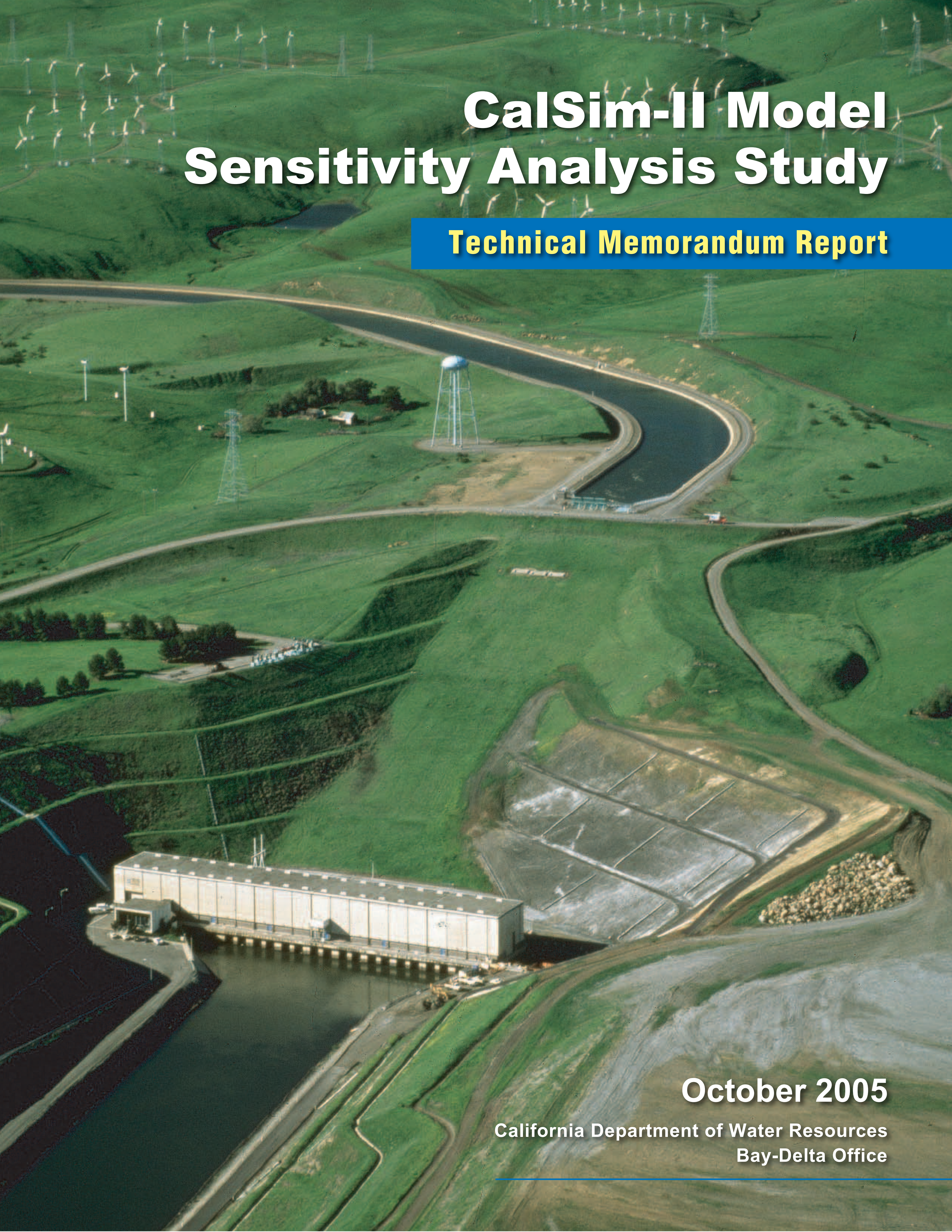

CalSim-II Model Sensitivity Analysis Study

Technical Memorandum Report

October 2005

California Department of Water Resources
Bay-Delta Office

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Department of Water Resources
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Executive Summary

Background

CalSim-II is a planning model developed by the California Department of Water Resources (DWR) and the U.S. Bureau of Reclamation (Reclamation). It simulates the State Water Project (SWP), the federal Central Valley Project (CVP), and areas tributary to the Sacramento-San Joaquin Delta. The primary purpose of the CalSim-II model is to evaluate the water supply capability of the CVP and SWP at current or future levels of land use development, with and without various assumed future facilities and under various regulations and project operations criteria.

The sensitivity analysis is an important component of any water resources planning model evaluation. It enhances understanding of the model, builds greater public confidence, and expands public acceptance of the model. The sensitivity analysis explores and quantifies the effects of various inputs on the model outputs. With a simple sensitivity analysis procedure, variations of model input parameters are generally investigated one at a time. With a more complex procedure, the investigation is conducted by changing a set of input parameters simultaneously. For this study, the simple sensitivity study procedure is used.

CalSim-II is a frequently used decision support tool in CVP and SWP planning and management investigations; as well as other federal, state, regional and local water resources planning efforts. To help the State Water Project contractors assess the reliability of the SWP component of their overall water supplies, DWR released *The State Water Project Delivery Reliability Report* in 2003. The report discusses the reliability of the SWP to deliver water under existing and future levels of land use development, assuming historical variations in precipitation for the period of 1922-1994. The report noted that a follow-up sensitivity analysis study of CalSim-II model would be conducted as a supplement to the report. Some of the issues raised during the public review of the 2003 *State Water Project Delivery Reliability Report* are also addressed in this report.

The sensitivity analysis study was also one of the recommendations by the CalSim-II peer review sponsored by the CALFED Science Program in December 2003. The review panel recommended such a study would help identify key input parameters that have significant effects on the model output, and to provide a systematic way to measure the sensitivity of the model output to variations of these parameters.

Study Objectives

There are three objectives of the CalSim-II Sensitivity Analysis Study:

- to examine the behavior of the SWP-CVP system performance in response to variations in selected input parameters within CalSim-II
- to help SWP contractors and others understand the impact of key assumptions within CalSim-II on the SWP delivery capability
- to aid CalSim-II modelers for prioritizing future model development activities on the basis of sensitivities of input parameters

Study Description

The development of the CalSim-II model is an ongoing effort. DWR and Reclamation periodically release updated versions of the model. This study uses the modified benchmark study of September 30, 2002, under the D-1641 regulatory environment as the base study.

The CalSim-II model uses many input parameters to define the physical characteristics of the system, as well as the regulatory environment and operational parameters. Input parameters include time series, single dimensionless coefficients, or monthly distribution curves. Some input parameters are estimated from the historical data and others are user-input or calibrated values. After discussions with model developers and project operators, 21 model input parameters in four major categories and their reasonable ranges of variations were selected for this study. The selected input parameters and their associated range of variation are summarized in Table 1, Chapter 3. Similarly, there are many output variables in different categories, including reservoir storage, flows at key locations, Delta outflows, project exports and deliveries that characterize the overall outcome of any particular simulation run. After discussions with model users, project operators, and model developers, 22 key output variables that cover various aspects of the SWP-CVP system performance were selected. These output variables are listed in Table 2, Chapter 4.

In this study, two performance measures – Sensitivity Index (SI) and Elasticity Index (EI) – are used to quantify the model output sensitivity with respect to a certain model input parameter. The SI is a first-order derivative of a model output variable with respect to an input parameter. It can be used to measure the magnitude of change in an output variable per unit change in the magnitude of an input parameter from its base value. The EI is a dimensionless expression of sensitivity that measures the relative change in an output variable to a relative change in an input parameter. As an example, assuming SI = 0.5 and EI = 0.25 for the output variable of total Delta outflow with respect to the input parameter of Oroville inflow, means that for one thousand acre-feet (TAF) increase in Oroville inflow, total Delta outflow increases by 0.5 TAF; and for 1 percent increase in Oroville inflow, total Delta outflow increases by 0.25 percent, respectively. These two performance measures, SI and EI, are derived and discussed in more detail in Chapter 2.

Study Results and Discussions

In Tables 2 and 3 of Chapter 4, the complete results of the study showing sensitivity and elasticity indices for each one of the selected output variables are listed in terms of their long-term (1922–1994) averages with respect to variations of input parameters. An excerpt from Table 2, Table ES-1 is presented on the next page to highlight the behavior of some of the key output variables that define the important aspects of SWP–CVP system performance. In Table ES-1, the top row is the list of model input parameters and the left-most column is the list of model output variables. In general, each cell in the table contains two numbers except cells in Columns 8 and 9. The number inside parentheses is the SI value and the number outside parentheses is the EI value. Signs in front of SI and EI values can be either positive or negative. In general, the positive sign indicates that the output variable changes in the same direction as the input parameter. For example, as shown in the Row 1 of Column 1 in the table, when SWP Table A demand increases, SWP total delivery, which is the sum of SWP Delta delivery and SWP North-of-Delta (NOD) delivery, increases as well (SI = +0.39). SWP Delta Delivery is defined as SWP Table A deliveries to South-of-Delta (SOD) plus deliveries to North Bay (Solano and Napa Counties) contractors. SWP NOD delivery is defined as the sum of deliveries to the Settlement Contractors in Feather River Service Area (FRSA) and Table A deliveries to Butte County and Yuba City. SWP delivery to Plumas County occurs upstream of Lake Oroville and it is not explicitly modeled in CalSim-II. The negative sign indicates that the output variable changes in the opposite direction as the input parameter. For example, as shown in the Row 5 of Column 1 in the table, when SWP Table A demand increases, Article 21 delivery decreases (SI = -0.13). In order to highlight relative sensitivity of the various input parameters, a color coded cell background has been used. A red color cell background represents a relatively higher sensitivity or (|SI| > 0.2); yellow background represents a moderate sensitivity or (0.1 <= |SI| <= 0.2); and white background shows a lower sensitivity or (|SI| < 0.1).

An examination of Row 3 of Table ES-1 highlights the behavior of SWP Delta delivery with respect to changes in some of the key input parameters. It shows that the SWP Table A demand, the Banks pumping limit, and the Oroville inflow affect SWP Delta delivery the most. Folsom inflow and historical land use display moderate effects on the SWP Delta delivery. A positive SI of 0.52 for the SWP Table A demand indicates that the SWP Delta delivery will increase by an average of 0.52 TAF if the SWP Table A demand increases by 1 TAF; and a positive EI of 0.55 for the SWP Table A demand indicates that the SWP Delta delivery will increase by an average of 0.55 percent if the SWP Table A demand increases by one percent. Similarly, a positive SI of 0.20 for the Oroville inflow indicates that the SWP Delta delivery will increase by an average of 0.20 TAF if the Oroville inflow increases by 1 TAF; and a positive EI of 0.26 for the Oroville inflow indicates that the SWP Delta delivery will increase by an average of 0.26 percent if the Oroville inflow increases by one percent.

As mentioned above, a more complete version of the summary Table ES-1 is presented in Tables 2 and 3, along with more discussions of results, in Chapter 4.

SI values are not computed for input parameters of the SWP Delivery-Carryover Curve and the SWP San Luis Rule-curve (see Columns 8 and 9) because the equivalent changes in the commensurate units of TAF are difficult to define for these two parameters. A more detailed discussion of their impact on the SWP Delta delivery is presented in Chapter 4.

Table ES-1 Summary Excerpt of Elasticity Index (EI) and Sensitivity Index (SI) for Selected Variables from Table 2

	Model Output Response	Model Input Parameters											
		SWP Table A Demand	Article 21 Demand	Banks Pumping Limit	Historical Land Use	Projected Land Use	Crop ET	Basin Efficiency	SWP Delivery-Carryover Curve	SWP San Luis Rule Curve	Shasta Inflow	Oroville Inflow	Folsom Inflow
		1	2	3	4	5	6	7	8	9	10	11	12
1	SWP Total Delivery	0.31 (0.39)[(1)]	0.01 (0.16)	0.15 (1.45)	0.09 (-0.13)	-0.05 (-0.03)		-0.15 (0.10)	-0.01	0.02	0.07 (0.05)	0.18 (0.19)	0.05 (0.14)
2	CVP total Delivery	-0.01 (-0.01)	(2)	-0.01 (-0.12)	0.10 (-0.18)	0.14 (0.11)	0.16 (0.09)	-0.32 (0.26)			0.25 (0.22)	0.05 (0.07)	0.03 (0.09)
3	SWP Delta Delivery	0.55 (0.52)	0.00 (-0.01)	0.07 (0.48)	0.12 (-0.13)	-0.09 (-0.04)	-0.21 (-0.08)	-0.17 (0.08)	-0.02		0.08 (0.04)	0.26 (0.20)	0.05 (0.12)
4	SWP NOD Delivery	-0.01 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.17 (0.02)	0.78 (0.08)	-0.17 (0.02)	0.00		0.00 (0.00)	0.01 (0.00)	0.00 (0.00)
5	Article 21 Delivery	-2.62 (-0.13)	0.15 (0.17)	2.63 (0.96)		-0.45 (-0.01)		0.30 (-0.01)	0.08	0.46	0.34 (0.01)	-0.51 (-0.02)	0.16 (0.02)
6	CVP SOD Delivery	-0.01 (-0.01)		-0.02 (-0.10)	0.15 (-0.15)	-0.25 (-0.11)	-0.27 (-0.09)	-0.10 (0.04)			0.38 (0.18)	0.08 (0.06)	0.04 (0.08)
7	CVP NOD Delivery	0.00 (0.00)		0.00 (-0.02)	0.03 (-0.03)	0.59 (0.21)	0.66 (0.18)	-0.59 (0.22)			0.10 (0.04)	0.02 (0.01)	0.01 (0.01)
8	Total Delta Outflow	-0.08 (-0.35)	0.00 (-0.16)	-0.04 (-1.48)	0.07 (-0.36)	-0.09 (-0.22)	-0.18 (-0.30)	-0.07 (0.15)	0.00	0.00	0.27 (0.69)	0.20 (0.74)	0.07 (0.75)
9	Banks Export	0.35 (0.37)	0.01 (0.16)	0.20 (1.63)	0.11 (-0.14)	-0.11 (-0.06)	-0.20 (-0.08)	-0.14 (0.08)	-0.01	0.02	0.10 (0.06)	0.21 (0.18)	0.05 (0.14)
10	Tracy Export	-0.01 (-0.01)		-0.02 (-0.10)	0.16 (-0.15)	-0.25 (-0.10)	-0.28 (-0.09)	-0.10 (0.04)			0.39 (0.18)	0.09 (0.06)	0.04 (0.08)
11	Banks SWP Export	0.37 (0.38)	0.01 (0.16)	0.18 (1.46)	0.11 (-0.13)	-0.10 (-0.05)	-0.20 (-0.08)	-0.14 (0.07)	-0.01	0.02	0.08 (0.05)	0.22 (0.18)	0.06 (0.14)
12	Banks CVP Export	-0.53 (-0.02)	0.00 (0.00)	0.79 (0.17)	0.42 (-0.01)	-0.37 (-0.01)	-0.43 (0.00)	-0.31 (0.00)	0.00	0.02	0.86 (0.01)	0.04 (0.00)	

Note: (1) Values inside parentheses are SI and outside are EI.
(2) Blank cells indicate that SI and EI are non-monotonic functions of the input parameters and their averages are not meaningful. See Chapters 2 and 4 for details.

High Sensitivity	0.2 < |SI|
Moderate Sensitivity	0.1 <= |SI| <= 0.2
Low Sensitivity	|SI| < 0.1

Future Work

This sensitivity study is mainly focused on Sacramento Valley hydrology, Sacramento-San Joaquin Delta water quality, and SWP operations. Additional sensitivity studies focused on San Joaquin Valley hydrology and CVP operations may be done in the near future by Reclamation.

A simple sensitivity analysis procedure has been used for this study. In order to evaluate the combined effect of varying two or more input parameters on the model outputs, future studies with a more complex sensitivity analysis procedure, which investigates changes in a set of input parameters simultaneously, may be needed.

Linear programming solution methodology used in the CalSim-II model has the potential to produce an array of sensitivity analyses as a by-product of the linear programming analysis automatically. Discussion of these results will provide a degree of transparency to model users and an internal diagnostic tool that the current CalSim-II does not provide. Studying these by-products of the linear programming solution procedure will be considered during the development of the next generation of the CalSim-II model.

The CALFED report, *A Strategic Review of CalSim-II and its Use for Water Planning, Management, and Operations in Central California* (December 2003), recommends a model uncertainty analysis be conducted. An uncertainty analysis is not the same as a sensitivity analysis. It takes a set of randomly chosen input values (that can include parameter values), passes them through a model to obtain the probability distributions (or statistical measures of the probability distributions) of the resulting outputs, while a sensitivity analysis attempts to determine the relative change in model output values given modest changes in model input values. The uncertainty analysis would help users of the model understand better the risks of various decisions and the confidence they can have in various model predictions. DWR is currently working on a contract with University of California, Davis to develop a strategy for the identification and reduction of the major sources of uncertainty in CalSim-II modeling studies, and implement a recommended procedure for the quantification of uncertainties in a CalSim-II study.

1 Introduction

1.1 CalSim-II Model

WRIMS, the Water Resources Integrated Modeling System, is a generalized water resources simulation planning tool developed by the Department of Water Resources (DWR) and the U.S. Bureau of Reclamation (Reclamation) Mid-Pacific Region. CalSim-II is an application of the WRIMS software to model the State Water Project (SWP), the federal Central Valley Project (CVP), and areas tributary to the Sacramento-San Joaquin Delta (Delta). The primary purpose of CalSim-II model is to evaluate the performance of the CVP and SWP systems:

- at current or future levels of land development
- with and without various assumed future facilities
- with different modes of facilities operations
- under various regulatory environments

Comprehensive analysis of model results can be used to assess the water supply effects of many what-if scenarios, such as proposed expansion of project facilities, changes in regulatory requirements, or changes in operating criteria. The model may also be used to support analysis for the California Water Plan Update, CALFED's Integrated Storage Investigations and Conveyance Programs, South Delta Improvement Program (SDIP), development of the CVP Operating Criteria and Plan (OCAP), the Federal Energy Regulatory Commission (FERC) Relicensing of Oroville, and other projects.

All models have limitations. CalSim-II is a mass-balance accounting model. Results depend on the quality of the input data including hydrologic data and estimated demands. Results also depend on the model operational logic and assigned priorities. Operational decisions must be formulized into mathematical algorithms even when they are subjective. Other limitations are imposed by the spatial and temporal resolution of the model. This report documents the CalSim-II sensitivity analysis study undertaken by DWR's Bay-Delta Office as a supplement to DWR's *The State Water Project Delivery Reliability Report* in 2002 and as a part of a comprehensive evaluation of the CalSim-II model.

1.2 Study Background

CalSim-II is frequently used in CVP and SWP planning and management, as well as in other federal, State, regional, and local water-related planning activities. In order to assist the contractors of the State Water Project in the assessment of the adequacy of the SWP component of their overall water supplies, DWR released *The State Water Project Delivery Reliability Report* in 2003. The report provided information on the reliability of SWP to deliver water under existing and future levels of development, assuming historical patterns of precipitation. Because assumptions on model input parameters are the foundation of reliability estimates, it is important to evaluate the effect that any particular assumption has upon the study results. For example, what effect would a significant change in water use in the source areas have upon the projected SWP water delivery reliability? Would it significantly change the amount of SWP supply and, if so, by how much? These types of questions can be answered by varying specific model input parameters to see the effect upon the results. These studies are referred to as sensitivity analyses and can be helpful in gauging the importance of certain assumptions to the study results.

As a part of a larger CalSim-II evaluation, the CALFED Science Program commissioned an external review panel to provide an independent analysis and evaluation of the strengths and weaknesses of CalSim-II model. The panel was to also offer suggestions on the appropriate uses of this modeling tool, on ways that its use might complement or be complemented by other models, future developments, quality assurance, and use in major water operations and planning in California. The peer review panel compiled a report, *A Strategic Review of CalSim-II and its Use for Water Planning, Management, and Operations in Central California*, in December 2003 that recommended improvements in CalSim-II. The sensitivity analysis study is one of the recommendations of that report (Page 8, Section 5.2).

1.3 Study Objectives

There are three objectives of the CalSim-II Sensitivity Analysis Study:

- to examine the behavior of the SWP-CVP system performance in response to variations in selected input parameters within CalSim-II
- to help SWP contractors and others understand the impact of key assumptions within CalSim-II on the SWP delivery capability
- to aid CalSim-II modelers for prioritizing future model development activities on the basis of sensitivities of input parameters

1.4 Study Focus

This sensitivity analysis study focuses on model-input parameters related to Sacramento Valley hydrology including reservoir inflows originated from the rim areas and local water supplies originated from the valley floor, Sacramento-San Joaquin Delta water quality, and SWP operations, which may have significant effects on both SWP and CVP systems. Additional sensitivity study of other CVP related parameters can and should be done in the near future.

1.5 Structure of the Report

This report contains five chapters and one appendix. Chapter 2 introduces the general methodology and performance measures for the sensitivity analysis. Chapter 3 describes each of the selected model input parameters and how the sensitivity analysis for each model input parameter is designed. Chapter 4 summarizes the study results, and discusses sensitivities of selected input parameters significantly affecting the SWP delivery capability. Chapter 5 summarizes the study and describes the future work for the model evaluation.

2 Methodology

2.1 Sensitivity Analysis

Sensitivity analysis is an important component of any water resources planning model development. It is aimed at describing how key model output variables are affected by changes in model input. The exact character of sensitivity analysis depends upon the particular context and the questions of concern. Sensitivity studies can provide a general assessment of model precision when used to assess system performance for alternative scenarios, as well as detailed information addressing the relative significance of potential errors in various input parameters.

A sensitivity analysis explores and quantifies the effect of possible changes in inputs on model outputs and system performance measures. With a simple sensitivity analysis, changes in model input parameters are generally investigated one at a time. With a more complex procedure, an investigation is conducted for changes in a set of parameters simultaneously. In this study, the simple sensitivity study procedure was adopted, that is, changes in model input parameters are investigated one at a time while all other input parameters are held at their base value.

2.2 Sensitivity Indices

In this study, the model output variable sensitivity with respect to a certain model input parameter is quantified by two performance measures: Sensitivity Index (SI) and Elasticity Index (EI)[1].

- Sensitivity Index (SI): This index is the first-order derivative of a model output variable with respect to an input parameter. It can be used to measure the magnitude of change in an output variable Q per unit change in the magnitude of an input parameter value P from its base value P_0. Let SI_{PQ} be the sensitivity index for an output variable Q with respect to a change ΔP in the value of the input variable P from its base value P_0. Noting that the value of the output Q(P) is a function of P, the sensitivity index is

$$SI_{PQ} = [Q(P_0 + \Delta P) - Q(P_0)] / \Delta P \qquad (1)$$

If there is more than one ΔP, then an average SI_{PQ} is

$$SI_{PQ,avg} = \sum_{i=1}^{n} \{ [Q(P_0 + \Delta P_i) - Q(P_0)] / \Delta P_i \} / n \text{ for } i = 1, 2, \ldots, n \qquad (2)$$

[1] The definitions of SI and EI adopted in this study are from Appendix H of *A Strategic Review of CalSim II and its Use for Water Planning, Management, and Operation in Central California* by the CALFED Science Program review panel in 2003. The appendix H is a draft of a book chapter by D. P. Locks and J. R. Stedinger.

where *n* is the number of ΔPs.

- Elasticity Index (EI): This index is a dimensionless expression of sensitivity that measures the relative change in output variable Q for a relative change in input parameter P. Let EI_{PQ} be the elasticity index, then:

$$EI_{PQ} = [P_0 / Q(P_0)] * SI_{PQ} \quad (3)$$

Similar to the sensitivity index, if there is more than one ΔP, then an average EI_{PQ} is

$$EI_{PQ,avg} = \sum_{i=1}^{n} \{ [P_0 / Q(P_0)] * SI_{PQ,i} \} / n \quad \text{for } i = 1, 2, \ldots, n \quad (4)$$

where *n* is the number of ΔPs.

An assumption of Q(P) being a monotonic function of P needs to be made in order for the $SI_{PQ,avg}$ calculated by equation (2) and $EI_{PQ,avg}$ calculated by equation (4) to be meaningful.

A monotonic function is a function that is either entirely non-increasing or non-decreasing over the entire range of variation under consideration. The first-order derivative of a monotonic function (which needs not be continuous) does not change sign. For example, Q(P) is monotonic non-increasing if $P + \Delta P > P$ implies $Q(P + \Delta P) <= Q(P)$; and Q(P) is monotonic non-decreasing if $P + \Delta P > P$ implies $Q(P + \Delta P) >= Q(P)$.

Figure 1 demonstrates types of monotonic and non-monotonic functions and behaviors of SI and EI corresponding to each type of function. As shown in this figure, both SI_{PQ} (EI_{PQ}) and SI_{PQ}’ (EI_{PQ}’) have the same signs for monotonic functions (Figures 1(a) and 1(b)) and opposite signs for non-monotonic functions (Figures 1(c) and 1(d)). The average SI_{PQ} or EI_{PQ} computed by Equations (2) or (4) will have the same signs as their individual SI_{PQ} or EI_{PQ} and may be used to represent the general trend of their individual SI_{PQ} or EI_{PQ} for monotonic functions, whereas, the averages in the case of non-monotonic functions may not represent the true behavior of those functions over the entire range of variations.

There are situations where values between SI_{PQ} and SI_{PQ}’ or EI_{PQ} and EI_{PQ}’ have large differences even if they have the same sign, in which case the average SI_{PQ} or EI_{PQ} may not accurately represent the true sensitivity or elasticity of an output variable in response to an input parameter, and individual analysis for each SI_{PQ} and EI_{PQ} should be conducted. However, in the current level of detail used in this study, only the average SI_{PQ} or EI_{PQ} for the monotonic SI_{PQ} and EI_{PQ} were evaluated.

As shown in Figure 1(c) and 1(d), the average SI_{PQ} or EI_{PQ} computed by Equations (2) or (4) for non-monotonic functions may not be used to represent their general trends. In these cases individual SI_{PQ} and EI_{PQ} need to be analyzed.

In the real world, SI may be more meaningful for water planners, operators, water users, and managers because of its intuitive character. They may propose different demand levels, such as agricultural and municipal and industrial (M & I) practices or water operations for more water deliveries and better water quality with the guidance of the SI. Meanwhile, EI may be more helpful to modelers. Modelers may use EI to guide their refinement of data input as well as the model structures. More discussions on the usage of SI and EI are made later in this report.

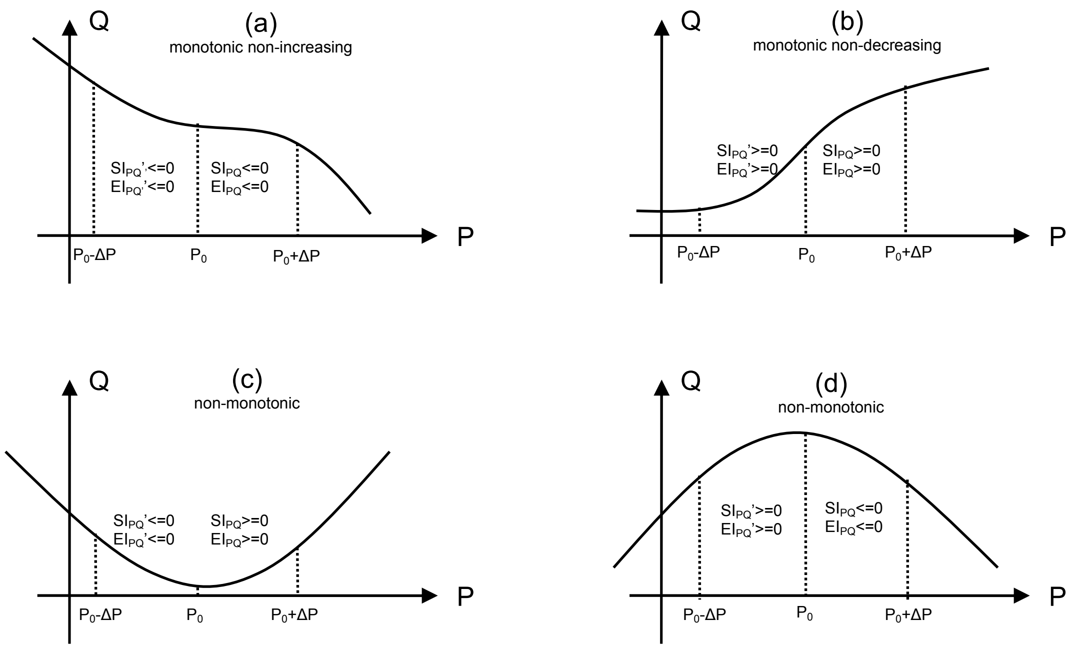

Figure 1 Monotonic and Non-monotonic Functions

2.3 SWP-CVP System Responses

There are a large number of output variables from CalSim-II model in different categories including reservoir storage, minimum flows to meet water quality requirements, project/non-project exports, and deliveries. After discussions with model users, project operators, and model developers who conducted the model coding and data preparation, a wide range of output variables covering different aspects of the SWP and CVP systems performance were selected. These output variables are listed in Table 2 of Chapter 4 and will be discussed in more detail in Chapters 3 and 4.

3 Description of Study

There are a large number of input parameters in the CalSim-II model. Some input parameters are used to define the hydrologic aspect of the model and others are used to describe the water demands, operational constraints, or water quality requirement. After discussions with model users, project operators, and model developers, 21 model input parameters and their associated ranges of variations in 4 major categories were selected for evaluation in this study. These parameters and their associated ranges of variation are summarized in Table 1. This chapter explains the selected input parameters and the design of their sensitivity analyses.

3.1 Base Model

This study uses the modified 2001 level of development benchmark study of September 30, 2002 under the D-1641 regulatory environment as the base study. For detailed model assumptions, documentation, and model studies at current (2001) and future (2020) levels of development, readers are referred to the DWR Modeling Support Branch website: http://modeling.water.ca.gov/hydro/studies/SWPReliability/index.html.

3.2 Hydrology

CalSim-II hydrologic input data was developed jointly by DWR and Reclamation. This joint hydrology has its roots in older simulation models: DWR's DWRSIM and Reclamation's PROSIM and SANJASM. This joint hydrology is not based on a single common method for Sacramento and San Joaquin Valleys. Instead, two different approaches are used: land use-based demand approach for the Sacramento Valley and Delta, and contract-based demand approach for the San Joaquin Valley and east side streams. As shown in Table 1, fourteen input parameters relating to Sacramento Valley hydrology including diversion requirement, reservoir inflows originated from the rim areas, and local water supplies originated from the valley floor were selected for the analysis. This section briefly describes these selected hydrologic input parameters and their sensitivity analysis formulations. Readers may refer to DWR publication *Central Valley Future Water Supplies for Use in DWRSIM* (September 1995) and *CalSim Hydrology Documentation* compiled by MBK inc. (2002), for more detailed information regarding these parameters.

Table 1 : Selected Model Input Parameters and Their Associated Range of Variations

Item No.	Category	Sub-Category	Selected Parameter	Range of Parameter Variation	No. of Scenarios
1	Hydrology	Rim Flows	Inflow to Shasta Lake	± 5 %	2
2			Inflow to Oroville Lake	± 5 %	2
3			Yuba River outflow	± 5 %	2
4			Inflow to Folsom Lake	± 5 %	2
5		Local Water Supplies	Historical land-use	± 5 %	2
6			Projected land-use	± 5 %	2
7			Historical GW extraction	± 10 %	2
8		Diversion Requirement	Non-recoverable loss factor	-50%, -75%	2
9			Crop evapotranspiration (ET)	± 10 %	2
10			Basin efficiency	± 10 %	2
11			Deep percolation of applied water	± 5 %	2
12			Outdoor M&I demands	± 50 %	2
13			Minimum GW pumping	± 10 %	2
14			Percentage project non-project split	± 5 % ± 10 %	4
15	SWP&CVP Project Operations	Delivery Allocation	SWP Delivery-Carryover curve	± 20 %	2
16			SWP San Luis Rule-curve	± 10 %	2
17		Demands	SWP Annual Table A Requests	2.5 maf 3.0 maf 3.5 maf 3.9 maf 4.15 maf	5
18			Article 21 Demand in peak months (Dec-Mar)	400 TAF 600 TAF 800 TAF 1000 TAF	4
19	Delta Water Quality	Delta Water Quality	ANN	± 10 % ± 20 %	4
20			X2	± 5 % ± 10 %	4
21	Existing Banks Pumping	Existing Banks Pumping	Permitted Banks pumping capacity	-5%	1

3.2.1 Hydrology Development

A major component of the hydrology development process is to modify historical water budget for an area to reflect water supplies at a future level of land-use development (LOD). The hydrologic input parameters in CalSim-II were prepared for current (2001) and future (2020) LOD. The general steps involved in the derivation of the hydrologic inputs are summarized in Figure 2.

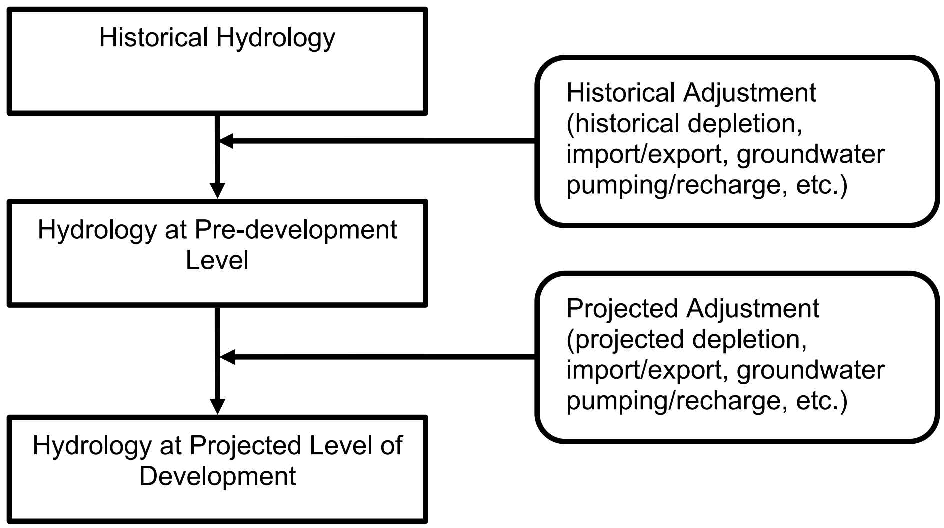

Figure 2 Conceptual Diagram for Developing Projected LOD Hydrology

3.2.2 Depletion Study Areas (DSAs)

In order to develop hydrologic input data for CalSim-II and its predecessors (DWRSIM, PROSIM and SANJASM), DWR and Reclamation developed a set of depletion study areas (DSAs) that divided the Sacramento and San Joaquin valleys into 37 regions as shown in Figure 3. These areas are large and hydrologic characteristics may vary significantly within each DSA. The boundaries were chosen to make it easier to calculate a water mass balance (budget). Typically, the delineation follows drainage lines and watershed boundaries in the foothills and a combination of drainage and water service areas on the Central Valley floor. The lowest elevation of the principal stream in a depletion study area is called the "outflow point." These points usually correspond with the location of stream gages where historical flow is known. Please refer to DWR documentation titled *Central Valley Future Water Supplies for Use in DWRSIM* (September 1995) for DSA details.

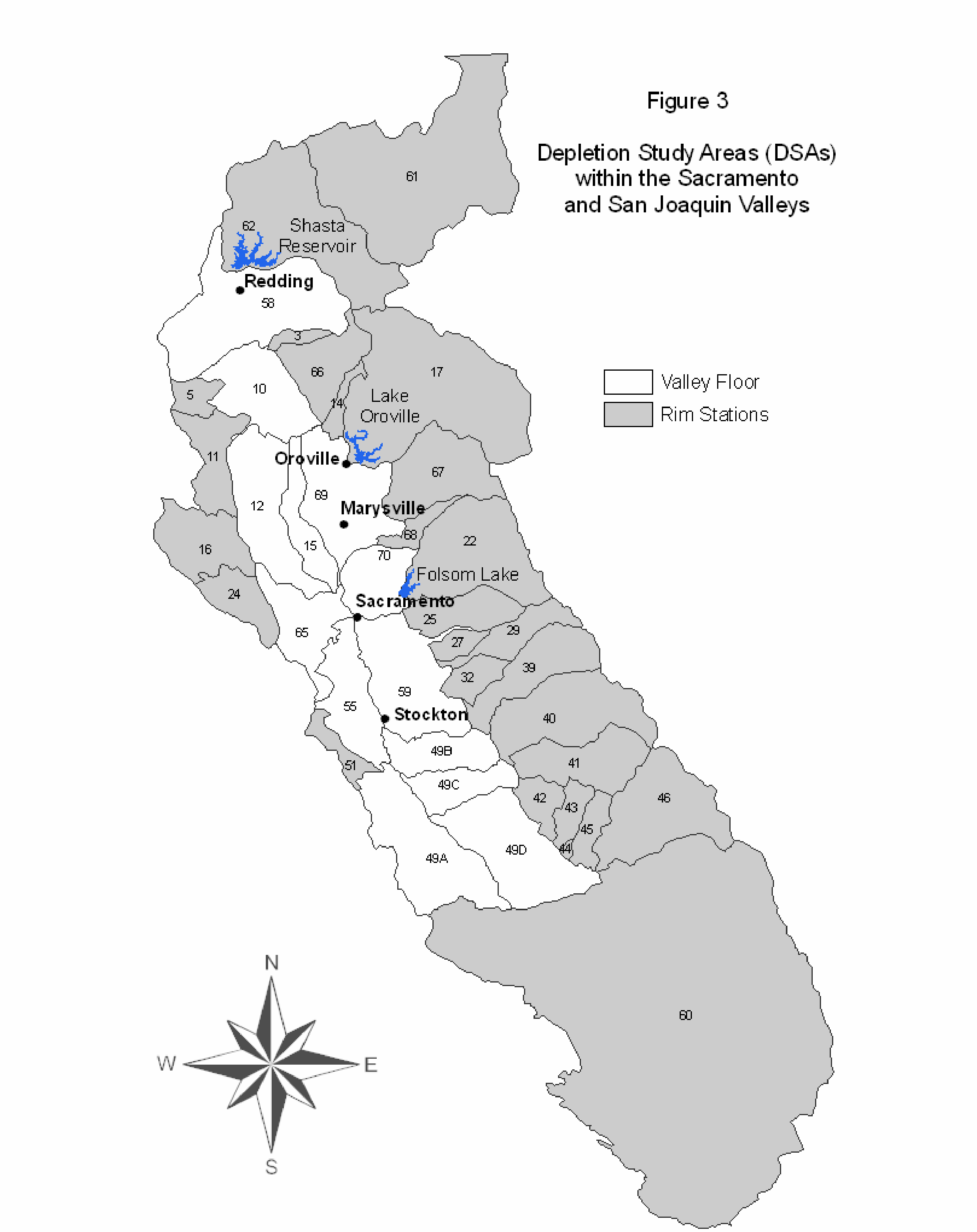
Figure 3
Depletion Study Areas (DSAs)
within the Sacramento
and San Joaquin Valleys
Valley Floor
Rim Stations
Shasta Reservoir
Redding
Lake Oroville
Oroville
Marysville
Folsom Lake
Sacramento
Stockton
61
62
58
3
66
17
5
10
14
11
67
12
69
68
22
16
15
70
24
25
65
27
29
32
39
59
55
40
49B
51
41
49C
42
43
46
45
44
49D
49A
60
N
W
E
S

3.2.3 Water Supply

CalSim-II is a water resources system simulation model. Currently it simulates a 73-year monthly system operation for a fixed level of land-use development (LOD). The input hydrologic data is based on the period of October 1921 - September 1994. CalSim-II represents surface water supplies as a time series of monthly inputs. These inputs can be sub-divided into:

- rim flows; and
- local water supplies

Rim flows represent streams that cross the boundary of the physical system being modeled. They, in general, refer to the inflows into the surface reservoirs modeled in CalSim-II; they may result from an upstream water budget analysis or reservoir simulation model reflecting a future level of land-use development. Local water supplies represent surface waters that are available to meet local water demands. They originate mainly within the boundary of the region being modeled (local precipitation), unmeasured minor streams flowing into the region, identifiable sources of water not modeled directly in CalSim-II (e.g., imports, exports or upstream reservoir releases), and any remaining residual error resulting from carrying out a water budget for an area (e.g., error in stream gage or measurements). The local water supplies are also referred to as accretions or gains.

3.2.3.1 Rim Flows

Inflows to Shasta Lake, Lake Oroville, Folsom Lake, and Yuba River outflow are the four important rim flow time series input data selected for the sensitivity analysis. These rim flow data were taken directly from the benchmark study. Inflows to Shasta Lake and Lake Oroville were estimated using the DWR *Depletion Analysis Model* or CVP and SWP monthly report of operations. Outflow from Yuba River and inflow to Folsom Lake were estimated using *HEC-5* and *HEC-3* model operation studies of their respective upstream watersheds.

Inflows at projected levels were determined by adjusting historical inflows for changes in consumptive use, reservoir operations, and changes in imports/exports from upstream basins. This was accomplished by performing a mass-balance or model simulation for basins with more complex water operations. Changes in consumptive use (CU) are estimated using the DWR CU computer program, which uses monthly precipitation, land-use, evapotranspiration (ET) rates, soil moisture criteria, irrigation timing, and other parameters to estimate consumptive use of applied water (CUAW) on a monthly basis. The CU model is described in greater detail in a DWR document titled *Consumptive Use Program Documentation,* dated April 11, 1979, and a DWR-WRMI, Inc. workshop handout titled *Consumptive Use Model and Depletion Analysis Overview* dated November 18, 1991. The above rim flow data are computed using measured data, with potential errors in measurement.

After discussions with modelers who prepared or evaluated these data, the range of data variation for the sensitivity analysis is designed to vary ±5 percent from their base time series for all four rim flows, one at a time.

3.2.3.2 Local Water Supply

Local water supply represents the surface water available within each DSA to meet local water demands, and may not be associated with any particular stream. The calculation of projected local water supply is a three-step process:

- calculating historical local water supply
- calculating pre-development local water supply
- calculating projected local water supply

The historical local water supply is estimated as the closure term in a water-mass balance at the DSA level. The historical depletion of water supply (whether surface water, groundwater or precipitation) by the developed area is calculated from the DWR CU Model using historical estimates of land-use. Historical net groundwater extraction is taken from a historical run of the *Central Valley Ground and Surface Water Model (CVGSM)*, which was developed by Montgomery Watson Engineers for Reclamation, DWR, the State Water Resources Control Board (SWRCB) and the Contra Costa Water District (CCWD). Imports, exports, and stream inflows and outflows are based on historical data. The historical local water supply can be expressed as

historical local water supply =
+ historical outflow
+ historical export
+ historical depletion of applied surface water and groundwater
+ historical deep percolation from applied surface water and groundwater
- historical groundwater pumping
+ historical stream seepage to groundwater
- historical stream gains from groundwater
- historical imports
- historical storage withdrawal
+ historical storage increase
+ historical reservoir evaporation
- historical inflows (5)

To calculate the unimpaired local water supply, the historical depletion of precipitation from developed lands is added to, and the consumptive use of historically replaced native vegetation is subtracted from the estimated historical local water supply:

Pre-development local water supply =
historical local water supply
+ historical consumptive use of precipitation by developed land
- historical replaced native vegetation consumptive use (6)

The final step is to calculate the projected accretion or gain for CalSim-II. The projected gain adds all the effects of going from a pre-development condition to a projected level condition. This includes additional runoff that occurs because of projected land-use, imports and exports not modeled in CalSim-II, and projected operation of upstream depletion areas not modeled in CalSim-II:

Projected local water supply =
Pre-development local water supply
+ projected replaced native vegetation consumptive use
- projected consumptive use of precipitation by developed land
+ modification for upstream depletion areas not modeled in CalSim-II
+ projected operations not modeled in CalSim-II
+ rice drainage (7)

The difference between the second and the third terms on the right-hand side of equation (7) represents the additional runoff due to the land-use change. Rice drainage that occurs in September of every year is included in the equation. This methodology is applied to each of the seven Sacramento Valley DSAs.

Based on discussions with modelers who either prepared or evaluated the local water supply data for CalSim-II, three input parameters, namely historical land-use, projected land-use, and historical groundwater extraction, are selected for the sensitivity analysis. The range of data variation for historical and projected land-uses is set at ±5 percent from their base values. The range of data variation for historical groundwater extraction is set at ±10 percent from its base values as shown in Table 1.

3.2.4 Sacramento Valley Floor Area Demands

Demands are classified as CVP project, SWP project, or non-project demands. Demands are also designated by geographic location: Sacramento River Basin (CVP and non-project), Feather River Service Area (SWP and non-project), American River Basin (CVP), San Joaquin River Basin, Delta, and south-of-the-Delta (CVP and SWP). Demands may be represented as time series, varying by month and year, or twelve monthly values repeated every year.

Demands in the Sacramento River Basin, including the Feather and American River basins, and Delta are determined based on land-use and vary by month and year according to hydrologic conditions.

Land-use based demands are developed by first estimating the consumptive use of applied water (CUAW), often referred to as evapotranspiration of applied water (ETAW). It is the amount of water required by crops from irrigation, in addition to any available precipitation in that month or previous month(s). It does not include water that is lost or returned to the water system.

CUAW is determined based on irrigated acreage using the CU model. Irrigated acreage for each DSA is obtained from DWR's land-use surveys conducted about every seven years and interpolated using the California Agricultural Commissioner's yearly crop data. For the purpose of the CU model, the crops are aggregated into 13 crop types; either single crops or a category based on crops which are similar in water use needs and soil-moisture characteristics. Parameters for the thirteen crop types are used as input to the CU model to estimate CUAW.

As shown in Figure 4, the DWR CU model incorporates monthly precipitation, ET rates, soil moisture criteria, rooting depth, irrigation timing, and other factors along with land use to estimate CUAW on a monthly basis.

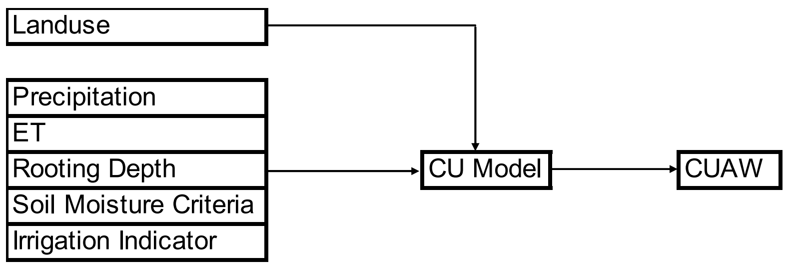

Figure 4 Graphical Representation of CUAW Computation

The land-use based demand, also referred to as diversion requirement (DR), and its components are shown in Figure 5.

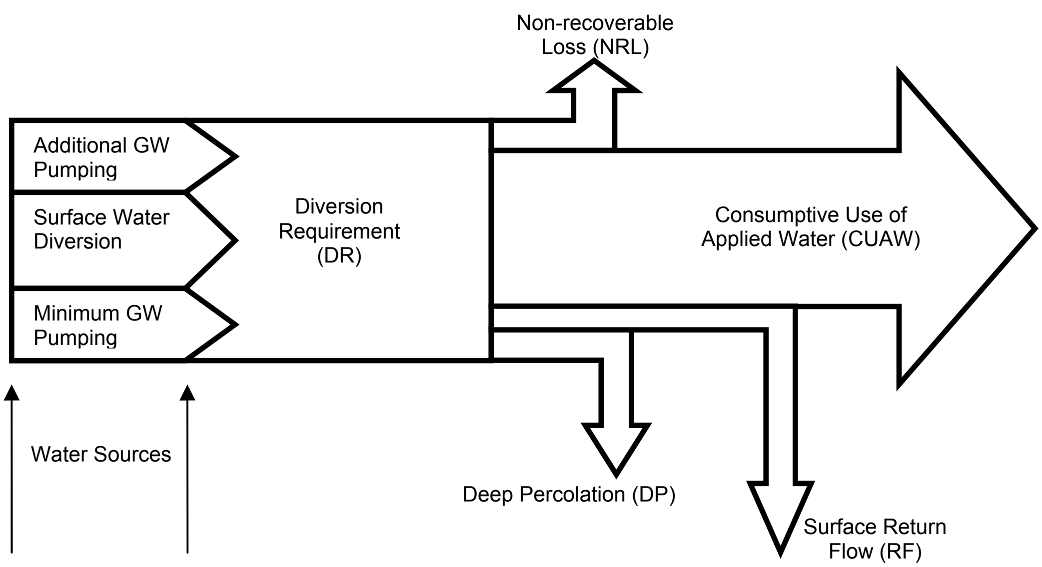

Figure 5 Components of Diversion Requirement

As shown in Figure 5, the following relationship exists between DR and its components:

$$DR = CUAW + NRL + RF + DP \quad (8)$$

where

DR is the diversion requirement;
CUAW is the consumptive use of applied water;
NRL is the non-recoverable loss;
RF is the irrigation return flow;
DP is the deep percolation;

and

NRL is defined as:

$$NRL = NRLF * CUAW \quad (9)$$

where *NRLF* = the non-recoverable loss factor;

RF is defined as:

$$RF = RFF * (DR - DP) \quad (10)$$

where *RFF* is the return flow factor expressed as:

$$RFF = 1 - (1 + NRLF) * BE \quad (11)$$

and *BE* is the basin efficiency expressed as:

$$BE = CUAW / (DR - DP) \quad (12)$$

DP is defined as:

$$DP = \alpha * (DR - RF) \quad (13)$$

where α is the deep percolation factor.

In the following sub-sections, parameters in Equations 8 through 13 and their corresponding designs of sensitivity analysis are described briefly one by one.

3.2.4.1 Consumptive Use of Applied Water (CUAW)

The consumptive use of applied water (CUAW) is the volume of irrigation water, whether from stream diversions or groundwater pumping, that is depleted through crop evapotranspiration (ET). The CUAW is the product of land use acreage and unit CUAW. Unit CUAW is calculated by DWR's CU model that performs soil-moisture accounting in the root zone on a monthly basis. CUAW is a function of plant characteristics, planting and harvest dates, soil characteristics, and climate. The CU model makes various simplifying assumptions. These include:

- No year-to-year variation in crop ET (except in the Delta where time series data is used)
- Available soil moisture storage capacity is 1.5 inches of water per foot of rooting depth
- No runoff or deep percolation occurs unless soil moisture is in excess of an upper limit

Any changes to Crop ET will change not only the diversion requirement but also the local water supply as shown in Equations 5 through 8. When Equations 5, 6, and 7 are used to estimate the projected local water supply, for example, when Crop ET increases, the projected local water supply increases as well. This gives the misconception that there is water being created. In actuality the net impact of increasing ET is a reduced net water supply. This is because modifying the ET at both historical and projected levels of development introduces other factors in the analysis that may result in anomalies unrelated to the ET changes itself. For example, the historical ground water pumping, deep percolation, and stream-aquifer interactions used in the computations of the local water supply, as mentioned earlier in this report, are obtained from the historical run of CVGSM. However, CVGSM itself uses estimated ET for its own computations of crop demands. Therefore any change to ET requires revisiting the historical CVGSM run and re-evaluating the results. This was felt to be beyond the scope of this report. Nevertheless to gauge the impact of the sensitivity of CalSim-II results, it was decided to limit the changes to ET to the projected level of development by which only the projected local water supply calculation in Equation 7 will be impacted. The range of Crop ET changes is designed as ±10 percent from its base value.

3.2.4.2 Non-Recoverable Losses (NRL)

Non-recoverable loss is a portion of applied water that is neither used in crop evapotranspiration, nor it is returned to the surface or groundwater system, but is depleted or lost from the system. This may happen through:

- evaporation from canals, laterals and farm reservoirs
- percolation to a saline aquifer
- disposal of sub-surface drainage using evaporation ponds
- surface runoff to a saline sink or the ocean

These non-recoverable losses are typically assumed to be 10 percent of CUAW on the valley floors and 15 percent in the foothills. For the CU models, 15 percent is assumed for DSA 58 and 10 percent is assumed for all other DSAs. The values used for these DSAs are believed to be conservative estimates. Therefore, the sensitivity analysis is done by reducing the non-recoverable loss factors (NRLF) for all DSAs by 50 percent and 75 percent from their base values in two separate simulation runs. The return flow factor (RFF) is assumed constant for both simulation runs.

3.2.4.3 Basin Efficiency (*BE*)

The basin efficiency (*BE*) for a DSA is the ratio of CUAW to the prime water supply. The prime supply is the sum of surface water diversions and net groundwater extraction. It does not include the pumping of water that had percolated from previously applied water. In CalSim-II, basin efficiency for each depletion area is used to determine the total diversion requirement based on CUAW (see Equation 12). Small portions of the prime supply would return to the surface water system, percolate to groundwater system, or become non-recoverable losses.

The calculations and supporting data of basin efficiency factor (*BE*) are in a DWR

Memorandum Report titled *Central Valley Hydrology Study: Basin Efficiencies*, dated June 1976. The estimates of basin efficiency are based on five years of data from 1966-1970 and 1967-1971 for various DSAs. Although irrigation and water district operations may have changed in the past 20 years, these estimates of efficiency are still used in the hydrologic analysis for the calculation of surface return flows. Basin efficiency factors are defined for each DSA and may vary by month and water-year type.

Basin efficiency (*BE*), return flow factor (*RFF*), and non-recoverable loss factor (*NRLF*) are related through Equation 11. Because *RFF* is greater than or equal to zero, the changes of *BE* has an upper limit as shown below:

From Equation (11):

$$RFF = 1 - (1 + NRLF) * BE >= 0$$
$$(1 + NRLF) * BE <= 1$$
$$BE <= 1 / (1 + NRLF) \qquad (14)$$

where

$NRLF$ = 0.15 for DSA 58
$NRLF$ = 0.10 for all other DSAs

In this study, basin efficiency (*BE*) is varied by ±10 percent from the base value and capped by equation 14.

