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

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Chapter 3
Enhanced Development of Flow-Salinity Relationships in the Delta Using Artificial Neural Networks: Incorporating Tidal Influence

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3.1 Introduction

The Sacramento-San Joaquin Delta (Figure 3-1) covers 738,000 acres interlaced with hundreds of miles of waterways. Much of the land is below sea level and relies on more than 1,000 miles of levees for protection against flooding. The Delta is unique, a valuable resource, and an integral part of California's water system. It receives runoff from 40 percent of the state's land area including Sacramento, San Joaquin, and east side streams. Its land and waterways support communities, agriculture, and recreation. The Delta is the nexus for water distribution throughout the state.

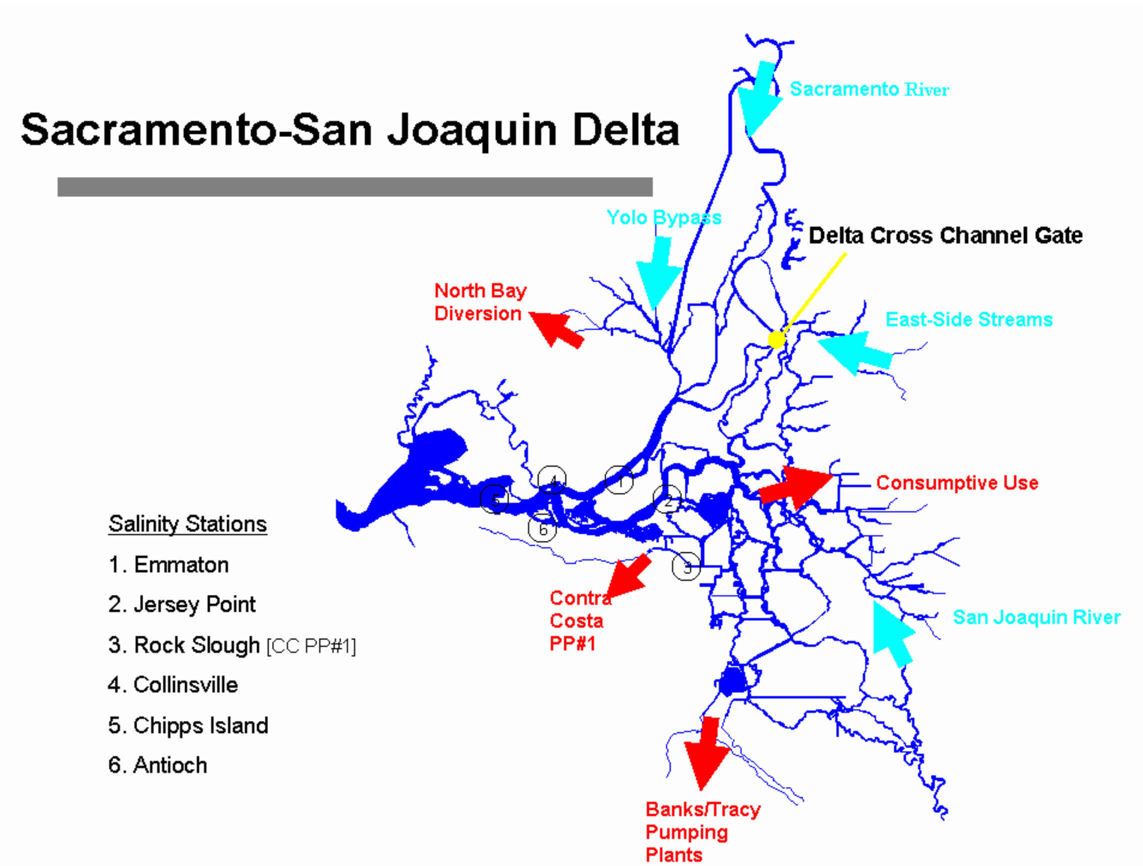


Figure 3-1 Sacramento-San Joaquin Delta

Water Resources Integrated Modeling System (WRIMS) is a generalized water resources simulation model for evaluating alternatives in a water resources system. CalSim II is an application of WRIMS, specifically used as a planning tool to simulate the State Water Project (SWP) and the U.S. Bureau of Reclamation Central Valley Project (CVP). CalSim II has been applied to simulate the SWP and CVP systems at various levels of development, system configurations, and demand scenarios and operations rules. One such operation rule is the salinity standards imposed at various locations in the Delta to protect the environment of the Delta. Currently, the controlling locations in CalSim II are Rock Slough, Jersey Point, Emmaton, Collinsville, Chipps Island, and Antioch.

DWR's 1D Delta simulation model DSM2 calculates stages, flows, and velocities; many mass transport processes, including salts, multiple non-conservative water quality constituents, temperature, THM formation potential; and particle tracking. To simulate 1 year of salinity in the Delta, DSM2 takes about 20 minutes of computing time in a 3.0 GHz Windows XP machine. This extensive computing time makes it infeasible to use DSM2 to calculate salinity at controlling locations in CalSim II.

Artificial Neural Networks (ANNs) were used to develop flow-salinity relationships in the Delta, enabling fast predictions of salinity at the controlling locations (Finch 1995; Sandhu and Finch 1995; Sandhu 1996; Sandhu and Wilson 1997; Wilson 1998; Sandhu and et al. 1999; Pranger 2000; Wilbur and Munevar 2001; Hutton and Seneviratne 2001; Mierzwa 2002). Because ANNs can accept multiple inputs of different units, carriage water need not be defined as zero and gate positions and other operations can potentially be modeled. ANNs are considered universal approximators, theoretically capable of modeling any continuous nonlinear function. With a proper network design and training (calibration), an ANN can be reasonably accurate and robust on new data.

3.2 Full Circle Analysis

The steps of a *full circle* analysis are:

1. Start with CalSim II with generic ANN or g-model, run a study, and generate output.
2. Run DSM2 with CalSim II outputs from step 1.
3. Train ANN with CalSim II and DSM2 outputs from steps 1 and 2.
4. Put newly trained ANN in CalSim II, run, and generate output.
5. Run DSM2 with output from step 4 and compare DSM2 output salinities with ANN salinities.

Several DSM2 studies with varied inflows and Delta operations were used to generate data for training of ANNs. Until 2005, four inputs (Northern and Eastern flows, San Joaquin flow, combined exports and consumptive use, and Delta Cross Channel operation) were used to train ANNs; these were implemented in CalSim II. The CalSim study that contains the trained ANN is used in DSM2 to calculate the electrical conductivity (EC) at some key locations in the Delta. Comparison between DSM2 results and ANN-generated EC in CalSim II will give an indication of the ability to mimic DSM2-simulated EC with ANNs. Of the six salinity standard locations in the Delta, we found that in the three western-most stations (Collinsville, Antioch and Chipps Island) ANNs always yielded good results. Hence, EC comparisons at Emmaton, Jersey Point, and Old River at Rock Slough (ORRSL) are shown (Figures 3-2—3-4). Although these results showed a fairly good comparison between DSM2 results and the ANN-generated CalSim II results, the scatter in the ORRSL station caused unacceptable and unpredicted water demand.

