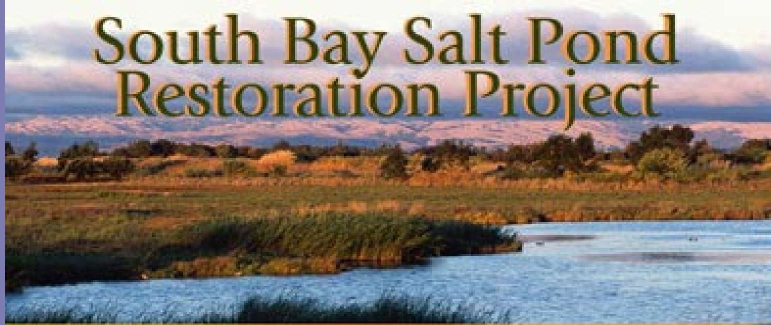

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A San Francisco Bay project provided by
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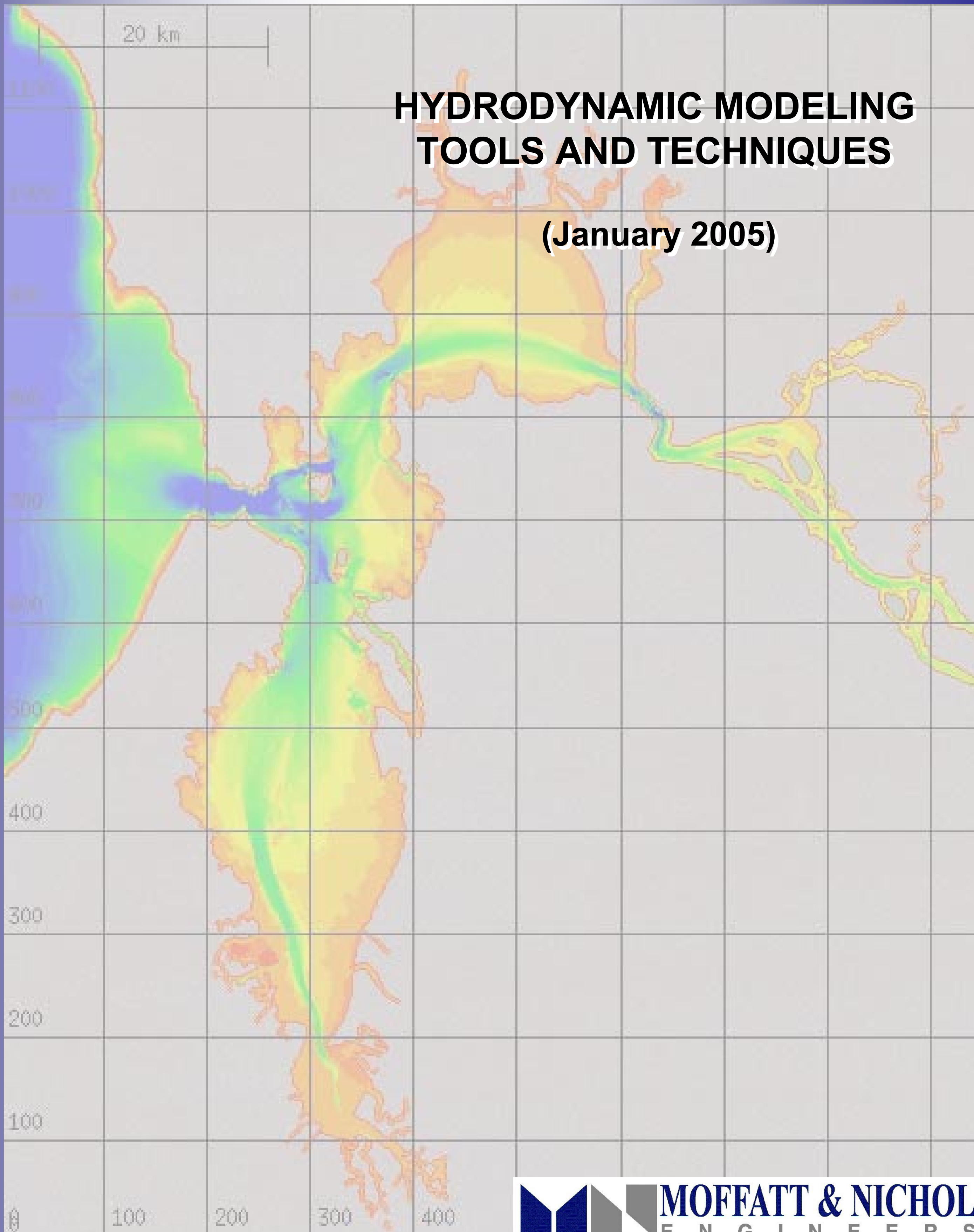
Coastal Conservancy and
U.S. Fish & Wildlife Service

HYDRODYNAMIC MODELING TOOLS AND TECHNIQUES

(January 2005)



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HYDRODYNAMIC MODELING

TOOLS AND TECHNIQUES

SOUTH BAY SALT POND RESTORATION PROJECT

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January 2005
M&N Job 5196-03

CONTENTS

1. INTRODUCTION

1.1 BACKGROUND

The South Bay Salt Ponds Restoration Project provides an opportunity for improving the physical, chemical, and biological health of the San Francisco Bay, while integrating flood management, public access, wildlife-oriented recreation, and education opportunities. The project will restore and enhance a mosaic of wetlands, while maintaining many of the ponds as managed ponds to maximize their use as feeding and resting habitat for migratory shorebirds and waterfowl. The project consists of enhancing the recently acquired ponds which consist of about 7,500 acres of existing salt ponds in the southern part of the South Bay, 4,800 acres of ponds along the East Bay shoreline, and about 1,500 acres along the West Bay shoreline.

The long-term restoration planning process is being managed by the Conservancy, USFWS, and DFG. USFWS and DFG will be the landowners/managers and will be responsible for planning and conducting the interim stewardship of the salt ponds (maintenance of levees and management of water), while the long-term restoration planning is taking place. The goals of the project are defined as follows:

- Restore and enhance a mix of wetland habitats;
- Provide for flood management;
- Provide wildlife-oriented public access and recreation opportunities.

Work described in this report was conducted for the California Coastal Conservancy, as part of the initial planning phase of the restoration project. The focus of this investigation is to provide an analysis of relevant hydrodynamic modeling tools and techniques that can be used during the design and environmental review phases, and identifying the type and sequence of data that is needed for numerical and/or other analytical or physical models.

A critical element of the Project is predictive numerical modeling, which will assist in designing the restoration alternatives and analyzing the impacts of the alternatives. Hydrological analysis and predictive modeling will be undertaken to evaluate the impacts of the project on existing levels of flood protection. Restoration planning and engineering, along with cost estimates of alternatives, will help the project management team assess the construction impacts of each alternative, compare the costs and benefits of the alternatives, and determine the feasibility of implementation[1].

Changes to the geomorphology of the South Bay are central to the impact analysis and potential for success of the restoration project. Channel and Bay bottom morphology strongly influences the system hydrodynamics, which in turn drives flooding, water quality, and geomorphic processes which affect habitat evolution. The rate of geomorphic change is directly related to the potential for erosion of the mudflats, and deposition in the newly created tidal wetlands, governing the time over which interim management measures (potentially costly) may be needed.

[1] California State Coastal Conservancy, U.S. Fish and Wildlife Service, California Department of Fish and Game, South Bay Salt Pond Long-Term Restoration Plan: Guiding Principles, Objectives, and Conceptual Model, June 4, 2003.

Historic geomorphic changes that have occurred in part due to salt pond construction and operations include:

- Loss of tidal prism causing tidal channels to become more narrow and shallow, significantly decreasing the capacity of local rivers and streams and increasing the local hazards of flooding and need for dredging;
- Decreased water quality and increased turbidity within the Far South Bay;
- Curtailment of the influence of tidal marshes on sediment transport leading to the accumulation of sediments from watersheds at the mouths of streams.

As existing salt ponds are opened to tidal action, the morphology of channels and the Bay bottom (mudflats) will be affected. Selection of a numerical model to evaluate the extent of these changes (the rate of channel scour; the rate of accretion within the salt ponds; implications for mudflat erosion; channel migration, etc.) is critical to the success of the overall modeling effort. This model selection must be supported by timely data collection.

1.2 SCOPE OF WORK

This task includes an analysis of relevant hydrodynamic modeling tools and techniques that can be used during the design and environmental review phases, and the type and sequence of data that will be needed for numerical modeling and/or other analytical or physical models. The report covers the following tasks :

1. Identify issues related to hydrodynamics, hydrology, water quality and sedimentation.
2. Evaluate existing tools and techniques in restoration planning and design.
3. Provide recommendations on modeling strategy and numerical models.
4. Identify Available Data For Preliminary Modeling And Analysis
5. Estimate Costs For Preliminary Modeling And Analysis

This report focuses on issues that are common to all parts of the South Bay Salt Pond Restoration project; it does not attempt to address issues such as infrastructure constraints or levee conditions that are specific to particular ponds. Additionally, the emphasis of this analysis is on general model types and gives examples of each type, not on which proprietary or public domain code or model(s) should be used.

2. ISSUES TO BE ADDRESSED THROUGH NUMERICAL MODELING

This memorandum relates modeling tasks to the specific decisions defined in the planning documents[2]. For convenience, those specific decisions that are appropriate for guidance through numerical and physical modeling efforts (those related to physical processes, contaminants and water quality) are listed below.

2.1 SPECIFIC DECISION 10: SEDIMENT BUDGET

In an iterative manner,

1. *determine if there is a sediment deficit by determining the sediment supply in the South Bay (taking into account sea level rise, sediment supply and dynamics, subsidence, and other projects in Bay);*
2. *determine how much sediment is needed for each restoration alternative in order to meet the project goals and objectives (habitat evolution, mix of tidal habitats);*
3. *determine the need for imported sediment for tidal restoration areas, if any. Determine potential sources and feasibility of importing sediment, if required. Conduct a cost-benefit analysis of speed of restoration (evolution rates to tidal marsh of individual ponds and phasing of tidal restoration over entire project area) versus costs of importing sediment, also taking into account the cost of on-going pond management versus sediment input.*

The first step towards addressing Specific Decision 10 is to understand existing conditions, particularly with respect to the sediment supply within the South Bay and water circulation within the South Bay and the restoration areas. The present behavior of the following quantities should be evaluated:

- Bed and suspended sediment characteristics (grain size and concentration), and sediment dynamics (patterns of scour, sediment transport, deposition, and subsidence) throughout the restoration area.
- Hydrodynamics (water levels and currents, including tides and storm surge) and sediment characteristics and dynamics in the South Bay. These quantities are required to provide boundary conditions for modeling the restoration area. Anticipated future changes unrelated to the restoration (sea level rise, climatic changes affecting Delta outflow, etc.) must also be characterized.
- Sediment supply and hydrodynamics near the limits of the restoration area (characteristics of creeks and Delta outflows) must be characterized. The upstream limit of the area impacted by the restoration (e.g., through tidal intrusion or headcutting) should be estimated conservatively; explicit numerical modeling above this limit may not be necessary. The upper reaches of watersheds, which will not be directly affected by the restoration, will provide boundary conditions (e.g., the sediment budget and fresh water inflows) for modeling the restoration area. Anticipated future changes to sediment supply unrelated to the restoration (continuing development, creek restoration projects, flood protection projects, and possibly climatic changes affecting Delta outflows) must be characterized.

[2] California State Coastal Conservancy, U.S. Fish and Wildlife Service, California Department of Fish and Game, South Bay Salt Pond Restoration Project: Major Decisions, Specific Decisions, and Key Questions, April 7, 2003.

- The sediment exchange between the Central and South Bay must be characterized, although an explicit modeling effort may not required. The large sediment influx from the Delta system, if a significant portion reaches the South Bay, could partly offset sediment trapping within the salt ponds and so mudflat erosion.

The overall modeling approach should be as follows:

- Perform screening-level modeling. At present, there is little understanding of such basic existing conditions as the level of tidal muting within the channels, and its relationship to existing levees and control structures. Relatively simple one-dimensional or analytical modeling of the channels and ponds based on limited field data (e.g., one month of tidal data together with a few channel cross-sections), combined with an existing 2-dimensional model for the South Bay, can be used to support the initial, screening-level alternatives formulation process.
- Construct, calibrate and verify a numerical model of the existing hydrodynamics and sediment transport through the restoration area and the South Bay. Since the restoration area and the South Bay interrelate so closely, particularly with regard to sediment supply, a model covering both areas should be constructed. The upland areas need not be explicitly included in the model, provided that the upstream boundary is above the area impacted by the restoration.
- The initial modeling should also cover salinity and flushing, to address South Bay impacts in support of Specific Decision 11 (see below).
- Modify the existing conditions numerical model, or construct/calibrate standalone models for specific issues as necessary (for example pond routing model), keeping in mind the scale of the proposed restoration alternatives.

Numerical modeling, if backed up by sufficient field data, can provide answers to specific questions relating to hydrodynamics and geomorphology such as the following:

- What is the present sediment budget of the South Bay and restoration area?
- Changes are likely upstream of any levee breaches due to head-cutting, as well as downstream due to increase in tidal prism. How will the channels of the existing tributary creeks and sloughs change in cross-section and in planform (meanders)?
- How rapidly will the salt ponds fill in to create tidal marshes? Is the ambient sediment load adequate to establish desired habitat grades within a reasonable time span, or will there be a need to import material to accelerate habitat formation?
- What will be the characteristics of the tidal marshes, in terms of habitat value (inundation frequencies, availability of high elevation refugia, etc.) and flooding?

