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CALIFORNIA DEPARTMENT OF WATER RESOURCES

The Use of a Potential Entrainment Index for Delta Smelt: An overview of a model and its application for developing operation criteria and calculating incidental take for the State Water Project and Central Valley Project

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Prepared for
National Research Council

Project
Sustainable Water and Environmental Management in the California Bay-Delta
DELS-WSTB-09-09

January 2010

Introduction

The following report and appendices contain the Department of Water Resources support material for the presentation by Deputy Director Jerry Johns given during the January 24-28, 2010 public comment meetings in Davis, California.

This paper presents evidence to support the relationship between specific environmental parameters and entrainment of delta smelt by the SWP and CVP pumping facilities located in the southern region of the Sacramento-San Joaquin Delta. While many researchers have been able to find similar relationships between flows or other environmental parameters and entrainment of delta smelt, it is noteworthy that we know of no substantial relationship between entrainment and the abundance of delta smelt. Manly and Chotkowski (2006) found that OMR flow (and presumably entrainment of delta smelt associated with it) could account for only a few percent of the long-term variation in adult delta smelt abundance. Recent papers by Kimmerer (2008) and Grimaldo (2009) summarize extensive studies on this topic and, as Kimmerer (2008) points out, the effect of these losses on the delta smelt population is unclear and obscured by a subsequent 50-fold variability in the survival of delta smelt from the summer to fall, possibly due to substantial variations in the summer zooplankton abundance. In addition, over the last four years actual OMR flows from January through June have been within the protective range established in the 2008 Delta Smelt Biological Opinion (BiOp) with no improvement in delta smelt abundance. This lack of improvement infers that controlling entrainment of delta smelt by the SWP and CVP alone is not providing the expected benefits to delta smelt abundance. A much more comprehensive program is needed that addresses other stressors, such as food availability, that are affecting smelt abundance.

Though current research has not been able to establish a substantial relationship between entrainment and abundance of delta smelt (even though many have tried), entrainment should be reasonably controlled to avoid peak entrainment events which could potentially have population effects. This paper presents implementable methods to reasonably control entrainment of delta smelt by the SWP and CVP that can be both protective of delta smelt and the State's water supplies.

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Background on Entrainment Issues

This document discusses the development and potential application of a method to aid State and federal water and fishery management agencies to determine State Water Project (SWP) and Central Valley Project (CVP) operational criteria to protect the populations of larval and juvenile delta smelt from entrainment at the SWP and CVP diversions in the southern Sacramento-San Joaquin Delta (Delta). It explains how this tool, the Potential Entrainment Index (PEI), can be used with the most recent and best available monitoring data on the abundance and distribution of smelt to more objectively assess the portion of the larval and juvenile fish populations potentially entrained in the SWP and CVP Delta diversions under different operational scenarios. This information can then be used to help define operational criteria on a real-time basis to keep such entrainment to levels as appropriate to protect the smelt population. Criteria established using the PEI methodology could be adjusted if other information is available to show that it is necessary to do so to protect the species.

Historically, delta smelt have been vulnerable to entrainment at the CVP and SWP water diversions in the southern region of the Delta. A major factor affecting the vulnerability of delta smelt to entrainment by the CVP and SWP is where they reside in the estuary during their different stages of life. From about early July through mid-December or January, most delta smelt reside in the brackish waters of the western Delta and eastern Suisun Bay. Some also reside year-round in the northern Delta. During this period, fish are far enough away from the south Delta export facilities that they have little risk of being entrained. Except in years of extremely high Delta outflow, the adult delta smelt in the western Delta migrate upstream to spawn in the north, central and south Delta in mid-December through March. In years of high flows, many of the adults in the western Delta remain there or are carried downstream to spawn in Suisun Bay, San Pablo Bay or the Napa River Estuary. The timing and extent of this adult migration varies from year to year. However, when the adults enter the central and south Delta, they become much more vulnerable to entrainment into the south Delta diversions. The adults usually spawn during February and March. The progeny of adults which spawned in the central and south Delta are also vulnerable to entrainment until they move or are carried downstream into the western Delta in June or early July.

Delta inflow, outflow and turbidity appear to stimulate or at least are closely associated with the upstream migration of adult smelt, and thereby their susceptibility to entrainment. In most years, adult delta smelt begin moving rapidly upstream soon after the initial pulse of winter runoff and turbidity from the delta tributaries. Peaks in adult entrainment at the water projects often coincide closely with the first pulse of freshwater runoff from Delta tributaries (Grimaldo *et al.*, 2009).

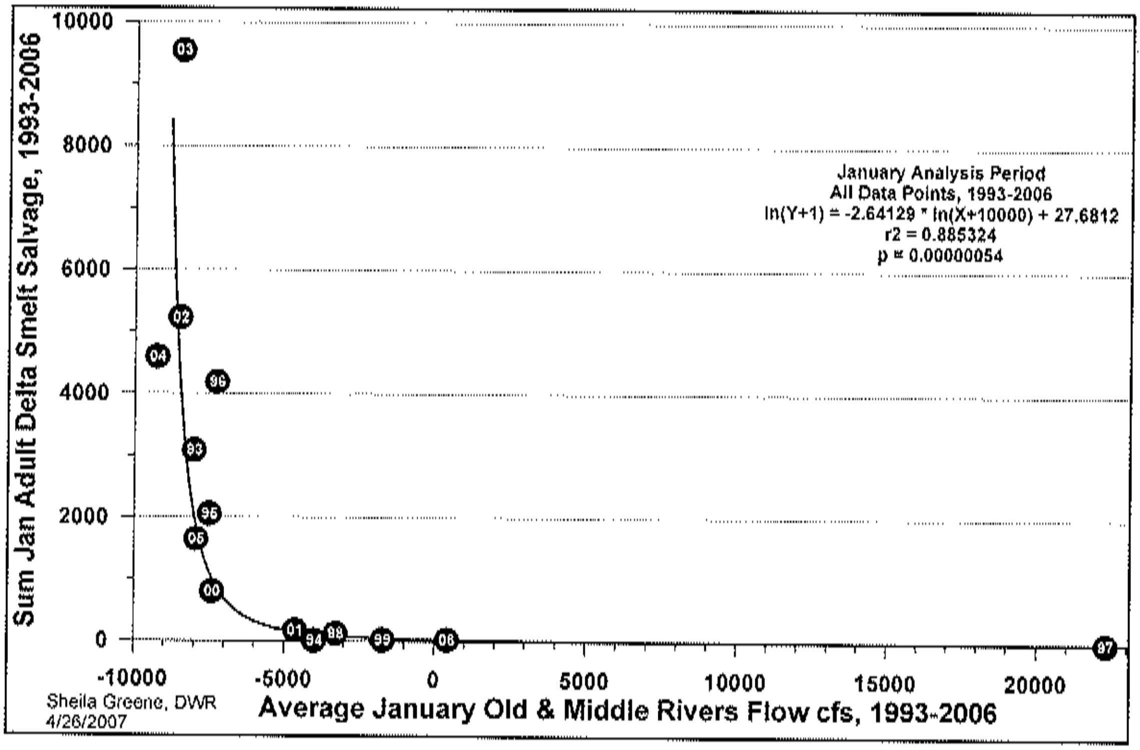
Flow in the south Delta has also been associated with delta smelt entrainment. Figure 1 shows the relationship between average combined flow in Old and

Middle rivers (OMR) in January and February and the salvage of adult delta smelt at the CVP and SWP south Delta export facilities. The average OMR is affected by a number of factors, including San Joaquin River inflow, CVP and SWP pumping rates and other in-Delta diversions. In Figure 1 the relationship between adult salvage and OMR flows is distinctly non-linear when reviewed on a monthly basis. Flows more negative than a -6,000 cfs (toward the pumping facilities) appear to be much more efficient at entraining delta smelt than lower flows. A very similar set of non-linear curves are shown for other fish species for January and February; most notably longfin smelt with the same threshold at about -6,000 cfs. If longer time periods are averaged together for example, over two or four months, this non-linearity is diluted and the relationship appears more linear. Peak entrainment events are a function of the proximity of the fish to the pumping facilities and the strength of the flows drawing them towards those facilities. Such events are typically short duration events lasting days or weeks rather than many months as will be discussed later. Note that in Figure 1 the years 2002, 2003 and 2004 have relatively high February OMR flows, but lower than expected salvage for that month. This is likely due to delta smelt moving out of the area in February. The non-linear monthly summary presented in Figure 1 is a more reasonable evaluation of the effects of OMR flows on adult delta smelt entrainment than the time frames used in the USFWS 2008 Biological Opinion.

Particle tracking modeling also suggests that OMR is associated with the entrainment of larval and early juvenile delta smelt March through May (Kimmerer and Nobriga, 2008).

Although the data show a relationship between OMR flow and the entrainment of adult smelt and the results of particle tracking models suggest a relationship between OMR flow and the entrainment of larval and perhaps juvenile smelt, the effect of entrainment on this portion of the delta smelt population as a whole is less clear.

The initial results of the Pelagic Organism Decline (POD) investigation found that winter entrainment of adult smelt from 1999 through 2003 was higher than in most of the previous 12 years. Because this period of higher entrainment started before and overlapped with the decline of the delta smelt population that occurred sometime during the 2002 to 2004 period, it has been suggested that high entrainment may have contributed to the subsequent decline. However, this view does not account for the fact that the entrainment was high for several years before the delta smelt population declined as might be expected of a species which rarely lives more than one year. Manly and Chotkowski (2006) also found that the OMR flow (and presumably the entrainment of delta smelt associated with it) could account for only a few percent of the long-term variation in the delta smelt adult abundance index.



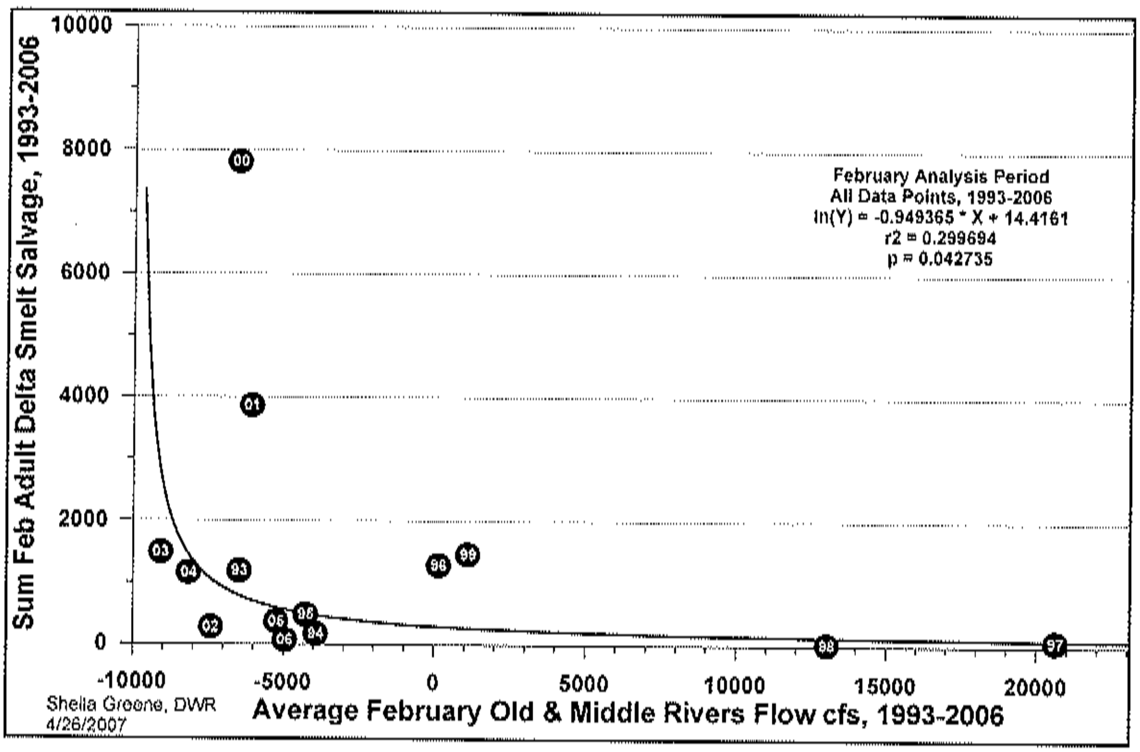


Figure 1. Relationships between average combined flow in Old and Middle rivers in January and February and the salvage of adult delta smelt at the CVP and SWP south Delta export facilities

Several reasons have been suggested to account for the weak relationship between the long-term trend in OMR flow or salvage and the variation in the delta smelt abundance. One reason might be that the smelt population may only be affected by episodic periods of very high entrainment which would be difficult to detect through a statistical analysis of the long-term variation of smelt abundance such as done by Manly and Chotkowski (2006). For example, a high level of entrainment in relatively few years might have a substantial and perhaps delayed effect on the population abundance but the extent of this effect would appear small when averaged out in an analysis that includes many more years when entrainment does not substantially affect smelt abundance.

