DRAFT

Final Report

Enhanced Calibration and Validation of DSM2 HYDRO and QUAL

by

DSM2 Project Work Team

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CONTENTS

ACKNOWLEDGMENTS

LIST OF TABLES

LIST OF FIGURES

GLOSSARY OF TERMS

1D	One-dimensional (model)
2D	Two-dimensional (model)
BLTM	Branched Lagrangian Transport Model
CCWD	Contra Costa Water District
DSM2PWT	Delta Simulation Model 2 Project Work Team (IEP)
HYDRO	Hydrodynamics model based on 4-Point model by Lew DeLong
IEP	Interagency Ecological Program
MWD	Metropolitan Water District of Southern California
NGVD29	National Geodetic Vertical Datum of 1929
QUAL	Transport model based on BLTM by Harvey Jobson
USBR	United States Bureau of Reclamation
USGS	United States Geological Survey

EXECUTIVE SUMMARY

Use a browser.
Continuous documentation.
Team effort.
Phased calibration, ongoing process.

I. INTRODUCTION

The DWR Delta Simulation Model (DSM2) has been re-calibrated and validated by The DSM2 Project Work Team (DSM2PWT) under the auspices of the Interagency Ecological Program (IEP). The Team collaborated on model development, numerical testing, sensitivity analysis, calibration design, and calibration/validation execution.

The opportunity to improve the DSM2 calibration was provided by
- Availability of new Delta flow data collected by the USGS.
- Availability of new Delta bathymetry data collected by DWR.
- New technology for collection of additional bathymetry data where needed.
- Recognition of the need for consensus among Bay-Delta modelers on efficacious applications and limitations of one-dimensional models.

The five-year Team effort has yielded the most accurate one-dimensional model of the Bay-Delta system to date. More importantly, the cooperative and open nature of the process developed trust and understanding among the participants and credibility for the result among the modeling community.

I.1 *Purpose*
The purpose of this report is to
- Document the DSM2PWT's collaborative effort to calibrate and validate the DSM2 model.
- Present results of the DSM2 calibration.
- Present future development issues and priorities.
- Discuss field data and application to models for physical forcing and assessment of model accuracy.

I.2 *Report Overview*
This report is complete as a stand-alone document covering the process and results of the DSM2 calibration by the DSM2 PWT. The reader can gain a more comprehensive appreciation of the process and results by using an Internet browser to examine the DSM2 PWT web-site. The report includes several URL links to relevant pages within the DSM2 PWT web-site.

This section provides a brief description of report sections including the name of the principal author. The IEP DSM2 PWT final report on enhanced calibration and validation of the DSM2 model is organized as follows:

In Chapter II, Pete Smith (USGS) and Henry Wong (USBR) recount the history of the IEP Hydrodynamics committee and the need for the IEP DSM2PWT as DSM2 was being developed. Ralph Finch (DWR) and Pete Smith document the need for a new 1D model and opportunities for 1D model improvement. Rick Oltmann (USGS) and Chris Enright (DWR) cover the need for consensus calibration/verification of the new model.

Chapter III outlines the search process for a new 1D Delta model. Pete Smith, K.T. Shum (CCWD) and Eli Ateljevich (DWR) report desirable attributes of 1D hydrodynamics and transport models. Parviz Nader reports the 1D model selection process carried out by the DWR Delta Modeling Section and describes the "Four-Point Model" [DeLong, 1992], and "BLTM" model [*Jobson,* 1980], chosen for application to the Bay-Delta system.

Chapter IV documents the development of the DSM2 modeling system by the DWR Delta Modeling Section. Ralph Finch outlines the development philosophy employed by the Delta Modeling Section that emphasized I/O equally with the model code. Parviz Nader describes the process by which the Four-Point model became DSM2 HYDRO, and the BLTM model became DSM2 QUAL. Future development issues and priorities are also discussed.

Chapter V covers the DSM2PWT deliberation process and presents several development and application topics the Team discussed including the approach to geometry grid development and the approach taken for open water area modeling. Ralph Finch and Eli Ateljevich co-edit this chapter with contributions from other Team members.

Chapter VI presents the Team calibration process. Section VI.1 covers field data and field data reliability. Ralph Finch covers stage data, Rick Oltmann covers flow data, Paul Hutton and Parviz Nader cover salinity data, and Parviz Nader covers agricultural consumptive use data. Section VI.2 covers DSM2 geometry development from bathymetry data with contributions from Brad Tom (DWR), Chris Enright, Rick Oltmann and Callie Harrison (DWR). Section VI.3 details the calibration process including historical calibration periods, output types, PWT decision logistics, and web-site features. Section VI.4 covers the HYDRO and QUAL calibration results and includes a discussion of calibration accuracy (Enright and Nader).

Chapter VI covers validation of DSM2. Henry Wong and Parviz Nader discuss data sets used for validation and present results of ten-year historical simulations for HYDRO and QUAL.

Chapters VII-IX summarize results with references and appendices.

II. BACKGROUND

DSM2 contains two modules that calculate, in turn, hydrodynamics (HYDRO) and salt transport (QUAL). The HYDRO module is a one-dimensional, implicit, four-point finite-difference model developed originally by Lew DeLong of the USGS in Reston Virginia [*DeLong et. al.,* 1992]. DWR adapted the model to the Sacramento-San Joaquin Delta by revising the input-output system, adapting Delta bathymetry, including open water elements, and incorporating water project facilities such as gates, barriers and Clifton Court Forebay. The salinity transport model, QUAL, is adapted from the BLTM model developed by Harvey Jobson of USGS, Reston Virginia [*Jobson*, 1980]. Both of the original models were widely tested, used, and documented in the literature prior to DWR's choice of these models.

II.1 *Need for New DSM2 PWT*
Pete Smith, Henry Wong

II.2 *Need for New 1D Bay-Delta Model*
Pete Smith, Ralph Finch

II.3 *Need for Consensus Calibration/Validation of Models*
Chris Enright

Numerical models have been used often in the past two decades for analysis of water project operations, water control facilities planning, estuarine species protection, and establishment of water quality standards. The issues are always controversial. Not surprisingly, application of models for planning and decision support has also brought controversy. Water resources planners and regulators have relied on models to help sort out the multi-dimensional impacts of alternative designs and standards. However, in their deliberations they have heard concerns expressed from members of the Bay-Delta modeling community about the efficacy of model applications by other members of the modeling community. This has often lead to confusion by managers, and disagreement among modelers.

Planners and regulators have encouraged modelers in the Bay-Delta system to work together toward estuary models and modes of application that can be relied upon for technical accuracy and modeling community consensus.

With the opportunity provided by availability of new Delta flow and bathymetry data, DWR, USBR, CCWD, MWD and USGS modelers agreed to collaborate on an enhanced calibration of DWR's new DSM2 model. The participants agreed that a cooperative effort would leverage the groups' considerable modeling development, calibration, and application experience to create a product of enhanced technical value. More importantly, the participants agreed that a transparent, inclusive process would generate understanding of the model's numerical characteristics and capabilities, and generate advance consensus in the efficacy of the model for planning and decision support application.

III. NEW ONE-DIMENSIONAL MODEL SEARCH PROCESS

III.1 *Desirable 1-D hydrodynamics model attributes*
Pete Smith, K.T. Shum

III.2 *Desirable 1-D transport model attributes*
Pete Smith, Eli Ateljevich

III.3 *1-D models considered (Process conducted by Delta Modeling Section based on desirable attributes)*
Parviz Nader

III.4 *Description of Delong's 4-Point model and Jobson's BLTM model*

Parviz Nader

IV. DEVELOPMENT OF DSM2 BY THE DWR DELTA MODELING SECTION

IV.1 *Modeling System Development*

Ralph Finch

DSM2 was developed with the idea that a modeling system is composed of several main components: input data and data input mechanism, the numerical engine, an output data mechanism, and the output data. Traditionally, most effort has gone into developing the numerical engine, but for a production model, inaccuracies and delays can happen at any stage in the entire model system, therefore each component should receive sufficient design and implementation effort so that no single component greatly contributes to either inaccuracies or delays in the desired final results.

To this end, extra attention was given to observed input data, the input/output system of DSM2, and data manipulation and viewing tools.

V. DSM2 PROJECT WORK TEAM ISSUE DELIBERATION

The DSM2 calibration Team chose to convene its work under the auspices of the Interagency Ecological Program because of the Program's interagency and interdisciplinary philosophy. The IEP Hydrodynamics Project Work Team provided oversight and IEP Management Team Support. Pete Smith of USGS represented the IEP Management Team at PWT meetings. The DSM2PWT had nearly continuous participation from staff of DWR (Delta Modeling Section, and Suisun Marsh Planning Section), USGS, CCWD, USBR and Metropolitan Water District of Southern California. Other agencies and universities provided periodic comment and support including Stanford University, UC Davis, and UC Berkeley.

A number of significant DSM2 features were discussed early in the calibration process. The Team reached no final agreement or resolution on many of these issues. On other issues, the Team agreed to postpone selection of an ultimate solution while adapting an interim approach for this calibration. On more difficult issues, the Team agreed to proceed with the understanding that the next calibration would be proceeded by efforts to understand and scientifically pursue solutions to the problems.

This section presents a recounting of several topic areas that the Team addressed including calibration to surface EC, open water area modeling, and geometry development mechanics. Other issues the Team discussed are presented in other sections of this report including data reliability (Chapter VI), geometry development approach using the CSDP (Chapter VII), calibration logistics (Chapter VIII), calibration approach (Chapter IX), and validation approach (Chapter XI).

V.1 *Selection of a Conservative Water Quality Tracer*

Paul Hutton

An unresolved issue associated with the DSM2 calibration and validation relates to the selection of a conservative water quality tracer. Electrical conductivity (EC) was utilized as the tracer in the 1997 DSM2-QUAL calibration. EC was utilized again in the most recent calibration. Contra Costa Water District suggests that, because of the non-conservative characteristics associated with EC, it should not be utilized as a tracer for QUAL calibration and validation. CCWD recommends calibrating on TDS data that has been derived from observed EC data.

We selected EC as a water quality tracer for DSM2-QUAL calibration based on the following considerations:

1. EC data are collected at high frequency and at several locations throughout the Delta. Mineral and TDS data are not collected at a sufficient number of locations or at sufficient frequency to use directly in the model calibration/validation process. Therefore, to employ mineral or TDS data in the model calibration/validation process, it must be derived through regression relationships with EC at model boundaries and at internal Delta locations. The accuracy of such regression relationships varies widely by location. Significant error is introduced into the calibration/validation process when derived data is used.

2. We recognize that the EC measure is in fact non-conservative. However, the standard laboratory technique used to measure TDS has its own shortcomings [Hem, 1985].

3. Given the tradeoff between errors associated with regression relationships and errors associated with non-conservative behavior, an eminent authority [Tanji, 1994] suggested that EC could be used to reasonably approximate a conservative tracer. EC reasonably conserves ionic strength rather than mass.

We take CCWD's concern about using EC as a conservative tracer very seriously and are investigating the matter further. As part of our investigation, we are looking into using practical salinity as a conservative water quality tracer. This process will entail converting observed EC data into practical salinity prior to calibrating DSM2-QUAL. At issue is the development of an appropriate correction for Delta practical salinity values below 2. The standard conversion from EC to practical salinity, originally valid only down to 2, has been extended to 0 through a correction. However, this correction is based upon progressive dilutions of seawater while lower Delta salinity is primarily due to inflow from the Sacramento and San Joaquin rivers. A correction to lower practical salinity is sought that would be applied to the entire Delta.

Finally, we believe the best long-term solution to this unresolved issue is to modify the existing data collection network. DWR's Central District staff has been using an instrument called a YSI 6600 Datasond to continuously monitor multiple constituents in the south Delta and at Old River at Rock Slough, including chloride. This type of instrument could be installed throughout the Delta to replace or supplement the existing EC data collection network.

V.2 *Use of Surface Salinity as Downstream Boundary Condition*

KT Shum and Pete Smith

The salinity transport module of DSM2 has been calibrated using surface salinity exclusively and uses surface salinity as model input at the downstream boundary. As a characteristic of one-dimensional models, it assumes that the salinity variation over a channel cross-section is constant.[1] However, significant salinity variations over a channel cross-section have regularly been observed in the Sacramento River up to Emmaton and beyond. Continuous electrical conductivity measurements near channel bottoms (in addition to surface salinity) were taken starting in the 1990s at Martinez, Mallard Island (Pittsburg), Antioch, and Emmaton.[2] Top and bottom salinity measurements at three Sacramento River stations near Emmaton (at Navigational Lights 14, 18, and 22) were collected by the U.S. Army Corps of Engineers between 1987 and 1993 at 15-minute intervals. In addition, USGS and Stanford University have performed detailed incidental monitoring of salinity and flow over the last decade in Suisun Bay and Honker Bay, and obtained fine temporal and spatial (in both the vertical and lateral directions) resolution. These measurements show that, to the east of Suisun Bay, the difference between surface and bottom salinity is generally small during ebb tides but could be substantial during flood tides. Instantaneous salinity at the channel bottom could be twice as high as that at the surface at high tides. At Martinez, however, salinity variations in the vertical could be substantial through most of a tide cycle. The *difference* between surface and bottom salinity at Martinez could at times be larger than the *actual* salinity at Pittsburgh.

Most salinity measurements are made close to the water surface, and only surface salinity is available in interior Delta except for intermittent data at isolated locations[3]. This lack of data has forced surface salinity to be used as model input and in comparison with model results in the past. Since the continuous bottom salinity measurements at Martinez started in December 1990, the use of weighted-averages to estimate the effects of vertical variation in boundary salinity has become possible.

In the Delta, higher salinity water at the downstream boundary makes its way to the interior Delta by tidal dispersion. Further upstream, ACOE measurements near Emotion shows that residual currents near the bottom of the channel could be in a direction opposite to that in surface water in the Sacramento River. Given the stratification prevalent in some conditions, whether surface salinity, or a weighted-average of surface and bottom salinity, would best simulate the effects of seawater intrusion remains an open question. Up to 3% of the water at urban intakes could originate from the Carquinez Strait at times of seawater intrusion, accounting for over 75% of the salinity (salt load) at the intakes.[4] An error in

[1] In most cases a constant salinity is assumed implicitly over the cross-section.

[2] Most measurements at channel bottoms are recorded at 15-minute intervals.

[3] For example, CCWD has been recording top and bottom salinity measurements monthly at its intakes since 1997.

[4] For example, daily mean Martinez salinity was around 25 mS/cm in the second half of 1999. Salinity increased to around 1.0 mS/cm in Old River at Holland Tract in early December when salinity in the Sacramento River inflow was under 0.2 mS/cm. Simple mass balance suggests that the fraction of seawater is proportional to the ratio of the salinity of seawater to that at the intake, to first approximation, given that San Joaquin inflow and Delta drainage are low in late fall.

salinity input at the downstream boundary would lead to a comparable percentage error in the salinity prediction in interior Delta.

The sloshing flows forced by tides, however, could be highly three-dimensional. The question of whether a longitudinal diffusion formulation, in which the salt flux between adjacent volumes along a channel is assumed to be proportional to the difference in their mean salinity, is an adequate approximation under highly stratified conditions remains to be addressed. Using surface salinity as boundary condition and a time-constant dispersion coefficient implicitly assume that vertical mixing in the channel close to the downstream boundary is negligible.[5] It is possible that the mass of more saline bottom water in the Carquinez Strait and Suisun Bay intrudes into interior Delta to an extent considerably less than surface water. However, the validity of this assumption has not been well quantified. In addition, lateral (cross-channel) salinity variations have also been observed which introduce additional uncertainty into the accuracy of using a point measurement of salinity at Martinez to quantify seawater intrusion in the entire Delta.

A focused review of the data collected by USGS and others on salinity and flow distribution in the vicinity of Martinez (model downstream boundary), possibly with additional field measurements, would allow for a better assessment of the potential error in existing model formulations. Data with sufficient spatial resolution to allow reliable estimates of vertical mixing, assisted by three-dimensional model simulations, could offer reliable answers to the outstanding questions.

