Feasibility Analysis

South Bay Salt Pond Restoration

San Francisco Estuary, California

WETLANDS AND WATER RESOURCES

Stuart W. Siegel, PWS
Philip A.M. Bachand, PhD

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Cover photo of Newark crystallizer ponds, February 28, 2001

Credits

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Restoring Cargill Salt Company's 26,000 acres of South Bay salt ponds to tidal marsh has been a treasured goal for decades. Once restored, a wealth of biological resources will benefit. Now, a deal is close at hand to acquire and restore more than half these ponds. This unprecedented opportunity motivated this study.

Inside the reader will find a wealth of information about what it will take to restore these ponds to tidal marsh and what issues should be addressed as part of acquiring lands from Cargill.

Should the public acquire and restore these lands? Absolutely.

Should the public and Cargill get a fair deal? Absolutely.

Are restoration costs reasonable and in line with other national efforts, such as the $7.8 billion Florida Everglades restoration effort? Absolutely.

WETLANDS AND
WATER RESOURCES

To: Interested Parties

From: Stuart Siegel and Philip Bachand

Date: March 2002

Re: Feasibility Analysis of South Bay Salt Pond Restoration, San Francisco Estuary, California

This Feasibility Analysis culminates two years of research and analysis into restoration feasibility of the South Bay Cargill salt ponds to tidal marsh. This work contributes to two major efforts: (1) current negotiations for public acquisition of a large portion of the salt ponds, and (2) restoration planning, design, and long-term implementation. The purpose of this report is to provide a scientifically based analysis independent of any particular interest group. In preparing this report, we followed standards for a peer reviewed publication: we drew information from relevant publications, interviewed nearly 40 experts, underwent peer review, and provided full references.

This report highlights issues that we believe require further consideration for acquisition and restoration. Though some or all of these issues may be part of the acquisition negotiations, those negotiations are closed to the public so we do not know their status. The report is not intended to provide a final determination on these issues. Rather, it is intended as a starting point to identify issues we consider very important to achieve a successful restoration effort. Our report contains all the data we used so that others can develop their own conclusions.

Our seven major conclusions are:

1. A comprehensive program must mix tidal marsh restoration with costly permanent management of shallow open water ponds in order to meet multiple ecological goals, as recommended by the Goals Report and the upcoming U.S. Fish and Wildlife Service Tidal Marsh Ecosystem and Snowy Plover recovery plans.

2. Phasing and/or dredged sediment reuse will be essential to resolve a massive sediment deficit without disrupting ecologically important South Bay mudflats.

3. Dredged sediment reuse may prove economically feasible and, because it could cut the overall restoration time in half, ecologically beneficial.

4. Acquisition negotiations must ensure that Cargill (a) removes all bittern and hypersaline brines from the sale area and (b) takes full long-term responsibility for bittern stored on public lands in Newark. We estimate total annual bittern production to be 4 times greater than Cargill estimates, highlighting the importance of addressing all forms of bittern.

5. Long-term operations, maintenance and monitoring will be costly and must be fully funded to avoid South Bay flooding risks and to maximize wildlife benefits.

6. Remaining salt production, invasive species, and constantly changing wildlife use of salt ponds all must be carefully considered for a successful restoration effort.

7. Relatively few ponds can be restored easily. The Cargill proposal transfers most of the "problem" ponds to public control and retains most of the "easy" ponds in Cargill control.

We have estimated that costs should range between $314 million to $1.1 billion (in 2001 dollars), plus $300 million for acquisition, to restore and manage the 16,000-acre package Cargill offered the public in 2000. Recent negotiations have scaled the acquisition down to $100 million for 13,000-15,000 acres. Too few details are public for us to evaluate this package equally but we estimate that the modest reduction in acreage translates into a modest reduction in restoration and management costs. These cost estimates consider restoration with and without dredged sediment reuse and the ranges are intended to reflect uncertainties in the estimate. We anticipate annual costs of $6.5-$14 million initially, with costs gradually dropping over many decades to $1.4-$3.4 million annually.

Executive Summary

The Cargill Salt Corporation produces about 1 million tons of common salt annually from its 26,190-acre South San Francisco Bay salt pond complex. Cargill owns 14,760 acres (56%) of these salt ponds. The Don Edwards San Francisco Bay National Wildlife Refuge owns the remaining 11,430 acres (44%), which it acquired in the 1970s. As part of that sale, Cargill (then Leslie Salt) retained the mineral rights for salt production on all these lands. Nearly the entire South Bay salt pond complex (97% total area) consists of former tidal marshlands diked for decades. Only about 670 acres (3%), representing about three-quarters of the Newark crystallizer ponds, were built outside the tidal marshlands on the adjacent grassland/vernal pool complexes. The historical condition affects ecological restoration goals and the extent of current federal regulatory jurisdiction under the Clean Water Act and Rivers and Harbors Act. Jurisdiction, in turn, can affect the property value of the salt ponds through its restrictions on development and therefore has bearing on the current acquisition negotiations.

A long-established and worthy goal of the regional resource management community has been to acquire the entire South Bay salt pond complex and restore it to its pre-existing tidal marsh condition. Two actions have taken place in the past few years that may bring this goal to fruition and which serve as the impetus for this Feasibility Analysis. First, the San Francisco International Airport has been evaluating salt pond restoration (in part or in whole) as mitigation for its proposed runway extension project. Second, in 2000 Cargill formally offered to sell about 16,000 acres plus 600 acres of South Bay tidelands and another 1,400 acres along the Napa River to the state and federal governments for $300 million. Those 16,000 acres include 12,000 acres Cargill owns and mineral rights on 4,000 acres the Refuge owns. Negotiations have been ongoing since 2000, and a smaller deal for $100 million representing 13,000 to 15,000 acres may soon be reached that may or may not involve SFO mitigation funds.

In negotiating with Cargill and other entities, resource managers will need to understand not only the short-term goals of acquiring property but also the long-term goal of sustainable restoration and management. Restoration, especially along the scale of the South Bay salt ponds, is a process and not an event. The complexity of this process crosses many scales. Most basically, each restoration site must undergo a number of changes to transform from the current salt pond condition to the ultimate goal for that site whether it be tidal marsh, ponds, pannes or some combination. Some of the important issues and challenges facing resource managers and planners that will affect the rate at which salt ponds can be restored to tidal marsh include: proximity to colonizing plants and animals, initial site elevations creating sediment deficits, sediment supply and dredged sediment availability, bittern and hypersaline brine removal and pond desalination, restoration and ongoing operations and maintenance costs, containing invasive species, protecting existing biological resources, and decreasing survival pressures on the many special status species that utilize tidal marsh and salt ponds. These issues have implications on a broad spatial scale and a long temporal scale, one of the most significant of which is resolving the sediment deficit with scouring ecologically important South Bay mudflats. Restoration does not mean that today it is a salt pond and the day after breaching a levee we have a vegetated, natural marsh.

The purpose of this Feasibility Analysis is to provide a starting point for evaluating all topics relevant to the purchase and restoration of some or all of the South Bay salt ponds. To achieve this purpose, we examined the suite of biological, physical, chemical, and economic issues relevant to restoring tidal marsh on the entire 26,000-acre South Bay salt pond complex as well as the smaller 16,000-acre Cargill proposed sale area. We then integrated these data into a pond-by-pond restoration feasibility determination and developed a set of key conclusions pertinent to undertaking acquisition and restoration. In this Executive Summary we summarize these seven key conclusions, provide summary South Bay salt pond statistics for use by planners and resource managers, and present a rough cost estimate for restoring the 16,000 acres Cargill has recently offered for public acquisition.

Seven Key Conclusions Summarized

From all the material we evaluated and people we talked with in preparing this Feasibility Analysis, we have identified seven key conclusions that we believe are the most salient to negotiating a purchase and planning the restoration of all or a portion of the South Bay salt pond complex. Although we support acquisition and restoration fully, addressing the challenges summarized in these seven key conclusions will require careful planning and thoughtful action to achieve the desired environmental and ecological benefits in a cost effective manner. The important message from these analyses is that a long-term commitment will be required to realize the benefits of salt pond purchase and restoration.

Conclusion 1: Mix Tidal Marsh Restoration and Shallow Open Water Management

Promoting recovery of federally listed species and species of concern should be a primary consideration in restoration planning and implementation. To accommodate conflicting ecological requirement between many of these species, an overall restoration plan should include about one-third of the salt ponds retained as managed shallow open water areas and two-thirds restored to tidal marsh. Tidal marsh represents the historical condition for nearly all the salt ponds and their loss is directly responsible for declines in numerous plant, fish and wildlife species around which a broad consensus exists for their recovery. Shallow open water, historically less common in the South Bay and currently provided almost entirely by the salt ponds, supports a thriving bird community around which a broad consensus also exists for its protection. Several threatened and endangered species depend on and/or utilize both ecosystem types. Reconciling these competing goals translates into retaining about one-third of the South Bay salt ponds as managed shallow open water habitats and restoring the remainder to tidal marsh. This approach is consistent with recommendations originally put forth by the Goals Project as well as goals to promote recovery of special status species as stated in the two draft U.S. Fish and Wildlife recovery plans applicable to the South Bay (Western Snowy Plover and Tidal Marsh Ecosystems). How these goals are accomplished in the context of ongoing Cargill operations presents a complex challenge for restoration planners. Though based clearly in conservation needs, permanently maintaining one-third of the salt ponds as shallow open water habitats will require a long-term operations and maintenance (O&M) funding commitment that would not be necessary were all ponds restored to tidal marsh. Thus, the resource management community must understand and accept the permanent costs associated with meeting its conservation goals as well as the consequences of failing to meet those funding needs (see Conclusion #4).

Conclusion 2: Resolve Sediment Deficit with Phased Restoration and/or Dredged Sediment Reuse

A very large sediment deficit exists for restoring tidal marsh elevations on subsided salt ponds that will require restoration phasing over many decades and/or dredged sediment reuse in order to protect South Bay mudflats. Subsidence is a common feature of San Francisco Estuary diked baylands. Most of the salt ponds from Mountain View to San Jose (the "Alviso Plant") have subsided from 6 to 8 feet below marsh height due to groundwater pumping ongoing through the 1960s. Surrounding uplands in the South Bay have subsided even more, up to 13 feet in some places. Most of the remaining salt ponds have subsided from 1 to 4 feet below marsh height.

We estimate this subsidence to represent a sediment deficit of about 108 million cubic yards (MCY) to restore tidal marsh elevations for the entire 26,000-acre South Bay salt pond complex and about 89 MCY for the 16,000-acre Cargill proposed sale area. The actual deficit will be less according to how many and which ponds are retained as managed shallow open water (or retained for salt production). Meeting this sediment deficit *without scouring the ecologically important South Bay mudflats* will require one of two approaches: (1) phase restoration over many decades to match sediment demand with the rate at which sediment naturally enters the South Bay (estimated by others at about 0.9 MCY per year), or (2) partially fill ponds with clean dredged sediment. We estimate the first option would require about 120 years to restore two-thirds of the entire South Bay salt pond complex and 99 years for two-thirds of the smaller Cargill proposed sale area. Dredged sediment reuse can reduce these time frames to as short as 56 years and 39 years for the full complex and Cargill proposed sale area, respectively, depending on the rate of dredged sediment availability. These time periods could be reduced further if greater quantities of dredged sediment could be made available more rapidly. Dredged sediment, however, has economic consequences that must be considered; these are discussed next.

Conclusion 3:
Dredged Sediment Reuse May Be Desirable and Economically Feasible

Our cost estimate ranges for "natural sedimentation" and "dredged sediment reuse" restoration approaches overlap considerably, suggesting that dredged sediment may be economically feasible. Further, dredged sediment reuse can speed the overall period of restoration, thereby achieving ecological goals decades sooner. A fundamental aspect of salt pond restoration is that the sediment supply to offset the sediment deficit cannot, as a matter of natural resource protection, come at the expense of South Bay mudflats. Our estimates indicate that the "mudflat-sustainable" natural sedimentation restoration approach will require on the order of 120 years to restore two-thirds of the total salt pond complex to tidal marsh and 100 years for two-thirds of the smaller Cargill proposed sale area ponds. The dredged sediment reuse options reduced that time frame to 56-72 years and 39-52 years for the total salt pond complex and the Cargill proposed sale area, respectively. The range in years reflects different amounts of dredged sediment reuse that could be considered. These time periods could be shortened further if suitable dredged sediment were available more rapidly than we assumed for our analyses. Because total restoration costs include interim and ongoing O&M costs, more rapid restoration shortens the duration of the more costly interim O&M and thus reduces costs further. Additionally, accelerated restoration efforts, if well planned, will also achieve the environmental and ecological benefits sooner. These benefits have not been estimated though their consideration is critical in developing any accurate cost-benefit analyses that considers using dredged sediment.

Our rough cost estimate for the "mudflat-sustainable" natural sedimentation approach consists entirely of interim and permanent O&M and comes in at $621 million to $1.49 billion for restoring two-thirds of the total South Bay salt pond complex (or about 18,000 acres). For the 16,000-acre Cargill proposed sale area, those costs span a range of $315 to $764 million. For dredged sediment reuse, we considered three scenarios reflecting variable quantities of dredged sediment. Though dredged sediment reuse has considerable up-front costs, it gains a vital economic benefit — it reduces the time period over which costly interim O&M is necessary. To calculate these costs, we used a suite of assumptions including that restoration sponsors would be responsible only for the incremental costs of dredged sediment reuse not normally paid for by dredging projects. Dredged sediment reuse cost estimates range from $457 to $1.48 billion for the full salt pond complex and $222 to $899 million for the Cargill proposed sale area. In other words, dredged sediment has the potential to be a very effective and economically competitive approach to restoring the South Bay salt ponds. In practice, the single greatest issue is dredged sediment availability, as competition now exists for reusing dredged sediment for wetland restoration (e.g., Montezuma and Hamilton-Bel Marin Keys).

Conclusion 4:
Account for All Bittern and Hypersaline Brine in the Short and Long Term

The current acquisition negotiations need to include requirement for full bittern and hypersaline brine removal from the Redwood City ponds included in the Cargill proposed sale area and a formulation of a binding plan for Cargill's long-term disposition of bittern and hypersaline brines stored in Newark. Bittern is the hypersaline byproduct of solar salt production. Bittern occurs in both a liquid and solid state and consists of naturally occurring minerals in bay water *minus* the commercially harvested common salt and some other salts that solidify within the pond system as part of evaporation (mainly gypsum). Bittern is thus distinguished from bay water by a salinity level over ten times higher and by its *ionic imbalance*, both of which make it toxic to aquatic organisms. Hypersaline brines are the concentrated bay waters that arise from salt production prior to salt harvesting and from any efforts to "clean" bittern and other high-salinity ponds during pond decommissioning. Three specific issues require incorporation into current acquisition negotiations.

Bittern Definition Must Include All Components of Bittern in Acquisition Negotiations

Considerably different estimates of the ongoing bittern production rates exist that we believe stem in part from varying definitions of bittern. Cargill currently estimates it produces 0.15 million tons of bittern annually. Leslie Salt, Cargillís predecessor, estimated 1 million tons annually. Resolving this disparity is critical to ensure that bittern in all its forms are properly removed from Redwood City as part of acquisition so that the public does not take on this costly liability as it did with the North Bay salt ponds in the 1990s. **Bittern is defined as the total liquid bittern, including dissolved ions and salts and the water in which they are dissolved, plus the precipitated bittern salts that have deposited on bittern pond bottoms.** Using this definition and assuming that Cargill stores bittern at the highest salinity possible in the region (dictated by rainfall and solar evaporation), our new mass balance analysis estimates an annual bittern production rate of about 0.6 million tons. We believe that Cargill's estimate of 0.15 million tons is too low to account for all forms of bittern regardless of storage salinity and liquid or solid phase and that Leslie's estimate of 1 million tons is too high because it failed to account for evaporative concentration in the bittern storage ponds.

Acquisition Should Provide Plan for Hypersaline Brines

Hypersaline brines are the concentrated bay waters that arise from salt production prior to salt harvesting and from post-acquisition efforts to "clean" (i.e., desalinate) bittern and other high-salinity ponds. Hypersaline brines pose similar toxicity issues to that of bittern, though at reduced levels of significance since their ionic imbalance is less than bittern. Negotiations should clearly define responsibilities, terms and conditions for the disposition of these brines. The volume produced will depend upon the desalination method and the initial salinity level of ponds being desalinated and could be an additional one to two volumes in addition to what is currently within a pond. Because of its very large volume, transferring brine into Cargill's salt production stream at a rate that is economically and logistically feasible while meeting state and federal restoration goals will require close coordination between Cargill and the resource management agencies.

Provide a Long-Term Plan for Existing Stockpiled Bittern Disposition

In the early 1970s, the federal Clean Water Act and the state Porter-Cologne Water Quality Act ended unregulated bittern discharge to the Bay. Since that time, the available market for bittern has been relatively minor. Consequently, Cargill has stockpiled roughly 30 years of bittern at Redwood City and Newark. We have estimated that stockpile to be about 19-20 million tons of bittern. It is our understanding that all the bittern stockpiled in Redwood City will be transferred to Newark. Most of Cargill's Newark-stored bittern is located in Ponds 12 and 13 in Newark Plant #2; these ponds are owned by the Refuge. Transfer of the Redwood City bittern to Newark may require converting additional ponds to bittern storage, and whether these additional ponds would be on Cargill or Refuge property is to be determined as part of the acquisition.

The 1979 operating agreement under which Cargill exercises its mineral rights on Refuge-owned salt ponds places Cargill under no obligation to clean up bittern or any other problems it has created on these publicly-owned lands. Solar salt production in the highly urbanized San Francisco Estuary may not be an economical operation in the long-term as suggested by Cargill's current efforts to reduce local salt production and increase production efficiencies. Over the anticipated period for sustainable restoration, it seems likely that Cargill will cease salt production altogether. **Thus, current acquisition negotiations are the forum to establish clear Cargill responsibility for long-term disposition of all bittern, including the existing stockpiles and all future bittern production.** The State of California has learned the hard way from the Napa River salt ponds just how difficult and costly bittern remediation can be. Cargill has currently undertaken efforts to reduce bittern volumes through reprocessing bittern in the salt production process and creating and enlarging commercial markets for bittern.

Conclusion 5:
Commit to Immediate and Long-Term Operations, Maintenance and Monitoring

Immediate and long-term ongoing operations, maintenance, and monitoring funds are essential to achieve ecological goals and protect against levee failures that could flood locally large segments of the South Bay. These funds represent a need for long-term political and fiscal commitment by local, state, and federal agencies. Securing these funds may be more important and difficult than the initial purchasing of the property. Beyond the first step in restoration (acquisition), it will be essential to maintain hundreds of water control structures and some significant portion of the 234 miles of levees enclosing the salt ponds. Adaptive management will provide the best approach for ensuring a successful restoration program that will take decades to complete. Monitoring data are the essential information resource for adaptive management and therefore monitoring should be adequately funded throughout the restoration effort.

Water Control Structures Provide the Means for Wildlife Management in Retained Ponds

Pond water levels, salinity and water quality are all essential elements for wildlife management in the salt ponds. These parameters are governed largely by the amount and rate of water exchange between ponds and the South Bay. Numerous pumps, pipes, gates, and related infrastructure are necessary to carry out any water management. Therefore, inadequately maintaining water control structures could compromise ecological goals and provide the potential for water quality problems (i.e., unintended "salt production" leading to hypersaline brines and gypsum deposition).

Flood Protection Levees Protect Subsided South Bay Uplands

Cargill currently maintains a total of 21 miles of levees that separate salt ponds from adjacent inland land uses and another 180 miles of levees bayward of these levees, some of which provide flood control protection remotely. Public agencies maintain another 17 miles of levees enclosing the salt ponds. Inadequate levee maintenance could lead to failures potentially flooding extensive areas of the South Bay that lie below sea level.

Estimated Operations and Maintenance Activities and Costs

O&M activities will vary according to the phase of overall restoration and the target ecosystem types being managed. We have divided the restoration effort into three phases: initial planning and design, interim management of ponds targeted for tidal marsh restoration, and permanent management of ponds retained as shallow open water habitats. The full range of O&M activities that will required for most of these phases includes water management, levee maintenance, water control structure maintenance, and meeting regulatory act requirements. We estimate annual O&M costs (in 2001 dollars) for all these activities to range between $284 and $686 per acre. These costs translate to $4.5 to $11 million total annually for the 16,000-acre Cargill proposed sale area (a slightly reduced version of which is currently being negotiated) and $7.4 to $17.8 million total annually for the entire salt pond complex. Annual costs will decline over time as described next. All O&M funds would need to go to the Don Edwards San Francisco Bay National Wildlife Refuge, the entity expected to own and be responsible for all the acquired salt ponds. Actual O&M costs will depend also on which ponds are restored to tidal marsh and which are retained as open water, as levee maintenance costs will vary depending on the nature of individual levees.

Initial planning and design period. During the initial planning and design period, which we assume would last five years, we expect that full O&M activities and funds will be required for all purchased properties. For the 16,000-acre Cargill proposed sale area, initial O&M will cost somewhere between $23 and $55 million total. For the entire 26,000-acre South Bay salt pond complex, these costs would be $37 to $89 million.

Interim management of ponds restored to tidal marsh. During the extended period over which two-thirds of the pond acreage would be restored to tidal marsh, O&M activities and costs will gradually decline. At the outset, the full range of O&M activities would be required. Once a pond is restored to tidal marsh, only levee maintenance would be required and we assume that ends once marsh vegetation becomes well established for levee erosion protection. For two-thirds of the Cargill proposed sale area, these O&M costs will be somewhere between $156 and $357 million for the longer implementation time required by the natural sedimentation approach and $62 to $151 million for a shorter period associated with dredged sediment reuse.

Permanent management of ponds retained as shallow open water habitats. The one-third of pond acreage retained as shallow open water habitat will require the full range of O&M activities and costs in perpetuity. For the Cargill proposed sale area, these costs will be between $1.4 and $3.4 million annually. These costs would be $2.3 to $5.5 million annually for the entire salt pond complex.

Monitoring

Monitoring funds will also be required and are likely necessary shortly after acquisition. We estimate that monitoring will cost $1.5 to $3.0 million dollars annually for the 16,000-acre Cargill proposed sale area and will extend over a 40-year period and perhaps longer. We would anticipate that actual monitoring costs will rise and fall from one year to the next, so this 40-year estimate should approximate those total costs. Total costs over those 40 years would range between $60 and $120 million, in 2001 dollars.

Conclusion 6:
Restoration Needs to Consider the Many Pressures on Biological Resources

During the restoration process, many environmental and economic pressures will threaten existing biological resources and thus are important considerations in acquisition and restoration planning. We have identified three topics of particular concern: increased importance to wildlife of remaining salt production ponds, dynamics of wildlife use of South Bay salt ponds, and the invasive eastern cordgrass, *Spartina alterniflora*.

Increased Importance of Remaining Salt Production Ponds

Converting two-thirds of salt ponds to tidal marsh (regardless whether of the entire salt pond complex or the smaller Cargill proposed sale area) will increase the importance of the remaining salt ponds for species that rely on shallow open water environments. The situation becomes more complex in the context of Cargill retaining salt production on a reduced area consisting of Newark #1 and #2 plants, which comprise about 10,000 acres. Cargill recently began a series of modifications to those plants intended to increase production efficiency by about 25% in anticipation of public acquisition. Historically, conflicts exist between salt production and wildlife management on existing Refuge-owned ponds in Newark #1 and #2 plants. Although these conflicts have diminished in recent years, Cargill's higher salt production expectations and the inherent need to optimize the salt production process could lead to less flexibility for pond operations in an ecologically friendly manner. Some of these modifications have, however, improved wildlife conditions by providing more ponding in certain areas that were previously difficult to keep flooded adequately.

Dynamic Ecological Resources

Wildlife resource use of the South Bay salt ponds is best characterized by its dynamics. Variability in pond environmental conditions occur from interannual climate differences as well as Cargill operations. Wildlife continually adjust their use of any particular salt pond in response to these varying conditions. Therefore, throughout the restoration planning and implementation effort, it will be important for restoration planners to have current information. These information needs emphasize the role of ongoing monitoring, within an Adaptive Management framework, to provide data on species recovery and decline that can be used to adjust restoration planning and goals as the process moves forward.

Spartina alterniflora

The invasive *Spartina alterniflora*, an aggressive eastern cordgrass, diminishes marsh habitat functions relative to the native cordgrass, *S. foliosa*. No current controls effectively prevent *S. alterniflora* spread once it has become established. It is particularly problematic in the East Bay between the San Mateo and Dumbarton bridges. Restoring ponds close to existing stands of *S. alterniflora* should be undertaken cautiously until more research into and demonstration of its control has been completed.

Conclusion 7:
Buyer Beware of Differential Restoration Feasibility

Not all ponds can be restored with equal ease. The current Cargill proposed sale area contains many of the most difficult and costly to restore ponds while retaining most of the easiest and least costly to restore ponds under Cargill control. Restoration costs for a given pond depend upon many factors but are most impacted by the degree of subsidence. The feasibility of restoring any given salt pond to tidal marsh varies according to a variety of site-specific factors as well as how surrounding ponds are treated. Thus, which ponds the public buys and which ponds Cargill retains in salt production have tremendous economic and ecological ramifications for all parties. Using a suite of biological, physical, and chemical criteria, we reached the following conclusions about restoration feasibility: 2,690 acres (10 percent total area) are high feasibility, 13,240 acres (51 percent total area) are medium feasibility, 8,430 acres (32 percent total area) are low feasibility, and 1,830 acres (7 percent total area) we had insufficient data to make a determination. Without dredged sediment reuse, we estimate per-acre restoration costs to be approximately $1,500 versus $5,000 for high and low feasibility ponds, respectively.

Most of the "high feasibility" ponds are not part of the Cargill proposed sale area. Cargill has offered to sell the most costly ponds to manage and restore, especially the deeply subsided Alviso ponds, while retaining the most easily restored ponds. Of the 108 MCY estimated sediment deficit for the total salt pond complex, those ponds Cargill has offered for public acquisition represent 89 MCY or 82 percent of that total deficit. Further, under the range of possible dredged sediment reuse options we evaluated, virtually all that sediment is needed only in the ponds Cargill is currently offering the public. Only under the maximum reuse scenario would ponds currently not part of the proposed acquisition be considered for dredged sediment reuse, and those ponds account for only 4 MCY of 58 MCY under that scenario.

In addition to these economic ramifications, this arrangement has ecological consequences. Most of the "high feasibility" ponds are represented by just three salt ponds — Mowry 1, 2 and 3 in Alameda

County. These three ponds have long been targeted for restoration because of their particular suitability to yield tremendous ecological recovery benefits. Because they are easily restored and have undergone minimal subsidence, those benefits could be reached with a minimum of cost and in comparatively short time periods. Their exclusion from the acquisition poses an important constraint on achieving ecological recovery goals for the San Francisco Estuary.

Rough Cost Estimate to Restore the 16,000 Acres Offered by Cargill

This feasibility analysis has identified seven general cost categories for managing and restoring the 16,000 acres of South Bay salt ponds that Cargill offered in 2000 for public acquisition. This cost estimate includes tidal marsh restoration on 11,000 acres and managed shallow open water on 5,000 acres. For each of the two restoration strategies — "mudflat-sustainable" natural sedimentation and dredged sediment reuse — we present a "low" and "high" cost estimate to bracket the uncertainties contained in estimating costs for each of the seven categories. The total costs are shown in Figure ES-1 and we break out these costs annually in Figure ES-2 and cumulatively in Figure ES-3. In Table ES-1 we have summarized seven myriad data from which we derived these cost estimates.

Figure ES-1. Estimated total restoration and management costs for 16,000-acre Cargill proposed sale area, excluding acquisition, 2001 dollars

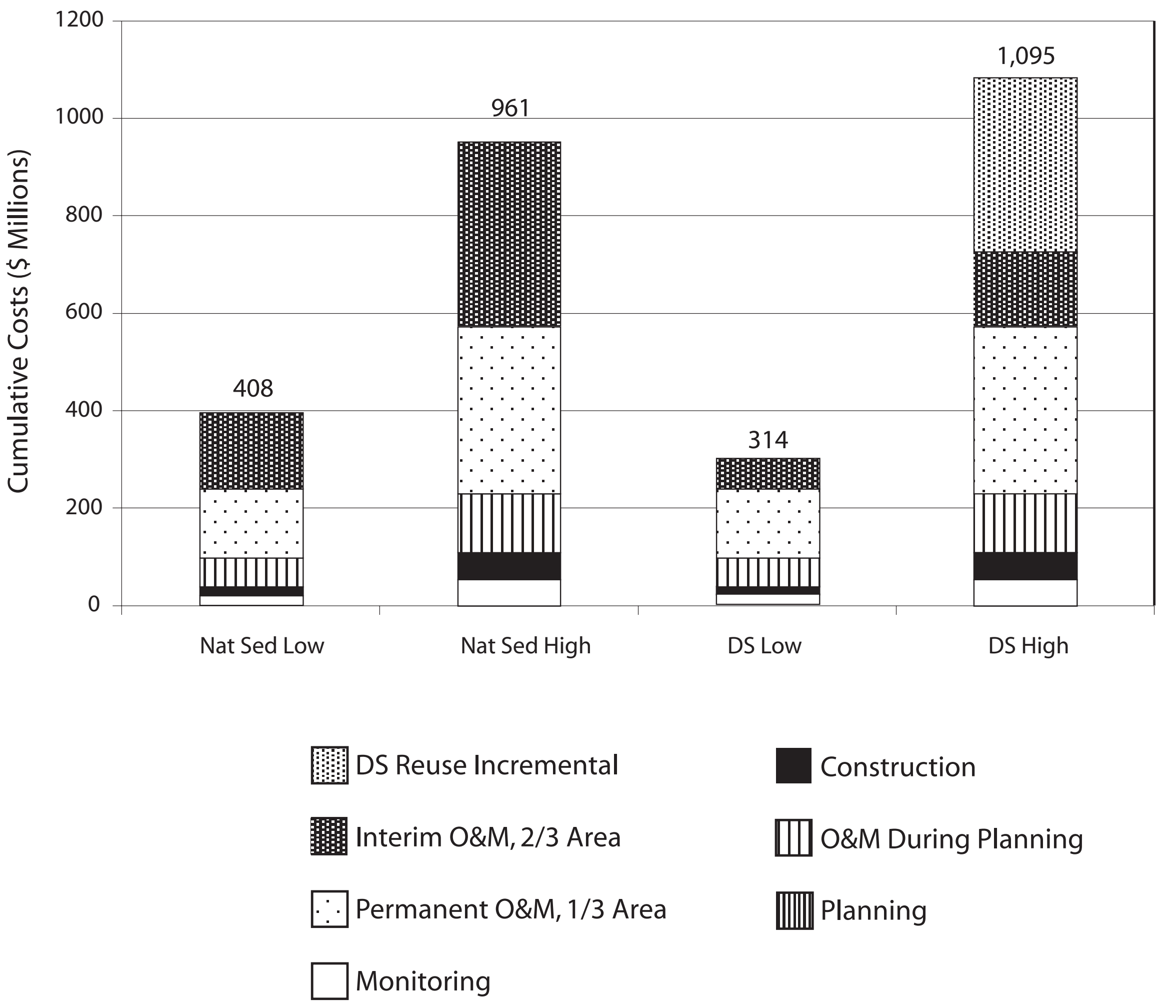

Figure ES-2. Annual restoration and management costs for 16,000 acre Cargill proposed sale area, excluding acquisition costs, 2001 dollars

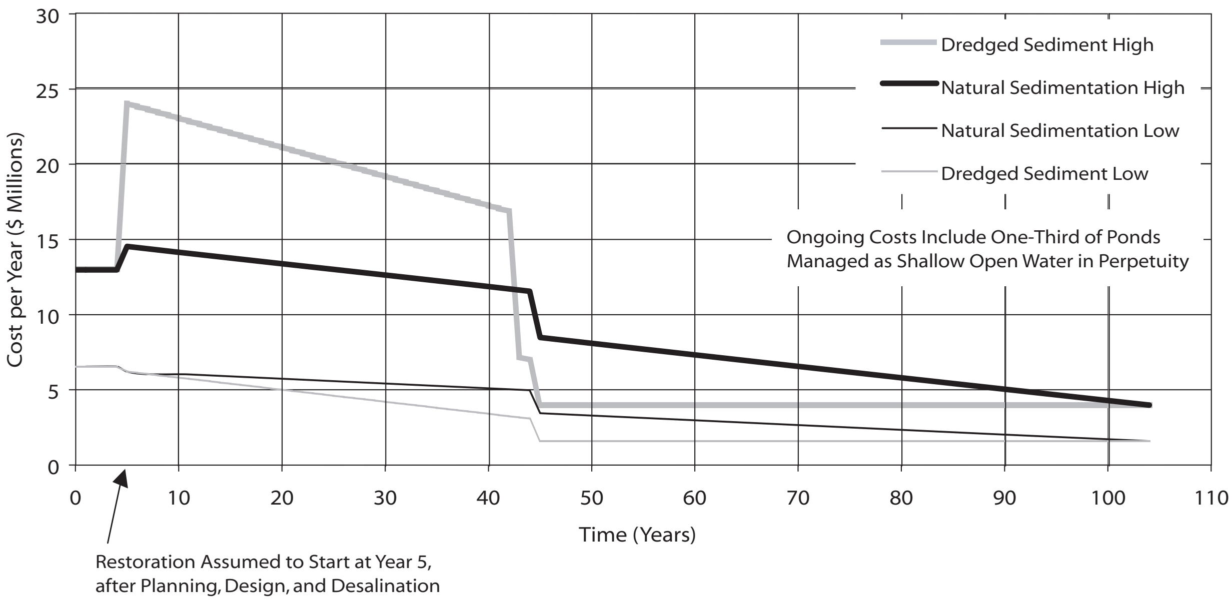

Figure ES-3. Cumulative restoration and management costs for 16,000 acre Cargill proposed sale area, excluding acquisition costs, 2001 dollars

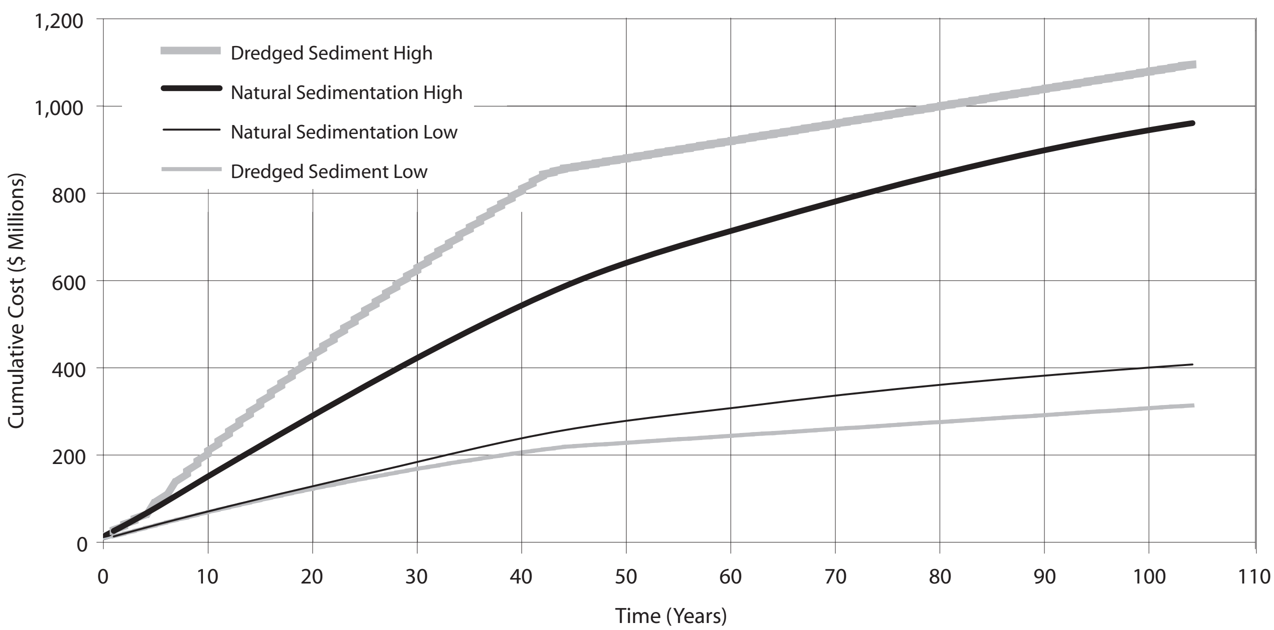

Table ES-1. Summary data for South Bay salt ponds

Description	Units	Value
Salinity Levels		
Median South Bay near intakes	part per thousand	15 - 30
Sea water	part per thousand	35
Gypsum formation, beginning of ionic toxicity	part per thousand	147
Crystallizers	part per thousand	356 - 395
Bittern storage and desalting ponds	part per thousand	395 - 447
Current Production		
Annual salt production	million tons	1
Annual bittern production	million tons	0.6
Bittern stockpiled on site	million tons	19-20
Current Salt Pond Ownership		
Total pond area	acres	26,190
Cargill owned	acres	14,760
Refuge owned	acres	11,430
Current Salt Pond Use		
Total pond area	acres	26,190
Brine concentrators	acres	23,240
Crystallizers	acres	1,340
Bittern desalting and storage	acres	1,610
Current Levees		
Total	miles	220
Upland unprotected	miles	21
Flood protection, publicly-owned	miles	17
Bayfront	miles	80
Internal to salt ponds	miles	76
No data	miles	26
Cargill's 2000 Proposed Sale		
Total cost	$ million	300
Total acreage of South Bay ponds	acres	15,860
Acreage owned by Cargill	acres	11,940
Acreage owned by Refuge — sell mineral rights	acres	3,920
Current Acquisition Negotiations (full details are not public)		
Total cost	$ million	100
Total acreage of South Bay ponds	acres	13,000 - 15,000
Restoration Feasibility		
High feasibility ponds	acres	2,690
Medium feasibility ponds	acres	13,240
Low feasibility ponds	acres	8,430
Insufficient data for feasibiilty determination	acres	1,830
Sediment Deficit and Supply		
Subsidence range of all ponds	feet	0 - 8
Total sediment deficit, entire complex	million cubic yards	108
Total sediment deficit, Cargill proposed sale area	million cubic yards	89
Sediment supply rate to the South Bay	million cubic yards per year	0.89
Estimated Mudflat-Sustainable Natural Sedimentation Restoration Time Periods		
On two-thirds total salt pond complex	years	120
On two-thirds Cargill proposed sale area	years	99
Estimated Dredged Sediment Reuse Restoration Time Periods		
On two-thirds total salt pond complex	years	56 - 72
On two-thirds Cargill proposed sale area	years	39 - 51

continued

Table ES-1. Continued

Description	Units	Value
Cost Estimate Components, 2001 Dollars		
Operations and maintenance (initial, interim, permanent)	$ per acre	284 - 686
Restoration construction — no dredged sediment	$ per acre	1,500 - 5,000
Restoration construction — with dredged sediment	$ per acre	up to 100,000
Incremental dredged sediment reuse costs	$ per cubic yard	0 - 10
Planning and design	$ million, lump sum	10
Monitoring	$ million, lump sum	60 - 120
Total Estimated Costs, Cargill Proposed Sale Area, excluding acquisition, 2001 Dollars, 99-Year Restoration Period*		
Natural sedimentation, low per unit costs	$ million	408
Natural sedimentation, high per unit costs	$ million	961
Dredged sediment reuse, low per unit costs	$ million	314
Dredged sediment reuse, high per unit costs	$ million	1,095

** includes planning, design, O&M, construction, monitoring, incremental dredged sediment reuse (if applicable)*

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Agency and Organization Abbreviations

BCDC	San Francisco Bay Conservation and Development Commission
CCMP	Conservation and Management Plan
CDFG	California Department of Fish and Game
Corps	U.S. Army Corps of Engineers. Also referred to as USACE.
CSCC	California State Coastal Conservancy
NGS	National Geodetic Survey, part of the National Oceanic and Atmospheric Administration
NOS	National Ocean Service, part of the National Oceanic and Atmospheric Administration
RWQCB	San Francisco Bay Regional Water Quality Control Board
SCWPCP	San Jose/Santa Clara Water Pollution Control Plant
SFBJV	San Francisco Bay Joint Venture
SFEP	San Francisco Estuary Project
SSFBA	Save San Francisco Bay Association
USACE	U.S. Army Corps of Engineers. Also referred to as Corps.
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
WRMP	Wetland Regional Monitoring Plan
WWR	Wetlands and Water Resources

Units of Measurements

ac	acres
°Be	degrees Baume. Salinity measurement convertible to specific gravity
cy	cubic yards
ft	feet
lf	linear feet
ls	lump sum
in	inches
m	meters
mcy	million cubic yards
mgd	million gallons per day
mm	millimeters
ppm	parts per million (one part of parameter for each million parts of solution or mass)
ppt	parts per thousand (one part of parameter for each thousand parts of solution or mass); one tenth of one percent
y	years

Definition of Terms

Anhydrite
Crystals formed from the chemical precipitation of calcium and sulfate to form calcium sulfate ($CaSO_4$)

Anion
Negatively charged ion. For instance, with NaCl chloride is the anion

Bittern
Residual brine or salt solution discharged from crystallizer ponds after harvesting of sodium chloride. Initially a liquid at discharge and composed of dissolved salts, primarily magnesium (Mg^{2+}), potassium (K^+), bromide (Br^-), chloride (Cl^-) and sodium (Na^+). Bittern continues to concentrate after discharge because of evaporation and separates into a solid and liquid phase

Bittern desalting ponds
Pond in which liquid bittern is concentrated further before being transferred to bittern storage ponds

Bittern storage ponds
Ponds in which bittern is stored

Bittern salts
Salts that exist in the bittern. These salts include magnesium sulfate, magnesium chloride, potassium chloride and magnesium bromide. Salts can be either dissolved or particulate. The ratio of dissolved to precipitate salts depends upon the bittern salinity

Brine
Hypersaline water

CFSTR
Continuous-Flow Stirred Tank Reactor. Reactor model used in mass balance analyses describing system in which water is well mixed and water quality parameters throughout pond are constant and equal to outflow concentrations

Choker
Small berm constructed on levee top on the side where slip-outs are deemed unacceptable. Constructed to contain dredge muds from slipping into marshes or ponds

Concentrator ponds
Ponds where evaporation concentrates salt in solution. Brine is reduced by about 90% to where it is saturated with respect to sodium chloride

Crystallizer ponds
Ponds in which approximately 95% of the sodium chloride precipitates from the brine and forms crystal deposits on the pond beds. Sodium chloride is commercially harvested from crystallizer ponds

DO
Dissolved oxygen

$CaCO_4$
Calcium carbonate. Sedimentary rock formed from the chemical precipitation of calcium and carbonate

$CaSO_4$
Calcium sulfate. See gypsum and anhydrite

Carbonates
Class of minerals in which carbonate (CO_3^{2-}) is the anion

Cation
Positively charge ion. For instance, with NaCl, sodium is the cation

Evaporites
Solids formed from the chemical precipitation of salts from saturated solutions

Evaporator ponds
See Concentrator ponds

Gypsum
Crystal formed from the chemical precipitation of calcium and sulfate to form calcium sulfate ($CaSO_4(2H_2O)$) crystals. Gypsum is the hydrated form of anhydrite and forms when water is added to anhydrite. Gypsum is therefore the form of calcium sulfate most likely to form on pond bottoms

Halite
Technical name for sodium chloride (NaCl). Also known as common salt or table salt. Halite occurs as crystals or granular masses

High marsh
Marsh area defined by tidal range between MHW and MHHW (Goals Report 1999)

HLR
Hydraulic loading rate (cm day^{-1})

HRT
Hydraulic retention time. The amount of time the water stays within a given pond system

Iron oxides
Solids formed from the chemical precipitation of iron. Does not readily dissolve

Intertidal marsh
Marsh defined by tidal datum between MTL and MHW

KCl
Potassium chloride

K_2SO_4
Potassium sulfate

Low marsh
Marsh area defined by tidal range between MTL and MHW

$MgBr_2$
Magnesium bromide

$MgCl_2$
Magnesium chloride

$MgSO_4$
Magnesium sulfate

MHHW
Mean higher high water, average of the higher of two daily high tides

MHW
Mean high water, average of all high tides

MLLW
Mean lower low water, average of the lower of two daily low tides

MLW
Mean low water, average of all low tides

MTL
Mean tide level, average of all tidal water levels

NaCl
Sodium chloride (see salt, halite)

NAVD 88
North American Vertical Datum of 1988. Fixed vertical geodesic datum established by NGS in 1988 to replace NGVD 29

NGVD 29
National Geodetic Vertical Datum of 1929. Fixed vertical geodesic datum established by NGS predecessor in 1929. No longer supported by NGS

pH
Logarithmic measure of hydrogen ion concentrations

Pickle
Brine at saturation with respect to halite

Pickle ponds
Final evaporative pond used for storing pickle. Salinity is approximately 317 ppt

Precipitation
Formation of solids through combination of dissolved ions. Occurs when the liquid is supersaturated with respect to the ions

Salt
Commonly used to describe sodium chloride. However, salts are technically any substances resulting from the reaction between an acid and a base. In the formed salts, the hydrogen ion on the acid is displaced by a metal ion. For instance, NaCl forms by displacing the hydrogen ion from the acid HCl (hydrogen chloride). Other salts include magnesium chloride, magnesium sulfate, calcium carbonate, and calcium sulfate. Salts can be in dissolved or solid forms. Solids form when solutions become supersaturated with respect to the ions which form the salts. For instance, NaCl forms when the solution becomes supersaturated with respect to sodium (Na^+) and chloride (Cl^-)

Slip-outs
When amounts of dredged material slips from exterior levee tops and falls onto the vegetated shoulder or onto the marsh plain

Stage 1 Ponds
Series of evaporative ponds before gypsum begins to form. Approximately 60% of the production pond area. Ranges in salinity from about 12 to 120 ppt. Brine volume is reduced by about 80%

Stage 2 Ponds
Series of evaporative ponds in which gypsum precipitation occurs. Approximately 30% of the production pond area. Ranges in salinity from about 120 to 250 ppt

Sulfates
Class of minerals in which sulfate (SO_4^{2-}) is the anion

Supersaturated
When the solubility product of a mineral is exceeded resulting in precipitation of the mineral

Specific gravity (SG)
The ratio of the mass of the liquid to the mass of water. For brine solutions can be considered a measure of salinity

TDS
Total dissolved salts

Tidal datum
Average local heights of the tides

Tidal flat
Defined by tidal range between MLLW and MTL

Tidal range
Local range of the tides, measured either from lowest to highest observed tides or from MLLW to MHHW

Upland ecotone
Defined by tidal range between MHHW and extreme high tide

Upland
Land areas currently outside the range of the tides and not supporting wetlands. Technically, refers to lands topographically above the range of tides. Commonly applied (and used in this report) to lands diked from San francisco Bay that reside behind levees (diked baylands) that are now in urban land uses.

Part I.

Introduction

Chapter 1.

Report Purpose and Background

The San Francisco Estuary and the Sacramento-San Joaquin Delta form the West Coast's largest estuary, draining approximately 40 percent of California's land. With its blend of fresh and ocean waters, thousands of miles of rivers and streams, and numerous microclimates and landscapes, the Estuary is an ecological treasure that supports an enormous diversity of fish, animals, and plants. Approximately 120 fish species, 255 bird species, 81 mammal species, 30 reptile species, and 14 amphibian species live in the Estuary, relying on the riparian and wetland habitats for breeding, nursing, and feeding. Nearly half the birds of the Pacific Flyway and two-thirds of California's salmon pass through the Estuary.