3.2.4.4 Deep Percolation of Applied Water (α)

Irrigation water returns to the stream network, percolates to groundwater, becomes non-recoverable loss, or is used consumptively as evapotranspiration. In CalSim-II, deep percolation is specified in a lookup table as a fixed percentage of water supply less the surface runoff. These percentages are based on average percolation rates that are computed from post-processing output from the historical run of CVGSM.

Base Deep Percolation Factors

	DSA 10	DSA 12	DSA 15	DSA 58	DSA 65	DSA 69	DSA 70
α	12%	17%	4%	12%	5%	17%	10%

In these sensitivity analysis studies, deep percolation factor (α) is designed to vary by ±5 percent simultaneously for all DSAs from their base values in the above table.

3.2.4.5 Project/Non-project Demands

The CU model is used to estimate demands for each DSA. However, demands within each DSA must be disaggregated into project and non-project demands. Project demands are subject to reduced water allocations based on contracts with the CVP and SWP, while non-project demands are met from sources other than the CVP and SWP project deliveries. Non-project demands may be met by senior riparian water right diversions, local groundwater pumping, and private storage. Releases from the CVP and SWP storage facilities are increased to satisfy project demands, but no additional storage releases are made to satisfy non-project demands.

The split between project and non-project demands in CalSim-II was determined by comparing project crop acreage within each DSA to the total crop acreage within each DSA. For a DSA with CVP-irrigated acreage the historical Reclamation crop acreage for project lands was compared with the DWR CU model crop acreage for the entire DSA for the concurrent period of 1979-94, prior to computing Project CU. For each year, the Reclamation project crop acreage was divided by the corresponding DSA total acreage. The resulting ratio was assumed to represent the percent of project acreage within each DSA. These percentages are then applied to the diversion requirement as calculated by the CU model to determine the project and non-project demands in a depletion area.

Project acreage within each DSA was determined by dividing the maximum annual Reclamation crop acreage during the period of 1979-97 for each crop by the acreage representing the desired projected level of development in the CU model. Values were prorated so that ratios greater than one meant that all acreage for that individual crop type, within the DSA, was irrigated with project water. Urban CU was also assumed to be project water. The maximum Reclamation crop acreage was used because it most closely reflects each water district's use of the maximum allotment of project water.

In these sensitivity analysis studies, the project and non-project split is varied by ± 5 percent and ±10 percent for all DSAs simultaneously from their base values.

3.2.4.6 Outdoor M&I Demands

M&I demands and water uses are not fully addressed in CalSim-II. From the perspective of the model, a large portion of M&I demands are non-consumptive indoor use or, in other words, these demands are recycled 100 percent[2]. However, M&I diversions, although not consumptive, can have a significant effect on reservoir operations, and have therefore been included in CalSim-II for the American River and Lower Sacramento River areas. M&I stream diversions are determined based on recent historical diversions for existing level of development and contract amounts for future level of development. Indoor M&I use is considered to be non-consumptive, and therefore has an efficiency of zero percent. Efficiency for outdoor use is assumed to be the same as for agricultural water use.

Outdoor M&I water use is based on urban acreage and an assumed percentage of irrigated landscape. The total urban acreage is characterized by three use types: hard tops, vacant lots, and lawns. The unit water requirement for lawns is assumed to be the same as that for irrigated pasture, and the requirement for vacant lots the same as that for native vegetation. Hard tops do not contribute to a consumptive use, but impacts the precipitation runoff. Therefore, estimates of outdoor M&I water use are very

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[2] This includes M&I groundwater pumping that subsequently returns to groundwater via percolation ponds, and M&I stream diversions that return to the stream system as outflow from a waste water treatment plant.

approximate. In this study, the sensitivity analysis is done by varying lawn acreages by ± 50 percent while keeping the total urban acreage and hard tops acreage fixed to their base values for all DSAs simultaneously. The reduction or increase in lawns is added to or reduced from vacant lots, respectively.

3.2.4.7 Minimum Groundwater Pumping

In the Sacramento Valley, demand is met by a mixture of surface and groundwater as shown in the left side of Figure 5. Farmers and urban areas may have access to either one or both of these supplies. In CalSim-II, minimum groundwater pumping is specified to represent demands that are met by groundwater only. CalSim-II WRESL code is written so that demand is first met by groundwater pumping, up to the minimum pumping amount (see Figure 5). It is subsequently met by surface water diversion up to the contract amount for project demands and up to availability of surface water for non-project demands. The difference between demand and supply is finally met by additional groundwater pumping. Minimum groundwater pumping amounts are based on data for water years 1981-1993 of the historical CVGSM run. They vary from 16 TAF/yr (DSA 12) to 348 TAF/yr (DSA 10).

In this study, the sensitivity analysis is done by varying minimum groundwater pumping by ± 10 percent simultaneously for all DSAs.

3.3 SWP and CVP Project Operations

State Water Project (SWP) and Central Valley Project (CVP) are the two major water delivery systems in California and they are the focus of CalSim-II modeling efforts. This section briefly describes both projects' delivery allocations, demands, and their sensitivity analysis designs.

3.3.1 SWP and CVP Delivery Allocation

SWP and CVP delivery logic in CalSim-II uses runoff forecast information, delivery versus carryover risk curves, and standardized rules (Water Supply Index versus Demand Index Curve) to estimate the total water available for deliveries and carryover storage. The model does not calculate monthly deliveries based upon "full knowledge" of what the runoff will be for the entire water year. The logic updates delivery allocations monthly from January 1 through May 1 as runoff forecasts become more certain. Demands are preprocessed. They vary according to the specified level of development (2001, 2020) and according to hydrologic conditions. Demands serve as an upper bound on deliveries. CalSim-II allocates deliveries based upon the estimated water supply available for delivery. In each year of the simulation, the delivery target is updated on January 1, February 1, March 1, April 1 and May 1 for SWP and March 1, April 1 and May 1 for the CVP. At each update, the model estimates a Water Supply Index (WSI) and estimates what portion of the WSI is available for delivery to contractors and carryover storage. The WSI-DI curve is used for estimating water available for delivery and carryover storage given a WSI value. Once the total water available for delivery and carryover storage is estimated, it is split into target delivery and estimated carryover storage by use of a delivery versus carryover risk curve defined by the user.

The WSI is the sum of the beginning of the month storage in project reservoirs and the forecast inflows for the remainder of the water year. For the SWP, the WSI is the sum of the beginning of the month storage in Lake Oroville and SWP portion of San Luis reservoir and the forecast Feather River inflow into Lake Oroville. For the CVP, the WSI is the sum of the beginning of the month storage in Trinity, Shasta and Folsom reservoirs and the CVP portion of San Luis reservoir and the forecast Sacramento River inflow into Shasta Lake and American River inflow into Folsom Lake. Once the WSI value is generated, CalSim-II calculates a Demand Index (DI) value from the WSI versus DI curve. The Demand Index is the sum of water available for target deliveries and carryover storage. The WSI changes monthly as storage levels change and the forecasts become more certain. Generation of the WSI-DI curves has been automated in CalSim-II using two steps. Initially a 1:1 relationship (45 degree line) is assumed; the model is run and subsequently the WSI-DI curve is recalculated to minimize the sum of the square of the differences between the delivery index and the actual deliveries and carryover storage.

DWR’s Division of Flood Management developed a procedure to forecast the rest-of-water year reservoir inflows to Lake Oroville, Shasta Lake and Folsom Lake. The first step of the procedure was to develop a regression equation relating annual runoff to annual precipitation to forecast water year inflow to a reservoir. Step two was to estimate the rest-of-water year inflow to a reservoir by subtracting the recorded year-to-date inflow from the forecasted water year inflow. The rest-of-water year inflow forecasts were made at the beginning of each month of January through May. For Lake Oroville, inflow forecasts were made at 99 percent exceedance level for January, February, and March, and 90 percent for April and May. For Shasta Lake and Folsom Lake, inflow forecasts were made at 99 percent for January and February, 90 percent for March, 75 percent for April, and 50 percent for May. The forecasted rest-of-water year inflows were used together with the beginning-of-month reservoir storages to compute the WSI. As an example, Figure 6 on next page is a representation of SWP allocation logic.

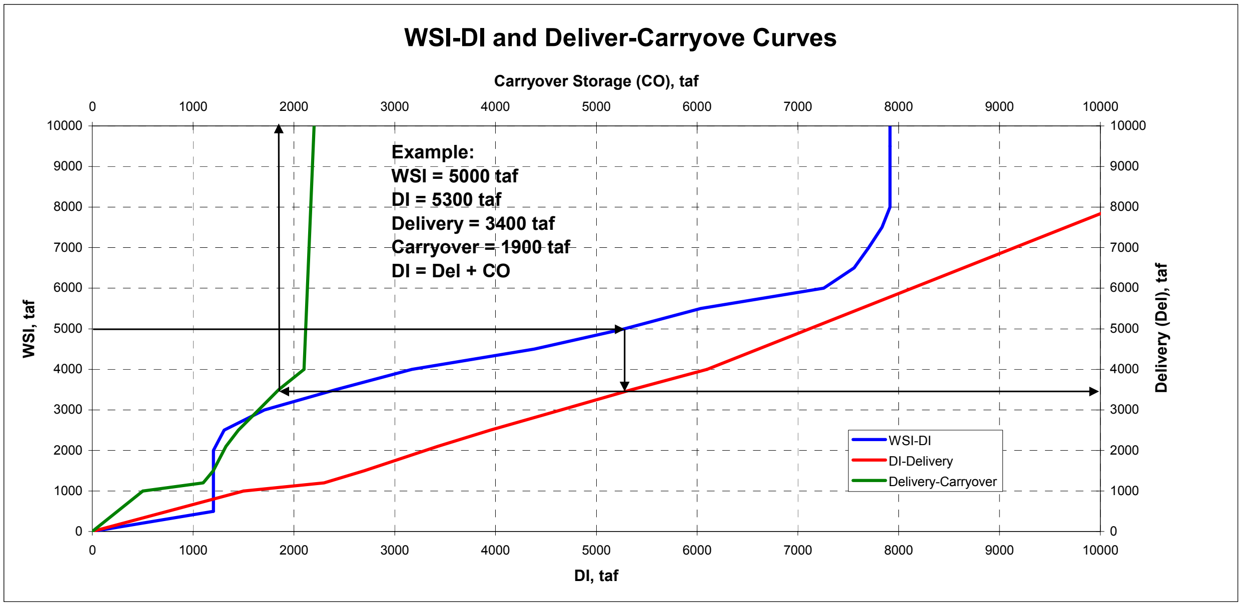


Figure 6 Representation of SWP Allocation Logic

In Figure 6, the blue curve is the CalSim-II generated WSI-DI. The line in green is the user-defined Delivery-Carryover curve. The Delivery-Carryover curve is not directly used in the model, instead, a derived curve of DI versus Delivery from delivery-carryover relationship, in which DI = Delivery + Carryover storage, is used. The example in Figure 6 summarizes the steps to determine the SWP project delivery and carryover storage targets using the WSI-DI relationship:

Step 1: Determine the best estimate of the water supply available to meet the system demands. This is termed Water Supply Index (WSI) and is the sum of the beginning of month storage in Lake Oroville and SWP portion of San Luis reservoir and the forecast Feather River inflow into Lake Oroville. In this example, WSI = 5,000 TAF.

Step 2: Determine the best estimate of the water delivery and carryover storage at the estimated WSI value. This is termed the Demand Index (DI) and is the sum of the SWP annual delivery target and carryover storage. With the given WSI value of 5,000 TAF, DI value is determined to be 5,300 TAF from the WSI-DI curve.

Step 3: Determine the annual water amount to be actually delivered and to be held in storage from the DI-Delivery curve using the current DI value. In this example, delivery of 3,400 TAF is obtained from the DI-Delivery curve with the current DI value of 5,300 TAF. The carryover storage is, then, 5,300 TAF – 3,400 TAF = 1,900 TAF.

There are separate WSI-DI curves for the SWP and CVP allocations. For SWP, the SWP contractors and NOD project M&I contractors allocations are made using the WSI-DI curve. The NOD CVP allocation is determined by using a system-wide CVP WSI-DI curve as well. Once the water available for use by SWP or the CVP system-wide is estimated, it is split into target delivery and estimated carryover storage by the use of a user-defined Delivery versus Carryover Risk curve. Because the WSI-DI procedures used by both SWP and CVP are similar, only the user-defined SWP Delivery-Carryover Risk Curve is selected for the sensitivity analysis in this study. As shown in Figure 7, the sensitivity analysis of the user-defined SWP Delivery-Carryover Risk curve is designed to vary carryover storage by ± 20 percent from its base value with a given delivery.

There are exceptions for both SWP and CVP allocations in which WSI-DI procedures are not used. For CVP SOD allocations, a Delta Index is computed as the sum of January-to-May Eight River Index values. An Export Index is created as a function of the Delta Index, and this Export Index is used in conjunction with the CVP San Luis storage conditions to determine the maximum South-of-Delta delivery allocations. CVP SOD delivery allocations are set to the minimums of the Delta-Export Index allocations or the WSI-DI system allocations. Delivery to the Feather River Service Area (FRSA) Settlement contractors is not subject to the WSI-DI allocation procedure. In drought years, FRSA Settlement contractors' demands can be reduced up to 50 percent in any one year and up to 100 percent in any series of seven consecutive years. These exceptions are not analyzed in this study.

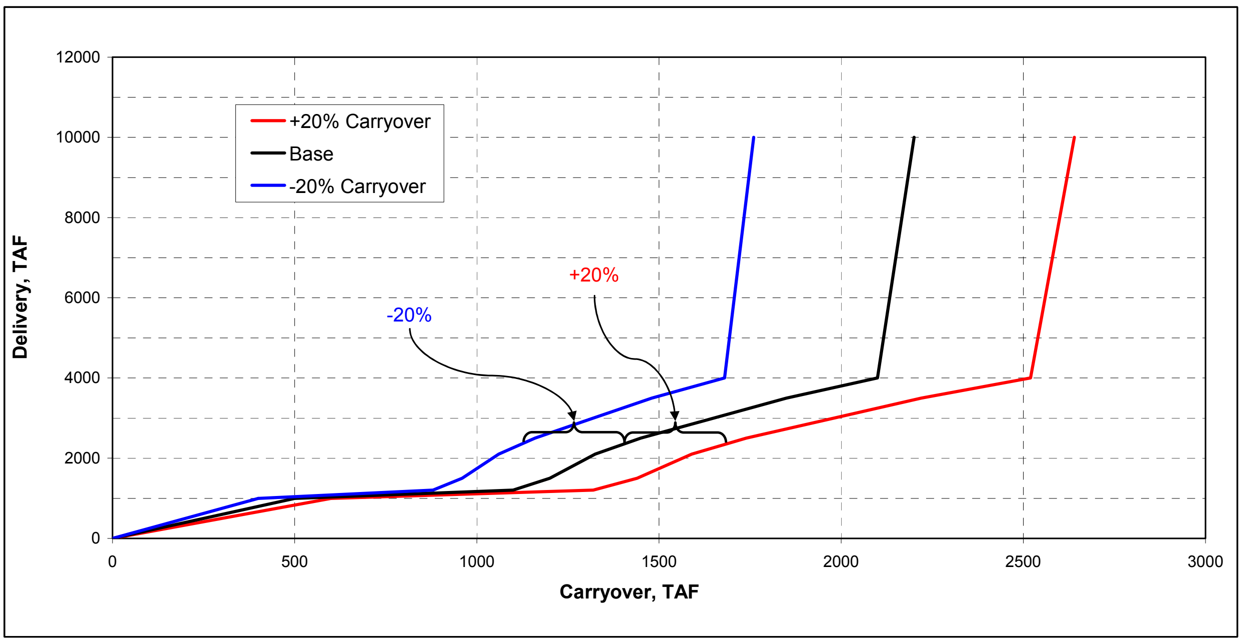


Figure 7 Sensitivity Analysis Design of SWP Delivery-Carryover Risk Curve

3.3.2 San Luis Rule-curves

Operation of the San Luis reservoir plays an important role in the system-wide performance of both SWP and the CVP. The ability to transfer and store water SOD provides greater project yield and improved flexibility in project operations. The rule-curve provides a storage target for the operation of San Luis reservoir to be met by transferring water from storage in northern reservoirs. The rule-curve sets two main targets, one for filling to the top of conservation pool (end of April) and another for carry-over (end of September). The targets for remaining months are computed as intermediate steps to these two targets. Two separate rule-curves, one for the SWP portion of San Luis reservoir and another for the CVP portion of San Luis reservoir are used in CalSim-II model. San Luis reservoir top of conservation pool is used as the cap of the rule-curve target. It is noted that the actual storages may differ from the rule-curve storage targets due to hydrologic conditions or other controlling factors of system operations. The same methodology is used for both SWP and the CVP unless otherwise noted.

3.3.2.1 Filling Targets

The filling targets for the San Luis rule-curves represent the period from October through April. During these seven months water is transferred from northern storage facilities if necessary to fill San Luis reservoir for later deliveries SOD. The procedure considers the current storage in northern reservoirs and the delivery target for the current delivery year through a four step process performed each month:

1. The delivery targets (SWP: SWP system, CVP: CVP SOD) are used, via lookup tables, to determine a maximum rule-curve target. The delivery targets take into account forecasted inflows to the system and the amount to be delivered. This forecasting allows the rule-curve to be reduced during drier years when less water is required to be transferred SOD. This represents the rule-curve to be used if carryover storage at the start of the year is relatively high.

2. During October through December, the storage in northern reservoirs (SWP: Oroville, CVP: Shasta and Folsom combined) is used, via lookup tables, to adjust the rule-curve values established in step 1. This adjustment is made to reduce the amount transferred SOD when the previous year's carryover storage is relatively low.

3. Next, the rule-curves are adjusted so that they gradually increase to their maximum step 2 values in March in equal amounts. This ramping procedure prevents large amounts of northern storage from being transferred too early in the delivery year. March and April use rule-curve values calculated in step 2 without any adjustments.

4. A final modification is made to the rule-curves by introducing a user-defined cap on San Luis storage, based on the previous month's storage in Shasta or Oroville reservoirs, for the CVP and SWP rule-curves, respectively.

There are three periods during the filling stage when delivery targets vary. These are:

1. October through December: During October through December, the rule-curve determination is unreliable as it is before the period of major precipitation. To compensate for this, the delivery targets used for modification of the rule-curve found in the second step are assumed to be the long-term average delivery target values.

2. January and February: January represents the first month when a calculation of the SWP delivery target is made with some confidence. As the delivery target is updated each month after January, the rule-curve calculation is also updated. The CVP uses a delivery calendar starting in March, so there is no estimation of the delivery target for January and February. To compensate for this, a forecast of the delivery target is made simulating the water supply index – demand index and delivery target – carryover curves.

3. March and April: March represents the first month that a delivery target for the CVP is estimated. The rule-curve is updated each month as the CVP delivery target is updated.

3.3.2.2 Emptying Targets

The emptying targets for San Luis reservoir rule-curve occur during the period of May through September. During this period storage is reduced as San Luis reservoir inflows decrease and SOD deliveries increase. The procedure used to decrease the storage also modifies the target storage, which decreases each month.

1. The procedure first estimates the end-of-month target for September. A lookup table is used which only considers the storage in San Luis reservoir. The rule-curve generally attempts to hold a combined SWP and CVP storage of 300 TAF at the end of September (SWP: 165 TAF, CVP: 135 TAF). The September target is made in May and is based on the end of April storage.

2. During May through August the rule-curve is gradually reduced so the September target is met. The reductions are determined by prorating the draw-down in the rule-curve according to the fraction of the current month's demand to the remaining delivery-year's demands. This is updated each month, calculating a new remaining draw-down and taking into account only the remaining delivery-year's demands. For example, if delivery for July represents 25 percent of the remaining delivery through September, the draw down in San Luis reservoir will be 25 percent of the available storage above the September rule-curve target.

Because the determination and usage of the San Luis reservoir rule-curves for both SWP and CVP are similar, only the effect of the variations in SWP San Luis reservoir rule-curve is examined in this study. As shown by the plot in Figure 8, all 12 monthly storage values on the base curve are scaled up or down by 10 percent at the same time to get the new curves. The new curves are still subject to the operational constraints of the reservoir – top and bottom of conservation pool.

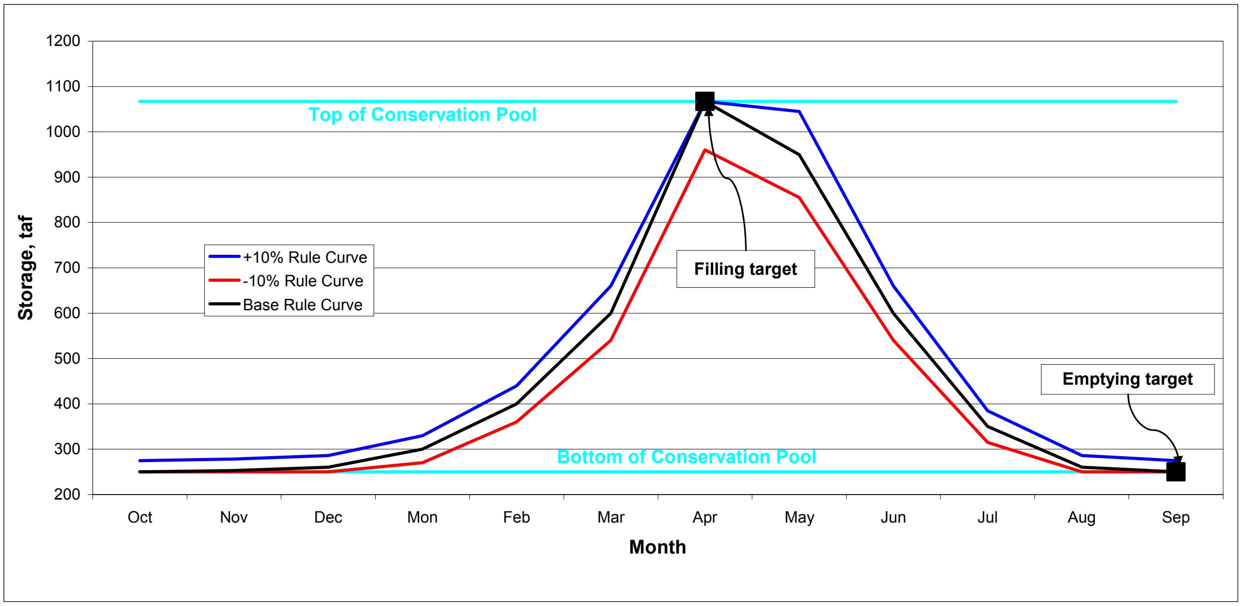


Figure 8 Conceptual Design of SWP San Luis Rule-curve Sensitivity Analysis

3.3.3 CVP and SWP Demands

Demands are classified as CVP project, SWP project, or non-project demands. CVP project demands are separated into several classes based on contract type. Demands also are designated by location; Sacramento River Basin (CVP and non-project), Feather River Service Area (SWP and non-project), American River Basin (CVP), San Joaquin River Basin, Delta, and South-of-Delta (CVP and SWP). Demands may be represented as time series, varying by month and year, or more simply as 12 repeating monthly values.

Demands in the Sacramento River Basin (including the Feather and American River basins) and the Delta are based on land use and vary by month and year according to hydrologic conditions. They are discussed in more detail in Section 3.2.4. Demands in the East-Side Streams area and the San Joaquin River Basin are set to fixed values each year. CVP SOD and SWP Delta demands are based on contract amounts; CVP demands are assumed constant each year, while SWP demands are assumed to vary depending on a wetness index.

In nearly all years, CVP SOD delivery is constrained by either the lack of conveyance capacity or by the available water supply. The current demand level is seldom a controlling factor for CVP SOD delivery. In contrast, SWP delivery is demand driven in wet years rather than supply or capacity constrained. Therefore, this section will only focus on the SWP demand.

3.3.3.1 South-of-the Delta Annual Table A Demands

Twenty-nine agencies have contracts for long-term water supply from SWP totaling about 4.15 million acre-feet annually, of which about 4.05 million acre-feet are for contracting agencies with service areas south of the Sacramento-San Joaquin Delta. About 70 percent of this amount is contract entitlement for urban users and the remaining 30 percent for agricultural users.

In the Benchmark Study of 2002, demand of San Joaquin Valley agricultural contractors is reduced in wetter years using a wetness index developed from annual Kern River inflow to Lake Isabella; and demand of the Metropolitan Water District of Southern California (MWDSC) is reduced in wetter years using the 10-station, two-year average precipitation index or based upon MWDSC integrated operations with Eastside Reservoir in future scenarios.

For modeling convenience, the variable annual SWP demand in the benchmark study is replaced by a fixed annual demand of 3.5 million acre-feet to create a new base model. The variations of the Table A Demands are set at 2.5, 3.0, 3.9, and 4.15 million acre-feet. The computation of the Sensitivity Index, Elasticity Index, and all other comparisons are measured against the base value of 3.5 million acre-feet.

3.3.3.2 Article 21 Demands

In addition to entitlement demands in Table A, SWP contractors also receive “Article 21” water. “Article 21” water is contractor requested water that may only be provided from Delta surplus water and only to SWP contractors requesting it. When available, “Article 21” water is delivered to SWP contractors in accordance with the following assumptions based on Monterey Amendment White Paper dated September 28, 1995:

- Article 21 water is delivered directly from the Delta at Banks Pumping Plant. It is not stored in San Luis reservoir for later delivery to contractors.
- A contractor may accept Article 21 water in addition to its monthly scheduled entitlement water. Article 21 water does not affect entitlement water allocations.
- If demand for Article 21 water is greater than the supply in any month, then the supply is allocated to the contractors in proportion to their Table A entitlements.

Because the “Article 21” water is mostly available in the winter, many SWP contractors make their requests year-round with peaks in the winter (December – March). Currently in CalSim-II the maximum Article 21 water request in winter (December – March) is 134 TAF per month. In this study, the sensitivity analysis is designed to vary the monthly Article 21 water request to 400, 600, 800, and 1,000 TAF per month, one at a time, for December through March period.

3.4 Delta Water Quality Standards

Meeting Delta water quality and flow standards as outlined by the provisions of the State Water Resources Control Board's May 1995 Water Quality Control Plan (WQCP) is one of the major responsibilities of both the CVP and SWP. This joint responsibility is coordinated between the two projects by the Coordinated Operations Agreement (COA) of November 1986, between Reclamation and DWR.

Due to limited resources, it is difficult to investigate the sensitivity of all Delta water quality standards and regulations. Therefore, based on discussions with modelers and model users, Delta minimum salinity flow requirement based on Artificial Neural Network (ANN) model and X2 flow requirements are selected for the sensitivity analysis in this study.

3.4.1 Minimum Salinity Flow Requirement (ANN)

Determination of flow-salinity relationships in the Sacramento-San Joaquin Delta is critical to both project and ecosystem management. However, the salinity in the Delta cannot be modeled accurately by the simple mass balance routing in the monthly time-step used in CalSim-II. Therefore, CalSim-II uses DWR's Artificial Neural Network (ANN) model which correlates DSM2 model-generated salinity at key Delta locations with Delta inflows, Delta exports, and Delta Cross Channel operations to simulate the flow-salinity relationships in the Delta.

DWR's Delta Simulation Model (DSM2) is a one-dimensional hydrodynamic and water quality model capable of simulating flow, stage, and water quality throughout the Delta. DSM2 requires input flows for the rivers that feed the Delta at the boundaries. The Artificial Neural Network (ANN) was developed by DWR in 1999, which tries to mimic the flow-salinity relationships as modeled in DSM2, but provide a rapid transformation of this information into a form usable by CalSim-II model. The ANN is implemented in CalSim-II to constrain the operations of the upstream reservoirs and the Delta export pumps in order to satisfy particular salinity requirements. The ANN considers antecedent river conditions up to 148 days, and a "carriage-water" type of effect associated with Delta exports. The ANN flow-salinity model estimates electrical conductivity (EC) at the following four locations:

- AWW - Collinsville at Sacramento River
- CCC - Contra Costa Canal Intake (Rock Slough)
- EMW - Emmaton on the Sacramento River
- JPW - Jersey Point on the San Joaquin River

In order for the ANN model to mimic DSM2 it must be calibrated and validated. This process, referred to as training, is based on a data set from a DSM2 simulation. The data used for this training comes from a 16-year, DSM2 simulation based on the Delta perimeter flows from a CalSim-II study at 2001 level of demand and D1485 regulatory environment. Ten years are used for calibrating, and the remaining six years are used for validation. There are two types of known errors associated with the ANN model. One is the bias error (overestimation or underestimation) and the other is the skew error. Bias error is the special case of skew error. For a time-series simulation, the bias error is considered to be a systematic overestimation or underestimation and the skew is the lack of ability to simulate the shape or trend of the time series (including the lag of the system response). Usually the simulation errors are not bias errors alone. Figure 9 illustrates these two types of errors.

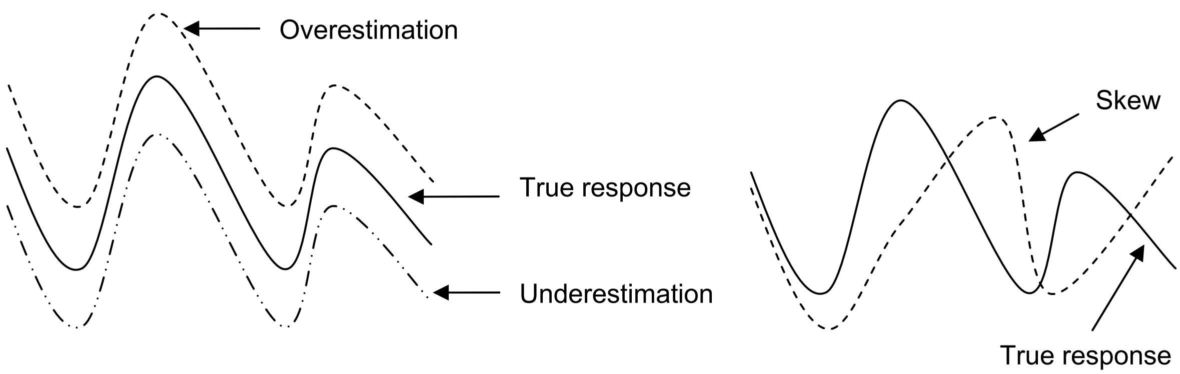


Figure 9 Types of Errors of ANN Simulation

In this study, only the bias error is considered for the sensitivity analysis. The ANN flow estimates in CalSim-II are varied by ±10 percent and ±20 percent, respectively, for all four locations at the same time.

3.4.2 Salinity Flow Requirements for Fisheries (X2)

X2 is the distance in kilometers from the Golden Gate Bridge to where the average daily salinity is 2 parts per thousand. The *1995 Water Quality Control Plan (WQCP)* establishes the minimum number of days during February to June that the salinity, measured in electrical conductivity at Chipps Island (74 km from Golden Gate Bridge) and Roe Island (64 km from Golden Gate Bridge) has to be maintained at 2.64 mmhos/cm or lower. This electrical conductivity corresponds roughly to the required salinity of 2 parts per thousand. Details on how this requirement is modeled in CalSim-II are:

- At the confluence (81 km from the Golden Gate Bridge), the full 150 days (February 1 - June 30) of 2.64EC is maintained in all years, with up to a maximum flow of 7,100 cfs. This requirement is dropped in May and June of any year for which the projected Sacramento River Index (SRI) in WQCP is less than 8.1 MAF. In those years when the criteria are dropped, a minimum outflow of 4,000 cubic feet per second (cfs) is maintained in May and June.
- The Kimmerer-Monismith equation, provided below, is used to calculate outflow

required (in cfs) to maintain the EC standard (average monthly position in kilometers). In this equation the EC position is given and the Delta outflow is solved for.

$$\text{EC position} = 122.2 + [0.3278 * (\text{previous month EC position km})] - [17.65 * \log_{10}(\text{current month Delta outflow in cfs})]$$

In months when the EC standard is specified in more than one place (for example, 19 days at the confluence and 12 days at Chipps Island), required outflow for the month is computed as a flow-weighted average of the partial month standards.

- The trigger to activate the Roe Island standard is set at 66.3 km from the previous month, as an average monthly value.
- The maximum required monthly outflows to meet the 2.64 EC standard are capped at the following limits: 29,200 cfs for Roe Island; 11,400 cfs for Chipps Island; and 7,100 cfs for the Confluence.
- Relaxation criteria for the February Chipps Island standard is a function of the January Eight River Index as follows:
  - X2 days = 0 if the Index is less than 0.8 MAF
  - X2 days = 28 if the Index is greater than 1.0 MAF
  - X2 days vary linearly between 0 and 28 if the Index is between 0.8 MAF and 1.0 MAF.

Since the X2 standard is specified as a required location the Kimmerer-Monismith equation is algebraically reversed as follows and solved to obtain the Delta outflow required for the current month to have the X2 line at the required location:

$$\text{Current month Delta outflow in cfs} = \text{POW}\{10, [122.2 + 0.3278 * (\text{previous month EC position km}) - \text{EC position}] / 17.65\}$$

If this outflow is larger than the Required Delta Outflow from all other standards it becomes the new controlling standard for the month and is imposed on the system during the monthly simulation. Since the final simulated total Delta Outflow may be larger than the outflow requirement the actual simulated X2 position is computed from the equation at the end of the month, for use in the next month's computations.

In this study, the sensitivity analysis is designed to vary the left-hand side of the reversed Kimmerer-Monismith equation by ± 5 percent and ± 10 percent subject to the maximum required monthly outflows at all three locations.

3.5 Existing Banks Pumping Capacity

The California Aqueduct is the major water conveyance of the State Water Project and extends 444 miles from Sacramento-San Joaquin Delta to Perris Reservoir in Southern

California. It transports water from the Delta to the San Joaquin Valley and Southern California and through branch aqueducts to the southern San Francisco Bay Area and to Santa Barbara and San Luis Obispo counties. The Harvey O. Banks Delta Pumping Plant is at the head of the California Aqueduct and it lifts water to an elevation of 244 feet where it flows by gravity into the aqueduct.

The Banks Pumping Plant was completed in 1969 and expanded by adding four more pumps in 1986. The Banks Pumping Plant is able to pump about 10,300 cfs. However, under SWRCB D-1485 and the U.S. Army Corps of Engineers permit (public notice 5820A, amended), Banks Pumping Plant capacity is restricted at a mean monthly pumping rate of 6,680 cfs. From December 15 to March 15, the average monthly pumping rate can be increased up to 8,500 cfs if San Joaquin flow at Vernalis exceeds 1,000 cfs.

In the real-time operation of the Banks Pumping Plant, however, the pumping may not reach its scheduled limits due to the following two reasons:

- Weed accumulation in front of the trash rack of the Skinner Fish Facility could retard flows reaching the pumps while they are allowed to pump water at their permitted capacity.
- Low energy tide from the San Francisco Bay could prevent water from flowing into the Clifton Court Forebay fast enough to feed the pumps while they are allowed to pump water at their permitted capacity.

Based on discussions with SWP Operations Control Office staff, the sensitivity analysis for Banks pumping capacity is designed to reduce the permitted capacity of 6,680 cfs for the period of March 15 through December 15 by 5 percent (334 cfs). The Sensitivity Index (SI) for various output variables will be computed by dividing their annual volume changes by the equivalent volume change of the monthly pumping capacity.

4 Results and Discussions

This chapter presents the results of sensitivity analysis of 21 selected model input parameters. Two model performance measures of Sensitivity Index (SI) and Elasticity Index (EI) defined in Chapter 2 are used to measure the sensitivity of model output variables with respect to the model input parameters. Selected input parameters that significantly affect the SWP are discussed in detail in order to show how the SWP delivery and other key model output relevant to SWP operations respond to the changes in model inputs. Bar charts for selected input parameters are also provided in Appendix A to highlight additional information.

SIs and EIs of 22 model output variables with respect to 21 model input parameters selected for the analysis are computed based on their 73-year average annual values and are summarized in Table 2. The top row of Table 2 lists the input parameters analyzed and the second column from the left lists the names of selected model output variables. Values outside parentheses are EIs and values inside parentheses are SIs. The color shadings indicate different levels of sensitivity; red represents high sensitivity (│SI│ > 0.2); yellow represents medium sensitivity (0.1 <= │SI│ <= 0.2); and white represents low sensitivity (│SI │< 0.1). Reader should keep in perspective the degree of perturbation made for each input parameter investigated in this study when drawing any conclusions from the computed sensitivities. Note that there are no SI values computed for input parameters of project/non-project split, X2, ANN, SWP Delivery-Carryover Curve, and SWP San Luis Rule-curve since relevant water volume changes cannot be properly defined and computed. Blank cells in Table 2 indicate that the SI and EI for that specific output variable are non-monotonic functions (see Chapter 2) of the corresponding input parameter, in which case individual EI and SI that are used to compute the averages should be evaluated separately.

Table 3 contains all individual SI and EI values that are used to compute the average SI and EI in Table 2 for all selected output variables. This table is useful in identifying the significance of the nonlinearity as well as verifying the monotonic assumption of SI and EI for output variables with respect to each of the input parameters. If SI and EI are non-monotonic functions of input parameters, their averages are no longer meaningful and the individual SI and EI contained in Table 3 should be analyzed.

The calculation and physical meaning of SI and EI are demonstrated by an example in section 4.1.1. Some major observations on selected input parameters are discussed in detail to demonstrate how Table 2 and Table 3 can be used by SWP contractors to understand the impact on their deliveries.

Output variable responses (SI and EI) with respect to input parameters are summarized based on their 73-year (1922-1994) averages. In addition to the Sensitivity Index (SI) and the Elasticity Index (EI), four bar charts reflecting absolute water volume changes of some major output variables are presented in Appendix A for each input parameter as a supplement to Tables 2 and 3. Among these four charts, two are for the 73-year (1922-1994) averages and the other two are for dry period (1928-1934) averages. Those charts provide additional details to give more insight on the responses of major output variables to input parameter changes.

Table 2 Summary of Elasticity Index (EI) and Sensitivity Index (SI)

	Model Response	Shasta Inflow	Oroville Inflow	Yuba Inflow	Folsom Inflow	Historical Land Use	Projected Land Use	Historical GW Extraction	Non-recoverable Losses	Crop ET	Basin Efficiency	Deep Percolation of Applied Water	Outdoor M&I Demands	Minimal GW Pumping	Project non-project Split	SWP Delivery-Carryover Curve	SWP San Luis Rule Curve	SWP Table A Demand	Article 21 Demand	ANN	X2 Standard	Banks Pumping Limit
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	SWP Total Delivery	0.07 (0.05)(1)	0.18 (0.19)	0.06 (0.12)	0.05 (0.14)	0.09 (-0.13)	-0.05 (-0.03)	-0.04 (-0.15)	0.00 (-0.02)	(2)	-0.15 (0.10)		0.00 (-0.20)	0.01 (0.04)	0.06	-0.01	0.02	0.31 (0.39)	0.01 (0.16)	-0.08	-0.04	0.15 (1.45)
2	CVP total Delivery	0.25 (0.22)	0.05 (0.07)	0.04 (0.11)	0.03 (0.09)	0.10 (-0.18)	0.14 (0.11)	-0.04 (-0.19)	0.02 (0.12)	0.16 (0.09)	-0.32 (0.26)	0.01 (0.06)	0.00 (-0.21)	0.02 (0.08)	0.26			-0.01 (-0.01)		-0.04	-0.03	-0.01 (-0.12)
3	SWP Delta Delivery	0.08 (0.04)	0.26 (0.20)	0.07 (0.12)	0.05 (0.12)	0.12 (-0.13)	-0.09 (-0.04)	-0.05 (-0.15)	-0.01 (-0.05)	-0.21 (-0.08)	-0.17 (0.08)	-0.01 (-0.03)	0.01 (-0.19)	0.03 (0.08)	0.05	-0.02		0.55 (0.52)	0.00 (-0.01)	-0.09	-0.05	0.07 (0.48)
4	SWP NOD Delivery	0.00 (0.00)	0.01 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.17 (0.02)	0.00 (0.00)	0.03 (0.03)	0.78 (0.08)	-0.17 (0.02)	0.03 (0.03)	0.00 (0.00)	-0.03 (-0.02)	0.16	0.00		-0.01 (0.00)	0.00 (0.00)	0.00	0.00	0.00 (0.00)
5	Article 21 Delivery	0.34 (0.01)	-0.51 (-0.02)		0.16 (0.02)		-0.45 (-0.01)		-0.02 (0.00)		0.30 (-0.01)			-0.14 (-0.02)	-0.44	0.08	0.46	-2.62 (-0.13)	0.15 (0.17)	-0.26*	-0.01*	2.63 (0.96)
6	CVP SOD Delivery	0.38 (0.18)	0.08 (0.06)	0.06 (0.09)	0.04 (0.08)	0.15 (-0.15)	-0.25 (-0.11)	-0.06 (-0.16)	-0.03 (-0.10)	-0.27 (-0.09)	-0.10 (0.04)	-0.03 (-0.10)	0.01 (-0.18)	0.05 (0.14)	-0.01		0.00*	-0.01 (-0.01)		-0.06	-0.05	-0.02 (-0.10)
7	CVP NOD Delivery	0.10 (0.04)	0.02 (0.01)	0.01 (0.02)	0.01 (0.01)	0.03 (-0.03)	0.59 (0.21)	-0.01 (-0.03)	0.06 (0.22)	0.66 (0.18)	-0.59 (0.22)	0.06 (0.15)	0.00 (-0.03)	-0.03 (-0.06)	0.59		0.00*	0.00 (0.00)		-0.01	-0.01	0.00 (-0.02)
8	Total Delta Outflow	0.27 (0.69)	0.20 (0.74)	0.10 (0.75)	0.07 (0.75)	0.07 (-0.36)	-0.09 (-0.22)	-0.03 (-0.39)	-0.01 (-0.29)	-0.18 (-0.30)	-0.07 (0.15)	-0.01 (-0.17)	0.00 (-0.41)	0.01 (0.09)	-0.01	0.00	0.00	-0.08 (-0.35)	0.00 (-0.16)	0.04	0.02	-0.04 (-1.48)
9	Banks+Tracy Export	0.23 (0.24)	0.16 (0.24)	0.07 (0.22)	0.05 (0.22)	0.13 (-0.29)	-0.17 (-0.16)	-0.06 (-0.32)	-0.02 (-0.17)	-0.24 (-0.17)	-0.13 (0.12)	-0.02 (-0.13)	0.01 (-0.39)	0.04 (0.21)		-0.01	0.01	0.19 (0.36)	0.00 (0.16)	-0.08	-0.05	0.11 (1.52)
10	Banks Export	0.10 (0.06)	0.21 (0.18)	0.07 (0.13)	0.05 (0.14)	0.11 (-0.14)	-0.11 (-0.06)	-0.05 (-0.16)	-0.01 (-0.06)	-0.20 (-0.08)	-0.14 (0.08)	-0.01 (-0.04)	0.01 (-0.21)	0.02 (0.07)	0.03	-0.01	0.02	0.35 (0.37)	0.01 (0.16)	-0.10	-0.05	0.20 (1.63)
11	Tracy Export	0.39 (0.18)	0.09 (0.06)	0.06 (0.09)	0.04 (0.08)	0.16 (-0.15)	-0.25 (-0.10)	-0.07 (-0.16)	-0.03 (-0.10)	-0.28 (-0.09)	-0.10 (0.04)	-0.03 (-0.10)	0.01 (-0.18)	0.06 (0.14)	-0.01			-0.01 (-0.01)		-0.06	-0.05	-0.02 (-0.10)
12	Banks SWP Export	0.08 (0.05)	0.22 (0.18)	0.07 (0.12)	0.06 (0.14)	0.11 (-0.13)	-0.10 (-0.05)	-0.05 (-0.15)	-0.01 (-0.06)	-0.20 (-0.08)	-0.14 (0.07)	-0.01 (-0.03)	0.01 (-0.19)	0.02 (0.06)	0.03	-0.01	0.02	0.37 (0.38)	0.01 (0.16)	-0.10	-0.04	0.18 (1.46)
13	Banks CVP Export	0.86 (0.01)	0.04 (0.00)	0.11 (0.01)		0.42 (-0.01)	-0.37 (-0.01)	-0.16 (-0.01)	-0.04 (-0.01)	-0.43 (0.00)	-0.31 (0.00)	-0.06 (-0.01)	0.01 (-0.01)	0.14 (0.01)	0.14	0.00	0.02	-0.53 (-0.02)	0.00 (0.00)	-0.13	-0.14	0.79 (0.17)
14	SWP End-of-Sept Storage		0.00 (0.00)	0.00 (0.00)		0.01 (-0.01)	0.00 (0.00)	0.00 (-0.01)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)		0.00 (-0.01)	0.00 (0.00)	0.00	0.00	0.00	-0.01 (-0.01)	0.00 (0.00)	0.00*	0.00	0.00 (0.00)
15	CVP End-of-Sept Storage	0.01 (0.01)	0.00 (0.00)	0.00 (0.00)	0.00 (0.01)	0.01 (-0.02)	0.00 (0.00)	-0.01 (-0.02)	0.00 (-0.01)	-0.01 (0.00)	-0.01 (0.01)	0.00 (0.00)	0.00 (-0.04)	0.00 (0.00)	0.00		0.00			0.00	0.00	0.00 (-0.04)
16	SWP SOD End-of-Sept Storage											0.00 (0.00)	0.00 (0.00)		0.00	0.00		0.00 (0.00)	0.00 (0.00)	0.00	0.00	0.00 (0.00)
17	SWP NOD End-of-Sept Storage		0.00 (0.00)	0.00 (0.00)		0.01 (-0.01)	0.00 (0.00)	0.00 (-0.01)	0.00 (0.00)	-0.01 (0.00)	-0.01 (0.00)		0.00 (-0.01)	0.00 (0.00)	0.00	0.00	0.00	-0.01 (-0.01)	0.00 (0.00)	0.00*	0.00	0.00 (0.00)
18	CVP SOD End-of-Sept Storage		0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)		0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00	0.00	0.00	0.00 (0.00)	0.00 (0.00)	0.00	0.00	0.00 (0.00)
19	CVP NOD End-of-Sept Storage	0.01 (0.01)	0.00 (0.00)	0.00 (0.00)	0.00 (0.01)	0.01 (-0.02)	-0.01 (0.00)	-0.01 (-0.02)	0.00 (-0.01)	-0.01 (0.00)	-0.01 (0.01)	0.00 (0.00)	0.00 (-0.04)	0.00 (0.00)	0.00		0.00			0.00	0.00	0.00 (-0.04)
20	San Luis SWP End-of-Sept Storage	-0.02 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	-0.01 (0.00)	0.01 (0.00)		0.00 (0.00)	0.00 (0.00)		0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00	0.00	0.00		0.00 (0.00)	0.01	0.01	0.00 (0.00)
21	San Luis CVP End-of-Sept Storage		0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)		0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00	0.00	0.00	0.00 (0.00)	0.00 (0.00)	0.00	0.00	0.00 (0.00)
22	GW NOD End-of-September Storage	0.00 (0.03)	0.00 (0.01)	0.00 (0.02)	0.00 (0.01)	0.00 (-0.30)	0.00 (-0.26)	0.00 (-0.23)	0.00 (-0.21)	0.00 (-0.22)	0.00 (-0.27)	0.00 (0.30)	0.00 (-0.12)	0.00 (-0.31)	0.00			0.00 (0.00)	0.00 (0.00)	0.00	0.00	0.00 (-0.01)

Model Parameters: columns 1–21.

Note: (1) Values inside parentheses are SI and outside are EI.
(2) Blank cells indicate that SI and EI are non-monotonic functions and their averages are not meaningful. Individual SI and EI values in Table 3 should be used instead.