V.3 *Calibration to Surface EC*

KT Shum, Eli Ateljevich

V.4 *Open Water Area Modeling*

Ralph Finch

The Sacramento-San Joaquin Delta/Suisun Bay/Marsh has several large bodies of water (Suisun Bay; Grizzly Bay; Sherman Lake; Franks Tract; etc.) which are either natural bays or flooded islands, and would be best modeled with at least a 2D model. However, DSM2 has only 1D channels, and Continuous Stirred Tank Reactor reservoirs. The question becomes, which combination of channels and reservoirs would introduce the least modeling error for any particular open area of water, knowing that any combination will probably not be too good. In fact, even the question of "least modeling error" was not resolved. It is possible that what best advects salt landward into the Delta might result in poor results in the vicinity of open area; or what might best approximate some crude hydrodynamics might produce the worst salt movement.

As a first step, the group tried to simply look at the different behavior of the model to a reservoir in series and in parallel with a channel. However there was not enough time to pursue this, and finally it was decided to proceed with a configuration proposed by the Suisun Marsh Section, which has 5 reservoirs (as opposed to 14 in the old grid), all in the interior Delta.

[5] Topographic features such as sills could also

V.5 *Geometry Development Mechanics*

Brad Tom

This section describes the process used to create geometry data for DSM2-Hydro. For more information, including the CSDP User Manual, go to

http://modeling.water.ca.gov/delta/models/dsm2/tools/csdp/index.html

Bathymetry data collection programs are discussed in Section VII.1, historical bathymetry data and common coordinate systems are discussed in Sections VII.2, and the geometry data viewer, CSDP, is discussed in Section VII.3.

The first issue resolved by the PWT was how to describe 3D bathymetry data to DSM2-Hydro, which is a 1D model. The group decided to use a process that involves using a computer program to develop a minimal representative data set that could be used by Hydro. The program that is used is called the Cross-Section Development Program (CSDP). The process involves selecting a portion of bathymetry data (discussed in section VII.3) to display in cross-section view. In this view, the user is able to draw a series of line segments to fit a curve to the data points. The group decided that the process of selecting data and drawing the cross-sections should be done by hand for the following reasons:

1. The user can easily ignore data that are thought to be less reliable, or give more weight to data that are thought to be more reliable.
2. The user has the ability to draw a cross-section that does not fit the data exactly. This ability is necessary for planning studies that involve proposed changes to the channel shapes, such as dredging.
3. The process reduces the large bathymetry data set to a minimal representative data set.

After drawing cross-sections, the CSDP calculates tables of cross-section conveyance characteristics, which are used as input to DSM-Hydro. Each row of the table of conveyance characteristics is called a *layer*.

Hydro calculates a quantity known as *dConveyance* for each *layer* of every cross-section. *dConveyance* is the derivative of conveyance with respect to elevation. If a cross-section has large changes in wetted perimeter and relatively small changes in cross-sectional area, usually caused by line segments with small rise/run slopes, then the value of *dConveyance* could be negative. A Hydro run will fail if the water surface enters a portion of any cross-section that has *negative dConveyance*. Some of the original cross-sections that were developed for the model were causing model runs to fail. The group decided that the best solution to this problem would be to adjust cross-section line segment slopes to eliminate *negative dConveyance* in the range of -5ft < Z > 15ft (NGVD). A subroutine was added to Hydro that would warn the user of all cross-sections that had negative *dConveyance*. It is not necessary to eliminate *negative dConveyance* in all layers of the cross-section.

Convergence problems can occur if

- There are large changes in cross-sectional area within a channel or on either side of a node that is connected to two channels.
- The sum of cross-section wetted areas adjacent to the node in the channels which are flowing into the node is significantly greater than or less than the sum of the wetted areas of the cross-sections adjacent to the node in the channels which are flowing away from the node.

A change in the quantities mentioned above is considered to be significant enough to cause convergence problems if one quantity is more than twice as large as the other.

The failure to converge can sometimes cause the water level in a channel to fluctuate enough to cause the channel to overflow or dry up. If a channel overflows or dries up, the model run will fail. Failure to converge can also cause a model run to fail by lowering or raising the water surface to a layer, which has *negative dConveyance*. If this happens outside the normal range of water surface elevations, then the real problem may be in a cross-section other than the cross-section with *negative dConveyance*. The best way to correct this problem is to adjust or remove the cross-section that is causing the instability. The cross-section that is causing the instability will often be far from the channel that is named in the error message when a hydro run fails.

A subroutine was added to Hydro in the input system that warns the user of all potential convergence problems due to large changes in cross-sectional area. Also, a diagnostic routine was added to determine which cross-sections are not converging during runtime. This routine is not included in the public release of Hydro.

The group initially wanted to have at least 3 cross-sections in every channel. The optimum number of cross-sections in a channel actually depends on data availability, the value of *deltax* that will be used for the model run (typically 5000-ft), and the channel length.

The bathymetry data set that existed at the time the DSM2 geometry development was taking place did not include complete coverage of all the channels in the model grid and contained some questionable data. The group recommended additional bathymetry data surveys in the following areas: Suisun Bay, most of the south Delta (except Old and Middle Rivers), the area near the confluence of the Sacramento and San Joaquin Rivers, and Sherman Lake. Surveys are being performed by DWR-Central District. Some surveys have been completed. New bathymetry data collected near the Sacramento-San Joaquin confluence indicate that channels in this area have significantly increased in size (both depth and cross-sectional area). The cross-section data set was modified to reflect these changes.

Reservoirs in DSM2 are highly nonlinear and their use significantly increases runtime. Also, DSM2-Qual does not allow water quality gradients in reservoirs, resulting in inaccurate simulation of salt transport. In previous versions of the DSM2 model grid, Sherman Lake was represented by a reservoir. The PWT decided to replace the reservoir with a network of channels to more accurately simulate the complex geometry and important conveyance characteristics of Sherman Lake, which include rapid changes in width and depth, and high flow velocities. Also, a channel was added to connect Sherman Lake to Broad Slough. Other reservoirs replaced with networks of channels include Grizzly Bay, Honker Bay, Suisun Bay, and Stone Lake. Rectangular cross-sections are used in all of these channel networks. Cross-section dimensions are calculated using estimated volumes of open water areas and average depths.

Cross-section resolution is defined as the number of cross-sections per channel and the number of points in a cross-section. Increasing the resolution could increase accuracy, but it could also increase Hydro's runtime and memory usage. (Note: because Hydro is written in FORTRAN, the memory usage is constant regardless of the number of cross-sections or the cross-section resolution). The PWT is considering a proposal that could decrease runtime and memory usage, allowing cross-section resolution to be increased. This proposal involves adding two subroutines to Hydro. One subroutine would remove all virtual cross-section layers that are outside the water surface elevation range. The other would remove layers of virtual cross-sections that could be approximated by interpolation. Both subroutines would occur before the actual run begins.

Another proposed feature would use a smoothing function to draw cross-sections. This function would be added to the CSDP. The main advantage of using this function would be consistency--cross-sections would be drawn in a more consistent way. The user would still have to view the results on the cross-section plot. The main disadvantage would be that the smoothing function would give equal weight to all bathymetry data points. The smoother would not be able to ignore data that the user would prefer not to use. However, a cross-section drawn with this function could be adjusted by hand; it would expedite the cross-section development process by serving as a starting point. This feature could also expedite the process of representative bathymetry data selection by updating the cross-section conveyance characteristics when a cross-section is moved to another location in a channel.

A third approach, which is currently being used, is to try to reduce cross-section resolution in the range of $-5 < Z > 15$ ft. Reducing the cross-section resolution in this range will reduce runtime.

Geometry could be improved if Hydro could handle negative dConveyance, but there is currently no proposal to add this feature to Hydro. It is not clear how significant the improvement would be. A new solver is being developed which may eliminate the convergence problem.

More information on eliminating problems caused by negative dConveyance and lack of convergence is available in the CSDP manual (revised October 2001) in the sections entitled "Problems to avoid when using irregular cross-sections with DSM2" and "Troubleshooting Geometry Problems." The CSDP manual is available on the CSDP website.

V.6 *Sensitivity Analyses*

Parviz Nader

A number of tests were performed to check the sensitivity of DSM2 (both Hydro and Qual) to changes in some of the basic input parameters. The goal of this testing was to determine what values (or range of values) should be assigned to each parameter and to ensure that the model response is fairly stable with respect to changes in those parameters. In addition, some further tests were done to ensure the validity of the model results.

I- DSM2-Hydro

The following is a list of input parameters that were used in the testing. All of these parameters are part of a group called scalars, and can be easily modified by the user.

Δx

Δx is the distance between two successive computational points within a channel. Each channel has at least two computational points, one at each end, but some channels may have more than two, depending on their length. The momentum and continuity equations are discretized at the computational points using a finite-difference scheme. A small value for Δx will lead to a more accurate discretization (in most cases) but it comes at a cost of longer run time. The object of this testing was to find an optimum value. In Hydro, the user can specify one value for Δx, but the actual Δx used by the model may be different in each channel because of the requirement that all the computational points be separated by an equal distance. For example, if the user selects a Δx of 5,000 feet, and a particular channel is 11,000 feet long, then a Δx of 5,500 feet will be assigned to this channel. Therefore, the actual value of Δx can vary from one channel to another.

The model was tested using three values of Δx equal to the channel length, 5,000 feet, and 2,500 feet. Flow and stage were compared at various locations in the Delta. The model response was very similar for all the runs. There was only a small difference in results between the first and second tests (Δx of channel length and 5,000 feet) and practically no difference in the results of the second and third tests (Δx of 5,000 feet and 2,500 feet). Test 2 took about 11 percent higher CPU time than test 1, but test 3 took about 92 percent higher CPU time than test 1. Based on accuracy and speed, the conclusion was to use Δx of 5,000 feet.

Time step

The time step was tested at 3, 5, and 15 minutes, with all the other input parameters set at standard values. The run length was set to 25 hours. There were very small differences observed during the first 4 hours, but after that the results did not vary much. It was decided that for ordinary application with no unusual abrupt changes, a time step of 15 minutes would be appropriate.

Maxiter

Maxiter is the maximum number of iterations allowed per time step. Three tests were conducted using a maximum of 10, 15, and 50 iterations. All other input parameters were standard values. The run length was 25 hours. Results did not vary by much and the amount of CPU time was nearly the same. However, in long-term model runs, it sometime took the model more than 30 iterations to converge. Thus it was decided to use Maxiter value of 50

θ (Time Integration Factor)

θ is the time-weighting parameter used in the discretization of momentum and continuity. At first glance it seems that a value of θ equal to 0.5 (trapezoidal rule) may be the most accurate. However, as Lew Delong (author of the original Four Point model) pointed out, a value of 0.5 may lead to instability. Lew Delong has suggested a value of 0.6 for θ. However, it is believed that a value of θ greater than 0.5 may dampen the response in a four-point finite-difference scheme. Three tests were conducted, with θ values set to 0.55, 0.6, and 0.75. The run length was set to 25 hours. During the first few hours, there were some small differences observed, but after that there was very little difference. Based on this experiment, it is suggested that a value of 0.6 be used for θ. Because there is very little difference between results for θ of 0.55 and 0.75, it may be safe to assume that dampening the response may not be a problem.

ToleranceQ/TolernaceZ

ToleranceQ and TolernaceZ specify the closure criteria for discharge and water-surface elevation, respectively. In other words, they are the maximum changes in flow and water surface elevation allowed between two successive iterations to satisfy convergence. A number of improvements have been added that to help achieve convergence with a lower closure criteria. In the latest model runs, the values of ToleranceQ and ToleranceZ have been set to 0.001 and 0.0008 respectively. This is a significant improvement compared with previous versions of DSM2. Test runs have shown that model results are not very sensitive to small changes in these values.

Pulse Flows

The effect of a one-hour pulse flow from the Sacramento and San Joaquin rivers was examined. The flow was suddenly raised to a high value and, after one hour, the flow was set to zero. The tide at Benicia was set to a constant stage. All inflows into and diversions from the Delta were set to zero. The results showed that the flows gradually damped out to zero and, after some fluctuations, the stage stayed constant at the tide level at Benicia.

Numerical Precision

Originally, all the variables in DSM2-Hydro and DSM2-Qual were declared as single precision. Because of the high number of simultaneous equations involved, numerical precision could become a potential problem. Two tests were conducted of the single precision variables. In the first test, channels were numbered in a standard manner so as to reduce array sizes. In the second test, the channels were renumbered randomly, thus changing the order in which the computations were taking place. In theory, if numerical precision is a problem, then the results would be somewhat different if the order of the computations is changed. The tests showed only a very small difference. The maximum difference observed was about 0.04%, thus suggesting that numerical precision is not a major issue. Even so, in 1998 all the variables were changed to double precision, since the RAM memory became very cheap.

II-DSM2-Qual

Three sensitivity tests were applied to Qual: time step, Hydro tide output interval in relation to Qual time step, and maximum number of parcels within a channel.

Time step

The time step was tested at 5, 10, 15, and 30 minutes with the tide output interval set at 30 minutes. All other input parameters were set at standard values. The run length was 8 days. The results showed that the difference between the first three runs (5, 10, and 15 minutes) is fairly small (about 1 percent), but the results for the 30 minute time step showed a noticeably bigger difference. Based on the above results, a Qual time step of 15 minutes was recommended.

DSM2-Hydro Tide Output Interval

The DSM2-Qual time step was fixed at 15 minutes, while the tide output interval was set to 15, 30, and 60 minutes. The tide output interval controls how often hydrodynamic results are stored in the binary tide file. All other input parameters were set at standard values with a run length of 8 days. The results showed very small differences, but no trends were observed. It is assumed that a tide output interval of 15 minutes is more accurate, but that accuracy comes at a cost of much bigger size files. For example, the sizes of the binary tide files for a 16-year run is about 4GB using a hour time-interval. Even with today's computers, this is a high number. Thus, a 60-minute time interval is recommended especially for a long-term simulation.

Maximum Number of Parcels in a Channel

Within DSM2-Qual each channel is divided into a series of parcels. During each time step, parcels are added and removed at each end of a channel. The number of parcels within a channel can change with time, and is dependent on the flow regime, and the time-step. The model has the capability to set a maximum number of parcels within a channel. To insure that the number of parcels never exceeds the maximum, smaller parcels are combined and mixed to form bigger parcels. Four tests were conducted with the maximum number of parcels set at 10, 16, 22, and 30. All other input parameters were set at standard values. The run length was 8 days. The results for runs with a maximum number of parcels of 16 and 22 were within 2 percent of the run with a maximum number of parcels of 30, but the run based on maximum number of parcels equal to 10 showed a bigger difference. Since the CPU time between 16 and 22 parcels varied by less than 5 percent, the maximum channel parcel of 22 remained standard.

V.7 *Forcing due to density variations in the Delta (the "Baroclinic Term")*

Pete Smith and K.T. Shum

The mixing of freshwater inflow to the delta with saltwater from the ocean results in a longitudinal density gradient within the San Francisco estuary. Figure V.7.1 presents contours of salinity data collected by the IEP along the centerline of the deepwater channel within the bay and along the lower Sacramento River downstream of Rio Vista. These data were collected on October 17, 1986 during a period of low delta outflow, which is a typical of late summer and early fall condition. Although the longitudinal salinity gradient in the Delta portion of the estuary (east of Chipps Island) is relatively small, the salinity gradient across Suisun Bay is quite large (a change in salinity of 10 psu occurs over a distance of about 15 kilometers). For the same surface elevation, the higher density of saltwater increases the hydrostatic pressures acting on a cross section of the channel and contributes to a landward-directed pressure force that affects the dynamics of the flow. Blumberg (1978) was one of the first investigators to quantify the influence of longitudinal density variation on estuarine tidal dynamics through a pair of numerical simulations, one with density variation included and one with density assumed constant. Blumberg provided quantitative estimates of the higher mean (tidally averaged) water surface at the landward end of an estuary when a significant longitudinal density gradient is present. In this section we refer to this incremental rise in the mean water surface height as "setup."

