T E C H N O L O G Y

Measuring Flow: The Master Variable

Stand on a tule island at the junction of two delta channels and you'd think you could tell which way the water was flowing. Surely anything that looks so much like a river naturally flows downstream, from the hills to the sea? But the Delta is not a one-way system, nor is nature entirely at the controls. Throw in ocean tides coming in and out, pumps directing water from here to there, and seasonal ups and downs, and the only people who can really tell which way the water is flowing at any given time or place aren't standing on a tule island. They're sitting in a dark room staring at computer screens showing the minute-by-minute measurements of the USGS flow station network.

The network is pretty comprehensive. Over three decades, and with the help of various state and local agencies, USGS has installed 33 stations at what scientist Jon Burau calls "every hydro-dynamically significant flow split or confluence" in the landscape of the delta's 700 miles of channels (see map). Most of these stations employ a gizmo called a sideward-looking acoustic Doppler current profiler, mounted on a piling or channel marker. These devices bounce sound waves off particles in the water across entire river channels, measuring flow, also called "discharge," as a volume per time (such as cubic feet of water per second). Small solar panels power the sensors, and help them relay the information they collect to computers in operations rooms and science labs throughout California.

"We happen to have a flowing system, and it's flowing not just in one direction but it's flowing every which way, because of tides, and rivers coming together, and pumping," says Anke Mueller-Solger, Lead Scientist of the Interagency Ecological Program for the Delta Stewardship Council. "Understanding anything in this system must start with a good understanding of flow, and how that interacts with more stationary variables like channel geometry, physical habitat, sediment beds, and point sources of pollution. Flow is a dynamic master variable."

Fresh water flow is also something 25 million Californians rely on — for drinking and irrigation water — in what has been called the "most managed watershed in the country." State and federal water managers use flow station network data to make critical daily decisions about how much fresh water they can pump to cities and farms, and when and where. Wildlife scientists also use this information to protect fish species endangered by pumping and loss of habitat. In California's long history of wrangles over water, many resulting court decisions, biological opinions, and water quality standards have become, to some extent, reliant on the numbers spit out by the flow stations.

The one number everyone has wanted from these submerged outposts scattered throughout the delta is the '"net flow, or the amount of water flowing in a channel with the tidal flows averaged out. In the early days, getting this number involved a lot more than a few clicks on a key pad. The technology to measure the pulse of fresh water moving through a system overwhelmed with twice-daily ocean tides simply did not exist before the mid 1970s. Particularly challenging was to try to extract this number in the 500 meter wide channels in the delta.

But that's exactly what the state's Department of Water Resources (DWR) set out to do in the late 1920s. Researchers first stretched a cable across the channel, called a tag line, then attached their boat to the cable. As the boat moved through 12-24 stations along the cable, they used a device called a Price AA meter to take individual water velocity measurements. By summing the flow curves at each station between tidal peaks, DWR produced a snapshot of net discharge at that time and place.

"These were incredibly labor-intensive, even Herculean, field efforts, working with multiple boats over 24-hour periods, but they did an amazingly accurate job given the technology they had," says USGS scientist Jon Burau.

Eight decades later in the 2010s, measuring net flow involves equally, if not more, complex efforts, but technology and computers do most of the heavy lifting. The biggest challenge overcome by the hydrodynamics team of the USGS California Water Science Center, which runs the network, has been to find a way — through data collection, math and modeling — to isolate the small signal (net flow) from what they call the big "noise" of the tides. At the Jersey Point Station, for example, daily peak tidal flows can be on the order of 150,000 cubic feet per second (cfs), while the net flow may be 2,000 cfs or less. According to Burau, this means