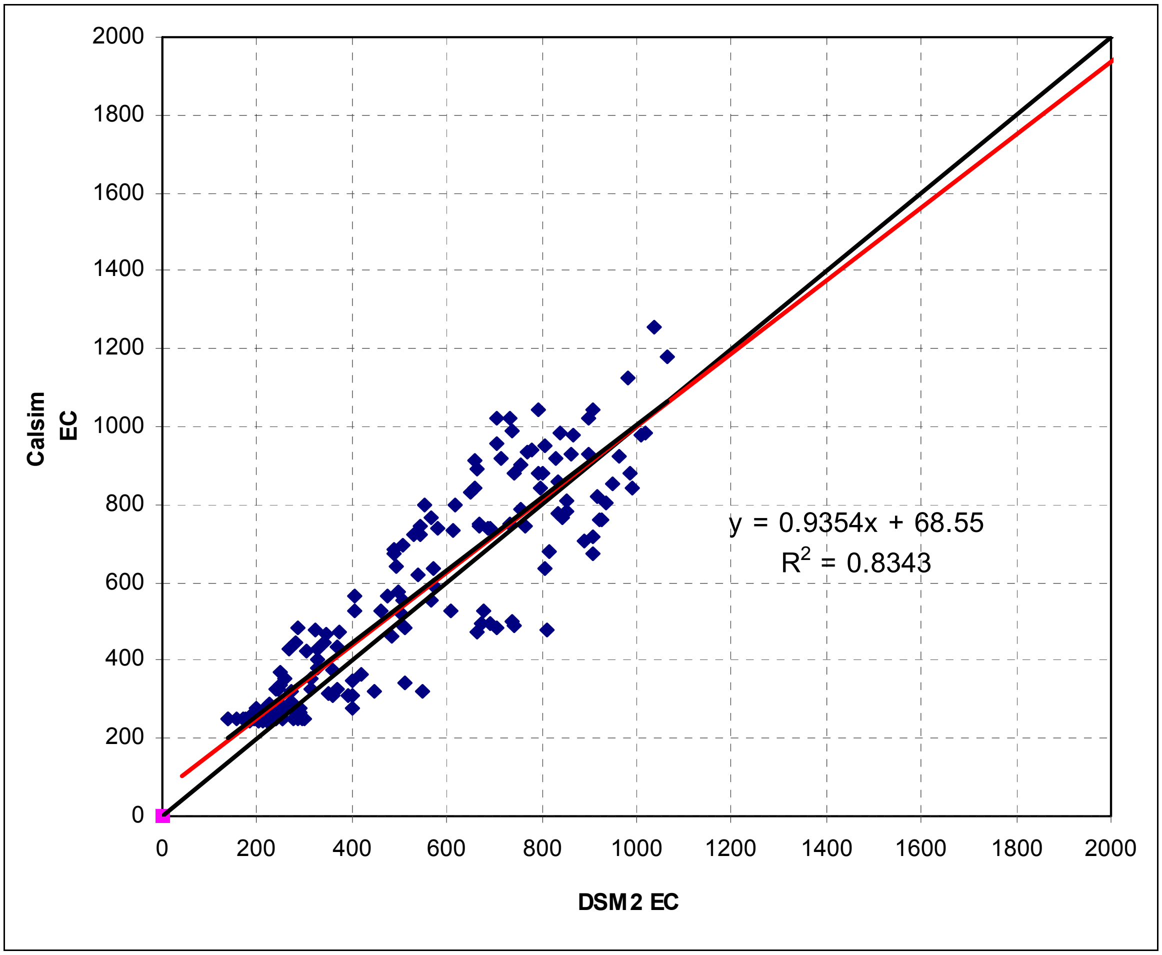


Figure 3-2 Four-Input ANN vs DSM2—Old River at Rock Slough

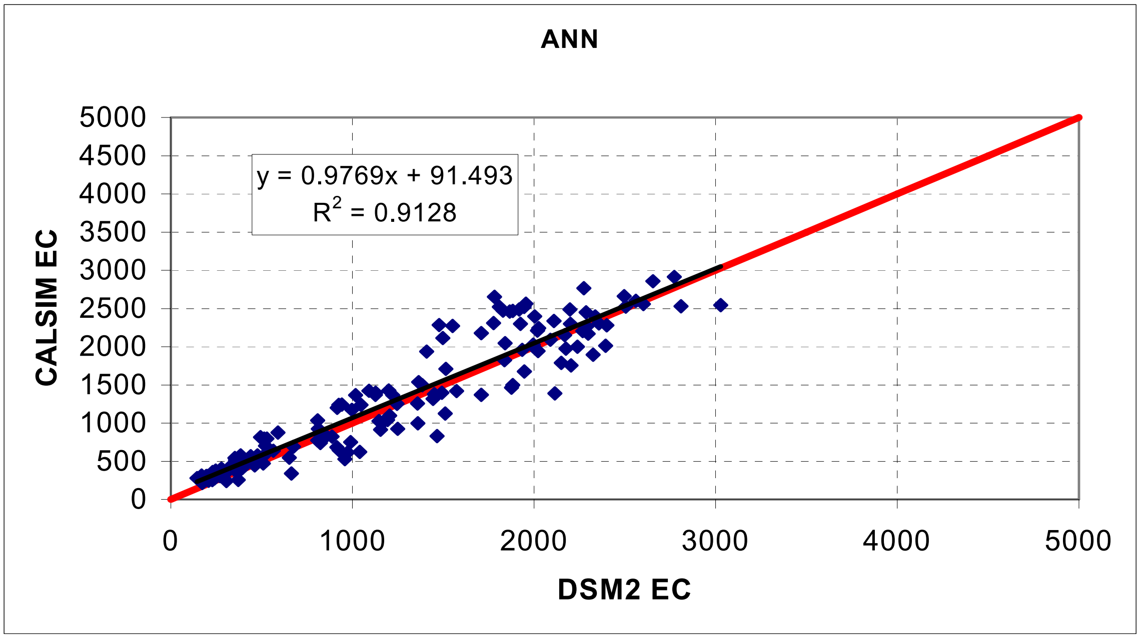


Figure 3-3 Four-Input ANN vs DSM2—Jersey Point

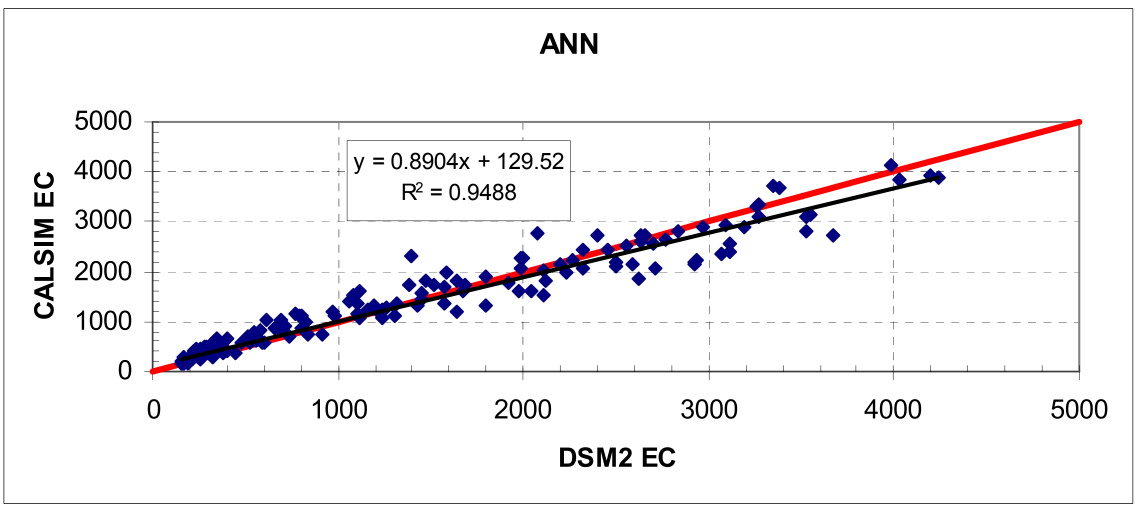


Figure 3-4 Four-Input ANN vs DSM2—Emmaton

3.3 Development of Enhanced Flow-Salinity Relationships

In February 2005, we began using the ANN toolkit in MATLAB to develop flow-salinity relationships because of high quality routines, software maintenance, and plotting capabilities. The following five scenarios were used in developing the hydrology for five different DSM2 studies between water years 1976 through 1991. We chose these scenarios to ensure that training (calibration) data encompassed a wide range of hydrology.

1. D1641
2. D1485
3. 2020 Level of Demand
4. Current level of Demand
5. 10,300 Banks pumping capacity

For the purpose of training the ANNs, each study was randomly perturbed up to ±30%. Of all the results, 80% were used for training ANNs, and 20% were used as verification. The data used for training were randomly selected. The following six inputs were used in ANNs to predict the salinity at the controlled locations. Other than separating the Delta consumptive use from exports, inclusion of tidal range was the major difference from the previous ANN.

1. Northern flows: Sacramento River + Yolo Bypass + East streams + Calaveras – (North Bay and Vallejo Exports)
2. San Joaquin River Flow
3. Exports: Banks, Tracy, Contra Costa diversions
4. Delta Cross Channel Gate: Open or Close
5. Net Delta Consumptive Use
6. Tidal Energy {(daily maximum – daily minimum), from NOAA forecast tide web site}

Full circle analysis for the study period (water years 1976 through 1991) yielded good results. In order to check the validity and robustness of the ANNs, the full circle study was expanded to include the data for water years 1923 through 1991. Results of the expanded full circle analysis are shown in Figures 3-5 through 3-7. These results show that the new six-input ANNs are better able to predict DSM2 results for any range of hydrology than the four-input ANNs.