2.2 SPECIFIC DECISION 11: SOUTH BAY IMPACTS

Determine the impacts of tidal restoration on hydrodynamics, geomorphology, and water quality of San Francisco Bay (including potential loss of mudflats, impacts on sediment budget, impacts to other projects in the Bay, increased velocity and scour, changes to currents and tides, impacts on navigation, impacts on infrastructure, increased residence time), and how adverse impacts can be minimized

As with Specific Decision 10, the first step towards Specific Decision 11 is to understand existing conditions. The hydrodynamics and sediment transport in the South Bay are intimately connected to those within the channels and ponds, and the plan should be to construct a single model or sequence of models that integrates both modeling domains.

The behavior of the following quantities should be evaluated:

- Hydrodynamics (water levels and currents) throughout the restoration area and the South Bay – as for Specific Decision 10.
- Sediment characteristics and sediment dynamics throughout the restoration area and the South Bay – as for Specific Decision 10.
- Salinity throughout the restoration area, upstream into the creeks to the limit of tidal intrusion, and the South Bay.
- Dispersion of other conservative constituents (including flushing time predictions) throughout the restoration area and the South Bay.
- Circulation and dispersion of contaminant plumes in the South Bay, both near-field and far-field (initial plume dispersion from ponds which were not connected in the ISP, contaminated sediment resuspension, etc.).

The last item relates specifically to the dispersion of pollutants such as BOD, metals, organics, pesticides, etc. from the sediment in the ponds. The study area is included within the modeling domain of hydrodynamics and sediment transport within the South Bay. However, a more detailed circulation model of the South Bay, possibly in three-dimensions, is likely to be required to address this issue. Often, the initial dilution is calculated with a near-field plume model such as the CORMIX or PLUMES (both EPA-approved); the resultant far field concentrations are used as input to the overall hydrodynamic model. Boundary conditions to the near-field plume model can be provided from field measurements (preferred).

For general water quality issues, in situations such as the South Bay Salt Ponds where relatively small bodies of water are connected to larger bodies of water that are assumed clean, the rate of contaminant dispersion is usefully expressed in terms of flushing times. It is often possible to use flushing time modeling to assess water quality for conservative or nearly conservative constituents directly, without further explicit modeling, particularly for conservative constituents. Although Specific Decision 11 requires that other water quality impacts such as methyl mercury concentrations be considered, since Specific Decisions 17 through 20 relate specifically to water quality, this issue is here treated only at a conceptual level.

The overall modeling approach should be as follows:

- Construct, calibrate and verify a numerical model of the existing hydrodynamics, sediment transport, salinity, and flushing times through the restoration area and the South Bay.
- Modify the numerical model to describe each of the proposed restoration alternatives, and run the model to predict the resulting hydrodynamic, geomorphic, salinity, and water quality changes.

- Make changes as necessary to the proposed restoration alternatives to attain desired goals, and re-run the models.
- Construct, calibrate and verify a separate, more detailed, numerical model(s) of near filed processes to evaluate water quality impacts as it relates to dispersion of contaminant plumes. Use the modeled hydrodynamics of the South Bay to provide boundary conditions for this plume dispersion model.
- Change the boundary conditions of the far field model based upon the modeled hydrodynamics of the near field model for each restoration alternative.
- Re-run the far field model as necessary based on changes to boundary conditions.

Numerical modeling, if backed up by sufficient field data, can provide answers to specific questions relating to hydrodynamics, geomorphology, salinity, and water quality such as the following:

- How will the area immediately offshore change (mudflat erosion) ?
- How will the water levels and velocities within these channels change as a result of scour (which will tend to increase tidal intrusion) and opening up the dikes to the ponds? Will the toes of the remaining dikes scour?
- Will tidal intrusion into the creeks increase?
- Will existing flood control levees need to be improved ?
- Will there be a significant change in hydrodynamic processes in the South Bay ?
- How will the rate of dispersion of pollutants within the South Bay change?

2.3 Specific Decision 12: Pond Management

Determine how enhanced ponds will be managed to meet project goals and objectives for managed pond habitat, including the engineering requirements of managed ponds, and how water will be circulated through managed ponds.

Modeling for this Specific Decision is very similar to the modeling in support of Specific Decisions 10 and 11. The quantities to be evaluated are a subset of those listed under Specific Decision 11: sediment transport and contaminant plume dispersion is not required, since the modeling relates to project goals for the non-tidal, managed, pond morphologies. The overall modeling approach should be as follows:

- Construct, calibrate and verify a numerical model of the existing hydrodynamics, salinity, and flushing times through the restoration area. This could be a subset of the existing conditions model described under Specific Decision 11, although more details of the control structures may be required here. It would not be necessary to model the entire restoration and South Bay areas: complexes of managed ponds that are to be interconnected by the interim management plan could be modeled in isolation from the rest of the system, with boundary conditions provided by the overall existing conditions model.
- Modify the numerical model to describe each of the proposed interim management alternatives, and run the model to predict the resulting hydrodynamic, salinity, and water quality changes.

- Make changes as necessary to the interim management alternatives to attain desired goals, and re-run the models.

Numerical modeling, if backed up by sufficient field data, can provide answers to specific questions such as the following:

- What pumping rates are required to provide a given (desirable) flushing time within each pond served by a pump?
- Is the water within each pond well-mixed, or might it be necessary to provide multiple pumps and other control structures for some ponds to avoid stagnant areas?
- Where should the control structures be located ?

2.4 Specific Decision 13: Modeling Framework

To evaluate Specific Decisions 10, 11, and 12 (and other specific decisions), determine the modeling framework or protocol that will be used to evaluate alternatives for pond management and tidal restoration (and associated hydrodynamic and geomorphologic changes to the Bay) and establish an ongoing / iterative approach to modeling in connection with decision-making. Determine the goals and objectives for modeling over the planning, construction, and monitoring and adaptive management period, the decisions that will be addressed by modeling, and the required accuracy and breadth of modeling (such as processes and grid sizes) required at various decision points. Determine how physical models will be integrated with other models, such as habitat models.

This Specific Decision is not guided by modeling efforts: rather, it guides the strategy for numerical modeling. This report provides preliminary guidance for this Specific Decision.

2.5 Specific Decision 14: Levee Improvements

Determine which levees will need improvements, whether and where new levees are required, and whether and where other new infrastructure, such as water control structures, are required, in order to manage ponds and protect South Bay communities from tidal flooding.

The ponds and particularly the South Bay communities require protection from both tidal and fluvial flooding. Therefore, although there are specific questions and data requirements (e.g., the state of existing levees and any levee subsidence) that relate only to tidal or to fluvial flooding, the numerical modeling should integrate both considerations. This is done under Specific Decision 15 below.

2.6 Specific Decision 15: Flood Management

Determine how the project will be integrated with flood management plans for creeks and rivers in the South Bay to achieve win-win situations.

Flooding within and near the restoration area will ideally be addressed using the hydrodynamic modeling developed in support of Specific Decisions 10 through 12. By integrating these hydrodynamic models with existing models of upland creeks such as those maintained by the Santa Clara Valley Water District, flood management planning for the entire South Bay area can be further supported. A pre-requisite for flood management is that appropriate flood protection requirements, such as FEMA, Army Corps, etc. be complied with. These are not described here. A separate report on urban flood management requirements was also prepared as part of these preliminary studies, and the requirements are discussed in more detail in that report[3].

Calibration data used to characterize extreme event flood conditions may differ from that used to calibrate the model to describe the normal hydrology of the restored system. Specifically, it will be necessary to characterize the normal and flood hydrographs for each tributary creek reaching the South Bay, at a point upstream of the area likely to be impacted hydrodynamically by the restoration. This requirement includes channels such as Alviso Slough that do not directly contact the salt ponds, but that may become connected to the restored marshes as a result of dike removal or breaching.

The overall modeling approach should be as follows:

- Construct, calibrate and verify a numerical model of the existing hydrodynamics and hydrology through the restoration area and upstream of that area. Specifically, integrate the relevant subset of the existing conditions model described under Specific Decisions 10 and 11 with the relevant subset of hydrologic models prepared for flood management purposes. The existing conditions model would be used to provide downstream boundary conditions.
- Construct, calibrate, and verify a numerical model to evaluate local wind-wave generation for locations where flooding could result from wave overtopping, or where levee erosion could occur due to wave action.
- Modify the numerical model to describe proposed upland flood management plans in coordination with each of the proposed restoration alternatives, and run the model to predict the resulting water levels and currents, to determine the required levee heights, and to predict the extent of any residual flooding.

This modeling will be used extensively during the later design phases to determine levee dimensions and control structure characteristics.

Questions that may be answered by this modeling effort include the following.

- What levee heights and what other control structure characteristics should be specified to provide a given level of protection ?
- Which levees should be improved, by how much, and what is the implication on existing flood control characteristics ?
- How do the proposed restoration actions impact upstream flood risk ? For example, when the tidal prism in the restoration area increases significantly, does the greater tidal intrusion increase the flood risk upstream, or does the increase in flood conveyance due to channel scour outweigh this impact ?
- What impacts will the restoration project have on existing and proposed flood management projects ?

Further questions related to flood management can be answered by the modeling performed in support of Specific Decision 10. For example, the risk that the toes of existing levees may

[3] Moffatt & Nichol Engineers, Urban Levee Flood Management Requirements, South Bay Salt Pond Restoration Project, Draft, March 2004, prepared for California State Coastal Conservancy,

be subject to scour in response to the increased tidal prism is addressed through that modeling effort.

2.7 Specific Decision 16: Infrastructure Constraints

Determine infrastructure constraints, and how these constraints will be addressed.

To a large extent, this Specific Decision constrains the restoration design without being explicitly addressed through modeling. Much of the effort related to this Specific Decision will be data gathering to locate existing infrastructure. Specific modeling efforts related to this Specific Decision will be addressed using the hydrodynamic modeling developed in support of Specific Decisions 12, 14 and 15, with a focus on existing infrastructure.

Questions that may be answered by this modeling effort include the following.

- Which components of existing infrastructure should be retained and which ones should be relocated ?
- Will the existing salt pond levees and operation at the Newark ponds be affected, in terms of levee erosion ?
- Will access considerations, to PG&E towers for example, guide the restoration alternative design?

2.8 Specific Decision 17: Mercury Methylation

Determine steps to be implemented to minimize mercury methylation and its effects on wildlife and humans. Identify the areas, if any, that require design adaptations due to elevated mercury levels.

Although many of the questions related to mercury methylation are addressed through approaches such as the history and soil/sediment chemistry of each salt pond and its adjoining levees, numerical modeling will help in quantifying the potential for methylation. For example, what is the inundation frequency for each restoration alternative ? This will be tied in to the ambient mercury in the sediments which will settle out in the ponds.

- Hydrodynamics (water levels and currents) throughout the restoration area and the South Bay – as for Specific Decisions 10 and 11.
- Sediment characteristics and sediment dynamics throughout the restoration area and the South Bay.
- The level of mercury in sediments throughout the restoration area and the South Bay. This can be evaluated using a model that has the ability to track the path of contaminated sediments, combined with models such as FIELDS which are GIS based.

The fate of contaminated sediments could be addressed using the same models as are used for hydrodynamics and sediment transport in the channels, ponds and the South Bay, with the addition of a separate model to track contaminated sediments.

The overall modeling approach should be as follows:

- Construct, calibrate, and verify a numerical model of the existing hydrodynamics, sediment transport, and the new element of contaminant transport bound to sediments. Hydrodynamic and sediment transport models constructed in support of Specific Decisions 10 and 11 could also be used if phasing of the modeling efforts allow it.

- Modify the numerical model to describe each of the proposed restoration alternatives, and run the model to predict the fate of the sediments contaminated with mercury.
- As necessary, make changes to some or all of the proposed restoration alternatives to avoid undesirable impacts, and re-run the models.

Questions that may be answered by this modeling effort include the following.

- What is the resuspension rate of existing contaminated sediments? What is the fate of contaminated sediments brought into suspension?
- What is the inundation frequency for each restoration alternative? This relates to the extent to which contaminated sediments in their present or new locations will be exposed to the air.

2.9 SPECIFIC DECISION 18: OTHER CONTAMINANTS

Determine how other contaminants (in water and sediment) will be addressed.

Surface water quality issues include the following:

- Conservative constituents such as salinity and certain metals. Many hydrodynamic models include advection-diffusion models, which allow the dispersion of conservative constituents. The flushing time modeling outlined in support of Specific Decision 11, if combined with a clear understanding of the sources of these constituents, is sufficient to address these constituents.
- Biologically reactive constituents such as nutrients, DO, BOD, bacteria, algae and other biological growths. More sophisticated water quality models are needed to describe these quantities and their reaction kinetics.
- Constituents bound to contaminated sediments that may be resuspended by the restoration, including PCBs and heavy metals including mercury. Some of these constituents remain bound to the sediment, while others exist both bound to the sediment and in a dissolved phase.

Groundwater quality issues must also be addressed. As the tidal prism within the restoration increases, there is a risk of increased saltwater intrusion into the groundwater. Groundwater models are typically not closely integrated with surface water models, and a distinct modeling effort will be required to address saltwater intrusion issues.

Quantities whose behavior is to be evaluated in support of this Specific Decision are the basic hydrodynamic, sediment transport, and salinity modeled in support of Specific Decisions 10 and 11, together with the following:

- Flushing time throughout the restoration area and the South Bay.
- Levels of conservative constituents in water throughout the restoration area and the South Bay.

- Levels of biologically reactive constituents in water throughout the restoration area and the South Bay.
- The levels of contaminants bound to sediments throughout the restoration area and the South Bay.
- The levels of contaminants (particularly heavy metals) both in solution and bound to sediments throughout the restoration area and the South Bay.
- Salinity levels in groundwater in areas influenced by the restoration effort.
- Tidal intrusion into the inlets and creeks entering the South Bay: specifically, the salinity at the bottom of such channels.