High Sensitivity	0.2 < |SI|
Moderate Sensitivity	0.1 <= |SI| <= 0.2
Low Sensitivity	|SI| < 0.1

Table 3 Detailed Summary of Elasticity Index (EI) and Sensitivity Index (SI)

Model Parameters

	Model Response	Shasta Inflow		Oroville inflow		Yuba inflow		Folsom inflow		Historical land use		Projected Land Use		Historical GW Extraction		Non-recoverable Losses		Crop ET		Basin Efficiency		Deep Percolation of Applied Water		Outdoor M&I Demands		Minimal GW Pumping	
		1		2		3		4		5		6		7		8		9		10		11		12		13	
		-5%	+5%	-5%	+5%	-5%	+5%	-5%	+5%	-5%	+5%	-5%	+5%	-10%	+10%	-50%	-75%	-10%	+10%	-10%	+10%	-5%	+5%	-50%	+50%	-10%	+10%
1	SWP Total Delivery[(1)]	0.10	0.05	0.21	0.16	0.05	0.06	0.04	0.05	0.09	0.08	-0.03	-0.07	-0.03	-0.04	-0.00	-0.00	0.13	-0.14	-0.15	-0.15	0.00	-0.01	0.00	0.01	0.00	0.01
		0.07	0.03	0.21	0.16	0.11	0.14	0.11	0.16	-0.14	-0.12	-0.02	-0.05	-0.13	-0.17	-0.02	-0.03	0.06	-0.07	0.09	0.11	0.02	-0.03	-0.19	-0.20	0.02	0.05
2	CVP total Delivery	0.23	0.27	0.05	0.06	0.03	0.05	0.02	0.03	0.09	0.10	0.16	0.12	-0.05	-0.03	0.02	0.02	0.20	0.11	-0.36	-0.29	0.00	0.01	0.00	0.01	0.01	0.02
		0.20	0.24	0.06	0.07	0.09	0.13	0.08	0.11	-0.17	-0.19	0.12	0.09	-0.22	-0.16	0.12	0.12	0.12	0.07	0.25	0.27	0.03	0.09	-0.17	-0.25	0.07	0.09
3	SWP Delta Delivery	0.10	0.05	0.28	0.25	0.06	0.07	0.05	0.06	0.13	0.10	-0.10	-0.08	-0.05	-0.06	-0.01	-0.01	-0.25	-0.18	-0.21	-0.12	-0.00	-0.02	0.01	0.01	0.02	0.03
		0.05	0.03	0.21	0.19	0.11	0.12	0.11	0.13	-0.15	-0.12	-0.05	-0.04	-0.13	-0.17	-0.05	-0.06	-0.09	-0.07	0.09	0.07	-0.00	-0.06	-0.21	-0.18	0.06	0.10
4	SWP NOD Delivery	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.26	0.09	-0.00	-0.00	0.02	0.03	1.50	0.05	-0.06	-0.27	0.03	0.02	0.00	0.00	-0.02	-0.03
		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.00	-0.00	0.03	0.01	-0.00	-0.00	0.03	0.03	0.15	0.01	0.01	0.04	0.03	0.02	-0.00	-0.00	-0.02	-0.03
5	Article 21 Delivery	0.52	0.16	-0.14	-0.88	-0.00	0.18	0.00	0.31	-0.14	0.05	-0.16	-0.74	-0.01	0.02	-0.02	-0.01	0.23	-0.29	0.47	0.12	-0.01	0.06	-0.02	0.01	-0.15	-0.13
		0.01	0.00	-0.01	-0.03	-0.00	0.01	0.00	0.04	0.01	-0.00	-0.00	-0.02	-0.00	0.00	-0.00	-0.00	0.00	-0.01	-0.01	-0.00	-0.00	0.01	0.02	-0.02	-0.02	-0.02
6	CVP SOD Delivery	0.34	0.42	0.07	0.09	0.05	0.07	0.03	0.05	0.14	0.17	-0.27	-0.22	-0.07	-0.05	-0.02	-0.03	-0.32	-0.23	-0.17	-0.02	-0.04	-0.02	0.01	0.01	0.05	0.06
		0.16	0.20	0.05	0.06	0.07	0.11	0.07	0.10	-0.14	-0.17	-0.11	-0.10	-0.19	-0.13	-0.10	-0.11	-0.10	-0.07	0.07	0.01	-0.13	-0.06	-0.15	-0.22	0.12	0.15
7	CVP NOD Delivery	0.10	0.09	0.02	0.02	0.01	0.01	0.01	0.01	0.03	0.03	0.66	0.52	-0.01	-0.01	0.06	0.06	0.81	0.52	-0.58	-0.60	0.06	0.06	0.00	0.00	-0.03	-0.03
		0.04	0.04	0.01	0.01	0.01	0.02	0.01	0.01	-0.03	-0.03	0.24	0.19	-0.03	-0.03	0.22	0.23	0.22	0.14	0.19	0.25	0.16	0.15	-0.03	-0.04	-0.06	-0.06
8	Total Delta Outflow	0.27	0.27	0.20	0.21	0.10	0.09	0.07	0.07	0.07	0.07	-0.10	-0.08	-0.03	-0.03	-0.01	-0.01	-0.20	-0.15	-0.09	-0.05	-0.01	-0.01	0.00	0.00	0.01	0.00
		0.70	0.69	0.72	0.75	0.79	0.72	0.80	0.71	-0.37	-0.35	-0.24	-0.20	-0.37	-0.42	-0.29	-0.29	-0.35	-0.26	0.17	0.13	-0.16	-0.17	-0.45	-0.37	0.13	0.06
9	MRDO	-0.09	0.14	-0.12	0.03	0.02	-0.01	-0.02	-0.01	-0.02	0.01	-0.05	0.03	0.00	0.01	-0.01	-0.01	-0.11	0.02	-0.09	0.04	0.00	-0.00	0.00	-0.00	-0.02	-0.01
		-0.11	0.17	-0.21	0.06	0.07	-0.05	-0.11	-0.05	0.06	-0.02	-0.05	0.03	0.03	0.08	-0.07	-0.12	-0.09	0.02	0.09	-0.05	0.01	-0.00	-0.06	0.14	-0.10	-0.05
10	Surplus Delta Outflow	0.60	0.39	0.48	0.36	0.17	0.19	0.16	0.13	0.16	0.12	-0.15	-0.18	-0.06	-0.07	-0.02	-0.01	-0.28	-0.31	-0.08	-0.12	-0.02	-0.02	0.01	0.01	0.03	0.02
		0.81	0.52	0.93	0.70	0.72	0.77	0.91	0.76	-0.43	-0.33	-0.19	-0.22	-0.40	-0.49	-0.22	-0.17	-0.25	-0.28	0.08	0.17	-0.16	-0.17	-0.39	-0.51	0.23	0.11
11	Banks+Tracy Export	0.22	0.23	0.17	0.15	0.06	0.08	0.04	0.06	0.13	0.14	-0.18	-0.16	-0.06	-0.05	-0.02	-0.02	-0.27	-0.21	-0.18	-0.08	-0.02	-0.02	0.01	0.01	0.03	0.04
		0.24	0.25	0.26	0.22	0.18	0.25	0.17	0.26	-0.29	-0.30	-0.17	-0.16	-0.33	-0.31	-0.16	-0.17	-0.19	-0.15	0.15	0.08	-0.15	-0.12	-0.34	-0.43	0.17	0.25
12	Banks Export	0.13	0.08	0.24	0.18	0.06	0.08	0.04	0.07	0.12	0.11	-0.11	-0.11	-0.05	-0.05	-0.01	-0.01	-0.22	-0.18	-0.17	-0.11	-0.00	-0.01	0.01	0.01	0.01	0.03
		0.07	0.05	0.21	0.16	0.11	0.14	0.11	0.17	-0.15	-0.13	-0.06	-0.06	-0.15	-0.17	-0.06	-0.07	-0.09	-0.07	0.08	0.07	-0.02	-0.05	-0.19	-0.22	0.05	0.09
13	Tracy Export	0.35	0.43	0.08	0.09	0.05	0.08	0.03	0.05	0.15	0.17	-0.27	-0.23	-0.08	-0.05	-0.03	-0.03	-0.32	-0.24	-0.18	-0.03	-0.04	-0.02	0.01	0.01	0.05	0.06
		0.16	0.20	0.05	0.06	0.07	0.11	0.07	0.10	-0.14	-0.16	-0.11	-0.10	-0.19	-0.13	-0.10	-0.11	-0.10	-0.07	0.07	0.01	-0.13	-0.06	-0.14	-0.21	0.12	0.15
14	Banks SWP Export	0.11	0.06	0.25	0.19	0.06	0.08	0.04	0.07	0.11	0.10	-0.10	-0.11	-0.04	-0.05	-0.01	-0.01	-0.22	-0.18	-0.17	-0.11	-0.00	-0.01	0.01	0.01	0.01	0.02
		0.06	0.03	0.21	0.16	0.11	0.14	0.11	0.16	-0.13	-0.12	-0.05	-0.06	-0.13	-0.16	-0.05	-0.06	-0.08	-0.07	0.08	0.07	-0.01	-0.05	-0.19	-0.20	0.04	0.08
15	Banks CVP Export	0.69	1.02	0.06	0.02	0.08	0.14	-0.01	0.06	0.45	0.38	-0.40	-0.35	-0.17	-0.15	-0.03	-0.04	-0.49	-0.37	-0.28	-0.33	-0.10	-0.03	0.01	0.02	0.12	0.16
		0.01	0.02	0.00	0.00	0.00	0.01	-0.00	0.00	-0.01	-0.01	-0.01	-0.00	-0.01	-0.01	-0.00	-0.01	-0.01	-0.00	0.00	0.01	-0.01	-0.00	-0.01	-0.02	0.01	0.01
16	SWP End-of-Sept Storage	-0.00	0.00	0.00	0.00	0.00	0.00	-0.00	0.00	0.01	0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.01	-0.00	-0.00	-0.00	-0.00	0.00	0.00	0.00	0.00	0.00
		-0.00	0.00	0.00	0.00	0.00	0.00	-0.00	0.00	-0.01	-0.01	-0.00	-0.00	-0.01	-0.01	-0.00	-0.00	-0.00	-0.00	0.00	0.00	-0.00	0.00	-0.02	-0.01	0.00	0.00
17	CVP End-of-Sept Storage	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	-0.01	-0.00	-0.01	-0.00	-0.00	-0.00	-0.01	-0.00	-0.01	-0.00	-0.00	-0.00	0.00	0.00	0.00	0.00
		0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.01	-0.01	-0.02	-0.00	-0.00	-0.03	-0.02	-0.01	-0.01	-0.00	-0.00	0.01	0.00	-0.00	-0.00	-0.05	-0.04	0.00	0.01
18	SWP SOD End-of-Sept Storage	-0.01	0.00	-0.00	0.00	-0.00	0.00	-0.00	0.00	-0.01	0.00	-0.00	0.00	-0.00	0.00	-0.00	-0.00	-0.00	0.00	-0.01	0.01	0.00	0.00	0.00	0.00	-0.00	0.00
		-0.00	0.00	-0.00	0.00	-0.00	0.00	-0.00	0.00	0.00	-0.00	-0.00	0.00	-0.00	0.00	-0.00	-0.00	-0.00	0.00	0.00	-0.00	0.00	0.00	-0.00	-0.00	-0.00	0.00
19	SWP NOD End-of-Sept Storage	0.00	-0.00	0.00	0.00	0.00	0.00	-0.00	0.00	0.01	0.00	-0.00	-0.00	-0.00	-0.01	-0.00	-0.00	-0.01	-0.00	-0.00	-0.01	-0.00	0.00	0.00	0.00	0.00	0.00
		0.00	-0.00	0.00	0.00	0.00	0.00	-0.00	0.00	-0.01	-0.00	-0.00	-0.00	-0.01	-0.01	-0.00	-0.00	-0.00	-0.00	0.00	0.00	-0.00	0.00	-0.02	-0.01	0.00	0.00
20	CVP SOD End-of-Sept Storage	0.00	-0.00	0.00	0.00	-0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.00	0.00	0.00	-0.00	-0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		0.00	-0.00	0.00	0.00	-0.00	0.00	0.00	0.00	-0.00	0.00	0.00	0.00	-0.00	0.00	0.00	-0.00	-0.00	0.00	-0.00	0.00	0.00	0.00	-0.00	0.00	0.00	0.00
21	CVP NOD End-of-Sept Storage	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	-0.01	-0.00	-0.01	-0.00	-0.00	-0.00	-0.01	-0.00	-0.01	-0.00	-0.00	-0.00	0.00	0.00	0.00	0.00
		0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.01	-0.01	-0.02	-0.00	-0.00	-0.03	-0.02	-0.01	-0.01	-0.00	-0.00	0.01	0.00	-0.00	-0.00	-0.05	-0.04	0.00	0.01
22	San Luis SWP End-of-Sept Storage	-0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.02	0.00	0.00	0.01	-0.00	0.01	-0.00	-0.00	0.00	0.00	-0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00
		-0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.00	0.00	-0.00	-0.00	0.00	0.00	0.00	-0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	San Luis CVP End-of-Sept Storage	0.00	-0.00	0.00	0.00	-0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.00	0.00	0.00	-0.00	-0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		0.00	-0.00	0.00	0.00	-0.00	0.00	0.00	0.00	-0.00	0.00	0.00	0.00	-0.00	0.00	0.00	-0.00	-0.00	0.00	-0.00	0.00	0.00	0.00	-0.00	0.00	0.00	0.00
24	GW NOD End-of-September Storage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.00	-0.00
		0.03	0.03	0.01	0.01	0.01	0.02	0.01	0.01	-0.29	-0.30	-0.24	-0.29	-0.24	-0.23	-0.21	-0.20	-0.15	-0.28	-0.32	-0.22	0.31	0.30	-0.12	-0.12	-0.31	-0.32

	Model Response	Project non-project Split				SWP Delivery-Carryover Curve		SWP San Luis Rule Curve		SWP Table A Demand				Article 21 Demand				ANN				X2 Standard		
		14				15		16		17				18				19				20		
		-10%	-5%	+5%	+10%	-20%	+20%	-10%	+10%	-28.6%	-14.3%	11.4%	17.5%	198.5%	347.8%	497.0%	646.3%	-20%	-10%	+10%	+20%	-10%	-5%	+5%
1	SWP Total Delivery[(1)]	0.07	0.07	0.04	0.05	-0.07	-0.10	0.02	0.01	0.42	0.36	0.22	0.24	0.01	0.01	0.00	0.00	-0.07	-0.08	-0.11	-0.07	-0.04	-0.05	-0.03
										0.47	0.40	0.25	0.45	0.25	0.17	0.13	0.10							
2	CVP total Delivery	0.28	0.28	0.26	0.24	-0.00	0.00	0.00	-0.00	-0.01	-0.01	-0.00	-0.00	-0.00	-0.00	-0.00	0.00	-0.03	-0.04	-0.04	-0.04	-0.03	-0.04	-0.04
										-0.01	-0.01	-0.00	-0.01	-0.01	-0.00	-0.00	0.00							
3	SWP Delta Delivery	0.03	0.07	0.06	0.06	-0.12	-0.17	0.01	-0.01	0.74	0.63	0.39	0.44	-0.00	-0.00	-0.00	-0.00	-0.09	-0.10	-0.12	-0.07	-0.06	-0.07	-0.05
										0.63	0.54	0.33	0.60	-0.02	-0.00	-0.00	-0.00							
4	SWP NOD Delivery	0.30	0.20	0.09	0.05	-0.00	-0.01	0.00	-0.00	-0.01	-0.01	-0.01	-0.01	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00
										-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00							
5	Article 21 Delivery	-0.28	-0.53	-0.59	-0.37	0.62	0.80	0.46	0.47	-3.49	-3.06	-1.76	-2.15	0.24	0.16	0.12	0.10	-0.05	0.06	-0.45	-0.59	0.07	0.05	0.20
										-0.15	-0.13	-0.08	-0.15	0.27	0.18	0.13	0.11							
6	CVP SOD Delivery	-0.07	-0.03	0.01	0.03	-0.00	0.01	0.00	-0.01	-0.02	-0.01	-0.00	-0.01	-0.00	-0.00	-0.00	0.00	-0.05	-0.06	-0.06	-0.06	-0.04	-0.06	-0.07
										-0.01	-0.01	-0.00	-0.01	-0.01	-0.00	-0.00	0.00							
7	CVP NOD Delivery	0.68	0.65	0.55	0.50	-0.00	0.00	0.00	-0.00	-0.00	-0.00	0.00	0.00	-0.00	0.00	0.00	0.00	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
										-0.00	-0.00	0.00	0.00	-0.00	0.00	0.00	0.00							
8	Total Delta Outflow	-0.01	-0.02	-0.01	-0.01	0.02	0.02	-0.01	-0.00	-0.11	-0.09	-0.06	-0.06	-0.00	-0.00	-0.00	-0.00	0.03	0.04	0.05	0.03	0.02	0.03	0.03
										-0.43	-0.36	-0.22	-0.39	-0.23	-0.17	-0.13	-0.10							
9	MRDO	-0.01	-0.04	-0.00	0.00	-0.02	-0.03	-0.03	-0.01	0.10	0.07	0.05	0.06	0.00	0.00	0.00	0.00	0.23	0.32	0.29	0.26	0.28	0.32	0.30
										0.20	0.13	0.09	0.18	0.23	0.14	0.11	0.08							
10	Surplus Delta Outflow	-0.01	-0.00	-0.01	-0.01	0.05	0.08	0.02	0.00	-0.30	-0.23	-0.15	-0.17	-0.01	-0.01	-0.00	-0.00	-0.15	-0.21	-0.17	-0.17	-0.21	-0.23	-0.22
										-0.63	-0.49	-0.31	-0.57	-0.46	-0.31	-0.24	-0.19							
11	Banks+Tracy Export	-0.02	0.01	0.02	0.04	-0.04	-0.06	0.02	0.00	0.27	0.22	0.14	0.15	0.01	0.00	0.00	0.00	-0.07	-0.08	-0.10	-0.08	-0.05	-0.06	-0.05
										0.44	0.37	0.23	0.39	0.23	0.17	0.13	0.10							
12	Banks Export	0.01	0.04	0.03	0.05	-0.08	-0.11	0.03	0.01	0.49	0.41	0.25	0.27	0.01	0.01	0.01	0.00	-0.08	-0.09	-0.13	-0.09	-0.05	-0.06	-0.04
										0.46	0.38	0.23	0.40	0.25	0.17	0.13	0.10							
13	Tracy Export	-0.07	-0.03	0.01	0.03	-0.00	0.01	0.00	-0.01	-0.02	-0.01	-0.00	-0.01	-0.00	-0.00	-0.00	0.00	-0.05	-0.07	-0.06	-0.06	-0.04	-0.06	-0.07
										-0.01	-0.01	-0.00	-0.01	-0.01	-0.00	-0.00	0.00							
14	Banks SWP Export	0.01	0.04	0.02	0.04	-0.08	-0.12	0.03	0.01	0.51	0.43	0.27	0.29	0.01	0.01	0.01	0.00	-0.08	-0.09	-0.13	-0.09	-0.05	-0.06	-0.04
										0.46	0.39	0.24	0.43	0.25	0.17	0.13	0.10							
15	Banks CVP Export	0.07	0.17	0.16	0.15	0.08	0.06	0.04	0.01	-0.27	-0.49	-0.63	-0.71	-0.00	-0.00	-0.00	-0.00	-0.10	-0.15	-0.15	-0.12	-0.07	-0.11	-0.24
										-0.01	-0.01	-0.02	-0.03	-0.00	-0.00	-0.00	-0.00							
16	SWP End-of-Sept Storage	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	-0.01	-0.01	-0.00	-0.00	0.00	0.00	0.00	0.00	-0.00	-0.00	-0.00	0.00	0.00	0.00	0.00
										-0.01	-0.01	-0.00	-0.01	0.00	0.00	0.00	0.00							
17	CVP End-of-Sept Storage	0.00	0.00	0.00	0.00	-0.00	0.00	-0.00	-0.00	-0.00	-0.00	-0.00	0.00	-0.00	-0.00	-0.00	0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	0.00
										-0.00	-0.00	-0.00	0.00	-0.00	-0.00	-0.00	0.00							
18	SWP SOD End-of-Sept Storage	-0.00	-0.00	-0.00	-0.00	0.01	0.00	-0.00	0.00	-0.00	-0.01	-0.00	-0.00	0.00	0.00	0.00	0.00	-0.00	-0.00	0.00	0.00	-0.00	-0.00	0.01
										-0.00	-0.00	-0.00	-0.00	0.00	0.00	0.00	0.00							
19	SWP NOD End-of-Sept Storage	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	-0.02	-0.02	-0.00	-0.01	0.00	0.00	0.00	0.00	-0.00	-0.00	-0.01	0.00	0.00	0.00	-0.00
										-0.01	-0.01	-0.00	-0.01	0.00	0.00	0.00	0.00							
20	CVP SOD End-of-Sept Storage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.00	-0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
										0.00	0.00	-0.00	-0.00	0.00	0.00	0.00	0.00							
21	CVP NOD End-of-Sept Storage	0.00	0.00	0.00	0.00	-0.00	0.00	-0.00	-0.00	-0.00	-0.00	-0.00	0.00	-0.00	-0.00	-0.00	0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	0.00
										-0.00	-0.00	-0.00	0.00	-0.00	-0.00	-0.00	0.00							
22	San Luis SWP End-of-Sept Storage	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	-0.01	-0.02	0.00	-0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.02
										-0.00	-0.00	0.00	-0.00	0.00	0.00	0.00	0.00							
23	San Luis CVP End-of-Sept Storage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.00	-0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
										0.00	0.00	-0.00	-0.00	0.00	0.00	0.00	0.00							
24	GW NOD End-of-September Storage	0.00	0.00	-0.00	-0.00	-0.00	0.00	0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	0.00	0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00
										-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	0.00	0.00							

Note: Upper cell: Elasticity Index; lower cell: Sensitivity Index

High Sensitivity	0.2 < |SI|
Moderate Sensitivity	0.1 <= |SI| <= 0.2
Low Sensitivity	|SI| < 0.1

4.1 Oroville Inflow

4.1.1 Performance Measures: SI and EI

As discussed in Section 3.2.3.1, monthly inflow time series to Lake Oroville are uniformly scaled up and down by 5 percent from their base time series for the sensitivity analysis. Two CalSim-II model runs are made with one modified time series at a time. The SI and EI for each of the model output variables with respect to modified Oroville inflow are computed using Equations (1) through (4). The following numerical example demonstrates how SI and EI for SWP total delivery, which is the sum of SWP Delta delivery and SWP NOD delivery, are computed:

	73-year average annual inflow to Oroville	73-year average annual SWP total delivery
Base	3833.5 TAF	3924.3 TAF
(1-0.05)*Base	3641.8 TAF	3884.0 TAF
(1+0.05)*Base	4025.2 TAF	3955.0 TAF

$SI_{-5\%}$ = (3884.0 – 3924.3) / (3641.8 – 3833.5) = 0.210
$SI_{+5\%}$ = (3955.0 – 3924.3) / (4025.2 – 3833.5) = 0.160
$SI_{Average}$ = (0.210 + 0.160) / 2 = 0.185

$EI_{-5\%}$ = (3833.5 / 3924.3) * 0.210 = 0.205
$EI_{+5\%}$ = (3833.5 / 3924.3) * 0.160 = 0.156
$EI_{Average}$ = (0.205 + 0.156) / 2 = 0.181

Note that two individual SIs and two individual EIs are slightly different from their respective average SI and EI, which indicates the non-linear response of SWP total delivery to the changes in Oroville inflow. However, since $SI_{-5\%}$ and $SI_{+5\%}$ or $EI_{-5\%}$ and $EI_{+5\%}$ have the same sign, both SI and EI are monotonic functions of Oroville inflow.

The positive signs of SI and EI imply that the SWP total delivery changes in the same direction as the changes in Oroville inflow, i.e. when Oroville inflow increases, the SWP total delivery increases. Conversely, negative signs of SI and EI indicate that the output variable response is in the opposite direction of input parameter changes. For example, SI = -0.02 (see Row 5 of Column 2 in Table 2) indicates that when Oroville inflow increases, SWP Article 21 delivery decreases.

The SI is the measure of the sensitivity of SWP total delivery with respect to Oroville inflow. The average SI value of 0.185 indicates that if Oroville inflow is over- or under-estimated by one TAF from its “true” value, the resulting SWP total delivery from CalSim-II model run will be larger or smaller than its “true” delivery by 0.185 TAF.

The EI is the measure of the elasticity of SWP total delivery with respect to Oroville inflow. The average EI value of 0.181 indicates that if Oroville inflow is over- or under-estimated by 1 percent from its “true” value, the resulting SWP total delivery from CalSim-II model run will differ from its “true” delivery by plus or minus 0.181 percent.

The value of SI differs from the value of EI in that SI represents the sensitivity of an output variable with respect to an input parameter in terms of the absolute water volume change, whereas EI is a measure of the elasticity of output variable with respect to an input parameter in terms of relative change. Hence, the difference of values between SI and EI is determined by the relative magnitudes of input parameters and the output variable. In this example, P_0 = 3833.5 TAF and $Q(P_0)$ = 3924.3 TAF, the ratio $P_0 / Q(P_0)$ = 3833.5 / 3914.2 = 0.979, which is close to one. Therefore, $EI_{Average} = SI_{Average} * [P_0 / Q(P_0)]$ = 0.185 * 0.979 = 0.181, which shows that the difference between values of SI and EI is not significant. However, the difference between values of SI and EI can be very large in some other cases depending on the relative magnitudes of input parameters and output variables.

Average SI and EI values for 22 model output variables with respect to Oroville inflow are computed and shown in Table 2. SI and EI values in the table indicate that some output variables are highly sensitive or elastic to changes in Oroville inflow and others are insensitive or inelastic. In the following sections, responses of a few typical output variables with respect to Oroville inflow are discussed in more detail.

4.1.2 SWP Delta Delivery and SWP NOD Delivery

SWP Delta delivery is defined as the sum of SWP Table A deliveries to South-of-Delta and deliveries to North Bay (Solano and Napa Counties) contractors. SWP NOD delivery is defined as the sum of deliveries to the Settlement Contractors in Feather River Service Area (FRSA) and Table A deliveries to Butte County and Yuba City. SWP delivery to Plumas County occurs upstream of Lake Oroville and it is not explicitly modeled in CalSim-II. Rows 3 and 4 of Column 2 in Table 2 show the average SI and EI values of SWP Delta delivery and SWP NOD delivery with respect to Oroville inflow. From the two cells it can be found that the SWP Delta delivery is highly sensitive (SI = 0.20) to changes in Oroville inflow, because the Oroville Reservoir storage, which is highly correlated with the Oroville inflow, is one of the most important factors in determining the amount of water available for SWP Delta delivery in the current SWP delivery allocation procedure. When Oroville inflow increases, greater allocation decisions due to the higher Oroville storages will be made, which may lead to higher SWP Delta delivery. Similarly, when Oroville inflow decreases, lower allocation decisions due to the lower Oroville storages may be made, which leads to lower SWP Delta delivery.

SWP NOD delivery (SI = 0.00) is not sensitive to Oroville inflow because its major portion is the delivery to FRSA Settlement Contractors, which is governed by a different set of operation rules based on Oroville inflow and is not subject to any other system operations criteria.

4.1.3 Article 21 Delivery

Row 5 of Column 2 in Table 2 contains SI and EI values for Article 21 delivery with respect to Oroville inflow. It can be seen that both average SI and EI are negative, which indicates that when Oroville inflow increases Article 21 delivery generally decreases. This situation is caused by the rules governing Article 21 delivery. As discussed in section 3.3.3.2, Article 21 delivery can only be made when the following three conditions are met at the same time:

- There is surplus water available in the Delta
- The SWP portion of the San Luis reservoir is full
- There is conveyance capacity available

Article 21 delivery has a lower priority than SWP Delta delivery. SWP Delta delivery increases with the increase in Oroville inflow (see Section 4.1.2). The increased SWP Delta delivery reduces the conveyance capacity that may be used for Article 21 delivery, and at the same time SWP San Luis storage may be used more aggressively, leaving less chance for the reservoir to be full. Therefore, Article 21 delivery decreases slightly (SI = -0.02) with the increase in Oroville inflow.

When Oroville inflow decreases, lower Banks export (SI = 0.18) and lower SWP Delta delivery (see Section 4.1.2) makes more conveyance capacity available for Article 21 delivery whenever there is surplus water in the Delta and SWP San Luis reservoir is full.

4.1.4 Comparisons of SI and EI among All Output Variables

Column 2 in both Table 2 and Table 3 list SI and EI values for all selected model output variables with respect to Oroville inflow. The comparison of SI and EI across the entire column can be used to identify which output variables are most sensitive or elastic with respect to Oroville inflow in either positive or negative directions. The table on next page summarizes some of the findings by comparing SI and EI values across the column in addition to what have been discussed in Sections 4.1.2 and 4.1.3. In this table only the negative changes to Oroville inflow are discussed although the similar explanation applies to the positive changes as well.

Figure A-5 in Appendix A is the bar chart presenting absolute water volume changes of total exports, deliveries, and Delta outflow in response to changes in Oroville inflow for the 73-year average. Figure A-6 is the bar chart presenting absolute water volume changes of some components of exports and deliveries. From these two charts it may be easily identified which output variable has the most volume change with respect to change in Oroville inflow. Figures A-7 and A-8 show the same output variables for the dry period (1929-1934).

	Findings	Discussion
1	SWP export decreases	As discussed in Section 4.1.2, when Oroville inflow decreases, lower allocation target due to the lower Oroville storage will be set. And the lower delivery target requires less SWP export from Banks.
2	SWP end-of-September storage is insensitive and inelastic to Oroville inflow	Decreased Oroville inflow results mainly in either decreased exports or decreased Oroville spills. The within-year reservoir storages may be affected as well. However, because reservoir storage carryover rules were unchanged, SWP end-of-September storage change is insignificant.
3	NOD groundwater end-of-September storage has decreased	Less surface water supply due to the decreased Oroville inflow may increase the need for the additional groundwater pumping.
4	CVP exports decrease	When Oroville inflow decreases, less water is available for CVP exports through Coordinated Operation Agreement (COA) which defines the responsibility of meeting Sacramento Valley in-basin use and share of unstored water for export between CVP and SWP.
5	CVP end-of-September storage is insensitive and inelastic to Oroville inflow	CVP and SWP are two relatively independent projects and they are connected with each other mainly through COA. The impact of the decreased Oroville inflow on CVP end-of-September storage is insignificant.

4.2 Crop Evapotranspiration (Crop ET)

As discussed in Section 3.2.4.1, Crop ET is the consumptive use of applied water (CUAW) for irrigation, whether from stream diversions or groundwater pumping. The sensitivity analysis is designed to vary the monthly crop ET that is used to estimate the projected diversion requirement and the projected adjustment for local water supply by ±10 percent.

The unit of crop ET is in inches and it cannot be used to compute SI directly. As discussed in Sections 3.2.3.2 and 3.2.4, crop ET is a key parameter used to estimate both the projected local water supply, also known as gain (I) if it is positive value or depletion (D) if it is negative value, and the CUAW which is used to compute the diversion requirements (DR). Therefore, a new term that combines both diversion requirement and local water supply changes may be defined to reasonably represent the total volume changes due to changes in the crop ET. The new term is (DR – I + D), which may be considered as the net diversion requirement for surface water diversion and groundwater pumping beyond local water supply. The SI of the crop ET can then be computed by bringing the term (DR – I + D) into Equations (1) and (2).

The EI of the crop ET is computed with modified Equations (3) and (4):

$$EI_{PQ,i} = 100\% * \{[Q(P_0 + \Delta P_i) - Q(P_0)] / Q(P_0)\} / \%\Delta P_i \quad (3a)$$

where

$\%\Delta P_i = 100\% * \Delta P_i / P_0$, and

$\%\Delta P_i = -20\%$ or $+20\%$

The average EI is computed using Equation 4a as:

$$EI_{PQ,avg} = \sum_{i=1}^{n} EI_{PQ,i} / n \qquad \text{for } i = 1, 2, \ldots, n \quad (4a)$$

where *n* is the number of %ΔPs.

The other input parameters including historical land use, projected land use, historical groundwater pumping, non-recoverable losses, basin efficiency, deep percolation of applied water, and outdoor M&I demands in Tables 2 and 3 are similar to crop ET, i.e., SIs are computed using the new defined term (DR – I + D) in Equations (1) and (2) and EIs are computed using Equations (3a) and (4a).

Column 9 of Tables 2 and 3 list SIs and EIs of the crop ET with respect to all selected model output variables. The comparison of SI and EI across the entire column can be used to identify which output variables are most sensitive or elastic to crop ET and which ones are most insensitive or inelastic.

As shown in Row 3 of Column 9 in Table 2, when Crop ET increases by one percent, SWP Delta delivery decreases by 0.21 percent (EI=–0.21) while SWP NOD delivery (Row 4 of Column 9) increases by 0.78 percent (EI=0.78); when net diversion requirement (DR - I + D) increases by one TAF due to the increase of Crop ET, SWP Delta delivery decreases by 0.08 TAF (SI=–0.08) while SWP NOD delivery increases by 0.08 TAF (SI=0.08). This is because the land-use based demands are only used in the Sacramento Valley floor north of Delta (NOD); the increase in crop ET will increase SWP NOD demand, and thereby the SWP NOD delivery. And the increased SWP NOD delivery makes less water available for the SWP Delta delivery.

It is noted that the behavior of Article 21 delivery is more complex as shown by the blank cell (Row 5 of Column 9 in Table 2) which implies that it is a non-monotonic function of Crop ET. In such case the average SI and EI indices are no longer meaningful. According to discussions in Section 2.2, the evaluation of SI and EI should be made based on Table 3 which contains the individual SI and EI values for Article 21 delivery. As shown in Row 5 of Column 9 in Table 3, when Crop ET increases by one percent, Article 21 delivery decreases by 0.29 percent (EI=–0.29); and when Crop ET decreases, Article 21 delivery, again, decreases by 0.23 percent (EI=+0.23). As discussed in Section 3.2.4., the land-use based demands are only used in the Sacramento Valley floor. The increase in crop ET requires more SWP NOD delivery (see Item 1 in the table below), which will, in turn, reduce the Delta surplus water available for Article 21 delivery. When Crop ET decreases, SWP NOD delivery decreases and the Oroville storage becomes higher. The higher Oroville storage results in a larger allocation that makes SWP San Luis reservoir operation more aggressive and at the same time takes up more conveyance capacity. This in turn decreases Article 21 delivery.

The behavior of SI for Article 21 delivery with respect to Crop ET is same as its EI's in Table 3. However, due to the relatively small magnitude of Article 21 delivery compared to the equivalent water volume change due to the Crop ET change, SI values in the table appear to be very small.

In addition to the above discussions on SWP deliveries and Article 21 delivery, the table below summarizes some other findings from comparing the SIs and EIs across column 9 in Table 2. In the table only positive changes of crop ET are discussed although the similar explanation applies to the negative changes as well.

	Findings	**Discussion**
1	CVP NOD delivery increase	Land-use based demands are only used in the Sacramento Valley floor north of Delta. Therefore, increase in crop ET will increase NOD demand, and thereby the delivery in NOD.
2	Banks and Tracy exports decrease	Higher NOD deliveries result in less water available for exports because of the reduced inflow to the Delta.
3	CVP SOD delivery decrease	The increases of CVP NOD delivery results in less water available for CVP SOD delivery.
4	NOD end-of-September groundwater storage decreases	As shown in Figure 5, the NOD demands are met by the minimum groundwater pumping, surface water diversion, and additional groundwater pumping. The minimum groundwater pumping has the highest priority. The surface water diversion is the next. Any shortage beyond surface water diversion will be met by the additional groundwater pumping. Therefore, the crop ET increase results in more additional groundwater pumping and less end-of-September groundwater storage.
5	Total Delta outflow decreases	Increased NOD deliveries reduce the total Delta inflow that is available for both Delta exports and Delta outflow.

Figure A-33 in Appendix A is a bar chart presenting the 73-year average changes in the absolute water volume of total exports, deliveries, and Delta outflow in response to the changes in crop ET. Figure A-34 is a bar chart presenting changes in the absolute water volume of some components of exports and deliveries. From these two charts output variables with the most volume change with respect to the changes in crop ET can be identified. Figures A-35 and A-36 present the same information for the dry period (1929-1934).

4.3 SWP Delivery-Carryover Risk Curve

As discussed in Section 3.3.1, the SWP delivery-carryover risk curve is a user-defined rule-curve to determine the current year delivery and carryover storage given the total water available (DI) from the WSI-DI curve. The sensitivity analysis for the delivery-carryover risk curve is designed to vary the carryover storage on the curve by ± 20 percent for the same delivery.

Because the sensitivity analysis is designed to shift the entire delivery-carryover risk curve by a percentage as shown in Figure 7, it is difficult to convert such a curve percentage change into its equivalent volume change in the commensurate unit of TAF, SI values for SWP delivery-carryover risk curve with respect to all output variables are not computed. A few other input parameters including project and non-project split of land use, SWP San Luis rule-curve, ANN, and X2 are also not amenable for converting into unit of TAF. Therefore, SI values for those input parameters are not computed, either. EI values for these five input parameters are computed using Equations (3a) and (4a) with their percent changes of both input parameters and output variables.

Column 15 of Table 2 lists EI values of all selected model output variables with respect to SWP delivery-carryover risk curve. The comparison of EIs across the entire column can be used to identify which output variables are most elastic to the SWP delivery-carryover risk curve in either positive or negative direction and which are most inelastic. The table on next page summarizes some of the findings by comparing the EI values across the column. In the table only positive change of the SWP delivery-carryover risk curve is discussed although the similar explanation applies to the negative changes as well.

	Findings	Discussion
1	Banks SWP export and SWP Delta delivery decrease	The delivery-carryover curve becomes more conservative, i.e. less delivery is made given the same carryover storage as in the base study, or in other words, more carryover storage is required given the same delivery.
2	Article 21 is most elastic to SWP delivery-carryover risk curve	The conservative delivery allocation (more carryover storage and less delivery) results in a more conservative operation of the SWP San Luis reservoir and leaving more chance for the reservoir to be full. Increased NOD storage and decreased SWP Delta delivery (see Item 1) also makes more Delta surplus water and more unused conveyance capacity available for Article 21 delivery; therefore, EI value is significant (+0.08).
3	Total Delta outflow increases	A more conservative SWP allocation reduces SWP Delta delivery and leaves more water in the SWP reservoir storage. The higher SWP reservoir storage will cause more frequent flood control releases that contribute to the total Delta outflow in Winter and Spring months. The local water supply in the Sacramento Valley may also contribute more to the total Delta outflow as well due to the reduced SWP allocation.

The findings and discussions in the table above are based on the long-term (73-year) average values to reflect the long-term general trend. However, when the detailed year-to-year (or even within year) operations were examined, it was found that, besides the general trend, SWP delivery changes depend not only on the delivery-carryover risk curve but many other factors, including Sacramento Valley water year types and its sequence in adjacent years, and previous year SWP carryover storage. In order to demonstrate how other factors affect SWP operations when SWP delivery-carryover risk curve is conservatively changed (increased carryover storage), a comparison of base and alternative allocation decisions and resulting carryover storage and deliveries is provided for selected years; a quantitative summary of the comparison is provided in Table 4.

Table 4
Selected Year-to-year SWP Operations
with a More Conservative Delivery-Carryover Risk Curve

1	2	3	4	5	6	7	8
Year	**Previous /Current WY Type[1]**	**Previous September SWP Carryover Storage[2,3]**	**April SWP Storage[2,3]**	**SWP Target Delivery[3]**	**SWP Target Carryover Storage[2,3]**	**Actual Table A Delivery[3]**	**Actual SWP September Carryover Storage[2,3]**
1929	2/5	2400 (293)	2866 (299)	1181 (29)	1253 (297)	1179 (29)	1787 (269)
1930	5/4	1787 (269)	4172 (234)	2916 (-63)	1940 (299)	2896 (-60)	2511 (293)
1931	4/5	2511 (293)	2767 (307)	1151 (34)	1145 (295)	1149 (35)	1422 (278)
1934	5/5	1988 (226)	3166 (257)	1719 (84)	1495 (267)	1711 (82)	1507 (196)
1943	1/1	3580 (0)	4004 (0)	3266 (-326)	2107 (211)	3298 (-304)	3160 (205)
1976	1/5	3720 (-19)	4230 (0)	2840 (-325)	1903 (187)	2875 (-327)	1956 (205)
1977	5/5	1956 (205)	1558 (272)	794 (113)	477 (137)	802 (119)	505 (197)
1992	5/5	1800 (98)	2989 (214)	1437 (-8)	1414 (232)	1427 (-9)	1611 (200)

1 Previous Water Year Type/Current Water Year Type
2 SWP storage = (Oroville Storage) + (SWP San Luis Storage)
3 Numbers inside parentheses are differences with their respective base values

1929: A critical year following an above normal year (see Column 2). The previous-year September SWP carryover storage (Oroville + SWP San Luis) in Column 3 of Table 4 is 2,400 TAF, 293 TAF more than the base value (see number within the parentheses). The April SWP storage in Column 4 is 2,866 TAF, 299 TAF more than the base value, which means the extra storage of 293 TAF from previous September is carried over to April. The April storage of 2,866 TAF is used, together with forecasted rest-of-water-year Oroville inflow, to determine the current calendar year SWP delivery target (see Section 3.3.1 for detailed allocation procedure) as 1,181 TAF, 29 TAF more than the base value in Column 5. Note that the additional 29 TAF target delivery is much less than the additional 299 TAF in April storage because the delivery-carryover risk curve is more conservative than the base model. This caution can also be seen by the target September carryover storage of 1,253 in Column 6, 297 TAF more than the base value. The higher delivery target results in a higher actual annual Table A delivery of 1,179 TAF, 29 TAF more than the base value in Column 7. Similarly, the actual September carryover storage is 1,787 TAF, 269 TAF more than the base value in Column 8.

1930: A dry year following a critical year. The previous-year September SWP carryover storage (Oroville + SWP San Luis) is 1,787 TAF, 269 TAF more than the base value. The April SWP storage is 4,172 TAF, 234 TAF more than the base value which means the extra storage from previous September is mostly carried over to April. The April storage of 4,172 TAF is used, together with forecasted rest-of-water-year Oroville inflow, to determine the current calendar year SWP delivery target as 2,916 TAF, 63 TAF less than the base value. The target September carryover storage is 1,940 TAF, 299 TAF more than the base value due to the more conservative delivery-carryover risk curve. The lower delivery target results in a lower actual annual Table A delivery of 2,896 TAF, 60 TAF less than the base value. Conversely, the actual September carryover storage is 2,511 TAF, 293 TAF more than the base value.

1931: A critical year following a dry year. The previous-year September SWP carryover storage is 2,511 TAF, 293 TAF more than the base value. The April SWP storage is 2,767 TAF, 307 TAF more that the base value. The April storage of 2,767 TAF is used, together with forecasted rest-of-water-year Oroville inflow, to determine the current calendar year SWP delivery target as 1,151 TAF, 34 TAF more than the base value. The target September carryover storage is 1,145 TAF, 295 TAF more than the base value. The higher delivery target results in a higher actual annual Table A delivery of 1,149 TAF, 35 TAF more than the base value. Similarly, the actual September carryover storage is 1,422 TAF, 278 TAF more than the base value.

1934: A critical year following a critical year and the last year of a six-year drought. The previous-year September SWP carryover storage is 1,988 TAF, 226 TAF more than the base value. The April SWP storage is 3,166 TAF, 257 TAF more than the base value. The April storage of 3,166 TAF is used, together with forecasted rest-of-water-year Oroville inflow, to determine the current calendar year SWP delivery target as 1,719 TAF, 84 TAF more than the base value. The target September carryover storage is 1,495 TAF, 267 TAF more than the base value. The higher delivery target results in a higher actual annual Table A delivery of 1,711 TAF, 82 TAF more than the base value. Similarly, the actual September carryover storage is 1,507 TAF, 196 TAF more than the base value.

1943: A wet year following two consecutive wet years. The previous-year September SWP carryover storage is 3,580 TAF. The April SWP storage is 4,004 TAF. Both are identical to their respective base values. The April storage of 4,004 TAF is used, together with forecasted rest-of-water-year Oroville inflow, to determine the current calendar year SWP delivery target as 3,266 TAF, 326 TAF less than the base value. The target September carryover storage is 2,107 TAF, 211 TAF more than the base value due to the more conservative delivery-carryover risk curve. The lower delivery target results in a lower actual annual Table A delivery of 3,298 TAF, 304 TAF less than the base value. Conversely, the actual September carryover storage is 3,160 TAF, 205 TAF more than the base value.

1976: A critical year following a wet year. The previous-year September SWP carryover storage is 3,720 TAF, 19 TAF less than the base value. The April SWP storage is 4,230 TAF, identical to the base value. The April storage of 4,230 TAF is used, together with forecasted rest-of-water-year Oroville inflow, to determine the current calendar year SWP delivery target as 2,840 TAF, 325 TAF less than the base value. The target September carryover storage is 1,903 TAF, 187 TAF more than the base value due to the more conservative delivery-carryover risk curve. The lower delivery target results in a lower actual annual Table A delivery of 2,875 TAF, 327 TAF less than the base value. Conversely, the actual September carryover storage is 1,956 TAF, 205 TAF more than the base value.

1977: A critical year following a critical year. The previous-year September SWP carryover storage is 1,956 TAF, 205 TAF more than the base value. The April SWP storage is 1,558 TAF, 272 TAF more than the base value. The April storage of 1,558 TAF is used, together with forecasted rest-of-water-year Oroville inflow, to determine the current calendar year SWP delivery target as 794 TAF, 113 TAF more than the base value due to the extra April storage. The target September carryover storage is 477 TAF, 137 TAF more than the base value. The higher delivery target results in a higher actual annual Table A delivery of 802 TAF, 119 TAF more than the base value. Similarly, the actual September carryover storage is 505 TAF, 197 TAF more than the base value.

1992: A critical year following two consecutive critical years and the last year of a six-year drought. The previous-year September SWP carryover storage is 1,800 TAF, 98 TAF more than the base value. The April SWP storage is 2989 TAF, 214 TAF more than the base value. The April storage of 2,989 TAF is used, together with forecasted rest-of-water-year Oroville inflow, to determine the current calendar year SWP delivery target as 1,437 TAF, 8 TAF less than the base value. The target September carryover storage is 1,414 TAF, 232 TAF more than the base value. The lower delivery target results in a lower actual annual Table A delivery of 1,427 TAF, 9 TAF less than the base value. Conversely, the actual September carryover storage is 1,611 TAF, 200 TAF more than the base value.

Figure A-57 in Appendix A is the bar chart presenting the 73-year averages for the absolute water volume changes of total exports, deliveries, and Delta outflow in response to the changes in the SWP delivery-carryover risk curve. Figure A-58 is the bar chart presenting absolute water volume changes of some components of exports and deliveries. These two charts identify output variables that display the most volume change with respect to the changes in the SWP delivery-carryover risk curve. Figures A-59 and A-60 are as same as Figures A-57 and A-58, respectively, but they are for the dry period (1929-1934) averages.

4.4 Basin Efficiency (*BE*)

As discussed in Section 3.2.4.3, basin efficiency (*BE*) is the ratio of CUAW to the prime water supply (DR). The sensitivity analysis is designed to vary the *BE* by ±10 percent from its base value. Similar to the consumptive use of applied water (CUAW) in Section 4.3, because the *BE* is dimensionless, it cannot be used to compute SI directly. The net diversion requirement (DR – I + D) defined in Section 4.2 is used in Equations (1) and (2) to compute SI. The EI for the *BE* is computed using Equations (3a) and (4a).

Column 10 of Table 2 lists SI and EI values of all selected model output variables with respect to the *BE*. Note that all SI values have signs opposite to the computed EI values. This is because when the *BE* increases (positive percentage) the diversion requirement (DR) for a DSA decreases (negative change) while the local water supply (I and D) remains the same. Such kind of relationship exists also with respect to Historical Land Use and Outdoor M&I Demand.

The comparison of SI and EI across the entire column can be used to identify sensitivities and elasticities of various output variables with respect to the *BE*. The table below summarizes some of the findings by comparing the SI and EI values across the column. In the table only the positive changes of the *BE* are discussed except where non-monotonic SI and EI appear, although the similar explanation applies to the negative changes as well.

	Findings	**Discussion**
1	SWP NOD and CVP NOD deliveries decrease	The increase in basin efficiency (*BE*) will decrease the diversion requirement (demand) from each DSA north of Delta; therefore less SWP NOD and CVP NOD deliveries are required.
2	NOD groundwater storage increases	As discussed in Section 3.2.4.7., the NOD land-use based demand is met by groundwater and surface water supplies in the order of minimum groundwater pumping, surface water diversion, and additional groundwater pumping. When the demand is decreased by increasing basin efficiency, the additional groundwater pumping is always decreased first. Therefore the NOD groundwater storage increases.
3	SWP and CVP exports, SWP Delta delivery and CVP SOD delivery decrease	When the *BE* increases, the additional groundwater pumping decreases (see Item 2) and its contribution, through its return flow, to the total Delta inflow decreases as well. On the other hand, the decreased groundwater contribution to the total Delta inflow forces more surface water storage releases in order to maintain the Delta water quality standards. The increased surface water storage releases decrease the NOD surface water storage that will, in turn, lower the SOD delivery targets through the WSI-DI allocation procedure. Therefore, when the *BE* increases, both CVP and SWP exports, SWP Delta delivery, and CVP SOD delivery decrease.

Figure A-37 in Appendix A is the bar chart presenting the 73-year average changes in the absolute water volume for total exports, deliveries, and Delta outflow in response to the changes in the *BE*. Figure A-38 is a bar chart presenting changes in the absolute water volume of some components of exports and deliveries. From these two charts output variables with the most volume change with respect to the changes in the *BE* can be identified. Figures A-39 and A-40 present the same information for the dry period (1929-1934).

4.5 Projected Land Use

As discussed in Sections 3.2.3.2 and 3.2.4, the projected land use is one of the inputs to the DWR CU model to estimate both the projected local water supply, also known as gain (I) if it is positive value or depletion (D) if it is negative value, and the diversion requirement (DR). The sensitivity analysis is designed to vary the projected land use by ±5 percent from its base value. Similar to the consumptive use of applied water (CUAW) in Section 4.3, because the projected land use is in acres, it cannot be used to compute SI directly. The net diversion requirement (DR – I + D) defined in Section 4.2 is used in Equations (1) and (2) to compute SI. The EI for the projected land use is computed using Equations (3a) and (4a).

Column 6 of Table 2 lists SI and EI values of all selected model output variables with respect to the projected land use. The comparison of SI and EI across the entire column can be used to identify sensitivities and elasticities of various output variables with respect to the project land use. For example, as shown in Row 3 of Column 6 in Table 2, when the project land use increases by one percent, SWP Delta delivery decreases by 0.09 percent (EI=–0.09) while SWP NOD delivery (Row 4 of Column 6) increases by 0.17 percent (EI=0.17); when net diversion requirement (DR - I + D) increases by one TAF due to the increase of project land use, SWP Delta delivery decreases by 0.04 TAF (SI=–0.04) while SWP NOD delivery increases by 0.02 TAF (SI=0.02). This is because the land-use based demands are only used in the Sacramento Valley floor north of Delta (NOD); the increase in project land use will increase SWP NOD demands, and thereby the SWP NOD deliveries. The increased SWP NOD delivery makes less water available for the SWP Delta delivery.

The table below summarizes some of the findings by comparing the SI and EI values across the column. In the table only the positive changes of the projected land use are discussed, although the similar explanation applies to the negative changes as well.

	Findings	**Discussion**
1	SWP NOD and CVP NOD deliveries increase	The increase in projected land use will increase the diversion requirement (demand) from each DSA north of Delta; therefore more SWP NOD and CVP NOD deliveries are required.
2	SWP Delta delivery and CVP SOD delivery decrease	In general deliveries for both SWP NOD and CVP NOD have a higher priority than SOD deliveries. Therefore, less water may be available for the deliveries to SOD if more water is delivered to NOD (see Item 1).
3	Article 21 delivery and the total Delta outflow decrease	Similar to Item 2, more NOD deliveries make less water available for Article 21 delivery and the total Delta outflow.
4	NOD groundwater storage decreases	More NOD deliveries require more additional groundwater pumping and decrease the groundwater storage.

Figure A-21 in Appendix A is the bar chart presenting the 73-year average changes in the absolute water volume for total exports, deliveries, and Delta outflow in response to the changes in the projected land use. Figure A-22 is a bar chart presenting changes in the absolute water volume of some components of exports and deliveries. From these two charts output variables with the most volume change with respect to the changes in the projected land use can be identified. Figures A-23 and A-24 present the same information for the dry period (1929-1934).

4.6 Comparisons of SI and EI among All Selected Input Parameters

CalSim-II users with different interests may be interested in different aspects of the model inputs and outputs. That is, water managers and contractors may be more concerned about water deliveries, while modelers may focus more on the model behavior and the effect of input data variations on the model output. Tables 2 and 3 provide information about this. For example, a comparison of SI values across Row 12 of Table 2 and Figure A-112 shows that Banks SWP export is most sensitive to Banks Pumping Limit (SI=+1.46). This fact indicates that the current Banks SWP export in CalSim-II is affected the most by the Banks pumping limit. Similarly, a comparison of EI values across Row 7 of Table 2 and Figure A-97 indicates that CVP NOD delivery is most elastic with respect to Crop ET (EI=+0.66), Projected Land Use (EI=+0.59), and Basin Efficiency (EI=–0.59). This information may provide some guidance in prioritizing input data refinement effort in order to improve the accuracy of CVP NOD delivery.

Figures A-85 through A-132 are graphical representations of SI and EI values of major selected output variables with respect to all 21 input parameters. These charts provide additional details to give more insight on the responses of major output variables to input parameter changes.

4.7 Summary of SWP Delivery Sensitivities

As discussed in Section 4.6, Tables 2 and 3 provide information on various model input parameters' impact on a specific model output variable. In order to assist SWP contractors and other interested parties to evaluate the impact of model input parameters on SWP deliveries, this section summarizes sensitivities of SWP deliveries (SWP Delta Delivery, SWP NOD Delivery, and Article 21 Delivery) with respect to all 21 input parameters analyzed.

As shown in the footnote of Table 2, three levels of sensitivity are defined:

High Sensitivity: $|SI| > 0.2$
Moderate Sensitivity: $0.1 <= |SI| <= 0.2$
Low Sensitivity: $|SI| < 0.1$.

These three levels of sensitivities are defined arbitrarily in this report for the purpose of illustrating the relative significance of various input parameters. The 21 input parameters are color coded according to their levels of sensitivities corresponding to each type of SWP deliveries in Table 2. Reader should keep in perspective the degree of perturbation made for each input parameter investigated in this study when drawing any conclusions from the computed sensitivities.

From row 3 of Table 2 it can be found that the SWP Delta delivery is highly sensitive to Oroville Inflow, SWP Table A Demand, and Banks Pumping Limit. In other words, Table A Demand and Banks Pumping Limit are most important factors affecting SWP Delta Delivery in addition to the natural Oroville water supply. The table shows that the SWP Delta Delivery has a moderate sensitivity to Yuba Inflow, Folsom Inflow, Historical Land Use, Historical Groundwater Extraction, and Outdoor M&I Demands and a low sensitivity to the rest of 21 model input parameters investigated.

From row 5 of Table 2 it can also be found that the Article 21 Delivery is highly sensitive to Banks Pumping Limit. The observation agrees with the common understanding that the Banks Pumping Limit is the most important controlling factor over any SWP deliveries to the South-of-Delta. The Article 21 Delivery shows a moderate sensitivity to SWP Table A Demand and a low sensitivity to the rest of 21 input parameters.

It is noticed that, in row 4 of Table 2, SWP NOD Delivery has a low sensitivity to all 21 model input parameters. This is because the major portion of SWP NOD delivery is to the Settlement Contractors in Feather River Service Area which are governed by a different set of operation rules based on Oroville inflow and are not subject to any other system operations criteria.

5 Study Summary and Future Work

5.1 Study Summary

This report documents the methodology and result of a CalSim-II model sensitivity analysis study, and how SWP contractors and other readers with different interests may be able to use it. Sensitivity analysis for 21 selected model input parameters were conducted under D-1641 regulatory environment. The model input parameters and their corresponding sensitivity analysis designs were introduced one by one or in groups. Two performance measures, Sensitivity Index (SI) and Elasticity Index (EI), were defined and computed for 22 selected model output variables with respect to changes in 21 selected model input parameters. The study results are summarized and key input parameters that significantly affect the SWP are discussed in some detail in order to show how the SWP delivery and other operations respond to the changes in model inputs. The discussion also demonstrates how SWP contractors and other water users can draw useful information from the study.

5.2 Future Work

This sensitivity analysis study is mainly focused on model input parameters related to Sacramento Valley hydrology, Sacramento-San Joaquin Delta water quality, and SWP operations, which may have significant effects on both the SWP and CVP. Additional sensitivity studies related to San Joaquin Valley hydrology and CVP operations can and should be done in the near future by Reclamation.

In this study, the simple sensitivity analysis procedure is used. That is, changes in model input parameters are investigated one at a time. However, often reasonable scenarios would have several model input parameters changing together. For example, possible changes in non-recoverable loss factors would be accompanied by corresponding variations in basin efficiency (see Section 3.2.4.3). Therefore, in order to evaluate the combined effect of two or more input parameters on model output, a more complex sensitivity analysis procedure, which investigates changes in a set of input parameters simultaneously, may be explored in future studies.

CalSim-II is a monthly time-step simulation model that simulates the SWP and CVP and areas tributary to the Sacramento-San Joaquin Delta. In each monthly step the linear programming technique is used to distribute water among different uses. Linear programming solutions could produce an array of sensitivity analyses as a by-product of the linear programming analysis automatically, in the form of Lagrange multipliers (also known as shadow prices or dual values), slack variables, and range of basis information. Such automated sensitivity analysis could potentially be included as an appendix to each CalSim-II run. With an appropriate discussion of these results, this should provide a degree of transparency to model users and an internal diagnostic tool that the current CalSim-II does not provide. A study of these by-products would be considered in the next generation of CalSim-II model.

The CALFED report, *A Strategic Review of CalSim-II and its Use for Water Planning, Management, and Operations in Central California* (December 2003) recommends a model uncertainty analysis be conducted. An uncertainty analysis is not the same as a sensitivity analysis. It takes a set of randomly chosen input values (that can include parameter values), passes them through a model to obtain the probability distributions (or statistical measures of the probability distributions) of the resulting outputs, while a sensitivity analysis attempts to determine the relative change in model output values given modest changes in model input values. The uncertainty analysis would help users of the model understand better the risks of various decisions and the confidence they can have in various model predictions. DWR is currently working on a contract with University of California, Davis to develop a strategy for the identification and reduction of the major sources of uncertainty in CalSim-II modeling studies, and implement a recommended procedure for the quantification of uncertainties in a CalSim-II study.

