SCIENCE SYNTHESIS

Key Science Issue 6: Impacts of Hydrological Modifications from Salt Pond Management And Ecosystem Restoration

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Introduction

Understanding how the South Bay ecosystem functions from a hydrological perspective is critical to evaluating impacts of the SBSP restoration project. Assessing impacts of hydrological modifications is one of the key uncertainties identified by the Science Team. This document provides a framework for assessing impacts of hydrological modifications associated with the restoration of a pond or system of ponds on the South Bay ecosystem. Available literature and ongoing research activities (both as part of project planning studies as well as Baywide efforts by scientists and others) are referenced in the document and a qualitative synthesis is presented, but the subject matter is too large to summarize in a single document such as this. The objective is summarize the level of knowledge and the level of confidence we have in the available literature.

The San Francisco Estuary is a large, complex coastal estuary system comprised of several large bays, with deep channels, shallow mudflats, and a sprawling tidal river delta. San Francisco Bay communicates with the ocean through the Golden Gate. The Bay is subject to semi-diurnal tides with a diurnal inequality and strong spring/neap variations. The tidal prism through the Golden Gate is approximately 1.59×10^9 m^3 (ADEC 2000). The Sacramento/San Joaquin Delta supplies about 90% of the freshwater flow into San Francisco Bay, and the average flow from the delta is approximately 500 m^3/s. The rivers discharge large volumes of freshwater during the winter and spring, due to a combination of rain and snow melt. Peak freshwater inflow varies from year to year, depending on climatic factors such as rainfall, temperature, and snowmelt.

The portion of Bay south of the Oakland Bay Bridge exhibits the characteristics of a shallow tidal lagoon, with a mean depth of about 11 feet (Denton and Hunt 1986). Tides coming through the north end are reflected and amplified at the closed south end. As a result, the tidal range near Dumbarton Bridge is about 50% higher than the tidal range near the Bay Bridge. The Far South Bay[1] is even shallower with a mean depth of about 3 feet, and about 75% of the surface area consisting of mudflats. There is little direct freshwater inflow to the Far South Bay except winter/spring runoff from the local streams and Water Polution Control Plant (WPCP) discharges. Freshwater input from the Sacramento-San Joaquin Delta influences the South Bay only under high outflow conditions (Walters et al., 1985). Daily flows from the Delta are monitored by the Department of Water Resources and USGS (Oltmann, 1998).

[1] To differentiate the Bay south of Dumbarton Bridge from the South Bay in general, the term "*Far South Bay*" is used in this report.

Historically the South Bay contained a substantial tidal marsh system south of the Dumbarton Bridge. Conversion of marshlands to salt ponds, and changes in the sediment budget of the South Bay as a result of construction of reservoirs in the upper watersheds and urbanization, have changed the characteristics of the South Bay substantially (see issue 1 synthesis). Presently, over half of the Far South Bay consists of shallow mudflats which are exposed at low tides.

The significance of the South Bay Salt Pond Restoration Project is apparent when comparing the size of the potential restoration area to the size of the Far South Bay. The area of the Far South Bay at high tide is approximately 15,000 acres (Moffatt & Nichol 2003a). This implies that full tidal restoration of the acquired Alviso ponds (about 7500 acres) would constitute an increase of about 50% in the surface area at high tide. The approximate diurnal tidal prism of the Far South Bay is 72,000 acre-feet (AF). Full tidal restoration of the acquired Alviso ponds[2] would constitute an increase of about 55% in the diurnal tidal prism, with six ponds (A2E, A2W, A3W, A5, A8, A12) contributing about half of the net increase (Moffatt & Nichol 2003a).

1.0 What is the importance of the issue as it relates to the Project objectives?

Hydrological modifications include making changes to the hydrology of the ponds and the sloughs in the project area by introducing new connections between the ponds and the local sloughs or Bay. Changes in hydrology will affect physical processes (water levels, circulation, water quality, and sedimentation) which in turn will affect the following characteristics of the South Bay (the specific objectives which are relevant to each of the characteristics are provided in parentheses).

- habitat functions and values (Objectives 1A, 1B, 1C);
- flood protection levels (Objective 2);
- public access opportunities (Objective 3);
- water and sediment quality (Objective 4);
- predation, non-native species, vector control (Objective 5);
- other infrastructure (Objective 6)

Flood conveyance characteristics of local creeks, flood control channels, and rivers will be affected when reestablishing connections to historical floodplains, and some of the ponds levees between the newly created tidal marsh and local communities will need to be enhanced to provide adequate flood protection. Physical processes such as channel scour and sedimentation and tidal hydrodynamics will also be affected. The restoration project will also interact with other water conveyance facilities such as water treatment plants and storm drains.

Hydrological modification(s) is therefore the key implementation measure that will influence physical processes, and ultimately influence the potential for success of the project in meeting any of the objectives. Physical processes are fundamental in the

[2] Assuming no muting, and based on pond volume estimates described in Siegel & Bachand, 2002

restoration and enhancement of the ecosystem in which they act. The importance of physical processes and their effects on the project objectives are addressed below.

1.1 Importance To Habitat Functions and Values (Objective 1)

Current hydrological conditions in the project area, although changing in response to the ISP, are supporting habitat functions and values for migratory birds and shorebirds, and other aquatic and terrestrial wildlife. As described in the synthesis for Issue 5 (Warnock, 2005), San Francisco Bay contains the most important salt pond complexes for waterbirds in the United States, supporting more than a million waterbirds through the year. The synthesis for Issue 5 also describes that single day counts of waterbirds in the salt ponds during winter months can exceed 200,000 individuals, and single day counts during peak spring migration have exceeded 200,000 shorebirds in a single salt evaporation pond. The data show highest densities of birds in salt ponds, followed by tidal flats, open water, and tidal marshes. The potential effect of the restoration of the 15,000 acres of South Bay salt ponds to other habitat types, particularly tidal marsh habitat, is therefore of significant concern.

The physical parameters which influence habitat functions in general can be described as follows, with some parameters influencing both hydrological as well as water quality functions (such as salinity, circulation, etc.).

- water depth,
- water temperature,
- flow velocity,
- circulation (affects vertical and horizontal mixing, as well as flushing),
- tidal prism,
- suspended sediment concentrations and sediment availability,
- sedimentation patterns (function of waves and tidal currents).
- salinity,
- dissolved oxygen (DO) concentration,
- nutrient and algal concentration,

Some of the restoration actions will result in changes in these parameters, albeit to varying levels depending on specific restoration designs. Understanding and quantifying the relationships between the above parameters, and the functions that they support, are therefore critical to assessing the effects of modifications. These relationships are discussed in this document, as well as several other ecosystem studies (*Chesapeake Bay - Introduction To An Ecosystem, Goals Report, PRBO Studies, Napa-Sonoma Marsh Restoration EIS*). Other Baywide studies (Goals Report, 1999) have also identified these physical parameters as critical elements in supporting existing habitat functions and values, and recognized that changes in these parameters will affect overall quality and type of habitat.

Some examples of cause and effect relationships are :

- Migratory birds depend upon a combination of water depth, salinity, and DO in the ponds to provide food and habitat (Goals Report, 1999). Water depth, salinity, and DO, which affect the food source and ultimate habitat quality for migratory birds, are in turn driven by the flushing characteristics of a water body.
- The Goals Report (1999) estimates that if 50% of the South Bay's salt ponds were converted to tidal marsh, that 15% of the 76,000 waterfowl that use those salt ponds could be lost. This suggests that water depth, salinity, and elevation (among other parameters) affect the size, quality, and longevity of the habitat – changes to these parameters affect habitat functions and values.
- An example of a direct effect of salinity is the vegetation type in marshes. Salinity preferences and tolerances of several species are discussed by Siegel and Bachand (2002) and in ISP documents (Life Science, 2003b). An example of an indirect effect of salinity is the effect of increased stratification on phytoplankton by reducing vertical mixing, thereby decreasing the ability of benthic organisms to graze on phytoplankton in the upper layer of a stratified water column (Cloern, 1985).
- Opening ponds will increase the vertical and horizontal SSC clearing rates (Shellenbarger et al. 2004) described in a conceptual framework for phytoplankton growth response to water column clearing (May et al. 2003). Thus, restoring salt ponds to wetlands can affect phytoplankton population dynamics, although inter-annual variability of benthic grazing rates on the shoals can have a greater influence on controlling phytoplankton populations than the increase in SSC clearing rates.

