METHODOLOGY FOR
FLOW AND SALINITY ESTIMATES
IN THE
SACRAMENTO-SAN JOAQUIN DELTA AND SUISUN MARSH

FOURTEENTH ANNUAL PROGRESS REPORT
TO THE
STATE WATER RESOURCES CONTROL BOARD
in accordance with
Water Right Decision 1485, Order 9

June 1993
Forward

This is the fourteenth annual progress report on the development of methodology to predict accurate salinity distribution in the Sacramento-San Joaquin Delta as required by Order 9 of the State Water Resources Control Board Water Right Decision 1485. With D1485 still in effect, the Delta Modeling Section will continue to comply with Order 9 by filing this report. This document also serves the purpose of reporting activities under the Bay-Delta Evaluation Program, DWR Work Order 1382. This year, Shawn Mayr compiled the report under the direction of Francis Chung, the program manager of the Bay-Delta Evaluation Program. A brief summary of the individual chapters is in order.

DWR Delta Simulation Model. Starting the report is the discussion of DWR's Delta Simulation Model, DWRDSM, the group's main production tool for a variety of engineering analyses in the Delta. A unique opportunity existed during the reporting year to further validate the performance of DWRDSM. Two sets of flows and stage data associated with the South Delta Barrier projects and the January 1993 high pumping test were used to check the performance of DWRDSM. Results were quite satisfactory even though more room for further improvement was identified as a result of the project. Mohammad Rayej, Hari Rajbhandari, and Ali Ghorbazadeh worked together on this project.

Particle Tracking Model for the Delta. A new model that can track the fate and position of particles in the estuary on an individual basis has been developed. A number of qualitative studies with the Particle Tracking Model were completed to provide insights on the movement of particles in the Delta. The initial application of the model has been targeted for the Striped Bass eggs and larvae. Extension to other species such as the Delta smelt or salmon will also be examined in the coming years. Tara Smith has been the leading engineer on this project. She also executed a contract with Dr. Gibb Bogle to develop the base framework for the model.

Data Assembly: Time Series Data. Efforts continued to further expand the data stored in-house. As of May 1993, the section has assembled 8.5 million data points on flow, stage, velocity, gate positions, water quality, and weather. Art Hinojosa and Ralph Finch worked on this project.

Delta Graphical User Interface. Based on the framework developed last year, additional features were developed. DGUI is extensively used by the group. With the use of DGUI, tasks are now done faster and more accurately. Jatinder Singh and Ralph Finch contributed to this effort.

Data Assembly: Channel Geometry. A major effort has been made to consolidate geometry data. First, many sources of data were contacted for data collection. Then, the collected data were converted to one coordinate system based upon the National Geodetic Vertical Datum (NGVD) for the vertical datum and the Universal Transverse Mercator (UTM) for the horizontal datum. This conversion was an important first step toward accurate mathematical modeling of the estuary. Further work is needed to check the compiled data and convert it into a form that can be recognized by mathematical models. Andy Chu and Ralph Finch worked together on this project.
New Model Development: Four-Point and BLTM. With the goal of creating a public
domain model for the Delta, Parviz Nader worked closely with the United States Geological
Survey (USGS) to adopt the Four-Point and the Branch Langrangian Transport (BLTM)
models for the Delta. The new model will have enhanced capabilities such as handling
irregular channels, baroclinic term, and bottom slopes. The target date of completing this
task is June 1995. There seems to be a good chance of completing the project before
that date.

Trihalomethane (THM) Formation Potential Modeling. This year a comparison between
the methods developed by DWR and the one adopted by the United States Environmental
Protection Agency (USEPA) is presented. Results suggest that DWR methodology has
many advantages over the EPA method in predicting different species of THM. Paul
Hutton continued working on this project.

Refinement of Carriage Water Routine. Several attempts were made to improve the
performance of the existing routine, Minimum Delta Outflow (MDO), that is used to estimate
the amount of carriage water. No conclusive findings are yet available. The report
summarizes the future plan of tackling this task. Paul Hutton has been leading this project.

North Delta Flood Modeling. A couple of important developments were made this year
which allowed a streamlined operation of flood modeling studies. Working with the North
Delta Environmental Impact Report/Statement preparation staff, the group planned
development of flood modeling activities. This plan is outlined in this report. Shawn Mayr
and Ali Ghorbanzadeh worked on this project.
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Chapter 1

DWR Delta Simulation Model
Major efforts on DWR Delta Simulation Model (DWRDSM) during 1992-93 were in the area of validating model performance by using field data. The availability of water level and flow data near temporary barriers in the South Delta region and Clifton Court Forebay provided a unique opportunity to check model performance. The stage and flow data near South Delta temporary barrier sites was collected as a part of the South Delta Negotiation project. The stage data gathered inside Clifton Court Forebay covered the period of the SWP high flow pumping test conducted by Division of Operations and Maintenance in January, 1993. These two sets of data were used to verify the performance of DWRDSM.

**South Delta Negotiations**

A series of model runs were performed to verify the performance of the DWRDSM hydrodynamic model against measured water level and flow data in the South Delta region near the temporary barriers. These runs were made with and without barriers in place. For these verification runs, the observed boundary tide at Benicia, the actual SWP pumping and Clifton Court Forebay gate operation schedule, the representative monthly Delta Consumptive Use values, and the observed rim flows (such as Sacramento River flow, San Joaquin River flow, and Eastside stream flow) were used.

**Validation Without Barriers**

The field measured water level and flow data at San Joaquin River near the head of Old River and at Old River near Delta Mendota Canal (DMC) for April 7 and 9, 1993 were used to verify performance of the model. During these periods, the temporary barriers at Old River were not in place yet. The results of model verification runs for flow and water level for these periods with no barriers are shown in Figures 1 through 6. Over all, the model performed well in simulating the field conditions.

**Validation With Barriers**

Validation studies with barriers in place were performed for the period of July and August of 1992 near Old River and Middle River. The simulation results showed that the model performed very well when simulating landward flow near Old River barrier, but it underestimated seaward flow (Figure 7). This underestimation could be due to seepage through the rock barrier not accounted for by the model. Figures 8 and 9 show upstream and downstream of the barrier field measured and model simulated water levels during flow measurement period. The extended month-long comparison between field and simulated water levels are shown in Figures 9 and 10. For the Middle River barrier, the model simulated flow reasonably well (Figure 12). The water levels were also simulated well during high tides but were underestimated during low tides. The results of these
verification runs are plotted in Figures 13 through 16. Further adjustments of barrier flow coefficients may improve the model results.

**SWP Pumping Test**

During January 1993, the Division of Operations & Maintenance (O&M) conducted a test to determine the maximum pumping capability of Bank's Pumping Plant. Delta Modeling staff provided technical information regarding the tide and flow at key locations in the Delta and helped O&M field staff design the proper timing for the test. In addition, Central District staff were asked to collect channel velocity data in West Canal and Old River, and also stage data both inside and outside of Clifton Court Forebay while the pumping test was in progress. These pumping tests gave us a unique opportunity to evaluate the performance of the Delta Hydrodynamics Model against field data under high SWP pumping conditions. The test lasted approximately 45 hours. The average pumping rate was 10,650 cubic feet per second with a maximum of 10,800 cfs.

Hydrodynamic model runs were made to verify the performance of the model under high SWP pumping during the pumping test period of January 1993. Computer simulated water levels inside and outside of the Clifton Court Forebay were compared to field measured data. The preliminary results showed that the model simulated the water levels very well both inside (Figure 17) and outside (Figure 18) the forebay. This model verification effort demonstrated the robustness of the DWRDSM under high SWP pumping. Currently, we are determining the maximum pumping capability of the Bank's Pumping Plant with existing Clifton Court Forebay under various tides and hydrologic conditions.

**Golden Gate Boundary Extension**

Efforts were made to extend the model boundary from the current location at Benicia to Golden Gate. This extension was done to provide a more reliable tide and salinity boundary for the model. Relocation of the model boundary also has the added advantage of minimizing the boundary effects on areas located in the vicinity of the boundary. One example of such an area is the Suisun Marsh. Relocating the boundary from Benicia to the Golden Gate required 128 additional channels, 86 junctions, and 6 open water areas in the existing network of DWRDSM. The new additions cover areas of Carquinez Strait, San Pablo Bay, Central Bay, and South Bay. Initial test runs with 19-year mean tide at Golden Gate produced no numerical problems. The hydrodynamic module was then tested using actual Golden Gate tide, calibrated and verified against actual May 1988 field data. The main test was to check if the tide from Golden Gate is correctly propagated in phase and amplitude to Benicia by the model. Also, a three-way comparison among field data and results of the model running from Golden Gate, as well as from Benicia, seemed satisfactory.
Though the DWRDSM model is intended to study one dimensional flow in the Suisun Marsh/Delta but not of the Bay, model results at a few locations in the Bay were compared with field data. Water surface elevation at Point San Pablo in San Pablo Bay, for example, was simulated reasonably well by the model for the entire simulation period of May 1988.

Currently work is under way to calibrate and verify the salinity module with four years of field data covering water years 1987, 1988, 1989 and 1990. When the salinity module is calibrated and verified, DWRDSM can be used in a variety of planning and operational studies in the Suisun Marsh area and the Delta with boundary information from the Golden Gate.
Figure 1.1
Flow at San Joaquin River near Old River, channel 7
No Barrier

Flow in cfs

Time in hours

-2000 -1000 0 1000 2000 3000 4000

Model
Field, Apr 7, 1992
Figure 1.3
Flow at Old River at head, channel 54
No Barriers

Flow in cfs

Time in hours

-2000
-1000
0
1000
2000
3000
4000

- Model
- Field, Apr 7, 1992
Figure 1.4
Stage at Old River at head, channel 54
No Barriers

- Model
- Field, Apr 7, 1992
Figure 1.5: Stage at Old River near DMC, channel 80
No Barrier

Model
Field, Apr. 9, 1992

Stage in feet

Time in hours

0  60  120  180  240

200  210  220  230
Figure 1.6
Flow at Old River near DMC, channel 80
No Barrier

- Model
- Field, Apr 9, 1992
Figure 1.7
Flow at Old River above Dam, channel 79
With Barrier

Model
Field, July 1992

Flow in cfs

Time in hours

110 120 130 140

-2000 -1500 -1000 -500 0 500 1000 1500 2000
Figure 1.8
Stage at Old River above Dam, channel 79
With Barrier
(Time = 110 to 140 hours)
Figure 1.10
Stage at Old River above Dam, channel 79
With Barrier
(Time = 0 to 450 hours)
Figure 1.11
Stage at Old River below Dam, channel 80
(Time = 0 to 450 hours)

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Model
Field, July 1992

Stage in feet, MLLW

Time in hours

0 1 2 3 4 5 6 7 8
Figure 1.12
Flow at Middle River above Dam, channel 133
With Barriers

Model
Field, Aug 1992
Figure 1.13
Stage at Middle River above Dam, channel 133
With Barrier
(Time = 150 to 170 hours)
Figure 1.14
Stage at Middle River below Dam, channel 135
With Barrier
(Time = 150 to 170 hours)
Figure 1.15
Stage at Middle River above Dam, channel 133
With Barrier
(Time = 80 to 200 hours)
Figure 1.16
Stage at Middle River below Dam, channel 135
With Barrier

(Time = 80 to 200 hours)
Chapter 2

Particle Tracking Model for the Delta
The following chapter is an expansion of the paper written for the American Society of Civil Engineers National Hydraulic Engineering Conference (Bogle et al. 1993).