Wetlands play a vital and often overlooked role in maintaining a healthy ecosystem, particularly in the Bay-Delta Estuary. Wetlands improve water quality, provide essential wildlife habitat, act as natural flood control, prevent shoreline erosion, recharge groundwater, and provide recreational and educational opportunities. More productive than all but tropical ecosystems, wetlands feed and shelter countless species, support a diverse plant community, and form a major foundation of the Bay's food web.

Unfortunately, more than 90 percent of California's original wetland acreage has been diked, drained, filled, and destroyed. Many of the remaining wetlands are threatened by pollutant runoff and diverted freshwater flows. Riparian areas have been lost as creeks are routed underground or channelized for flood control and urban development. The San Francisco Bay Area—the nation's fourth largest metropolitan region—has suffered severe wetland losses due to urban development, agricultural conversion and salt production. As a result, we have lost nearly 95 percent of our historic wetland and riparian habitats, particularly in San Francisco and San Pablo Bays. Scientists estimate that a minimum of 100,000 acres must be restored to tidal marsh to keep the Estuary a well-functioning ecosystem.

For these reasons, many governmental and non-governmental organizations have long sought acquisition and restoration of the 26,000-acre complex of salt production ponds located in the southern portion of the San Francisco Bay (Map 1). Although the Cargill Salt Company (Cargill) currently operates on all of these ponds, the ponds have mixed ownership. Cargill owns 56 percent of the land area (14,760 acres), and the Don Edwards National Wildlife Refuge owns the remaining 44 percent on which Cargill owns mineral rights for salt production (11,430 acres; Map 2). The Don Edwards National Wildlife Refuge (Refuge) is one of four refuges contained in the San Francisco Bay National Wildlife Refuge system.

After decades of salt production in the San Francisco Bay Area, in 2000 Cargill announced its intention to consolidate its salt production operations and offer decommissioned ponds for public acquisition and restoration. Improved efficiency means that Cargill can continue making salt at half its current production levels on roughly one-third the amount of land it currently uses. Therefore, Cargill began negotiations with the State of California and the federal government for sale of mineral rights on lands already owned by the Refuge and outright sale of other lands in South San Francisco Bay for a total of $300 million. The area involved in the negotiation totals nearly 16,000 acres of South Bay salt production ponds plus another 1,400 acres of former salt production ponds in the North Bay along the Napa River and 600 acres of open bay in the South Bay. The restoration potential of these ponds is enormous. Map 3 shows the areas subject to these negotiations. Chapter 12 provides more details on Cargill's proposal and this historic opportunity. Recent economic conditions have adjusted the negotiated lands and price downward to a package totaling $100 million and encompassing a slightly smaller area that presumably excludes lands in the Redwood City Plant that have higher appraised value.

The San Francisco International Airport has also examined the South Bay salt pond complex as possible mitigation areas for its proposed runway expansion project. Though there has been substantial publicity about the potential link between these two projects, currently there is no connection between these two projects. Current acquisition negotiations reportedly do not include San Francisco Airport funding.

The proposed salt pond purchase is a unique, once-in-a-lifetime opportunity that we cannot afford to let slip away. This historic opportunity prompted preparation of this report to evaluate the feasibility of restoring some or all of these ponds to tidal marsh and related habitats. Wetland restoration has not been attempted on this scale in the Bay Area, but the significance of this acquisition makes it imperative that we try. Though Cargill has offered only a portion of the total South Bay salt pond complex, we chose to evaluate the entire complex in this Feasibility Analysis. Salt pond restoration would provide approximately 15 percent of the Estuary's overall restoration needs and roughly two-thirds of the South Bay's restoration goals.

Ecological restoration of the South Bay salt ponds will be an enormous and complicated undertaking. It will take many years and require considerable financial resources and ongoing commitment from the region's natural resource managers. The salt ponds have important ecological, environmental, and hydrologic impacts on the San Francisco Bay Area and beyond. Although the constraints presented by existing conditions will shape the final outcome to some extent, a variety of approaches exist to achieve successful ecological restoration. Therefore, solid planning and decision making must proceed from a clear understanding of the opportunities and challenges present.

This feasibility analysis is designed to help with the complex planning and decision making process for the South Bay salt pond acquisition and restoration. We have organized the information into five parts:

- **Introduction** – Chapters 1 and 2
- **Existing conditions affecting restoration** – Chapter 3 thru 6
- **Challenges and opportunities** – Chapters 7 through 11
- **Planning for the acquisition and beyond** – Chapters 12 through 14
- **Conclusions** – Chapter 15

Following these chapers are a **map atlas** depicting a variety of restoration constraint "overlays" (Maps 5 through 13) that are then compiled into a single map (Map 14) rating each salt pond's restoration feasibility, and **appendices** containing more detailed technical materials.

For easy access, a list of acronyms and definitions for chemical, engineering, and operational terms are provided in the front of the report.

Acknowledgements

We would like to acknowledge a number of organizations that made this report possible. First and foremost, Save San Francisco Bay Association provided the impetus and initial funding, through Packard Foundation grants and other sources, that paid for the research and analysis contained in this report. Save the Bay also provided invaluable editorial guidance. The California State Coastal Conservancy funded production of the Geographic Information System (GIS)-based map atlas presented in this report. The U.S. Fish and Wildlife Service, through the Don Edwards San Francisco Bay National Wildlife Refuge and the Endangered Species Mare Island Field Office, provided invaluable input, advice, and review. The California Department of Fish and Game, California State Coastal Conservancy and U.S. Army Corps of Engineers provided essential background on the Napa River salt pond case study that helped inform a variety of issues for South Bay salt pond restoration. Cargill Salt Company provided us with some additional information. Especially helpful were members of the Citizens Committee to Complete the Refuge, who provided a wealth of information along with funding for report production. Many others answered our countless questions and requests for documents (see Communications references) and we offer our gratitude to all those who helped make this work possible.

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Adam Klein, a California Registered Geologist, provided invaluable peer review on several complex quantitative analyses.

Chicory Bechtel of Wetlands and Water Resources provided editorial assistance.

Disclaimers

The views and opinions expressed herein are solely those of its authors, Stuart Siegel and Philip Bachand, and not of any other persons or entities. Within the confines of budgetary constraints, we have attempted to be as thorough as possible in data gathering, quality checking, and analysis. These data necessarily span a wide range of subject matter, sources, intent for original preparation, quality, and completeness. We understand that others may evaluate the same data in different ways and reach different conclusions. We recognize that errors in our analyses could exit, though we have tried diligently to omit them. Further, we recognize the public interest value of this work and the appropriateness of scrutiny by others. Consequently, we have tried to make available within this report the data and logic processes we used so that others can go back to that original data, examine it independently, and, if interested, apply different analytical approaches. This report is not intended for use in preparing a salt pond restoration design but instead is intended to provide a starting point for evaluating all topics relevant to the purchase and restoration of some or all of the South Bay salt ponds. The sole risk of using this report is assumed by the user, and any warranty or merchantability, or any other warranty of fitness for any purpose, is expressly disclaimed.

Chapter 2.

Ecological Goals – a Regional Perspective

Chapter 2.

Ecological Goals – a Regional Perspective

The San Francisco Estuary and the Sacramento-San Joaquin Delta form the West Coast's largest estuary, draining approximately 40 percent of California's land. With its blend of fresh and ocean waters, thousands of miles of rivers and streams, and numerous microclimates and landscapes, the Estuary is an ecological treasure that supports an enormous diversity of fish, animals, and plants. This resource is surrounded by the nation's fourth largest metropolitan region, bustling with shipping, commerce, and an expanding population. The Bay Area provides a home to a population of six million people that is expected to soar in the next two decades.

There have been—and will continue to be—significant alterations to the San Francisco Estuary's watershed. Wetlands have been drained, filled, and converted to farmlands, salt ponds, highways, sewage lagoons, landfills, industrial complexes, shopping malls, parking lots, housing developments, and airports. These impacts have prompted broad community interest in protecting existing wetlands from destruction and in restoring degraded wetlands and diked, former wetlands (known as baylands) to productive ecosystems.

Several regional efforts have been initiated to address bayland restoration. The first such effort resulted in the Comprehensive Conservation and Management Plan (CCMP). The CCMP identifies 145 actions necessary to restore the San Francisco Estuary and specifies the design of an estuary-wide plan to protect, enhance, restore, and create wetlands. By 1994, several resource agencies discussed the development of a "shared vision" for Bay wildlife. These included the San Francisco Estuary Institute (SFEI), the California Department of Fish and Game (CDFG), National Marine Fisheries Service (NMFS), and the U.S. Fish and Wildlife Service (USFWS). This led to the Baylands Ecosystem Habitat Goals Project (Goals Project).

The Goals Project involved more than 100 participants from local, state and federal agencies, academia, and the private sector. It developed a collaborative blueprint for future estuary restoration based upon an ecological foundation. More recently, the USFWS has begun developing regional plans for the recovery of several threatened and endangered species dependent in part or in whole on the region's wetlands.

In this chapter we discuss the six major plans that establish goals for tidal salt marsh restoration in the San Francisco Estuary:

1. The Comprehensive Conservation Management Plan.
2. The Baylands Ecosystem Habitat Goals Report.
3. The USFWS Endangered Species Recovery Plans.
4. The San Francisco Bay Regional Water Quality Control Board Basin Plan.
5. The Bay Conservation and Development Commission Bay Plan.
6. The San Francisco Bay Joint Venture Implementation Strategy.

2.1 Comprehensive Conservation Management Plan

The Comprehensive Conservation and Management Plan (CCMP) resulted from a five-year cooperative effort called the San Francisco Estuary Project (USEPA 1993). The U.S. Environmental Protection Agency funded this effort, which involved local, state and federal government agencies; environmental, agricultural and recreational organizations; and private sector interests. The CCMP was developed under the National Estuary Projects as defined by the Clean Water Act. The Act states as one of its purposes the "develop(ment) of a comprehensive conservation and management plan that recommends priority corrective actions … to restore and maintain the chemical, physical, and biological integrity of the estuary."

The CCMP found that wetland loss had led to declines in San Francisco Estuary wildlife and reduced the Estuary's capacity to support sustainable fish and wildlife populations as well as provide other benefits associated with wetlands. These benefits included water purification and filtration, flood control, and scenic and recreational enjoyment.

The CCMP established several goals for wetland management in the San Francisco Estuary:

- Protect and manage existing wetlands,
- Restore and enhance the ecological productivity and habitat values of wetlands,
- Expedite a significant increase in the quantity and quality of wetlands, and
- Educate the public about the value of wetland resources.

Two actions were recommended to meet these goals:

1. The acquisition of South Bay salt ponds should salt production cease.
2. Large-scale restoration of these and other former wetlands in the South Bay.

The CCMP also made recommendations for Estuary management—e.g., pollution prevention and reduction, dredging and waterway modification, and land use:

- Protect against toxic effects such as bioaccumulation and toxic sediment accumulation;
- Eliminate unnecessary dredging activities;
- Maximize the use of dredged material as a resource; and
- Manage modification of waterways to avoid or offset the adverse impacts of dredging, flood control, channelization, and shoreline development and protection projects.

To maximize the benefit of South Bay salt pond and/or other bayland restoration, these recommendations must be integrated into the restoration strategy wherever possible.

2.2 Baylands Ecosystem Habitat Goals Report

The Baylands Ecosystem Habitat Goals Project was a four-year effort in the San Francisco Bay Area involving more than 100 participants from the public, nonprofit, academic, and private sectors. The Goals Project focused on ecological restoration of the San Francisco Estuary. The end result was the Baylands Ecosystem Habitat Goals Report (Goals Project 1999). The report identified key species and habitats, assembled and evaluated information, and developed recommendations to improve key bayland habitats and the plant and animal species dependent upon those habitats. The Goals Report did not specifically address other environmental and hydrologic services provided by wetlands such as nutrient cycling, flood control, or water quality improvements.

The Goals Report provided general ecological restoration goals for the South Bay salt ponds, identified the differing perspectives on such restoration goals, and considered connectivity to the surrounding habitats (e.g., intertidal mudflats, wetlands, streams, uplands). The following sections describe in more detail the recommendations presented in the Goals Report for the South Bay salt ponds.

It is important to recognize that dissenting opinions emerged during preparation of the Goals Report. On the one hand, the full restoration of salt ponds to tidal marsh is a fundamental goal that has been articulated in numerous contexts for several years. In contrast to full tidal marsh restoration, some Goals Project participants desired restoration of only a portion of the ponds. This would preserve the ecological functions currently provided by the salt ponds in their highly managed state, namely shorebird and waterfowl habitat (see Chapter 4 of this report). The significance of these differing perspectives is that restoring all South Bay salt ponds to tidal marsh would adversely affect at least some shorebird and waterfowl species. Consequently, the Goals Report identified a number of ecological restoration goals for the South Bay salt ponds as described below, and it presented geographic distributions of these multiple goals in a broad context. The Goals Report did not provide a specific pond-by-pond blueprint.

2.2.1 General Recommendations for the South Bay

The Goals Report's overall goal is to restore between 16,000 and 21,000 acres of the existing South Bay salt ponds to intertidal marsh and to manage between 10,000 and 15,000 acres for shorebird and waterfowl habitat. These areas should be connected by wide corridors of similar habitat, and both the restored tidal marsh and managed salt ponds should be interspersed throughout the South Bay. There should be natural transitions from mudflat through tidal marsh to adjacent uplands wherever possible. Adjacent moist grasslands, particularly those with vernal pools, should be protected and improved for wildlife. Riparian vegetation and willow groves should be protected and restored wherever possible.

The planning efforts also concluded that different ecosystems should be intermingled as much as possible and need not follow existing salt pond boundaries. Restored areas should be linked to each other and to existing or restored riparian corridors. Uplands, transitional habitats, and existing wildlife should be protected. In addition, the ecosystems must be buffered from urban development.

We opted not to include a map depicting this information because the Goals Project membership generated several alternative scenarios. Copies of this report can be obtained from the U.S. Environmental Protection Agency, Region IX, San Francisco, CA, and the San Francisco Regional Water Quality Control Board, Oakland, CA.

2.2.2 Specific Recommendations for the South Bay Shoreline

The Goals Report divided the South Bay into six subregions in San Mateo, Santa Clara, and Alameda counties. Recommendations for each segment follow and can be found on pages 126 to 137 of the Goals Report (Goals Project 1999).

- **Segment N:** Steinberger Slough to Dumbarton Bridge, San Mateo County
    - Manage crystallizer ponds on Redwood Creek for shorebirds and waterfowl.
    - Create tidal marsh along Westpoint Slough and Redwood Creek and in a wide band along the bayfront down to the Dumbarton Bridge.
    - Retain inland salt ponds for shorebird and waterfowl habitat.

- **Segment O:** Dumbarton Bridge to Alviso Slough, San Mateo and Santa Clara Counties
    - Restore large areas of tidal marsh with continuous bayfront corridor.
    - Create more and wider buffers from human activities because existing Palo Alto marshes contain the highest density of California clapper rails in the Bay Area.
    - Manage two or three salt pond complexes for shorebird and waterfowl habitat, including the pond located just south of the Dumbarton Bridge.
    - Enhance seasonal wetlands in Sunnyvale.
    - Connect wetlands to riparian corridors at San Francisquito Creek, Guadalupe Slough, and other streams where possible.

- **Segment P:** Alviso Slough to Albrae Slough, Santa Clara and Alameda Counties
    - Restore large areas of tidal marsh.
    - Link restored wetlands to the vernal pool complex in Warm Springs and the Coyote Creek riparian corridor.
    - Manage a large complex of salt ponds for shorebird and waterfowl habitat.
    - Mitigate the effects of the City of San Jose's freshwater effluent.

- **Segment Q:** Albrae Slough to Dumbarton Bridge, Alameda County
    - Create tidal marsh along the bayfront and transition to uplands at the upper end of slough channels.
    - Manage some salt ponds for shorebird and waterfowl habitat, including the crystallizer pond complex located between Mowry and Newark Sloughs.
    - Protect the harbor seal haul out in Mowry Slough.
    - Contend with Hetch Hetchy aqueduct.

Table 2-1. Ecological types identified in the USFWS Tidal Marsh Ecosystem Recovery Plan

Ecosystem Type	Description	Species Benefits
Tidal Marsh	Pickleweed- and cordgrass-dominated marsh with tidal action.	Habitat for California clapper rail, salt marsh harvest mouse, fisheries.
Tidal Marsh – Salt Panne Complex	Vegetated tidal marsh interspersed with unvegetated salt pannes.	Same as tidal marsh, plus snowy plover nesting. If panne is tidal, habitat for other shorebirds and waterfowl.
Salt Panne	Unvegetated flat substrate.	Nesting habitat for snowy plover, shorebird roosting, possible least tern foraging.
Microtidal Lagoon	Shallow open-water lagoon with dampened tidal action, seasonal variation in water level, variable salinities. Most reflects existing salt ponds.	Feeding and roosting habitat for waterfowl, shorebirds, and other birds. Habitat for invertebrates and fish.

Source: USFWS (in preparation)

- **Segment R:** Dumbarton Bridge to Alameda County Flood Control Channel, Alameda County
    - Retain salt ponds in southern section for shorebird and waterfowl habitat.
    - Restore tidal marsh in northern section.
    - Consider removing lower reaches of flood control levees along Alameda County Flood Control Channel.
    - Address the invasion of smooth cordgrass (*Spartina alterniflora*).

- **Segment S:** Alameda County Flood Control Channel to San Mateo Bridge, Alameda County
    - Manage salt ponds around Turk Island and parts of Baumberg Tract for shorebird and waterfowl habitat.
    - Restore remaining area to tidal marsh.

2.3 U.S. Fish and Wildlife Service Endangered Species Recovery Plans

The USFWS is mandated under the Endangered Species Act to address the recovery of species listed as endangered under the Act. In 1984, the Service developed a recovery plan to address two of the Estuary's tidal marsh-dependent endangered species, the California clapper rail and the salt marsh harvest mouse (USFWS 1984). That recovery plan focused on habitat requirements for the two endangered species and provided the basis for USFWS habitat enhancement and restoration approaches and recommendations.

The concept of recovery plans has evolved since that time from a species-specific approach to a broader approach that addresses the restoration of overall ecosystem functions. The objective is to conserve the ecosystems on which endangered or threatened species depend. This includes restoration of habitats that will reliably promote recovery of federally listed species and species of concern (federal, state, or regional). The USFWS is currently preparing two new recovery plans. These plans are the Tidal Marsh Ecosystem Recovery Plan and the Snowy Plover Recovery Plan.

The Tidal Marsh Ecosystem Recovery Plan will supersede previous recovery plans and will address a broader suite of species as well as tidal marsh ecosystems as a whole. Once completed, this plan will help define ecological goals for South Bay salt pond restoration and present guidelines for achieving those goals. The plan incorporates the recommendations developed in the Snowy Plover Recovery Plan and should reflect a synthesized perspective for all tidal wetland-dependent wildlife species (Baye, personal communication). The plan emphasizes re-establishment of diverse wetland habitats within the South Bay, including the range of habitats that would have persisted under natural conditions. In addition, the plan recommends restoration designs that minimize engineering or ongoing maintenance.

The new recovery plan is not yet available for public review. Recent drafts of the plan identified four ecosystem types applicable to the salt ponds considered in this Feasibility Analysis: tidal marsh, tidal marsh—salt pan complex, salt pans, and microtidal lagoons (i.e., managed salt ponds). The functions and species benefits of each are detailed in Table 2-1.

2.4 San Francisco Bay Regional Water Quality Control Board Basin Plan

The overall mission of the San Francisco Bay Regional Water Quality Control Board (RWQCB or Regional Board) is to protect the beneficial uses supported by the Bay Area's surface and ground waters. By law, the Regional Board is required to develop, adopt and implement a water quality control plan (known as the Basin Plan) for the San Francisco Bay. The Basin Plan is the master policy document that contains descriptions of the legal, technical and programmatic basis for water quality regulation in the region. The plan must include three items. First, a statement of beneficial water uses that the Regional Board will protect. Second, a list of water quality objectives necessary to protect the designated beneficial water uses. Third, a discussion of the strategies and time frame needed to achieve these water quality objectives.

The San Francisco Bay Basin Plan recognizes many beneficial uses of wetlands (RWQCB 1995). These uses include wildlife habitat, preservation of rare and endangered species, water-based recreation (both contact and non-contact), marine and estuarine habitat, fish migration and spawning, shellfish harvesting, and ocean, commercial and sport fishing (RWQCB 1995). In other words, the Regional Board recognizes that wetlands and related habitats comprise some of the most valuable natural resources in the San Francisco Estuary.

To protect the beneficial uses of wetlands and other aquatic systems, the Regional Board uses narrative and numerical water quality objectives. When factors degrade water quality beyond the designated levels or limits, the Regional Board conducts a case-by-case, cost-benefit analysis. When the analysis indicates that beneficial uses will be adversely impacted by further degradation, the Regional Board will not allow controllable factors to degrade water quality further.

The Estuary's beneficial uses are often affected by diking and draining wetlands, or by discharging fill material into them. The Regional Board regulates these activities. Discharge of fill material into waters of the United States must comply with a permit obtained from the U.S. Army Corp of Engineers (USACE). Under the Clean Water Act, Section 401, the State—through the Regional Board—must certify that any Section 404 permit issued by the Corps complies with water quality standards set by the State. However, the State can waive such certification. Generally, the Regional Board has independent authority to regulate waste discharges into wetlands that would adversely affect their beneficial uses.

2.5 San Francisco Bay Conservation and Development Commission Bay Plan

The overall mission of the San Francisco Bay Conservation and Development Commission (BCDC), a state regulatory agency, is to protect and enhance San Francisco Bay. To do this, the BCDC ensures that minimum bay fill occurs as part of any development project and promotes public access to the Bay shoreline. The regulatory activities of the BCDC are based on the McAteer-Petris Act and the San Francisco Bay Plan (BCDC 1998).

The Bay Plan contains several general findings and policies regarding the South Bay salt ponds, and it contains a number of site-specific planning recommendations. The Bay Plan findings recognize economic importance, climatic and air pollution benefits, and ecological functions of the salt ponds. The Bay Plan policies regarding the salt ponds are summarized below:

- If public funds are available, purchase and tidally restore salt ponds no longer needed for salt production.
- If public funds are not available, pursue other alternatives for protecting salt ponds:
    - If areas are proposed for development, obtain an open space dedication.
    - When development occurs, retain substantial amounts of open water, provide substantial public access, and develop the site in accordance with BCDC policies regarding non-priority shoreline uses.
    - Promote saltwater aquaculture activities to retain area as open water.
- Build recreational developments, such as marinas and parks, in appropriate areas outboard of salt ponds or in sloughs, so long as the ability to produce salt and restore tidal action to salt ponds is not compromised.
- Pursue purchase of development rights on salt ponds.

The specific geographic policies and suggestions for the South Bay salt ponds are contained in Plan Map 7 of the Bay Plan, reproduced here as Map 4. The policies and suggestions fall into five main categories:

- Acquisition for wildlife protection (many areas).
- Improvements for public access (interspersed).
- Reservation for possible future airport (ponds B1 and A2E immediately north of Moffett Field in Mountain View).
- Reservation for possible shallow-draft port (bayward edge of ponds B1, A2E, and B2 immediately north of Moffett Field). Note that this designation is proposed for deletion under Bay Plan Amendment 3-00.
- Flood flow storage (ponds near Ravenswood Slough in Menlo Park).

2.6 San Francisco Bay Joint Venture Implementation Strategy

The San Francisco Bay Joint Venture (SFBJV) is a partnership that brings together public and private agencies, conservation groups, development interests, and others to collaborate in restoring wetlands and wildlife habitat in the San Francisco Estuary. The SFBJV is one of 11 habitat joint ventures in the United States created to help implement the North American Waterfowl Management Plan, an international agreement among the United States, Canada, and Mexico. The goal of the SFBJV is "to protect, restore, increase, and enhance all types of wetlands, riparian habitat, and associated uplands throughout the San Francisco Bay region to benefit waterfowl and other fish and wildlife populations". To carry out its mission, the SFBJV recently prepared an Implementation Strategy (SFBJV 2001) that outlines specific measures to achieve its goals over a 20-year time frame.

The primary waterfowl goal of the SFBJV is to support diving ducks at recent peak population levels, and the secondary goal is to support dabbling ducks at recent peak population levels. The main impediments currently faced by these species are limitations in habitat quantity and quality, limited submerged aquatic vegetation as a food resource, and exotic aquatic species displacing native aquatic flora and fauna. The Implementation Strategy identifies a number of measures to achieve its goals and to overcome these impediments. These measures center largely on habitat protection, enhancement, and restoration, as well as improved management of existing habitats.

The Implementation Strategy identifies the South Bay salt ponds as important habitat for a variety of waterfowl species, with different ponds providing different levels of ecological support functions (see Chapter 4 of this report). To meet its goals, the SFBJV recommends several strategies for restoring the South Bay salt ponds:

- Where appropriate, restore higher salinity salt ponds (> 70 parts per thousand [ppt]) rather than low salinity ponds to tidal marsh or seasonal ponds because low salinity ponds have higher waterfowl habitat value.
- Where consistent with other goals, retain large (200 to 550 hectare) salt ponds of moderate salinity (20-30 ppt) for large diving ducks, and manage those ponds for production of widgeon grass (Ruppia maritima).
- Where consistent with other goals, retain medium (50 to 175 hectare) salt ponds of variable salinity (low to medium; <70 ppt) for small diving ducks and dabbling ducks (especially the northern shoveler).
- If salt production ceases in the South Bay, explore the possibility of maintaining several high salinity ponds (<140 ppt) for production of brine shrimp and brine flies, an important food source for some waterfowl species.
- Related points identified in the Implementation Strategy pertinent to the South Bay salt ponds include incorporating large ponds within tidal marsh restoration designs.
- For ponds slated for restoration, manage in their current condition during the interim period before restoration.
- For ponds slated for retention as salt ponds, manage over the long term.

Part II.

Existing Conditions Affecting Salt Pond Restoration

Chapter 3.

Salt Production and its South Bay History

Chapter 3.

Salt Production and its South Bay History

Understanding salt production operations in the South Bay and its history is fundamental to developing ecological restoration strategies. These factors both constrain future restoration efforts (see Chapters 4 through 10) and provide opportunities (see Chapter 11). This chapter provides an introduction to salt and solar salt production, describes current and historical salt production practices, outlines the State and federal regulatory authorizations under which Cargill currently operates, and explains Cargill's relationship with the Don Edwards National Wildlife Refuge.

To discuss salt or solar salt production requires the use of numerous chemical, engineering and operational terms describing water quality and the precipitation and formation of solids. These terms are defined at the beginning of this report following the table of contents. One such term is degrees Baume (°Be), a measure of salinity commonly used in the solar salt production industry but not in the environmental community. To bridge the two, we use both °Be and parts per thousand (ppt) throughout this report. Acronyms and abbreviations related to this discussion are defined at the beginning of this report for convenience.

3.1 An Introduction to Solar Salt Production

This section describes the general principles of solar salt production and the Ver Planck (1958) ten-pond model of salt production. Current Cargill South Bay operations reasonably reflect the Ver Planck (1958) model but with variations that are described in Section 3.2.

3.1.1 Salt Precipitation from Sea Water

Common salt (NaCl) is defined as the mineral halite, which occurs as crystals or granular masses. It is present in almost all natural waters and is very soluble. Halite is transparent, colorless, or white in its pure form, and gray or various shades of yellow, brown, or red in its impure form (Ver Planck 1958). The term "salt" is a broader term that includes many other minerals such as magnesium chloride, magnesium sulfate, calcium carbonate, and calcium sulfate. These minerals precipitate out of solution when saline waters (brines) evaporate and become concentrated. Solids then become saturated in solution and precipitate as various salts.

Seawater is essentially 3.5 percent salt (35 ppt) with nearly 77 percent as common salt or halite (Table 3.1; Clarke 1924). The remaining salts in seawater are very soluble salts: magnesium chloride ($MgCl_2$), magnesium sulfate ($MgSO_4$), calcium sulfate ($CaSO_4$), potassium sulfate (K_2SO_4), calcium carbonate ($CaCO_3$), and magnesium bromide ($MgBr_2$) (Ver Planck 1958).

Solar salt production is essentially fractional crystallization of seawater (Ver Planck 1958) in which the order of precipitation depends upon both the concentration of the various ions in solution and their solubility products (Table 3-2). If all ions were present at equal concentrations in seawater, then the relative solubility determines the order of precipitation. Salts with lower solubility precipitate first and salts with higher solubility precipitate later in the evaporation process. However, all ions are not present in equal concentrations in seawater. Sodium and chloride are the dominant ions in seawater and have concentrations an order of magnitude greater than most of the remaining ions. Thus, even though they are more soluble than some of the ions found in seawater, they precipitate before many but not all of the other salts (Table 3-2).

Table 3-1. The chemical composition of seawater

Ions[1]		Approximate Concentration (ppt)
Cl^-	Chloride	19.352
Br^-	Bromide	0.066
SO_4^{2-}	Sulfate	2.692
CO_3^{2-}	Carbonate	0.072
Na^+	Sodium	10.708
K^+	Potassium	0.387
Ca^{2+}	Calcium	0.419
Mg^{2+}	Magnesium	1.313
Fe^{2+}	Iron	<<0.001

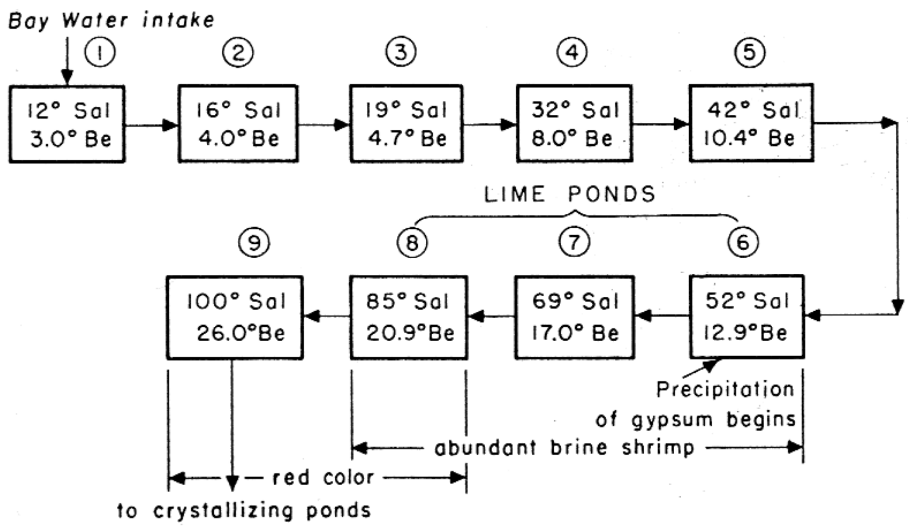
1 Common salt (NaCl) composes approximately 77% of the dissolved solids.

Source: Clarke (1924)

3.1.2 The Ver Planck Ten-Pond Solar Salt Production Model

To help characterize the process and define where through the system certain salts form, Ver Planck (1958) describes a system in which the solar salt production process is divided into a theoretical ten-pond system consisting of evaporator ponds, pickle ponds, and crystallizer ponds (Figure 3-1; Table 3-3). Evaporator (or concentrator) ponds are defined as Ponds 1 to 9, and they are divided into two stages. Ponds 1 to 6 are considered Stage 1, and Ponds 7 to 9 are considered Stage 2. The salinity at which gypsum begins to precipitate marks the transition from Stage 1 from Stage 2 ponds. This occurs at 147 ppt (12.9 °Be) when the brine is approximately 60 – 65% into the evaporative process, depending upon the inflow salinity levels (Ver Planck 1958; Appendix A). Net evaporation rates

Figure 3-1. Ver Planck ten–pond salt production model[1]



1 Salometer values are another measure of salinity. °Salometer = 4.065 x °Be (Ver Planck 1958).

Source: Ver Planck (1958)

decrease with increasing salinity so as the brine passes through the salt production process, increasingly more time is required to concentrate the brine (Appendix A). Typical Bay water at the inflow ranges from approximately 20 to 30 ppt, so this represents a volumetric reduction of the brine by 80 – 85% depending upon inflow salinity levels.

Table 3-2. Solubility of salts found in seawater

	Salt Solubility[1](g/L)	Temperature[1] (°C)	Order of Precipitation[2]
$CaCO_3$	0.014	25	1
$CaSO_4$	2.09	30	2
NaCl	357/397	0/100	3
$MgSO_4$	260/738	0/100	4
K_2SO_4	120	25	NA
$MgBr_2$	101.5	20	NA
KCl	238	2	5
MgCl	542.5	20	6

1 Solubility for given temperature CRC (1985).

2 Order of precipitation as presented by Ver Planck (1958). 'NA' means not available.

Source: Ver Planck (1958)

Evaporator ponds are characterized by shallow water, relatively large areas (200 to 800 acres), and impervious Bay muds (Ver Planck 1958). In these evaporator ponds, suspended solids, calcium carbonates, and gypsum are removed. Long residence times and generally quiescent waters promote the settling of solids. The brine solution remains in the evaporator ponds until it is saturated with sodium chloride and bittern salts. This occurs at a salinity of approximately 312 ppt (25.6 °Be). Pond 9 is the last of the Stage 2 ponds and is the pickle pond which acts as a "manifold" to distribute the highly concentrated brine into the numerous small crystallizer ponds where most halite precipitates from solution for harvest as salt.

Salt precipitation occurs predominantly in the crystallizer ponds. Sodium chloride (halite or common salt) is the primary salt precipitated from the brine. The precipitation of gypsum and bittern salts is unavoidable in the range in which halite forms. To avoid precipitation of either in the crystallizer ponds, a narrow salinity range of 356 to 369 ppt (29 to 30 °Be) is maintained by withdrawing bittern and adding fresh pickle. In the crystallizer ponds, most of the sodium chloride (common salt) precipitates from the brine.

The residual brine solution, defined as bittern, is the byproduct of solar salt production. The bittern is composed of chloride, bromide, sulfate, sodium, potassium, and magnesium ions—the same ions as those found in seawater (Ver Planck 1958; Table 3-4). However, precipitation of carbonates, calcium, sulfate, chloride, and sodium and the reduction of brine to less than 2 percent of the original water volume significantly changes the concentration and distribution of these ions from that found in seawater or Bay water (compare Table 3-1 to Table 3-4). In the bittern pond, additional halite precipitation occurs as the brine continues to evaporate.

3.2 Cargill South Bay Salt Production System

Salt production in the San Francisco Estuary has occurred for over a century. Salt production began in the 1860s, and the consolidation of many small plants occurred primarily from 1924 to 1941 (Ver Planck 1958). The Leslie Salt Company produced 300,000 to 325,000 tons of salt in 1936 on roughly 12,500 acres. By 1946, approximately 500,000 tons were harvested on a total of 25,000 acres, which increased to 750,000 tons four years later. By 1959, production was up to one million tons and included production in the North Bay. The current network of South Bay salt production ponds has operated for approximately fifty years. Cargill produces approximately one million tons of salt per year on 25,000 acres of South Bay salt production ponds (Cargill 2000a; Ransom, personal communication).

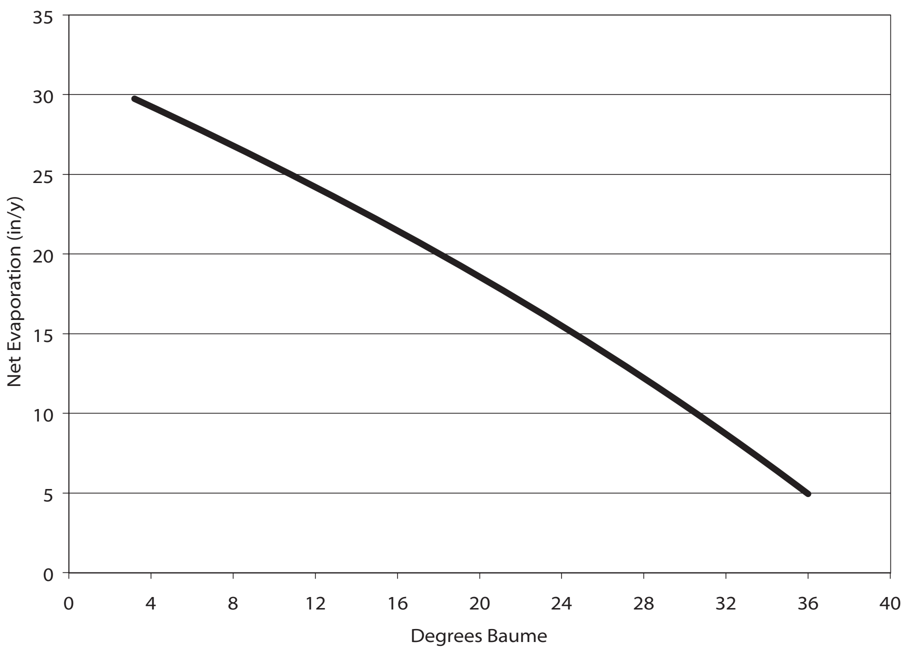
The following sections describe the general features of the South Bay salt production complex, the evaporator ponds, the crystallizer ponds, and bittern storage ponds. Chapter 10 presents a detailed analysis of bittern production, storage, possible approaches to desalinating bittern ponds in preparation for ecological restoration, and issues relevant to addressing the bittern problem within the context of the current sale negotiations.

Table 3-3. The Ver Planck ten-pond salt precipitation model

Process	Pond No.[1]	Pond Description	Approximate Salinity ° Be[2]	ppt[3]	SG[3,4]	Volume (% of intake)[5] Remaining	Decrease
STAGE 1: EVAPORATOR PONDS[6]							
Evaporation process begins			**6.6**	**65**	**1.048**		
	1	Inflow pond. Most suspended solids entering pond complex settle.[7]	3.2	21	1.023	87	13
	2		4.0	31	1.028	74	26
	3		4.7	40	1.033	61	39
Calcium carbonates precipitation begins[2]			**6.6**	**65**	**1.048**		
	4	First pond in which calcium carbonate precipitates.	8.0	83	1.058	50	50
	5		10.4	114	1.077	39	61
Gypsum precipitation begins[2]			**12.9**	**147**	**1.098**		
STAGE 2: LIME PONDS[6,8]							
	6	Pond in which gypsum reaches saturation in solution	12.9	147	1.098	28	72
Calcium carbonate precipitation complete[2]			**16.0**	**187**	**1.124**		
	7	All calcium carbonate precipitation completed in this pond. First pond with significant gypsum precipitation.	17.0	200	1.133	19	81
	8		20.9	251	1.168	11	89
90% gypsum precipitated from water column[2]			**25.0**	**304**	**1.208**		
Brine saturated with respect to NaCl. NaCl begins to precipitate[2]			**25.6**	**312**	**1.214**		
STAGE 2: PICKLE PONDS[6]							
	9	Saturated with respect to sodium chloride (halite). Distribution pond for crystallizers. Final pond with significant gypsum precipitation.	25.6	312	1.214	5	95
Bittern salts begin to precipitate[2,9]			**26.0**	**317**	**1.218**		
CRYSTALLIZER PONDS[6]							
	10	Lower salinity level for crystallizers.	29.0	356	1.250		
Most sodium chloride (halite) precipitated from solution; gypsum precipitation complete[2]			**30.0**	**369**	**1.261**		
		Upper salinity level for crystallizers	30.0	369	1.261	3	97
BITTERN DESALTING AND STORAGE PONDS[1]							
Bittern desalting process in bittern desalting ponds		Lower salinity level for bittern desalting ponds	32.0	395	1.283	1.6	98.4
		Upper salinity level for bittern desalting ponds and maximum salinity achievable under Bay Area climate	36.0	447	1.330	1.1	98.9
Bittern ready for stockpiling, processing, and marketing; stored in bittern storage ponds			**36.0**	**447**	**1.330**		

1 Pond numbering represent a theoretical area distribution.
2 From Ver Planck (1958). Actual values will vary with inflow salinity levels.
3 Conversions: TDS=(13 x °Be)-21; SG=145/(145-°Be)
4 The specific gravity of freshwater is 1.000. The specific gravity is the ratio of the mass of the liquid to that of water.
5 Volume change estimated from evaporation changes with salinity (Appendix D). Volumes shown are pond outflows.
6 Step in Ver Planck (1958) 10 pond model describing salt production.
7 Bay water is more dilute than seawater. Salinity represents typical inflow salinity to salt pond complex of 20 - 30 ppt.
8 Stage 2 Evaporator ponds are termed "Lime Ponds" because of gypsum precipitation.
9 Bittern salts precipitate over the same range as halite but do not precipitate until most of the halite has been removed.

Figure 3-2. Decreasing net evaporation rates with increasing salinity[1,2]



1 See Appendix B for all notes and assumptions

2 Net Evaporation rates are estimated for the Bay Area

3.2.1 General System Operation

In the South Bay, five discrete "plants" produce salt through solar salt production: Redwood City, Baumberg, Newark #1, Newark #2, and Alviso (see Map 1 for geographic distribution and Table 3-5 for acreage). Each plant consists of a series of salt ponds that concentrate and precipitate saline bay water through solar evaporation. The Leslie Salt Company, which was purchased by Cargill in the late 1980s, assigned sequential numbers to the ponds at each plant. In several areas, additional ponds were added through consolidating smaller operations. These ponds were distinguished by adding letters. Currently, the final processing plants are located in Newark and Redwood City. Salt harvested from all five plants is processed at these two sites. Table 3-6 provides a general description of salt production operations in the South Bay, and Map 5 shows the geographic distribution of these features.

In all, there are slightly over 26,000 acres of salt ponds and crystallizers operated by Cargill in their South Bay salt production facility. Cargill owns slightly more than half these lands (56 percent) and the Don Edwards San Francisco Bay National Wildlife Refuge owns the remainder, with Cargill retaining mineral rights for salt production on Refuge lands.

Cargill currently produces about one million tons of common salt annually. Approximately 700,000 tons are produced at the Newark #2 Plant and approximately 300,000 tons are produced at the Redwood City Plant (Cargill 2000a). Depending on intake salinity, this requires approximately 40 million tons of Bay water. Assuming that the crystallizer ponds are operated at a salinity of 30 °Be as defined by Ver Planck (1958) for optimum salt production, approximately one million tons of bittern liquid are pumped from the crystallizers annually, though the volume of bittern liquid will vary with salinity and decreases with higher salinity levels.

The salt production process begins with the intake of bay waters at eight intake ponds (Map 5). Bay water enters the ponds through pumps or automatic tide gates that open at high tide and close when the tide drops below pond water level. Water is generally taken into the system during the highest tides and in the dry months when salinity is highest (Ver Planck 1958). Salinity of the intake water is controlled largely by Delta outflow and water exchange with the ocean via the Golden Gate, with smaller contributions from local watersheds seasonally and from wastewater treatment plant discharges year round (Conomos *et al*. 1985; Peterson *et al*. 1996). Climatic conditions and Central Valley water management strongly influence Delta outflow and hence South Bay salinity. Dry season salinities have historically ranged from 20 – 35 ppt (Conomos *et al*. 1979) though more recent data gives mean values in the South Bay near 18 ppt and maximum values around 30 ppt (SFEI 2001).

Once in the system, the bay water becomes known as "brine" and it moves through the system with a combination of gravity feed and pumping (Ver Planck 1958). Water flows through siphons under sloughs, railroads, highways, and other infrastructure, and through gravity-flow gates and through pumps and pipelines between ponds (SFBBO 1998). There is some dependence upon prevailing summer winds to push water between ponds that have narrow gaps in the levees separating them (SFBBO 1998). Map 5 shows the general brine flow path through the system.

The salt production process takes several years and the time period is primarily controlled by net evaporation rates with some contribution of rainfall variability. Evaporation generally occurs from April or May through October or November, with the greatest rates

Table 3-4. Bittern ionic composition at 32 °Be (395 ppt)

Ion		Concentration[1] (%)
Cl^-	Chloride	19.52
Br^-	Bromide	1.20
SO_4^{2-}	Sulfate	6.93
Na^+	Sodium	5.12
K^+	Potassium	1.30
Mg^{2+}	Magnesium	5.55
	Total	**39.62**

1 Based on bittern from Mediterranean seawater.

Source: Ver Planck (1958)

Table 3-5. Summary of pond area by type, each production plant

Plant	Pond Area (acres) Evaporator Ponds	Crystallizers	Bittern Storage	Bittern Desalting	Total
Alviso	8,280				8,280
Baumberg	4,760				4,760
Newark #1	3,930				3,930
Newark #2	4,280	870	780	450	6,380
Redwood City	1,990	470	270	110	2,840
Total	**23,240**	**1,340**	**1,050**	**560**	**26,190**

occurring during the summer months. During the remaining portion of the year, no net evaporation occurs and some dilution is possible during periods of heavy rainfall during the winter (SFBBO 1998). Ver Planck (1958) estimated that net evaporation rates varied between 34 – 49 inches per year around the Bay Area. Our analyses show that net evaporation rates near Newark have a mean of approximately 32 inches per year and near Redwood City of approximately 27 inches per year. Ver Planck (1958) estimated that salt production required one year to pass through the concentrat-

Table 3-6. Summary of Cargill salt pond operations

LOCATION AND ACREAGE[1]			
Plant sites	Redwood City, Baumberg, Newark #1, Newark #2, Alviso		
Final processing plants	Newark #2 and Redwood City		
Total system acreage[2]	26,190 acres		
ESTIMATED POND AREAS[2]			
Pond	**Salinity (ppt)**	**Area (ac)**	**Percent Total Area**
Evaporator ponds[3]			
Stage 1	< 145	~15,000	60
Stage 2 including pickle ponds	145 –312	~8,000	30
Crystallizer ponds[4]	356 – 369	1,340	5
Bittern storage ponds[4]	generally > 369	1,050	4
Bittern desalting ponds[4]	generally > 369	450	2
PRODUCTION RATES			
Salt Production			
Newark		0.7 million tons per year	
Redwood City		0.3 million tons per year	
Total		1.0 million tons per year	
Maximum salt production rate		~40 tons per acre per year	
Total water used		40 – 45 million tons per year	
Bittern byproduct at 369 ppt (30 °Be)		1 million tons per year	
Net evaporation rate		34 – 49 inches per year (varies by location)	
PRODUCTION SCHEDULE			
Intake to first evaporator pond		At high tides during dry season (April or May – October or November)	
Filling pickle ponds		Early Fall	
Filling crystallizer ponds		Beginning of dry season (April or May)	
Harvesting		End of dry season (October – December)	
Total time of production		Estimated at 1 – 2 years	

1 General description is an approximation of the Cargill operating system based upon the best available information.

2 Pond designations based on a variety of sources; areas based on Bay Area EcoAtlas Geographical Information System (GIS) (SFEI 1998). See Map 5 for pond locations. All acreage totals rounded to nearest 10 acres.

3 Evaporator pond areas based on Ver Planck (1958) model. Actual areas probably vary.

4 Crystallizers and bittern and bittern desalting pond designations based on a variety of sources; areas based on Bay Area EcoAtlas GIS. See Map 5 for pond locations.

ing ponds to the pickle pond. Once there, the brine required another 5 to 6 months in the crystallizers. Thus, approximately 1.5 years was predicted for the entire process. Our calculations suggest that 1 to 2 years are required from the time brine enters the system until the salt is harvested. Because of variations in net evaporation around the South Bay with higher net evaporation rates along the eastern shore, the hydraulic retention time of the brine in the salt ponds will vary as well, with shorter times along the east shore.

