Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh

22nd Annual Progress Report
August 2001

Chapter 8:
An Initial Assessment of Delta Carriage Water Requirements Using a New CALSIM Flow-Salinity Routine

Authors: Paul Hutton and Sanjaya Seneviratne

8 An Initial Assessment of Delta Carriage Water Requirements Using a New CALSIM Flow-Salinity Routine

[Editor's Note: Chapter 8 was originally circulated as a technical memorandum. The memo was reformatted to be consistent with the Annual Progress Report, but its content remains unchanged. The CALSIM flow-salinity routine has been modified subsequent to circulation of the memorandum, resulting in water supply impacts that are lower than those presented in Figure 8-5. The modification corrects a model bias towards over-estimation of Old River at Rock Slough salinity, which is discussed in Section 8.3.2. At the time that this editor's note was prepared, carriage water estimates had not been updated to reflect the refined flow-salinity routine. But as noted in the discussion (Section 8.6), it is anticipated that other factors will need to be considered in the next update of carriage water estimates, including (but not necessarily limited to) input from the Bay-Delta Modeling Forum Carriage Water Review Team and progress in the modeling of CVPIA b(2) and EWA operations.]

8.1 Introduction

The purpose of this study is to report (1) the water supply impacts associated with a new CALSIM flow-salinity routine for modeling Delta standards and (2) the range of carriage water costs as computed by the new CALSIM routine.

Properly accounting for Delta standards is essential for effective planning and management of CVP and SWP facilities and has a major impact on reservoir releases and Delta export pumping. Key standards include:

- M&I and agricultural water quality standards
- Delta outflow (X2) standards
- Maximum percent of Delta inflow diverted (E/I ratio)

In order to properly simulate Delta standards in a CVP-SWP system planning model such as CALSIM, hydrology, hydraulics and flow-salinity relationships must be accurately specified. This study focuses on the specification of flow-salinity relationships in CALSIM.

Carriage water is closely interrelated with Delta flow-salinity relationships. While the concept of quantifying carriage water is controversial, it is necessary to determine the true costs of meeting Delta standards and transferring water across the Delta. In the State Water Resources Control Board's Notice of Resumption of Public Hearing for Phase 8 of the Bay-Delta Water Rights Hearing dated April 19, 2000, the State Board identified as a key issue the determination of the amount of carriage water when water is exported from the Delta. The Bay Delta Modeling Forum created a review team to develop a recommendation to the State Board on the methodology for calculating carriage water. Staffs from the department and Contra Costa Water District are working with this review team to undertake technical analyses on carriage water.

The study presented in this report summarizes work to date conducted by DWR Modeling Support staff.

Carriage water calculation is also important for estimating the water supply benefits or costs of alternate Delta operations and configurations. For example, the following types of operations or facilities may incur water supply benefits through carriage water savings: more frequent Delta Cross Channel opening, construction and operation of through-Delta or isolated Delta facilities, strategic levee restorations for wetland enhancement, and construction and operation of in-Delta storage facilities. Tradeoffs for these types of projects would likely exist between water supply benefits and water quality benefits. Conversely, more frequent DCC closings and strategic levee failures may impact water supply through higher carriage water costs.

8.2 Background

8.2.1 Carriage Water Definitions

The term "carriage water" has different meanings to different people under different circumstances. The following definitions are introduced to clarify its concept:

Carriage Water Cost to Meet Delta Water Quality Standards. Carriage water may be defined as the extra water necessary to carry a unit of water across the Delta for export while maintaining all agricultural and M&I water quality standards in the Delta. This "traditional" carriage water definition evolved from the D-1485 regulatory environment and applies to conditions when water quality standards are in danger of being violated.

Carriage Water Cost to Prevent Water Quality Degradation. Carriage water may also be defined as the extra water necessary to carry a unit of water across the Delta for export while maintaining water quality at a specified location. This definition, also referred to as a "marginal export cost", is similar to the traditional definition but is independent of prescribed water quality standards.

Carriage Water Cost to Meet Delta Water Quality and Ecological Standards. The "traditional" carriage water definition may be expanded to include the extra water necessary to carry a unit of water across the Delta for export while maintaining ecological standards such as export-to-inflow (E/I) ratio, X2 position, and minimum Delta outflow. This carriage water definition, which is most appropriate for quantifying potential water transfer costs under the D-1641 regulatory environment, is employed in this study to estimate carriage water requirements.

8.2.2 Previous Efforts to Model Delta Flow-Salinity Relationships

The ability to quantify Delta flow-salinity relationships is critical to CVP-SWP project operations and management. The physics of Delta flow-salinity relationships is highly complex and is a function of several variables, including, but not limited to, the time history of Delta hydrology, water facilities and agricultural operations, channel geometry, tidal action, wind, and barometric pressure. DWR's Delta Simulation Model 2 (DSM2), a 1-dimensional hydrodynamic and water quality model, simulates most of the complex interactions described above and is therefore able to accurately predict Delta flow-salinity relationships. However, the computation time necessary to conduct a DSM2 simulation prohibits direct implementation in CALSIM.

The first attempt to model Delta water quality standards in DWRSIM was through a mass balance routine called Minimum Delta Outflow, or MDO (DWR 1987, 1991). The MDO routine calculated required Delta outflow given a level of export, a salinity target, and a Delta Cross Channel gate position. The required Delta outflow increased in a nonlinear fashion as the export level increased. The MDO routine was criticized for its steady-state net flow assumptions and poor validation with observed data and was replaced with Contra Costa Water District's G-model in 1995.

The G-model (Denton and Sullivan 1993) relates salinity at various locations in the Delta to the time history of net Delta outflow. The use of antecedent outflow conditions was a significant improvement in the development of flow-salinity relationships. The G-model is based on historical observations of flow and salinity in the Delta and uses an equation similar in form to the advection-dispersion equation for salinity transport. The parameters required for the solution of this equation, however, are determined by field measurements at the locations of interest. The equation may be solved for a required Delta outflow given a particular outflow history (G value) and desired salinity. While the G-model is in the current version of CALSIM, its basic formulation limits its use in CVP-SWP system planning. The model has a single, independent variable – an antecedent Delta outflow term – and is therefore insensitive to the relationship between water quality and Delta inflows, exports and gate operations for a constant Delta outflow. Because it does not explicitly model the relationship between Delta exports and water quality, the G-model formulation cannot be used to estimate carriage water requirements.

8.3 A New CALSIM Routine to Estimate Delta Flow-Salinity Relationships

DWR has adopted artificial neural network technology to simulate flow-salinity relationships and carriage water in the Delta. The ANN routine was developed and recently implemented in a CALSIM beta version (DWR 1999, 2000). The ANN routine will be an integral part of the next major release of CALSIM, i.e. CALSIM2. This routine statistically correlates DSM2 model-generated salinity at key locations to the time histories of Delta exports, DCC operations, and major Delta inflows. Accounting for these individual flow and operation components is essential for estimating carriage water requirements.

8.3.1 Formulation and Implementation

The ANN routine implemented in CALSIM is calibrated or "trained" on a DSM2 simulation of CALSIM Study 898. This study represents current Delta facilities, operations, and channel configuration. However, the ANN routine is capable of being retrained to account for alternate Delta facility, operation and channel configurations. This robust feature is useful for modeling the interrelationship between Delta conditions and Delta flow-salinity relationships. Delta reconfigurations, such as channel improvements for through-Delta conveyance or levee modifications for wetland enhancement, could significantly affect overall system hydrodynamics. The ANN routine could simulate the resulting flow-salinity regimes by first being retrained on a DSM2 simulation that includes the new Delta configurations.

The current ANN flow-salinity module predicts electrical conductivity at three locations for the purpose of modeling Delta water quality standards: Old River at Rock Slough, San Joaquin River at Jersey Point, and Sacramento River at Emmaton. Salinity is estimated based on a time history of the following variables: Sacramento River inflow, San Joaquin River inflow, DCC gate position, and several Delta export and diversion variables. The Sacramento River inflow term combines flows from the Sacramento River at Freeport, the Yolo Bypass, and the Mokelumne, Cosumnes, and Calaveras rivers. San Joaquin River inflow is the flow measured at Vernalis. DCC gate position is assumed to be fully open or fully closed. Delta exports and diversions include SWP exports at Banks and the North Bay Aqueduct, CVP exports at Tracy, Contra Costa Water District diversions at Rock Slough and Los Vaqueros, and Delta agricultural net channel depletions. The time history for each variable spans 148 days, representing an estimate of the length of water quality “memory” in the Delta.

