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

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Chapter 3: Developing a Residence Time Index to Study Changes in 1990 – 2004 Delta Circulation Patterns

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3 Developing a Residence Time Index to Study Changes in 1990 – 2004 Delta Circulation Patterns

3.1 Introduction

Long-term trends in historical Sacramento-San Joaquin Delta circulation patterns were studied by developing indexes of residence time for the two major sources of inflow to the Delta. Hydraulic residence time is an important factor affecting a number of estuarine processes. By releasing particles at the major estuary inflows and tracking them until they are no longer in Delta channels, it is possible to calculate the length of time and path those particles took through the Delta. An index of residence time can be created by using a series of daily injections and the associated travel times and particle fates for each day. These indexes were used by DWR in support of its current investigations related to the Pelagic Organism Decline (POD). This chapter presents the methodology used to generate residence time indexes, briefly describes results from the POD studies, and discusses future applications of this modeling methodology. A more detailed paper describing this methodology and its appropriateness to addressing estuarine ecological processes is being drafted for publication.

3.2 Methodology

The residence time indexes were developed by modeling the movement and fate of particles traveling with the Sacramento River and San Joaquin River inflows. Daily residence time indexes are defined to be the time it takes a given percent of buoyant particles that are inserted at a Delta inflow boundary to either travel out of the Delta or be removed from Delta channels. Thus, an index of Delta residence time is defined by the location of particle injection and by the threshold of the portion of injected particles no longer in Delta channels.

For this study two modules of the Delta Simulation Model 2 (DSM2), DSM2-HYDRO and DSM2-PTM, were used to simulate historical Delta hydrodynamics and particle movement respectively. DSM2 is a numerical model that can simulate non-steady state hydrodynamics, water quality, and particle tracking in a network of riverine or estuarine channels. DSM2 has been used to perform various studies of the Delta including water quality compliance forecasts and Delta impacts due to proposed features of the South Delta Improvements Program, In-Delta Storage Program, and through-Delta facilities.

In order to develop an indexes of residence time, DSM2-HYDRO, a 1-dimensional hydrodynamic model, first calculated hourly velocities throughout the Delta based on historical operation of Delta structures, the 15-minute stage at the downstream boundary, daily historical inflows, exports and diversions, and estimated monthly consumptive use. The results of the historical Delta hydrodynamic simulation by DSM2-HYDRO of January 1990 through December 2004 were input into DSM2-PTM.

DSM2-HYDRO is a 1-dimensional hydrodynamics model that, when simulating Delta in-channel velocity, stage, and flow, uses a downstream boundary tide at Martinez and flows at the upstream boundaries.

DSM2-PTM is a quasi 3-dimensional particle tracking model that first converts the 1-dimensional velocity input from DSM2-HYDRO to a 3-dimensional velocity profile and then uses dispersion and diffusion terms to move particles through the Delta's network of channels. DSM2-PTM is capable of tracking injections at multiple locations over the extent of the Delta, a requirement for generating residence time indexes. The interaction of the two DSM2 modules is shown in Figure 3.1 and a more detailed description on the methodology used to generate a series of residence time indexes is given below.