The Sacramento-San Joaquin Delta supports a number of fish species that are valued for recreational, commercial, or ecological reasons. Decline in fish populations has led to an increased focus on the fate of fish eggs and larvae in the Delta. A quasi two-dimensional computer simulation model has been developed to simulate the transport and fate of those fish eggs and larvae. The base model was developed by Water Engineering and Modeling and is currently being modified by DWR's Delta Modeling section.

The model uses 15-minute velocity, flow, and depth output from a one-dimensional hydrodynamic model (DWRFLO). The Delta's geometry is modeled as a network of channel segments connected by junctions (Figure 2-1), and the particles move throughout the network of channel segments under the influence of flows and random dispersive effects. The location of a particle at any 15-minute time step is given by the channel segment location, the distance from the end of the channel, and the distance from the channel bottom (Figure 2-2). The change in a particle's position in the Delta is calculated using theoretical and empirical relationships. These relationships incorporate the effects of advection, longitudinal dispersion, vertical mixing, and gravity on the particle. When a particle enters a junction where flow is leaving through two or more channels, the path which the particle takes is determined probabilistically.

Calibration and verification of the model is being accomplished using available striped bass egg characteristics and behavior under various conditions. New calibration/verification procedures will be necessary for each different fish species or particle type. This model will be used to evaluate the impacts of proposed water operations on the fate and transport of fish eggs in the Delta.

Theoretical Basis

Longitudinal Motion

Longitudinal particle motion is implemented as the sum of a deterministic component and a random component.

Deterministic Displacement: The deterministic part is the displacement of the particle caused by the mean velocity in the channel, while the random part accounts for the effects of longitudinal dispersion. For deterministic motion, the mean velocity from the flow model is adjusted to account for the vertical position of the particle. The Von Karman logarithmic velocity profile is used to provide an approximation to the velocity profile. Using this
profile, the longitudinal velocity at any point in the vertical column is a function of the mean velocity, the shear velocity, the depth of water, and the vertical location. The profile results in higher velocities closer to the surface of the water (Figure 2-3).

Random Displacement: The random component of the motion of a particle in a channel is computed by generating a random velocity from a Gaussian distribution with zero mean and a variance as discussed in the following paragraphs.

Fischer (Fischer et al. 1979) showed that in typical streams, with width/depth greater than 10, the dominant mechanism of longitudinal dispersion is transverse shear resulting from the transverse velocity profile. The dispersion coefficient \( K \) is proportional to the square of the distance over which the shear flow extends. This implies that the transverse profile is typically more than 100 times as important as the vertical profile in determining longitudinal dispersion. Fischer derived the following expression for \( K \):

\[
K = \frac{1}{\sqrt{\pi}} \frac{h^2 \bar{u}^2}{\nu}
\]

where:
- \( I \) = a dimensional integral of the velocity profile, approximate constant for real streams = 0.07,
- \( h \) = characteristic length = 0.7W,
- \( W \) = channel width,
- \( \bar{u}^2 \) = expected square of the deviation of the depth averaged velocity from the mean velocity = 0.2\( \bar{u}^2 \)
- \( \bar{u} \) = mean velocity,
- \( \nu \) = transverse mixing coefficient = 0.6\( Du' \),
- \( u' \) = shear velocity = 0.1u for streams,

Substituting the above approximations yields:

\[
K = 0.11\bar{u}W^2/D
\]

The value of the dispersion coefficient, \( K \), is further adjusted to reflect effects of periodic flows and the velocity of the particle at the vertical location in the channel.

The formula for the longitudinal dispersion coefficient assumes a constant rate of flow in the channel. When there is a periodic component to the flow resulting from tidal influence, the dispersion coefficient is reduced. This is because the dispersive effect produced by transverse shear when flow is in one direction tends to be cancelled out when the flow reverses, particularly if the reversals occur rapidly. The change in \( K \) is determined by the ratio \( T/T_o \), where \( T \) is the period of flow oscillation, and \( T_o \) is the transverse mixing time. The dependence of the dispersion coefficient on the ratio \( T/T_o \) was calculated by Fischer (Fischer et al. 1979), who showed that if \( T \) is much less than \( T_o \), \( K \) tends towards zero, while for \( T \) greater than \( T_o \), \( K \) takes the value that it would if the flow were steady at a succession of levels making up the cycle. In the model, \( K \) is adjusted by using a lookup table based on Fischer's results.
The value of the dispersion coefficient is further adjusted by multiplying it by the ratio of the deterministic velocity of the particle at its depth above the channel bottom to the mean channel velocity.

The effect of longitudinal dispersion on particle motion is simulated by adding a random velocity component to the deterministic particle velocity. The dispersion coefficient $K$ is one-half of the time rate of change of the variance of a cloud of particles:

$$\frac{d\sigma^2}{dt} = 2K$$

where $\sigma^2$ is the variance in particle position with respect to the center of mass of the cloud. The random particle velocity averaged over the timestep $\delta t$ is assumed to have a Gaussian (normal) distribution with zero mean. It can be shown that the variance of the velocity is proportional to the dispersion coefficient, resulting in

$$\sigma_v^2 = 2K/\delta t = 0.22\bar{u}W^2/D\delta t$$

The standard deviation of the particle's velocity around the center of mass of the cloud is multiplied by the Gaussian random number. This value is multiplied by the time step in order to obtain the distance traveled due to dispersion.

**Vertical Motion**

The position of a particle in the water column, as measured from the channel bottom, is influenced by vertical turbulent mixing and by the particle's tendency to settle to the bottom. In addition, changes in the vertical position $z$ occur when the particle crosses a junction into another channel. The change in water depth in a channel from one timestep to the next is also reflected in the vertical position of particles in the channel — the ratio $z$: depth is preserved when the depth changes.

**Deterministic Displacement:** The deterministic component of vertical motion is described by a settling velocity, which could be a rising velocity in the case of a buoyant particle. The change in $z$ over a time step is simply equal to $-U_s dt$, where $U_s$ is the settling velocity and $dt$ is the time step. When the particles being modeled are fish eggs, the settling behavior may be required to vary with the age of the egg.

**Random Displacement:** The random component of vertical motion is described by vertical mixing. Fischer showed that a vertical mixing coefficient can be derived from the velocity profile. By assuming a logarithmic velocity profile, the depth-averaged vertical mixing coefficient can be derived in the simple form:

$$\varepsilon_v = 0.067D\bar{u}^+ = 0.0067D\bar{u}$$
where \( D \) is the channel depth and \( u' \) is the shear velocity which is assumed to be approximately equal to one tenth the mean velocity, \( \bar{u} \).

In a close analogy to the treatment of longitudinal dispersion, vertical mixing is modeled through a random vertical velocity component where the random vertical velocity \( U \) has zero mean and variance given by

\[
\sigma^2_u = (2e_c) / \delta t
\]

The net vertical particle displacement created by the fall velocity and vertical mixing can cause the particle to cross a boundary - either the water surface or the channel bottom. In this event, the particle trajectory is reflected in the boundary in order to return the particle to the water column.

**Application of the Model to Striped Bass Egg and Larval Tracking**

This model lends itself well to the tracking of striped bass egg and larval data for the following reasons:

1. Particles can be inserted at any location in the Sacramento San-Joaquin Delta to reflect various spawning areas.

2. Each particle is tracked individually. The age and location of each particle is recorded at every time step. The effects of different hydrologies and new facilities on particle movement can be shown in the path a particle takes to a particular location.

3. Particles have different velocities at various depths. The vertical velocity profile results in a longer travel time for particles that are located closer to the bottom of the channel.

4. The vertical distribution of particles varies over time. The vertical position of a particle is based on its previous location, its settling velocity, and vertical mixing. The amount of vertical mixing that occurs is based on the channel velocity. If there are higher velocities, the particles are more uniformly distributed within the water column. If there are lower velocities, the settling velocity has a greater effect on the particle, and the particle settles to the bottom (Figure 2-4).

5. Physical characteristics of particles can be modeled by varying the settling velocity. At specified intervals after release, the settling velocity can be changed to simulate the settling velocities of eggs and larvae at different ages.

6. Mortality can be modeled. Along with modeling particles that are lost to pumping and agricultural diversions, particles can be assigned a mortality rate which can be a function of age or location in the Delta.
7. When a particle reaches a junction that has flow leaving from two or more channels, the probability of a particle entering a channel can either be in proportion to the amount of flow through that channel, or it can be changed to reflect a disproportionate probability (Figure 2-5).

Sample Simulations

Three simulations were made to do some preliminary testing of the model. Two simulations were accomplished by using the particle tracking model. One simulation was accomplished by using the mass tracking part of DWR's Delta Simulation Model (DSM). One thousand particles were inserted into the Sacramento River at I Street. The Sacramento River flow was set at 38,000 cfs. The San Joaquin River flow was 1,000 cfs, Delta consumptive use was 2,500 cfs, and total exports were 6,000 cfs. In one of the particle tracking simulations, the velocity profile and dispersion were "turned off" so that the particles were traveling at the average velocity in the channel. This simulation was done in order to mimic the processes occurring in the DSM mass tracking simulation. The results of the two simulations (particle tracking versus mass tracking) differed by no more than 3 percent.

In the second particle tracking simulation, all of the model's capabilities were used and the settling velocity was set so that the majority of the particles would remain at the bottom. This simulation significantly increased the travel time of the particles.

Calibration and Verification

The model is currently being calibrated and verified using Striped Bass egg and larvae data. The types of data being investigated for calibration are travel times, spatial dispersion or distribution, settling velocity, and mortality rates.

Continuously sampled data at various locations in the Delta, like those data found in C. Hanson's report (Hanson 1991), are being used to calibrate the model to match the travel time, attenuation, and spreading of a pulse of eggs and larvae. Egg data from an upstream location (at a station where the flow does not reverse) will be used as the input to the model. Simulations will be made using actual flow conditions and the upstream egg distribution. The model's parameters will be adjusted to match the egg and larval distributions at the downstream stations (Figure 2-6).

Spatial dispersion data are being used to calibrate the model for the vertical distribution of eggs for various flows. Spatial dispersion data consists of data taken at more than one depth at various cross sections (USBR, 1990) (Figure 2-7).
Laboratory data from M. Meinz's 1978 report (Meinz and Heubach 1978) are being used to determine the settling rates of eggs and larvae (Figure 2-8). Using the age-sinking rate relationships shown in the report, settling velocities will be varied for each particle as a function of time.

Mortality rates will be set initially to 50 percent for eggs over the spawning to hatching period (approximately 48 hours) and 10 to 18 percent mortality per day for 5- to 10-mm larvae. These rates are estimates by L. Miller (Miller 1992) based on data collected in the field.

Conclusions

A quasi two-dimensional physically based model has been developed to track the transport and fate of individual particles in an estuarine environment. The particle's movement is based on advection, longitudinal dispersion, vertical mixing, and gravity. The model is being calibrated using striped bass egg and larval data.

Future goals are to extend the model to other estuarine species and to incorporate bioenergetic relationships found in biological life cycle models. These relationships address among other factors, food availability, predation, and temperature.