1.2 Importance To Flood Protection Levels (Objective 2)

Over the past several years, local flood control districts have implemented flood protection projects in the study area such as along Alameda Creek, Guadalupe River, Coyote Creek, and others, which has reduced the risk of flooding to local communities (Moffatt & Nichol 2003a, SCVWD 2002). However, most of the creeks offer just enough conveyance capacity to convey the design flood flows (100-year in most cases). Some creeks which do not offer this protection are being modified to contain the design flood flows and the projects are in various stages of development (Coyote Hills Slough, Lower Guadalupe River, Permanente Creek, San Francisquito Creek, etc.). Changes in tidal water levels in these creeks, even minor, will change the conveyance capacity and affect the level of flood protection to adjacent communities.

Parameters Affecting Flood Protection Levels

Changes in the following parameters will impact the conveyance capacity of sloughs and tributaries, and in turn affect the level of flood protection that is provided in the area. Naturally occurring changes in the area such as subsidence, sea-level rise, or changes in flow or sediment regime are not included here because they are long-term parameters which need to be addressed in flood control regardless of the restoration project.

- Water level (for example, due to changes in tidal prism)
- Circulation/hydrodynamics (for example, due to increase in velocity)
- Fluvial hydrology (for example, due to flood routing resulting from availability of ponds for flood overflow)

The primary flood protection concern with pond restoration is that several interior levees which do not function as flood control levees at present may become Bayfront levees. This fact, coupled with changes in water levels, circulation, and wave exposure due to the restoration project, will require that post-project conditions be accurately characterized during the planning and design process to develop realistic planning budgets. In addition, opening of the ponds to tidal action will result in wave-induced erosion of existing levees which have not been designed to withstand wave action and overtopping.

Changes in diurnal tidal prism of a conveyance channel (for example due to restoration of a pond) will cause tidal water levels to change in the channel (O'Brien, 1931) . A significant increase in tidal prism will act in the short term to lower high water levels and increase channel velocities, which may result in channel bottom scour. The effects of the increase in velocities and scour on levee integrity will need to be evaluated.

Variations in tidal range are not by themselves the critical consideration for flood protection in the sloughs. Flood protection is impacted most by coinciding high tide and high fluvial flow events. Water elevations in the sloughs during these periods are highest as flood and tidal waves superimpose.

1.3 Importance Related To Public Access Opportunities (Objective 3)

Public trails and other access require safe and unimpeded access to certain portions of the restoration project. The existing Bay Trail system is along levees around certain salt ponds. Hydrological modifications may include levee breaches and channels in areas which may affect the existing and/or proposed Bay Trail.

1.4 Importance To Water And Sediment Quality (Objective 4)

Water quality in the Far South Bay has been an ongoing issue of concern, and several stringent objectives are being considered even without the restoration project (Basin Plan, etc.). Primary issues are increased pollutant loading and flushing characteristics of the South Bay, which result in violations especially during summer. From a regulatory perspective, if hydrological conditions were to change, they should result in an increase in the number of exceedances of water quality objectives. Specific parameters of relevance to water quality associated with the restoration project include the following:

- temperature,
- salinity,
- residence time,
- circulation (vertical and horizontal mixing),
- suspended sediment concentrations.

Hydrological modifications associated with the Project may change some or all of the above parameters both inside and outside the area of the Project, and result in changes to the measures of water quality such as:

- dissolved oxygen (DO) concentration,
- pH,
- concentrations of contaminants in the dissolved and adsorbed phases,

For example, the Project may alter tidal circulation patterns which will affect residence time of contaminants, or may alter turbidity which will affect primary productivity and DO. Some of the issues which have already been identified as potential threats to water and sediment quality are methylation of mercury (associated with tidal exchange and inundation regimes as described in the synthesis for Issue 7), spread of contaminants to the rest of the Bay (associated with redistribution of relic sediments), and longer flushing times (which results in longer duration of ambient contaminants in the water column),.

The project is likely to alter salinity conditions locally in tidal sloughs primarily due to changes in tidal prism, that will result when restoring ponds to tidal action, and operations of the managed ponds (as will be described in Section 3.0). Salinity will change inside ponds as they are operated according to the Initial Stewardship Plan, as opposed to traditional salt making operations, and, later, as levees are breached to restore ponds as part of the Project.

1.5 Importance To Predation, Non-native Species, and Vector Management (Objective 5)

This is tied in to habitat function and value, and as such the criteria of relevance are the same as those described for Objective 1. Specifically, changes in inundation regime within a restored area could result in changes in vector management.

Direct effects of bringing tidal flow into areas which are presently non-tidal are the advection of non-native plant seed and material into restored areas. In addition, changes in salinity and/or inundation levels may result in establishment of non-native species (such as *spartina alterniflora*).

1.6 Importance To Infrastructure (Objective 6)

Infrastructure include power towers, waste water treatment plant (WWTP) operations, and road/railroad bridges. This public infrastructure provides essential services to the local community, which can not be reduced or otherwise affected by the restoration project. The parameters which could affect infrastructure operations as a result of the SBSP restoration project are described below.

> *Water Depth*: Restoring tidal action to ponds where power towers are present will affect water levels and circulation. This may affect existing maintenance access to the towers (catwalks could be submerged for some period), and may require modifying foundations (corrosion related).

Circulation: Modifications that result in changes in circulation within the sloughs and creeks could affect the operations of the WWTPs, due to changes in residence time and flushing. Significant changes in velocities and resulting scour in the larger creeks/sloughs could affect foundations of existing bridges.

Therefore, evaluating the effects of hydrological modifications including water levels, circulation, and flushing times become important.

2.0 What do we know about this issue as it relates to the Project?

This section presents the state of knowledge related to existing hydrological conditions and the extent to which it affects habitat functions and values, flood control objectives, water and sediment quality objectives, existing infrastructure, and public access.

The current knowledge base related to hydrological conditions in the project area is listed in Table 1. Several of these reports were reviewed and pertinent results presented in a subset of recent documents (Moffatt & Nichol 2003a, 2003b, Philip Williams & Associates 2004). Several agencies have collected, and are still collecting, data on hydrology, hydrodynamics, water quality, and sediment quality for San Francisco Bay. These include :

- NOAA (tidal elevation, currents, bathymetry),
- USGS (streamflow, tidal hydrodynamics, salinity, sediment),
- Santa Clara Valley Water District, SCVWD (streamflow, salinity)
- Alameda County Flood Control and Water Conservation District, ACFCWCD (streamflow, salinity)
- Waste Water Treatment Plant Operators (temperature, salinity, DO, nutrients, organics, contaminants)
- San Francisco Estuary Institute (Regional Monitoring Program)
- Other private and non-profit organizations, Universities, consultants as part of specific projects

These data are the primary sources of information which is needed for calibrating and verifying numerical models which will be developed to assess impacts of the restoration project.

2.1 <u>Fluvial Flows</u>

Long-term streamflow data from USGS are available for the Sacramento San Joaquin Delta, Alameda Creek, Coyote Creek, Guadalupe River, San Francisquito Creek, and Matadero Creek. In addition, the SCVWD and ACFCWCD gage flows and/or monitor water levels in various other creeks in Alameda and Santa Clara Counties. Flows from streams tributary to the South Bay have been analyzed by the Army Corps and local flood control agencies (Santa Clara, Alameda,and San Mateo Counties) as part of several Flood Insurance Studies for Alameda Creek, Guadalupe River, Coyote Creek, and San Francisquito Creek (USACE . In addition, other smaller creeks (for example

Permanente, Adobe, Barron, etc.) have also been analyzed by local agencies for FEMA levee certifications. Each county maintains countywide Flood Insurance Studies (FIS), along with Flood Insurance Rate Maps (FIRM) and Flood Boundary and Floodway Maps (FBFM). A summary of applicable data including flood flows and flooding history was provided in earlier studies (Moffatt & Nichol 2003a). However, a comprehensive hydraulic/hydrodynamic analysis for all the creeks in the South Bay, combining tidal and stream flows, does not exist at present.