Another reason might be that losses of adult, larval and juvenile smelt due to water project related effects are small compared to other controlling factors like temperature or food availability. Kimmerer (2008) estimated that losses from entrainment of adult delta smelt from 1997 through 2005 varied between 1 and 50%, with a median of 15%. He also estimated entrainment losses of larval and juvenile delta smelt between 0 and 25%, with a median of 13%. However, Kimmerer (2008) also pointed out that the effect of these losses on the population abundance was unclear and obscured by subsequent 50-fold variability in the survival of delta smelt from summer to fall, possibly due to substantial variations in summer zooplankton abundance. This high variability in summer to fall survival could obscure episodic events of high entrainment that might have affected delta smelt populations, as discussed in the preceding paragraph. Basically summer mortality might be so great that it might overwhelm the effect of entrainment earlier in the year.

Actions to Limit Entrainment of Larval and Juvenile Delta Smelt at CVP and SWP South Delta Diversion Facilities

USFWS identified several Reasonable and Prudent Alternatives (RPAs) in its "Delta Smelt OCAP Biological Opinion" (BiOp; USFWS, 2008) which would prevent CVP and SWP operations from jeopardizing the threatened delta smelt. RPA Component 2, Action 3 is the one specifically designed to limit the entrainment of larval and juvenile delta smelt by the two projects' south Delta diversions. This RPA, like the others, specifies actions deemed by the USFWS as needed to ensure that long-term operations of the CVP and SWP do not reduce the likelihood of both the "survival and recovery" of delta smelt and do not "preclude the intended conservation role of critical habitat."

The objective of RPA Component 2, Action 3 is to maintain flow conditions in the central and south Delta channels to limit larval and juvenile delta smelt entrainment and thereby increase their chances of successfully rearing and moving downstream when appropriate. When larval and juvenile delta smelt are likely to be present (as determined by specific criteria) this RPA requires the CVP and SWP to jointly modify their operations to maintain OMR flows no more negative than -1,250 to -5000 cfs based on a 14-day running average with a simultaneous 5-day running average within 25 percent of the applicable 14-day OMR flow requirement. This action ends when one of the following occurs: (1) June 30, by which time the vast majority of the smelt population has likely moved outside the area where they are at risk of being entrained, or (2) when the 3-day mean water temperature at Clifton Court Forebay reaches 25° C, a temperature which is likely to be lethal to fish remaining in the entrainment area.

The entrainment of larval and juvenile delta smelt is to be limited by adjusting CVP and SWP operations to limit negative OMR flows. USFWS expects that an OMR ranging between -2,000 to -3,500 cfs would be sufficient to avoid jeopardizing the species in most years. However, the USFWS also notes that in years of unusual smelt distribution when the predicted or measured larval and juvenile delta smelt distribution is in the area where entrainment risk is greatest, it could specify that OMR flows should be no more negative than -1,250 cfs.

The USFWS uses the Smelt Work Group (SWG) to advise it on what OMR flows should be during the time Action 3 is in effect according to guidelines specified in the BiOp. The SWG consists of fish biologists from the USFWS, U.S. Bureau of Reclamation (Reclamation), U.S. Environmental Protection Agency (USEPA), California Department of Fish and Game (DFG), and California Department of Water Resources (DWR). The SWG uses available physical and biological real-time monitoring data to determine level of entrainment risk. The BiOp provides several fairly general examples of how the SWG may do that through the season. One example assumes a large portion of the delta smelt population is located the central or south Delta. At such times the risk of entraining a significant number of delta smelt is higher and a stricter limit on OMR flow of -1,250 cfs might be recommended. Alternatively, in years when sampling indicates that most adults have spawned in the northern or western Delta and relatively few larvae are likely to be entrained, an OMR flow of about -3,500 cfs might be recommended as adequate. Later in the season, if more juvenile delta smelt are found seaward and as physical conditions in the Delta become less conducive to smelt larvae, OMR flow recommendations may become less restrictive.

The BiOp also specifies that the SWG and the USFWS will use a Particle Tracking Model (PTM) to determine specific OMR criteria that they will recommend. The Delta Simulation Model 2- Particle Tracing Model (DSM2-PTM) is a model developed by DWR to simulate the transport and fate of individual neutrally-buoyant "particles" traveling throughout the Delta and has been used by the SWG. DSM2-PTM uses velocity, flow, and depth output from DWR's one-dimensional hydrodynamic model for the Delta, DSM2-Hydro, as input. More information on the DSM2-PTM and DSM2-Hydro can be found at DWR's Delta Modeling Section website;

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

The BiOp describes (in Appendix B) how the USFWS and SWG would apply a PTM to help determine the OMR necessary to keep the entrainment risk of particles at one particular location in the central Delta, Station 815 (Prisoner's

Point), to less than 1% over a 20-day period. This approach has generally been termed the "Control Point Method" and is used as a default mechanism. Because of the hydrodynamic characteristics of the Delta, this approach has usually generated an OMR recommendation of about -2000 cfs regardless of the actual distribution of delta smelt in the Delta.

The BiOp indicates that the SWG and USFWS will use the Control Point Method in years of low delta smelt abundance, when the USFWS is concerned that the existing fish surveys may not accurately characterize the distribution and relative abundances of smelt through the Delta. The Control Point Method limits entrainment risk to the predetermined level irrespective of fish distribution. In circumstances where it is known or suspected that the central or south Delta is a principal source of emerging larvae, the BiOp indicates that the SWG and USFWS might base their OMR recommendations on a reduction of entrainment to less than 1% at Station 815 over 20-days or other methods as needed to ensure protection of the larval population in conditions of such severe vulnerability.

Potential Entrainment Index

While the BiOp's Action 3 specifics how entrainment of larval and juvenile delta smelt is to be controlled through the management of the OMR flow, it does so without objective criteria to assess the proportion of the smelt population effected by the recommended OMR flows. To help address this issue, DWR has developed and proposed the use of the Potential Entrainment Index (PEI) methodology. The Potential Entrainment Index (PEI) evaluates the relative susceptibility of larval and young juvenile delta smelt at specific survey stations to entrainment by the SWP/CVP. The PEI approach attempts to create a reproducible method for evaluating entrainment risk that can be used to meet near-term and annual goals for entrainment. This methodology can be used to estimate the proportion of the smelt population that might be entrained during a season or short-term time period under various hydrodynamic conditions, project operations and smelt distribution in the Delta. Conversely, it can also be used to help determine OMR criteria to keep delta smelt entrainment below some specified proportion of the population. The PEI values are derived from near real-time hydrodynamic conditions and fish survey data (DFG 20-mm Survey) showing the relative abundance and distribution of delta smelt. Though the PEI methodology described in this paper uses different applications of DWR's DSM2-PTM, PEI values can also be derived using other particle tracking computer models since the input data (fish abundance and distribution and hydrodynamics) would be the same.

The use of the PEI approach has a couple of substantial advantages over tools that have been used in the past to protect larval and juvenile delta smelt. First and foremost is that it clearly ties the operational criteria to the proportion of the fish population at risk of entrainment. The greater the proportion of the smelt population exposed to entrainment, the greater the operational response will be to reduce that risk. Second, the proposed method is similar to the approach used by Kimmerer (2008) in that it estimates the percentage of the smelt larvae and juveniles potentially entrained by the CVP and SWP. Kimmerer used a different method to estimate entrainment risk from that used in the PEI method, but the method to develop the annual PEI used many of Kimmerer's assumptions. The PEI can be used to avoid peak entrainment periods as suggested by Kimmerer (2008) by adjusting OMR requirements on a near real-time basis to minimize entrainment when a sizable percentage of the larval and juvenile delta smelt population is determined to be located in the central and south Delta and at high risk.

If the fish population falls below levels that can be detected by both the DFG Spring Kodiak and 20mm surveys, more intensive and effective monitoring could be implemented to improve the detection of larval and juvenile delta smelt in the Delta and the use of delta smelt salvage could be used to estimate delta smelt density in the southern Delta.

PEI Development

PEI values can be generated using either the DSM2-PTM (full runs) or from a regression based model (PEI calculator) developed by DWR that is built upon DSM2-PTM runs. For some applications described below, an additional model (amortization model) was created to cumulatively calculate PEI values on an annual basis from the PEIs developed for each 2-week 20-mm delta smelt sampling run. Most applications described below utilize the PEI Calculator instead of DSM2-PTM full runs, but either method could be used on a real-time basis and used in conjunction with each other.

The concept of PEI can be simply explained using an ideal situation where the location in the Delta of every Delta smelt is known at a specific point in time. After a time interval, the location of each smelt again is known, including the number of smelt entrained at the export pumps during that time interval. The entrainment index over that time interval is the percentage of smelt lost to exports relative to the total population. (For example, if there were 10,000 smelt in the Delta and 100 were lost to exports, the entrainment index would be 100/10,000 or 1% for that time interval).

The PEI method simulates as best as possible that process and relies on the relative abundance and distribution of delta smelt at any given time period. It utilizes fish monitoring data to determine the location of fish. The relative number of fish throughout the Delta is estimated by multiplying the density of fish found at a station by the volume of water surrounding that station. A Particle Tracking Model (PTM) is run using historical or projected inflows, diversions, and exports. The relative abundance of delta smelt particles are injected at each location and the particles are followed throughout the Delta channels and counted as they are taken by the exports in the model. With the calculation of the estimated relative abundance at the different stations at the beginning of the simulations and the number of particles taken at the SWP/CVP export facilities after the end of the simulation time interval, the PEI is determined.

The PEI calculator works similarly in the use of the fish monitoring data and the Delta monitoring station volumes. Instead of making full PTM simulations, regression equations relating OMR flows and Qwest flows to percent particle entrainment are used. Qwest represents net flow in the lower San Joaquin River used as a regulatory parameter in SWP/CVP operations. Given an OMR flow or a Qwest flow for each monitoring station, percent particles lost to exports are determined from the regressions and PEI is calculated based on the relative distribution of fish in the Delta.

The paragraphs below describe in greater detail the data sources and PEI methodology

Data Sources: Delta smelt abundance and distribution data

The 20-mm Survey is a fish monitoring study conducted by DFG, beginning in 1995 and continuing through the present. The 20-mm Survey monitors postlarval-juvenile delta smelt distribution and relative abundance throughout their historical spring range in the Delta. The 20-mm survey occurs from 8 to 10 times a year, at a frequency of every two weeks. Survey stations are sampled throughout the Delta and downstream to the eastern portion of San Pablo Bay and Napa River (Figure 2). Samples are collected using an egg and larval rigid opening net, constructed of 1,600 µm mesh. The survey usually reports sampling results within 72 hours.