Research is also underway to make the model a quasi three-dimensional model. A transverse velocity profile will be included in the model and the particle's position will be defined in three dimensions.
References


Figure 2-1. DWRDSM Delta model grid

Figure 2-2. Defining each particle's location
AVERAGE VELOCITY OF A PARTICLE IN A CHANNEL

\[ \text{VAVE} = \frac{x(\text{VEL 2})}{L} + \frac{(1-x/L)(\text{VEL 1})}{L} \]

- \( x \) = particle's distance from the upstream end of channel
- \( L \) = channel length
- \( \text{VEL 1} \) = velocity at the upstream end of the channel
- \( \text{VEL 2} \) = velocity at the downstream end of the channel
- \( \text{VAVE} \) = average velocity of particle

VELOCITY OF A PARTICLE USING A VELOCITY PROFILE

\[ V = \text{VAVE} + \frac{U^*}{K} + \frac{(U^*/K)\ln(z/d)}{D} \]

- \( \text{VAVE} \) = average water (and particle) velocity
- \( U^* \) = shear velocity = \( \text{VAVE}(f/8)^{0.5} = 0.1(\text{VAVE}) \)
- \( K \) = Von Karman constant = \( 0.4 \)
- \( z \) = vertical location of particle measured from bottom of channel
- \( D \) = depth of water in the channel
- \( V \) = velocity of the particle using the Von Karman vertical velocity profile

*NOTE - When \( z/D = 0.368 \) then \( V = \text{VAVE} \)

Figure 2-3. Velocity of a Particle
Figure 2-4. Vertical distribution of particles

Figure 2-5. Particles behavior at a junction
Figure 2-6. Average striped bass egg and larvae densities observed at Bryte, Courtland and Walnut Grove.
Figure 2-7. Striped bass egg and larvae concentrations (/cm³)

Figure 2-8. Mean sinking rates of Sacramento River striped bass larvae in relation to age
Chapter 3

Data Assembly: Time Series Data
The data assembly process for time series data was explained in last year's report. This section will simply provide an update of new data added to the database.

As of June, 1993, the Delta Modeling Section has assembled 8.8 million time series data points. Included in this number are 3.9 million regular time series (RTS) stage data points, 3.7 million RTS water quality points, 1.1 RTS million miscellaneous data such as flow, velocity, gate positions, air and water temperature, and 100,000 grab-sample data points, collected on an irregular time basis. The latter will be especially valuable in THM modeling work because a single grab sample is analyzed for up to 30 different parameters, including minerals and organic compounds. Over two hundred sites are available over a period of several years.

Some database utilities were converted from PC computer versions to Sun computers. The most important is DSSMATH, a collection of powerful mathematical operators specifically for DSS data files. This utility allows operations such as detecting all values over a certain amount and converting them to missing data. This capability helps speed up data checking and correcting and reduces the chance of error.

Future Directions

Additional data will be added in two categories: first, previously collected data, often several years old, that has never been added to any easily accessible database, referred to as 'backlogged' data. Several years of multi-parameter RTS hourly data from the Environmental Services Office and 15-minute stage and EC data from the Central District, as well as other sources, are included in this category.

The second type of data is recently collected data from sources that continually collect data in the field (as opposed to one-time data collection projects). Procedures are being developed to access that data on a periodic basis and add it to the database. Operations and Maintenance, with their involvement in a real-time modeling project, will assist in this effort by providing real-time data in their own database.

To further streamline data assembly, an investigation is being conducted to implement more automatic checking of data for bad values. An automatic checker would reduce the human involvement needed, allowing us to concentrate on the more complex aspects of data assembly.
Chapter 4

Delta Graphical User Interface (DGUI)
Chapter x

Title: Organization and Implementation (OCII)
The DGUI is a program used to plot and manipulate observed and computed data pertaining to the Delta. The initial version of the DGUI was reported last year. This year, we will report new developments and future directions.

**Additional Features Added**

**North Delta Flood Model**

The DGUI is now used to display output from the program used to model flooding in the North Delta. This has decreased the time required to analyze flood studies.

**Profile Plot**

In this plot (Figure 4.1), the x-axis is distance from a point in the Delta, and the y-axis, data values (stage, electro-conductivity, etc.), at a single instant of time. The plot is animated over the desired time period. A variation, used in flood studies, is to plot the maximum stage at each location during the study period, using the mathematical filtering functions described in last year's report.

**Scatter Plot**

One time-series is plotted on the x-axis, and another time-series on the y-axis (Figure 4.2). This plot is useful to identify relationships between stations, or between different parameters at the same station.

**Particle Plot**

Output from the particle tracking model is displayed in the DGUI Delta map. Particle colors correspond to values associated with each particle, such as relative depth in the channel, or age of the particle. The particle plot needs to be more fully integrated with the entire system, however, particularly the spatial plots.
Mark Missing Data

The DGUI has been used from its start to easily locate bad data in our observed database. Previously it was necessary to edit the original ASCII files to change the bad data to 'missing' values. Now the DGUI can be used to directly and intuitively mark certain data with 'missing' values, which speeds up the data checking process in the data assembly project and results in more data with fewer errors.

Calculator

One can now add, subtract, multiply, and divide different time series, either in combination with each other or with scalar (constant) values. This allows one to average together time-series, calculate differences between top and bottom EC values, and execute other relevant operations quickly and easily without downloading the data to another utility such as a spreadsheet.

Time Lagging

Time-series can be lagged or advanced from their actual starting times. This allows easier estimation of phase differences between different locations, or between different parameters at the same location, for instance, between stage and flow, or stage and EC.

Irregular Time-series.

Previously, only data sampled on a regular time basis could be displayed in the DGUI. Grab-sample data, however, is collected irregularly. The DGUI was reprogrammed to enable display of this type of data.

Mouse Menu System

Previously the menu system which controlled the DGUI was keyboard-based; the user would type single-character commands from the keyboard. Now the DGUI is controlled with the mouse attached to the computer workstations, and as a result is easier to learn to use.
Future Directions

Analysis of data in the frequency domain (Fourier analysis) would allow the user to easily detect frequency components in the data, and remove high- or low-frequency components to perform certain analyses of the data. For instance, by removing all frequencies with a period of less than 14 days, it would be relatively easy to estimate the volume of water draining and filling the Delta during a spring-neap cycle.

Allowing more customization of plots would be helpful to users by allowing them to avoid transferring data to custom plotting programs to produce plots for presentations and reports. As a start, user-specified pathnames and plot titles will be allowed. Then generalized annotation of plots with notes and symbols would be provided.
Chapter 5

Data Assembly: Channel Geometry
Channel geometry data is an essential component to successful mathematical modeling of the Delta. The geometry data currently used in DWRDSM was derived from the RMA channel geometry, which was completed several years ago. The field data was converted to rectangular or trapezoidal equivalents, thus losing information about actual cross-sections. Moreover, in the last several years, channel geometry in many Delta locations has undergone significant changes.

**Purpose of the Project**

To our knowledge, all sources of channel geometry data have never been assembled into a single database. Therefore, the primary objective was to develop a channel geometry database using the same principles which guided development of the Delta Modeling Section's time varying database; existing sources of data would be assembled, and transformed into a single, unified database. The first objective necessary for this task was to locate all sources of existing data. The data then had to be organized into a common format and coordinate system, and finally, examined for errors. The second objective was to leave the data in as primitive a form as possible and use programs to convert the data to the final form needed by the models. In other words, we would leave the data in x-y-z form and not convert it to idealized cross sections as has been done in the past. Leaving the data in x-y-z form allows a single database to serve as input to many different Delta models.

**Process Steps**

There are four steps in the development of the database: data collection, reformatting/conversion, error checking, and model application (Figure 5.1). As of this writing, the data collection and reformatting/conversion, and part of the data error checking, have been completed. The data has not yet been fully checked for errors and has not been converted to a form suitable for model use; this will be done when software is located for handling large databases of geometric data.

1. **Data Collection**

Sources of data (organizations that have conducted field surveys) in federal and state agencies, local administrations, and private consulting firms were located through telephone calls, correspondence, and in-person visits. Table 5.1 lists source agencies, contact persons, and original database format. In screening the sources, survey location, purpose of survey, quantity of data, accessibility, format organization, time of survey, and cost were considered to determine if the data was worth acquiring. The National Oceanographic and Atmospheric Agency, U.S. Geologic Survey, U.S. Army Corps of Engineers, and
Department of Water Resources were selected and copies of their data acquired. We welcome hearing about other sources of data.

2. Data Formatting/Conversion

One of the major problems in this project is that the data comes in quite different formats. Thus, the first part of data conversion is to change all the sources into a single format. Secondly, the data sources use different measurement units. The final result of conversion is a combined database with a unified coordinate system, same datum reference, and consistent units. The Universal Transverse Mercator (UTM) coordinate system and National Geodetic Vertical Datum (NGVD) in feet are currently employed in the combined database. Varying from source to source, the appropriate corrections were applied accordingly. For example, the local Mean Lower Low Water (MLLW) datum in NOAA data was changed to NGVD and its coordinate system from geodetic (degrees latitude and longitude) to UTM.

3. Error Checking/Final Assembly

Once a unified system has been reached, the location and the depth of each data point needs to be verified. Verification is needed both to check the validity of the original data as well as the correctness of the transformations applied to the data and is most easily done graphically. To check the horizontal coordinates, the database is first imported into AutoCAD, where a drawing file that has most of the Delta channel boundaries in UTM coordinate is available for location verification. The vertical coordinates (depths) are not easily checked in AutoCAD, and other software is needed to easily display, in 3-D, the channel shapes.

Finally, all the data is stored into a combined file that contains the x-y location in UTM coordinates, depth in feet referenced to NGVD, date of survey, and an identification code that indicates the source agency. The file is about 13 megabytes and contains 335,000 data points. Figure 5.2 shows the general location of each data source. A summary of each source's contribution is tabulated in Table 5.2.

4. Model Application

The primary goal of this project is to upgrade the channel geometry data currently used in the hydrodynamic and water quality models. In general, the models require input data that is in cross-sectional form: y and z values along channel cross-sections. However, the data is stored as x-y-z, not as cross-sections. Thus, some sort of interpolation is needed to generate elevation contours in the channels, then to take a cross-section, perpendicular to the channel, from the contours. We are trying different computer packages to find one suitable for this task. Since it is unlikely that cross-sections can be reliably generated automatically, we are searching for an easy-to-use, interactive, graphically-oriented package.
Future Work

Both the observed channel geometry data and the estuary models should be used together to determine where new fields surveys should be conducted to obtain better data to more closely simulate the actual Delta. Field surveys should be done where current data is old, sparse, or thought to be unreliable, and at the same time, where model runs indicate that the model is sensitive to small changes in channel geometry. Thus, data need not be collected where it is not critical to model performance, saving scarce resources for other tasks.
### TABLE 5.1: DATA SOURCES LIST