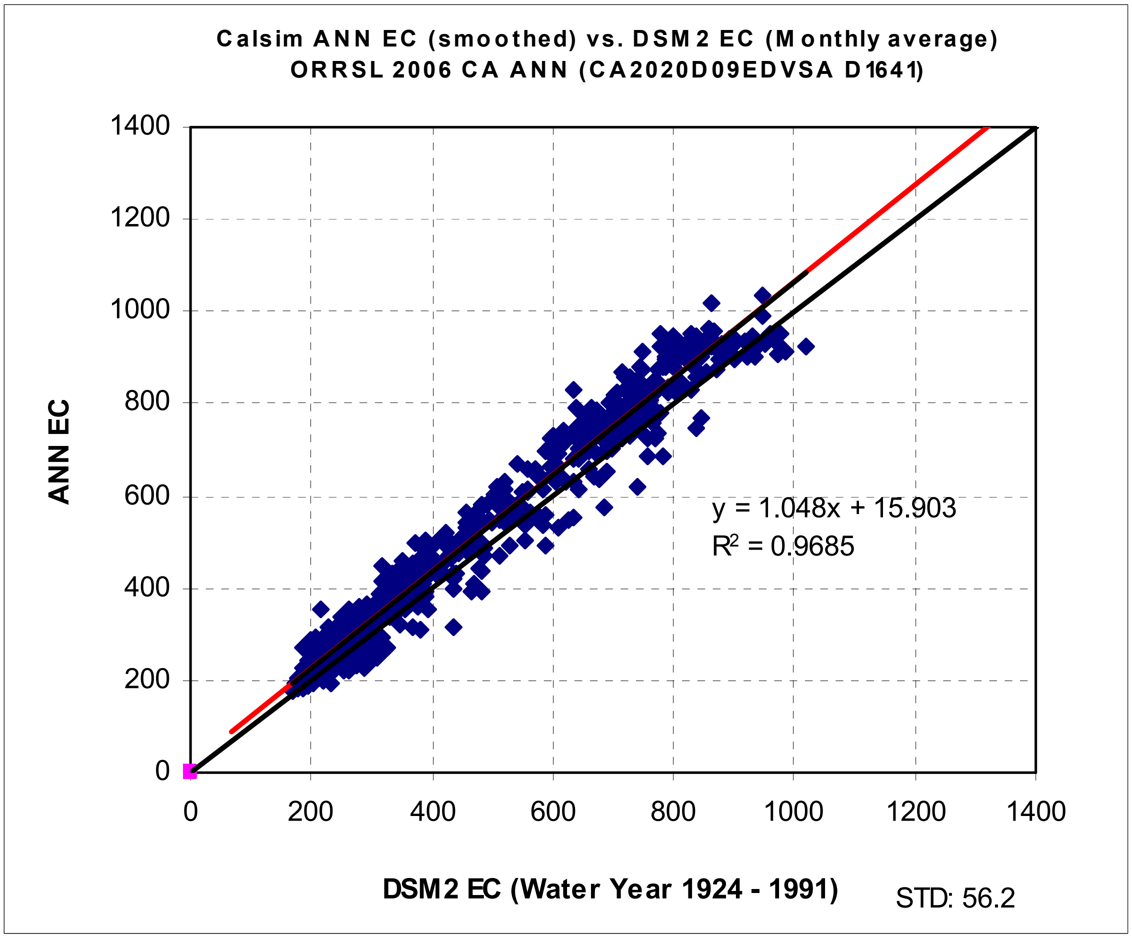


Figure 3-5 Six-Input ANN vs DSM2—Old River at Rock Slough

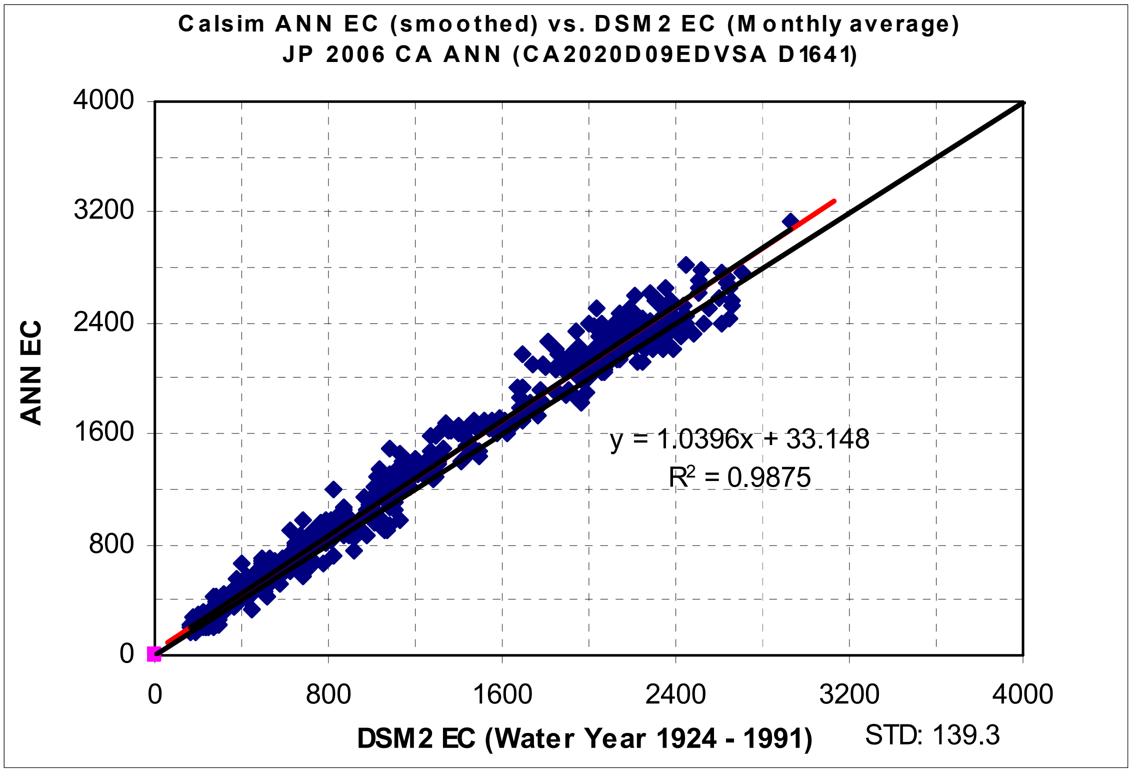


Figure 3-6 Six-Input ANN vs DSM2—Jersey Point

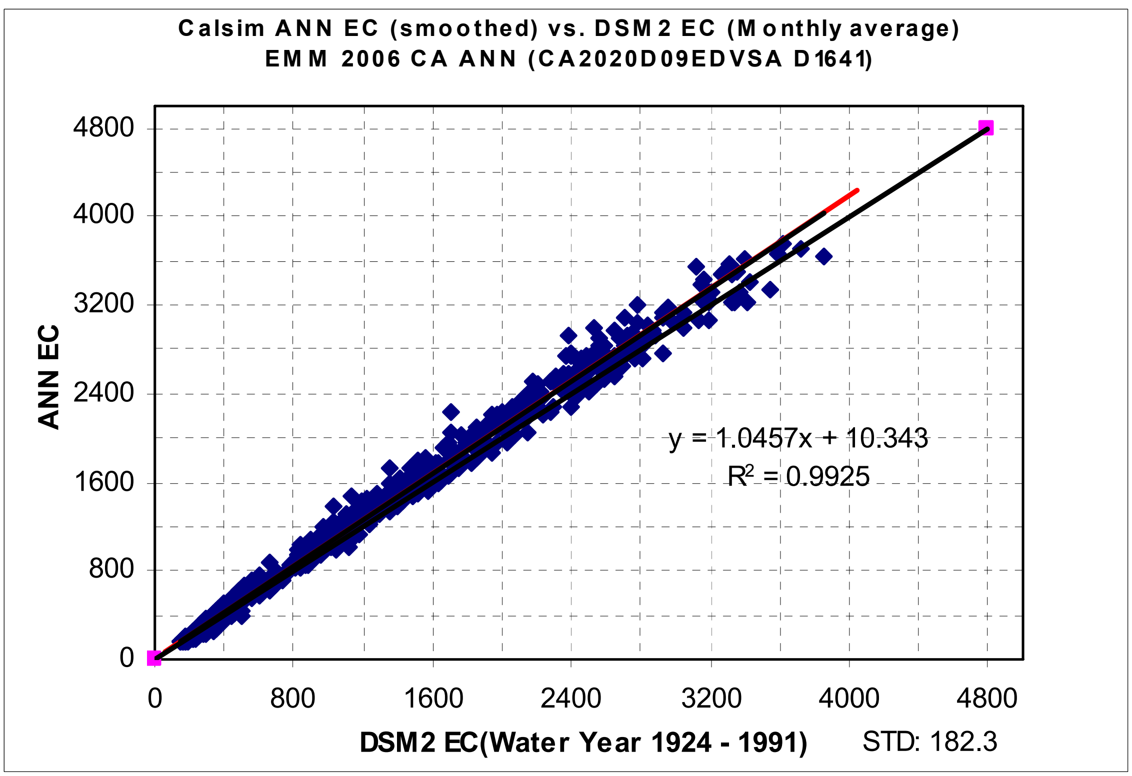


Figure 3-7 Six-Input ANN vs DSM2—Emmaton

While doing the study, we observed the scatter for the study period (water years 1976 through 1991) was much less than for the period water years 1923 through 1991. The following plots (Figures 3-8 through 3-11) show the comparison between ANN- and DSM2-simulated EC for the different study periods, all at Old River at Rock Slough.