CALSIM utilizes a linear programming solver to route water throughout the CVP-SWP network, and therefore requires all constraints to be in a linear form. This framework necessitates approximating the ANN flow-salinity relationships such that a linear constraint may be formulated. CALSIM dynamically approximates the relationship between Sacramento River flow and Banks/Tracy exports (both CALSIM decision variables) at each time step as a linear function. This linear approximation is illustrated in Figure 8-1. CALSIM implementation is described in detail elsewhere (DWR 2000).

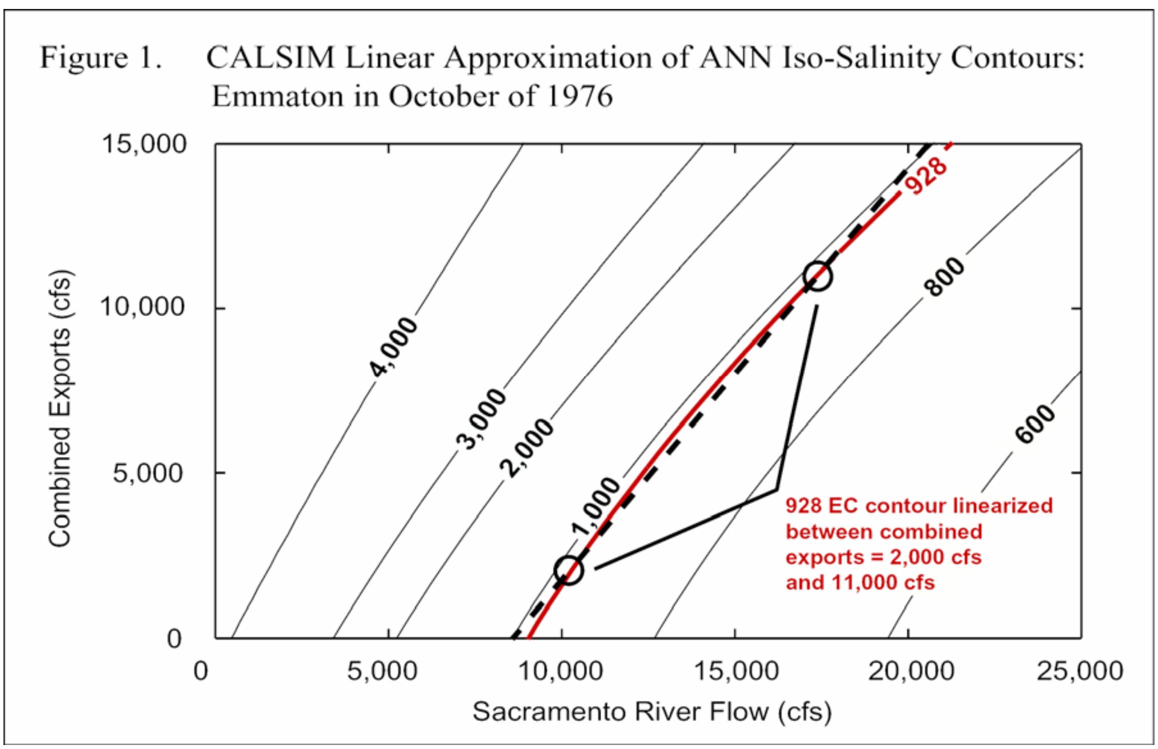

Figure 8-1: CALSIM Linear Approximation of ANN Iso-Salinity Contours: Emmaton in October of 1976.

8.3.2 Validation

A "full-circle" analysis was conducted to confirm that the ANN replicates DSM2 model results. The analysis consists of the steps outlined below and presented schematically in Figure 8-2.

1. Train the ANN module on an appropriate set of DSM2 simulations and implement in CALSIM.
2. Conduct a CALSIM simulation. Evaluate water quality results at key standard locations, i.e. Rock Slough, Jersey Point, and Emmaton.
3. Conduct a DSM2 simulation assuming Delta inflows, exports, and operations from the CALSIM output generated in Step 2. Evaluate water quality results at key standard locations, i.e. Rock Slough, Jersey Point, and Emmaton.
4. Compare water quality results from Steps 2 and 3. If the results compare favorably, the ANN module is validated. If the results are not favorable, retrain the ANN module.

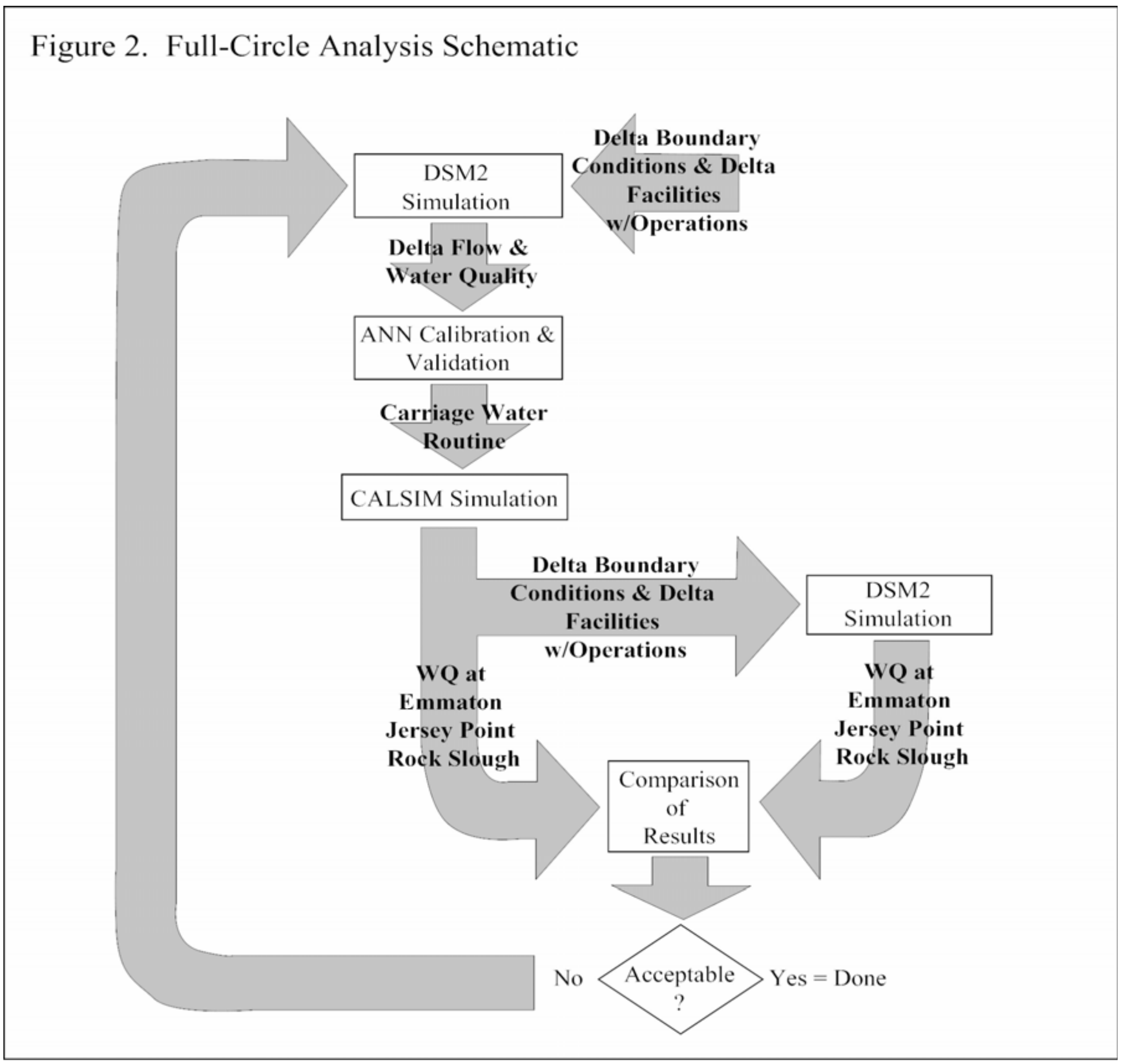

Figure 8-2: Full-Circle Analysis Schematic.