<table>
<thead>
<tr>
<th>AGENCY</th>
<th>CONTACT PERSON</th>
<th>ORIG. FORM</th>
<th>VERT. DATUM</th>
<th>COORD. SYSTEM</th>
<th>SURVEY YEAR</th>
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</thead>
<tbody>
<tr>
<td>Cal. DWR</td>
<td>Wayne Wolber</td>
<td>Written</td>
<td>NGVD</td>
<td>None</td>
<td>1986</td>
</tr>
<tr>
<td>Central Dist.</td>
<td>(916)445-2649</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sacramento,CA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cal. DWR</td>
<td>John Ho</td>
<td>5 1/4&quot;</td>
<td>NGVD</td>
<td>None</td>
<td>1991</td>
</tr>
<tr>
<td>Central Dist.</td>
<td>(916)445-3781</td>
<td>Floppy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sacramento,CA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>USGS Sacto. Dist.</td>
<td>Rick Ottman</td>
<td>Written/</td>
<td>NGVD</td>
<td>None</td>
<td>1977~</td>
</tr>
<tr>
<td></td>
<td>(916)978-4648</td>
<td>5 1/4&quot;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sacramento,CA</td>
<td>Floppy</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(916)373-1617</td>
<td>Floppy</td>
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<td></td>
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</tr>
<tr>
<td></td>
<td>West Sacto.,CA</td>
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<td></td>
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<tr>
<td>COE S.F. Dist.</td>
<td>John Brady</td>
<td>3.5&quot;</td>
<td>NGVD</td>
<td>State Zone #2</td>
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<td>Disk</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>S.F., CA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NGDC NOAA/NESSDIS</td>
<td>Lee Cohen</td>
<td>1600</td>
<td>Local</td>
<td>Geodetic (LL</td>
<td>1935~ 1995</td>
</tr>
<tr>
<td></td>
<td>(303)497-8467</td>
<td>Density</td>
<td>MLLW</td>
<td>degr)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Boulder, CO</td>
<td>Magnetic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tape</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thompson Hysell Engr. Consultant Co.</td>
<td>Mike Persak</td>
<td>3.5&quot;</td>
<td>NGVD</td>
<td>None</td>
<td>1990</td>
</tr>
<tr>
<td></td>
<td>(209)521-8986</td>
<td>Disk</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Modesto, CA</td>
<td></td>
<td></td>
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</table>

### TABLE 5.2: FINAL TALLY IN "DELTA.GEOM"

<table>
<thead>
<tr>
<th>FILES (../utm/data/)</th>
<th>REGION/SOURCE</th>
<th>NO. OF DATA POINTS</th>
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</thead>
<tbody>
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<td>nos-371.utm</td>
<td>37-121 LL/NOAA</td>
<td>38243</td>
</tr>
<tr>
<td>nos-381.utm</td>
<td>38-121 LL/NOAA</td>
<td>81286</td>
</tr>
<tr>
<td>nos-382.utm</td>
<td>38-122 LL/NOAA</td>
<td>40775</td>
</tr>
<tr>
<td>coe-371.utm</td>
<td>37-121 LL/COE</td>
<td>14172</td>
</tr>
<tr>
<td>coe-381.utm</td>
<td>38-121 LL/COE</td>
<td>126172</td>
</tr>
<tr>
<td>sb.utm</td>
<td>Suisun Bay/COE</td>
<td>24615</td>
</tr>
<tr>
<td>DWR.utm</td>
<td>Scour &amp; ND86/DWR</td>
<td>6688</td>
</tr>
<tr>
<td>USGS.utm</td>
<td>North &amp; Central Delta/USGS</td>
<td>3460</td>
</tr>
</tbody>
</table>

LL means "Latitude and Longitude."
FIGURE 5.1: CHANNEL GEOMETRY PROJECT FLOW CHART

DATA COLLECTION

- DWR ND 86
- DWR Scouring
- USGS, Sac
- COE Sac Dist
- COE S.F. Dist.
- NOAA
- T&H Engr.

DATA FORMATTING/CONVERSION

- Prepare *.org (depth data) & *.txt (coord. data) files
- Study the contents of original database & investigate necessary corrections
- Require more AutoCAD expertise to extract the Xsec info. from the drawing file.

- Run Assigned Re-formatting Programs
- DWR/USGS
- COE/Sac
- COE/SF
- NOAA

- 'arrange.scpr' is a script file that consists a series of AWK & script files. It basically takes the data from *.org and *.txt & then re-organizes them into one file that contains necessary info.
- 'format.scpr' extracts the needed info from the org. database & applies the appropriate corrections.
- 'quad awk' sorts data into one LL-degr regions & 7.5min quad map regions. 'noaa.pro' is an IDL program that generates a mesh using the known datum corrections & interpolates for the unknowns.

ERROR CHECKING/FINAL ASSEMBLY

- Location Verification & Depth Comparison (AutoCAD)
- Sort Data into 7.5min Quad Regions (reduces the size of database.)
- Convert Coordinate System to UTM (Tralaine software -in DOS)

- 'delta.geom'

MODEL APPLICATION

- Final Error Checks
- Extract Data to Designed Format

- Identification number
- X-coordinate in UTM
- Y-coordinate in UTM
- Depth in ft. (NGVD)
- Year of survey
Figure 5.2
BATHYMETRIC DATA MAP
Chapter 6

New Model Development: Four-Point and BLTM
Efforts have been under way to develop a more sophisticated tool to study the complex hydraulic system found in the Delta. The Delta Modeling Section intends to develop public domain flow and transport models, surpassing the capabilities of the current models. The following are some of the desirable features that were used as criteria for selecting the best model:

- maintaining continuity conditions in all channels (i.e., no leakage);
- simulating irregular channels;
- including bottom slope in the formulation;
- including baroclinic (density driven flow) term.

After months of investigation, Four-Point and BLTM (Branched Lagrangian Transport Model) have been chosen as the most suitable models.

Four-Point Model

Four Point is a finite-difference, one-dimensional, unsteady, open channel, hydrodynamic model, written by Lew Delong and his colleagues at U.S. Geological Survey. The main advantages of the Four Point Model are:

1. The method is fully implicit and unconditionally stable. As a result, larger time steps can be used, unlike an explicit model which requires smaller time steps for stability considerations.

2. The model is capable of handling trapezoidal, completely irregular and nonprismatic channels. DWRDSM can only model rectangular prismatic channels. The capabilities of a model to properly represent irregular cross-sections is particularly important to accurately simulate the hydraulics of the Sacramento-San Joaquin Delta, where a number of natural channels exist. Unlike man-made channels, some natural channels cannot be adequately represented by rectangular or trapezoidal shapes.

3. The model already has the baro-clinic term (density driven flow) in the mathematical formulation. It assumes the density is known for all the channels. If the density of the water is allowed to vary, its effect can be included in the analysis by adding the term \( g \frac{dp}{dx} \) to the momentum equation. The density gradient created by the tidal action and seawater intrusion can have a considerable impact on the results. A sample test run based on "normal" hydrology showed that the inclusion of the baro-clinic term lead to about a 0.3 feet difference on the average stage calculated at different locations. The difference could be more drastic if a "dry" hydrology is used, as there would be a greater amount of seawater intrusion. Benicia, which is on the edge of San Francisco Bay, is now being used as the ocean boundary in the model. However, in the future
the grid may be extended to the Golden Gate Bridge to cover most of San Francisco Bay. In that case, the baro-clinic term might play an even more important role.

4. In DWRDSM continuity is maintained at a junction, but within a channel continuity is only approximated. The amount of water volume unaccounted for is small for a channel, but when accumulated for all the channels, it could have a considerable magnitude. In a typical steady state model run, the amount of leakage is about 1 to 3 percent of the sum of all the inflows (without the "leak-plug" option). On the other hand, Four-Point Model is capable of enforcing continuity both at a junction and within a channel, because of its implicit nature. There was no leakage detected in any of the model test runs. As a result, no leakage within the modeling region as a whole or within individual channels results.

Theoretical Background

Four-Point Model solves the momentum and continuity differential equations. These equations are discretized using a finite difference scheme requiring four points of computation, thus the name "Four Point". This is done by integrating the equations in time and space, leading to a solution of a set of nonlinear equations, with the incremental changes in stage and flow at the computational points as the unknowns. These equations are linearized using truncated Taylor series, and are then solved iteratively.

Delta Geometry

The DWRDSM grid model of the Delta is composed of approximately 496 channels, 416 junctions, 13 open water areas, and 17 hydraulic barriers and gates. As a first attempt, the same grid was used when running Four-Point (without the gates and reservoirs). All the input files were created using a pre-processor that converts the DWRDSM geometry file into a format readable by Four-Point. To use this grid, some of the arrays used in the code had to be redimensioned, since the original code was written for use on a relatively small network.

The first test revealed an unusually high CPU time requirement. The speed of the model was improved about twenty fold with the help of Lew Delong (the leading author of the model). Major steps taken in speeding up execution can be summed up in two areas:

1. The equation solver was modified to take advantage of the fact that the matrices are sparse in nature, and thus eliminating a lot of unnecessary operations. In addition, the equation solver was modified so that the Jacobian matrix is updated every nth iteration (n an integer specified by the user), instead of every single iteration.

2. Unlike explicit models where channel numbers have no impact on the amount of computations, the efficiency of an implicit model highly depends on how the channels
are numbered. All the channels were carefully renumbered so that all entries in the Jacobian matrix were as close to the diagonal as possible, leading to a more efficient system of equations.

Newly Developed Features In the Model

In order to use Four-Point Model in the Delta, several new features were implemented. The main features incorporated in the model are:

1. Open Water Areas

Thirteen open water areas are modeled in the DWRDSM grid. These are bodies of water that are too big to be modeled as channels. Open water areas are treated like tanks, with a known surface area and bottom elevation. An open water area can be connected to one or more channels. The flow interaction between the open water area and each of the connecting channels is determined using the following formula:

\[ q = C \sqrt{\Delta h} \] ............................... (1)

where \( q \) is the flow from open water area to the channel, \( C \) is the flow coefficient, and \( \Delta h \) is the head difference between the open water area and the channel. The flow is calculated for every time step and is then added to the connecting channel as an external source. The surface elevation of the open water area is updated every time step for the flows added or removed. Equation (1) can potentially introduce sudden surges of flow, causing numerical oscillations. To dampen these oscillations, the following steps are taken by the model:

a) The flow in Equation (1) is calculated based on the head difference at the beginning and end of the time step, then the two are averaged. This averaging process seems to reduce the numerical oscillations.

b) A filtering equation is used to make the changes in the computed flows as smooth as possible:

\[ Q^{(t+1)} = f \times q + (1 - f) \ Q^t \] ............................... (2)

where \( Q \) is the adjusted flow assigned to the channel, \( f \) is the filter coefficient (0<\( f \)<1), and the index \( t \) represents the time step number.
Test runs show that the model requires small filter coefficients because of numerical oscillations and larger time steps. For now, values of \( f \) between 0.05 and 0.10 seem to be adequate.

2. Hydraulic Gates

The flow through gates is calculated using the orifice flow equation:

\[
q = C A \sqrt{\Delta h}
\]  

(3)

where \( q \) is the flow through the gate, \( C \) is the gate flow coefficient, \( A \) is the flow area, and \( \Delta h \) is the hydraulic gradient between the two sides of the gate. Both \( A \) and \( \Delta h \) are updated in every time step. Gates can be placed either at the upstream or downstream end of a channel. Two values of gate flow coefficients are assigned for every gate, corresponding to seaward and landward flow. For a one-way gate, the flow coefficient assigned to the obstructed direction is set to zero. For a complete barrier, the gate flow coefficients for both directions are set to zero.

Four Point Model enforces an "equal stage" boundary condition for all the channels connected to a junction with no gates. Once the location of a gate is defined, the boundary condition for the gated channel is modified from "equal stage" to "known flow" with the assigned flow calculated from equation (3).

Gates are even more susceptible to oscillations than open water areas. The same steps taken to reduce the oscillations for open water areas were implemented for gates. Studies show that weirs require much higher filtering \((f=0.05)\) due to larger flow areas. For pipes and culverts \(f=0.25\) seems to be adequate.