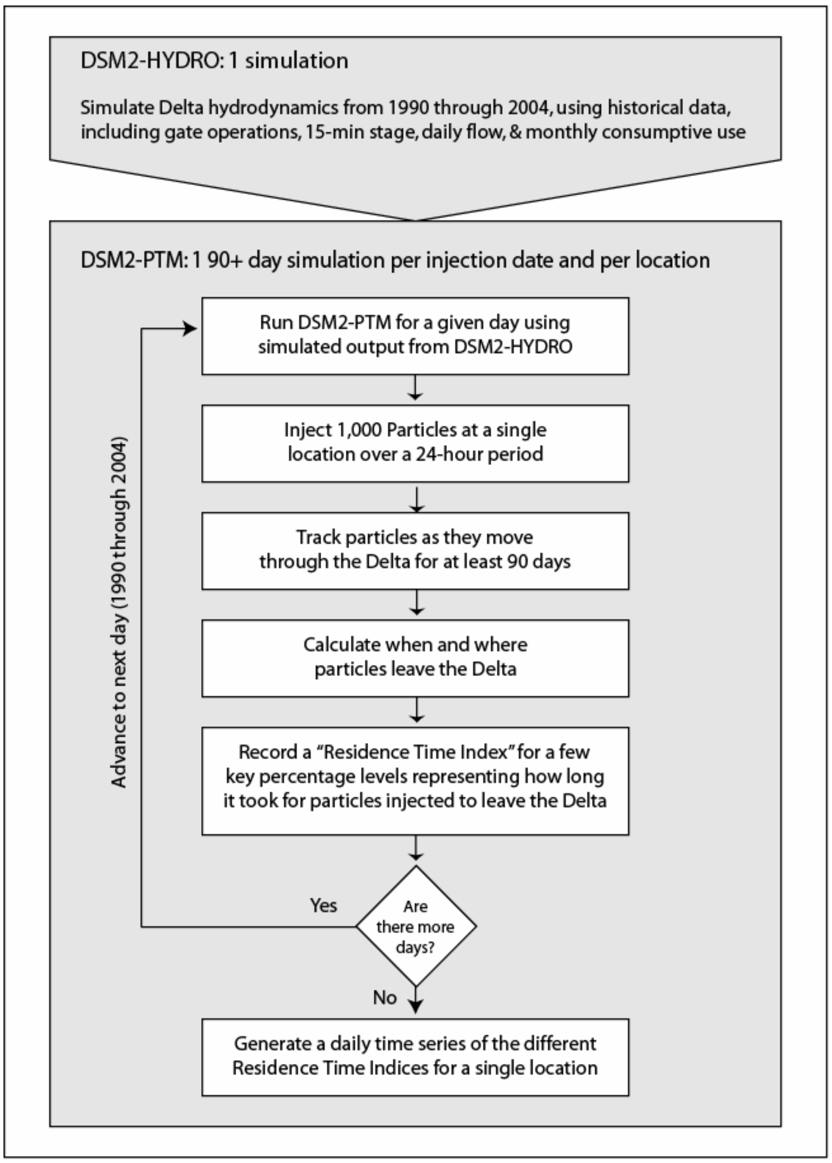

Figure 3.1: Overview of modeling methodology to calculate residence time indexes.

3.3 Model Calibration

DSM2-HYDRO was calibrated to flow and stage in the Delta by a multi-agency group under the direction of the IEP (Nader-Tehrani, 2001). Due to the limited data available throughout the Delta, four month-long periods (May 1988, Apr. 1997, Apr. 1998, and Sep.-Oct. 1998) were chosen as the calibration periods in which the model's friction parameter was adjusted until simulated values best matched observed daily average and instantaneous flow and stage data. The DSM2-HYDRO was then validated by comparing simulated flow and stage with field data from 1990 through September 1999. The results of the 2000 IEP calibration and validation are available on the Department of Water Resources' modeling support web page:

http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/dsm2studies.cfm

DSM2-PTM uses average channel velocities computed by DSM2-HYDRO to create a quasi 3-dimensional velocity cross section, with the 3-dimensional profiles assuming a zero slip condition at the bottom and sides of the channels and locating the fastest moving particles at the water surface in the center of the channel (Wilbur, 2000). Acoustic Doppler current profiler (ADCP) velocity data collected at 16 different sites in the Delta by the USGS (Oltmann, 1998) were used to calibrate the DSM2-PTM transverse and vertical velocity profiles (Wilbur, 2000). Simulated quasi 3-dimensional profiles in the model were validated using dye concentration data collected from three stations in the Delta as part of a U.S. Geological Survey rhodamine WT tracer dye study.

3.4 Calculation of Residence Time Indexes

Consistent with the definition of residence time by Monsen et al. (2003), the residence time indexes developed using DSM2 particle injections were based on two specific injection locations: the Sacramento River at Freeport and the San Joaquin River at Vernalis. The daily resident time index was defined as the time required for a specified percentage of particles continually injected at a location over a period of 24 hours to leave or be removed from Delta channels. Each index value reflected the hydrology and hydrodynamics when the particles were injected and during the subsequent time that the particles were in the Delta channels.

The process of counting particles passing by or through a specific location is referred to as particle flux. For the present analysis, DSM2-PTM tracked the cumulative hourly particle flux for the following locations: the State Water Project (SWP) and Central Valley Project (CVP) pumps, the Contra Costa Water District (CCWD) and North Bay Aqueduct intakes, the Delta island diversions, and the Sacramento River at Chipps Island. With the exception of Chipps Island, particles exiting a Delta channel through a diversion were physically removed from the Delta. The cumulative particle fluxes at these locations therefore uniformly increased over time and the final fate of particles at these locations was known. In contrast, the particle flux at Chipps Island fluctuated as particles moved past Chipps towards the ocean during an ebb tide and then back inland on the following flood tide. Much of this tidal signal in the flux results was removed by taking the daily average of the cumulative particle flux of particles passing past Chipps Island. These average values were assumed to be the net count of particles that moved out of the Delta.

An example of tracking particles injected on a single day at Vernalis is shown in Figure 3.2. In this example, 1,000 particles were injected on June 15, 2003 and tracked for the next 90 days. On the day of the injection, 100% of the particles were still in the Delta channels. Five days later, 21% of the injected particles had already exited the Delta channels, with the majority of these particles having been entrained on the Delta islands or by the CVP pumps. Fifteen days after the injection, the Delta islands had entrained 22% of the originally injected particles and the CVP pumps had removed 38%. On July 23, thirty-eight days after the initial injection, 97% of the particles were no longer in the Delta channels.