2.2 Bathymetry, Water Levels, and Currents

The National Ocean Survey (NOS) branch of NOAA has prepared bathymetry charts for the South Bay based on surveys from the mid 1980's. Creek and river cross sections are available from the SCVWD and ACFCWCD. These, along with USGS mudflat surveys from the early 1990's, form the basis for the bathymetry information in South Bay. Several recent surveys have also been undertaken as part of the restoration project, and should be available as part of the project database (Foxgrover et. al., 2004). As described in the synthesis for Issue 2, approximately 61 percent of salt ponds have bottom elevations between mean tide level and mean high water (Siegel and Bachand 2002). About 22 percent of the ponds, all within the Alviso system, are below mean tide.

One of NOS's functions is also to measure tide induced water levels and prepare tidal benchmark data sheets. Applicable tide gages in the study area have been summarized in earlier reports (Moffatt & Nichol, 2003a). Tidal harmonics and constants have also been investigated and summarized by USGS (Cheng & Gartner, 1984).

NOS also has published current predictions for several locations in SF Bay. A comprehensive set of tidal currents data from the mid-1980's was also published by the USGS as part of characterizing San Francisco Bay (Cheng & Gartner 1984, Cheng & Gartner 1985, Gartner & Walters 1986).

2.3 Salt Transport Processes

Salinity in South San Francisco Bay depends on:

- salinity in Central Bay and exchange between SSFB and Central Bay,
- freshwater input to SSFB,
- evaporation,
- salt transport processes in SSFB (function of tidal dynamics and dispersion).

The properties of water in the Bay (density, salinity, and temperature) vary seasonally. The Bay is generally well mixed during the summer and fall, when the river flows are at their minimum and South Bay salinity approaches that of the ocean. Seasonal and yearly variations in salinity are driven primarily by variability in freshwater flow. General overviews of mixing processes in San Francisco Bay are provided by Walters et al. (1985) and Smith (1987).

During periods of high freshwater inflow, longitudinal salinity gradients can cause dynamic three-dimensional circulation patterns (McCulloch, 1970). A key feature of these circulation patterns is density-driven exchange between SSFB and Central Bay (Walters et al., 1985). Therefore, winter and spring salinity conditions in SSFB are dynamic, characterized by unsteady inflows, spatially variable salinity and periodic vertical stratification. Large interannual variability in winter and spring salinity results from natural variability in Delta flows and local tributary flows and, to a smaller extent, from variations in management actions such as operation of dams (Knowles, 2002). Large-scale weather patterns have several effects on salinity, including the effect of winter precipitation on flows, the effect of temperature on spring runoff and the effect of coastal upwelling due to spring/summer winds on coastal salinity (Peterson et al., 1995). When freshwater flows decrease, generally in late spring, the salinity in SSFB gradually increases as salt mixes into SSFB from the ocean (via Central Bay). During summer the largest sources of freshwater input to SSFB are wastewater treatment plants and their flows are the same order of magnitude as evaporation in SSFB (Denton and Hunt, 1986).

The variability of salinity within the South Bay depends on a variety of salt transport mechanisms. These transport mechanisms are driven by the tides, winds, freshwater inflows and density gradients in the South Bay. Therefore salinity varies over many time scales. Over the tidal time scale salinity gradients are advected several kilometers by tidal currents and vertical stratification can be created (or reduced) as a result of tidal straining and reduced by vertical mixing (Simpson et al. 1990). Over the spring-neap cycle the strength of the tides varies substantially and during neap tides the largest stratification is noted due to reduced vertical mixing (Cloern et al., 1985). Wind driven circulation can result in differential advection of salt. For example, a typical summer wind can cause landward transport of salt in the surface layer (the entire depth of the shoals) and seaward transport of salt at depth in the channel (Walters et al., 1985). River inflows reduce salinity by adding freshwater to the South Bay causing a net seaward advection of salt as the bay water is displaced seaward by the incoming freshwater. Therefore, freshwater input results in longitudinal density gradients and may cause gravitational circulation and stratification with the freshwater flowing seaward near the water surface and a landward return flow at depth (Walters et al., 1985).

Several dispersion mechanisms may be important in South San Francisco Bay under different conditions as explained below.

> *Tidal Trapping*: This term was used by Fischer et al. (1979) to provide a simple understanding of how tidal dispersion mechanisms can cause landward transport of salt. The classic case of tidal trapping occurs in an estuary with side embayments when some of the salt mass that enters the side embayments on the flood tide does not exit the side embayment on the ebb tide but instead remains “trapped” in the subembayment. Viewed at a single cross-section in the estuary, tidal dispersion/trapping can cause the salinity during flood tides to be higher on average than the salinity during the ebb tides, leading to net landward transport of salt.
>
> *Tidal Pumping*: This results from asymmetric flow patterns between flood tide and ebb tide that result in residual (tidally-averaged) velocities (Fischer et al., 1979). For example water passing the constriction at Dumbarton Bridge is likely to enter as a jet on flood tide but exit from a broader area leading to net landward

currents in the channel and seaward currents in the shoals. More generally, tidal dispersion can occur as the result of tidal flows over bathymetric features.

Gravitational Circulation: During and following high flow events, gravitational circulation can cause transport of salt into the estuary at depth that partially compensates for the mean (freshwater) seaward advection of salt.

Shear Dispersion: This results from a sheared velocity distribution, in the vertical or lateral direction, combined with small scale mixing (e.g., turbulent diffusion) in the direction of the velocity gradient (Fischer et al., 1979).

Continuous observations of salinity by the USGS are available at the west end of the Oakland Bay Bridge, at the San Mateo Bridge on the east side of the ship channel (Buchanan et al. 1996) and on the east span of the old Dumbarton Bridge (Schemel, 1998). These observations indicate the response of South Bay salinity to flow events and the tidal variability in salinity.

The USGS has collected salinity transect data in San Francisco Bay since 1969 as part of the pilot Regional Monitoring Program (e.g., Edmunds et al., 1995). These data are collected at least once a month at a maximum of 17 stations in the channel of South San Francisco Bay extending from the Oakland Bay Bridge to the mouth of Coyote Creek. The winter and spring salinity data frequently indicate relatively strong longitudinal salinity gradients in the channel and vertical stratification. Higher salinity, weaker longitudinal salinity gradients and vertically well-mixed conditions are typically present during summer.

The USGS has also collected salinity observations that provide insight into lateral salinity gradients (Huzzey et al., 1990, Powell et al., 1989 and Schemel, 1981). During periods of high flow, freshwater from Alameda Creek can depress salinity near the mouth of Alameda Flood Control Channel on the eastern shoals of SSFB (Huzzey et al., 1990). However, the opposite pattern, higher salinity in the shoals than the channel, has been noted when large pulses of freshwater from the Delta enter the channel of South Bay from Central Bay (Huzzey et al., 1990). During winter conditions, lateral salinity gradients can be as large as longitudinal salinity gradients.

2.4 Salinity in Tidal Sloughs

Strong salinity gradients are common in several tidal sloughs. South Bay tidal sloughs that receive runoff from local watersheds and discharges from local water pollution control plants (WPCPs). Descriptions of individual tidal sloughs are provided in the Hydrodynamics and Sediment Dynamics Existing Conditions Report (PWA 2004) and the Inventory of Water Conveyance Facilities Report (Moffat Nichol, 2003a) prepared for the Project. What follows is a general description of physical conditions and processes in tidal sloughs.

A study of the effects of water discharges from WPCPs (Kinnetic Labs, 1987) showed strong gradients are typically present Artesian Slough and Coyote Creek as a result of the San Jose/Santa Clara WPCP and in Guadalupe Slough as a result of the Sunnyvale WPCP discharge. Continuous salinity observations collected by the City of San Jose at several stations in Coyote Creek, Artesian Slough, Mud Slough and Alviso Slough show large variability in salinity during the tidal cycle. For example, in Artesian Slough it is common for salinity to vary by more than 20 ppt during a single tidal cycle. The strong longitudinal salinity gradients present in these sloughs can result in strong vertical salinity stratification during part of the tidal cycle (Simons, 2000). Salinity in most sloughs is highly variable seasonally, with lower salinity during winter and spring (Kinnetic Labs, 1987). The above data and observations indicate that some of the tidal sloughs/lower reaches of creeks behave as typical estuaries, albeit significantly smaller than historic conditions.

In a detailed study of the hydrodynamics in a channel running through a mudflat near the University of California's Richmond Field Station, Ralston and Stacey (2004) showed that stratification was periodic, forming at high water and the following ebb tide with relatively well mixed conditions typical during flood tides. The authors conclude that the conditions in the channel are three-dimensional and dynamic, varying greatly on the tidal timescale, and that stratification is likely to have important effects on transport in similar subtidal channels and intertidal regions.