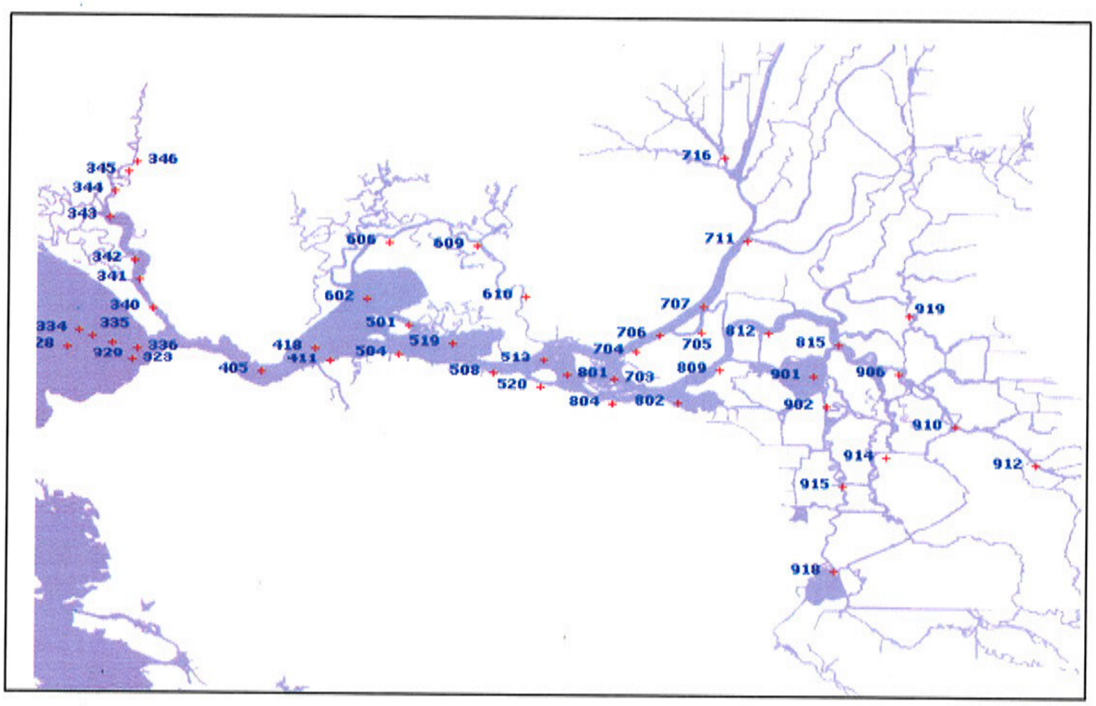


Figure 2. Select 20-mm survey locations and particle injection sites.

Data Sources: DSM2 Hydrodynamics Module (DSM2-Hydro)

DSM2-Hydro provides velocity, flow and depth information for numerous locations on a model grid for the Delta. The model grid uses the actual physical bathymetry of the Delta Channels. DSM2-PTM utilizes this information to track particles movement throughout the Delta channels.

Data Sources: Water Volumes

The volume of water surrounding each survey station is determined using Voronoi tessellation and bathymetry data accessed through the USGS Gr visualization software (http://ca.water.usgs.gov/program/sfbay/gr/). In a Voronoi diagram, an area is partitioned into cells so that the points within that cell are no closer to a particular object than they are to any other objects. The Voronoi diagram for the Delta partitions the Delta into cells so that all points in that cell are closest to the cell's station and not to other stations. Figure 3 shows the estuary separated into different polygon areas using a Voronoi diagram. The Delta bathymetry is then used to determine the volumes of water around the stations.

One of the assumptions used for the volume calculation is that the fish are distributed uniformly in the station areas and they are distributed throughout the water column. This uniform distribution is an assumption because fish distribution information is unavailable or limited. It can be modified if needed.

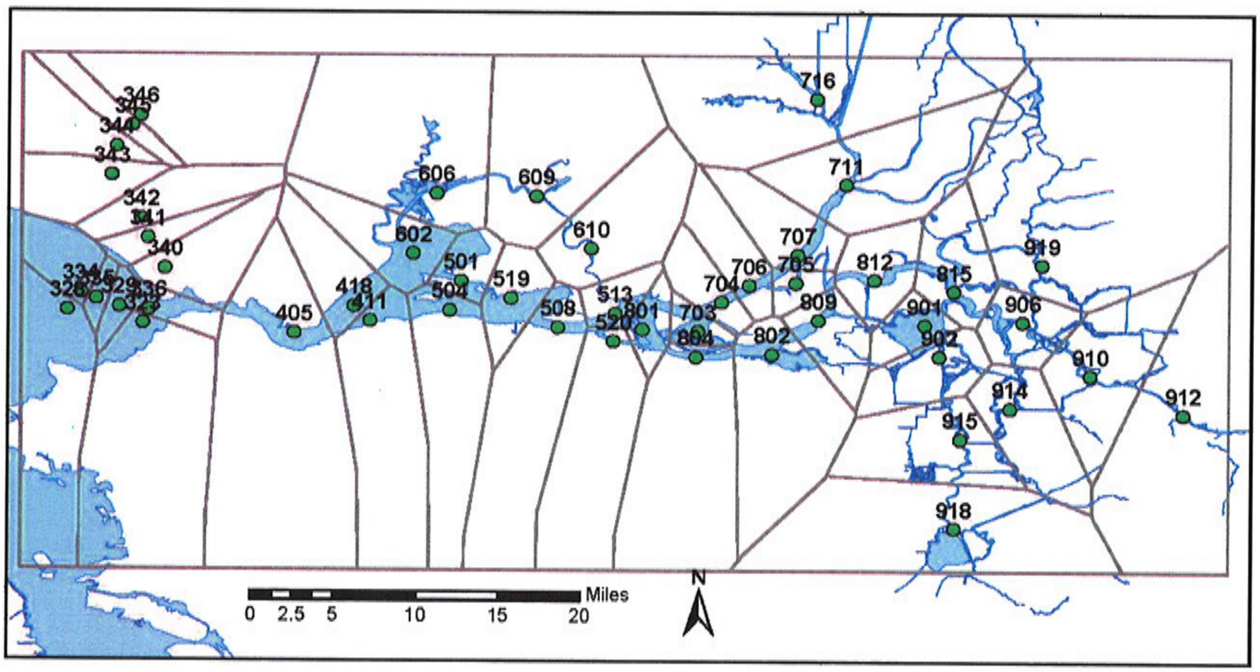


Figure 3. Voronoi Diagram for 20-mm Survey stations.

DSM2-PTM-based PEI values

As mentioned earlier, the DSM2-PTM is a physics based computer model developed by DWR to simulate the transport and fate of neutrally-buoyant individual "particles" traveling throughout the Delta. To track the fate of particles using the PTM, a group is injected at a desired node in the DSM2-PTM model grid during a simulation. For calculating PEI, the particles are injected at nodes closest to the 20 mm survey station locations. These particles are tracked individually through each time step, with their ultimate fate recorded. Ultimate particle fates could include entrainment through CVP/SWP export pumps, entrainment through other in-Delta diversions, or transit beyond the DSM2 grid boundary as outflow. Particles are assumed to be neutrally buoyant. Phenomenon such as behavior, predation, and mortality are not simulated in this DSM2-PTM representation of fish species, but these characteristics could be added as this information becomes available.

Using DSM2-PTM, PEI is calculated as follows:

$$PEI = \sum_{i=1}^{N} (PP_i * RA_i)$$

Where:

- PP_i is the PTM % entrained particles to the CVP/SWP export pumps over a period of time for each survey station
- N is the total number of survey stations
- RA is the relative abundance of delta smelt at each station.

The relative abundance of delta smelt at a given survey station is calculated as the density of delta smelt at a station, reported as Catch per Unit Effort (CPUE) from the 20-mm survey, multiplied by the volume of water associated with each survey station:

$$RA_i = (P_i \times V_i) / \sum_{i=1}^{N} (P_i \times V_i)$$

Where:

- Pi : Number of particles at station i
- Vi : Water volume of station i
- N: Number of stations

PEI Calculator PEI values

The first step in developing this model was to determine relationships between hydrodynamics and particle entrainment at the CVP and SWP export facilities for the 20-mm Survey stations. This was accomplished by running the DSM2-PTM using historical hydrodynamic conditions (as contained in the DSM2 simulation) as input and injecting particles at the 20-mm survey stations. The historical DSM2 simulation uses historical Delta inflows, Delta exports, and barrier/gate operations as input, reflecting actual Delta hydrodynamic conditions.

One thousand particles were injected at the 20-mm survey stations on the midpoint date of 78 historical 20-mm survey from 1995 to 2005 (Table 1). Surveys initiated after the end of June were not included in the analysis. Additionally, survey stations that did not detect delta smelt were omitted. The source and fate of each particle was tracked over simulations lasting for10, 20, 30, and 40 days

Table 1. Start and end dates of historical 20-mm surveys

Year	Survey	Start Date	End Date	Year	Survey	Start Date	End Date
1995	1	4/24/95	4/28/95	2001	1	3/19/01	3/24/01
	2	5/8/95	5/12/95		2	4/2/01	4/7/01
	3	5/22/95	5/26/95		3	4/16/01	4/21/01
	4	6/5/95	6/9/95		4	4/30/01	5/7/01
	5	6/19/95	6/24/95		5	5/14/01	5/19/01
1996	1	4/10/96	4/17/96		6	5/29/01	6/4/01
	2	4/24/96	4/30/96		7	6/11/01	6/16/01
	3	5/9/96	5/14/96		8	6/25/01	6/30/01
	4	5/21/96	5/29/96	2002	1	3/18/02	3/23/02
	5	6/8/96	6/14/96		2	4/2/02	4/7/02
	6	6/24/96	6/29/96		3	4/15/02	4/20/02
1997	1	3/31/97	4/5/97		4	4/29/02	5/4/02
	2	4/14/97	4/19/97		5	5/13/02	5/18/02
	3	4/28/97	5/3/97		6	5/28/02	6/2/02
	4	5/12/97	5/17/97		7	6/10/02	6/15/02
	5	5/27/97	6/1/97		8	6/24/02	6/29/02
	6	6/9/97	6/14/97	2003	1	3/24/03	3/29/03
	7	6/24/97	6/29/97		2	4/7/03	4/12/03
1998	1	4/6/98	4/11/98		3	4/21/03	4/26/03
	2	4/21/98	4/25/98		4	5/5/03	5/10/03
	3	5/4/98	5/9/98		5	5/19/03	5/24/03
	4	5/18/98	5/23/98		6	6/2/03	6/7/03
	5	6/1/98	6/6/98		7	6/16/03	6/21/03
	6	6/15/98	6/20/98		8	6/30/03	7/3/03
	7	6/28/98	7/3/98	2004	1	3/29/04	4/3/04
1999	1	4/12/99	4/17/99		2	4/12/04	4/17/04
	2	4/26/99	5/1/99		3	4/26/04	4/30/04
	3	5/10/99	5/15/99		4	5/10/04	5/15/04
	4	5/23/99	5/28/99		5	5/24/04	5/28/04
	5	6/7/99	6/12/99		6	6/7/04	6/12/04
	6	6/21/99	6/26/99		7	6/21/04	6/25/04
2000	1	3/20/00	3/25/00	2005	1	3/14/05	3/19/05
	2	4/3/00	4/8/00		2	3/28/05	4/2/05
	3	4/17/00	4/22/00		3	4/11/05	4/16/05
	4	5/1/00	5/5/00		4	4/25/05	4/29/05
	5	5/15/00	5/19/00		5	5/9/05	5/13/05
	6	5/29/00	6/2/00		6	5/23/05	5/27/05

Year	Survey	Start Date	End Date	Year	Survey	Start Date	End Date
	7	6/12/00	6/17/00		7	6/6/05	6/11/05
	8	6/26/00	6/30/00		8	6/20/05	6/24/05

For each sampling station and simulation duration, regression models were used to describe the relationship between the percentage of particles entrained and either OMR flow or QWest (Figures 4 through 6). Potential entrainment was better predicted based on Qwest for survey stations west of the confluence of the San Joaquin and Sacramento Rivers (Figure 7).