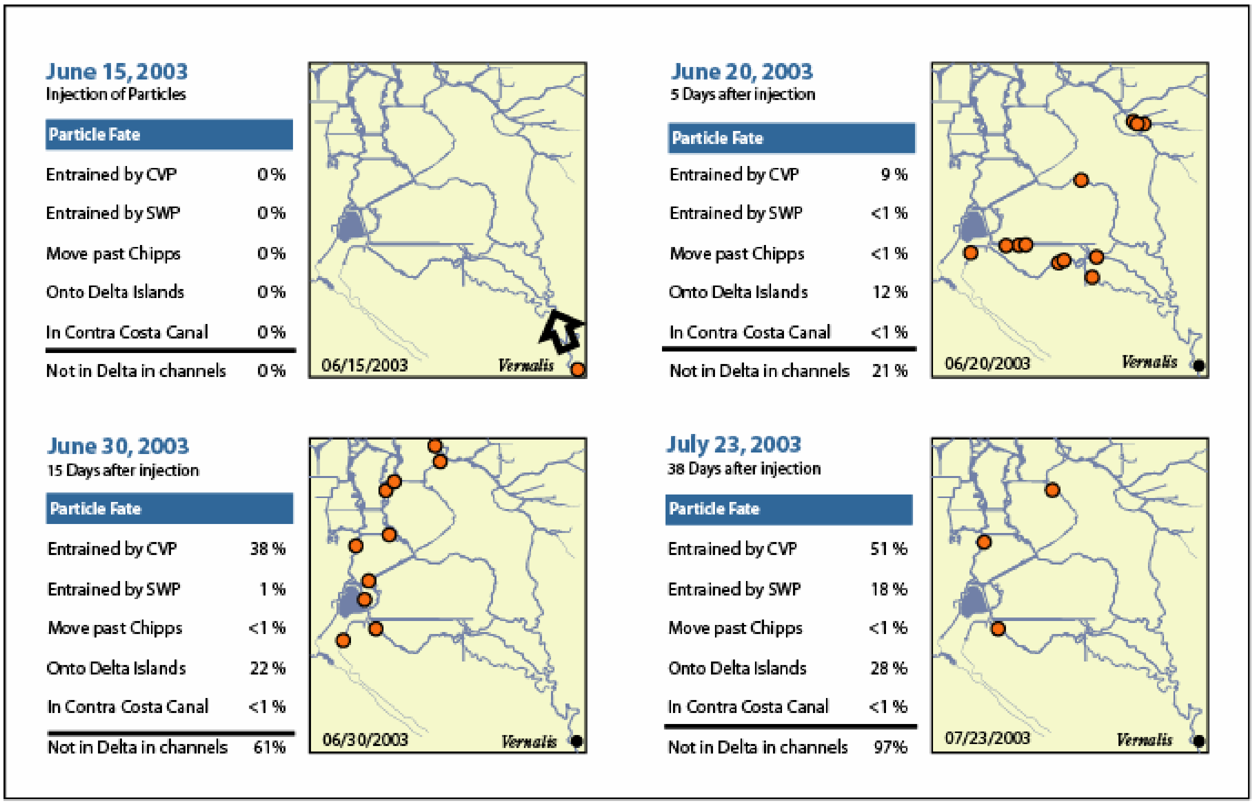

Figure 3.2: Example of tracking a single Vernalis particle injection.

The net cumulative flux of particles leaving the Delta was found by summing the daily cumulative fluxes for each source of particles being removed. This daily sum was then used to create a cumulative distribution function of residence time (see Figure 3.3) for each injection date for each of the two injection locations. Each daily residence time distribution represents the number of days it took for a given percentage of the particles originally injected to no longer be located in the Delta channels. As the percentage of particles removed increases, the total number of days required for the particles to be removed increases.