3.2.2 Evaporator (Concentrating) Ponds

Bay water is drawn into the system through intake ponds where it begins its path through the Stage 1 and 2 evaporator ponds. In Stage 1 ponds, the volume is reduced by about 70% with salinity increasing to approximately 145 ppt (12.9 °Be; Ver Planck 1958). Stage 1 ponds cover approximately 60% of the salt production area (approximately 15,700 acres; Table 3-5). In Stage 2, salinity further increases to about 312 ppt (25.6 °Be; Ver Planck 1958). Stage 2 is defined by the precipitation of gypsum and in these ponds most of the calcium in solution is removed as gypsum. These ponds cover approximately 30% of the pond area or 8,000 acres (see Chapter 5). Gypsum precipitation occurs through crystalline growth, is often patchy, and typically occurs around fibrous vegetation (Ransom, personal communication). The final Stage 2 pond is termed the "pickle pond". The pickle pond distributes brine to the crystallizer ponds and its salinity is maintained such that the brine is saturated with sodium chloride and approximately 90% of the gypsum has precipitated from solution (Table 3-3). The pickle pond is normally filled in the early fall. Little evaporation occurs during the rainy winter season. By the time brine leaves the pickle pond the following spring, its volume is estimated at 5 percent of the original surface water intake.

3.2.3 Crystallizer Ponds

In the crystallizer ponds, sodium chloride (common salt) precipitates for harvest at an optimum rate of approximately 40 tons per evaporator pond acre annually (Ver Planck 1958). In the South Bay, the crystallizer ponds were constructed by filling slough channels and raising bed elevations with pumped Bay mud (Ver Planck 1958). The ponds are rectangular with specially smoothed, flat bottoms to facilitate mechanical harvesting of the salt (Cargill 2000a, SFBBO 1998). The area ratio of evaporator ponds to crystallizer ponds in the South Bay system is 18:1, which differs from the 10:1 ratio predicted by the Ver Planck (1958) model. Crystallizer pond locations are shown in Map 5.

Cargill uses an elaborate system of ditches and pumps to fill and empty the crystallizer ponds rapidly in order to control salinity and optimize salt production. Brine pumping from the pickle ponds begins as soon as the winter rains end. The brine's salinity is 312 ppt (25.6 °Be; Ver Planck 1958). Bittern is removed from the crystallizer ponds at a salinity of 356 to 369 ppt (29 to 30 °Be) and transported to the bittern desalting and bittern ponds in bittern ditches. The crystallizer ponds are freshened with new pickle to prevent the precipitation of bittern salts. Process optimization requires that they be emptied and refilled with fresh pickle two to five times during the season (Ver Planck 1958). By September, the salt bed is five to eight inches deep and ready for harvest before the winter rains (Cargill 2000a).

During harvest, ponds are drained and harvested one at a time to minimize the time salt is left uncovered in the ponds. Mechanical harvesters break up the salt bed with a rotating "pickroll," scrape the pieces up with a blade, and lift the salt into hopper cars. A residual layer of halite is allowed to remain as to form a "pavement" on the bed to support equipment and machinery. Harvesting begins in October and continues 24 hours per day until the end of December. Diesel locomotives pull the hopper cars along temporary track laid on the crystallizer floor. Each hopper car holds approximately two tons of salt. The harvesting machine cuts a swath over thirteen feet wide and four to six inches deep. After harvesting, the crystallizer ponds are flooded with weak brine solution to dissolve any remaining salt, particularly fine salt that accumulates on the windward side. The brine is then returned to intermediate concentrating ponds (Ver Planck 1958).

After the winter rains, typically around April, the crystallizer ponds are dried in preparation for next season (Ver Planck 1958). Ponds are dried almost to the point where the dust blows from them. The dried ponds are then leveled with scrapers and rolled.

Once harvested, the salt is washed and processed for a variety of industrial and commercial processes. In all, approximately 250 different salt products leave the Cargill refinery for over 14,000 uses in the food, agriculture, health care, and industrial arenas.

3.2.4 Current and Historical Bittern Storage and Handling

This section discusses the current and historical bittern storage and handling practices in the South Bay salt pond complex. Chapter 10 contains a technical analysis of the environmental significance of bittern as a salt production by-product. Locations of bittern storage and desalting ponds are shown in Map 5. Bittern storage ponds include 270 acres in Redwood City and 780 acres in Newark (Table 3-5). Bittern desalting ponds apparently include 110 acres in Redwood City and another 450 acres in Newark (Table 3-5). Cargill (2001a) recently began identifying these pond locations. Salinity in the bittern ponds can become as high as 447 ppt (36 °Be) and is limited by evaporation rates in the San Francisco Bay Area (Ransom, personal communication).

Historical Practices

Over the last century bittern has been marketed for a variety of purposes. Bittern is primarily composed of chloride, magnesium, sodium, sulfate, potassium and bromide ions (Ver Planck 1958) and there have been markets from time to time for some of the salts that precipitate from bittern. Until the 1930s, magnesium chloride was an important byproduct from bittern. By the late 1950s, bromine, magnesia, gypsum and magnesium chloride were commercial products produced in the Bay Area (Ver Planck 1958). Until about 1968, bittern was used by FMC in Newark for a variety of commercial products (Moore, personal communication; Refuge records).

In addition to being marketed as a commercial product, prior to 1969 bittern was also removed off-site by its discharge to the Bay when there was no viable commercial market (Delfino, personal communications; Refuge records). Between 1967 to 1972, the federal government passed the Clean Water Act and State of California passed the Porter-Cologne Water Quality Control Act. These two laws ended unregulated bittern discharge to the Bay. The San Francisco Bay Regional Water Quality Control Board (RWQCB) regulates disposal of bittern and brines into bay waters pursuant to these two laws.

These two laws and the cessation of bittern sales to FMC in 1968 marked the beginning of long-term on-site bittern storage in bittern ponds. Leslie Salt Company did sell 55,000 tons of bittern over two consecutive years in the mid 1980s (Refuge records). This amount, however, was only approximately 5% of annual bittern generated. Cargill currently markets some bittern for dust suppressants and de-icers. How much they market for these purposes and for how long these markets have been open to Cargill is not clear. Estimates of the bittern market range from a small amount (Ransom, personal communication) to the volume of liquid bittern produced annually (Cargill 2001a). Thus, much if not most of the bittern produced since 1972 has been stored within the South Bay salt pond complex.

Current Practices

Two changes in bittern handling and storage have occurred over the last 30 years (Ransom, personal communication). Cargill has been investigating markets for bittern since at least the mid-1980s (Jean Takekawa, personal communication). Current bittern commercial applications include de-icer (Hydro Melt™), a de-icer amendment that improves the flowability and performance of salt in de-icing roads (ClearLane™) and a dust suppressant for unpaved roads (Dust-Off®) (Cargill 2001a). Cargill de-icer and dust suppressant products have been historically geographically limited to California and nearby states (e.g., Arizona, Nevada) because magnesium sulfate precipitated from solution at cold temperatures. Thus, marketing to geographic areas where this could occur during transport was not feasible.

Cargill has reported that more recently, a proprietary process to de-sulfate the bittern has been developed such that no magnesium sulfate remains in the bittern. This desulfating process prevents precipitation of salts at lower temperatures and thus has expanded the market geographically for bittern (Cargill 2001a). One such method would be by the addition of calcium chloride in which sulfate precipitates as gypsum (calcium sulfate) and magnesium stays in solution as magnesium chloride (Delfino, personal communication). Until February 2001, Cargill had not provided information on the extent of the market, the exact time this process began nor the amount of bittern sold in recent years (Ransom, personal communications). Cargill has not provided this information since the mid-1980s (Jean Takekawa, personal communications).

The April 2001 "Bay's Edge" newsletter produced by Cargill (2001a) states that the volume of the bittern market equals the amount of liquid bittern it produces each year though no specific timetable on when this market was fully developed is provided. However, the desulfating process used to broaden the geographic markets is new with the bittern recovery process coming on line in October 2000 (Cargill, 2001a). Thus, the improved bittern market is presumed to coincide with the desulfating process coming on line in late 2000. These products recover at least a portion of the magnesium ions and associated anions from solution. However, it does not appear to recover the other remaining ions in solution and does not address the precipitated bittern salts that result from the salt production process. These issues are discussed in more detail in Chapter 10.

The second change in bittern handling has been to improve the efficiency of the salt production process. Cargill now operates desalting ponds, which are defined as interim ponds used to process bittern before it is stored on-site (Ransom, personal communication). Maps from the 1970s also show "bittern desalting ponds" but those ponds are currently used for brine evaporation. These desalting ponds are essentially temporary bittern storage ponds used to "strengthen" or make the bittern more concentrated. Sodium chloride and magnesium sulfate both precipitate from solution between 395 and 447 ppt (32 – 36 °Be). Cargill stores bittern in the desalting ponds from the time it is discharged from the crystallizers until it reaches a salinity around 36 °Be, at which time it is pumped to the bittern ponds for on-site storage. An impure salt composed of magnesium sulfate and sodium chloride precipitates on the beds of the desalting ponds. Occasionally (e.g., approximately one to two year intervals [Ransom, personal communication]), these ponds are flooded with Bay water to dissolve those salts and that water is then sent back to the pickle ponds. Thus, the sodium chloride precipitated in the desalting ponds is recovered back to the brine for removal in the crystallizers. This operational change is relatively recent and has led to a reduction in bittern production and on-site storage (Ransom, personal communications). Cargill has not provided information on when this practice began.

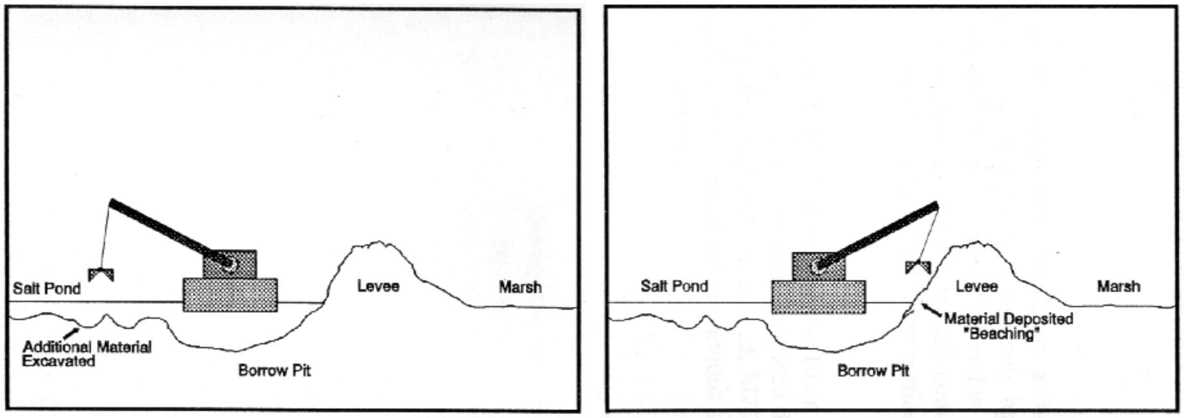
3.3 System Maintenance

Maintenance of the Cargill South Bay salt pond complex consists of a variety of activities. The most common activity is levee maintenance. Salt ponds are accessed from the bay via dredge locks, and the access channels and locks themselves require maintenance. A variety of operational equipment also requires maintenance, such as pumps, pipes, siphons, gates, and so forth.

Extensive levee maintenance is required throughout the South Bay salt pond system due to erosion, subsidence and consolidation (WRA 1992, WRA 1994). Muds excavated from within the salt ponds are placed on top of the levees using a floating dredge operated from within the ponds. The dredge enters and exits the ponds through dredge locks that consist of small open water ponds surrounded by a levee. Dredge locks require maintenance themselves to remain accessible and usable. This includes removal of accumulated sediments and maintenance of the dredge lock levees. Much of Cargill's regulatory requirements stem from dredge lock use and maintenance. Levee maintenance also includes placing concrete rubble rip-rap as shoreline protection on the bayward side of bayfront levees.

Levee maintenance costs are driven largely by the cost of obtaining materials to place onto the levees. Currently Cargill uses the least expensive technique available. They float the dredge Mallard II into a salt pond via a dredge lock, excavate sediments from the borrow ditches (also called borrow pits) and the adjacent salt pond bottom, and place the sediment directly onto the levees (see Figure 3-3). When borrow ditches are used, a beach approximately 12 – 20 ft wide and at least as wide as the levee crest separates the borrow ditch from the levee so that the levee will not collapse into the ditch (Baye, personal communications). (This construction detail is not reflected in Figure 3-3; that figure came from the 1994 Environmental Assessment prepared as part of the Corps and BCDC permits; see Section 3.4.) The borrow ditch can be up to 200 feet wide. As long as the area from which the dredge can excavate sediment is within the reach of the dredge arm, the material is handled once. This scenario describes the most cost-effective maintenance approach.

Figure 3-3. Typical salt pond levee maintenance technique



Step 1: Dredge excavates additional material from borrow pit or salt pond bottom adjacent to borrow pit.

Step 2: Dredge deposits excavated material on levee at water line (referred to as "beaching").

Source: WRA 1994 Draft EA

When decades of levee maintenance deplete sediments within the dredge arm's reach, however, then another maintenance approach is used. The dredge must "double-handle" sediment by moving farther into the salt pond to extend its reach, temporarily stockpiling these sediments in the borrow ditch, and returning near the levee to re-excavate the stockpile and place it on the levee. This method requires considerable additional time to handle the material, thereby increasing costs. An alternative method involves using an external source of material for the levees, imported either via the water (i.e., on a barge) or via the land (i.e., trucked in on the levees). This method can be very expensive.

Excavation and use of salt pond bottom sediments for levee maintenance can pose adverse environmental impacts to species that utilize the salt ponds, levees, and outboard tidal marsh. Short-term impacts include increased turbidity (reducing bird foraging) and decreased dissolved oxygen (resulting in fish kills). These effects are typically isolated to the construction area (WRA 1994). Double-handling and stockpiling sediments within the salt pond borrow ditches could increase this effect. Additional impacts not considered in the 1994 Draft Environmental Assessment for Cargill maintenance activities (WRA 1994) were impacts to important benthic organisms (those living on the bottom of a body of water) that provide food for birds (see Chapter 4 for more details).

Additional system maintenance is also needed. Approximately every 15 years, the loading dock at Redwood City is dredged. The Corps dredges the channel to the Redwood City loading dock and Cargill dredges the area directly in front of the off-loading dock. Dock repair is occasionally required at the Redwood City off-loading dock and at smaller docks throughout the system. Small marine crossings and siphons throughout the system are inspected and repaired as needed (WRA 1994). Intake channels require cleaning and maintenance because they eventually fill with sediment. Dredged material from this type of channel maintenance is placed in the salt pond borrow ditches. Maintenance or in-kind replacement of infrastructure such as pumps, pumping facilities, culverts, pipes, siphons, tide gate structures, fences, bridges, roads, walkways, bulkheads, and other infrastructure is performed throughout the year to keep the system operating. New pipes, culverts, intake structures, electrical distribution lines, and pumping facilities are installed as needed. Tide gates, brine ditches, and pumps are cleaned out and maintained throughout the year.

3.4 Regulatory Authorizations for Salt Pond Operations

Cargill currently operates under permits from the Corps (Permit No. 19009S98, issued July 10, 1995) and BCDC (Permit No. 4-93, issued March 14, 1995, amended June 15, 1995 and August 31, 2001). These permits were issued following preparation of an Environmental Assessment of salt production maintenance activities (WRA 1994). These permits specified development and implementation of best management practices as well as annual reports for advance notification of work to be completed and to summarize work already completed (e.g., Cargill 2000b). These annual reports—in combination with the five-year review of best management practices (Cargill 2000d), the Environmental Assessment (WRA 1994), and the two permits (see above)—provide considerable information on operational issues, including recent system modifications in anticipation of the proposed salt pond sale (see Chapter 12 for more details).

The BCDC permit findings (permit Section III.B) explicitly state the agency's intent to authorize *maintenance of the existing salt pond system only* (BCDC 1995). To this end, the permit authorizes both a wide variety of maintenance activities and installation and use of new pipes, culverts, siphons, intake structures, electrical distribution lines, and pumping facilities for Cargill operations. The BCDC permit does not authorize any activities intended to modify *how the system operates.* Activities that fall into this latter category require new or amended BCDC permits. Such activities include a number of modifications recently constructed or proposed by Cargill to modify the system to produce salt on a smaller, reconfigured system and to shut down the Redwood City plant (Cargill 2000b, 2000c, 2001b).

The Corps permit is less specific in segregating activities associated with maintaining the existing system from new modifications to that system. The stated project purpose in the Corps permit is "[t]o sustain operation and production of the solar salt facilities in the south San Francisco Bay" (USACE 1995). The permit authorizes maintenance of existing facilities and new work, but never defines the purpose of any new work beyond the project purpose just cited. The permit requires that all new work activities receive site specific review and approval by the Corps in consultation with several regulatory and resource agencies and with public input. Consequently, the wide variety of modifications recently constructed or proposed by Cargill to modify the system to produce salt on a smaller, reconfigured system and to shut down the Redwood City plant (Cargill 2000b, 2000c, 2001b) *may* be authorized under the Corps permit *so long as they receive individual review and approval*.

The Corps permit issued to Cargill in 1995 applies to the entire South Bay salt pond complex, including evaporator ponds, pickle ponds, crystallizer ponds, bittern ponds, and the sloughs, creeks and marshes surrounding the complex (USACE 1995). Inherent in this permit is the federal assertion that the Corps has jurisdiction over these areas under Section 404 of the Clean Water Act and thus the responsibility to regulate these activities. Cargill has repeatedly challenged Corps jurisdiction over the crystallizers; the Corps and U.S. EPA have never issued final rulings on this jurisdictional question. Nonetheless, Cargill has signed a Corps permit applicable to the areas about which they challenge jurisdiction (Baye, personal communication).

Cargill has proposed or already constructed a number of changes both on Cargill property and on Refuge-owned salt ponds (see Chapter 12). These changes are likely to have significant adverse ecological consequences and decrease the feasibility of tidal marsh restoration on at least some of those salt ponds being affected by the changes. Adequate agency and public review of these changes, as provided for by the BCDC and Corps permits, should be carried out expeditiously.

3.5 Salt Production Operations within the Don Edwards National Wildlife Refuge

The Don Edwards National Wildlife Refuge owns 11,430 acres of the salt ponds still in active production by Cargill (Map 2) pursuant to a 1979 operating agreement reached between Leslie Salt and the U.S. Fish and Wildlife Service when the Refuge was originally established (USFWS and Leslie Salt 1979). Within the Refuge-owned ponds, Cargill currently uses two ponds totaling 670 acres (Newark #2 Plant Ponds 12 and 13) for long-term bittern storage.

The 1979 operating agreement laid out each party's responsibility for infrastructure maintenance. It also allowed modifications necessary for salt production and identified salt production as the dominant activity for pond operational decisions. This agreement has not provided the level of biological resource protection desired by the Refuge, and over the past 21 years differences have arisen regarding salt production operations (Refuge records).

Cargill has stated that they plan to create more efficient salt production facilities when they downsize their production facilities (Cargill 2000c), with an increase in production from the optimum of 40 tons of salt annually per acre as stated by Ver Planck (1958) to a level of 50 tons annually per acre (Cargill 2000c). This expected 25% increase in production may be achieved in several ways which include several that we discuss in Chapters 9 and 10:

- Improved recovery of sodium chloride from new and stock piled bittern
- Better control of brine flows to increase inflow salinity level
- Decommissioning ponds in areas with lower evaporation rates.

Chapter 12 contains a detailed analysis of the recent system changes Cargill has proposed. Those discussions include an analysis of the anticipated adverse environmental impacts the changes could bring about if implemented. It is important to note that in 2001 Cargill had to receive an amended permit from BCDC to implement some of these changes and action-specific approvals from the Corps following consultation with State and federal regulatory and resource agencies and public input.

The 1979 operating agreement is included here as Appendix B.

Chapter 4.

Biological Conditions Affecting Salt Pond Restoration

Chapter 4.

Biological Conditions Affecting Salt Pond Restoration

A primary goal of salt pond restoration is to enhance ecological function by increasing ecosystem complexity and species richness and diversity. However, just as restoration may benefit many species, it may also negatively affect others that have come to depend on the salt ponds in their managed state. Restoration strategies should attempt to minimize adverse affects on species that currently benefit from the salt ponds, with particular attention paid to special status species, and those species of shorebirds and waterfowl that have become dependent on the salt ponds. This section will describe existing ecological functions of the salt ponds and considerations for protecting these critical resources during the restoration process.

4.1 Salt Pond Ecology and Wildlife Values

The South Bay ecosystem has been dramatically altered as a result of the development and continued operation of the salt ponds in the region. The establishment of a broad expanse of open water in a region formerly characterized by tidal marsh, coupled with an abundant prey base of fish and invertebrates, has contributed to the development of important habitats for avian species. Most bird species found on the adjacent Bay waters, mudflats, and salt marshes also use the salt ponds for foraging or roosting. However, some species occur in much higher densities in the salt ponds than in the adjacent Bay environment, and several use the salt ponds almost exclusively. Currently, salt ponds in the South Bay provide valuable habitat for many bird species, as well as for other fauna and flora.

The dependence of many species on these ecosystems combined with the historic loss of tidal marsh necessitates that the discussion of salt pond ecology and tidal marsh restoration focus on special status species. Table 4-1 lists the two plant, one invertebrate, 25 bird, three mammal, and two fish special status species that occur in the vicinity of the salt ponds. Although salt pond restoration will be beneficial to some of these species, such as the salt marsh harvest mouse and the California clapper rail, other species, such as the Western snowy plover, may be negatively impacted by a net loss of salt pond habitat. This Section discusses the ecology of some of these species. Section 4.2 addresses the constraints of managing for special status species.

4.1.1 Plants

South Bay salt ponds themselves provide little habitat for vegetation. The primary plants occurring within salt ponds are wigeon grass (*Ruppia maritima*) and green algae (*Enteromorpha* spp.). *Enteromorpha*, an important part of salt pond food webs, can be found in salt water but cannot live in salinities greater than 35 ppt (Lonzarich 1989). Both green algae and wigeon grass are important food items for waterfowl (Harvey *et al*. 1992). Smaller phytoplankton also contribute to the salt pond food web.

Salt pond levees and dredge locks support a variety of native and ruderal (weedy) vegetation. Adjacent habitat may include small pockets of native salt marsh, dominated by pickleweed (*Salicornia virginica*), Pacific cordgrass (*Spartina foliosa*), and saltgrass (*Distichlis spicata*). Areas with more fresh water input may be dominated by bulrush (*Scirpus californicus* and *S. maritimus*). Invasive non-native species that occur in the vicinity of South Bay salt ponds include perennial pepperweed (*Lepidium latifolium*) and smooth cordgrass (*Spartina alterniflora*). See Section 4.2.4 for more information on smooth cordgrass.

Two special status species occurred historically in the South Bay: Point Reyes bird's-beak (*Cordylanthus maritimus palustris*) and California sea blite (*Suaeda californica*). These species are extirpated locally (Baye *et al*. 2000).

4.1.2 Invertebrates

The composition of invertebrate communities in the South Bay salt ponds is determined, to a large extent, by salinity. Major invertebrates in mid- to high-salinity salt ponds include brine shrimp (*Artemia franciscana*), brine flies (*Ephydra cinera, E. millbrae*, and *Lipochaeta slossonae*), and water boatmen (*Trichocorixa reticulata*). These species are important food items for many bird species. More common in lower salinity ponds are benthic organisms (those living on the bottom of a body of water) and epibenthic organisms (those living between the low tide level and a depth of 100 fathoms, such as polychaete worms) (Lonzarich 1989). Changes in salinity of as little as 30 to 40ppt can have dramatic effects on invertebrate communities (Lonzarich 1989).

Invertebrates tolerant of higher salinities are important prey for several species of salt pond specialist birds. Brine shrimp can be found in ponds ranging in salinity from 70 to 200 ppt, but have an optimum range of 90 to 150 ppt (Larsson 2000). Abundance of brine shrimp peaks in summer, when ponds are warmest. Optimum conditions for reproduction in brine shrimp are 120 ppt at 24°C (Browne and Wanigasekera 2000). Water boatmen have a slightly lower salinity range, with a tolerance of about 20 to 170 ppt, but a peak reproductive range of 35 to 80 ppt (Maffei 2000).

One special status invertebrate has been documented in the vicinity of the South Bay salt ponds. The California brackishwater snail (*Tryona imitator*), a federal candidate species, has been found in Alviso Pond A9 (WRA 1994). In addition, two insects—the Western tanarthrus beetle (*Tanarthrus occidentalis*) and Jamieson's compsocryptus wasp (*Compsocryptus jamiesoni*)—will be discussed in the Tidal Marsh Ecosystem Recovery Plan as species of special conservation status. These species are both found in the vicinity of South Bay salt ponds.

Table 4-1. Special status species occurring in the vicinity of South Bay salt ponds

Common Name	Scientific Name	Conservation Status[1]	Breeding Status[2]	Probable Tidal Marsh Restoration Impact[3]
PLANTS (2)				
Pt. Reyes bird's beak	*Cordylanthus maritimus palustris*	FSC, EX	X	+
California sea blite	*Suaeda californica*	FE, EX	X	+
INVERTEBRATES (1)				
California brackish water snail	*Tryonia imitator*	FSC	X	-
BIRDS (25)				
American white pelican	*Pelecanus erythrorhynchos*	SSC		-
California brown pelican	*Pelecanus occidentalis californicus*	FE, SE		-
Double-crested cormorant	*Phalacrocorax auritus*	SSC	X	0
White-faced ibis	*Plegadis chihi*	FSC, SSC		0
Aleutian Canada goose	*Branta canadensis leucopareia*	FT		0
Barrow's goldeneye	*Bucephala islandica*	SSC		0
White-tailed kite	*Elanus leucurus*	SSC	X	0
Northern harrier	*Circus cyaneus*	SSC	X	0
American peregrine falcon	*Falco peregrinus anatum*	FD, SE		0
Western least bittern	*Ixobrychus exilis hesperis*	FSC, SSC	X	+
California clapper rail	*Rallus longirostris obsoletus*	FE, SE	X	+
Western snowy plover	*Charadrius alexandrinus nivosus*	FT, SSC	X	-
Long-billed curlew	*Numenius americanus*	SSC		+
California gull	*Larus californicus*	SSC	X	-
Black skimmer	*Rynchops niger*	SSC	X	-
California least tern	*Sterna antillarum browni*	FE, SE	X	-
Elegant tern	*Sterna elegans*	FSC, SSC		-
Black tern	*Chlidonias niger*	FSC, SSC		-
Burrowing owl	*Athene cunicularia hypugea*	FSC, SSC	X	0
Short-eared owl	*Asio flammeus*	SSC	X	+
California horned lark	*Eremophila alpestris actia*	SSC	X	0
Tricolored blackbird	*Aegelaius tricolor*	FSC, SSC	X	0
Yellow warbler	*Dendroica petechia brewsteri*	SSC	X	0
Saltmarsh common yellowthroat	*Geothlypis trichas sinuosa*	FSC, SSC	X	+
Alameda song sparrow	*Melospiza melodia pusillula*	FSC, SSC	X	+
FISH (2)				
Coho Salmon	*Oncorhynchus tshawytscha*	FT		+
Steelhead	*Oncorhynchus mykiss irideus*	FT		+
MAMMALS (3)				
Saltmarsh wandering shrew	*Sorex vagrans halicoetes*	FSC, SSC	X	+
Salt marsh harvest mouse	*Reithrodontomys raviventris halicoetes*	FE, SE	X	+
Pacific harbor seal	*Phoca vitulina richardsi*	MMPA	X	0

1 *Conservation Status: FE = Federally Endangered; FT = Federally Threatened; FD = Federally Delisted; FSC = Federal Species of Concern (candidate species); SE = State Endangered; ST = State Threatened; SSC = California Species of Special Concern; MMPA = protected under Marine Mammal Protection Act; EX = locally extinct*

2 *Breeding Status: Past, current or potential reproduction within or in the vicinity of the South Bay salt ponds*

3 *Probable Tidal Marsh Restoration Impact: Positive impact (+), negative impact (-), unknown or negligible impact (0); actual impacts depend on restoration details*

4.1.3 Fish

Lonzarich found 15 species of fish in South Bay salt ponds, six of which reproduced in the ponds. Fish initially enter the salt pond system through intake structures supplying Bay water to the ponds. Primary species in the salt ponds are salt-tolerant estuarine fish, including topsmelt (*Atherinops affinis*), longjaw mudsucker (*Gillichthys mirabilis*), and staghorn sculpin (*Leptocottus armatus*) (Carpelan 1957). Although these three species can all tolerate salinities over 60 ppt, larvae do better at lower salinities (10 to 30 ppt).

Fish species diversity decreases with salinity, but overall abundance does not always decrease with salinity (Lonzarich 1989, WRA 1994). Macroalgae is a critical resource for fish and invertebrates in low salinity ponds, which suggests that the salinity tolerance of Entermorpha may play an important role in fish community structure in the salt ponds. In general, fish are most abundant in low salinity ponds.

Although none of the fish species known to occur in the South Bay have special conservation status, they may be key elements for supporting populations of many bird species, including several special status bird species. American white pelicans, California brown pelicans, California gulls, elegant terns, and California least terns all utilize small prey fish of the salt ponds.

Steelhead (*Oncorhynchus mykiss irideus*) spawn in tributary streams entering the South Bay. This federally threatened species does not utilize salt pond habitat, and would likely benefit from salt marsh restoration. Coho salmon (*Oncorhynchus tshawytscha*) do not spawn locally, but young fish exiting the Sacramento River Delta have been found in the South Bay. This federally threatened species may also benefit from salt marsh restoration.

4.1.4 Birds

The San Francisco Estuary is of great importance to migratory shorebirds and waterfowl. More than one million shorebirds use Bay wetlands each winter, leading to the designation of the Bay as a Western Hemisphere Shorebird Reserve Network site of international importance. San Francisco Bay is also an important wintering area for waterfowl, with more than 50 percent of the diving ducks in the Pacific Flyway wintering here.

Due to the loss or alteration of more than 90 percent of wetlands in the San Francisco Estuary, there is a need for restoration of tidal salt marsh and other historic ecosystems. However, the South Bay salt ponds have become important habitats for many shorebirds and waterfowl. Restoration of South Bay salt ponds could negatively affect several species that now depend heavily on the salt ponds as habitat for breeding, migration stopover, or wintering. For this reason, the Goals Project (1999) recommended maintaining between 10,000 and 15,000 acres of managed salt pond in the South Bay, and managing for no net loss of shorebirds and waterfowl using the South Bay.

The South Bay salt ponds also provide important habitat for other birds, including raptors, owls, and passerines (songbirds). Several species of birds using the salt ponds are protected under federal and state Endangered Species Acts, and all native non-game species are protected under the Migratory Bird Treaty Act. The following sections discuss South Bay salt pond use by bird type, highlighting certain key bird species. Table 4-2 lists the common and special status bird species found in the vicinity of South Bay salt ponds and presents the anticipated impact of restoration on each species.

Shorebirds

Page *et al*. (1989) estimated that close to a million shorebirds were using San Francisco Estuary wetlands in April 1989. Of these shorebirds, more than half these species were observed in the South Bay (south of the San Mateo Bridge). The majority of the shorebirds using the Estuary are sandpipers (*Calidris* spp.), which use tidal flats as their primary foraging habitat.

Surveys conducted in South Bay salt ponds in the early 1980s found more than 200,000 shorebirds using this habitat in winter (Harvey *et al*. 1988). Salt ponds can provide relatively safe roosting habitat, foraging habitat, and nesting habitat for some species. Abundant brine flies and brine shrimp in medium to higher salinity ponds (75 to 200 ppt) provide a predictable food source. More importantly for most shorebirds, the lack of tidal action in the ponds make them important high tide foraging habitats, when tidal flats along the margins of the South Bay are submerged. Additionally, these birds require high tide roosting habitat, which salt pond levees and islands provide. Map 6 shows the relative shorebird use of different South Bay salt ponds.

The following species are salt pond specialists or have special conservation status. Any South Bay salt pond restoration efforts must take the needs of these species into consideration.

Western snowy plover (*Charadrius alexandrinus nivosus*) occurs year-round in coastal California, nesting on sandy beaches and salt panne habitat. Due to loss of suitable nesting habitat (free of predators and human disturbance) the coastal population of the Western snowy plover was federally listed as threatened in 1993. In South Bay, snowy plovers nest on salt pannes (mainly crystallizers), sand fills in the salt ponds, and unvegetated salt pond levees south of the San Mateo Bridge. Most of the population nests on the eastern side of the South Bay, primarily on the Baumberg tract, but not all suitable habitat has been adequately surveyed and nesting locations shift with changes in habitat management (e.g., levee maintenance and changing water levels). However, in four surveys conducted since 1978, 87 percent of snowy plovers nesting in the South Bay were found on the eastern side of the South Bay (Page *et al*. 2000). The South Bay salt ponds are also important to wintering plovers. Over 750 snowy plover have been counted in winter surveys in the South Bay (WRA 1994).

Western snowy plovers are not believed to have nested in natural salt panne habitat prior to the creation of the salt ponds (Page *et al*. 2000). By the 1920s, snowy plovers were common around man-made salt ponds in the South Bay (Grinnell and Wythe 1927). South Bay salt pond habitat is now one of the primary breeding sites for the coastal population. During a statewide survey in June 2000, 96 adult snowy plovers were found in the South Bay salt ponds, almost 10 percent of the California population (PRBO unpublished data). The number of breeding birds in the South Bay, and in California as a whole, is declining (Page *et al*. 2000). The USFWS currently estimates the total South Bay breeding population at roughly 125 to 150 breeding pairs (Albertson, personal communication).

Although there is not currently enough monitoring of the South Bay population to provide good estimates of chick fledging

Table 4-2. Common and special status bird species found in the vicinity of South Bay salt ponds

Common Name	Scientific Name	Conservation Status[1]	Primary Habitat[2]	Period of Use and Breeding Status[3]	Diet	Probable Tidal Marsh Restoration Impact[4]
SHOREBIRDS						
Black-bellied plover	*Pluvialis squatarola*		SP,SM	Aug-Apr	Invertebrates	-
Killdeer	*Charadrius vociferus*		LE,SP,UP	YR*	Invertebrates	-
Western snowy plover	*Charadrius alexandrinus nivosus*	FT, SSC	LE,SP	YR*	Invertebrates	-
Black-necked stilt	*Himantopus mexicanus*		SP,LE	YR*	Invertebrates	-
American avocet	*Recurvirostra americana*		SP,LE	YR*	Invertebrates	-
Willet	*Catoptrophorus semipalmatus*		SP,SM	Aug-Apr	Invertebrates	o
Marbled godwit	*Limosa fedoa*		SP,SM	Aug-Apr	Invertebrates	o
Sanderling	*Calidris alba*		SP,SM	Aug-Apr	Invertebrates	-
Red knot	*Calidris canutus*		SP,SM	Aug-Apr	Invertebrates	-
Western sandpiper	*Calidris mauri*		SP,SM	Aug-Apr	Invertebrates	-
Least sandpiper	*Calidris minutilla*		SP,SM	Aug-Apr	Invertebrates	-
Long-billed curlew	*Numenius americanus*	SSC	SM,SP	Aug-Apr	Invertebrates	o
Dunlin	*Calidris alpina*		SP,SM	Oct-Apr	Invertebrates	-
Short-billed dowitcher	*Limnodromus griseus*		SP,SM	Aug-Apr	Invertebrates	-
Long-billed dowitcher	*Limnodromus scolopaceus*		SP,SM	Aug-Apr	Invertebrates	-
Wilson's phalarope	*Phalaropus tricolor*		SP	Jun-Sep	Invertebrates	-
Red-necked phalarope	*Phalaropus lobatus*		SP	Jul-Oct	Invertebrates	-
WATERFOWL						
Aleutian Canada goose	*Branta canadensis leucopareia*	FT	FW	Nov-Jan	Vegetation	o
Northern pintail	*Anas acuta*		SP,FW	Aug-Mar	Vegetation	-
Northern shoveler	*Anas clypeata*		FW,SP	Aug-May	Vegetation	-
Gadwall	*Anas strepera*		FW	YR*	Vegetation	-
American wigeon	*Anas Americana*		FW,SP	Sep-Apr	Vegetation	-
Canvasback	*Aythya valisineria*		SP	Nov-Mar	Inverts, Veg.	-
Greater scaup	*Aythya marila*		SP	Nov-Mar	Inverts, Veg.	o
Barrow's goldeneye	*Bucephala islandica*	SSC	SP	Nov-Mar	Invertebrates	o
Bufflehead	*Bucephala albeola*		SP	Nov-Mar	Invertebrates	o
Ruddy duck	*Oxyura jamaicensis*		SP,FW	Sep-Apr	Inverts, Veg.	-
SEABIRDS						
Eared grebe	*Podiceps nigricollis*		SP	Sep-Apr	Brine Flies, Shrimp	-
American white pelican	*Pelecanus erythrorhynchos*	SSC	SP	July-Dec	Fish	-
California brown pelican	*Pelecanus occidentalis californicus*	FE, SE	LE	July-Jan	Fish	-
Double-crested cormorant	*Phalacrocorax auritus*	SSC	SP	YR*	Fish	o
Bonaparte's gull	*Larus philadelphia*		SP	Oct-Apr	Brine Flies, Shrimp	-
Mew gull	*Larus canus*		SP	Oct-Apr	Invertebrates, Fish	-

Continued

Table 4-2. Continued

Common Name	Scientific Name	Conservation Status[1]	Primary Habitat[2]	Period of Use and Breeding Status[3]	Diet	Probable Tidal Marsh Restoration Impact[4]
SEABIRDS - *continued*						
Ring-billed gull	*Larus delawarensis*		SP	Aug-Mar	Opportunistic	-
California gull	*Larus californicus*	SSC	LE,SP	YR*	Opportunistic	-
Herring gull	*Larus argentatus*		SP	Nov-Mar	Opportunistic	-
Western gull	*Larus occidentalis*		LE,SP	YR*	Opportunistic	-
Glaucous-winged gull	*Larus glaucescens*		SP	Nov-Mar	Opportunistic	-
Black skimmer	*Rynchops niger*	SSC	LE,SP	Jul-Aug	Fish	-
California least tern	*Sterna antillarum browni*	FE, SE	LE,SP	Apr-Oct*	Fish	-
Caspian tern	*Sterna caspia*		LE,SP	Apr-Oct*	Fish	-
Elegant tern	*Sterna elegans*	SSC	SP	Jul-Oct	Fish	-
Forster's tern	*Sterna forsteri*		SP	YR*	Fish	-
WADING BIRDS						
Great egret	*Ardea alba*		SM	YR*	Fish, Amphibians	o
Great blue heron	*Ardea herodias*		SM	YR*	Fish, Amphibians	o
Snowy egret	*Egretta thula*		SM	YR*	Invertebrates, Fish	o
Black-crowned night heron	*Nycticorax nycticorax*		SM	YR*	Fish, Invertebrates	o
White-faced ibis	*Plegadis chihi*	SSC	FW,SP,SM	Aug-Oct	Invertebrates	o
OTHER BIRDS						
Pied-billed grebe	*Podilymbus podiceps*		FW	YR*	Fish, Invertebrates	o
Black tern	*Chlidonias niger*	SSC	SP,FW	Jul-Sep	Insects	o
California clapper rail	*Rallus longirostris obsoletus*	FE, SE	SM	YR*	Invertebrates	+
Burrowing owl	*Athene cunicularia hypugea*	SSC	UP	YR*	Rodents, Insects	+
Short-eared owl	*Asio flammeus*	SSC	SM	Oct-Mar	Rodents	+
Red-tailed hawk	*Buteo jamaicensis*		All	YR*	Rodents	o
California horned lark	*Eremophila alpestris actia*	SSC	LE,UP	YR*	Seeds, Invertebrates	o
Tricolored blackbird	*Aegelaius tricolor*	SSC	FW	YR*	Insects	+
Red-winged blackbird	*Aegelaius phoeniceus*		FW	YR*	Insects	+
Cliff swallow	*Petrochelidon pyrrhonota*		FW,SP	Mar-Sep*	Insects	o
Barn swallow	*Hirundo rustica*		FW,SP	Mar-Sep*	Insects	o
Turkey vulture	*Cathartes aura*		UP	YR	Carrion	o
American kestrel	*Falco sparverius*		All	YR*	Rodents, Insects	o
American peregrine falcon	*Falco pereginus anatum*	SE, FD	All	YR	Birds	o
Northern harrier	*Circus cyaneus*	SSC	All	YR*	Rodents, Birds	o
White-tailed kite	*Elanus leucurus*		All	YR*	Rodents	o
Marsh wren	*Cistothorus palustris*		FW,SM	YR*	Insects	+
American pipit	*Anthus rubescens*		LE,UP	Nov-Mar	Insects	o

Continued

Table 4-2. Continued

Common Name	Scientific Name	Conservation Status[1]	Primary Habitat[2]	Period of Use and Breeding Status[3]	Diet	Probable Tidal Marsh Restoration Impact[4]
OTHER BIRDS - *continued*						
Yellow warbler	*Dendroica petechia brewsteri*	SSC	UP	Apr-Sep*	Insects	+
Salt marsh common yellowthroat	*Geothlypis trichas sinuosa*	SSC	SM	YR*	Insects	+
Savannah sparrow	*Passerculus sandwichensis*		LE,SM	YR*	Seeds	+
Alameda song sparrow	*Melospiza melodia pusillula*	SSC	UP,SM	YR*	Seeds	+
House finch	*Carpodacus mexicanus*		LE,UP	YR*	Seeds	-
Lesser goldfinch	*Carduelus psaltria*		LE,UP	YR*	Seeds	-
American goldfinch	*Carduelus trista*		LE,UP	YR*	Seeds	-
House sparrow	*Passer domesticus*		LE,UP	YR*	Seeds	-

1 *Conservation Status: FE = Federally Endangered; FT = Federally Threatened; FD = Federally Delisted; SE = State Endangered; SSC = California Species of Special Concern*

2 *Primary Habitat: FW = Fresh Water; LE = Levees; SM = Salt Marsh; SP = Salt Ponds; UP = Upland*

3 *Breeding Status: (*) indicates breed in the San Francisco Bay Area*

4 *Probable Tidal Marsh Restoration Impact: Positive impact (+), negative impact (-), unknown or negligible impact (0); actual impacts depend on restoration details*

success, with proper management the salt ponds could contribute significantly to the growth of the Pacific Coast snowy plover population. Human-created salt panne habitat is currently being successfully managed at the Moss Landing Wildlife Area (Monterey County) with high snowy plover fledging success. The Goals Report (Goals Project 1999) recommends managing for 500 nesting snowy plovers in the Estuary. Page *et al.* (2000) recommend managing for at least 300 breeding snowy plovers in the South Bay. The USFWS Western Snowy Plover Draft Recovery Plan, expected for release in 2002, will provide more detailed information on recovery goals for the South Bay and is anticipated to recommend at least 300 breeding pairs for the South Bay. Management for snowy plovers includes predator management and maintenance of salt pond water levels to reduce vegetation and provide shoreline foraging habitat.

Along with snowy plovers, the **black-necked stilt** (*Himantopus mexicanus*) and **American avocet** (*Recurvirostra americana*) are the primary breeding shorebirds in the South Bay salt ponds. Stilts and avocets nest on salt pond levees and similar habitat. Stilts prefer to nest in more vegetated areas (e.g., *Salicornia*). Both species forage primarily in medium to higher salinity ponds (130 to 180 ppt) up to about ten centimeters deep (Harvey *et al.* 1992). Stilt and avocet populations increase greatly in the winter with the influx of non-breeding birds. The Goals Report (Goals Project 1999) recommends managing for 5,000 to 7,000 wintering black-necked stilts and 25,000 American avocets in the Estuary.

Wilson's phalarope (*Phalaropus tricolor*) and r**ed-necked phalarope** (*Phalaropus lobatus*) breed in northern latitudes and stop over in San Francisco Estuary during their fall migration, from June to September. Red-necked phalaropes also occur in smaller numbers during spring migration, in April and May. Both species apparently prefer high salinity (150 to 210 ppt) salt pond habitat where they forage on brine shrimp and brine flies (Harvey *et al.* 1992). However, Rubega and Inouye (1994) found that red-necked phalaropes could not survive on brine shrimp alone. They suggested that medium to high salinity conditions, which are favorable to brine shrimp but exceed the tolerance of brine flies, could be detrimental to red-necked phalaropes. Combined totals of both species in the San Francisco Estuary have been as high as 70,000 (Harvey *et al.* 1988). The Goals Report (Goals Project 1999) recommends managing for tens of thousands of migrating phalaropes in the Estuary.

Waterfowl

The San Francisco Estuary provides wintering habitat for more than 300,000 ducks and geese (Accurso 1992). More than 50% of the diving ducks in the Pacific Flyway winter in the Estuary, including one of the largest winter populations of Canvasback (*Aythya valisineria*) in North America.

The South Bay salt ponds provide important habitat for many species of waterfowl. More than 100,000 ducks were recorded in the salt ponds in winter surveys in the early 1980's (Harvey *et al.* 1988). South Bay ponds supported 21-27% of waterfowl in the Estuary between 1988-1990, including 90% of Northern Shovelers (*Anas clypeata*) (Harvey *et al.* 1992). Waterfowl prefer lower salinity ponds (20-63 ppt) of moderate size (50-175 ha). Loss of salt pond habitat is expected to have a direct negative effect on the number of waterfowl wintering in the Estuary (Takekawa *et al.* 2000).

Numbers of breeding waterfowl at the South Bay salt ponds are much lower. Six species of waterfowl are known to breed in the South Bay salt ponds: Canada Goose (*Branta canadensis*), Mallard (*Anas platyrhynchos*), Gadwall (*Anas strepera*), Northern Pintail (*Anas acuta*), Northern Shoveler (*Anas clypeata*), Cinnamon Teal (*Anas *cyanoptera*), and Ruddy Duck (*Oxyura jamaicensis*). All of these species are much more abundant in the non-breeding season.

Two waterfowl species that occur in the Estuary have special conservation status. The Aleutian Canada Goose (*Branta canadensis leucopareia*) is federally Threatened, and Barrow's Goldeneye (*Bucephela islandica*) is listed as a California Species of Special Concern. Both species are uncommon in the South Bay.

We have selected three key waterfowl species that use South Bay salt ponds to discuss in some detail as representative of the many waterfowl species that use the salt ponds: ruddy duck, northern pintail, and canvasback. We have chosen not to map their distribution as we did for shorebird use because the data sources (Miles 2000, Casazza and Miller 2000, Takekawa and Marn 2000) all present their data in a manner that is very difficult to transfer to our GIS maps. However, the common habitat requirement for all these birds is low salinity ponds (see Map 7), with shallower ponds (up to 40 cm) for Pintail and deeper ponds (up to 3 m) for ruddy duck and canvasback. Pond depth varies based on Cargill salt production needs so are not mapped.

Ruddy Duck (*Oxyura jamaicensis*). Although this small diving duck can be found in a variety of shallow water habitats, it appears to prefer low salinity salt ponds. As many as 19,000 Ruddy Ducks have been recorded on South Bay salt ponds (Accurso 1992). Winter counts from 1988 to 1990 showed that 67% of Ruddy Ducks wintering in San Francisco Estuary used South Bay salt ponds (Accurso 1992). Miles (2000) cites 40 specific South Bay salt ponds that are currently important for this species.

Northern Pintail (*Anas acuta*). Populations of this dabbling duck have declined dramatically in the last decade throughout North America, and numbers wintering on San Francisco Bay have declined at an even greater rate (Casazza and Miller 2000). Pintails wintering in the South Bay have little interchange with populations in the Central Valley, and may be a unique sub-population (Casazza and Miller 2000). Pintails utilize low salinity South Bay salt ponds extensively (Accurso 1992). Casazza and Miller (2000) recommend maintaining at least 2100 hectares of salt pond in the South Bay for this species. Particularly important ponds for this species are the Sunnyvale sewage pond, Pond A9, and Pond A10 (Casazza and Miller 2000). Management for this species, including retention of low salinity salt ponds, should also benefit other dabbling ducks that use South Bay salt ponds, including Northern Shoveler, American Wigeon (*Anas americana*), Gadwall, and Mallard.