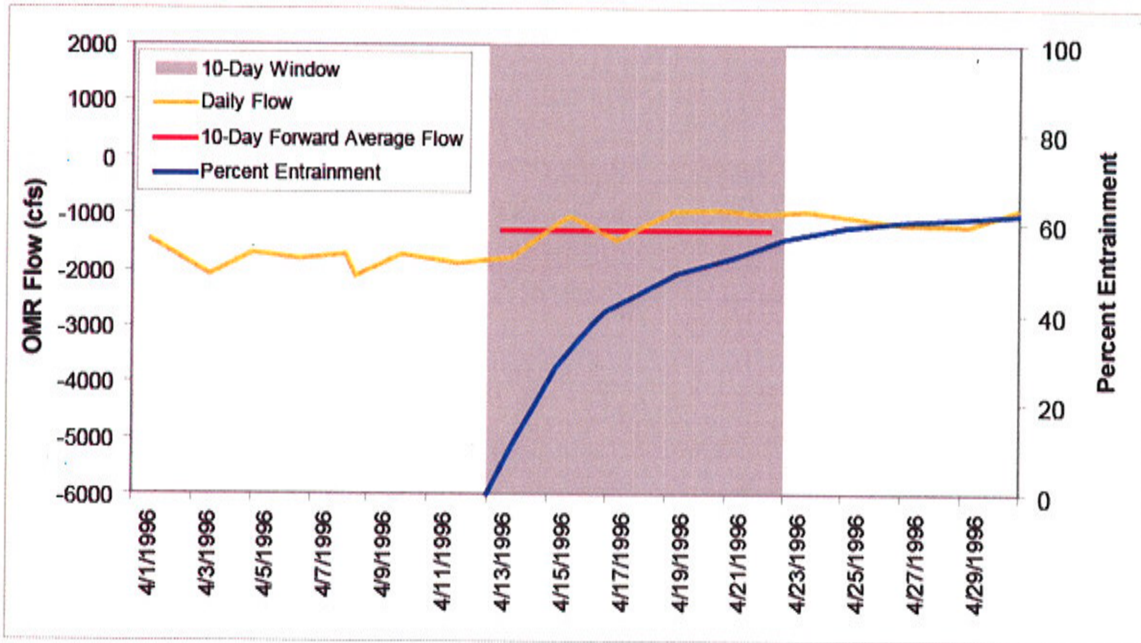


Figure 4. Example of cumulative PEI calculation and averaged hydrology.

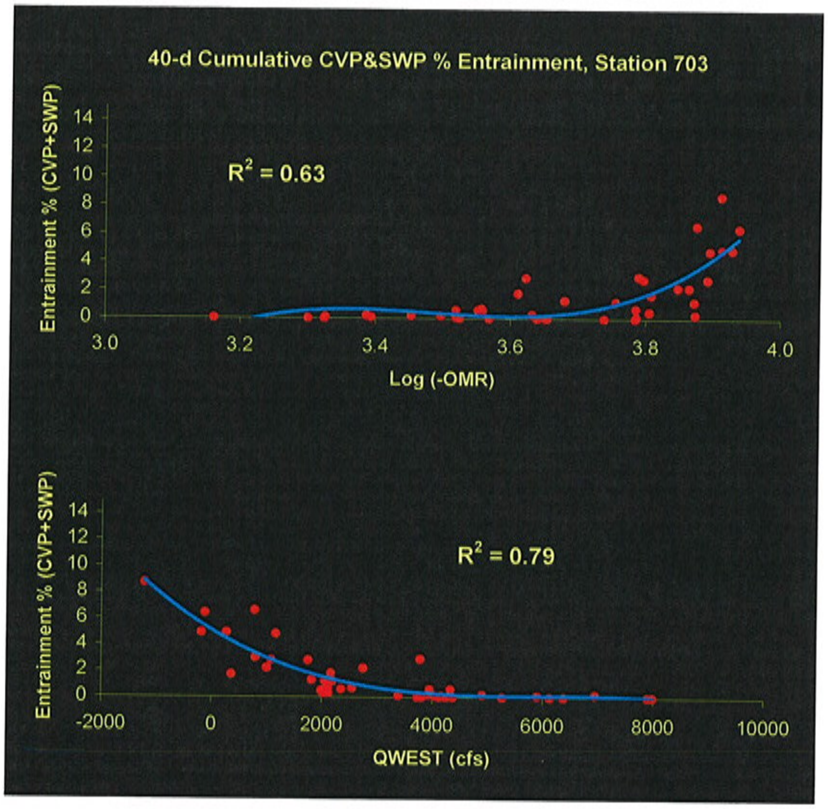


Figure 5. Regression equations developed for percent entrainment vs. OMR and Qwest.

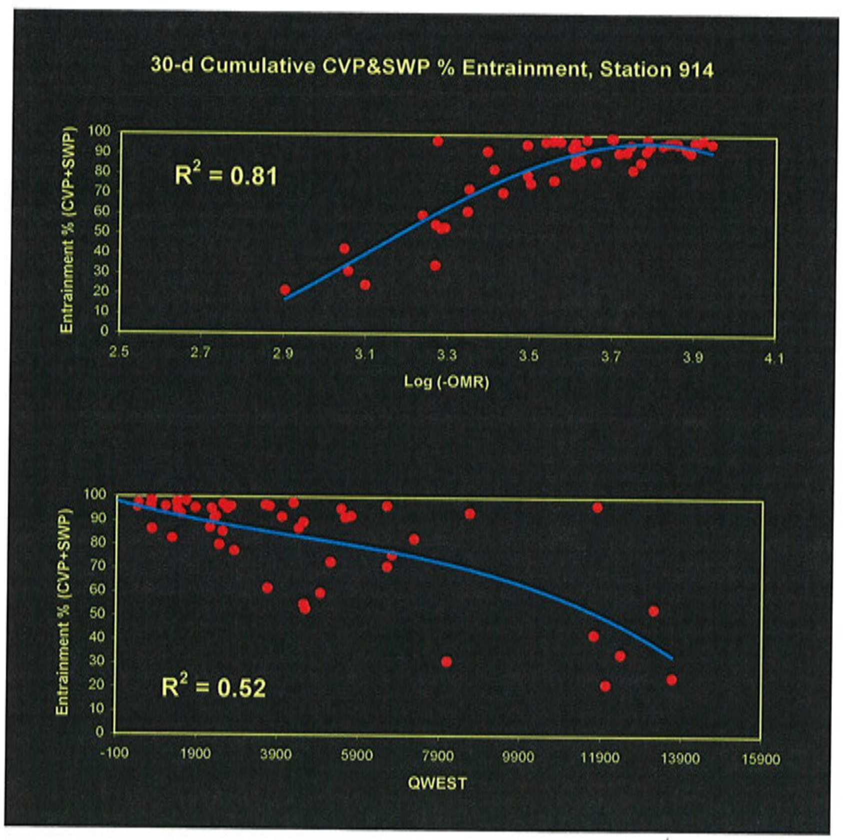


Figure 6. Regression equations developed for percent entrainment vs. OMR and Qwest.

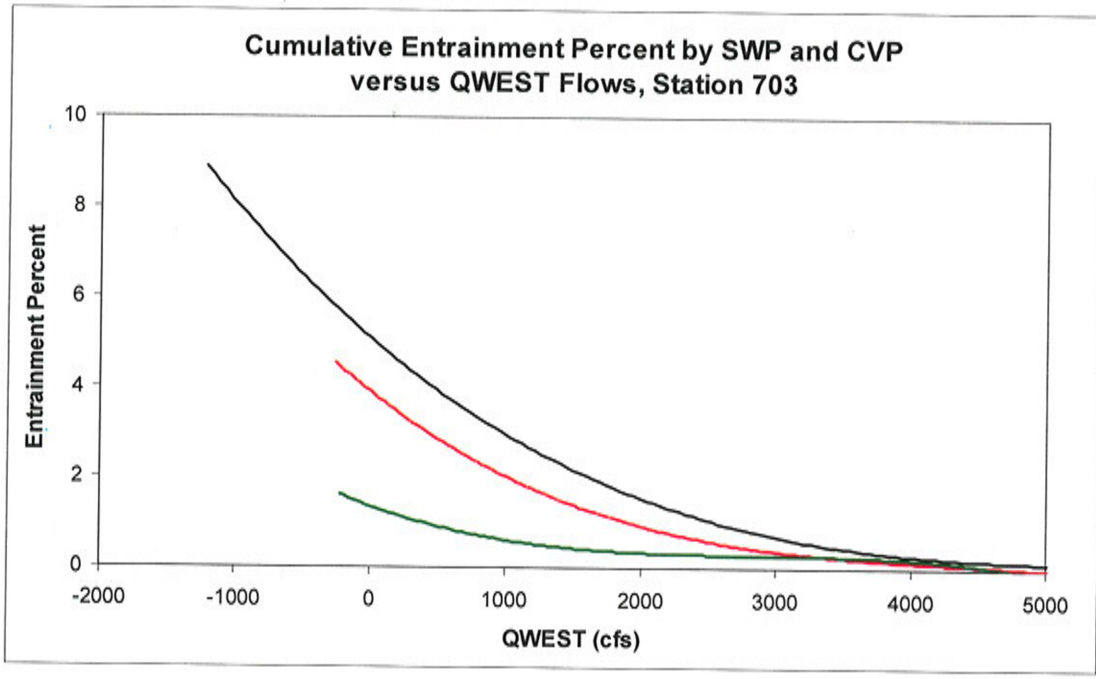


Figure 7. Example regression equations of potential entrainment versus flow for 10-day (Green), 30-day (Red), and 40-day (Blue) time periods.

The resulting regression models were then applied to data on delta smelt distribution to determine the percentage of delta smelt likely to be entrained for each station. Values from each station are summed to calculate the Potential Entrainment Index (PEI), which represents the total percentage of the delta smelt population likely to be entrained given their distribution and the hydrodynamic conditions for the given time period.

This PEI methodology was initially developed using regressions for select 20 mm survey stations in Suisun Bay and the interior Delta. However, the 20 mm survey includes additional stations west of Suisun Bay, in the Suisun Bay and Marsh area, and the Cache Slough area that were not included in the regression development. To more accurately represent the relative distribution of delta smelt, an effort was made to represent all fish detected in the 20 mm surveys and the volumes associated with all survey stations in the PEI methodology. The CPUE and volumes associated with 20 mm survey stations that did not have a PEI regression were assigned to the nearest 20 mm survey station that did have a regression equation. This assumption may lead to higher than actual PEI values, since a proportion of the relative abundance is assumed to be closer to the export pumps than actually detected in the 20 mm survey.

Finally, this methodology assumed that hydrology was stable over the cumulative period being analyzed. Since an average was used for OMR and Qwest flow, large fluctuations in hydrology and subsequent fluctuations in potential entrainment were masked. This fluctuating hydrology is the cause for much if not all of the variation in the PEI regressions. If this proposed method is used in the future and the system is in balanced conditions, then these variations in hydrology will be much reduced and the equations more predictive.

Model Assumptions

The PEI methodology is based on the assumption that the predicted entrainment is applicable to fish that act as particles, meaning the fish do not exhibit any behavior and act as neutrally buoyant particles. Since adult and older juvenile delta smelt are known to exhibit behavior, including diurnal vertical movements in the water column and lateral movement through channels triggered by environmental cues such as food abundance and turbidity, thus this analysis only predicts PEI values for larval delta smelt and perhaps young juveniles. To the extent that larval or young juveniles exhibit behavior that tends to allow them to stabilize their position, the PEI method overestimates potential entrainment.

Lastly, given the simplifying assumptions described above, the PEI was developed to be a relative index and used as a tool to compare potential entrainment under various CVP/SWP operational criteria along with other information.

Applications Using PEI Methodologies

PEI and Historical Salvage

To evaluate the ability of the PEI Calculator to accurately estimate entrainment, this PEI methodology was modified to simulate historical delta smelt salvage. To perform the analysis, historical 20-mm survey data and historical hydrology was used to predict the PEI for each historical 20-mm survey. The PEI was then related to salvage on a seasonal basis to simulate seasonal historical delta smelt salvage.

There are several difficulties in relating PEI to salvage. PEI is calculated as potential entrainment at the CVP and SWP pumps, but does not consider mortality that occurs in the Delta and Clifton Court Forebay (CCFB). However, salvage is determined by measuring the number of delta smelt counted at the Skinner Fish Facility at the intake to Banks Pumping Plant. The number of fish counted at the Skinner Fish Facility likely would not be represented by the PEI calculated at the CCFB entrance due to many reasons, including sources of mortality such as predation within CCFB and daily accounting of fish at the Skinner Fish Facility versus the every 2-week sampling of delta smelt distribution in the Delta.