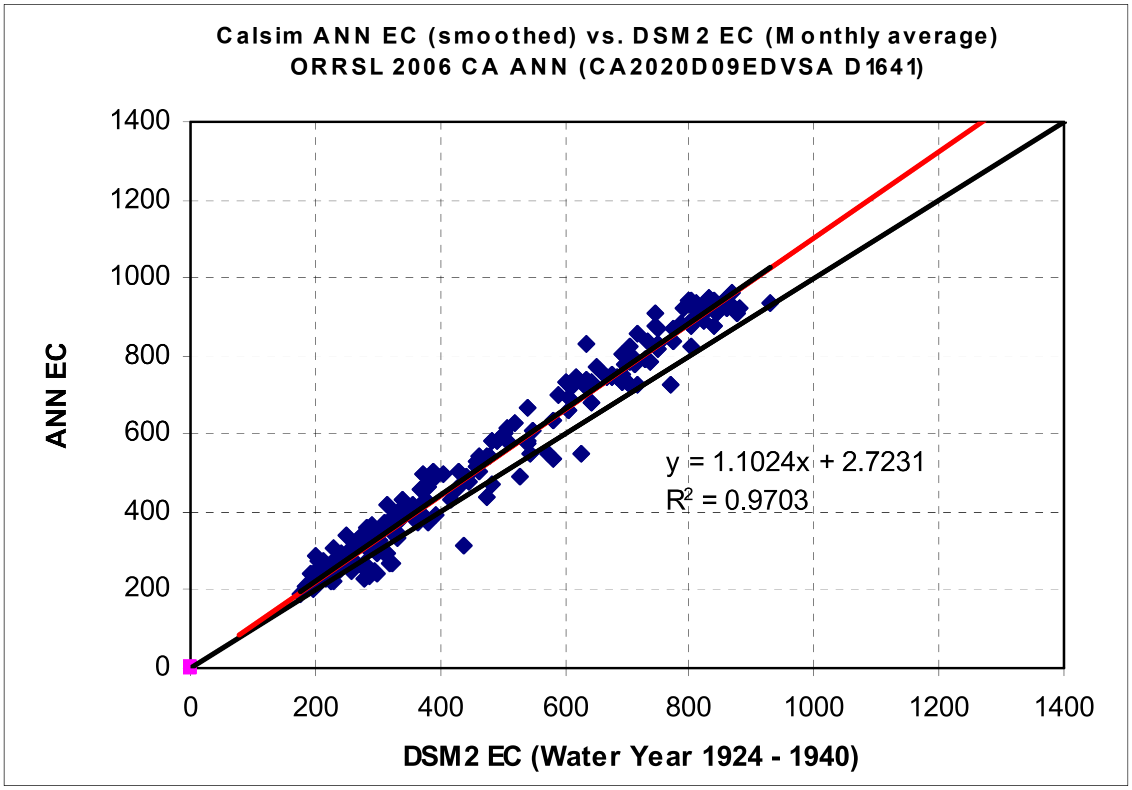


Figure 3-8 Six-Input ANN vs DSM2 WYs 1924-1940—Old River at Rock Slough

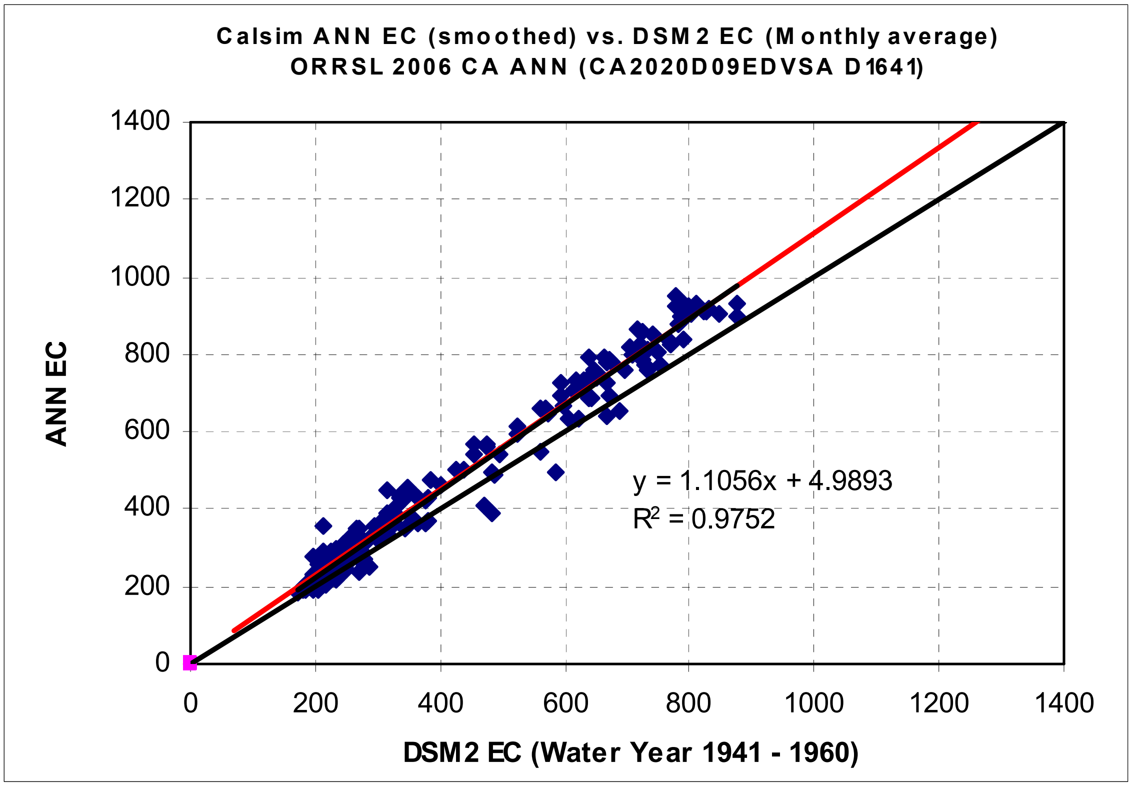


Figure 3-9 Six-Input ANN vs DSM2 WYs 1941-1960—Old River at Rock Slough

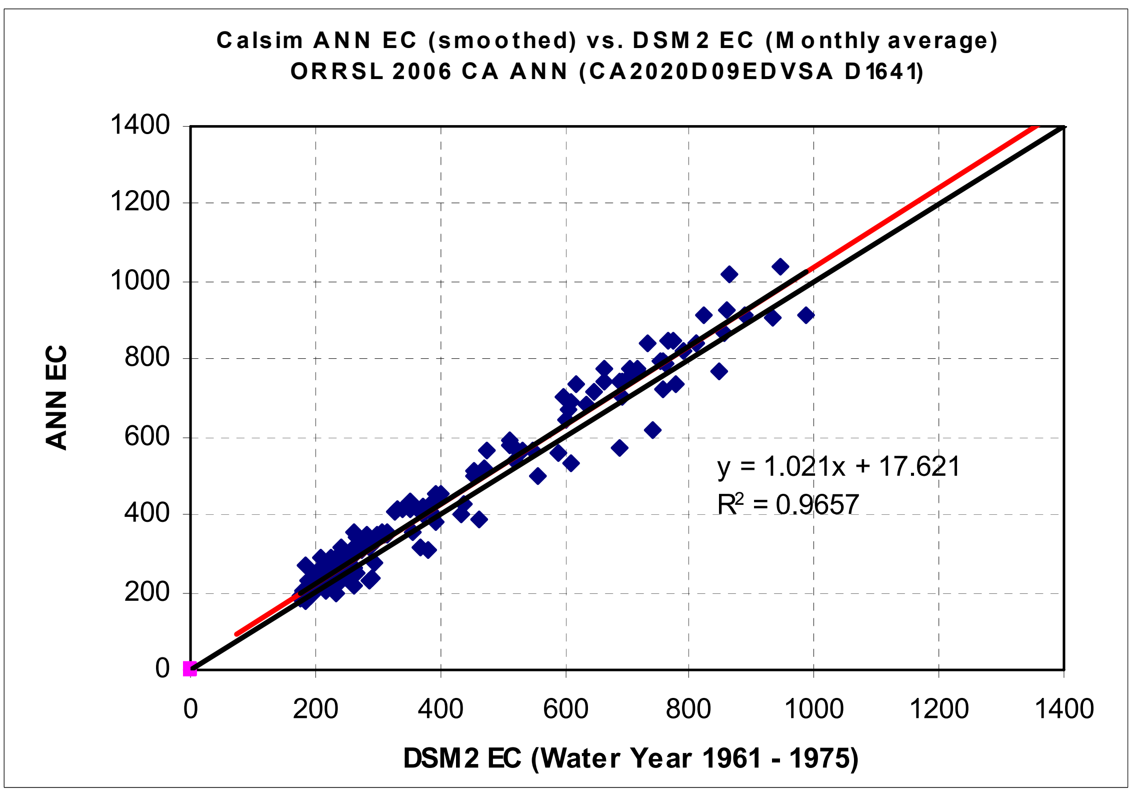


Figure 3-10 Six-Input ANN vs DSM2 WYs 1961-1975—Old River at Rock Slough

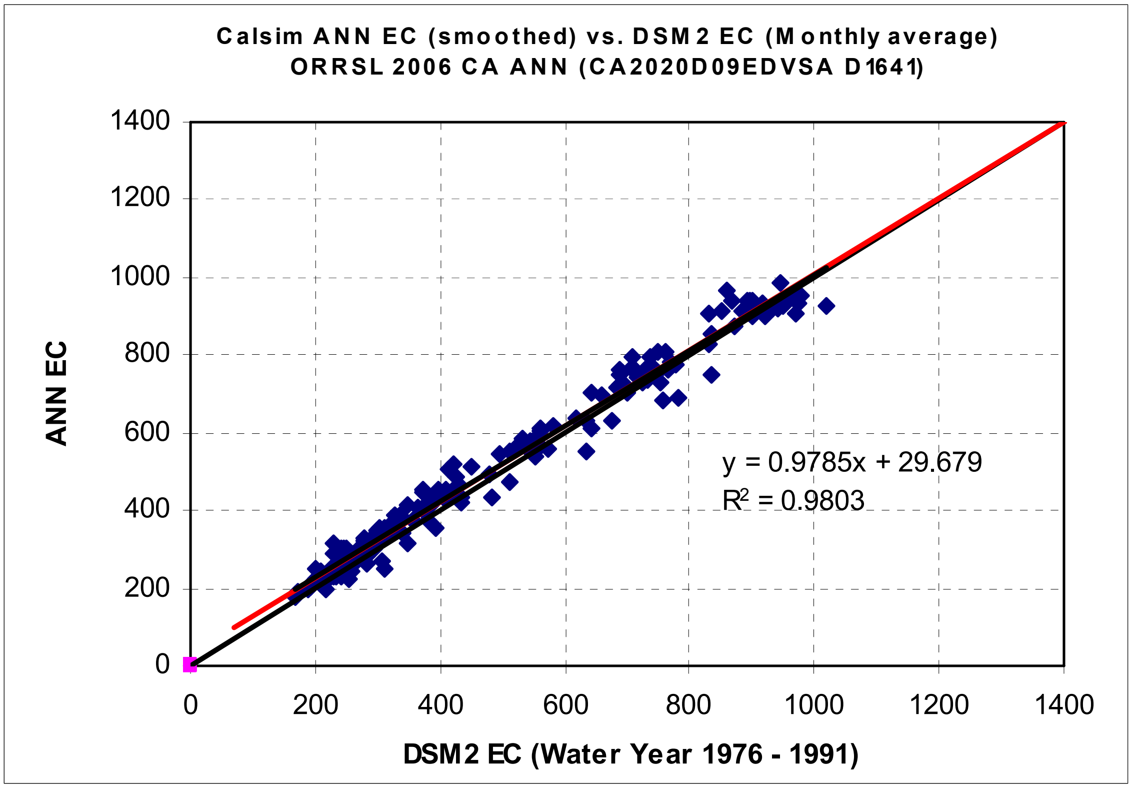
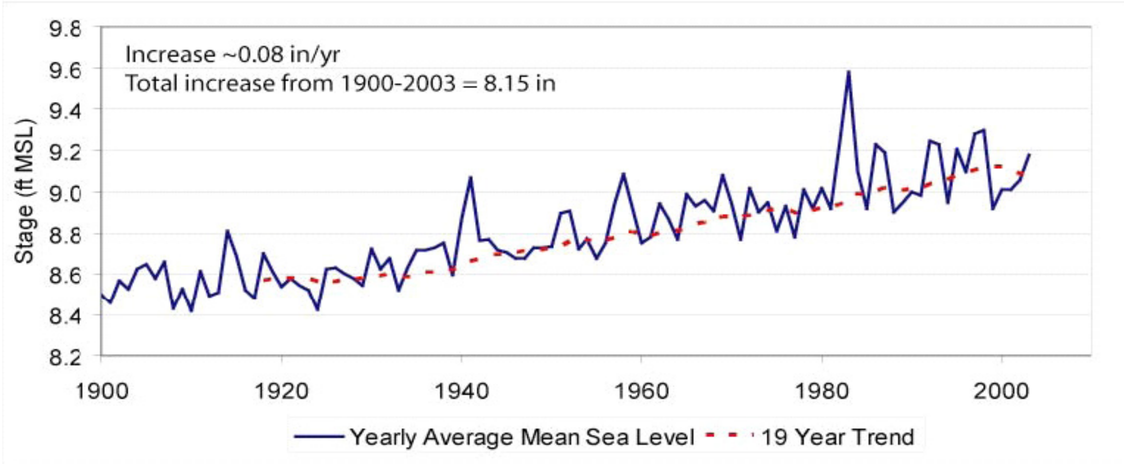


Figure 3-11 Six-Input ANN vs DSM2 WYs 1976-1991—Old River at Rock Slough

The four study periods show similar scatter (R^2 values). However the line of best fit (upper line) departs from the 45-degree slope line in the early part of the simulation, but in the last 16 years, the two lines are very close together. This means that DSM2 had lower EC values than the ANN in the first half of the simulation and, in the last 16 years, the DSM2-simulated EC was almost identical to the ANN-generated EC.

The effects of sea level rise were investigated to determine why DSM2 and ANN comparison differed over time. The mean sea level at Golden Gate is shown in Figure 3-12 (DWR 2006). This graph shows that in the early part of the century sea levels were more than 8 inches below the current levels, thus possibly leading to lower EC values.



Source: DWR 2006

Figure 3-12 Sea Level Rise and Trend—Golden Gate

To eliminate the effects of sea level rise, a new planning tide was developed (Ateljevich and Yu 2007). When this tide was used, DSM2-simulated EC values increased in the years prior to 1991 due to a higher boundary stage. The full circle study results with sea level rise removed are shown in Figures 3-13 through 3-16.