Canvasback (*Aythya valisineria*). The wintering population of this diving duck in San Francisco Estuary is the largest in North America. Due to a decline in the wintering population, this species is considered a species of special concern by the USFWS (Takekawa and Marn 2000). Of this wintering population, approximately 17% are found in South Bay salt ponds (the majority winter in North Bay salt ponds; Accurso 1992). Takekawa and Marn (2000) recommend maintaining large, shallow, low salinity salt ponds in the South Bay as habitat for Canvasback. Management for this species should also benefit other diving ducks, such as Bufflehead (*Bucephala albeola*).

Seabirds

Seabirds that use the South Bay salt ponds include grebes, pelicans, cormorants, gulls, and terns. Gulls and terns now nest in large numbers on salt pond levees and artificial islands in the South Bay. The following species are salt pond specialists or have special conservation status.

The **eared grebe** (*Podiceps nigricollis*) is probably historically less abundant in the South Bay relative to its current population levels, but wintering numbers have increased with available salt pond habitat. Small numbers of birds have nested in the area, but they are much more abundant in winter. More than 40,000 eared grebes have been observed on South Bay salt ponds in winter (Harvey *et al*. 1992), and the total number may be as high as 100,000 (Cogswell 2000). Eared grebes prefer mid-salinity salt ponds (in the 90 to 150 ppt), where they forage extensively on brine shrimp.

The **American white pelican** (*Pelecanus erythrorhynchos*) is a California species of special concern. These gregarious pelicans disperse to the Estuary from inland and northern breeding sites in the fall and winter. More than 3,000 wintering birds were counted in the South Bay salt ponds in 1984 (Harvey *et al*. 1988). White pelicans use lower salinity salt ponds (20 to 40 ppt) for foraging on fish and for roosting.

California brown pelicans (*Pelecanus occidentalis californicus*) breed in Southern California and Mexico from March through July and disperse north to the Bay Area in summer and fall. Due to reproductive failure linked to agricultural use of the pesticide DDT, the brown pelican was federally listed in 1970 as endangered, although numbers are now increasing. Pelicans require disturbance-free and predator-free nocturnal roosting habitat. Pelicans use salt ponds primarily for roosting, either on levees or artificial islands, or directly in shallow ponds. The number of brown pelicans using South Bay salt ponds is relatively small.

Bonaparte's gulls (*Larus philadelphia*) are abundant winter visitors to South Bay salt ponds, with as many as 10,000 using the ponds each year (Harvey *et al*. 1992). Bonaparte's gulls prefer fairly saline ponds (90 to 200 ppt), where they forage on brine flies and brine shrimp.

The **California gull** (*Larus californicus*) is a state species of special concern that began nesting in small numbers at the South Bay salt ponds in 1980. To date the number has increased to over 8,000 nesting pairs, making them the most abundant breeding bird in the South Bay (Shuford and Ryan 2000, Ryan 2000b). The majority of this nesting has occurred at the Knapp property near Alviso, a long-inactive salt pond that remains diked from tidal action. California gulls nest colonially on salt pond levees and artificial islands in or near salt ponds and are vulnerable to opportunistic predators, such as the non-native red fox, entering colony sites in years when water levels recede before nesting is completed.

Caspian and **Forster's terns** (*Sterna caspia* and *S. forsteri*) nest on dredged sediment islands, levees, and similar habitats in the vicinity of South Bay salt ponds. Both species have increased in the last century, probably as a result of an increase in man-made nesting habitat around the salt ponds. Caspian terns were first documented breeding in San Francisco Estuary in 1922, and Forster's terns in 1948 (Ryan 2000a, 2000c). As of 1997, there were 1,362 Forster's tern nests, and 136 pairs of Caspian terns nesting in the South Bay (Ryan 2000a, 2000c).

Due primarily to loss of suitable nesting habitat on coastal beaches, **California least terns** (*Sterna antillarum browni*) are listed as endangered both federally and by the State. Small numbers of California least terns have nested in the past on unvegetated levees and pannes in the South Bay salt ponds. Currently, least terns do not nest in the South Bay, though they have nested in the past on salt pond levees (Feeney 2000) and around Baumberg in particular. Least terns use South Bay salt ponds to forage for fish, preferring pond depths of about two feet. Currently least terns nest at the former Alameda Naval Air Station, the largest northern California breeding site. After fledging in late summer, juvenile least terns rely heavily on salt ponds as foraging habitat (Feeney 2000).

Wading Birds

Six species of herons and egrets breed in the South Bay: **great blue heron** (*Ardea herodias*), **great egret** (*Ardea alba*), **black-crowned night heron** (*Nycticorax nycticorax*), **snowy egret** (*Egretta thula*), **little blue heron** (*Egretta caerulea*), and **cattle egret** (*Bulbulcus ibis*). The little blue heron and cattle egret are both recent colonizers of the South Bay, and they breed in small numbers. Herons and egrets forage primarily in sloughs and tidal flats, but they sometimes nest in the vicinity of salt ponds, primarily in trees and large shrubs. Currently the largest mixed-species colony is at Mallard Slough. A major colony at Bair Island was abandoned in the early 1990s, apparently due to loss of nesting habitat (primarily Baccharus) and predation by the non-native red fox (Ryan and Parkin 1998).

Rails

The **California clapper rail** (*Rallus longirostris obsoletus*) is federally and state listed as endangered. Secretive clapper rails require tidal salt marsh habitat with sufficient vegetation (*Spartina* or *Salicornia*) to provide cover for nesting and roosting. Ideal habitat includes extensive tidal channels, extensive high salt marsh, and refugia for extreme high tide events. Salt ponds do not provide habitat for this endangered species. The **black rail** (*Laterallus jamaicensis*), a California species of special concern, nests in the North Bay, but it is not known to nest in the South Bay. Black rails require similar habitat to clapper rails. Restoration of tidal salt marsh in the South Bay would provide habitat for both species.

4.1.5 Mammals

Small mammal species occurring in the vicinity of the South Bay salt ponds include the **salt marsh harvest mouse** (*Reithrodontomys raviventris*), and the **salt marsh wandering shrew** (*Sorex vagrans halicoetes*). Both species inhabit dense stands of pickleweed in mid-elevation tidal marsh, and they rely on high marsh vegetation for refugia (Harvey *et al*. 1992). The salt marsh harvest mouse is both federally and state listed as endangered, and the salt marsh wandering shrew is a candidate species for federal listing.

Two non-native mammal species now established in the South Bay are the **red fox** (*Vulpes vulpes*) and the **Norway rat** (*Rattus norvegicus*). The red fox was first observed in the South Bay in the mid 1980s, and it was established by the early 1990s (Lewis *et al*. 1993, Foerster and Takekawa 1991). Red fox are opportunistic, generalist predators that are capable of exploiting a variety of food resources including small mammals, birds, reptiles, amphibians, and insects. Declines in populations of the federally listed California clapper rail and Western snowy plover have been linked to the establishment of the red fox in coastal California (Foerster and Takekawa 1991, Parker and Takekawa 1993). Establishment of the Norway rat in the South Bay probably occurred in close association with increasing human settlement. Norway rats are known to prey on California clapper rail nests (Foerster and Takekawa 1991).

The **Pacific harbor seal** (*Phoca vitulina richardsi*) is the only common marine mammal in the South Bay. This species is protected under the federal Marine Mammal Protection Act. Several harbor seal haul-out sites occur in the South Bay, some of which are on the margins of salt ponds. Mowry Slough is the largest pupping site in San Francisco Bay, with a population that ranges from an average of 30 seals in winter to over 300 in the height of pupping season (WRA 1994). The Greco Island site in Redwood City holds from 20 seals during the winter months to an average of 40 seals during the pupping season. Harbor seals also use Corkscrew Slough at Bair Island in Redwood City (Albertson, personal communication).

4.2 Protecting Existing Biological Resources

Solar salt production has dramatically altered the South Bay ecosystem. Nevertheless, the salt ponds provide valuable habitat for many species. Although tidal marsh restoration benefits many species, it may negatively affect others that depend on the existing biological resources.

Many species depend on the salt ponds in their current managed state. Some species occur in much higher densities in the salt ponds than in the adjacent bay environment, and several use the salt ponds almost exclusively. In some cases, these species were not historically abundant in San Francisco Estuary, but are so today because the habitats they may have utilized elsewhere are greatly reduced (e.g., the Central Valley). Wholesale restoration of the salt ponds would adversely impact these species. Incorporating existing or restored habitats for salt pond-dependent species was an essential part of the recommendations expressed in the Goals Report (Goals Project 1999).

Historically, tidal marsh species were more abundant, and they still occur in reduced numbers near the salt ponds. While these species will benefit from an increase in tidal marsh habitat, they are vulnerable to disturbance during restoration.

A primary constraint to salt pond restoration is preserving existing biological functions in both tidal marsh and salt pond habitats. Many of the species that currently utilize the salt ponds and the adjacent tidal marsh for breeding, foraging, over-wintering, and migration are protected by federal and state laws. In the following section we discuss the problems associated with restoring tidal marsh habitat while retaining species currently utilizing salt ponds.

4.2.1 Special Status Species

Numerous special status species are present in the South Bay salt ponds (Table 4-1). Federal and state laws protect these species and their habitats. Therefore, salt pond restoration efforts must take these species and their habitat needs into account.

Tidal Marsh Species

The California clapper rail is entirely dependent on tidal marsh habitat and the salt marsh harvest mouse is dependent on tidal and non-tidal pickleweed (*Salicornia virginica*) marshes. Although these species will benefit in the long term from an increase in available habitat, restoration activities that cause short-term habitat loss, degradation and disturbances could result in adverse impacts. Increased erosion, construction noise, and visual disturbance may displace these species from existing marsh habitat, including habitat around salt pond dredge locks. Both the clapper rail and salt marsh harvest mouse tend to disperse only short distances, so any activity resulting in probable displacement should be carefully considered.

Restoration activities would be additionally constrained by the clapper rail nesting season. The season extends from February to late August. Any proposed changes to the salt pond ecosystem and accompanying construction schedules must minimize these impacts and mitigate unavoidable ones.

Salt Pond Species

Species that currently utilize the salt ponds will be adversely impacted in the short term by restoration-related construction and in the long term by a net habitat loss. Short-term construction impacts include noise, visual disturbance, and increased erosion that may adversely impact available foraging resources or the quality of roosting habitat (e.g., loss of shallow water ponds for pelican night-roosts). These immediate impacts may displace salt pond-dependent species for the duration of restoration activities. Restoration construction also would be constrained by the breeding seasons of several bird species that are protected under the Endangered Species Act and the Migratory Bird Treaty Act. The Western snowy plover currently nests at salt pond flats, unvegetated levees, and sand fills in the salt ponds. California gulls, Caspian terns, Forster's terns, several species of herons and egrets, ducks, and other water birds nest at or near the salt ponds. These species, as are most birds, are extremely sensitive to disturbance at colony or nest sites. Any restoration activities must minimize or mitigate impacts to listed and protected species during the construction phase.

The long-term effects of habitat net loss for special status species currently using the salt ponds may be a significant restoration constraint. For example, the Western snowy plover nests at various locations around the South Bay salt ponds. Conversion of salt pan habitat (crystallizer ponds) to salt marsh would result in a net loss of habitat for this federally listed species. The California least tern does not currently breed at the salt ponds but may rely on salt ponds for critical foraging habitat. Any change in habitat for listed species will require careful consideration and may involve extensive regulatory issues.

Harbor Seals

Harbor seals are protected by the Marine Mammal Protection Act. Several South Bay locations provide essential habitat during the pupping season and are critical haul-out sites. Noise and visual disturbance will probably displace seals from favored haul-outs. Therefore, buffer zones are required to eliminate or minimize this disturbance. Any proposed management change must not reduce the total amount of habitat available to this species.

4.2.2 Migratory Birds

The federal Migratory Bird Treaty Act protects all breeding non-game birds. The South Bay salt ponds provide a critical stopover and wintering site for migratory shorebirds and waterfowl. During migration, water birds typically make long, sustained flights of several hundred miles per day. In the northward migration, some individuals may fly nonstop from the San Francisco Estuary to their breeding grounds in Canada and Alaska.

South Bay wetlands provide critical foraging resources that allow these birds to accumulate the fat reserves necessary for sustained flight. A wetland mosaic with varying degrees of tidal action provides a range of roosting and foraging habitat. Crystallizer and evaporator ponds become inundated in late winter and early spring, providing critical food resources. Salt ponds provide important low-disturbance roosting sites for thousands of migratory water birds.

The most significant long-term effect of a net reduction in salt pond habitat is the potential reduction in population size and overall biological health of dozens of species of migratory water birds. These water birds currently rely on the South Bay salt ponds for over-wintering habitat and migratory staging and refueling. Takekawa *et al*. (2000) recommends conversion of no more than 50 percent of the South Bay salt ponds, or 15,000 acres, to tidal marsh without habitat mitigation. The Goals Project (1999) recommended restoring between 16,000 and 21,000 acres of tidal marsh in the South Bay. The various stakeholders will need to work together to reconcile these differing targets.

4.2.3 Fish

Although no known breeding populations of protected fish species exist in the salt ponds, fish provide a prey base for numerous avian species such as the California least tern. Any modification of the salt pond system must protect local fish populations that provide a prey base for protected avian species. Changes in water flow and stream channel morphology could benefit struggling populations of salmonids, including the federally threatened steelhead and coho salmon found in the South Bay. Restoration strategies should be integrated with upstream efforts to restore these fisheries.

4.3 Non-Native Introductions

Ecological restoration runs the risk of providing new habitat for invasive non-native species, some of which can be extremely deleterious to native species. The two most serious problems with invasive non-native species in the South Bay are smooth cordgrass (*Spartina alterniflora*) and non-native bird predators (primarily red fox and Norway rat).

4.3.1 *Spartina alterniflora*

Smooth cordgrass (*Spartina alterniflora*) is an aggressive, non-native plant that poses a serious threat to the success of future tidal marsh restoration throughout the San Francisco Estuary. The plant was introduced to the Estuary in the 1970s as part of a tidal marsh restoration project in Pond 3, located on Coyote Hills Slough. *Spartina alterniflora* is now established in south San Francisco Bay, with about 1,000 acres located south of the Bay Bridge (O'Brien 2000).

S. alterniflora and the less common non-native *S. anglica* displace and hybridize with the native Pacific cordgrass (*S. foliosa*). Unlike the native cordgrass, *S. alterniflora* grows in very dense stands, eliminating small tidal channels. Elimination of these channels reduces tidal flow and may impair the ecological function of the salt marsh. This elimination may also negatively impact the endangered California clapper rail, which uses small channels for foraging and protection from predators (Evens, personal communication). Although *S. alterniflora* does not provide good foraging habitat for clapper rails, these birds do use the dense vegetation as nesting habitat.

S. alterniflora successfully colonizes a wider range of habitats than does the native cordgrass. *S. alterniflora* can take over pickleweed (*Salicornia*) habitat, negatively impacting the endangered salt marsh harvest mouse and other species that use this habitat. *S. alterniflora* also extends further into exposed mudflats, disrupting tidal flow and impacting migratory shorebirds that rely on this habitat for foraging. Two other non-native cordgrass species, *S. densiflora* and *S. patens*, are also invading higher wetland habitat in the Estuary.

In the South Bay, *S. alterniflora* is associated with two primary centers of distribution, one in San Bruno on the west and one at Alameda Creek Flood Control Channel on the east associated with the Pond 3 restoration project. *S. alterniflora* is widespread to dominant in young tidal marsh from San Leandro Bay south to Ideal Marsh just north of the Dumbarton Bridge in Fremont, locally common in the Mowry-Dumbarton area south of the Dumbarton Bridge, and relatively infrequent south of Calaveras Point in Fremont (see Map 1; Baye, personal communication). South of the San Mateo Bridge, small stands have been found at Steinberger Slough, Palo Alto Baylands, Guadalupe Slough, and scattered from Coyote Creek north to the San Mateo Bridge. Larger stands have been found at Bair Island and Greco Island (Smith, personal communication). Although *S. alterniflora* was found on the Baumberg tract as early as 1992 (WRA 1994), many of the South Bay invasion locations have been documented only recently. Unfortunately in the South Bay, the problem may be worse than previously thought (Smith, personal communication). The San Francisco Estuary Invasive Spartina Project is currently mapping the full extent of *S. alterniflora* distribution in the South Bay.

South Bay salt marsh restoration should be conducted in light of the threat of *S. alterniflora* invasion. Newly restored wetlands are especially vulnerable to invasion (O'Brien 2000). Cordgrass spreads with floating seeds carried by tidal currents. These seeds germinate easily at sites with disturbed soil and limited competition from other vegetation, such as sites in the early stages of restoration. Three East Bay restoration sites—Cogswell Marsh, Oro Loma Marsh, and the Martin Luther King, Jr. Shoreline—were quickly colonized by *S. alterniflora* in the initial stages of restoration (O'Brien 2000, WWR 2001). Once a small patch of *S. alterniflora* becomes established, clones grow quickly through rhizomes.

Controlling *S. alterniflora* is very difficult once it becomes established. *S. alterniflora* hybridizes extensively with the native cordgrass, *S. foliosa*, so control efforts must target not only pure *S. alterniflora*, but also hybrids (Ayers *et al.* 1999). Once a small patch of *S. alterniflora* is established within a stand of *S. foliosa*, these hybrids can quickly spread as a result of abundant pollen production by *S. alterniflora*, making control of *S. alterniflora* within native stands a high priority. Several methods of control appear to be of limited use, including burning and covering stands with black plastic (O'Brien 2000). The most effective control efforts currently include hand pulling (for very small stands) and the use of herbicides; Rodeo® is being used currently in experimental control efforts. Control efforts in some areas are limited to winter months when California clapper rails that may be using *S. alterniflora* habitat are not nesting. Researchers at the Invasive Spartina Project are currently working to determine the best ways of controlling *S. alterniflora*.

Salt pond restoration should occur only after consultation with the San Francisco Estuary Invasive Spartina Project. This will help discourage restoration from occurring in close proximity to stands of *S. alterniflora* and hopefully limit further invasion. In addition, restoration sites must be closely monitored for signs of *S. alterniflora*.

Since the East Bay shoreline between the San Mateo and Dumbarton Bridges is so heavily infested with *Spartina alterniflora*, these areas should be designated for tidal marsh restoration in the later phases of the restoration effort. The time offered by delaying restoration in this area will provide regional control efforts the maximum time to develop an effective control strategy or, if that fails, to understand more fully the ecological implications of restoring tidal marsh in the midst of extensive stands of *S. alterniflora*.

4.3.2 Predators

As discussed in Section 4.1.5, the Norway rat and the red fox are predators of ground nesting birds, including the California clapper rail and the Western snowy plover. Restoration activities could potentially provide new corridors that would allow increased dispersal of these non-native species (Harding *et al.* 1998). Restoration efforts should not benefit and hopefully limit these predators. Trapping efforts currently underway should be continued. Restoring large tracts of land to tidal marsh should help reduce predation pressures. Large tracts of marsh have a small edge area relative to the large interior area, hindering predator access to the interior and thereby benefiting target prey species.

4.4 Accounting for Dynamic Salt Pond Biology

Choosing which ponds to restore and which to retain as shallow open water habitats will offer a great challenge to restoration planners. Annual variability is high in the distribution of key salt pond species, such as Western snowy plover and many wintering ducks. A certain salt pond identified as key habitat for these species one year may go unused the next (John Takekawa, personal communication). For example, Cargill recently lowered water levels in Redwood City Pond 1 over an extended period for maintenance purposes which lead to Western Snowy Plovers nesting there in 2001 (Clyde Morris, personal communication). Restoration stakeholders must work closely with wildlife experts to choose the pattern of restoration in the South Bay carefully. In addition, long-term monitoring should be an integral part of any restoration effort so that implementation carried out over extended time periods is carried out based on current information.

Chapter 5.

Physical Conditions Affecting Salt Pond Restoration

Chapter 5.

Physical Conditions Affecting Salt Pond Restoration

Successful wetland restoration depends upon understanding and accommodating several important physical conditions that directly affect the feasibility of restoring each salt pond to tidal marsh. This chapter describes seven key physical conditions that influence the feasibility for tidal marsh restoration of individual salt ponds:

- Pond Sediment Characteristics (Section 5.1)
- Pond Bottom Elevations and Subsidence (Section 5.2)
- Antecedent Channel Networks (Section 5.3)
- Borrow Ditches (Section 5.4)
- Hydrologic Connections to Tidal Waters (Section 5.5)
- Flood Control and Surrounding Land Uses (Section 5.6)
- Infrastructure (Section 5.7)

Ponds currently less feasible for tidal marsh restoration may be better suited as managed open water shorebird and waterfowl habitat or they could be modified such that impediments to marsh restoration can be eliminated or mitigated.

5.1 Pond Sediment Characteristics

Most of Cargill's salt ponds are composed entirely of Reyes soils (USDA 1998, WRA 1994). These soils are silty clays deposited from Bay waters and tributary freshwater streams. They are poorly drained and highly organic. Reyes soils that are flooded daily by tides are now recognized as Novato series (USDA 1998). Novato soils are similar to Reyes soils but are moderately alkaline (pH 8). Organic matter content (e.g., from vegetation roots), is higher near the surface and decreases with depth. Table 5-1 provides a comparison of Reyes and Novato soils.

The USDA gave Reyes soils good or favorable ratings for pond reservoirs and marsh restoration (WRA 1994, USDA 1975). Most other options for use of Reyes soils receive poor or unfavorable ratings. These options include embankment, dike, and levee construction (WRA 1994, USDA 1975). Novato soils would probably receive a similar rating. Thus, levee construction in the salt ponds requires special skills. Care must be taken not to break through the marsh's weak crust by building levees too rapidly (Ver Planck 1958). Levees require construction in stages with shallow slopes (Ver Planck 1958), and levee maintenance is ongoing throughout the salt pond system. The resulting salt pond levees are not capable of withstanding extreme weights or seismic activities.

These soils are also not well suited as upland fill. Oxidation and compaction occurs because of the soil's high organic content and results in acidic conditions (low pH) when dried, making these soils a poor choice for the establishment of many upland vegetation species (DeJager 2000). The soils do however provide a water-tight seal in the salt ponds, one of three factors necessary for successful solar salt production (Ver Planck 1958). Thus, these soils are well-suited for salt production and wetland restoration—and little else.

Table 5-1. Summary of Reyes and Novato soil series descriptions

Attribute	Reyes	Novato
Summary	Deep, somewhat poorly drained soils that form in alluvial settings from mixed sources.	Deep, poorly drained soils that form in alluvium deposited along bay margins.
Location	Reclaimed and protected marsh areas.	Tidal marsh areas.
Slopes	0 to 2 percent.	0 to 2 percent.
Taxonomic class	Fine, mixed, acid, thermic Sulfic Fluvaquents.	Fine, mixed, nonacid, isomesic Typic Hydraquents.
Distribution	Around edges of Suisun and San Pablo Bays and scattered throughout the Sacramento Delta.	Along the margins of San Francisco, San Pablo, and Tomales Bays.
Drainage and permeability	Somewhat poorly drained; very low runoff; slow permeability	Very poorly drained; very slow runoff; slow permeability.
Geographic setting	In current and former tidal marshes. Former marsh areas are drained by ditches and protected by levees and dikes.	In current and former tidal marshes. They are nearly level and were deposited as bay mud. Former marsh areas are drained by ditches and protected by levees and dikes.
Characteristics	Major strata of mineral soil low in organic content and thin strata of soil with 5 to 30% organic content and 35 to 60% day. When cultivated, soils become increasingly acidic as they are drained.	Organic matter decreases irregularly with increasing depth. Soils are saturated with water at all times. Average clay content is 35 to 60 percent. Textures are silty clay, silty loam, or clay. The soil is mildly to strongly alkaline and noncalcereous.

Source: USDA (1998)

5.2 Pond Bottom Elevations and Subsidence

The existing pond bottoms elevations reflect decades of subsidence brought about by various mechanisms. Nearly every South Bay salt pond elevation is below intertidal marsh elevations. Consequently, nearly every salt pond will need sedimentation to return pond bottoms to suitable elevations. This section describes the importance of elevation to restoration, the mechanisms that have caused subsidence, current pond bottom elevations, and the magnitude of the associated sediment deficit. Chapter 8 presents a detailed discussion of methods to restore suitable marsh elevations and possible associated consequences along with other approaches to reduce the overall sediment deficit.

5.2.1 Relevance of Elevation to Restoration

Tidal marsh vegetation is often described as occurring in discrete "zones." These zones are based in large part on elevation. Other factors contribute to this zonation, such as distance from tidal source, salinity, and competition. Nevertheless, elevation remains a useful tool for determining restoration feasibility because existing pond bottom elevations in relation to tidal height define the amount of sedimentation necessary to bring each salt pond back up to intertidal marsh height.

Intertidal marsh occurs in three distinct zones. Low intertidal marsh vegetation typically ranges from mean tide level (MTL) to mean high water (MHW), and high marsh vegetation ranges from MHW to mean higher high water (MHHW). Cordgrass dominates the low tidal marsh, and pickleweed dominates the high marsh. The upland ecotone typically occurs in the range of MHHW to extreme high tide and is exposed to the tides relatively infrequently (i.e., less than about 5 percent of the time). Salt grass dominates these areas. Figure 5-1 shows the relationship between the various zones.

In general, the closer existing salt pond elevations are to the heights at which tidal marsh plants can colonize, the more rapidly colonization will occur after restoring tidal action. In contrast, where pond elevations are lower, it will take more time for sedimentation to raise elevations to suitable heights for plant colonization. In larger ponds, wind-driven waves can resuspend sediments, further extending the time frame for accretion. Were shorter time frames desired, subsided ponds would need sediment augmentation to speed tidal marsh restoration and/or methods to reduce wind-wave resuspension. Another option involves interim management of the ponds as non-tidal or muted tidal systems. This would control water levels relative to the pond surface. These options are discussed in Chapter 9.

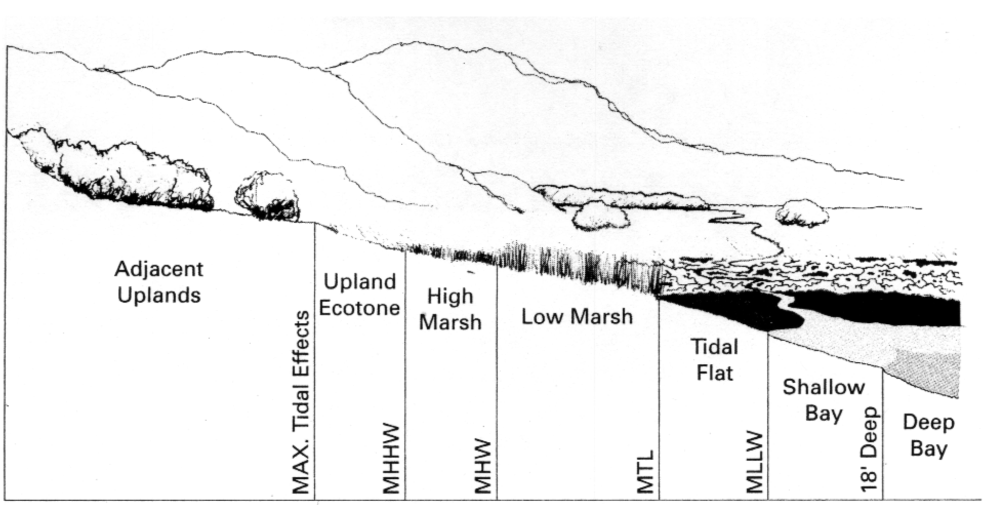
5.2.2 Subsidence Mechanisms

There are two reasons why former tidal marshlands subside once they are isolated from tidal action: (1) compaction through soil oxidation and (2) groundwater withdrawal. Soil oxidation, and the resulting compaction, occurs when marsh soils are drained. For ponds that are periodically drained as part of ongoing salt production activities, soil oxidation can occur and may have led to some subsidence. However, most South Bay salt ponds are normally flooded and thus oxidation is not likely a significant factor. Groundwater withdrawal, on the other hand, is well documented as a cause of considerable subsidence in the South Bay (USACE 1988). Aquifer overdraft between 1912 and 1969 resulted in as much as 13 feet of subsidence, with increasing severity towards the south (USACE 1988). Its affect on salt ponds and adjacent lands is easily seen in the area between Mountain View and San Jose (see Maps 8 and 9).

5.2.3 Existing Pond Bottom Elevations

With the exception of the Newark #2 pond complex, Wildlands *et al*. (1999) compiled recent pond bottom elevation data for the South Bay salt ponds and compared these elevations to local tidal datums (which vary throughout the South Bay). Data for the Newark plant, excluded from the Wildlands' analysis, have not yet been obtained. Map 8 shows the elevation data relative to the fixed vertical datum of the National Geodetic Vertical Datum (NGVD) of 1929, and Map 9 shows these data relative to the spatially varying tidal datums. Many flood control and engineering analyses utilize the NGVD datum, whereas tidal marsh restoration typically utilizes the tidal datum. The

Figure 5-1. Tidal marsh vegetation versus elevation
Source: Goals Project (1999)



NGVD datum itself is now obsolete, having been replaced with the North American Vertical Datum (NAVD) of 1988. Benchmark conversions from NGVD to NAVD are ongoing throughout the region but could take several years to complete (NGS 2000). Data for each pond are included in Appendix C.

Map 9 data show that most South Bay salt pond bottom elevations lie between MTL and MHW (15,930 acres or 61 percent). In these ponds, colonization by low marsh species should occur during restoration with relative rapidity, assuming that processes for colonization are present (Siegel 1993). Species expected to colonize these areas initially are Pacific cordgrass (*Spartina foliosa*), the invasive smooth cordgrass (*S. alterniflora*), alkali bulrush (*Scirpus maritimus*) where salinities are lower due to daily treatment plant discharges, and pickleweed (*Salicornia virginica*) at the higher elevations near MHW.

Map 9 also shows that a large area (5,790 acres or 22 percent) of the salt pond system has subsided in the region extending from Mountain View east to San Jose. All these ponds are within the Alviso Plant. Most of these ponds were identified as having pond bottom elevations between mean low water (MLW) and MTL. One pond—A3W in Sunnyvale—lies between mean lower low water (MLLW) and MLW, requiring 7.9 feet to reach MHHW (see Table 5-2). In all cases, existing elevations are too low to support intertidal marsh vegetation were these areas opened to unrestricted tidal exchange. Thus, accretion or tidal muting (at least on an interim basis) is necessary for tidal marsh formation. Accretion can take the form of natural sedimentation or augmentation with suitable fill material such as clean dredged material. Tidal muting can take the form of managed hydraulic controls such as gated culverts. Methods of addressing these subsided Alviso ponds are discussed in Chapter 8.

5.2.4 Magnitude of the Sediment Deficit

Knowing the degree of subsidence and the acreage of subsided ponds allows us to estimate the magnitude of the sediment deficit necessary to return salt ponds to intertidal marsh elevations. We have assumed equilibrium marsh elevations are local MHHW. Using data from Wildlands *et al.* (1999), we multiplied each pond area by the vertical distance between local MHHW and the average existing pond bottom elevation then added these individual pond volumes to reach total sediment deficit estimates. The results are summarized in Table 5-2 by elevation range. The full data are provided in Appendix C. Separate estimates are given for the entire salt pond complex for which data are available and for the 16,000 acres that Cargill is currently proposing to decommission and sell.

Table 5-2 contains two significant findings. First is the magnitude of the South Bay salt pond sediment deficit. The estimates calculated must be considered approximate primarily because they exclude the volume occupied by the slough channels and also because they represent the void space only, and thus do not account for sediment compaction characteristics. These estimates indicate that a total of 108 million cubic yards of sediment is required to bring all South Bay salt ponds (excluding portions of the Newark #2 Plant not included in the calculations) to the MHHW elevation. For the 16,000 acres that Cargill is currently proposing for restoration, the volume total is roughly 89 million cubic yards. *These volumes are very large.*

Second, Cargill is retaining some of the least subsided (and thus most easily restored) ponds in the South Bay complex. The ponds that Cargill will retain for salt production constitute only about 18% of the total sediment deficit volume but 39% of the total pond area. This disparity is also evident by comparing the weighted average unit volume for the total salt pond complex (4,100 cubic yards per acre) versus that for the Cargill proposed sale area (5,600 cubic yards per acre) (Table 5-2). These values describe on average how much sediment volume per acre is needed to restore marsh elevations, and we see a 37% increase by restricting restoration to the lands Cargill is currently proposing to sell. Figure 5-2 illustrates this point graphically. Figure 5-2(A) plots the necessary sediment thickness as a function of pond area, and Figure 5-2(B) plots the necessary sediment volume.

5.2.5 Possible Sediment Sources

Several potential sediment sources exist to meet the demand created by this deficit. These sources include net import of sediment from the North Bay, local watershed inputs, the South Bay's intertidal mudflats and subtidal flats, and augmentation (e.g., from dredged sediment reuse). Note that if dredged

Figure 5-2. Sediment deposition thickness and volumes as a function of pond area

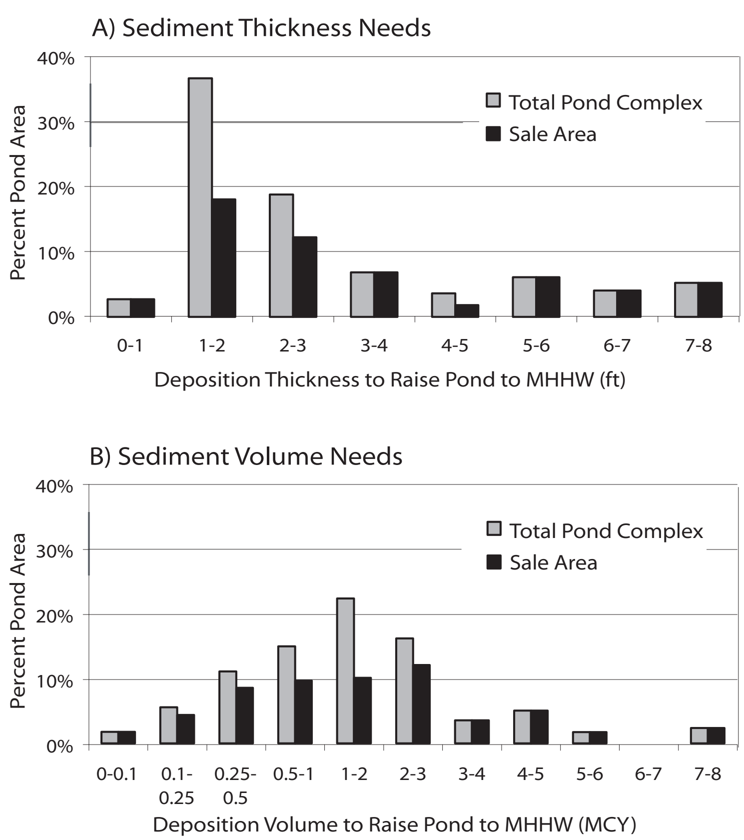


Table 5-2. Range of sedimentation needs to reach local mean higher high water

Elevation Range[1]					Range of sedimentation requirements to MHHW				
			Pond		Thickness				Unit
		Number	Area[2]	% of Total	Low	Mean	High	Volume[3]	Volume[4]
From	To	of Ponds	(acres)	Area				(mcy)	(cy/ac)
TOTAL POND COMPLEX									
Mean High Water and Above:									
MHHW	Highest	1	170	0.6	0	0	0		
MHW	MHHW	4	580	2.2	0	0.3	0.6	0.1	172
Mean Tide Level to Mean High Water:									
1 ft < MHW	MHW	31	5,650	21.6	0.7	1.2	1.6	11.5	2,035
1 ft > MTL	1 ft < MHW	32	8,350	31.9	1.6	2.1	3	28.6	3,425
MTL	1 ft > MTL	9	1,950	7.4	2.9	3.5	3.7	10.8	5,538
Mean Low Water to Mean Tide Level:									
1 ft < MTL	MTL	10	1,290	4.9	3.7	4.3	5.2	9.3	7,209
1 ft > MLW	1 ft < MTL	10	3,130	12.0	5.2	5.9	6.6	30.5	9,744
MLW	1 ft > MLW	2	760	2.9	7.5	7.6	7.7	9.7	12,763
Mean Low Water and Below:									
MLLW	MLW	1	610	2.3		7.9		7.7	12,623
No data[5]			3,700	14.1					
Total Acreage			**26,190**						
Total Deficit Volume								**108**	
Weighted Unit Volume All Ponds[6]									**4,131**
CARGILL SALE AREA									
Mean High Water and Above:									
MHHW	Highest	1	170	1.1	0	0	0		
MHW	MHHW	4	580	3.7	0	0.3	0.6	0.15	259
Mean Tide Level to Mean High Water:									
1 ft < MHW	MHW	19	2,600	16.4	0.7	1.1	1.5	4.6	1,769
1 ft > MTL	1 ft < MHW	22	4,770	30.0	1.6	2.1	3	16.5	3,459
MTL	1 ft > MTL	9	1,950	12.3	2.9	3.5	3.7	10.8	5,538
Mean Low Water to Mean Tide Level:									
1 ft < MTL	MTL	10	1,290	8.1	3.7	4.3	5.2	9.3	7,209
1 ft > MLW	1 ft < MTL	10	3,130	19.7	5.2	5.9	6.6	30.5	9,744
MLW	1 ft > MLW	2	760	4.8	7.7	7.9	8.1	9.7	12,763
Mean Low Water and Below:									
MLLW	MLW	1	610	3.8		7.9		7.7	12,623
No data[5]		3	20	0.1					
Total Acreage			**15,880**						
Total Deficit Volume								**89**	
Weighted Unit Volume All Ponds[6]									**5,620**

1 *Elevation data obtained from Wildlands* et al. *(1999) and excludes portions of Newark #2 Plant. See geographic distribution of pond topography in Map 9 and full data in Appendix A.*

2 *Area estimates from EcoAtlas GIS with pond boundaries updated with aerial photography. Acreages must be considered approximate, as footprints of levees and related features cannot be well represented in a regional scale GIS.*

3 *Sediment volume estimates calculated as sum of individual pond volume needs, with each pond calculated as area times vertical distance below local mean higher high water. Volumes rounded to nearest 50,000 cubic yards.*

4 *Sediment unit volume calculated as total volume within each group divided by total acreage in that group.*

5 *Newark #2 North of Mowry Slough, 220 acres of Newark #1, and 20 acres of Redwood City, no data available.*

6 *Weighted unit volume is sum of the unit volume per elevation category times percent total area per elevation category.*

cy = cubic yards; mcy = million cubic yards; ac = acres; ft = feet; MHHW = mean higher high water; MHW = mean high water; MTL = mean tide level; MLW = mean low water; MLLW = mean lower low water.

sediment reuse were considered for any South Bay salt pond, the volume of sediment placed would be less than that indicated in Table 5-2 because constructing tidal marshlands with dredged sediment necessitates "underfilling" and allowing natural sedimentation to create the final marsh surface. See Chapter 8 for more information on restoring tidal marsh elevations.

5.3 Antecedent Channel Networks

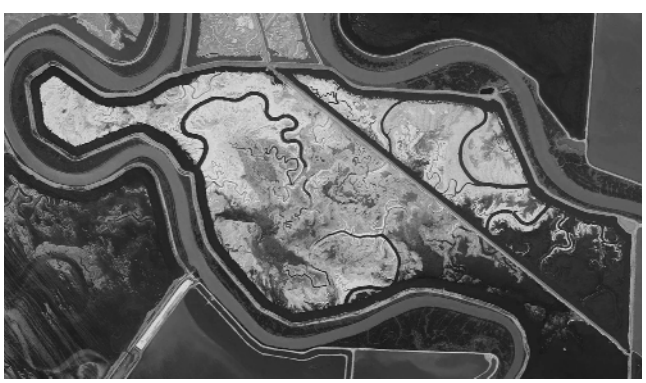
All tidal marshes require channels to carry water, sediments, nutrients, and biological organisms into and out of the marsh. The easier these channel networks can be restored, the simpler and less costly the overall restoration effort. Thus, whether a salt pond retains its antecedent channel networks (i.e., remnants of the original tidal marsh channel network) contributes to the feasibility of restoring that pond. These channel networks provide the greatest insight into the density, shape, and location of tidal channels for each pond (vital to restoration design), and potentially provide the template for reestablishing tidal channel networks in restored ponds. Where channels still exist, they are expected to have become smaller from gypsum precipitation, sedimentation over decades of salt production and bank collapse.

Figure 5-3 shows a typical antecedent channel network visible with aerial photography. (Shown is portions of Ponds A5 and A7 in Sunnyvale.) This photograph also shows borrow ditches adjacent to the levees (see Section 5.4) and, to a small extent, how levees dissect some channels.

Antecedent channel networks are assumed to be present in every evaporator pond, but not in the crystallizer ponds. A review of several series of aerial photographs reveals that these networks are more intact in some ponds than in others.

The presence of antecedent channel networks will generally benefit salt pond tidal marsh restoration. In Chapter 10 we discuss specific opportunities provided by their presence. In contrast, ponds without or with altered antecedent channel networks may pose a constraint to tidal marsh restoration. Higher elevation ponds may require construction of new channels as part of their restoration design. Lower elevation ponds may need little or no initial construction efforts to promote channel formation. Gypsum layers can impede channel formation. Thus, the absence of channels in high-elevation ponds with gypsum layers could be problematic (see Section 6.5).

Figure 5-3. Typical antecedent channel network



An important point regarding antecedent channel networks is that while a network may be present in any pond, its natural morphology may be significantly altered by levees. Several channel networks extending across multiple ponds are "cut" by levees. In such instances, restoration feasibility may be greatly enhanced by levee removal, effectively combining multiple ponds into a single restoration area. There are also numerous instances where the largest point in the channel network—the logical place to breach a levee for restoring tidal action—may be far removed from where levee breaching is possible. In these instances, re-establishing the historic channel network may be difficult to accomplish.

5.4 Borrow Ditches

Borrow ditches are found in the salt ponds alongside most salt pond levees. Figure 5-3 shows typical borrow ditches adjacent to levees in Sunnyvale Ponds A5 and A7. Sediments from borrow ditches were originally used to construct the salt pond levee system, and levee maintenance activities over the past several decades have continued to mine these ditches. Because of the relatively short reach of the dredge equipment, these ditches run alongside levees. Borrow ditches can be quite substantial in size.

Because borrow ditches affect the hydrology, sedimentation and ecology of a pond, borrow ditches can affect the restoration in many ways. First, if returned to tidal action, borrow ditches could completely alter the hydrologic flow and sedimentation regimes relative to a natural channel network for at least an interim period. These effects would arise from short-circuiting flow paths, from affecting flow velocity and magnitude, and from atypical sediment transport. In some cases these effects may be acceptable, and in other cases they may not.

A recent example involving borrow ditches occurred during restoration of the 165-acre Pond SF-1 in East Palo Alto (Orr *et al*. 2001). This project is known as the Cooley Landing restoration project, and it was conducted by Rhone-Poulenc to mitigate nearby wetland impacts. Borrow ditches were partly filled at the levee breach locations and additional small berms were placed within borrow ditches. These efforts were to promote sedimentation within the borrow ditches and prevent them from dominating flows. The effectiveness of this strategy will not be known for several years, as the project was only recently constructed. Some erosion of these cutoff berms has already occurred, which may reduce their effectiveness (Orr, personal communication).

Second, from an ecological point of view, borrow ditches may enhance the shorebird and waterfowl habitat in restored ponds because they provide large channels with variable depths that potentially offer good forage opportunities (Takekawa *et al*. 2000). This approach lends itself well to adaptive management techniques. Restoration phasing combined with scientific monitoring would increase our understanding of how borrow ditches affect hydrology and ecology and how these effects change over time.

Third, and perhaps most significantly, is their decreasing ability to provide material for ongoing levee maintenance. Maintenance needs will decline over time in some areas but it will be many years before levee maintenance can end. In many places throughout the South Bay salt pond complex, maintenance will be needed in perpetuity, especially for salt ponds retained as waterfowl and shorebird habitat.

Thus, borrow ditches will affect the outcome of restoration efforts. Each pond will require a case-by-case analysis and potential impacts will need to be anticipated and addressed during the design.

5.5 Hydrologic Connection to Tidal Waters

The nature of each pond's hydrologic connection to the Bay fundamentally affects their feasibility for tidal marsh restoration. The two attributes of these hydrologic connections are distance from tidal waters (or proximity to the tides) and the existence of tidal marsh on the Bay or "outboard" side of the pond levees. These two related attributes largely define the ease of restoring tidal action to a given pond. The rankings provided below, which consider both these attributes, categorizes ponds along a gradient from very amenable to restoring tidal action to very constrained.

5.5.1 Proximity to Tides

Proximity to tidal waters determines the ease with which tidal action can be brought to a pond. We have identified three broad categories of proximity: open Bay edge, tributary channel, and no tidal edge. An open Bay edge means that a considerable edge of the pond fronts directly on the open Bay. This type of proximity generally provides the most effective tidal connection, and thus would be considered most feasible.

Proximity to a tributary channel means that a considerable edge of the pond fronts along a tidal channel that is tributary to the Bay, such as a creek or flood control channel. The most significant aspect of this type of connection is the size of the tributary channel. Although we have included all tributary channel connections into one category, there are many gradations of tributary channel size. Tributary channels can range from a few feet wide (i.e., extremely small channels requiring extensive enlargement) to several hundred feet wide (i.e., relatively large channels requiring little, if any, enlargement). The need for channel enlargement reduces restoration feasibility.

The third category of hydrologic connection is no tidal edge. These ponds are surrounded entirely by other salt ponds or uplands and are in effect, isolated. Providing tidal action requires construction of a connection to an adjacent pond (via a levee breach), to a tributary channel or to the open Bay. The restoration feasibility of such ponds depends largely on restoration plans for adjacent salt ponds.

5.5.2 Outboard Tidal Marsh

Tidal marsh on the Bay side of salt pond levees potentially hinder returning tidal action to a given pond. Three methods exist for restoring tidal action where outboard tidal marsh is present: (1) mechanically excavate a channel through the marsh; (2) allow natural erosive forces to excavate the channel; and (3) relocate the connection channel to a place in the levee where little or no outboard tidal marsh exists. The second approach has been shown by the Sonoma Baylands tidal marsh restoration project to extend the restoration timeline by an unknown period of time.

All three methods present environmental concerns that must be addressed during restoration design. The first concern is loss of the marsh due to excavation of a tidal connection channel. Relying on natural erosion or heavy equipment to open the tidal connection requires careful consideration but in the end, outboard marsh would still be lost. The second concern is disturbance to wildlife utilizing the outboard marsh. In most instances the mitigation for this type of impact is to restrict construction to times when wildlife use of the marsh is at a minimum (e.g., prohibiting construction during California clapper rail breeding or harbor seal pupping periods).

5.5.3 Five Categories of Hydrologic Connections

Using these criteria, we have defined five categories of potential hydrologic connections for the South Bay salt ponds. These categories combine proximity to the tides and presence or absence of significant outboard tidal marsh. One difficulty we encountered when making these classifications is what to call open Bay and what to call tributary channel at the Bay's southern end. We opted to select the confluence of Mud Slough and Coyote Creek, at the western tip of Pond A21, as the dividing point. (West of this point Coyote Creek is roughly 1,000 feet wide. East of this point it rapidly shrinks to roughly 350 feet.) A second difficulty we encountered is that several ponds could be placed into more than one category. In such cases, we selected the one that appears most suitable for achieving successful tidal marsh restoration. Good examples of this difficult choice are Ponds 1 and 4 in Redwood City along Ravenswood Slough. Even though both have a large open Bay edge, we classified these ponds as having tributary channel connections because the antecedent channel network clearly connects to Ravenswood Slough, not to the open Bay.