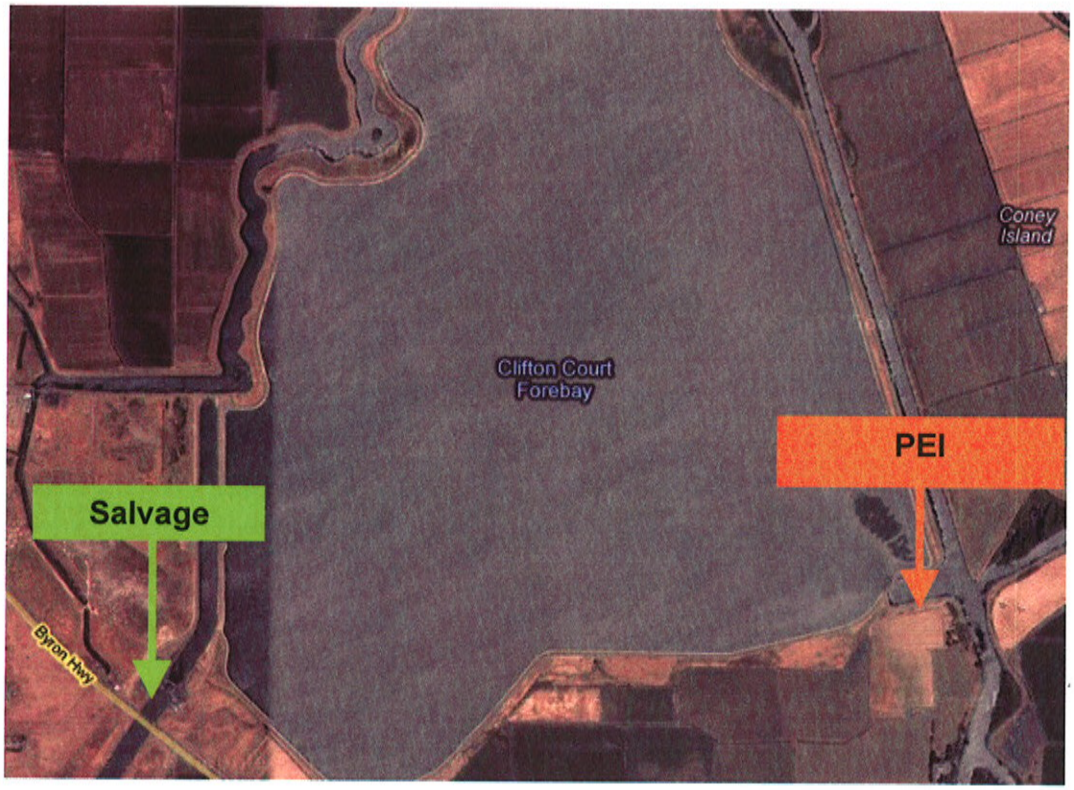


Figure 8. Comparison of locations for measurement of salvage and calculation of PEI.

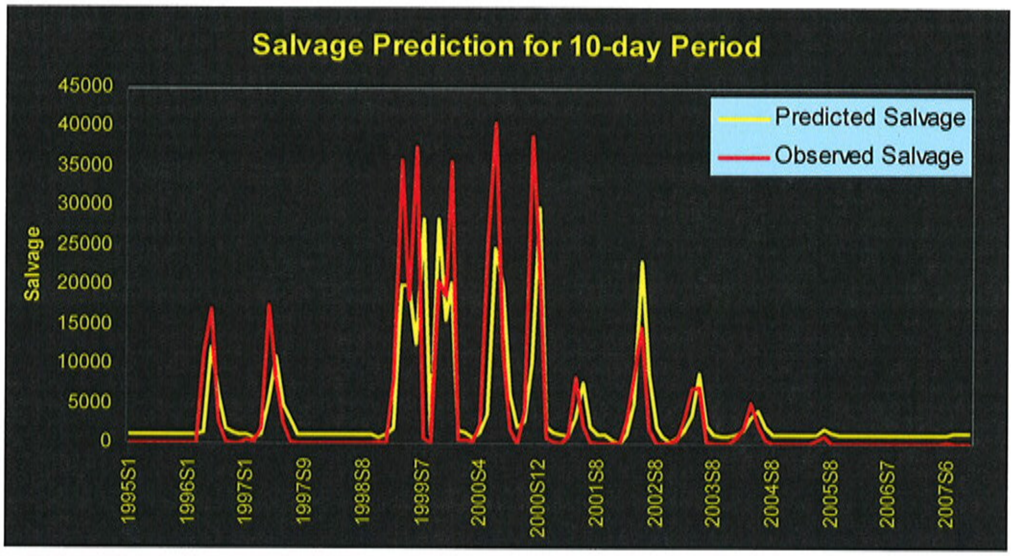
Due to these concerns, an additional adjustment to the relationship between PEI and salvage was included as follows, adding a factor for antecedent salvage:

$$PS = C1*PEI + C2*AS$$

Where:

- PS is predicted salvage
- PEI is the entrainment index
- AS is the antecedent salvage
- C1 and C2 are coefficients

This equation was used to simulate seasonal historical salvage using the PEI Calculator over 10 and 20-day cumulative periods. Comparisons with actual historical salvage (Figures 9 and 10) indicate the pattern of peaks is generally predicted, but the magnitude of the peaks is not always as accurate. This is likely due to the simplifying assumptions made in the development of the PEI and the PEI versus salvage relationship and the "dilution and delay" effects caused by Clifton Court Forebay.



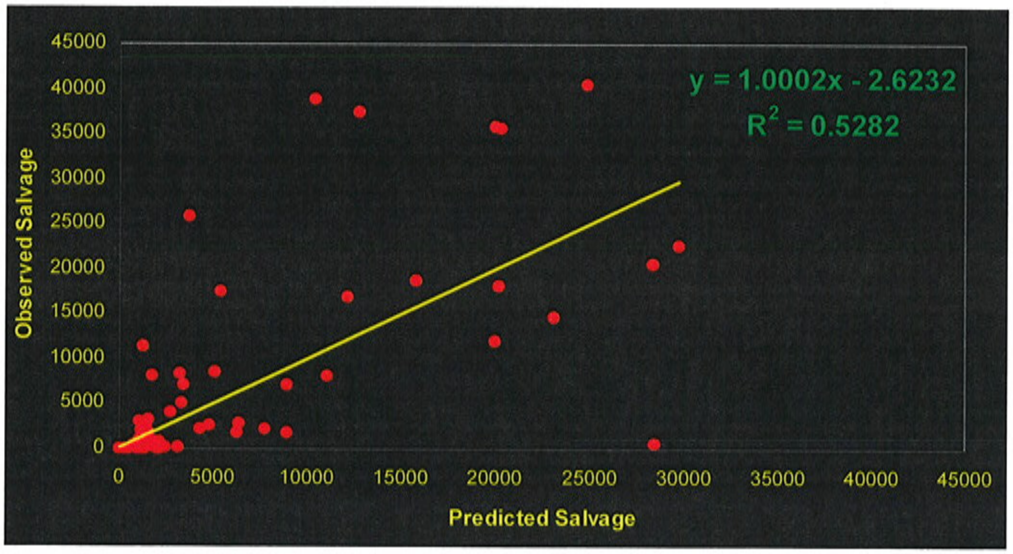


Figure 9. Comparison of 10-day PEI-based salvage prediction versus historical salvage.

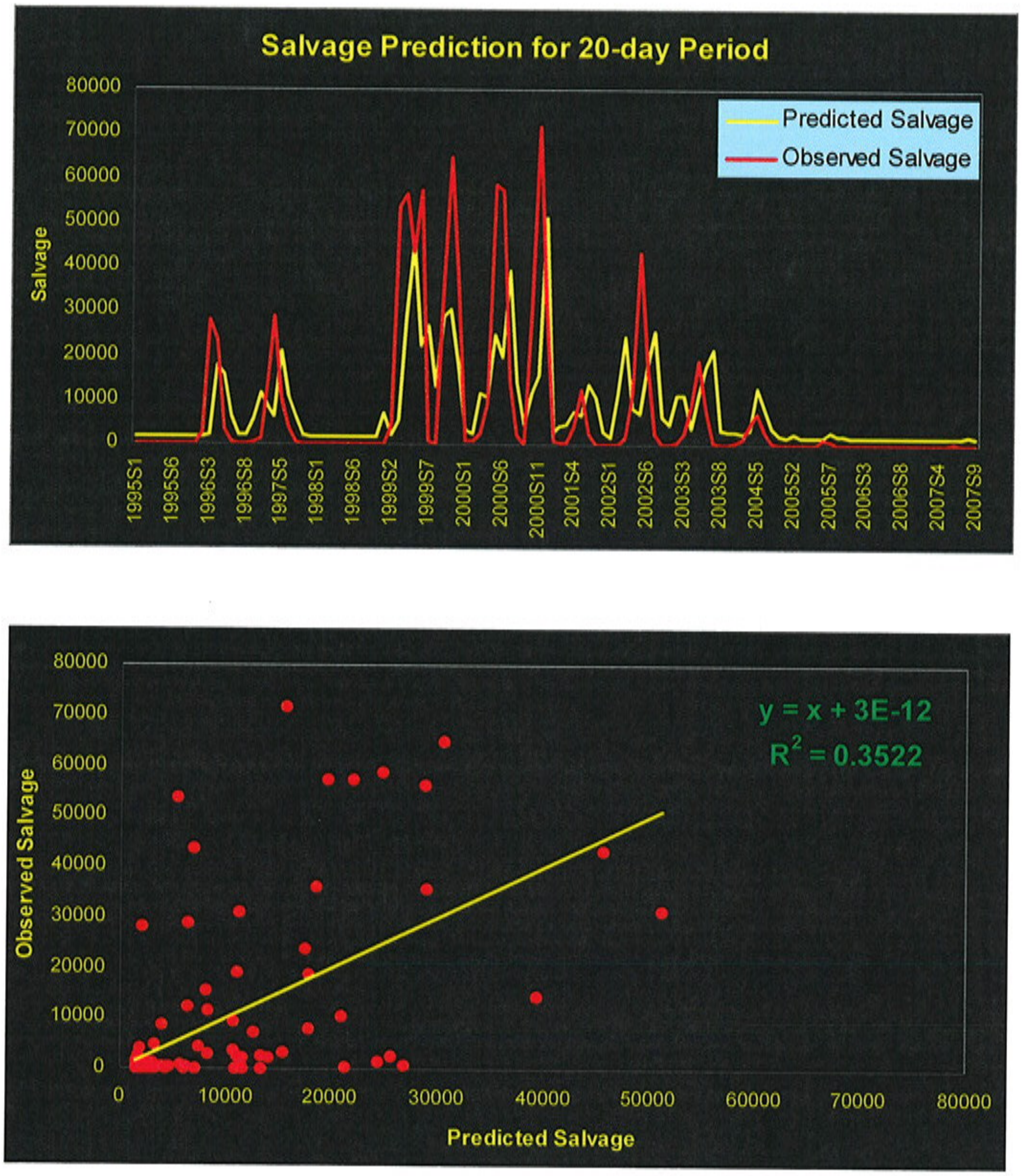


Figure 10 Comparison of 20-day PEI-based salvage prediction versus historical salvage.

PEI and Real-time Operations

Potentially, the PEI could be used in real-time management of the CVP/SWP export operations and OMR flow to keep delta smelt entrainment below a pre-determined target level. To determine the OMR flow that would result in a PEI less than a pre-determined target and the associated water costs, the PEI methodology could be used with historical 20-mm survey data as input, but with modified hydrology (OMR flow and Qwest). For each historical 20-mm survey and for a given cumulative time period, the average OMR flow and Qwest flow over the same cumulative time period could be iteratively adjusted until the maximum target PEI was not exceeded. This exercise would quantify how the hydrology and exports relate to affect PEI and what a maximum PEI target means in terms of water supply costs.