2.5 Pond Salinity

Many observations of pond salinity have been made by Cargill, typically on a weekly basis. The pond salinities typically vary slowly in response to changing bay salinity at the Cargill intakes, pond operations, evaporation and precipitation. Salinity at the Cargill intakes is also measured periodically during periods in which water is brought into the ponds. Evaporation and precipitation have been measured by Cargill in Newark and Redwood City since 1945.

In the Cargill operation of the salt ponds a range of salinity was present, from near bay salinity in and near intake ponds, to very high salinity towards the crystallizer ponds where salt was harvested by Cargill. In some ponds salinity exceeded 150 ppt, at which point gypsum precipitates and the ionic balance of the water changes making the water toxic to many organisms (Siegel and Bachand, 2002). While the Cargill observations of pond salinity were made at a single location in each pond, recent USGS observations show the distribution of salinity within ponds. In many ponds salinity is quite uniform while in others some spatial gradients were observed.

The salinities in the South Bay salt ponds have been changing substantially, and several ponds were emptied entirely, as Cargill reduced pond salinity in several ponds in order to transfer ownership of the ponds to CDFG and USFWS. Salinity also changed in several ponds now operated according to the Initial Stewardship Plan (ISP). Under the ISP the ponds in the Project area are or will be disconnected from salt production operations and water will be circulated through the ponds and back to the Bay. Specific operation of the proposed and existing infrastructure was proposed in the Initial Stewardship Plan (Life Science, 2003a) to control circulation and water levels in the ponds. In several pond systems the operation of the ponds will vary seasonally to provide seasonal habitat in the ponds, to reduce pumping expense, and/or to minimize potential ecological impacts.

USGS is presently modifying a numerical model developed for the Napa salt ponds (Lionberger et al. 2004), as part of the ISP management of the Alviso ponds for optimal bird habitat.

Ponds A1 through A17 in the Alviso System are currently operated according to the ISP. In July 2004 water was circulated through ponds A1 through A7 and discharged at pond A2W, A3W and A7. The initial salinity in these ponds was moderate and by November 2004 was reduced to bay salinity levels (Coastal Conservancy, 2005). In March of 2005 water was circulated through ponds A9 through A17 and discharged at A14 and A16. These ponds started at higher initial salinity.

The Eden Landing ponds E1, E2, E4, E7 and E10 are currently open to Bay circulation and are operating at below 44 ppt salinity, as proposed in the ISP (CDFG, 2005). Due to failure of some existing water control infrastructure and incomplete installation of some of the proposed structures, these ponds are operated somewhat differently than was proposed in the ISP (CDFG, 2005).

2.6 Observed Effects of Pond Discharges

Relatively few observations have been made of the effects of salt pond discharges on salinity in San Francisco Bay tidal sloughs. A small set of observations of salinity in South Slough (near Napa River) during discharge of Napa pond 3 at 64 ppt salinity indicated both localized salinity increases and vertical stratification near the discharge (Wyckoff, 2004). Limited salinity observations made by the California Department of Fish and Game near the Napa pond 2A breach also showed effects of the pond discharge on slough salinity. More detailed monitoring would be useful to better characterize the effects of salt pond discharges on slough salinity.

Some slough monitoring data is also available from the ISP, including salinity, temperature, DO and pH observations. As part of the impact evaluations and monitoring studies for the Initial Stewardship Plan, dissolved oxygen field studies and laboratory studies were conducted for several ponds in different salinity ranges (USGS, personal communication; Hansen, 2003). These studies suggested that DO in the ponds is typically supersaturated during daylight hours and can be low (below 5 mg/L) during night and morning hours. Monitoring of dissolved oxygen in the Initial Stewardship Plan discharges from ponds A2W, A7, B2 and B10 showed large diurnal variability in DO, with observed values frequently below 5 mg/l (CDFG, 2005; Coastal Conservancy, 2005), and were generally consistent with the studies conducted for the ISP, while the observed dissolved oxygen at the discharge point of pond A3W was consistently lower than expected (below 5 mg/l) and did not exhibit a strong diurnal pattern (Coastal Conservancy, 2005). Surveys of dissolved oxygen distribution in pond A3W indicate large spatial variability in DO and consistently low DO near the A3W discharge as a result of dead algae that were blown to the southeast side of Pond A3W, near the discharge, which decomposed and produced a region of persistently low dissolved oxygen (Coastal Conservancy, 2005).

2.7 Nutrient Cycling and Primary Productivity

Primary productivity is of fundamental importance because "an estuarine food web obtains its energy from organic carbon fixed by primary production" (Kimmerer, 2005). The most important primary producers in South San Francisco Bay are phytoplankton though benthic microalgae may also be substantial producers of biomass (Jassby et al., 1993). Substantial research exists on primary productivity in South San Francisco Bay, primarily by researchers at the USGS and several syntheses of existing knowledge are available, including a recent synthesis by Kimmerer (2005) and a discussion of restoration implications of recent studies of primary productivity (Lucas et al., 2002). What follows is a brief outline of key concepts and findings with citations of references that provide more detailed information.

A recent conceptual model of primary production in South San Francisco Bay is provided by May et al. (2003). This model indicates that primary production is typically not limited by nutrient availability but, instead, is more commonly light limited, and therefore, decreases with increased turbidity. Turbidity increases due to sediment resuspension during stronger tidal and wind conditions and in areas with longer wind fetch (May et al., 2003). The primary grazers of phytoplankton are benthic grazers (Cloern, 1982) while grazing of phytoplankton by zooplankton is considered to be minor (Cloern et al., 1995). Given the importance of both light availability and benthic grazing, both water column depth and stratification can have a large effect on phytoplankton biomass. Because solar radiation decreases with depth, phytoplankton in shallow water columns are generally are exposed to more light and grow more rapidly (Lucas and Cloern, 2002). However, phytoplankton in shallow water columns may also be filtered more rapidly by benthic grazers. Because irradiance and benthic grazing are nonlinear functions of water column depth, tidal fluctuations in water column depth can have a large effect on phytoplankton growth, particularly when the tidal range is a substantial fraction of mean water column depth (Lucas and Cloern, 2002). Stratification can affect phytoplankton both by confining phytoplankton biomass in or closer to the photic zone, thereby allowing rapid increase in biomass, and by reducing grazing due to decreased vertical transport (Koseff et al., 1993). Therefore phytoplankton blooms typically occur during stratified periods of spring, particularly during weak (neap) tides and weak wind conditions when vertical mixing is reduced (Cloern, 1984). Due to spatial variability in turbidity, stratification and benthic grazing rates, phytoplankton biomass is often spatially heterogeneous (Powell et al., 1989) and both the shoals and channels can either be net sources or net sinks of phytoplankton (Lucas et al., 1999). For this reason, horizontal transport between channels and shoals can have a large effect on primary productivity (May et al., 2003).

Much of the annual productivity in South Bay occurs in spring blooms, which tend to occur during stratified periods during spring. Nutrient concentrations have been observed to decrease during phytoplankton blooms in South San Francisco Bay, suggesting that nutrient availability can limit biomass under these conditions (Hager and Schemel, 1996). Key macronutrients in San Francisco Bay include dissolved inorganic nitrogen (DIN), soluble reactive phosphorus (SRP) and silicate (Kimmerer, 2005). Micronutrients are common in San Francisco Bay and are not believed to limit primary productivity

(Kimmerer, 2005). The primary sources of nutrients to South San Francisco Bay are WPCPs (Hager and Schemel, 1996).

Most of the South Bay does not exhibit symptoms of eutrophication largely due to control of phytoplankton biomass by benthic grazers (Cloern, 1982). However portions of the far South Bay and tidal sloughs do occasionally experience depressions of dissolved oxygen (Cloern 1982, Kinnetic Labs, 1987). Dissolved oxygen concentration in these areas typically follows a strong diurnal cycle with supersaturated conditions during daylight hours, due to production of oxygen by photosynthesis, and lower dissolved oxygen during night and morning hours due to respiration by phytoplankton, bacteria and other organisms (Kimmerer, 2005). During night and morning hours oxygen concentrations at the water surface typically exceed near-bottom oxygen concentrations due to exchange gas exchange between the water and the atmosphere (Kimmerer 2005).