The five categories of hydrologic connection are shown on Map 10 and defined below:

1. **No tidal edge:** The pond does not front either the Bay or a tidal tributary channel. The only means of linking the pond to the tides is through an adjacent pond. This category totals 5,230 acres, or 20 percent, of the salt pond system.
2. **Open bay edge with tidal marsh:** The pond fronts open bay waters, but with considerable outboard tidal marsh separating the pond from the bay. This category totals 3,680 acres, or 14 percent, of the salt pond system.
3. **Open bay edge without tidal marsh:** The pond fronts open bay waters with little or no outboard tidal marsh separating the pond from the bay. This category totals 2,780 acres, or 11 percent, of the salt pond system.
4. **Tributary channel edge with tidal marsh:** The pond edge fronts a tidal tributary channel with considerable tidal marsh separating the pond from the tributary channel. This category totals 14,330 acres, or 55 percent, of the salt pond system.
5. **Tributary channel edge without tidal marsh:** The pond edge fronts a tidal tributary channel with little or no tidal marsh separating the pond from the tributary channel. This category totals 180 acres, or less than one percent, of the salt pond system.

5.5.4 Significance to Restoration Feasibility

The single most important element of tidal marsh restoration is bringing the tides to the restoration site. The above analysis examined each pond in the South Bay salt pond complex from two perspectives: distance or proximity to the tides and whether or not there is tidal marsh on the outboard (bayward) side of the salt pond levee which could interfere with bringing the tides to the site.

We derived five categories (or landscape configurations) of hydrologic connections that combine these two perspectives. Two of the five landscape configurations – open bay with and without outboard tidal marsh – are relatively amenable to bringing tidal action to the salt ponds. Together these two configurations account for 6,460 acres or 25 percent of the South Bay salt pond complex. The next two of the five landscape configurations – tributary channel with and without outboard tidal marsh – may or may not present a constraint to restoring tidal action. In these cases, the size of the tributary channel will largely dictate the degree of constraint. For example, Baumberg Pond 1A is alongside a reasonably large tributary channel and probably would be minimally constrained. In contrast, Newark Plant 2 Pond 5 is alongside Albrae Slough. Albrae Slough is only a few feet wide and would likely constrain returning this pond to tidal action. These two configurations account for 55 percent of the South Bay salt pond complex. The final landscape configuration – no tidal edge – presents the greatest constraint to restoring tidal action. Returning tidal action to these ponds necessitates connection through an adjacent pond. Thus, these ponds need to be considered in the context of a multiple-pond restoration scenario. This configuration accounts for 5,220 acres or 20 percent of the South Bay salt pond complex. Map 10 shows these configurations.

5.6 Flood Control and Surrounding Land Uses

The fifth aspect of salt pond morphology in relation to restoration feasibility is the topography of the border between the salt ponds and adjacent uplands. The bayward levees of most South Bay salt ponds provide the primary flood protection for many (but not all) areas. Breaching the bayward levees transfers the flood protection concern inland to an internal salt pond berm or to the upland edge. If the upland edge is sufficiently high, major concerns do not exist, although wind-driven erosion and similar issues must be addressed on a site-specific basis. In contrast, if the upland edge is not high enough, flood protection is needed to protect adjacent land uses. These measures typically involve a flood control levee. Internal salt pond berms were not designed to serve as flood protection, so strengthening or more likely full reconstruction would be needed. Additionally, recent approaches to better integration of levees into the surrounding landscape—such as building levees with gentler slopes and using native vegetation for erosion control—would be appropriate rather than the traditional engineering approach of steep levee slopes with rock or concrete rubble rip rap shoreline protection.

5.6.1 Five Categories of Enclosing Levees and Upland

In the South Bay salt pond complex, five types of levees and berms separate the ponds from the Bay and adjacent uplands. These five types are defined below.

1. **High ground:** Locations where the adjacent uplands are high enough not to need additional flood protection. Therefore, no special flood protection measures are necessary as part of wetland restoration efforts.
2. **External salt pond levee:** Locations where levees currently separate the salt ponds from the Bay and in many cases provide the primary flood protection for adjacent uplands. Elevations of these levees vary from +9 to +12 feet NGVD (USACE 1988, Wildlands *et al.* 1999). Therefore, if the levee is breached or removed, additional flood protection measures may be necessary as part of wetland restoration efforts.
3. **Internal salt production berm:** Locations where berms currently separate the salt ponds from one another. Cargill determines the berm elevation based on its water level management needs. Elevations of these berms vary from +3 to +9 feet NGVD, with the average roughly +7 feet (USACE 1988, Wildlands *et al.* 1999). Additional flood protection measures would be necessary as part of wetland restoration efforts if these berms become primary flood control levees. In that case, the levee heights must be raised and will likely require full reconstruction to meet modern flood control and seismic safety requirements.
4. **Upland edge depends on external salt pond levees for flood protection:** Locations where the upland edge consists of smaller berms maintained for salt production purposes that lack flood control functionality. In these areas we can assume new flood protection measures will be necessary as part of wetland restoration efforts.
5. **Publicly maintained flood control levee:** Locations where the upland edge consists of a publicly maintained flood control levee. For these areas we assume that the responsible public

Table 5-3. Lengths of South Bay salt pond complex levees and berms

Type[1]	Levee and Berm Lengths (feet) for each Plant[2]					Total	
	Alviso	Baumberg	Newark #1	Newark #2	Redwood City	Feet	Miles
High Ground	11,387	5,944	34,183	0	16,829	68,343	12.9
External	185,738	49,316	53,367	75,289	57,738	421,447	79.8
Internal	84,991	117,982	86,944	27,887	84,214	402,018	76.1
Upland unprotected	47,615	16,163	2,383	10,702	35,940	112,802	21.4
Public	48,342	36,286	7,277	0	0	91,905	17.4
No data	0	0	0	139,000	0	139,000	26.3
Total, ft	**378,073**	**225,691**	**184,153**	**252,878**	**194,721**	**1,235,515**	
Total, mi	**71.6**	**42.7**	**34.9**	**47.9**	**36.9**		**234**

1 *Classifications from Wildlands* et al. *(1999).*

2 *Lengths determined from Bay Area EcoAtlas GIS (SFEI 1998).*

entity will continue to maintain that levee for its intended purpose. Therefore, little if any additional flood control measures are necessary as part of wetland restoration efforts. However, the public agencies that maintain these levees should be consulted on a site-specific basis, since altered water levels might change their maintenance requirements.

The geographic distribution of these fives types of levees and berms is shown on Map 11. The lengths of these levees and berms are shown in Table 5-3.

5.6.2 Significance to Restoration Feasibility

Protection against flooding from high tides is a fundamental requirement for the entire Bay Area. Under current conditions, the bayfront (external) salt pond levees are the primary means of flood control for vast amounts of property in the South Bay worth tens or hundreds of billions of dollars. Map 11 and Table 5-3 show that about 21 miles of interior levees between the salt ponds and the adjacent uplands would need to be converted to flood control levees. Conversion is more than simply raising the levees; typically full reconstruction would be needed as the original levees were never constructed to regional seismic safety and flood control standards. Such reconstruction efforts will be very costly yet essential.

Considering the South Bay salt pond complex as a whole, not all salt ponds would be restored to tidal marsh. Instead, following the ecological goals for the region discussion in Chapter 2, roughly two thirds of the salt ponds would become tidal marsh. One consideration in selecting which ponds to restore as tidal marsh and which to retain as managed open water ponds is the amount of levee reconstruction needed and the costs of that work. Ideally, one would seek maximum acreage of restored tidal marsh with a minimum amount of levee reconstruction costs, thereby improving restoration economics. For example, one could restore Newark Plant 2 Ponds 1, 2 and 3 (between Mowry Slough and Coyote Creek) to tidal marsh and construct one small flood control levee between Pond 3 and 6 (see Map 11). In this instance, a single half-mile levee would yield about 1,500 acres of restored marsh.

5.7 Infrastructure

Infrastructure can form impediments and barriers to restoration. Infrastructure includes overhead utilities, above- and below-ground pipelines, rail crossings, roads and bridges, structures, flood control facilities, and the like. Strategies to accommodate this infrastructure can be difficult to develop or result in considerable expense in restoration. Infrastructure information will be required to develop the most cost-effective restoration strategies that meet environmental and ecological goals. This section provides baseline infrastructure information.

5.7.1 Types of Infrastructure Impediments

Research on existing infrastructure has proven to be very complex due to a very large number of entities that may have facilities, the various formats with which these entities store the relevant information, and the lack of any centralized information database. There are multiple scales at which information can be obtained and mapped. Unlike construction at a particular site in which one can contact Underground Service Alert for on-the-ground markings, no such service (free of charge) exists on a regional basis for 26,000 acres.

For this analysis we obtained the following data and mapped them in Map 12.

- **Pacific Gas and Electric above- and below-ground electrical transmission and distribution lines.** We used a PG&E (1999) map to locate these facilities.
- **PG&E natural gas pipelines.** These pipelines are reported to run along the railroad right of way in the East Bay. We have not mapped these facilities.
- **Sewer force mains and outfall pipes.** There are six separate districts that have or may have facilities in the vicinity of the South Bay salt ponds. These facilities are mapped to the extent we could obtain reliable data. These entities and the data sources include:
    - East Bay Dischargers Authority (USEPA 1976)
    - South Bayside System Authority (SBSA staff, personal communication)
    - Union Sanitary District (Beacon, personal communication; flows into EBDA pipeline)
    - City of Palo Alto (not mapped since no salt ponds in the immediate vicinity)
    - City of Sunnyvale (Carlino, personal communication)
    - City of San Jose (RWQCB 1995)
- **Roads and rail.** We obtained these data from the USGS 7.5-minute quadrangle maps.
- **Hetch Hetchy Aqueduct.** We obtained these data from the USGS 7.5-minute quadrangle maps. This aqueduct crosses the bay just south of the Dumbarton Bridge.

We also determined that a number of other possible facilities may exist but have yet to be investigated in any detail:

- **Storm drain systems.** These facilities may be owned by cities, counties, and flood control districts. To obtain a complete inventory requires contacting every jurisdiction around the South Bay. Facilities would include underground pipelines, outfall pipes, and pump stations.
- **Petroleum pipelines.** These facilities could be owned by any of several private corporations and none have been contacted to date.
- **Fiber optic cables.** These facilities could be owned by any of several private corporations and none have been contacted to date.

5.7.2 Significance to Restoration Feasibility

Infrastructure impediments must be addressed during restoration planning. Electrical towers generally require vehicular access, concrete footings, and minimum line sag clearance. Below-ground pipelines may lie at elevations that would partially or wholly block tidal exchange. Generally these pipelines require a minimum depth-of-cover and vehicular access. Road and rail crossings, as well as flood control facilities, can limit or interfere with tidal exchange. Structures, especially those that may qualify as historic, are interspersed among the salt ponds. Their fate must be considered carefully.

Chapter 6.

Environmental Chemistry Issues Affecting Salt Pond Restoration

Chapter 6.

Environmental Chemistry Issues Affecting Salt Pond Restoration

Salt production operations over the past century have affected sediment chemistry and water quality within the South Bay salt ponds. Understanding pond chemistry is necessary to identify affected wetland zones that will require more effort and consideration to develop an environmentally safe restoration strategy. This chapter focuses on the environmental chemistry issues associated with all but the bittern ponds; Chapter 10 discusses all aspects of bittern including its production, effects on environmental chemistry, management and desalination.

This chapter is organized into the following sections:

- Water quality (Section 6.1)
- Pond sediment chemistry (Section 6.2)
- Hypersaline brine disposition with Cargill sale (Section 6.3)
- Gypsum (Section 6.4)
- Nuisance algae and odors (Section 6.5)
- Sediment pH after cessation of salt production (Section 6.6)

6.1 Existing Water Quality

As brine passes through the salt ponds, it becomes concentrated and increasingly saline. Exact salinity levels at a given pond vary seasonally and annually due to variations in annual climate and Cargill operational variability. As the brine becomes more concentrated, salinity increases and this affects the suitability of ponds as habitat for various species of plants, invertebrates, birds, fish, and mammals (see Chapter 4). The changes in salinity also directly and indirectly affect water quality through the system. Affected characteristics include ionic balance, suspended solids, nutrient concentrations, temperature, dissolved oxygen, sulfides, and alkalinity. These characteristics affect the suitability of salt ponds as aquatic habitat and are summarized in Table 6-1.

The changes most directly related to salt production are ionic distribution and balance. As brine evaporates, chemical precipitation removes ions from solution and alters the ionic balance. Approximately 100 percent of the calcium ions, 100 percent of the carbonate ions, and 33 percent of the sulfate ions precipitate out of solution in the evaporator ponds (see Table 3-3 in Chapter 3). This change in ionic balance could result in fish toxicity (Goodfellow *et al*. 2000, Pillard *et al*. 2000, Mount *et al*. 1997) and is likely important in defining each pond's biotic community.

Suspended solids and nutrient concentrations change due to settling, biotic uptake and nutrient cycling. In the intake ponds, suspended solids entering the salt pond complex settle from the brine because of quiescent waters. Biotic uptake reduces nitrogen and ammonia, resulting in a significant decrease in nitrogen concentrations (CFR 1989). Phosphorus concentrations do not change (CFR 1989) because the salt ponds are nitrogen limited. As brine passes through the system, different biotic communities establish themselves at different salinity levels. For instance, water boatmen are found in a wide range of salinity levels from 20 to 170 ppt with optimum ranges at 35 to 80 ppt. Brine shrimp are found in ponds with a salinity of 70 to 200 ppt with optimum ranges at 90 to 150 ppt (Larsson 2000). Population die-offs can occur in ponds that undergo a salinity increase due to normal salt production operations that raises salinity levels above that suitable for a given species. For instance, mass brine shrimp die-offs occur in higher salinity salt ponds causing the water to be almost foggy with brine flies and resulting in odor problems (Baye, personal communication). These changes in biological community likely lead to increases in nutrient, dissolved organic matter and suspended solids concentrations in these higher salinity ponds.

Because of their shallow depths and limited tidal exchange, water temperature in the salt ponds is elevated, with wide daily variations (CFR 1989, Lonzarich and Smith 1997, Carpelan 1953). Annual water temperature extremes range from 40 to 80 °F (Swarth *et al.* 1982, CFR 1989) and, unlike Bay water, generally track air temperature (Swarth *et al.* 1982). These wide temperature variations are likely another important factor affecting the pond's aquatic communities.

Dissolved oxygen (DO) and pH also present water quality concerns. In lower salinity ponds (less than 30 ppt), DO concentrations vary widely between ponds, ranging from 1.4 to 20 milligrams per liter (mg/L), reflecting a productive algal community (CFR 1989). (For comparison purposes, the RWQCB Basin Plan DO standard is a minimum of 5 mg/L [RWQCB 1995].) In low salinity ponds, pH varies between 7.2 and 9.5 and tends to decrease and become less variable as salinity increases (CFR 1989). Both DO and pH characteristics indicate a productive algal community in low salinity ponds and a decrease in that productivity as salinity increases. The productive algal community can lead to anoxia, fish kills, and odor problems. This is discussed in more detail in Section 6.6

6.2 Pond Sediment Chemistry

Salt production has also altered the chemistry of the sediments in all the salt production ponds. The following sections discuss these changes for evaporator ponds (Section 6.2.1) and crystallizer ponds (Section 6.2.2). Bittern pond sediment chemistry is discussed in Chapter 10.

6.2.1 Evaporator Pond Sediment Chemistry

Salt production has affected sediment chemistry in the evaporator ponds from both physical and chemical processes that occur during salt production. Pond sediments likely reflect pond operation and the resident biotic communities. Lower salinity ponds which are generally more productive than higher salinity ponds will likely have higher organic levels in their sediments. For certain salinity ranges, different salts and solids will precipitate or settle from the water column. For instance, calcium carbonate precipitates from the water column at a salinity from 66 – 147 ppt and gypsum precipitates at a salinity from 147 – 374 ppt (Table 6-2). Pond sediments will reflect these processes as well.

Contaminant levels in pond sediments are expected to be lower than that found in the surrounding marsh. Suspended sediments are a transport mechanism for many contaminants, including mercury, PCBs, DDT, and chlordanes (SFEI 1996). Because the intake ponds will trap most suspended solids entering the pond complex from the Estuary, the bulk of these contaminants entering the salt ponds will be incorporated into the intake pond sediments. However, two factors suggest that contaminant accumulation within the salt ponds is less than that of surrounding marsh soils. First, detention times are relatively long in each pond (e.g., weeks or months). This water management regime requires extremely muted flows, minimizing the import of suspended solids into the salt ponds. Second, biomass growth in the intake ponds can be relatively high (Lonzarich and Smith 1997). Macroalgae growth and subsequent settling may increase the sediment organic content and essentially bio-dilute the contaminants in these soils. For these reasons, sediment-associated contaminant loading to salt ponds is presumably lower than that to adjacent tidal marshes. Table 6-2 qualitatively compares sediment characteristics of evaporator ponds to that of nearby tidal marsh.

6.2.2 Crystallizer Pond Sediment Chemistry

In the crystallizer ponds, approximately 95 percent of the sodium ions and 80 percent of the chlorine ions precipitate from solution (see Table 3-3 in Chapter 3). The operating salinity of 356 to 369 ppt (29 to 30 °Be) keeps other precipitates, such as gypsum or magnesium sulfate, at a minimum.

Crystallizer sediments differ from the original Bay muds used during construction. Sediments are compacted because of annual drying, leveling and rolling. Sodium chloride concentrations are

Table 6-1. Predicted water quality and odor characteristics of Cargill salt ponds

Water quality characteristic	Changes through pond system[1]	Processes
Salinity	• Increases toward crystallizer ponds • Varies between years with greater variations in higher salinity ponds • Change in ionic distribution and balance • In pond which are at a threshold for a given species (e.g., brine shrimp, water boatman), increases in salinity or flushing of brine to more concentrated ponds can lead to species die-off and subsequent odor problems.	Evaporation, rainfall, and Bay water characteristics
Nitrate and ammonia	• Majority of uptake occurs in initial pond • Ammonia and nitrate concentrations decrease by an order of magnitude in ponds downstream[2] of initial ponds • Total inorganic nitrogen concentrations <0.2 ppm after initial pond. • Nutrient pulses are expected to occur in which species die-offs and population declines occur.	Microbial, algal, and plant uptake
Suspended solids	• Bulk of settling probably occurs in intake ponds • May increase temporarily in higher salinity ponds subject to episodic species die-off (e.g., brine shrimp die-offs occur when salinity increases above a threshold for survivability).	Abiotic settling
Phosphorus	• Relatively constant through system	Biotic and abiotic cycling
DO (dissolved oxygen)	• Widely variable from supersaturated to anoxic in low salinity ponds (<30 – 40 ppt) • Vertically stratified with greater stratification in low salinity ponds • Less spatially and temporally variable in high versus low salinity ponds. • Likely influenced by nutrient concentrations and water temperature	Biotic cycling
Water temperature	• Expected range of 6 to 28 °C • Daily and seasonal variation • Daily means track air temperatures	Abiotic
Dissolved sulfide	• Occurs in low salinity ponds (approximately 30 - 40 ppt) • Patchy spatial distribution; highest in areas where macroalgae is dying • Probably worst along leeward shoreline	Biotic
pH	• Inversely correlated with salinity • Greater variability in low salinity ponds	Abiotic and biotic processes
Chlorophyll a	• Higher in low salinity ponds	Biotic
Odor	• Occurs in areas where species die-offs are occurring. Can result from die-offs of macroalgae, fish and invertebrates	Biotic

1 Based on Ver Planck salt production model shown in Table 3-3 in Chapter 3.

2 "Downstream" refers to movement through the salt pond complex toward final halite harvest in the crystallizer ponds.

Table 6-2. Characteristics of evaporator pond sediments relative to nearby tidal marsh sediments

Parameter	Pond[1]	Approximate Salinity (ppt)	Percent total pond area	Comparison to surrounding marsh soils/sediments
PCBs	1	18 – 35	10	Lower
DDT	1	18 – 35	10	Lower
Chlordanes	1	18 – 35	10	Lower
Mercury	1	18 – 35	10	Lower
Trace elements	1	18 – 35	10	Lower
Calcium as calcium carbonate	3 – 6	66 – 187	40	Negligible
Calcium as gypsum ($CaSO_4$•$2H_20$) and anhydrite ($CaSO_4$)	6 – 9	147 - 374	30	Very elevated. Percent concentration in sediments varies inversely with pond productivity and biomass accumulation. Gypsum may form fairly homogeneous layer over underlying sediments if biomass production rates are low. Gypsum deposition rates are likely not uniform throughout.

1 Based on theoretical ten-pond model from Ver Planck (1958). See Table 3-3 in Chapter 3. Crystallizer and bittern ponds are not included.

most probably higher because, though much of the sodium chloride is harvested, a thin residual crust acting as "pavement" is left behind during harvesting to support heavy equipment and machinery (Delfino, personal communications). Even after flushing, some residual salts are likely left behind in these sediments.

6.3 Hypersaline Brine

As part of the current purchase negotiations for the South Bay salt ponds, one important assumption has been made regarding hypersaline brine: Cargill will retain all of the hypersaline brine for use in its salt production operations (Barroll, personal communication; Moore, personal communications). While clearly desirable as a means to remove hypersaline brine before making ponds available for restoration, this assumption is problematic because no exact definition of hypersaline brine exists. Adequately defining this term is a complex issue because the definition will undoubtedly affect the restoration process. Two possible options exist: (1) the term could be limited to the brine currently within the salt pond system; or (2) it could include the hypersaline wash water generated from desalinating the high salinity and bittern ponds (desalination is discussed in Chapters 9 and 10).

The least controversial ponds will be the low- to medium-salinity evaporator ponds (< 140 ppt) in which minimal gypsum precipitation has occurred. At higher salinity levels, ionic imbalances and precipitated salt (especially gypsum) can complicate desalination efforts. As discussed in greater detail in Chapter 9, desalination of the evaporator ponds will require significant amounts of water to flush the ponds adequately so that outflow into the South Bay has a salinity near background levels. Even if Cargill removes all the brine (option 2 above), it is a separate issue whether Cargill will flush sufficient volumes of water through the system for complete desalination to the satisfaction of the natural resource managers. As part of the purchase negotiations, the parties must carefully define Cargill's responsibilities in this regard. The extent to which Cargill desalinates the system before turning it over to the USFWS will impact not only the rate of restoration, but also the available interim management strategies and the amount of funds needed.

6.4 Gypsum

Gypsum forms a hard, relatively insoluble layer. Because calcium and sulfate ions make up approximately 9 percent of the ions in the initial brines, precipitation of both in the salt ponds as gypsum may pose challenges during restoration. Dissolution rates are determined by many factors including water velocities and flow characteristics, salinity and water chemistry. If gypsum persists in the salt ponds, then its presence may hinder restoration efforts, especially in higher elevation ponds, and will need to be considered during restoration planning and implementation. This section discusses the chemistry behind gypsum and identifies possible factors that may need consideration during the restoration of the salt ponds.

During the salt production process, calcium precipitates from solution as calcium carbonate and calcium sulfate (gypsum). Calcium first precipitates as calcium carbonate, beginning when approximately 40 - 50 percent of the brine remains and corresponding to a salinity of 65 ppt (6.6 °Be; see Table 3-3). It is completed at a salinity of approximately 187 ppt (16 °Be) when 20 percent of the brine remains. Gypsum ($CaSO_4$•$2H_2O$) precipitation begins after a volumetric reduction of the brine of 80 – 85 percent (Table 3-3), corresponding to a salinity of 147 ppt (12.9 °Be). By the time salinity reaches 312 ppt (25.6 °Be), or when 5-10 percent of the brine remains (depending upon inflow salinity levels), nearly all the calcium in solution has precipitated as gypsum (Ver Planck 1958). When dried it then becomes anhydrite ($CaSO_4$). Because carbonate ions are less than three percent that of sulfate ions in the brine, calcium carbonate precipitation is negligible when compared to calcium sulfate (gypsum) precipitation.

6.4.1 Accumulation

In the ten-pond Ver Planck model (Figure 3-1 in Chapter 3), gypsum precipitation occurs in the Stage 2 ponds which comprise 30 percent of the total pond area (see Table 3-3). Gypsum precipitation is rather patchy and often occurs around fibrous vegetation material (Ransom, personal communication). An earlier feasibility study indicates that gypsum has accumulated on about 6,300 acres or 24% of the salt production pond area (Wildlands *et al.* 1999). This discussion therefore assumes that 24% of the pond area is affected by gypsum precipitation. Based on these assumptions, gypsum deposits at an average rate of approximately 10.2 tons ac^{-1} y^{-1} or approximately 1 mm y^{-1} (see Table 6-3). We have estimated the timeframe for gypsum accumulation to be the 50-year period during which South Bay salt production has been at or near full capacity. We have also assumed that the pond order in the salt production process has not changed much over that period. Over that period, approximately 510 tons of gypsum have accumulated per acre of gypsum ponds. If the ponds have few other inputs (e.g., organic material, suspended solids) and the precipitation is uniform, then this represents an average gypsum thickness of 2 inches through these Stage 2 ponds (Table 6-3).

6.4.2 Dissolution

During restoration, ponds will generally be flushed to desalinate water and sediments. At salinity levels below 145 ppt, equilibrium relationships will favor gypsum dissolution though kinetics may not. Gypsum dissolution will depend upon many different environmental characteristics:

- Gypsum density in the sediments
- Water exchange rates with gypsum layers
- Surface flow velocities
- Water chemistry including salinity and trace metal concentrations
- Period of inundation.

The first four factors are typical of many aquatic systems and are important variables when modeling gypsum dissolution rates. Of these four, salinity and water velocities are most important. Gypsum dissolves more rapidly at water velocities considered high (above 0.5 m s^{-1}) and at lower salinity levels. Thus, depending upon site environmental characteristics, dissolution rates vary widely ranging from 67 – 1300 tons ac^{-1} y^{-1} (Raines and Dewers, 1997; James *et al.*, 1981). Though these dissolution rates are for specific systems, they provide reasonable estimates and guidelines for predicting gypsum dissolution rates under permanently flooded conditions (Table 6-4). From these values, approximately 4 months to 8 years is the predicted range required to dissolve the accumulated gypsum in the Stage 2 ponds if they were permanently flooded and depending upon location characteristics (e.g. salinity, water velocities, water chemistry).

In the South Bay salt ponds, the ponds in which gypsum has formed are at elevations ranging from mean tide level to mean higher high water (Map 9). These elevations correspond to those for high and low marsh (Figure 5-1 in Chapter 5). Once restored to tidal action, these ponds would be inundated only 10 to 40% of the time depending upon their elevations (Table 6-5). This intermittent inundation regime dramatically extends dissolution time periods. Assuming that dissolution only occurs during periods of flooding, we have estimated the time period necessary to dissolve gypsum for various marsh elevations (Table 6-5; See Appendix D).

Based upon this analysis, we estimate that 4 to 70 years will be required to dissolve gypsum from the highest elevation ponds such as Baumberg Pond 8A (see Map 13) assuming it has a relatively uniform layer deposited throughout and depending upon dissolution rates. Except in channel areas, water velocities are likely to be low and actual dissolution times will probably be closer to 70 years than to 4 years. Maximum dissolution rates occur in the lowest elevation gypsum ponds and range for a low of around one year along sloughs and other areas with high flows to around 20 years for areas more remote and with more quiescent waters (Table 6-5). These predicted rates correspond well with observations noting that gypsum deposits remain intact seemingly

Table 6-3. Estimates of calcium sulfate (gypsum) accumulation rates

	Units	Optimal production
SALT PRODUCTION DESCRIPTION		
Annual halite production per year	Tons ac^{-1} y^{-1}	40
Average areal water use per year[1,2]	Tons ac^{-1} y^{-1}	1,530
	Ac-ft y^{-1}	1.1
Estimated pond area in which gypsum is accumulating	%	24
AVERAGE CALCIUM PRECIPITATION[2,3,4]		
As calcium	Tons ac^{-1} y^{-1}	2.36
As anhydrite ($CaSO_4$)	Tons ac^{-1} y^{-1}	8.03
As gypsum ($CaSO_4$-H_2O)[5]	Tons ac^{-1} y^{-1}	10.16
	mm y^{-1}	0.98
GYPSUM ACCUMULATION OVER 50-YEAR PRODUCTION PERIOD		
Total mass	Tons ac^{-1}	508
Total thickness	mm	49
	in	1.9

1 Ver Planck (1958)

2 Variable throughout ponds depending upon salinity.

3 Calcium precipitation occurring in 6,260 acres (24%) of pond area (Wildlands et al. 1999).

4 Assumes near complete removal of calcium as gypsum (Ver Planck 1958).

5 Specific gravity of gypsum equals 2.32 (145 lbs ft^{-3}) (Ludman and Coch 1982).

Table 6-4. Gypsum dissolution times for permanently flooded conditions

Scenario	Rates (Tons ac^{-1} y^{-1})	Time (Years)	Time (Days)	Dissolution characteristics
Maximum Dissolution Rates	67	7.58	2,767	- Low salinity - High water velocities (> 0.5m s^{-1})
Minimum Dissolution Rates	1,300	0.39	143	- Quiescent waters - High salinity

1 Gypsum accumulation (508 tons ac^{-1}) is estimated for a 50-year discharge period assuming maximum salt production rates; see Table 3-3.

2 Dissolution rates shown are estimated from the literature.

indefinitely in areas not subject to regular tidal action (on levees within salt ponds and in the inactive salt ponds such as at Bair Island) (Baye, personal observations; Morris 2001; Siegel, personal observations). With only intermittent flooding and rainfall, gypsum will apparently remain intact for very long periods of time.

6.4.3 Effects on Restoration

The extent to which gypsum can impede tidal marsh restoration is largely a function of the pond elevation. In lower elevation ponds in which accretion is expected, bay muds will bury the gypsum layer and its presence will likely negligibly affect restoration efforts. A total of 3,810 acres (61 percent) of the gypsum ponds fall into this group. However, in mid elevation ponds in which initial pond elevations are closer to target tidal marsh elevations, and especially those in which the crust is more consolidated and uniform, gypsum may persist for over 50 years and may impede restoration. A total of 2,140 acres (34 percent) of the gypsum ponds fall into this category. In these ponds, gypsum could hinder tidal channel formation, sediment redistribution, and plant colonization, effectively slowing marsh restoration and recovery. In the highest elevation pond, Baumberg 8A at 310 acres (5 percent) of the gypsum ponds, gypsum is likely to hinder restoration. Map 13 shows the geographic distribution of these three categories of ponds. Table 6-5 shows predicted periods required for gypsum dissolution within those categories.

6.5 Nuisance Algae and Hydrogen Sulfide Production

Nuisance algae and the resulting low dissolved oxygen levels, hydrogen sulfide production, and odor problems have historically plagued low salinity salt ponds (Oswald 1986, CFR 1989). This problem has been associated with elevated nitrogen and phosphorus concentrations in ponds with salinity levels below a range of approximately 30 to 50 ppt. Shallow depths, good light attenuation, warm temperatures, and relatively high nutrient concentrations provided an ideal environment for rapid algal growth in such ponds during the 1980s (Oswald 1986, CFR 1989). Persistent macroalgal mats (CFR 1989) and heavy algal blooms (Oswald 1986) led to anoxia and the accumulation of biomass along the shoreline. Its decomposition led to odor problems caused by releases of hydrogen sulfide. This problem did not occur in higher salinity ponds because algal growth is limited at salinity levels above a range of 30 – 45 ppt (CFR 1989, Carpelan 1953, Lonzarich and Smith 1997).

Aside from odor problems, eutrophication affects the biota in other ways. Macrophytic and planktonic algae provide cover and food for invertebrates in low salinity ponds. However, macrophyte dieback becomes a major issue when hypoxia (very low dissolved oxygen levels) either kills fish and invertebrates or forces them into areas of increased predation (Lonzarich and Smith 1997).

Once restoration and pond desalination begin, this problem could return as pond salinity levels decrease and no longer suppress biological activity and algal growth. Algal blooms occur in the San Francisco Bay, with the greatest frequency occurring in spring (SFEI 1999). Thus, nutrient levels probably remain high enough to cause algal blooms in ponds in which salinity no longer limits growth. This problem could be exacerbated if treatment plant effluent is used for pond desalination or maintenance (see Chapter 9).

6.6 Sediment pH after Cessation of Salt Production

In the North Bay salt ponds, insufficient water inflows decreased sediment pH (i.e., acidified the sediments) due to sediment oxidation and made the ponds more inhospitable for vegetation colonization (see Chapter 7). This could pose a problem for the South Bay salt ponds as well. To avoid this problem, the availability of sufficient funds for interim and long-term water level management is crucial (see Chapter 14).

Table 6-5. Gypsum dissolution times for intermittent flooding

Elevation Range Minimum	Elevation Range Maximum	Area (Acres)	Estimated inundation period (%)	Estimated Time to Dissolve Gypsum Layer[3] Maximum Dissolution[1] (Years)	Estimated Time to Dissolve Gypsum Layer[3] Minimum Dissolution[2] (Years)
MHW	MHHW	310	10	76	4
1ft < MHW	MHW	2,140	20	38	2
1 ft > MTL	1ft < MHW	2,950	30	25	1
MTL	MLW	855	40	19	1

1 Includes sloughs and areas adjacent to bay and sloughs receiving highest surface water flows.

2 Includes high marsh and areas far from bay and sloughs which are most likely to receive low flows.

3 Gypsum accumulation (508 tons ac^{-1}) is estimated for a 50-year discharge period assuming maximum salt production rates; see Table 3-3.

Part III.

Restoration Challenges and Opportunities

Chapter 7.

Lessons Learned from the Napa River Salt Ponds

Chapter 7.

Lessons Learned from the Napa River Salt Ponds

In 1994, the State of California purchased 10,000 acres of Cargill's Napa River salt pond complex in the North Bay for approximately $10 million. Of this acreage, about 7,500 acres are salt evaporators (ten ponds) and a bittern storage pond (Pond 7); the remaining lands are intertidal marsh and open water adjacent to these salt ponds. The California Department of Fish and Game (CDFG) has managed these lands since the 1994 purchase and intends to restore them to a mix of tidal marsh and managed ponds. CDFG returned tidal action to one pond, Pond 2A, as an emergency measure during winter storms in January 1995. Three additional ponds, Ponds 1, 1A, and 2, have been restored as managed shallow open water ponds. The remaining eight ponds have yet to be restored pending resolution of how to remove hypersaline bittern and brine and completion of a restoration plan.

The Napa Salt Ponds have many similarities with the South Bay salt ponds in that both contain large expanses of contiguous bayland wildlife habitat in the San Francisco Estuary and both have a long history of salt production. The tidal wetlands, diked ponds, and salt ponds in both provide vital habitat for migrating and wintering waterfowl and shorebirds along the Pacific Flyway, as well as for resident species. In the Napa Marsh, many upland and wetland vegetation species inhabit the marsh with their location depending upon elevation and salinity levels. Twenty-five fish species have been found in the Napa Marsh with juvenile striped bass the most abundant but many others also abundant as well (Delta smelt, yellow-fin goby, tule perch, Pacific staghorn sculpin, splittail, longfin smelt, and threadfin Shad) (USACE 1997). At least 25 waterfowl species, 31 species of shorebirds and wading birds, ten species of raptors, nine species of reptiles and amphibians, and 22 species of mammals have been counted in the Napa Marsh (USACE 1997). Additionally, several state or federally listed threatened and endangered species are present. These include the California clapper rail, western snowy plover, salt marsh harvest mouse, Sacramento River winter-run chinook salmon, Sacramento splittail, and steelhead trout (USACE 1997). Adjacent to the marsh, the Napa River is an important steelhead, salmon and bass nursery (DeJager, personal

Table 7-1. Summary of bittern and pickle acute and chronic toxicity results

	Chronic[1,2,3]			Acute[1,2,3]			ACRS[4]
	EC25[5] (%[7])	NOEC[6] (%[7])	Most Sensitive Species[1]	LC50[8,9] (%[7])	LC10[8,10] (%[7])	Most Sensitive Species[1]	
Bittern	**1.16 –** 6.28 (2.5)	**1.00 –** 5. (1.9)	Mussel Silverside Amphipod Mysid shrimp	**1.75 –** 7.5 (3.8)	**1.15 –** 3.5 (2.4)	Mysid shrimp Bay shrimp Sanddab	1.55
Pickle	**1.38 –** >10.00 (3.9)	**0.50 –** > 10.00 (~3.1)	Mussel Silverside Amphipod Mysid shrimp	**6.67 –** 7.63 (6.7)	**2.57 –** 5.67 (4.5)	Mysid shrimp Sanddab Rainbow Trout Bay shrimp	1.43
Dissolved Crystallizer Solids	8	5	NA	NA	7.7	NA	1.6

1 *Toxicity responses vary with organism tested. Species tested included Bay shrimp (*Crangon *spp.), Sanddab (*Citharichys stigmaeus*), Island silverside (*Menidia beryllina*), Striped bass (*Morone saxatilis*), Rainbow/steelhead trout (*Oncorhynchus mykiss*), Mysid shrimp (*Mysidopsis bahia*), Amphipod (*Ampellisca *spp.), Top Smelt (*Atherinops affinis*), Pacific Oyster (*Cruassostrea gigas*), mussel (*Mytilus *spp.) and Alga (*Thalassiorsira pseudonana*).*

2 *Values in parentheses are means.*

3 *Values in bold represent minimum concentration (most conservative estimate) for described effect.*

4 *Acute-to-chronic toxicity ratios. Based upon EC25 range.*

5 *EC25 is the effective toxicant concentration that causes a response in 25% of the test organisms. If the effect is death or immobility, the term lethal concentration (LC) may be used.*

6 *NOEC (No-Observable-Effect Concentration) is the highest tested concentration of an effluent or a toxicant at which no adverse effects are observed on the aquatic test organisms at a specific time of observation, based on hypothesis testing.*

7 *Concentration in solution as percent of solution.*

8 *LC stands for Lethal Concentration.*

9 *The concentration of a material that will kill 50 percent of a group of test animals with a single exposure.*

10 *The concentration of a material that will kill 10 percent of a group of test animals with a single exposure.*

Source: Hansen and Associates (1993)

communication). It supports five miles of nursery habitat and an additional 30 miles along its tributaries. Sonoma Creek, located west of the salt ponds, also has a small annual steelhead run (DeJager, personal communication).

Numerous problems have plagued the restoration planning and interim management efforts. This section summarizes the three most significant problems in the context of lessons learned from the Napa River salt pond case study that are relevant to the purchase and restoration of the South Bay salt ponds:

- Developing a strategy to remove hypersaline brines and bittern (Section 7.1)
- Operating and maintaining ponds under insufficient funds required for maintaining levees and water control structures and for managing pond salinity levels (Section 7.2)
- Resolving differences in ecological restoration goals of tidal marsh and open water habitats including discussion of the 1997 U.S. Army Corps of Engineers (Corps) Reconnaissance Study (Section 7.3).

CDFG has faced these problems during the interim period between the cessation of salt production and the completed restoration of the salt ponds. Underlying all these problems are inadequate funds within CDFG for proper management and planning during the interim and restoration periods. Section 7.4 summarizes the findings of this review of the Napa River salt ponds. Two short-term consequences have resulted from these problems. First, ecological function is declining in the system as it currently stands due to increasing salinity and drying of some pond areas. Second, levees continue to deteriorate without adequate maintenance funding and this increases the risk of a catastrophic release of salts into the Napa River and San Pablo Bay. As time elapses, these risks increase.

7.1 Bittern Management and Removal

The North Bay salt pond purchase did not include sufficient consideration of bittern disposal. With the purchase of the ponds, the State also purchased the bittern (stored in Napa Ponds 7 and 8 originally and now stored only in Pond 7) and hypersaline brine (stored in Napa Pond 7A) with no feasible disposal or reuse plan at the time of purchase (Moore, personal communication).

Criteria for bittern discharge have been largely based upon chronic and acute toxicity studies conducted on the Napa Marsh salt ponds by Hansen and Associates (1993) and summarized in Table 7.1. The values shown in bold represent the minimum concentration at which toxicity occurs (i.e., the most conservative estimate of toxicity). Thus, bittern toxicity effects began to show when bittern comprised anywhere from 1.0 – 1.75 percent of the solution depending upon the toxicity criteria used and the species tested. Based upon these results, FlowScience (1994) recommended a minimum 100:1 dilution for bittern and a 10:1 dilution for pre-diluted bittern. Earlier toxicity testing by CDM (1972) and Marine Bioassay Laboratories (1986) provided similar results. Additionally, FlowScience (1994) recommended that the diluted discharge be dispersed (and not pooled) with sufficient freshwater flow to provide further dilution. Based upon these criteria and the logistics of diluting the bittern in the North Bay, FlowScience (1994) estimated that 40 to 60 months, or 3.5 to 5.5 years, would be needed to dilute and discharge the bittern to the North Bay.

Currently CDFG does not consider bittern disposal a problem (Wyckoff, personal communication). The Corps and CDFG have developed a preliminary strategy to desalinate and dilute the bittern with low salinity water to a range near background levels (USACE 1997; Wyckoff, personal communication). Napa River water and potentially recycled water from North Bay sanitation districts will be used to dilute the bittern at a 100:1 dilution ratio prior to discharge. It is expected that this process will take at least 5 years, and potentially much longer, depending upon the amount of precipitated salt in the sediment.

Additionally, as the North Bay salt ponds continue to operate in their existing mode and as water control structures deteriorate, salt accumulation continues and further complicates the disposal issue of high-saline water in many of the ponds.

7.2 Interim Management

The transitional period for the North Bay salt ponds began in 1994 and continues to this day. Its focus has been maintaining the system until restoration can be implemented. However, it has become increasingly apparent that the State purchased these salt ponds with inadequate operation and maintenance (O&M) funds in place (Moore, personal communication; Huffman, personal communication; Rugg, personal communication).

Simply put, the State did not understand the O&M requirements for an operation of this scale. Prior to the North Bay salt pond purchase, Cargill's annual O&M budget has been estimated at approximately $500,000 (Moore, personal communication). In contrast, the State currently allocates approximately $60,000 annually for this purpose (Huffman, personal communication; Moore, personal communication). This funding shortfall has critically hampered a broad range of O&M activities: water pumping and management; repair and replacement of water control structures; levee repair and maintenance; bittern management; and habitat management efforts (Rugg, personal communication; Moore personal communication; USACE 1997; DeJager, personal communication; Huffman personal communication). Of these problems, levee repair and maintenance and water management activities have suffered the most from inadequate funding.

7.2.1 Levee Repair and Maintenance

Maintaining levees will be the primary O&M cost for the South Bay salt ponds. In the South Bay, Cargill has a levee maintenance program that consists of: (1) topping the levees with fresh dredged sediment; (2) discing and grading the levees two to three years after topping; and (3) grading the levees and constructing chokers (small berm constructed on the levee top to prevent dredged muds from slipping into marshes or ponds) (BCDC 1995). Cargill maintains approximately 10 miles of its 200 miles of levee each year, representing levee repairs on a 20 year cycle (WRA 1994). Approximately 17 acres of wetlands and waters of the United States are adversely impacted annually by Cargill's levee repairs in the 26,000-acre South Bay system (BCDC 1995), via accessing dredge locks and placing sediments onto the levees.

Cargill followed a similar maintenance program in the North Bay. Following Cargill's levee maintenance schedule, approximately one third of the North Bay levees would have undergone maintenance since their purchase by the State in 1994. However, that schedule has not been maintained. CDFG cannot keep up with the levee repair schedule because of funding shortages as well as other factors. Many levees are inaccessible with the equipment available to CDFG (e.g., drag lines and excavators, versus the Mallard, a dredge used by Cargill) and levee repair can occur only during the months of October and November due to the logistics of accommodating endangered species regulations and to avoid the rainy season (Huffman, personal communication; USACE 1997). Thus, these levees are now degraded (Huffman, personal communication).

An important implication resulting from this funding shortage has been the increased risks of levee failure and the associated risks of an accompanying and uncontrolled release of salts. In January 1995, to decrease the risk of an uncontrolled levee failure in a more critical area, CDFG intentionally breached levees in Pond 2A as an emergency measure (USACE 1997). This breaching occurred during a period when rainfall caused high pond water levels, which in turn threatened to break levees. Fortunately, the controlled breach occurred in a pond that could be detached from the remaining pond system (Huffman, personal communication). In the future, if excessive rainfall again threatens system integrity, the risk of uncontrolled releases will be higher and fewer options to minimize the risks will exist.

The second serious implication involves levee stability for ponds proposed to be retained as managed tidal ponds (Napa Ponds 7, 7A and 8). These levees need to be maintained in the interim to avoid catastrophic release of the bittern and hypersaline brine in these ponds. These levees will also have to be maintained in perpetuity to allow for water level management in these three ponds so that the ecological goals for these ponds can be achieved and maintained. Levees will also need to be maintained around Ponds 1, 1A, and 2, which are being managed as ponds, and around Ponds 6 and 6A, at least for the next decade. If Ponds 6 and 6A are restored to tidal marsh, the restoration will be phased over one to two decades.

7.2.2 Water Management

Water pumping and management is required in the North Bay salt ponds because annual evaporative losses exceed the region's rainfall rates. Water delivery relies on freshwater pumping from two sources: the Napa River and Sonoma Creek (DeJager, personal communication). However, CDFG has never had adequate funding for this activity. Huffman (personal communication) estimates that prior to their purchase, Cargill spent approximately $350,000 annually to provide sufficient water to the 7,500 acres of North Bay salt production ponds. Assuming that all O&M funds are used for water management and when adjusted for 3% inflation annually, CDFG has less than 15% of the financial resources for this purpose. Since levee maintenance also consumes a portion of the $60,000 O&M budget, CDFG has in reality has even less funding available for this purpose.

Inadequate water management has caused the salt ponds to become increasingly saline with some areas evolving into salt flats (USACE 1997; Rugg, personal communication). Pickle ponds in the North Bay have begun to dry out for the first time since their construction years ago (DeJager, personal communication). In these ponds, approximately two to four tons of residual salts remain. As the ponds have dried and become more saline, habitat value for water birds and other wildlife species has decreased (USACE 1997).

Besides increasing the system's overall salinity, insufficient water management has changed the salinity gradient throughout the pond system. Historically, ponds increased in salinity as one moved away from the intake ponds and as brine passed northerly through the salt production process. Since their purchase in 1994, the salt ponds have received water from the Napa River and San Pablo Bay (Huffman, personal communication). Ponds that are geographically central to the system (namely Ponds 4 and 5) are farthest removed from the intake structures, and therefore are least apt to receive water. Thus, unlike the historical pond system in which the salinity gradient increased northerly, the salinity gradient now increases towards the system's center and salinity differences between ponds can be very high. This change has resulted in the formation of saline plugs in the siphons between Ponds 6/6A and 5 and between Pond 3 and 4, in which higher-density saline water settles in the siphon and prevents lower-density low-salinity water from passing through. These plugs can stop flow from a low salinity pond to a high salinity pond despite a head difference between the ponds of two to three feet (Huffman, personal communication). Continuous pumping for several days or heavy rains is often needed to clear the plugged pipes. The altered salinity gradient, resulting from inadequate water management, has exacerbated water transport throughout the system and increased costs.