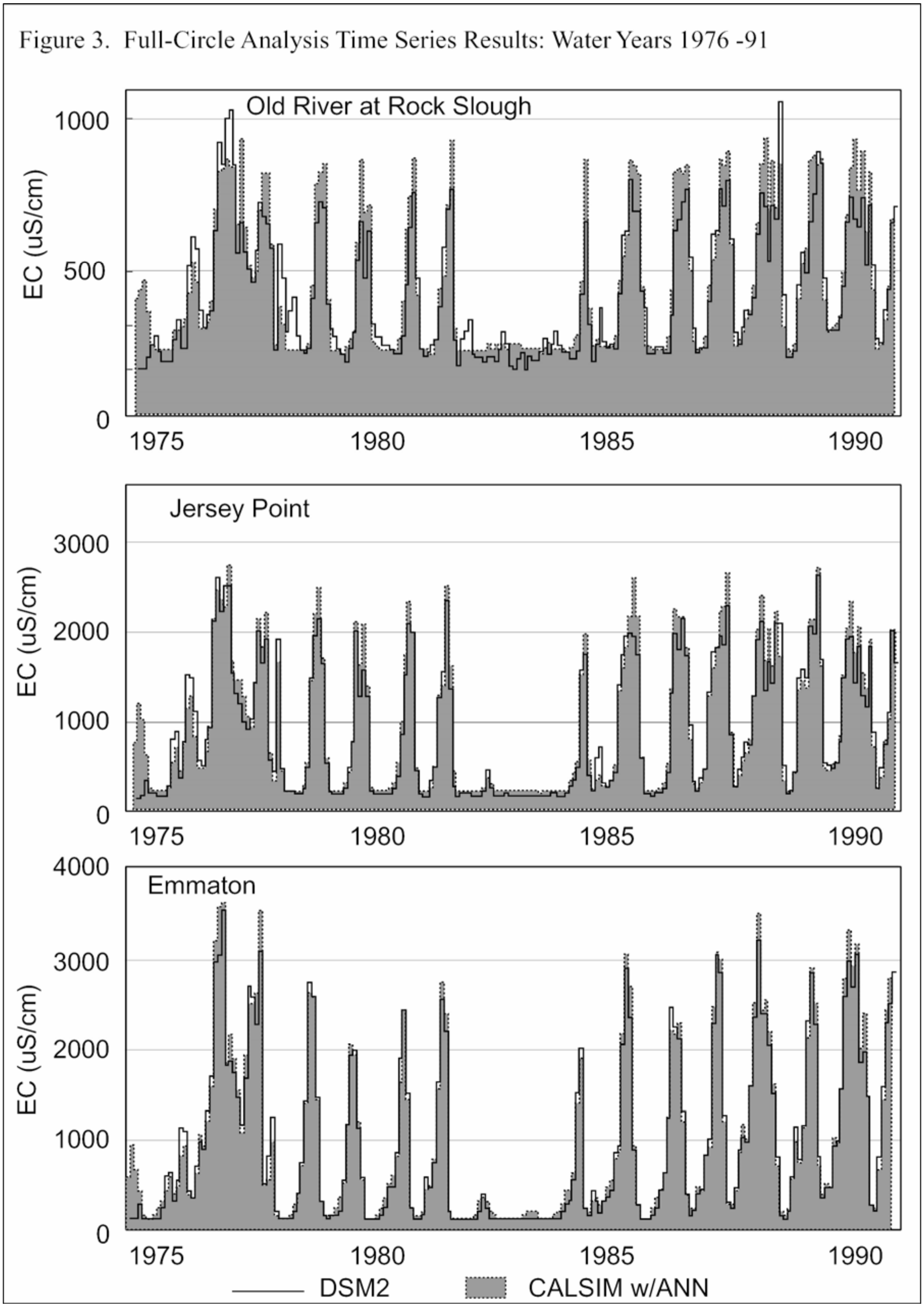

Figure 8-3: Full-Circle Analysis Time Series Results: Water Years 1976 – 1991.

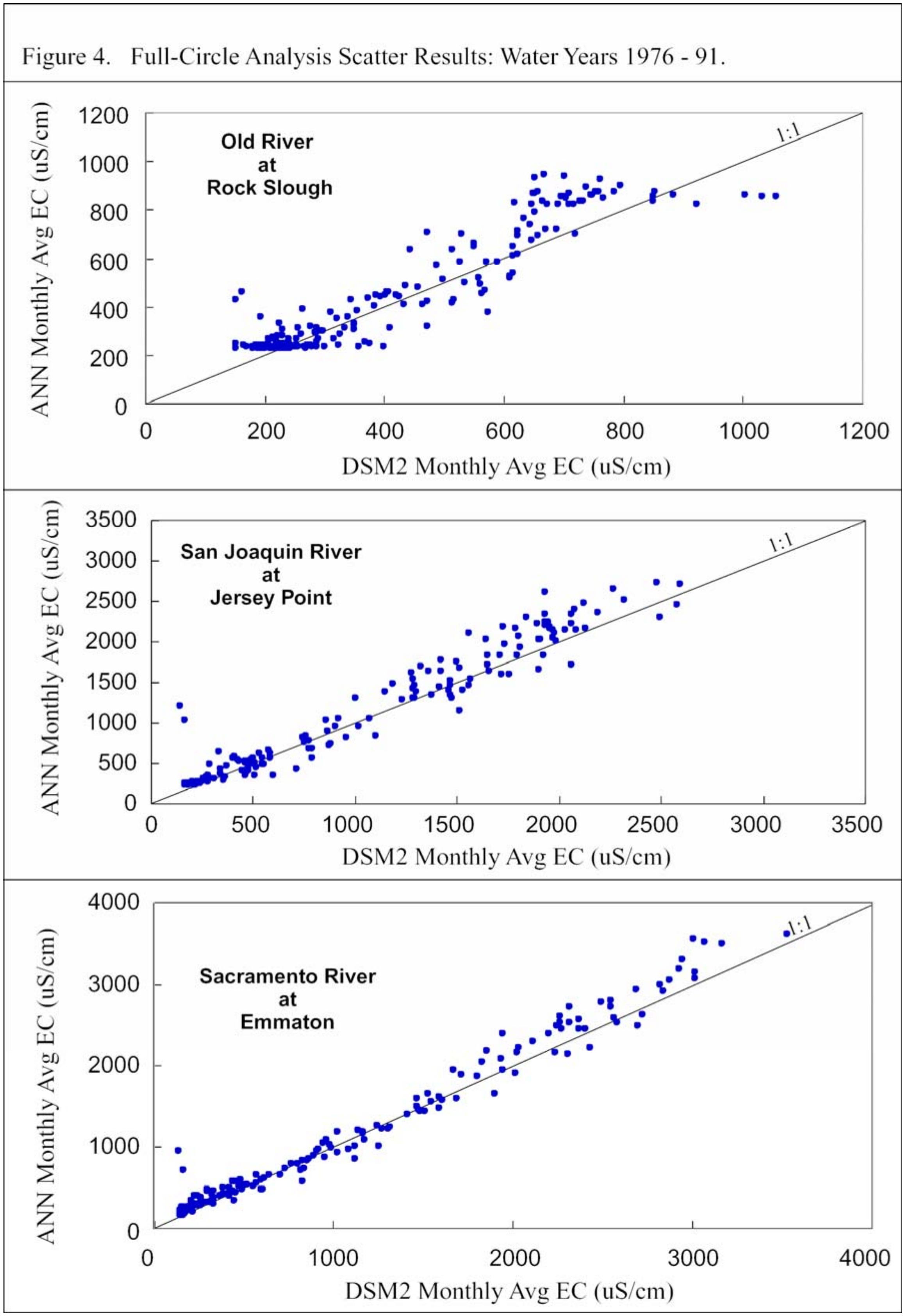

Figure 8-4: Full-Circle Analysis Scatter Results: Water Years 1976 – 1991.

