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Accounting for Antecedent Conditions in Seawater Intrusion Modeling - Applications for the San Francisco Bay-Delta

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Abstract

A new method for predicting salinity variation with outflow is developed for the western Sacramento-San Joaquin Delta in northern California. A simple routing equation is used to calculate the equivalent steady-state (antecedent) outflow at each time step. Salinity at a given location is assumed to vary exponentially with antecedent outflow.

Introduction

Salinity intrusion into the Sacramento-San Joaquin Delta (Figure 1) has important implications for the allocation of water resources throughout the State of California. A major condition affecting the export of water from the Delta by the Federal Central Valley Project and the State Water Project is the requirement of the Projects to meet Delta water quality standards. Existing and future impacts of changes in Delta standards cannot be accurately assessed unless computer planning models accurately account for the amount of outflow required to meet standards. The relationship between salinity and outflow is also a key component of studies currently underway to determine the location of the biologically-important entrapment zone in Suisun Bay.

Figure 2 shows surface measurements of electrical conductivity (in µmhos/cm) at Antioch on the lower San Joaquin River for the period October 1968 through

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September 1988 as a function of Delta outflow (in cfs). The data are presented as 14-day averages to remove the semi-diurnal and 28-day spring-neap cycles and plotted at 7-day intervals. The Delta outflows are based on estimates of the inflows to the Delta developed by the California Department of Water Resources (DAYFLOW) and DWR's most recent estimates of historical consumptive use on Delta islands. At similar values of outflow, data for periods of increasing Delta outflow show higher salinity than periods of decreasing outflow. To remove this hysteresis in the response of salinity to outflow it is necessary to include the contribution of outflows from previous months.

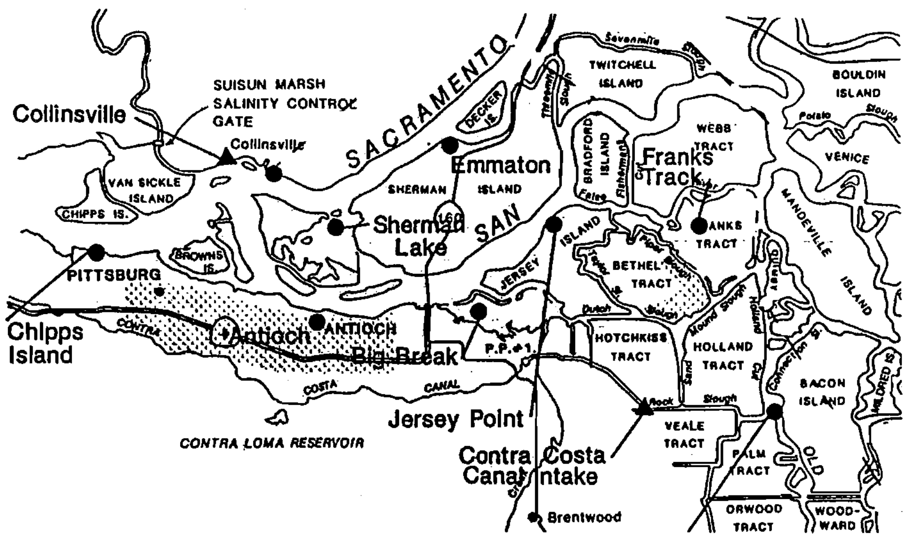

Figure 1: Location of electrical conductivity monitoring stations in the western Sacramento-San Joaquin Delta.

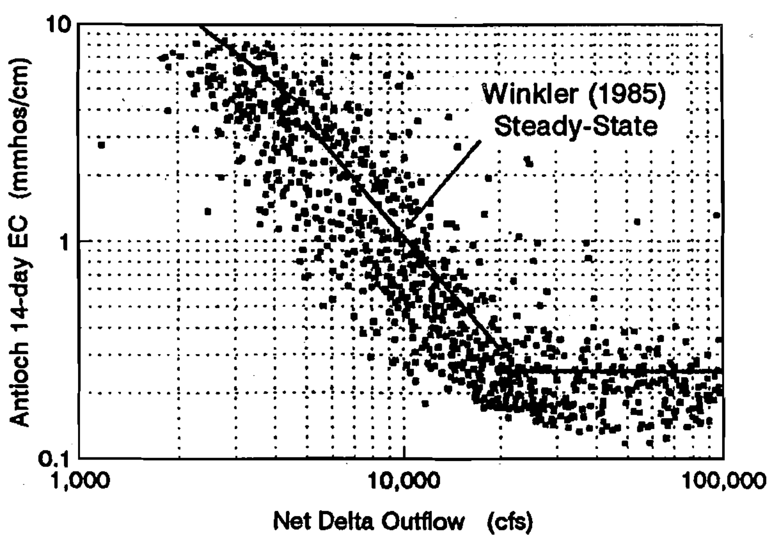

Figure 2: Surface measurements of EC (in µmhos/cm) at Antioch from October 1968 through September 1988.