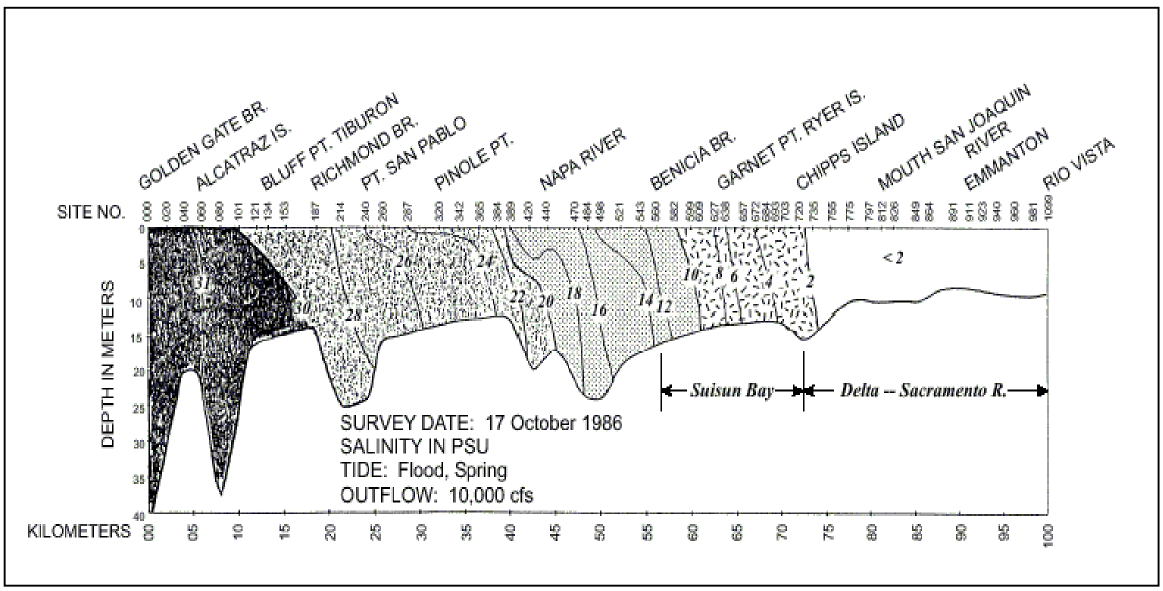

Figure V.7.1. Salinity contours, center channel (Golden Gate Bridge to Rio Vista)
Data from IEP ('running-with-the-tide) study, modified from Hachmeister, 1987

In the applications of multidimensional hydrodynamic models to the Bay portion of the San Francisco Estuary, a density forcing term has traditionally been included (e.g. Smith and Cheng, 1987; Smith and Cheng, 1990). However, one-dimensional hydrodynamic models of the Delta and Suisun Bay region have not explicitly accounted for the effects of density variations in the dynamic (force) equation. Prior to the recalibration of DSM2, the PWT considered including a density-forcing term in the model. Here, we summarize the issues considered both pro and con, and the considerations that led to the decision to leave it out of the model.

The pressure gradient for a 1-D flow can be expressed as (Odd, 1981; Delong and others, 1997):

$$\frac{1}{\rho_0}\int_A \frac{\partial p}{\partial x} dA = g\rho_0 A\frac{\partial \zeta}{\partial x} + \rho_0 g X_0 \frac{\partial \rho}{\partial x} \qquad (1)$$

where g is the gravitational acceleration, A is the cross-sectional area of flow, ζ is the elevation of the water surface measured from a common datum, X_0 is the distance measured downward from the free surface to the center of gravity of the cross section, ρ is the cross-sectional averaged density, and ρ_0 is the average density. The first term on the right side of equation (1) is referred to as the barotropic pressure gradient, and the second term as the baroclinic pressure gradient.[6]

In 1-D flow simulation, a baroclinic term is only an approximation for the 3-D effects of density variations that can occur in real estuaries. The validity of equation (1) depends on the assumption that density variation over a cross section is negligible. This is rarely true in estuaries because even relatively small quantities of freshwater inflow can cause significant vertical and lateral variations in salinity. Nevertheless, measurable setups in the mean water surface elevation in estuaries have been observed due to the longitudinal density gradient (e.g. Uncles and Jordan, 1980).

An estimate for the setup in mean tidal height at the head of an estuary, $\Delta\zeta$, due to a longitudinal density variation, $\Delta\rho$, is (Odd, 1981):

$$\Delta\zeta = h\frac{\Delta\rho}{2\rho_0} \qquad (2)$$

where h is the average depth of the estuary. Applying this formula to estimate the setup in water surface elevation across Suisun Bay using the data for salinity in Figure V.5.1 gives an estimate of $\Delta\zeta = 4$ cm. This is consistent with the estimate reported by Smith and Cheng (1987) in a 2-D model study of Suisun Bay. Although there are data on water level height collected at both ends of Suisun Bay, it is difficult to extract from these data a precise estimate of the portion of the setup attributable to density effects alone. There is considerable variability in setup that occurs due to the effects of the spring-neap tidal cycle, wind, and hydraulic gradient due to the Delta outflow. There also is an uncertainty of approximately 1-2 centimeters in the elevations of datum for the gages within Suisun Bay that are used for measuring setup. The data records for setups across Suisun Bay during typical summertime conditions indicate a range of values between 0 and 12 cm. Walters and Gartner (1985) reported that the variation in setup across Suisun Bay due to changing density in the summer is small and is generally less than 1 cm.

A key issue is whether a 1-D baroclinic term would simulate the hydraulic effects of longitudinal salinity gradients in Suisun Bay and elsewhere. When the longitudinal salinity

[6] The term "barotropic" and "baroclinic" originate from the field of physical oceanography. Flows are referred to as barotropic when the fluid surfaces of constant hydrostatic pressure (isobaric surfaces) are parallel to the fluid surfaces of constant density (isopycnal surfaces). Flows in which these surfaces are inclined to one another are referred to as baroclinic. Mathematically, baroclinic flow is a flow field in which $-\nabla p \times \nabla \rho \neq 0$. The first term in the vector product is the spatial pressure gradient and the second term is the spatial density gradient. In a flow with a non-vanishing vector product, the pressure and density gradients are not parallel. The definition of a "baroclinic term", as used in the present context, is different since this vector product is always non-zero (for a water surface in a channel that is not flat) in one-dimensional model formulations.

gradient is significant, the water column could be highly stratified. The data from Hachmeister (1987) indicate that the most severe stratification in salinity at Benicia occurs near high slack water, on a neap tide, for a medium-high freshwater inflow of about 1000 m^3/sec (35,000 cfs) to the bay. For example, the stratification measured near Benicia under these conditions on April 18, 1986 was 10 psu. For higher flows into the bay, the saltwater is driven farther seaward and the stratification at Benicia is reduced. Using the measured density distribution of April 18, 1986 presented in Hachmeister (1987), the setup calculated by equation (1) was 4 cm. The error in this setup was estimated using exact two-dimensional integrations (but assuming no lateral variation in density) as about 1.5 cm too large. Of all the measured density distributions presented in Hachmeister (1987), it was only for this most severe case (of April 18, 1986) that the error term was greater than 0.5 cm. Salinity gradient in the lateral direction, however, could lead to a larger error.

A tidally averaged setup of 4 cm is small compared to tidal variations. However, a setup of this magnitude, if imposed as boundary conditions (as measured water surface elevations), can have a large effect on the simulated mean flow through the estuary if a baroclinic term is not included in the model. Smith and Cheng (1987) estimated the magnitude of this forced flow in a 2-D model study of Suisun Bay. Two "rating curves" relating mean flow and water surface setup across the bay were developed from model simulations. One rating curve was developed with a baroclinic term included in the model and the other without. The simulated flow obtained without accounting for the longitudinal density effect on the setup was much higher than measured estimates, especially at low flows. However, this forced flow would not be present if the model is not forced by stage at both boundaries (and hence no explicit forcing by a setup). If a model is applied with a boundary condition in which flow is specified at the landward side of the estuary, the inclusion of density gradient effects is likely to have little or no effect on the flow computation.

In the DSM2 model, flow is specified as the boundary condition for each of the landward boundaries. Only at the seaward boundary (at Martinez) is water surface elevation specified. The error due to neglecting the density variation in the DSM2 model, therefore, will mostly involve under prediction of setup in the mean water surface elevation. This error is small compared with other model uncertainties (such as inadequate knowledge of the bottom stress parameterization in Suisun Bay and the effects of wind on setup).

Although the baroclinic term in equation (1) is already coded into the DSM2 model formulation, a significant technical difficulty to including this term is that it requires coupling with salinity computation. The DSM2 model was designed to run the hydrodynamic program first, and then to save the results in files for use as input to the salinity program. The coupling of the two programs is not a priority of the recalibration effort, and would have required extensive program changes. The PWT decided that the additional work to couple the models was not worth the relatively small improvement in accuracy that would be gained under some conditions by including the baroclinic term. However, a baroclinic term and a capability for doing coupled simulations of the equations for hydrodynamics and salinity, could be included in future enhancements to the model.

V.8 *Optimization Approach to Calibration*

Chuching Wang, Eli Atelevich

V.9 *Momentum Transfer at Nodes*

Eli Ateljevich

VI. INPUT DATA AN DATA RELIABILITY

Ralph Finch

Input data is obviously a crucial element to the calibration of any model. Ideally, ample data for calibration and validation should be available. It should be free of missing and erroneous values and the measured values should accurately reflect the field conditions at the time of measurement.

Real data, of course, does not meet the ideal. At around 25 million data points each, it is inevitable that the observed hydrodynamics and water quality databases used in the calibration have some problems, which must be dealt with.

Probably the biggest problem hindering calibration is missing data, or unusable data due to invalid values. Input data is checked visually using tools developed in the DWR's Delta Modeling Section, and invalid values are marked so they are treated as missing.

DSM2 can detect missing data in its input streams. However, it requires some kind of valid value for each input stream at every time step. So for each missing value, a replacement is used at the user's discretion: use a value from an alternative input stream, use the last non-missing value, or use filled-in (mathematically generated) data.

This method is not considered acceptable for the long term for several reasons. The biggest problem is that by switching pathname streams at runtime, unknown and possibly large changes in value can happen between time steps. If the last good value is used for more than a few time steps, this can result in significant inaccuracies. Instead, the Delta Modeling Section is working on a solution to produce an accepted, agreed-upon time series path for each data stream, by combining alternate observed data streams and sophisticated filled-in data.

Beyond problems with missing or obviously bad values, other questions remain about the data, which have not been investigated. Are the values measured reproducible? Can we estimate the error in the observed value? Are the values representable? Does a point measurement of EC in a channel represent only the immediate area, or the cross section at the point, or even a large volume of water within the channel? At this time, we do not have a good idea of the answers to those questions.

VI.1 *Stage Data*

Ralph Finch

VI.2 *Flow Data*

Chris Enright

Since 1989, the USGS has established a network of continuous flow monitoring stations in Delta based on improving ultrasonic velocity meter (UVM) and acoustic Doppler current profiler (ADCP) technology. USGS has also conducted special flow measurement studies with short-term ADCP deployments at critical Delta and Suisun Bay locations. Both technologies collect index velocity data based on the back-scatter of acoustic pulses from moving particles in the water column. The continuous index velocity data is calibrated based on instantaneous flow measurements made by boat mounted ADCP instruments integrated with GPS [*Simpson and Oltmann, 1992*].

Figure VI.2.1 shows the continuous flow measurement network currently maintained by the USGS. The network provides an accurate, long-term tidal flow data set at critical junctures in the Delta. These data have been used to describe complex tidal currents at important Delta channels including Three-Mile slough, the Delta Cross-Channel, Turner Cut, and the Sacramento-San Joaquin River confluence. The Rio Vista, Three-Mile Slough, Jersey Point and Dutch Slough stations, taken together, provide a direct measurement of Delta outflow not before available. The network also provided the primary source of calibration and validation data for the DSM2 PWT's effort.

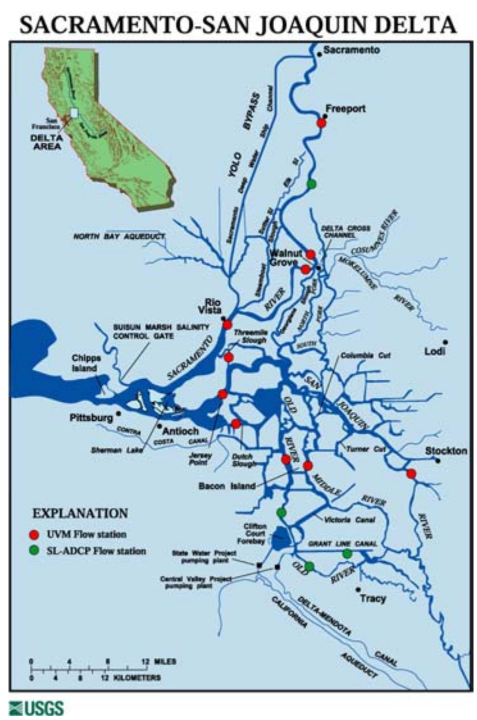

Figure VI.2.1 Continuous Flow Measurement Network

Tidally averaged (residual) flow can be calculated at each station using a digital filter. Since residual flows are often less than ten percent of tidal flow magnitudes, tidal flows must be measured accurately to keep residual flow error small. Simpson and Bland (1999) showed that data from Three Mile Slough net flows are accurate within 0.5% of the peak tidal flows.

Tidal residual estimation at wide channel sites like Rio Vista and Jersey Point are likely to be somewhat less accurate.

VI.3 *Salinity Data*

Parviz Nader

VI.4 *Delta Channel Depletions*

Parviz Nader

Delta channel depletions represent the exchange of water between the channels and rivers and the agricultural lands. Diversions and drainage flows are difficult to measure in the field. The diversions are drawn at more than 1800 location in the Delta (Sacramento-San Joaquin Delta Atlas, 1983). The only Delta-wide field measurements are available for 1954-1955. As a result, DWR developed a computer model called DICU (Delta Island Consumptive Use), to estimate the Delta Channel Depletions. DICU is a basically soil-moisture accounting model. DICU divides the Delta into 142 regions, and estimates consumptive use on each region separately. All the three modules in DSM2 (Hydro, Qual, and PTM) rely on these estimates to accurately represent the conditions in the field. Among all the data parameters that are input to DSM2, DICU data is probably the crudest with highest degree of uncertainty. Among the three DSM2 modules, DSM2-Qual has shown to be the most sensitive to small changes in channel depletion estimates. This is especially true during low flow periods, where small changes in the net Delta outflow (NDO), can potentially cause large changes in the salinity intrusion. In fact, during the calibration of DSM2-Qual, it was suspected that for certain periods (1990-1992), the DICU data may be questionable and a primary cause for the large mismatch between the model output and the field data. DWR Delta Modeling Section plans to use indirect means of estimating the net channel depletions. If these efforts are successful, they will be utilized in the next round of calibration.

DICU refers to a series of modules, which are all related. The main module, estimates the water exchange within individual sub-regions. The second module is the nodal allocation program (NODCU), and is used to map the regional information to DSM2 nodes. Each DSM2 node can be part of one or more sub-regions. The allocation factors are static values, which are assumed to be constants. NODCU incorporates assumptions regarding the irrigation efficiency, which directly impacts the magnitude of agricultural drainage flows (lower irrigation efficiency leads to higher agricultural drainage flows). There are additional modules related to DICU, however, since they are not related to calibration/validation of DSM2, they will not be discussed here.

Channel depletion estimates are computed for each month. These estimates take into account monthly precipitation (seven Delta stations) and pan-evaporation data, crop patterns, evapo-transpiration rates (ET), and seepage estimates.

Estimates for the salinity concentration of all the agricultural drainage flows have been developed by DWR. This data is based on a 1954-55 study. According to this study, Delta is divided into three regions. Representative monthly values of salinity have been developed and have been assumed to be constant within each region. These values are considered semi-static as the values as the values change monthly, but do not change from one year to next.

