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

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Chapter 9:
Carriage Water

Authors: Ralph Finch and Nicky Sandhu

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[Editor's Note: This is an electronic reprint of the original document. Electronic copies of the original figures were not available. However, scanned copies of the original figures are included.]

Definition of Carriage Water

Carriage water is defined as marginal export costs, that is, the extra water needed to carry a unit of water across the Delta to the pumping plants while maintaining a constant salinity. Or more practically, when the exports are increased by one unit, the Sacramento flow is increased by one unit plus carriage water to maintain a constant Delta salinity.

Previous Work

It has been known for several years that the current method of estimating carriage water in DWRSIM, called the Minimum Delta Outflow (MDO) Routine, is not particularly accurate in individual years and a better method needed. The Delta is a complex system and past attempts at developing a useful method for measuring carriage water and ultimately an MDO replacement always had at least one major flaw.

An attempt was made to search for carriage water directly in the historical data, that is, to find a period of time when Net Delta Outflow (NDO) is fairly constant, but Sacramento flow and exports are increasing. If carriage water existed, salinity at interior Delta stations should increase. While there are a few times when this seems to be true (e.g. summer 1979 and 1994), the salinity increase could also be explained by antecedent conditions, that is, previous to the period of constant NDO, NDO was much higher, and the salinity increase could be simply due to the Delta gradually reaching new equilibrium. Thus it became apparent that only a model of the Delta could say anything about carriage water.

Most efforts at modeling the Delta and improving MDO involved using NDO, with perhaps some lagged NDO as memory, as the only input. However an NDO-only model cannot say anything about carriage water as it is defined above, nor can it deal with other questions about rim flow combinations, gate operations, and so on. Thus a model is needed that can handle multiple inputs and nonlinear behavior. DSM has been used to investigate carriage water and related issues. Like all numerical models, it is rather slow compared to the time step needed for DWRSIM and therefore not a serious candidate for an MDO replacement. Even with a reduced channel grid, run times would be far longer than the current MDO routine. A "Transal" model was proposed as a fast and reasonably accurate method of modeling the Delta. In this method flows and salt are tracked from and to different locations in the Delta. However, this type of model cannot be used directly with historical data, and was therefore unacceptable.

Statistically-based models have been tried and found lacking; traditional time-series analysis is often linear or requires transformation to a stationary time-series, which renders the resulting model unsuitable as an MDO replacement.

Application of Artificial Neural Networks (ANNs)

Feed-forward ANNs are used to relate the flows to the salinity at interior and boundary locations in the Delta. Inputs to the model are the flow conditions and gate positions at various locations in the delta and the output is the salinity in the form of electrical conductivity.The ANNs provide a fast and reasonably accurate method of modeling the relationship between flows and water quality.

Salinity data, in the form of electrical conductivity, is used from Collinsville, Contra Costa Canal Pumping Plant #1, Clifton Court Forebay, Union Island and Jersey Point. Years 1981-1991 are used to calibrate the ANN model and years 1971-1981 are used to validate the ANN model. The years 1981-1991 were years in which salinity remained high for longer periods of time due to extended droughts and to extract this information the ANNs were trained on this set.The sum squared error criteria was used in evaluating the fit in calibration and validation data sets.

Approaches Tried and Experiments Done

MATLAB, Timothy Master's code and SNNSv3.3 were few of the packages tried for training of the neural networks. SNNSv3.3 was chosen as it was a freely available public-domain package and had the greatest variety of architectures available. Also it under goes major improvements every six months which keeps it updated. Radial basis, Feed-forward, Elman, Jordan, Cascade correlation and Time-delay and fully Recurrent were some of the neural network architectures that were tried. Radial-basis and Cascade correlation did well in calibration but did not do well on the validation set. Feed-forward, Elman and Jordan and Time-delay networks did equally well in calibration. Time-delay outperformed the feed-forward,Elman and Jordan networks slightly in the validation error. The best performance was that of the recurrent networks. At present Feed-forward networks are being used as that is the only network architecture for which SNNSv3.3 can output stand alone C code. Also the feed-forward networks give reasonable results with faster run-time. Preprocessing of inputs by taking logarithms and inverses was done to try to improve performance. No improvement in performance was noted in the calibration set while the error increased on the validation set. The number of hidden neurons and number of hidden layers required was experimented with to determine a network with enough flexibility to do well on the calibration set and yet generalize well enough to do well on the validation set. Pruning or link elimination of ANNs was done to improve its generalization characteristics. Memory of inputs play an important role in the prediction of salinity. Various memory lengths were experimented with to arrive at a reasonable memory length. Using individual components of Net Delta Outflow (NDO) such as boundary inflows and outflows, channel depletions, precipitation and gate positions instead of a single lumped input NDO value lead to improved prediction of salinity. Daily, weekly and monthly time steps were tried. Seasonality was attempted to be modeled by limiting data to summer time only and also by splitting the data set into quarters corresponding to the four seasons. No improvement was noted in the generalization properties of the network. Further studies will have to done to incorporate the seasonality factor in the prediction.