A routine is also made available to specify the gate operations for gates that can be opened or closed only once or several times during simulations. In addition, to avoid numerical oscillations induced by the sudden opening of a gate, the gates are allowed to open or close gradually. This is a better representation of the field conditions.

**BLTM (Branched Lagrangian Transport Model)**

BLTM is a transport model which can be used for simulating water quality constituents, and was written by Harvey E. Jobson and his colleagues at USGS. The model has the following attractive features that make it very suitable for the studies in the Delta.
The model can simulate up to ten different constituents simultaneously. DWRDSM can only handle one constituent at a time.

Non-conservative constituents can easily be simulated. The user can supply the reaction kinetics in a few easy steps in the form of a subroutine.

The model does not need to know the shape or dimensions of the channel. The flow area along with other flow information is supplied to the model through a tide file generated by a hydrodynamic model. Thus no special provisions are required for a trapezoidal or an irregular or even a non-prismatic channel.

Theoretical Background

BLTM solves the convective-dispersion equations in a Lagrangian (moving) Coordinate system. Each channel is divided up into a number of moving parcels. These parcels are assumed to be completely mixed. The volume of these parcels is determined using the flow at the junctions and will remain constant when they are completely inside a channel (unless lateral inflows are present). Parcels from connecting channels are mixed at the junctions, and new parcels are created. During the simulation, smaller adjacent parcels are mixed to form a bigger parcel. Currently the maximum number of parcels in a channel is set at 50, as opposed to 24 for DSM.

Dispersion occurs at the interface between the parcels. The dispersion equation is integrated using a simple explicit finite-difference approximation. Furthermore, it is assumed that dispersion cannot occur at the junctions, thus junctions are assumed to be points of zero dispersive flux. Since dispersion is a function of discharge, there will be no dispersion at zero discharge. To include non-flow induced effects such as wind, the user can specify a minimum dispersive velocity.

Delta Geometry

All the input files necessary to run the bigger DWRDSM Delta geometry were created using a pre-processor. Most of the arrays in the code had to be redimensioned, since the original code was written for a small network with less than 30 channels. The model cannot handle open-water areas at this point. However, gates do not require any special provisions, since they represent the flow interaction between the interior channels. DWRFLO model was modified to create a tide file, containing the hydraulic information which BLTM requires.

The model test run was completed, and all results were in the appropriate range. The CPU time was higher than DWRDSM by a factor of about 3, mainly due to a more accurate dispersion formulation used in BLTM. The dispersion formulation will be simplified to make
It more efficient, since the advection term is a much more dominant driving force in carrying the salt in the Delta.

**Future Plans**

This modeling activity started as a 3 year project. The results presented in this report represent this branch's progress in the first year. The following is a list of tasks planned for the next phase of this project:

1. **Coupling Four Point Model and BLTM**

   These two models will be merged to form a combined hydrodynamic-transport model. The purpose of coupling these two models is to take the baro-clinic term (density-driven flow) into account. Once these two models are linked, the data can readily be exchanged between them. In one time step, the flow and stage will be calculated using the existing density pattern predicted by BLTM. The density pattern will then be updated using the newly calculated flows from Four Point Model, and this process is continued.

2. **Calibration and Verification**

   The combined model will be completely calibrated and verified using the available flow and water quality data. Manning's and dispersion coefficients will be used as the calibrating parameters. This will be a very complex task and will probably be performed using an automated technique.

3. **Improved Input/Output and Delta Graphical User Interface**

   The input data files will undergo a drastic change to make it easier for the user to specify all the model parameters. All the time-varying data will be stored using HEC-DSS. To run the model, the user will specify the start and end dates and times of the run, and most of the input parameters will be retrieved automatically.

   A post processor called DGUI is already available for use with DWR BDSM. With DGUI the user can plot the results of the output in a few simple keystrokes. DGUI is menu-driven and has a lot of useful features, including animation, time series, and stage profile plots. A similar system will be developed for use with Four Point Model and BLTM.

4. **Updating the Delta Geometry**
Currently, all the channels are assumed to be rectangular. The process of selecting the dimensions of an "equivalent" rectangular channel is not straightforward. Different results can be obtained depending on the criteria selected. In addition, having the proper dimensions and shape of the channel could be quite important in certain studies, such as the ones dealing with the dredging of the channels. Four-Point Model enables the user to use actual channel dimensions. The Modeling Support Branch intends to retrieve actual dimensions of major channels from navigational charts, and use them in the model. In addition, in certain reaches of the Delta, the river is modeled as a series of short channels in DWRDSM grid, mainly because of changes in the channel dimensions. Some of these neighboring short channels will be combined into a few longer channels, thus leading to reduced computational efforts.

Discussion

Once fully developed and calibrated, Four Point Model integrated with BLTM will be a very valuable tool for studying the Delta. The new system will be much more powerful than the existing one and should provide better insight and more flexibility in handling the complex hydraulic system found in the Delta. The added insight is crucial because the future water managers in California will be faced with tough decisions in satisfying agricultural and urban water needs, while answering all the environmental concerns.
Chapter 7

Trihalomethane Formation Potential Modeling
The Sacramento-San Joaquin Delta is a source of drinking water for 20 million Californians. Because the Delta is part of a tidal estuary and its land use is predominantly agricultural, Delta waters tend to reflect high levels of bromides and organic material. Organics and bromides promote the formation of disinfection by-products (DBPs) in the presence of a strong oxidant. Trihalomethanes (THMs), one class of DBPs, are a suspected threat to human health when present in sufficient quantities in drinking water.

In 1979, the Environmental Protection Agency (EPA) established a drinking water standard of 0.1 milligrams per liter for THMs. Anticipating revisions to the current standards and recognizing problems Delta water users may face in meeting more stringent requirements, the Department of Water Resources (DWR) has been studying THM precursors in Delta waters for several years. More recently, the Department has become active in modeling THM precursor fate and movement in the Delta as well as modeling THM formation and speciation.

This chapter summarizes DWR's most recent efforts to mathematically model THM formation potential in Delta waters. The first section presents a comparison between DWR's model and the THM kinetic equations employed by the EPA-Malcolm Pirnie (MPI) water treatment plant (WTP) model (Harrington et al. 1992). The second section of this chapter summarizes work that was undertaken to characterize THM speciation according to first order chemical kinetics. The final section briefly discusses a current project to simulate historically-observed THM precursor transport in the Delta.

A Comparison with EPA-MPI THM Equations

At the request of the Municipal Water Quality Investigations committee, a comparison of the modeling approaches developed by DWR (Hutton and Chung 1992a, 1992b, 1993a, 1993b) and EPA-MPI (Harrington et al. 1992) was undertaken. The DWR approach was contrasted with EPA-MPI's THM kinetic equations, not with the entire WTP model. Several aspects of the EPA-MPI THM equations were evaluated both qualitatively and quantitatively. Sensitivity analyses show the EPA-MPI kinetic equations tend to respond erroneously (in an incremental sense as well as in an absolute sense) to changes in bromide concentration.

To provide an "apples-to-apples" comparison, the DWR model was recalibrated with the University of Arizona database (Amy et al. 1987) to generalize its applicability to varying reaction conditions. This database is herein referred to as the UA database. Although the recalibrated DWR model is similar to the EPA-MPI model in terms of fit to the UA database, the DWR model responds in a more appropriate manner to incremental changes in bromide concentration. Furthermore, the DWR model requires the calibration of only two equations (14 model constants) to predict individual THM species concentrations, compared with EPA-MPI requiring calibration of 6 equations (38 model constants).
Recognizing limitations associated with high chlorine doses used to develop the UA database, the EPA-MPI and DWR models were recalibrated with a small data set provided by the Metropolitan Water District (MWD). This exercise showed the DWR formulation provides a superior fit to observed data and provides superior sensitivity to incremental changes in bromide concentration. This exercise also illustrated the potential difficulty of calibrating the EPA-MPI formulation to a small database.

Conclusions and Recommendations

Based on the aforementioned comparison between THM models, the following recommendations are offered:

1. An extensive database being developed by MWD should be used to calibrate a THM submodel employing the bromine distribution factors, rather than relying on the current EPA-MPI power function formulation.

2. It may be desirable to include different variables or otherwise improve upon the proposed form of the bromine incorporation factor ($\eta$). For example, Symons et al. (1993) shows that the initial bromide to average free available chlorine molar ratio is an important variable in predicting $\eta$. The DWR approach is not constrained to predicting $\eta$ directly, however. As an alternative to predicting $\eta$ directly, chloroform concentration could be predicted, possibly in a manner similar to the current EPA-MPI methodology. Then from the bromine distribution factor relationship $s_0 = [\text{CHCl}_3]/[\text{TTHM}]$, $s_0$ could be estimated. And since $s_0$ is functionally related to $\eta$, the remaining THM species could be determined. This may be an attractive alternative, particularly if differential rate equations can be developed for chloroform and [TTHM].

3. The bromine distribution factor relationships have been validated for delta waters treated under a variety of conditions. They have also been shown to be valid for the waters and conditions incorporated in the UA database. Nevertheless, these equations should be validated with additional data to test their general applicability. Assuming the worst case in which the bromine distribution factors have to be recalibrated for different waters, the proposed formulation will require the calibration of six equations with 26 constants (which is still preferable to the EPA-MPI requirement of six equations and 38 model constants).

4. For planning studies that focus on source water management impacts, it may be desirable to agree upon a set (or sets) of "standard" treatment conditions, e.g. simulated distribution system (SDS-THM) three-hour or 24-hour reaction conditions. These conditions can then be substituted into the THM submodel to develop a simplified form that varies only with influent water quality conditions. This simplified set of equations can be used to estimate THM formation from DWRDSM model output. This simplified analysis of source water management impacts is referred to as a "Level I" analysis.
5. Similar to recommendation 4, for planning studies that focus on WTP design and operational impacts, it may be desirable to agree upon a set (or sets) of "standard" influent conditions, e.g., critical winter, dry summer, or normal year. These conditions can then be employed as input to the EPA-MPI WTP model. A simplified analysis of WTP design and operational impacts is also referred to as a "Level I" analysis.

6. Finally, more refined planning studies (particularly those where THM formation at a particular WTP is the main objective) may wish to consider source water management and WTP design and operations as one system. For this type of study, DWRDSM output can be used directly as input to the EPA-MPI WTP model. This more sophisticated approach is referred to as a "Level II" analysis.

Critique of EPA-MPI THM Equations

The EPA-MPI THM equations were evaluated both qualitatively and quantitatively. The qualitative critique focused on model form, while the quantitative critique focused on model sensitivity.

