

Fixed-Site Monitoring Associated with
the 2-Gates Fish Protection
Demonstration Project Operations

Author: Jon Burau, USGS

Fixed-Site Monitoring as a Tool for Understanding Hydrodynamic Transport Processes, Salinity, and Turbidity Distributions Associated with 2-Gates Project Operations

APPROACH / METHODOLOGY – GENERAL EXPERIMENTAL DESIGN

In order to understand the effects of 2-Gates Project Operations on transport processes we propose to use a network of fixed-site sampling stations placed at key locations throughout the delta ([Figure 1](#)) to not only monitor time-histories of various constituents such as temperature, salt, turbidity, and Chl-a at these locations, but also to measure the flux (or load) of these constituents. Thus, each Eulerian sampling station shown in [Figure 1](#) will consist of a sideward-looking Acoustic Doppler Current Profiler (ADCP), a conductivity-temperature-depth (CTD-turbidity) probe, and, at a few key stations Cl-a sensors ([Figure 1](#)). Flow (discharge, mass flux) at each of these stations is computed from the ADCP measured index velocities through calibrations that relate the index velocity to discharge measurements obtained using a moving-boat system made over several twelve hour flood-ebb tidal cycles ([Simpson and Oltmann \(1993\)](#), [Morlock \(1994\)](#), and [Simpson \(2001\)](#), [Ruhl and Simpson, 2005](#)). The discharge at each of these stations is then used to compute conductivity, temperature, chl-a, and turbidity fluxes at each station location. The constituent flux, $\mathcal{E}(t)$, is simply the product of the mass flux and concentration, $\mathcal{E}(t) = Q(t)C(t)$, if one assumes lateral variability in a generic constituent, $C(t)$, is negligible (which is a reasonable assumption in the predominantly narrow channels in the Delta). By co-locating constituent and discharge measurements and making these flux calculations, we will not only know how constituents vary in time at key locations in response to 2-Gates Project operations but we will also have a record of how 2-Gates Project operations alter exchanges between regions in the delta through these key channels.

In addition to simply documenting how much of a given constituent is moving past a given location, fluxes also integrate, in a local (within a tidal excursion) sense, processes that fundamentally occur in a Lagrangian reference frame. For example, the flux of a constituent measured past a given location encapsulates a combination of advective and dispersive mixing processes that occur within a tidal excursion of the measurement location. Constituent flux decompositions, which allow us to separate advective from dispersive transport mechanisms, have been used extensively to understand the processes that control transport in estuaries throughout the world ([Geyer and Nepf \(1996\)](#), [Jay et al. \(1997\)](#), [Dyer \(1974\)](#), [Dronkers and Van De Kreeke, \(1986\)](#), [Fischer, \(1979\)](#)) and in the San Francisco Bay and Delta ([Lacy et al. \(1996\)](#), [Ruhl et al. \(1999\)](#), [McKee et al. \(2002\)](#), [Warner et al. \(1997\)](#)). Constituent fluxes can be decomposed into advective and dispersive components to get at the underlying transport mechanisms, at least in a bulk, or regional sense. Flux decompositions are accomplished by first separating the concentration and mass fluxes (discharge) into tidal (primed terms) and tidally averaged components (bracketed, $\langle \rangle$, see below), $C(t) = C'(t) + \langle C(t) \rangle$, $Q(t) = Q'(t) + \langle Q(t) \rangle$, respectively (see *computation of tidal averages* section below). These relations are used to decompose the total tidally averaged constituent flux into advective and dispersive components through a number of simplifying assumptions as

$$\langle \mathcal{E}(t) \rangle = \langle Q(t)C(t) \rangle = \langle Q(t) \rangle \langle C(t) \rangle + \langle Q'(t)C'(t) \rangle$$

$$\langle \mathcal{E}(t) \rangle = \langle \mathcal{E}(t) \rangle_{Adv} + \langle \mathcal{E}(t) \rangle_{Disp}$$

where $\langle \mathcal{C}(t) \rangle_{Adv} = \langle Q(t) \rangle \langle C(t) \rangle$ and $\langle \mathcal{C}(t) \rangle_{Disp} = \langle Q'(t)C'(t) \rangle$ are the advective and dispersive flux components, respectively.