PEI Application for CVP/SWP Operations Management

As an illustrative example of applying a maximum PEI target, an analysis of historical and adjusted historical PEI estimates was conducted. For this analysis, the 20-day cumulative PEI regressions and 20-day averaged input hydrology were used. For each historical 20-mm survey, the PEI was calculated using historical hydrology and adjusted historical hydrology, with OMR flow between -500 cfs and -5,000 cfs in 500 cfs increments. The Qwest and change in exports associated with each increment of adjusted OMR flow was also calculated over the 20-day period. The OMR and associated change in exports was determined for two potential maximum target PEI levels: 3.2%, and 5%. (F).

In this analysis, if the historical PEI was already less than the maximum target PEI, the historical PEI and hydrology was maintained. This means exports did not increase to meet the maximum target PEI value. Also, in some cases, the historical PEI was higher than the maximum target PEI value, even when OMR flows were more positive than -500 cfs. In those cases, the minimum PEI attainable through modification of OMR flows was targeted.

This analysis shows that as the maximum target PEI value decreases, the required export reductions to reach the maximum target PEI increases. Also, there are some occasions where the maximum target PEI could not be met historically with export reductions. This type of historical analysis could be used with other historical population indicators such as the Fall Midwater Trawl (FMWT) index to determine if the effects of potential entrainment are related to changes in the subsequent abundance of delta smelt. So far, the work by Kimmerer (2008) and Manly and Chotkowski (2006) have not been able to see such an effect.

Managing CVP/SWP export operations to meet a maximum PEI target was shown to successfully reduce potential entrainment over individual 20-day periods. To compare this PEI methodology with annual estimates of potential entrainment from Kimmerer (2008), annual PEI estimates were calculated using the PEI calculator (regression based model) and amortization model for 1995 to 2005. Annual PEI estimates were calculated by assuming a constant rate of potential entrainment over the period, a constant rate of population introduced at the beginning of each period, and no natural mortality. Population was introduced at a constant rate beginning with the first detection of delta smelt a single survey location in a 20-mm survey.

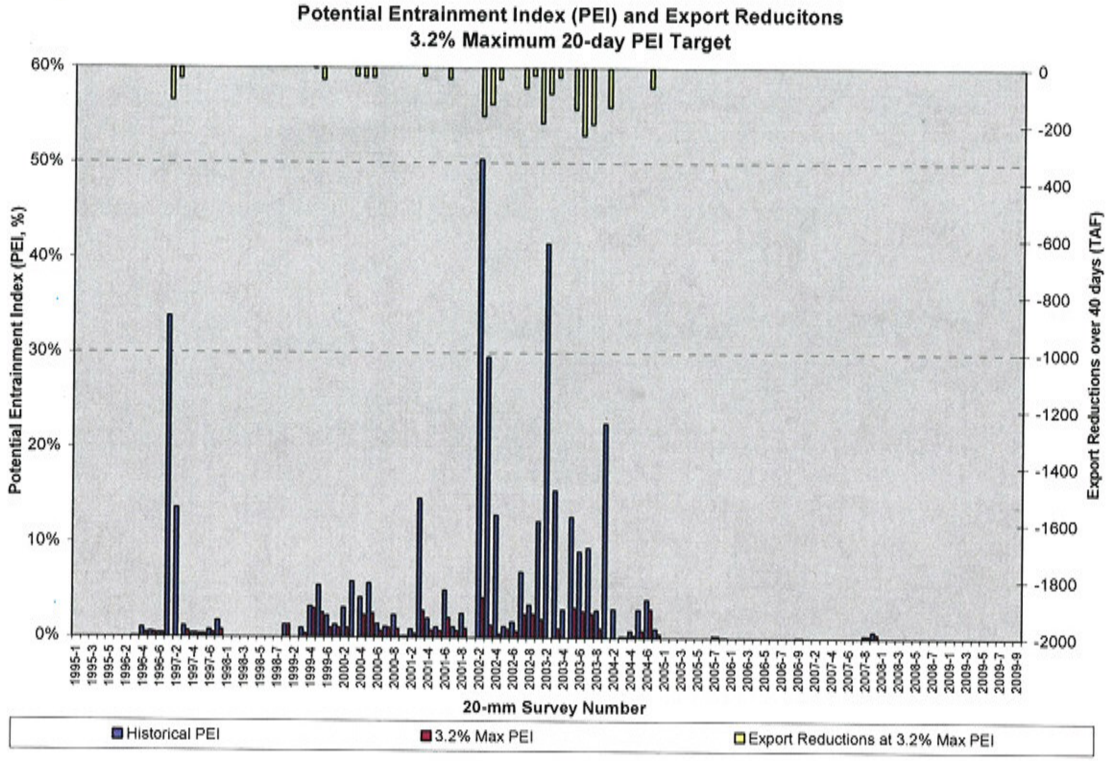


Figure 11. Comparison of historical PEI and 3.2% maximum target PEI.

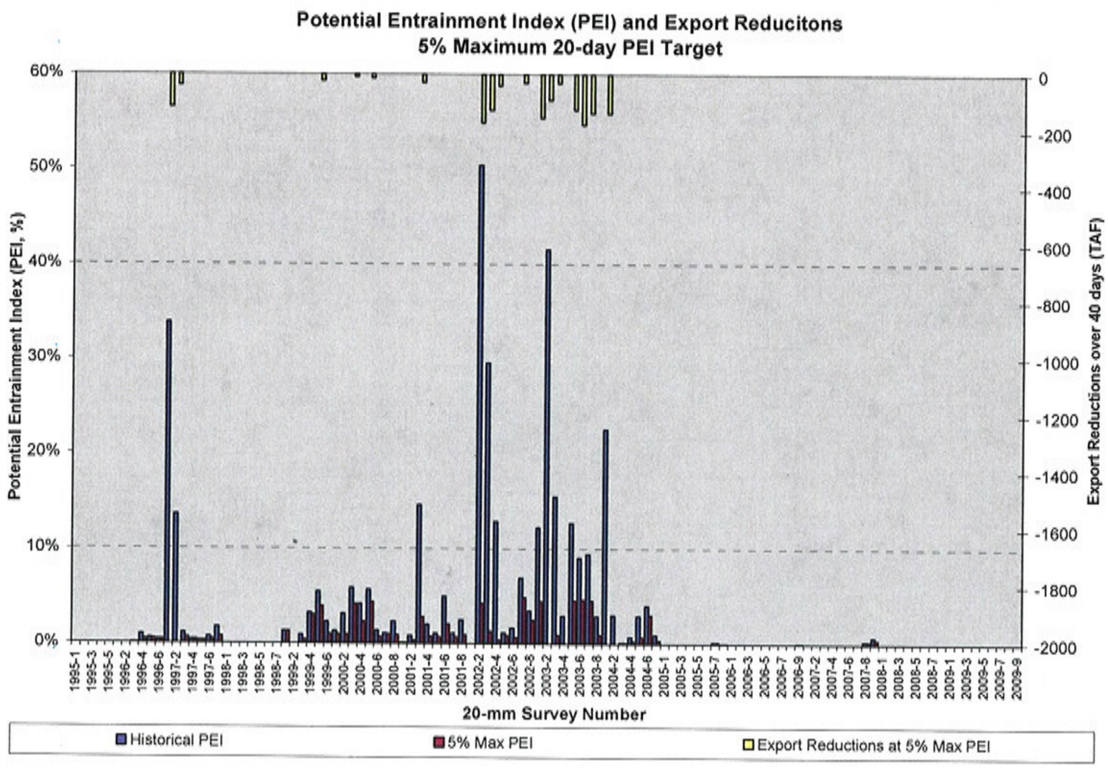


Figure 12. Comparison of historical PEI and 5% maximum target PEI.

First, the annual total population introduced (TPI) was calculated, assuming no entrainment or mortality:

$$TP_i = TP_{i-1} + CP$$

$$TPI = TP_N = CP \times N$$

Next, the annual total population remaining (TPR) after accounting for potential entrainment was calculated:

$$P_i = (P_{i-1} + CP) * (1 - PEI_i)$$

$$TPR = P_N$$

Finally, the annual potential entrainment index (APEI) was calculated as the percent of total population not remaining:

$$APEI = 1 - \frac{TPR}{TPI}$$

Where:

- i is the period.
- N is the total number of periods in a year.
- PEI is the potential entrainment for a period.
- CP is a constant population introduced at the beginning of each period.
- TP is the total introduced population without entrainment in a period.
- P is the population in a period, calculated as:

$$P_i = (P_c + P_{i-1}) * (1 - PEI_i)$$

The APEI values for both historical and a maximum PEI target of 5% were plotted with Kimmerer's annual values (2008) for comparison (Figure 13). Historical APEI values were generally lower than Kimmerer's estimates with no mortality, but followed the same general patterns. Implementation of a maximum PEI target of 5% reduced APEI in years such as 1997 and 2002, when historical APEI values were high.

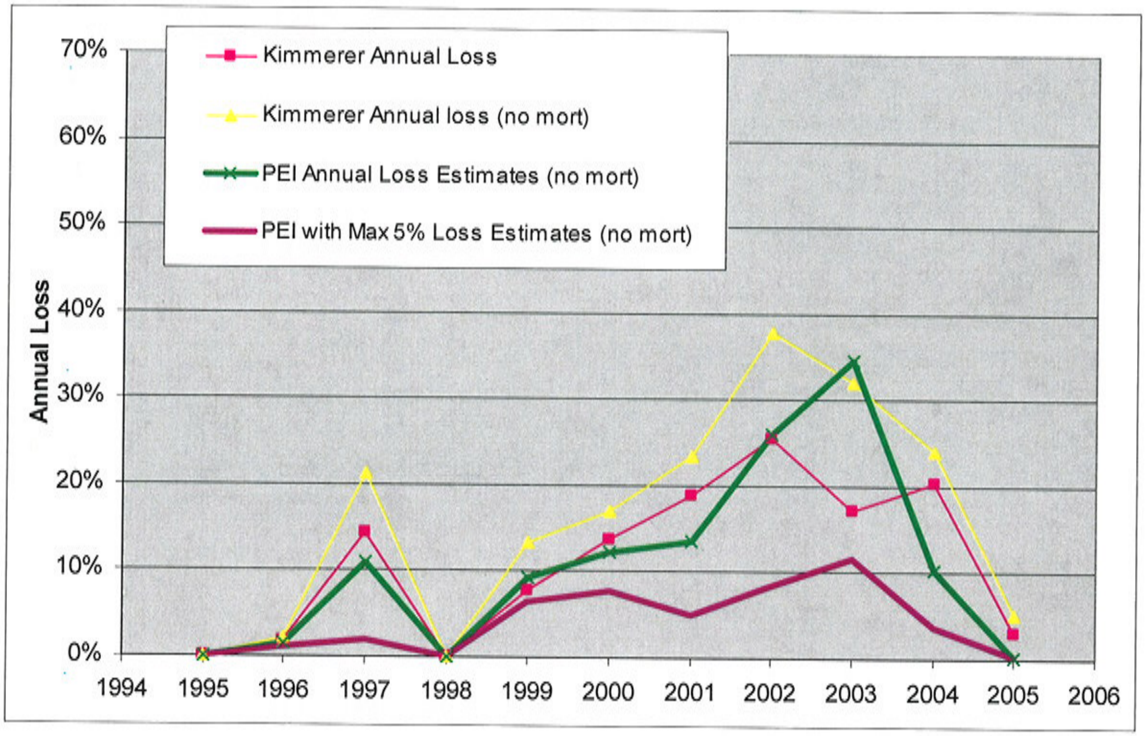


Figure 13. Estimated historical annual losses by Kimmerer and by the PEI method compared to projected losses using a 20-day PEI of 5%.

