January 2014

INNOVATION IN MONITORING:
The Delta Flow Station Network

The U.S. Geological Survey (USGS) installed the first gage to measure fresh water flow from the Sacramento River in the late 1800s. Today a network of 35 hydro-acoustic meters measures flow and flow dynamics throughout the 700 square miles of waterways, sloughs and islands that comprise California's Sacramento-San Joaquin River Delta. With the data provided by this flow station network—updated every 15 minutes—state and federal water managers make critical daily decisions about how much fresh water can be pumped for human use, at which locations in or out of the Delta, and when. Fish and wildlife scientists, working with water managers, also use this information to protect fish species affected by pumping and loss of habitat. In the future, it may also be used to assess the success or failure of efforts to restore ecosystem processes in what has been called the "most managed" watershed in the country.

Understanding flow would be less challenging if managers and scientists were only trying to measure the outflow of the watershed's myriad rivers and streams into San Francisco Bay and the ocean. But the Delta not only receives river water from upstream watersheds, it also receives a massive amount of seawater from the Pacific Ocean, with peak tidal flows of 1.7 million cubic feet per second exchanged through the estuary via the tides. Twice every day tides surge into the Delta, resulting in reversed flows as far upstream as Freeport, before ebbing back to the ocean. It is an extraordinary challenge to measure the amount of fresh water flowing downstream in a labyrinth so strongly influenced by tides that scientists liken it to "a mixing bowl." Yet in the last few decades, the USGS Bay-Delta hydrodynamics team has tackled this challenge in measuring Delta flows head on, pioneering novel techniques for improving measurements of shifts in tides, currents and fresh water flows, and facilitating the integration of the data into computer models to more accurately reflect real-time conditions in the Delta.

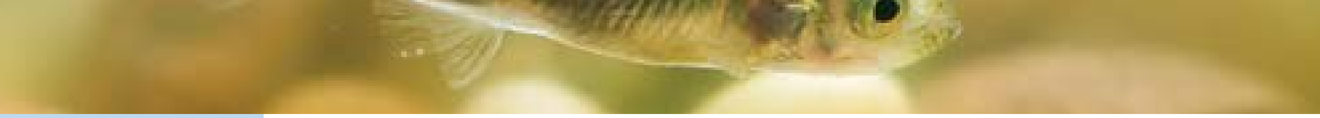
The flow station network employs technology similar to sonar, mounting hydro-acoustic devices and other monitoring tools on pilings on the edges of delta channels. Measurements from these stations feed directly into computers, which upload the data to the Internet within minutes of being taken. In more recent years, scientists have added more devices to certain stations to measure components of water quality such as salinity, turbidity, contaminants, chlorophyll, and nutrients. By combining water quality related data with hydrodynamic conditions—taken at the same time, place and frequency—a whole new level of understanding of changes in the Delta's physical environment is emerging.

Flow station on channel piling. Photo USGS.

Photo courtesy Department of Water Resources.

The data generated by the Delta flow station network is available not only to water managers, regulators, and scientists, but also to the public. Indeed without this sophisticated flow station network, Californians would have no way of knowing if the billions of tax dollars spent on dams, canals, and other Delta modifications, not to mention the billions they may soon be asked to spend on a new water conveyance facility, are actually buying them a more reliable water supply and healthier ecosystem. The flow station network is the foundation for understanding Northern California's water management system.

USGS
science for a changing world



Measuring Net Flows in a Dynamic Tidal Environment

The Delta is a tidal system in which water, and the organisms and constituents in the water, are in constant motion. The water can move rapidly, more than two miles per hour, and travel long distances over each six-hour flood-ebb tide cycle. For example, a water parcel residing on Liberty Island (station LIB) at high tide can end up below the Rio Vista Bridge (eight to nine miles down-estuary, station RIO) in six hours due to an outgoing tide. The density of flow stations in the current network is due in part to the intensely dynamic nature of transport processes in this system. Calculating net flows (fresh water discharge) using measured tidal flows is the classic signal (net flows) to noise (tidal flows) problem. Because the net flows are small and tidal flows large, calculating the net flow places extremely rigorous demands on the accuracy of tidal flow estimates and every aspect of the data collection process.