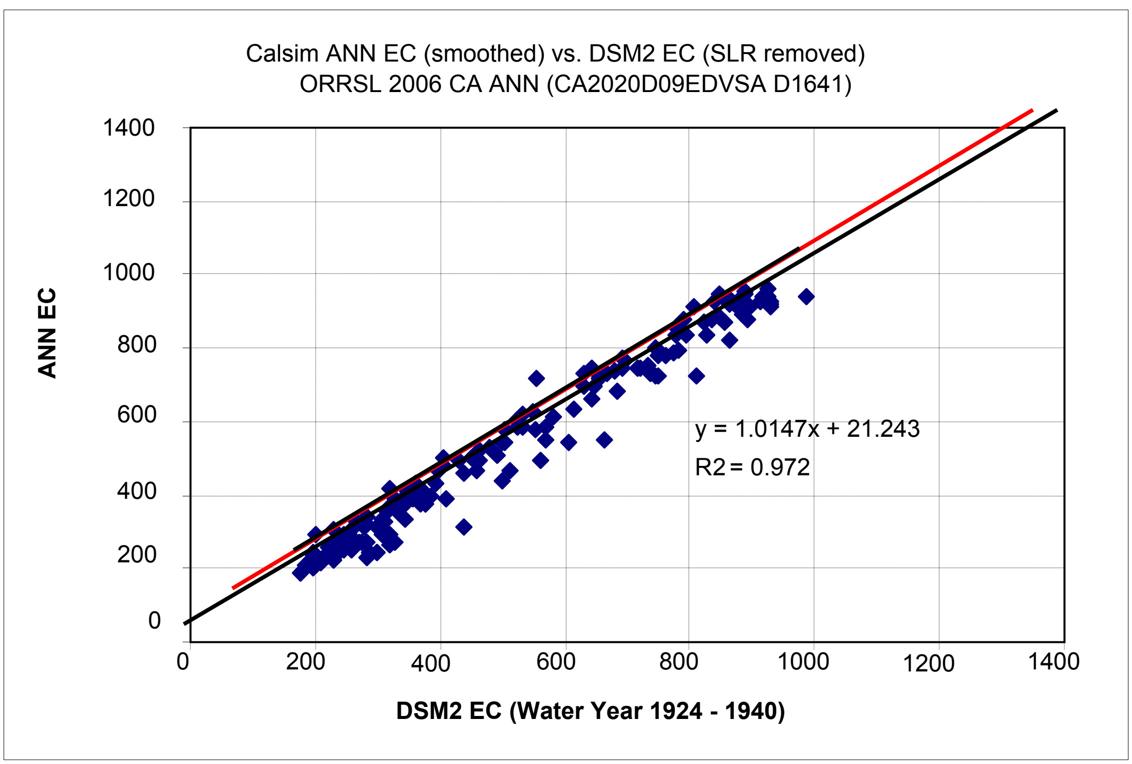


Figure 3-13 Six-Input ANN vs DSM2 WYs 1924-1940 Sea Level Rise Removed—Old River at Rock Slough

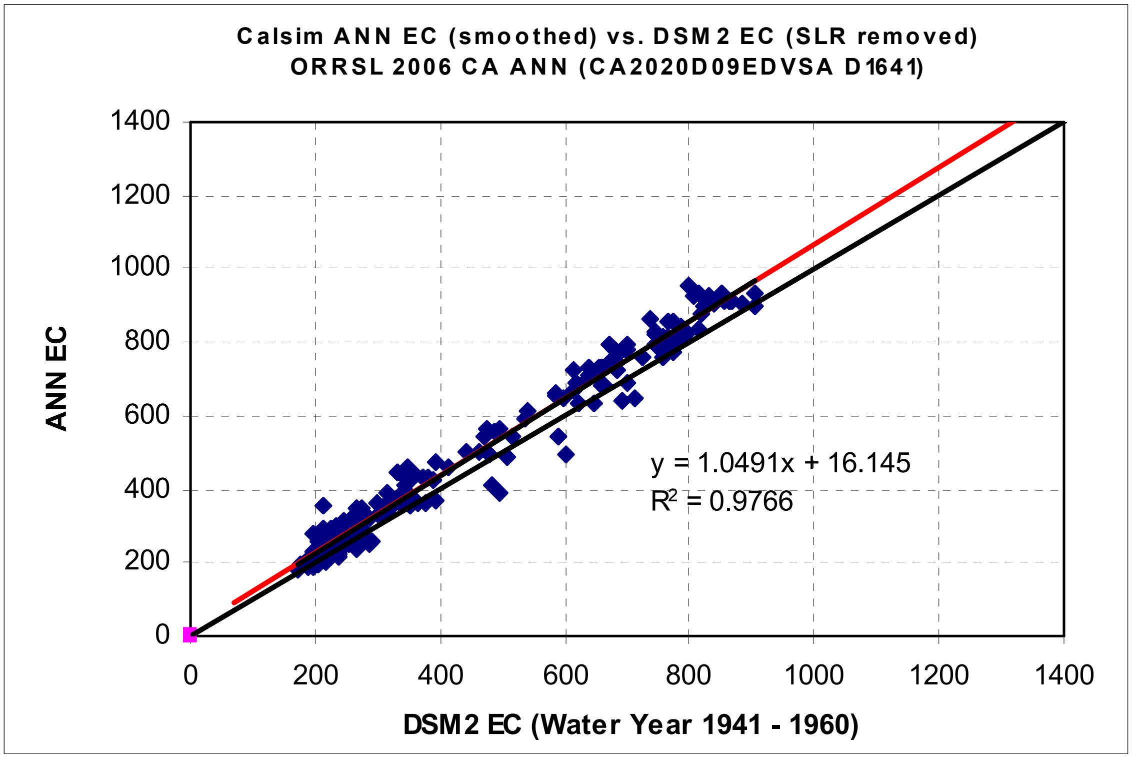


Figure 3-14 Six-Input ANN vs DSM2 WYs 1941-1960 Sea Level Rise Removed—Old River at Rock Slough

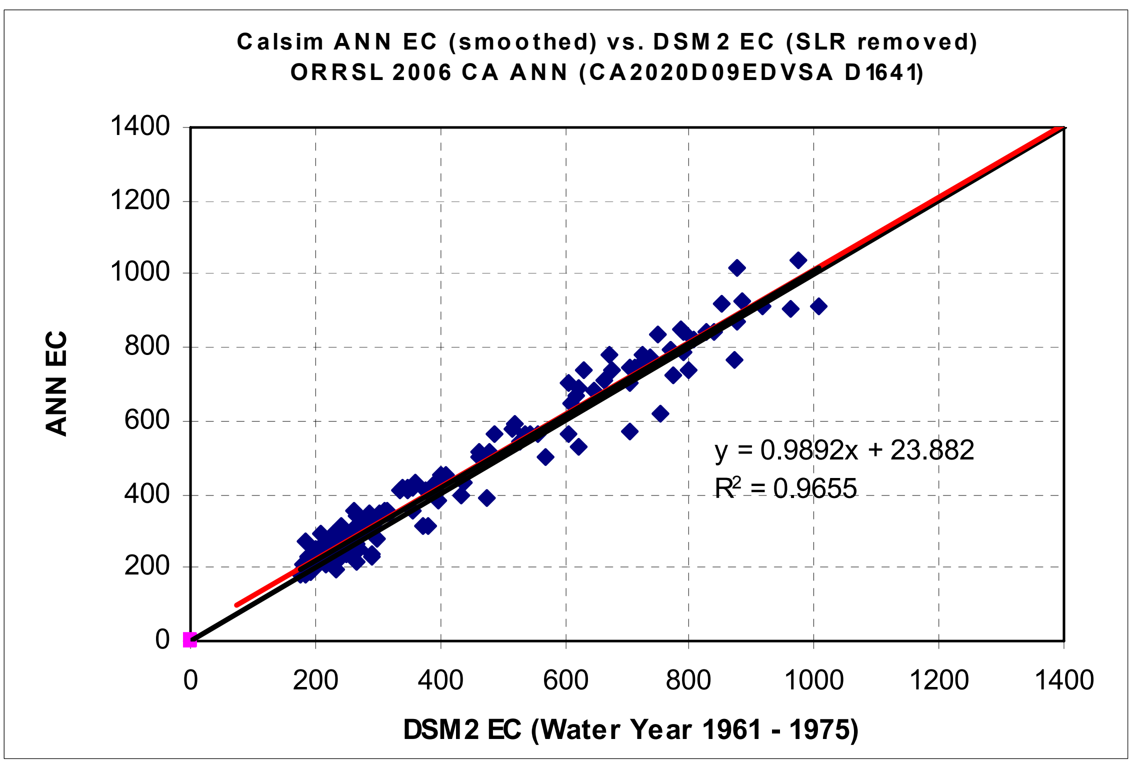


Figure 3-15 Six-Input ANN vs DSM2 WYs 1961-1975 Sea Level Rise Removed—Old River at Rock Slough

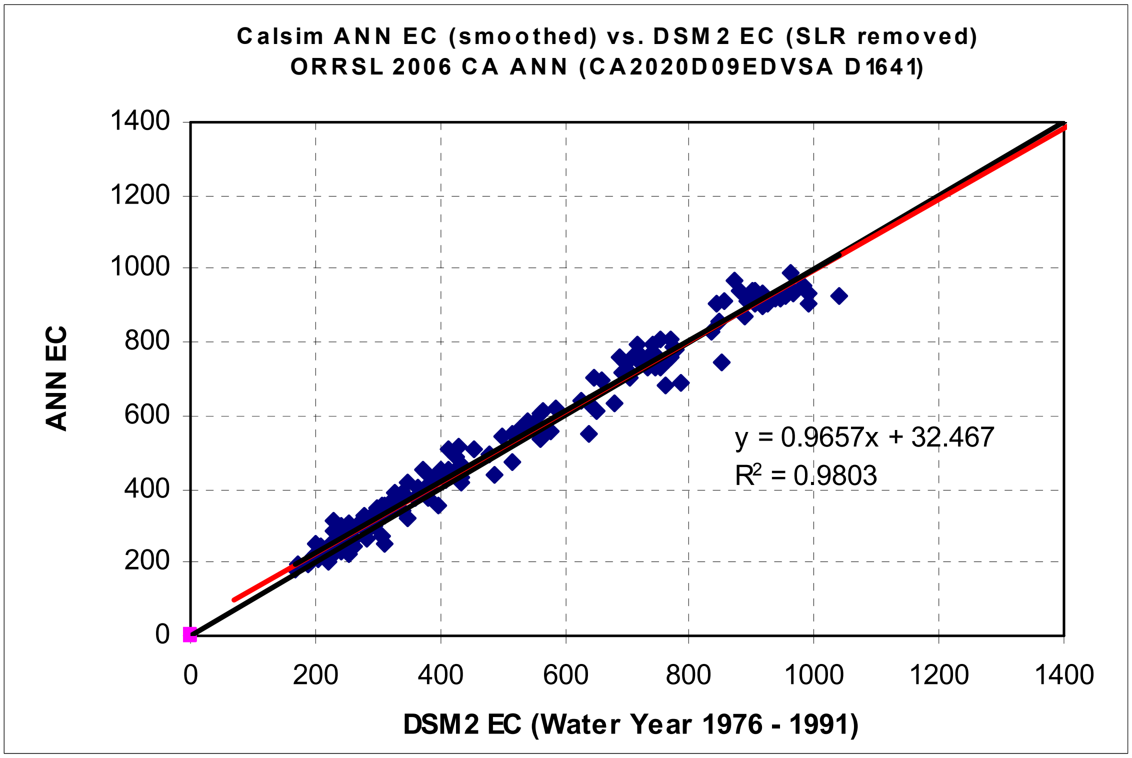


Figure 3-16 Six-Input ANN vs DSM2 WYs 1976-1991 Sea Level Rise Removed—Old River at Rock Slough