A recent attempt to relate the salinity at Chipps Island and Antioch to outflow (Winkler, 1985) relied on power-law regression of monthly outflows. The monthly-averaged salinity was assumed to depend on the present month's outflow, the previous month's outflow and the total outflow for the prior 12 months. Separate regression equations were found for three ranges of outflow: 2,000 < Q < 5,000 cfs, 5,000 < Q < 20,000 cfs and Q > 20,000 cfs. Note: 1 cfs equals 0.0283 cubic meters/second.

At steady-state, Winkler's (1985) power-law regressions take the form of three straight lines on a log-log plot of salinity versus outflow (Figure 2). This power-law regression approach has the disadvantage of discontinuities at the limits of the three ranges of outflow. Also, the resulting equations are not linked to any physical processes in the estuary.

A basic form for the salinity-discharge relationship

A simple form of the tidally-averaged advection-dispersion equation for salinity transport in a one-dimensional estuary is:

$$A\frac{\partial S}{\partial t} - Q\frac{\partial S}{\partial x} = \frac{\partial}{\partial x}KA\frac{\partial S}{\partial x} \ . \tag{1}$$

In the following, the estuary is assumed prismatic with constant area A; the longitudinal dispersion coefficient, K, is constant; flowrate, Q, is a function of time only; and the hydrodynamic response of the estuary is much faster than the salinity response.

The simplified boundary conditions are a constant ocean salinity, S_o, at x = 0, and a constant upstream river salinity, S_b, (at large x). The steady-state solution to this simplified estuary problem (Eq. 1) is

$$\bar{S} = (S_o - S_b)\, e^{-\bar{Q}x/KA} + S_b \ . \tag{2}$$

In the San Francisco Bay-Delta, however, steady-state conditions are rarely achieved, and account must be taken of the flow history. Motivated by Eq. 2, a salinity-flow relationship of the form,

$$S(t) = (S_o - S_b)\, e^{-\alpha G(t)} + S_b \ , \tag{3}$$

is considered, where α is a fitting parameter which varies with distance, x, and G(t) is the "antecedent" outflow.

Solving for Antecedent Outflow G(t)

Consider the empirical routing function

$$\frac{\partial G}{\partial t} = \frac{(Q - G)\,G}{\beta} \quad . \qquad (4)$$

Eq. 4 is similar to a relation used by Harder (1977) to generate salinity data to test his non-linear model of salinity-outflow. Eqs. 3 and 4 suggest that the rate of change of salinity decreases as the system approaches steady-state, and that the parameter β/G governs the rate at which G approaches its steady-state (i.e. the response of the estuary to changes in outflow will be slowest at low antecedent outflow G).

In a practical implementation, antecedent outflow, G(t), can be recalculated at each monthly or daily time step, using Eq. 4. Figure 3 shows the Antioch EC data as a function of antecedent outflow, G(t), updated on a weekly basis. Using β = 500 cfs-years in Eq. 4 reduces most of the lagged-response scatter in Figure 2. The data in Figure 3 appear to follow the exponential shape assumed in Eq. 3. The corresponding time series of measured Antioch EC and the antecedent outflow-salinity model prediction is shown in Figure 4 for water years 1976 through 1981.

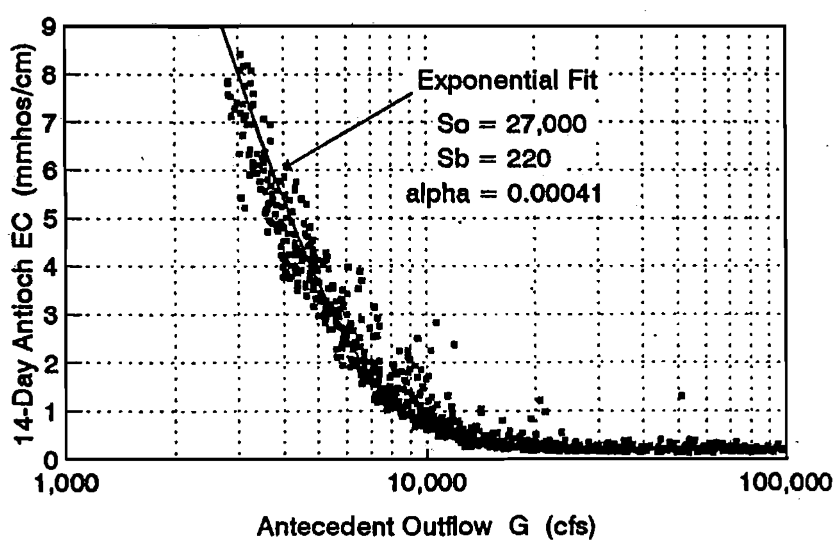

Figure 3: Antioch 14-day average EC as a function of antecedent outflow for β = 500 cfs-years.