Questionable Functional Forms. Amy et al. (1987) emphasized the development of "chemically rational yet statistically valid" models. Many aspects of the EPA-MPI THM equations do not adhere to this philosophy:

1. The precursor-related parameter UVA+DOC was determined by Amy et al. to be the best overall in terms of chemical significance and statistical fit. According to the authors, "The chemical significance of this parameter is that DOC represents a means of defining precursor concentration while UV absorbance provides an indication of precursor reactivity in forming THMs." The EPA-MPI equations for individual THMs use a variety of precursor-related parameters: UVA+DOC, UVA/DOC, UVA, and Br/DOC. This deviation from a single precursor-related parameter appears to be a compromise of "chemical significance" for statistical fit. The EPA-MPI equations (six equations and 38 model constants) developed from the UA database are as follows:

\[
\begin{align*}
\text{CHCl}_2 & = 0.278 \times (\text{UVA}+\text{DOC})^{0.414} \times (\text{Cl}_2)^{0.265} \times (T)^{0.18} \times (\text{pH}-2.6)^{0.300} \times (\text{Br}+1)^{0.22} \\
\text{CHClBr} & = 0.863 \times (\text{UVA}+\text{DOC})^{0.777} \times (\text{Cl}_2)^{0.300} \times (T)^{0.371} \times (\text{pH}-2.6)^{0.300} \times (\text{Br}+1)^{0.722} \\
\text{CHClBr}_2 & = 2.57 \times (\text{UVA}+\text{DOC})^{0.544} \times (\text{Cl}_2)^{0.276} \times (T)^{0.285} \times (\text{pH}-2.6)^{0.30} \times (\text{Br}+1)^{0.06} \\
\text{CHBr}_3 & = 61.4 \times (\text{UVA}+\text{DOC})^{0.580} \times (\text{Cl}_2)^{0.474} \times (T)^{0.110} \times (\text{pH}-2.6)^{0.30} \times (\text{Br}/\text{DOC})^{0.179} \\
\text{TTTHM} & = 0.00309 \times (\text{UVA}+\text{DOC})^{0.449} \times (\text{Cl}_2)^{0.400} \times (T)^{0.16} \times (\text{pH}-2.6)^{0.714} \times (\text{Br}+1)^{0.054} \\
\text{AMW} & = 105 \times (\text{UVA})^{0.500} \times (\text{Br}+1)^{0.48}
\end{align*}
\]
2. The EPA-MPI model does not sum the four individual THM species predictions to arrive at a total mass weight. Rather, the predictive approach is to estimate total mass weight as the product of total molar weight (Eq. 5) and apparent molecular weight (Eq. 6). This approach does not constrain total THMs to equal the sum of the four species. The magnitude of deviation associated with this approach has not been explored.

3. Eq. 6 does not take advantage of a priori knowledge of boundary conditions, i.e. a minimum AMW of 119.4 μg/μmole at 100 percent chloroform and a maximum AMW of 252.7 μg/μmole at 100 percent bromoform. Disregarding these boundary conditions permits the regression equation to predict infeasible values under extreme conditions.

4. Eqs. 1 through 4 do not approximate the nonlinear response of THM formation to bromide over a wide range of bromide. Fig. 1 gives examples of the response to bromide as observed by others. Harrington et al. (1991) attempted to circumvent this problem by segregating data into bromide ranges and modeling in a piece-wise fashion. While a piece-wise approach is certainly valid, it can result in a discontinuity at the interface between bromide ranges.

5. The resulting piece-wise equations show that while a given parameter may be directly related to THM formation under one bromide range, the same parameter may be inversely related to THM formation under another bromide range. This behavior, while easily handled by the DWR model with the bromine distribution factors, is not addressed by Eqs. 1 through 4.

**Sensitivity Analyses.** Performing sensitivity analyses on the EPA-MPI individual THM equations revealed erroneous model sensitivities, particularly with respect to bromide.

1. The base conditions employed for sensitivity analyses are adopted from Chowdhury et al. (1991), a paper on the original development of the EPA-MPI individual THM equations. Base conditions are: DOC = 3 mg/L, UVA = 0.045, pH = 7.5, Cl₂ = 4 mg/L, T = 25°C, and bromide takes on alternate values of 0.03, 0.3 and 0.6 mg/L. An additional base condition set for this analysis was t = 24 hrs.

2. See Figs. 2 and 3. While the CHCl₃ sensitivity given by Eq. 1 appears to follow the general pattern shown in Fig. 1, the CHCl₂Br and CHClBr₂ estimates from Eqs. 2 and 3 "blow up" with increases in bromide. The CHBr₃ estimates from Eq. 4 are relatively insensitive to bromide increases.

3. The piece-wise approach constrains the model from "blowing up". However, note the extreme discontinuities produced by this approach. The piece-wise model results in CHBr₃ being even less sensitive to bromide increases and results in total THMs decreasing with increasing bromide, an erroneous result. Fig. 4 shows
Trihalomethane Formation Potential Modeling

TTHM as the sum of Eqs. 1 through 4, rather than as the product of Eqs. 5 and 6.

Recalibration of DWR’s Model

DWR’s model was originally developed to predict THM formation under pre-defined test conditions, first for THMFP and later for SDS-THM. In this study, the model was reconfigured to predict individual THM compounds under varying test conditions and was calibrated with the UA database. As with the original formulation, individual species mass concentrations are calculated as follows:

\[
\begin{align*}
\text{CHCl}_3 & = 119.36 \cdot [\text{TTHM}] \cdot s_3(n) \\
\text{CHClBr} & = 163.62 \cdot [\text{TTHM}] \cdot s_5(n) \\
\text{CHClBr}_2 & = 208.28 \cdot [\text{TTHM}] \cdot s_7(n) \\
\text{CHBr}_2 & = 252.74 \cdot [\text{TTHM}] \cdot s_9(n)
\end{align*}
\]  

where [TTHM] is now predicted from Eq. 5 and \( s_3, s_5, s_7, \) and \( s_9 \) are the bromine distribution factors previously defined as:

\[
\begin{align*}
s_3(n) &= -.0222n^2 + .2444n^2 - .8667n + 1 \\
s_5(n) &= .0731n^3 - .4621n^2 + .7298n \\
s_7(n) &= -.0753n^3 + .1723n^2 + .1607n \\
s_9(n) &= .0296n^3 + .0223n^2
\end{align*}
\]  

It was unnecessary to recalibrate Eqs. 11 through 14 to the UA database. The bromine incorporation factor (\( \eta \)) was modeled with a form previously suggested:

\[
\eta = \frac{k}{1 + \beta}
\]  

where \( k \) is the bromine saturation level and takes on a value of 3. To predict THM speciation under varying test conditions, \( \beta \) was expanded into a multivariable function:

\[
\beta = 0.418(\text{UVA}^*\text{DOC}^{0.501}\cdot\text{Cl}_2^{0.135}\cdot\text{H}^{0.04}\cdot\text{T}^{0.207}\cdot(\text{pH} - 2.6)^{0.174}\cdot\text{Br}^{0.37})
\]  

The generalized bromine incorporation factor formulation shown in Eqs. 15 and 16 are preliminary and alternative formulations are being considered. Eq. 16 was developed with a backward stepwise log-linear regression procedure using a copy of the UA database provided by MPI. The database has 1,025 data points varying somewhat from the 995 database reported by Amy et al. (1987). As a caveat on the bromine incorporation factor, note that the EPA-MPI model implicitly uses the concept of bromine incorporation factor through the AMW term. AMW is a linear function of the bromine incorporation factor:
AMW = 119.36 + 44.46 * \eta  \hspace{10cm} (17)

Comparison of the DWR Model with the EPA-MPI Model

The previous discussion shows that the DWR model requires the calibration of two equations, one for [TTHM] and one for \beta. Model calibration of 14 constants is required, compared with the EPA-MPI calibration requirements of 38 model constants.

Observed values from the UA database were compared with predictions from the DWR model and the EPA-MPI model. Comparisons are shown in Figs. 5 through 7 as relative frequency histograms of percent deviation, where:

\%
\text{Deviation} = \frac{(\text{Predicted} - \text{Observed})}{\text{Observed}} \cdot 100 \hspace{10cm} (18)

1. To allow for an unbiased comparison, the EPA-MPI model was also recalibrated to the available UA database. Recalibration was necessary because, while the equations for \eta and AMW were based on 1025 observations (Harrington et al. 1992), Eqs. 1 through 5 were developed from only 995 observations. Recalibrated equations are as follows:

\begin{align*}
\text{CHCl}_3 & = 0.248 \cdot (\text{UVA} \cdot \text{DOC})^{0.444} \cdot (\text{Cl}_2)^{1.423} \cdot (T)^{0.277} \cdot (pH \cdot 2.6)^{0.488} \cdot (\text{Br}+1)^{1.93} \hspace{10cm} (19) \\
\text{CHClBr} & = 0.782 \cdot (\text{UVA} \cdot \text{DOC})^{0.180} \cdot (\text{Cl}_2)^{1.347} \cdot (T)^{2.252} \cdot (pH \cdot 2.6)^{0.866} \cdot (\text{Br}+1)^{0.770} \cdot (\text{Br})^{0.811} \hspace{10cm} (20) \\
\text{CHClBr}_3 & = 0.974 \cdot (\text{UVA} \cdot \text{DOC})^{0.444} \cdot (\text{Cl}_2)^{0.108} \cdot (T)^{2.242} \cdot (pH \cdot 2.6)^{1.18} \cdot (\text{Br})^{1.98} \hspace{10cm} (21) \\
\text{CHBr}_3 & = 63.7 \cdot (\text{UVA} \cdot \text{DOC})^{0.468} \cdot (\text{Cl}_2)^{0.977} \cdot (T)^{0.190} \cdot (pH \cdot 2.6)^{0.36} \cdot (\text{Br}+\text{DOC})^{1.98} \hspace{10cm} (22) \\
\text{TTHM} & = 0.00309 \cdot (\text{UVA} \cdot \text{DOC})^{0.423} \cdot (\text{Cl}_2)^{0.205} \cdot (T)^{2.86} \cdot (pH \cdot 2.6)^{0.608} \hspace{10cm} (23)
\end{align*}

Note that the Br+1 term was dropped from Eq. 23. Regression gave a negative exponent for this term. The backward stepwise procedure indicated that this term and several others were not statistically significant. Other terms were not dropped from the equations for this analysis, however.

2. For CHClBr\textsubscript{2} predictions, percent deviation is not displayed in Fig. 6 when bromide is less than 0.10 mg/L. Similarly for CHBr\textsubscript{3}, percent deviation is not displayed in Fig. 7 when bromide is less than 0.25 mg/L. These omissions are justified by observing that within these bromide ranges the species concentrations tend to take on values much less than 1 \text{ \mu g/L}.

3. Overall, both models are similar in their abilities (or lack thereof) to match the UA database.

DWR model sensitivity to bromide is shown in Figs. 2 through 4. Unlike the EPA-MPI model, DWR's model sensitivities correspond in a relative sense to trends shown in Fig. 1.
Calibrating Site-Specific Models

While the DWR model is superior in its incremental response to bromide, it is reasonable to assume that it does not adequately predict THM formation under delta drinking water conditions because of UA database limitations cited by Harrington et al. (1992). In an attempt to overcome this limitation, the DWR model was recalibrated with a small database provided by MWD. This data represents 60 observations of June 1992 conditions at Greene’s Landing, West Branch SWP water at Foothill, and East Branch SWP water at Devil Canyon.