Full-circle validation results for this study are presented in Figure 8-3 as time series plots and in Figure 8-4 as scatter plots. The figures show favorable comparisons between DSM2 and CALSIM water quality estimates at Rock Slough, Jersey Point, and Emmaton. The figures reveal a systematic ANN bias toward over-estimation at Rock Slough.

8.3.3 Impact on CALSIM Water Supply Estimates

A CALSIM base study (Study 898) was run with the G-model and with the ANN module to evaluate water supply impacts associated with the new flow-salinity routine. The ANN module generally requires more water than the G-model to meet Delta water quality standards and therefore results in lower dry-year and 73-year average CVP-SWP deliveries. For the 1928-to-1934 and 1987-to-1992 dry periods, the ANN model shows average annual delivery reductions of 430 and 350 TAF, respectively. Over the 73-year period, the ANN model shows an average annual delivery reduction of 30 TAF. Figure 8-5 displays the ANN water supply impacts.

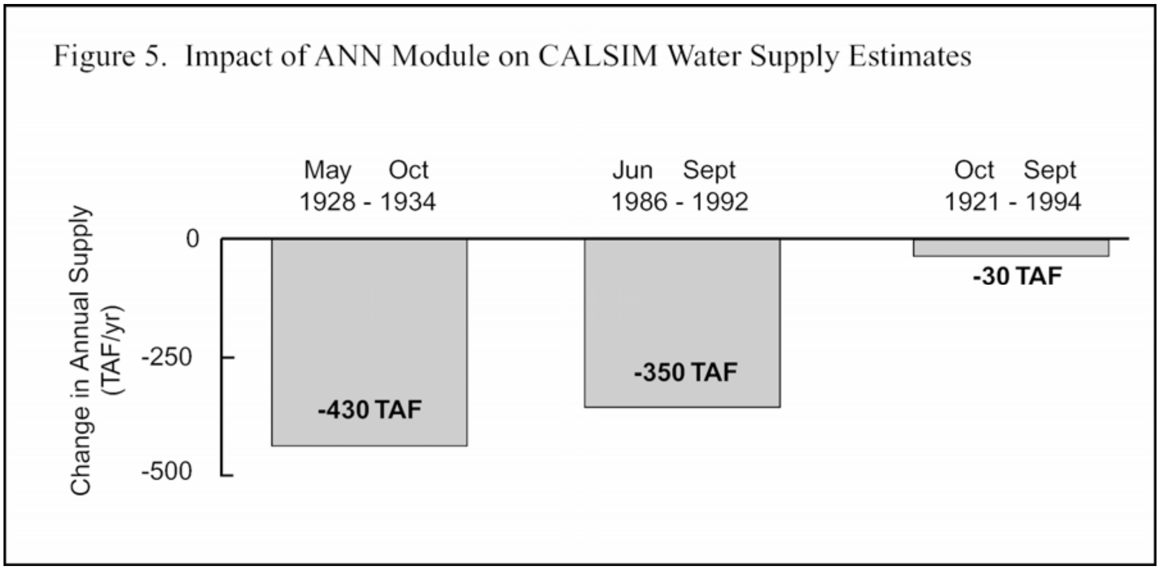

Figure 8-5: Impact of ANN Module on CALSIM Water Supply Estimates.

The difference in the CALSIM base study water supply required to meet Delta standards can be explained by simulating the resulting Delta inflows and operations in DSM2. Figure 8-6 shows a 1976-91 time series comparison of DSM2-predicted water quality with the applicable water quality standards at Old River at Rock Slough, Jersey Point, and Emmaton. The figure shows that the G-model CALSIM operation systematically gives higher Delta salinity than the ANN CALSIM operation. As a result, the G-model CALSIM operation frequently violates water quality standards. At Rock Slough, the G-model operation exceeds the standard in 37 months (18% of the time) while the ANN operation exceeds the standard in only three months. At Jersey Point, the G-model operation exceeds the standard in 18 months (9% of the time) while the ANN operation exceeds the standard in only two months. Finally, at Emmaton, the G-model operation exceeds the standard in 10 months (5% of the time) while the ANN operation does not exceed the standard.

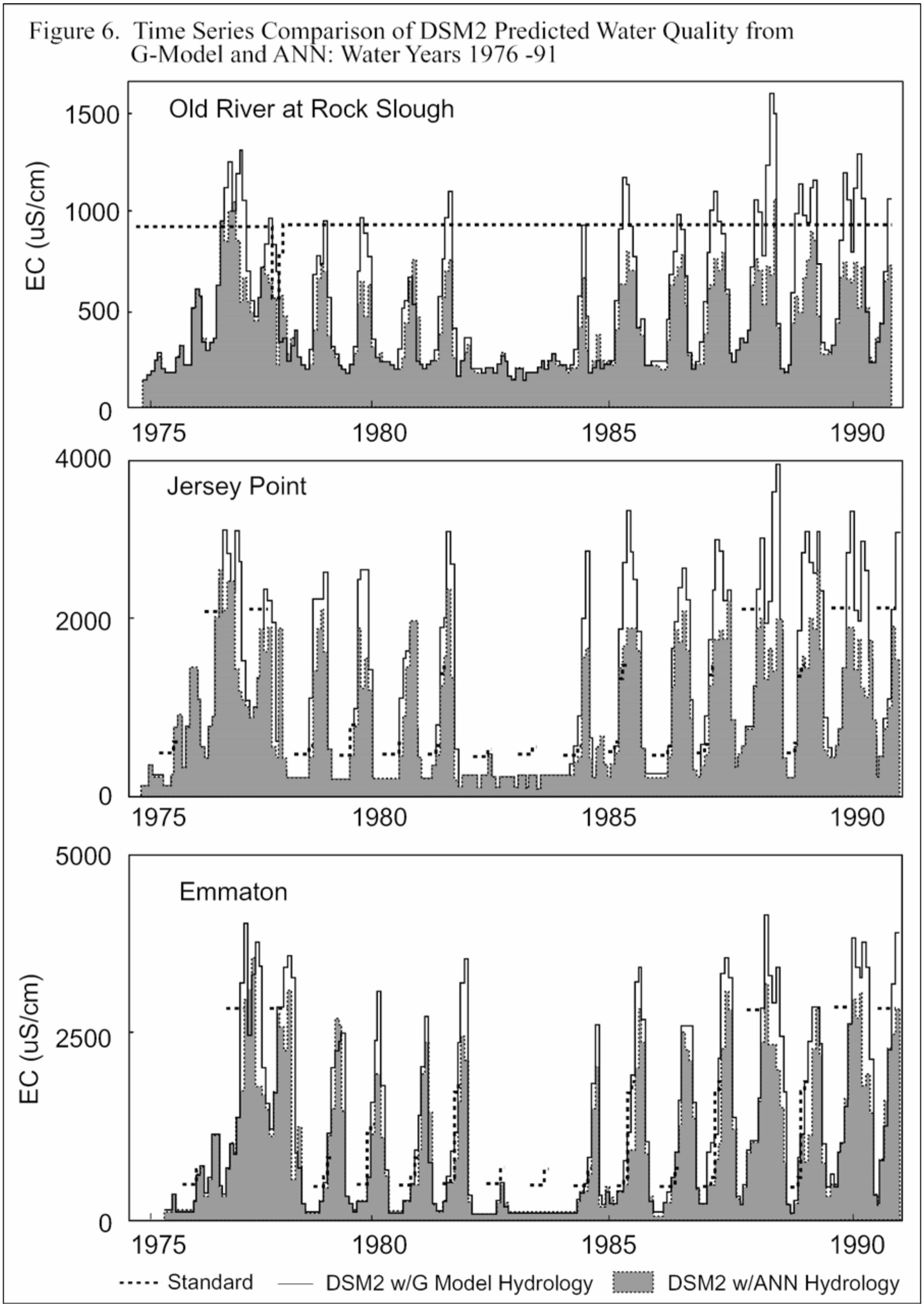

Figure 8-6: Time Series Comparison of DSM2 Predicted Water Quality from G-Model and ANN: Water Years 1976 – 1991.