The advective flux represents the transport of the tidally-averaged concentration of a constituent through a given cross-section (or point) by the net discharge. The dispersive flux, on the other hand, represents the transport of a constituent that occurs when and where the tidal discharge and tidal concentrations are correlated. For example, the dispersive flux will be large and in the flood direction in situations where higher concentrations occur on (are correlated with) flood tides over ebbs. Similarly, in situations where higher concentrations occur on ebbs over floods, the dispersive flux will be in the ebb direction. Mechanistically, flood/ebb concentration differences occur whenever the concentration within a tidal excursion of a sampling location is mixed as it travels along its tidal excursion trajectory. Mixing, in tidally forced systems, is primarily due to velocity shears created by bathymetric variability. Generally, then, the greater the bathymetric variability within a tidal excursion of a given sampling location, the greater the mixing and concomitant dispersive flux. The dispersive flux can therefore be thought of as a bulk measure of the amount of mixing (dispersion) that occurs within a tidal excursion of a given sampling location, for a given spatial concentration gradient. For example, [Figure 2](#) provides an example of a salt flux decomposition derived from data collected in False River which shows that the dispersive flux is a large fraction of the total salt flux at this location during the period these data were collected. Significant dispersive fluxes are created at this location because high salinity water from the western delta traveling down False River is injected far within Franks Tract, where it is efficiently mixed with the lower salinity ambient water there. Therefore, overall, constituent fluxes help us get at mechanisms in a way that simply looking at time-series of constituent variations can't.

COMPUTATION OF TIDAL AVERAGES

Based on the frequency content (power spectral density estimates) of historical sea level, flow, and salinity data collected in the Delta one can see that transport in the Delta occurs at two distinct timescales: the tidal and tidally averaged, or residual timescales ([Dyer, 1974](#); [Fischer et al., 1979](#); [Walters and Gartner, 1984](#))([Figure 3](#)). This is the fundamental observation that allows us to separate discharge and constituent data into tidal and tidally averaged components. This separation is useful because the influence of the rivers and water project operations, including 2-Gates Project operations, on transport within the Delta can operate at both of these timescales. This time separation suggests a linearity that somewhat oversimplifies the dynamics and mixing that occurs within this system; nonetheless, the concept separating data into tidally averaged and tidal components has been a useful construct that has helped us understand and manage the Delta for several decades. Tidal averages of discharge and constituent concentrations will be computed using a digital tidal filter after [Walters and Heston, 1982](#); and [Wang and Cheng, 1993](#). Digital filters have been widely used in this estuary ([Lacy et al., 1996](#), [Ruhl et al. 1999](#), [Warner et al., 1997](#)) and in estuaries around the world ([Dronkers and Van De Kreeke, 1996](#); [Geyer and Nepf, 1996](#)).