Photo USGS.

For example, at the Jersey Point station (JPT) the daily peak tidal flows can be on the order of 150,000 cubic feet per second (cfs), while the net flows may be 2,000 cfs or less. Thus, estimates of the net flows require the tidal flow data to be accurate to within approximately one percent, a challenging requirement. Even a small bias, on a percentage basis, in either the flood or ebb tidal discharge estimates can result in completely erroneous calculations of net flow, possibly in the wrong direction. These are the types of technological and analytical challenges regularly overcome by the USGS Bay-Delta hydrodynamics team.

HISTORY OF THE NETWORK

The flow station network developed over time in response to a series of questions. The first question, how much fresh water was flowing into the Delta from the Sacramento River, was answered with the installation of the first hydro-acoustic meter at Freeport (Station FRE) in 1978. A decade later, water managers and scientists wanted to monitor the influence of the export facilities on the north-to-south movement of water from central to south Delta. So USGS installed two more acoustic velocity meters at Old River (station OLD) at Bacon Island and at Middle River (station MID, 1987). In the early 1990s, USGS installed two stations in the Walnut Grove area, so water project operators could find out how much water was flowing from the Sacramento River into the central Delta through the Delta Cross Channel (DCC) and Georgiana Slough, the so-called Delta Transfer Flow. Finally, a combination of four stations in the south Delta, just upstream of the export pumps, was installed to estimate Delta export flows. As of January 2013, the USGS operates 35 stations located throughout the Delta.

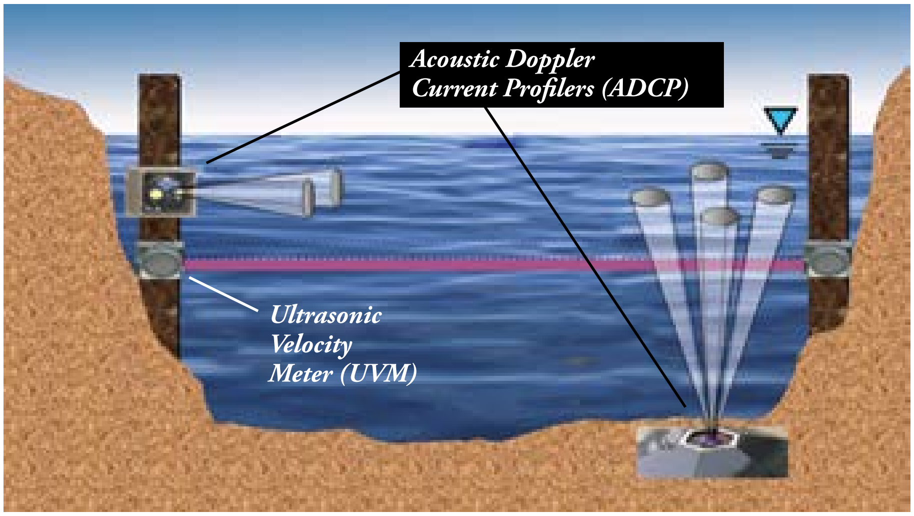
TECHNOLOGICAL ADVANCES

Until the 1970s, getting even a snapshot of flows required Herculean campaigns over 30-hour periods

Inside a flow station. Photo USGS.

employing multiple boats, multiple current meters (Price AA), and long tag lines stretched across wide channels. In other words, it was virtually impossible back then to routinely collect a time series of the net flows, the type of data that managers now take for granted. Today most of the flow stations employ sideward-looking acoustic Doppler current profilers (SL-ADCPs) mounted on pilings or channel markers, and measure flow, also called "discharge," as a volume per time (e.g., cubic feet of water per second). In 2008, "robot boats," unmanned vessels equipped with acoustic devices, were added to the toolbox. More recently, new systems have been set up that enable scientists to repair or reset stations remotely. Such improvements significantly cut the costs of running the flow stations.