8.4 Methodology for Estimating Carriage Water Requirements

A CALSIM study was designed to estimate a range of carriage water costs for each month of the year under a variety of water year types. The study defines carriage water as the additional volume of water necessary to transfer water across the Delta while maintaining water quality and ecological standards. Carriage water was released in the Sacramento River to accommodate water transfers from the Sacramento River Region to an unspecified South-of-Delta location. Water transfers from the San Joaquin River Region were not considered in this study. The initial study design considered water transfers of 30 TAF (500 cfs) and 60 TAF (1000 cfs).

8.4.1 Study Assumptions

CALSIM study assumptions are outlined below:

1. An artificial neural network (ANN) representation of the Delta was employed in CALSIM. The ANN was trained on data generated by the new production version of DSM2, which was recently calibrated by the IEP DSM2 Project Work Team.
2. The base CALSIM study is Study 898. Study 898 assumes 1995-level hydrology and demand levels and SWRCB Decision 1641 Delta standards.
3. Water transfers are independent of each other and have no impact on upstream or downstream system operations. A “position analysis” was employed to ensure the independence of each transfer. The Delta component was de-coupled from the upstream and downstream components of CALSIM.
4. The simulated transfer must meet all Delta constraints.
5. A Banks Pumping Plant capacity of 10,300 cfs was assumed. Water transfers that were constrained by this capacity were dropped from the analysis.
6. Downstream conveyance capacity constraints were not enforced.
7. Carriage water was not quantified in April and May, as pumping restrictions severely limit opportunities to transfer water in these months.
8. Extraordinarily high water requirements were not included in the carriage water estimates. In two months of the 30 TAF study (October 1947, October 1961), project operations could not meet the Rock Slough salinity standard and Sacramento River flow was constrained to 25,000 cfs. In these studies, water transfers did not trigger high water requirements to meet the Roe Island X2 standard.

8.4.2 Study Mechanics

A CALSIM “position analysis” was conducted to ensure the independence of each transfer and required the following steps:

1. Run base CALSIM Study 898.
2. Use output from Study 898 as initial conditions for the position analysis.
3. Simulate a 12-month period, beginning with a single water transfer in October 1921.
4. At the end of the 12-month period, reset all Delta conditions to the base condition in October 1992 (Study 898).
5. Simulate another 12-month period, beginning with a single water transfer in October 1922.
6. Repeat Steps 4 and 5 for the entire hydrologic period (water years 1922-94).
7. Repeat Steps 2 through 6 for other months.

8. Repeat Steps 2 through 6 for additional water transfer scenarios.

CALSIM was run 20 times (10 months x 2 transfer scenarios) in accordance with the steps outlined above.

8.5 Results

Tables 8-1 and 8-2 show 73-year average carriage water requirements by month and year type for transfers of 30 TAF (500 cfs) and 60 TAF (1000 cfs), respectively. Carriage water requirements are shown as percentages. Figures 8-7 and 8-8 show the same information graphically. Carriage water requirements are presented as average monthly flows rather than as percentages in the figures. The figures differentiate between salinity-based carriage water requirements and other carriage water requirements.

Table 8-1: Carriage Water Requirements for a 30-TAF Transfer by Month and Water Year Type (values in percent of transfer).

Table 1. Carriage Water Requirements for a 30 TAF Transfer by Month and Water Year Type (values in percent of transfer)

Year Type	Oct	Nov	Dec	Jan	Feb	Mar	Jun	Jul	Aug	Sep
Wet	23	-	-	-	-	-	78	-	4	-
Above / Below Normal	50	19	-	-	-	-	153	63	42	61
Dry / Critical	68	45	18	6	44	101	78	38	39	53

Table 8-2: Carriage Water Requirements for a 60-TAF Transfer by Month and Water Year Type (values in percent of transfer).

Table 2. Carriage Water Requirements for a 60 TAF Transfer by Month and Water Year Type (values in percent of transfer)

Year Type	Oct	Nov	Dec	Jan	Feb	Mar	Jun	Jul	Aug	Sep
Wet	16	-	-	-	-	-	74	-	-	-
Above / Below Normal	51	20	-	-	-	-	153	64	42	57
Dry / Critical	66	47	18	7	52	107	84	40	39	52

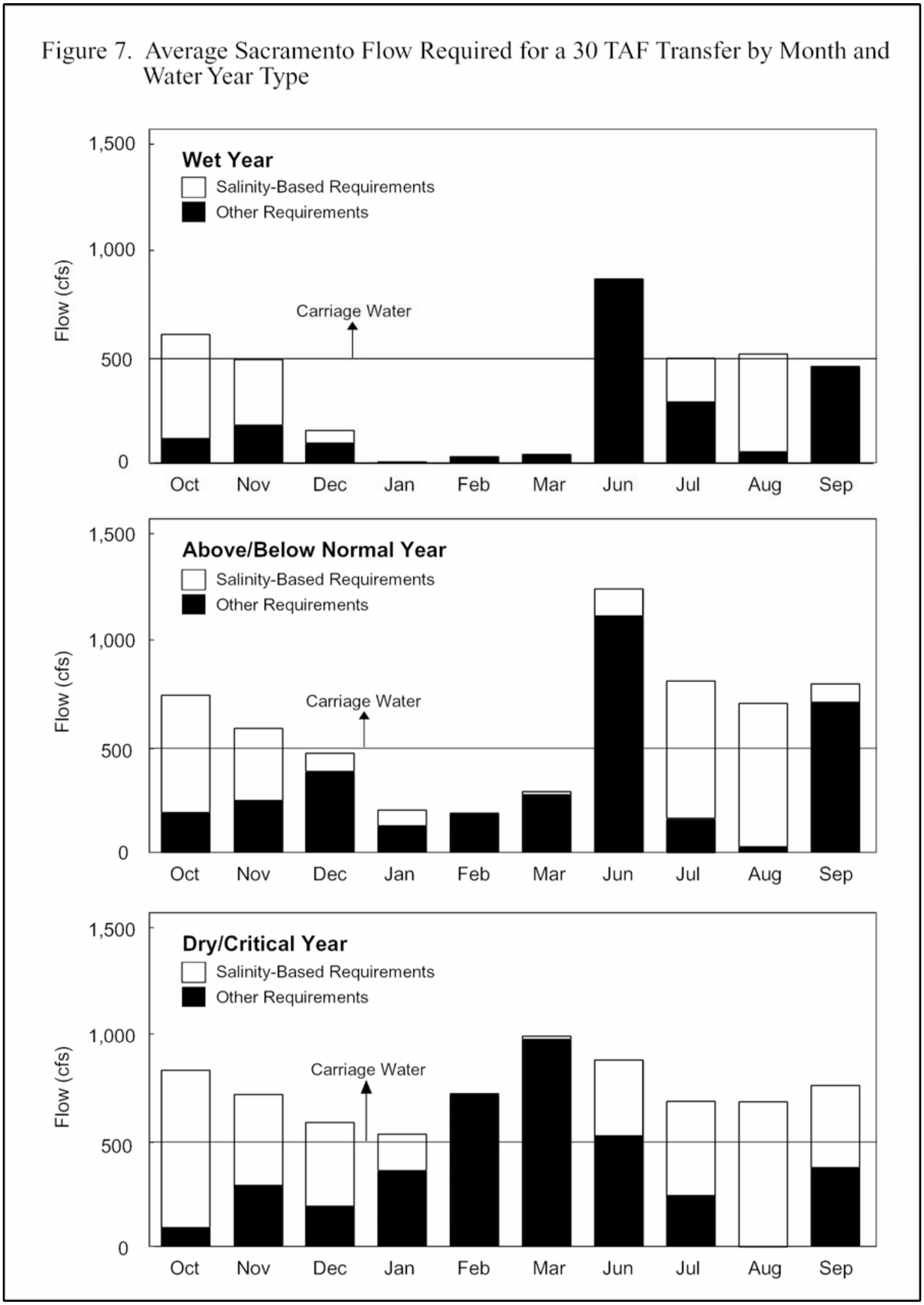

Figure 8-7: Average Sacramento Flow Required for a 30-TAF Transfer by Month and Water Year Type.