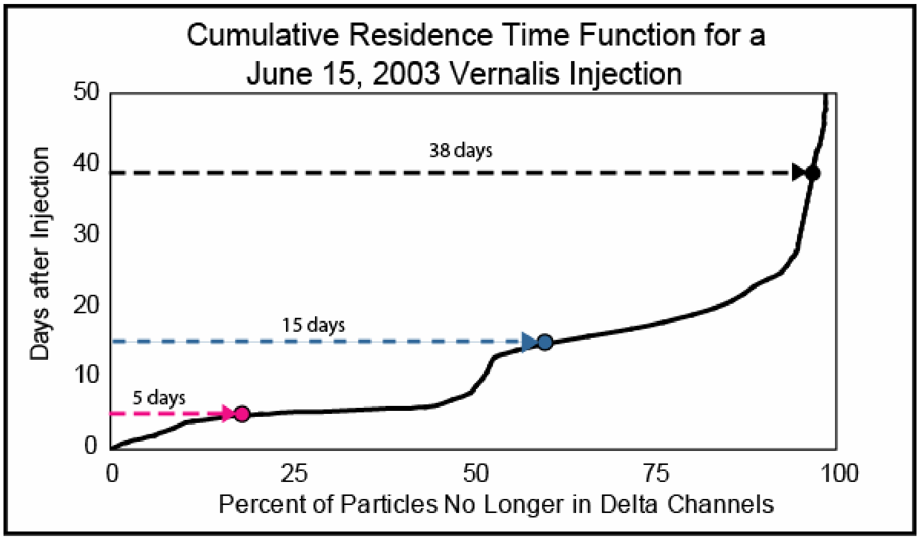

Figure 3.3: Cumulative residence time function for a single date of particle injection.

Using these daily cumulative residence time functions, a residence time index for the particle injection date can be found for any given percent of particles removed that is of interest. Thus, for any given milestone of percentage of particles no longer in the Delta, the associated daily residence time can be used to construct a time series of residence time indexes. Each of these daily index values is specific to the location and date of injection and is a function of the number of particles no longer left in the Delta. Figure 3.4 shows an example of using the daily cumulative residence time functions for June 15, 2003 to develop two residence time indexes for 2003, one representing when 25% of the injected particles have been removed from or left the Delta and the other for 75%.

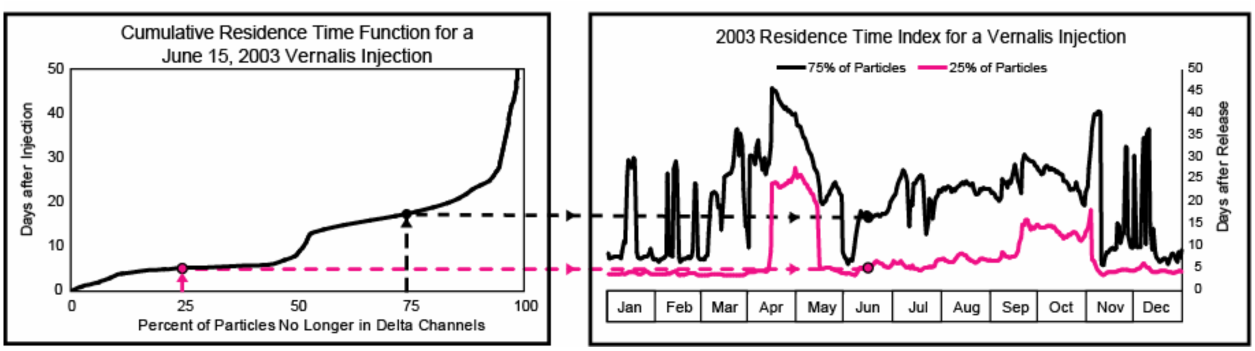

Figure 3.4: Creating annual residence time indexes using daily cumulative residence time functions.

There are advantages and disadvantages to using smaller and larger percent of injected particles moving out of or being removed from Delta channels as a residence time index criterion. For the purpose of analysis of residence time indexes, only a few percentage levels were studied. The residence time associated with a small fraction of particles, for example when 25% of the particles injected have left the Delta, is the product of a shorter period of time. Shorter periods have a greater probability of a more uniform distribution of flows. Such a more homogenous set of conditions makes it easier to relate a specific location's residence time to Delta hydrodynamics. However, a large percentage of particles are still unaccounted for during shorter periods and the particles could be days or weeks away from exiting the Delta. A residence time representing a larger fraction of particles, such as when 75% of the particles injected have left the Delta, tends to be more variable than an index based on a lower amount of particles; however, there will be more information included about the particles that exited the Delta. This results in less uncertainty about the fate of the remaining particles.

3.5 Model Boundary Conditions

Historical hydrology during the period 1990 through 2004 was used as the basis for the DSM2 simulations (Figure 3.5). The simulation included the installation and operation of the south Delta temporary barriers which were modeled instantaneously installed and removed according to when observed flows and water levels were significantly affected. Daily average flow was input at the major tributaries to the Delta, including the Sacramento, San Joaquin, Mokelumne, and Cosumnes rivers and the Yolo Bypass. Daily average exports were input for the SWP and CVP pumping plants, Contra Costa's diversion, and the North Bay Aqueduct. Monthly average diversions to Delta islands and the corresponding return flows from these islands were calculated using the Department's Delta Island Consumptive Use (DICU) model (CDWR, 1995). DICU uses total monthly precipitation and pan evaporation in the Delta and assumed land use patterns to calculate island consumptive use, which DICU then distributes for use in DSM2. Observed 15-minute tidal data at Martinez was used as the downstream boundary condition.