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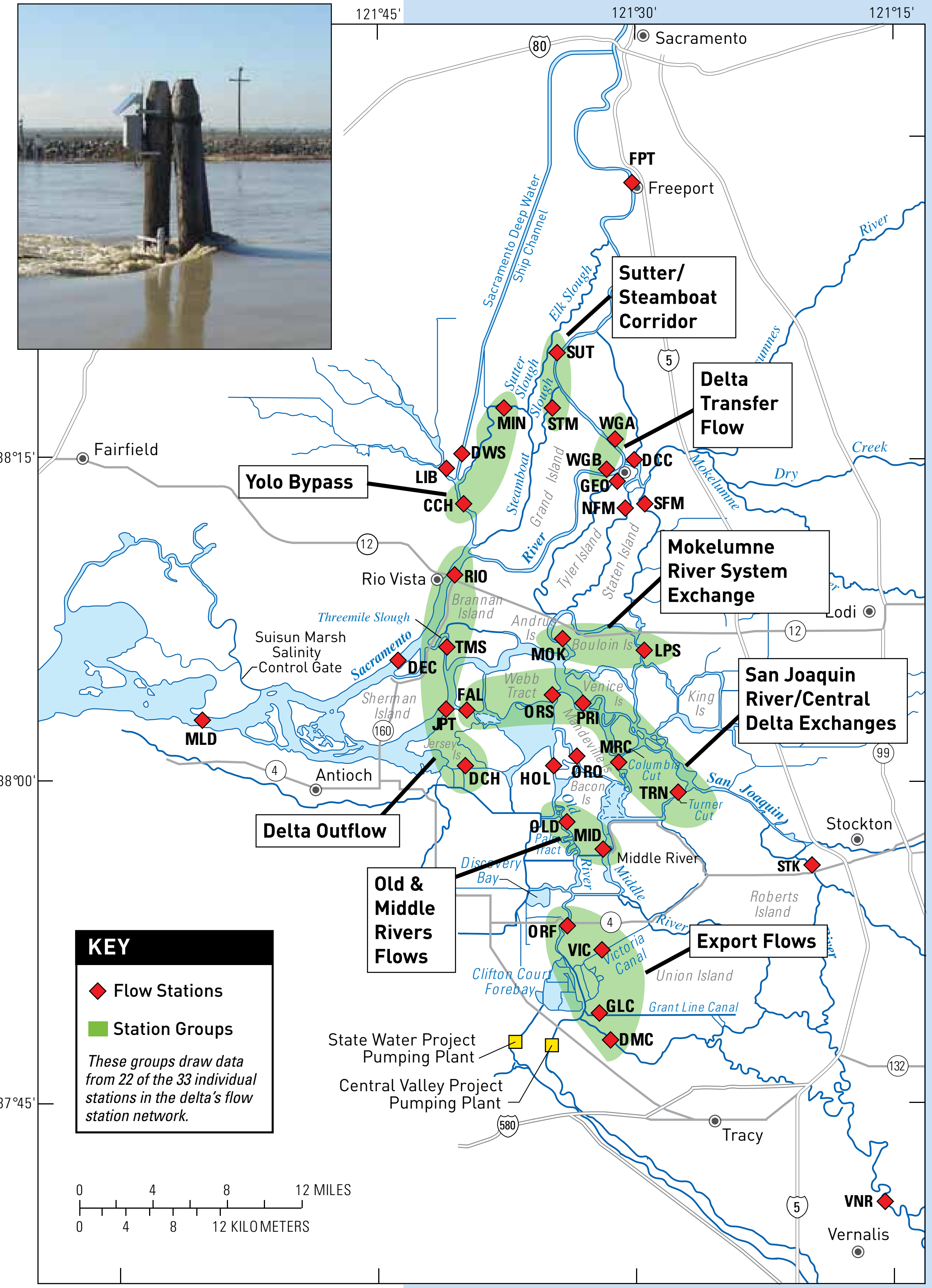

Location of USGS-operated flow station sites in the Delta. Source: USGS, CWSC

NETWORK SNAPSHOT

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 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 they installed two more acoustic velocity meters at Old River at Bacon Island and at Middle River (1987). In the early 1990s, water project operators installed two stations in the Walnut Grove area, so they could find out how much water was flowing from the Sacramento River into the central Delta through the Delta Cross Channel and Georgiana Slough, the so-called Delta Transfer Flow. Finally, a combination of four stations in the south delta were installed to estimate delta flow to the export pumps. Below is a description of the groups of stations used to address specific regional scale questions.

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 received by San Francisco Bay (i.e. inputs less exports and consumptive use).

Delta Transfer Flow - The delta transfer flow is computed as the difference between the flows measured at stations WGA and WGB, two flow stations located near Walnut Grove. The calculation helps water managers estimate the amount of Sacramento River water that flows into the central Delta through the Mokelumne system (the Delta Cross Channel 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 14-day average of the sum of the Old and Middle River flows is known as OMR and appears in numerous regulatory documents and court cases.

Sutter-Steamboat Corridor - Sutter and Steamboat Sloughs are significant conveyance channels that carry, at times, half of the water that passes the city of Sacramento. 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 is 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). The 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 consistently captured.

Mokelumne River System Exchange - Most of the Sacramento River water that is exported south of the delta flows through the Mokelumne River system. When the Delta Cross Channel gates are open this region is essentially riverine, but when the gates are closed, this system is virtually tidal. The data from the MOK and LPS stations may also be relevant to salmon outmigration, 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 the salt and sediment fields evolve. 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 salmon outmigrants into the central delta.

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

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that to correctly measure the net flow his team has to be accurate in its tidal estimates for Jersey Point to within one percent. "Even a small bias in our tidal estimates can indicate completely erroneous net flows, possibly in the wrong direction," he says.