In order to model salinity intrusion into groundwater, a separate groundwater model must be used. The salinity at the bottom of the inlets and creeks entering the South Bay will be used to provide a boundary condition to the groundwater model.

The overall modeling approach should be as follows:

- Based on the hydrodynamic and sediment transport models constructed in support of Specific Decisions 10 and 11, construct, calibrate, and verify a numerical model of the existing hydrodynamics, sediment transport, and contaminant levels. It may be desirable to construct different models for different contaminants, particularly where interactions between certain constituents are significant.
- Modify the numerical model to describe each of the proposed restoration alternatives and each of the interim management alternatives, and run the model to predict the contaminant levels.
- As necessary, make changes to the proposed restoration and interim management alternatives to attain desired goals, and re-run the models.
- Collect and analyze field data relating to salinity stratification within the inlets and creeks entering the South Bay. Using this field data, determine whether stratification is a significant feature of these inlets. If necessary, construct, calibrate and verify a more detailed numerical model of hydrodynamics and salinity to determine salinity levels at the bottom of the inlets and creeks entering the South Bay.
- Construct, calibrate and verify a groundwater quality model using a previously constructed model or this more detailed numerical model to provide boundary conditions (bottom salinity levels).
- Modify the numerical model describing hydrodynamics and salinity intrusion to describe each of the proposed restoration alternatives, and run the model to predict the bottom salinity levels.
- Re-run the groundwater quality model using the modified salinity bottom levels as the new boundary condition.

Questions that may be answered by this specific modeling effort include the following.

- Will eutrophication occur in the managed ponds or the restored marshes? What actions can be taken to avoid this?
- What would be the impact of releasing wastewater into the managed ponds in terms of biological cycling?

- Will the restored ponds be scoured significantly at any point during the restoration cycle? What will be the fate of sediments scoured from the salt ponds? Are the sediments that will be scoured anticipated to be contaminated?
- What is the present distribution of salinity within groundwater? Will groundwater salinity levels change as a result of the proposed restoration?

2.10 Specific Decision 19: Nutrient Cycling

Determine the effects of nutrients, nutrient loads, and nutrient cycling on the restoration effort (in both managed ponds and tidal areas) and define approaches to minimize risks of eutrophication.

This Specific Decision can be addressed using the same set of modeling tools as described in support of Specific Decision 18.

2.11 Specific Decision 20: Salinity Effects

Determine the effects of salinity on other contaminants and water quality parameters, and how salinity ranges should be defined to optimize water quality in the project area.

This Specific Decision is not explicitly addressed through numerical modeling. The main focus of the effort related to this Specific Decision will be to develop the necessary chemical understanding of the interactions between salinity and other constituents.

3. EVALUATION OF MODELING TOOLS

The hydrodynamics and sediment transport within the restoration area will become increasingly complex as the restoration proceeds. Water that presently flows in large part through diked channels will follow the dendritic slough/channel network, intertidal wetland channels, and open ponds. Sediment will initially be scoured from channels in response to dike breaching, from new channels formed as the salt ponds accrete to become intertidal marshes, and possibly from other channels. In the long term, sediment will settle in the salt ponds and possibly at the mouth of creeks (ebb shoal bars), while being eroded from the mudflats.

No single model will handle the full range of flow conditions and hydrodynamic, geomorphic, and sediment and water quality characteristics of the system. However, once a single model has been constructed and calibrated – and in particular, once the necessary field data have been collected, verified and integrated – it is generally much easier to construct a different model covering the same area. There is a tradeoff to be made between construction of a single, overarching model that – once it is complete – can be applied to different modeling domains without duplication, and parallel development of a number of simpler models that each address one domain, with one model used to provide a boundary to another.

This section begins by describing the main categories of models, in terms of model dimension (one, two or three dimensional models); the distinction between finite difference and finite element models; and the types of model grid (rectilinear, curvilinear, or unstructured). It goes on to summarize specific technical issues related to the modeling needs summarized in the previous section – for example, the need to model biologically reactive contaminants to address Specific Decisions 18 and 19. Finally, it describes potential combinations of models that could address all of the decision requirements. More specific recommendations for the data collection and modeling strategy are given in Section 3.4.

3.1 Basic Model Categories

The partial differential Navier-Stokes equations of motion describe fluid motion and pressures at a point; differential equations also describe the transport of sediment, salinity, and other constituents, together with interactions between constituents. For a simple geometry and flow condition, it is possible to solve these equations to describe a system analytically. Numerical computation of hydrodynamics and constituent transport is necessary over the complex geometry of natural water bodies with varying boundary conditions such as tides, inflow, winds, and evaporation. Advances in computer power have made such numerical simulations increasingly feasible.

The first step in a numerical solution is to discretize the solution domain (the water body) in one, two, or three dimensions, representing the system as a one-, two-, or three-dimensional network. The next step is to define the quantities to be modeled (water levels, currents, constituent levels, etc.) across this numerical grid. The grid dimension and the representation of the model quantities significantly affect the level of detail available from a model, the quantity of data required to calibrate the model, the time taken to set it up, and the computational requirements. While the following discussion focuses on hydrodynamics (water levels and currents), the same considerations apply to modeling other quantities.

3.1.1 One-Dimensional Models

One-dimensional models are the simplest option, best suited for representing flows within interconnected networks of channels. The channels are described by stream cross sections, and the model produces, for each time step, water surface elevations at each cross section and average velocities between each cross section. Although this approach does not provide details of vertical and horizontal velocity distributions, salinity stratification, or circulation within large water bodies such as lakes, it does yield accurate flows and is an adequate representation for many kinds of problems. One-dimensional models have some capability to address problems beyond simple channel flow. For example, they can model well-mixed ponds (in which currents, salinity, etc., are essentially uniform throughout the pond), and they can predict the horizontal extent of flooding within a floodplain dominated by a small number of channels if the overbank areas are included in the channel cross sections and a flow network can be defined.

Advantages of one-dimensional models as follows:

- One-dimensional models can usually be set up quickly and computations are fast. A time series simulation of even a large network will generally require only minutes of computer time to run.
- Can accurately represent cross-sectional area of channels at all stages because they do not require grids to approximate cross-section (like 2-D and 3-D models).
- Relatively little field data is required to set up the models.
- Since one-dimensional models have traditionally been used for flood prediction, they generally include more powerful capabilities to describe control structures than do higher-dimensional models.

The disadvantages of one-dimensional models lie in their inability to describe true two-dimensional characteristics such as channel meander, circulation within large water bodies, or stratification.

3.1.2 Two-Dimensional

Two-dimensional models go a step further by considering the lateral circulation in large water-bodies such as lakes or estuaries. The flow characteristics are assumed to be uniform down through the water column at each computational point, so that stratification is not described.

A two-dimensional model is indispensable if the problem involves complicated circulation patterns, as may be the case within the large salt ponds. However, these models are more time consuming to set up and run, and require much more field data, than one-dimensional models. Two specific drawbacks of two-dimensional (and three-dimensional) models compared to one-dimensional models are as follows:

- Two-dimensional models generally do not describe control structures (such as weirs, pumps, and tide gates) as well as one-dimensional models do.
- Two-dimensional models may have problems maintaining numerical stability in situations involving rapid wetting and drying cycles as are common in tidal marsh environments.

Two-dimensional models require significantly more computer resources (memory and run-time) than do one-dimensional models. Therefore, it is necessary to perform a tradeoff between the density of the computational network used to define the model area, and the resultant run-times, requirements for computer memory, and disk storage space. In performing this tradeoff, the choice of finite difference or finite element models, and the type of grid, becomes important.

3.1.3 One Plus One-Dimensional

A subset of two-dimensional models uses one horizontal and one vertical dimension, rather than two horizontal dimensions. This allows the vertical structure of the hydrodynamics of a narrow channel to be evaluated, albeit to a limited extent such as 2 or 3 layers only, without the large computational and data requirements of full three-dimensional models. Such models are particularly useful for modeling salt wedge and tidal intrusion characteristics into a creek or narrow channel.

3.1.4 Three-Dimensional

Three-dimensional models are similar to two-dimensional models, except that the vertical dimension is also modeled through a number of layers. The layers may be of uniform thickness, or may divide the water depth in a constant number of layers over the entire water body. The number of layers can range from two to ten or more. Therefore, a three-dimensional model describes the vertical structure of the water column. A three-dimensional model should be used when there is stratification in a water-body, such as where freshwater flows override an underlying salt-water wedge. In the present context, this is most likely to be of importance in the context of pollutant dispersion from sediments mobilized by scour, or salinity intrusion into the creeks. Three-dimensional models provide the most detailed look at a hydrodynamic system, at a penalty of much longer computer simulation times and the requirement for a substantial amount of field data to capture the complexities of flow in all three dimensions.

3.1.5 Finite Difference and Finite Element Models and Grid Types

There are two popular approaches to implementing the solution of the partial differential equations.

- The **finite-difference** method represents the water levels at a set of discrete points, for each time step. The typical solution grid is a network of straight or curved lines with nodes at the intersections[4]. Currents are normally described at the links between the nodes.
- The **finite-element** method divides the solution domain (the water body) into a set of triangular or polygonal elements. The water levels and currents are described as linear or quadratic functions across each finite element.

Time is advanced in steps in both solution methods.

Finite difference calculations are more computationally efficient for a given network size than finite element calculations. However, this is often offset by the fact that finite difference models are generally limited to a rectangular or curved grid[5], while finite element grids are

[4] An exception to this is the UnTRIM model developed by the USGS and Trento University, Italy which is unstructured.

[5] *Ibid*

better able to accommodate irregularly shaped model domains. This means that finite difference solutions often require finer grids than finite element solutions to model complex shapes. The time step for finite element solutions can also be longer, which may speed up the simulation.

The different types of grids have the following characteristics.

- Rectangular grids suffer from the significant drawback that the boundaries of channels and other water bodies are represented as stair-step edges, requiring a fine grid to represent edges in detail. Increasing the resolution of the grid for a small region to account for narrow channels or structures may require changes to the spacing throughout the model domain. This can more than offset the relatively high computational efficiency of finite difference models. Some models allow nested grids, in which a small area of a fine rectangular grid is embedded within a larger area of a coarse rectangular grid (see SFO case study in next section).
- Curvilinear orthogonal grids represent the configuration of a water body more accurately than rectangular grids, since the curvilinear grid can be fitted along boundaries and contours. Transformation relations are used to map this fitted grid to a rectangular grid for solution. Curvilinear orthogonal grids are available for some finite difference models.
- Unstructured grids can incorporate model elements that vary in size, facilitating simulations that are detailed where needed, and less detailed elsewhere. Complex boundaries and contours can be smoothly fitted, and local changes to the waterbody shape need not affect the rest of the grid. This means that the model size can be relatively small, decreasing computational requirements. However, unstructured grids can be very time-consuming to set up, and the preprocessing tools used to construct the model become critical.

In summary, while the choice of finite difference versus finite element models is important, the decision as to model type will probably be made on the basis of shape and size of model domain, length of simulation, coupling requirements with other models, etc. For one-dimensional systems, the choice of network type is not an issue and the selection of one-dimensional model is made on other grounds such as numerical stability.

3.1.6 Combination Models

As the model dimension increases from one to two to three dimensions, the level of detail, the data requirements, the time required to set up and modify the model, and the data requirements all increase exponentially.

In modeling the South Bay Salt Ponds restoration, it is likely to be appropriate to use a mix of model dimensions, with channels and control structures modeled as one-dimensional systems, shallow pond and marsh areas in two, and limited areas where stratification is important in one+one or three dimensions. An example of this approach was the modeling for the North Bay in support of the San Francisco Airport Runway Reconfiguration, which included a simple one-dimensional model of a large area, a more detailed two-dimensional model of a smaller area, and a three-dimensional salinity model (ADEC 2002).

The RMA2 model suite also allows one-dimensional elements to be incorporated within a two-dimensional system. The feasibility of this kind of coupling varies significantly from model to model, and must be specified in detail.

3.2 REQUIREMENTS FOR MODEL CONTENT

3.2.1 Requirements related to model scope

The following list describes some specific model requirements related to the Specific Decisions. Table 1 at the end of this section summarizes the requirement for model content.

Hydrodynamic Model

- Desirable attributes of the hydrodynamic portion of the model are as follows.
- All hydrodynamic models provide **water levels and velocity**, within the creeks, ponds, and the South Bay.
- **Wetting and drying** of tidally influenced areas of the system should be incorporated as a stable part of the hydrodynamic model. Some models can become numerically unstable when wetting and drying is included.
- **Evaporation and precipitation** should be included in order to model the managed ponds.
- **Control structures** such as pumps, siphons and tide gates should be described by the hydrodynamic portion of the model. As previously noted, generally one-dimensional models describe control structures better than most two-dimensional models.
- **Temporal variation (short term, unsteady flow)** should be incorporated to simulate fluctuations in water levels due to tides, as a stable part of the hydrodynamic model. Some models can become numerically unstable when flows vary rapidly, for example during flood conditions.
- **Spatial variation (2-D modeling)** should be provided to model spatial variation within the ponds, marshes, and the South Bay.
- **1-D / 2-D model integration** should be available. As described above, one-dimensional models are appropriate to model the main channels within the marshes, and generally provide better capabilities for modeling control structures. Some mechanism for coupling the one- and two-dimensional portions of the model, for example, treating the levee breaches as sources and sinks for a two-dimensional pond model, is required.
- **Vertical stratification (one plus one-D and 3-D modeling)** of flow may need to be modeled in order to describe the dispersion of pollutants from mobilized sediment, and to describe changes to salinity at the bottom of channels due to tidal intrusion.