Appendix A

Additional Figures

Figure A-1
Responses of Average Annual Export, Delivery and Delta Outflow to Shasta Inflow Change, WY 1922-1994

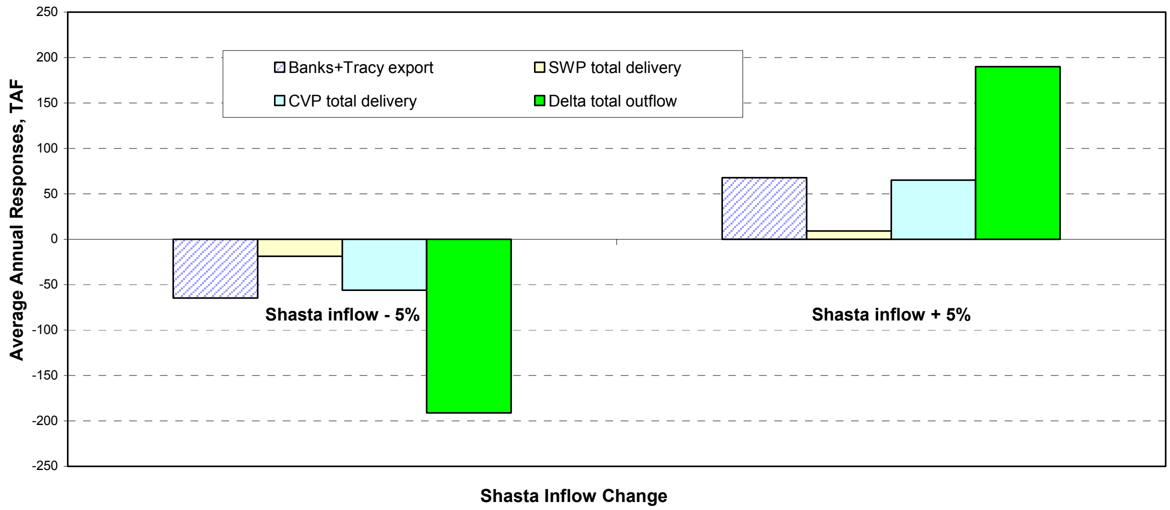


Figure A-2
Responses of Average Annual Export and Delivery Components to Shasta Inflow Change, WY 1922-1994

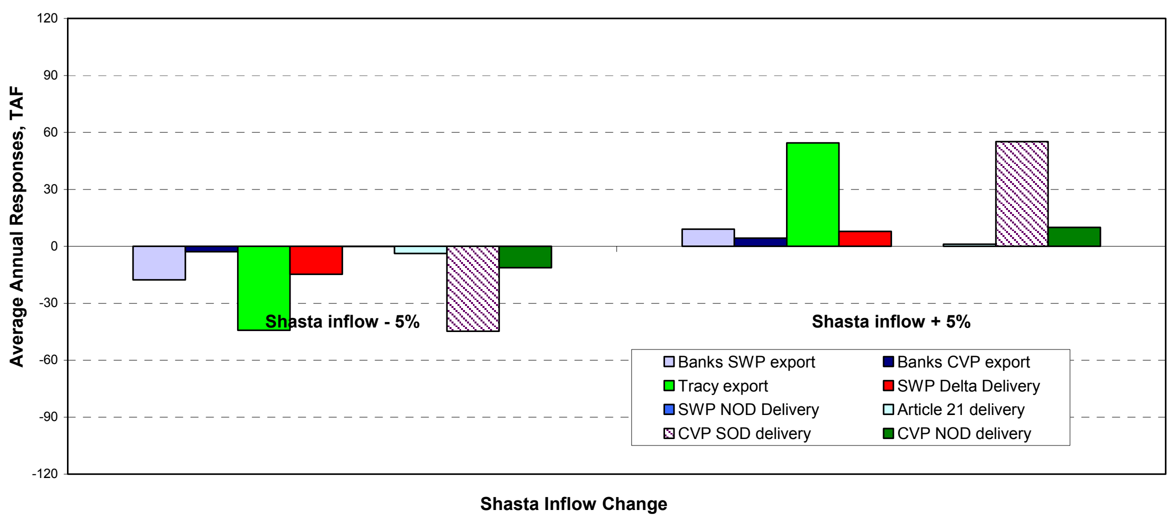


Figure A-3
Responses of Average Annual Export, Delivery and Delta Outflow to Shasta Inflow Change, WY 1929-1934

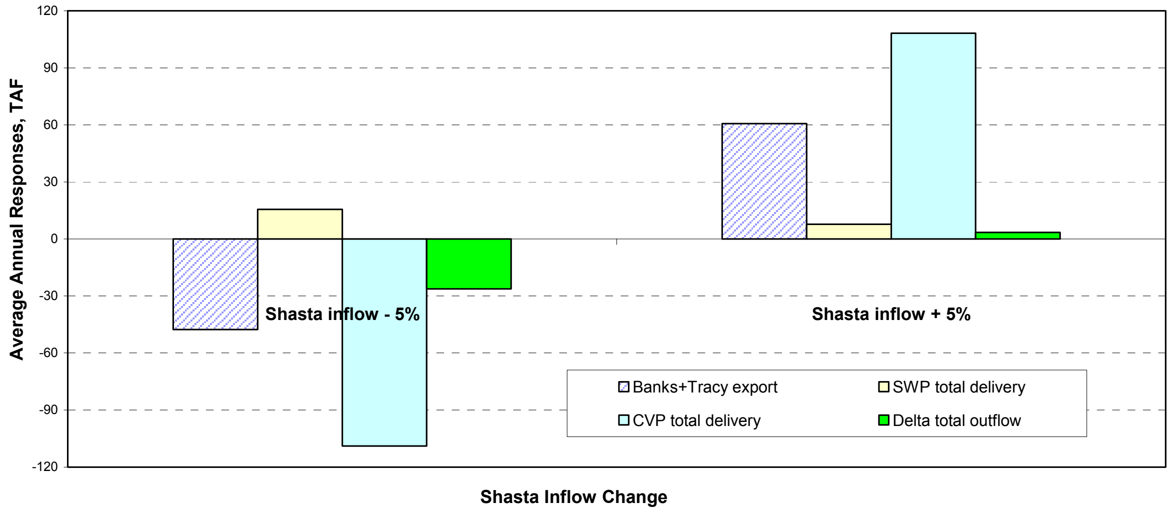


Figure A-4
Responses of Average Annual Export and Delivery Components to Shasta Inflow Change, WY 1929-1934

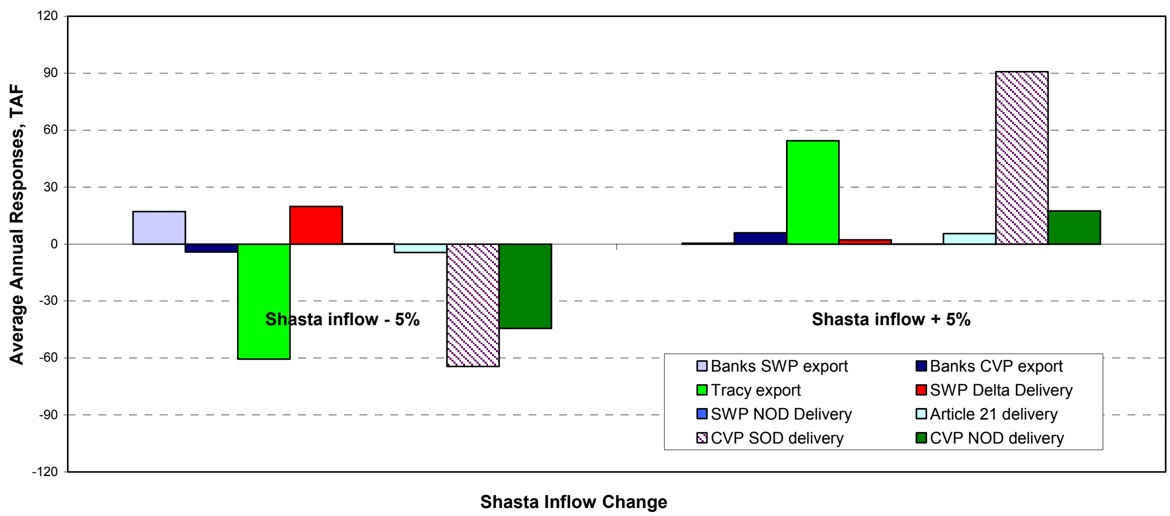


Figure A-5
Responses of Average Annual Export, Delivery and Delta Outflow to Oroville Inflow Change, WY 1922-1994

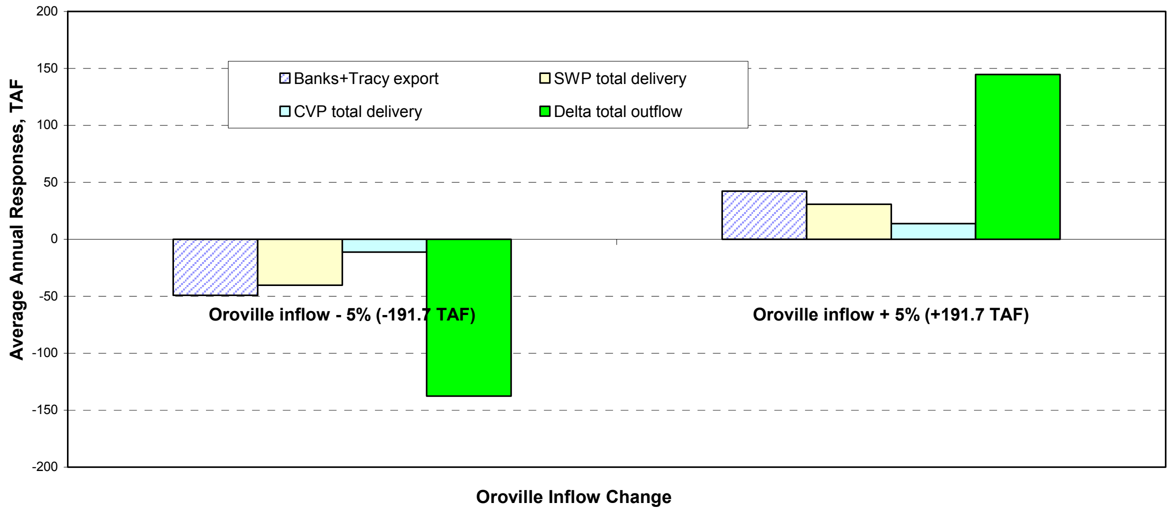


Figure A-6
Responses of Average Annual Export and Delivery Components to Oroville Inflow Change, WY 1922-1994

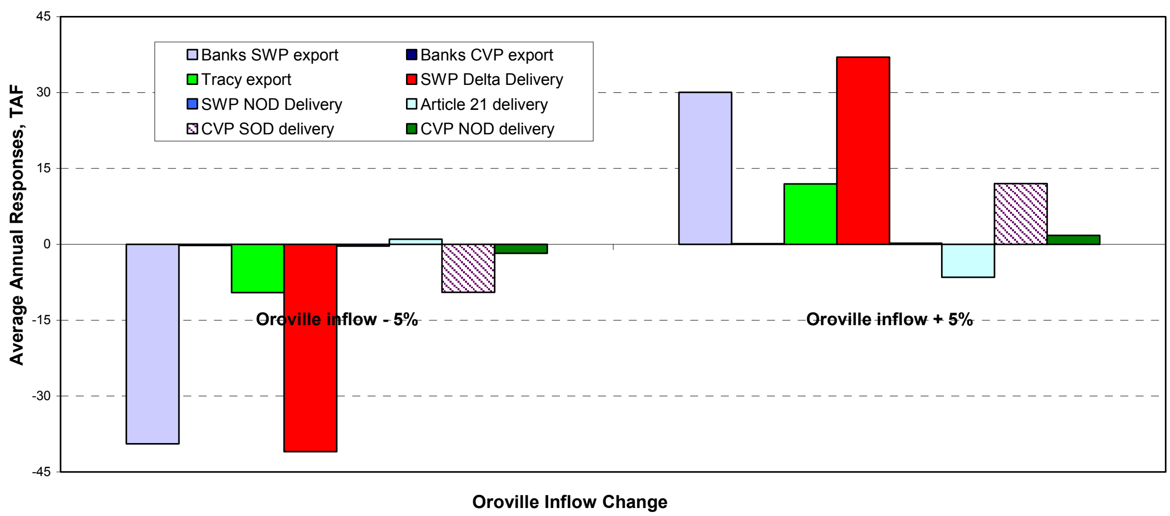


Figure A-7
Responses of Average Annual Export, Delivery and Delta Outflow to Oroville Inflow Change, WY 1929-1934

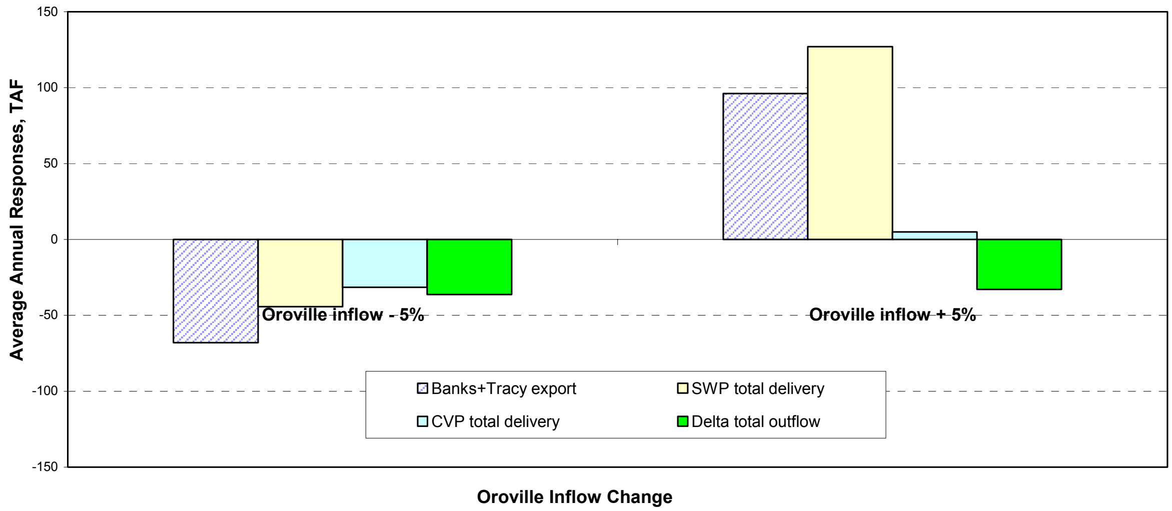


Figure A-8
Responses of Average Annual Export and Delivery Components to Oroville Inflow Change, WY 1929-1934

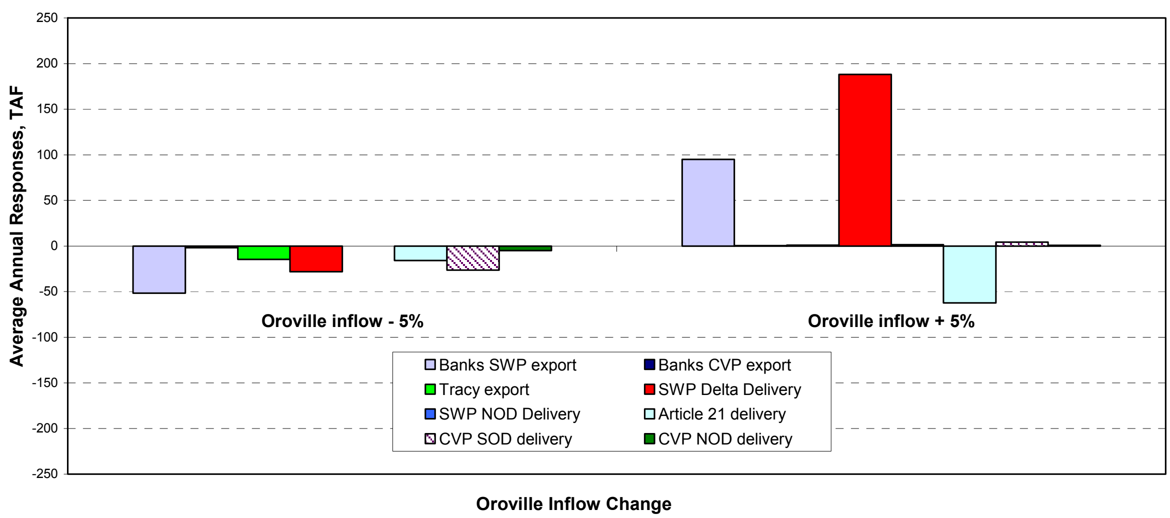


Figure A-9
Responses of Average Annual Export, Delivery and Delta Outflow to Yuba Inflow Change, WY 1922-1994

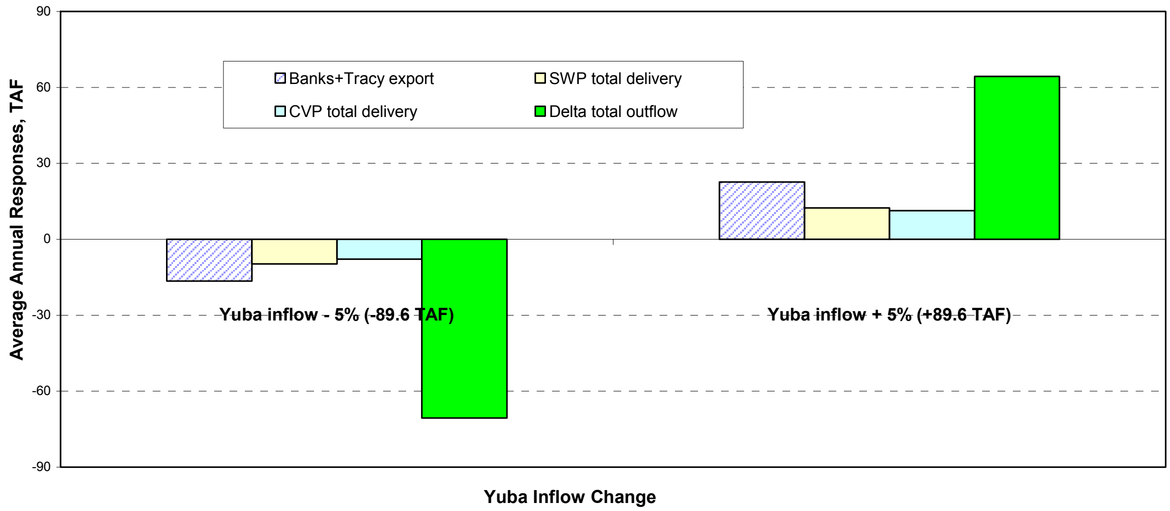


Figure A-10
Responses of Average Annual Export and Delivery Components to Yuba Inflow Change, WY 1922-1994

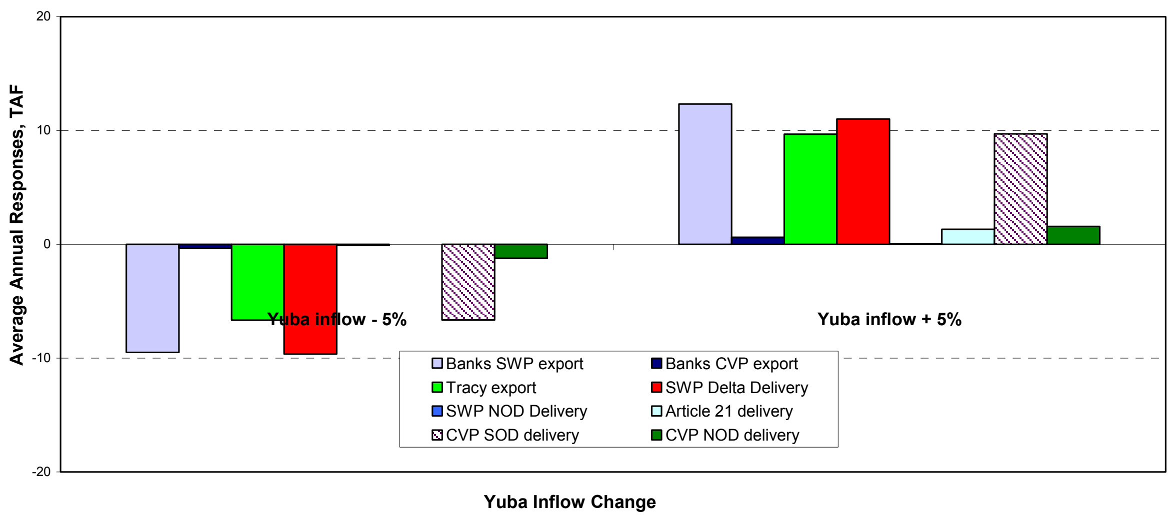


Figure A-11
Responses of Average Annual Export, Delivery and Delta Outflow to Yuba Inflow Change, WY 1929-1934

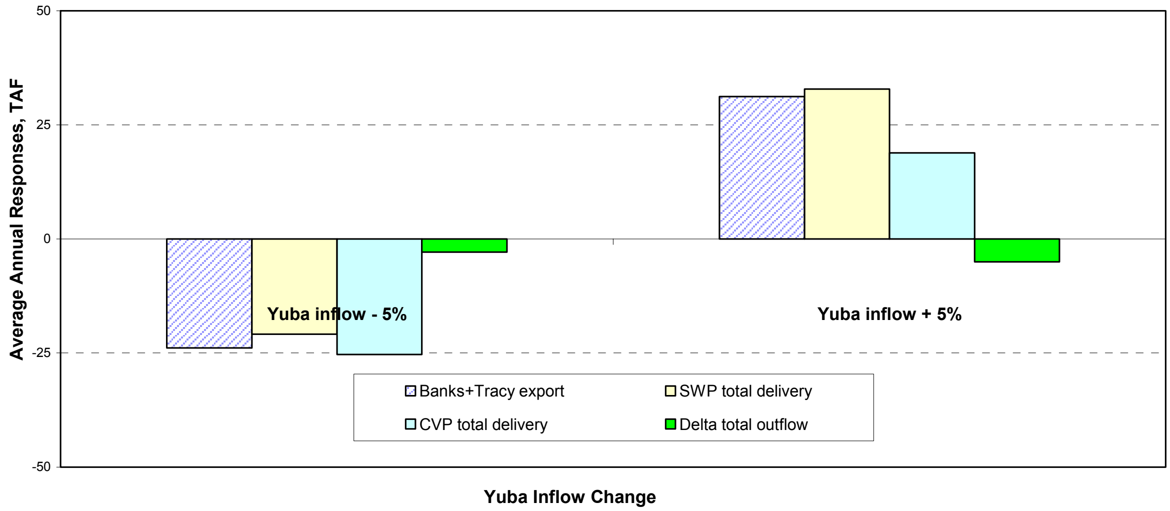


Figure A-12
Responses of Average Annual Export and Delivery Components to Yuba Inflow Change, WY 1929-1934

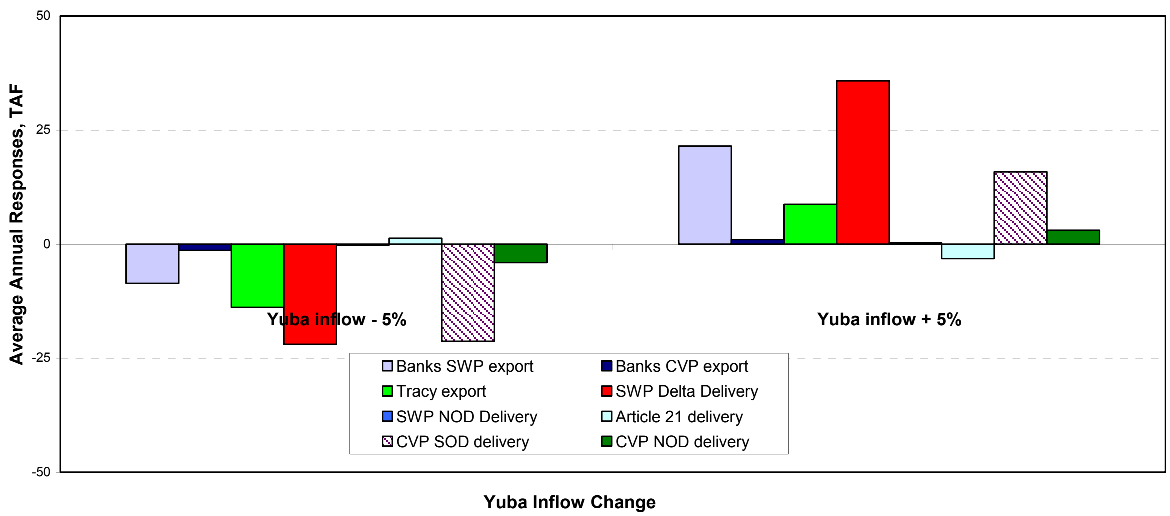


Figure A-13
Responses of Average Annual Export, Delivery and Delta Outflow to Folsom Inflow Change, WY 1922-1994

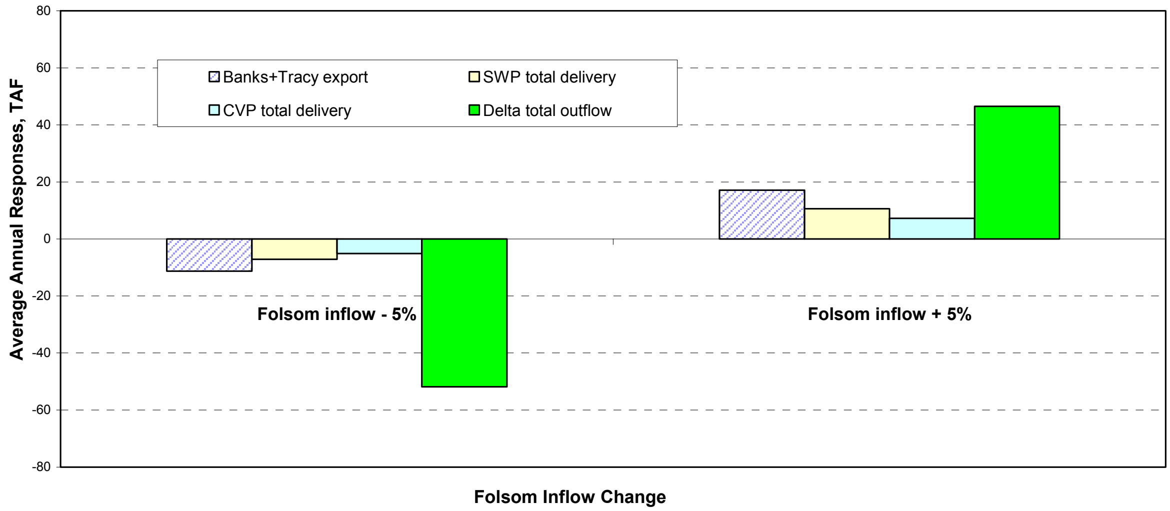


Figure A-14
Responses of Average Annual Export and Delivery Components to Folsom Inflow Change, WY 1922-1994

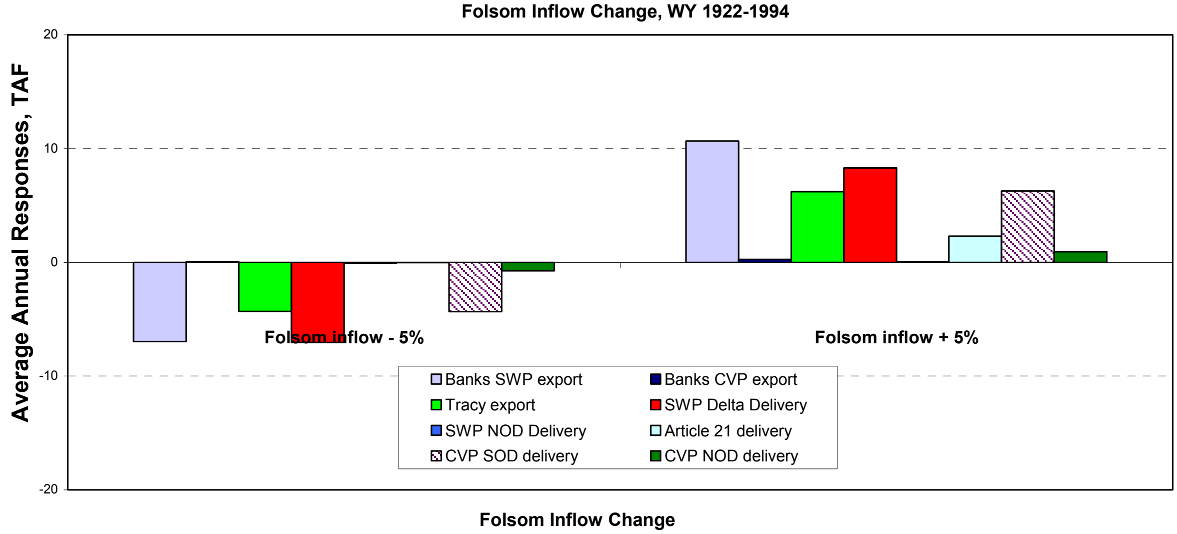


Figure A-15
Responses of Average Annual Export, Delivery and Delta Outflow to Folsom Inflow Change, WY 1929-1934

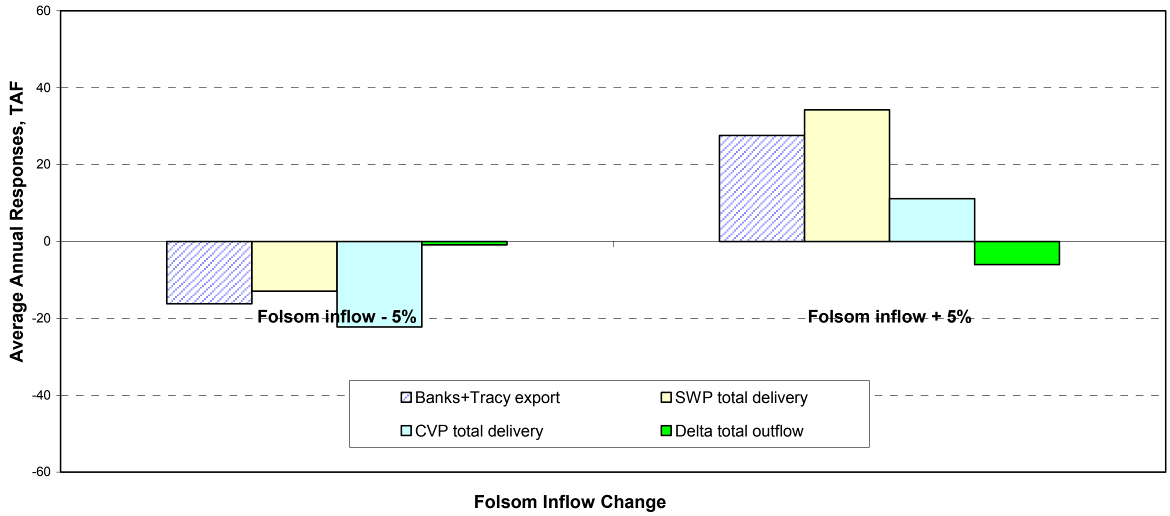


Figure A-16
Responses of Average Annual Export and Delivery Components to Folsom Inflow Change, WY 1929-1934

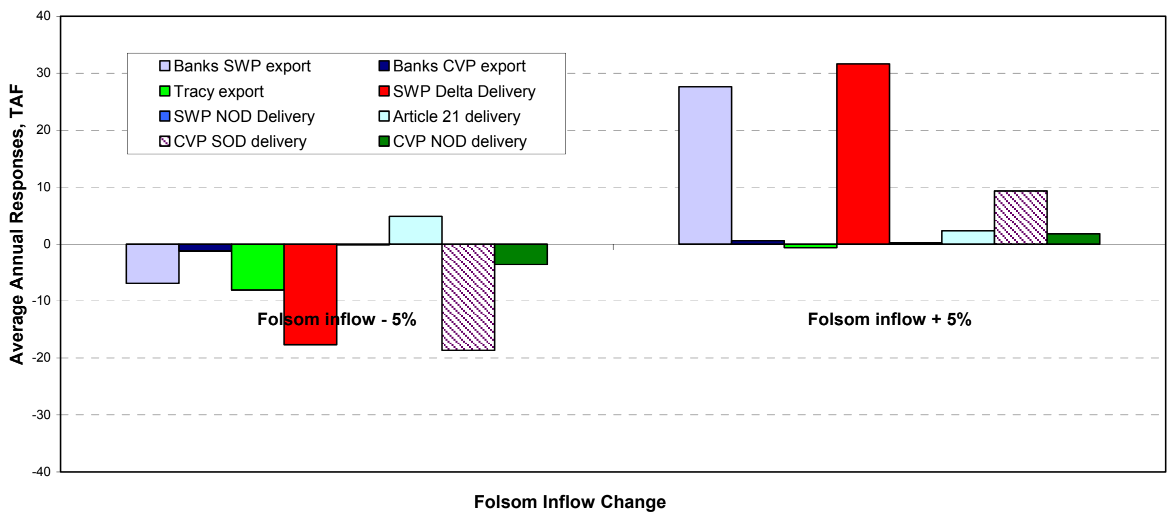


Figure A-17
Responses of Average Annual Export, Delivery and Delta Outflow to Historical Land Use Change, WY 1922-1994

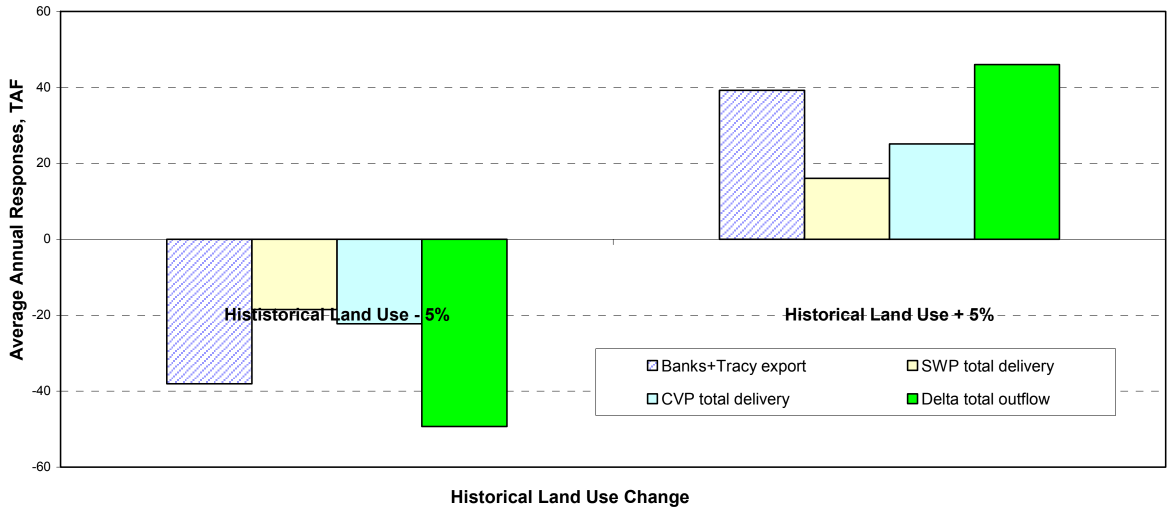


Figure A-18
Responses of Average Annual Export and Delivery Components to Historical Land Use Change, WY 1922-1994

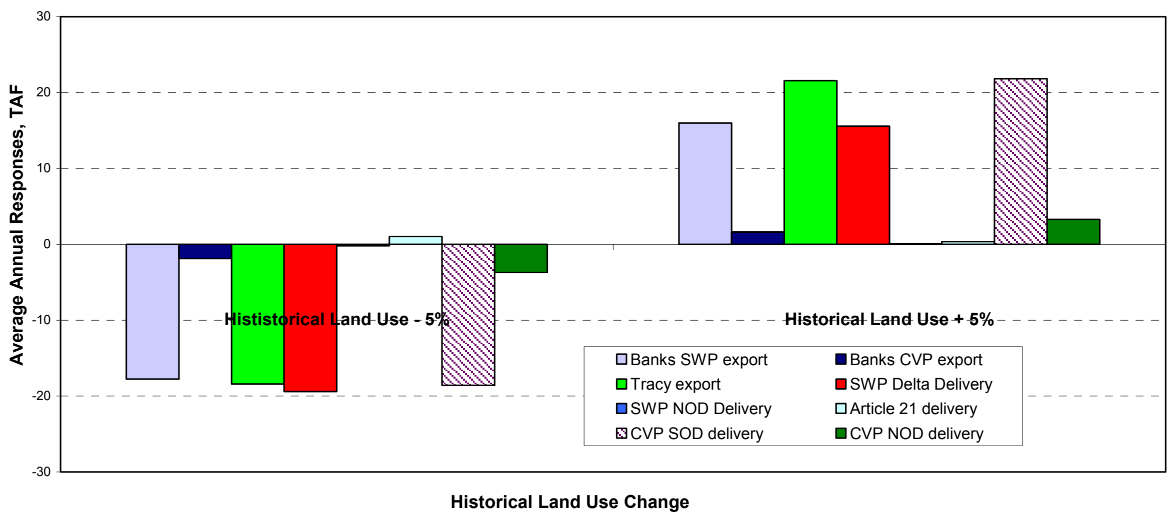


Figure A-19
Responses of Average Annual Export, Delivery and Delta Outflow to
Historical Land Use Change, WY 1929-1934

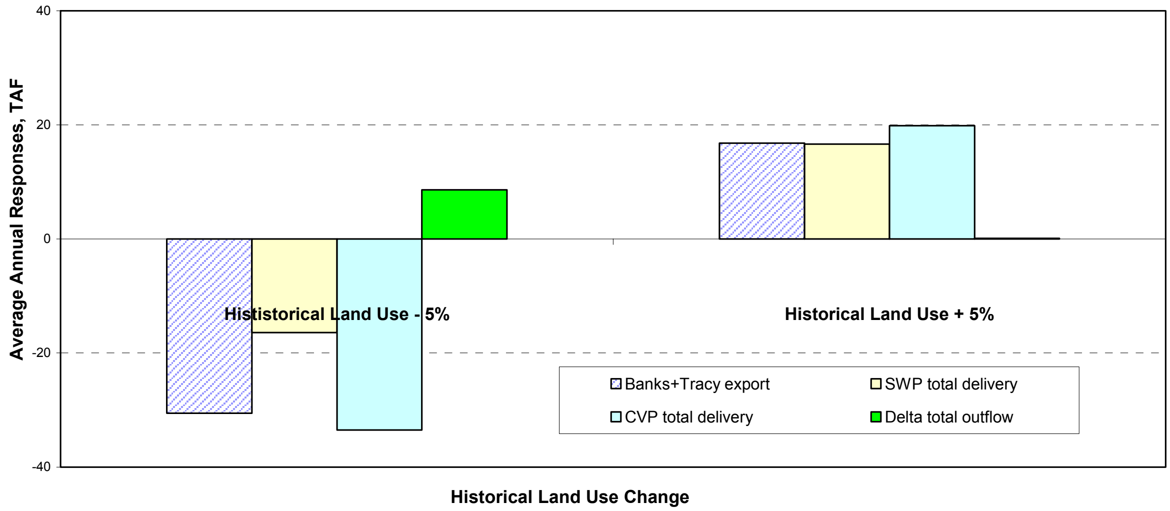


Figure A-20
Responses of Average Annual Export and Delivery Components to
Historical Land Use Change, WY 1929-1934

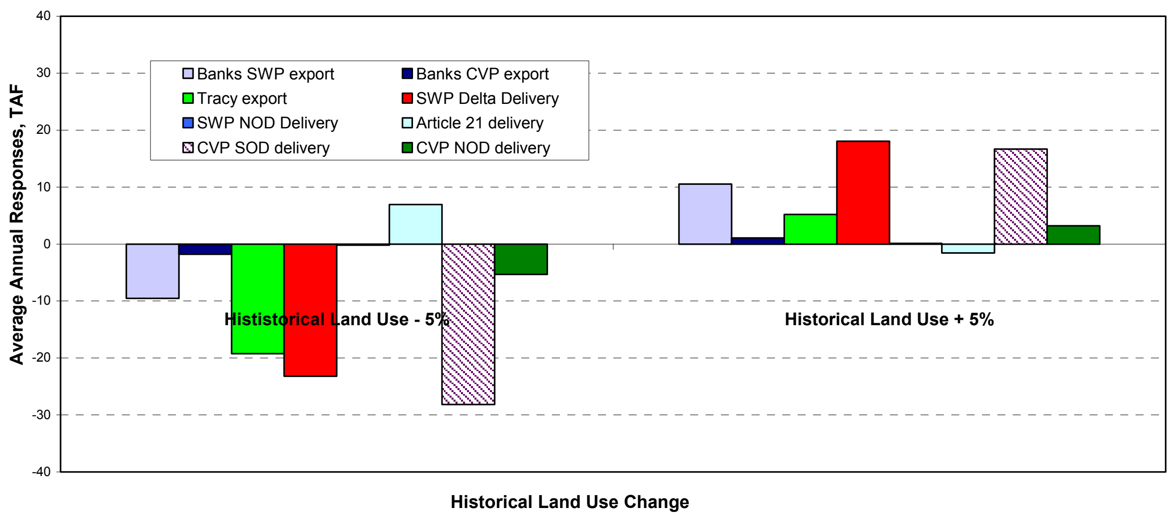


Figure A-21
Responses of Average Annual Export, Delivery and Delta Outflow to Projected Land Use Change, WY 1922-1994

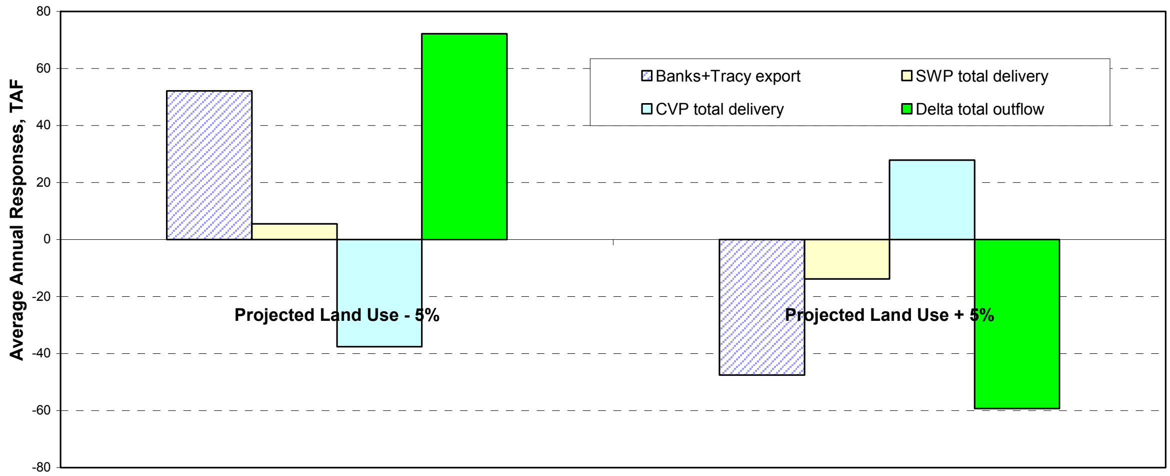


Figure A-22
Responses of Average Annual Export and Delivery Components to Projected Land Use Change, WY 1922-1994

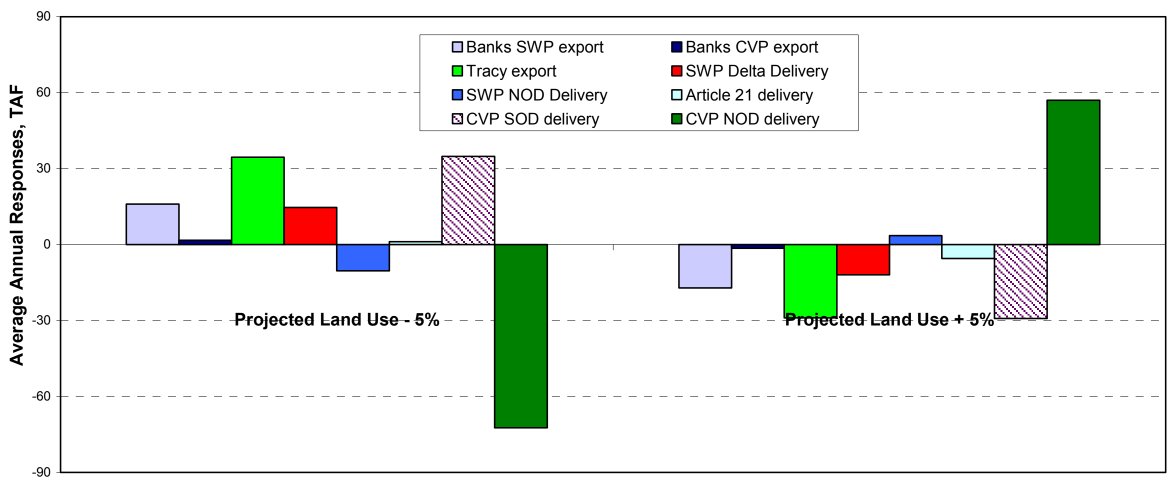


Figure A-23
Responses of Average Annual Export, Delivery and Delta Outflow to Projected Land Use Change, WY 1929-1934

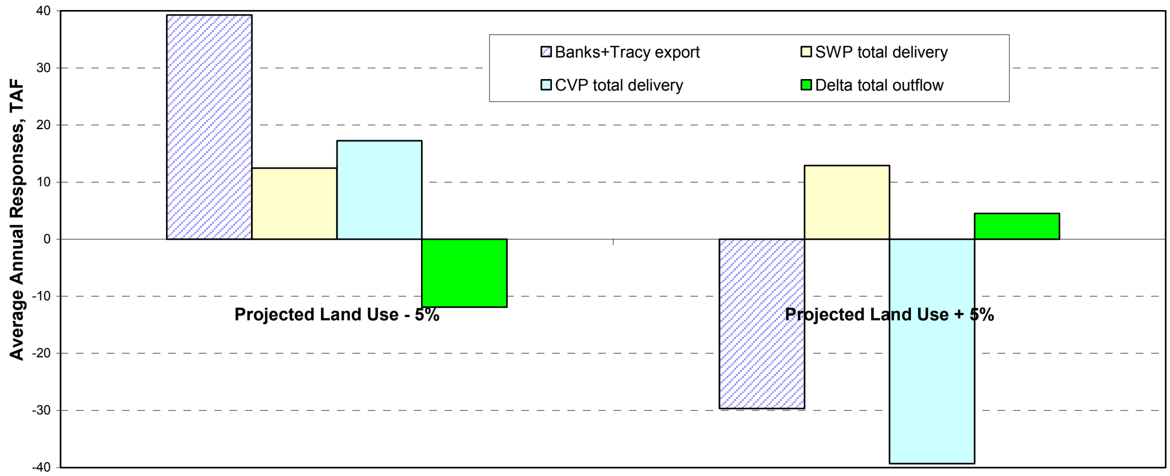


Figure A-24
Responses of Average Annual Export and Delivery Components to Projected Land Use Change, WY 1929-1934

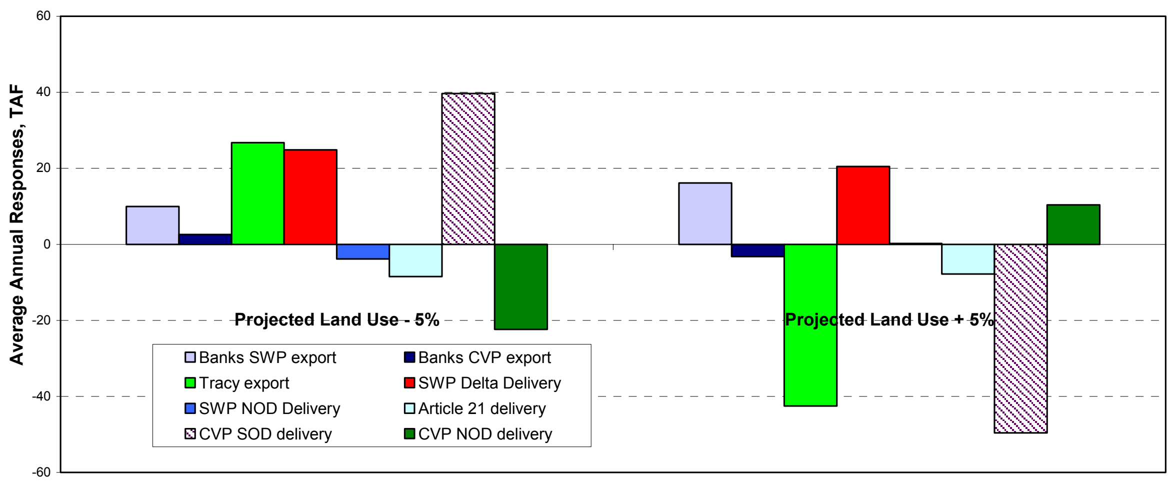


Figure A-25
Responses of Average Annual Export, Delivery and Delta Outflow to Historical Groundwater Extraction Change, WY 1922-1994

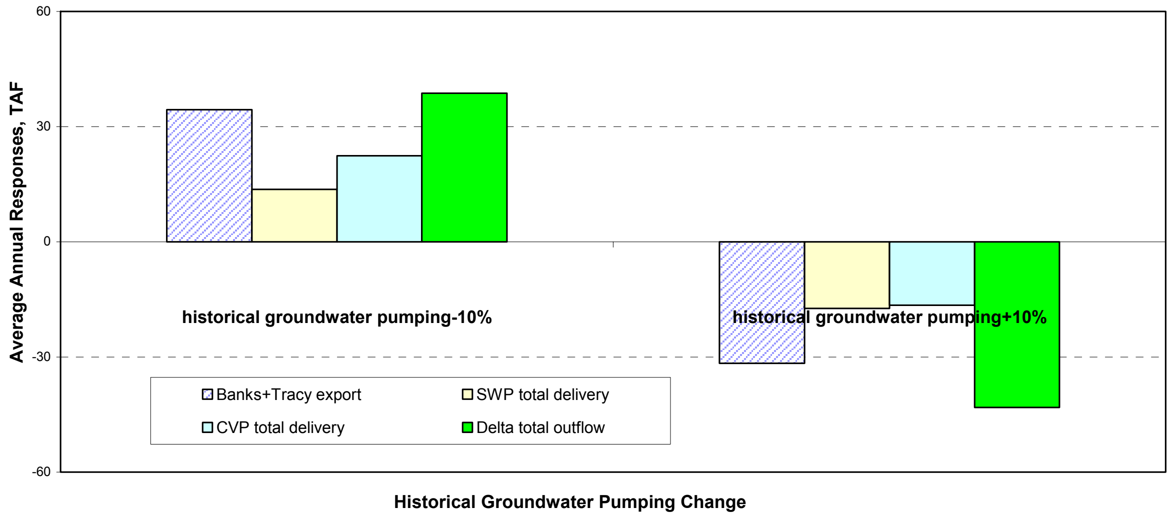


Figure A-26
Responses of Average Annual Export and Delivery Components to Historical Groundwater Extraction Change, WY 1922-1994

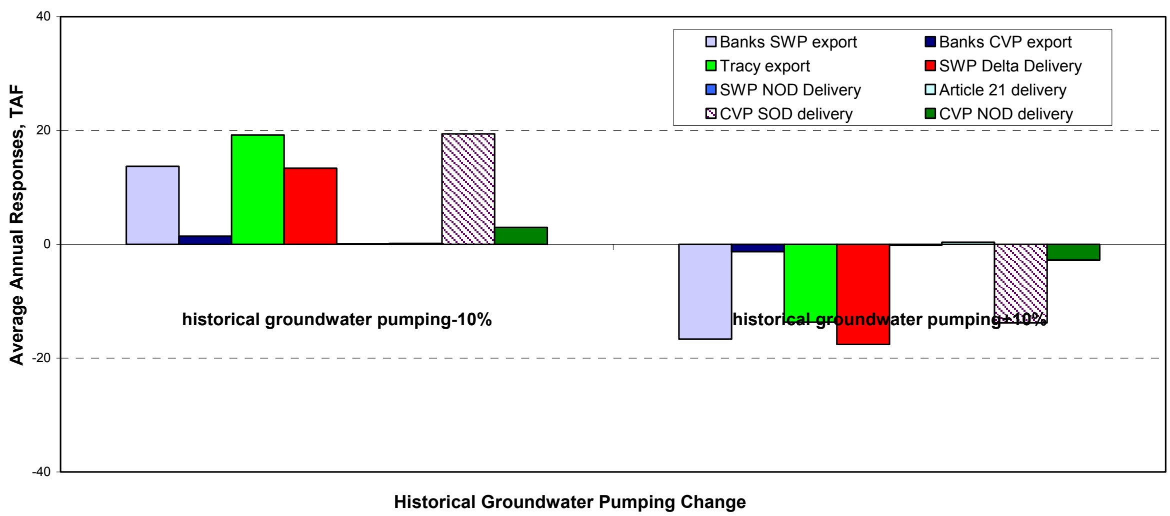


Figure A-27
Responses of Average Annual Export, Delivery and Delta Outflow to Historical Groundwater Extraction Change, WY 1929-1934

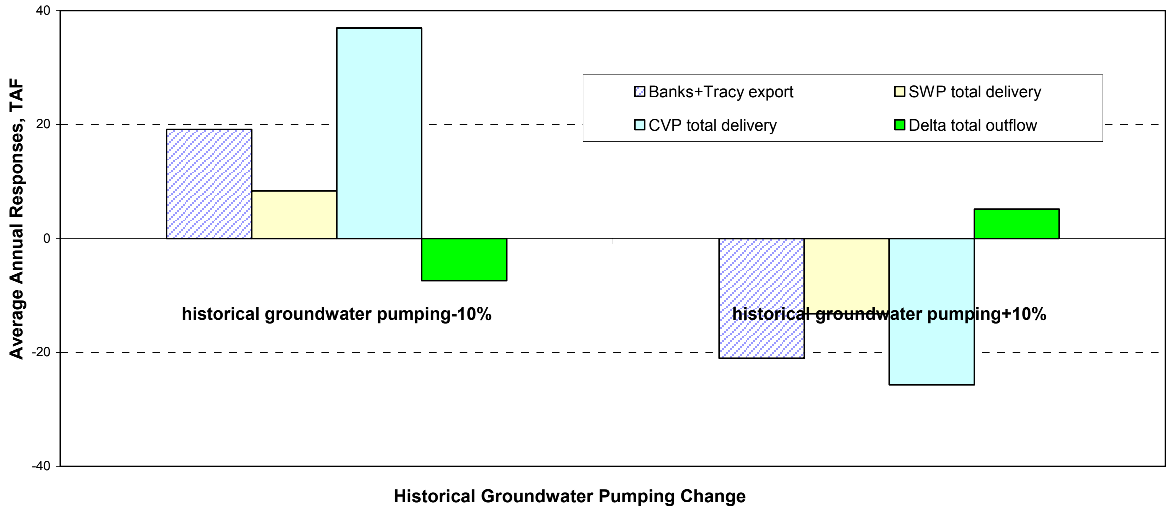


Figure A-28
Responses of Average Annual Export and Delivery Components to Historical Groundwater Extraction Change, WY 1929-1934