For further information about DICU and the assumption details, refer to "Estimation of Delta Island Diversions and Return Flows" (DWR, 1995)

VII. DSM2 GEOMETRY DEVELOPMENT

VII.1 *Bathymetry Data Collection Programs*

Brad Tom

The DWR Bathymetry database included data collected by various Bay-Delta agencies including, NOAA, DWR, COE, and USGS, since 1934. Since 1998, bathymetry data has been collected primarily by the Central District of DWR in support of ongoing scour monitoring and modeling. Specifically, the Central District has collected bathymetry data for the following three clients.

- DWR Central District north and south Delta scour monitoring program
- DWR OSP Delta Modeling Section sponsored bathymetry data monitoring
- DWR ESO Suisun Marsh Branch sponsored bathymetry data monitoring

DWR North and South Delta Scour Monitoring Program

DWR Central District collects bathymetry data at a number of locations in the north and south delta for the North Delta Scour Monitoring Program [DWR 1998] and the South Delta Scour Monitoring Program [DWR 1998].

More information about these programs is available at the DWR Central District web site at http://wwwdpla.water.ca.gov/cd/delmon/

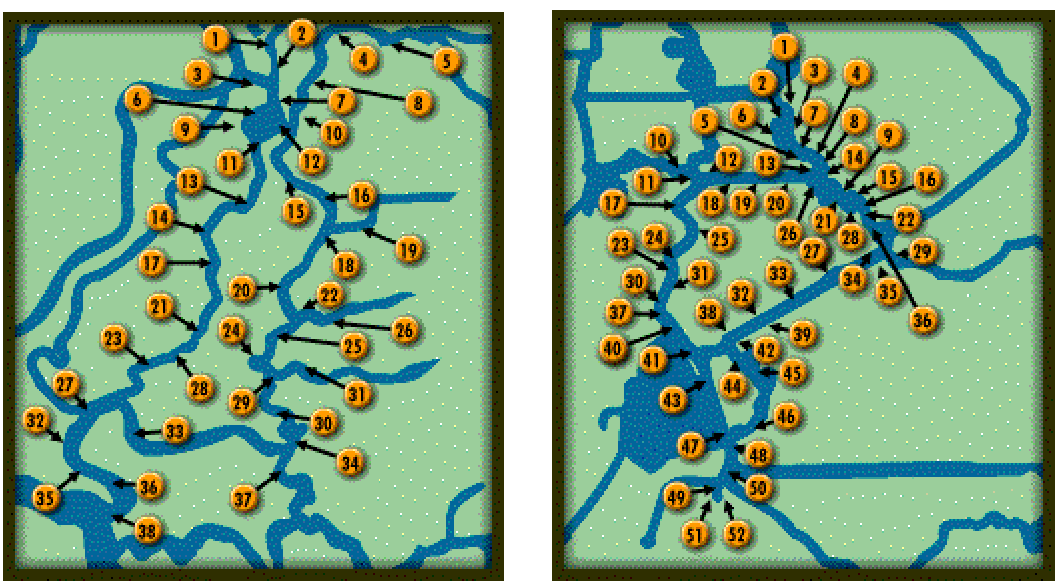

Figure VII.1.1. North and south Delta scour monitoring locations.

Since scour monitoring data is collected as channel cross-sections, model cross-sections were drawn at the same location scour monitoring data was collected. Most other data from previous surveys in these locations line up well with the scour monitoring data. The data that do not line up well were collected in 1934 and were disregarded.

DWR OSP Delta Modeling Section sponsored bathymetry data monitoring
The DWR OSP Delta Modeling Section sponsored bathymetry data collection in various parts of the Delta to meet model calibration needs. Areas surveyed were those that did not have adequate coverage. Coverage was deemed inadequate because the existing bathymetry data were considered unreliable due to age or insufficient to completely describe the channels. The data were collected using a moving boat mounted depth sounder synchronized with on-board GPS. A zig-zag boat course was adopted because the CSDP can readily display the data and boat coverage was relatively efficient. Figures VII.1.2 through VII.1.6 how the bathymetry data collection course for the Sacramento-San Joaquin River confluence (Figure VII.1.2), Barker Slough (Figure VII.1.3), north Delta (Figure VII.1.4), central Delta (Figure VII.1.5), and south Delta (Figure VII.1.6).

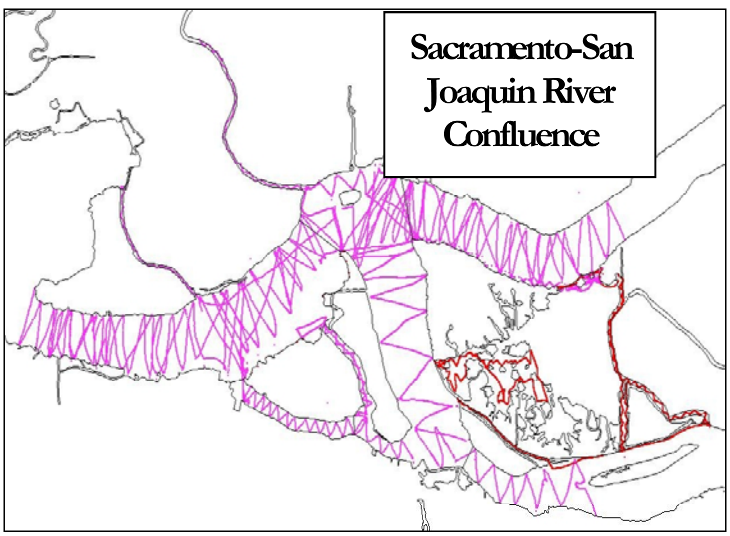

Figure VII.1.2: Bathymetry data collected by DWR Central district in 1998 and 1999 near the confluence using boat mounted depth sounder and GPS in a zig-zag pattern

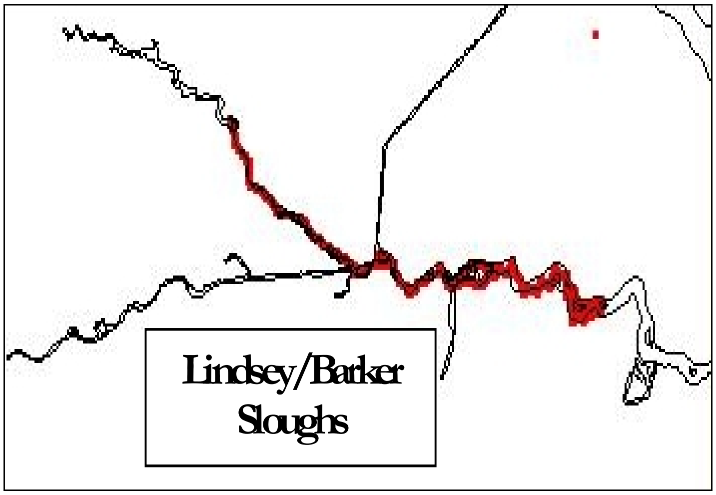

Figure VII.1.3: Bathymetry data collected by DWR Central district in 1999 in Barker Slough using boat mounted depth sounder and GPS in a zig-zag pattern.

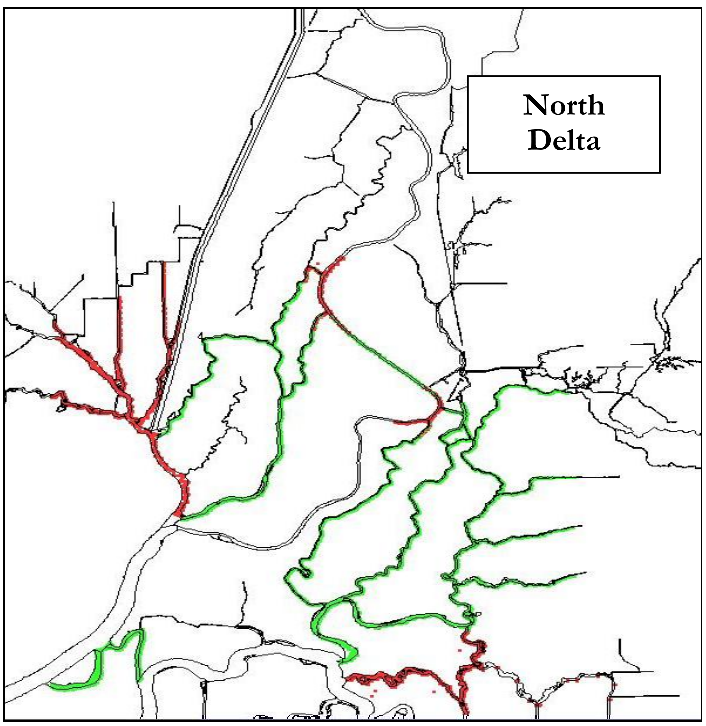

Figure VII.1.4: Bathymetry data collected by DWR Central district in 1999 and 2000 in the North Delta using boat mounted depth sounder and GPS in a zig-zag pattern.

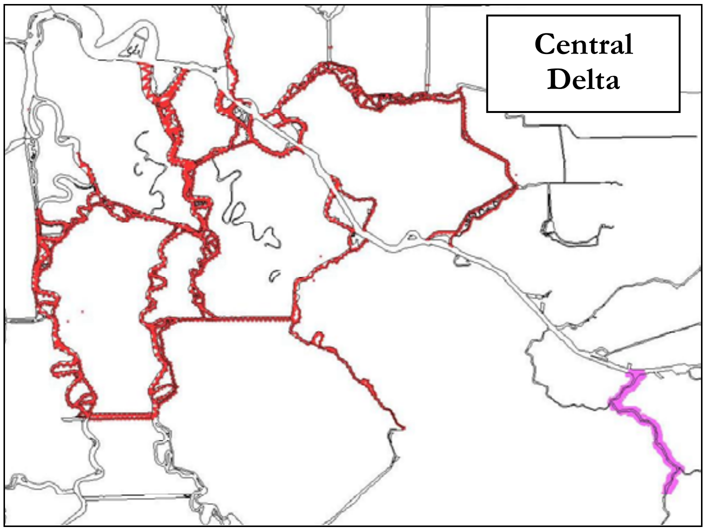

Figure VII.1.5: Bathymetry data collected by DWR Central district in 1998 and 1999 in the central Delta using boat mounted depth sounder and GPS in a zig-zag pattern.

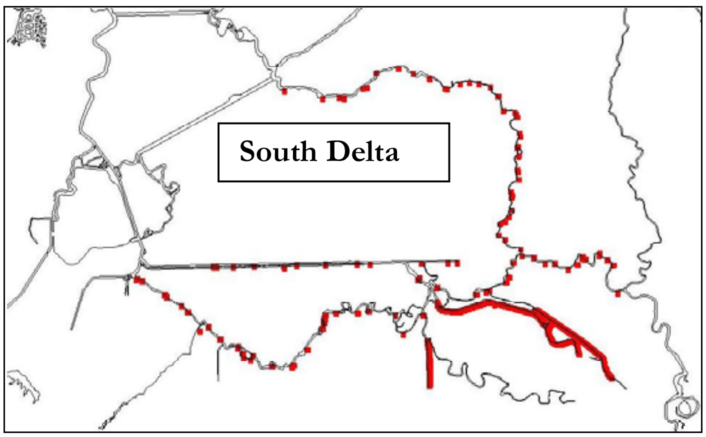

Figure VII.1.6: Bathymetry data collected by DWR Central district in 1999 using the zig-zag method in Paradise Cut and Tom Paine Slough. Data in Old River, Middle River, and Grant Line Canal were collected as discrete cross-sections.

DWR ESO Suisun Marsh Planning sponsored bathymetry data monitoring

The DWR ESO Suisun Marsh Branch sponsored bathymetry data collection in the Suisun Marsh to meet model calibration needs. The Marsh is known to have dynamic sediment transport characteristics leading to significant bathymetry changes over time. The data were collected using a moving boat mounted depth sounder synchronized with on-board GPS. Figure VII.1.7 shows the bathymetry data collection in Cordelia, Peytonia, Hill, Cutoff, Boynton, and Denverton Sloughs.

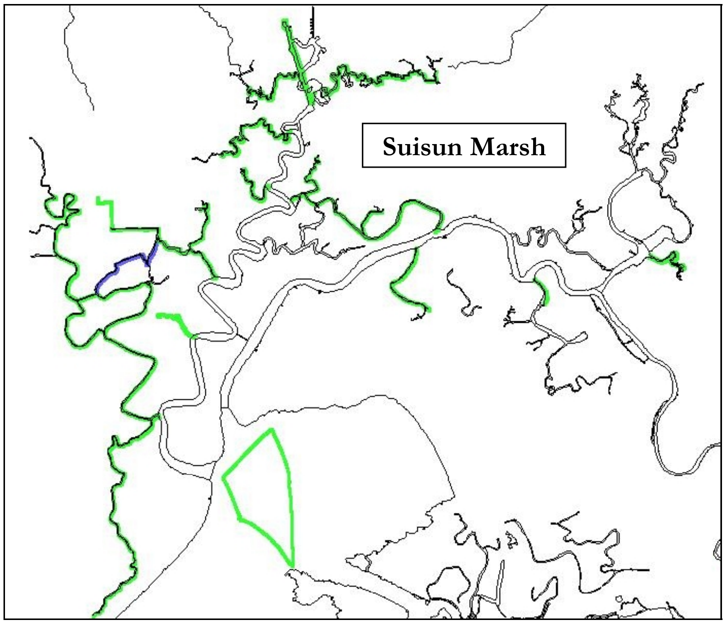

Figure VII.1.7: Bathymetry data collected by DWR Central district in 2000 and 2001 in Suisun Marsh boat mounted depth sounder and GPS in a zig-zag pattern.

VII.2 *Historical Bathymetry Data and Common Coordinate System*

Brad Tom

The CSDP uses bathymetry data collected by various Bay-Delta agencies including, NOAA, DWR, COE, and USGS. The data consists of individual points with two horizontal coordinates and one vertical coordinate. The datum for the horizontal coordinates is UTM zone 10 NAD 27. The vertical datum is feet with respect to NGVD 1929. Most bathymetry data are now collected using the UTM zone 10 NAD 83 datum, and must be converted to UTM zone 10 NAD 27 to be used with the CSDP data files. All horizontal coordinates will eventually be converted to UTM zone 10 NAD 83.

A number of methods have been used to convert bathymetry data coordinates from one datum to another. Some of the older bathymetry data from COE and NOAA were converted to the UTM zone 10 NAD 27 datum and to NGVD 1929 using Tralaine, a coordinate conversion program, and IDL, a programming language. Vertical coordinates were converted using triangulation with tidal benchmarks.

The data collected by NOAA in 1991 and 1992 were converted using Tralaine and IDL (see "Channel Geometry Project Summary Report" by Any Chu). Tralaine was used to convert the horizontal coordinates from lat/long NAD 83 to UTM zone 10 NAD 27. IDL (a programming language) was used to create a rectangular mesh of corrections to convert the vertical coordinates from MLLW to NGVD 1929. In October 1996, errors in the vertical coordinates were corrected (see "Explanation of Unit Conversion for the 1991/1992 NOAA Data in the DWR Database" by Nancy Winter). In July 2001, errors in the horizontal coordinate conversion for a portion of the data set were corrected.

Some of the older bathymetry data were not georeferenced; instead, horizontal coordinates were measured as distances along a line between two points. The exact locations of these points were unknown. For these data, it was necessary to estimate the locations of the two points and interpolate between them to estimate horizontal coordinates. The results were sometimes very inaccurate.

All recent bathymetry data have been measured with respect to the UTM zone 10 NAD 83 datum, and were converted to the UTM zone 10 NAD 27 datum using CORPSCON, a program developed by the National Geodetic Survey (NGS).

Significant differences are sometimes seen when comparing older data to newer data. Figure VII.2.2 is a cross-section in the Sacramento River just downstream of the confluence. The data indicate that the elevation of the channel bottom has decreased over time. This could be because the bottom is actually lower, the benchmarks used to convert vertical coordinates to elevations are sinking, and/or less accurate methods were used to collect and process data.