Ponds restored to tidal action are expected to be sediment sinks and, therefore, may lead to decreased turbidity in portions of the South Bay (see Issue 2). Other parts of South Bay and associated tidal sloughs may become more turbid as a result of increased tidal prism and tidal velocities leading to scour of sediment. Ongoing research at the USGS (Shellenbarger, personal communication) is examining possible effects of the Project on phytoplankton concentrations as a result of changes in turbidity and mixing. Many Alviso ponds are located near WPCP discharges and, therefore, these ponds may have a particularly large effect on nutrient cycling due to intake of nutrient rich water.

The South Bay Salt Pond Restoration Project may affect nutrient cycling and primary productivity in several ways and the net effect may be difficult to estimate. Recent studies of primary productivity in tidal lakes in the Sacramento-San Joaquin River Delta (Lucas et al., 2002) are relevant to South Bay restoration efforts although the physical and ecological settings of these tidal lakes are quite different than restoration sites in South San Francisco Bay. A comparison of phytoplankton production and biomass in two seemingly similar habitats, Mildred Island and Franks Tract were quite different with Mildred Island acting as a net source of phytoplankton and Franks Tract acting as a net sink (Lucas et al., 2002). This study showed the importance both of local conditions, including the abundance of benthic feeders and water column depth, and hydrodynamic conditions, including connectivity between the restored areas and adjacent channels (Lucas et al., 2002). In South San Francisco Bay, spatial and temporal variability in salinity, benthic feeders, mean depth and tidal range in restored areas, wind conditions, connectivity to adjacent environments, and several other physical and ecological conditions are likely to cause spatial and temporal variability in phytoplankton production and biomass within the Project area.

Studies of the expected effects of nutrients in pond discharges on DO in receiving water were also conducted as part of the ISP (Hansen, 2003). The pond discharges will directly affect the DO in the receiving water when the pond DO is different than the receiving water DO. These localized decreases in DO that can occur near discharge points will be quantified by ongoing USGS monitoring. Pond discharges also contain phytoplankton, nutrients and other substances. Laboratory studies conducted on mixtures of pond water and slough water suggest that DO in receiving waters will follow a diurnal cycle similar to conditions currently present in tidal sloughs (Hansen, 2003).

3.0 What is the level of certainty of our knowledge?

The level of certainty of our knowledge depends both upon the degree to which we understand relevant physical and ecological processes and their interrelationships, and our knowledge of the possible range of future conditions. Also, the level of certainty of how hydrological modifications affect project objectives are dependent on available data from prior studies conducted for each of the hydrological criteria, experience from past projects, and monitoring for projects already implemented. In many cases, the natural variability within a system is large enough that predicted changes resulting from a project are masked (for example, salinity changes over several years). However, over the long-term these changes could have a cumulative effect on the system itself (such as a sustained increase in salinity). The following factors are important in evaluating the level of certainty:

Duration and frequency of measurements of the hydrological criteria

There are numerous locations in the project domain where it is important to understand conditions in order to develop and evaluate restoration alternatives for nearby ponds. The USGS and SCVWD are two agencies with continuous monitoring programs in the immediate vicinity. But the number of permanent continuous monitoring stations that record hydrodynamic and water quality data in the project vicinity is limited. Also, the certainty of predictions of the effects of a project decreases with increasing time scale of simulations. One reason is the accumulation of error in predictions of long-term effects.

Geographical extent of locations that are monitored

The USGS supports water level and water quality stations through their Water Quality of SF Bay Program with stations at the San Mateo Bridge, the Dumbarton Bridge, and Channel Marker 17 (upstream of Dumbarton). The SCVWD supports flow and water surface data stations at several stream tributaries of the Far South Bay, but they do not collect water quality information. The Regional Monitoring Program for Trace Substances (RMP), which is a collaborative effort between several agencies and dischargers run by the San Francisco Estuary Institute (SFEI), is a program to monitor contamination in the Estuary. It focuses on determining spatial patterns and long term trends of contaminants through sampling of water, sediment, benthic community, and fish. Status and trends reports and other information are available through SFEI.

Weight of Evidence

This is based on the number of projects in the South Bay region that have been analyzed and that are in agreement with each other (for example salinity results from USGS, Stanford, and City of San Jose monitoring and modeling efforts). The type, duration and frequency of monitoring data from projects implemented recently (Sonoma Baylands, Warm Springs, Guadalcanal, Carl's Marsh, Napa Pond 2A, Napa Pond 3, and the ISP) vary based on need, regulatory compliance, and budget.

Knowledge of future changes in the environment

This includes climate change, sea level rise, changes in land use, and potential colonization by invasive species. Future weather conditions are quite uncertain due to climate change. While climate change predictions vary among climate models, common projections estimate 5^{o} C of warming by 2100 and small changes in annual precipitation (Dettinger, 2005). Although the changes in annual precipitation are predicted to be small, the runoff is expected to occur earlier in the year due to increased snowmelt as a result of warmer temperatures (Dettinger, 2005). These changes in runoff will affect both salt and sediment transport processes in San Francisco Bay. The amount of sea level rise is another long-term uncertainty and is discussed in the syntheses for issues 1 and 2. Land use practices and human influences such as flood control projects, sediment management, water use, and others, will also impact future conditions significantly. This will make predictions of future *baseline conditions*, and changes caused by the project difficult to estimate.

Some of the uncertainties related to hydrological parameters, in the same order as Section 2 are described below.

3.1 Fluvial Flows

Fluvial flows coming down the rivers and creeks have been well documented, and are expected to be reliable data. Backwater calculations need to be performed for the lower reaches, and can be estimated with a high degree of confidence relatively easily.

3.2 Bathymetry, Water Levels, and Currents

Bathymetric data for the Far South Bay and the ponds did not exist until recently. However, due to the recent efforts by the USGS related to pond and South Bay bathymetry, these data are now available. Slough bathymetry has not been characterized to the same level of detail though, and will need to be performed. However, surveying can be done with a high degree of accuracy and uncertainties are limited, if any.

A significant increase in tidal prism in a receiving water body (by opening up a non-tidal area to tidal action) affects water levels and velocities in the vicinity of the breach. The size of the impacted area depends on the amount of change in tidal prism. The increase in tidal prism results in an immediate decrease in high water level near the breach, followed by a period of scour as the breach and the adjoining bathymetry responds to the increase in velocity. These physical changes can be estimated to a reasonable degree of accuracy by using numerical methods, physical modeling, etc. but the accuracy depends on quality of available field data (temporal duration, spatial extent, instruments, etc.). These data can be collected fairly accurately, and need to be collected for the South Bay (see Section 3.1 above). With the stratification that exists in the tidal sloughs in the South Bay, the location of current meters or ADCP's needs to be well thought out.

A significant increase in tidal prism in a receiving water body affects flushing characteristics of the water body. This may alter residence time and affect parameters such as DO, concentration of nutrients and pollutants, and possibly temperature.

Although circulation changes can be estimated within reasonable confidence limits using available tools, its effects on water quality parameters are much more uncertain, because of the influence of other non-hydrological parameters.

3.3 Baywide Salinity

Salinity at San Mateo and Dumbarton bridges, and at Marker 17 is being collected on a continuous basis in the upper and lower water column by the USGS. Similar data in the Central Bay and near the Golden Gate are also being collected. This dataset will be important for model calibration and validation, particularly for circulation, but will need to be supplemented with data from the tidal sloughs to assess effects of stratification as well as over the mudflats. However, simulations of salinity can be performed with a reasonable degree of accuracy.

3.4 Salinity In Tidal Sloughs

A significant increase in tidal prism in the tidal sloughs may alter salinity conditions in the sloughs. Much of the Project area is located near creeks and treatment plants that discharge to the South Bay, and, therefore salinity gradients are common in tidal sloughs (Kinnetic Labs, 1987). Restoring ponds to tidal action will increase tidal prism in these sloughs and tend to shift salinity gradients (Life Science, 2003b). The ponds will act as reservoirs that will store water and salt that enters near high water and discharge some of this water and salt near low water. The exact effects on salinity will depend on the location of the breach, size of the levee breach and pond(s), etc. In many cases, restoration may shift salinity gradients landward in the tidal sloughs and decrease the variability in salinity during the tidal cycle.