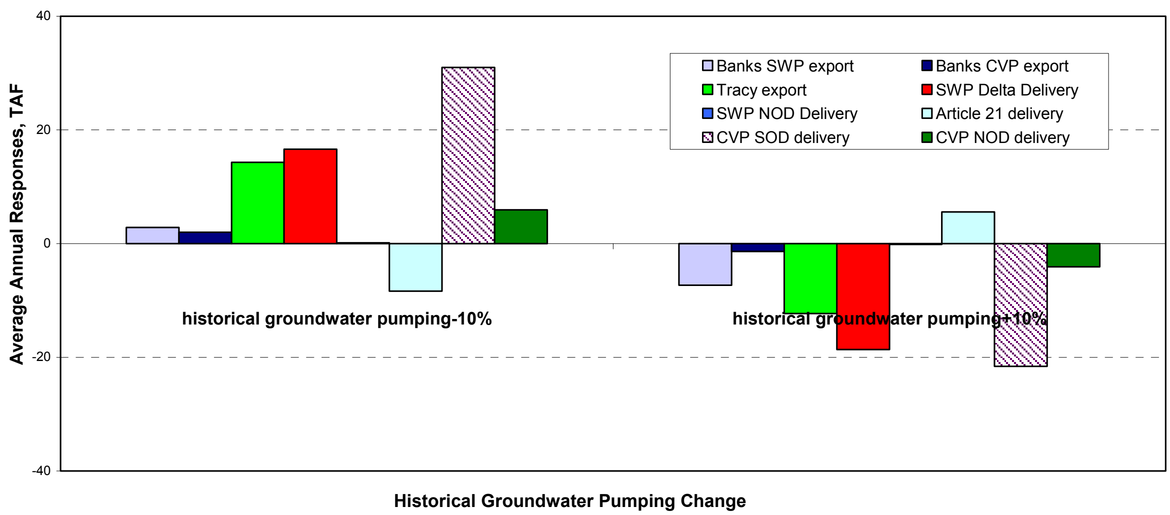


Figure A-29
Responses of Average Annual Export, Delivery and Delta Outflow to Non-recoverable Loss Change, WY 1922-1994

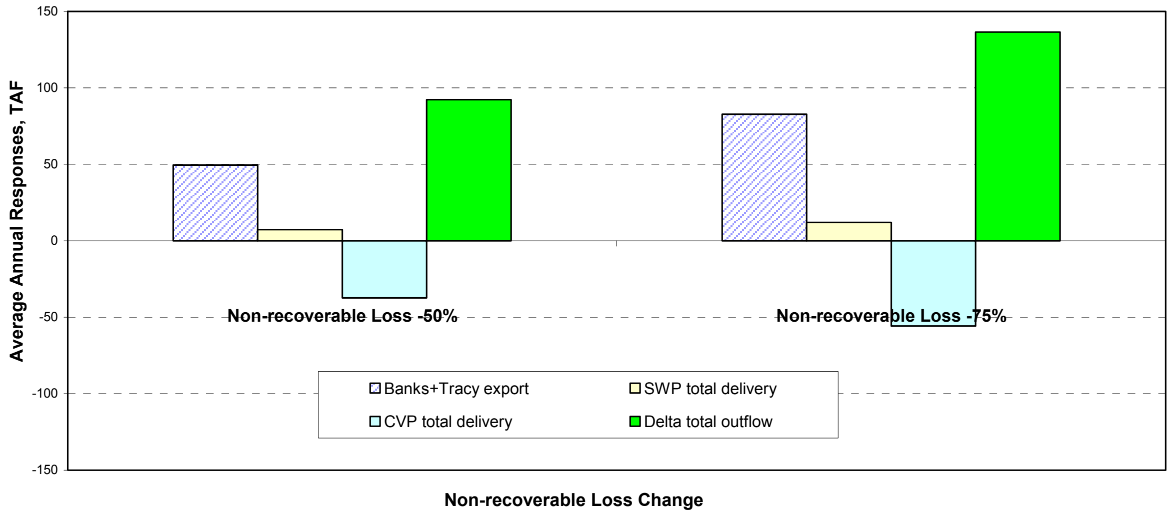


Figure A-30
Responses of Average Annual Export and Delivery Components to Non-recoverable Loss Change, WY 1922-1994

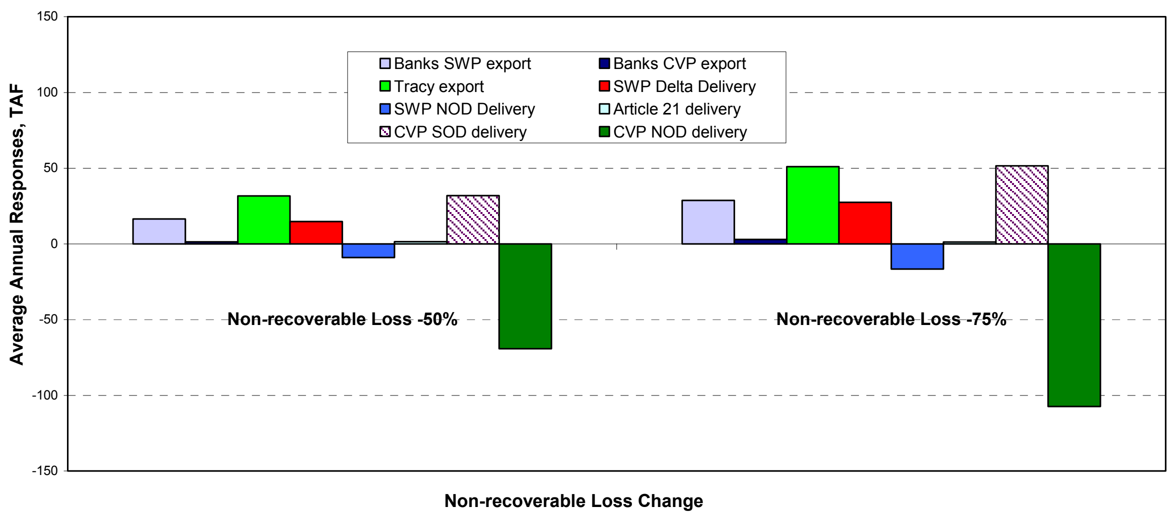


Figure A-31
Responses of Average Annual Export, Delivery and Delta Outflow to Non-recoverable Loss Change, WY 1929-1934

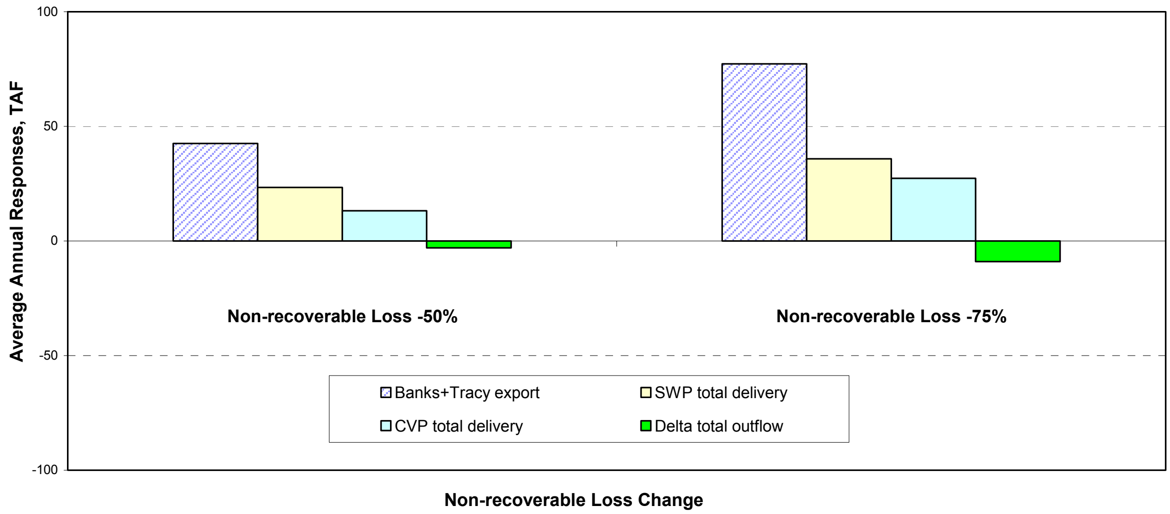


Figure A-32
Responses of Average Annual Export and Delivery Components to Non-recoverable Loss Change, WY 1929-1934

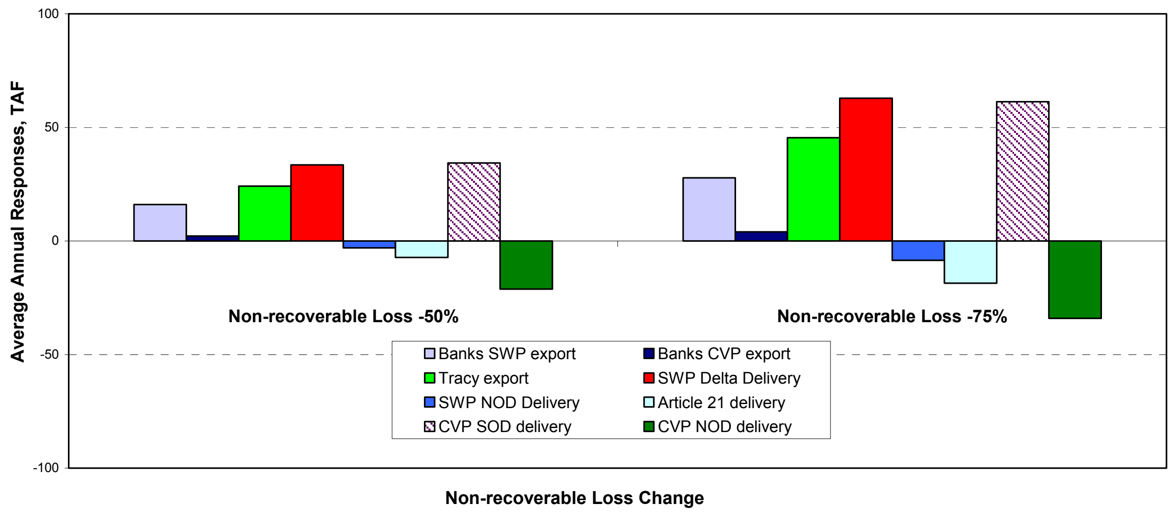


Figure A-33
Responses of Average Annual Export, Delivery and Delta Outflow to Crop ET Change, WY 1922-1994

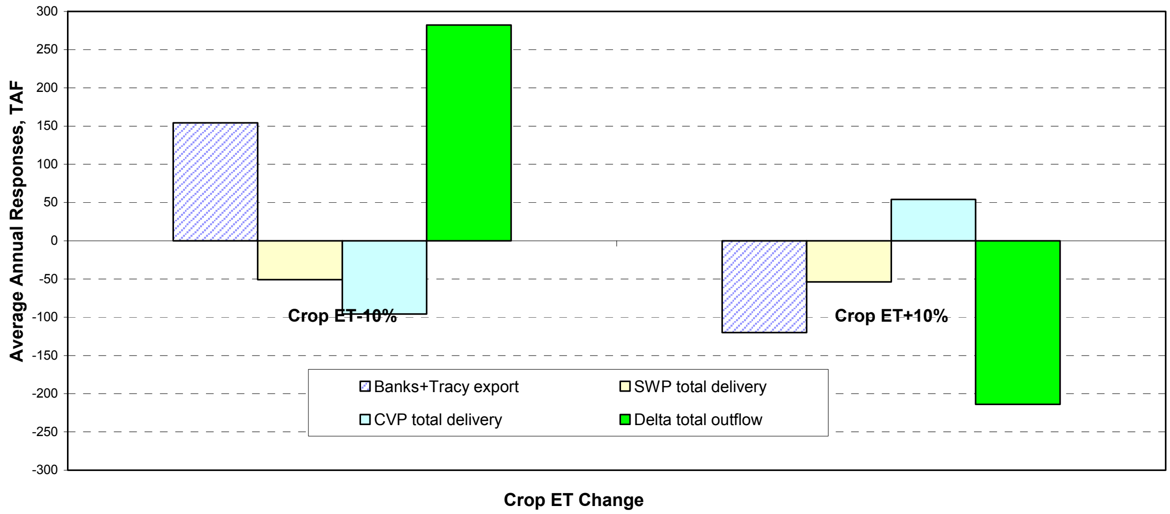


Figure A-34
Responses of Average Annual Export and Delivery Components to Crop ET Change, WY 1922-1994

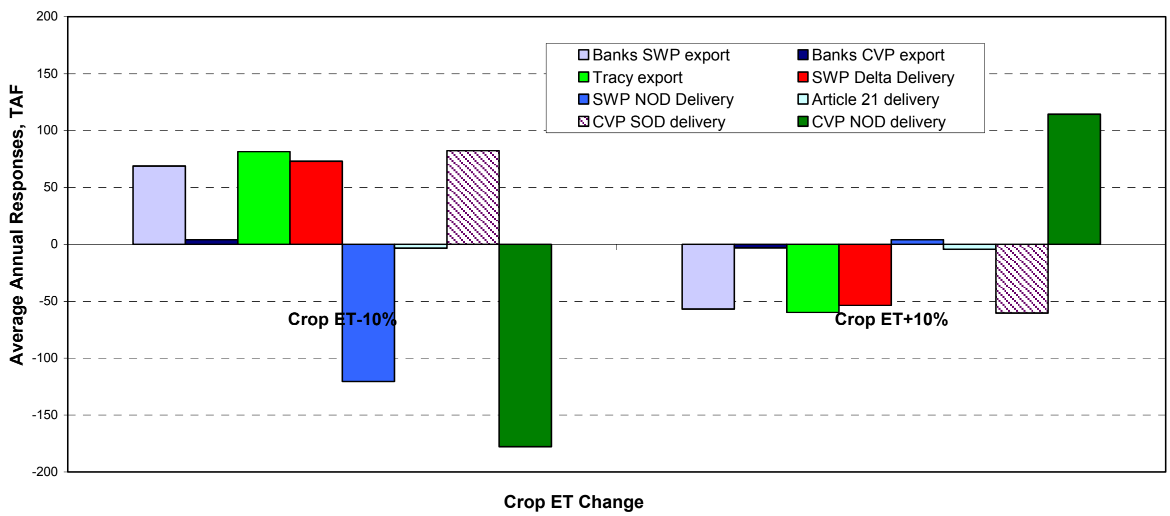


Figure A-35
Responses of Average Annual Export, Delivery and Delta Outflow to Crop ET Change, WY 1929-1934

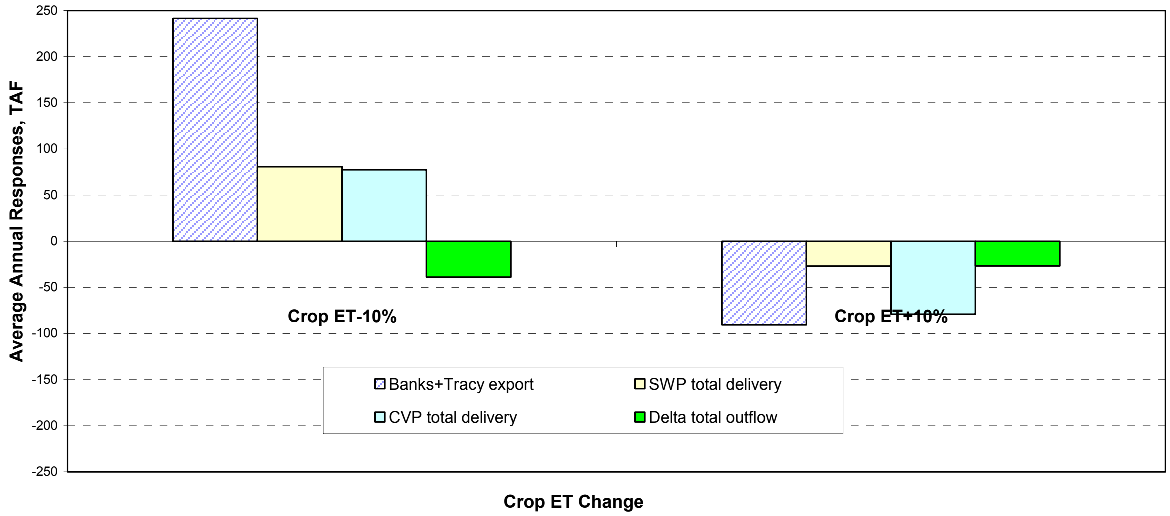


Figure A-36
Responses of Average Annual Export and Delivery Components to Crop ET Change, WY 1929-1934

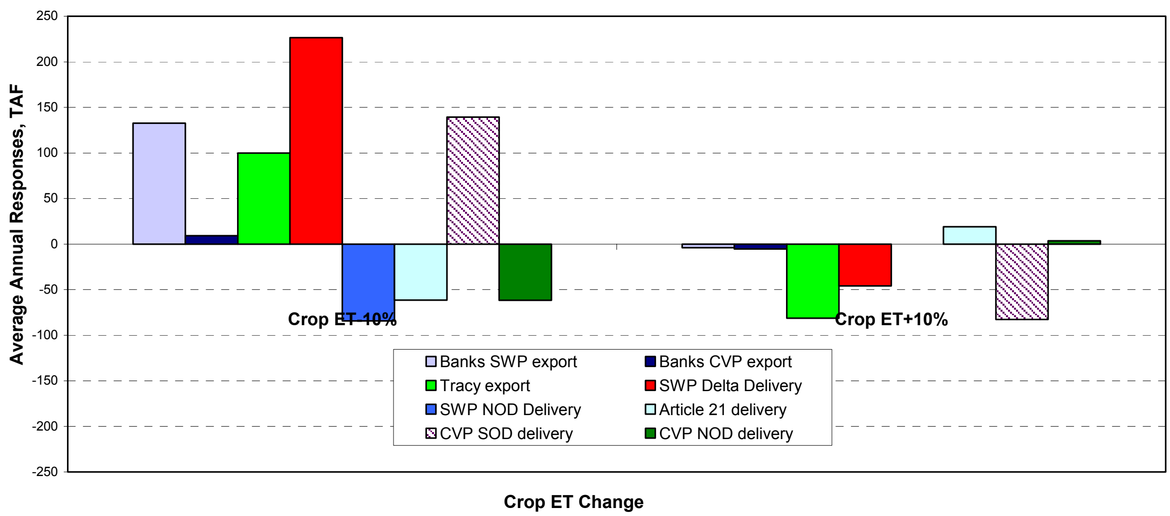


Figure A-37
Responses of Average Annual Export, Delivery and Delta Outflow to Basin Efficiency Change, WY 1922-1994

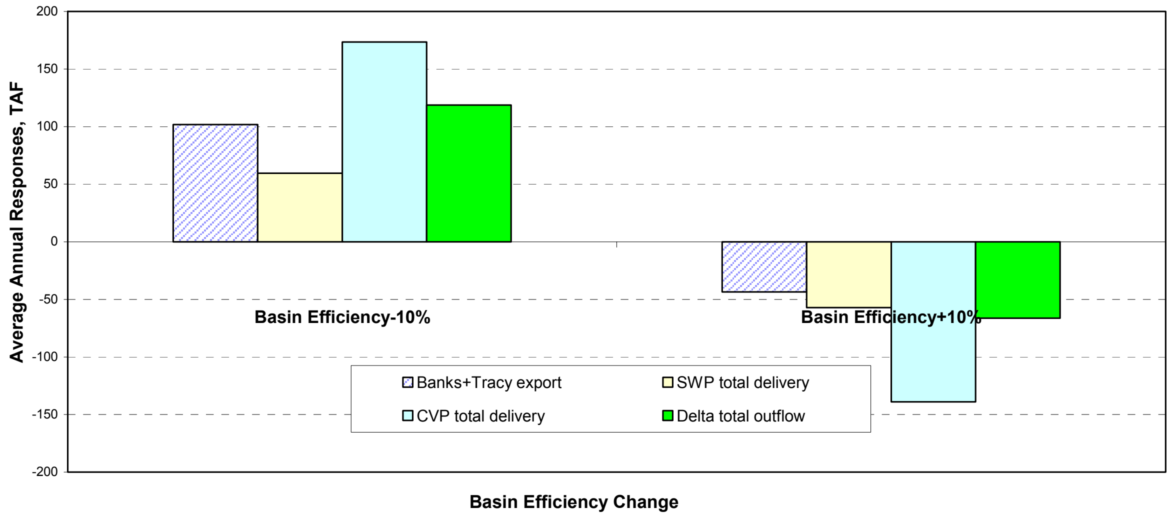


Figure A-38
Responses of Average Annual Export and Delivery Components to Basin Efficiency Change, WY 1922-1994

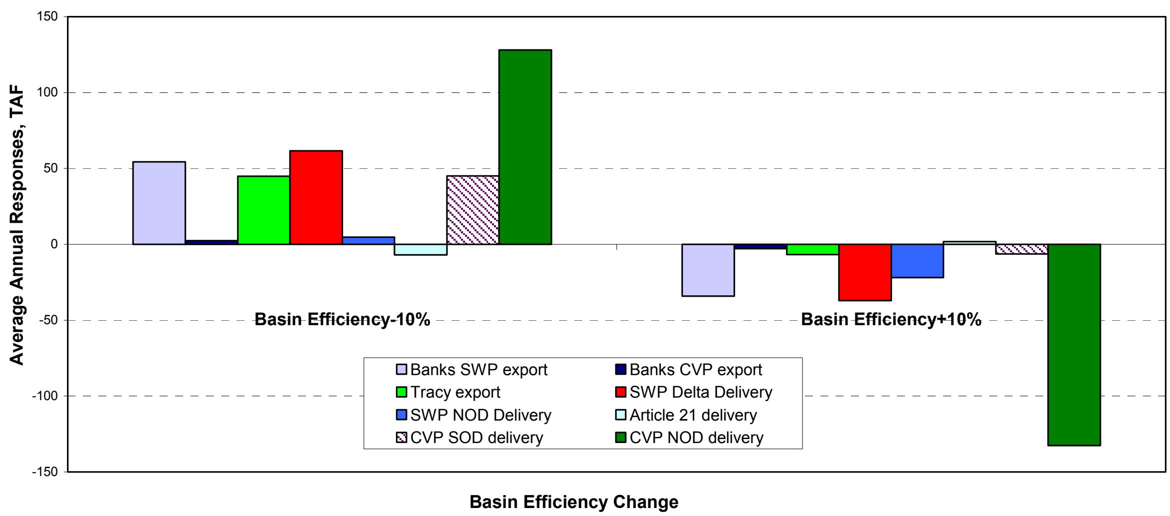


Figure A-39
Responses of Average Annual Export, Delivery and Delta Outflow to Basin Efficiency Change, WY 1929-1934

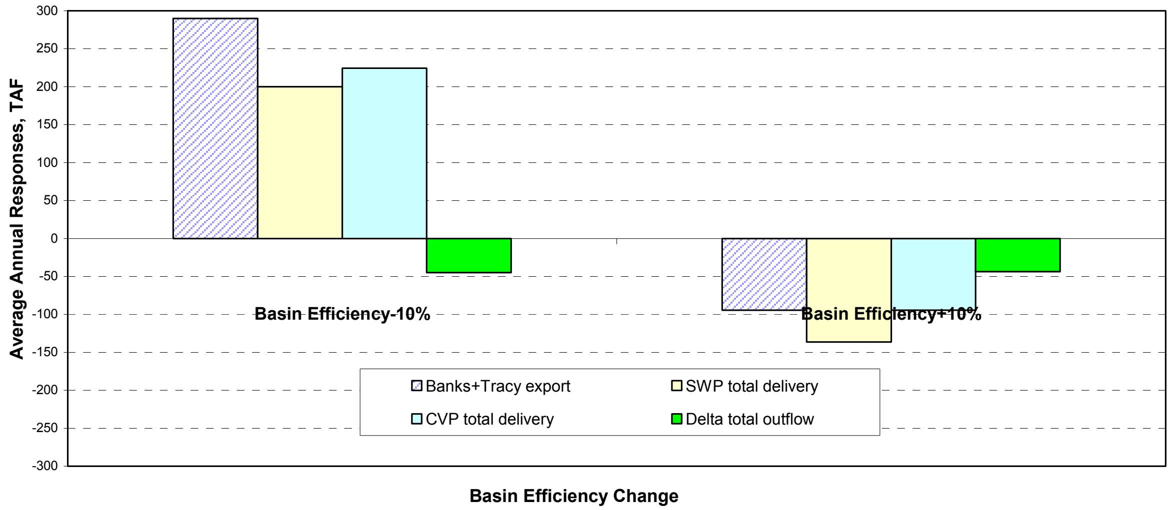


Figure A-40
Responses of Average Annual Export and Delivery Components to Basin Efficiency Change, WY 1929-1934

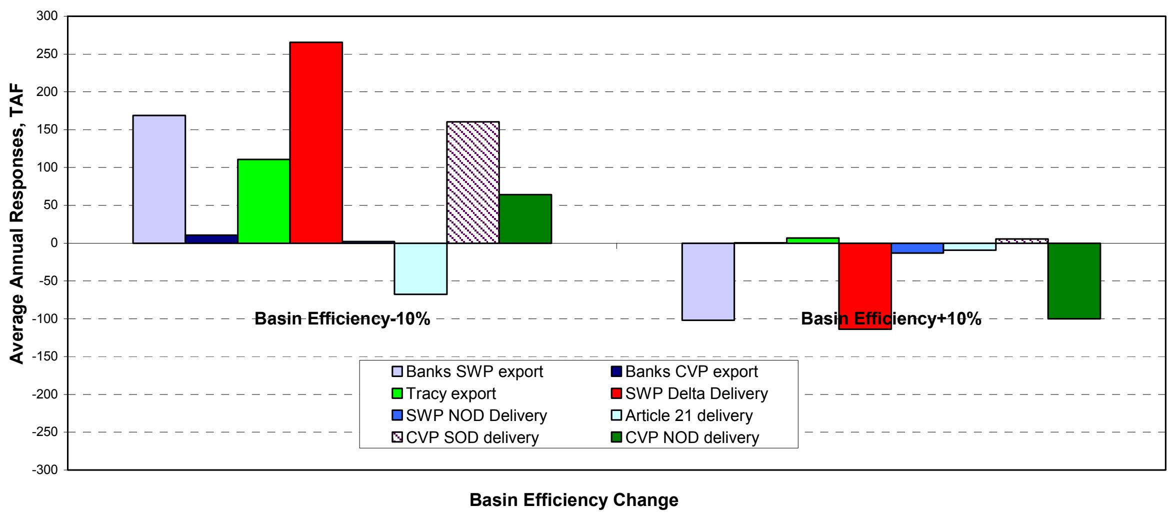


Figure A-41
Responses of Average Annual Export, Delivery and Delta Outflow to Deep Percolation of Applied Water Change, WY 1922-1994

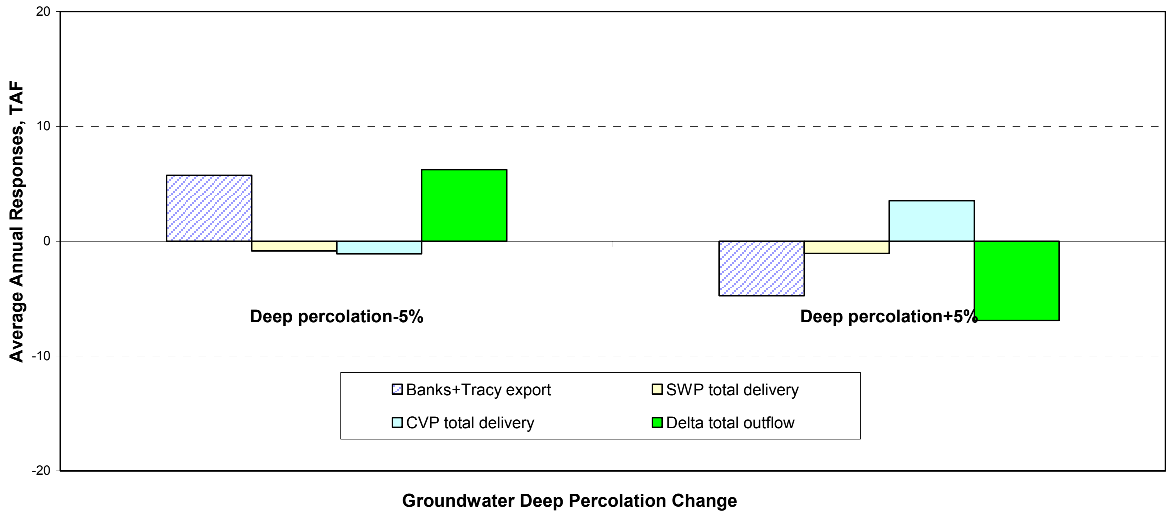


Figure A-42
Responses of Average Annual Export and Delivery Components to Deep Percolation of Applied Water Change, WY 1922-1994

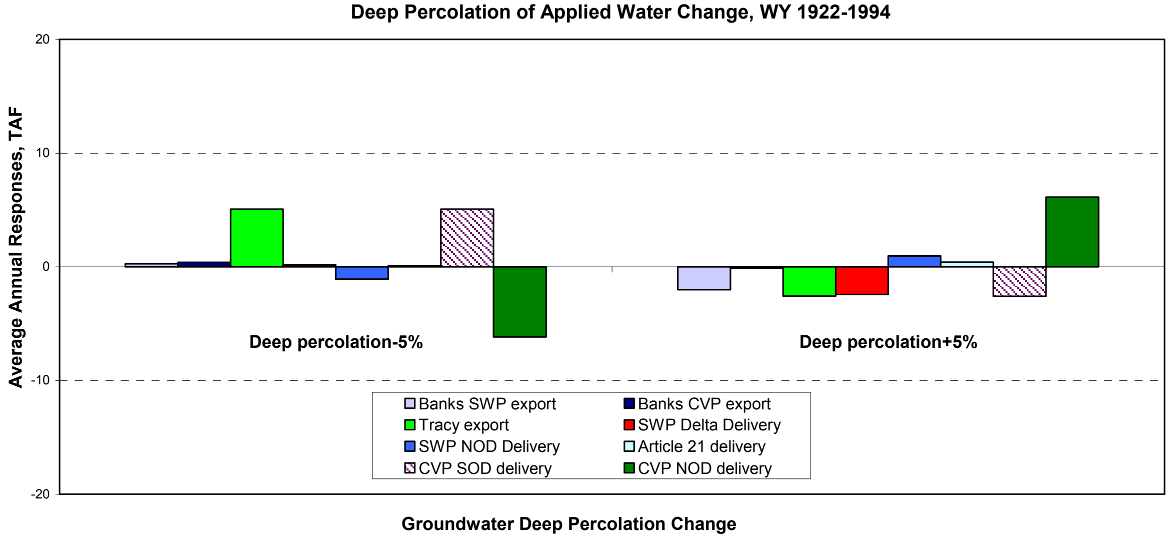


Figure A-43
Responses of Average Annual Export, Delivery and Delta Outflow to Deep Percolation of Applied Water Change, WY 1929-1934

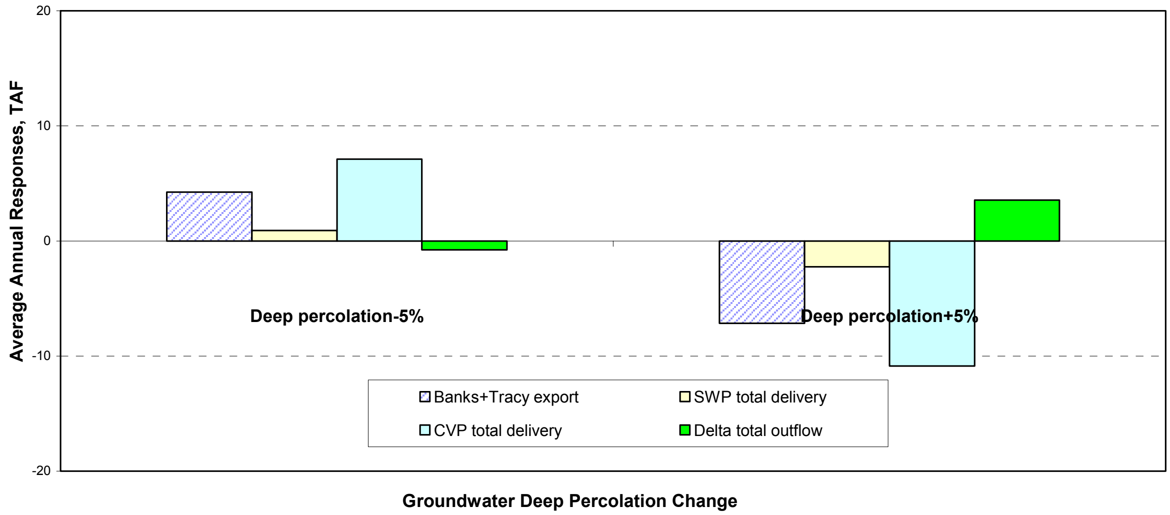


Figure A-44
Responses of Average Annual Export and Delivery Components to Deep Percolation of Applied Water Change, WY 1929-1934

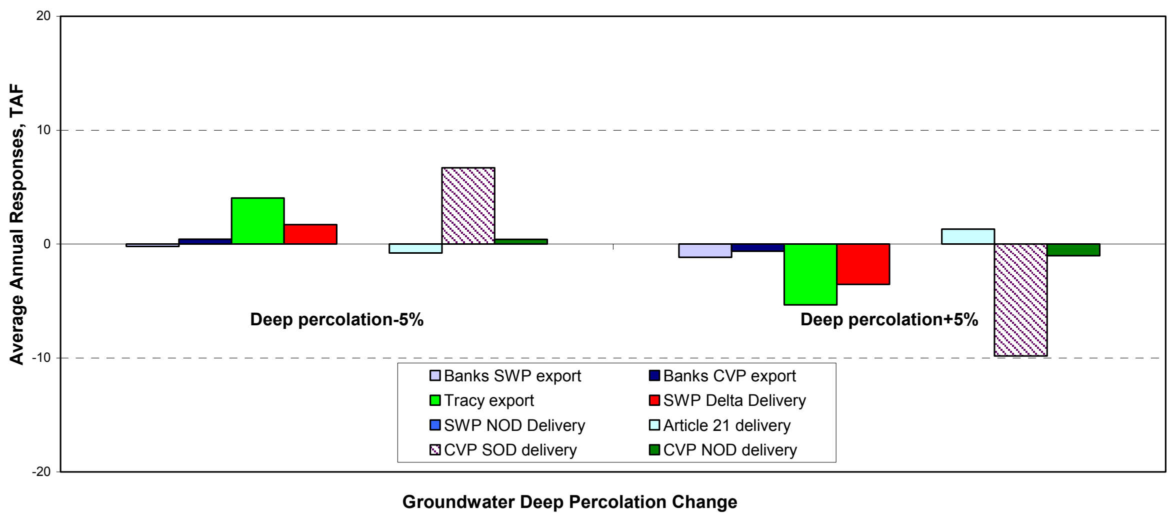


Figure A-45
Responses of Average Annual Export, Delivery and Delta Outflow to Outdoor M&I Demands Change, WY 1922-1994

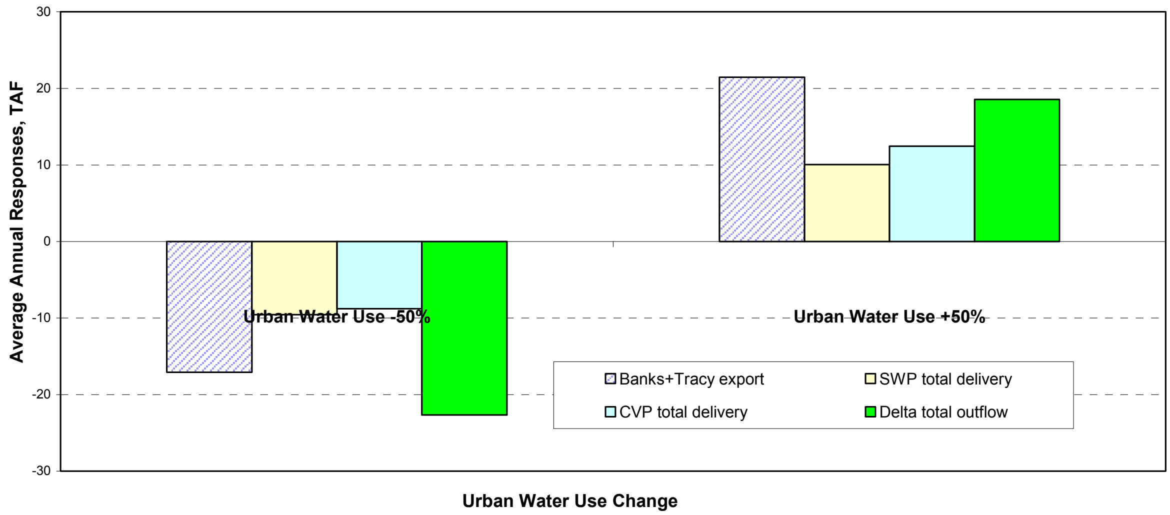


Figure A-46
Responses of Average Annual Export and Delivery Components to Outdoor M&I Demands Change, WY 1922-1994

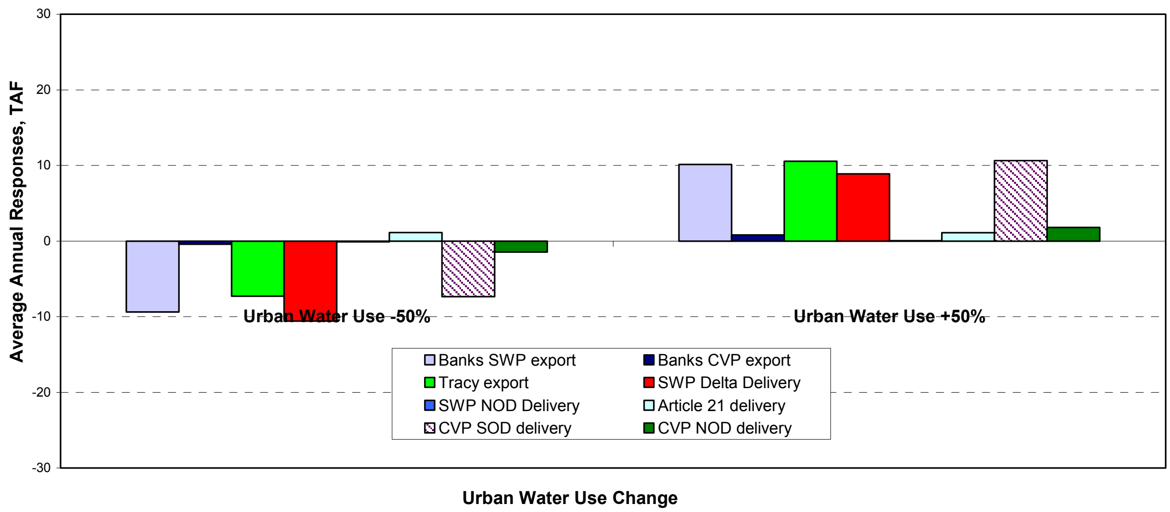


Figure A-47
Responses of Average Annual Export, Delivery and Delta Outflow to Outdoor M&I Demands Change, WY 1929-1934

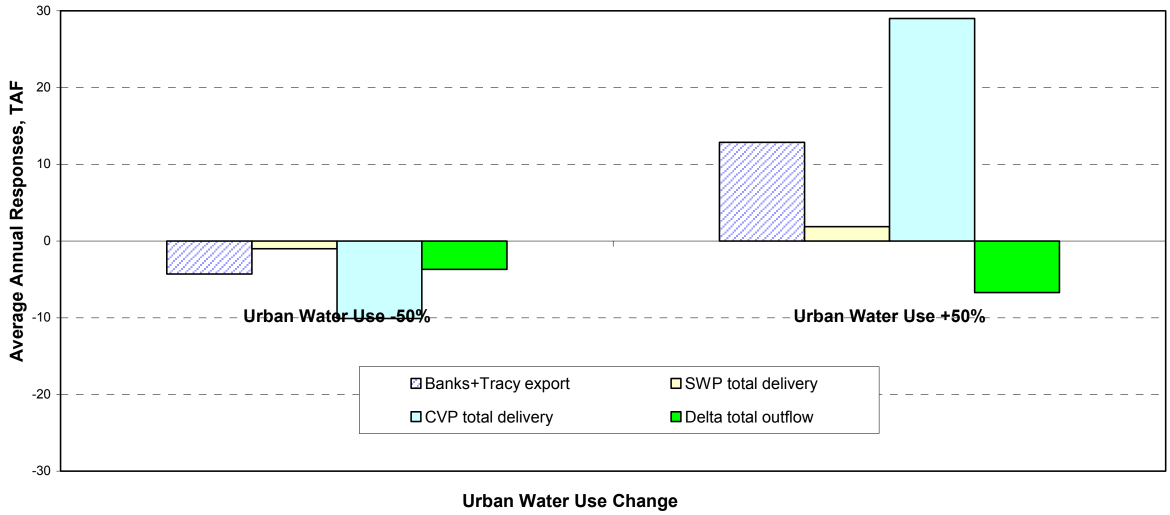


Figure A-48
Responses of Average Annual Export and Delivery Components to Outdoor M&I Demands Change, WY 1929-1934

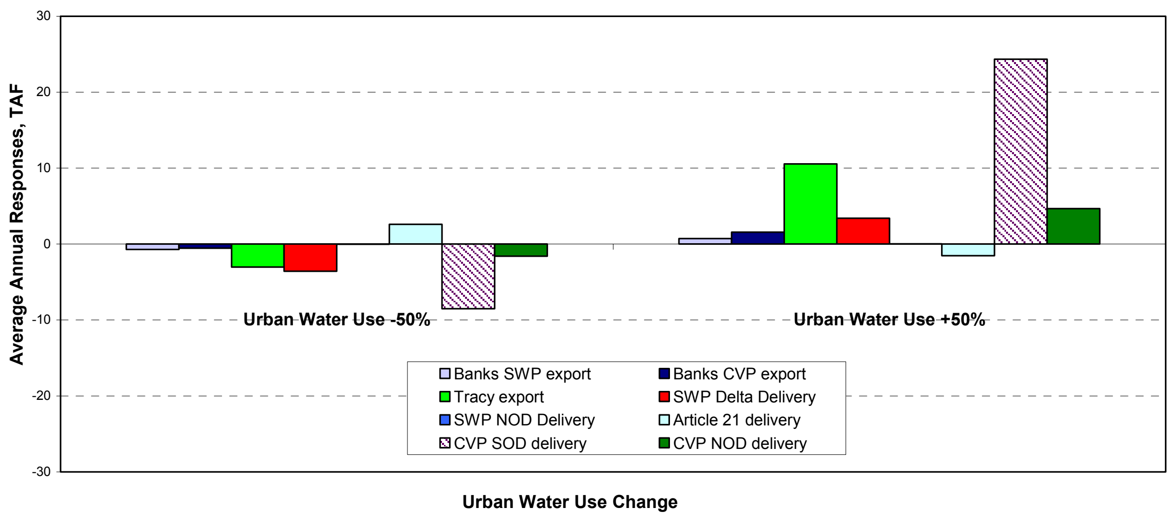


Figure A-49
Responses of Average Annual Export, Delivery and Delta Outflow to Minimal Groundwater Pumping Change, WY 1922-1994

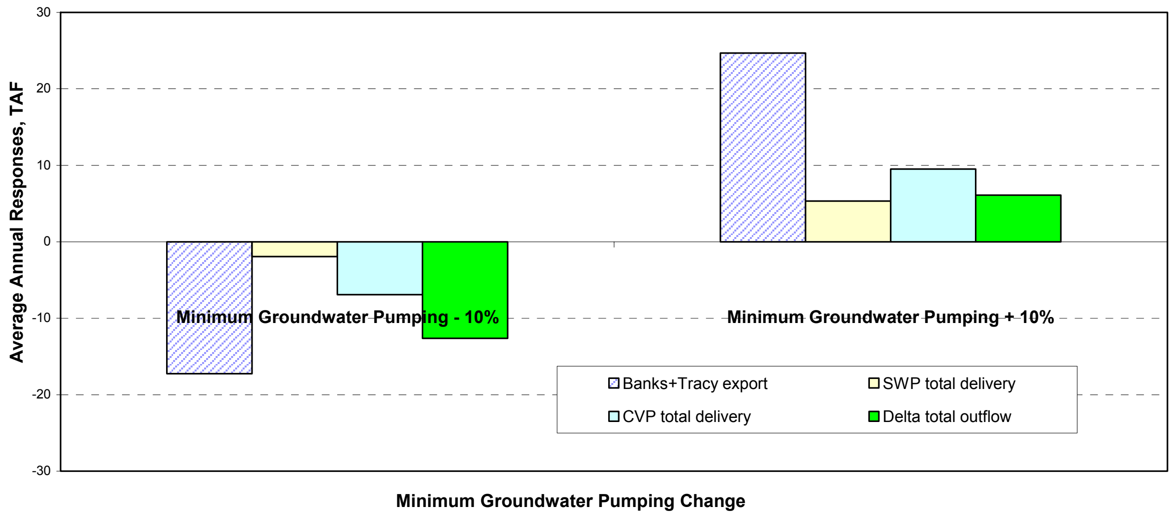


Figure A-50
Responses of Average Annual Export and Delivery Components to Minimal Groundwater Pumping Change, WY 1922-1994

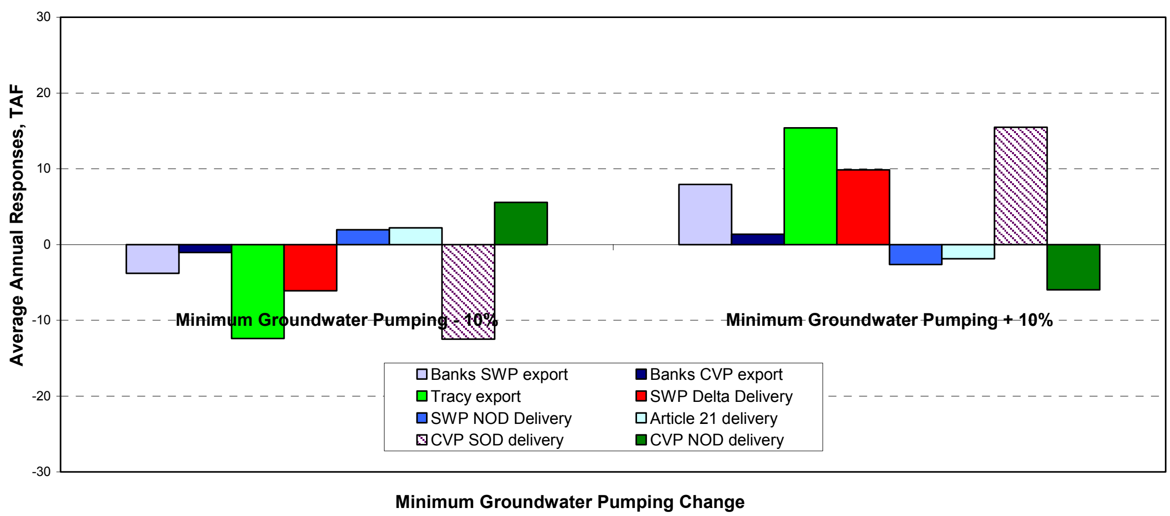


Figure A-51
Responses of Average Annual Export, Delivery and Delta Outflow to Minimal Groundwater Pumping Change, WY 1929-1934

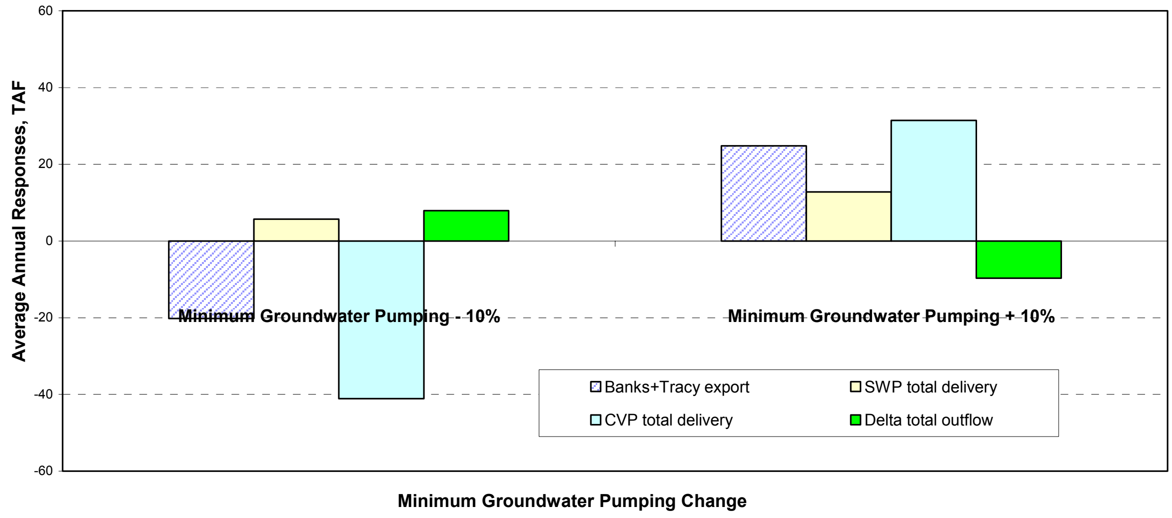


Figure A-52
Responses of Average Annual Export and Delivery Components to Minimal Groundwater Pumping Change, WY 1929-1934

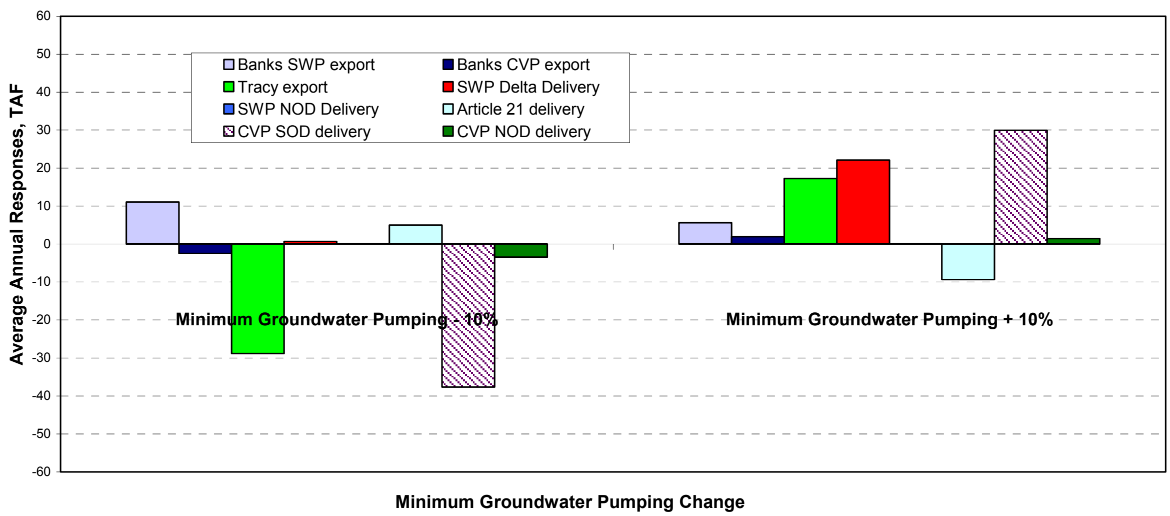


Figure A-53
Responses of Average Annual Export, Delivery and Delta Outflow to Project Non-project Split Change, WY 1922-1994

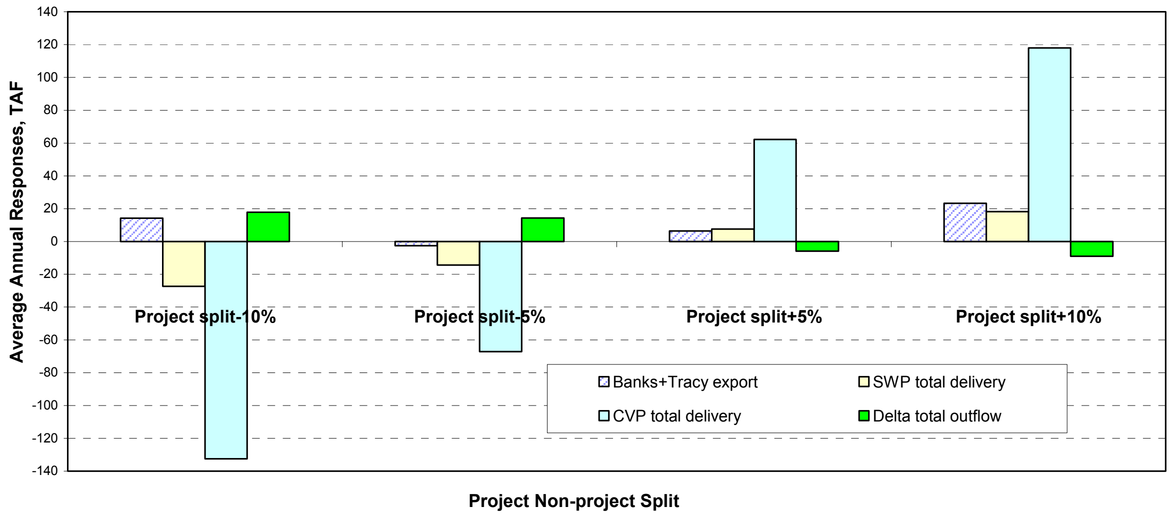


Figure A-54
Responses of Average Annual Export and Delivery Components to Project Non-project Split Change, WY 1922-1994