Figure VII.2.1 is a cross-section from Old River near Woodward Island. The older data in this cross-section do not define the shape of the cross-section as well as the newer data.

Newer data is considered to be more reliable than older data. The difference between newer and older data is usually small; when it is not, the older data has been discounted for the cross-section development process.

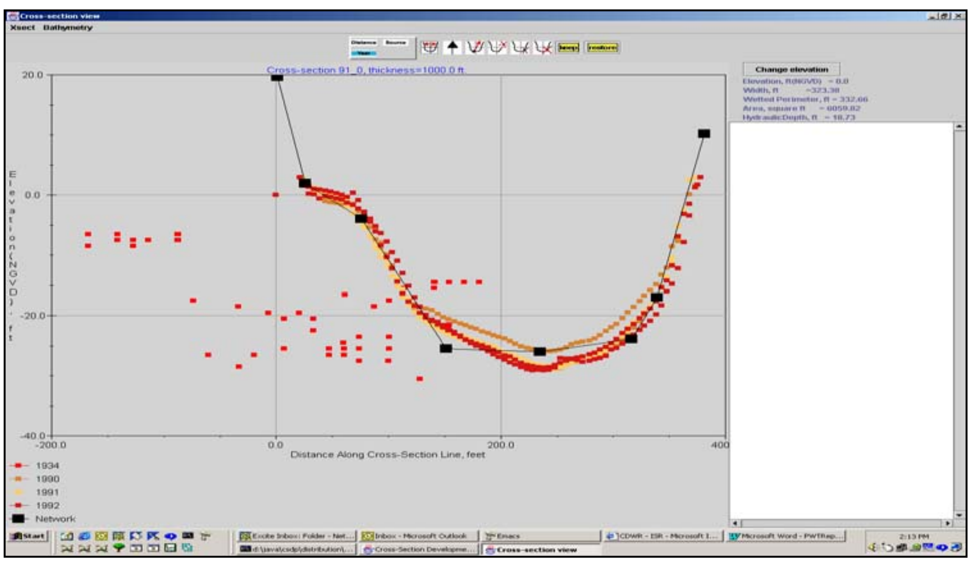

Figure VII.2.1: Cross-section in Old River

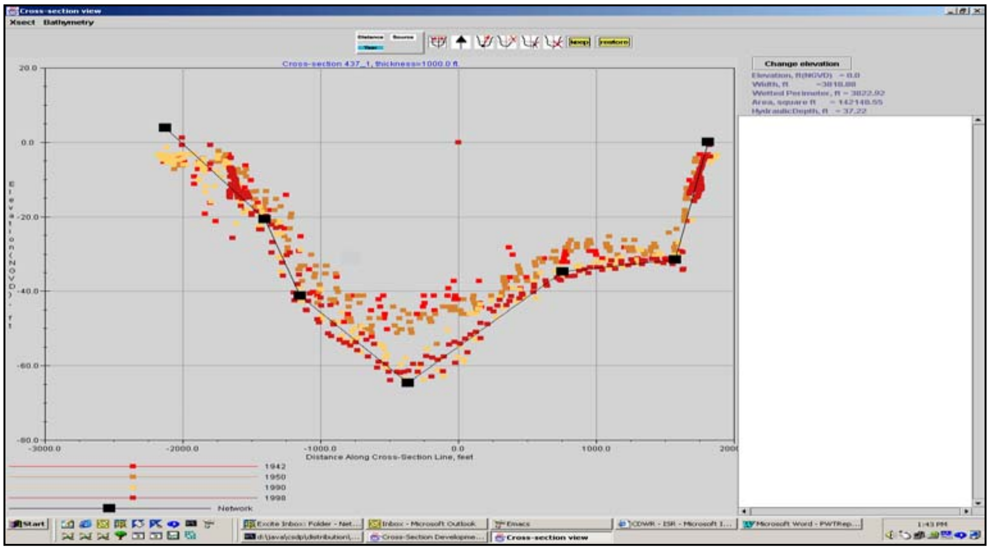

Figure VII.2.2: Cross-section at Sacramento San Joaquin River Confluence

VII.3 *Geometry Data Viewer and CSDP*

Brad Tom

The Bathymetry Data Display (BDD) program was written by John Crapuchettes in 1993. The BDD was written in C++, which is an object-oriented platform-dependent language. The BDD had the advantages of being very fast and easy to use. However, the BDD has a number of problems. The source code was not documented and was indecipherable to anyone other than the author. The use of the BDD to process data for DSM2 was very inefficient. The Cross-Section Development Program (CSDP) was developed to replace the BDD. The CSDP was written in Java, which is an object-oriented platform-independent language. The CSDP code is documented. The following features were added to the CSDP to improve the efficiency of processing data for DSM2.

- All input for DSM2 can be produced in a single step
- A cross-section metadata feature allows the user to describe why changes were made. This is especially important when the user-created cross-section does not line up with bathymetry data.
- Data can be colored by year, source, and distance, in plan view, and year and source, in cross-section window.
- In the plan view, data can be filtered by year, source, and distance.
- The cross-section window includes display of cross-section conveyance characteristics for a specified elevation, which is updated when cross-section is modified.
- A "Create DSM chan" feature allows user to draw a centerline with ends automatically placed at nodes

VII.4 *Historical Barrier Configurations*

Callie Harrison

Barrier configurations are documented and updated as changes occur. The compilation of all gate and barrier configurations from October 1986 to present is accessible via the DSM2PWT website "Barrier Geometry" link. Updates to the configurations file are made upon notification of a barrier change from the Office of State Water Project Planning, Temporary Barriers, or a SMSCG change from Suisun Marsh Planning.

Recent corrections were made to the barrier configuration file for all historical dates for the Morrow Island Distribution System (MIDS) and Seven-Mile Slough coefficients. The MIDS coefficients were changed to reflect west to east flow through the system. This correction was made for all dates in this file retroactively in August 2001 when the error was discovered. Subsequent review of the directionality of the rest of the barriers showed a similar problem for Seven-Mile Slough. Seven Mile Slough flow coefficients have also been changed for all historical dates based on field observations by Delta Modeling Section staff in late July 2001. The Seven-Mile Slough changes are temporary pending investigation into actual properties and operation of these gates.

When an updated file is posted on the website, email notification is made to the DSM2PWT. Delta Modeling Section is then responsible for processing the file to develop a current gates.dss file.

VII.5 *Approach to Development of the DSM2 Geometry*

Chris Enright

Experience has shown that accurate geometrical representation of the Bay-Delta system is one of the most important determinates of model accuracy. Model geometry development from bathymetry data requires knowledge of how the model uses cross-section data, and system knowledge to effectively translate spatial estimates of point channel elevation (bathymetry) to representative cross-sections. The goal is to develop cross-sections which, taken together, preserve conveyance characteristics of the prototype system and can be used efficiently by the model. This section covers:

- How DSM2 uses cross-section data
- Sources of bathymetry and geometry error
- Using the CSDP
- Preserving plan area in Suisun Bay
- Future needs.

How DSM2 Uses Cross-Section Data

Section V.2 described the mechanics of cross-section development in detail. The key points include:

- DSM2 HYDRO interpolates channel characteristics between a limited number of cross-sections depending on user chosen delta x.

- The cross-sections actually used by the model are interpolated from the locations where they are defined to computational locations on the model grid, one at each end of the channel, and others at regular computational intervals depending on the length of the channel and delta x.
- Cross-sections are read by the model as cross-section area and top-width as a function of water surface elevation relative to mean sea level (NGVD29). Computational efficiency is served by using the minimum number of cross-section points while ensuring accuracy within the limits of data reliability.

Sources of Bathymetry and Geometry Error

Several sources of bathymetry and geometry data errors should be considered as model geometry is constructed:

- The Bay-Delta bathymetry database contains approximately one million points collected between 1934 and 2001.
- Several state and federal agencies have collected bathymetry data using various methods, different approaches to horizontal and vertical control and standards of quality control.
- Much of the data is not documented.
- Much of the data was collected relative to local mean sea level for navigation purposes (NOAA). This data required conversion to a common (NGVD 1929) datum with some error.
- Bay-Delta channel bathymetry is dynamic. Cross-section area has changed plus or minus approximately ten-percent in many channel reaches over time.
- Vertical control of bathymetry data is obtained by tying in to the water elevation nearest stage monitoring station. The offset to the nearest station could be large, and the datum for the station could be incorrect an unknown amount.

Using the CSDP for Channel Cross Section Design

The CSDP (described in Section VII.3) is a tool for resolving three dimensional point bathymetry data into two dimensional (x-z) cross-sections. Cross-sections are defined orthogonal to a user drawn channel thalweg line. Cross-sections include all data in the region of the cross-section upstream and downstream a user chosen distance.

When designing channel cross-sections, the object is to capture volume and conveyance characteristics with a few cross-sections. In practice, this entails significant trial and exploration of the channel reach buy generating several trial cross-sections. Channel end cross-sections control conveyance, center channel cross-sections control continuity.

The rules for copying and interpolating cross-sections (Section V.2) must be kept in mind as representative cross-sections are defined. Cross-sections defined near the upstream and downstream end of channels should, if integrated over the channel length, equal the channel volume. Cross-sections most likely to be copied or interpolated to interior channel computation locations should capture hydraulic control (like geometric convergences).

Example: Preserving Plan Area in Suisun Bay

Representing open water areas with one-dimensional channels presents special challenges. Off-channel areas of Suisun Bay have historically been treated using zero-dimensional "reservoirs" which account for volume but not routing (e.g. DWRDSM1). With irregular channel geometry, DSM2 affords the opportunity to orient one-dimensional channels along principal flow axes in Grizzly Bay, Honker Bay, and Sherman Lake. Care must be taken to assure that one-dimensional channels account for the proper plan area of the Bay.

Figure VII.5.1 shows the approach taken for establishing a network of one-dimensional channel in Suisun Bay. The nodes and channels of the DSM2 model are shown as black circles and segments.

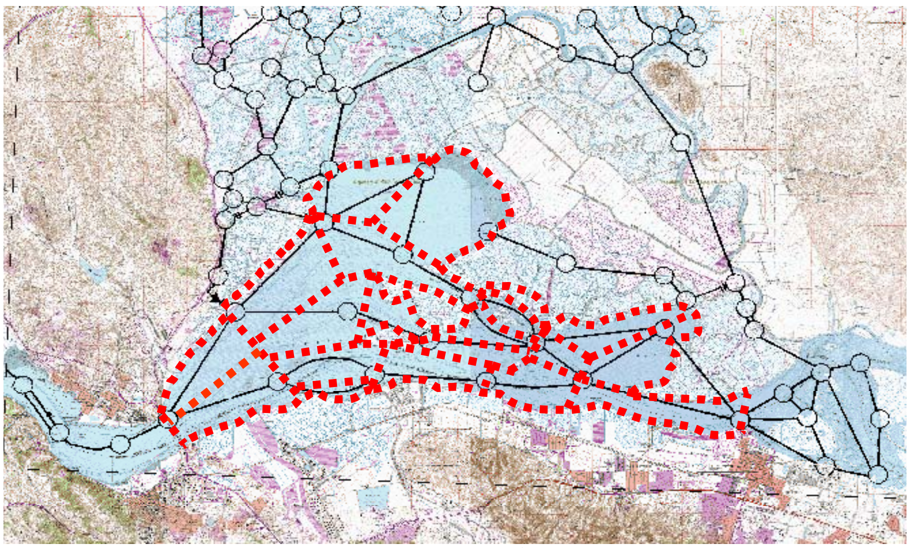

Figure VII.5.1. Network paths of a one-dimensional channel in Suisun Bay

First, the plan area of Suisun Bay was measured with a planimeter. The geographic area of each channel was laid out based on NOAA navigation charts with attention to the location of channels and shoals. The plan area of each channel area was measured and summed together as a check against the whole-bay measurement. The CSDP was used to lay out representative cross-sections along each channel, at least one per four to five thousand feet. Once satisfied with several cross-sections, associated top widths were integrated over the length of the channel and the resulting area compared to the measured area. Adjustments were made as needed to achieve agreement within a few percent.

A special concern in applying the CSDP to complex open water areas with parallel one-dimensional channels is that the geometry information is not double counted or missed entirely. Figure VII.5.2 shows three cross-sections that together span Suisun Bay from Wheeler Island (north) to the Contra Costa shoreline (south). An idiosyncrasy of the CSDP is that cross-sections span centerline thalwegs equally on each side. As a result, there is often cross-section overlap as shown in the figure.

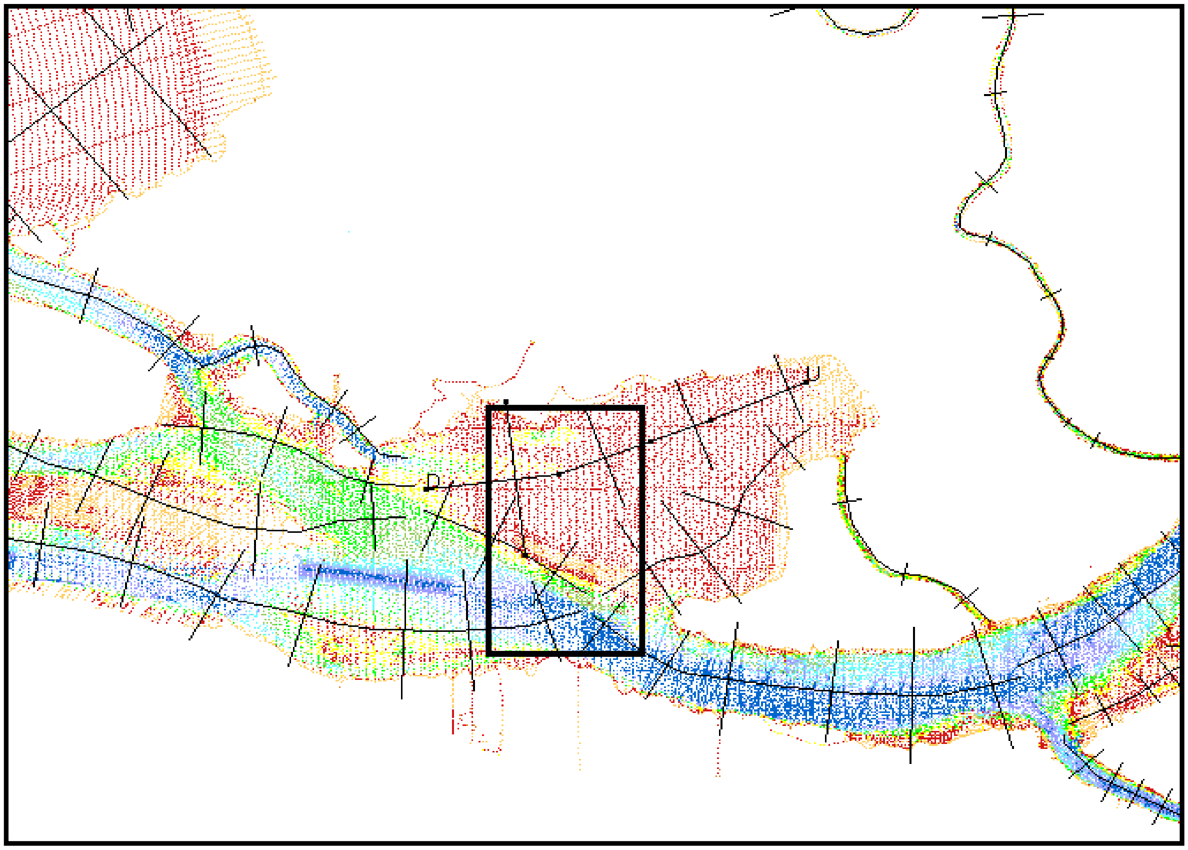

Figure VII.5.2 Example of Overlapping Cross Sections: Contra Costa Shoreline (south) to Wheeler Island (north)

To avoid overlap and double counting, cross-sections can be laid out side-by-side (Figure VII.5.3). At point of contact, or near contact at channel area boundaries, user drawn cross-sections are abruptly ended.