3.4 Marginal Export Cost Response

The marginal response of the ANN to a unit impulse is important to examine because CalSim II adjusts flows and exports each time-step in a marginal (incremental) manner. A useful diagnostic introduced in Sandhu et al. (1999) is the Marginal Export Cost. MEC is defined as “the extra water needed to carry a unit of water across the Delta … while maintaining a constant salinity at a given location.” An MEC calculation is computationally costly because at each time-step the Sacramento River flow must be adjusted by trial and error to bring the salinity back to its former (pre-unit export increase) value. Here we simply introduce a constant unit increase of 500 cfs to the State and federal exports (250 cfs each) and an equal constant increase of 500 cfs to Sacramento flow. We then examine the salinity response at several locations by subtracting the base salinity from the alternative salinity. The unit input perturbation is constant. Following the terminology in Sandhu et al. (1999), we call this the continuous carriage water response.

To illustrate the responses, we show time-series graphs for a 4-year period (water years 1985 through 1988) out of the 16-year run for the three locations using daily values (Figures 3-17 through 3-19).

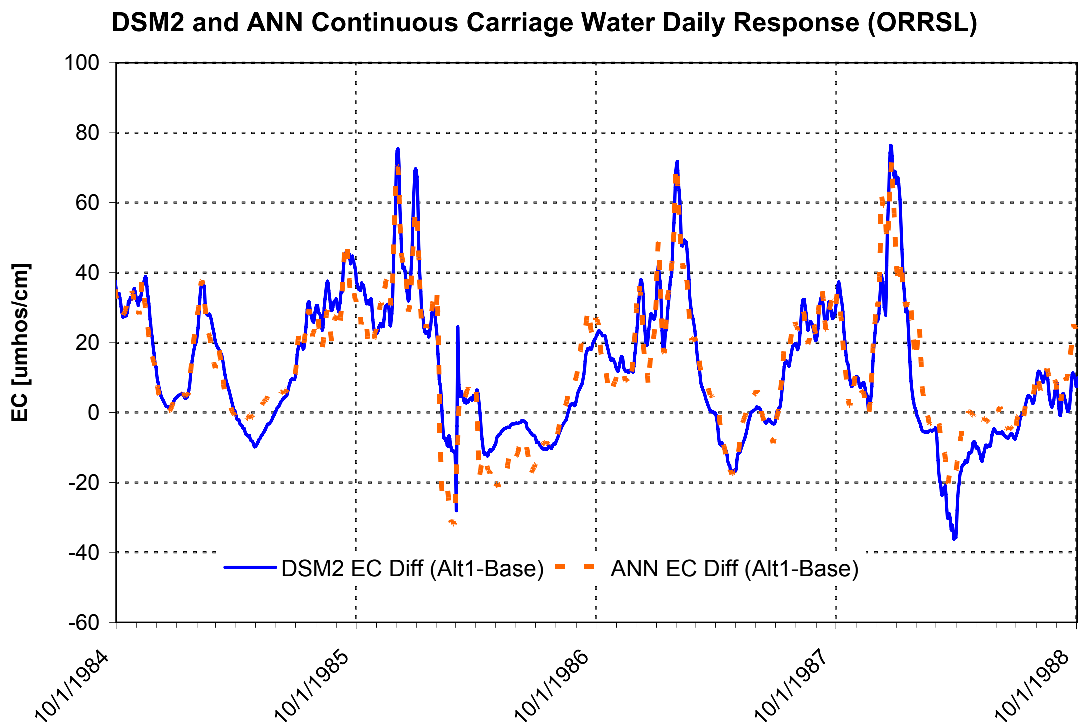


Figure 3-17 Continuous Carriage Water Response—Old River at Rock Slough

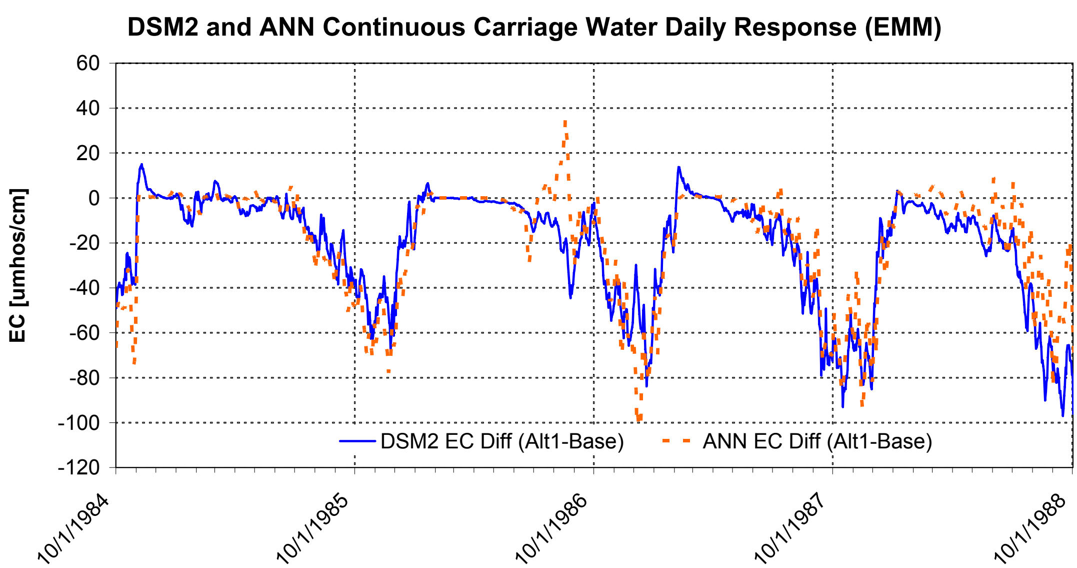


Figure 3-18 Continuous Carriage Water Response—Emmaton

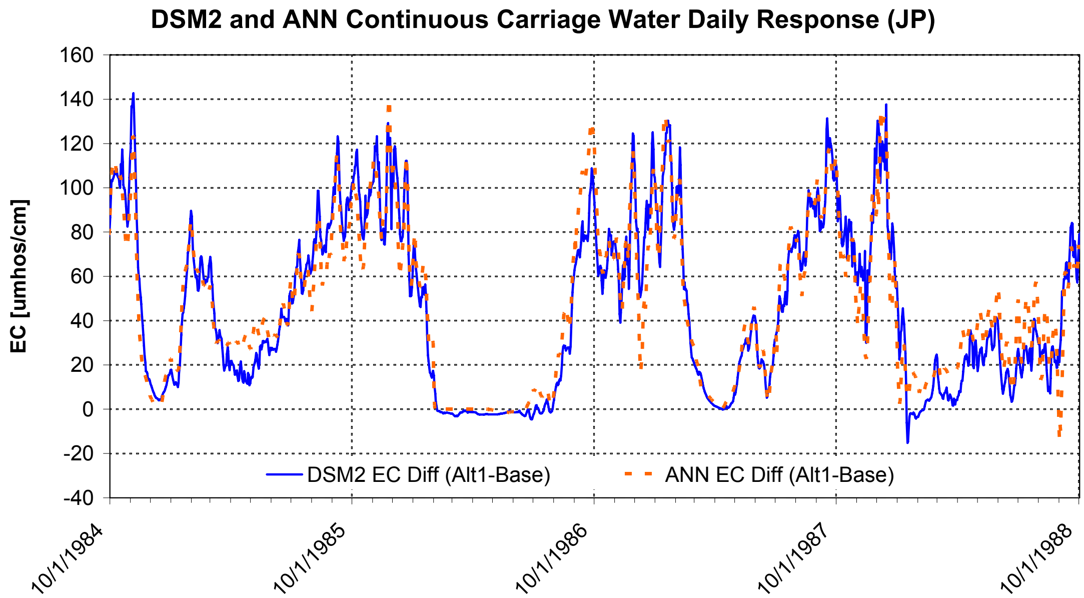


Figure 3-19 Continuous Carriage Water Response—Jersey Point

Ideally, the ANN salinity response to the unit flow changes would be a 1:1 correspondence to DSM2 salinity response with little scatter. Figures 3-20 through 3-22 compare the ANN salinity response to the DSM2 response at the three locations using daily values.