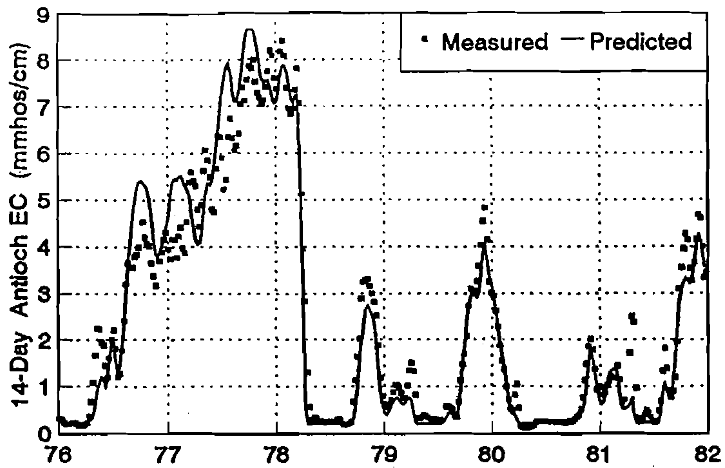

Figure 4: Measured Antioch 14-day average EC and antecedent outflow-salinity model prediction for water years 1976-1981 (ß = 500 cfs-years).

Data from a Lagrangian transport model

Output from a Lagrangian salt transport model of the Sacramento-San Joaquin Delta, the Fischer Delta Model (Version 8), originally developed by Hugo B. Fischer, can also be used to evaluate the antecedent outflow-salinity model. Figure 5 shows the daily variation in Chipps Island EC computed by the Fischer Delta model and the prediction using the antecedent outflow-salinity model. The parameters for the exponential fit in this example are S_o = 47,000, S_b = 190, and α = 0.00028. Also shown is the salinity predicted by a steady-state analysis (equivalent to $\beta \rightarrow 0$ in Eq. 4). Figure 5 demonstrates that antecedent conditions must be taken into account when modeling estuarine salinities.

A comparison of measured data, numerically simulated data and results from the present empirical method indicates possible errors in the estimates of Delta outflow. In some cases, such as during the 1976-1977 California drought, there are differences between results from the empirical model and field data (Figure 4); however, the empirical model data and Fischer model data are in good agreement. This discrepancy may be attributed to errors in estimates of Delta consumptive use, resulting in errors in estimates of Delta outflow.

Summary and Conclusions

The empirical routing function for antecedent outflow appears to represent the time-history of Delta flow in such a way that salinities are predicted with a good degree of accuracy. At most of the Suisun Bay and western Delta locations, the variation in salinity over the full range of antecedent outflow is well represented by the exponential fit, Eq. 3.

Application of the present model at Emmaton on the Sacramento River and Jersey Point on the San Joaquin River suggests that salinity at these locations also depends on the magnitude of tidal exchange between the two rivers. The antecedent outflow-salinity model can also be used to determine response times of salinity to flow in Delta transport models such as the Fischer Delta model.

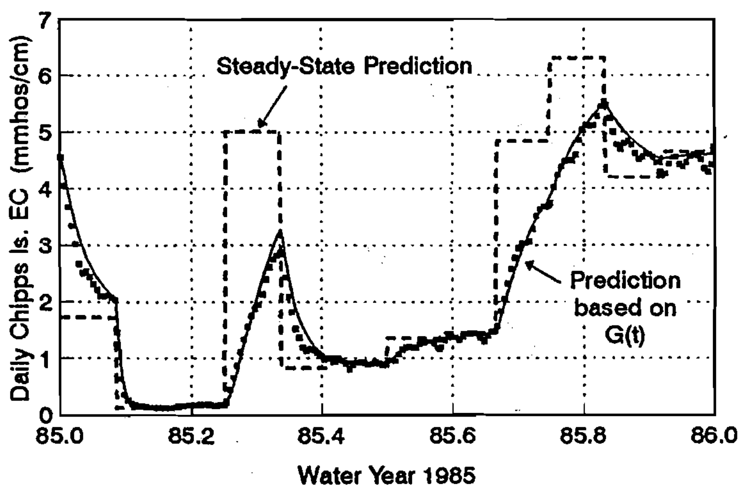

Figure 5: Daily Chipps Island EC prediction from the Fischer Delta model and the antecedent outflow-salinity model. Steady-state predictions are shown for comparison.

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