FLOW MEASUREMENT TECHNOLOGIES



Source: Burau, USGS

Station Locations & Groups

Scientists specifically selected the station locations to assess transport (the movement of water and everything in it) at a variety of spatial scales, from the individual channel to regional scales and the Delta as a whole. The network covers all of the major hydrodynamic exchanges within and between regions. The USGS hydrodynamics team uses groups of stations (see map and explanations below) to verify localized inputs and outputs of water, and localized storage. The exchange into and out of a given region can also be checked through a summation of stations bordering a region.

Delta Outflow — The sum of the measured flows from stations at Rio Vista (RIO), Three Mile Slough (TMS), San Joaquin River at Jersey Point (JPT) and Dutch Slough (DCH) are used to estimate Delta outflow. Delta outflow is a key ecosystem metric because it is a measure of water flowing into San Francisco Bay (i.e., inputs less exports and consumptive use).

Delta Transfer Flow — Delta transfer flow is computed as the difference between the flows measured at stations Walnut Grove above the DCC (WGA) and Walnut Grove below Georgiana Slough (WGB). The calculation helps water managers estimate the amount of Sacramento River water that flows into the central Delta through the Mokelumne system, including the DCC and Georgiana Slough. The Delta transfer flow is critical for maintaining salinity standards in the central Delta.

Old and Middle Rivers — The sum of the flows at stations OLD and MID represent the flow to the export facilities from the north. Typically, Old River is saltier than Middle River at this location, suggesting the former carries the lion's share of the water from the western Delta. The data from these stations are currently required to comply with a variety of court decisions and biological opinions under the Endangered Species Act.

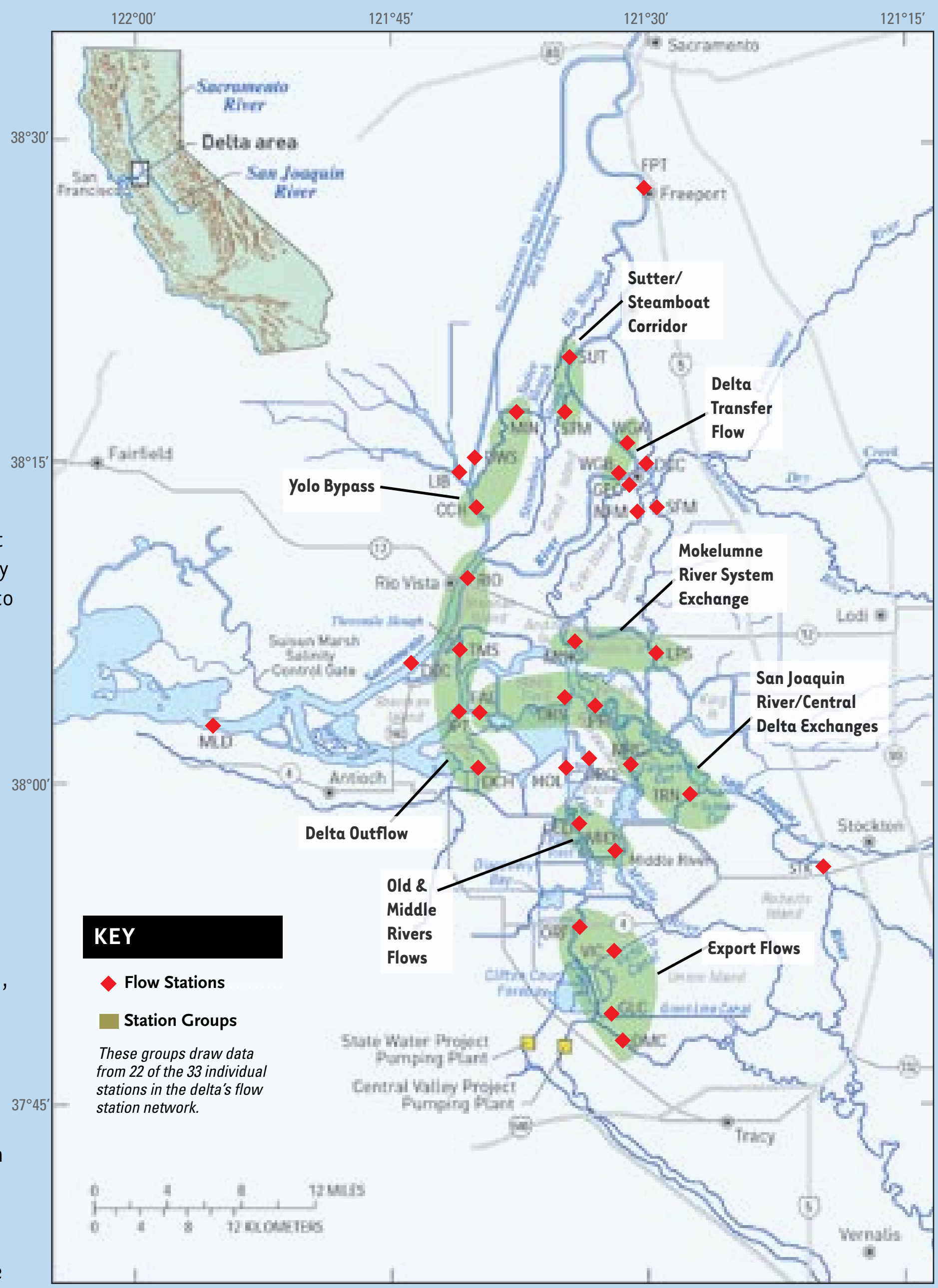
Sutter-Steamboat Corridor — Sutter and Steamboat Sloughs are significant conveyance channels that carry half of the water that flows past the city of Sacramento at high water. Sutter Slough carries the bulk of the net flow; Steamboat Slough is much more strongly tidally affected. The flows in both of these channels are strongly influenced by Sacramento River flows and Delta Cross Channel gate operations. Hydrodynamics data gathered from SUT and STM are important in the study of salmon outmigration.