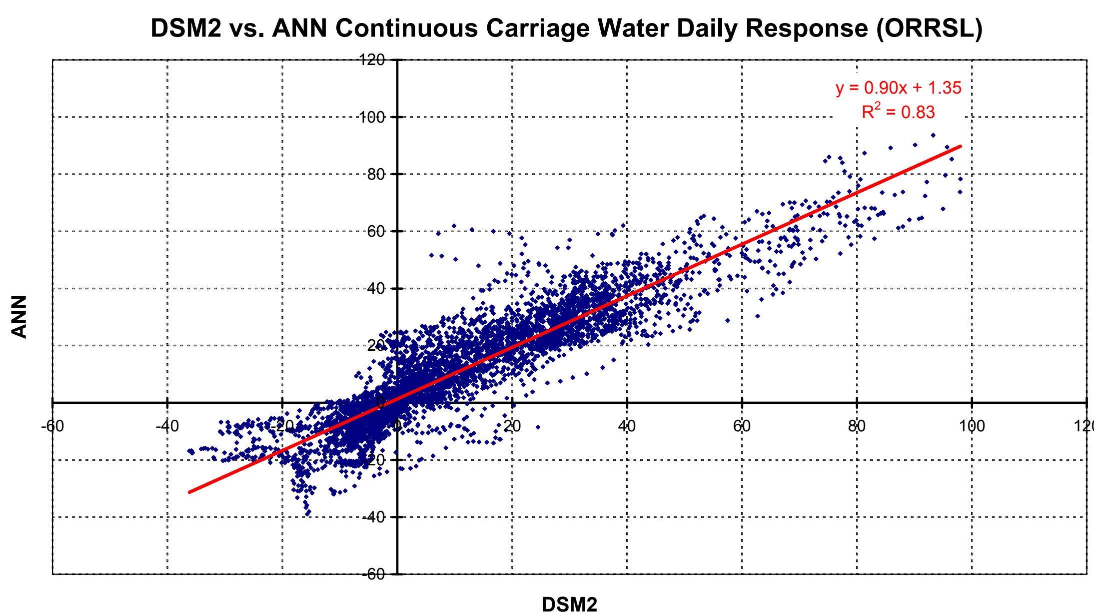


Figure 3-20 DSM2 vs ANN Continuous Response—Old River at Rock Slough

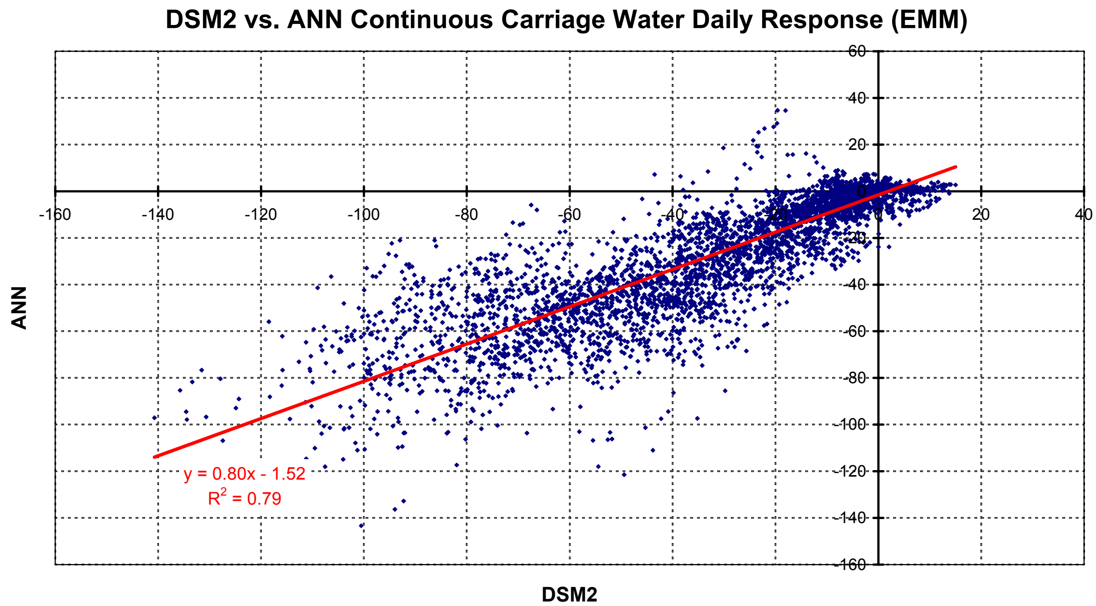


Figure 3-21 DSM2 vs ANN Continuous Response—Emmaton

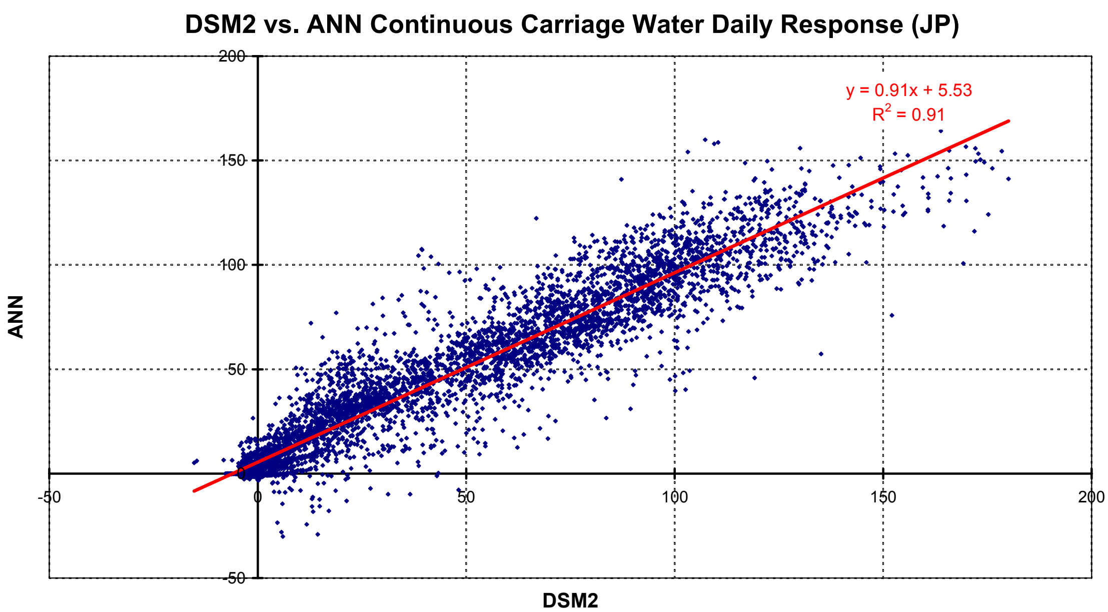


Figure 3-22 DSM2 vs ANN Continuous Response—Jersey Point

Another type of impulse-response test is a transient impulse. In this test, the unit flow perturbation is applied for a time, then removed, to examine the transient response of the system. This is a very difficult test, not only for the ANNs, but for DSM2. It is instructive to view the complex transient behavior that DSM2 exhibits on occasion. For instance, in summer 1988 the salinity response at Old River at Rock Slough first dropped below the base case, then increased, then dropped again during the 3-month 500-cfs Sacramento River flow and CVP/SWP-export increase. The ANN response is often good during the transient impulse, but shows more jitter than the DSM2 response after the transient (Figures 3-23—3-25).