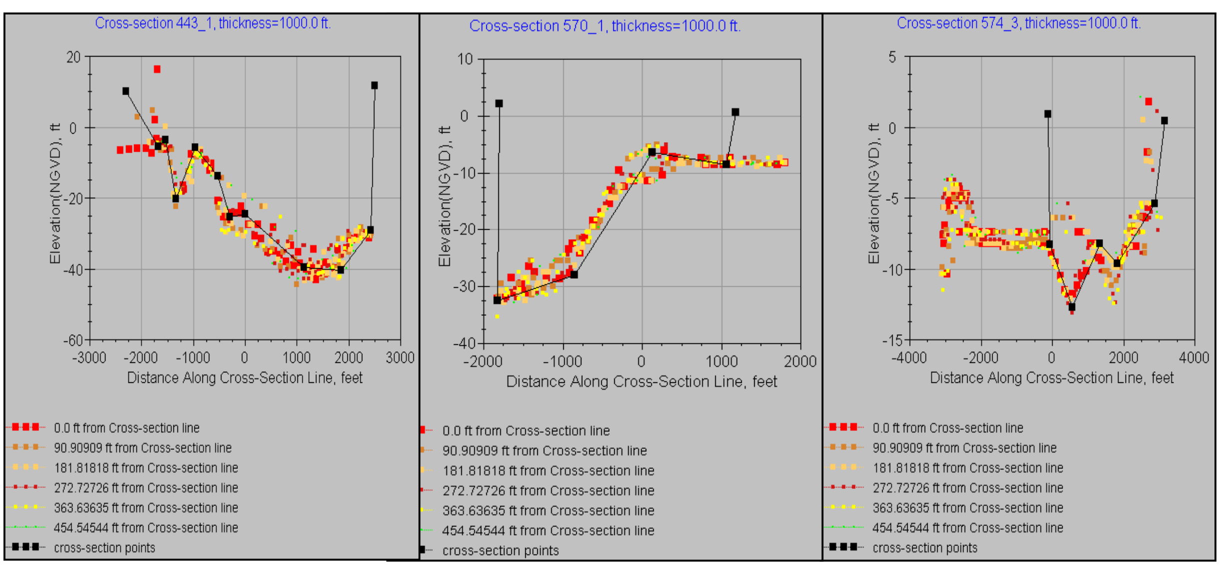

Figure VII.5.3 Overlapping Cross-sections: Contra Costa Shoreline(left) to Wheeler Island (right).

VIII. DSM2 PWT CALIBRATION PROCESS

Chris Enright, Parviz Nader

With the availability of new flow and bathymetry data, DWR, USBR, CCWD, MWD and USGS modelers agreed to collaborate on an enhanced calibration of DWR's new DSM2 model. The participants agreed that a cooperative effort would leverage the groups' considerable modeling development, calibration, and application experience to create a product of enhanced technical value.

The participants also agreed that a transparent, inclusive process would generate understanding of the model's numerical characteristics and capabilities, and generate advance consensus on the effectiveness of the model for planning and decision support application.

This chapter covers facilitation and logistics of calibrating DSM2 among several diverse and dispersed participants.

VIII.1 *Web-Site Features*

Chris Enright

The goal of the DSM2 PWT calibration web site was to facilitate calibration decisions by the core calibration team, and to present a complete documentation of the process to the public.

Model calibration requires comparison of model and field data over the domain of the system. Over forty continuous water level and electrical conductivity monitoring stations and twenty-five continuous and temporary flow measurement stations distributed around the Bay-Delta were used for the calibration of DSM2. The DSM2 PWT expended significant effort organizing calibration output information in a clear and concise way to facilitate both informed group decision making and transparent documentation of the calibration process.

A web-site was used as the principle calibration output tool. The main web site page is located at http://www.iep.ca.gov/dsm2pwt/dsm2pwt.html. The page is shown in Figure VIII.1.1.

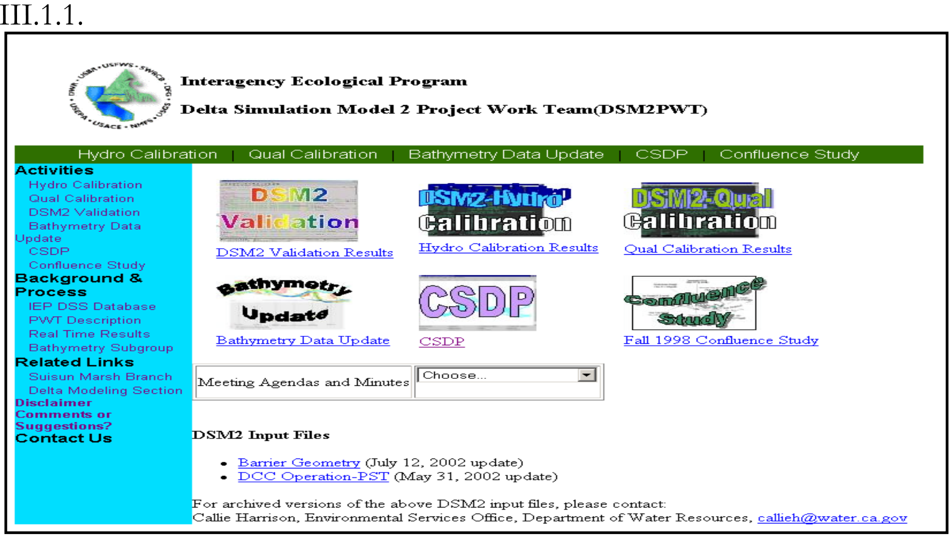

Figure VIII.1.1 DSM2 Calibration Web-Site

From this page, interested people can link to

- HYDRO calibration
- QUAL calibration
- Bathymetry data
- Cross-Section Development Program
- Confluence Study (special current measurement study by USGS)

The page also provides links to the IEP DSS database, the Real-Time modeling web-site, meeting notes and other related links.

VIII.2 *HYDRO Calibration Web Site Features*

The HYDRO Calibration web page provides a complete documentation of the 4-point model calibration. The main HYDRO calibration page is located at http://www.iep.ca.gov/dsm2pwt/calibrate. Results for each of the fifty-six separate calibration runs is available. Individual run pages contain a "Run Description" link that shows the suite of Manning's n's used for that run.

The calibration began by designating eighteen regions of constant channel roughness (Manning's n), and ended (run 56) with over fifty-five designated regions of constant Manning's n. The run description also describes the changes made for that run, and all runs that came before it. Figure VIII.2.1 shows an example run description page that documents changes made for HYDRO run 56.

```
Run:                        56
Channel Group filename: channel_groupsQ.txt

------ Manning's n Groups ------------------------------------------------------------------------
  1     2     3     4     5     6     7     8     9    10    11    12    13    14    15    16    17    18    19    20
.022  .022  .018  .018  .022  .022  .033  .019  .022  .022  .024  .028  .033  .032   .022  .028  .027  .022   .033  .030

 21    22    23    24    25    26    27    28    29    30    31    32    33    34    35    36    37    38    39    40
 .030  .035  .028  .022  .022  .022  .022  .022  .019  .019  .028  .019  .025  .020  .019  .020  .020  .022  .019  .024

 41    42    43    44    45    46    47    48    49    50    51    52    53    54    55    56    57    58    59    60
 .024  .037  .022  .024  .024  .026  .030  .027  .022  .045  .045  .033  .030  .038  .034  .019  .040   N/A   N/A   N/A
------- Dispersion Coefficient Groups ------------------------------------------------------------
  1     2     3     4     5     6     7     8     9    10    11    12    13    14    15    16    17    18    19    20
N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A

 21    22    23    24    25    26    27    28    29    30    31    32    33    34    35    36    37    38    39    40
N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A

 41    42    43    44    45    46    47    48    49    50    51    52    53    54    55    56    57    58    59    60
N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A

--------------------------------------------------------------------------------------------------
Run Descriptions

Run Number Description
-------------------------------------------------------------------------------------------------
56          Started with Run55, compare to Run55.  Made the following
                 manning's n changes:

                 group        description    old  - new
                 ----------------------------------------------------
                 7            7 mi & 3 mi Sl .038 - .033
                 31           New York Sl.   .031 - .028

55          Started with Run53, compare to Run53.  Made the following
                 geometry changes in Three Mile Slough, using
                 25jul2000.cdn:

                 1. 3 mile slough at Sac end (309 d/s xsection) is
                    reduced by 20% flow area and at SJR end (310 u/s)
                    is increased by 20% flow area.
```

Figure VIII.2.1 Run Description Page for Run 56

Individual run pages also provide a clickable Delta map where results for field and model data comparisons can be viewed. Clicking on a location brings up a page containing stage and flow plots for the four calibration periods. Each plot can contain up to three traces: 1) field data in red (if available), the current calibration run result in black, and the Team chosen best run so far for comparison. For example, Figure VIII.2.2 shows the results for Run 56 (Three-Mile Slough) where the current best run is represented in blue by Run 55.

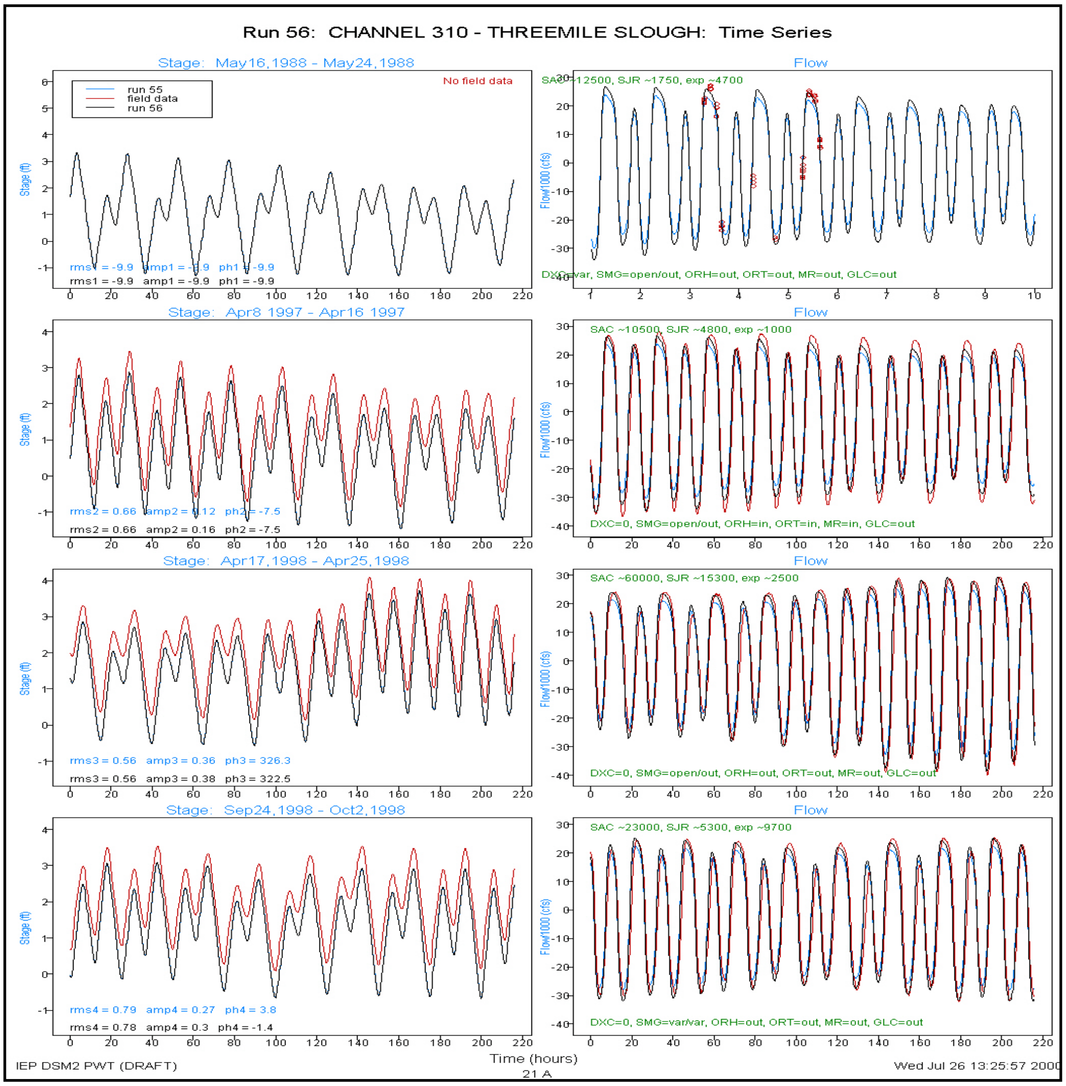

Figure VIII.2.2 Three-Mile Slough Run 56 Results

The output result plots were designed to help the viewer by supplying as much information as possible about the run along with the results. In addition to flow and stage output, a summary of the average hydrology, Delta Cross-Channel status, Suisun Marsh Salinity Control Gate status, and south Delta barrier status for each period is also shown .

VIII.3 *QUAL Calibration Web Site Features*

The QUAL calibration page is organized similarly with the HYDRO calibration page (http://www.iep.ca.gov/dsm2pwt/dsm2pwt.html). QUAL calibration runs were made based on interim HYDRO calibration runs 31 and 49. The Team took advantage of the information feedback between current velocity and water level simulation and transport of salt. Final QUAL calibration runs were based on the final HYDRO calibration run (56). The final calibration run considered twenty-two regions of constant dispersion coefficients (Figure VIII.3.1).

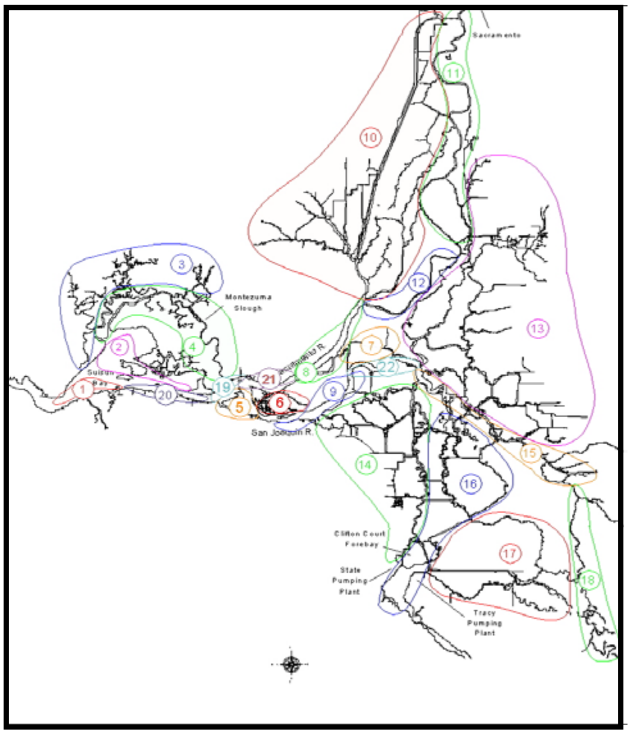

Figure VIII.3.1 Final Qual Dispersion Regions

VIII.4 *HYDRO, QUAL Calibration Periods*

VIII.5 *Calibration Outputs*

VIII.6 *PWT Calibration Logistics*

HYDRO calibration run preparation, execution, and post-processing was conducted by the Suisun Marsh Branch of DWR. The Suisun Marsh Branch also scheduled and led periodic DSM2 PWT meetings.

Conference calls were the primary mode of communication during the calibration. Conference calls were held approximately once per week over the year the HYDRO calibration was in progress. Access to the calibration web site by all participants facilitated the discussion of results.

The Delta Modeling Section of DWR conducted QUAL model preparation, execution, and post-processing. The Delta Modeling Section also scheduled and led conference calls as QUAL calibration milestones were reached.

Two email reflectors were used often during the calibration to discuss technical problems and schedule meetings and conference calls. The dsm2working@osp.water.ca.gov reflector was established for core calibration team discussion of details. The dsm2@osp.water.ca.gov reflector–including over fifty participants--was used to announce meetings and calibration milestones.