3.5 Pond Salinity

Water will enter a pond only when the water elevation in the bay/slough is higher than the water elevation in the pond and the invert elevation of the breach. Therefore the pond salinity (and other water quality parameters) will only be affected by bay/slough salinity during part of the tidal cycle, typically part of flood tides near high water. The salinity in the ponds will depend largely on the breach geometry which will evolve in time as the breach geometry evolves (Shellenbarger et al, 2005)

In most of the ponds, salinity is expected to be uniform (not stratified) due to a combination of shallow depths and wind shear, and can be measured with a reasonable degree of accuracy. However, the spring-neap cycle could result in salt trapping in the ponds which will need to be measured at specific times of the year to assist in model simulations.

3.6 Effects Of Pond Discharges

Managing pond discharges into tidal sloughs, as opposed to restoring tidal action to certain ponds, will also alter Bay and slough salinity and water quality. The effects of managed pond discharges will depend on the salinity and discharge rate of the managed ponds. Under the Initial Stewardship Plan most ponds are being managed in a relatively low salinity range, but this operation may be altered by the Project to increase habitat value of the ponds. The discharge rate from the ponds will vary seasonally and with the tidal cycle but will generally be substantially smaller than tidal flows in the tidal sloughs (Life Science, 2003a). The discharges will typically occur by gravity flow (without pumps) near low water, including low slack water, when tidal currents are weak and both water volume and salinity are at a tidal cycle minimum. Therefore, salinity effects are expected to be largest near low water near the discharge point and the bed of the channel but decreasing during flood tides and with distance from the discharge point as the pond water mixes with ambient water.

4.0 What predictive tools exist for gaining an understanding of this issue and what tools are needed to reduce uncertainty to an acceptable level?

Predictive tools are used widely in ecological restoration projects. A main strength of predictive tools such as empirical analyses (based on field data and observations) and computer models is their ability to simulate, albeit to various levels of accuracy, the effects of potential restoration actions. Potential predictive tools for the Project include a combination of analytical/statistical tools, empirical tools using field data, numerical modeling tools, and physical modeling. Analytical, statistical, and geomorphic tools are used initially on many projects because they have the ability to provide quick, order of magnitude estimates which can be used to screen project features or alternatives. A subset of these are then carried forward into a more exhaustive analysis using numerical modeling or physical modeling tools or a combination of both. Since numerical modeling approaches are widely used and are likely to be the primary modeling tools used in project planning, the following discussion is limited to numerical models.

Many tools are available for predicting hydrodynamics, salinity and water quality in South Bay, tidal sloughs and ponds. Specific hydrodynamic tools and techniques relevant to the Project were discussed in detail in the *Hydrodynamic Modeling Tools and Techniques* report (Moffat & Nichol, 2003b). This document suggests that the appropriate tool for a hydrodynamic analysis depends on the relevant physical process(es) studied and the level of accuracy required. The specific information in that document is not repeated here, but, instead, a general discussion of uncertainties and limitations inherent to different modeling approaches is discussed.

The equations governing fluid motion and salt transport, representing conservation of water volume, momentum and salt mass, are well established, but can not be solved analytically for complex geometry and boundary conditions. Therefore models are used to give approximate solutions to these governing equations. Many decisions are made in constructing and applying numerical models. The governing equations are first chosen to represent the appropriate physical processes in one, two or three-dimensions and at the appropriate time scale. Then these governing equations that describe fluid motion and salt transport in a continuum are discretized to apply over distinct volumes. The resulting discretized equations must be solved, often requiring the use of an iterative matrix solver. The discretization and matrix solution must be developed carefully to yield a numerical approach that is consistent with the governing equations, stable and efficient. To apply the models, the models bathymetric grid, boundary conditions, initial conditions and several model parameters must be chosen. The accuracy of the model application will depend on the accuracy of this input, including site-specific parameters and reduction of numerical error by choosing appropriate time step and grid size and orientation for the solution. Various modeling approaches, including finite element, finite difference and finite volume methods, and various types of model grids are discussed in the SBSP project reports (Moffat & Nichol, 2003b). The following discussion will proceed from the models with the fewest assumptions and simplifications to models with the largest assumptions and limitations. The discussion is limited to simulating water motion and salinity. Issue 2 discusses tools for simulating sediment transport. Discussions on modeling of water quality, contaminants, and eutrofication processes, although recognized to be very important to the project, are not included in this syntheses until more is known about these processes in the specific sub-region. Also, these processes cannot be simulated with the same level of accuracy and/or reliability as hydrodynamics, and will need to be monitored and the restoration design adaptively managed to reduce adverse effects.

4.1 Three-Dimensional Models

The most detailed description of fluid motion is provided by the three-dimensional turbulent time scale models. However, simulation of turbulent motions for a domain the size of South San Francisco Bay is not computationally feasible because it would require prohibitively small grid cells and time steps. Therefore, large scale models typically average over the turbulent time scale to describe tidal motions. The resulting three-dimensional hydrodynamic models represent the effect of turbulent motions as small scale mixing of momentum and salt, parameterized by eddy viscosity and eddy diffusivity coefficients, respectively. These turbulent mixing coefficients are estimated from the tidal flow properties (velocity and density) by “turbulence closure” models embedded within the three-dimensional models. The resulting three-dimensional tidal time scale models are now commonly applied in research and consulting applications. These three-dimensional models estimate the variability in velocity and salinity in all dimensions and through the tidal cycle, therefore provide a detailed description of hydrodynamics and salinity. However, there are several limitations inherent in the application of three dimensional models:

- Spatial resolution/computational cost – the spatial resolution of the bathymetry of the model domain, and velocity and salinity distributions, is limited by the large computational expense associated with high-resolution models. The description of the Bay bathymetry may be improved by the use of a flexible grid, as described in the *Hydrodynamic Modeling Tools and Techniques* report (Moffat & Nichol, 2003b) but, the total number of grid cells is limited for all grid structures.
- Site-specific parameters – at a minimum, three-dimensional models require bottom friction coefficients to parameterize the resistance to flow at solid boundaries. These parameters are specified in model calibration either from standard reference manuals (e.g. Chow, 1959) or by tuning to improve calibration and may be specified globally or in map form.
- Turbulence closure – the effect of turbulent motions on the tidal time scale motions is estimated by a turbulence closure. While many turbulence closures are available (GOTM, 2004), this is an ongoing area of research and, particularly in

stratified settings, the effect of turbulence on tidal flows and salinity is not easy to estimate accurately and different turbulence closures may give significantly different results (e.g., Stacey, 1996) in stratified settings. It is therefore important to conduct sensitivity type of analyses to determine which method(s) is most appropriate for the parameter being simulated.

- Numerical errors –a numerical method approximates the governing equations to some level of accuracy. The predictions of the model can vary substantially among different numerical methods (e.g., Gross et al. 1999a) and refinement of numerical methods is an ongoing area of research. Even numerical methods that are theoretically accurate often have unfavorable stability properties that require use of unrealistic diffusion or "sub-grid" dispersion coefficients or diffusive filters to maintain stability. Some models may have additional limitations, for example, not allowing wetting and drying of computational cells.

4.2 Vertically-Averaged Two-Dimensional Models

Vertically-averaged two-dimensional models average the three-dimensional (turbulent averaged) equations of motion over the vertical dimension and discretize the resulting equations. Laterally-averaged two-dimensional models are also available but are less likely to be applied in South San Francisco Bay or associated tidal sloughs. Vertical averaging typically provides an order of magnitude reduction in the total number of grid cells, and computational expense, associated with these models relative to three-dimensional models. The vertical distributions of velocity and salinity are not represented by these models and, therefore, they have a limited ability to represent density-driven flow, wind-driven flow and several salt transport mechanisms. The effect of the unresolved vertical distributions of velocity and salinity on transport and mixing are parameterized by dispersion coefficients. These dispersion coefficients represent "three-dimensional processes" and are typically several orders of magnitude larger than eddy diffusivity (the effect of turbulence), indicating substantial reliance of two-dimensional models on these empirical parameters, particularly during winter conditions. In unstratified summer conditions, two-dimensional models may be able to adequately simulate salinity conditions in South San Francisco Bay (but not tidal sloughs with treatment plant inputs) without reliance on dispersion coefficients (e.g. Gross et al. 1999a). The limitations of vertically-averaged models are:

- All of the limitations associated with three-dimensional models, except reduced computational cost.
- The models do not describe the vertical variation of velocity and salinity. Therefore if bed shear stresses and bed salinity are estimated from the predicted vertically-averaged quantities, some assumptions are required to extrapolate from the predicted depth-averaged quanties (e.g., vertically well-mixed conditions for salinity). In stratified settings this can lead to substantial inaccuracy.
- These models rely on dispersion coefficients. These site-specific parameters vary spatially and should theoretically be varied with flow conditions and tidal conditions (Monismith et al., 2002, Uncles and Peterson, 1996). In practice a constant set of dispersion coefficients, often in map form, are often applied for all flow and tidal conditions. For this reason, two-dimensional models are likely to be

less accurate than three-dimensional models for unusual flow and/or tidal conditions. Furthermore, dispersion coefficients that are appropriate for existing conditions may be inappropriate for project conditions because they will not account for altered salt trapping in restored ponds or other changes in tidal hydrodynamics.