Figure 3.5 presents important Delta hydrology for the 1990 through 2004 period of simulation. Shown are inflows from the Sacramento and San Joaquin rivers, combined SWP and CVP export pumping, and a daily Net Delta Outflow Index. This calculated index was the sum of the major flow sources and sinks input in the DSM2 simulation (see Anderson, 2004 for details on calculating Net Delta Outflow). Figure 3.5 shows high San Joaquin River flows and a high Net Delta Outflow Index in the winter months of 1995 through 1998. The floods of 1997 resulted in high Net Delta Outflows and San Joaquin River flows that extend beyond the scale used in the graphs for only a few days in early January. During those floods, water overtopped San Joaquin River levees in the south Delta. Although DSM2 confined the high San Joaquin River flows to the channels, the January 1997 daily residence time indexes appear similar to other January periods. Thus it can be assumed that the DSM2 assumption of no overtopping did not negatively affect the indexes during the flood event. This additional flow is accounted for in the corresponding Net Delta Outflow Index.

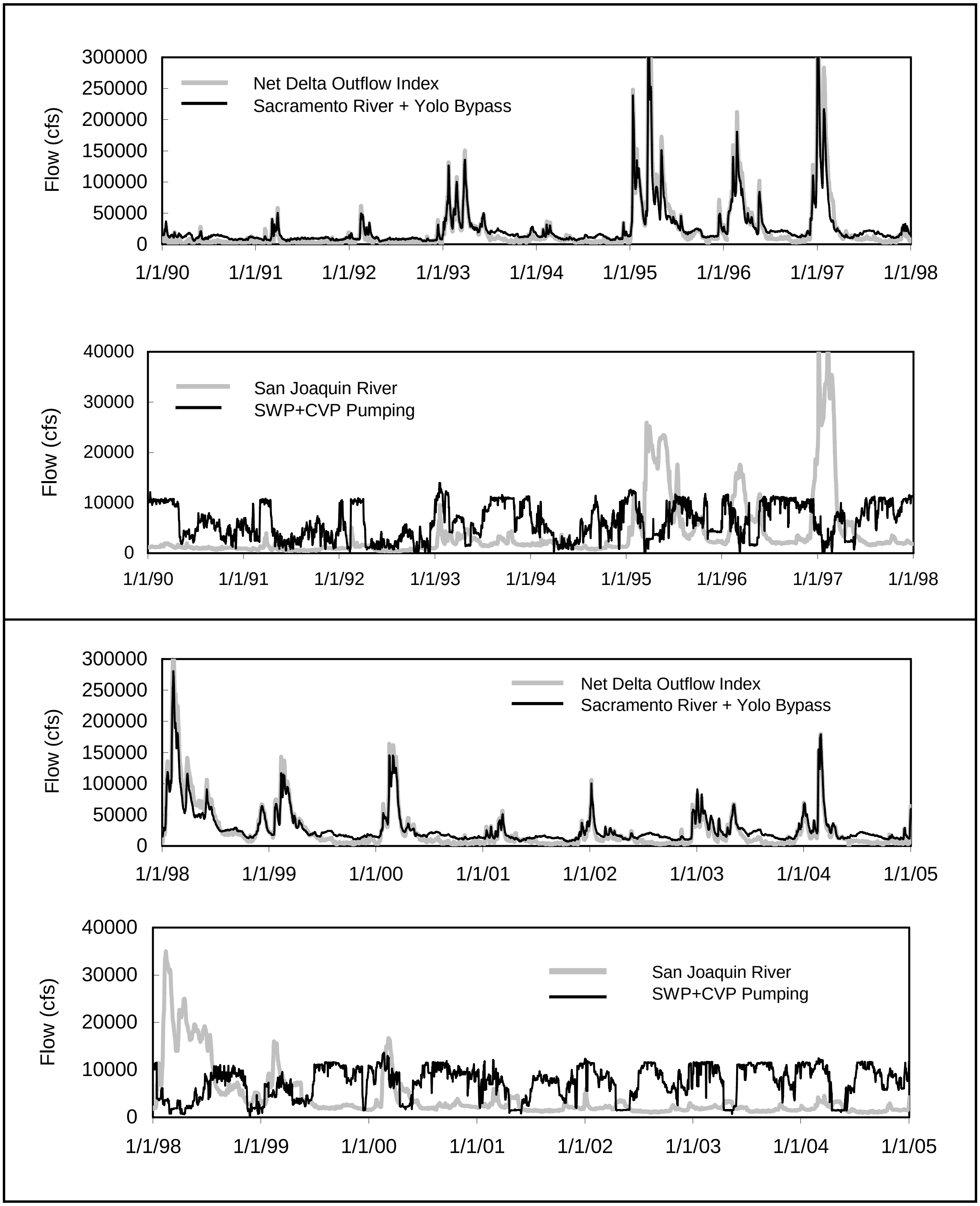

Figure 3.5: Significant Delta boundary flows and exports (1990 – 2004).