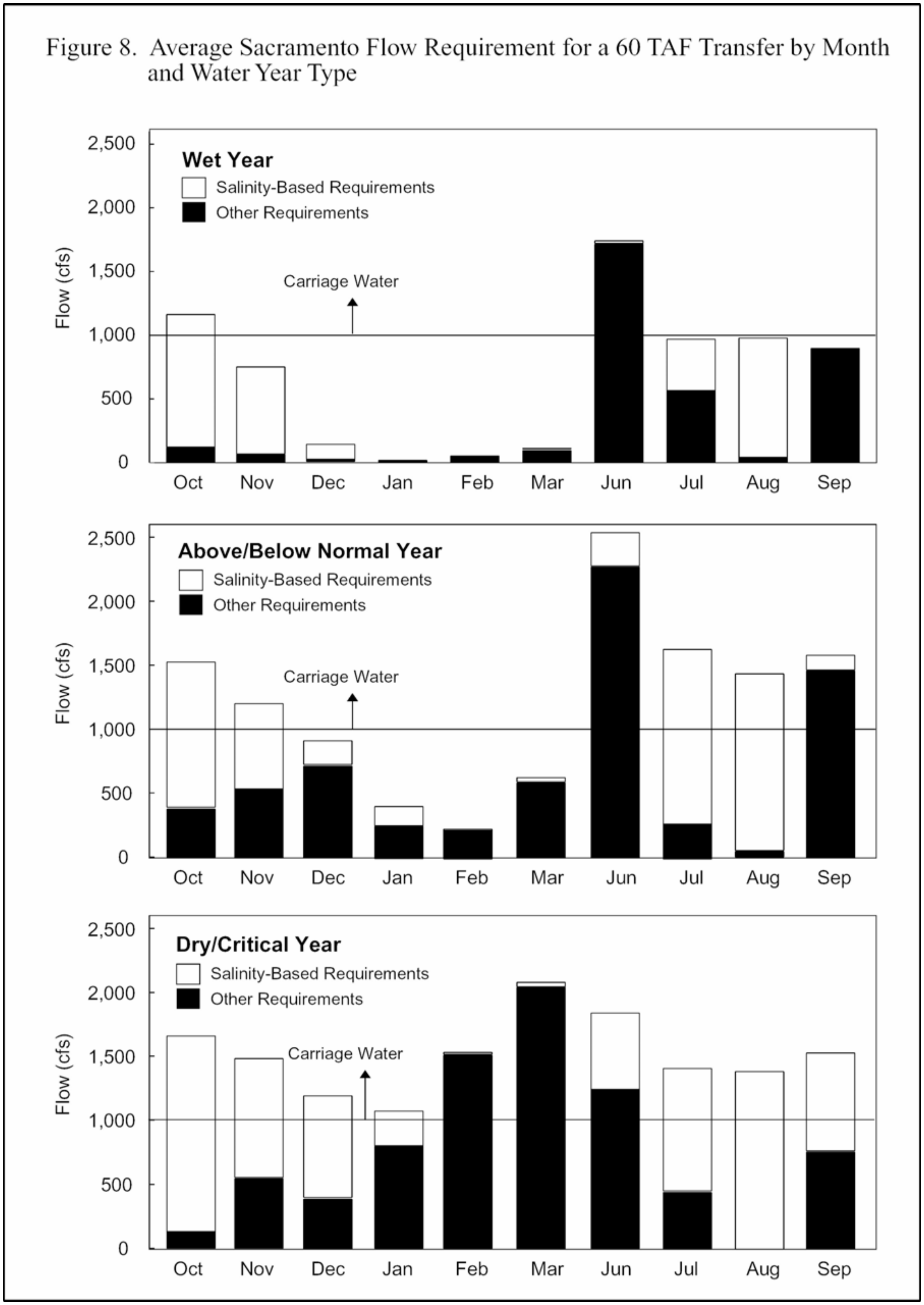

Figure 8-8: Average Sacramento Flow Requirement for a 60-TAF Transfer by Month and Water Year Type.

Key explanations and observations are provided below:

1. A 10 percent carriage water requirement suggests that, to export an additional 1,000 cfs from the South Delta, 1,100 cfs must be released upstream to meet Delta standards.

2. Several periods show no average carriage water requirement. In these months, the 73-year average upstream release required to export an additional 1,000 cfs from the south Delta vary up to 1000 cfs. Under certain hydrologic regimes, additional pumping draws water from the Sacramento River without significant salt intrusion, thus improving water quality in the south Delta.

3. Water year types are aggregated into three groups – wet, above/below normal, and dry/critical – to increase statistical sample sizes.

4. Carriage water requirements are sensitive to water year type, particularly those requirements associated with meeting salinity standards. In wet years, average carriage water requirements are at or near zero except during the months of October and June. In above/below normal water years, average carriage water requirements are typical in summer and fall months. In dry/critical water years, average carriage water requirements exist in all months.

5. The month of June is of special significance, showing high 73-year average carriage water requirements, regardless of water year type. The E/I ratio of 0.35 often controls in June, requiring 2.86 units of additional inflow for every additional unit of export (1/0.35). This additional inflow increases Delta outflow by 1.86 units (2.86 – 1) and results in a 186% carriage water requirement. Average carriage water requirements are significantly higher in June of above/below normal water years than in dry/critical water years. This is because the E/I ratio usually controls in June of above/below normal water years but rarely controls in June of dry/critical water years.

6. The month of October is also of special significance, showing a significant 73-year average carriage water requirement in all water year types. The CCC PP #1 salinity standard is often controlling in October. Table 8-2 shows an average carriage water requirement in the range of 20 to 70%.

7. The CCC PP #1 salinity standard often controls in November, December, and January of dry/critical water years and results in average carriage water costs of 10 to 50%. Meeting the E/I ratio in November of above/below normal water years typically requires carriage water of 20%.

8. February and March show 73-year average carriage water requirements of 40 to 110% in dry/critical water years to meet E/I standards.

9. Minimum outflow and Jersey Point salinity standards typically control in July and August, and result in average carriage water costs in the range of 40 to 60% in above/below normal years and approximately 40% in dry/critical water years. Average July carriage water requirements are significantly higher in above/below normal water years than in dry/critical

water years. This is because the Jersey Point salinity standard is more stringent in above/below normal water years.

10. The month of September shows 73-year average carriage water requirements in the range of 50 to 60% in all but wet water years. The E/I ratio controls more frequently in above/below water years and the CCC PP #1 salinity standard controls more frequently in dry/critical water years.

Differences in 73-year average carriage water requirements (on a percent basis) between the 30-TAF transfer and the 60-TAF transfer are not significant. See Figure 8-9 for a comparison.