Final ANN Structure

SNNSv3.3 was the public domain package used for the training and simulation of the networks. Feed-forward structure was chose due to its faster run time and superior generalization characteristics. It was chosen over the recurrent networks due to the non-availability of stand alone code generation for the recurrent type networks. No pre-processing of data was deemed necessary except for scaling the inputs and outputs to the range of 0.2 to 0.8. This was done so that the output would lie in the linear region of the log-sigmoid transfer function in the output layer. Two layers with four neurons in the first layer and two in the second layer were used for most locations. Memory of at least eleven weeks was needed in most locations and in some locations more memory was required. The daily time-step model was chosen as the December Water Quality Control Plan is written in terms of daily standards and for eventual use with a stage model. The individual components of flow were Channel Depletions (CD), Precipitation (PREC), Contra Costa Canal flow (CCC), East stream flows (EAST), San Joaquin River flow (SJR), Sacramento River flow (SAC), State Water Project Pumping (SWP) and Central Valley Project Pumping (CVP). The Cross-Channel gate position (DXC) was also used. Each individual component was an input along with previous seven days and every weeks weekly averaged value prior to that making for a memory of 78 days for most locations except Clifton Court Forebay where the memory was extended to 113 days for better performance results.

DSM and ANN Carriage Water Demonstrations

Figure 9-1 illustrates the increase in salinity predicted by the DSM model when increasing Sacramento flow and exports by the same amount. Figure 9-2 illustrates the increase in salinity predicted by ANN model when increasing Sacramento flow and exports by the same amount.

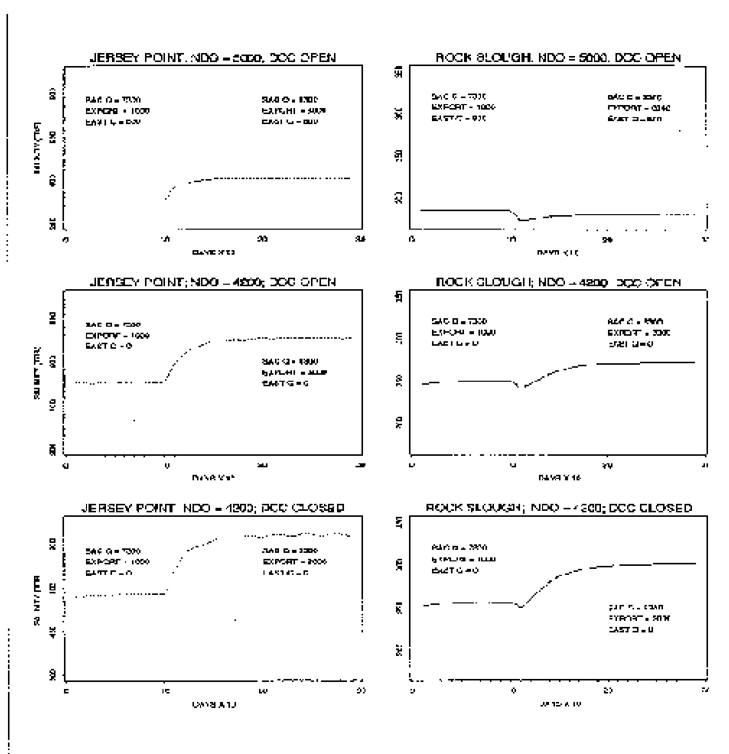

Figure 9-1. Change in Salinity When Increasing Sacramento River Flow and Exports by the Same Amount (DSM Model Run)