Additionally, drying out ponds severely affects their soil chemistry. Soils in the North Bay salt ponds have been identified as Reyes soils (USACE 1997). These organic soils become highly acidic when dried, in contrast to the near neutral pH found in wetlands and aquatic systems. A pH of 1 to 2 is typical in the sediments of these ponds when they become dry (Rugg, personal communication). Even when these ponds are flooded, pH conditions are lower than normal because of the acidic sediments (Huffman, personal communication). See Section 5.1 for more information on Reyes soils.

Finally, with or without proper water management, the salt ponds continue to produce salt that is never harvested. As seawater progresses through the pond system, evaporation continues to impound salts, including sodium chloride and bittern salts (Huffman, personal communication). As the ponds continue to operate in their current mode, solar salt production continues (without harvest or management) and complicates future salt and bittern disposal.

Thus, an inadequate water management budget has had several negative impacts on the North Bay salt ponds: increased salinity; increased costs to move water; reduced wildlife value; lowered sediment and water column pH in parts of the system; and increased impoundment of sodium chloride and bittern salts. These effects essentially complicate and increase costs for future restoration efforts.

7.3 Restoration Planning

A multi-agency effort has been underway for several years to plan the North Bay salt pond restoration. Relatively little quantitative hydrologic information was available on these ponds prior to purchase by CDFG because the complex was privately owned (USACE 1997). Therefore, insufficient data existed to develop or screen detailed habitat restoration alternatives, identify areas where historic sloughs could be used, assess water quality effects, anticipate erosion, and analyze effects of levee breaches. Consensus existed that a hydrologic model was needed to develop an effective restoration strategy for the North Bay salt ponds (Rugg, personal communication; Wyckoff, personal communication; DeJager, personal communication; Moore, personal communication).

The USACE (1997) initiated a reconnaissance study in 1996 and developed a single alternative restoration concept to determine whether there is a federal interest in restoration of the North Bay salt ponds. The reconnaissance report concluded that there is sufficient interest and recommended that the report provide the basis for completing a two-phase feasibility study to evaluate alternative restoration options more precisely. This early report can be used as a case study that addresses many of the concerns that arise during restoration.

7.3.1 Protecting Biological Resources and Setting Ecological Goals

Controversy over San Francisco Estuary salt pond restoration efforts generally centers on balancing the tradeoffs between restoring historic habitats (e.g., tidal marsh) and preserving existing salt pond habitats for shorebirds and waterfowl. Restoring the salt ponds to tidal marsh will provide habitat for many native species of plants, fish, and wildlife. However, managed salt ponds have become habitat for some species of migratory birds and other species (USACE 1997; John Takekawa, personal communication; see Chapter 4). For example, higher salinity ponds (greater than 100 ppt) provide denuded conditions free of vegetation that provide good habitat for snowy plover. In general, as salinity increases, the species richness may decrease but specific shorebird species are drawn in fairly high numbers (Huffman, personal communication).

All interested parties agree that increased habitat of all types is essential. Changes in the salt ponds seriously affected wildlife. Populations of several native fish species have suffered serious declines (USACE 1997). The Sacramento splittail, an endemic fish to California, requires flooded vegetation. Diversions, reduced freshwater flows, drought, introduced aquatic species, and loss of wetlands and shallow-water habitat have decimated splittail habitat and led to population declines. Delta smelt populations have declined by an order of magnitude over the last decade for many reasons. River channel modifications and loss of spawning and rearing habitat have contributed to declines in winter-run chinook salmon populations.

In coordination with CDFG and the Coastal Conservancy, the Corps outlined a single restoration alternative weighted heavily towards CDFG restoration preferences (USACE 1997). The Corps study concluded that the proposed restoration alternative (described below in Section 7.3.2) would significantly increase habitat for several threatened and endangered species, including the California clapper rail, the salt marsh harvest mouse, the Sacramento River winter-run chinook salmon, and the Sacramento splittail. Additionally, increased productivity was expected to increase waterfowl, shorebird, and fish populations. The Corps noted that efforts could adversely affect some wildlife populations such as the endangered western snowy plover (USACE 1997). Thus, they suggested that a portion of the salt pond system be maintained as shallow, open water aquatic habitat (i.e., salt ponds). These areas would help mitigate the lost habitat caused by converting the remaining salt ponds to tidal marsh. To minimize costs for maintaining levees and water control facilities, the Corps recommended locating salt ponds where land access was available (USACE 1997).

7.3.2 Preliminary Restoration Approach from 1997

The preliminary restoration approach outlined by the Corps (USACE 1997) divided the Napa salt pond complex into three groups, with different recommendations for each group of ponds. These groups consisted of the low salinity ponds (Napa Ponds 1, 1A, 2,and 3), high salinity ponds (Napa Ponds 4, 5, 6, and 6A), and the hypersaline brine and bittern ponds (Napa Ponds 7, 7A, and 8). The Corps proposed operating the ponds during restoration under a desalination regime. This alternative included preliminary strategies for flushing low salinity ponds, high salinity ponds, and bittern ponds (USACE 1997). The proposal for each of these groups is discussed below.

Low Salinity Ponds

Low salinity ponds (equivalent to Stage 1 evaporator ponds as defined in the Ver Planck model; Table 3-3 in Chapter 3) cover approximately 3,000 acres in the North Bay and do not have greatly elevated residual salt concentrations. The Corps concluded that these ponds could be immediately opened to tidal action and marsh restoration could begin. However, the Corps recommended that restoration be delayed in the event these ponds would be needed as dilution ponds for flushing the higher salinity evaporator and bittern ponds.

High Salinity Ponds

High salinity ponds (equivalent to Stage 2 evaporator ponds in the Ver Planck model; Table 3-3 in Chapter 3) cover approximately 3,000 acres. The Corps concluded that these ponds had sufficient residual salt accumulation to require flushing before restoration could begin. Flushing would occur by restricted tidal exchange and be controlled through gravity flow. Flushing was planned to occur during fall and winter months to avoid impacting the endangered Delta smelt, which is present in tidal sloughs during the spring and summer. Flushing would require constructing new water control structures and weirs. The Corps estimated that five years of controlled flushing would reduce the salt concentrations in these ponds to background levels. Following salt flushing, interior and exterior levees would be breached to allow tidal action. It would take an estimated 20 years for the ponds to revert to tidal marsh by natural sediment deposition and revegetation.

Hypersaline Brine and Bittern Ponds

Bittern and hypersaline brine ponds were expected to be the most difficult and time-consuming to restore because of high residual salt concentrations. These ponds cover approximately 770 acres, making up approximately 10 percent of the total pond area. Because of their proximity to uplands and roads, access to these ponds reduces maintenance difficulties. The Corps study identified these ponds for permanent management as tidal ponds. These ponds were selected for this purpose because land-based access for levee maintenance would minimize costs.

Estimated Restoration Costs

The Corps estimated restoration costs for 5,600 acres of re-created tidal marsh and 770 acres of managed tidal ponds at $19 million (USACE 1997). Lands, easements, rights-of-way, and relocation expenses made up approximately $13 million of this total. The remaining $6 million was for construction, operations, and monitoring. Operations consisted primarily of managing water control structures during the initial five-year salt removal process. Monitoring would occur over 15 years. These preliminary estimates averaged out to approximately $3,000 per acre, which includes one-time and recurring costs.

These estimates are likely low in the context of the South Bay. In Chapter 13 we present restoration costs for low feasibility and high feasibility ponds, which yielded estimates of $1,500 to $5,000 per acre for high feasibility ponds and $5,000 to $110,000 for low feasibility ponds (the higher value being associated with dredged sediment reuse and assuming maximum dredged sediment incremental costs).

7.3.3 Feasibility Study (1998 to Present)

After completion of the 1997 reconnaissance study, the Corps and the Coastal Conservancy entered into a Feasibility Cost Share Agreement in 1998. During the Feasibility Study, costs are shared evenly between the federal and non-federal partners. Restoration planning by the Corps, Conservancy, CDFG, and partner agencies over the past four years has included several work areas as described below (Hutzel, personal communication; Hitchcock, personal communication).

Development of a Napa-Sonoma Marsh Restoration Group

This restoration planning group consists of several categories of interested parties. Trustee and regulatory agencies include BCDC, RWQCB, USFWS, NMFS, USACE, CDFG, Conservancy, Sonoma County Water Agency, Napa County Resource Conservation District (RCD), and Southern Sonoma County RCD. Nongovernmental organizations include Ducks Unlimited, Save the Bay, The Bay Institute, and National Audubon Society. Research organizations include San Francisco Estuary Institute, USGS, and UC Davis. The group also included other stakeholders not affiliated with any of these groups.

Data Collection to Determine Baseline Conditions

- Topographic and bathymetric survey of the project area.
- Hydrodynamic and water quality data collected in the slough system of the Napa-Sonoma Marshes (John Warner and Dave Schoellhamer, UC Davis and USGS).
- Invertebrate, fish, and waterbird surveys, along with water quality analysis, in five of the salt ponds (John Takekawa, *et al.*, USGS).
- Monitoring of the Pond 2A restoration project, including sedimentation and vegetation rates, and fish, invertebrate, and avian usage.
- Water quality and sediment quality analysis at 40 sites in the system. Parameters, developed with the RWQCB, included total metals, dissolved metals, volatile and semi-volatile organics, pesticides, PCBs, pH, temperature, and several others.

Development and Analysis of Restoration Alternatives

- **Development of a hydrodynamic model of the site** (based upon survey and hydrodynamic data) to model salinity reduction and habitat restoration alternatives.
- **Development of habitat restoration objectives**, based upon the Habitat Goals Report, development of habitat restoration alternatives, and preliminary geomorphological analysis of habitat evolution of alternatives.
- **Habitat Restoration Alternative 1:** Mixture of Tidal Marsh and Managed Ponds: Restore ponds 3, 4, and 5 to tidal habitats, manage ponds 1, 1A, western half of pond 2, 7, 7A, and 8 as ponds. Determine fate of ponds 6 and 6A after 10 to 20 years, based upon success of ponds 3, 4, and 5, availability of shorebird and waterfowl habitat in region, and available maintenance funds.
- **Habitat Restoration Alternative 2:** Tidal Marsh Emphasis: Restore eastern half of pond 2, and ponds 3, 4, 5, 6, and 6A to tidal habitats, manage ponds 1, 1A, western half of pond 2, and 7, 7A, and 8 as ponds.
- **Habitat Restoration Alternative 3:** Managed Ponds Emphasis: Restore ponds 3 and 4 to tidal habitats, manage ponds 1, 1A, western half of pond 2, 6, 6A, 7, 7A, and 8 as ponds.

Development and Hydrodynamic Modeling of Salinity Reduction Alternatives

- **Salinity Reduction Alternative 1:** Napa River and Napa Slough Discharge. Under this alternative, salinity reduction in the lower ponds (3, 4/5, and 6/6A) is achieved via a phased approach in which restoration to near-ambient Napa River salinity levels begins at Pond 3 (Phase 1), continues to Ponds 4/5 (Phase 2), and potentially to Ponds 6/6A (Phase 3), with intakes from and discharges to the Napa River. Salinity reduction in the upper ponds (7, 7A and 8) is carried out separately. Discharges from Ponds 7, 7A and 8 will be combined in a mixing chamber, potentially with recycled water, before discharge into Napa Slough.
- **Salinity Reduction Alternative 2:** San Pablo Bay Discharge. Under this alternative, salinity reduction in the lower ponds (3 and 4/5) is achieved via a phased approach in which restoration to near-ambient Napa River salinity levels begins at Pond 3 (Phase 1) and continues to Ponds 4/5 (Phase 2) with intakes from and discharges to Napa River. Salinity reduction in the upper ponds (Ponds 7, 7A and 8) and Pond 6/6A consists of discharge via Ponds 1, 1A, and 2. Make-up water is introduced into the upper ponds and conveyed southward through Ponds 6A, 6, 2, and 1/1A before being discharged into San Pablo Bay.

Design, Modeling, and Cost Estimating

- Restoration design for Ponds 3, 4, and 5, incorporating design features to accelerate habitat evolution.
- Restoration modeling, which will better inform the geomorphological analysis of habitat evolution.
- Civil design of the salinity reduction and habitat restoration alternatives in order to determine construction costs more accurately and conduct the Corps' incremental cost analysis. Costs will probably greatly exceed the original $6 million estimated in the Reconnaissance Report.
- A Real Estate Appraisal to determine the non-federal contribution to the cost share agreement for construction.

EIR/S and Regulatory Work

- Water quality discharge modeling and development of a water discharge permit from the Regional Water Quality Control Board.
- Development of an Environmental Impact Report/Environmental Impact Statement analyzing the

impacts of habitat restoration and salinity reduction alternatives.
- Section 7 consultation with the National Marine Fisheries Service and the US Fish and Wildlife Service.
- Development of a Coordination Act Report and Habitat Evaluation Procedure with the US Fish and Wildlife Service.

Overall Status

The Conservancy, CDFG, and Corps are working to complete a Feasibility Report and EIR/S by the end of 2002 and get the project authorized for construction by Congress under the Water Resources Development Act (WRDA), in order to get federal funds appropriated for construction. The appraised value of the land would count towards the non-federal share of the project (authorized restoration projects with the Corps require a 65% federal/35% non-federal cost-share). If the project is authorized in the 2002 WRDA, preconstruction engineering and design would occur in 2003 and construction would optimistically begin in 2004. If the project is not authorized until WRDA 2004, construction will be delayed by at least one year, and the State of California will have to risk entering into preconstruction engineering and design prior to a signed project cost share agreement. The State of California (Conservancy and CDFG) has also applied for funds from CALFED and the State Water Resource Control Board in order to begin the restoration project by desalinating and potentially restoring Ponds 3, 4, and 5 to tidal action.

7.4 Summarizing Lessons Learned from the Napa River Salt Ponds

By reviewing the Napa River Salt Ponds, several important lessons can be learned directly applicable to restoration of the South Bay salt ponds:

- O&M funding needs to be sufficient to cover levee maintenance, water management, bittern management, and other associated costs and must become available immediately upon purchase. Inadequate and tardy O&M funding will compromise the short-term ecological value of the salt ponds; increase the risks of uncontrolled salt releases and other catastrophic events; continue salt production but without harvesting capabilities; and make water management ultimately more expensive.
- Funding for restoration planning must be secure and appropriate to the size and scale of the project. Funding for construction must be available early in the project in order to phase in restoration work and apply lessons learned to future phases. Funding sources must recognize the value of phased restoration and adaptive management.
- Hydrologic models, based upon topographic surveys and hydrodynamic data, are an important first step in the restoration process as they can provide important guidance with regard to restoring tidal action to ponds, minimizing risks associated with levee breaches, predicting salt transport and assessing sedimentation needs.
- Restoration will require tradeoffs between habitat types; consensus between agencies is important for developing guiding strategies for restoring the entire salt pond complex. Consensus among scientists, resource managers, and trustee and regulatory agencies about ecological restoration goals and objectives is necessary in order to proceed to the development of restoration alternatives and the design and analysis of those alternatives. The Habitat Goals Report (Goals Project 1999) reiterated an already established project goal of providing a mix of tidally restored ponds with managed ponds to benefit a diversity of species.
- A clear understanding of the fate of bittern and hypersaline brine is a critical component of a successful restoration and will reduce long-term restoration costs.
- Special status species effectively increase restoration costs by complicating logistics.
- Soils are poor for many upland vegetation species.
- Per acre restoration costs will generally increase with salinity. Hypersaline brine and bittern ponds will be the most difficult and time-consuming to restore because of high residual salt concentrations.
- Restoration will likely take a minimum of decades.
- The lower end for restoration costs is a few thousand dollars per acre. Low feasibility ponds will be at least an order of magnitude more costly to restore.

Chapter 8.

Restoring Salt Ponds to Tidal Marsh Elevations

Chapter 8.

Restoring Salt Ponds to Tidal Marsh Elevations

A fully functioning tidal marsh typically occurs in the elevation range from roughly mean high water (MHW) to somewhat above mean higher high water (MHHW). Subsidence below these elevations is a fundamental characteristic of the South Bay salt ponds (see Chapter 5). The resulting sediment deficit will hinder restoration efforts because plants cannot begin to colonize until elevations are above mean tide level (MTL) and higher depending on the species. Therefore, successful restoration efforts will need to overcome this constraint without causing adverse impacts to existing biological resources. Of particular concern is the potential loss of existing intertidal and subtidal mudflats caused by shifting vast amounts of sediment into the restored salt ponds via natural processes. Mudflat loss would greatly decrease available shorebird and waterfowl habitat and must be avoided if we are to achieve the stated ecological goals.

In this chapter we discuss sediment supply and transport in the South Bay and how these factors will impact sediment deficits in the salt ponds. We also describe three approaches to restoration of tidal marsh elevations: relying on natural sedimentation, importing dredged sediment, or retaining the most subsided ponds as managed open water habitat. For each approach we examine a variety of topics to shed light on which scenario will resolve the sediment deficit in the most rapid and cost-effective manner while sustaining existing South Bay mudflats.

8.1 Sediment Dynamics in the South Bay

Scientists and engineers still do not have a comprehensive understanding of the San Francisco Estuary system, but research has increased considerably in recent years. In this section we present an overview of South Bay sediment dynamics based on recent information.

The San Francisco Estuary is one of the most complex estuarine systems in the world. Restoring vast areas in the South Bay to tidal marsh will significantly alter the region's sediment dynamics—the erosion, transport, and deposition of sediments. An understanding of these dynamics is necessary to evaluate options for resolving the sediment deficit found in the South Bay salt ponds because these processes determine the sizes and elevations of deep-water channels, mudflats, and tidal wetlands, all of which have ecological significance. They also determine the amount of sediment potentially available to restore subsided salt ponds, which in turn affects the timeframe in which natural processes can restore salt ponds to intertidal elevations.

We have attempted to capture the important elements of South Bay sediment dynamics and their interactions in Figure 8-1. Figure 8-1 presents the different sources of sediment, both internally supplied and externally supplied, to the Bay. It also shows the various actions creating a sediment demand (also referred to as "sediment sinks"). Of these different possible sediment sinks, most are outside control or influence of the actions that would be taken to restore the salt ponds. Thus, these different sinks will be important factors controlling the available supply of sediment for restoring the salt ponds and whether restoration efforts are sustainable with regard to the salt pond restoration itself and the Bay. Finally, this figure shows various feedback mechanisms that cycle sediment from various sinks back to being part of the internal sediment supply. These feedback mechanisms are dredging, erosion and resuspension. The many features in this figure are discussed in greater detail throughout this chapter.

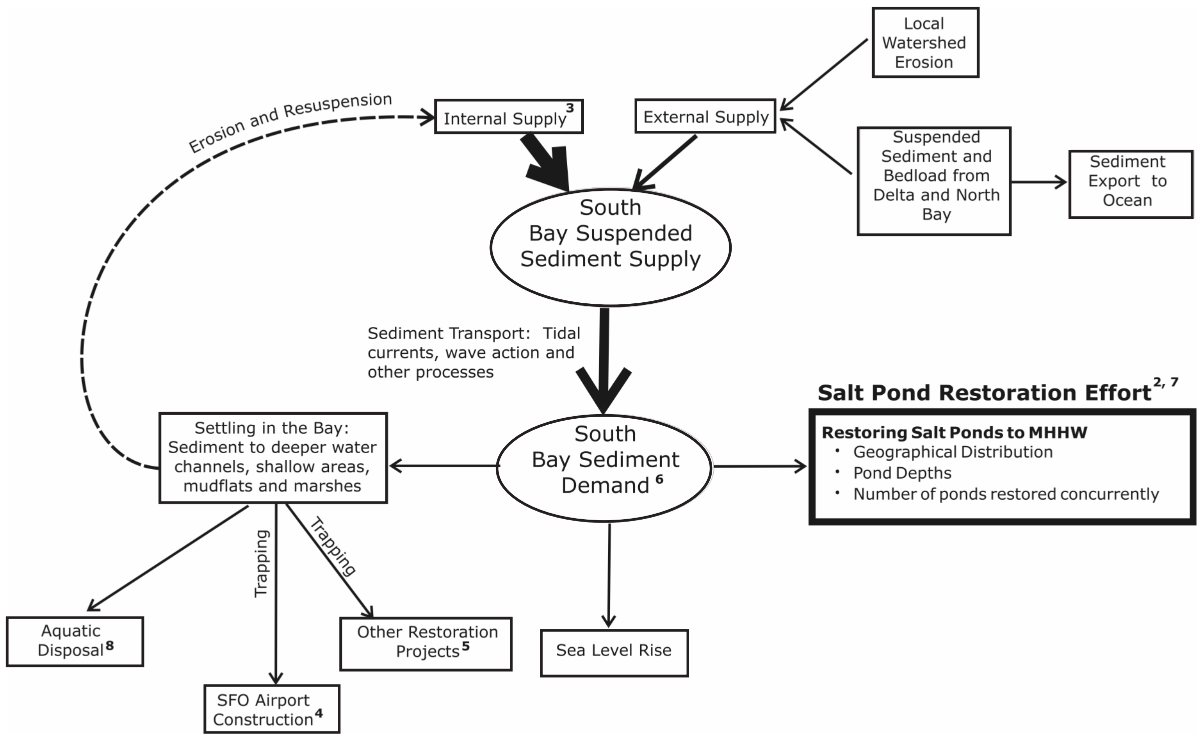
The single most important point that we want to bring to the reader's attention from the following discussion is that the source of sediment to restore salt ponds to marsh plain elevations is one of the most critical factors dictating the methods, costs and time period of salt pond restoration. First, on any given day there is a tremendous volume of sediment suspended in the water column available for deposition. Second, a vast majority of that suspended sediment comes from internal resuspension off South Bay mudflats and only a small amount comes from external inputs and the main South Bay deep water channel. Third, almost every salt pond has subsided and thus becomes a sediment sink when opened to tidal action. Therefore, the rate at which these sediment sinks are created directly affects the sustainability of the South Bay mudflats. Achieving restoration through natural deposition without starving the mudflats of their sediments will require more than 100 years.

8.1.1 Sediment Sinks

Within the San Francisco Bay, there are several sediment sinks. Each of these by definition creates a sediment demand (Figure 8-1). Sediment that is transported into or within the bay at first settles onto mudflats, in marshes and into deeper water channels. These sediments can have many fates. Some of these sediments find their way to restoration sites where natural sedimentation is the mechanism restoring marsh plain elevations. Some of these sediments, especially those in the tidal flats and deeper water channels, are subsequently eroded, resuspended, and transported elsewhere. These resuspended sediments provide an "internal" sediment source and in this way sediment cycles through the system from sources to sinks and back. For sediments in deeper water channels and other areas impeding shipping traffic, dredging is conducted.

Dredging equates to a sediment sink in that it repeatedly creates a new location into which suspended sediments can deposit. Unless dredged sediment is reintroduced into another sediment sink (e.g., a wetland restoration project or other beneficial use), it is permanently lost from the Estuary's sediment supply. Historically, dredged sediments have been disposed of in the Bay at several locations (mostly near Alcatraz) with the expectation that tidal currents would transport the sediment through the Golden Gate and out

Figure 8-1. Sediment cycling in South San Francisco Bay



1 Solid lines represent direction of sediment flow from supplies to demands. Dashed lines represent feedback mechanism (flow of sediment back into supply).

2 Thickened box represents salt pond restoration effort. All other variables (e.g., other projects, natural processes) are outside the direct control of the restoration effort.

3 Volume of internal sediment supply, largely from mudflat sediment resuspension, is far greater than external sediment supply.

4 Proposed SFO runway expansion could create sediment demands (sinks) on the lee side of new runways, in wetland mitigation projects, and from in-bay borrow pits.

5 Other large tidal marsh restoration projects plan to use dredged sediment and/or natural sedimentation: Hamilton-Bel Marin Keys (Marin County), Montezuma (Solano County), Bair Island (San Mateo County), Eden Landing (Alameda County), and Pond A4 (Santa Clara County). See Map 1.

6 In this view of sediment cycling, "demand" is defined as creation of a sediment sink by the action noted.

7 Demand created by restoring South Bay salt ponds will depend upon many factors including those listed.

8 Aquatic disposal includes ocean disposal or in-Bay (near Alcatraz) disposal with the expectations that tidal currents will transport sediments to the ocean.

into the ocean. The relatively high environmental cost of in-bay disposal along with the recognition that dredged sediment can be used as a beneficial resource led to creation of the Long-Term Management Strategy (LTMS) for Dredged Sediment Placement in the San Francisco Estuary in 1990. The LTMS, consisting of the four dredging regulatory agencies (USACE, USEPA, BCDC, and RWQCB) along with resource agencies and a wide variety of interested parties, completed its final management plan in 2001 (LTMS 2001). Through its efforts, beneficial reuse of dredged sediment for marsh restoration has been undertaken along with ocean disposal (LTMS 1996). There are several restoration projects in the region for which dredged sediment has been used (Pond 3 in Hayward (1974), Faber Tract in Palo Alto (1969), Muzzi Marsh in Corte Madera (1976), and Sonoma Baylands in Sonoma County (1996)) or is being considered (Hamilton Airfield, Bel Marin Keys, Montezuma, Bair Island, Eden Landing and Pond A4 in Santa Clara County).

Other anthropogenic activities that would create a sediment demand (i.e., become sediment sinks) include:

- San Francisco and Oakland International airports runway expansion projects. The new runways would create a larger leeward sediment trap.
- In-bay borrow pits created as part of runway expansion construction activities.
- Salt pond restoration efforts. The large sediment deficits that occur in the salt pond system (Chapter 5) would create an additional demand on sediment resources.
- Other tidal marsh restoration projects currently being planned or soon to be under construction, including Bair Island in Redwood City, Eden Landing in Hayward, and Pond A4 in Sunnyvale (see Map 1).

All of these possible sinks need to be considered in the context of sea level rise. Sea level rise along the California coast is expected to range from 1.3 to 2.0 millimeters per year or more depending upon location (Titus and Narayanan 1995, IPCC 2001). As sea level rise occurs, tidal flats, mudflats and marshes will need to raise their elevations in order to maintain their current environmental characteristics. This process of maintaining elevations relative to sea level will create a sediment demand throughout the San Francisco Estuary.

8.1.2 External Sediment Inputs

South San Francisco Bay receives a net annual average sediment influx of 0.89 million cubic yards (MCY) (Krone 1996). The Delta provides between 80 – 90 percent of the total sediment load to the Estuary, transmitting sediment from throughout the entire Sacramento-San Joaquin valleys, which represent about 40 percent of California's land area. Local watersheds contribute the remainder (Krone 1979). Most sediment enters the Bay during winter and early spring, corresponding to periods of maximum runoff. The Sacramento River supplies the most sediment, on average seven times more than the next largest river draining into the Estuary, the San Joaquin River (Schoellhamer, personal communication).

Over the past 150 years, the Estuary's sediment inputs have undergone two major shifts. First, hydraulic mining in the Sierra Nevada from the mid- to late-1800s dramatically increased sediment loads into the Bay. From 1856 until 1884, when hydraulic mining was stopped, more than 340 MCY of sediment were deposited into San Pablo Bay alone. Another 170MCY continued to accumulate in San Pablo Bay over the next 70 years. Only since the early 1950s has this trend reversed, with 9 MCY eroding between 1951 and 1983 from San Pablo Bay (Jaffe *et al*. 1996). Second, the construction of dams throughout the Central Valley decreased sediment loads into the Bay. From 1909 until 1966, 86 percent of the Estuary's sediment came from the Central Valley. Since the 1960s, inputs have markedly decreased because sediments have been retained in reservoirs (Schoellhamer 1996). As a result, sediment loads into the Bay in the early 1990s were approximately 50 to 70 percent of their pre-1960 levels.

Previous studies, summarized in Krone (1996), show that the South Bay deepened from 1870 to 1950 and then accumulated an average of 0.89 MCY year from 1955 to 1990. Despite the Sacramento River's prominent role in providing sediment to the Bay-Delta Estuary, its role in providing sediment to the South Bay is less certain. Yancey and Lee (1972) showed the mineral assemblage of South Bay sediments was glaucophane-jadeite, an assemblage very common to the California Coast Range. The mineral assemblage for the remaining Bay sediments (i.e., Central, San Pablo, and Suisun Bays) was hornblende-augite-hypersthene. This assemblage originates in the Central Valley and results from the mixing of volcanic, metamorphic, and sedimentary rocks. These findings suggest that the South Bay's primary sediment supply is local mountains and watersheds, not the Central Valley. Local South Bay watersheds do have some dams and reservoirs, but there are relatively few and thus have probably not decreased significantly the sediment loading from its historic level. Therefore, local watershed sediment supply to the South Bay is probably not as reduced relative to historical levels as is the case for the sediment supply originating from the Central Valley.

8.1.3 Sediment Resuspension and Internal Inputs

Though a relatively small amount of new sediment enters the South Bay annually, a far greater volume of sediment is continually resuspended into the water column and subsequently redeposited internally (Krone 1979, 1996), due in large part to the fact that the South Bay is predominantly shallow tidal flats with a single large deep-water channel (see Map 1). These natural processes result in an internal sediment supply in the South Bay. Resuspension of sediment from the Bay bottom requires flow velocities high enough to overcome sediment resistance to erosion. Four mechanisms contribute to current strength in the Estuary: tides, winds, freshwater inflows, and salinity-induced density differences. Tidal currents and winds contribute far more to South Bay sediment resuspension than does freshwater inflows and density gradients (Schoellhamer 1996).

Tidal currents. The daily rise and fall of the tides represent an important physical force contributing to sediment resuspension. The magnitude of this forcing function varies on a daily basis with the inequality of tidal heights and associated tidal ranges, on a roughly two-week lunar basis (the spring-neap tidal cycle), and on a seasonal solar basis (summer and winter solstices and spring and fall equinoxes). However, the spring-neap tide cycle accounts for more than half the variation in South Bay suspended sediment concentrations (Schoellhamer 1996).

Winds. Additionally, winds generate a shear on the water surface that influences tidal flow. In periods of strong wind, these flows can erode South Bay sediment from the Bay bottom, especially in shallow areas. Schoellhamer (1996) found that the greatest South Bay sediment concentrations occur during summer afternoons when the strongest winds typically occur.

8.1.4 Mechanisms of Sediment Transport

Once sediments are suspended in the water column, tidal currents are the primary force causing sediment transport in the South Bay, though other currents play a lesser but important role (Schoellhamer 1996). Wind-driven currents can reach velocities two to five percent of the wind speed. Salinity-density currents originate with the onset of winter storms; freshwater inflows push down through the Central Bay, lowering water density. The saltier, higher density water moves seaward along the Bay's bottom and is replaced by fresher, lower density water flowing near the surface. The same mechanism also occurs, but at a much smaller scale, from local freshwater stream discharges. Finally, prop wash from boats moves sediments as well. For all these currents, the greater its magnitude the larger and greater amount of suspended sediments is transported around the Bay.

Spring-Neap Tidal Cycles

During spring tides, shorter duration slack water periods limit sediment deposition and consolidation of newly deposited sediment. During neap tides, longer duration slack water periods promote sediment deposition and bed consolidation. Consequently, sediments accumulate in the water column as spring tides approach and slowly deposit as neap tides approach (Schoellhamer 1996). These conditions result in sediment transport from shallow areas to the main channel during spring tides and the reverse during neap tides, with net transport toward the shallow margins (Schoellhamer 1996).

Seasonal Cycles

Sediment transport is also affected by season. During summer, diurnal breezes generate wind waves that increase sediment concentrations, resulting in a landward flux of suspended sediments in shallow water and a seaward flux in deeper channels. During winter, lighter winds, lower suspended solid concentration, and greater variance in wind direction result in less sediment transport.

Role of Bathymetry and Bay Shape

Though sediment transport depends upon many factors including tidal currents, winds, freshwater runoff and longitudinal density differences, these forces interact with the Bay bathymetry (depth) and shape to control sediment transport and distribution (Schoellhamer 1996). To understand the effects of the various forces transporting sediments, understanding the effects of the Bay's bathymetry and shape provides context.

On submerged tidal flats, wave action predominates over current velocity as a distributing force (Sustar 1982). Variation in sediment grain size correlates directly with wave energy distribution. In other words, bigger waves move larger sediments. In deep-water areas, current velocity is the predominant estuarine force. Currents reach a maximum velocity at the channel's center and diminish towards the banks. Thus, bathymetry determines which tidal forces most affect sediment transport.

Shape also effects water flow and sediment transport. Because the South Bay acts essentially as an enclosed basin, wave reflections from the Bay's south end are superimposed upon the incoming tides, forming nearly standing waves. The strength of these currents depends on the magnitude of freshwater inflows, the intensity of vertical mixing, and the tidal amplitude. During neap tides, vertical mixing is reduced and salinity-density currents are relatively strong. In contrast, during spring tides these currents are weak.

The South Bay is most dynamic during the winter with the onset of storms. South Bay hydraulic retention times (HRTs) are typically less than a month during this time of year because of the density-driven exchange with the Central Bay. Inversely, during the summer the South Bay can be described as a tidally oscillating lagoon. Water enters along the northeastern side and exits over the remainder of the entrance with HRTs on the order of months. Eventually, with declining freshwater inflows and with the resulting increased salinity in the Central Bay, the flow circulation that occurs in the winter can sometimes reverse (Walters *et al*. 1985).

8.2 Estimating the Sediment Deficit for Salt Pond Restoration

We define the sediment "deficit" as the difference between existing salt pond bottom elevations and the tidal marsh plain elevation. In order to present our analysis of how to address the sediment deficit, we must first develop an estimate of the sediment deficit volume based on restoration goals. We arrive at this volume by taking three results into account and making one critical assumption.

The first result, from Chapter 5, is that the sediment deficit of all South Bay salt ponds (excluding only those ponds in the Newark area for which we could not obtain reliable topographic data) is about 108 million cubic yards (MCY). The second result, from Chapter 5, is that the estimated net annual sediment influx to the South Bay is about 0.89 MCY (Krone 1996), a small fraction of the sediment deficit. The third result, from Chapters 2 and 4, is that not all salt ponds should be restored to tidal marsh. Instead, retaining about one-third of the total pond acreage as managed open water areas will be essential to support a wide variety of wildlife species that currently depend upon the salt ponds. Finally, we must make a simplifying assumption about which one-third of all salt ponds should be retained; we have opted simply just to remove one-third the total sediment deficit volume of 108 MCY, or about 36 MCY, which leaves a sediment deficit of 72 MCY that must be addressed.

The actual deficit will depend upon the specific ponds selected for tidal marsh restoration and would be reduced if fewer of the deeply-subsided Alviso ponds are restored to tidal marsh. Additional planning efforts are necessary to develop an integrated restoration approach for the entire salt pond complex to identify specifically which ponds should be restored to tidal marsh. The GIS data provided in Appendix C contains all the data necessary to recalculate a sediment deficit for any future restoration scenario.

This estimate does not account for sea level rise, which has varied between 0.8 and 2.1 millimeters per year along the Pacific Coast. Near San Francisco, current sea level rise is estimated at 1.3 millimeters per year (Titus and Narayanan 1995). A recent review of global climate change (IPCC 2001) has increased the estimates of global sea level rise over the next century to 3 feet, or roughly 10 mm/yr. If these predictions hold close to true, then the sediment deficit estimates here are considerably low and the region would have a few other issues to be concerned about beside wetland accretion.

Once we have an understanding of the size of the sediment deficit, perhaps the largest challenge facing South Bay salt pond restoration is resolving the disparity between the sediment demand created by subsided salt ponds and the available sediment supply *without scouring the South Bay mudflats and damaging their habitat functions.* In practice there are three options to resolve this disparity, each of which is discussed in the following three sections and each of which has its pros and cons:

- Natural sedimentation (Section 8.3)
- Dredged sediment reuse (Section 8.4)
- Retaining the most-subsided Alviso ponds as open water (Section 8.5).

8.3 Using Natural Sedimentation to Restore Elevations

For the natural sedimentation approach, the primary issue is whether South Bay mudflats are sustained at their current levels or significantly eroded. Natural processes, especially during windy summer conditions, continually resuspend and redistribute sediment from the mudflats, creating high sediment concentrations in the water column. In the absence of restoration efforts, these sediments eventually redeposit onto the mudflats and maintain an overall bathymetric equilibrium (or slow net change; insufficient data exist to accurately characterize mudflat bathymetric changes over time).

However, restoration of the South Bay salt ponds would change this equilibrium. The resuspended sediments would, on average, be transported into the restoration sites, and thus not redeposit onto the mudflats. Were restoration implemented too quickly, a massive transfer of sediment from the mudflats to the restored salt ponds would likely occur. If all South Bay salt ponds were rapidly opened to tides, we estimate the ponds would reach intertidal marsh elevations relatively quickly over an estimated period of 15 to 50 years. This rapid sediment relocation would result in loss of considerable mudflat habitat causing significant adverse environmental impacts to shorebird and waterfowl habitats.

These impacts can be avoided under the natural sedimentation approach by phasing the restoration over many decades. Phasing restoration would balance sediment demand from the restored salt ponds with the sediment inputs into the South Bay. In the next section (Section 8.4), we compare the economics of natural sedimentation, including its associated long-term O&M costs, to that of dredged sediment reuse which would speed the total time of restoration and thus reduce the time period over which O&M would be necessary.

Results

We used three scenarios to estimate the time necessary to reach tidal marsh plain elevations on two-thirds of the salt ponds (approximately 18,000 acres) using natural sedimentation. In all three scenarios, we assumed a constant annual net sediment supply rate of 0.89 million cubic yards (Krone 1996). This value is the best available, although additional studies are needed to refine it (Schoellhamer, personal communication). The differences between the three scenarios are the rates of projected sea level rise (1.3 and 2.0 millimeters per year) and the areas requiring "maintenance" sediment deposition (mudflat only or marsh plus mudflat). A description of the three scenarios, including assumptions and potential outcomes, are provided in Appendix E. The results of our calculations are presented in Table 8-1.

Assuming that sediment supply is adequate and that restoration is phased slowly enough to avoid mudflat scour, roughly 107 to 164 years are required to raise elevations to MHHW in two-thirds of the total South Bay salt pond complex (Table 8-1). Such an extended time frame is well beyond the 50-year planning horizon of the Goals Report (Goals Project 1999) and warrants public debate regarding its acceptability. Given this lengthy time frame, we believe that restoration of the entire salt pond complex should be considered, as has been done in this Feasibility Analysis, because Cargill may not operate in the South Bay during this entire time period. By considering the entire complex, restoration can be prioritized to achieve maximum ecological benefits in the minimum amount of time. Such a prioritization scheme serves as a foundation for the USFWS Tidal Marsh Ecosystem Recovery Plan currently in preparation (see Chapter 2).

Amongst these three scenarios, we believe the most realistic scenario must consider elevation maintenance of mudflats and existing tidal marshes in the South Bay. Scenarios 2 and 3 incorporate this perspective and differ only in the rate of sea level rise used. Scenario 1, which excludes sediment for maintaining existing South Bay tidal marshlands, is not as realistic because in practice, sediment will accumulate in tidal marshes.

Table 8-1. Timeframe for restoration with mudflat-sustainable natural sedimentation

	Scenario 1	Scenario 2	Scenario 3
	Sediment deposition restores salt ponds and maintains existing mudflats[1,2]	Sediment deposition restores salt ponds and maintains existing mudflats and marshes[1]	Sediment deposition restores salt ponds and maintains existing mudflats and marshes under higher rate of sea level rise[1]
SCENARIO DESCRIPTION			
Sea level rise	1.3 mm/yr	1.3 mm/yr	2.0 mm/yr
Area of restored salt pond	18,000 ac	18,000 ac	18,000 ac
Sediment deficit for two-thirds of total salt pond complex (see Table 8-2)	**72 MCY**	**72 MCY**	**72 MCY**
Existing marsh area requiring sediment	NA	10,000 ac	10,000 ac
Existing mudflat area requiring sediment	15,000 ac	15,000 ac	15,000 ac
SEDIMENT MASS BALANCE[3]			
South Bay sediment supply rate from external sources	+0.89 MCY/yr	+0.89 MCY/yr	+0.89 MCY/yr
Sediment needed to maintain current marsh and mudflats relative to sea level rise	-0.10 MCY/yr	-0.17 MCY/yr	-0.26 MCY/yr
Sediment needed to maintain future restored salt ponds relative to sea level rise	-0.12 MCY/yr	-0.12 MCY/yr	-0.19 MCY/yr
Remaining sediment available to restore salt ponds to intertidal elevations	**+0.67 MCY/yr**	**+0.60 MCY/yr**	**+0.44 MCY/yr**
RESTORATION PERIOD			
Time to restore salt ponds without net scour of mudflats or drowning of tidal marshes	**107 years**	**120 years**	**164 years**

1 *Assumes that current sediment supply and sea level rise rates are constant over the period of time estimated. Sediment supply is likely to vary but by how much is too difficult to predict. Recent predictions (IPCC 2001) have suggested sea level rise rates up to 10 mm/yr in some areas.*

2 *MCY = million cubic yards.*

3 *Net sediment supply available for restoration equals sediment supplies minus sediment sinks.*

Conclusions

Our review of the existing studies and the calculations presented below suggest that a restoration strategy reliant solely on natural sedimentation will require about 120 years to complete if done in a manner that sustains the existing South Bay mudflats. This conclusion is based on four considerations: (1) the best available estimate of 0.89 million cubic yards per year net sediment influx (Krone 1996); (2) a calculated sediment deficit of 72 million cubic yards (Section 8.2); (3) the assumption that most all other sediment sources and sinks remain constant; and (4) the lowest rate of predicted sea level rise. We know that many other changes to the system have and will continue to occur. The biggest possible changes that would alter the sediment source-sink relationships are: (1) increased tidal prism from large-scale tidal marsh restoration; (2) new sediment sinks from proposed San Francisco and Oakland airport runways, in-bay borrow areas, and other restoration projects; and (3) alterations in bay circulation from proposed San Francisco and Oakland airport runways (see Figure 8-1; NOAA 1999). During future restoration planning efforts, a more sophisticated model will need to consider these and other factors when predicting natural sedimentation trends and timelines. We offer these results as a first step in quantifying the necessary restoration timeline and providing a basis for future discussions.

One very important point regarding the natural sedimentation approach and the time frame calculated in Table 8-1 is that during the entire time period identified above, the salt ponds will require interim operations and maintenance (O&M) until they are restored. We provide a rough estimate of these costs in the next section, alongside comparable costs for dredged sediment reuse.

8.4 Using Dredged Sediment to Restore Elevations

The primary alternative to natural sedimentation involves placing clean dredged sediment in salt ponds prior to restoring tidal action. Beneficial reuse of suitable dredged sediment could help offset the shortage in sediment supply (see Figure 8-1). The Long-Term Management Strategy (LTMS) for dredged sediment disposal in the Bay Area proposes that clean dredged sediment be used in three ways. It proposes that 20 percent be disposed in-Bay (0.7 to 1.2 million cubic yards), 40 percent be disposed in the ocean (1.4 to 2.4 million cubic yards), and 40 percent be used for beneficial reuse purposes, including wetland habitat restoration (LTMS 1998, 2001).

With natural sedimentation, mudflat-sustainable restoration is expected to take over 100 years (Section 8.3). Using dredged sediment shortens the time required to achieve tidal marsh restoration and allows for more restoration without significant mudflat erosion. When using dredged sediment, total time to complete restoration of the entire salt pond system depends on the time required to place dredged sediment and on the time required for the remaining pond area to fill through natural sedimentation. By using dredged sediment, the restoration time for the entire system is shortened to a range of 56 to 72 years. This shortened O&M period has an important economic benefit: reduced O&M costs.

For the dredged sediment approach, there are several issues discussed in this section:

- Dredged sediment suitability (Section 8.4.1)
- Dredged sediment sources (Section 8.4.2)
- Dredged sediment availability (Section 8.4.3)
- Logistical and economic challenges of locating a suitable offloading facility in the South Bay (Section 8.4.4)
- Ecological opportunities and constraints (Section 8.4.5)
- Economics of dredged sediment reuse in contrast to natural sedimentation (Section 8.4.6).

8.4.1 Dredged Sediment Suitability

Bay sediments can be categorized as old Bay mud, young Bay mud, sand, and peat. Throughout most of the estuary, the underlying sediment is a marine clay-silt termed "old Bay mud." This older sediment is generally dense, with low moisture and organic carbon content. An exception occurs in the North Bay, where highly organic, natural peat deposits underlie the young Bay mud, and in the vicinity of Oakland and Alameda, where a fine-grained, hardened sand known as "Merritt Sand" is located relatively close to the surface.

The upper several feet of sediment usually consists of recently deposited marine or riverine sediments. In areas of low current velocities (i.e., most areas of the estuary), young Bay mud is present. This sediment is a combination of silt and clay. Young Bay mud varies in thickness and tends to have a low density, with high moisture and organic carbon content—in contrast to the older, underlying sediment. In the South Bay, shell debris covers a wide expanse.

Older sediments are typically dredged only during new projects, such as new navigation channels. Most Bay dredging projects involve newly accumulated material found in existing navigation channels. Except in areas with significant water movement, this material is typically 80 to 90 percent silt or clay and is very soft.

Dredged sediment must be suitable for use in wetland restoration projects. The contaminant levels of sediments depend largely upon their age, location and physical characteristics. Trends in sediment contamination have been studied as part of the San Francisco Bay Regional Monitoring Program and the Bay Protection and Toxic Cleanup Program. Ancient sediment deposits as well as sediments deposited in the past 30 years (since water regulations have been in effect) tend not to be contaminated at significant levels unless they are near a contaminant source such as shipyards, naval facilities, industrial facilities, oil refineries, water treatment plants, and storm drain discharges. Sediments that were contaminated during Sierra Nevada hydraulic mining activities and began entering the Bay around the 1860s to around the 1950s tend to be more contaminated. Some of these sediments that originally deposited in San Pablo Bay appear to be eroding and thus could be distributed elsewhere within the Bay (Jaffe *et al.* 1996). Finer grain material tends to be more contaminated because of their higher adsorptive capacity. Thus, dredged sediments can vary greatly in contaminant concentration throughout the Bay.

Depending upon the nature of the dredging activities, different aged sediments are likely to be dredged. New dredging projects either excavate older geologic deposits or deposits from hydraulic mining. Maintenance dredging, which accounts for much of the annual dredging volume, typically excavates relatively recently deposited sediment. Thus, sediments collected tend to be new relatively recent deposits the contaminant levels of which are influenced by proximity to local contaminant sources. For these many reasons, the LTMS (1998) assumes 20 percent of all dredged sediment will be unsuitable for aquatic disposal because of contamination. The San Francisco Bay Regional Monitoring Program and the Bay Protection and Toxic Cleanup Program continue to study sediment concentration trends.

8.4.2 Dredged Sediment Sources

Overall, the San Francisco Estuary receives an excess of sediments. Dredging these sediments is needed routinely to maintain navigable depths for ports, military bases, marinas, and the channels linking these areas to the Golden Gate. Because of the net influx of sediments into the Bay, LTMS (2001) anticipates that about 6 million cubic yards of sediment will be dredged annually over the next 50 years. Most of this dredging occurs at the Ports of Oakland, Richmond, and San Francisco, the industrial berths in San Pablo and Suisun Bays, and the main navigation channels through San Pablo and Suisun Bays. This volume represents both maintenance and new project dredging, but it excludes dredging for the proposed runways at the San Francisco and Oakland Airports.

Dredged sediment source is an important consideration, particularly with respect to the ease with which the sediment can be transported, offloaded, and placed within a targeted salt pond and to its suitability. Other considerations include the sediment's grain-size characteristics and its suitability as wetland substrate.