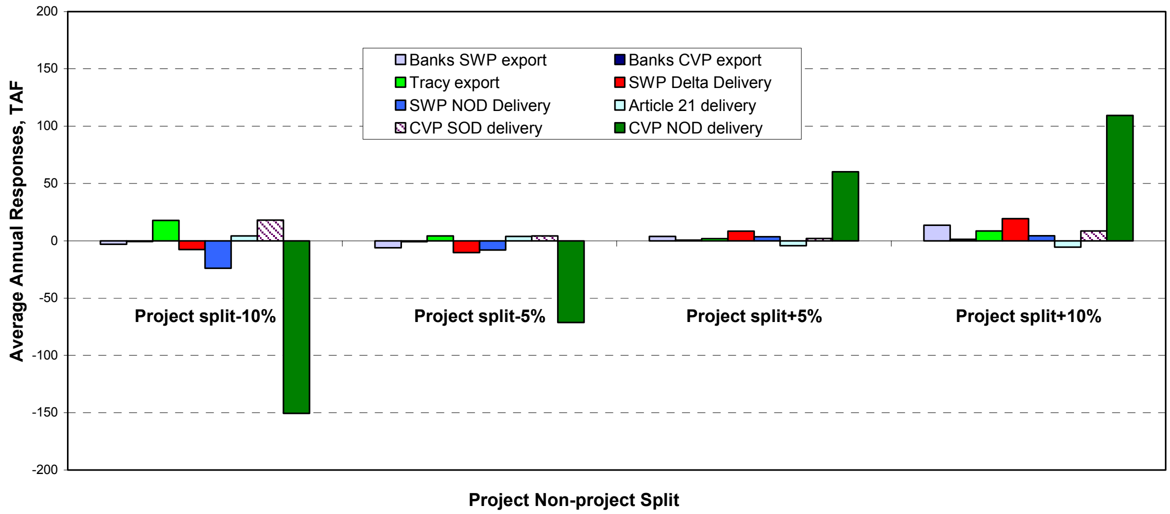


Figure A-55
Responses of Average Annual Export, Delivery and Delta Outflow to Project Non-project Split Change, WY 1929-1934

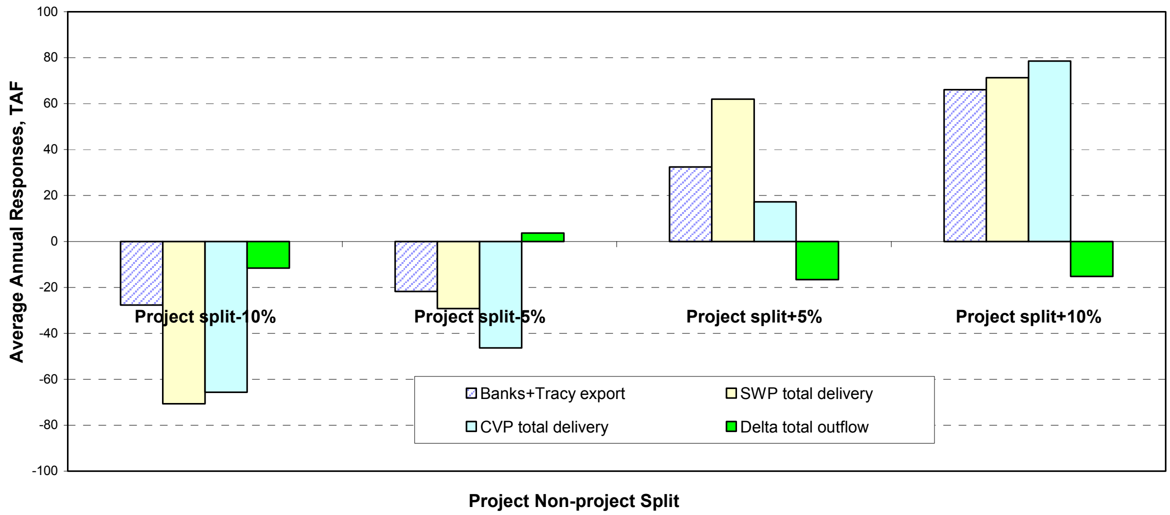


Figure A-56
Responses of Average Annual Export and Delivery Components to Project Non-project Split Change, WY 1929-1934

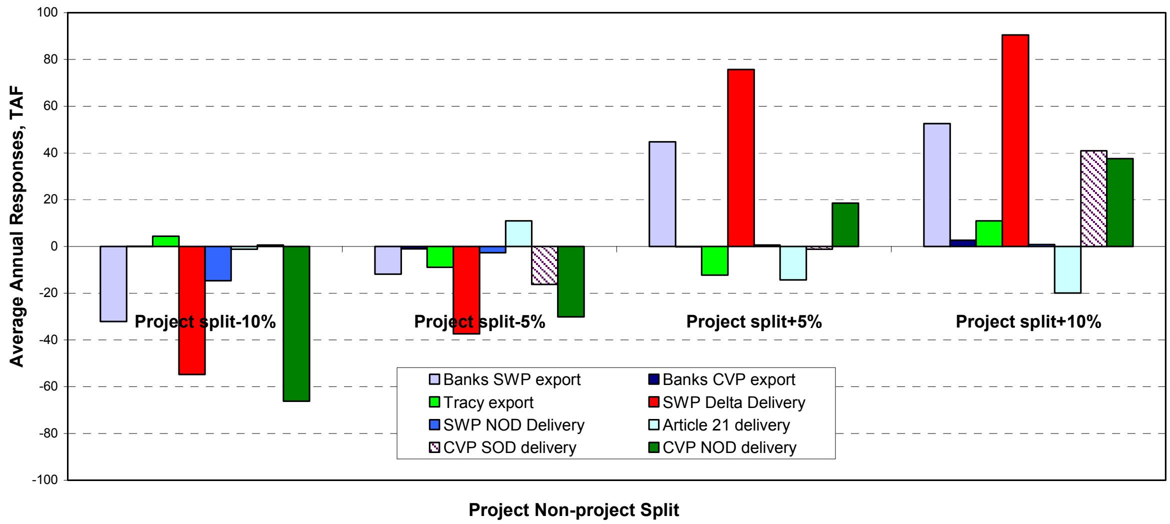


Figure A-57
Responses of Average Annual Export, Delivery and Delta Outflow to SWP Delivery - Carryover Curve Change, WY 1922-1994

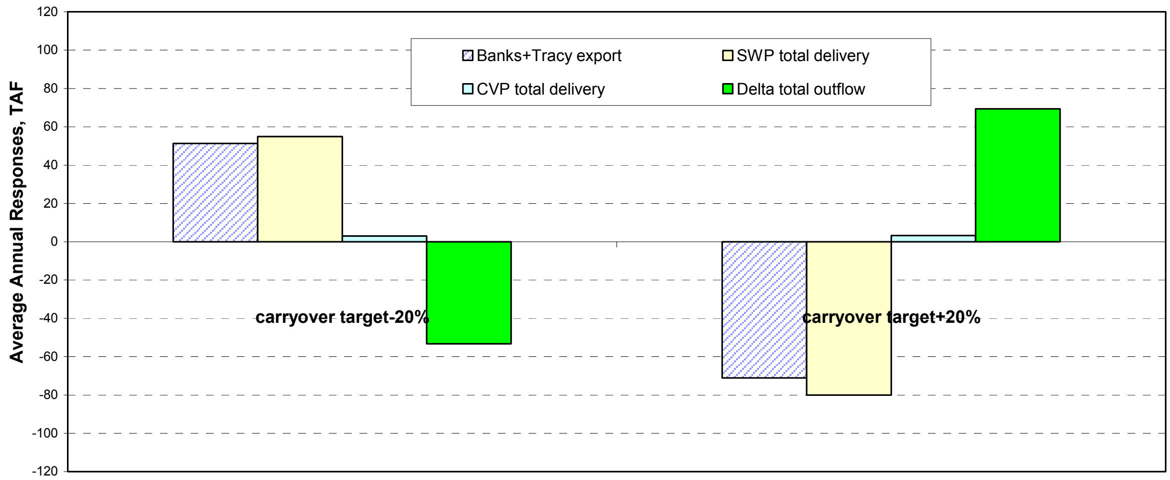


Figure A-58
Responses of Average Annual Export and Delivery Components to SWP Delivery - Carryover Curve Change, WY 1922-1994

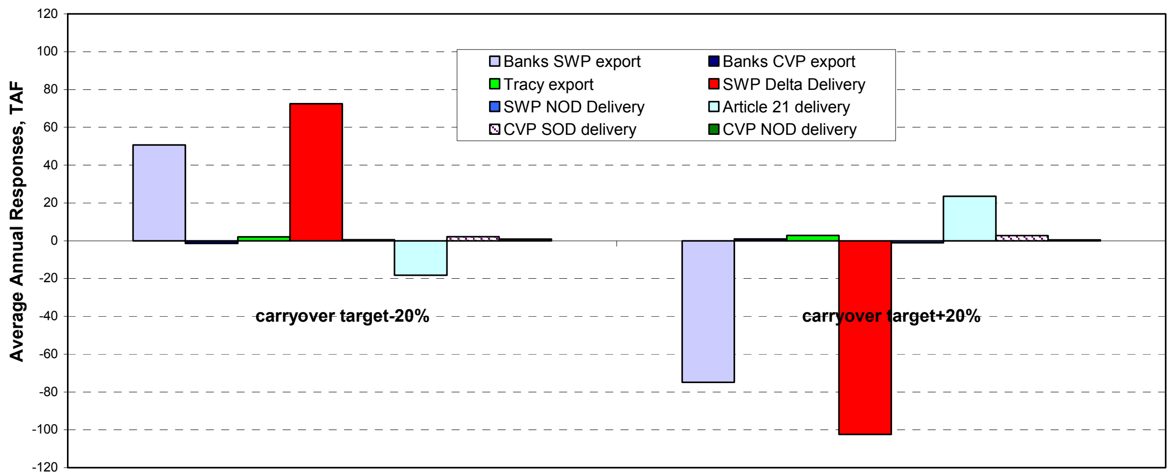


Figure A-59
Responses of Average Annual Export, Delivery and Delta Outflow to SWP Delivery - Carryover Curve Change, WY 1929-1934

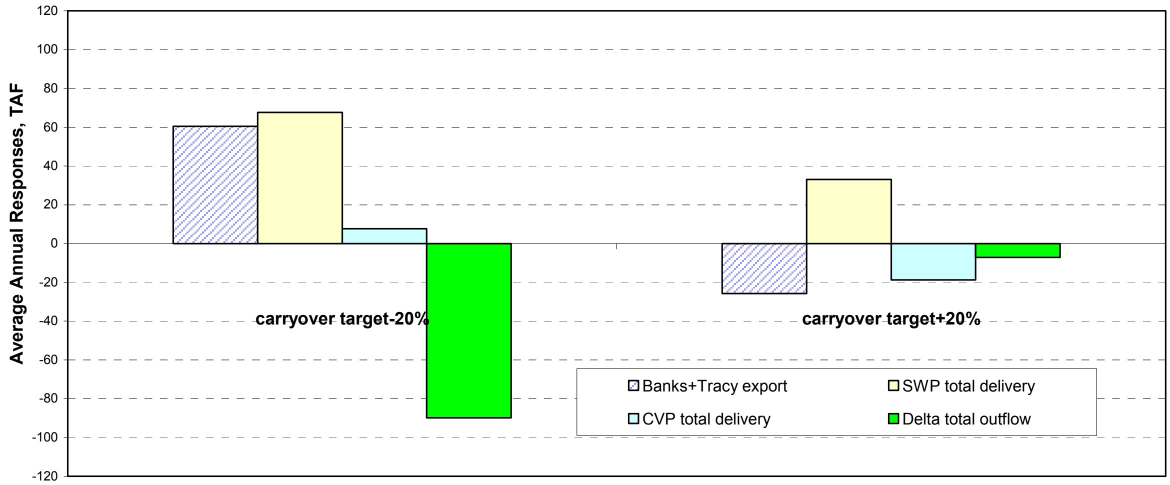


Figure A-60
Responses of Average Annual Export and Delivery Components to SWP Delivery - Carryover Curve Change, WY 1929-1934

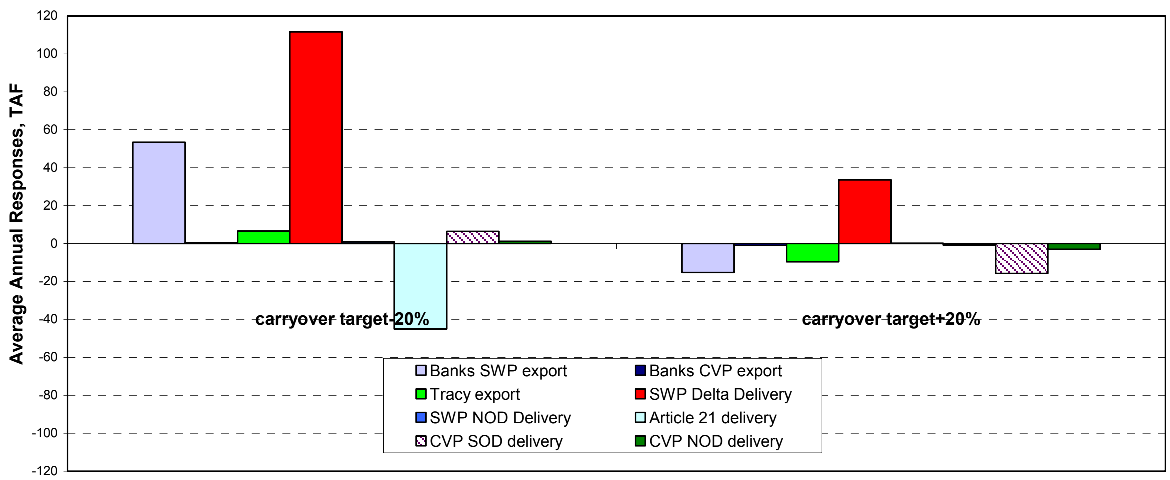


Figure A-61
Responses of Average Annual Export, Delivery and Delta Outflow to SWP San Luis Rule Curve Change, WY 1922-1994

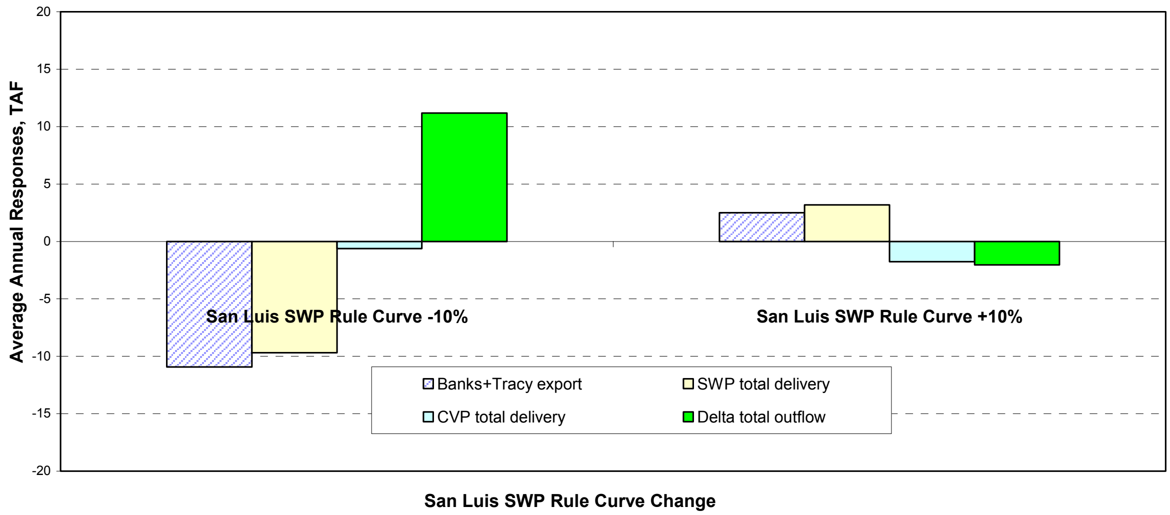


Figure A-62
Responses of Average Annual Export and Delivery Components to SWP San Luis Rule Curve Change, WY 1922-1994

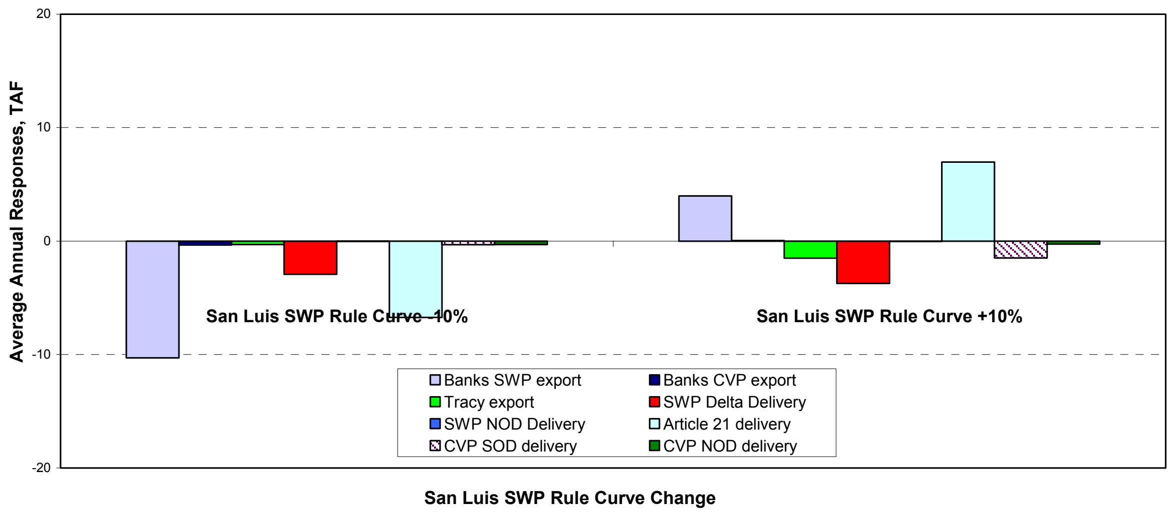


Figure A-63
Responses of Average Annual Export, Delivery and Delta Outflow to SWP San Luis Rule Curve Change, WY 1929-1934

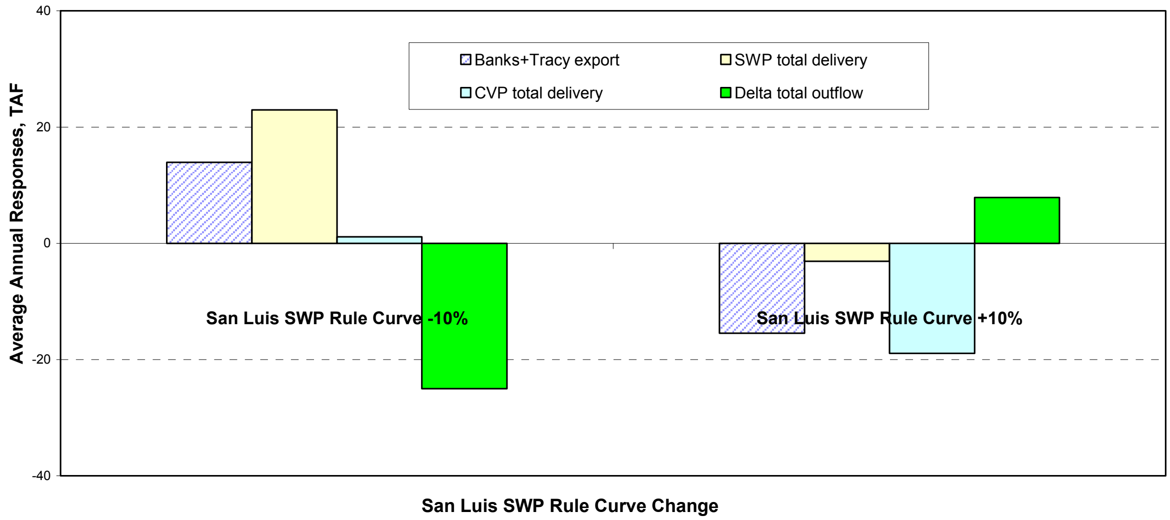


Figure A-64
Responses of Average Annual Export and Delivery Components to SWP San Luis Rule Curve Change, WY 1929-1934

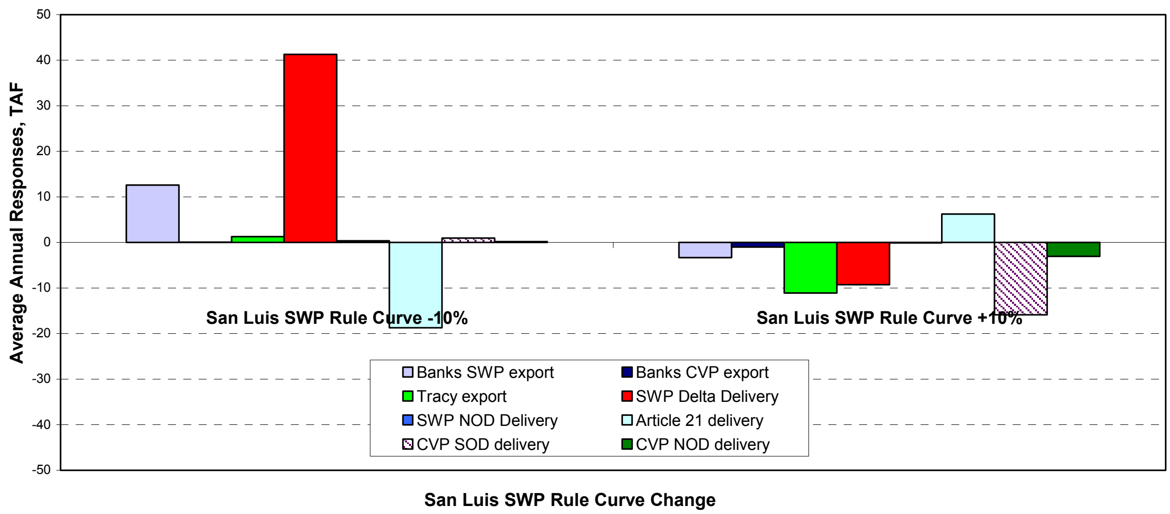


Figure A-65
Responses of Average Annual Export, Delivery and Delta Outflow to SWP Table A Demand Change, WY 1922-1994

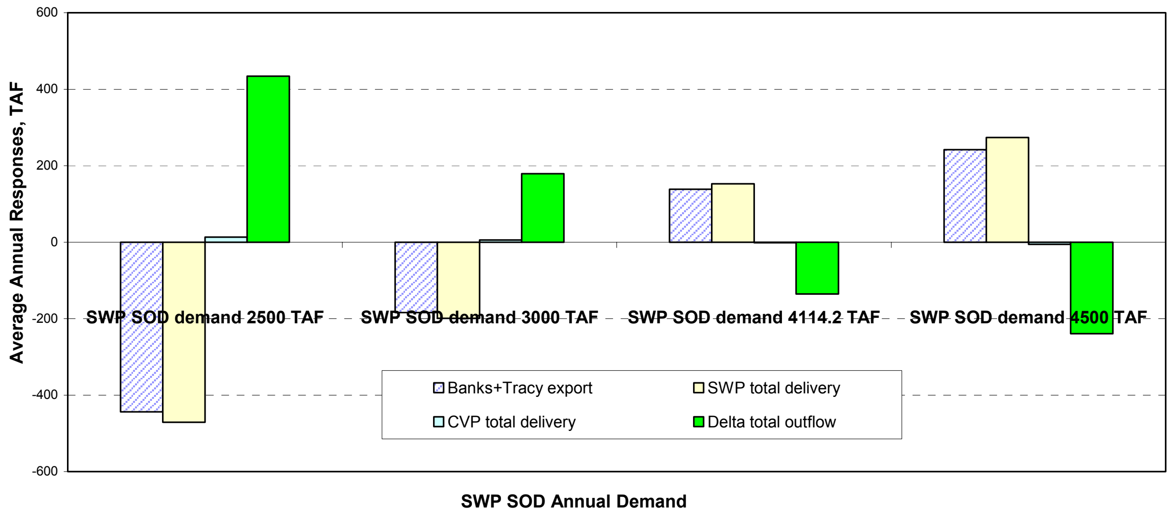


Figure A-66
Responses of Average Annual Export and Delivery Components to SWP Table A Demand Change, WY 1922-1994

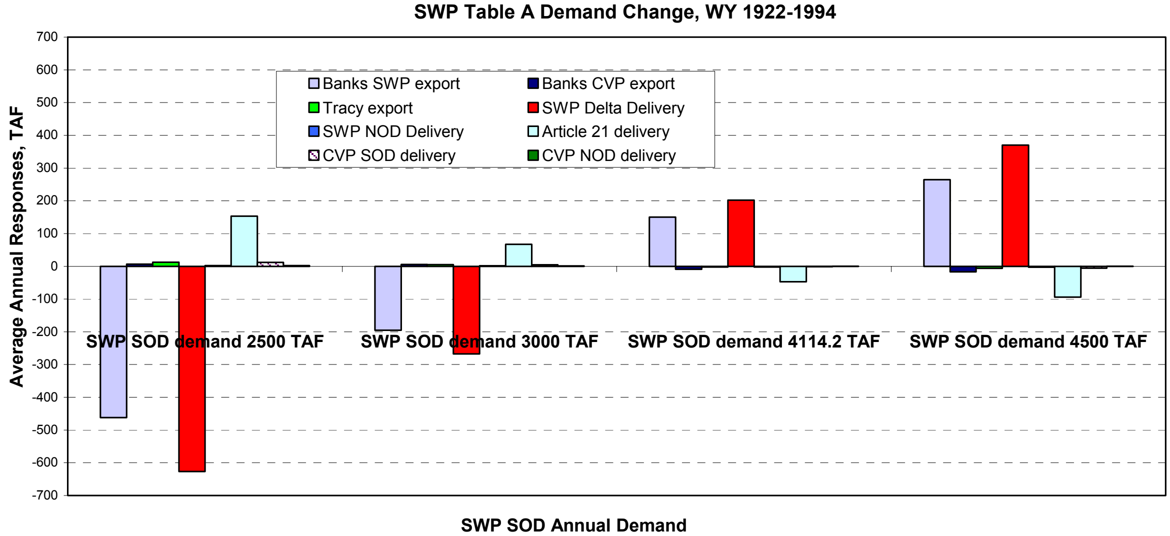


Figure A-67
Responses of Average Annual Export, Delivery and Delta Outflow to SWP Table A Demand Change, WY 1929-1934

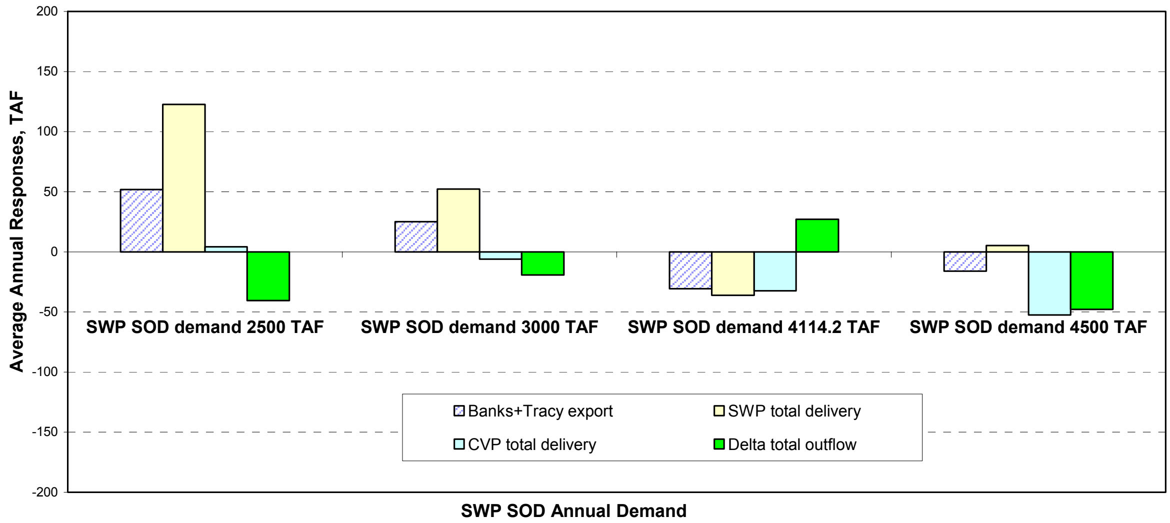


Figure A-68
Responses of Average Annual Export and Delivery Components to SWP Table A Demand Change, WY 1929-1934

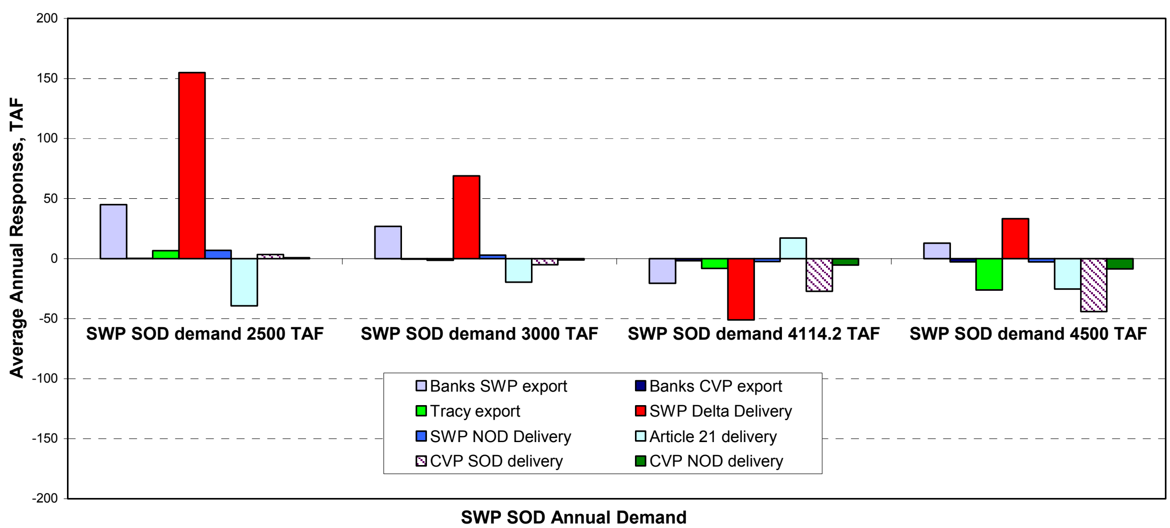
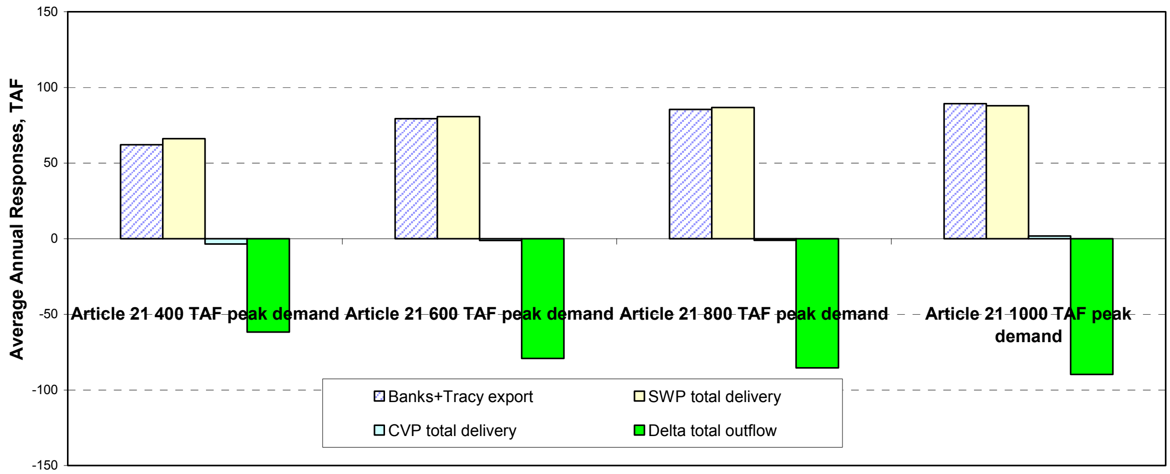
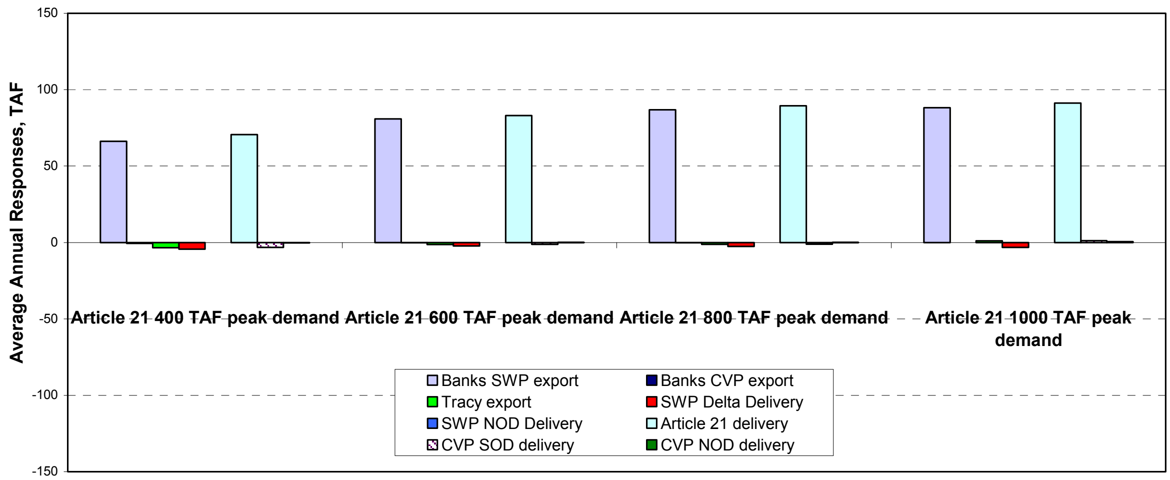


Figure A-69
Responses of Average Annual Export, Delivery and Delta Outflow to Aricle 21 Water Demand Change, WY 1922-1994



Article 21 peak monthly demand

Figure A-70
Responses of Average Annual Export and Delivery Components to Aricle 21 Water Demand Change, WY 1922-1994



Article 21 peak monthly demand

Figure A-71
Responses of Average Annual Export, Delivery and Delta Outflow to Aricle 21 Water Demand Change, WY 1929-1934

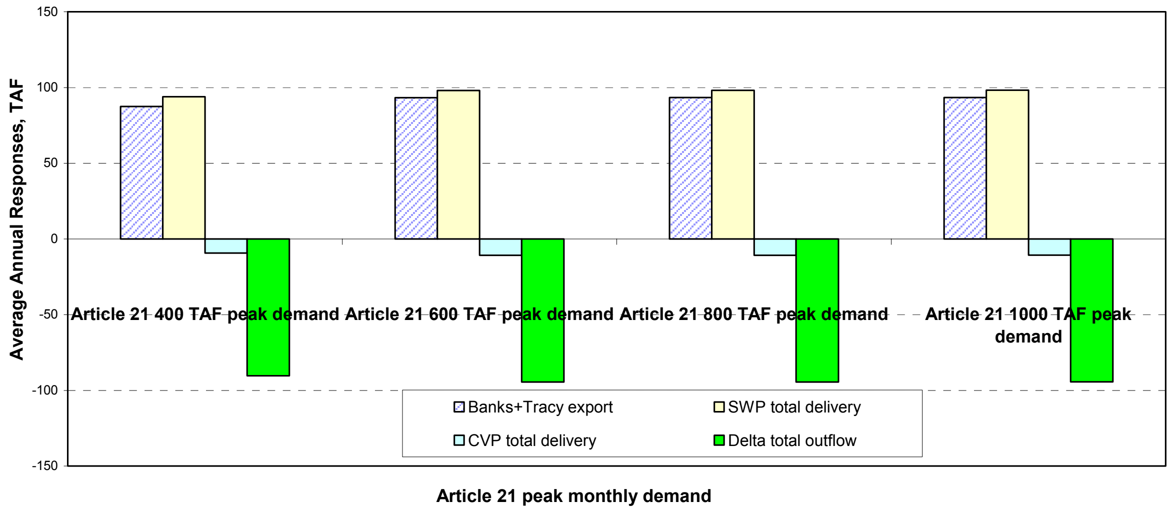


Figure A-72
Responses of Average Annual Export and Delivery Components to Aricle 21 Water Demand Change, WY 1929-1934

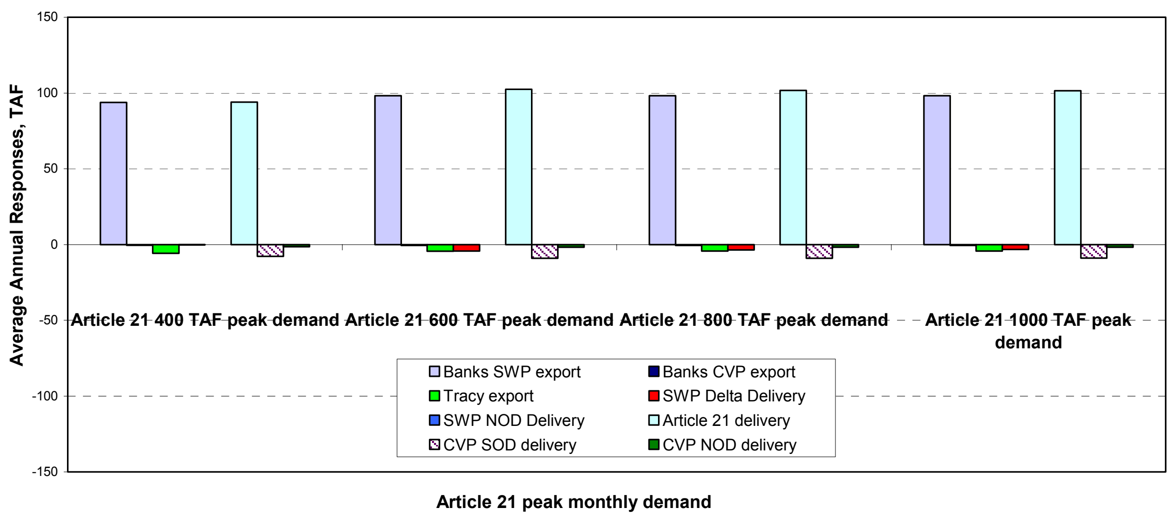


Figure A-73
Responses of Average Annual Export, Delivery and Delta Outflow to ANN Change, WY 1922-1994

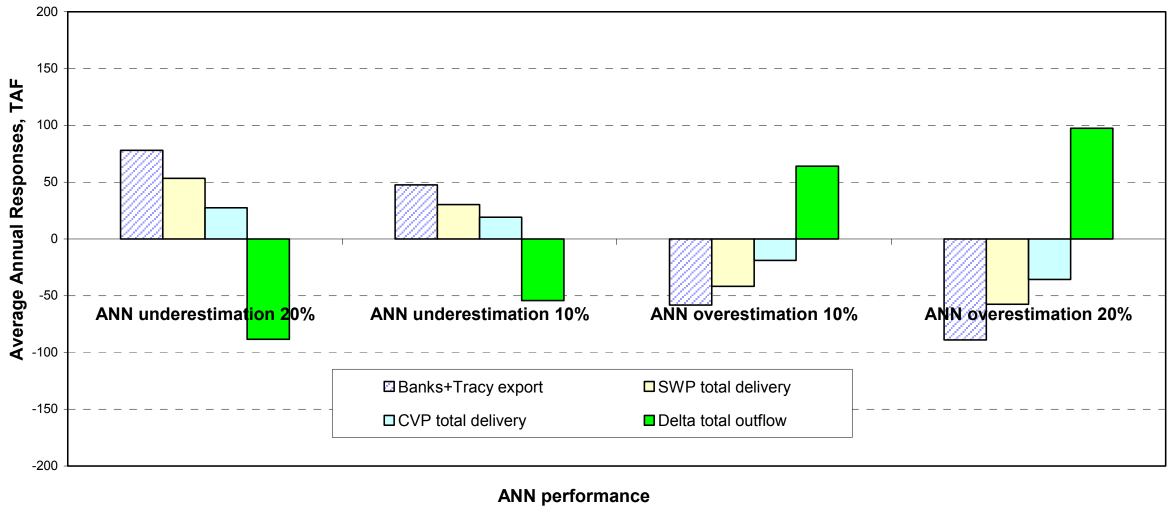


Figure A-74
Responses of Average Annual Export and Delivery Components to ANN Change, WY 1922-1994

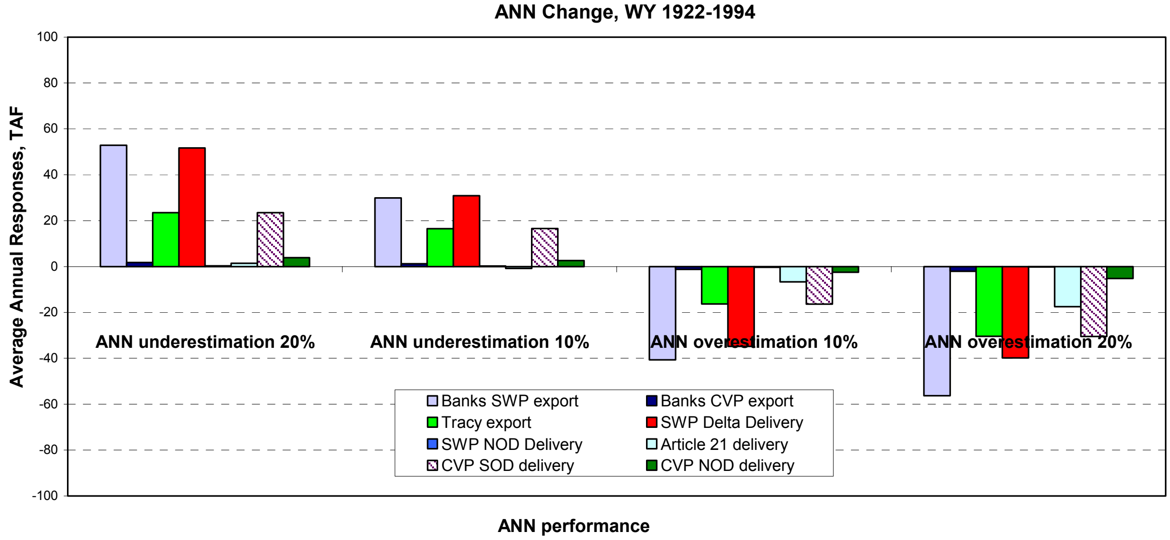


Figure A-75
Responses of Average Annual Export, Delivery and Delta Outflow to ANN Change, WY 1929-1934

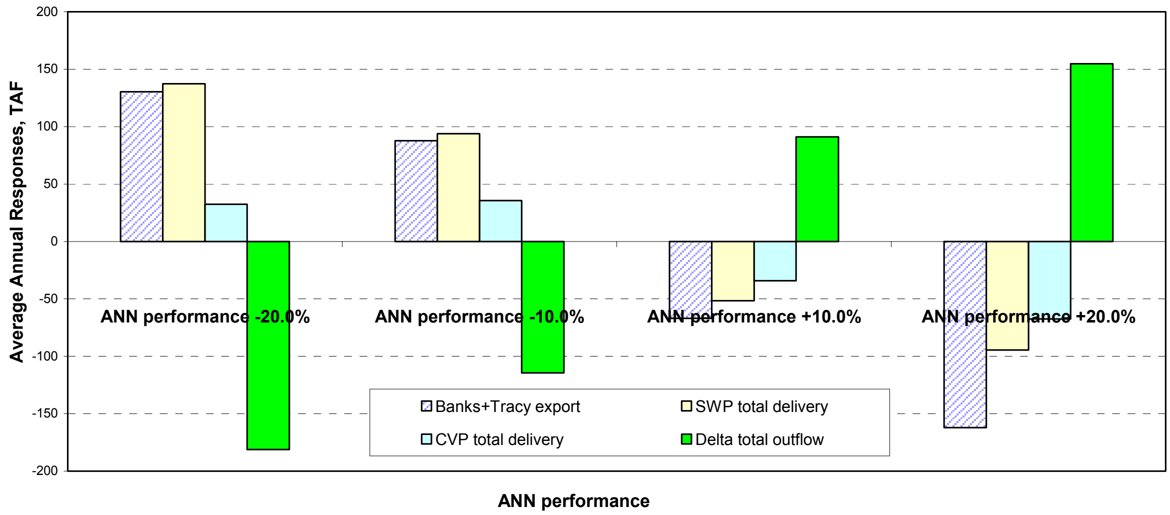


Figure A-76
Responses of Average Annual Export and Delivery Components to ANN Change, WY 1929-1934

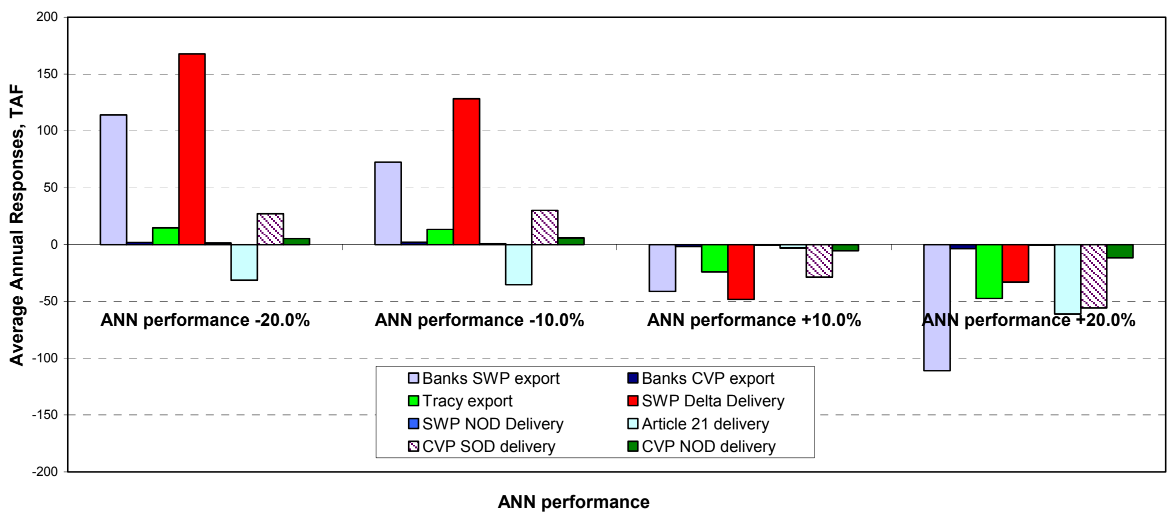


Figure A-77
Responses of Average Annual Export, Delivery and Delta Outflow to X2 Standard Change, WY 1922-1994

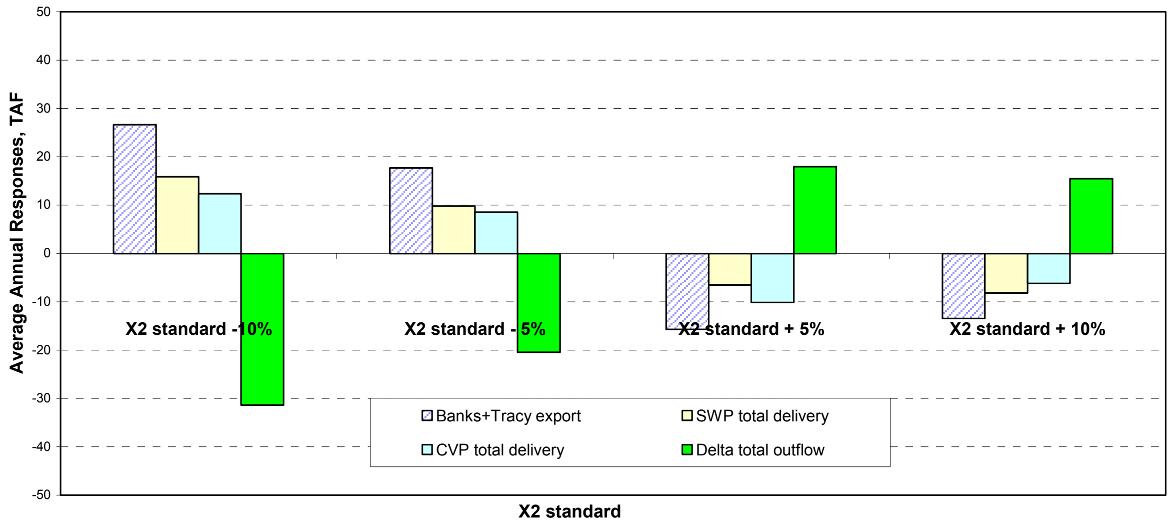


Figure A-78
Responses of Average Annual Export and Delivery Components to X2 Standard Change, WY 1922-1994

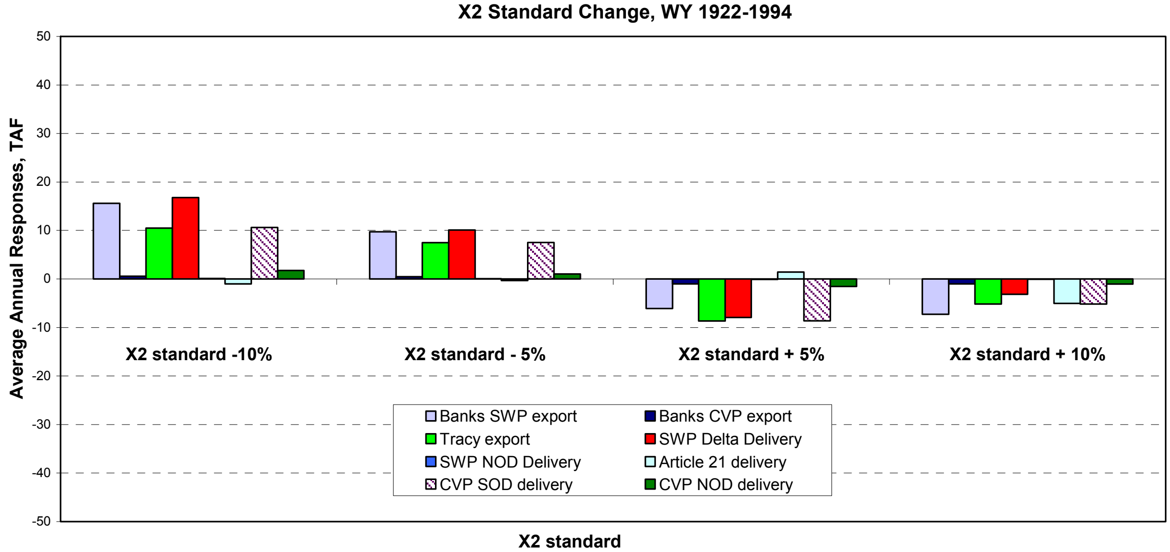


Figure A-79
Responses of Average Annual Export, Delivery and Delta Outflow to X2 Standard Change, WY 1929-1934

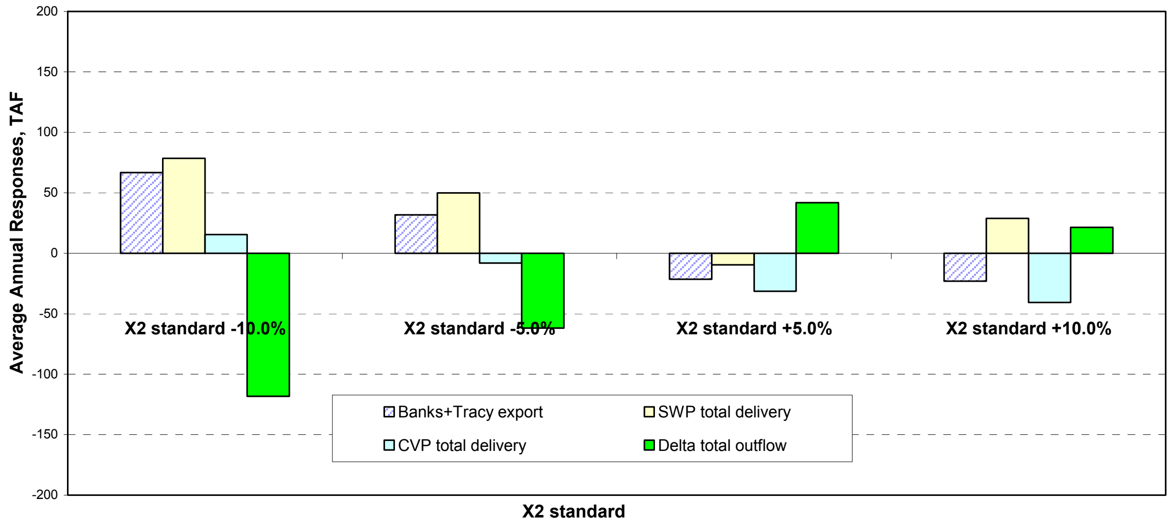


Figure A-80
Responses of Average Annual Export and Delivery Components to X2 Standard Change, WY 1929-1934

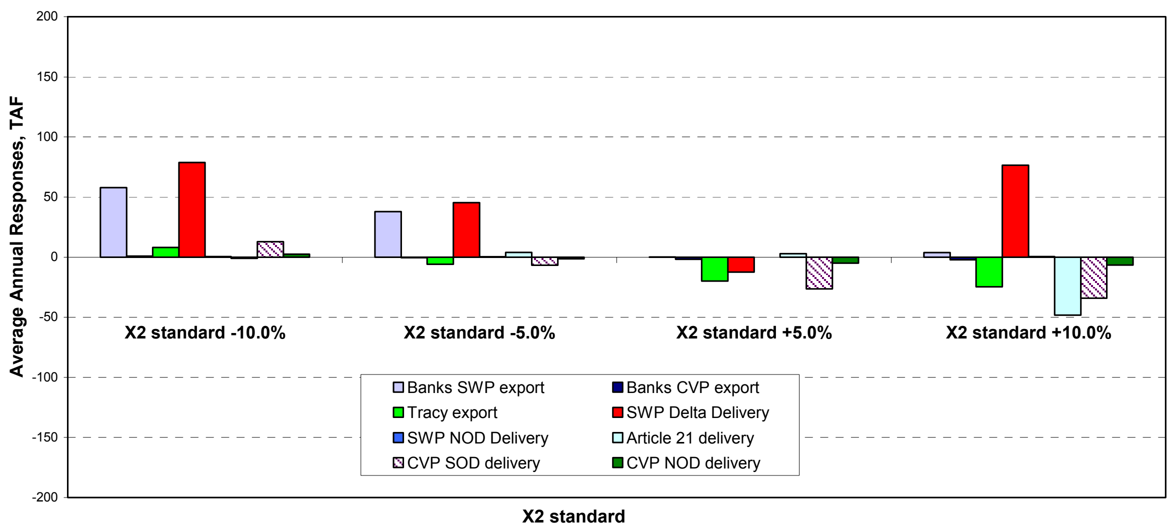


Figure A-81
Responses of Average Annual Export, Delivery and Delta Outflow to Banks Pumping Limit Change, WY 1922-1994