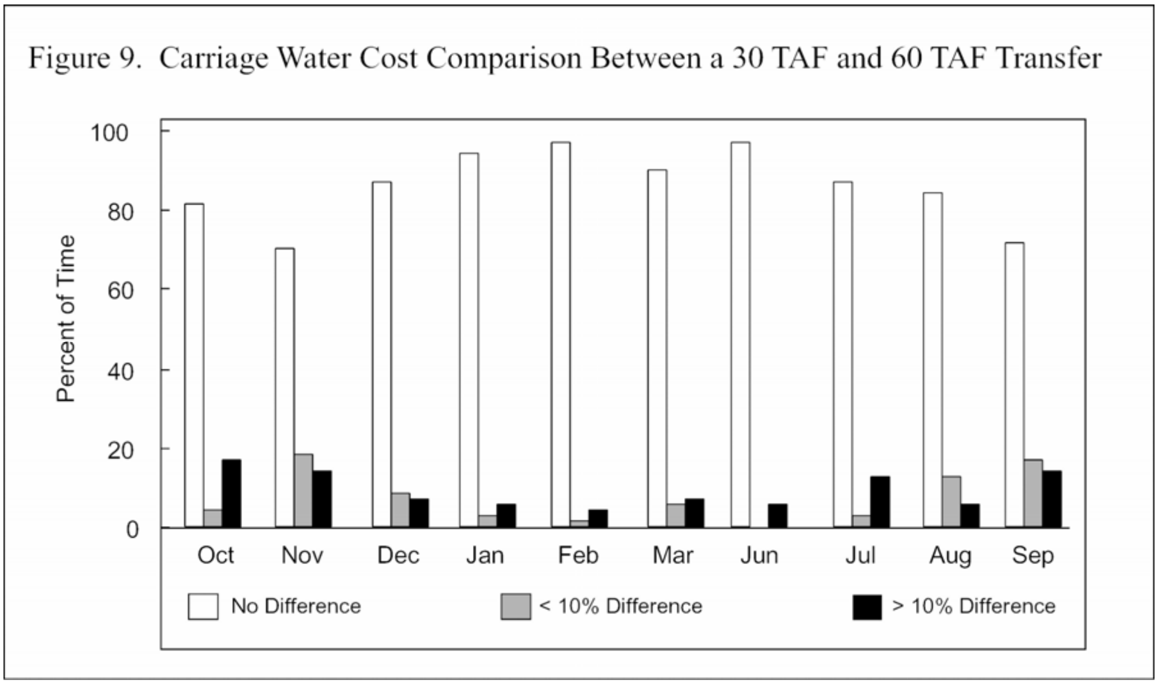

Figure 8-9: Carriage Water Cost Comparison Between a 30-TAF and 60-TAF Transfer.

Carriage water is sometimes required in months subsequent to the transfer month. Table 8-3 illustrates this “lag” carriage water effect over the 73-year hydrologic sequence when 60 TAF (1000 cfs) is transferred in September. In many years, particularly during dry/critical water years, carriage water is required in September to meet outflow or salinity standards. However, even with this additional release of water, additional pumping results in Delta water quality degradation and triggers the CCC PP #1 salinity standard in October. Additional water must be released in October to meet the standard; and this additional carriage water is assessed to the September transfer. While this lag effect can be significant for a particular transfer, it is small over a 73-year average.

Table 8-3: Required Sacramento Flow for September Water Transfers (60 TAF) Over the 73-year Hydrologic Sequence.

Table 3. Required Sacramento Flow for September Water Transfers (60 TAF) Over the 73-year Hydrologic Sequence

		Required Sac Flow (cfs)				Required Sac Flow (cfs)				Required Sac Flow (cfs)	
Year	Type	Sep	Oct	Year	Type	Sep	Oct	Year	Type	Sep	Oct
1922	AN	1538	0	1951	AN	1538	0	1981	D	1124	810
1923	BN	1538	0	1952	W	0	0	1982	W	0	0
1924	C	1000	703	1953	W	1538	0	1983	W	0	0
1925	D	1538	0	1954	AN	1538	0	1984	W	1538	0
1926	D	1000	0	1955	D	1459	0	1985	D	1432	0
1927	W	1538	0	1956	W	1538	0	1986	W	1538	0
1928	AN	1538	0	1957	AN	1538	0	1987	D	1000	789
1929	C	1448	0	1958	W	0	0	1988	C	1478	0
1930	D	1130	444	1959	BN	1538	0	1989	D	1538	0
1931	C	1402	0	1960	D	1538	0	1990	C	1451	0
1932	D	1534	0	1961	D	1043	476	1991	C	1504	0
1933	C	1456	0	1962	BN	1538	0	1992	C	1473	0
1934	C	1440	0	1963	W	1538	0				
1935	BN	1000	1028	1964	D	1000	0				
1936	BN	1538	0	1965	W	1538	0				
1937	BN	1260	329	1966	BN	1410	0				
1938	W	0	0	1967	W	0	0				
1939	D	1000	983	1968	BN	1086	615				
1940	AN	1538	0	1969	W	0	0				
1941	W	1538	0	1970	W	1538	0				
1942	W	1538	0	1971	W	1164	0				
1943	W	1538	0	1972	BN	1538	0				
1944	D	1000	1072	1973	AN	1538	0				
1945	BN	1133	644	1974	W	0	0				
1946	BN	1538	0	1975	W	796	0				
1947	D	1000	0	1976	C	1000	913				
1948	BN	1538	0	1977	C	1342	0				
1949	D	1538	0	1978	AN	1538	0				
1950	BN	1538	0	1979	BN	1538	0				
1951	AN	1538	0	1980	AN	1538	0				

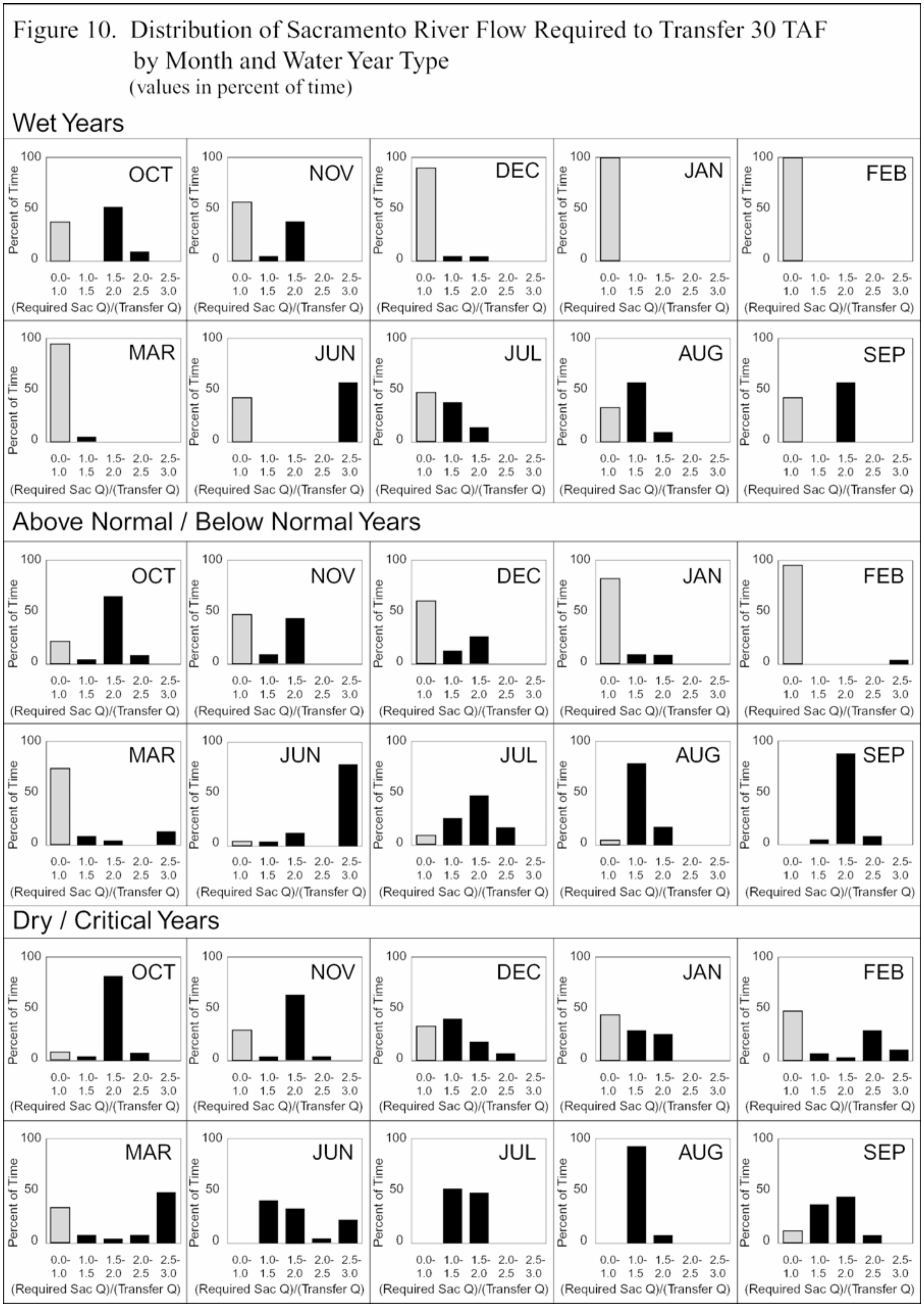

Figure 8-10: Distribution of Sacramento River Flow Required to Transfer 30 TAF by Month and Water Year Type.