Wind Wave Model

- **Wind-generated waves** should be included in the model. Sediment resuspension in the South Bay mudflats is significantly driven by waves, and the large size of the salt ponds means that these are also subject to wave-driven sediment resuspension. Wind data are generally more readily available than wave data, so the model should be capable of predicting wave spectra based on the winds.
- **Wave-current interactions** will describe the effects of tidal currents upon wind-generated waves. However, this interaction is significant for coastal processes, and less so for the restoration project.

Sediment Transport Model

- **Cohesive sediment transport** should be included in the model, because sediment within the salt ponds and offshore is largely mud. Sand behaves in a very different way from mud, particularly for erosion, and is treated using a non-cohesive model.
- **Bedload transport**, that is, transport of sediment along the bed rather than suspended throughout the water column, is a desirable feature. However, since the sediment under consideration is largely mud this is not a critical feature.
- **Wave resuspension** of the sediment should be included in the model, as well as the more standard suspension and transport due to currents. Wave resuspension is known to be important within the mudflats.
- **Coupling** of one- and two-dimensional models is required, as with the basic hydrodynamic model. This is most likely to be achieved through the use of **source / sink terms** at the boundaries between the one- and two-dimensional model domains, although other mechanisms are possible.
- **Dynamic morphological model** couples the hydrodynamic and sediment transport modules; the sediment transport module updates the bed morphology, which in turn affects the system hydrodynamics. An alternative to dynamic morphological models is the use of uncoupled models, in which the hydrodynamic model is run first, and provides input to the sediment transport model. Some manual or semi-automated analysis of sediment suspension, transport, and settling is required with uncoupled models to address the impacts on the bed morphology. Dynamic morphological models are desirable since they decrease the time spent in manual analysis of intermediate results.
- **Channel migration** models represent a special case of dynamic bed morphology models. Typically, dynamic morphological models of rivers are one-dimensional models; channel scour and accretion are modeled as changing the bed elevation, but not the channel course. Furthermore, channel slumping is often not included in the modeling. Channel migration models are desirable to more fully describe the impacts of sedimentation on channel characteristics.

Water Quality Model

- **Solute transport (advection-diffusion)** modeling is required to treat salinity and other conservative constituents. This is the simplest approach to water quality modeling, and is included in all models that have a water quality element.
- **Particle tracking**, to determine the eventual fate of contaminated sediments that may be resuspended and transported away from their current locations, should be included.
- **Heavy metals (absorption-desorption)** should be modeled, to analyze their transport in the dissolved phase and bound to sediments.
- As an input to biochemical and other water quality parameters with temperature-dependent kinetics, a **temperature model** should be included.
- **Biochemical processes**, to address water quality impacts such as DO, BOD, nutrient cycling, and biological growths, should be modeled.

Groundwater Model

- **Groundwater modeling**: a separate model will be required to address salinity intrusion into groundwater. As with surface water modeling, there is a choice of model dimension: two- or three-dimensional groundwater codes are available. In situations where the groundwater flow has been disturbed by extraction or significant construction, three-dimensional models are indicated[6]. Unfortunately, sufficient data for the three-dimensional modeling effort is rarely available. Apart from the fact that the data are often sparse spatially, consisting at best of a set of boreholes, the long timescales associated with saltwater intrusion means that the system data may not reflect equilibrium even before the changes introduced by restoration begin to occur. In conclusion, while the selection of a groundwater model should not be taken lightly, the availability of data is likely to impact the prediction adequacy more than the model limitations.

3.2.2 General Requirements

Characteristics of the model that affect the cost of the modeling effort and the general acceptability of the results to a broad group of stakeholders are critical to the overall success of the project. Model characteristics that fall into this category include the following:

- **Numerical solution method**: This is not critical in itself, but it limits the numerical grid types that can be made available.
- **Numerical grid type**: Curvilinear and finite element grids can more accurately describe the bathymetry, meaning that larger grid spacing can be used so less computer memory must is needed. Even today, the computational requirements of numerical hydrodynamic models are significant. However, if curvilinear or finite element grids are used, powerful preprocessing tools are critical for setting up the grid for a large and complex model.
- **General Model Availability**: This covers a number of issues. First, in-house models are generally less acceptable, and selecting an in-house model ties the project to a single modeling group. For example, the CH2D/CH3D models are generally not made available outside the USACE; modeling using the GEMSS model is generally performed cooperatively with the model vendors.

  Second, for non-commercial models that have had limited distribution, the availability of technical support and quality of documentation can be limited. This can greatly increase the labor costs associated with a modeling effort.

  Finally, for commercial models the cost to purchase the necessary modules can be significant.

[6] Essink, G.H.P.O. Mathematical models and their application to salt water intrusion problems. TIAC'03: Coastal aquifers intrusion technology: Mediterranean countries, Alicante, Spain, March, 11-14, 2003

Table 1: Model content requirements

Type of Model	Characteristics of Numerical Model(s) \ Specific Decision	10: Sediment Budget	11: South Bay Impacts	12: Pond Management	14: Levee Improvements	15: Flood Management	16: Infrastructure Constraints	17: Mercury Methylation	18: Other Contaminants	19: Nutrient Cycling
Hydrodynamic Model	Water Levels and Velocity	■	■	■	■	■	■	■	■	■
	Wetting and Drying	■	■	■	■	■	■	■	■	■
	Evaporation and Precipitation	◪	◪	◪	◪	◪	◪	◪	◪	◪
	Control Structures	◪	◪	■	■	■	■	◪	◪	◪
	Temporal Variation (Unsteady Flow)	■	■	■	■	■	■	■	■	■
	Spatial Variation (2-D Modeling)	■	■	■	◪	◪	■	■	■	■
	1-D / 2-D Model Integration	■	◪	■	◪	◪	◪	■	■	■
	Vertical Stratification (3-D Modeling)		◪ [1]						■ [2]	
Wave Model	Wind-Generated Waves	◪	◪	◪	■	■	◪	◪	◪	◪
	Wave-Current Interactions	◪	◪	◪	◪	◪	◪	◪	◪	◪
Sediment Transport Model	Cohesive Processes	■	■					■	■	
	Bedload Transport	◪	◪					◪	◪	
	Wave Resuspension	■	■					■	■	
	Source / Sink Terms	■	◪					■	■	
	Dynamic Bed Morphology	◪	◪					◪	◪	
	Channel Migration	◪	◪					◪	◪	
Water Quality Model	Solute Transport (Advection-Diffusion)		■	■				■	■	■
	Particle Tracking							◪	◪	◪
	Heavy Metals (Absorption-Desorption)							■	■	
	Temperature Model								■	■
	Biochemical Processes								■	■
	Groundwater Modeling								■	

Key:
■ Required; ◪ Desirable

Notes:

1. Vertical stratification desirable for determining impacts to salinity, sediment transport, and pollutant dispersion within the South Bay.

2. Vertical stratification required only to provide boundary conditions for groundwater intrusion of salinity; one + one dimensional modeling may be sufficient for this.

3.3 Inventory of Models

3.3.1 Models Considered

A very large number of numerical hydrodynamic models is available worldwide, and inventorying and screening all possible models is not possible, nor necessary at this point. This report concentrates on generally accepted and available models that go beyond purely hydrodynamic modeling to address sediment transport, water quality, or both; and that are readily available with adequate levels of documentation and technical support, either through commercial or non-commercial channels. The following models are considered.

- **HEC Model Series**, including HEC-UNET, HEC-6, and HEC-RAS, is a set of one-dimensional models of river hydrodynamics and sediment transport provided by the U.S. Army Corps of Engineers.
- **RMA Model Series**, together with the SED-2D model, is a set of one-, two, and three-dimensional models of hydrodynamics, sediment transport and water quality. The RMA models are finite element models, and are in the public domain, although normally combined with (relatively inexpensive) preprocessing for grid and model setup. One such processing system is the Surfacewater Modeling System (SMS). A two-dimensional model of San Francisco Bay was used by Moffatt & Nichol for hydraulic scour analysis of the proposed replacement span of the San Francisco Oakland Bay Bridge.
- **MIKE Model Series** together comprises a very extensive set of finite difference models in one-, two-, one+one-, and three dimensions. Most of the MIKE models (MIKE-11, MIKE-21, MIKE-12 and MIKE-3) use a rectangular, potentially nested, grid. Modules exist to cover hydrodynamics, sediment transport, water quality, and wave generation/ transformation. The MIKE models are commercially available from DHI. A two-dimensional model of San Francisco Bay has been constructed using the MIKE model by Moffatt & Nichol. Other types of models include the two-dimensional MIKE-FM, which is similar to the RMA model in terms of its grid (finite element), and MIKE-C, which is a two-dimensional version with a curvilinear orthogonal grid. Both these models are relatively new (less than a year old), and have not been used widely except by the developers.
- **DELFT Model Series** together comprises a set of finite difference models in two, and three dimensions. They include hydrodynamics, wave generation/ transformation, water quality, and sediment transport with dynamic bed morphology. The models use a curvilinear orthogonal grid. DELFT2D and DELFT3D are commercially available from Delft Hydraulics. A two-dimesional model of the South Bay, and a 3-dimensional model of San Francisco Bay has been constructed using the DELFT model series by Moffatt & Nichol.
- **TELEMAC Model Series** comprises a set of two- and three-dimensional finite element models of hydrodynamics, with modeling of salinity provided by WQ-2D and WQ-3D, and sediment transport by SUBIEF. The model uses irregular triangular grids. Telemac and the associated models are commercially available from H.R. Wallingford, U.K.
- **GEMSS** consists of a three-dimensional finite difference hydrodynamic, water quality, and sediment transport model, with a curvilinear orthogonal grid. The model uses the same basic hydrodynamic model (GLLVHT) as CE-QUAL-W2. The model is developed by J.D. Edinger Associates. Model development and application are possible only through a cooperative agreement with the developers.

- **TRIM** is a three-dimensional finite-difference hydrodynamic model developed by Professor Vincenzo Casulli of Italy. There is a version of this model, UnTRIM, that uses an irregular grid which is presently being used widely by universities and scientists. A two-dimensional model of San Francisco Bay, and other three-dimensional models of portions of the Bay and Delta, have been constructed by the USGS and others using the TRIM model. TRIM is not commercially available but various versions are being used by universities and researchers, although model documentation and user support is limited.
- **CH2D / CH3D** are two- and three-dimensional finite difference models of hydrodynamics, salinity, and sediment transport. The model uses a curvilinear orthogonal grid, and is supported by the SMS pre- and post-processing programs, similar to the RMA suite. It can be used together with CE-QUAL-ICM to model water quality. CH2D / CH3D are developed and maintained by the Army Corps of Engineers. However, the software is not freely available to users outside the Corps. Model development and application are possible through a cooperative agreement with the Waterways Experiment Station or other branches within the Corps.
- **ADCIRC** is a two- and three-dimensional finite element hydrodynamics model using an irregular grid and provided by the Corps. ADCIRC is supported by the SMS preprocessing and display suite.
- **CE-QUAL-W2** can be run as a one plus one-dimensional as well as a two-dimensional finite difference hydrodynamic and water quality model. The model can be run in vertical or horizontal planes, so that it can simulate deep, narrow channels as well as large water bodies. The model is provided by the Corps.

More specialized models that are applicable to single specific decisions include the following:

- **WASP** is a very extensive water quality model provided by the EPA. The focus of this modeling suite is on water quality (e.g., eutrophication kinetics, and toxic chemicals bound to sediments) rather than on hydrodynamics. WASP can be applied in one, two or three dimensions. It imports the hydrodynamics from another model; it is often used in concert with the one-dimensional DYNHYD model or the three-dimensional EFDC model (these are relatively simple hydrodynamic models). The model is commercially available at a relatively low cost.
- **CORMIX** which is a three-dimensional hydrodynamic and water quality model developed specifically to describe plume dispersion, for example at wastewater outfall pipes. It is commercially available.
- Three-dimensional groundwater flow models include **GMS**, **MODFLOW**, and **MOC-3D**, all provided by the U.S.G.S.

3.3.2 Model Capabilities

Table 2 summarizes the capabilities of the above model suites in terms of the model content requirements listed in Table 1; cost levels are also provided. It is important to realize that **not all listed capabilities are available simultaneously** for a given model suite, nor is the **accuracy or efficiency of a model suite** reflected in the Table. For example, the MIKE model suite is shown as having both a channel migration model, and control structures. However, the MIKE-21C model, which is the version incorporating channel migration, does not have the control structure capability of the one-dimensional MIKE-11 model. Similarly, the HEC model suite includes unsteady flow through HEC-UNET, and sediment transport through HEC-RAS; it does not model both simultaneously.