Yolo Bypass — The flows entering the Delta from the Yolo Bypass are computed as the flow in Cache Slough (CCH), minus the flow in Miner Slough (MIN). This computation also measures the tidal and net exchanges into the Liberty Island/Cache Slough region, an area slated for significant restoration efforts. Moreover this region is one of the few places where Delta smelt are found year round.

Mokelumne River System Exchange — Most of the Sacramento River water that is exported flows through the Mokelumne River system. When the Delta Cross Channel gates are open this region is essentially riverine. Conversely, when the gates are closed, this system is virtually tidal. The data from the Mokelumne (MOK) and Little Potato Slough (LPS) stations may also be relevant to salmon migration, and critical in monitoring the system's response to the proposed restoration of McCormack-Williamson Tract and Staten Island.

San Joaquin River/Central Delta Exchanges — Exchanges of water from the San Joaquin River into the central Delta are important for understanding how salinity and turbidity (from suspended sediments and organic matter) change in the system. The four stations used to calculate this exchange are Turner Cut (TRN), Middle River north of Mildred Island (MRC), Old River north of Frank's Tract near the confluence of the San Joaquin and Mokelumne Rivers (OSJ) and False River (FAL). These exchanges strongly influence the rate of entrainment of San Joaquin River salmon outmigrants into the central Delta.

Exports — The volume of water entering the federal and state export facilities from the various "feeder" channels is calculated from the following stations: Old River near the Forebay (ORF), Victoria Canal (VIC), Grant Line Canal (GLC), and Delta Mendota Canal (DMC).

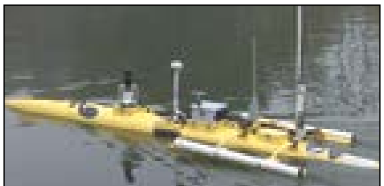


Location of USGS-operated flow station sites in the Delta. Source: USGS, CWSC

THE FUTURE

Data from the flow stations are used in many ways by Delta managers and scientists to help plan for the future, including to calibrate numerical computer models that can predict water levels, currents and discharges, and even the spatial and temporal evolution of the salt field in the Delta and Bay. The quality of the results from these models is in no small part due to the availability of flow station network data from throughout the system under a variety of conditions.