IX. CALIBRATION APPROACH

Parviz Nader, Chris Enright

DSM2-HYDRO (HYDRO) and DSM2-QUAL (QUAL) were originally calibrated and validated in 1997 (see DWR Delta Modeling Section's Eighteenth Annual Progress Report, June 1997). In 1999 IEP-PWT initiated efforts to recalibrate and validate DSM2. The Team agreed that the calibration/validation of DSM2 should be an open process. All results should be posted on a public web-site at each stage of the calibration. Conference calls would be used to facilitate frequent PWT discussions of the results and agree upon what changes to make for the next iteration of the calibration.

Comparison of model-predicted values and field data was done both in an instantaneous and tidally averaged sense. The comparison of instantaneous data shows the model's capability to predict the tidal amplitude and phase. The comparison of the tidally averaged data demonstrates the long-term effects. It is also useful for evaluating sub-tidal time scale flow splits and tidal pumping at key locations in the Delta. All the activities with regards to the calibration can be found at the IEP web-site at:

http://www.iep.ca.gov/dsm2pwt/dsm2pwt.html

The balance of this chapter details several dimensions of the calibration approach taken by the PWT including discussions of

- Automatic or manual calibration (Section IX.1)
- Regions of Constant Manning's n (Section IX.2)
- Geometry Modification for Calibration (Section IX.3)
- Historical Calibration Periods (Section IX.4)
- Goodness-of Fit Measures (Section IX.5)
- Choice of Model Grid (Section IX.6)

IX.1 *Automatic or Manual Calibration?*

The DSM2 PWT engaged in extensive debate on the approach to take for calibrating DSM2 HYDRO. The two basic options were to 1) apply operations research methods toward a nominally automatic calibration or, 2) calibrate the model "by hand." Some members of the Team have extensive experience developing and applying optimization techniques for optimal resource allocation or management decisions in conjunction with physical models. One Team member developed an approach to minimizing the high computational burden this class of problem tends to create. The approach uses the method of Rosenbrock that requires no gradient evaluations. The optimization approach has several advantages including,

- The solution process is systematic and self-consistent.
- Assumptions about the relative importance of decision variables (water level and flow) are rendered explicitly.
- Within the context of the explicit assumptions, there is an opportunity for superior goodness-of-fit compared to hand calibration.

Despite the promise of the optimization approach, several disadvantages were not overcome including,

- The final solution is sensitive to the initial estimation of the solution. The solution space for this class of problem tends to be "flat," and there are many local optimum solutions.
- There is considerable uncertainty in the field data, especially water level datum.
- Characterization of the decision variables as absolute or percentage differences between field and model data has a significant affect on the solution.
- The approach to characterizing tidal phase and tidal amplitude error was not resolved.
- Weighting the relative importance of flow versus water level data was not resolved.
- Weighting the relative importance of different monitoring locations was not resolved.
- Despite advanced mathematical programming techniques, the computational burden remains extremely high for this class of problem.

The Team determined that hand calibration of DSM2 HYDRO was preferable because of the unresolved issues. Moreover, hand calibration provided the opportunity for the Team to observe the sensitivity of model (and presumably the prototype) response directly. Team decisions on incremental changes to calibration coefficients and subsequent discussion of the result enhanced everyone's intuition of hydrodynamical tendencies in the Bay and Delta.

Ultimately the Team agreed that a combination of hand and automatic calibration approached would be desirable. A careful hand calibration would provide a good "initial guess" for the optimization solution. Applying the optimization approach to the last hand calibration would thereby "polish" the result. However, at the end of the hand calibration process, some the technical optimization issues had not yet been solved. The Team looks forward to using the optimization approach in the near future.

IX.2 *Manning's n Calibration Regions*

The chief calibration parameter is the roughness coefficient, commonly referred to as Manning's n. Manning's n represents channel friction under steady state, uniform flow conditions. Used in the one-dimensional version of the shallow-water equations represented in the Four-Point model, Manning's n becomes a catch-all for certain shallow water equation assumptions and physical processes not represented by the one-dimensional approximation. Physical processes not directly modeled include velocity shear, angular momentum, density gradients, and non-hydrostatic pressure distributions. Given a "perfect" representation for the system geometry, calibration decisions that deviate Manning's n from theoretical steady-state/uniform flow values represent the missing treatment of higher order processes. Geometry errors are inherent despite vast improvements in the geometrical representation of the system. Manning's n is adjusted in response to geometry errors as well. Manning's n can be modified in each of the over 500 computational channels in the DSM2 grid. However, this poses an overwhelming dimensionality problem. The Team chose to limit the degrees of freedom by initiating the calibration with eighteen Bay-Delta regions of common roughness/approximation error characteristics (Figure IX.2.1). As the calibration progressed, additional sub-regions of constant Manning's n were defined as needed to improve overall goodness-of fit. Figure IX.2.2 shows the final map for HYDRO RUN 56 with over 50 regions of constant Manning's n. The region numbers refer to the Manning's n assignment contained in each "Run Description" (discussed in Section VIII.1)

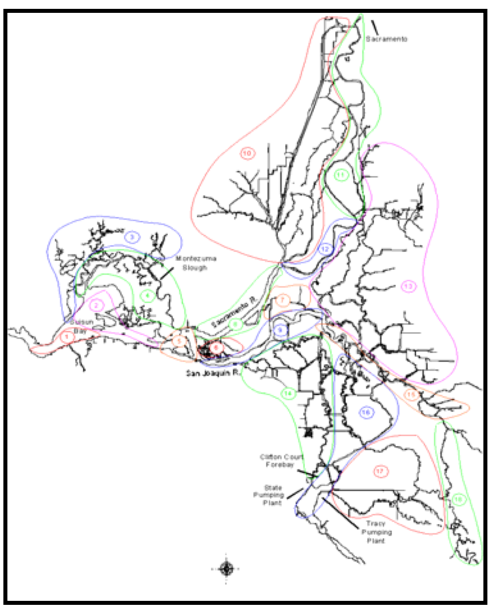

Figure IX.2.1 Initial Manning's regions

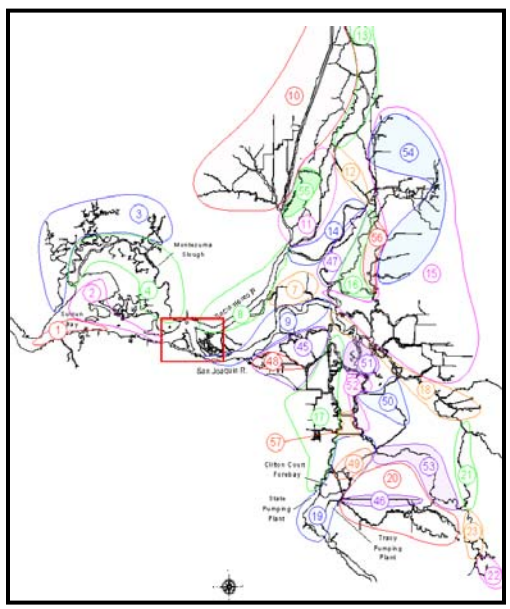

Figure IX.2.2 Final Manning's regions

IX.3 *Geometry Modification for Calibration*

Bathymetry data collection programs in the Bay-Delta system have documented the dynamic nature of system bathymetry over time. DWR has documented the annual natural variation in bathymetry caused by scour and sedimentation in the north and south delta since 1993. The data for over eighty surveyed cross-sections shows that significant change in cross-section area and shape can occur on an annual basis (DWR 1998).

Dramatic changes in western Delta cross-sections can be seen using the CSDP (Chapter VII). For example, Figure VII.2.1 and Figure VII.2.2 shows a greater than 10% change in cross-section area between 1950 and 1998 surveys.

In addition to natural sediment dynamics, bathymetry data for generating DSM2 cross-sections using the CSDP is subject to significant engineering interpretation. From one analyst to the next, cross-section area differences of up to several percent may be generated. Systematic procedures that use GIS tools are expected in the future.

Despite vast improvements in bathymetry data collection and application to model geometry, there is uncertainty related to system sedimentation dynamics, data collection and interpretation error. Consequently, the Team agreed that the model geometry is not untouchable when model/data fit diverges within the reasonable range of Manning's n values. Indeed, the Team agreed that the model is capable of alerting us to geometry errors when lack of fit cannot otherwise be explained.

The Team experimented with incremental geometry changes throughout the HYDRO calibration to gain a better sense of the system response. Ultimately, most of the changes were reverted to the best engineering interpretation fit of the latest bathymetry data. A notable exception is the Sacramento River entrance to Three-Mile Slough where the cross-section area was increased about 10% from the nominal best fit. The entrance to Three-Mile Slough on the Sacramento River side is significantly wider than the location of the first DSM2 cross-section. Higher dimensional hydrodynamics effects are also likely affecting the prototype response. The Team agreed that geometry changes of plus or minus 10% are within the uncertainty bounds of the data.

IX.4 *Historical Calibration Periods*

The Team designated four, approximately ten-day, time windows for the HYDRO calibration. The goal of the simulation period designations was to exercise the model under a variety of conditions including

- Wide hydrologic variability
- High and low project pumping
- Variable Delta Cross-Channel operation
- Variable south Delta temporary barrier operation

Additional criteria for calibration period choices include the need to keep simulation period short enough to facilitate Team understanding of the results, yet long enough to capture the lunar time-scale. Table IX.4.1 exhibits a summary of the four HYDRO calibration periods, the average rim-flows, and the nominal operation of Suisun Marsh and Delta gate facilities.

Rim Flows and Facilities Operation	Calibration Periods May 16 - May 24 1988	April 8 - April 16 1997	April 17 - April 25 1998	Sept 24 - October 2 1998
Sacramento River	12,500	10,500	60,000	23,000
San Joaquin River	1,750	4,800	15,300	5,300
Total Export	4,700	1,000	2,500	9,700
Delta Cross Channel Position	variable	closed	closed	closed
Suisun Marsh Salinity Control Gate	gates open-logs out	gates open, logs out	gates open, logs out	variable
Old River Head Barrier	out	in	out	out
Old River Tracy Barrier	out	in	out	out
Middle River Barrier	out	in	out	out
Grantline Canal Barrier	out	out	out	out

Table IX.4.1 HYDRO Calibration Periods and Period Average Rimflows and Facilities Operations

HYDRO was calibrated using data from four different time-periods:

1- May 1988
2- April 1997
3- April 1998
4- Sept.-Oct. 1998

IX.5 *Goodness-of-Fit Measures*

The Team chose to calibrate the HYDRO and QUAL models "by hand" as discussed in Section IX.1. Determining the success of a particular calibration run was done using a combination of objective measures and the qualitative judgement of the Team.

Objective Measures

All stage output was analyzed for three goodness-of-fit measures: 1) Root-mean square (RMS) error, 2)-phase error, and 3) amplitude error. Figures IX.5.1 and IX.5.2 provides a graphical summary of the procedure. RMS error provides an overall index of the error variance, phase error indicates the amount of lag or lead in the model tide versus the field data, and amplitude error measures the difference in tidal range in the model tide versus the field data. Field stage data often exhibits erroneous datum shifts due to subsidence of the monitoring site. As a consequence, the Team decided to discount datum measures completely. RMS error contains datum difference information. Therefore, the Team considered the RMS error statistic only as an objective index of calibration performance.

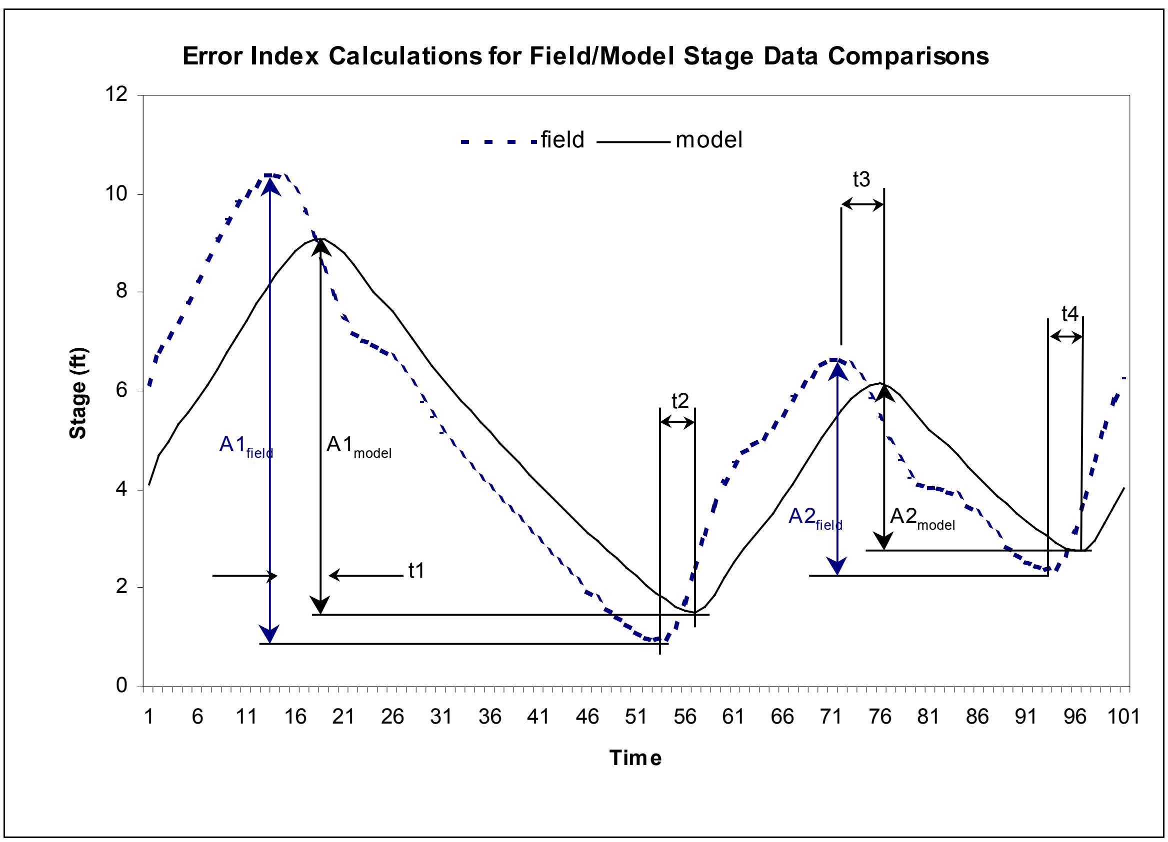

Figure IX.5.1: Error Index Calculations for Field / Model Stage Data Comparisons.

RMS, phase, and amplitude error indexes were posted on each stage plot if continuous field data was available.

Error Index Equations:

$$\text{rms error} = \frac{[\text{sum(model-field)**2}]\text{**.5}}{\text{n**.5}}$$

$$\text{amp error (feet)} = \frac{\text{dif1+dif2}}{2}$$

where: dif1 = A1model - A1field
dif2 = A2model - A2field

$$\text{ph error (minutes)} = \frac{(\text{t1+t2+t3+t4})}{4}$$

where: t1 = time of model peak1 - time of field peak2
t2 = time of model peak2 - time of field peak2
t3 = time of model peak3 - time of field peak3
t4 = time of model peak4 - time of field peak4

Figure IX.5.2: Error Index Equations for Field / Model Stage Data Comparisons.

Qualitative Measures

The calibration output plots show stage and flow response for the latest run and Team's choice for the best fit run so far. The choice of best so far was qualitative, based on several qualitative criteria including

- Performance of key monitoring sites
- Relative effect of Manning's n
- Level of uncertainty about bathymetry data

Team generally quickly agree on the best-run-so-far choice, especially as group experience with model response improved.

IX.6 *Choice of Model Grid*

Staff from DWR ESO (Environmental Services Office) had made several changes to the DSM1 grid. Most of the changes were in the Suisun Marsh area. IEP-PWT decided to adapt ESO's version of its grid map for the DSM2 calibration/validation effort. For a more in-depth explanation of the differences between the two grids, refer to the DWR Delta Modeling Section's Twenty-First Annual Progress Report (pg. 10-2).