Table 2: Content of available model suites

Type of Model	Characteristics of Numerical Model(s) / Specific Model	HEC-UNET, HEC-6, HEC-RAS	RMA-2, -4, -10, -11, SED-2D	MIKE-11, -21, -21, -3, -FM, -C	TRIM, UnTRIM	DELFT2D, DELFT3D	TELEMAC	CH2D, CH3D, ICM	WASP	ADCIRC	CE-QUAL-W2	GEMSS (GLLVHT)
General	Numerical Solution Method	FE	FE	FD[1]	FD	FD	FE	FD	FE	FE	FE	FD
	Numerical Grid Type	NA[2]	IR	RE[1]	RE[7]	CU	IR	CU	NA[3]	IR	RE	CU
	General Model Availability	F	$	$$	L	$$	$$	L	$	$	F	L
Hydrodynamic Model	Water Levels and Velocity	■	■	■	■	■	■	■	□[3]	■	■	■
	Wetting and Drying	■	■	■	■	■	■	■	□	■	■	■
	Evaporation and Precipitation	□	■	■	□	■	■	■	□	□	□	■
	Control Structures	■	■	■	□	◪	■	□	□	■	□	■
	Temporal Variation (Unsteady Flow)	■[4]	■	■	■	■	■	■	□	■	■	■
	Spatial Variation (2-D Modeling)	□	■	■	■	■	■	■	□	■	◪[6]	■
	1-D / 2-D Model Integration	□	◪	◪	□	□	□	□	□	□	□	◪
	Vertical Stratification (3-D Modeling)	□	■	■	■	■	■	■	□	■	◪[6]	■
Wave Model	Wind-Generated Waves	□	□	■	□	■	■	■	□	□	□	□
	Wave-Current Interactions	□	■	■	□	■	■	■	□	■	□	■
Sediment Transport Model	Cohesive Processes	■[4]	■	■	□	■	■	■	□	□	□	■
	Bed Load Transport	■	□	■	□	■	■	■	□	□	□	■
	Wind-Driven Wave Resuspension	□	■	■	□	■	■	■	□	□	□	■
	Source / Sink Terms	□	■	■	□	■	□	□	□	□	□	□
	Dynamic Bed Morphology	■	□	◪[5]	□	■	□	■	□	□	□	□
	Channel Migration	□	□	◪[5]	□	□	□	□	□	□	□	□
Water Quality Model	Solute Transport (Advection-Diffusion)	■	■	■	□	■	■	■	■	□	■	■
	Particle Tracking	□	■	■	□	■	□	■	◪	□	□	■
	Heavy Metals (Absorption-Desorption)	□	□	■	□	■	□	□	■	□	□	□
	Temperature Model	■	■	■	□	■	□	■	■	□	■	■
	Biochemical Processes	■	■	■	□	■	□	■	■	□	■	■
	Groundwater Modeling	□	□	□	□	□	□	□	□	□	□	□

Key:

FE	Finite Element	FD	Finite Difference	CU	Curvilinear orthogonal
RE	Rectangular	UN	Unstructured	F	Public Domain
$	Available at low cost	$$	Relatively high cost	L	Limited availability (coop agreement, etc.)
■	Addressed	◪	Partially Addressed	□	Not Addressed

Notes:

1. Curvilinear grid for MIKE-21C, and finite element for MIKE-FM
2. Not Applicable (1-D model)
3. The WASP model can take input hydrodynamics from a number of other models
4. Unsteady flow and sediment transport are not available simultaneously
5. Channel migration is available as a specialized module, not integrated with other morphologic modules
6. CE-QUAL-W2 can be run in a 2-D or a 1+1-D mode
7. Irregularly shaped finite difference grid for UnTRIM

3.3.3 Specific Model Recommendations

Based on the above summary of model requirements and capabilities, recommendations regarding the models are provided in this section. The main screening characteristics for the hydrodynamic and sediment transport modeling are: model dimension, wetting and drying, unsteady flow, 1-D/2-D model integration, control structures, and cohesive sediment transport. These specific characteristics should be addressed adequately for any model proposed for the restoration project.

Models that appear suitable for the design and environmental review process are described below. One-dimensional models in conjunction with other models will be necessary throughout the design and environmental review process. Specifically, they will be used to provide upstream boundary conditions when Specific Decisions related to flood management are being addressed. In common with all of the hydrodynamic and water quality models, additional standalone models would be required to address the specialized issues related to plume dispersion and groundwater. This is not a significant drawback; different model combinations are typically used throughout the course of a project.

- **HEC Model Series** could be used for initial screening-level modeling. As widely used one-dimensional models, they can be set up rapidly to address such screening-level criteria as flood risk and the potential for channel scour. However, the lack of any 2-D modeling capability means that it could not be used by itself to address detailed design and management issues. They could be used for rapid modeling of linear portions of the system to address specific questions. An example might be to investigate operation of control structures to limit levee toe scour along a specific reach.
- **RMA Model Series**, together with the SED-2D model, appears suitable to address the hydrodynamic, sedimentation, and water quality issues that are at the heart of many of the Specific Decisions. Additionally, this model can be run with 1D elements which can have a significant computational efficiency. It has the capability of addressing certain control structures, but not all the structures envisioned for the ponds.
- **MIKE Model Series** together appears suitable to address the hydrodynamic, sedimentation, and water quality issues that are at the heart of many of the Specific Decisions. The one-dimensional version, MIKE-11, could also be used as an alternative to the HEC model series for the screening-level modeling, as well as addressing control structures. The rectangular grid system has limitations for the type of modeling required for the restoration project. The other systems (finite element and curvilinear) are relatively new in the market and not widely tested.
- **DELFT Model Series** together appear suitable to address the hydrodynamic, sedimentation, and water quality issues that are at the heart of many of the Specific Decisions. By itself it has limited capability to dynamically link one-dimensional systems or control structures to a multi-dimensional system. However, integration at the 1D-2D boundaries are possible by developing appropriate boundary conditions using separate 1-D models.
- **TELEMAC Model Series** appears suitable to address the hydrodynamic, sedimentation, and water quality issues that are at the heart of many of the Specific Decisions. TELEMAC has been little used in North America, so that its applicability is

likely to be limited by the availability of experienced modeling staff and general model acceptability.

- **GEMSS** appears suitable to address the hydrodynamic, sedimentation, and water quality issues that are at the heart of many of the Specific Decisions. The modeling work would necessarily have to be performed by the model vendors, unless agreements for purchase or cooperative use could be worked out with the vendors.
- **TRIM** appears suitable to address the hydrodynamic issues that are at the heart of many of the Specific Decisions. It has limited capability to address essentially one-dimensional systems or control structures, and does not provide sediment transport or water quality modeling capabilities without substantial model development effort. It also has limited support, flexibility, and model documentation compared to the commercially available packages.
- **CH2D / CH3D** appears suitable to address the hydrodynamic, sedimentation, and water quality issues that are at the heart of many of the Specific Decisions. It has a limited capability to address essentially one-dimensional systems or control structures. However, integration at the 1D-2D boundaries are possible by developing appropriate boundary conditions using separate 1-D models. The modeling work would have to be either performed by the Army Corps or a cooperative use agreement would have to be worked out. It has limited support, flexibility, and model documentation compared to the commercially available packages.
- **ADCIRC** appears suitable to address the hydrodynamic issues that are at the heart of many of the Specific Decisions. It does not provide sediment transport or water quality modeling and has limited capability to address one-dimensional systems or control structures.
- **CE-QUAL-W2** appears suitable to address the hydrodynamic and some of the water quality issues that are at the heart of many of the Specific Decisions. It could be used in limited areas to describe stratification within inlets. It does not provide sediment transport modeling and has limited capability to address one-dimensional systems or control structures.

Additional Standalone Models Required To Address Surface / Ground Water Quality

- **WASP** appears to have applicability to Specific Decisions 17 through 19, relating to water and sediment quality. It would need to be used in conjunction with a separate hydrodynamic model.
- Specialized models such as **CORMIX** for plume modeling and **GMS**, **MODFLOW**, or **MOC-3D** would be needed to address specific issues.

3.4 Physical Modeling

A physical hydraulic model can be used both to verify numerical model results, and as a public outreach tool. Prior to the advent of modern computer systems, physical models were heavily used. Factors addressed by such models include circulation and tidal forcing, sedimentation, water quality and establishing base-line conditions against which future changes can be measured.

The worth of any model study – physical or numerical – is completely dependent on the verifiable ability of the model to reproduce, with reasonable accuracy, the behavior of the full-scale system. Therefore, significant efforts must be made to collect field data in order to calibrate the physical model. Even with proper calibration, with small-scale models significant discrepancies can occur. As a result, physical models are not normally used to predict post-restoration or post-development conditions directly. Instead, after model verification, observations are made throughout the physical model to define the existing or base conditions in the model. Changes caused by the proposed development or restoration are then modeled and observed, and impacts due to the proposed development are evaluated on the basis of the changes in the model.

Physical hydraulic models can be used to obtain quantitative and qualitative results.

- **Quantitative Uses:** After a physical model has been properly adjusted and verified, measurements are taken at selected points in the physical model in order to characterize the base conditions as well as changes due to the alternative tested. Data collected can include water levels, current velocities at various depths, and salinity.
- **Qualitative Uses**: An advantage to a physical model is the opportunity for the general public and agencies to view proposed improvements. A physical model can provide a qualitative impression of the physical processes. For example, confetti can be placed in the water to observe tidal current patterns, which can be documented using time lapse photography.

3.4.1 Advantages/Disadvantages

The main advantages of physical models are the ability to measure the actual processes without simplifying assumptions that have to be made for analytical or numerical models; and the visual feedback provided by physical models.

Physical models can provide consistent and systematic conditions (mainly water levels and currents) that can be used to supplement/verify the findings of numerical models. With numerical models, it is sometimes difficult to determine whether a discrepancy between the model and the prototype is the result of a poor numerical simulation or bad field data. Obtaining additional field measurements to resolve these discrepancies may be expensive and difficult. The physical model can avoid this additional field data acquisition program. Additionally, there can be uncertainties regarding lateral mixing (i.e. eddy viscosity values) in numerical models, and the impact of distortion in the physical models. It can be useful to compare physical and numerical models to address this.

The disadvantages of physical models include scale effects and laboratory effects. An example of a common scale effect is viscous forces: these are relatively larger in a scale model than in the prototype. Sediment transport must be modeled at a relatively large scale (typically 10:1 or better) because sediment cohesiveness does not scale – fine sediments behave very differently from coarse sediments.

Laboratory effects typically arise from the inability to create realistic forcing conditions and the impact the model boundaries have on the processes being simulated. To minimize boundary effects, the model limits need to extend beyond the zone of influence of the area to be studied – increasing the physical size of the model.

If a physical model is used to verify a numerical model, the results should be reviewed using engineering judgment. Although both models will provide quantitative results, comparisons between the two models need to consider the limitations of each model as well as the advantages.

3.4.2 Uses of a Physical Model

Within the context of the South Bay Salt Ponds restoration, physical modeling could be used in at least three contexts.

- The entire Bay could be modeled to investigate circulation patterns – and so the potential for sediment transport between the Delta and the South Bay – and changes to those overall circulation patterns that might arise due to the Salt Ponds restoration. Although sediment transport is difficult to model directly with a small scale physical model, the underlying hydrodynamics are suitable for this approach. An existing physical model of San Francisco Bay (referred to as the Bay Model) is located in Sausalito, California, and owned by the USACE; the model history and condition are outlined in Section 3.4.3.
- At a larger scale, a physical model of one of the salt pond complexes and associated sloughs and creeks could be constructed. This would be useful to address overall circulation and its impacts on water quality in the ponds, both during the interim management period and after restoration (levee breaching). Such a model could also be used to investigate tidal intrusion (water levels and salinity) and flood-related impacts (the tradeoff between greater tidal range in the creeks, levee breaching, and the greater conveyance due to anticipated scour). A new physical model would have to be created for this; suitable facilities are listed in Section 3.4.4. These two possibilities (modeling the entire Bay or a salt pond complex) could confirm trends observed in any numerical modeling; for example, patterns of flow could be compared to verify that the physical and numerical models are producing similar results. These models could also be used to develop dispersion coefficients for use in numerical models, and in other ways to increase the confidence in numerical modeling results.
- A third option, at a still larger scale – at or near full scale – would address sediment transport (settling and transport) in the mudflats, the sloughs and the newly opened salt ponds. The proposal here would be to collect samples of the mud in the mudflats, to place the mud in a flume or wave tank, and to measure sediment pickup and settling rates at under different hydrodynamic conditions. The resulting sediment behavior would be used in calibrating the numerical models. This laboratory testing could be performed at any of the facilities listed in Section 3.4.4.

The disadvantage of using any physical model is the amount of time that would be required to set the model up and obtain data. Results from the physical model may not be available on time to support and/or influence the numerical modeling effort.

3.4.3 San Francisco Bay Model

The proximity of an existing physical hydraulic model of the Bay – the Bay Model, located in Sausalito and owned by the USACE - and history of past studies conducted at the facility warrant investigation into the Bay Model's possible use for the South Bay Salt Ponds restoration project.

The model was created by the USACE in the 1950s to study the feasibility of constructing significant structures (vehicular and rail transbay crossings using solid fills or bridges) in order to satisfy anticipated defense needs. The model was built using a grid of reinforced concrete slabs shaped by hand. Adjusting screws were used to support each slab and to allow leveling of individual slabs. In 1969, the model was expanded to include the Sacramento-San Joaquin delta. The upstream limits of the model are near Sacramento and Stockton. Additional field data were collected in order to re-calibrate the expanded model.

Although operated by the USACE from inception, recent changes have occurred with the operation of the facility. There is no longer a USACE engineering staff for the Bay Model. The Bay Model Association, a non-profit group, now coordinates with the USACE for use of the model facilities. Operators familiar with physical hydraulic models would have to be hired or otherwise brought in to operate the model.

The vertical scale for the Bay Model is 1:100 and the horizontal scale is 1:1000; distorted scales of this kind are common in models of estuaries, harbors, and other enclosed water bodies. The model occupies approximately 2 acres of floor space. The bathymetry was the most recent available at the time of model construction, and included features such as the fringing mudflats in the South Bay and North Bay areas and shipping channels. The Bay Model has been used for a variety of studies including salinity intrusion, circulation/current studies, shoaling, and dispersion studies. Recent studies have been predominantly for navigation channel improvements and effects to salinity intrusion.

Recent upgrades have enhanced the Bay Model facilities. The data acquisition system is now operated on PCs rather than the original main frame. Instrumentation for measuring water levels, current velocities, and constituent concentrations are available. Most of the instrumentation have been upgraded and do not require rehabilitation or repair. The tide generator controls have been upgraded. However, the model has not been calibrated using the upgraded tide generator system.

