAGE-ZONE' units 'TAF'}
goal S1Zone3 {S1_3 < Shsta_Level3-Shsta_Level2}

define Shsta_Level4 {timeseries kind 'STORAGE-LEVEL' units 'TAF'}
define S1_4 {std kind 'STORAGE-ZONE' units 'TAF'}
goal S1Zone4 {S1_4 < Shsta_Level4-Shsta_Level3}

define Shsta_Level5 {timeseries kind 'STORAGE-LEVEL' units 'TAF'}
define S1_5 {std kind 'STORAGE-ZONE' units 'TAF'}
```

```
goal S1Zone5 {S1_5 < Shsta_Level5-Shsta_Level4}

define S1 {std kind 'STORAGE' units 'TAF'} !SHASTA RESERVOIR
goal storage1 {S1=S1_1+S1_2+S1_3+S1_4+S1_5}

define F1 {std kind 'FLOW-SPILL-NON-RECOV' units 'CFS'}
define E1 {lower unbounded kind 'EVAPORATION' units 'CFS'}
:
:
:

define S4level1 {value 55}                     !SWP-SL
define S4_1 {std kind 'STORAGE-ZONE' units 'TAF'}
goal S4Zone1 {S4_1 < S4level1}

define S4level2 {value 55}
define S4_2 {std kind 'STORAGE-ZONE' units 'TAF'}
goal S4Zone2 {S4_2 < S4level2-S4level1}

define S4_3 {std kind 'STORAGE-ZONE' units 'TAF'}

define S4level4 {value 1067}
define S4_4 {std kind 'STORAGE-ZONE' units 'TAF'}

define S4level5 {value 1067}
define S4_5 {std kind 'STORAGE-ZONE' units 'TAF'}

define S4 {std kind 'STORAGE' units 'TAF'} !SWP SOD Reservoir
goal storage4 {S4=S4_1+S4_2+S4_3+S4_4+S4_5}
:
:
:

define S5level1 {value 45}                          !CVP-SL
define S5_1 {std kind 'STORAGE-ZONE' units 'TAF'}
goal S5Zone1 {S5_1 < S5level1}

define S5level2 {value 45}
define S5_2 {std kind 'STORAGE-ZONE' units 'TAF'}
goal S5Zone2 {S5_2 < S5level2-S5level1}

define S5_3 {std kind 'STORAGE-ZONE' units 'TAF'}

define S5level4 {value 972}
define S5_4 {std kind 'STORAGE-ZONE' units 'TAF'}

define S5level5 {value 972}
define S5_5 {std kind 'STORAGE-ZONE' units 'TAF'}

define S5 {std kind 'STORAGE' units 'TAF'} !CVP SOD Reservoir
goal storage5 {S5=S5_1+S5_2+S5_3+S5_4+S5_5}

define F5 {std kind 'FLOW-SPILL-NON-RECOV' units 'CFS'}
```

```
define E5 {lower unbounded kind 'EVAPORATION' units 'CFS'}
define A5 {std kind 'SURFACE-AREA' units 'ACRES'}
define evap_S5 {timeseries kind 'EVAPORATION-RATE' units 'IN'}
:
:
:
```

Seepage-table.wresl

```
define Seep58 {lower unbounded kind 'Seepustment' units 'CFS'}
goal Seepust58 {
  lhs Seep58
  rhs S58x
  lhs>rhs penalty 9000
  lhs<rhs constrain }

define Seep10 {lower unbounded kind 'Seepustment' units 'CFS'}
goal Seepust10 {
  lhs Seep10
  rhs S10x
  lhs>rhs penalty 9000
  lhs<rhs constrain }
:
:
:

define Seep12 {lower unbounded kind 'Seepustment' units 'CFS'}
goal Seepust12 {
  lhs Seep12
  rhs S12x
  lhs>rhs penalty 9000
  lhs<rhs constrain }

define Seep70 {lower unbounded kind 'Seepustment' units 'CFS'}
goal Seepust70 {
  lhs Seep70
  rhs S70x
  lhs>rhs penalty 9000
  lhs<rhs constrain }
```

system.wresl

```
! THIS FILE CONTAINS THE NAMES OF ALL INCLUDE FILES FOR THE SYSTEM DESCRIPTION
INCLUDE 'inflow-table.wresl'
INCLUDE 'channel-table.wresl'
INCLUDE 'delivery-table.wresl'
INCLUDE 'adjustment-table.wresl'
INCLUDE 'seepage-table.wresl'
INCLUDE 'reservoir-table.wresl'
INCLUDE 'connectivity-table.wresl'
```

Weight-table.wresl