3.6 Results

Although the daily residence time indexes for criteria of 25%, 50% and 75% of the injected particles from Freeport and Vernalis were examined, only the monthly-averaged results of the 75% residence time index are presented here for brevity. The 25% and 50% indexes often provided little insight into patterns of residence time and circulation because of very small values (e.g. one or two days). The greater variability in the 75% index between 1990 and 2004 relative to the variability in the 25% and 50% indexes provides a better means with which to assess the potential scale of any large-scale changes in Delta circulation patterns.

The monthly averages of the 75% residence time index for particles injected in the Sacramento River at Freeport and the San Joaquin River at Vernalis were summarized graphically to examine long-term trends, and in tabular format to examine statistical trends. For each month a time series of monthly-averaged residence time indexes was plotted for the period of study (see Figures 3.6 and 3.7). The long-term mean for each monthly time series was then plotted to illustrate the annual variability in the monthly-averages. The statistical variability in the residence time indexes was further expressed as the minimum, mean, and maximum monthly-averages for each month (Table 3.1).

Table 3.1: Range of monthly-averaged 75% residence time indexes for Freeport and Vernalis injections (in days).

Month	Freeport			Vernalis		
	Min	Mean	Max	Min	Mean	Max
Jan	3	21	56	6	16	28
Feb	3	16	38	6	17	27
Mar	4	22	58	7	21	46
Apr	5	34	89	8	33	54
May	5	39	87	13	29	49
Jun	6	38	80	9	18	25
Jul	16	35	70	6	17	27
Aug	22	40	71	7	16	29
Sep	25	49	82	17	28	62
Oct	37	51	74	18	31	70
Nov	19	40	70	18	32	60
Dec	6	28	64	12	21	42