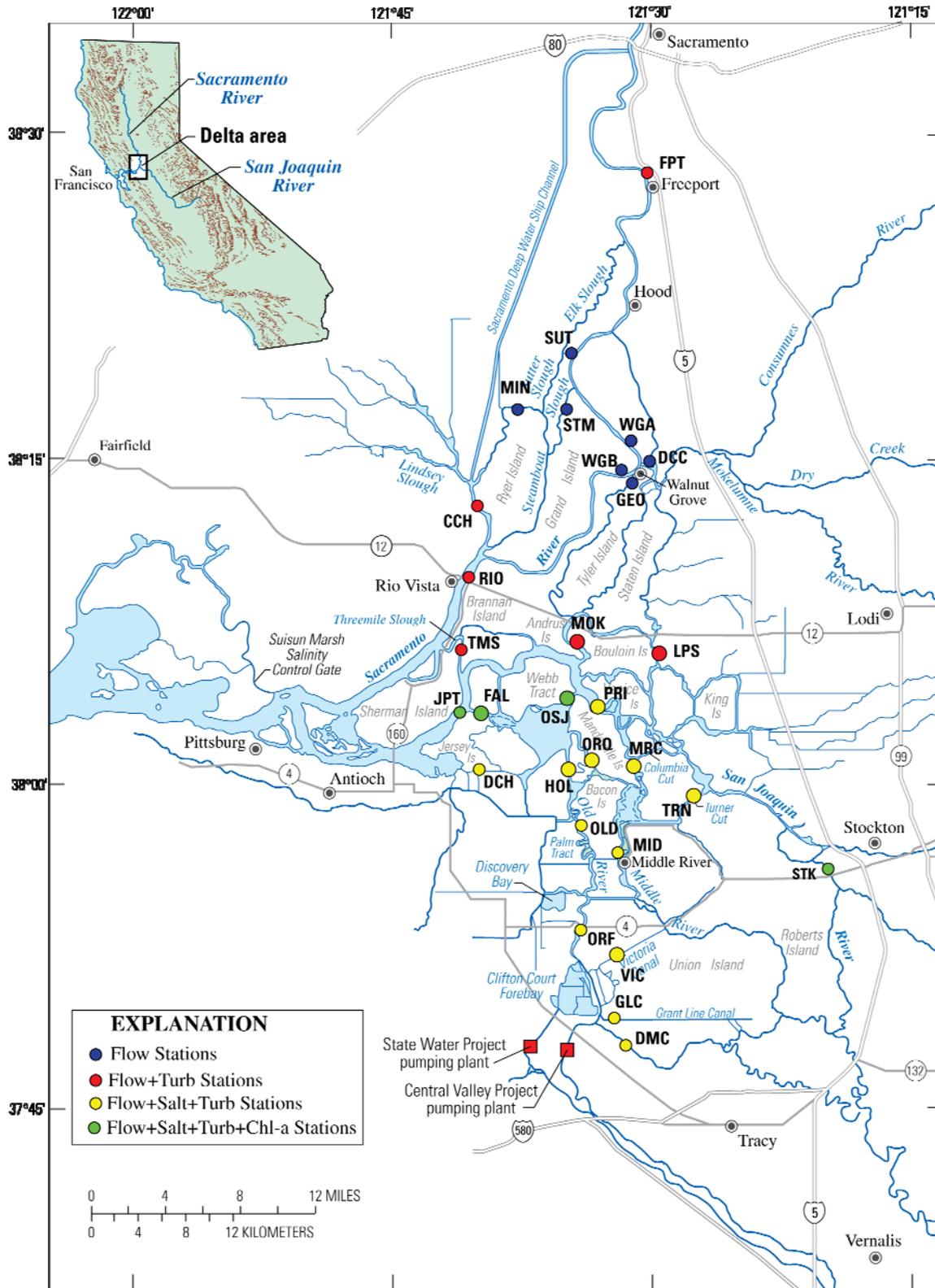
EXAMPLES

i) Turbidity boundary conditions

In order to optimize 2-Gates Project operations in real time and to understand how 2-Gates Project operations perturb the background turbidity distributions, it will be important to place the contributions of the various river inputs in creating the observed turbidity fields in the central delta. Therefore, it is imperative that we monitor the flux of turbidity into the central delta through Three mile Slough, from the Mokelumne system (including Georgiana Slough), and the San Joaquin River ([see Figure 1](#)) because these exchanges create the background turbidity fields we propose to manipulate with 2-Gates Project operations.

ii) Dispersive salt flux in False River as a measure of the “dispersive mixing mechanism” used to protect larval and juvenile delta smelt

We intend to use changes in the salt (and perhaps Cl-a) flux in False River to test the “dispersive mixing mechanism” behind 2-Gates Project operations designed to reduce entrainment of larval and juvenile delta smelt that are hatched in a broad region of the central and southern Delta in the CVP and SWP exports. If 2-Gates Project operations do increase dispersive exchange of water (and hopefully larval and juvenile delta smelt) from the central and southern Delta into the western delta AND salinities are elevated in the San Joaquin, then we could use San Joaquin River salt as a conservative tracer. If the “dispersive mixing mechanism” is working as planned, then we should be able to detect an increase in dispersive flux in False River directed from Franks Tract into the western San Joaquin Delta – a direct measure of the effectiveness of 2-Gates Project operations in creating this transport mechanism. Moreover, if 2-Gates Project operations facilitate westward transport of organic carbon (e.g. phytoplankton) originating in the upper San Joaquin River and southern Delta, then we should see an increase in Chl-a flux through False River (presuming it is not completely grazed down by the benthos). These are but a handful of examples of how fluxes will be used in this project to inform real time operations and evaluate performance.



Location of sampling locations in the Delta Area of California.

Figure 1 – Location of sampling locations for flow, salinity, turbidity, and Chl-a.