Due to the age of the structure, the physical model is in need of repairs that include re-leveling of the slabs and sealing of the joints. The leveling screws for the individual slabs are frozen due to corrosion. The bathymetry of the model may require modification, depending on the project conditions to be tested.

The Bay Model covers the entire Bay area. It does not include details of the South Bay Salt Ponds, and it is at too small a scale to address changes to the ponds and mudflats in detail. As such, its use would be limited to assessing large-scale impacts to circulation within the South Bay. The cost to repair, rehabilitate and recalibrate are anticipated to be hundreds of thousands of dollars[7], with a similar cost to perform the studies.

3.4.4 Other Physical Model Facilities

Design, construction and operation of a hydraulic physical model require experienced and knowledgeable personnel. Organizations that offer physical modeling facilities for hire may be able to provide physical modeling services include, but are not limited to, the following:

- U.S. Army Waterways Experiment Station, Vicksburg, Mississippi
- Northwest Hydraulics Consultants, Vancouver, British Columbia, Canada
- Delft Hydraulics Laboratory, Netherlands

[7] Airfield Development Engineering Consultant (ADEC). SFO – Airfield Development Program Preliminary Report No. 8: Phase 2 & 3 – Water Circulation, Sedimentation, and Water Quality Studies.

- Canadian Hydraulics Centre
- Universities (e.g. University of Delaware, University of Oregon, Texas A&M)

The time period to construct and calibrate a model of significant extent (e.g., a complete salt complex including local sloughs and mudflats) is estimated to be at 12 to 18 months. Thus it may not be feasible to construct an extensive physical model for the early, screening phases of the restoration design.

3.5 CASE STUDIES

No single model will handle the full range of flow conditions and hydrodynamic, geomorphic, sediment transport, and water quality characteristics of the South Bay Salt Ponds system, while allowing relatively rapid modification for alternative analysis. This is typical of modeling efforts in support of large restoration or development projects. The following pattern is quite typical:

- A relatively simple model is developed early in the project, for concept design and screening-level assessment.
- A more detailed model is constructed in support of preliminary designs and alternatives analysis.
- This more detailed model is used throughout the environmental review and design process, being modified as alternatives evolve.
- Additional models are constructed, often but not always based on the detailed overall model, to investigate specialized areas such as plume dispersion and control structure management.

3.5.1 SFO Runway Reconfiguration

Numerical modeling was performed by Moffatt & Nichol Engineers in support of runway reconfiguration alternatives for SFO, concentrating on the construction duration and long-term operational effects of the reconfigured runways and associated activities within San Francisco Bay.

- A MIKE-21 two-dimensional hydrodynamic model of the Bay Delta system extending out beyond the Golden Gate, and up to the Delta and the Far South Bay was developed and calibrated for use in alternatives formulation and screening level analysis. The model was subsequently used in developing boundary conditions for more detailed, higher resolution models of the North Bay and the South Bay.
- The MIKE model was used to conduct water quality analysis for the South Bay, including assessment of flushing time, and effects of runway reconfiguration on the existing North Bay System Unit's wastewater discharge operations. It was also used to assess screening-level effects of restoration of the Alviso and Baumberg Ponds on hydrodynamics, flushing time, and sedimentation processes of the South Bay.
- A 3-dimensional morphological sediment transport model using the DELFT model suite was developed by refining the bathymetry and calibration parameters. The objective was to assess long-term morphological changes to the shoreline, mud flats, and navigation channels in South San Francisco Bay as a result of the alternative runway layouts. The morphologic model was driven by a cohesive sediment transport module, which was in turn driven by the tidal hydrodynamic and wind wave modules

in a step-wise fashion. Special routines were developed to assess the circulation effects of runways constructed on pile supported piers, rather than fill.

- A 3-dimensional salinity model for the Bay Delta system was developed using the DELFT model suite, and calibrated using USGS cruise data. The objective was to understand and characterize existing conditions, such that long-term effects of the project could be analyzed if necessary. The model was successfully calibrated for summer and winter seasons. The model was also validated over the 1997 El Nino season with high Delta outflow.
- A more detailed, higher resolution MIKE model was developed for the North Bay to assess screening-level effects of restoration of several diked baylands around San Pablo Bay on hydrodynamics, flushing time, and sedimentation processes of the North Bay. A one-dimensional model was used to develop upstream boundary conditions for Sonoma Creek, Napa River, and Petaluma River. Based on the sediment transport simulation, the time required to attain target marsh elevations was estimated using a two-dimensional cohesive sediment transport model. The model was used in a step-wise fashion to simulate the morphologic evolution of the marsh channels and floodplain towards equilibrium conditions.
- Finally, a two-dimensional hydrodynamic and sediment transport model for the area offshore the Golden Gate was developed using the MIKE suite, to characterize existing conditions and analyze the effects of deepening the navigation channel on beaches in the vicinity. Existing conditions were simulated and characterized, and the effects of deepening on near-shore processes including tidal currents, waves, and sand transport were analyzed with the emphasis being changes to the beaches in San Francisco and Marin County.

3.5.2 Bolsa Chica Restoration

Moffatt & Nichol performed numerical modeling in support of restoration of approximately 880 acres of degraded wetlands as mitigation for Port of Long Beach/Los Angeles expansion projects. The following models were constructed as part of the concept design, environmental review, and preliminary design process.

- An in-house model, HCS, was used for concept design efforts leading to the Environmental Impact Report certified by the County of Orange in 1996. The one-dimensional model was used for hydrodynamic modeling of alternatives. Specific issues were the size of a new inlet planned to connect the wetlands to the ocean, the resulting scour rate at the inlet, the amount of tidal muting, and the grading plan required to provide desirable inundation frequencies and habitat values after construction. HCS was used for the concept design and environmental review efforts because it was fast to set up and run, and the long, narrow lagoons in the proposed wetland were well suited to a one-dimensional model.
- Starting in 1997, the two-dimensional finite-element RMA-2 model was used for hydrodynamic modeling of five of the eight restoration alternatives. RMA-2 also provided hydrodynamic information to the related water quality model RMA-4 (to describe contaminant transport and water quality) and the sediment transport model SED2D (to describe sedimentation patterns in the restored wetland). Specific issues were whether water quality (particularly salinity, heavy metals, and bacteria loads) would be acceptable throughout the lagoon, adjacent beach, and ocean; and whether scour and sedimentation would be at acceptable levels. Two-dimensional modeling

was selected to investigate these issues at a greater level of detail: for example, contaminant concentration levels throughout the wetlands, adjacent beach and ocean. At that time, the RMA-2 model suite was clearly the preferred two-dimensional model based on its wide acceptability to regulatory agencies and technical committees.

- In order to evaluate the impact of the adjacent East Garden Grove-Wintersburg (EGGW) Flood Control Channel flood flows on the restored habitat, the HEC-RAS model together with a side weir hydraulic analysis program were used to describe flows within the channel and over the diversion structures to the proposed wetlands. The modeled flood flows over the diversion structures were used as an input to the RMA-2 model. This one-dimensional model was used because it provided adequate resolution for the narrow flood control channel, and it was easy to set up and run for different scenarios. Three different control structures and six management alternatives were investigated as part of this effort.
- The one-dimensional HCS model continued to be used to provide rapid results for discrete parts of the system: for example, culvert sizing.
- Finally, the Shoreline Modeling System (SMS) featuring the GENESIS shoreline evolution model was used to evaluate shoreline impacts resulting from inlet construction and maintenance. This included the impacts of bar formation, jetty construction, and maintenance dredging on the updrift and downdrift shoreline. Maintaining a high quality recreational beach was of particular importance in this area, and the shoreline modeling evaluated potentially adverse impacts of the restoration. The SMS model was not linked directly to the RMA-2 model: however, it did take as input the jetty details previously designed using RMA-2. SMS is the industry standard for one-dimensional shoreline change.

The Bolsa Chica project did not require modeling of contaminated sediment: although there are contaminated sediments within the project site, the plan is to dredge those sediments, transport them off-site, and cap the dredged area with clean fill. It was a smaller project than the South Bay Salt Ponds restoration, and did not have the same complexities related to water quality and flood management.

4. DATA COLLECTION AND MODELING STRATEGY

The numerical model strategy cannot be defined in isolation from the data collection strategy. No numerical model can be considered reliable without calibration and verification against field data. (Model calibration refers to the process of adjusting model parameters so that the results match field data; model verification refers to the process of running the calibrated model and testing the results against field data, for a period and a data set independent of that used in model calibration).

This report therefore proposes a combined strategy for numerical modeling and data collection, linked to the Alternative Formulation, Engineering, Costing & Design, and Environmental Clearance parts of the South Bay Salt Ponds Restoration Long-term Planning Schedule.

4.1 MODEL DIMENSION

The salt ponds, tidal marshes, and South Bay are large water bodies, which do not exhibit extreme stratification. Their large horizontal extent means that horizontal circulation is likely to be important, and a one-dimensional model could fail to capture water quality and sedimentation changes across the ponds. The water column can be assumed to be well-mixed since the restoration would occur after pond salinities have been reduced from present levels (objective of ISP), so a three-dimensional model may not be required except for ponds that were not part of the ISP.

For the rivers and creeks upstream of the restoration area, a one-dimensional model is appropriate for flood management and sedimentation. It may also be appropriate to use a one-dimensional model to describe portions of the restoration area, particularly the major inlets and channels and the control structures, because two-dimensional models generally do not describe control structures as well as one-dimensional models (which have traditionally focused on flood control). However, given the importance of circulation, water quality, and sedimentation processes, a combination one- and two-dimensional model would provide a better representation of the restoration area than a pure two-dimensional model.

We therefore recommend that the main modeling effort consist of a combined one- and two-dimensional model, with the South Bay and salt ponds (and eventual tidal marshes and managed ponds) described by a two-dimensional model, and the channels (including inlets, sloughs, and upstream channels) and control structures described by a one-dimensional model linked to the two-dimensional model. The two-dimensional model domain should extend farther north of the San Mateo Bridge, based on evaluation of boundary effects, and include the South Bay and the salt ponds to the urban levees (levee separating ponds from urban developments). The one-dimensional model should include the sloughs and channels upstream of the urban levees to at least the limit of expected tidal influence. Commercially available models suitable for this effort include the RMA, MIKE, and DELFT model suites as the main two-dimensional hydrodynamic engine[8], with linkages to one-dimensional models as appropriate.

There are two main contexts in which vertical stratification may become important: in the dispersion of contaminants from sediments that are mobilized due to restoration; and in salinity intrusion into channels and its impact on groundwater salinity. If initial analyses

[8] TELEMAC or GEMSS are also technically suitable, although less widely accepted.

suggest that stratification is indeed important, three-dimensional models covering limited areas (or a one + one dimensional model for the salinity intrusion) could be used to address these issues. Specialized plume dispersion and groundwater models are also likely to prove useful.

An alternative approach would be to use a one-dimensional model to describe all of the inland areas, including the salt ponds as well as the channels. A two-dimensional model would still be required for the South Bay. Since there are existing two-dimensional models of the South Bay, a one-dimensional model could be constructed very rapidly if sufficient data were available. Although a one-dimensional model would not adequately describe circulation within the individual salt ponds, given their large horizontal extent, it could be used to assess flood risk, tidal prism, degree of tidal muting, and current velocities and resulting scour in the channels at a screening level if the planning schedule is tight. In this case a rapid one-dimensional model development could be performed to assist with alternatives formulation and screening-level analysis of major alternatives, with the two-dimensional model used for detailed alternative refinement and for engineering design. The HEC-UNET or MIKE-11 model suites appear suitable for the one-dimensional part. However, based on the current state of knowledge of Far South Bay processes, we believe that the advantages gained by using a combined one- and two-dimensional model outweigh the limitations of a one-dimensional modeling effort.

4.2 PLANNING TIMELINE

4.2.1 Major Data Collection and Modeling Tasks

The following general approach to data collection and model development is proposed.

1. **Collect Existing Data and Perform Literature Review:** Complete the process of assembling existing data related to water levels, suspended sediment, salinity, etc. Perform a literature review to fully define the conditions under which mercury methylation may occur, and to determine desirable salinity ranges.
2. **Perform Screening-Level Field Data Collection:** Begin field data collection, particularly hydrologic data collection, as soon as possible – beginning in late 2003 if possible. Section 4.3 provides a suggested screening-level data collection program, based on our understanding of present data gaps.
3. **Construct Screening-Level Modeling:** Based on early results from the field data collection, construct, calibrate, and verify a combined one- and two-dimensional hydrodynamic model to assess existing conditions. Use existing two-dimensional models of the South Bay to obtain boundary conditions (water level or flux) at northern boundary of the model, and existing flood management models of the tributary rivers and creeks to give flow hydrographs at the upstream limits. Use this model development to support initial alternative formulation and screening-level analysis.
4. **Construct Baseline Model:** As soon as sufficient bathymetry is available, refine the hydrodynamics model, and construct, calibrate, and verify a combined one- and two-dimensional model of existing sediment transport, salinity, and flushing times (advection-diffusion modeling of conservative water quality constituents).
5. **Construct Restoration Model:** Once the Baseline Model is calibrated and verified to describe existing conditions, construct refined models to describe those restoration alternatives that passed the screening-level analysis and were selected for further

analysis. The combination of the Baseline and modified models would fully support Specific Decisions 10 through 16. Different boundary conditions (extreme rather than typical conditions) would be used in support of the flood-related Specific Decisions 14 and 15.

6. **Construct Specialized Models:** Construct and run additional models in support of the other Specific Decisions (plume dispersion, sediment-bound and dissolved contaminants, mercury methylation, nutrient cycling, groundwater, etc.), using the Baseline Model to provide geomorphology and hydrodynamics. For each additional model, the existing conditions must be modeled first, with restoration modeling performed after the existing conditions models are calibrated and verified.
7. **Continue Field Data Collection:** Continue field data collection throughout the design, environmental review, and modeling process, in support of the Baseline Modeling, Restoration Modeling, and Specialized Modeling.