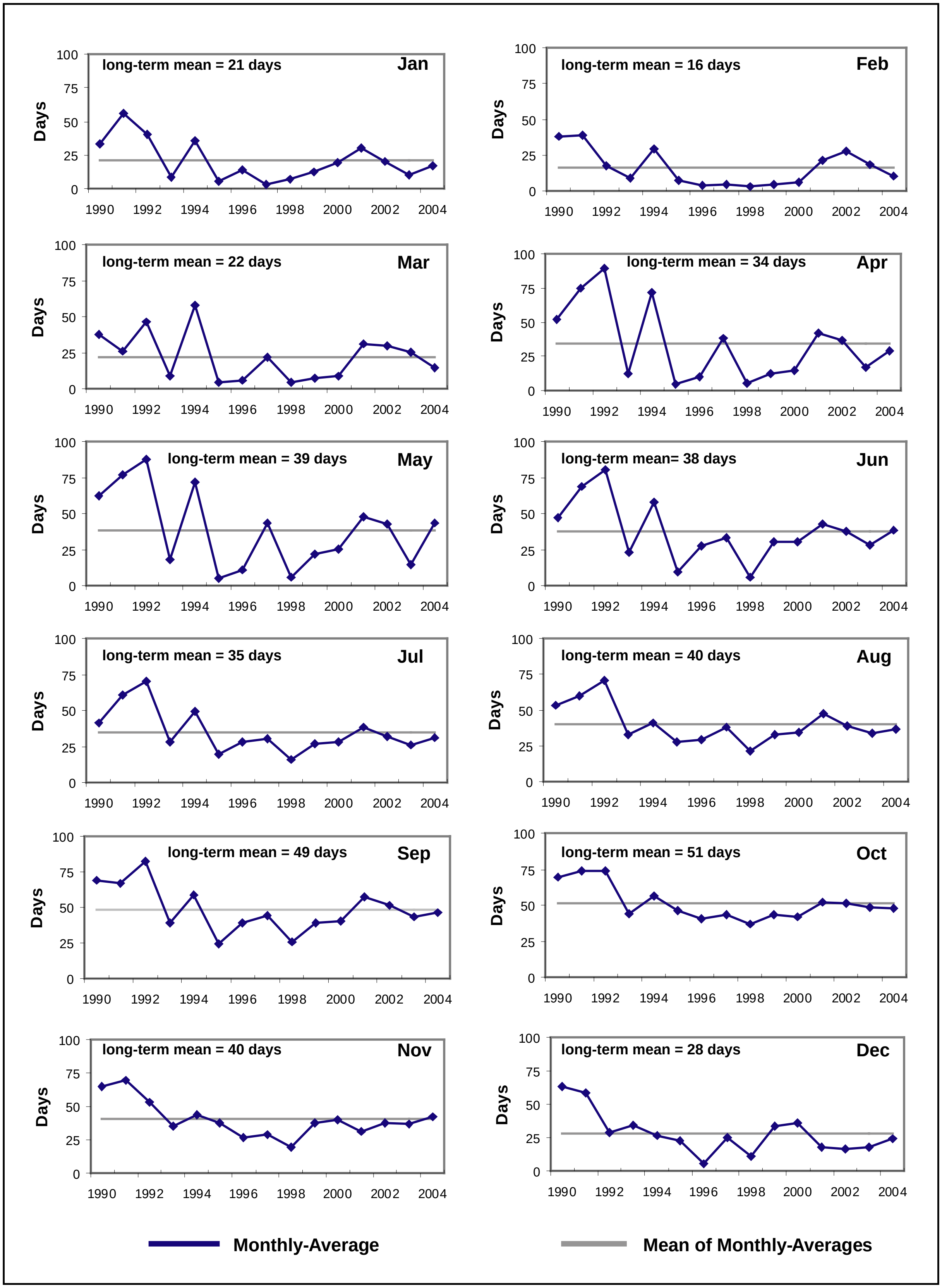

Figure 3.6: Monthly-averaged 75% residence time indexes for a Freeport injection.

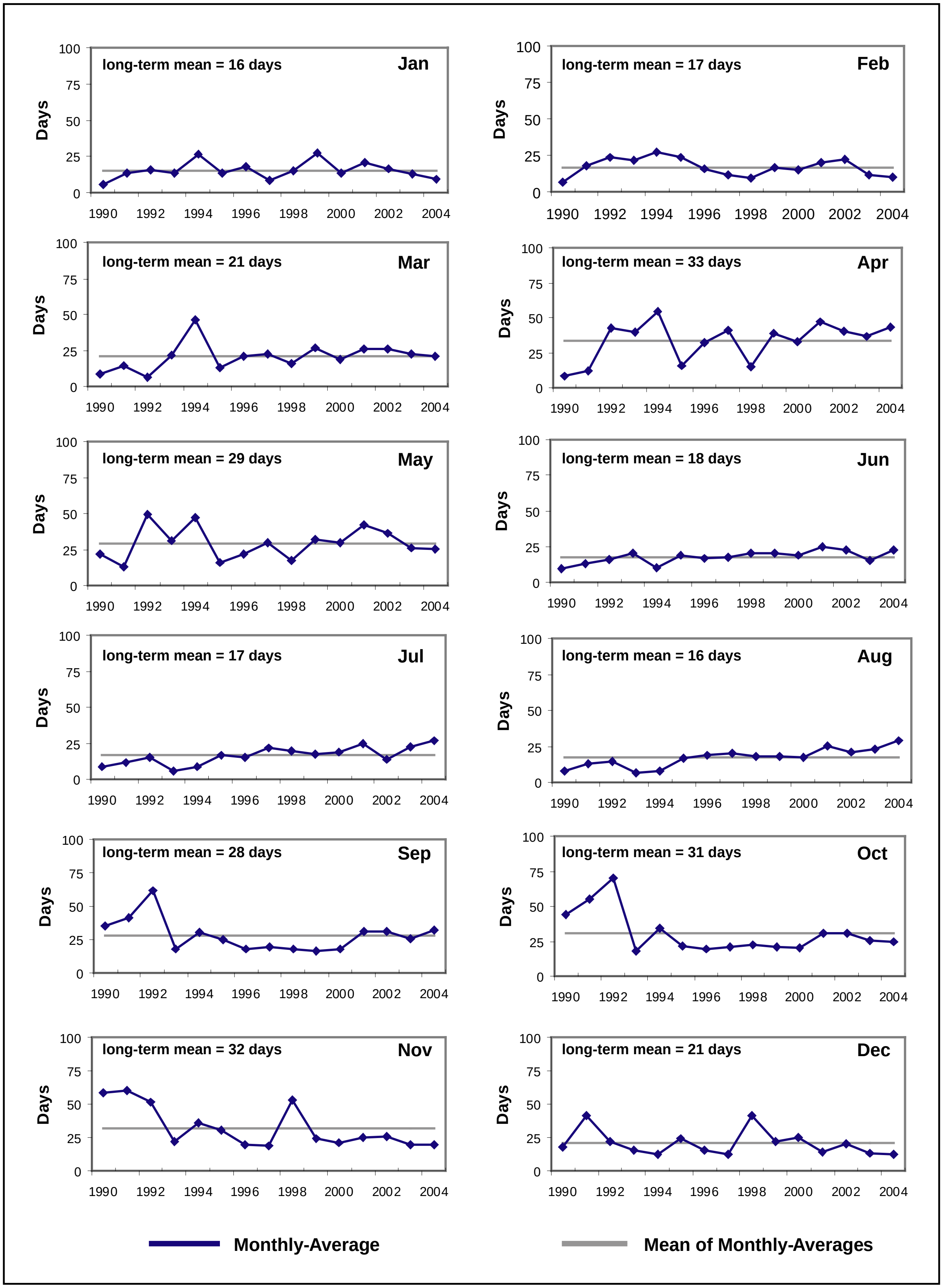

Figure 3.7: Monthly-averaged 75% residence time indexes for a Vernalis injection.