1. The [TTHM] equation was recalibrated with a backward stepwise log-linear regression procedure. The chlorine dose term was redefined as an "available chlorine" dose by accounting for ammonia chlorine demands. A bromide term was not included in the calibration because the data set is biased in its distribution of bromide and precursors, i.e., Greene’s Landing has low bromide and low precursors while the other stations have high bromide and high precursors. Inclusion of a chlorine residual term did not appear to improve the regression:

\[ [\text{TTHM}] = 0.0203 \times (\text{UVA} \times \text{DOC})^{0.336} \times (\text{Cl}_2)^{0.330} \times (T)^{1.246} \times (\text{pH-2.6})^{3.895} \]  

(24)

2. The \( \beta \) equation was also recalibrated. Stepwise regression eliminated terms for \( t \), \( T \), and \( \text{pH} \). Again, the chlorine dose term accounts for ammonia chlorine demand:

\[ \beta = 0.217 \times (\text{UVA} \times \text{DOC})^{0.613} \times (\text{Cl}_2)^{0.713} \times (\text{Br})^{1.30} \]  

(25)

3. Bromine distribution factors (Eqs. 11 through 14) were not recalibrated.

The MPI-EPA THM equations were also recalibrated with the same data. Again, a backward stepwise log-linear regression procedure was used. This procedure eliminated a number of variables from the predictive equations, pointing out a disadvantage of using an approach that requires more equations and calibration constants. It is possible that these terms would not drop out if more data were available for calibration.

Observed values were compared with predictions from the recalibrated DWR and EPA-MPI models. The recalibrated DWR model gives superior predictions for TTHM and all four compounds. The difference between models is most pronounced for total THMs, where DWR estimates are within \( \pm 10 \) percent for 55 of the 60 observations and the EPA-MPI estimates are within \( \pm 10 \) percent for only 34 of the 60 observations. Again, the DWR model shows good sensitivity to changes in bromide while the EPA-MPI model does not.

Characterizing THM Speciation with First-Order Chemical Kinetics

By assuming that bromine is not actively involved in the oxidation of precursor material and is involved only in substitution reactions, THM speciation was modeled as a consecutive
irreversible three-stage reaction:

\[
\begin{align*}
\text{CHCl}_3 & \rightarrow \text{CHCl}_2\text{Br} \rightarrow \text{CHClBr}_2 \rightarrow \text{CHBr}_3 \\
\end{align*}
\]

where \( k_1, k_2, \) and \( k_3 \) are first order reaction rate constants defined by the following differential equations:

\[
\begin{align*}
\frac{d[\text{CHCl}_3]}{dn} &= -k_1 \cdot [\text{CHCl}_3] \quad (26) \\
\frac{d[\text{CHCl}_2\text{Br}]}{dn} &= k_2 \cdot [\text{CHCl}_3] - k_2 \cdot [\text{CHCl}_2\text{Br}] \\
\frac{d[\text{CHClBr}_2]}{dn} &= k_3 \cdot [\text{CHCl}_2\text{Br}] - k_3 \cdot [\text{CHClBr}_2] \\
\frac{d[\text{CHBr}_3]}{dn} &= k_3 \cdot [\text{CHClBr}_2] \\
\end{align*}
\]

The following bromine distribution factor relationships result after solving this system of differential equations and assuming that the initial chloroform concentration is equal to [TTHM]:

\[
\begin{align*}
s_4(n) &= e^{k_1 n} \\
s_5(n) &= \frac{k_2}{k_2 - k_1} \cdot e^{k_2 n} - \frac{k_2}{k_2 - k_1} \cdot e^{k_1 n} \\
s_6(n) &= \frac{k_3}{(k_3 - k_2)(k_3 - k_1)} \cdot e^{k_3 n} + \frac{k_3}{(k_3 - k_2)(k_3 - k_1)} \cdot e^{k_2 n} + \frac{k_3}{(k_3 - k_2)(k_3 - k_1)} \cdot e^{k_1 n} \\
s_7(n) &= 1 - \frac{k_3}{(k_3 - k_2)(k_3 - k_1)} \cdot e^{k_3 n} - \frac{k_3}{(k_3 - k_2)(k_3 - k_1)} \cdot e^{k_2 n} - \frac{k_3}{(k_3 - k_2)(k_3 - k_1)} \cdot e^{k_1 n} \\
\end{align*}
\]

From Eq. 30, a value for the rate constant \( k_1 \) may be estimated by plotting \( \ln(1/s_4) \) versus \( n \) and determining a best-fit slope. This technique results in an estimate of \( k_1 = 1.19 \) for the calibration data. Rate constant \( k_2 \) may be estimated by setting Eq. 27 equal to zero, dividing through by [TTHM], substituting in \( k_1 = 1.19 \), and determining values of \( s_5(n) \) and \( s_6(n) \) for the value of \( n \) such that \( s_5 \) is maximized. This step can be satisfied by visual inspection of the data, resulting in \( s_5 = 0.334 \) and \( s_6 = 0.340 \) at \( n = 1.05 \) and:

\[
k_2 = 1.19 \times (0.334/0.340) = 1.17
\]

In a similar manner, \( k_3 \) may be estimated by setting Eq. 28 equal to zero, dividing through by [TTHM], substituting in \( k_2 = 1.17 \), and determining values of \( s_6(n) \) and \( s_7(n) \) for the value of \( n \) such that \( s_6 \) is maximized. Values of \( s_6 = 0.218 \) and \( s_7 = 0.411 \) were estimated for \( n = 1.90 \) and:

\[
k_3 = 1.17 \times (0.218/0.411) = 0.62
\]

The first order kinetic representation of the bromine distribution factors can be summarized
by substituting values for the rate constants into Eqs. 30 through 33:

\[ s_4(n) = e^{1.1n} \]  \hspace{2cm} (36) \\
\[ s_5(n) = -59.50 \ e^{1.1n} + 59.50 \ e^{1.7n} \]  \hspace{2cm} (37) \\
\[ s_6(n) = 122.13 \ e^{1.1n} - 126.57 \ e^{1.5n} + 4.44 \ e^{0.4n} \]  \hspace{2cm} (38) \\
\[ s_7(n) = 1 - 63.63 \ e^{1.1n} + 67.07 \ e^{1.7n} - 4.44 \ e^{0.4n} \]  \hspace{2cm} (39)

While these relationships provide some correspondence between observed and predicted values, the correspondence is inferior to that provided by probability-based polynomial relationships (Hutton and Chung 1993b). Deviation between observed and predicted values, particularly at high values of \( n \), may suggest that bromine substitution reactions do not always follow first order kinetics.

**Historic Simulation of Delta THM Precursors**

The purpose of this project is to validate DWRDSM's use as a tool to track bromide and THM precursors in the delta. DWR is currently running a 24-month DWRDSM simulation (12-month model "warm-up") of historic conditions from October 1989 through September 1991, tracking bromide, dissolved organic carbon (DOC), ultraviolet absorbance at 254 nm (UVA), and THMFP as carbon (TFPC). The simulation employs a monthly time step, a 19-year mean tide, and DAYFLOW hydrology. When available, water quality boundary conditions are based on historic grab-sample bromide and precursor data collected by DWR (Input 1993). It is anticipated that results of this historic simulation will be presented at the American Society of Civil Engineers Hydraulics Division's 1993 National Conference in San Francisco (Hutton and Enright 1993).
References


Effect of Salt Water Intrusion on THM Formation Potential

from: Lange & Kacwzynski (1978) JAMA 70:11

Concentration of trihalomethanes as a function of weight ratio of bromide ion to chlorine (chlorine dose—11.5 mg/L; HA—2.83 mg as NVTOC/L; time—168 h; pH—7; temperature—25°C)

from: Pourmoghaddas et al. (1993) JAMA 85:1

Figure 7.1
THM MODEL SENSITIVITY ANALYSIS
CHCl3 (TOC=3; UVA=0.045; CL2=4; t=24; T=25; pH=7.5)

THM MODEL SENSITIVITY ANALYSIS
CHCl2Br (TOC=3; UVA=0.045; CL2=4; t=24; T=25; pH=7.5)

Figure 7.2
THM MODEL SENSITIVITY ANALYSIS

CHClBr2 (TOC=3; UVA=0.045; CL2=4; t=24; T=25; pH=7.5)

THM MODEL SENSITIVITY ANALYSIS

CHBr3 (TOC=3; UVA=0.045; CL2=4; t=24; T=25; pH=7.5)

Figure 7.3
Figure 1. Relative Frequency of Percentage Deviation Between Predicted and Observed CHCl$_3$ Concentrations:
University of Arizona Data Set (0.01 mg/L ≤ Br ≤ 1.25 mg/L)
Relative Frequency of Percentage Deviation Between Predicted and Observed CHCl₃Br Concentrations:
University of Arizona Data Set (0.01 mg/L ≤ Br ≤ 1.25 mg/L)

Figure 7.5
Relative Frequency of Percentage Deviation Between Predicted and Observed CHBr₃ Concentrations:
University of Arizona Data Set (0.25 mg/L ≤ Br ≤ 1.25 mg/L)

Relative Frequency of Percentage Deviation Between Predicted and Observed Total THM Concentrations:
University of Arizona Data Set (0.01 mg/L ≤ Br ≤ 1.25 mg/L)

Figure 7.6
Chapter 8

Refinement of Carriage Water Routine
During 1992 various studies have been conducted to refine the carriage water routine used in the Minimum Delta Outflow (MDO) model used by DWRSIM. To date, a modeling approach superior to the current routine has not been developed. This chapter outlines specifications for a refined model and suggests studies (or experiments) that will be undertaken to explore alternative methodologies.

Specifications for an MDO Replacement

1. The model must be compatible with DWRSIM, implying two critical design considerations:
   a. The model should operate on a monthly time step.
   b. Input variables to the model are limited to current month inflows and outflows, antecedent inflows and outflows, and cross-channel gate operations.

2. DWRSIM is a planning model, not a forecasting model. Therefore, it must be robust enough to account for future facilities. An empirical model based strictly on historic conditions would not meet such a specification.

3. The model must be able to predict outflow requirements to meet target salinity standards. Previous efforts have focused on developing models that predict salinity from flows. While these efforts were somewhat successful, these models were unable to solve the inverse problem (i.e., predicting flows from salinity).

4. Given that Delta water quality is a complex function of several conditions in addition to inflows and outflows, it would be desirable to develop a model with stochastic characteristics. For example, the model could give outflow requirements for various levels of probability in meeting a water quality standard.

Suggested Experiments

From a roundtable discussion held by the Delta Modeling Section, a number of suggestions for this project resulted. Outlined below are recommended "experiments" to undertake. The term "experiment" is used in recognition of the difficulties associated with this project. Experiments should be conducted on the following stations: Rock Slough, Mallard, Jersey Point, and Emmaton. If a particular experiment looks promising, other stations should be considered.
Statistical Analysis of Observed Data

Partial correlations between observed salinity and various observed or calculated flow parameters at Delta stations of interest should be defined. Correlations with other real-time influences, such as wind or barometric pressure, could also be included in this analysis. Such an analysis should show that project operations have a limited influence on Delta water quality and that other variables must be taken into account to fully explain salinity conditions in the Delta.

This task is not truly experimental in nature. It seems fairly well defined and could be performed independently of the other tasks. It is recommended that this task be undertaken by a student or a consultant with a strong statistics background.

Develop Salinity Relationships Using Steady-State DWRDSM Analysis

The purpose of this experiment is to define isosalinity curves for various combinations of Sacramento River flows and export pumping. These curves would be location specific and specific to a range of other hydrologic parameters, e.g., set bounds on San Joaquin river flow or east side streams flow.

Probability Analysis of Observed Data

Similar to the prior experiment, an attempt could be made to construct from observed data isoprobability curves for various combinations of Sacramento River flows and export pumping that meet a defined salinity level. For this experiment, one will be looking at salinity as an expected value rather than as a deterministic value. For example, suppose one wishes to determine what flows and exports can be maintained to meet a standard of 150 ppm of chloride at Rock Slough. The observed data could be segregated into ranges of Sacramento flow and exports. Within this subset, one can determine the percentage of observations that are at or below 150 ppm chloride. This probability can be plotted for each range of Sacramento flow and exports. Then contours can be plotted through similar probabilities, resulting in a figure that shows the probability of meeting a salinity standard for a given combination of Sacramento flow and export.