4.3 One-Dimensional Models

One-dimensional model average the three-dimensional (turbulent averaged) equations of motion over the vertical and lateral directions and discretize the resulting equations. One-dimensional models are logistically quicker to develop, and the simulations are performed much faster than two- and three-dimensional models. Due to minimal computational expense, and the ability to provide a precise representation of cross-sectional area as a function of water elevation (stage), one-dimensional models are appropriate for many studies, in particular studies of flood management issues. While one-dimensional models are often used for simulations of tidal prism and elevation they are less commonly applied to simulate salt transport in estuaries because they provide quite limited information about velocity and salinity distribution. In one-dimensional models, dispersion coefficients represent the effect of "two-dimensional processes" and "three-dimensional processes" on salt transport. The limitations of one-dimensional models include:

- All of the limitations of two-dimensional models except reduced computational expense.
- Do not describe the lateral variability of salinity.
- Rely even more heavily than two-dimensional models on dispersion coefficients.

In summary, all numerical modeling approaches have substantial limitations. However, three-dimensional models provide much more information about the spatial distribution of salinity than lower dimensional models. Perhaps more critically, three-dimensional models are more mechanistic and, therefore, rely on fewer empirical parameters (dispersion coefficients) to accurately simulate salinity.

4.4 Expected Challenges With Using Numerical Models

Additional discussion of modeling approaches, previous model applications to San Francisco Bay, and specific models that may be appropriate for the Project is provided in the *Hydrodynamic Modeling Tools and Techniques* report (Moffat & Nichol, 2003a). Instead of repeating the discussion presented in the report, some expected difficulties in numerical modeling of hydrodynamics and salinity for project conditions are emphasized below.

Process resolution – All models choose to represent a limited number of processes and neglect other processes as described below.

- Near-field mixing – The actual mixing processes near managed pond discharges are turbulent mixing processes and will occur at the "sub-grid" scale of large-scale models. This small scale mixing is difficult to simulate due to the complex geometry of tidal sloughs and the density differences between the pond discharges and the ambient water. Small scale mixing can be estimated using plume models (e.g., Cormix) but these models are difficult to link with large scale models. Addition of the discharges to large scale models typically assumes instant mixing over the grid volume that contains the discharge. In a one dimensional model, for example, this assumes instant vertical and lateral mixing of the discharge.

- Dispersion coefficients – One-dimensional and two-dimensional models often rely on dispersion coefficients. Even if appropriate dispersion coefficients can be determined for existing conditions, they may not be appropriate for project conditions. Given substantial changes expected in the tidal prism and salinity of tidal sloughs, it will be particularly difficult to specify dispersion coefficients that are appropriate for these regions.

Grid resolution – Due to substantial model development and computational effort associated with two-dimensional and three-dimensional modeling, feasible grid resolution is likely to limit model accuracy.

- Representation of breach geometry – Levee breaches are relatively small scale features that will be difficult to represent in model grids.
- Representation of tidal slough geometry –Tidal sloughs are long and narrow. Therefore representing them accurately in two-dimensional or three-dimensional models requires many grid cells and substantial computational expense.

Boundary conditions – The salinity (and other water quality parameters) in South San Francisco Bay vary laterally (e.g. Huzzey et al., 1990) but this lateral variability can not be described by existing observations. Limited observations are available to describe the vertical distribution. For example, at the Oakland Bay Bridge, salinity observations are available at two elevations near the deepest part of the channel (Buchanan et al., 1996). Therefore, lateral and vertical distributions must be assumed to interpolate and extrapolate from the limited observations.

4.5 Near Field Models

While three-dimensional models probably will provide a better description of mixing processes near a managed pond discharge point than either two-dimensional or one-dimensional models, important near-field mixing processes are not represented by large-scale three-dimensional models. Near-field mixing of the discharge occurs largely as a result of vigorous turbulent mixing resulting from different velocities of water in the discharge plume and ambient water (Roberts et al., 1989). Many studies of mixing of jets and plumes have been performed (e.g., List et al., 1982) in uniform density and stratified settings, allowing development of largely empirical models of near-field mixing (e.g., Roberts et al., 1989). These models have been applied to many studies of coastal WPCP outfalls (e.g., Washburn et al., 1992) but require extensive information regarding ambient currents and stratification be supplied to the plume model. These plume models typically have large limitations, for example, requiring steady flow and vertically uniform currents. Therefore, a typical approach to represent complex unsteady conditions would be to perform many simulations at different current speeds and stratification (e.g., Roberts, 1999). Furthermore, these models can only crudely represent the effect of horizontal boundaries and, for this reason, are likely to estimate dilution in narrow tidal sloughs very approximately.

In some cases near-field models have been coupled with large scale numerical models (e.g., Connoly et al., 1999) while, in many studies, near-field processes are not resolved by the model (e.g., Blumberg et al., 1996). The far-field simulation results may be accurate even if near-field mixing is not represented accurately (e.g., Blumberg et al., 1996) but this will not always be the case. Particularly for salt pond discharges with substantially different density than ambient (slough/bay) water, there is a potential for errors in representing near-field mixing to cause substantial error in the far-field estimates of dilution. The most likely form this error will take in modeling salt pond discharges is an overestimate of near-field mixing and a resulting underestimate of stratification and near bed salinity in tidal sloughs.

5.0 What are the potential restoration targets and performance standards for evaluating the progress of the restoration project?

Earlier documents (SBSP Science Team, 2004) had presented linkages between the Project Objectives and the Key Uncertainties/Issues which exist in meeting these objectives. The hydrological modifications issue was described as being relevant to the following project objectives:

- Habitat Function and Value (Project Objective 1)
- Flood Protection Levels (Project Objective 2)
- Water and Sediment Quality (Project Objective 4)

This section presents restoration targets and performance measures for evaluating project progress as related to the hydrological modifications issue. The degree to which other project objectives are met (for example, enhance habitat or provide public access) will also be influenced by hydrology, but relevant targets and performance measures for those objectives are discussed in other syntheses. Also included are recommended measures to minimize potential negative impacts to the restoration project.

5.1 Habitat Function And Value (see also syntheses for Issues 1, 2, 3, 4, 5)

Restoration Target: Improve the quality and size of existing habitat (abundance or diversity) for native and special status species.

Performance Measure: Measures for assessing habitat functions are discussed in the other synthesis documents. The measures will also include monitoring of the hydrological parameters described in Section 1.1 as well as the following

- inundation regime that creates and maintains desired habitats
- salinities that create and maintain desired habitats
- effects on primary production in South Bay (which cannot be significantly altered as a result of the project)

5.2 Flood Protection Levels

Restoration Target: Existing flood protection function of the levees in the project area should not be reduced.

Performance Measure: The restoration target implies that there should be no increase in the following parameters, which are directly related to flood protection.

- frequency of upland flooding
- area of upland flooding
- amount of scour or erosion of proposed Bayfront levees (implies that although current interior levees will function as Bayfront levees after restoration, they should be improved to provide a similar or better level of protection).

To ensure that these measures are satisfied, monitoring of hydrological parameters as described in Section 1.2 should be conducted.

5.3 Water And Sediment Quality (see also syntheses for Issue 7)

Restoration Target: In general, there should be no degradation of water or sediment quality in the study area (near-field or far-field) as caused by the restoration project.

Performance Measure: The synthesis for Issue 1 (ecosystem) and Issue 7 (pollutants) describe some of the performance measures for adaptive management of restoration in the Estuary that could be applied to the project. These could be based on results of monitoring, for example the foodweb, fish, toxicity, levels of mercury, etc. The measures will also include monitoring of the hydrological parameters described in Section 1.4.