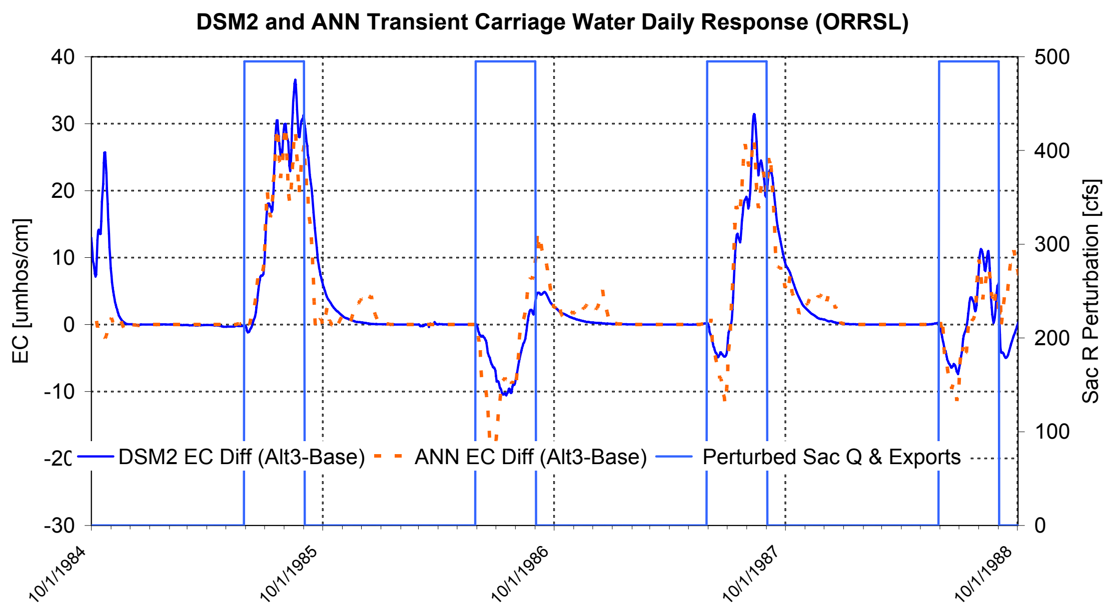


Figure 3-23 Transient Carriage Water—Old River at Rock Slough

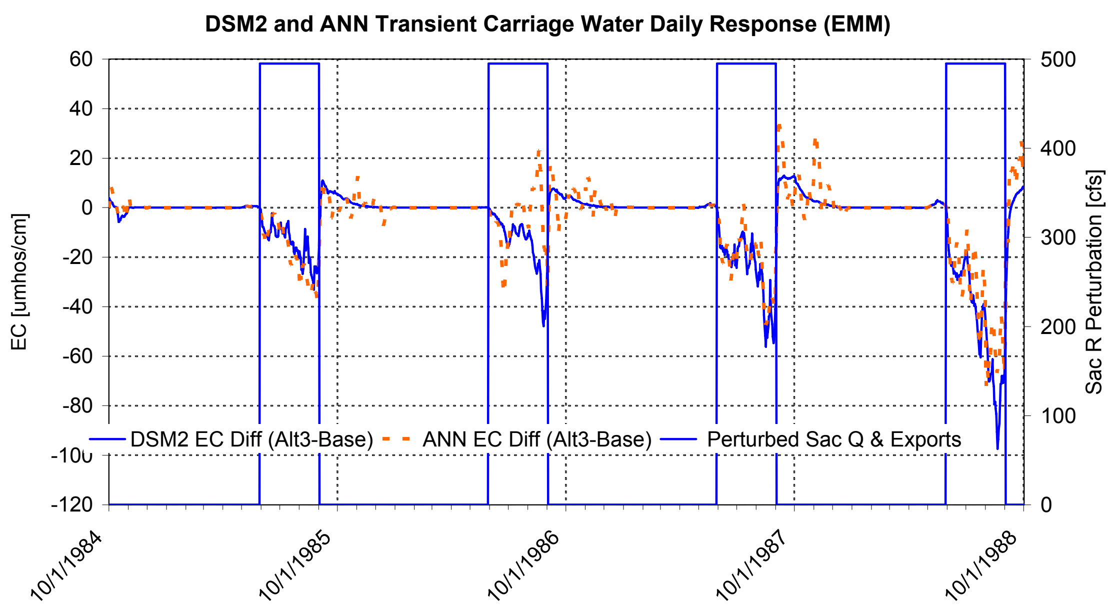


Figure 3-24 Transient Carriage Water—Emmaton

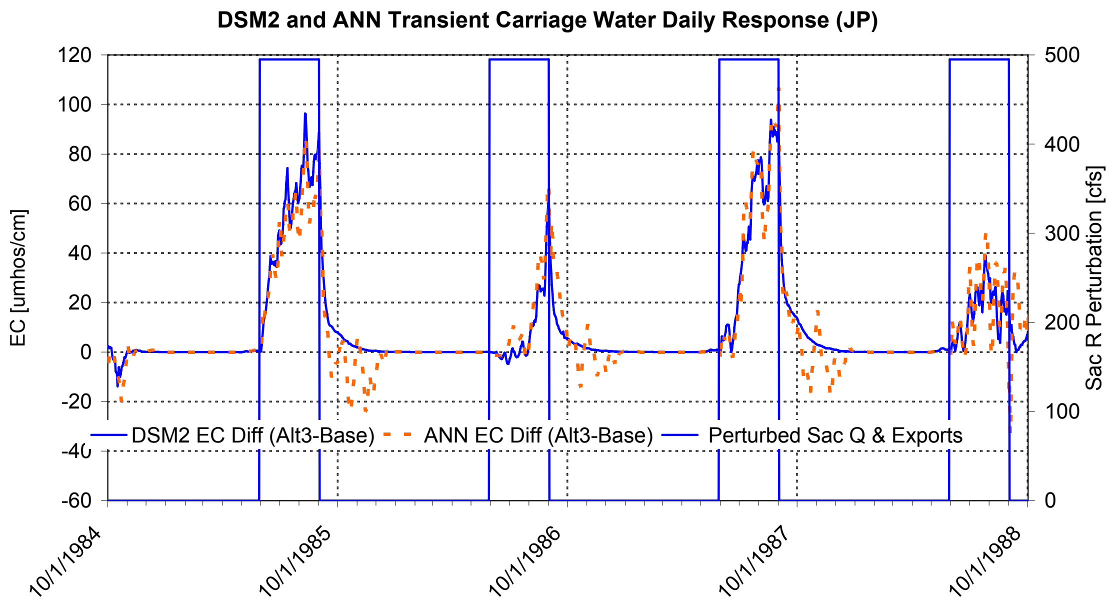


Figure 3-25 Transient Carriage Water—Jersey Point

As with the continuous impulse, we show the DSM2 and ANN responses using scatter plots (Figures 3-26—3-28). We consider the ANN response to generally follow the DSM2 response, especially given the demanding nature of the transient impulse test.

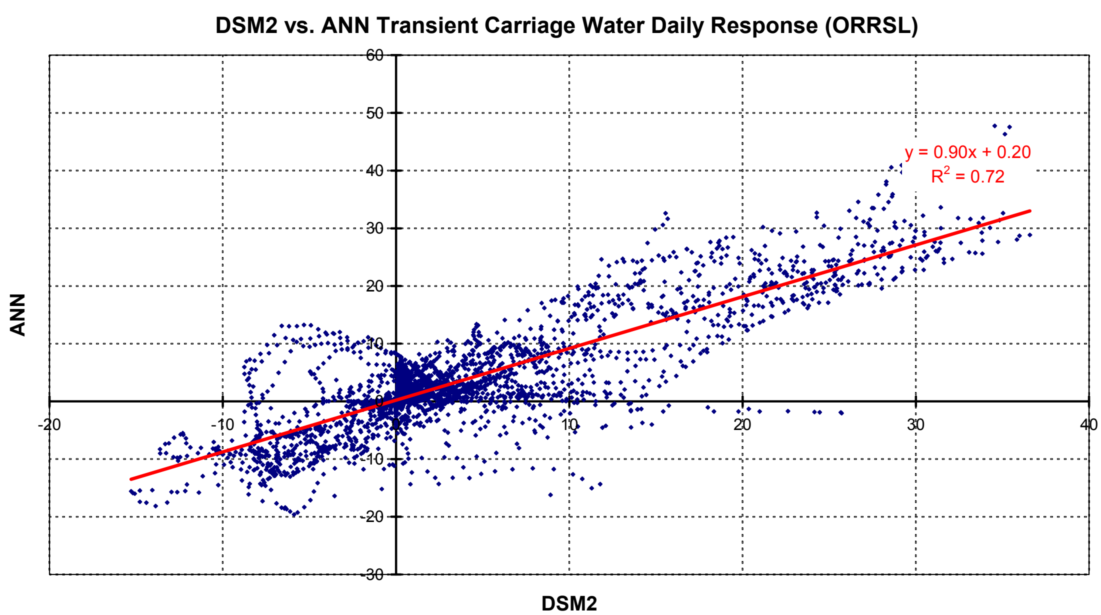


Figure 3-26 DSM2 vs ANN Transient Response—Old River at Rock Slough

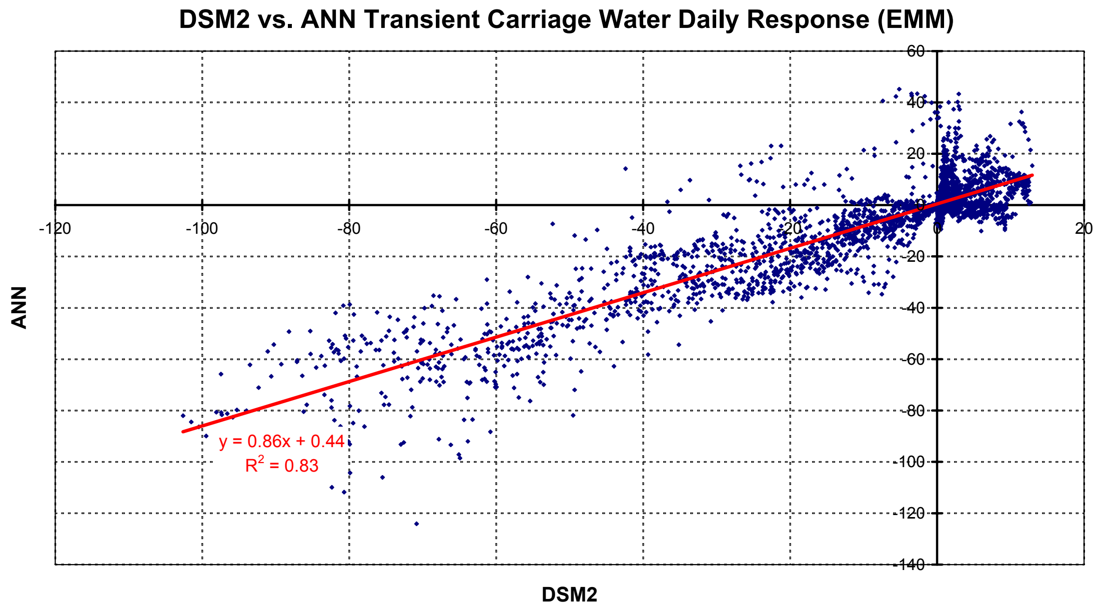


Figure 3-27 DSM2 vs ANN Transient Response—Emmaton

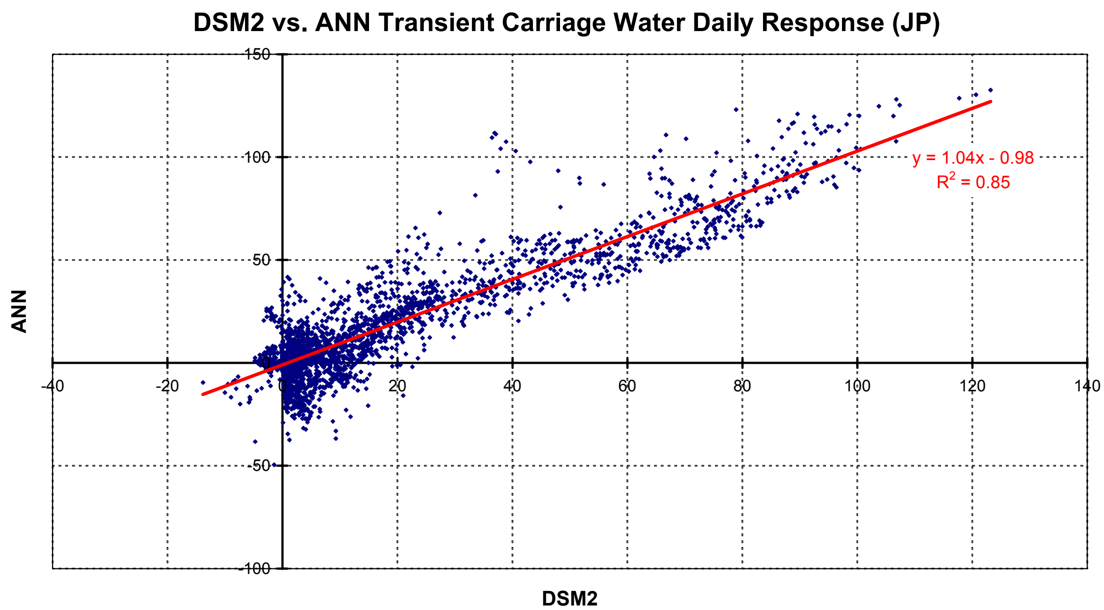


Figure 3-28 DSM2 vs ANN Transient Response—Jersey Point

3.5 Conclusion

ANNs (Artificial Neural Networks) trained well with six inputs that included the tidal range-mimicked, DSM2-simulated data. Good results were obtained in periods outside the calibration data period, proving the capability of these ANNs to handle a wide variety of hydrology. The marginal or incremental salinity response to a unit flow and export change was also generally faithful to the DSM2 response in both continuous and transient modes, lending more credibility to this version of the ANN Delta emulator.

3.6 References

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