```
! THIS FILE CONTAINS THE NAMES OF ALL INCLUDE FILES FOR THE SYSTEM DESCRIPTION
INCLUDE 'inflow-table.wresl'
```

```
INCLUDE 'channel-table.wresl'
INCLUDE 'delivery-table.wresl'
INCLUDE 'adjustment-table.wresl'
INCLUDE 'seepage-table.wresl'
INCLUDE 'reservoir-table.wresl'
INCLUDE 'connectivity-table.wresl'
```

WYTYPES Folder

wytypes.wresl

```
! WATER YEAR TYPE DEFININITIONS
! the 40-30-30 index for Sacramento Basin
define wyt_SAC {
   select index
   from wytypeSAC
   where wateryear=wateryear
}

! the following year type names can be used to represent the numbers found in the tables
define Wet         {value 1.}
define AboveNormal  {value 2.}
define BelowNormal  {value 3.}
define Dry         {value 4.}
define Critical     {value 5.}
```

Appendix H. Algorithm for Running CVSIM

The algorithm for running CVSIM (the iterative process between SIM2 and C2VSIM) is as follows:

1. All files and codes for each iteration are stored in a separate folder: Iter1, Iter2, etc.

2. Each iteration folder (Iter1, Iter2,….) has two cascading sub-folders:

   C2vsim

      a. Code
      b. Run
         - Budget
         - Preprocessor
         - Simulation
      c. Post
      d. Transfer

   SIM2

      - Dss
      - Run
      - Transfer

3. In each iteration "k" there are two cycles; a C2VSIM cycle and a SIM2 cycle.

C2VSIM cycle

a. Make a copy of the "k-1" iteration folder and name it "iter k'"

b. In the "SIM2/transfer" subfolder from the last "k-1" iteration:
   - Copy the "cvdiversion(proj).newnew", "cvpump(proj).newnew", and the "cvstream(proj).newnew" files to the "c2vsim/run/simulation" folder (of this "k" iteration).

c. In the "C2VSIM/b. run/simulation" folder:
   - Delete the cvdiversion(proj).new, cvpump(proj).new, and cvstream(proj).new files (these are the files from the previous iteration c2vsim run).
   - Rename the cvdiversion(proj).newnew, cvpump(proj).newnew, and cvstream(proj).newnew files to respective *.new file.
   - Change the cvsim-"k".in to cvsim-"k+1".in and edit the c2vsim-"k+1".in file to reflect new "cvsim-k".in name inside, and possibly reset the STOPC parameter to 0.001.
   - Run "rsim.bat". If aborts, increase STOPC and re-run. Repeat until successful run.
   - Copy the *.bin files to the c2vsim/run/budget folder.

- Copy the files special-10.out, special-15.out, special-58.out, special-59.out, special-65.out, special-69.out, special-70.out to the c2vsim/d. transfer folder.
- Copy the cvdiversion(proj).new, cvpump(proj).new, and cvstream(proj).new files to the SIM2/transfer folder

d. In the c2vsim/b. run/budget folder:
   - Run rbud.bat to create the budget output files.
   - Copy the cvstream.bud file to the c2vsim/d. transfer folder.

e. In the c2vsim/d. transfer folder:
   - From the SIM2/dss folder of the last iteration, copy the ex1_sv.dss file into this folder.
   - Run the c2vsimTOSIM2 program to get the ex1_sv_new.dss file.
   - Copy this file to the SIM2/dss folder of this iteration. Rename the file to ex1_sv.dss.

SIM2 Cycle

- Initiate SIM2 (WRIMS v1.5.1).
- Update the *.sty paths to reflect the new iteration number and save.
- Run the program.
- Copy the Ex1_dv.dss file to the SIM2/transfer folder.
- In the “SIM2/transfer” folder:
  - o copy the “cvdiversion(proj).new”, “cvpump(proj).new”, and the “cvstream(proj).new” files from the “c2vsim/run/simulation” folder (of this “k” iteration) to this folder.
  - o run the SIMtoC2VSIM.exe program to get the cvdiversion(proj).newnew, cvpump(proj).newnew, and cvstream(proj).newnew files for use in the next iteration c2vsim run.
  - o use the output.out results to update the iterative spreadsheet.

4. After each cycle, check if the average annual value for each for the variables transferred between C2VSIM and SIM2 (see Table 5.1 and Table 5.2) have converged to the previous iteration values to within a tolerance limit. If convergence is achieved the run is complete, otherwise repeat Step 3). Both C2VSIM and SIM2 are based on continuity and mass balance. The drivers of both models are the hydrological components that get swapped back and forth during the iterative process. Since both systems must achieve similar mass balances and simulated flows, it can be expected that “errors” continuously reduce to convergence.