5.4 Management Measures for addressing negative impacts to the restoration project

Negative impacts to the restoration project may be mitigated for in the following ways:

- adaptive management of channel geometry and configuration (adjust breaches),
- improve levees to maintain flood control function,
- locating levee breeches where impacts are minimized,
- selection of appropriate pond/control structure design features.
- modification of managed pond operation
- aeration of pond discharges
- phase breaching of ponds to gradually increase tidal prism.

6.0 What key questions essential to the success of the restoration need to be addressed through further studies, monitoring, or research?

This section identifies priority areas of research that are essential to the success of the restoration project. All the hydrological criteria described earlier and their relationships to the functions that they support need to be quantified in greater detail than presently know, in light of their potential cumulative impact to the project. Specifically, the following general categories need further attention:

1. Hydrodynamics (less uncertain than following ones, but system-wide hydrodynamics have not been evaluated)

2. Water quality (wide range of parameters need to be characterized, including salinity, DO, total suspended solids, etc.)
3. Contaminants (see Issue 7 synthesis)
4. Sediment dynamics (see Issue 2 synthesis)
5. Nutrient cycling and primary productivity

The present state of knowledge of all the above in the South Bay is limited and should be improved. Implementing monitoring programs tailored towards achieving project objectives is essential to reducing uncertainty in restoration activities.

Specific questions related to hydrological modifications that should be addressed in future monitoring and research efforts include:

1. What effect does increased tidal prism have on tidal hydrodynamics particularly water levels, circulation, and dispersion in sloughs and the South Bay ?
2. Will altered water levels in sloughs affect flood protection levels ?
3. What effect does restoration of tidal marsh and operation of managed ponds have on slough and bay salinity ? Do these salinity changes affect habitat value?
4. Will altered water levels and increased tidal inundation restrict public access?
5. Will altered water levels, increased tidal inundation, and increased slough velocities threaten existing infrastructure?
6. What effect does increased tidal prism have on near-and far-field sediment dynamics ? (see Issue 2)
7. What effect does increased tidal prism have on water quality and transport of legacy contaminants ? (see Issue 7)
8. What are the biological effects of managed pond discharges on benthic organisms in tidal sloughs (aquatic toxicology), especially salinity effects, DO effects and pH effects ?
9. What are the effects of managed pond operation and pond restoration on primary productivity and nutrient cycling ?

Table 1: Hydrological Parameters and Information Sources

Location(s)	Agency or organization	Source
Fluvial Flows		
Lower Guadalupe R.	SCVWD	Jun 2002 Eng.'s Report & Final EIR
Guadalupe Sl. (Pond A4)	SCVWD	Jul. 2003 Draft Preliminary Opportunities and Constraints
San Tomas Cr., Guadalupe R. above Almaden Expwy., Coyote Cr. at Madrone	SCVWD	ALERT online database: http://alert.valleywater.org, FIS Studies for FEMA
Streams/sloughs relevant to project	Moffatt & Nichol	Oct. 2003 conveyance report
Guadalupe R. at San Jose & above 101; Coyote Cr. Above Hwy 237	USGS	NWIS database, URL http://waterdata.usgs.gov/nwis
Water Depths		
Pond Interior	Cargill	Depth surveys
Ponds, Mudflats, Sloughs	USGS	Depth surveys
Sloughs	Moffatt & Nichol	Field collection data report, 2005
Coyote Cr., Guadalupe R., Guadalupe Sl. San Fracisquito Cr., Stevens Cr., Permanente Cr.	SCVWD	URL www.valleywater.org (HEC XS data from Flood Insurance Studies)
Water Quality (temperature, salinity, DO, nutrients, organics, contaminants)		
Artesian Sl. (SJ/SC WPCP), Guadalupe Sl. (Sunnyvale WPCP), Palo Alto WWTP Outlet (PA RWQCP), South Bay (north of SMB) South Bay (south of SMB)	SJ/SC WPCP, Sunnyvale WPCP, PA RWQCP, NPDES permits	NPDES PCS Permit Data, Moffatt & Nichol Oct. 2003 (Conveyance report lists pollutants, flow magnitudes)
Coyote Hills Sl., Ravenswood Sl., Dumbarton Br., Railroad Br., Stevens Cr., Power Tower, Alviso Sl., Guadalupe Sl.	Moffatt & Nichol	Field collection data report , 2005
South SF Bay (salinity, temperature)	USGS Database	Sevral studies on WQ of SF Bay, URL http://sfbay.wr.usgs.gov
South SF Bay (nutrients, organic matter)	USGS	Bergamaschi, B.A., et al 2003 (organic matter from wetlands), Cloern and Lucas (primary productivity and phytoplankton blooms)
Guadalupe R. (temperature, turbidity)	SCVWD	Lower Guadalupe Flood Control Project EIR
Guadalupe R., Coyote Cr.	San Francisco Estuary Institute (SFEI)	RMP Reports, Leatherbarrow et al 2002, Estuary Interface Pilot Study 1996-1999 (contaminant & sediment from river inputs)

Location(s)	Agency or organization	Source
Flushing characteristics		
General intertidal and baylands zones	SFEI	Collins, J 2001. (physical relationships between intertidal and shallow bay)
South Bay Various	WWTPs	Studies conducted by Cities of San Jose, Sunnyvale, Palo Alto in support of NPDES permits
South Bay (south of Bay Bridge)	Moffatt & Nichol, SFO	SFO Runway Studies
Water levels		
South Bay Various	NOAA	Tide gage stations (http://www.nos.noaa.gov)
Coyote Hills Sl., Ravenswood Sl., Dumbarton Br., Railroad Br., Stevens Cr., Power Tower, Alviso Sl., Guadalupe Sl.	Moffatt & Nichol	Oct. 2003 conveyance report ; 2005 field data collection report
San Francisquito Cr., Matadera Cr., Calabaza Cr., San Tomas Cr., Guadalupe R. ab Almdn Exp., Coyote Cr. at Madrone, Stevens Cr.	SCVWD	ALERT online database: URL http://alert.valleywater.org
Circulation/hydrodynamics		
South SF Bay	Moffatt & Nichol, SFO	SFO Runway Studies
South SF Bay	USGS	Several studies on WQ of SF Bay, URL http://sfbay.wr.usgs.gov; Ruhl, C. A. et al 2002 (hydrodynamics and circulation in shallow sub-embayment); Cheng et al 1993 (TRIM 2-D model of hydrodynamics and salinity)
South SF Bay	Stanford Univ.	Gross, E.S., et al 1999. (3-D salinity model of South San Francisco Bay)
General SF Bay	Moffatt & Nichol, SFO	SFO Runway Studies ; Cañizares, R et al 2002 (3-D model of seasonal salinity in SF Bay)
Sediment dynamics		
South SF Bay	USGS	Continuous Monitoring Data, WQ of SF Bay, URL http://sfbay.wr.usgs.gov (includes TSS)
General SF Bay	USGS	Schoellhamer, D.H. et al, 2003 (suspended sediment variability of SF Bay); Buchanan, P.A , et al (sediment at SMB, DMB, M17 for water years 1999, 2000); Foxgrover, A. C., et al 2004. (Deposition, Erosion, and Bathymetric Change in South San Francisco Bay: 1858-1983)
General SF Bay	Ogden Beeman & Assoc.	Ogden Beeman & Assoc. 1992 (sediment budget of SF Bay)
Guadalupe R., Coyote Cr.	San Francisco Estuary Institute (SFEI)	Leatherbarrow et al 2002, Estuary Interface Pilot Study 1996-1999 (contaminant & sediment from river inputs)

Location(s)	Agency or organization	Source
Waves		
South Bay	Moffatt & Nichol, URS, SFO	SFO Runway Studies
South Bay	USACE	Shoreline Erosion Study
Tidal currents		
SF Bay	USGS	PORTS program (http://sfports.wr.usgs.gov); Several studies on tides and currents (Gartner et. Al) Several studies on SF Bay, URL http://sfbay.wr.usgs.gov;
SF Bay	NOAA	Online links to PORTS website maintained by USGS and NOAA (http://tidesandcurrents.noaa.gov/sfports/sfports.html);
South Bay (south of Bay Bridge)	Moffatt & Nichol, URS, SFO	SFO Runway Studies
General SF Bay	Uncles & Peterson, 1995	Long-term (> day) salinity variations.

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