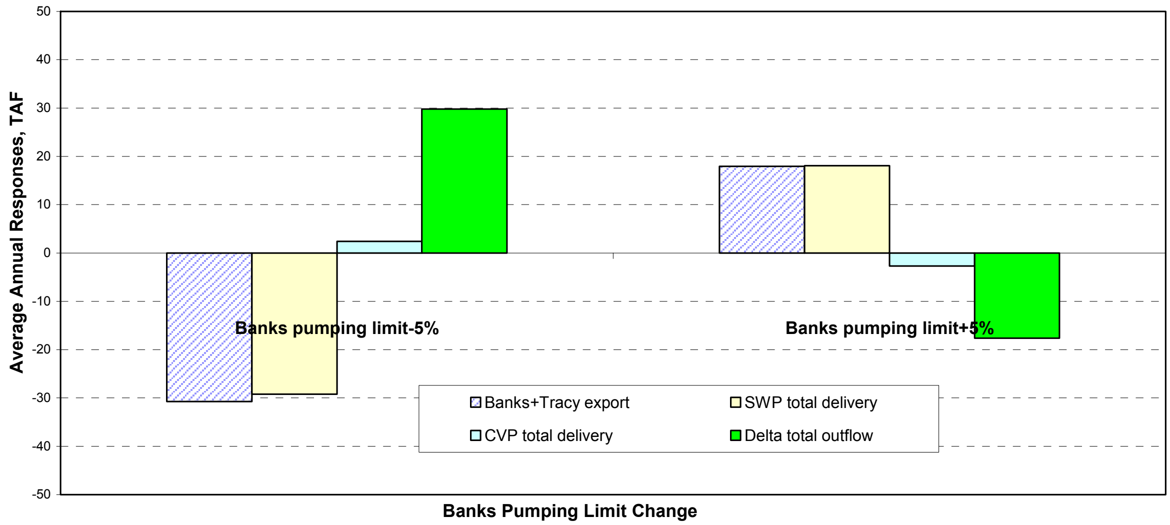


Figure A-82
Responses of Average Annual Export and Delivery Components to Banks Pumping Limit Change, WY 1922-1994

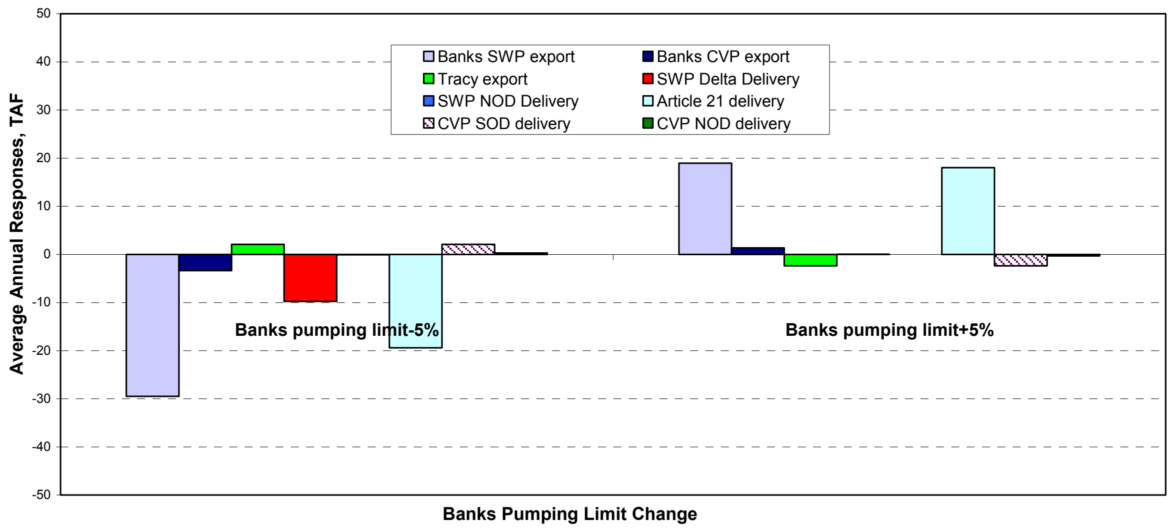


Figure A-83
Responses of Average Annual Export, Delivery and Delta Outflow to Banks Pumping Limit Change, WY 1929-1934

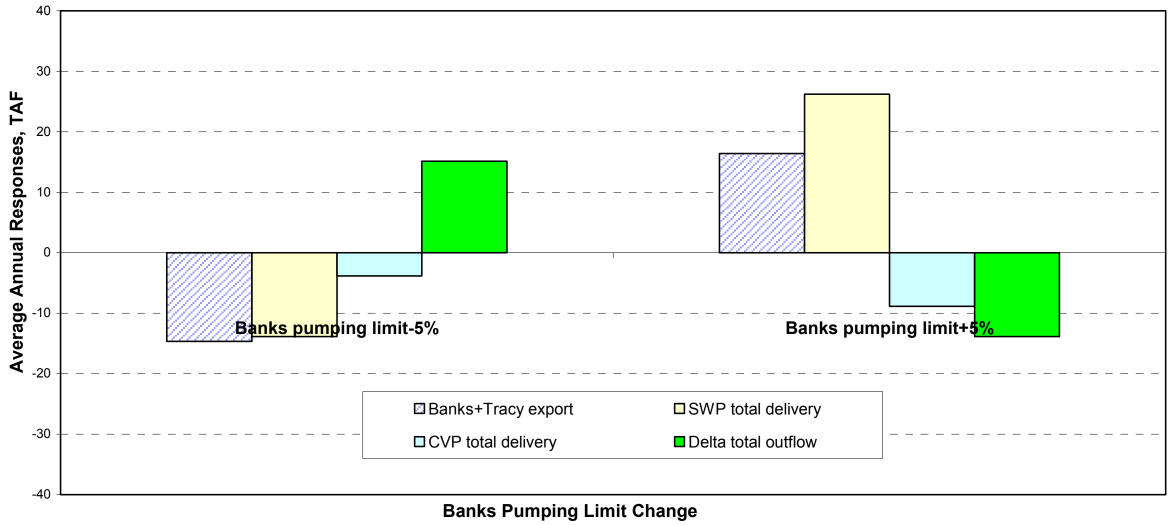


Figure A-84
Responses of Average Annual Export and Delivery Components to Banks Pumping Limit Change, WY 1929-1934