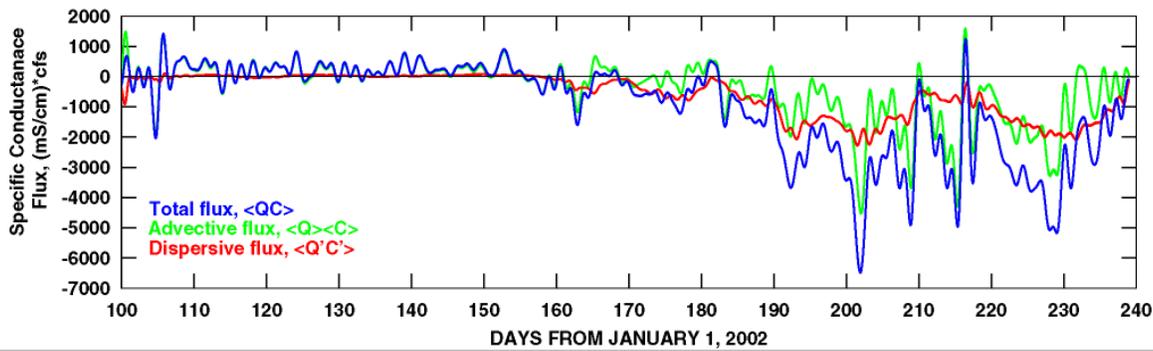


Figure 2 – Time-series of the total (blue), advective (green), and dispersive salt flux measured in False River in 2002. The dispersive flux contributes roughly half of the total, suggesting that tidal timescale mixing within a tidal excursion of this sampling location (e.g. Franks Tract) significantly contributes to the upstream transport of salt (e.g. EC) in this region.

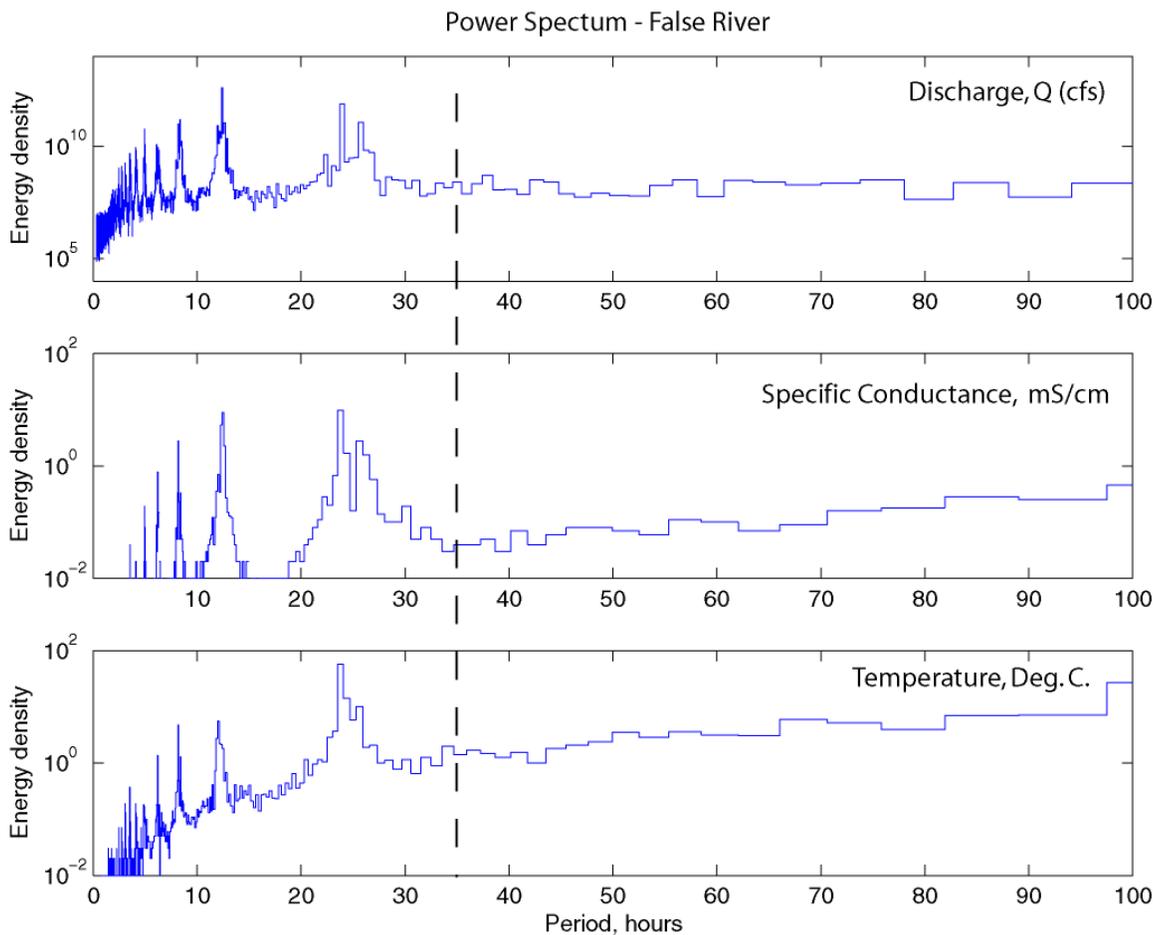


Figure 3 - Power spectrum of (a) discharge, (b) specific conductance, (c) temperature based on time-series collected in False River.