Developing OMR for the spring season using a PEI target level of 5%

Following are the specific steps that would be taken to determine and adjust OMR target flows through the spring to levels that would keep the annual PEI of larval/juvenile delta smelt at the CVP and SWP south Delta facilities at less than 5% in any 20-day period. This application could use either a Particle Tracking Model or PEI Calculator to generate PEI values for the season and would also use the amortization model for calculating cumulative short-term PEI values to equal the seasonal one. Exact steps to carry out this application are as follows:

1. After Action 3 of the OCAP BIOP is triggered, determine the preliminary target OMR needed to achieve the calculated 20-day PEI. This preliminary target OMR will be determined using DFG's most recent 20-mm delta smelt larval survey results and the PTM-derived regression equations, the PEI calculator. The preliminary target OMR flow will be determined within a day of the triggering of the action and receipt of the most recent fish survey data from DFG. If 20-mm Survey results are not available or did not detect delta smelt, the latest Kodiak Survey will be used as an indication of larval/juvenile delta smelt distribution and abundance.

2. The Water Operations Management Team (WOMT) confirms the action trigger has been met and reviews and adopts the preliminary target OMR flow.

3. The adopted OMR target flow will be implemented within 2 days of its adoption by WOMT, and will remain in effect until it is replaced by a refined OMR target based on a full PTM run using the most recent 20-mm or Kodiak survey results.

4. The refined target OMR flow will be determined using the fish survey data and a full PTM run within 4 days of receiving the fish survey data from DFG. Operations will be adjusted to the refined OMR target within a day of its determination. This target OMR flow will be used until it is readjusted based on new fish survey information.

5. The previous four steps will be repeated after each fish survey until the action ends on June 20.

As an example, if this method was used in 2008 the following would have been the dates for the adjustment of the OMR flow targets.

OMR Target 1 - February 21 to March 26 - Action 3 would have been triggered by the detection of spent female at the CVP's salvage facility on February 17. The February Kodak Trawl (that was conducted February 4-8) would have been selected as the most recent fish survey available to use to estimate the distribution and relative geographical abundance of delta smelt. A preliminary target OMR to achieve the 20-day PEI of 5% would have been calculated using the February Kodiak Trawl survey results and the PEI Calculator for 20-days. The full PTM would have also been started to refine the preliminary OMR target. All the above tasks would have occurred by February 18.

On February 19, the WOMT would have confirmed the triggering event and adopted the preliminary target OMR. The preliminary OMR flow target would have gone into effect February 21 and operations begin to achieve the flow target. Within a day or two the refined OMR target would have been determined using the full PTM and operations would be immediately adjusted to meet that refined target. The 14-day mean would have been achieved 14 days later (March 5) and the running average would have been kept at or below the OMR target flows. Furthermore, the 7-day mean after the first 7 days (February 27) would have been kept within 1000 cfs of the 14-day mean target flows. The CVP and SWP would have operated to this initial OMR target until March 26, when it would have been replaced by a new target based on the fish distribution and abundance data from the March Kodiak Trawl.

OMR Target 2 - March 27–April 23 - The March Kodiak Trawl was conducted March 10–14, and its data was available on March 18. The 2nd preliminary OMR target would have been calculated using this data. WOMT would have considered and adopted the second preliminary OMR target on March 25, which would have been implemented on March 27. Within a couple of days the refined target would be available and the projects would modify their operations to meet that target.

The first and second 20-mm surveys were conducted March 17-21 and March 31-April 4 respective. Their results were available by March 28 and April 11, respectively. These results would have been reviewed, but since neither detected delta smelt, they would not have been used to revise the OMR target. Therefore, the second OMR target would have been left in place until April 23, when it would have be revised based on the April Kodiak results.

OMR Target 3, April 24–April 30 - The April Kodiak Trawl was conducted April 4 - 11, and the results became available on April 15. This information would have been used to calculate a new preliminary target OMR which the WOMT would have considered at its April 22 meeting and begun to implement on April 24. This target would have been in effect for a few days until it was replaced by the refined target. The refined target would have been in place until May 1, when it would have been revised based on the results of the third 20-mm Survey.

OMR Target 4, May 1- May 14 - The third 20-mm Survey was conducted April 14-19, and its results became available on April 25. These results would have been used to calculated the fourth preliminary OMR target for adoption at the April 29 WOMT meeting. The project would have begun operating to the new target OMR on May 1. It would have been maintained as the target until it was replace by the refined target, which would have been in place until May 14, when it would have been modified based on the result of the fourth 20-mm Survey.

OMR Target 5, May 15-May 28 - The fourth 20-mm trawl was conducted April 28 to May 2, and its results were available on May 9. These results would have been used to calculate a new preliminary OMR target for WOMT approval on May 13 and implementation on May 15. It would have been maintained as the target until it was replaced by the revised target a couple of days later. The revised target would have remained in place until May 14, when it would have been modified based on the results of the fifth 20-mm Survey. The May Kodiak Trawl was conducted May 5 – 9, and its data became available on about May 13. However, because the 20-mm Survey data was now available and showing delta smelt distribution, the Kodiak trawl data would no longer be used during the rest of the season to set OMR flows.

OMR Target 6, May 29-June 11 - The fifth 20-mm survey was conducted May 12–16, and its results were available May 23. Based on these results a new preliminary OMR target would have calculated for approval by WOMT on May 27 and implementation on May 29. This preliminary target OMR would have been replaced within a couple of day with the refined target, which would have been maintained through May 14, when it would have been modified based on the results of the sixth 20-mm Survey.

OMR Target 7, June 12–June 20 - The sixth 20-mm survey was conducted May 26 – 30, and its results were available June 6. Based on these results a new preliminary OMR target would have calculated for approval by WOMT on June 10 and implementation on June 12. This target OMR would have been replaced by the refined target within a couple of days, which would have been maintained through June 20 when Action 3 ended.

The schedule described above assumes the following:

1. DFG's Kodiak Survey results are available within two working days of the completion of the survey.
2. DFG's 20-mm Survey results of the first tow are available estuary-wide within four working days and the most significant of the results of 2nd and 3rd tows are available within five working days of the last day of the survey. For the 2nd and 3rd tows of a survey, the most significant stations for the modeling might be those (1) where smelt are found in the 1st tow, (2) which are adjacent to stations where smelt are found in the 1st tow, and (3) between the pumps and where smelt are found in the previous tows.
3. The PEI calculator can be used to calculate the preliminary target OMR flow within a day of receiving DFG's fish survey data. The full particle tracking runs can determine the refined target OMR in 4 days.
4. The WOMT can consider the preliminary OMR target the day after it is calculated.
5. The projects can begin operating to a new OMR target within two days of its adoption by WOMT.

Using PEI to Estimate Salvage at the CVP and SWP

This last application utilizes annual PEI values generated from the PEI calculator and DFG's Fall Midwater Trawl Indices (FMWT Indices) to estimate salvage of larval and juvenile delta smelt at the CVP and SWP.

Currently, incidental take for juvenile delta smelt for the SWP and the CVP is calculated using a specific methodology outlined on pages 389-396 in the BiOp. This methodology is based on previous statistical analysis that indicates there is a relationship between fall parental abundance and salvage of progeny the following spring. Average cumulative monthly salvage values are scaled to the current water year's FMWT Index to increase predictability of take.

Specifically, a Juvenile Salvage Index was calculated for the months of April through July over four years (2005-2008) using cumulative monthly salvage values and FMWT Indices for these water years.

The average JSI values by month (April through July) for the 2005 to 2008 spring seasons are 0.29, 13.03, 33.02 and 37.47, respectively. The average of the four values is 20.9

This Juvenile Salvage Index (JSI) is calculated as:

> Monthly JSI = cumulative seasonal salvage ≥ 20mm by month end divided by current water year FMWT Index.

These more recent years were used because apparent abundance of delta smelt since 2005 as indexed by the 20-mm Survey and Summer Townet Survey are the lowest on record setting these years apart from previous years. Also, USFWS believes these four years best represent current conditions under the BiOp RPA for predicting salvage.

To calculate the concern level for incidental take, the JSI value for each month is multiplied by the current water year FMWT index or

> Concern Level = Monthly JSI 2005-2008 mean * Current WY FMWT

To calculate the larval/juvenile incidental take the calculated concern level is multiplied by 1.5 or

> Larval/Juvenile Incidental Take = 1.5 * Concern Level

It was determined by USFWS that the monthly JSI multiplied by the current water year FMWT is sufficient to calculate the concern level for take, given the variability in salvage and uncertainty of other factors. These factors include fish distribution, spawning success, adult entrainment in winter months. USFWS found that this enhanced survival under the RPA and other extant natural conditions would provide that incidental take would be 50% above the concern level. DWR has concerns with this methodology.

The current USFWS methodology only uses a few years (2005 to 2008) for calculating incidental take or salvage. Both 2005 and 2006 were classified as wet years on the San Joaquin River system with very low salvage at the south Delta facilities. These years drive the cumulative average for salvage down dramatically. If the last two years, 2007 and 2008, were used to estimate take we see much higher and perhaps more realistic numbers. The average JSI values per month would become 0.45 (April), 20.78 (May), 54.36 (June) and 65.72 (July). The average monthly JSI value would be 35.2 instead of 20.9, an increase of 68%. To illustrate the difference, for 2009 the allowable salvage would have gone from 1293 to 2267 if these last two years were the only used. This example illustrates a fairly weak relationship between the FMWT indices and salvage of delta smelt. The PEI greatly improves this relationship by incorporating distribution of young delta smelt into the equation.

As a proposed alternative to the methodology used by USFWS in the BiOp, we have developed a means to estimate salvage using PEI values along with the current water year's FMWT Index. As with the USFWS methodology, this calculation also takes into account the relationship between fall parental abundance and progeny salvaged. Our methodology also accounts for distribution and relative abundance of larval young juvenile fish, through the PEI, along with hydrologic conditions at the time.

For our proposed methodology, we used historical FMWT Indices, PEI annual estimates of loss and juvenile delta smelt salvage data from 1995 to 2009 to develop the regression equations to calculate expected salvage. We originally included 1999 in our models, but statistical analysis indicated that 1999 was an outlier and attempts to transform the salvage data failed to even out the variance introduced by 1999 values. The data collected during 1999 showed an unusually high salvage value (155,000 adult smelt) when compared to the previous FMWT Index. This was alluded to at the time as the "smelt down". Further investigation showed that the April abundance of good smelt food resources (Euretemora and Pseudodiaptomus) was extremely high in 1999 and is related to the high FMWT that year. The FMWT Index in 1999 was the highest in several years. It is hypothesized that in April 1999 the survival of delta smelt was abnormally high due to excellent food availability and this resulted in both higher than expected salvage and was also reflected in a high FMWT Index later that year. The chances of encountering these fish numbers again any time soon given the current conditions in the Delta, both at the survey sites and as salvage, are extremely low to none. Therefore, the 1999 data point was excluded in our analysis.

We chose to look at a longer time period than did the USFWS for developing this methodology because we felt more data points would be needed to conduct statistical analysis. As this is an extension of work described in the first section of this document on PEI, we chose to use the same time period as had been used previously. This period of time includes all available data from the 20-mm survey that started in 1995 and is used to calculate PEI, encompasses pre and post POD years, post-*Corbula* years (after 1987) and covers a wide variety of FMWT indices, salvage values and water year types. However, as noted above the 1999 data point was excluded.

Data from the FMWT are used to calculate indices of relative abundance for delta smelt. The program has been conducted each year since 1967, except that no sampling was done in 1974 or 1979. Samples (10-minute tows) are collected at 116 sites each month from September to December throughout the Delta. Detailed descriptions of the sampling program are available from Stevens and Miller (1983) and Feyrer et al. (2007). To calculate the annual FMWT Index the total number of fish caught for all tows at each of 100 of the 116 stations sampled is used as opposed to catch per unit effort or CPUE. The 100 individual sites are grouped into 14 areas according to geographic location. Each area has been assigned a weight factor. The number of fish caught for the area are summed and then averaged and this average is then multiplied by the weight factor for the area to produce an area index. All area indices are summed to produce a monthly index. After the four monthly surveys (September, October, November, December) are completed and the monthly indices are calculated these four monthly indices are summed to produce the annual FMWT Index used to detect trends in delta smelt abundance.