In addition, flow station data, and the USGS California Water Science Center hydrodynamics team, have played a significant role in numerous interdisciplinary investigations into subjects such as sediment transport processes, the behavior of the low salinity zone, the outmigration of Chinook salmon and the upmigration of delta smelt. The flow station network was the foundation for conducting the process-based, large-scale adaptive management experiments undertaken by the CALFED Science Program, and would also support those envisioned by the Delta Stewardship Council (the Delta Plan) and the Bay Delta Conservation Plan in the future. Without the expertise of hydrodynamics team, or the data from the flow station network it maintains, we would not understand how water moves within the Delta under current management nor be able to document and understand how proposed restoration and changes in conveyance will affect water movements in the future.



Robot boat. Photo USGS.

Uncertainty about New Facilities & Habitats — Decades of hydrodynamics monitoring, modeling and special studies suggest that restoration or changes in water conveyance in one area may substantially affect basic hydrodynamic processes and transport in others. Many changes are proposed for the Delta to meet the state's co-equal goals of "providing a more reliable water supply for California and protecting, restoring, and enhancing the Delta ecosystem." Understanding how these changes may affect flows in the Delta will be important. The proposed flooding of Sherman Island, for example, could impact hydrodynamics and transport prossess, including salinity intrusion, throughout the Delta, and as far upstream as Freeport. Withdrawing water from the system into an isolated water conveyance facility (IF), such as the currently proposed twin tunnels, would also alter aquatic conditions. If built, net flows throughout the north and western Delta would be proportionately reduced by the amount withdrawn into the IF, increasing the influence of the tides throughout the same area. The north-to-south draw of water across the Delta that has existed for a couple decades would be reduced greatly, if not cease if the IF is built, creating significantly longer overall residence times in the central and southern Delta. Longer residence times are associated with high rates of algal growth, which could fuel eutrophication in some regions, including increased blooms of nuisance algae, such as *Microcystis*, which is toxic to humans and other organisms. In the coming decades, the flow station network can provide data that addresses uncertainty concerning the location of proposed new water conveyance facilities and habitat restoration, and track how these efforts may evolve.

Climate Change, New Listings and Other Curveballs — The comprehensive coverage of the flow network provides proven tools for responding to any new endangered species listings and ecosystem changes, as well as to flooding and hydrodynamic changes due to earthquakes, storms and sea level rise.

Taking the Network to the Next Level — The dynamic nature of the Delta system makes it very difficult to understand the transport and fate of constituents. Indeed, efforts are currently being made to add technology to existing flow stations that can measure a broad suite of physical, optical, particle, and water quality indicators and report that data in real-time. This multi-analytical approach allows for better integration of results and more powerful diagnostic tools. It allows scientists and water managers to continuously characterize parameters related to nutrient uptake, phytoplankton community structure, zooplankton and fish foraging efficiency at the same time as more common water quality information (e.g., dissolved oxygen, nutrients, and pH) in the context of the existing flow and turbidity monitoring network. When further coordinated with monitoring of biological attributes, such as fish, birds, and invasive species, these simultaneous data sets can also help scientists better understand influences on the extent of estuarine and riparian habitats, and the distribution of species in the Delta.

Using the Flow Station Network Data

Raw data in real-time:
http://cdec.water.ca.gov/

Quality assured data:
http://waterdata.usgs.gov/ca/nwis/

DATA USED TO CALIBRATE AND VERIFY MODELS

DSM2 calibration documents see:
http://bayDeltaoffice.water.ca.gov/modeling/

RMA model calibration see: www.rmanet.com/Projects/SFBay-Delta/SFBay.htm

UTRIM calibrations in the Delta see:
www.deltamodeling.com

DATA USED TO SUPPORT LARGER STUDIES

Chinook Salmon Outmigration study
http://bayDeltaoffice.water.ca.gov/nDelta/salmon/index.cfm

FLOW STATION SUPPORTERS — 1970s-2100

California Department of Water Resources

City of Stockton, Sacramento County

Contra Costa Water District

Interagency Ecological Program

Sacramento Regional County Sanitation District

State Water Resources Control Board

U.S. Bureau of Reclamation

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