One way the team detects errors is by cross-checking data with flow stations nearby. The team uses groups of stations, for example, to verify localized inputs and outputs of water, and localized "storage." To get more information about what's going on at each location, the team has also added another gizmo called a "CTD" to many stations. These devices measure electrical conductivity (salt) and turbidity (sediment in the water).

Despite all the automation, things do go wrong with the flow stations. "Electronics and water don't get along too good," says Burau. Passersby can't help but be curious about the bright shiny devices sitting out in the water on posts. "If the fishing's bad, folks start fooling around with our equipment," says Burau. Most of the time, USGS can tell if equipment's malfunctioning remotely, using telemetry and a "data crawler" that looks at key status variables such as electrical power. "If any of our stations fail any of our tests, the crawler sends us a text," he says. Even with all the remote fail-safes, something's always up when you have 35 stations running 24-7. Burau estimates his techs are out in a boat doing repairs and site maintenance, and collecting calibration data, at least three times a week.

USGS also uses robot boats to monitor flows. The ten-foot-long-length of these boats, which are equipped with acoustic Doppler current profilers, enables them to span the 4-5 foot wave lengths common in wide delta channels without bobbing. The robot boats also maintain a much steadier course than any heavier, human-controlled vessel.

In places with a lot of boat or shoreline traffic, USGS will sometimes hide its flow station entirely underwater by tethering it to an anchor and buoy system. The buoy has an acoustic release catch on it. One time, the USGS maintenance team approached one of these cloaked stations to find two fishermen, rods up, beers open, parked right on top of it looking out at the Bay. The team couldn't resist sending the "wake-up" signal to the underwater station. As they watched, a beach ball sized orange buoy leapt out of the water into the air right in front of the fishermen, then splashed down hard. "It scared the hell out of them, it was a terrible trick," says Burau.

Collecting the data is one thing, using it another. According to IEP's Mueller-Solger, the data from the flow station network is useful in two obvious ways. First, everyone uses it to calibrate and validate their hydrodynamic models, not only simpler "mass balance" equations like the much-used "Dayflow" calculation of delta outflow, but also in more sophisticated 3-D computer models of where water might flow in the future given sea level rise, levee failure, or the construction of a new canal to reroute water around the delta's biological weak spots. "If you don't have any flow stations to groundtruth delta models, you lose all faith in predicting what will happen with new water projects," says Deanna Sereno, an engineer with the Contra Costa Water District.

Though Sereno doesn't use flow station data much for day-to-day district operations, she does use it for other purposes. A couple years ago, when the district was building a new drinking water intake at Victoria Canal, Sereno was alarmed one day to see a spike in turbidity. Sereno checked to see if the spike was coming from up or downstream of the nearest flow station. "Since the flow and turbidity data are paired, it was easy to determine that it was coming from the opposite direction from our intake, and that our construction wasn't the cause," she says.

Sereno remembers working on a big research study as a graduate student aimed at tracking phytoplankton on two islands. As part of the study, Burau's group put flow sensors and CTDs on all seven boundary channels for Frank's Tract to measure what was coming and going out of the system. "It helped us understand that Frank's Tract was a net sink, or trap, for fish food, and that Mildred Island was a net source. You can't do that without the flow stations to determine the flux at those boundaries," says Sereno.

Station measurements also become useful for entities like the State Water Resources Control Board, or other regulators, when they are trying to determine compliance with flow objectives, water export standards, and biological opinions created to protect the beneficial uses of the system's water and fish. "Real time measurements of flow help us do a number of things," says the Board's Leslie Grober. "They help us to determine compliance with flow objectives, to adjust flows in real time to make them more functional for fish, and to decide on future changes based on how species responded to actual recorded flows."

Regardless of water management's reliance on the data, only a few of the flow stations are currently mandated by the State Board, the agency with the regulatory authority over withdrawals of water from the delta. Mueller-Solger thinks such mandates are a two edged sword. On the good side, you have long term security and consistency in monitoring; on the bad side, as management questions and technology change, mandates can get in the way of needed updates.

One thing scientists from many agencies agree on now is the need to "co-locate" data collection. As researchers measure variables, such as turbidity, salinity, plankton, or fish numbers, the value of this information is enhanced if they also have information on the hydrodynamic context from the same time and place.

Experts say the flow station network will become even more foundational to delta planning in the future. "When we start putting in new conveyance facilities and doing marsh restoration, we're going to change the hydrodynamics and transport processes in the delta dramatically. So what you want to do in that situation is monitor it now, so you know how it works, and then again, when you make the change, so you'll know what's happened," says Burau. **ARO**

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

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