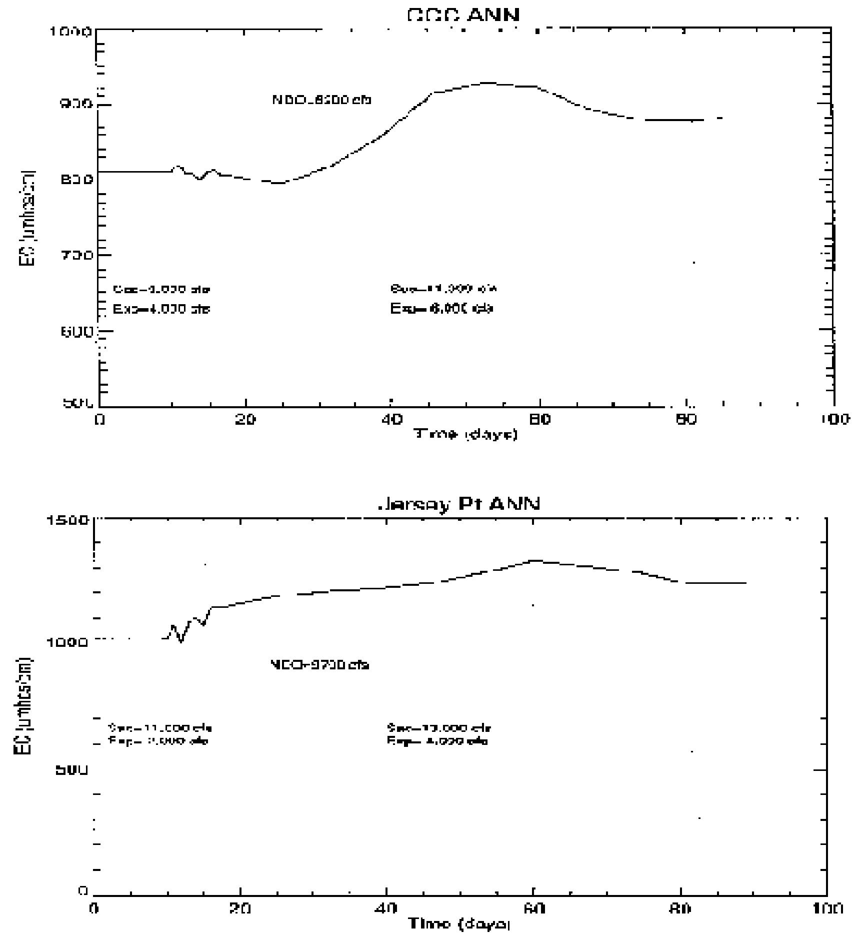

Figure 9-2. Change in Salinity When Increasing Sacramento River Flow and Exports by the Same Amount (ANN Model Run)

Results

The neural network model and DSM shows that carriage water (additional water needed to maintain salinity levels during increased pumping) is needed for certain locations under certain conditions. The amount required is probably smaller than previous estimations. Further work will have to be done to quantify this amount. The change in salinity with change in inputs has a transient response due to the memory of the system. This transient response may show positive and negative carriage water and may be different from the final steady-state carriage water.

Future Directions

Replacement of Minimum Delta Outflow with ANNs

This will replace the MDO with a more accurate and more conceptually sound salinity simulator. The final product required by DWRSIM is the SAC flow given the other flows and salinity standard. Further work needs to be done to reverse the ANN or train a new one to predict SAC flow given the other flow conditions, gate positions and salinity requirements.

The G-model is an improvement over MDO but it conceptually lacks the ability to investigate carriage water. This is because the G-model salinity predictions are based on one lumped parameter the NDO. Thus if Exports and Sacramento flow are changed by the same amount the NDO does not change which in turn implies that the salinity prediction by the G-model does not change. Also due to its lack of flexibility it cannot say anything about gate positions, their effect and importance. All these objections are overcome by the ANNs and thus the ANNs would be a better tool for investigating carriage water and quantifying it.

Real-Time Prediction of Salinity

An extension of the above described daily time-step salinity ANN model will be used for prediction of salinity. This will be used by Operations and Maintenance branch for estimating salinity in the Delta for various scenarios over the next 1-2 weeks. Stage difference and Stage will be used as inputs to get the effect of filling and draining of the delta. Wind and barometric pressures may be used to incorporate their effect on salinity changes in the Delta. Previous history of salinity may also be used as an input to further enhance the accuracy of the model.