4.2.2 Relationship to Long-Term Planning Schedule

The following lists major task completions summarized from the Alternative Formulation and Environmental Clearance parts of the South Bay Salt Ponds Restoration Long-Term Planning Schedule. The purpose of this summary listing is to tie the proposed data collection and modeling tasks into the long-term planning schedule.

Q1 2004 **Alternatives Formulation (Goals, Objectives & Constraints)**

The schedule may not permit the Baseline Model to contribute to the initial formulation of alternatives. However, the proposed screening-level modeling effort (Task 3 of Section 4.2.1) based on existing data and initial hydrodynamic field data could be used to support this process.

Q3 2004 To Q2 2005 **Revise / Refine Alternatives**

This task is supported by the Baseline Model of hydrodynamics (including integration with upland flood management models), sedimentation (including geomorphic changes), salinity, and flushing times. The Restoration Models will be constructed and run for each alternative that passed the initial screening.

If available, initial results from the Specialized Models of water and sediment quality can be used to guide the alternative refinement, although the modeling schedule would have to be extremely aggressive to allow the alternatives to be modeled in detail by early 2005.

Q3 2005 **Final Evaluation of Alternatives & Restoration Concept Plan**

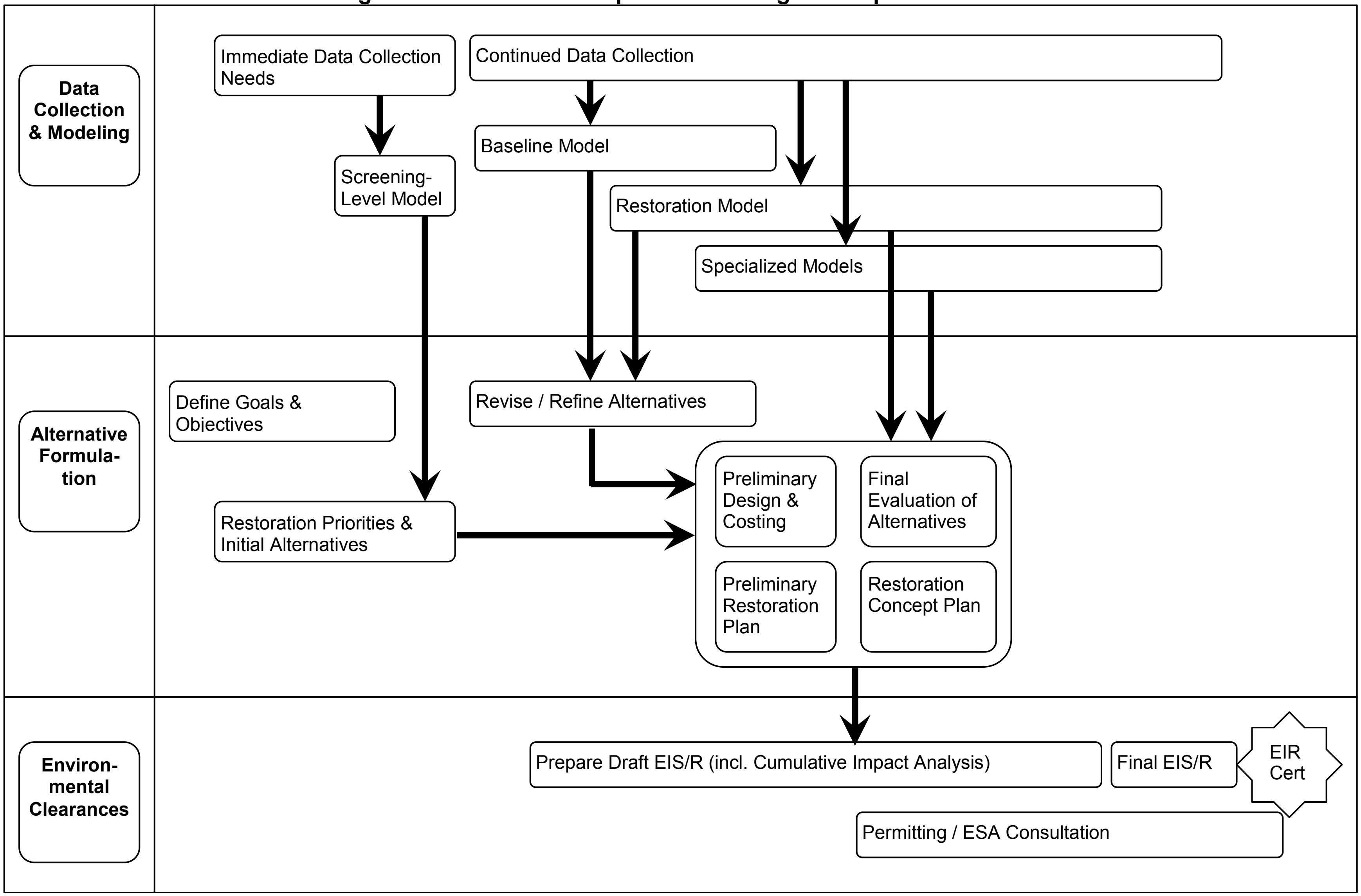
Q4 2005 **Draft EIS/R**

These tasks are supported by the Baseline and Restoration Models, and the Specialized Models that describe plume dispersion, sediment-bound and dissolved contaminants, mercury methylation, nutrient cycling, groundwater, etc. (Specific Decisions 11 and 17 through 19).

Q4 2006 **Detailed Engineering Design**

Figure 1 illustrates the interrelationship between the outline modeling strategy and the long-term planning schedule. Dependencies are shown schematically.

Figure 1: Overview of Proposed Modeling and Dependencies



4.3 Data Collection

The basic requirement of any successful modeling exercise is having sufficient data for model setup (i.e., bathymetry and topography), definition of boundary conditions, and for model calibration and verification. These measurements must encompass the range of conditions of interest; in particular, a full range of climatic events must be available.

Screening-level modeling is on the critical path for understanding and assessing existing conditions, which requires adequate data for developing the existing conditions model. Since these data are not available at present, this interim screening-level data collection is therefore discussed in more detail. The requirements for continued data collection highlight the areas where significant data needs are anticipated.

4.3.1 Screening Level and Baseline Model Data Needs

Although data collection will occur throughout the design and environmental review process, a broad data collection exercise may not be possible in the immediate near-term given the planning timeline. This section recommends an interim data collection exercise, intended to obtain hydrologic, sediment transport, and salinity data starting Fall 2003 and continuing beyond the wet weather season – allowing existing conditions to be analyzed and used in formulating and screening alternatives, as well as evaluating impacts of the restoration project. A subset of these data collection locations should be continued, preferably over the next 2 years, as described in the next section (Section Continued Data Collection)

Hydrologic Data

Existing and historical hydrologic (water level and flow) data are illustrated in Figure 2.

- **Water level fluctuation (Tides)**: The only real-time, operational tide gage in the South Bay is in Redwood Creek, near the Port of Redwood City. This is part of the SFPORTS monitoring system for navigation. Tide range and statistics were measured until the mid-1980s in the vicinity of Dumbarton Bridge and the mouths of Alviso Slough and Matadero Creek. Short-term data collection was performed by NOAA-NOS in Guadalupe River, Coyote Creek, Alviso Slough and the Baumberg area in the mid-1970s; significant flood control projects and deposition in the creeks have occurred since this time. These earlier data collection sites are indicated on Figure 2 as needing data verification.
- **Treatment plant flows**: Flows from the treatment plants are monitored and available.
- **River stage and flow data**: Very limited data are available at present on water levels near the mouth of the creeks. The SCVWD, the City of Palo Alto, and the USGS collect river stage and flow data for tributaries to the South Bay. However, almost all of these measurement sites are upstream of the salt ponds levees and only one (on San Francisquito Creek) shows tidal intrusion. Figure 2 indicates the locations of stream gauges in the vicinity of the project.

The Flood Management component of the restoration project will require hydrodynamic analysis, including modeling, of water levels and flow including the creeks up to the limit of tidal influence. Calibration and verification of the models should be based on recent data including stage and tidal phase. This calls for an update of SCVWD's upstream hydraulic analysis, based on 100-year water level estimates established by the USACE in 1984. Critically, however, additional water level data in the tidally influenced area will be needed.

Sediment Data

Real time total suspended sediment data (TSS) are collected by USGS near both bridges (Dumbarton and San Mateo) and in the far South Bay (Marker 17). Near-bottom and mid-depth continuous measurements are collected. Short-term vertical profiles of suspended sediment have been collected as part of the regional Monitoring Program (RMP) by USGS cruises along the primary tidal channel (spine) of the Bay.

Establishing a sediment budget for the South Bay and modeling of cohesive sediment transport processes will be critical in determining the potential for mudflat erosion and deposition in the restored areas, and resulting restoration timeline. The primary sources and processes leading to sediment suspension in the far South Bay (wind re-suspension versus currents, outflow from local creeks versus Bay Delta) need to be characterized both in the main tidal channels and in the mudflats. Sediment cores should be sampled and tested, to determine physical characteristics as well as bulk chemistry. These will be used in determining grain size for the sedimentation models, as well as shear strength of shallow depth sediments which can be used as a measure of erodibility.

Salinity Data

Very limited salinity data are available for the study area. USGS cruise data have been collected as part of the RMP program along the primary tidal channel of the Bay. Limited additional data is available from the City of San Jose as part of monitoring activities related to treatment plant operations.

Salinity data will be required for the creeks to establish the limits of salt water intrusion, including the potential for groundwater intrusion.

Bathymetry

The far South Bay has not been surveyed since the mid-1980s, and the tidal reaches of the creeks have very limited survey information. Successive bathymetric data over the mudflats is limited, and model calibration for scour/deposition processes will be qualitative at best. USGS has mapped the mudflats in the mid-1990's, and some of the creeks have been surveyed as part of flood control studies.

Given the very shallow depths in the far South Bay, the system hydrodynamics will be very sensitive to the channel and mudflat bathymetry. In particular, the lower reaches of the creeks should be surveyed to determine flow capacity and the potential for flooding.

Recommendations

We understand that the USGS plans to measure the bathymetry in a number of the salt ponds, inlets, and mudflats in the area[9]. Assuming these measurements will be available in early 2004, additional pond bathymetry will not be required. However, hydrologic, suspended sediment, and salinity measurements in the restoration are needed for this winter for the screening-level analysis.

We believe that data for the following locations will be needed. Duration of data collection would range from short-term (spring-neap cycle) to over 3 months depending on location and

[9] Science Support for Salt Pond Restoration and Management: Short-term Data Collection Needs, Scope of Work and Budget. USGS, 2003.

type of instrument, with a subset of the data collection locations continuing beyond the winter. Figure 3 illustrations the proposed data collection station locations.

Table 3: Recommended Data Collection Stations

	Location	Water Level	Currents and/or Waves[w]	Suspended Sediment (OBS)	CTD (Salinity)
1	Coyote Hills Slough, near mouth[1]	●		●	
2	Coyote Hills Slough, upstream	●			
3	Dumbarton Br. [1]	●	●	●	●
4	East Mudflats (so of Dumbarton) [1]		●[w]	●	
5	Mountain View Slough, upstream	●			
6	West Mudflats (near Palo Alto) [1]		●[w]	●	
7	Stevens Creek, near mouth	●			
8	Stevens Creek, upstream	●			
9	Guadalupe Slough, upstream	●			
10	Alviso Slough, near mouth[1]	●	●	●	●
11	Alviso Slough, upstream	●			●
12	Mud Slough	●	●		
13	Coyote Creek, U/S of Artesian Sl. [1]	●	●	●	●
14	Mowry Slough, near mouth	●			
15	Ravenswood Slough	●		●	
16	East Mudflats (near San Mateo Br) [1]		●	●	●
17	West Mudflats (at San Mateo Br) [1]	●	●[w]	●	●
18	Bay Bridge[1]	●	●	●	●

Notes

[1] Recommend continuing data collection beyond winter 2003. Some are already USGS stations.

- Some of the locations are already being monitored by Flood Control Districts, USGS, City of San Jose, RMP program. They are shown here for clarity and as essential for numerical modeling
- Simultaneous measurements at all locations not necessary. A mix of short-term and long-term would be adequate.

The following additional data should be collected:

- TSS/ADCP profiles along 3-4 sections across the South Bay (over mudflats in Far South Bay, near San Mateo Bridge, and Dumbarton Bridge)
- Bathymetry along 2-3 sections across the mudflats.
- Bottom grab samples / shallow cores at 8-10 of the above station locations to determine sediment type.
- Bathymetry across the creeks (Mountain View, Stevens, Guadalupe, Alviso, Coyote and Mud) at 2-3 locations, including the above station locations.

4.3.2 Continued Data Collection

Data collection is anticipated to continue throughout the design and environmental review process, and will be guided by the model domain extents, alternatives selected for further study, and initial data collection and modeling results. The following list summarizes the long-term data requirements of the modeling, with particular emphasis on those quantities that vary seasonally.