For HYDRO, the Manning's n parameter was chosen as the calibration parameter. The Manning's n set corresponding to the 1997 calibrated version was used as the initial set. With each subsequent run, these values were modified with the hope of achieving a better match. Phase and tidal amplitude error indexes were introduced to quantify the goodness of fit for stage. The magnitude of the error indexes was calculated for each period separately, and values were written directly on the figures. The presence of these indexes directly on the plot made it a lot easier to improve the fit. See Figures IX.5.1 and IX.5.2 for an explanation of these error indexes.

A total of 56 iterations were completed. In the final version, the Delta was divided into 59 regions, each containing one or more channels. Each group was assigned a single Manning's n value. Overall, model predictions for the final iteration of the calibration are noticeably closer to the field data than the 1997 version. This is especially true for the flow data. This is clearly important, since one expects that an improvement in flow predictions would naturally follow with improvements in water quality predictions. For a direct comparison of the results corresponding to the final iteration of the calibration with the 1997 version, the reader is referred to:

http://www.iep.ca.gov/dsm2pwt/calibrate/Run56vsRun1/index.html

X. CALIBRATION RESULTS

Chris Enright, Parviz Nader

A key goal of the DSM2 PWT was to provide continuous documentation of calibration results to all interested parties. The web-site at http://www.iep.ca.gov/dsm2pwt/ is a complete accounting of the calibration process. It is possible for an interested person to use the "Run Description" and the clickable map to follow the Team's decision making process through each step of the calibration. This level of documentation was valuable to the Team as various calibration approaches were pursued. The Team also believes that progressive documentation enhanced the credibility of the process among interested parties not directly involved in the calibration effort.

This section presents the highlights of HYDRO and QUAL calibration results. The web-site provides a more complete presentation for the interested reader.

X.1 *HYDRO Calibration Results*

The Team executed a total of fifty-six HYDRO calibration runs. After run 56, the Team was satisfied that significant improvement had been made in the HYDRO models' ability to match the phasing and magnitude of tidal stage and flow over the domain. The website contains a link to calibration results reflecting the final calibration run (Run 56), the first calibration run (Run 1) and the data. This set of plots was made to show the improvement in model fit compared to the original DSM2 calibration.

- Tidal stage amplitude underestimated
- Tidal stage

X.2 *QUAL Calibration Results*

Unlike HYDRO, QUAL was calibrated in one continuous interval. In general, QUAL needs about two to six months to 'warm-up'. In other words, the model results are affected by the initial conditions (initial water quality in all the channels) during that time span. HYDRO's predictions, on the other hand, are only affected by the initial conditions for about two days. This renders QUAL calibration for short periods impractical.

QUAL was calibrated using electric conductivity (EC) data. This was primarily due to the fact that EC data is in plentiful supply. The assumption was that EC behaves like a conservative substance. Ideally, one would prefer to calibrate using chloride data, which is believed to be truly conservative. However, chloride data are only available on a limited basis. Regression equations have been developed to convert EC to chloride, but these equations have their own errors. A recent investigation (literature search and data analysis) conducted by the DWR Delta Modeling Section concluded that EC values of up to about 3,000 umhos/cm can be considered as conservative. EC values of 15,000 umhos/cm or higher are clearly in the non-conservative range. IEP-PWT will study this issue in more detail in the next phase of calibration.

Meanwhile, the Team feels that the recent calibrated model is suitable for use with EC, but may not be for predicting other minerals, simply because the calibrated parameters were selected based on EC predictions. Use of the model for predicting organic constituents is also appropriate, since the ocean is not a major source of organics. See DWR Delta Modeling Section's Twenty-Second Annual Progress Report (Chapter 3) for information about the validation of DSM2-Qual for DOC and UVA.

The choice of time period for QUAL calibration is also an important one. Periods with high flows with little salinity intrusion are not really suitable. Most suitable periods are dry periods, during which highly saline water from the ocean enters the Delta and blends in with the water that is from 100 to 300 times less saline. During dry periods, a small change in flow regime can potentially lead to noticeable changes in water quality. If the model predictions are close to field data for various dry periods, that would increase the level of confidence in the model. The Team selected the 3-year period from October 1991 to September 1994. This period contains four sub-periods when high-salinity intrusions were recorded.

With DSM2-Qual, dispersion factors were considered to be the calibration parameter. The Delta was divided into 22 regions, each containing many channels. Adjustments of the dispersion factors started from Martinez (the downstream boundary). The dispersion factors for regions further upstream were modified with each iteration. After 16 iterations, the Team decided that the objective was met and calibration considered complete. The reader is referred to:

http://wwwdelmod.water.ca.gov/studies/calibration/base-hydro-56/run16cv15a/index.html

for a clickable map showing a comparison of the model results versus the field data. Overall, there is a good agreement. Salt intrusion into the Delta is captured fairly well. However, in the San Joaquin River between Antioch and Jersey Point and continuing up the Old River to Bacon Island, the model seems to over-predict the high peak of salt intrusion. This is especially evident in the summer of 1992. For an example, see Figure X.2.1. For additional comments on the QUAL calibration, please refer to Sec. 2.6.

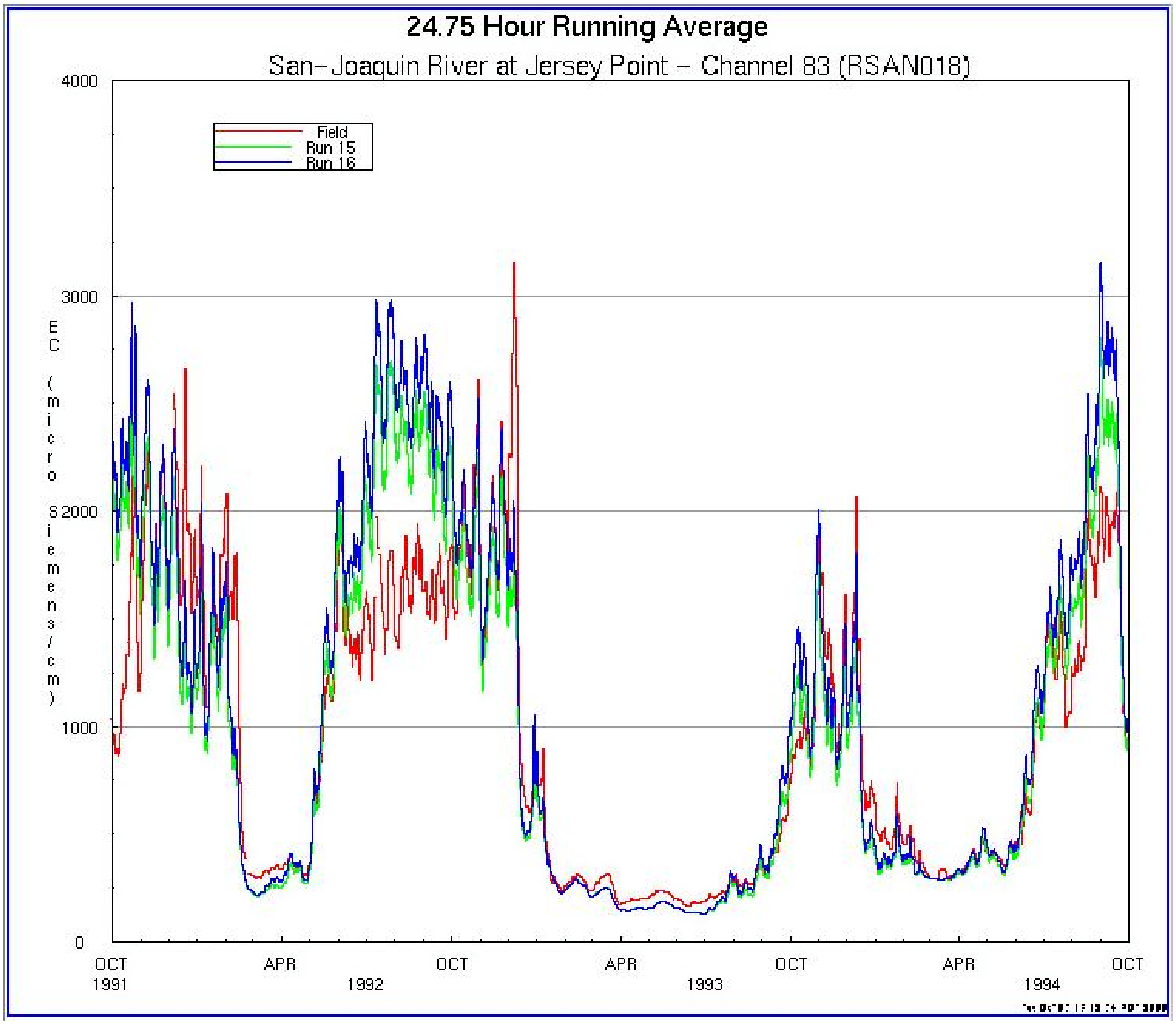

Figure X.2.1: San Joaquin River EC at Jersey Point.

X.3 *Discussion: Sources of Uncertainty*

XI. DSM2 VALIDATION

Parviz Nader, Henry Wong

Once the calibration parameters were selected, these parameters were kept constant. The validation period selected was from early 1990 to September 1999. The reader is referred to:

http://wwwdelmod.water.ca.gov/studies/validation/

for a clickable map pointing to all validation plots. There, the reader will find a three-way comparison of model predictions (flow, stage, and EC) for the new calibrated version (referred to as the new grid), the 1997 calibrated version (referred to as the old grid), and the observed data. These comparisons are available as 14-day moving averages, tidal day averages, and instantaneous plots. Overall, the results for the new calibrated model are in much better agreement with observed data.

XI.1 General Comments

With HYDRO, flow predictions improved the most. This is especially true for Cross-Delta Flow (sum of flow going through Delta Cross Channel and Georgiana Slough), flow at Old River at Bacon Island, and Middle River at Bacon Island. During the course of calibration, it was discovered that the datum position for measuring the stage for many locations was questionable. This made it difficult to compare stage in an absolute sense. So the IEP-PWT decided to check stage amplitude and phase, and not rely on stage data in an absolute sense. Stage predictions also improved somewhat. The biggest improvement came in South Delta (Grant Line Canal and Old River near DMC), and North Delta (Sacramento River above Delta Cross Channel and below Georgiana Slough).

With QUAL, the validation period actually contained the calibration period. So to check the validation, one should look for the comparison of model output, either prior to October 1991, or beyond September 1994. Comparison of model results clearly shows a much better match for almost all locations with the new validated model. Surprisingly, in the reach from Antioch to Old River at Holland's Tract, model results show a better match during the validation period than during the calibration period.

The IEP-PWT looked for reasons for the EC over-predictions in the San Joaquin River during the calibration period. The IEP-PWT believes that inaccuracies in the channel depletion estimates are one possible cause of the over-predictions. Channel depletions are estimated by the Delta Island Consumptive Use (DICU) model. DICU computes channel depletions based on water needs of the plants, and assumes diversion water is in plentiful supply. As an example, according to DICU, Delta channel depletions for July 1992 were around 4200 cfs. When one computes the Net Delta Outflow (NDO) using this estimate, NDO values that approach 1000 cfs are observed (see Figure XI.1). Under such hydrologic conditions, a great amount of salinity intrusion is expected. This is clearly reflected in the model results. Yet, there is no trace of huge salinity intrusion in the field data. In fact, the field data show the peak salinity intrusion in 1992 to have occurred from October through December, with EC values about double those for the summer (as an example, see EC data for Jersey Point). This is an inconsistency since the computed NDO was, in fact, higher in October through December 1992 than in summer. The IEP-PWT performed a sensitivity test (run 17 versus run 16) with channel depletion values adjusted for 1992. This was done by decreasing the irrigation water demands for June through September by around 500 cfs. That, in turn, increased the water demands in October through November due to a lower stored soil moisture. The result is a predicted salinity that is noticeably closer to the field data. Channel depletion estimates can easily be off by 500 cfs or more. The IEP-PWT decided to concentrate on improving QUAL's performance during the next phase of calibration. Overall, the IEP-PWT does not feel that the mismatch from 1992 through 1994 in the San Joaquin River can be resolved without adjusting the flow field (i.e. NDO).

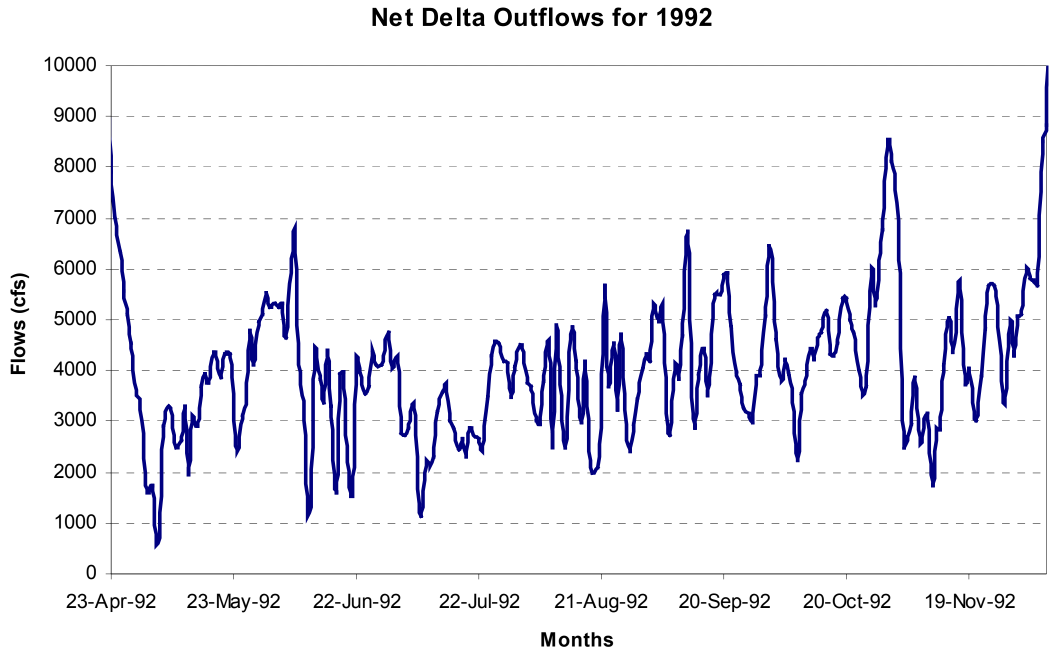

Figure XI.1.1: Net Delta Outflow for 1992.

XI.2 Summary

Overall, model predictions using the most recent calibration seem to capture field conditions much better than the 1997 version. Since January 1, 2001, DWR Delta Modeling Section has officially started using the new calibrated version. It is, however, expected that there will be future calibration efforts when significant new bathymetry, flow, stage, and water quality data become available. The IEP-PWT also plans to look for ways to clarify some of the unresolved issues (such as DICU estimates).

Refer to DWR Delta Modeling Section's Annual Progress Report (August 2001) Chapter 3 for work done in simulation of other water quality constituents such as DOC and UVA. For additional work done in dissolved oxygen and water temperature calibration, refer to Chapter 6.

XII. WHAT DID WE LEARN?

Confluence area hydrodynamics are strongly influenced by physical geometry
Tidal flow asymmetry is important (clockwise tidal pumping at confluence)
Assessment of 1D model applicability to Bay-Delta hydrodynamics questions.
Phase errors are regional: change n regionally
Amplitude errors are local: change n locally
North Delta flow data is needed
Salinity

XIII. PREPARING FOR THE NEXT CALIBRATION

- DICU (explain DSM2 overestimate of salinity in dry years)
- Parameterize Franks Tract and Mildred Island openings based on arial photos
- Convert datum to NAVD 88
- Analysis of surface salinity versus cross-section average
- Improve and expand objective measures of goodness of model fit. This was attempted but not well executed. Changes from run to run are subtle and different from place to place….
- Automatic calibration (Chuching Wang)
- GIS based geom tools
- New DCC Steamboat, Mildred Is flow data: Mildred data allows flux calculation
- Suisun Marsh
- Extend Yolo Bypass Toe Drain, put Yolo flow in at head
- Better representation of CCFB gates

XIV. SUMMARY

XV. REFERENCES

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XVI. APPENDICES