References

- Dronkers, J.J. and J. Van De Kreeke, 1986, Experimental determination of salt intrusion mechanisms in the Volkerak Estuary. *The Netherlands Journal of Sea Research* 20:1-19.
- Dyer, K.R., 1974. The salt balance in stratified estuaries. *Estuarine and coastal marine science*, 2, pp. 273-281.
- Fischer, H.B., E.J. List, J. Imberger, R.C.Y. Koh, and N. H. Brooks, 1979, *Mixing in Inland and Coastal Waters*, Academic Press. pp 483.
- Geyer, W.R. and H. Nepf. 1996. Tidal pumping of salt in a moderately stratified estuary. *Coastal and Estuarine Studies*, 53: 213-226.
- Jay, D.A., W.R. Geyer, R.J. Uncles, J. Vallino, J. Largier, W.R. Boynton, 1997, A review of recent developments in estuarine scalar flux estimation, *Estuaries*, 20(2), p. 262-280.
- Lacy, J.R., Schoellhamer, D.H., and Burau, J.R., 1996, Suspended-solids flux at a shallow-water site in South San Francisco Bay, California: Proceedings of the North American Water and Environment Congress, Anaheim, California, June 24-28, 1996.
- McKee, L., Ganju, N., Schoellhamer, D., Davis, J., Yee, D., Leatherbarrow, J., and Hoenicke, R., 2002. Estimates of suspended sediment flux entering San Francisco Bay from the Sacramento and San Joaquin Delta. Report prepared for the Sources Pathways and Loading Workgroup (SPLWG) of the San Francisco Bay Regional Monitoring Program for Trace Substances (RMP). SFEI contribution 65. San Francisco Estuary Institute, December 2002. 28pp.
- Morlock, S.E., 1994, Evaluation of acoustic Doppler current profiler measurements of river discharge: U.S. Geological Survey Water-Resources Investigations Report 95-4218, 37 p.
- Ruhl, C.A. and M.R. Simpson, 2005, Computation of Streamflow in Tidally Affected Areas Using the Index Velocity Method, Scientific Investigations Report, 2005-5004, 41 p.
- Ruhl C.A. and D.H. Schoellhamer, 1999, Time series of suspended-solids concentration in Honker Bay during water year 1997, SFEI. 1999. 1997 Annual Report: San Francisco Estuary regional Monitoring Program for Trace Substances. San Francisco Estuary Institute, Richmond, CA.
<http://www.sfei.org/rmp/1997/c0304.htm>
- Simpson, M.R., 2001, Discharge measurements using a broad-band acoustic Doppler current profiler: U.S. Geological Survey Open-File Report 01-1, 123 p.
- Simpson, M.R., and Oltmann, R.N., 1993, Discharge-measurement system using an acoustic Doppler current profiler with applications to large rivers and estuaries: U.S. Geological Survey Water-Supply Paper 2395, 32 p.

Walters, R.A. and C. Heston, 1982, Removing tidal-period variations from time-series data using low-pass digital filters, *Journal of Physical Oceanography*, V.12, No.1. pp. 112-115.

Walters, R.A. and J.W. Gartner, 1984, Subtidal sea level and current variations in the Northern reach of San Francisco Bay, "Estuarine, Coastal, and Shelf Science, 21, pp. 17-32.

Warner J.C., D.H. Schoellhamer, J.R. Burau, 1997, A sediment transport pathway in the back of a nearly semi-enclosed subembayment of San Francisco Bay, California, In: environmental and coastal hydraulics: Protecting the aquatic habitat, edited by: Wang S.Y. and T. Carstens, proceeding of the 27th Congress of the International Association of Hydraulic Research, August 10-15, 1997, San Francisco, California. pg. 1096-1101.

Wang, J. and Cheng, R.T. 1993, On low-pass digital filters in oceanography, *Acta Oceanologica Sinica* 12:22, pp. 183-196.