From a geographic perspective, dredged sediments are available from two general sources. South Bay sources include maintenance dredging for flood control projects, Port of Redwood City, local marinas, and navigation channels. The proximity of these sources to the salt ponds makes their transport, offloading, and placement more flexible and perhaps less costly, depending on the actual dredging and placement locations. However, the amount of available material is likely to be small. For example, the largest source of South Bay dredged sediment is currently the Port of Redwood City. It typically dredges on a three-year cycle, with total volumes per cycle ranging between 250,000 to 970,000 cubic yards (HT Harvey and Associates 2000).

The second source is more distant: maintenance and new project dredging at the Port of Oakland, Port of San Francisco, and Central Bay navigation channels. This category could also include the proposed runway expansions at San Francisco and Oakland Airports. The distance of these sources dictates a comprehensive strategy for sediment offloading and distribution into the salt ponds. However, these sources are probably much larger (i.e., several million cubic yards) than South Bay sources. Potential sources further north in the Estuary exist, but we assume that other, more local beneficial reuse sites would utilize those sediments (e.g., restoration projects at Hamilton-Bel Marin Keys in Novato and Montezuma in Suisun Bay).

8.4.3 Dredged Sediment Availability

A considerable difference exists between the volume of dredged sediment likely to be available and the volume actually available. The LTMS (1996, 2001) anticipates that up to 2.4 million cubic yards of dredged sediment will be available annually for wetland restoration. Dredged sediment volumes available for wetland restoration could increase if the amount LTMS anticipates for deep ocean disposal (up to another 2.4 million cubic yards annually) is diverted for beneficial reuse.

Competition for beneficial reuse of dredged sediment already exists. Reuse capacity soon may exceed supply. The 1,800-acre Montezuma Wetland Project in Solano County, with an estimated capacity of 17 MCY, received its permits in fall 2001, began site preparation work, and should be available in 2002 for accepting dredged sediment. The 900-acre Hamilton Wetland Restoration Project also began construction in 2001 and may be available in 2002 for accepting dredged sediment. Adjacent to the Hamilton project is the 1,600-acre Bel Marin Keys Unit 5. These two sites may be joined into a single project with a combined capacity of about 30 MCY. The Port of Oakland's 50-ft deepening project will place about 7 MCY at its nearby Oakland Inner Harbor subtidal habitat restoration area.

The consequence of this competition for dredged sediment is that it may be difficult to secure the necessary volume of sediment to speed restoration of the South Bay salt ponds. Combining the beneficial reuse needs of Hamilton/Bel Marin Keys, Montezuma, and only the deeply subsided Alviso salt ponds totals approximately 90 million cubic yards. This volume represents 35 to 60 years of dredging, assuming that 40 percent of the total dredged sediment goes to beneficial reuse projects as proposed by the LTMS. Diverting all sediments slated for ocean disposal to beneficial reuse projects doubles the available sediment volume. This reduces the timeframe to 17 to 30 years.

Beneficial reuse is generally the most expensive option for dredged sediment disposal. The cost estimates derived in Section 8.4.6 below recognize this reality and present the cost differential of using dredged sediment for beneficial reuse above that for ocean disposal. Because of these potentially high incremental costs, one cannot assume that the 40 percent designated for ocean disposal can be diverted to beneficial reuse without considerable additional funding. The only circumstance in which beneficial reuse may be less costly than ocean disposal is where the dredging location and the reuse project are in close proximity, thereby reducing transportation, offloading, and distribution costs.

If the San Francisco and Oakland Airports obtain approval for their runway expansion projects, each would generate substantial volumes of dredged sediment. Current estimates for dredging needs at the San Francisco Airport are between 20 and 60 million cubic yards. The Draft Environmental Impact Report, due for public release in fall or winter 2002, should provide a better estimate of these volumes. No dredging estimates are available for the proposed Oakland Airport expansion. If these sediments are clean, they could make a considerable contribution towards offsetting South Bay salt pond sediment needs.

8.4.4 Dredged Sediment Offloading, Distribution, and Placement

The most complicated aspect of using dredged sediment to raise salt pond elevations will be getting the material from the dredging area into the target salt ponds. For all large dredged sediment sources (i.e., distant sources), sediment will be shipped from the dredging location to the offloading location on large barges with drafts ranging between 8 and 16 feet (CSCC and USACE 1998). From the offloading location, dredged sediment will then be pumped as a slurry through pipelines to the target salt ponds. The slurry will be 80 to 90 percent water and 10 to 20 percent dredged sediment. The primary issues associated with this approach will be practicality, logistics and economics. Three potential scenarios are presented below with each assuming that most of the targeted receiving ponds will be the deeply subsided Alviso ponds that extend from Mountain View to San Jose.

Offloading Scenario 1: Offload at Port of Redwood City and Pump to Targeted Salt Ponds

This scenario includes transporting the dredge barges from the dredging area to the Port of Redwood City using the port's deep-water navigation channel and industrial infrastructure (see Map 1). From this offloading point, a pipeline and a series of booster pumps would be built to distribute the sediment roughly 8 to 13 miles (12 to 20 kilometers [km]) to the targeted Alviso salt ponds. Piping and booster pumps are relatively simple technologically with determinate costs. However, the pipeline right-of-way could be extremely complicated and expensive to obtain since it must be either on land (i.e., passing through many cities) or in the Bay. Additionally, the pipeline could be subject to vandalism.

Offloading Scenario 2: Construct In-Bay Offloading Facility at Southern Edge of Existing Deep Water Channel and Pump to Targeted Salt Ponds

This scenario includes transporting the dredge barges to the southernmost location where existing water depths will support a dredge scow. An open-water offloading facility would need to be constructed at that location, along with a pipeline to shore. Such an arrangement would be quite similar to that recently constructed for the Hamilton project in Marin County. The large dredge scows require about 16 feet of draft. The deep-water channel (at least 18 feet below MLLW) extends about 1.5 miles south of the Dumbarton Bridge (see Map 1). Assuming placement in the deeply subsided Alviso ponds, pumping distances would range from three to nine miles (5 to 14 km). Pipes would cross the open Bay bottom, so the right-of-way issue would be straightforward assuming Coast Guard approval. Once on land, the pipeline could extend on existing salt pond levees to various targeted salt ponds.

Offloading Scenario 3: Dredge Channel to Central Offloading Location and Pump to Targeted Salt Ponds

This scenario includes dredging a temporary deep-water channel to a central location along the South Bay shoreline and constructing an offloading facility at this location. Assuming placement in the deeply subsided Alviso ponds, the offloading facility could be located at the edge of Pond B2 (already designated in the BCDC Bay Plan as a possible shallow-draft port; see Map 4). An approximately four-mile channel would need to be dredged from the southern extent of the existing deep-water channel to this point. This would require roughly 0.5 to 1 million cubic yards of dredging, depending on the route and existing water depths. From the offloading station, pipes would transport the dredged sediment to the targeted ponds, with pumping distances ranging from three to four miles (5 to 6 km). Pond B2 could also be used as a temporary storage pond, with dredged sediment initially pumped into this pond and subsequently pumped to targeted ponds. Such a strategy could speed offloading operations.

Dredged Sediment Placement

Once the dredged sediment has been pumped to a targeted salt pond via one of these pipeline distribution approaches, the sediment is generally discharged directly into the salt pond from the pipe. Many recent and proposed restoration projects (e.g., Sonoma Baylands, Hamilton/Bel Marin Keys, Montezuma, Bair Island in Redwood City) contemplate multiple discharge points for each pond to create a more uniform placement elevation. In some of these projects, internal berms are constructed to create "cells" separating areas designated as marsh plain from tidal channels (where dredged sediment is generally not desirable). As can be expected, these internal containment berms add cost to the project. In the case of Bair Island, these internal berms serve the sole function of preserving the antecedent channel network (HT Harvey and Associates 2000).

Once the sediments are placed, the large volume of water used to slurry the sediment (for pumping) must be discharged back to the Bay. Slurry water discharge typically involves use of overflow weirs pursuant to water quality permit requirements.

Sediments are continuously saturated for a period of time to allow the placed sediments to consolidate, after which tidal action is returned. For some uses, such as upland ecotones and seasonally saturated areas, dredged sediments might be allowed to dry. Coarser sediments also may be dried first and graded with heavy equipment to create more specialized wetland features.

8.4.5 Ecological Opportunities and Constraints of Using Dredged Sediment

Two ecological issues with respect to using dredged sediment for tidal marsh restoration in the salt ponds are noteworthy: protecting antecedent channel networks and creation of high marsh. As described in Chapter 5, antecedent channel networks generally will provide a template for channels in the restored salt ponds and, for less subsided ponds, may be very important to ensure adequate tidal circulation (see Section 5.3). In the latter instance, it is generally desirable to retain these networks, which can be achieved by constructing internal berms on either side of the network and placing dredged sediment outside the confines of the channel. This design approach preserves the larger channels but may not be particularly feasible for the smaller ones. Smaller channels will likely be lost with use of dredged sediment, and whether this loss is significant or not requires a case-by-case analysis that considers pond elevations and channel size.

Dredged sediment can be particularly useful to create high marsh rapidly. Under a natural sedimentation approach, high marsh can take many years to restore naturally, as the rate of sedimentation decreases as elevation increases (French and Reed 2001). Dredged sediment, in contrast, can be placed at any desired height (within construction tolerances), such that high marsh can be built directly with dredged sediment. Previous studies have correlated dredged sediment placed at high elevations (approximately 0.5 ft below MHHW) with poor tidal channel formation (LTMS 1994); if the high marsh goal does not depend on extensive channel formation, then such a concern would not apply. Therefore, high marsh creation can be a distinct ecological benefit of dredged sediment reuse in salt pond restoration.

8.4.6 Rough Cost Estimate of Dredged Sediment Reuse

A comprehensive estimate of dredged sediment reuse costs for the South Bay salt ponds is a complex task beyond the scope of this report. Instead, we generated a rough cost range based on our review of publicly available data (LTMS 1996, 1998, 2001; USACE 1998; USACE and Port of Oakland 1998). We updated these data to 2001 dollars, factoring in inflation and higher energy costs. This rough estimate provides a general framework that offers a starting point for evaluating the relative merits of different restoration approaches. It is not intended to be used for decision-making purposes; we recommend a present worth analysis be performed for decision-making purposes that considers all economic, environmental, and ecological costs and benefits.

General Considerations

Three considerations are important when evaluating the relative costs of dredged sediment reuse versus natural sedimentation. First, natural sedimentation derives much of its cost from O&M activities during the extended interim management period. Therefore, to assess the relative cost of the two approaches, we also compared O&M costs for each. Given the lengthy timeframe for elimination of the sediment deficit using natural sedimentation, O&M costs for this approach are much higher than for dredged sediment reuse. A detailed discussion of O&M costs associated with salt pond restoration is presented in Chapter 14.

Second, while dredged sediment reuse has lower O&M costs, it has many additional costs associated with the acquisition, movement, and placement of dredged sediment. Costs associated with this approach depend on many factors such as dredging location, offloading location, pumping distance, equipment used, necessary rehandling, land ownership, pre-placement site preparations, labor and energy costs, and economies of scale. We reflect these cost ranges in our analysis below by considering a "minimum" and "maximum" per-yard dredged sediment reuse cost.

Third, the cost of dredged sediment reuse relative to other disposal options must be considered. The U.S. Army Corps of Engineers conducts an economic analysis for every federally funded dredging project that identifies the "least cost" disposal alternative and then compares other options (such as wetland reuse) against that least cost alternative. LTMS (2001) sets a goal of disposing 20 percent of dredged sediment in-Bay. Since in-Bay disposal is the least expensive and most convenient disposal option, dredgers will always use this option fully. For the remaining dredged sediment, half is slated for ocean disposal and half for wetland or upland beneficial reuse (LTMS 2001). For that sediment, ocean disposal typically will represent the "least cost" alternative. The per-cubic-yard cost difference between ocean disposal and wetland reuse, inclusive of all that is necessary to achieve disposal in each environment, is termed the "incremental" cost. These incremental costs do not receive any federal cost share and thus are the sole responsibility of the local sponsor (LTMS 1996, 2001). Federal cost sharing (typically 75 percent federal/25 percent local sponsor) applies to those costs excluding the incremental costs.

Finally, we assume that any dredged sediment placement will reach elevations no higher than 1.5 ft below local MHHW and that natural sedimentation would provide the final 1.5 ft to MHHW in all cases. This assumption assumes that dredged sediment would not be used for creating high marsh, which may not be the case. We have made this assumption for simplification purposes only to illustrate economics of dredged sediment reuse.

Reuse Scenarios Considered

In order to use dredged sediment effectively, one must decide into which ponds to place the material, how high to place the dredged sediment, and what total volume is desired. Putting aside logistical matters of dredged sediment placement, the choices derive largely from:

- Practical emphasis of putting dredged sediment in more deeply subsided ponds only and allowing less subsided ponds to restore through natural deposition
- Desired geographic distribution of restored tidal marsh and retained ponds within the context that the most subsided ponds are geographically clustered almost exclusively in the Alviso Plant
- Trade off with deeply subsided ponds between the cost of dredged sediment reuse versus comparatively high levee maintenance costs if retained as ponds (assumes that the taller the levee is from base to crest, the more costly maintenance is per unit levee distance)
- Maintaining the overall ecological goal of two-thirds total area as tidal marsh and one-third total area as managed ponds.

For the purposes of our analysis, we have estimated roughly 108.3 MCY total sediment deficit for the entire South Bay salt pond complex (see Tables 5-2 and 8-2) which translates into 72.2 MCY for restoring two-thirds of that area to tidal marsh (Table 8-2). For the 16,000-acre Cargill sale area, the total deficit drops to 89.2 MCY (see Tables 5-2 and 8-2) which translates into 59.5 MCY for restoring two-thirds of this smaller area to tidal marsh (Table 8-2). All these deficits represent the difference between local MHHW (the approximate elevation of tidal marsh) and existing pond elevations.

Desired ecological outcomes are more likely to be reached when natural sedimentation provides the final one to two feet of tidal substrate. Therefore, ponds that fall within this range are not considered in this analysis for dredged sediment reuse. (However, dredged sediment can be useful for rapid creation of high marsh; see Section 8.4.5.)

This framework provides three options for determining which ponds should be considered for dredged sediment placement. With each option, we consider sediment volume needs and overall costs for two acquisition scenarios: the entire 26,000-acre South Bay salt pond complex, and the 16,000-acre Cargill proposed sale area. Options are described below and the sediment volumes are shown in Table 8-2 that we used for the cost estimates presented in Tables 8-3 and 8-4.

- **Option 1: Fill only deeply subsided ponds, same volume for both acquisition scenarios.** Deeply subsided ponds include all ponds below mean tide level (MTL) (see Map 9). These ponds encompass 5,790 acres (Table 5-2) comprising most of the Alviso Plant plus four Redwood City crystallizers. Their area makes up 22.1% of the total salt pond complex and 36.4% of the Cargill proposed sale area. They have a total sediment deficit to MHHW of 57.2 MCY, which translates into a dredged sediment placement volume to 1.5 ft below MHHW of 43.2 MCY. Assuming that two-thirds of these ponds are restored to tidal marsh, these ponds represent a dredged sediment reuse volume of 28.8 MCY. This reuse volume provides 40% of the total sediment deficit to MHHW for two-thirds of the entire complex and 48% for two-thirds of the Cargill proposed sale area.
- **Option 2: Fill deeply and moderately subsided ponds, same volume for both acquisition scenarios.** Moderately subsided ponds include ponds between MTL and 1 ft above MTL (see Map 9). These ponds total 1,950 acres (Table 5-2) located largely in the Alviso Plant plus five Redwood City crystallizers. Their area makes up 7.4% of the total salt pond complex and 12.3% of the Cargill proposed sale area. They have a total sediment deficit to MHHW of 10.8 MCY, which translates into

Table 8-2. Sediment volumes used to calculate restoration costs in Tables 8-3 and 8-4

Ponds	Acres	Sediment Volumes (MCY): Total Deficit up to MHHW	Dredged Sediment Reuse up to 1.5ft < MHHW: Option 1	Option 2	Option 3	Options Apply to: Full Pond Complex	Cargill Sale Area
POND GROUP (CARGILL PLANT)							
Alviso	8,280	68.7	42.4	46.9	48.8	Yes	Yes
Baumberg	4,760	10.8	0.0	0.7	1.7	Yes	Yes
Newark #1	3,930	9.3	0.0	0.0	0.8	Yes	No
Newark #2[1]	6,380	9.8	0.0	0.0	2.7	Yes	No
Redwood City[2,3]	2,840	9.7	0.8	1.7	3.6	Yes	Yes
FULL SALT POND COMPLEX VOLUMES							
All Ponds	26,190	108.3	43.2	49.3	57.6		
Two-Thirds Tidal Marsh	18,000	72.2	28.8	32.9	38.4		
CARGILL SALE AREA VOLUMES							
All Ponds	15,880	89.2	43.2	49.3	54.1		
Two-Thirds Tidal Marsh	11,000	59.5	28.8	32.9	36.1		

1 Topographic data incomplete for Newark Plant #2 therefore sediment volumes underestimate actual conditions.

2 Redwood City contribution to Options 1 and 2 consists of crystallizer ponds only.

3 Acquisition negotiations in 2002 for a reduced-area sale may exclude part or all of Redwood City Plant.

a dredged sediment placement volume to 1.5 ft below MHHW of 6.1 MCY. Assuming that two-thirds of these ponds are restored to tidal marsh, these ponds represent a dredged sediment reuse volume of 4.1 MCY, bringing the cumulative dredged sediment volume to 32.9 MCY. This reuse volume provides 46% of the total sediment deficit to MHHW for two-thirds of the entire complex and 55% for two-thirds of the Cargill proposed sale area.

- **Option 3: Fill deeply, moderately and slightly subsided ponds.** Slightly subsided ponds are defined as ponds subsided between one foot above mean tide level and one foot below mean high water.
    - **Total salt pond complex acquisition.** These ponds are spread out through all five Cargill salt production plants and total 8,350 acres or 31.9% of the total salt pond complex (Table 5-2). They have a total sediment deficit to MHHW of 28.6 MCY, which translates into a dredged sediment placement volume to 1.5 ft below MHHW of 8.3 MCY. Assuming that two-thirds of these ponds are restored to tidal marsh, these ponds represent a dredged sediment reuse volume of 5.5 MCY, bringing the cumulative dredged sediment volume to 38.4 MCY. This reuse volume provides 53% of the total sediment deficit to MHHW for two-thirds of the entire complex.
    - **16,000-acre Cargill proposed sale area.** These ponds are spread out through the Alviso, Baumberg and Redwood City plants and total 4,770 acres or 30.0% of the Cargill proposed sale area (Table 5-2). They have a total sediment deficit to MHHW of 16.5 MCY, which translates into a dredged sediment placement volume to 1.5 ft below MHHW of 4.8 MCY. Assuming that two-thirds of these ponds are restored to tidal marsh, these ponds represent a dredged sediment reuse volume of 3.2 MCY, bringing the cumulative dredged sediment volume to 36.1 MCY. This reuse volume provides 61% of the total sediment deficit to MHHW for two-thirds of the entire complex.

Determining which ponds might be appropriate for dredged sediment placement is beyond the scope of this report. But considerations include proximity of ponds to other subsided ponds (to obtain economies of scale), the amount of dredged sediment available, the funds available (for both dredged sediment reuse and interim maintenance prior to restoration), and similar issues. Though we have included the Redwood City crystallizers in these calculations for the sake of simplicity, in practice those ponds are likely to be retained as managed tidal pannes rather than be restored to tidal marsh for ecological reasons described in Chapter 4.

Assumptions Used in Rough Cost Estimates

We used a number of assumptions to generate our rough cost estimates and it is important for readers to understand these assumptions in evaluating the results.

- **Sustainable mudflat natural sedimentation.** The period of time necessary for restoration to take place, which is used to calculate cumulative O&M costs, is based on natural sedimentation occurring without scouring mudflats, or the 0.89 MCY annual sediment inputs into the South Bay.
- **Dredged sediment availability.** The period of time necessary for placing dredged sediment, which is used to calculate cumulative O&M costs, is based on LTMS estimates of annual dredging volumes and assuming that half of sediment des-

tined for wetland reuse goes to South Bay salt ponds.

- **Duration of O&M costs.** We assume that permanent O&M costs for managing the one-third of total pond area retained as shallow open water habitats goes on for the entire period over which natural sedimentation would be necessary to restore tidal marsh. This assumption allows us to prepare a cost estimate that evenly compares between using and not using dredged sediment. We also assume that interim O&M costs for managing the two-thirds of total pond area being restored to tidal marsh drops to zero after tidal marsh is restored.
- **Permanent O&M costs.** We assume that no measures are taken to reduce permanent O&M costs on ponds retained as shallow open water habitats. In other words, the same maintenance levels for water control and related infrastructure and levees are required in perpetuity. It might be possible to reduce maintenance levels, such as by using dredged sediment in the more deeply subsided ponds retained as shallow open water to reduce maximum water depths and associated highest unit levee maintenance costs. Such measures must consider target ecological goals for such ponds to identify range of optimal water depths.
- **Incremental dredged sediment reuse costs.** We assume that salt pond restoration sponsors would be responsible for the incremental cost of dredged sediment reuse, a cost derived as the difference from lower-cost disposal options (assumed to be ocean disposal).

Results, Per-Cubic-Yard Costs

Given all these unknowns, the best estimate we can offer is that the cost for using dredged sediment in the South Bay salt ponds (in 2001 dollars) probably falls somewhere in the range of $12 to $20 per cubic yard. This compares to approximated costs on the order of $5 to $8 per cubic yard for in-Bay disposal and $10 to $14 per cubic yard for ocean disposal.

Results, Annual Operations and Maintenance Costs

We estimated permanent O&M costs to range between $2.3 and $5.5 million dollars annually for the entire salt pond complex (Table 8-3, II-d) and $1.4 and $3.4 million for the Cargill proposed sale area (Table 8-4, II-d). We estimated interim O&M costs to range between $5.1 and $12.3 million dollars annually for the entire salt pond complex (Table 8-3, II-c) and $3.1 and $7.5 million for the Cargill proposed sale area (Table 8-4, II-c). Interim O&M costs decline to zero over a period equal to the time necessary for tidal marsh to establish in restored ponds. These costs are based on the per-acre O&M cost estimates derived in Chapter 14. Finally, we estimated initial O&M costs during the planning and design period (which we assume to be five years) to be $7.4 to $17.8 million dollars per year for the entire salt pond complex (Table 8-3, II-b) and $4.5 to $11 million dollars per year for the Cargill proposed sale area (Table 8-4, II-b).

Tables 8-3 and 8-4 use these results to present the estimated relative costs of restoring the South Bay salt ponds for the four scenarios (natural sedimentation and three levels of dredged sediment reuse described above). Table 8-3 presents the estimates for the entire 26,000-acre South Bay salt pond complex and Table 8-4 addresses the 16,000-acre Cargill proposed sale area. For each scenario, we estimated a "minimum" to "maximum" cost estimate that reflects the per-cubic-yard and total O&M cost ranges.

Results, Natural Sedimentation Restoration Costs

The natural sedimentation option requires the longest time period to implement, 120 years for the entire salt pond complex and 99 years for the Cargill proposed sale area. **Total costs range from $621 million to $1.49 billion for the entire complex and $315 to $764 million for the Cargill proposed sale area.** These cost estimates comprise O&M costs only and exclude all other costs, such as restoration planning and design, construction, monitoring, and so forth. We present a comprehensive cost estimate for the Cargill proposed sale area in Section 12.2 in Chapter 12.

Results, Dredged Sediment Reuse Incremental Costs

The three dredged sediment options will shorten the tidal marsh restoration time to an estimated 56 to 72 years for the entire salt pond complex and 39 to 51 years for the Cargill proposed sale area, depending on quantity of dredged sediment used. Entities carrying out salt pond restoration using dredged sediment would have to pay the incremental increase in cost of using dredged sediment for tidal marsh restoration versus disposing that same dredged sediment at the deep ocean disposal site. Combining these incremental costs with the reduced-duration but still necessary O&M costs yields a **salt pond restoration with dredged sediment cost range of $457 million to $1.48 billion for the entire 26,000-acre salt pond complex (Table 8-3) or $222 to $899 million for the 16,000-acre Cargill proposed sale area (Table 8-4).** It is these ranges that are appropriately compared to the natural sedimentation approach when evaluating relative costs.

Discussion of Cost Estimate Results

We have attempted to bracket a reasonable estimate of uncertainty in actual costs by presenting "low" and "high" cost estimates. To the extent that our assumptions used in the analysis are valid and our input cost data reasonably accurate, then the resulting cost estimate range should be valid. **Our results show that using dredged sediment may be competitive with and possibly less expensive then relying solely on natural sedimentation.** Whether in fact dredged sediment reuse has higher, equivalent, or lower costs depends on how regional dredge disposal costs evolve over time and to what extent actual O&M costs reflect the estimates shown here and developed in detail in Chapter 14.

It is possible to reduce dredged sediment reuse costs below that shown in Tables 8-3 and 8-4. Our cost estimates assume an annual rate of dredged sediment availability of 0.94 MCY, thus requiring many decades to obtain the full volume of each scenario. The period of interim O&M costs, which we estimate to be $5.1 to $12.3 million or $3.1 to $7.5 million per year initially, respectively, for the total salt pond complex and the Cargill proposed sale area, is based on the time period over which dredged sediment is delivered. Therefore, reducing the delivery period would reduce the overall interim O&M duration and thereby reduce total O&M expenditures. The rate at which dredged sediment could be made available to the South Bay depends on several factors: (1) how much dredging is actually taking place, which could be massively influenced by dredging associated with the proposed San Francisco and Oakland airports runway expansions; (2) how much clean dredged sediment is available; (3) how much dredged sediment goes to wetland restoration versus ocean disposal, the even balance of which could be altered as a policy and economic matter; and (4) how much dredged sediment is allocated to other wetland restoration projects, such as Montezuma and Hamilton-Bel Marin Keys.

Table 8-3. Predicting restoration implementation costs with and without dredged sediment, full salt pond complex

Cost Factors	Natural Sedimentation: No Fill		Dredged Sediment Reuse Options: Fill Option 1[1]		Fill Option 2[2]		Fill Option 3[3]	
PART I: INPUTS TO COST ESTIMATE								
a) Sediment Balance (MCY)								
Total sediment deficit to MHHW[4]	72.2		72.2		72.2		72.2	
Required dredged sediment	0.0		28.8		32.9		38.4	
Total deficit met by natural sedimentation	72.2		43.4		39.3		33.8	
b) Dredged Sediment Supply (MCY/yr)								
Average annual SF Estuary dredging[5]			4.70		4.70		4.70	
Average annual rate dredged sediment will be available for upland reuse[6]			1.88		1.88		1.88	
Average annual rate of dredged sediment allocated for South Bay reuse [7]			**0.94**		**0.94**		**0.94**	
c) Restoration Period (yr)								
Estimated time required to provide necessary dredged sediment for areas receiving fill	NA		31		35		41	
Estimated time required for natural sedimentation rates to meet sediment demand for areas not receiving fill[4]	120		72		66		56	
Years required for restoration and O&M [8]	**120**		**72**		**66**		**56**	
PART II: OPERATIONS AND MAINTENANCE COST ESTIMATES								
a) Time Periods for Operations and Maintenance (Years)								
Initial O&M during planning and design	5		5		5		5	
Permanent O&M for ponds retained as shallow open-water habitat	120		120		120		120	
Interim O&M for ponds restored to tidal marsh	120		72		66		66	
	Max	Min	Max	Min	Max	Min	Max	Min
b) Initial O&M during Planning and Design (26,000 acres) ($ Million/yr)								
Fixed annual O&M costs	17.8	7.4	17.8	7.4	17.8	7.4	17.8	7.4
c) Interim O&M for Ponds Restored to Tidal Marsh (18,000 acres) ($ Million/yr)								
Initial annual O&M costs[9]	12.3	5.1	12.3	5.1	12.3	5.1	12.3	5.1
Final annual O&M costs[10]	0	0	0	0	0	0	0	0
Average annual O&M costs over the period of restoration[11]	6.2	2.6	6.2	2.6	6.2	2.6	6.2	2.6
d) Permanent O&M for Ponds Retained as Open Water (8,000 acres) ($ Million/yr)								
Average annual O&M costs over the period of restoration[12]	5.5	2.3	5.5	2.3	5.5	2.3	5.5	2.3
e) Total O&M Costs over 99-Year Restoration Period ($ Million)								
Initial + Interim + Permanent O&M costs	**1,491**	**621**	**1,196**	**498**	**1,154**	**481**	**1,097**	**457**
PART III: DREDGED SEDIMENT REUSE COST ESTIMATES								
a) Unit Dredged Sediment Reuse and Disposal Costs ($/cubic yard)								
Estimated costs for reuse of dredged sediment in wetlands	20	12	20	12	20	12	20	12
Estimated ocean disposal costs[13]	10	14	10	14	10	14	10	14
Incremental annual costs associated with wetland reuse and disposal of dredged sediment[14]	**10**	**0**	**10**	**0**	**10**	**0**	**10**	**0**
b) Total Incremental Dredged Sediment Reuse and Disposal Costs ($ Million)								
Total estimated incremental dredged sediment wetland reuse costs above that required for ocean disposal	**0**	**0**	**288**	**0**	**329**	**0**	**384**	**0**
PART IV: TOTAL INCREMENTAL COSTS (O&M + INCREMENTAL DREDGED SEDIMENT REUSE) ($ MILLION)								
Total estimated incremental restoration costs above that required for ocean disposal[15]	**1,491**	**621**	**1,484**	**498**	**1,483**	**481**	**1,481**	**457**

Table 8-4. Predicting restoration implementation costs with and without dredged sediment, Cargill 2000 proposed sale area

	Natural Sedimentation		Dredged Sediment Reuse Options					
Cost Factors	**No Fill**		**Fill Option 1[1]**		**Fill Option 2[2]**		**Fill Option 3[3]**	
PART I: INPUTS TO COST ESTIMATE								
a) Sediment Balance (MCY)								
Total sediment deficit to MHHW[4]	59.5		59.5		59.5		59.5	
Required dredged sediment	0.0		28.8		32.9		36.1	
Total deficit met by natural sedimentation	59.5		30.7		26.6		23.4	
b) Dredged Sediment Supply (MCY/yr)								
Average annual SF Estuary dredging[5]			4.70		4.70		4.70	
Average annual rate dredged sediment available for upland reuse[6]			1.88		1.88		1.88	
Average annual rate dredged sediment allocated for South Bay reuse[7]			**0.94**		**0.94**		**0.94**	
c) Restoration Period (yr)								
Estimated time required to provide necessary dredged sediment for areas receiving fill	NA		31		35		38	
Estimated time required for natural sedimentation rates to meet sediment demand for areas not receiving fill[4]	99		51		44		39	
Years required for restoration and O&M[8]	**99**		**51**		**44**		**39**	
PART II: OPERATIONS AND MAINTENANCE COST ESTIMATES								
a) Time Periods for O&M (Years)								
Initial O&M during planning and design	5		5		5		5	
Permanent O&M for ponds retained as shallow open-water habitat	99		99		99		99	
Interim O&M for ponds restored to tidal marsh	99		51		44		39	
	Max	Min	Max	Min	Max	Min	Max	Min
b) Initial O&M during Planning and Design (16,000 acres) ($ Million/yr)								
Fixed annual O&M costs	11.0	4.5	11.0	4.5	11.0	4.5	11.0	4.5
c) Interim O&M for Ponds Restored to Tidal Marsh (11,000 acres) ($ Million/yr)								
Initial annual O&M costs[9]	7.5	3.1	7.5	3.1	7.5	3.1	7.5	3.1
Final annual O&M costs[10]	0	0	0	0	0	0	0	0
Average annual O&M costs over the period of restoration[11]	3.8	1.6	3.8	1.6	3.8	1.6	3.8	1.6
d) Permanent O&M for Ponds Retained as Open Water (5,000 acres) ($ Million/yr)								
Average annual O&M costs over the period of restoration[12]	3.4	1.4	3.4	1.4	3.4	1.4	3.4	1.4
e) Total O&M Costs over 99-Year Restoration Period ($ Million)								
Initial + Interim + Permanent O&M costs	**764**	**315**	**584**	**241**	**558**	**230**	**538**	**222**
PART III: DREDGED SEDIMENT REUSE COST ESTIMATES								
a) Unit Dredged Sediment Reuse and Disposal Costs ($/cubic yard)								
Estimated costs for reuse of dredged sediment in wetlands	20	12	20	12	20	12	20	12
Estimated ocean disposal costs[13]	10	14	10	14	10	14	10	14
Incremental annual costs associated with wetland reuse and disposal of dredged sediment[14]	**10**	**0**	**10**	**0**	**10**	**0**	**10**	**0**
b) Total Incremental Dredged Sediment Reuse and Disposal Costs ($ Million)								
Total estimated incremental dredged sediment wetland reuse costs above that required for ocean disposal	**0**	**0**	**288**	**0**	**329**	**0**	**361**	**0**
PART IV: TOTAL INCREMENTAL COSTS (O&M + INCREMENTAL DREDGED SEDIMENT REUSE) ($ MILLION)								
Total estimated incremental restoration costs above that required for ocean disposal[15]	**764**	**315**	**872**	**241**	**887**	**230**	**899**	**222**

Conclusions

The purpose of this analysis is to provide an economic point-of-reference and framework for assessing the feasibility of using dredged sediment during the restoration of the South Bay salt ponds. Ultimately determining whether using dredged sediment is economically competitive with natural sedimentation will require a far more detailed and precise estimate of O&M and dredged sediment reuse costs as well as the added planning and design costs. Additionally, the analyses will likely require a method to quantify less definable costs such as those associated with the ecological, recreational and educational value of the salt ponds. Longer periods of restoration and the subsequent delay of a functional marsh/salt pond complex will increase these costs, which are clearly real but more difficult to quantify. Thus, when deciding whether the economics ultimately support using dredged sediment, planners, engineers and others will need to be further along in the design, have more precise cost estimates, have a better understanding of dredged sediment availability, and include the less definable regional costs associated with delays in restoration of these salt ponds.

Notes for Tables 8-3 and 8-4

MCY = million cubic yards

1 *Filling only most subsided ponds.*

2 *Filling most subsided and moderately subsided ponds.*

3 *Filling the most subsided, moderately subsided, and slightly subsided ponds.*

4 *Assumes Option 2 in Table 8-1 that salt ponds are restored at a rate that allows existing marshes and flats to accrete at a rate equal to sea level rise.*

5 *Assumes an annual average of 4.7 MCY. LTMS (1996) predicts that approximately 3.5 - 5.9 MCY of dredging will be required annually over the next 50 years.*

6 *Assumes 40 percent of dredged sediment is reused in wetlands and uplands, 40 percent is disposed of in the ocean, and 20 percent is disposed of in the bay (LTMS 1996).*

7 *Assumes half of the dredged sediment allocated for wetlands will be available for use in the South Bay.*

8 *Estimated as the greater of the two time periods: the time period required for natural sedimentation and the time period required to place dredged sediment.*

9 *Assumes predicted water control structure and levee maintenance O&M costs (see Chapter 14).*

10 *Assumes that all restored ponds will require no water control structure or levee maintenance once tidal marsh has established.*

11 *Assumes linear decrease in interim O&M costs over the period of restoration.*

12 *Assumes water control structures and levee maintenance required permanently in ponds retained as shallow open-water habitats.*

13 *Minimum and maximum are reversed in order to show maximum incremental difference between the two.*

14 *Assumes wetland disposal costs always exceed ocean disposal costs.*

15 *Summation of incremental dredging costs (line III-b) and total O&M costs (line II-e) over the period of restoration.*

8.5 Retaining Subsided Alviso Ponds as Open Water Habitats

The final approach is to retain most or all of the deeply subsided Alviso ponds as managed open water and wetland areas rather than restoring them to tidal marsh. This approach significantly reduces the volume of the sediment deficit. These ponds account for about 48 MCY of the deficit, or nearly half the total deficit of the entire South Bay salt pond complex. Yet they make up only 21 percent of the total area. However, this approach has two issues that must be resolved before it can be implemented.

1. **Flood control.** The flood control levees and water control structures would need to be maintained in perpetuity. Because these ponds are deeply subsided, their levees are presumably the tallest in the entire salt pond complex from base to crest and thus the most difficult and costly to maintain of all levees in the system. These levees presumably would also be most prone to failure during catastrophic events such as major storms or earthquakes.
2. **Spatial distribution of ecosystem types.** The ecological goals described in Chapter 2 envision a roughly uniform geographic distribution of tidal marsh and managed open water habitats throughout the South Bay. However, the subsided Alviso ponds are geographically clustered and their elimination as tidal marsh would preclude a continuous band of tidal marsh around the entire edge of the South Bay. This problem could be alleviated by dividing the salt ponds parallel to the bay margin and creating narrower bands of bayfront tidal marsh with large, managed open water areas inland.

Were these ponds managed as shallow open-water habitats, they could provide ecological benefits for shorebird and waterfowl foraging, roosting, and nesting habitat along levees and islands for western snowy plover and other shorebirds. These ponds could be managed flexibly with respect to water levels and salinity. Were these ponds managed as non-tidal or micro-tidal wetlands, the could provide ecological benefits for salt marsh harvest mice, nesting habitat along levees and islands for western snowy plover and other shorebirds, and possible roosting habitat for shorebirds and waterfowls.

Chapter 9.
Evaporator Pond Desalination

Chapter 9.

Evaporator Pond Desalination

Preparing the decommissioned salt ponds for restoration requires desalinating those ponds and managing water levels and salt concentrations up to the time that each pond is restored to tidal marsh. For those ponds to be retained permanently as managed open water areas, water levels and salt concentrations will have to be managed in perpetuity. The lessons learned from the North Bay salt ponds (see Chapter 7) demonstrate the problems that can arise if these activities are not carried out effectively.

This chapter addresses evaporator pond desalination in considerable detail and water and salt management in brief. We begin with an introduction to the technical concepts in desalination and water and salt management (Section 9.1), followed by an overview of the desalination process (Section 9.2). In Section 9.3 we present three strategies for evaporator pond desalination. Each of these three strategies could work effectively, and they differ in their relative implementation costs and degree of coordination required with ongoing Cargill salt production activities. We conclude with some comments regarding interim and long-term water level and salt concentration management (Section 9.4).

9.1 Introduction to Desalination and Water and Salt Management

Decommissioning the South Bay salt ponds will be a complex and lengthy process. Desalination will be needed for many ponds in preparation for restoration. Water and salt management will be needed for nearly every pond during the interim restoration planning and implementation period as well as in perpetuity for ponds not restored to tidal marsh. The interim period begins with the cessation of salt production at a given pond and continues until the completion of its restoration. Interim management consists of two elements, desalination and maintenance of desired salt concentrations and water levels. Water and salt management will need to shift from current protocols designed to concentrate salts for salt production to new protocols designed to decrease then maintain water and sediment salt concentrations. Additionally, the logistics and challenges associated with hypersaline brine and bittern will need to be understood to avoid repeating the costly hypersaline waste problem that has occurred in North Bay salt pond complex (see Chapter 7). Chapter 10 examines the bittern management issues.

This section describes the four important elements that affect pond desalination and water and salt management. Section 9.1.1 defines the three phases of restoration through which all ponds will have to pass. Section 9.1.2 describes the characteristics and restoration suitability of ponds based on their existing salinity concentrations. Section 9.1.3 defines the two key concepts used for quantifying desalination requirements: hydraulic loading rates (HLR) and hydraulic retention times (HRT). Finally, Section 9.1.4 estimates existing Cargill HLRs and HRTs for use in developing and evaluating operational alternatives that integrate desalination water into ongoing Cargill salt production activities.

9.1.1 Three Phases of Restoration: Desalination, Maintenance and Ecosystem Restoration

The restoration process will occur in three phases: desalination, maintenance, and ecosystem restoration. Table 9-1 describes the three phases.

For each pond, restoration may proceed slowly or rapidly within each of these phases, depending on a variety of factors such as:

- Initial salinity levels
- Presence of precipitates (e.g., gypsum or salts) on pond bottom sediments
- Pond bed elevations
- Proximity to the Bay
- Proximity to invasive species
- Condition of antecedent channel network
- Levee conditions
- Availability and type of water source (e.g., storm water, freshwater, Bay water, reclaimed water)

Table 9-1. Three phases of restoration

Phase	Description
Desalination	Process of reducing salt pond salinity to acceptable levels. The rate at which pond salinity decreases will depend on several factors, including the initial salinity levels, the presence or absence of salts in the sediments, the available water supply and its salinity, and the pond's size.
Maintenance	Process of maintaining desired salinity concentrations and water levels. Salinity concentrations, under most circumstances, should approximate Bay water, which varies from 15 – 35 ppt. Actual maintenance salinity levels will be determined in the future by results from studies currently under way to establish RWQCB salinity standards. Water levels should focus on providing diverse wildlife habitats.
Ecosystem Restoration	Process of returning salt ponds to desired wildlife habitat (e.g., tidal marsh, open water, salt panne).

Table 9-2. Water and sediment characteristics in relation to salinity

Salinity Range (ppt)	Pond Type	Water characteristics: Ionic Imbalance	Water characteristics: Salinity Classification	Sediment characteristics: Gypsum	Sediment characteristics: Sodium Chloride	Sediment characteristics: Bittern Salts
21 – 140	Evaporator	No	Low – Medium			
140 – 356	Evaporator, pickle	Yes	Medium – High	Present		
356 – 395	Crystallizer	Yes	High		Present	
395 – 447	Bittern desalting & storage	Yes	Very high		Present	Present

- Access
- Restoration goal (e.g., tidal wetland, perennial aquatic environment, salt pannes)
- Available funds
- Infrastructure constraints (e.g., roads, transmission lines, railroads, pipes)
- Jurisdictional or regulatory considerations
- Sediment supply

Although each pond identified for restoration will probably proceed through the three phases, deviations are possible. Regardless, the phases will not occur concurrently in all ponds. Ponds and groups of ponds will proceed through the phases at different rates because some will be easier to restore than others. At any one time, individual ponds could be in one of the three phases.

9.1.2 Pond Characteristics and Restoration Compatibility Based on Existing Pond Salinity

The activities necessary to desalinate, maintain, and restore each salt pond will differ depending on the existing salinity of each pond. Salt ponds can be classified into four distinct salinity classes as described in Table 9-2. Each of these salinity classes has water and sediment characteristics that will affect pond management before, during, and after restoration. Table 9-2 summarizes these characteristics.

The USFWS Tidal Marsh Ecosystem Recovery Plan (USFWS, in preparation; see Chapter 2) recommends including four ecosystem types in any South Bay restoration plan. The four ecosystem types are tidal marsh, salt pannes, mixed tidal marsh and salt panne complexes, and managed shallow open water (the USFWS plan identifies these ponds as microtidal lagoons and they provide functions of existing salt ponds). Existing pond salinity can influence which of these four ecosystem types are suitable at any given pond. For instance, crystallizer ponds would not require desalination were they restored to salt pannes that benefit from high salinities. Restoration of these ponds to another ecosystem type would require desalination as well as other activities. Thus, to optimize restoration efforts, a clear understanding of the current pond type configuration is necessary to develop the ultimate distribution of tidal marsh, salt pannes, mixed tidal marsh and salt panne complexes, and managed shallow open water. Table 9-3 shows relationships between existing pond salinity, required conversion actions, and ecosystem compatibility.

9.1.3 Defining Hydraulic Loading Rates and Hydraulic Retention Times

Pond desalination and interim salinity management require the introduction of low-salinity water into the salt ponds, with low salinity being defined as any water at or less than the salinity of Bay water. This section describes the two hydrologic terms used to describe the desalination process: hydraulic loading rate (HLR) and hydraulic retention time (HRT). Both terms are used in environmental engineering to describe hydrologic processes. Hydraulic loading rates are values standardized against area, and hydraulic retention times are values standardized against volume.

Hydraulic Loading Rate

The HLR defines the rate at which a depth of water is introduced into a pond. For example, one very large pump can pump water at

Table 9-3. Required conversion steps and ecosystem type compatibility as a function of existing pond salinity

Existing Salinity (ppt)	Pond Type	Required Conversion Actions: Desalination	Required Conversion Actions: Maintenance	Required Conversion Actions: Restoration	Ecosystem Type Compatibility: Managed open water	Ecosystem Type Compatibility: Tidal marsh	Ecosystem Type Compatibility: Salt panne	Ecosystem Type Compatibility: Tidal marsh/ salt panne complex
0 – 140	Stage 1 Evaporator Ponds	X	X	X	X	X		X
140 – 356	Stage 2 Evaporator Ponds, Pickle Ponds	X	X	X	X	X		X
356 – 395	Crystallizer		X	X			X	X
395 – 447	Bittern Storage Ponds, Bittern Desalting Ponds	X	X	X	X	X	X	X

the rate of 30,000 gallons per minute (gpm). Continuously pumping at this rate is equivalent to 50,000 acre-feet per year, where an acre-foot defines the quantity of water necessary to cover one acre of land one foot deep. The North Bay salt ponds cover about 7,000 acres. Therefore, if this pump were operated continuously for one year to pump water across the entire 7,000 acres, then this pumping rate of 30,000 gpm would represent an HLR of about 7 feet per year. An HLR of this magnitude can be put into context in several ways. Net evaporation rates for freshwater systems around the Bay are approximately 2.5 feet per year, which is about one third the HLR presented above. Wetlands managed to provide water treatment are operated at HLRs an order of magnitude greater.

Hydraulic Retention or Residence Time

The HRT defines the time required for a unit of water to pass through a pond, with units of days or years. For example, with a 5-day HRT, water takes 5 days to pass through a pond. HRT varies with water depth because as depth increases, there is more water per acre to flush through the pond. Therefore, if the 7,000 acres of North Bay salt ponds are operated at a depth of 1.5 feet, their volume is approximately 10,500 acre-feet of water. At a flow rate of 50,000 acre-feet per year from the HLR example, water flushes through the system every 0.2 years or 80 days. HRT also varies with operations; inflows and outflows can be sped up or slowed down using water control structures and pumps. Thus, the HRT for any given pond can be managed by altering ponding depths and adjusting inflow and outflow rates.

Another way to view HRTs is in the context of pond volumes. Every pond in the South Bay salt pond complex has a maximum or operational volume that is unique to that pond based on its area, levees, and so forth. The HRT, as defined above, equals the amount of time it takes to exchange 100 percent of that volume of pond water under a given operational regime. Consequently, pond water volumes can be viewed as numbers of HRTs. In this view, one pond water volume is equal to one HRT for that pond, and two pond water volumes are equal to two HRTs for that pond. Using this approach allows us to discuss pond desalination in terms of numbers of HRTs necessary to flush a pond (see Section 9.2). The fact that HRTs can be adjusted by altering water depths and inflow and outflow rates allows us then to describe a variety of operational approaches to pond desalination (see Section 9.3).

9.1.4 Estimating Cargill's Existing South Bay Hydraulic Loading Rates and Retention Times

Knowing the amount of water Cargill uses currently for salt production is important for two reasons. First, it defines a baseline for evaluating how much water will be required for pond desalination of the 16,000 acres Cargill has offered for public acquisition. Second, it provides information necessary for integrating desalination activities as much as possible with ongoing Cargill salt production on about 10,000 acres. Increasing HLRs beyond Cargill's existing level requires sufficient water control structures throughout the salt pond system to move that water, along with the levee integrity to handle the water volumes and heights that could pass through the ponds.

Unfortunately, there is no reliable information on the HRT of the South Bay salt production facility. Ver Planck (1958) estimated that the water took one year to pass through the evaporator ponds and reach the pickle pond (see Chapter 3). In other literature, HRTs through the salt production ponds have been estimated as high as five years.