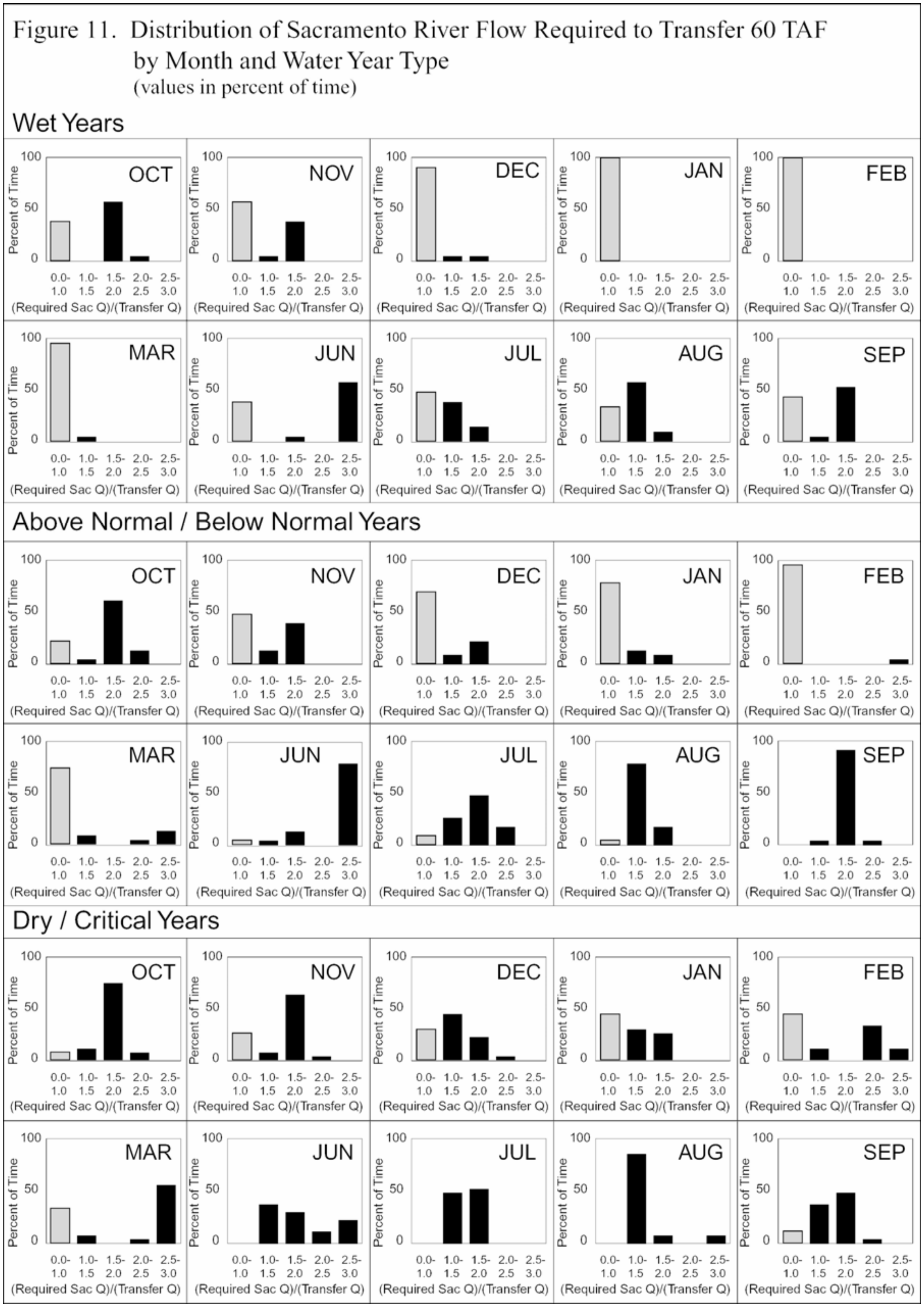

Figure 8-11: Distribution of Sacramento River Flow Required to Transfer 60 TAF by Month and Water Year Type.

Carriage water requirements can vary widely from year to year, depending on the particular monthly hydrology and Delta operation. Figures 8-10 and 8-11 show the carriage water requirement frequency by month and year type for transfers of 30 TAF (500 cfs) and 60 TAF (1000 cfs), respectively. Carriage water requirements are shown in these figures as the ratio of required Sacramento River flow to transfer flow. Consider a 60-TAF (1000 cfs) transfer in September of wet years. While Table 8-2 shows no average carriage water requirement for such a transfer, Table 3 reveals a Sacramento River flow requirement of 1,538 cfs in 11 of 21 wet years over the 73-year hydrologic sequence. The additional wet year flow is needed to meet the E/I standard. In other words, even though a 60-TAF transfer in September of wet years has no carriage water requirement on average, such a transfer would have a 54% carriage water requirement roughly half the time.

8.6 Discussion

8.6.1 Significance of Results

This study shows that ANN technology provides a fast and accurate method of approximating the flow-salinity relationships in DSM2, and therefore is a good candidate for modeling Delta salinity standards in CALSIM. The ANN approach will be adopted in CALSIM 2. Adopting ANN will have some impact on CALSIM base study water supply.

This study, which is the first to quantify Sacramento River water transfer costs over a long-term hydrologic sequence, supports DWR's typical carriage water assessments of 10 to 30%. As expected, the study shows carriage water costs to be fairly sensitive to water year type. Carriage water costs associated with meeting salinity standards are particularly sensitive to water year type. Over the long-term period, carriage water costs are small in wet water years and large in dry/critical water years. Carriage water costs in above/below normal water years are typical in summer and fall months. June uniquely shows high carriage water costs to meet E/I requirements, regardless of water year type. The department or other interested parties may wish to consider alternate statistical approaches to presenting carriage water results.

8.6.2 Using DSM2 to Quantify Carriage Water Costs

Tables such as those provided in Tables 8-1 and 8-2 should provide an appropriate level of detail for many planning-level carriage water estimates, including those needed for the State Board’s Term 91 computations. However, it is noteworthy that DSM2 could be used to obtain a refined estimate of carriage water costs associated with a specific water transfer. In a practical application, the following steps could be followed to estimate carriage water costs for a specific water transfer:

1. Utilize the carriage water table to arrive at a reconnaissance-level carriage water estimate.
2. Update the carriage water estimate 2 to 3 weeks before the water transfer is to take place through a DSM2 forecast simulation.
3. Estimate the realized carriage water requirement after the water transfer has taken place through a DSM2 postcast simulation.

8.6.3 Negotiations with BDMF

The findings of this report have been shared with the BDMF Carriage Water Review Team. It is the intent of this team to reach a settlement among interested parties regarding the calculation of carriage water. If the team members do not reach a consensus, this report will provide the department with information on which to base its individual testimony regarding carriage water requirements.

8.6.4 Future Refinements

The carriage water estimates provided in this report will be updated as new information and model enhancements become available. In particular, carriage water estimates will be updated to include input from the BDMF Carriage Water Review Team and to reflect progress in baseline modeling of CVPIA b(2) and EWA operations.

8.7 References

California Department of Water Resources. (1987). Summary of SWRCB Phase I Testimony by Mike Ford on Export-Outflow Relationships. Exhibits DWR-260 through DWR-264. July.

California Department of Water Resources. (1991). Implementation of Delta Water Quality Standards in DWRSIM. Unpublished memorandum report, May.

California Department of Water Resources. (2000). Integration of CALSIM and Artificial Neural Network Models for Sacramento-San Joaquin Delta Flow-Salinity Relationships. Unpublished memorandum report, December.

Denton, R. and G. Sullivan. (1993). *Antecedent Flow-Salinity Relations: Application to Delta Planning Models*. Contra Costa Water District.

Sandhu, N., D. Wilson, and R. Finch. (1999). *Modeling Flow-Salinity Relationships in the Sacramento-San Joaquin Delta Using Artificial Neural Networks*. Technical Information Record OSP-99-1. California Department of Water Resources. Sacramento, CA.