3.7 Future Directions

A future analysis might compare the distribution of final particle destinations (also known as flux locations) with residence time indexes. Similar in concept to comparing water quality fingerprints (Anderson and Wilde, 2005) with hydrologic information, such a comparison would allow a visual means to associate changes in the ratio of particle destinations with changes in residence time index (as shown in the left pane of Figure 3.8). For example, Figure 3.8 compares the Vernalis daily 75% residence time index in 2001 with the percentage of particles from each daily injection that exited the Delta by passing Chipps Island or being entrained at the project exports (SWP and CVP) or Delta islands (via the agricultural diversions).

Another possible study would be to explore how hydrologic boundary conditions affect a greater extent of the estuary by injecting particles in the interior of the Delta to (see the middle pane in Figure 3.8). Since particles injected at locations closer to the major exit vectors out of the Delta will not remain in the estuary as long as particles injected at Freeport or Vernalis, the two residence time indexes presented here could be used as upper bounds on the simulation length for any additional simulations with particles injected at interior locations. In addition to providing more detailed insight into internal circulation patterns, the particle injection locations can also be chosen to address entrainment related questions.

DSM2-PTM can be used to calculate regional residence time indexes by simultaneously injecting particles at multiple locations in a given region and then tracking how long these particles remain in the region (see the right pane of Figure 3.8). This approach calculates the number of particles in the channels in the region during each model time step and the time it takes for fixed percentages of particles to leave a predefined region.

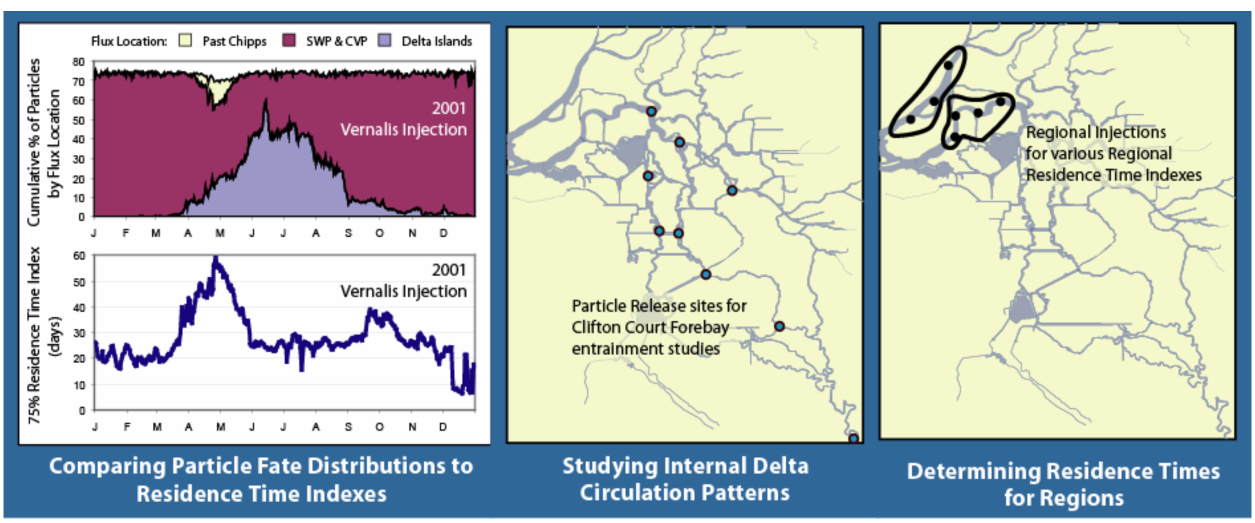

Figure 3.8: Examples of potential future applications for residence time indexes.

Summary of Key Findings

- Residence time indexes based on when a smaller percentage (25% or 50% compared to 75%) of particles exited the Delta were less sensitive to changing hydrologic conditions.
- Residence time indexes for the Sacramento and San Joaquin Rivers were not significantly lower in recent years (2002 – 2004) compared to long-term averages.
- The Sacramento River tended to have higher (longer) residence time indexes in the early 1990s (drier years), and the San Joaquin River tended to have higher residence times in the late Fall / early Winter months in the early 1990s.
- Late summer and early fall tended to have higher residence time indexes, while late winter tended to have lower residence time indexes.
- Residence time indexes have greater variability in the spring.

3.8 References

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