To provide enough data for this experiment, daily values should be used. To take into account antecedent conditions, these daily values should be transformed into 28-day running average values. Data should be segregated into similar hydrologic subsets, maybe using, for example, San Joaquin River flow, east side streams flow, or net Delta outflow.
Probability Analysis of Model Output

If the above experiment appears promising, it should be repeated with data generated by a multi-year DWRDSM run. This run would probably need to be rather large to generate enough data for a statistical analysis.

Optimization Approach

The premise of this approach is that to meet a given salinity standard, a variety of flow combinations can potentially be employed. Therefore, the objective of the optimization problem would be to minimize a "cost" associated with each flow combination. The main constraint would be to maintain the salinity standards. Some work was undertaken on this project back in 1990. The unpublished Delta Modeling Section document "Carriage Water Baseflow Analysis: Methodology and Assumptions" summarizes this work.

Transfer Function Model

An outside contract could be awarded to develop a simplified Delta model. A work proposal was submitted by Dr. Gilbert Bogle in July 1991 to develop a "Delta transfer function" model. Because much of the work outlined in his proposal has already been accomplished, the contract scope and cost may now be much less than originally estimated.

CCWD Modeling

We should remain open to suggestions by Contra Costa Water District and others on how to improve the carriage water routine.
Chapter 9

North Delta Flood Modeling
Chapter B

North Otago Road Network
Progress in the past year in North Delta flood modeling occurred both in development and in flood event analysis. New developments include the collection and application of levee crown and stage frequency data, an interface with the section's Delta Graphical User Interface, and model replacement studies. Also completed were flood studies for the 300-, 100-, and 2-year floods. In the upcoming months, the section will investigate alternatives to the DWOPER/Network Flood Model and develop hydrologic tools to do work that was previously completed in other units.

Flood Studies Performed

Using the DWOPER/Network model, flood simulation studies were performed to analyze the impacts of 300, 100, and 2-year flood events on the North Delta. The studies were performed using existing geometry and two different planning alternatives: dredging only, and dredging combined with levee setbacks.

300-Year Flood Study

The purpose of the 300-year flood study was to evaluate secondary and tertiary impacts of implementing flood control measures in the North Delta Project (NDP) study area. It was shown that because of the larger flow areas obtained with combining dredging with levee setbacks, peak flood elevations were substantially reduced. It was also shown, however, that substantially increased upstream flow areas had the negative impact of slightly raising downstream peak flood stages.

100-Year Flood Study

The purpose of the 100-year study was to evaluate the impact of various alternatives of NDP on reducing the 100-year flood elevations in the North Delta. Overall, it was shown that peak flood stages were reduced by the planning alternatives. Dredging does not reduce the peak stages as much as levee setbacks and dredging combined.

2-Year Flood Study

The purpose of the 2-year study was delineate wetlands as impacted by possible NDP alternatives. Wetland area was slightly reduced due to dredging. Combined dredging and levee setbacks reduced the wetland areas somewhat more significantly.
Use of Levee Crown and Stage Frequency Data

To complete the flood studies this year, new data was collected to help verify model results. For the 300-year flood study, for example, there was no data from a flood of that magnitude on record. When expected 300-year flows and tides were analyzed by the model, it was very difficult to determine whether or not the computed results were reasonable. Results from the model could not be compared to any event that had actually occurred. Therefore, other sources of data had to be relied upon to give clues as to what the water surface elevations might be like in extremely severe floods.

Recorded data from an observed flood is the best benchmark to determine if modeled water surface elevations are correct. Because observed data is often lacking, especially for rare events, alternative methods must be employed. Clues of what the maximum flood stage must be gathered elsewhere. In the case of the 300-year flood study, the clues used are the elevation of the top of Delta levees and stage-frequency data. Stage frequency curves are statistically calculated from historical data. They relate flood stage to various magnitudes of floods. Magnitudes are expressed in terms of frequency of occurrence. Even though a flood that has a likelihood of occurring once every 100 years may be the highest flood on record, a 300-year stage may be predicted by extrapolating the stage-frequency curves. While the certainty of this prediction is not very high, it is much better than no prediction at all.

Compared to stage-frequency data, levee crown elevation data is more reliable. Although levee elevation in a given location may change slightly from year to year, it can be measured more reliably than temporal flood stages. Levee crown elevation data is used two ways: as a factor in the determination of levee failure and also as an indicator of maximum possible stage values.

The levee crown elevation and stage frequency data was extracted from "Hydrology, Sacramento-San Joaquin Delta, California, Special Study," U.S. Army Corps of Engineers, Sacramento District, February 1992. Stage frequency curves for estimated 1986, 50-year, 100-year, and 300-year floods are included, along with levee crown elevations for most islands and tracts in the Delta.

To convert the data included in the Army Corps' document into a form usable in flood studies, data points in the Corps' data were correlated to North Delta stations as they are defined in the flood model. Once a correlation was established, values from digital representations of the plots were extracted to form a table of values that can be used in flood studies. Table 10.1 is a sample from that table.
Table 10.1  Sample of Extracted Data

<table>
<thead>
<tr>
<th>Sect.</th>
<th>Dist.</th>
<th>Local Name</th>
<th>Right Levee</th>
<th>Right Crown</th>
<th>Left Levee</th>
<th>Left Crown</th>
<th>Stage Frequency Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>94327</td>
<td>JUNCTION NF MOK &amp; SNOGRASS SLOUGH</td>
<td>14.0</td>
<td>13.4</td>
<td>13.7</td>
<td>14.3</td>
<td>15.1</td>
</tr>
<tr>
<td>101</td>
<td>98127</td>
<td></td>
<td>13.2</td>
<td>13.0</td>
<td>13.3</td>
<td>13.9</td>
<td>14.7</td>
</tr>
<tr>
<td>102</td>
<td>101877</td>
<td></td>
<td>12.4</td>
<td>12.4</td>
<td>12.7</td>
<td>13.3</td>
<td>14.1</td>
</tr>
<tr>
<td>103</td>
<td>105677</td>
<td></td>
<td>12.6</td>
<td>11.9</td>
<td>12.3</td>
<td>12.8</td>
<td>13.5</td>
</tr>
</tbody>
</table>

300-year flood simulation runs were performed and the above data was plotted along with model output to accurately compare values. In Figure 9.1, for example, computed water surface profiles of preliminary 300-year flood studies are plotted against the levee crown and 300-year stage frequency data. In the base run, stages were computed that exceeded levee crown elevation. In a run that included channels with dredging and levee setbacks, the stage was calculated to be mostly below levee crowns. With the data displayed in this format, modeling decisions can be made with the best available information.

DGUI — Network Model Interface

Computer technology has progressed to the point where the quantity of computed data far exceeds the ability of engineers to analyze data in a tabular format. Luckily, the ability to transfer this data into graphical representations from which engineering decisions can be made is also progressing.

The Delta Graphical User's Interface (DGUI) is an important link between large quantities of tabulated data produced by the section's computer models and a visualization package. The DGUI is used to produce a variety of plots very quickly. A simple t-y plot can be generated almost as easily as a complex animated profile plot. Analyses that used to take days or weeks, can often be completed in hours due to the decreased post processing time. Errors in model output are more easily detected. Additionally, important trends in the data are not lost because of the difficulty in retrieving that data. The flexibility of the DGUI has enabled modelers to produce a unique plot that is especially useful in flood modeling. The maximum water surface elevation profile plot is a good illustration of the benefits of interfacing the flood model with the DGUI.

Maximum Water Surface Elevation Profile Plots

The object of any flood analysis is to determine the maximum stage produced by various physical conditions in the flood plain. The tool that is often used to display maximal stage
conditions is the profile plot. The profile plot displays river stage on the vertical axis and distance along the river on the horizontal axis. Profiles can be composed of up to 60 stations. Traditional profile plots (Figure 9.1) represent a snapshot of the water surface elevation along the length of a river during the flood. Determining the correct instant of time to take the "snapshot" is difficult because the peak water surface elevation occurs at different times at different points along the river. To simplify plotting, however, a central location is used as a reference point. At the time when the maximum stage occurs at the reference point, the stage is plotted for all points along the channel of interest. It is assumed that when the peak stage occurs at this point, peak stages are occurring along the entire channel. While this is an easy way to produce a profile plot of peak stages, it is not an accurate representation of maximum stages at all locations for all time. By combining two simple features of the DGUI, the maximum filter, and the profile plot, an accurate plot of maximum stage at all designated locations along a river can easily be produced. Previously, this plot was so labor intensive that it was never attempted. This useful plot can now be produced in minutes.

The DGUI Interface

The output of the Network Model was relatively simple to connect to the DGUI. The tasks that were required are listed below.

1. Digitize the Grid

The DGUI was originally developed for DWRDSM. Because the DWRDSM grid is different than the Network model's, its grid needed to be digitized so that the DGUI could display the North Delta study area on the computer screen in the same way as it displays the DWRDSM grid. See Figure 9.2. This representation is manipulated interactively with a mouse to access specific portions of model output. For example, if water surface elevation data is desired at New Hope Landing, the user places the mouse pointer over that location on the grid, and selects a line segment that represents that station. The data is then automatically retrieved and is available for use in a variety of plots.

2. Name Channel Segments

To use the digitized grid interactively, the line segments that represent river channels must be named in a look-up table. The table describes which channel each line segment
defines. This information allows the DGUI to retrieve the appropriate channel's model output depending on the channels that are selected on the grid's image.

3. Convert Model Output

Model output must be in HEC-DSS format to be used by the DGUI. Minor modifications were made to the DWOPER/Network flood model's codes, both in the input file and the source code. DSS output files are converted to binary form by using the DSSTS utility. Once in the binary form they can be used directly by the DGUI.

Future Directions

Potential Network Model Replacement

Investigations are currently under way to implement the Four Point Model for use in North Delta flood modeling. The Four Point Model, which has the capability to model high flows, is also being developed for use as the section's main hydrodynamics model. (See Chapter 6.) Currently, different models with different grids are being used to model flood flows and low flows. If the section can use one model for two uses, it will consolidate both model development, and training of staff.

Replacing the Network model with the Four Point Model, if proven feasible, is more of a modeling operations management improvement than a model upgrade. By using a generalized model, any advancements that are made are usable in a wider scope of studies. It will also enable managers to more efficiently use staff in developing models and performing model runs. In the long term, using one model will improve the overall quality of flood modeling studies.

Other Planned Developments

To improve the performance and efficiency of the flood modeling studies, the ability to store, manage, and model all types of flood modeling data will be transferred to the Delta Modeling Unit. In the past flood studies, hydrology and channel geometry data generally were provided from outside the unit. This arrangement caused inefficiencies in documenting and transferring data. When all of the modeling activities are conducted under one roof, management of various modeling activities is consolidated, thus allowing more control and better understanding of the modeling process. To reach the goal of consolidating flood modeling operations, the following developments are planned:

1. Channel geometry data management system development (the storage of geometric data and related records).
Figure 9.1
WATER SURFACE PROFILE A, 300-YR FLOOD
Base and Preferred Alternative
at time of peak at Lambert Road Upstream and New Hope Landing
(COE's 300-yr and levee crown data also plotted)