As described earlier in this document, annual PEI (20-day runs, no mortality) loss estimates were used as one of the independent variables in developing this methodology. For the 1995 through 2009 time period, annual estimates of PEI ranged from 1^{-9} (1995, 1998) to approximately 0.30 (2003). Annual PEI loss estimates were calculated using regression equations (PEI calculator) developed by DWR's Bay-Delta Office (also described in this document).

Salvage estimates have been calculated since 1957 for the U.S. Bureau of Reclamation (USBR) at the Tracy Fish Collection Facility (TFCF). The Department of Fish and Game's Fish Facilities Unit, in cooperation with DWR, began salvaging fish at the Skinner Delta Fish Protective Facility (SDFPF) in 1968. The salvaged fish are trucked daily and released at several sites in the western Delta. The schedule of fish hauling is dependent on salvage rates, debris loading, and special-status-species procedures. Salvage of fish at both facilities is conducted 24 hours a day, seven days a week at regular intervals. Fish counts at the federal facility are conducted every 2 hours when pumping is occurring. For the State facility fish are counted every 2 hours or at the next hour if there is a change in flow. Fish counts are conducted for a specific amount of time (i.e. 30 minutes) so that the final daily fish count is multiplied or "expanded" by a factor of 4 to account for the fact that only a quarter of the entire day's fish are actually counted. These expanded numbers are what are reported as fish salvage. Sampling of entrained fish at the SDFPF and TFCF is the source for DFG's daily salvage and loss estimates for the monitoring of incidental take of listed fish species.

To determine whether using PEI values and FMWT Indices to calculate incidental take was feasible we conducted a multiple regression analysis using salvage as the dependent variable and PEI and previous FMWT (previous calendar year index, current water year index) as the independent variables. Initially we ran the multiple regression analysis without transforming any data and also included 1999 in the dataset. The results of this analysis produced an R-squared (adjusted) value of 24.4 and a p-value of 0.074. In addition, the PRESS value was extremely high, the normal probability plot of the residuals was not normally distributed and the residuals versus fitted values plot indicated non-constant variance with 1999 as an outlier.

Conducting tests for normality on the residuals indicated that the dependent variable, Salvage, was skewed and required transformation. We conducted several iterations of transforming salvage, including using the natural log, reciprocal, square-root, cube-root and quartile-root with each transformation (in this order) providing slightly better R-squared (adjusted) and p values. R-values (adjusted) ranged from 46.8 to 55.3 and p-values ranged from 0.009 to 0.003.

Because 1999 continued to be an outlier throughout the various data transformations and for the other biological reasons stated above, we decided to run a multiple regression analysis without data from this year. We again ran through all of the iterations of different transformations for the dependent variable, salvage, and determined the best model overall uses the cube-root of salvage versus PEI and FMWT for 1995 through 2009, excluding 1999. The R-squared value for this analysis was 0.73 and the p-value was 0.001 (Figure 13). The regression equation was Cube Rt. Salvage = 8.28 + 71.9PEI + 0.0238 FMWT.

Residuals were normally distributed with data transformation (Anderson-Darling value = 0.380). The PRESS value was low (1122.17) and the VIF values were 1.119 indicating a lack of multicollinearity between the independent variables.

We also evaluated the independent variables' distributions, PEI and previous FMWT Indices, using partial plots and determined that the data were normally distributed and did not require transformation. The results of the partial plots also indicated significant relationships occurred between the dependent and independent variables as did the results of the multiple regression analysis which had significant P values for Salvage vs. PEI (p = 0.011) and Salvage vs. previous FMWT (p = 0.008).

Incorporating actual salvage values for 1995 to 2009 into the regression equation and transforming the resulting estimated salvage from cube root values resulted in the following (Figure 14):

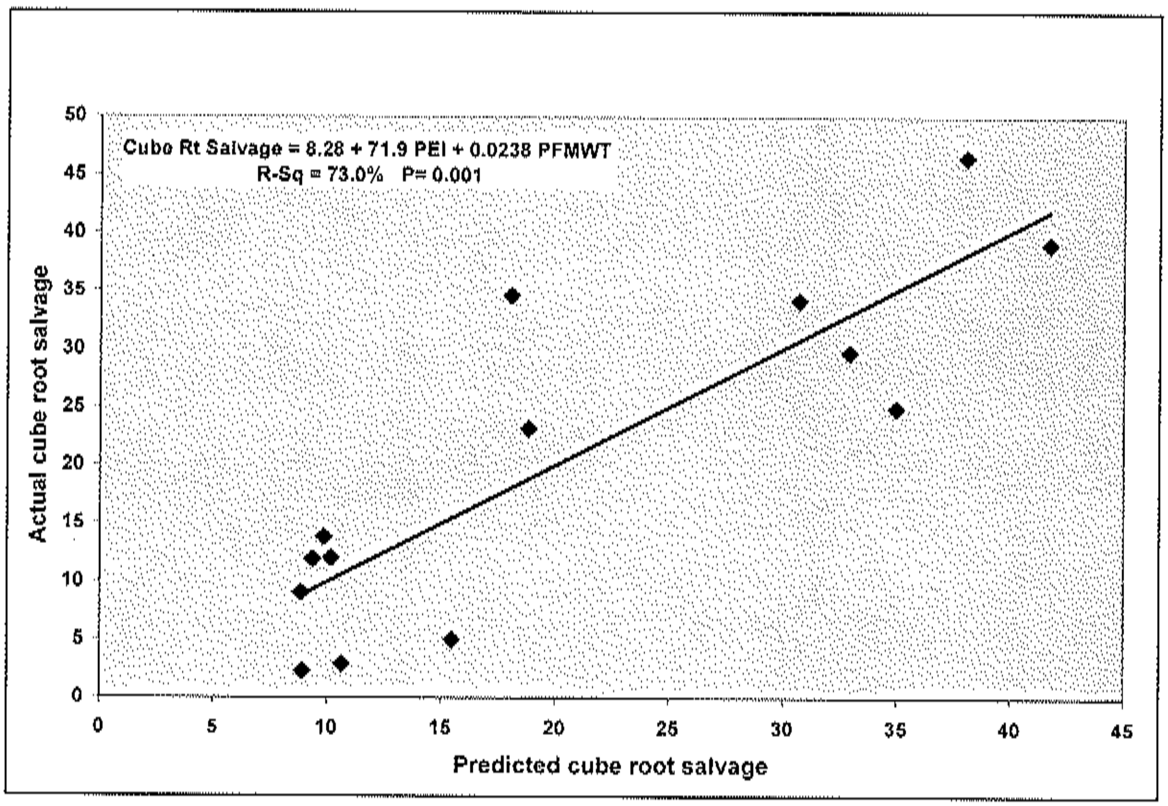


Figure 14. Actual versus Predicted Juvenile Delta Smelt Salvage for 1995-2009 excluding 1999.

Using the regression equation produced we also developed tables to illustrate estimated salvage given different PEI target levels and different FMWT Indices. An example of this is provided below.

Table 2. Predicted salvage of juvenile Delta smelt using annual PEI target level of 10% and FMWT Indices ranging from 1 to 200.

FMWT	PEI goal	PEI expected salvage	BIOP take level
1	0.1	3719	56
5	0.1	3788	281
10	0.1	3876	562
15	0.1	3965	843
20	0.1	4055	1124
30	0.1	4239	1686
40	0.1	4429	2248
50	0.1	4624	2810
60	0.1	4825	3372
70	0.1	5032	3934
80	0.1	5244	4496
90	0.1	5463	5058
100	0.1	5687	5621
110	0.1	5918	6183
120	0.1	6155	6745
130	0.1	6398	7307
140	0.1	6647	7869
150	0.1	6902	8431
160	0.1	7165	8993
170	0.1	7433	9555
180	0.1	7708	10117
190	0.1	7990	10679
200	0.1	8279	11241

This new methodology is preliminary and is currently undergoing extensive internal and external review. If this methodology proves to be useful as an alternative means to calculate incidental take of juvenile delta smelt by the SWP and CVP then there are numerous benefits to utilizing this tool. These benefits include the use of real time fisheries survey and hydrodynamics data (including OMR flow restrictions) to estimate population size and distribution of juvenile delta smelt. The use of this information should allow for flexibility in operations of the water projects to minimize entrainment while continuing to supply water at quantities acceptable given the current conditions.

Some key questions that are being addressed during the review process include;

- validity of the variables used (Salvage vs. standardized salvage values, FMWT Index, PEI) including the use of 20-mm survey data for generating PEI values

- whether assumptions made when generating the PTM/PEI results are still applicable for this methodology (i.e. particles do not exhibit behavior, fish distribution at sites is uniform and volume estimates for each site are accurate) and are there additional assumptions that must be made
- are annual PEI loss estimates accurate
- robustness of regression equations used to calculate PEI

Concerns for using the PEI Methodology and Solutions

As with all new methods, the PEI methodology warrants a thorough review and suggestions of ways to improve this tool. Some initial concerns that have been raised include; (1) issues with using the PEI methodology alone to determine operational criteria; (2) the lack of robust delta smelt distribution data due to the low abundance of fish in the Delta and perhaps due to sampling effort or gear issues; (3) setting annual PEI target levels too high for the current populations; (4) the short duration of the model runs generating PEI (20-days); (4) the lack of behavior simulations in the DSM2-PTM and need for recruitment and mortality estimates to be included in the model runs; and, (5) 20-mm Survey data is not available real-time for adjusting the PEI.

All of these concerns need to be addressed as the process is reviewed. Some initial thoughts regarding these potential issues are that the PEI could be used in conjunction with all of the available tools and information for managing operational criteria. This is just one tool to assist in the decision-making process. The PEI method is currently the best available tool for estimating effects on the entire distribution of delta smelt and utilizes the best available fisheries (20-mm Survey) and hydrodynamic (DSM2-Hydro) information. Better smelt distribution data would improve model output and sensitivity and actions such as more intensive sampling or more effective sampling gear should be considered. In absence of improved abundance and distribution data, assumptions need to be used for abundance and distribution of larval smelt for stations where smelt not detected or for stations not sampled during the surveys. Also, with some work, salvage at the SWP/CVP could be used to estimate delta smelt density outside the pumping facilities which could be used as input into the PEI calculations.

Regarding PEI target levels, these can be set annually or periodically (i.e. between surveys) and adjusted as needed. Given that fish monitoring data is only available about every two weeks initial OMR criteria can be determined using available data and PEI target levels and OMR refined as the year progresses. The PEI method allows for flexibility both in terms of allowable entrainment and OMR criteria. This is one of the advantages of this methodology. Also, PEI target levels can be set by regulatory agencies and the Water Operations Management Team (WOMT) as described in the BiOp allowing for reasonable protection for smelt.

The PEI approach is different from the "Control Point Method" used by the USFWS. The "Control Point Method" uses DSM2-PTM runs that look at the movement of particles inserted at one station (815) at the beginning of the simulation and track the final fate of the particles over time. Results from individual station were not looked at. This method generally shows the trend of movement of the particles past the time interval of the fish surveys. PEI values are generated using shorter-term time periods (20 days) because new distribution data is available from the surveys about every two weeks and this becomes the starting point for estimating entrainment risk for the next period.

Lastly, PEI values can be generated using various particle tracking models, including those with behavior simulations. Additionally, recruitment is currently included in some PEI applications and could be used in DSM2-PTM. Mortality estimates are not currently available, but could also be incorporated as input data.

Conclusions

Despite concerns and the uncertainties of using the PEI method, there are distinct advantages for including this methodology into the decision-making process for managing OMR criteria and entrainment (salvage) of larval and juvenile delta smelt. These advantages include: (1) providing the best available means for estimating the effects of export entrainment on the entire distribution of delta smelt; (2) providing a systematic and reproducible means for estimating entrainment risk and to assist in minimizing peak entrainment events; (3) utilizing the DSM2-PTM model which is widely accepted and familiar, but at the same time not being limited to use of the Control Point Method; (4) incorporating the best available fish abundance and distribution data, as well as current hydrodynamic information; (5) providing rapidly assessed results; (6) ability to predetermine level of entrainment and adjust operations to comply with this level; and, (7) providing flexibility for CVP/SWP exports when entrainment risk is low.

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