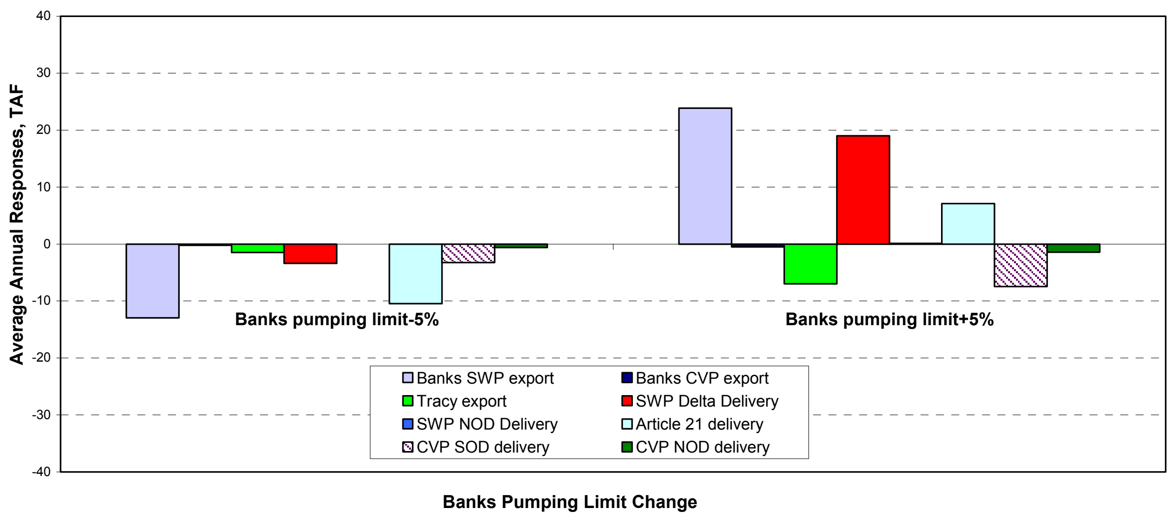


Figure A-85
Elasticity Index of SWP Total Delivery

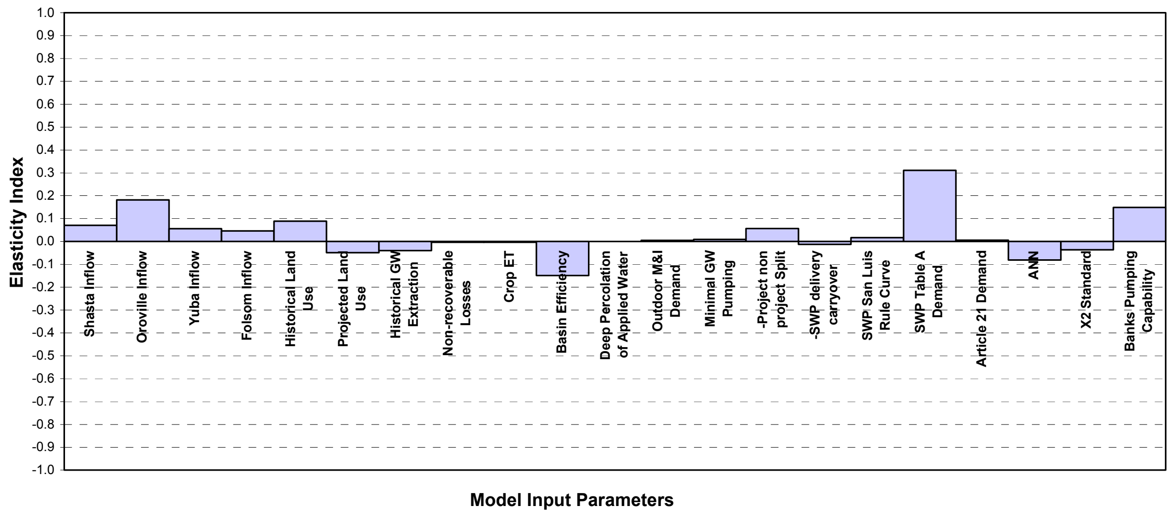


Figure A-86
Sensitivity Index of SWP Total Delivery

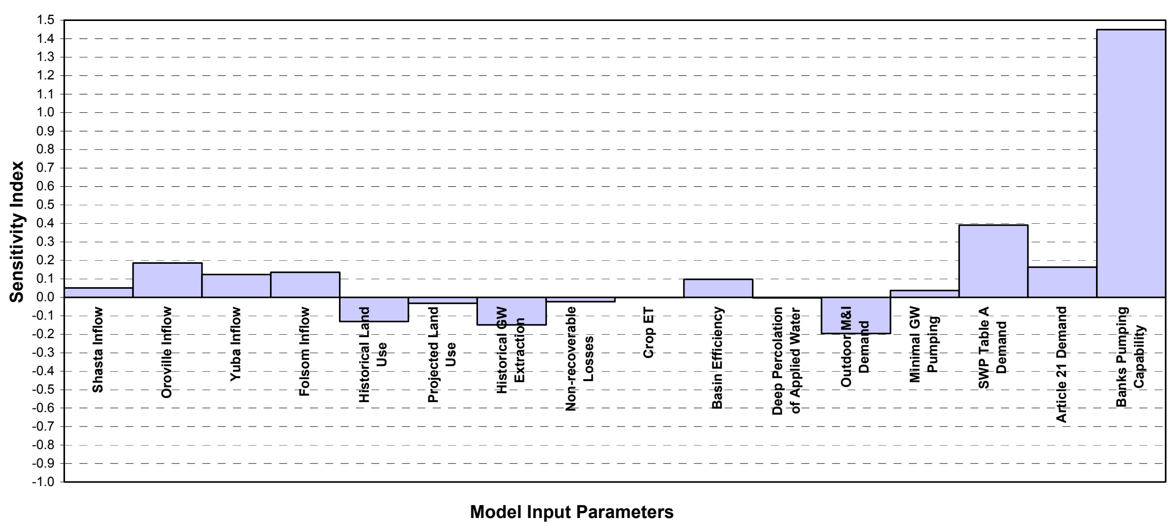


Figure A-87
Elasticity Index of CVP Total Delivery

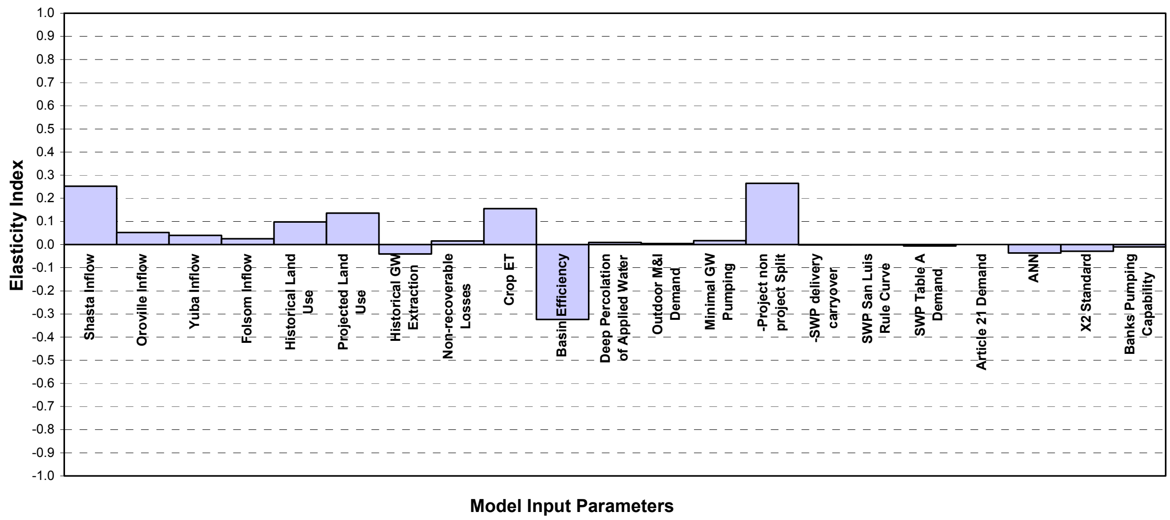


Figure A-88
Sensitivity Index of CVP Total Delivery

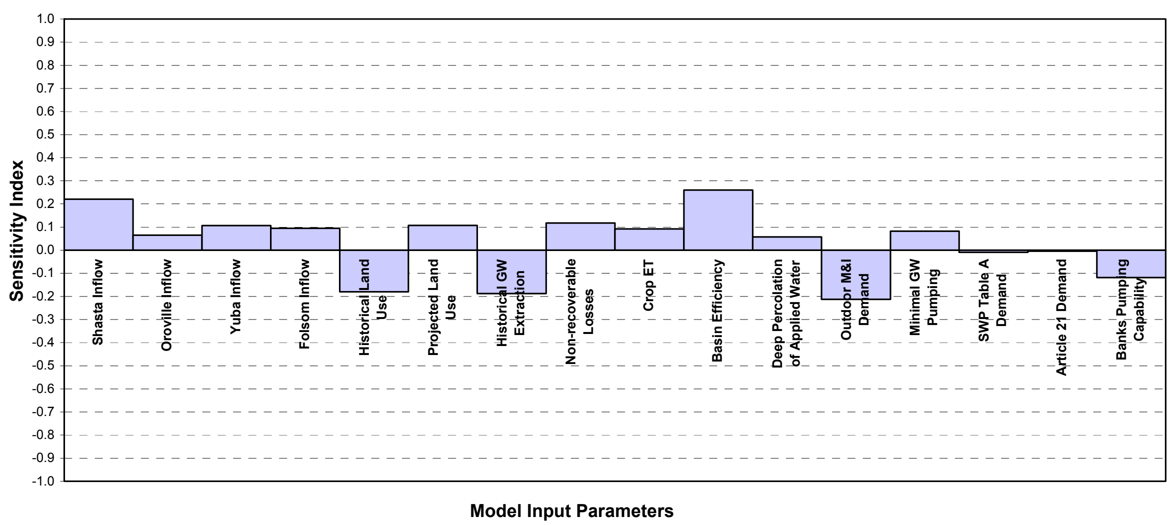


Figure A-89
Elasticity Index of SWP Delta Delivery

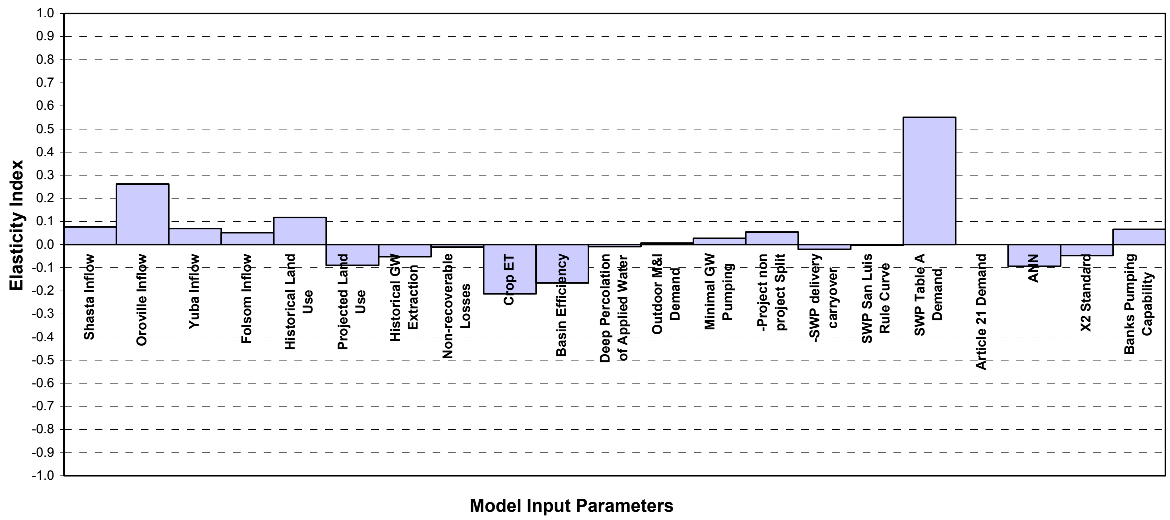


Figure A-90
Sensitivity Index of SWP Delta Delivery

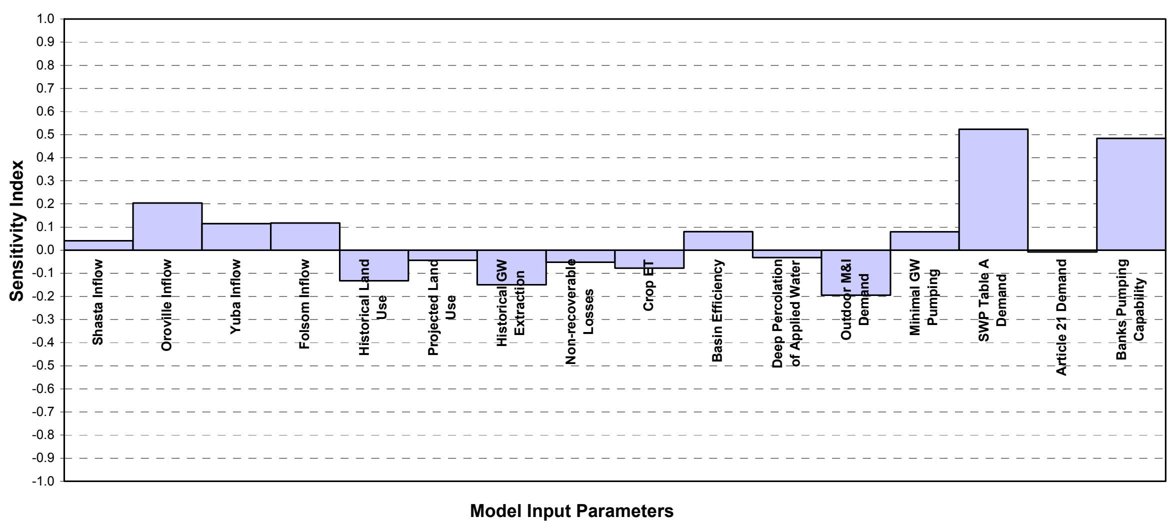


Figure A-91
Elasticity Index of SWP NOD Delivery

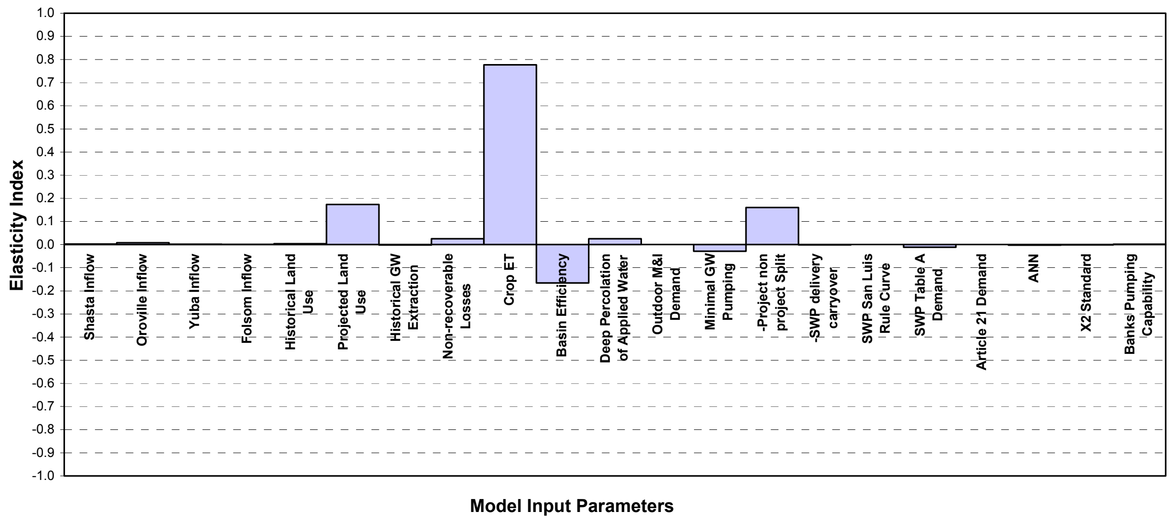


Figure A-92
Sensitivity Index of SWP NOD Delivery

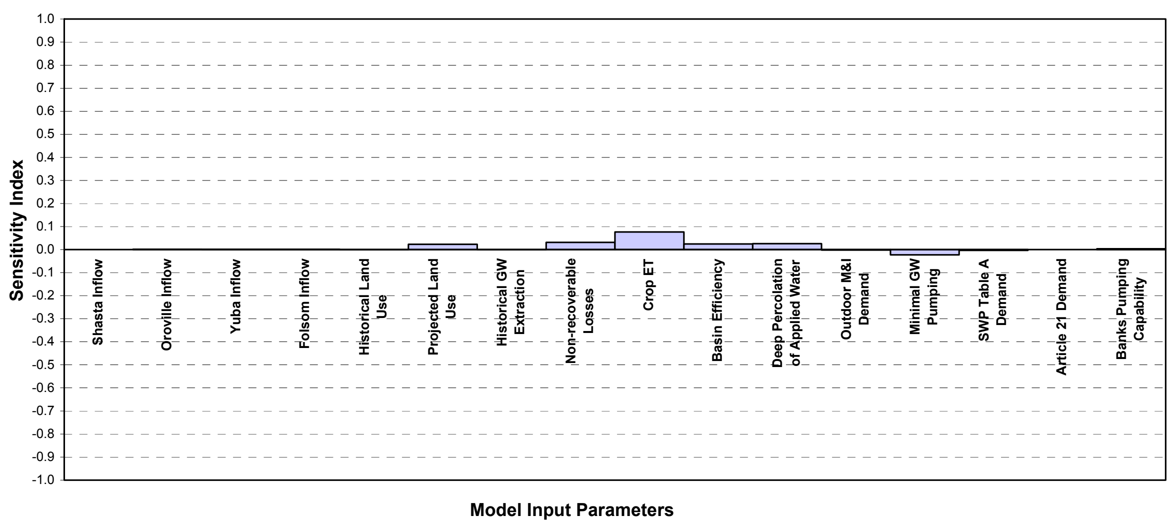


Figure A-93
Elasticity Index of Aricle 21 Water Delivery

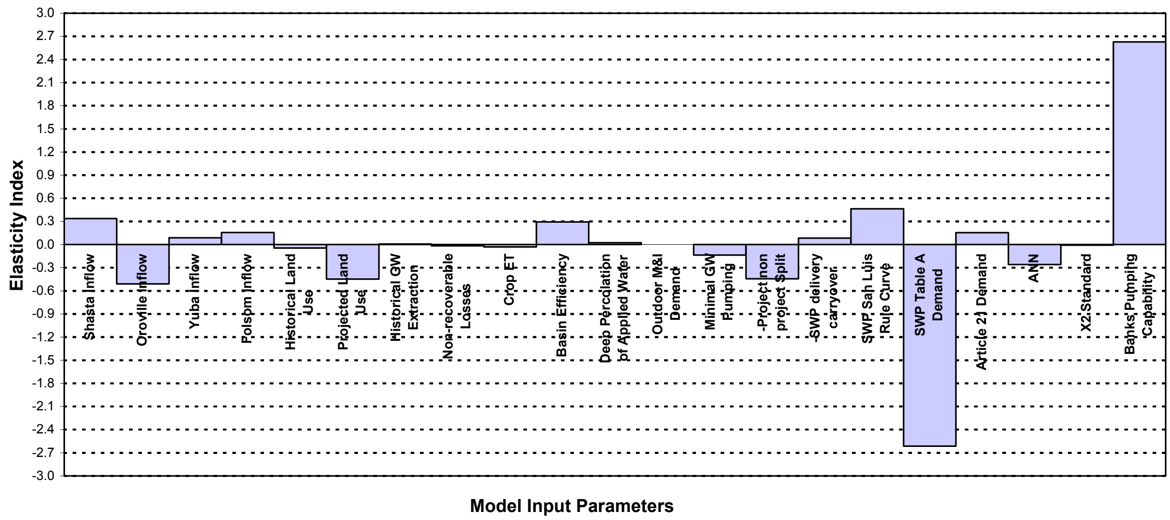


Figure A-94
Sensitivity Index of Aricle 21 Water Delivery

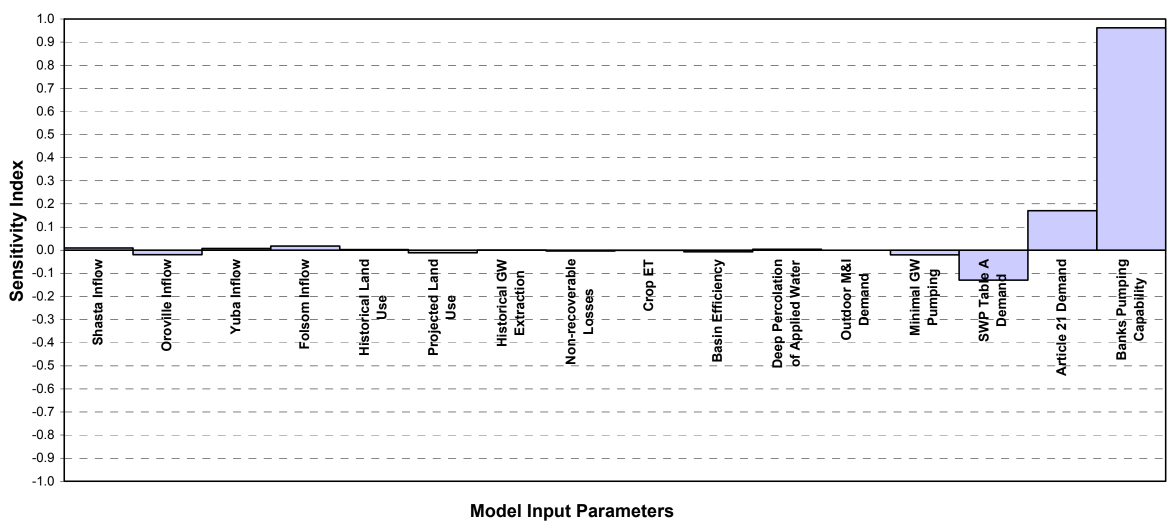


Figure A-95
Elasticity Index of CVP SOD Delivery

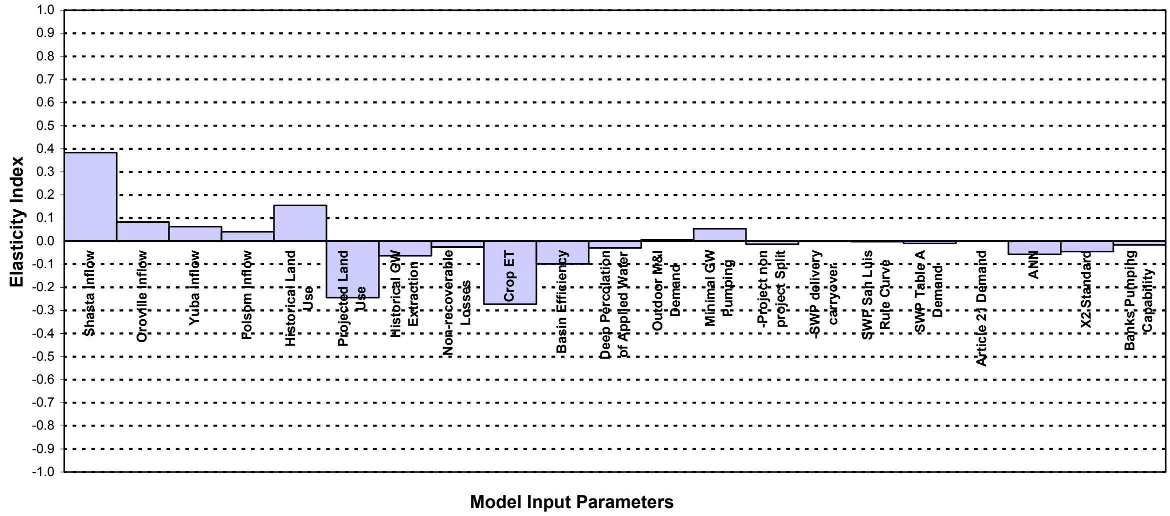


Figure A-96
Sensitivity Index of CVP SOD Delivery

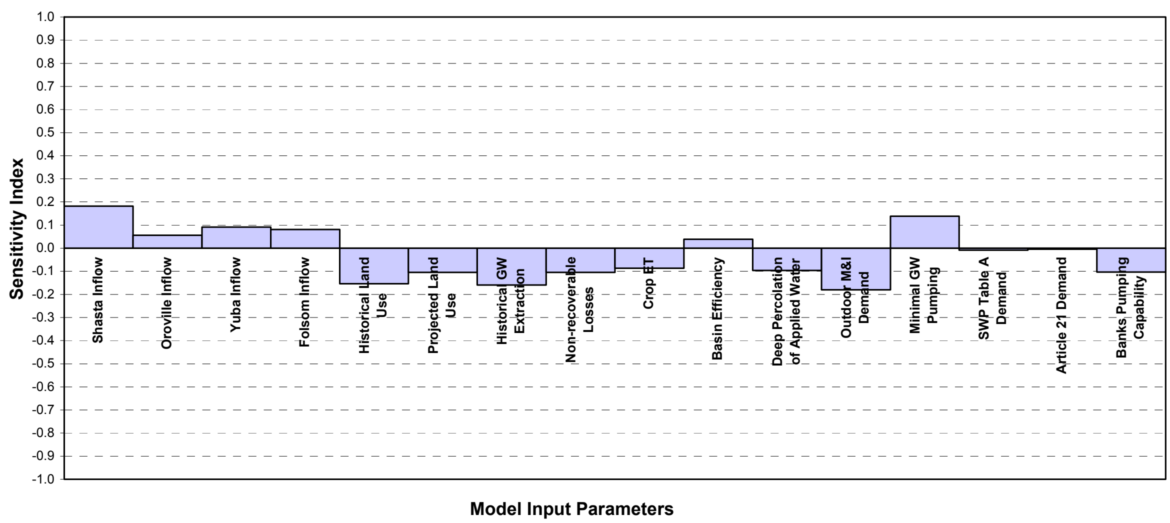


Figure A-97
Elasticity Index of CVP NOD Delivery

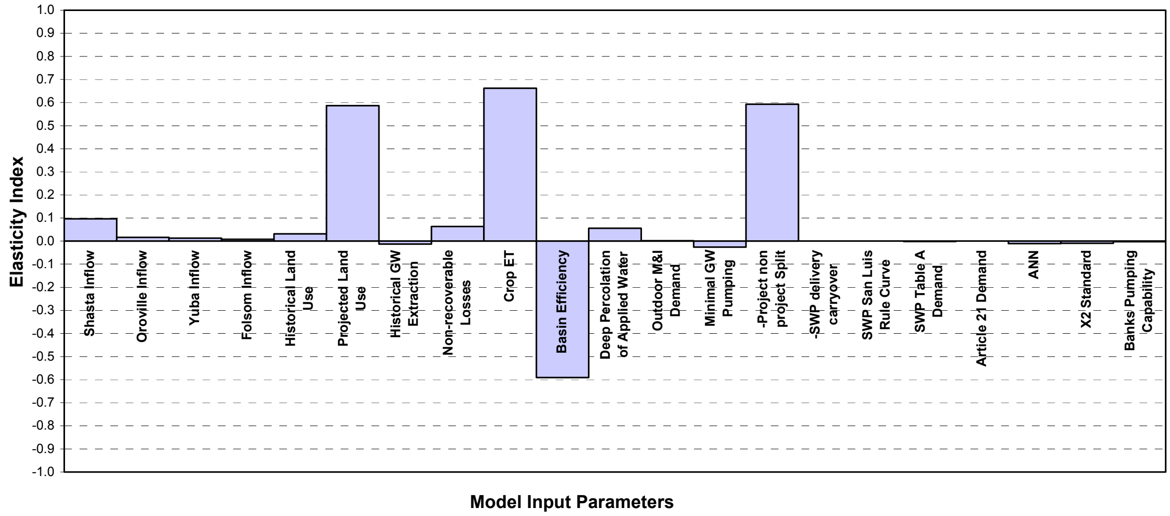


Figure A-98
Sensitivity Index of CVP NOD Delivery

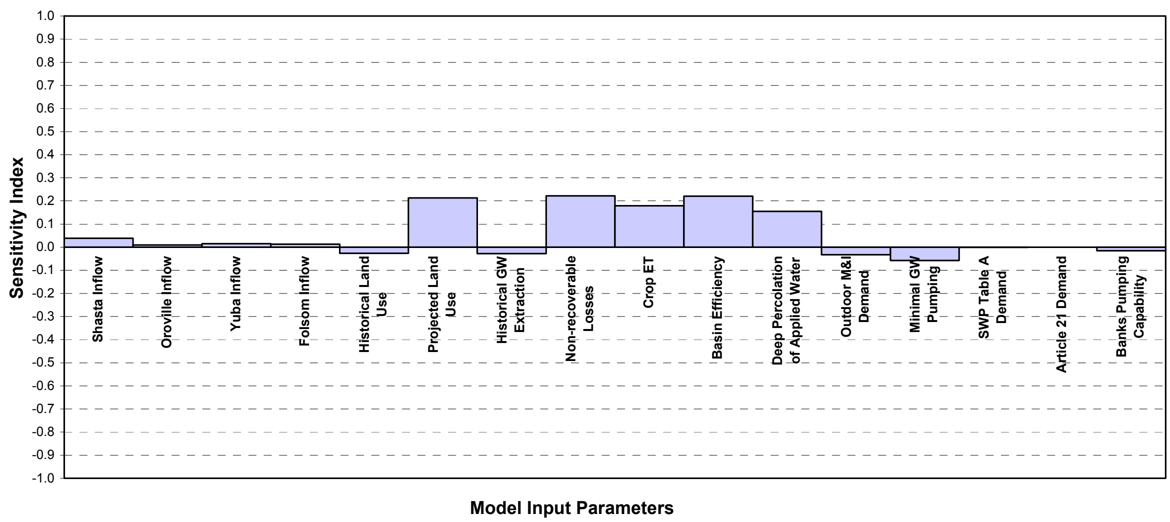


Figure A-99
Elasticity Index of Total Delta Outflow

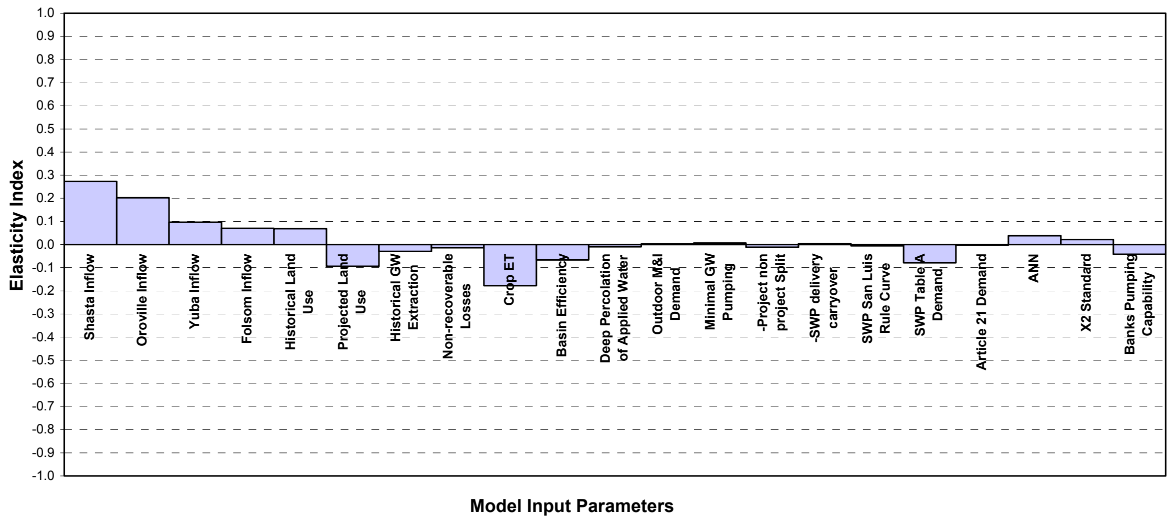


Figure A-100
Sensitivity Index of Total Delta Outflow

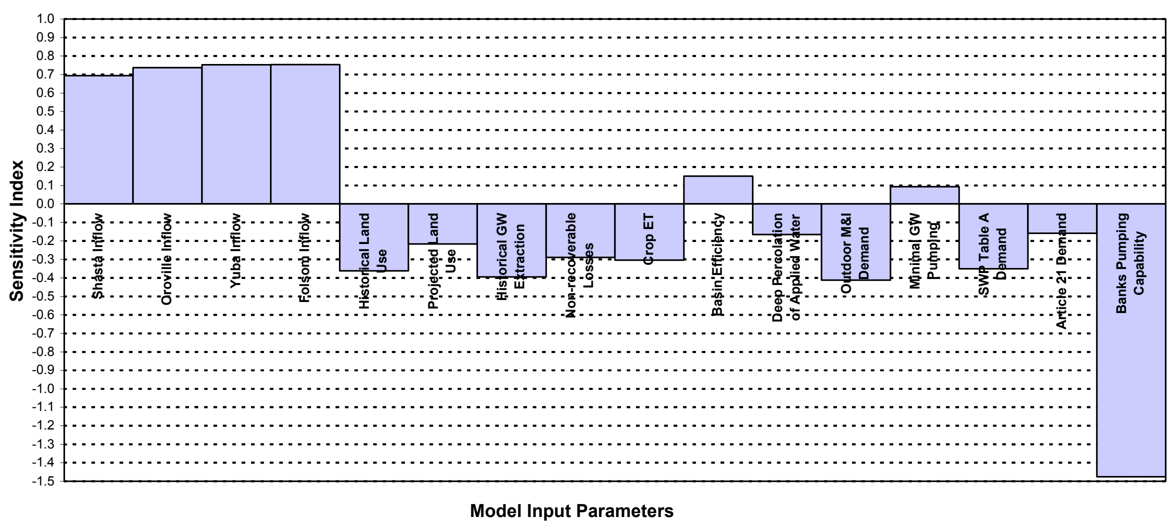


Figure A-101
Elasticity Index of MRDO

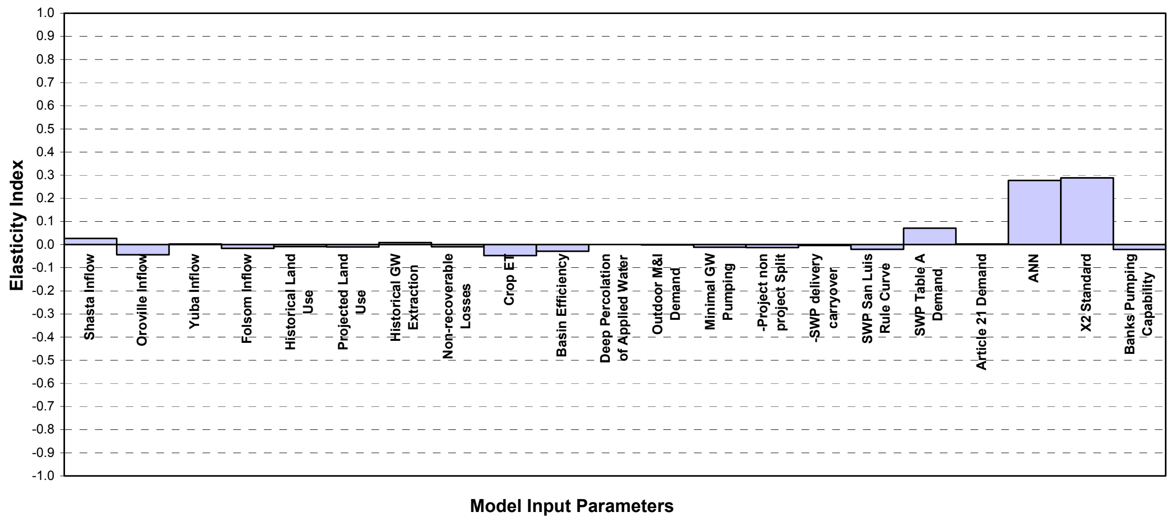


Figure A-102
Sensitivity Index of MRDO

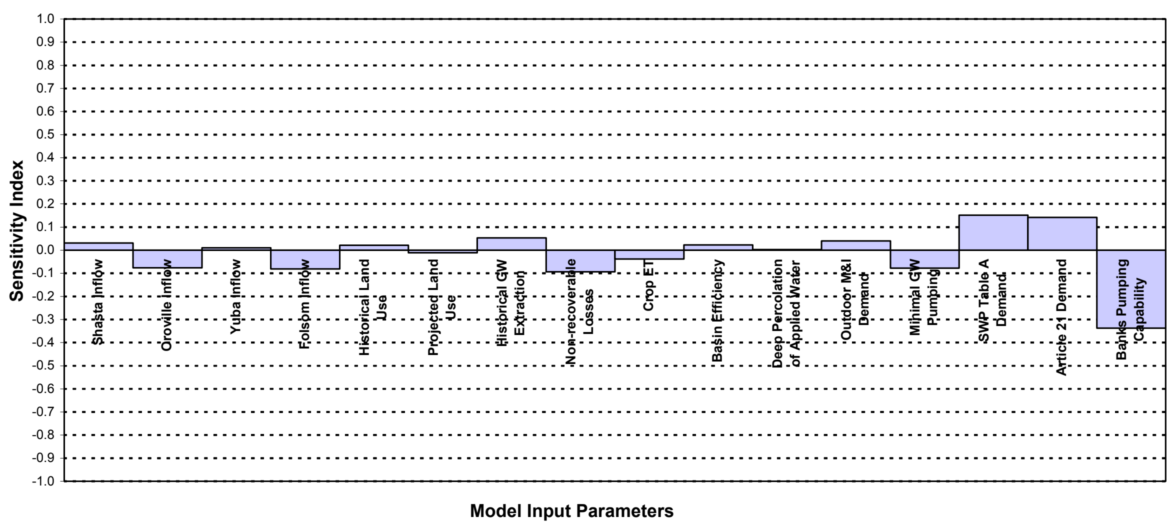


Figure A-103
Elasticity Index of Surplus Delta Outflow

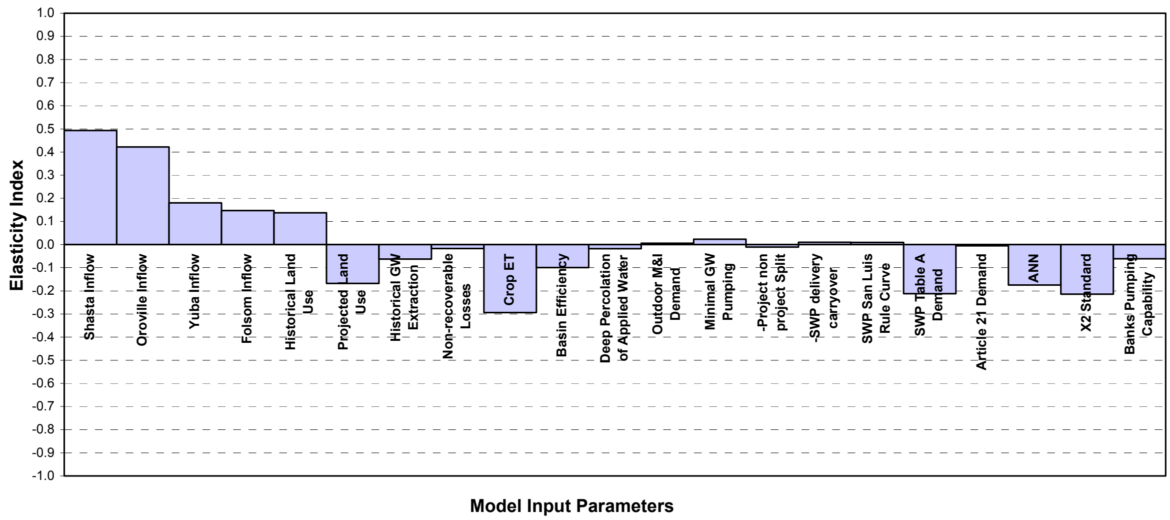


Figure A-104
Sensitivity Index of Surplus Delta Outflow

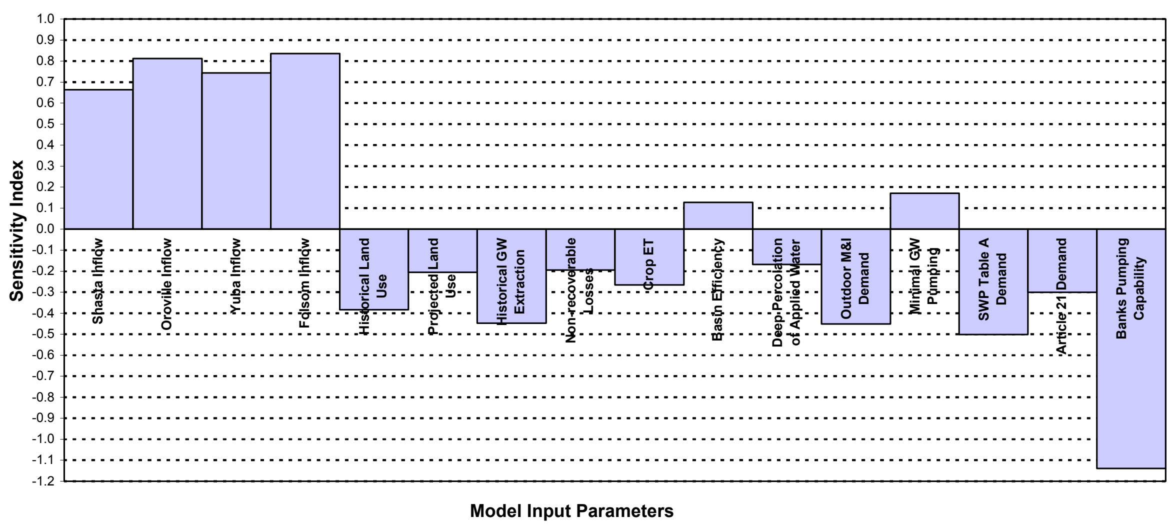


Figure A-105
Elasticity Index of Total Banks and Tracy Pumping

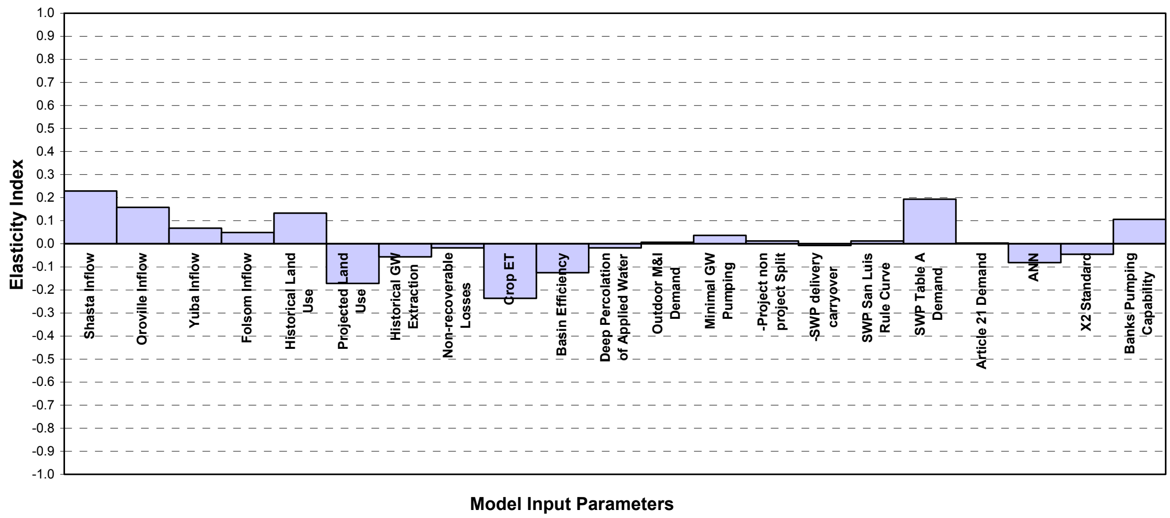


Figure A-106
Sensitivity Index of Total Banks and Tracy Pumping

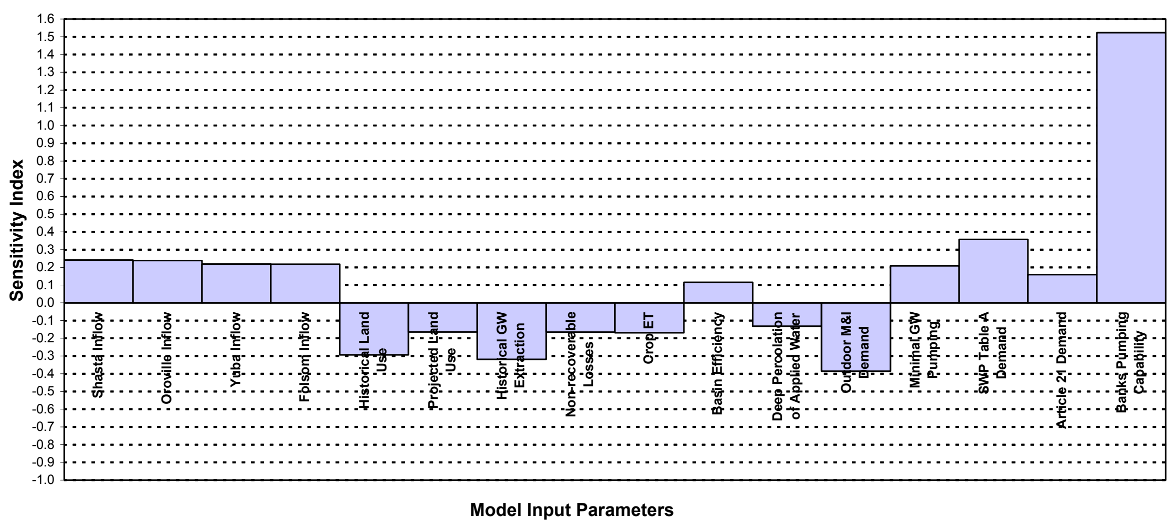


Figure A-107
Elasticity Index of Banks Export

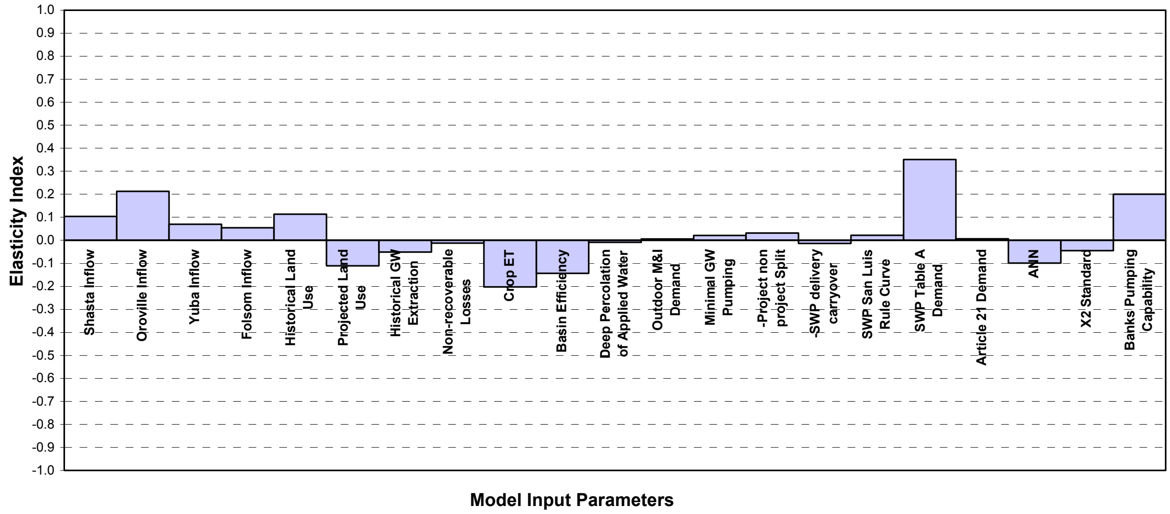


Figure A-108
Sensitivity Index of Banks Export

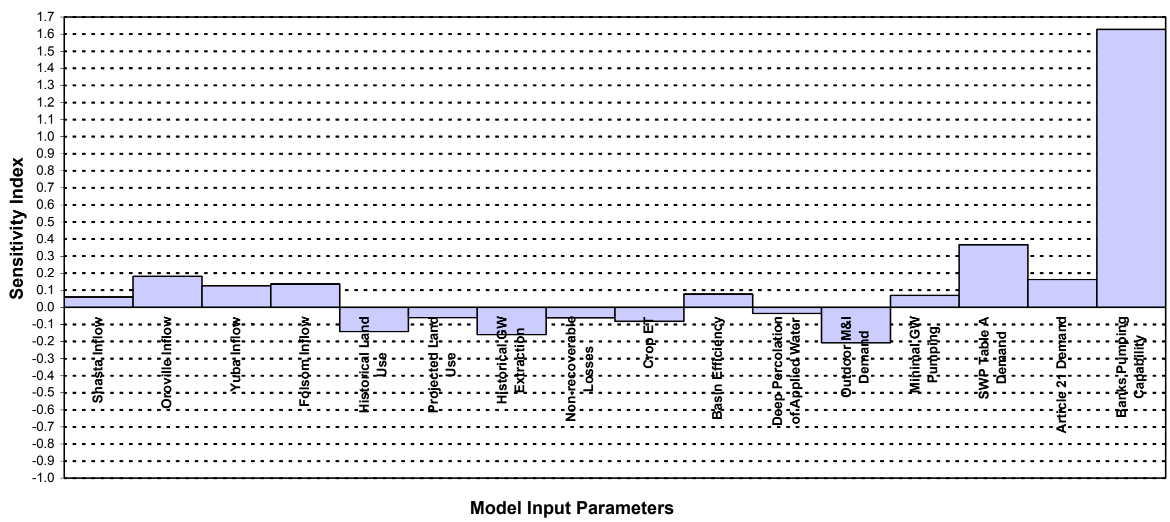


Figure A-109
Elasticity Index of Tracy Export

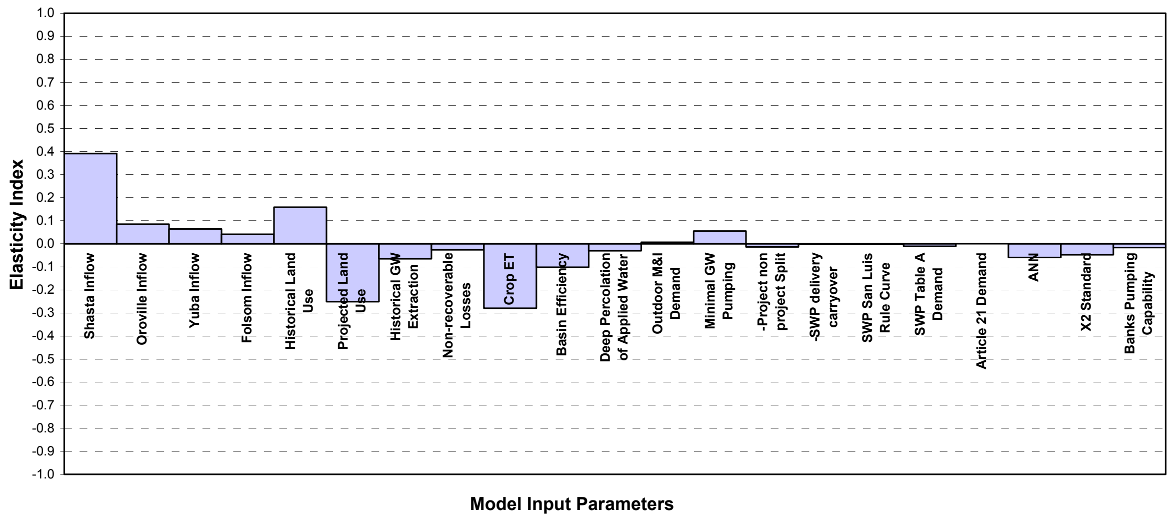


Figure A-110
Sensitivity Index of Tracy Export

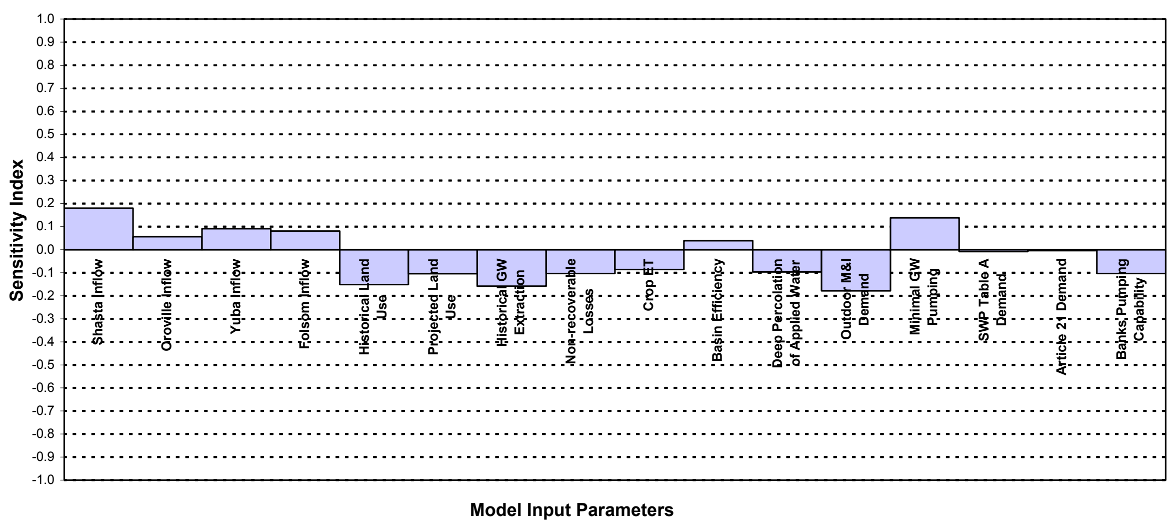


Figure A-111
Elasticity Index of Banks SWP Export

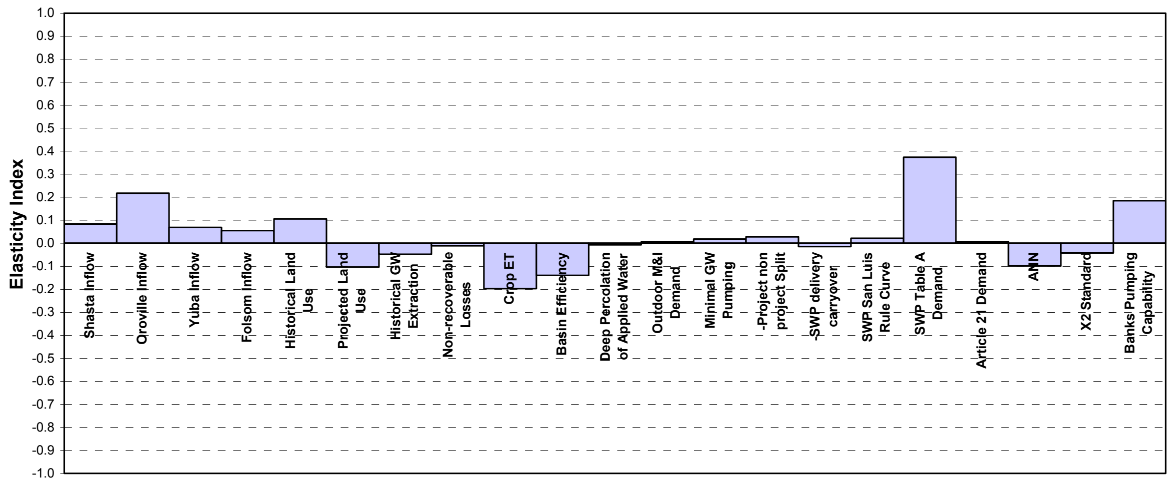


Figure A-112
Sensitivity Index of Banks SWP Export

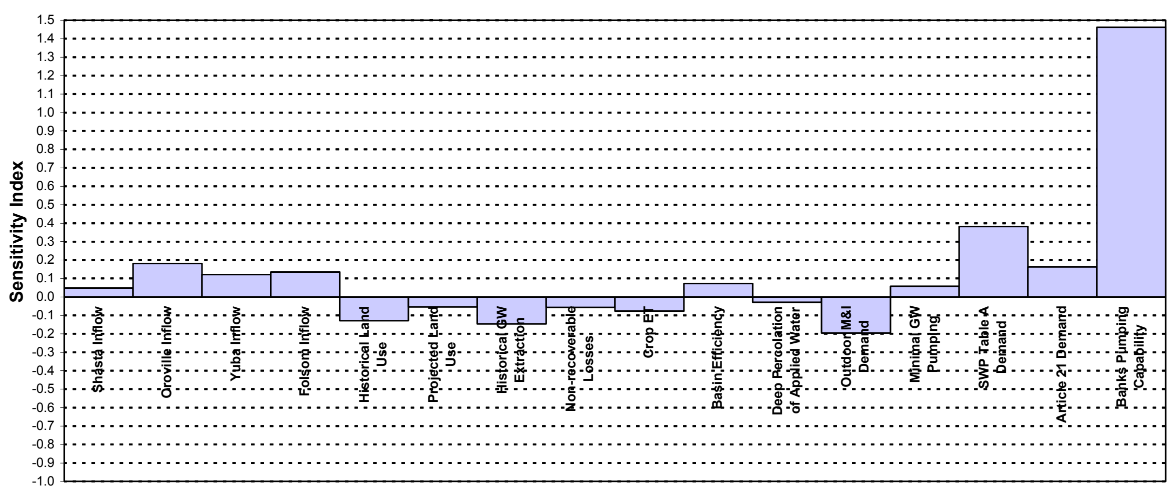


Figure A-113
Elasticity Index of Banks CVP Export

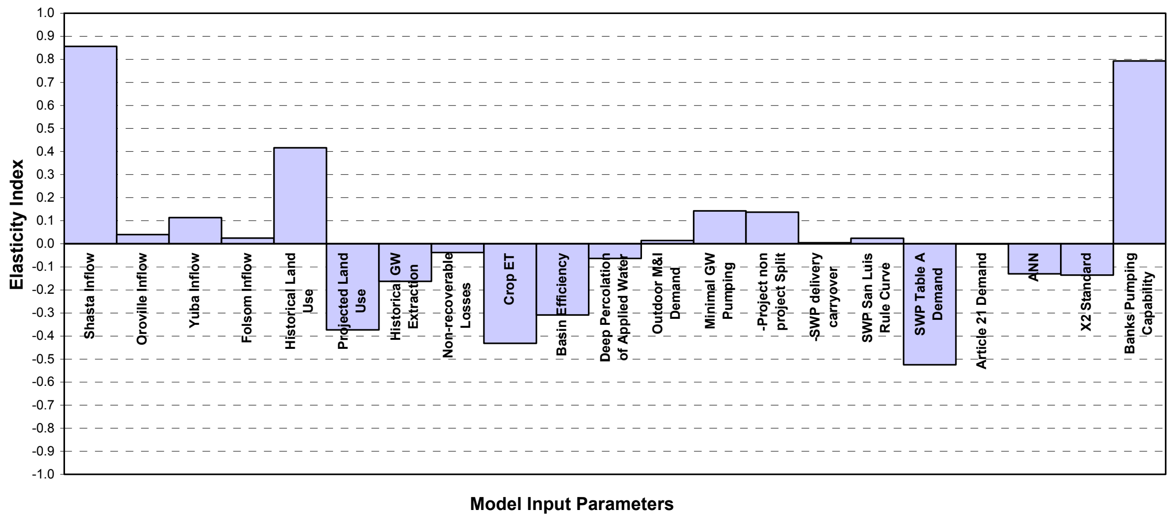


Figure A-114
Sensitivity Index of Banks CVP Export

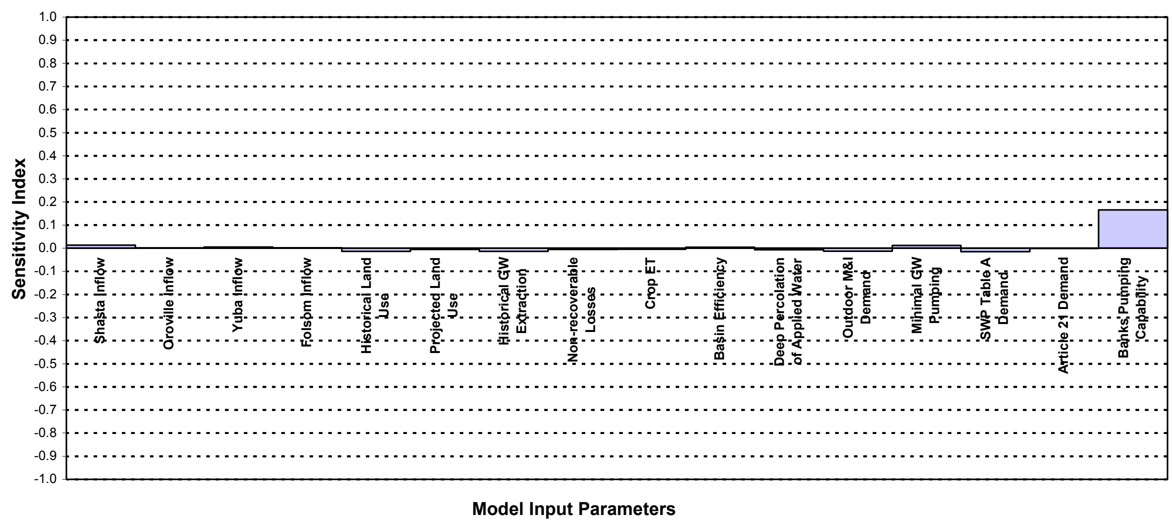


Figure A-115
Elasticity Index of SWP End-of-Sept Storage

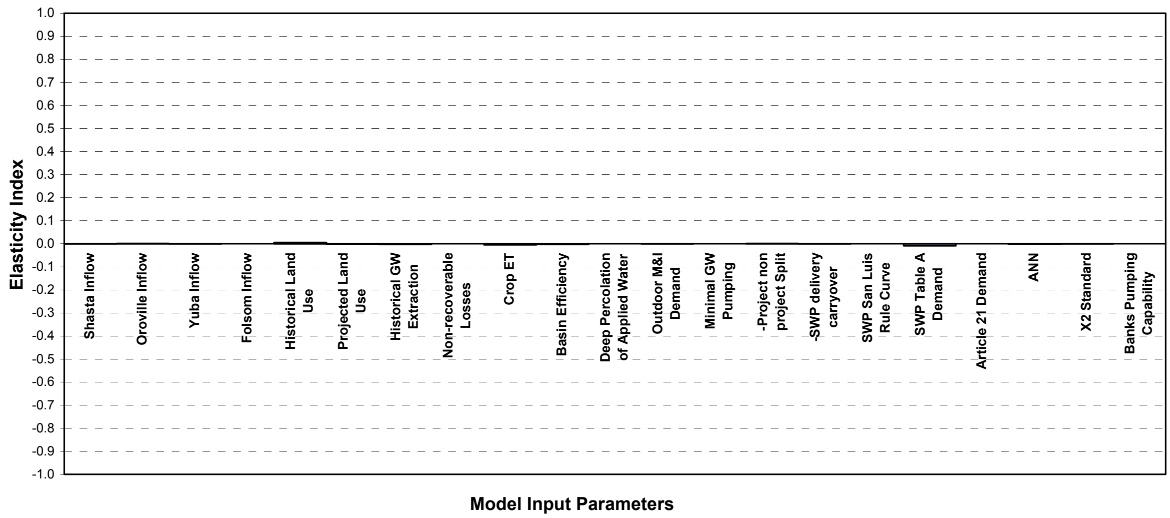


Figure A-116
Sensitivity Index of SWP End-of-Sept Storage

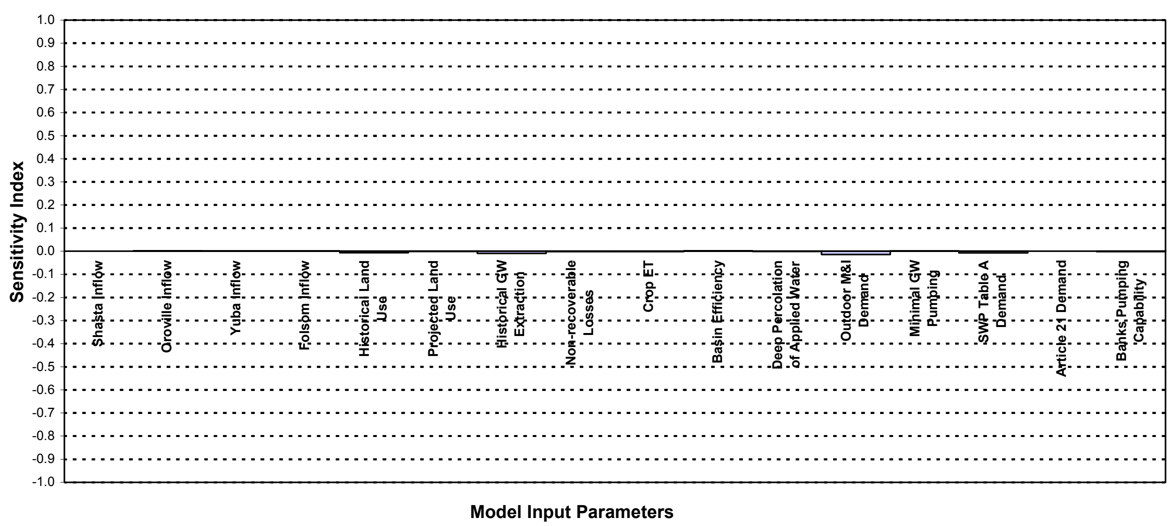


Figure A-117
Elasticity Index of CVP End-of-Sept Storage

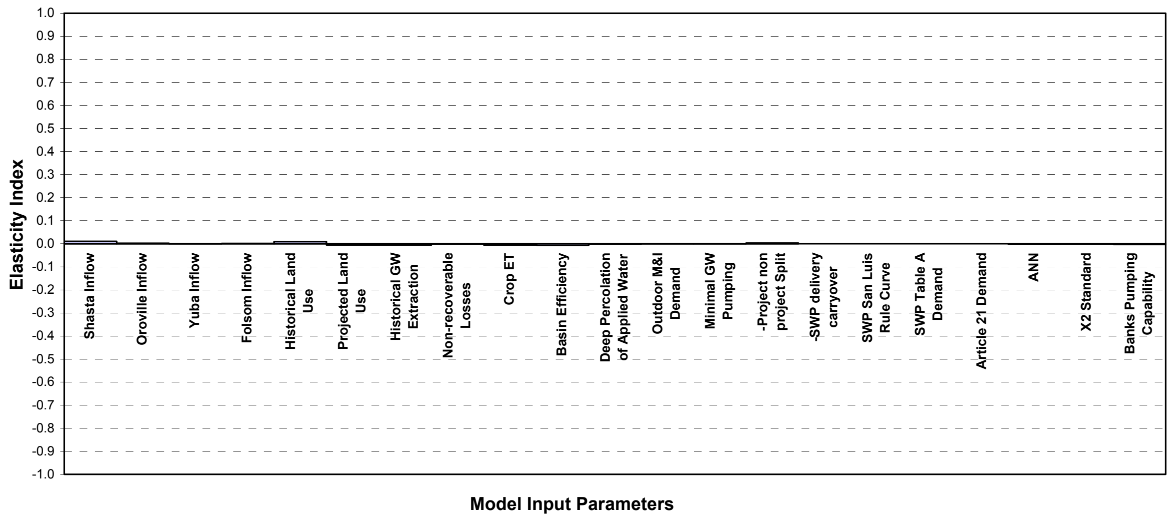


Figure A-118
Sensitivity Index of CVP End-of-Sept Storage

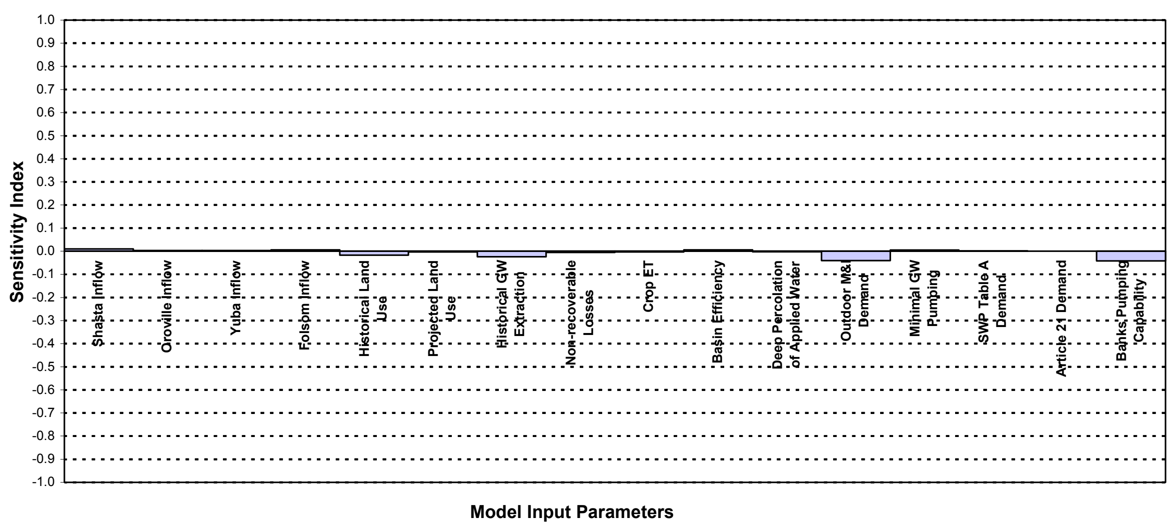


Figure A-119
Elasticity Index of SWP SOD End-of-Sept Storage

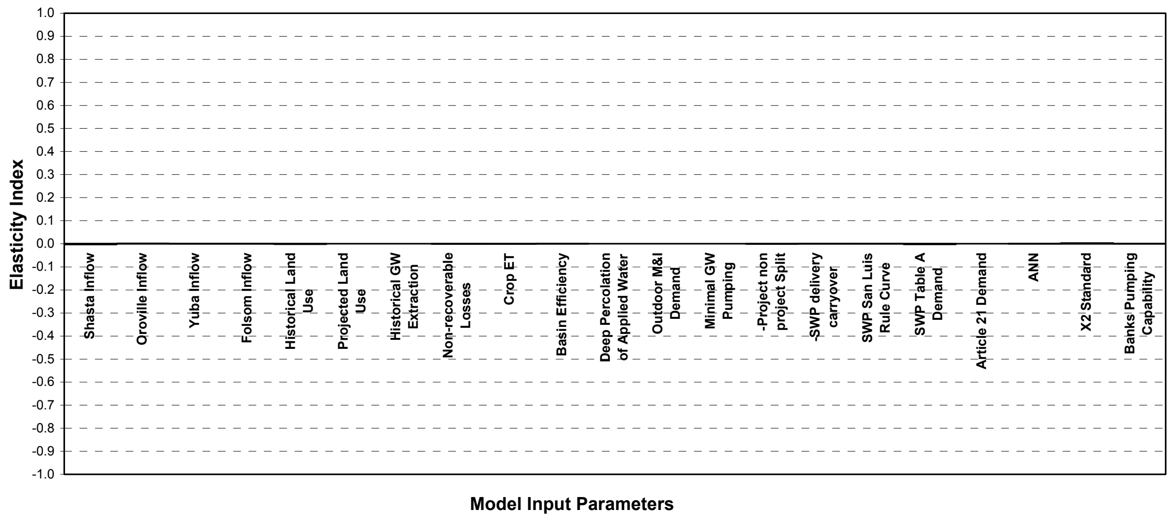


Figure A-120
Sensitivity Index of SWP SOD End-of-Sept Storage

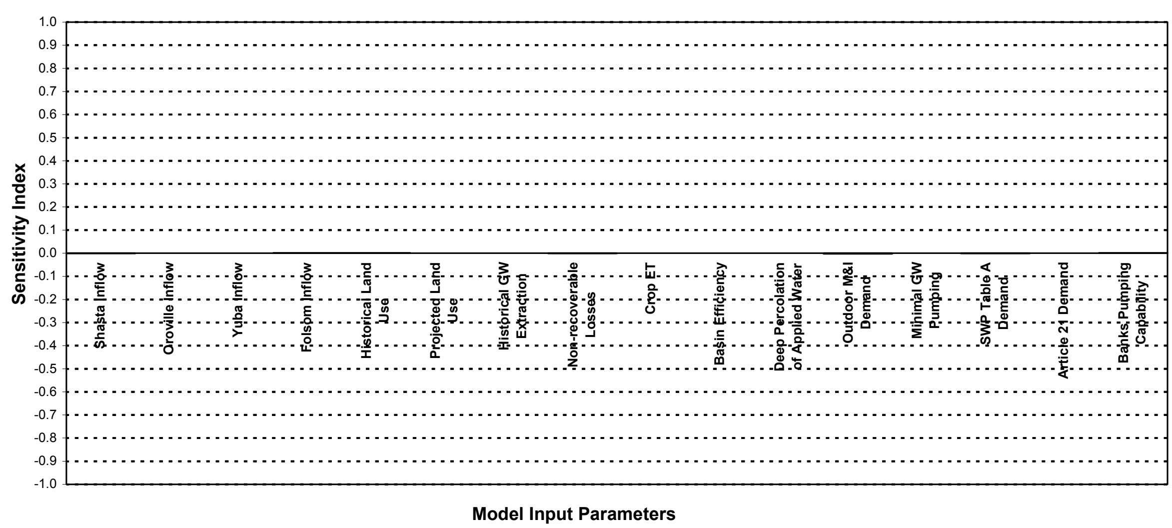


Figure A-121
Elasticity Index of SWP NOD End-of-Sept Storage

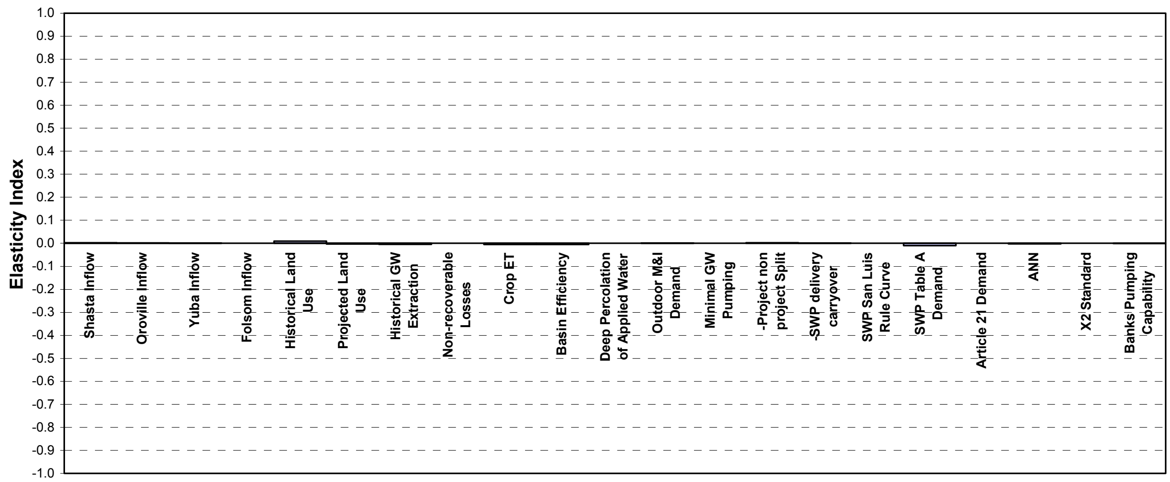


Figure A-122
Sensitivity Index of SWP NOD End-of-Sept Storage

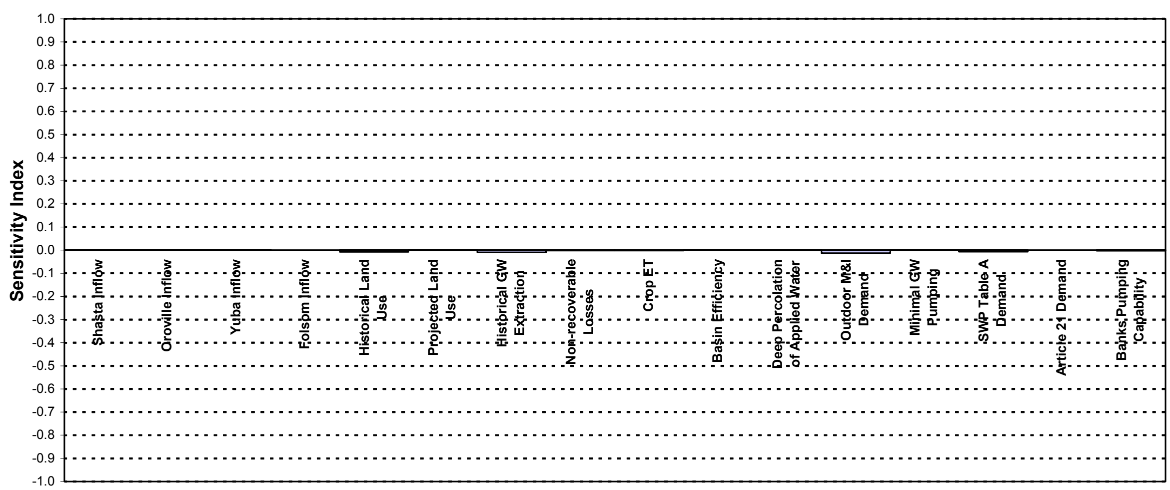


Figure A-123
Elasticity Index of CVP SOD End-of-Sept Storage

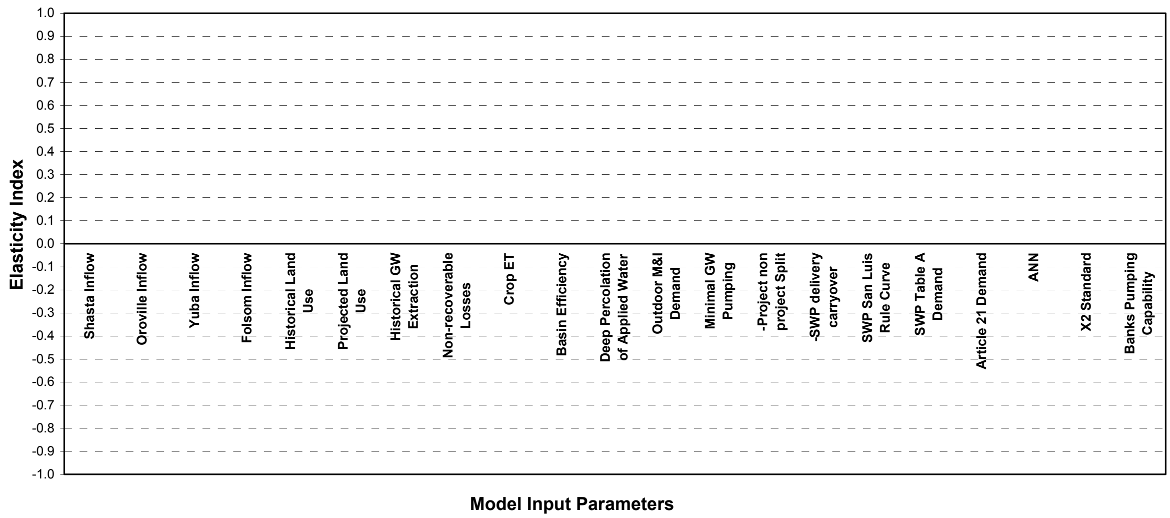


Figure A-124
Sensitivity Index of CVP SOD End-of-Sept Storage

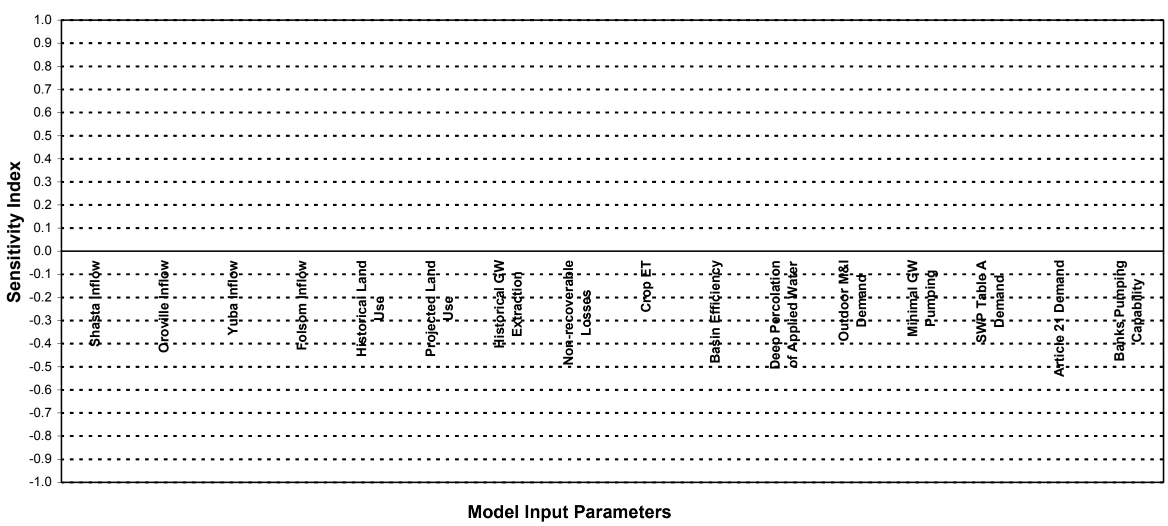


Figure A-125
Elasticity Index of CVP NOD End-of-Sept Storage

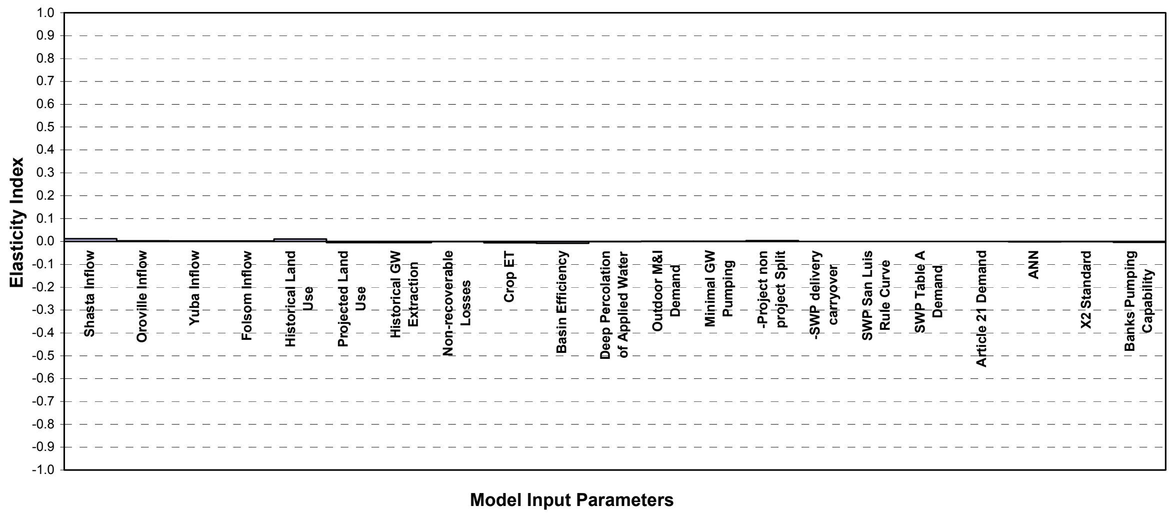


Figure A-126
Sensitivity Index of CVP NOD End-of-Sept Storage

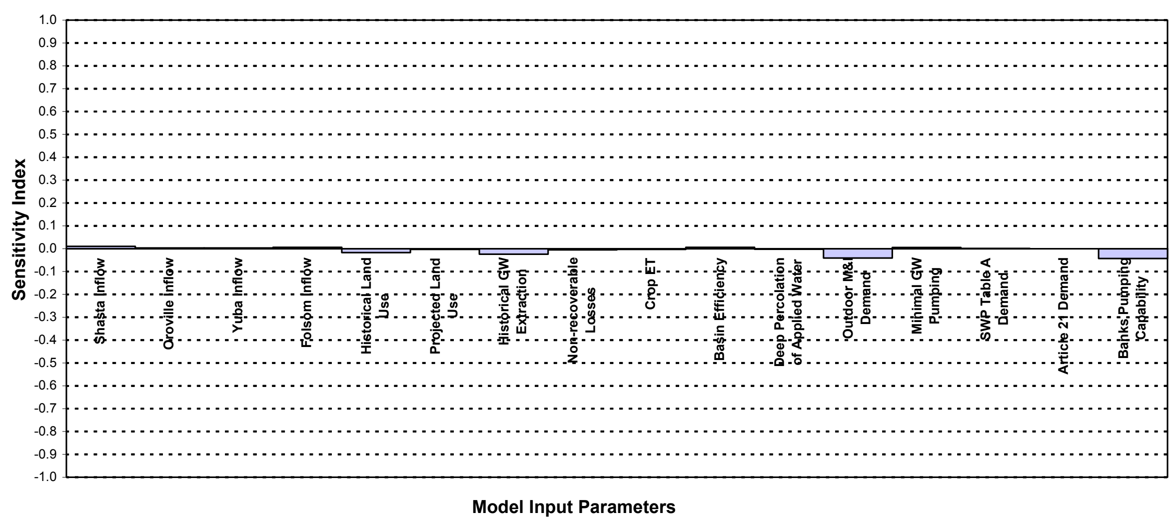


Figure A-127
Elasticity Index of San Luis SWP End-of-Sept Storage

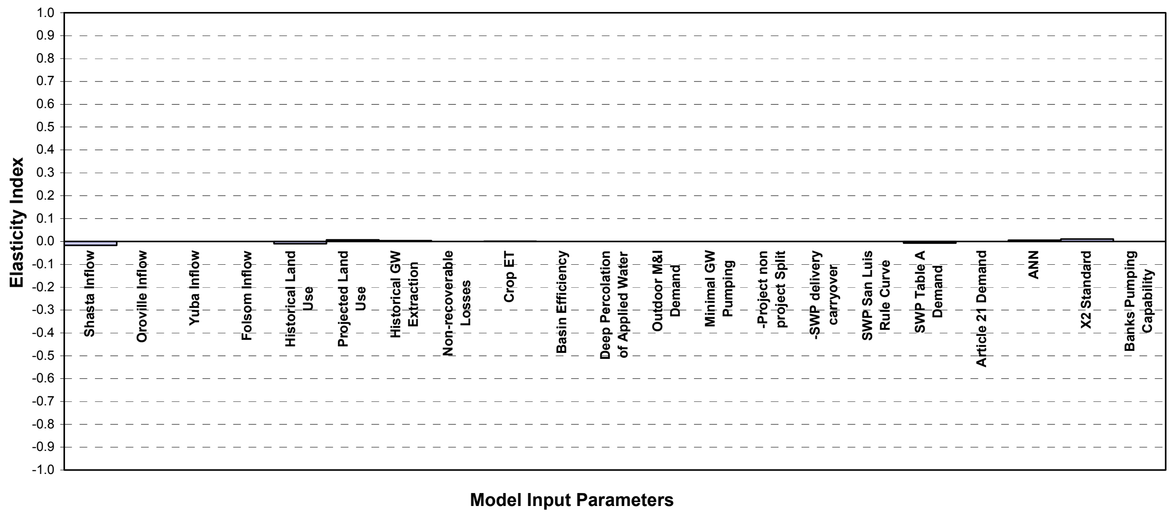


Figure A-128
Sensitivity Index of San Luis SWP End-of-Sept Storage

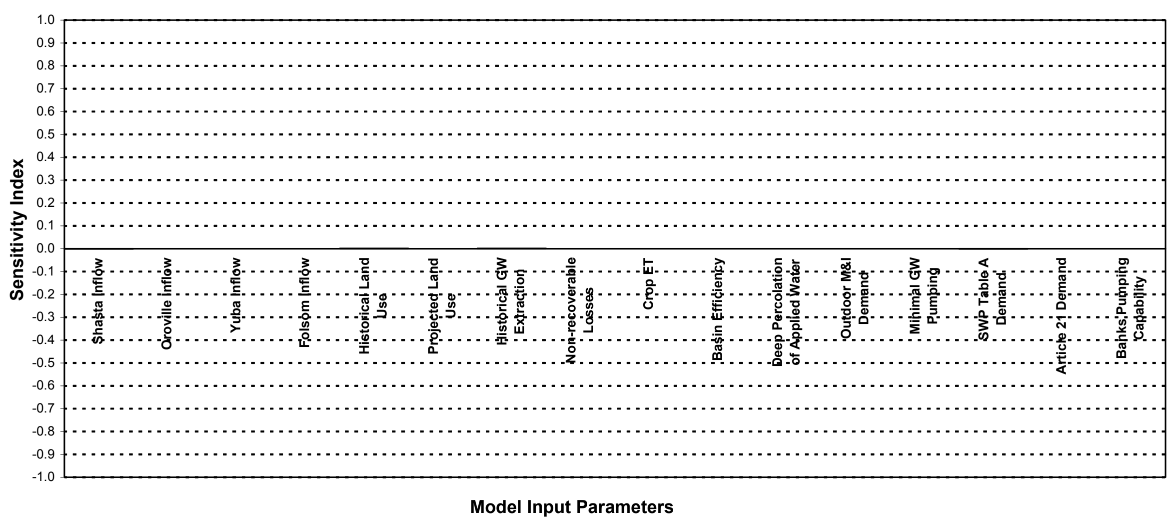


Figure A-129
Elasticity Index of San Luis CVP End-of-Sept Storage

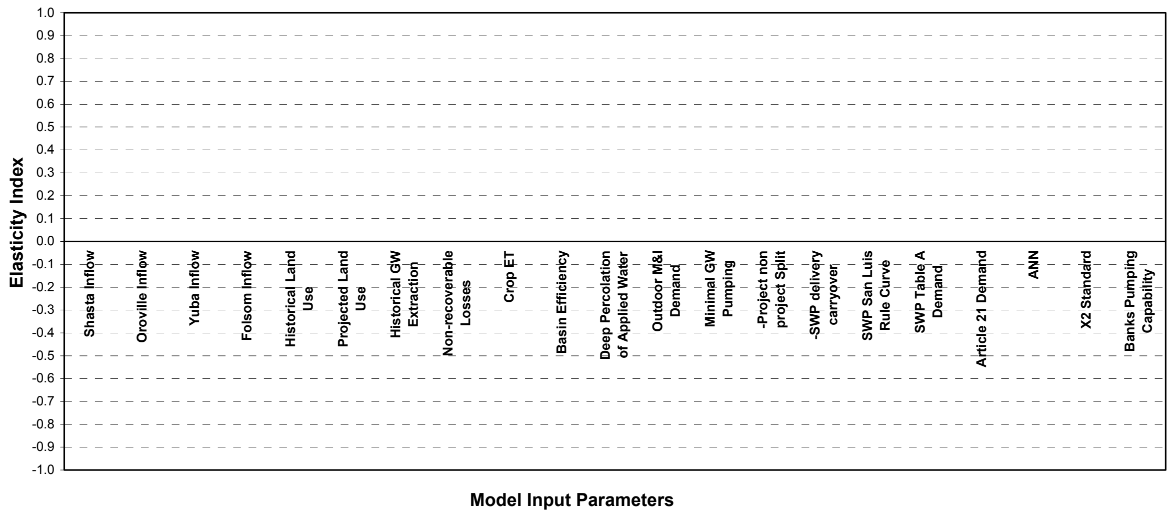


Figure A-130
Sensitivity Index of San Luis CVP End-of-Sept Storage

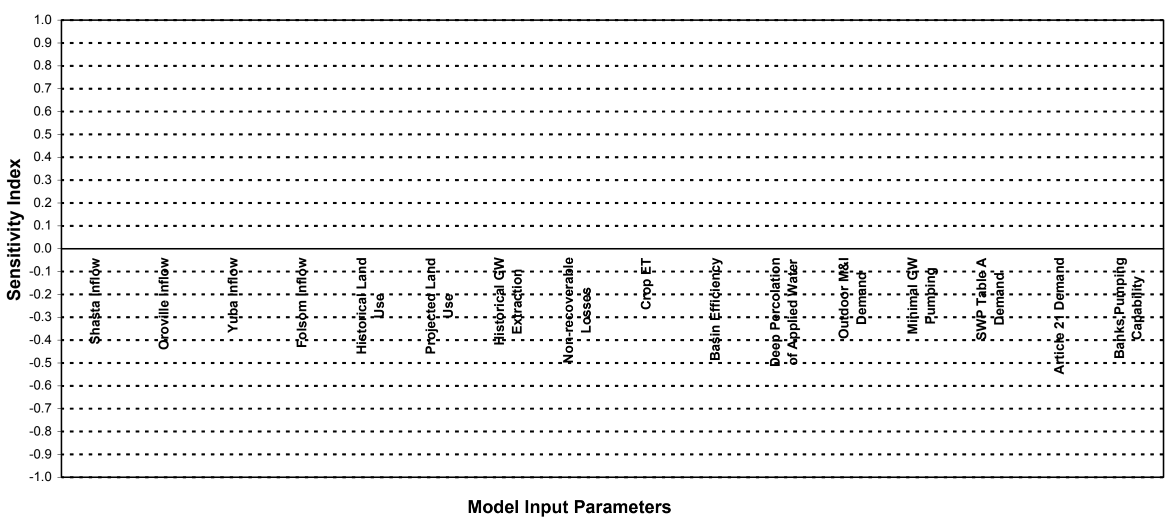


Figure A-131
Elasticity Index of GW NOD End-of-September Storage

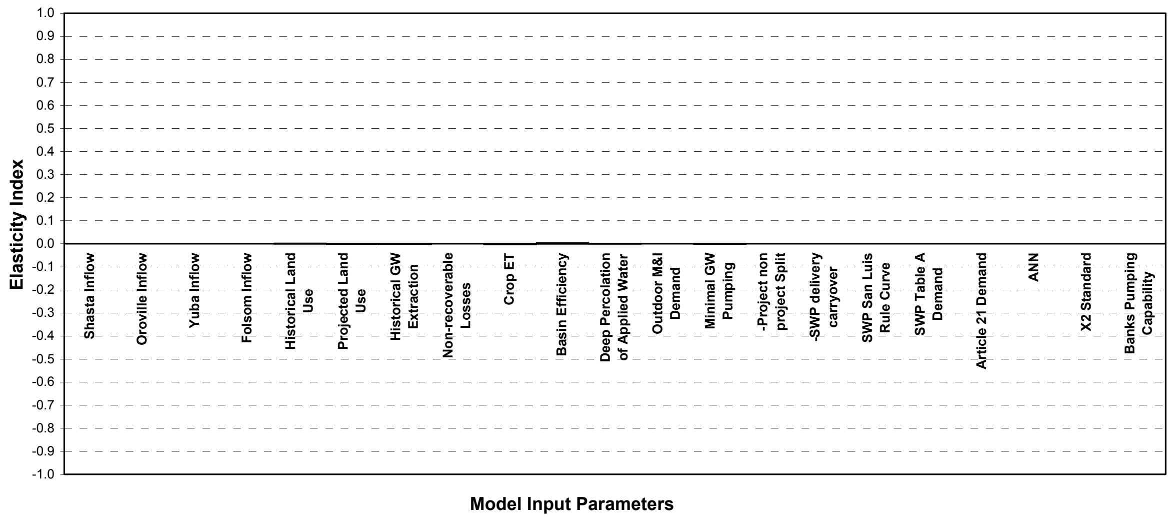
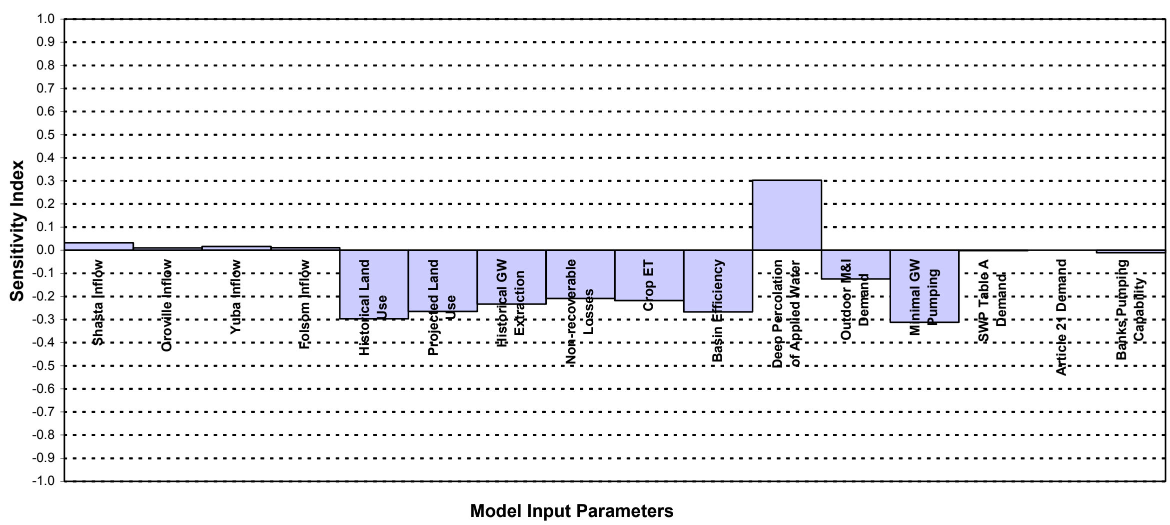
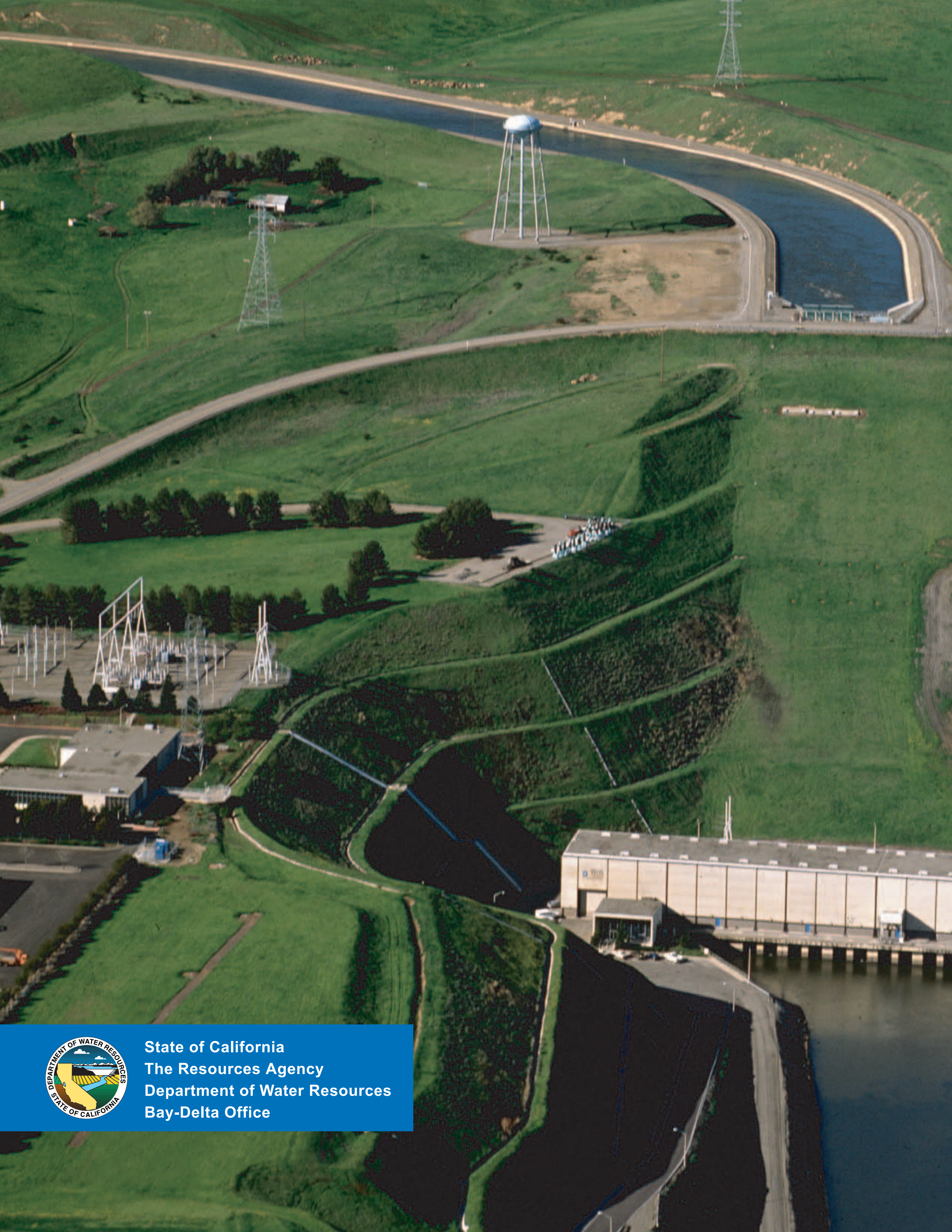


Figure A-132
Sensitivity Index of GW NOD End-of-September Storage





State of California
The Resources Agency
Department of Water Resources
Bay-Delta Office