- **Hydrologic** variables – specifically water levels and currents – are required at key locations. Recommended locations are the Far South Bay (near mouths and upstream in some of the larger creeks), Dumbarton Bridge, either side of the San Mateo Bridge, and near the Bay Bridge. These gages should be maintained over at least 2 full seasons, with a subset continuing as monitoring locations, as restoration is implemented in successive stages.
- **Salinity** within the channels, and near the baseline/restoration model boundaries is required. For each channel, this should include simultaneous measurements at two or more locations through an entire spring-neap tidal cycle and during both summer and winter flows. Initial exploratory data collection will be needed to determine the upland limit of tidal intrusion and to determine whether stratification is likely, and so to locate the salinity measurements appropriately. Salinity measurements should be obtained at multiple depths at locations where stratification may occur.
- **Sediment** data collection should include suspended sediment loads as well as bed sediment characteristics. Short-terms suspended sediment measurements should be taken in concert with the salinity measurements described above, and should consider the location of water level and current gages. Additional monitoring of suspended sediment loads, again for at least one spring-neap cycle and during both summer and winter, should be performed for at least three nearshore locations around the South Bay (to characterize transport at the mudflats), at least one location near the east end of San Mateo Bridge, and one location farther north (preferably Bay Bridge). Wave and current measurements should be taken in association with these nearshore and offshore measurements.
- Optionally, a **flume study** could provide additional information about sediment cohesiveness and transport, by collecting a sediment core and conducting erodibility studies in a flume. The rate of sediment erosion or deposition as a function of current velocity could be measured directly, and used to calibrate transport models.
- **Bathymetry, levee, and control structure** information is required. This should include channel cross sections from the channel mouths to the upland limits of potential tidal influence – and beyond the upland limits of the salt pond. While the gross bathymetry of the South Bay is available, it may be necessary to perform further measurements of the mudflats. The USGS is presently measuring salt pond bathymetry. In addition to this information, details of levee heights and condition, and of existing control structures used to manage the salt ponds, should be gathered. While this information is not seasonally dependent, it should be collected as rapidly as possible since it is critical to model setup – both the screening-level modeling proposed for alternative formulation and the larger modeling effort proposed for alternative evaluation and design.
- **Sediment cores** should be collected from the channels and mudflats, and tested for contaminants. This could be postponed until initial geomorphic modeling is complete, so that the likely depth of scour is known.

- **Water quality** monitoring is required, particularly in relation to biological characteristics such as nutrients, DO and BOD. Depending on which constituents are modeled, monitoring stations should be installed in the creeks at the locations of the long-term hydrologic monitoring stations.
- **Groundwater salinity** and **transmissivity** are required, and additional monitoring wells together with well draw down tests may be required.

4.4 MODELING & DATA COLLECTION - LEVEL OF EFFORT

It is recognized that the restoration planning study will be conducted over several years, with implementation of selected restoration projects occurring over several more years. Modeling and data collection efforts will continue throughout the planning and design phase, and may continue to some extent even beyond implementation as part of monitoring and adaptive management. With this in mind, it would not be practical to estimate long-term modeling and data collection budget, especially considering that the scope of these activities will depend on as yet undefined constraints, understanding of processes in the Far South Bay, and the number of alternatives to be simulated. However, near-term efforts which are envisioned as part of alternatives formulation and screening-level modeling can be estimated based on experience and judgment.

Modeling (Existing Conditions & Screening Level)

The level of effort for the existing conditions summary and screening-level phase of modeling is based on the following assumptions :

- Literature review, model selection, data collection is limited to needs for characterizing existing conditions and screening-level modeling;
- A combined one- and two-dimensional model will be used for this phase (not necessarily coupled). Input for one-dimensional model including flows and geometry will be provided by Flood Control Districts;
- An existing calibrated two-dimensional model is used for this phase;
- Simulations will be conducted for “normal” outflow from creeks/Delta and “high” outflow from creeks/Delta to evaluate flood control needs;
- Only the Hydrodynamics model is calibrated (water quality and sediment transport models calibrated based on existing data and judgment);
- Hydrodynamics for up to ten conceptual alternatives will be simulated;
- Meetings / presentations are limited to Project Management Team only.

Based on these assumptions, tasks and order of magnitude budgets were developed as presented on Table 4.

Table 4: Approximate Level of Effort

For Characterizing Existing Conditions & Screening of Alternatives

(based on several assumptions - see above)

	Task	Labor (Weeks)	Budget ($4000/wk)
1.	Literature Review / Gather Data for boundary conditions	3	$12,000
2.	Model Setup (Combined 1D / 2D)	5	$20,000
3.	Simulate Existing Conditions (Normal Flow + High Flow)		
	Hydrodynamics	6	$24,000
	Flushing	4	$16,000
	Sediment Transport	7	$28,000
4.	Model Setup For Conceptual Alternatives (up to 10 Alts)	5	$20,000
5.	Simulate Conceptual Alternatives (Hydrodynamics only)	12	$48,000
6.	Prepare Report	6	$24,000
7.	Meeting / Presentations	2	$8,000
8.	Expenses (copying, plotting, etc)		$1,000
	Subtotal	50	$201,000

Data Collection

The level of effort for field data collection to be used for model calibration and understanding existing conditions is based on the following assumptions :

- Existing data from USGS, City of San Jose, Flood Control Districts will be made available;
- New instrumentation limited to the project area and immediate vicinity (for calibration/ validation of screening-level model);
- Several gages are combined on a single "platform" to reduce mobilization/ demobilization costs;
- Existing piles/dolphins/bridges are used to the maximum extent to reduce costs and potential for equipment loss;
- Data collection is limited to 6 water level gages, 4 CTD gages, 3 OBS gages, 2 current meters, 2 wave rider buoys, and 1 week of surveying

Based on these assumptions, tasks and order of magnitude budgets were developed as shown on Table 5.

Table 5: Approximate Level of Effort For Initial Field Data Collection

(based on several assumptions - see above)

	Task	Duration (weeks)	Budget
1.	Install / operate five (4) platforms with multiple gages (about $1,000/week/station)	12	$48,000
2.	Install / operate three (3) gage clusters at existing structures (about $800/week/station)	12	$29,000
3.	Survey bathymetry (up to 1 week of sections/profiles)	1	$15,000
4.	Data Reduction / Summary		$10,000
	Subtotal		$102,000

The gage locations shown above are a subset of the locations shown on Table 3 (see Section 4.3), and more data will be required as recommended in section 4.3. However, data collection is anticipated to be a cooperative effort between the cities, Flood Control Districts, and USGS and the costs are therefore not included in the above. If cooperative agreements cannot be worked out, or the agencies have to be compensated, the budget shown above should be increased by as much as 100%.

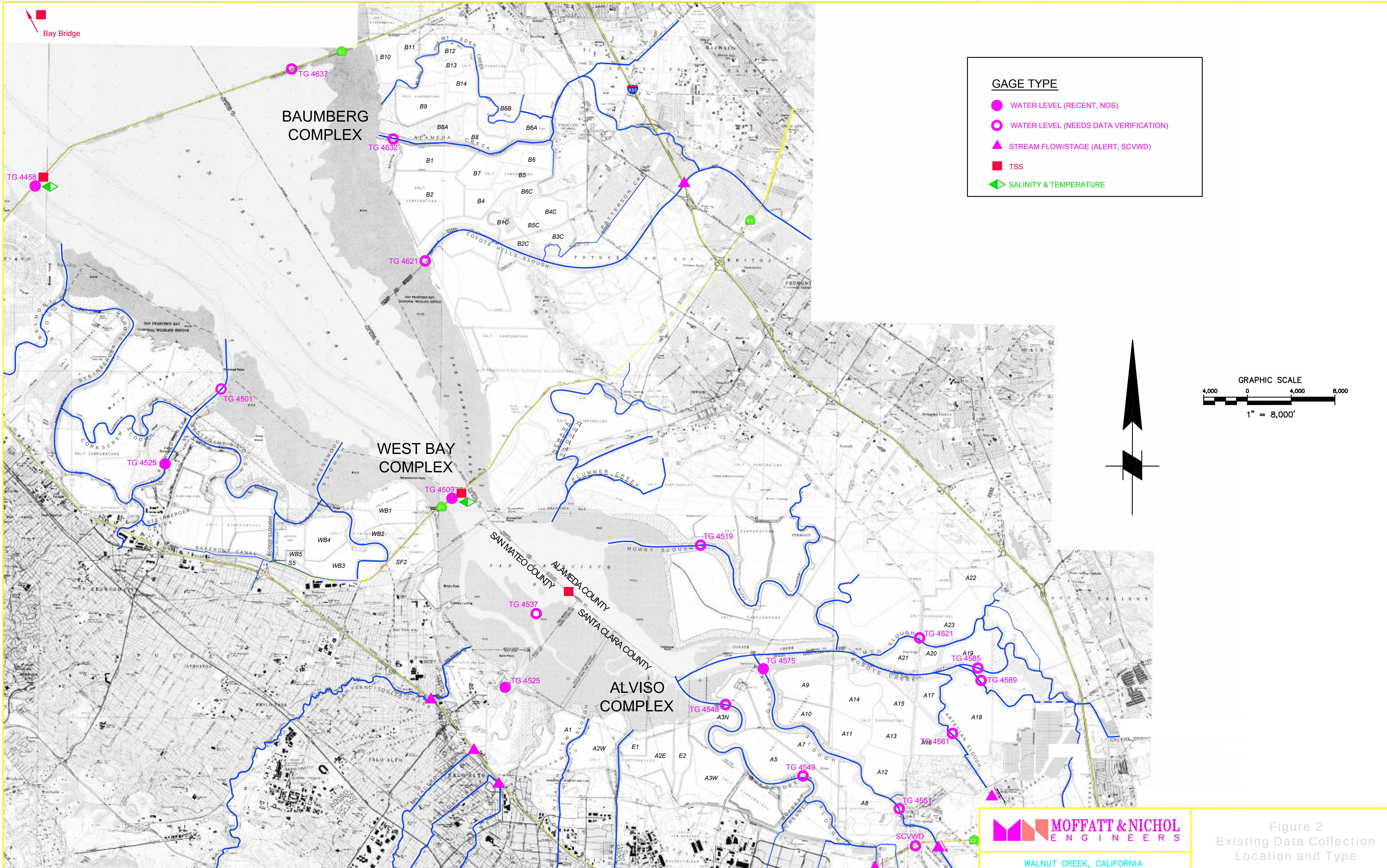


Figure 2
Existing Data Collection Location and Type

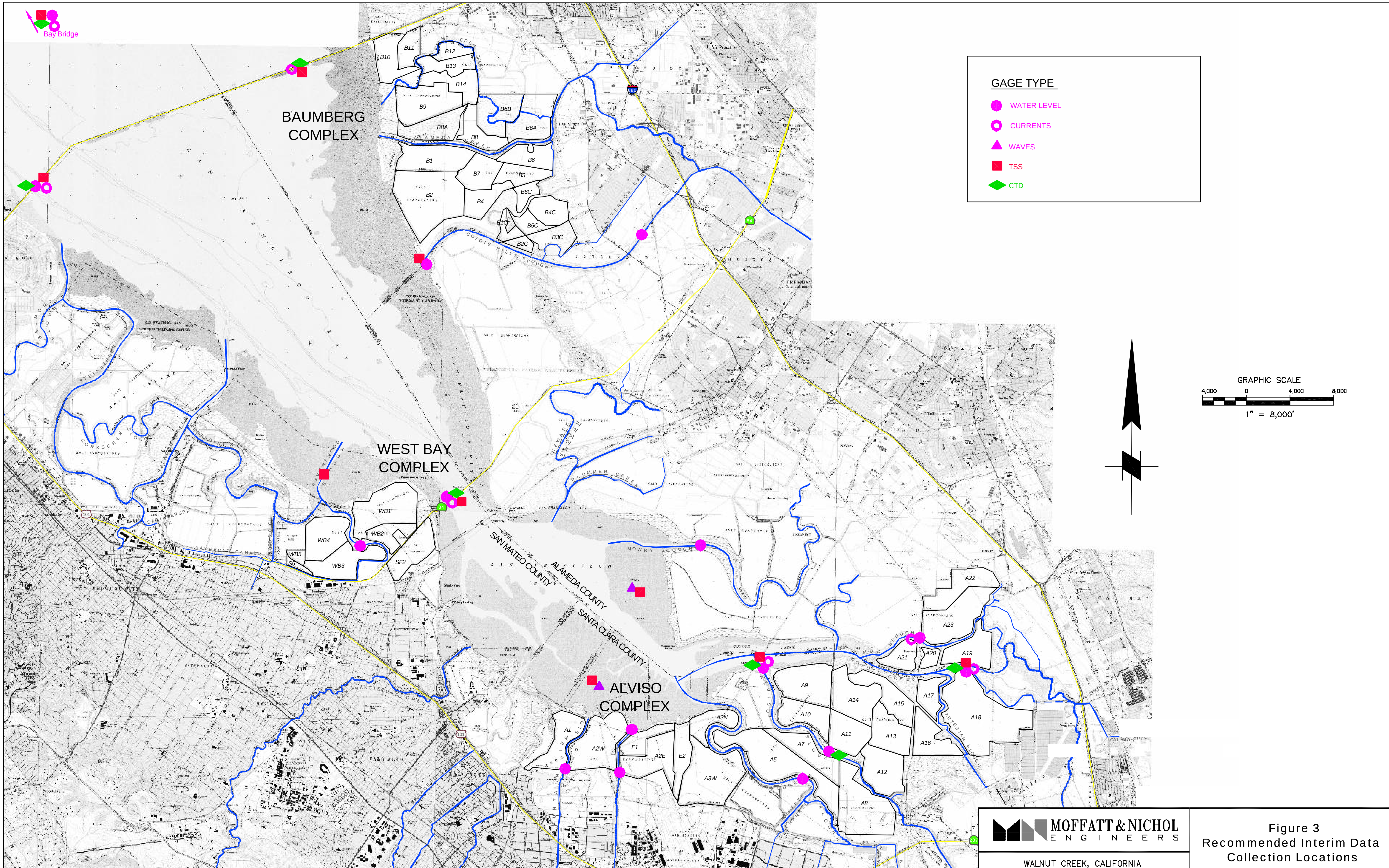


Figure 3
Recommended Interim Data Collection Locations