HLRs can be estimated from data on water depth and flow rates. At the production level of 40 tons of salt per acre annually (Ver Planck 1958), an influx rate of approximately 2,400 tons per acre per year of Bay water at 24 ppt is required. This value translates to an HLR of 1.75 ft (21 inches) per year. This predicted inflow rate is in rough agreement with our predicted outflow losses for the salt ponds through evaporation. Ver Planck (1958) estimated net evaporation rates in the Bay Area at 34 to 43 inches per year. Because evaporation decreases as salinity increases, we estimate net evaporation to be approximately 23 inches per year (1.9 feet per year). Calculations and assumptions are presented in Appendix A.

Table 9-4. Estimated existing HRTs based on salt pond water budgets

Source	Hydraulic Loading Rate (ft/yr)	Hydraulic Retention Time (yr)	
		Shallow Ponds (1.5 ft deep)	Deep Ponds (3.0 ft deep)
Estimated inflow rates based on existing salt production levels	1.75	0.9	1.7

Information on salt pond water depth is inconsistent. Ver Planck (1958) states that concentrator pond depths are shallow to maximize exposure of brine to sun and wind. Lonzarich and Smith (1997) report that water depths in low- to high-salinity ponds in the South Bay are 3 to 6 feet (1 to 2 meters) and similar to depths of salt ponds throughout the area. Oswald (1986) reports that Baumberg Pond 1 has an average water depth of 2.5 feet (0.8 meters). CFR (1989) states that ponds vary from shallow to deep, with a deep pond exceeding 5 feet (1.5 meters). Cargill (2000a) reports that the evaporator ponds are operated at approximately 1.5 feet (0.5 meters). Based on these references, an estimated water depth range of 1.5 to 3.0 feet (0.5 – 1 meters) seems reasonable. Incorporating this information into a steady state water budget analysis results in a predicted HRT of 0.9 to 1.7 years for the salt production ponds, depending on the water depth and the actual flow rate (see Table 9-4).

9.2 Evaporator Pond Desalination and Disposal Overview

Evaporator ponds comprise the largest area in the salt pond complex. They vary in salinity from essentially bay concentrations at the bay intake ponds to hypersalinity at the pickle pond; thus they span a salinity range of 21 – 356 ppt (3.2 – 29 °Be). Desalinating these ponds and disposing of the resulting brine and wash water will be an important task associated with restoration. In this section we discuss the desalination process and the implications on the various disposal options. Disposal will likely require considering the needs of the involved agencies as well as Cargill. Cargill has agreed to incorporate the bittern and hypersaline brine into its production stream (Moore, Barroll, personal communications). However, it is unclear whether this includes waters used in desalinating the many evaporator ponds.

In the evaporator ponds, sodium chloride and bittern salts have not accumulated in the sediments and thus desalination is necessary only for removing salts and ions present in the water column. The evaporator ponds can be separated as low to medium salinity Stage 1 ponds (< 147 ppt, 12.9 °Be) and medium to high salinity Stage 2 ponds (> 147 ppt, 12.9 °Be) (Table 9-2). Initiation of gypsum precipitation defines this division between Stage 1 and Stage 2 ponds. Gypsum precipitation selectively removes ions from solution, leading to an ionic imbalance in the water column and the formation of a hard, relatively insoluble precipitate layer on the pond bottom. These two issues are important with regard to restoration. Chapter 7 discusses ionic imbalance toxicity in the context of lessons learned in the North Bay. Chapter 6 discusses gypsum chemistry, accumulation and dissolution kinetics. We do not believe gypsum is an important consideration specifically to the desalination process.

Section 9.2.1 develops an operational estimate of time and water volumes necessary to desalinate the South Bay salt ponds acquired for restoration. Section 9.2.2 describes a variety of operational logistics and regulatory considerations that the desalination process will face. Section 9.2.3 develops an operational method that would dilute desalination water to levels acceptable for discharge to South San Francisco Bay under RWQCB authorization. That method is then used in development of three desalination strategies presented in Section 9.3.

9.2.1 The "Push" and "Pull" Methods of Pond Desalination

Pond desalination can occur in two general ways. The first approach we define as the "pull" method as it involves pumping a pond dry of all brine and then replacing that brine with Bay water or other low salinity water. The second approach we define as the "push" method as it involves introducing low salinity water repeatedly over a period of time and concurrently removing diluted brine. Pond desalination using the "Push" method in which low salinity brine is introduced into the pond and used to dilute and flush high salinity brine will likely be easier to implement, as it will be able to utilize much of the existing infrastructure without requiring costly additional pumps. Selection of desalination methods will also be influenced by the rate at which Cargill can accept these desalination brines. Our preliminary analysis suggests the "push" method may prove to be the more feasible, so we have focused the subsequent discussions on this method.

9.2.2 Salinity Trends during Evaporator Pond "Push" Desalination

The operational details of using the "push" method depend on the salinity of the wash water, how rapidly water is moved through the pond and thus how much additional evaporative concentration occurs, how deep the pond is operated during the process, and how the diluted brine is disposed. The speed with which water can move through any given pond is determined largely by economics. Tidal and mechanical pumping combined will be necessary to increase hydraulic loading rates to that needed for desalination. However, faster water exchange requires additional gates and/or larger pumps; pumps are more expensive to purchase, install, and maintain and have higher energy costs). Other limitations control HLRs, such as pond levee height and integrity and maximum achievable supply rate of wash water.

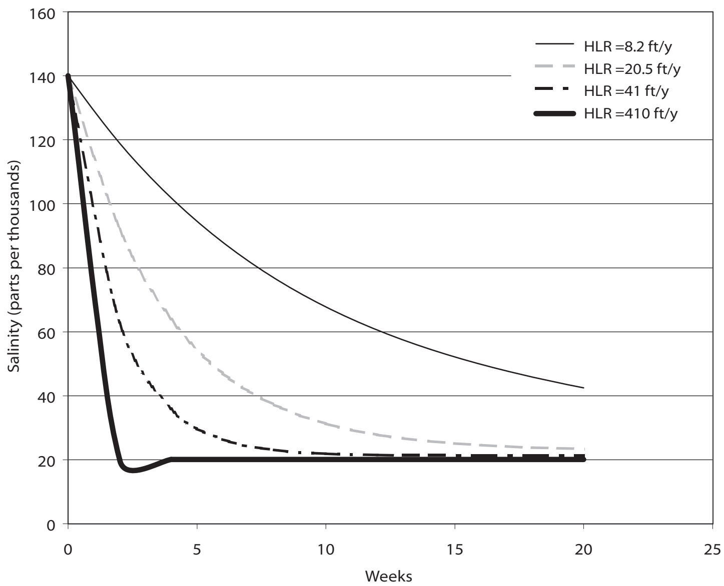
During evaporator and pickle pond desalination via the "push" method, outflow salinity asymptotically approaches background concentrations, decreasing rapidly at first and then more gradually over time. During desalination, two processes are occurring. Evaporation continues to concentrate water and increase pond salinity. Concurrently, low salinity feed water reduces pond salinity by flushing and diluting the high salinity pond water. The time required for salinity to achieve background concentrations depends on HLR and water depth. Figure 9-1 presents mass balance results for the hypothetical 1.5-foot deep pond in Table 9-5. This typical pond has an initial salinity of 140 ppt and is being flushed with water at 20 ppt. At an HLR of 8 feet per year—approximately three times that of net evaporation—outflow salinity approaches 40 ppt after 20 weeks of flushing. Essentially, the outflow has twice the salinity level as the inflow. At an HLR five times greater (e.g., 40 feet per year), outflow salinity reaches 40 ppt in about 4 weeks. After 8 weeks of flushing at that HLR, salinity approaches background levels. At moderate to high HLRs (i.e., greater than 20 feet per year), approximately 4.5 feet of water is required to desalinate the 1.5-foot deep ponds to background salinity levels. This amount of flushing equals three times the operational water depth, or roughly three pond volumes or three HRTs. At lower HLRs, evaporation counteracts dilution more relative to higher HLRs, leading to a greater total water volume to desalinate the pond. See Appendix A for more detailed discussions.

Table 9-5. Operating characteristics for a typical evaporator pond

Parameter	Value
Initial pond salinity, $C_{pond,t0}$	140 ppt or 12 °Be
Net evaporative rate	2.5 feet/year
Water depth	1.5 feet
Intake water salinity, C_{inflow}	20 ppt

Table 9-6 generally quantifies Figure 9-1 for ponds undergoing desalination at HLRs much greater than net evaporation rates (HLR approximately 20 ft y^{-1} or higher). Table 9-6 shows that when flushing time equals one HRT, 37 percent of the pond water being flushed still remains within the pond. It is not until three HRTs that nearly all of the original pond water has been flushed from the pond. At three HRTs, only 5 percent of the original pond water remains in the pond. At this point, the outflow salinity is near the steady state condition. At higher loading rates, outflow salinity approaches the inflow salinity levels (see Figure 9-1).

Figure 9-1. Flushing characteristics of evaporator ponds



9.2.3 Regulatory and Logistical Considerations during Desalination

Several regulatory and logistical considerations will affect the implementation and logistics of desalination and are discussed in this section:

- Salinity discharge standards
- Hydraulic residence times as a function of initial pond salinity
- Desalination time as a function of pond depth and hydraulic loading rates
- Seasonal affects on desalination process.

Salinity Discharge Standards

The RWQCB will have the responsibility to establish salinity limits for any discharge that may be contemplated for pond desalination. According to the RWQCB, there is insufficient information at this time to establish that salinity standard (Moore, personal communication). The RWQCB is likely to consider several factors when determining these salinity discharge standards, including species sensitivity to salinity variation, the area affected by the discharge, dilution effects driven by other inflows or mixing, discharge location, and the time of year discharge occurs.

The discharge standard may differ based on pond types because of what is termed "specific ion toxicity." Ionic toxicity presents a concern for brine originating from ponds with salinities above the gypsum precipitation threshold (140 ppt); this threshold delineates Stage 2 evaporator ponds from the lower salinity Stage 1 ponds. Ionic imbalances can vary in intensity depending on the stage of brine concentration in the Stage 2 ponds. The ionic imbalance reaches it maximum with bittern (Chapter 10), which is known to be toxic to aquatic organisms. Whether or not the less-severe ionic imbalances of hypersaline brine prior to sodium chloride harvesting pose any toxicity concerns is another issue requiring more investigation. Thus, in establishing salinity discharge standards, not only a specific salinity level may be set but also standards based on origin of the desalination water.

The area affected by discharge will also likely be considered when establishing salinity discharge standards. Some data suggest the dilution area within the Bay will not be large. Trace metal discharge data at Sand Point in Palo Alto show the dilution area is relatively small, on the order of a few acres (Moore, personal communication). The implications of this finding is that if the dilution area is relatively small, negative environmental impacts from elevated salinity on the biota would be relatively minor in the context of the entire estuary. Cargill is currently investigating this issue in cooperation with the Regional Board (Moore, personal communication).

Table 9-6. Reduction in pond salinity as a function of HRT

Number of Hydraulic Retention Times	Percent initial pond water remaining in outflow
0	100
1	37
2	14
3	5
4	2

HRTs as a Function of Initial Pond Salinity

Initial pond salinity level may affect the period of time required for desalination. As described in Table 9-6, original pond water is displaced with inflow water as time passes. For a given HLR, higher initial salinity of a pond requires more water, and thus more time, for desalination to occur. For instance, ponds flushed with 20 ppt water and meeting a salinity discharge standard of 25 ppt requires three HRTs for ponds with initial salinity levels of 70 ppt and four HRTs for ponds with a salinity of 140 ppt or higher (Table 9-7).

As discussed in the previous section, some flexibility may be possible on discharge standards. If discharge standards can be set higher, less time will be required to flush the ponds. For instance, raising the discharge standard to 40 ppt would shorten the time for desalination to 1 HRT for ponds with an initial salinity of 70 ppt, 2 HRTs for ponds with an initial salinity of 140 ppt and 3 HRTs for higher salinity ponds. This reduction assumes an inflow salinity of 20 ppt for the flush water. By raising the discharge standard, less time and less water is needed to desalinate ponds.

Desalination Time as a Function of Pond Depth and HLRs

The amount of flush water required for a given pond will be directly related to its depth. Deeper ponds have greater volume and thus require more water for flushing, which translates into more time for a given HLR. Table 9-8 presents estimated desalination times for ponds with different water depths and HLRs. Data presented in that table assumes that 3 HRTs are required to flush each pond. At very low HLRs (e.g., 8 feet per year), ponds take anywhere from 3 months

Table 9-7. Pond outflow salinity for different HRTs and initial pond salinity levels

Stage in Desalination	Time (HRTs)	Salinity Concentrations (ppt)				
Initial Pond Salinity		70	140	210	280	312
Pond Outflow Salinity[1,2]	1	38	64	90	116	127
	2	27	36	46	55	60
	3	22	26	29	33	35
	4	21	22	23	25	25

1 Pond outflow salinity is an approximation and will depend up the HLR, with HLRs greater than 20 ft per year yielding better approximations.

2 Assumes an inflow salinity of 20 ppt.

to more than one year to desalinate, depending on their water depth. At an HLR five times greater (e.g., 40 feet per year), the desalination time ranges from 8 weeks to 5 months. At very high HLRs (e.g., 400 feet per year), desalination can occur in a number of days regardless of water depth. (Such high HLRs, roughly 100 times existing salt production rates, may not be achievable operationally.) Therefore, for virtually any low salinity pond in the South Bay complex, desalination could occur in just over a year or less.

Table 9-8. Estimated desalination times for ponds with different water depths and HLRs

HLR[1] (feet/yr)	Outflow salinity[2] (ppt)	Desalination time as function of pond depth(days)[3] 1 foot	1.5 feet	2 feet	3 feet
8	35	134	200	267	401
20	25	53	80	107	160
40	22	27	40	53	80
400	20	3	4	5	8

1 HLR for salt production is about 1.9 feet per year.

2 For inflow salinity of 20 ppt and initial evaporator pond salinity of 140 ppt, see Table 9-5.

3 Assumes 3 HRTs for all ponds.

Seasonal Affects on Desalination Process

From a regulatory perspective, the wet season offers the optimal period for discharge into the Bay due to lower salinity levels at that time (Moore, personal communication). Data collected from 1993 to 1998 from the Coyote Creek, South Bay, and Dumbarton USGS gauging stations show that the median salinity has been 15 ppt during the wet season (January to April) and 22 ppt during the dry season (May to December) (SFEI 2001). At some South Bay locations, salinity levels are near 0 ppt during peak winter flows. Daily freshwater discharges of up to 120 million gallons per day from the San Jose wastewater treatment plant (shown in Map 12) also contribute to year-round reduced salinities in the southern end of South San Francisco Bay.

Wet season desalination offers two advantages. First, inflow water used for flushing will have a lower salinity and thus will be more effective for desalination. Second, wet season desalination could be managed such that wet season discharges would not raise salinity levels above dry season maxima (i.e., discharges would stay within background variability). These two advantages may simplify the logistics and costs associated with desalination. However, an offsetting consideration is that the wet season only offers a 120-day window for pond desalination. This short window may prove especially problematic for high salinity ponds and deep ponds.

9.2.4 Discharge Options for Desalination Water

Original pond water as well water used to flush ponds of high salinity brine will need to be disposed. Fundamentally, there are two options for this water: discharge to South San Francisco Bay or incorporation into Cargill's salt production system it retains in Newark Plants #1 and #2 (see Map 3).

As an approximation, we estimate that three HRTs (or three pond volumes) will be required to flush each pond, assuming rapid water flows to avoid evaporative concentration during the desalination process. The estimated HRT for the entire South Bay salt production system is approximately 0.9 to 1.7 years (see Table 9-4). Desalination time for the entire existing salt pond system could require up to 5 years, with the smaller Cargill proposed sale area requiring a minimum 0.5 to 1 year under optimal desalination conditions. If Cargill were to accept all brines used for flushing ponds, it would equal roughly 1 to 3 years of salt production inflows based on current operating conditions. The exact amount of flushing time would depend on the actual HRT for current salt pond operation and the number of HRTs required to achieve desired salinity levels in the pond outflows. Because flushing must occur quickly to avoid further evaporative concentration, these waters would need to be accepted over a relatively short period of time. Given the large quantity of water required to flush the system and the relatively short period to flush each pond, the capacity of the remaining operating salt ponds to accept and store these brines becomes a critical question when planning desalination.

These constraints suggest that salt pond restoration will need to occur in a piecemeal fashion over several years. Cargill should continue salt production on portions of the transferred lands so that ponds not undergoing desalination, maintenance, or restoration can remain in operation. This strategy will allow Cargill to accept the greatest amount of brine from the desalination efforts and thus minimize or eliminate the need for bay discharge. If the effort is not well planned, it may be overly optimistic to expect Cargill to accept all these brines.

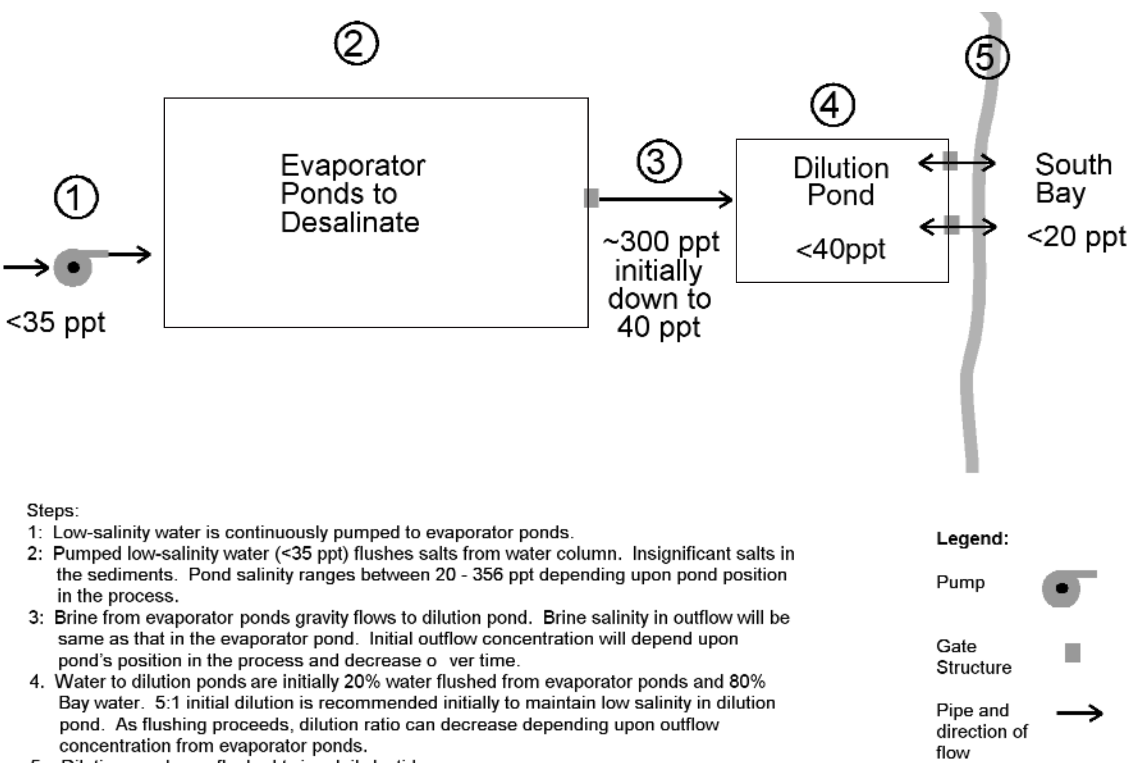
If Cargill does not accept some or all of these brines, the question becomes what to do with the brines that have salinity levels too high for Bay discharge. One scenario involves using an intermediate dilution pond for additional salinity reduction followed by Bay discharge (see Figure 9-2). In this scenario, flushed brine from an evaporator pond is continuously pumped into a dilution pond where muted tidal exchange supplies Bay water at a 5:1 ratio. A maximum daily 3-foot tidal exchange is assumed. The dilution pond area can vary and, because tidal exchange provides large volumes of water inexpensively, the dilution pond area can be less than that of the evaporator pond.

Table 9-9. Estimated time to dilute and discharge evaporator pond brines

Evaporator Pond[1] HLR (ft/yr)	Dilution Pond[2,3,4,5,6] Area: 50% of Evaporator Ponds Dilution Pond HLR (ft/yr)	(ft/day)	Days	Area: 25% of Evaporator Ponds Dilution Pond HLR (ft/yr)	(ft/day)	Days
21	205	0.6	80	410	1.1	80
41	410	1.1	40	820	2.2	40
62	615	1.7	27	**1230**	**3.4**	**27**
82	820	2.2	20	**1640**	**4.5**	**20**
103	1025	2.8	16	**2050**	**5.6**	**16**
123	**1230**	**3.4**	**13**	**2460**	**6.7**	**15**
144	**1435**	**3.9**	**11**	**2870**	**7.9**	**15**
164	**1640**	**4.5**	**10**	**3280**	**9.0**	**15**
185	**1845**	**5.1**	**9**	**3690**	**10.1**	**15**
205	**2050**	**5.6**	**8**	**4100**	**11.2**	**15**

1 Water flushed from evaporator ponds assumed to need an additional 5:1 dilution.
2 Area ratio (e.g., 25 percent, 50 percent) represents the dilution pond area relative to the evaporator pond being flushed.
3 Assumes 1.5-foot water depth.
4 Dilution pond water provided by tides. A maximum daily tidal exchange is assumed to be 6 feet (tidal range from mean low water to mean high water). A typical operational daily tidal exchange is assumed to be 3 feet and represents the amount of water available for flushing a pond through muted tidal exchange.
5 See Appendix F for details on assumptions and calculations.
6 Italicized items below the horizontal line require tidal exchanges in excess of that which is assumed as available.

Figure 9-2. Conceptual model for desalinating ponds with low to medium salinity levels



Steps:
1: Low-salinity water is continuously pumped to evaporator ponds.
2: Pumped low-salinity water (<35 ppt) flushes salts from water column. Insignificant salts in the sediments. Pond salinity ranges between 20 - 356 ppt depending upon pond position in the process.
3: Brine from evaporator ponds gravity flows to dilution pond. Brine salinity in outflow will be same as that in the evaporator pond. Initial outflow concentration will depend upon pond's position in the process and decrease o ver time.
4. Water to dilution ponds are initially 20% water flushed from evaporator ponds and 80% Bay water. 5:1 initial dilution is recommended initially to maintain low salinity in dilution pond. As flushing proceeds, dilution ratio can decrease depending upon outflow concentration from evaporator ponds.
5. Dilution ponds are flushed twice daily by tides.

Table 9-9 presents estimated desalination times under this scenario. Depending on the dilution pond area and the evaporator pond HLR, our analysis predicts that desalination of a given pond can occur in 9 to 80 days.

9.3 Three Desalination Strategies for Evaporator Ponds

This section presents and evaluates three specific strategies for desalinating the salt ponds within the Cargill proposed sale area: rapid desalination; desalination to optimize salt production efficiencies; and production, dilution, and discharge. See Table 9-10 for a brief description of each of these desalination strategies. All have a similar goal of desalinating pond water in preparation for restoring these ponds to tidal marsh of managing them in perpetuity as shallow open water habitat. The first two scenarios assume that Cargill accepts all the flush water; the third scenario requires some Bay discharge. Each scenario is also constrained by the principles of desalination as discussed in Section 9.2. Figure 9-3 shows a conceptual model for each of these management strategies compared to current salt production methods. Each strategy will be discussed in greater detail in the following three subsections.

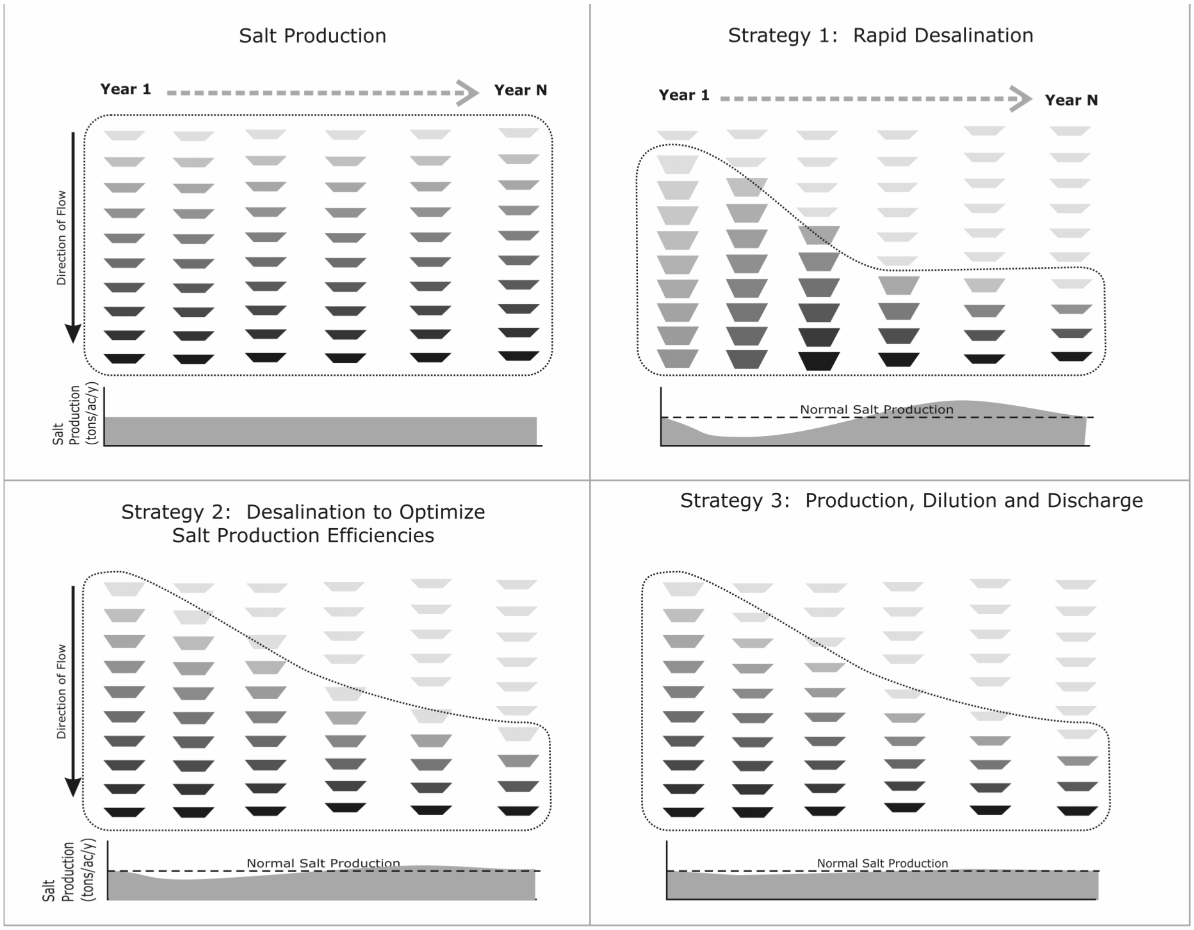
The annual water volume supplied to the Cargill salt ponds under current operations is estimated to be approximately 44,000 acre-feet of low salinity Bay water (i.e., 20 to 24 ppt or ~3 °Be) is estimated as the. At higher salinity (i.e., 35 ppt or ~4.3 °Be), the volume needed for current salt production decreases to approximately 28,000 acre-feet annually. Following completion of the acquisition, Cargill anticipates producing salt on 40 percent of the current South Bay acreage, or about 10,000 acres. With the increased production efficiency and reduced acreage, we estimate that future salt production efforts will need approximately 22,000 acre-feet of low-salinity Bay water annually. These volumes provide limits on how much volume Cargill might be able to accept each year from the desalination activities. Assuming that harvesting capacity is the rate-limiting step in salt production, then starting with higher salinity brine from the desalination process would not increase the maximum volumes Cargill could accept. However, if evaporation is the rate-limiting step, then further increases in inflow volumes from the desalination process might be possible because the initial salinity would be higher than bay water. In any event, volume limitations need to be considered when determining the number of ponds to undergo desalination at any given time, the required HLRs, the duration of flushing, and salinity discharge limits.

In considering the timeframe within which ponds become available for restoration under the three strategies presented below, one must also consider other factors that influence restoration rates. The single most significant rate-limiting factor we have identified in this Feasibility Analysis is the sediment deficit (Chapter 8). In practice, the sediment supply limitation may influence restoration implementation time frames far more than pond desalination. However, estimates for all these factors carry a fair measure of uncertainty so all must be explored and identified for future analysis as part of detailed restoration planning.

Table 9-10. Three strategies for interim management

Interim management strategies	Description and discussion
Rapid desalination	Maximize desalination rates by rapidly flushing ponds. Cargill receives all brine and flush water into its salt production process. Production efficiencies are reduced in the short term, and the production cycle is affected for several years. Minimizes Cargill's involvement with operation and management during the interim period and places greater burden on the Refuge.
Desalination to optimize salt production efficiencies	Desalination of ponds is conducted in phase with Cargill salt production cycle. Cargill receives all brine and flushed water into the salt production process. Production efficiencies are somewhat reduced in the short term as less concentrated brine sources used for flushing ponds are introduced into the system. Cargill O&M cost will increase by an unknown amount due to more complicated water transfer. Cargill's involvement with the operation and management likely to continue for 2 to 5 years. Reduced burden on the Refuge to manage ponds during the maintenance period.
Production, dilution, and discharge	Desalination of ponds is conducted in phase with Cargill salt production cycle. Cargill receives all brine above a salinity threshold balancing benefits to Cargill and discharge effects on the Bay. Salinity threshold is set to minimize negative effects on the estuary while also minimizing production costs to Cargill. Cargill likely to have increased O&M costs due to more complicated water transfer. Cargill's involvement with the O&M likely to continue for 2 to 5 years. Reduced burden on the Refuge to manage ponds during the maintenance period.

Figure 9-3. Conceptual models describing three alternative salt pond desalination strategies



Legend

Pond salinity:
- Low Salinity (~3 deg Be, 20 - 24 parts per thousands)
- High Salinity (~30 deg Be, ~374 parts per thousands)

Pond depth:
- Normal
- Deep (twice normal)

Cargill production area:

Strategy Notes:

Salt Production
1. About 25,000 acres of ponds currently in salt production.
2. Assume pond operations generally consistent year to year.
3. Salt production rate stable.

Rapid Desalination
1. Assumes Cargill accepts all brines.
2. Decrease in production acreage expedited by flushing ponds at a rate that maximizes brine storage in remaining salt production ponds. Key to strategy is maximizing pond depths during transition period and across salinity ranges.
3. Large initial salt production decrease due to salinity decrease across all ponds.
4. Above-normal salt production rates occur temporarily later in the process due to increasingly saline ponds.
5. Assumes excess crystallizer area.
6. Maximizes O&M costs to Refuge.

Desalination to Optimize Salt Production Efficiences
1. Assumes Cargill accepts all brines.
2. Strategy involves flushing ponds at a rate that maintains near-maximum salt production efficiencies.
3. Ponds removed from production more gradually than under Rapid Desalination strategy.
4. Upstream ponds likely operated above normal depths to increase pond volume for accepting brine.
5. Production rates reduced slightly due to pond flushing logistics.

Production, Dilution and Discharge
1. Assumes Cargill accepts all brines above a certain threshold salinity.
2. Strategy utilizes Bay discharge to minimize brines to Cargill. Brine to Cargill introduced at rates that maintain maximum salt production efficiencies.
3. Impacts production least.

General Notes
1. Pond salinities increase as brine passes through the system.
2. Symbol height represents pond depth.
3. Cargill pond acreage expected to decrease from 26,000 to about 10,000 acres, a 60% drop.
4. Total production area represented by the number of ponds within the dashed line. Area outside the line represents ponds not being used for salt production.
5. Assume Cargill ceases O&M for ponds removed from salt production.
6. Time to reach reduced area varies by strategy.
7. 40 tons of salt produced annually under current production.

9.3.1 Strategy 1: Rapid Desalination

The rapid desalination strategy aims to maximize desalination rates for each salt pond so ponds can be made available for restoration as soon as possible. This strategy requires maximizing the operating depths of all salt production ponds during the desalination period (see Figure 9-3). Under this scenario, Cargill receives all brine with salt concentrations above Bay background levels, including all brines currently in the salt ponds and all brines used to desalinate the salt ponds.

Based on the analysis provided in Section 9.2, physics and chemistry constrain the rate that Cargill could receive the brines. If Cargill were to accept all brine and flush water from desalinating the evaporator ponds, that would provide enough water to operate the current 25,000 acres of salt production ponds for a period of 1 to 3 years. If one assumes the production area to be only 40 percent of its current size after public acquisition, this is sufficient water to operate the system for 2.5 to 7.5 years. This estimate does not include bittern and wash water from the Redwood City bittern ponds, which is estimated as another 9,600 acre-feet after desalinating of the water column and sediments (see Table 10-11 in Chapter 10). This bittern and wash water will be stored, and some may be reprocessed. It represents another half-year of water under assumed operational conditions (e.g., 10,000 acres at a water depth of 1.5 feet). Thus, Cargill would have 3 to 8 years of brine available to it after desalination of the ponds currently considered for sale and restoration.

Cargill may be able to store excess water in its ponds. Normal operations assume an average depth of 1.5 to 3 feet. Some ponds operate at deeper levels (Lonzarich and Smith 1997, Oswald 1986). Assuming capacity in the remaining 10,000 acres of salt production ponds can increase 50 percent, approximately 5,000 acre-feet of additional water could be stored. Assuming existing evaporator ponds are operated at a depth of 1.5 to 3.0 feet and three HRTs (or pond volumes) are required to flush each pond, between 550 to 1100 acres could become available for restoration very quickly. However, because evaporation rates limit brine processing, the time required to desalinate all the decommissioned ponds would remain on the order of 3 to 8 years.

This desalination strategy requires Cargill to maximize brine depths in its ponds. Because evaporation decreases as salinity increases (see Appendix A), keeping the ponds deep would maximize early evaporation rates and allow the introduction of more brine and flush water from the ponds being restored. Initially, this strategy would dramatically reduce salt production rates in the remaining salt production ponds by lowering average salinity. However, salts would build up in the system over time, and eventually an overproduction of salt would occur. This transient overproduction would exceed normal production rates as excess salts were harvested from the system. Eventually, a steady-state condition would be approached, and salt production would level out to a more normal rate. Use of this desalination strategy would therefore result in lower salt production rates initially, overproduction after a period of time, and an ultimate return to normal salt production rates (see Figure 9-3). Average salt production during the period preceding return to normal production rates would be slightly lower than those normal rates. Consequently, Cargill's income from sales of harvested salt could decline for a limited period of time.

This desalination strategy will result in other costs for Cargill. Production rates will vary more than normal from year to year, at times resulting in underproduction and at times resulting in overproduction. This fluctuating salt production could place a marketing burden on Cargill. Higher water volumes and maximized water depths will increase the costs associated with pumping water. In light of California's recent power shortage, pumping costs could be expensive. Deeper ponds may require increased maintenance costs for levee and water control structure repairs. Overall, this scenario will probably result in higher maintenance and operational costs for Cargill for a limited time.

The Refuge may also face higher costs under this strategy. Because this strategy's goal is to free up ponds for restoration as quickly as possible, ponds may need to be maintained in a low salinity regime for an extended period of time while restoration planning occurs. In other words, ponds might be desalinated faster than restoration can occur, which could have two implications for the Refuge. First, pond maintenance becomes the Refuge's responsibility once ponds are removed from salt production. As long as ponds are in salt production, a strong argument can be made for Cargill to maintain the ponds. However, once they are no longer in production, Cargill's maintenance responsibilities will likely end. This change shifts the burden of maintaining levees and water control structures to the Refuge early in the restoration process. Second, this strategy requires the Refuge to maintain pond salinities near background Bay levels. This will require managing flows into the ponds at rates that are currently maintained during salt production. Low flows will either result in increasing salinities or high steady-state salinity levels. Based on Figure 9-1, flows must exceed evaporation rates by several times, and we recommend a minimum HLR of 20 feet per year (five times the current rate). Providing these flows will be an expensive burden to the Refuge due to staff time for managing water control structures, pumping costs, and so forth.

In summary, although rapid desalination will quickly release ponds for restoration, it does so at a high cost to all parties. These costs are further increased because decommissioned ponds might be out of step with restoration rates. Although this strategy will reduce Cargill's profits and increase their operating and maintenance (O&M) costs for a limited time, it provides Cargill the opportunity to reduce their overall costs more quickly by handing over decommissioned ponds sooner, resulting in higher maintenance costs for the Refuge.

9.3.2 Strategy 2: Desalination to Optimize Salt Production Efficiencies

The second desalination strategy focuses on desalinating ponds in a way that optimizes salt production efficiencies. This strategy would entail close cooperation and planning between Cargill and the Refuge for several years during its implementation. As with the rapid desalination strategy, Cargill receives all brine with salt concentrations exceeding Bay background levels, including all brines currently in the salt ponds and all flush water. Under this strategy, the brine and flush water are incorporated into the salt production stream at a rate that maintains Cargill's current salt production efficiency. This rate would be less than that for the "rapid desalination" strategy presented in the previous section.

Under this optimized salt production desalination strategy, ponds become available for restoration gradually. Whereas the rapid desalination strategy targets a 3- to 8-year desalination period, this scenario targets a longer period. Although the exact timeframe cannot be defined now, it is conceivable that it would be twice that for the rapid desalination strategy (e.g., 6 to 16 years). This timeframe allows Cargill time to phase out production in the salt ponds gradually, and it allows the Refuge time to plan for restoration effectively.

Because the process is more gradual, the optimized desalination strategy affects salt production less than the rapid desalination strategy (see Figure 9-3). Ponds at the intake end of the system are operated at greater water depths than normal in order to accommodate relatively rapid pulses of water from ponds undergoing desalination. These ponds will be operated at HLRs exceeding evaporation rates and higher than necessary for salt production.

Under the optimized salt production desalination strategy, salt production will decrease below normal for a period of time. This reduction occurs for three reasons. First, ponds must accept pulses of flush water. Second, Cargill has less control over its water source. Lastly, the logistics of flushing and desalination must be integrated into the salt production process. These production decreases are expected to be small, however, and efficiencies should return to normal over time.

The optimized salt production desalination strategy may constrain restoration options, however, and these constraints must be incorporated into the restoration planning process. First, the order in which ponds become available for restoration will depend on the salt production process. Lower salinity ponds will become available for restoration first, and pond desalination will follow behind the salt production process as brine is extracted from the decommissioned ponds. Second, the number of ponds that can be desalinated at any one time depends on the system's capacity to accept additional water. Harvesting rates from the Newark crystallizer ponds, currently at 700,000 tons annually, will become the limiting factor. However, other factors (e.g., the sediment supply problem discussed in Chapter 8) may constrain the pond restoration rate more than desalination.

Cargill may bear additional costs under the optimized salt production desalination strategy. Pumping costs would likely increase due to more complex logistics associated with coordinating salt production and desalination. Some increase in flow is likely, especially during pond desalination. Levee costs may also increase because several ponds would need to be operated at deeper than normal levels in order to accept water flushed from desalinated ponds. Finally, Cargill production rates may decrease somewhat for a finite period of time because they may need to accept inflow waters with salinity less than desired for optimal production. All these impacts can be mitigated to some extent by close cooperation between Cargill and the Refuge.

We assume Cargill will be responsible for operations and maintenance costs for ponds still in salt production. As ponds are decommissioned, the Refuge will likely assume the associated O&M costs as well as costs associated with providing sufficient flow rates to maintain pond salinities near background levels. These costs are inevitable but will be less than those accrued under the rapid desalination strategy because the maintenance period for each pond targeted for restoration will be less (see Table 9-1).

In summary, under the optimized salt production desalination strategy, salt production rates will decrease somewhat at the outset. Over time, production efficiencies are expected to increase. By minimizing the maintenance period for all salt ponds undergoing restoration, the Refuge's maintenance costs will be less than with the rapid desalination strategy. This strategy may constrain restoration options, however, because ponds will become available for restoration more slowly. This slower rate of pond availability may not be a problem, however, because the rate-limiting step on overall restoration to tidal marsh may be resolving the sediment deficit (Chapter 8).

9.3.3 Strategy 3: Mixed Production, Dilution, and Discharge

The mixed production, dilution, and discharge strategy is similar to the optimized desalination strategy in that it attempts to desalinate ponds while maintaining salt production efficiencies. In this strategy, much of the brine from pond desalination is discharged to the Bay with only the highest salinity brine going into Cargill's salt production stream. This approach relieves Cargill of the burden of accepting much of the brines and flush waters and thus it minimizes its effect on Cargill's salt production process.

For higher salinity brine, sodium chloride concentrations may provide value to Cargill. The mixed production, dilution, and discharge strategy assumes that Cargill will accept some brine with salinity levels above a certain threshold for further processing. Below certain thresholds, the RWQCB would allow discharge of diluted brine and flush water into the Bay. The salinity levels of these thresholds require RWQCB adopting discharge standards (see Section 9.2.2) and Cargill determining its minimum brine concentration levels it can accept into its production stream economically.

The mixed production, dilution, and discharge strategy has the same advantages as the optimized salt production desalination strategy, even though it requires Cargill to accept only a portion of the total brines and flush waters. Therefore, this strategy interferes less with ongoing salt production operations and further minimizes the costs to both Cargill and the Refuge. Because Cargill will accept less low salinity brine, ponds can be operated at more optimal water depths since less capacity is required to accept brines and flush waters from ponds undergoing desalination. This strategy translates to lower levee maintenance costs, lower water control structure maintenance costs, lower water management costs, and fewer impacts to salt production. The Refuge's costs decrease due to streamlined coordination with Cargill. These costs shrink further when desalination and maintenance operations are simplified.

9.4 Ecological Goals for Interim and Long-Term Management

Once decommissioned salt ponds have been desalinated, we assume that ongoing operations and maintenance responsibilities would transfer to the Don Edwards San Francisco Bay National Wildlife Refuge. We anticipate that the underlying Refuge management objective will be to maintain suitable conditions for target wildlife species. The Refuge would seek to meet this objective for the interim period between taking over management responsibilities and restoration implementation and in perpetuity for those ponds not restored to tidal marsh.

From an ecological perspective, management objectives for shallow open water areas would follow from the ecological requirements of target species, primarily a variety of shorebirds and waterfowl. (Refer to Chapter 4 for a complete discussion of wildlife issues.) A vast majority of these species, and the ones identified with the highest conservation status, utilize the low salinity ponds. Eighty-three percent of waterfowl were found in ponds with salinities ranging between 20 and 93 ppt, with most birds preferring 20 to 33 ppt (Takekawa *et al.* 2000). Variable water depths are required to support dabbling and diving ducks as well as small and large wading shorebirds. These ecological requirements provide the target physical conditions sought by interim and long-term management.

There are a variety of operational approaches that would meet these physical requirements. In all cases, the goal is to avoid salt concentration and consequent discharge problems. Cargill currently operates these ponds as one-way systems, from the intake to the crystallizer (see Map 5). Wildlife management without salt production must fundamentally reverse this arrangement, such that the ponds operate as a two-way system that allows periodic exchange of pond water with tidal waters for all ponds and minimal salt concentration. In essence, all ponds would be operated as muted tidal systems, with the degree of muting ranging widely to the point where tidal exchange may occur only a few times per month or less. Salinity monitoring will be an essential component of any management regime. Ponds further removed from a tidal source will require closer monitoring as water exchange may be more difficult. The USFWS Tidal Marsh Ecosystem Recovery Plan (USFWS, in preparation) is expected to provide a variety of detailed approaches for achieving these wildlife management objectives.

Chapter 10.

Bittern

Chapter 10.

Bittern

Bittern is the hypersaline waste byproduct of solar salt production. As brine moves through the salt production process, various ions are removed from solution creating what is termed an "ionic imbalance." The combination of hypersalinity and the ionic imbalance makes bittern toxic to aquatic organisms. The federal Clean Water Act and state Porter-Cologne Water Quality Act do not allow its direct discharge to the bay because of its toxicity to aquatic organisms. Few commercial applications have existed for bittern since the 1960s, though Cargill has recently developed new processing technologies in an effort to generate commercial applications. Consequently, considerable quantities of bittern are currently stored in Newark and Redwood City and the quantities grow each year with ongoing salt production. Since the Redwood City bittern ponds are part of the 16,000 acres that Cargill has proposed for sale to the public, full removal of that bittern to the level where the ponds can be opened to tidal action without adverse environmental consequences must be addressed within the current negotiations.

Further, over the many decades we estimate tidal marsh restoration will take (see Chapter 8), it is entirely possible that Cargill will cease salt production altogether in the Bay Area. Much of the current bittern storage in Newark is on Refuge-owned lands and the Cargill mineral rights agreement places them under no obligation to clean up any of these ponds upon termination of salt production. Consequently, now is the time within the current negotiations to ensure that Cargill and not the public has the future obligation for full bittern remediation throughout the entire South Bay salt pond complex.

This chapter provides the technical background necessary to undertake acquisition negotiations in a manner protective of public resources. This chapter is organized into the following sections:

- Section 10.1 defines bittern in all its forms so that differences in terminology do not create a situation in which some portion of the total bittern byproduct is not remediated fully.
- Section 10.2 presents our new estimates of the bittern production rates, based on new mass balance analyses included in Appendix D. These rates are higher than current Cargill estimates and lower than other previous estimates.
- Section 10.3 presents our estimate of the total quantities of bittern stock-piled in Redwood City and Newark, based on production rates developed in Section 10.2 and on bittern pond acreage at each location. The Redwood City bittern needs to remediated as part of any current acquisition area and the Newark bittern will need to be remediated in the future when and if Cargill ceases salt production altogether in the Bay Area.
- Section 10.4 presents our estimates of how much water will be necessary to flush all the bittern from the Redwood City ponds to make them suitable for tidal marsh restoration. Disposition of this "flushing" water volume must be addressed in the acquisition negotiations as well.
- Section 10.5 reports on cost estimates for bittern pond dilution in order to provide a sense of the magnitude of costs the public would be burdened with if Cargill does not take full responsibility for all South Bay bittern now and in the future.
- Section 10.6 concludes with a summary of the issues we believe must be addressed in the current acquisition negotiations.

10.1 Defining Bittern

Bittern is an inevitable byproduct of solar salt production. As brine moves through the salt production process, various ions are removed from solution creating what is termed an "ionic imbalance." Gypsum and calcium carbonate are removed in the lime ponds and sodium chloride is removed in the crystallizer ponds (see Chapter 3). However, more soluble salts and ions remain in solution after brine is removed from the crystallizers, resulting in the bittern byproduct (Table 10-1). Thus, the bittern byproduct is primarily composed of chloride, magnesium, sulfate, potassium, and bromide ions (Ver Planck 1958) the remaining sodium chloride and more soluble salts, and water. Though these ions only make up a small percent of the source Bay water, they become highly concentrated in the bittern liquid discharged from the crystallizers. Exact ion concentrations depend upon the chemical characteristics of the source water and the final salinity of the bittern (Table 10-2).

When the bittern is withdrawn from the crystallizer ponds, it is entirely in liquid form and all ions and salts in it are dissolved. Bittern salinity at this stage is generally in the range of 369 to 395 ppt (30 to 32 °Be) and its volume has been reduced to between 1.6 and 3 percent of the original brine volume (Ver Planck 1958; Ransom, personal communication). However, once the bittern begins to be stored or stockpiled, it becomes more saline from ongoing solar evaporation and salts continue to precipitate from solution and settle to the bittern pond bottom (Figure 10-1). As the bittern becomes more saline, additional salts precipitate from solution, primarily more sodium chloride and magnesium sulfate, and settle to the pond bottom. As discussed in Chapter 3, the order of precipitation depends upon the concentrations of the various ions in solution and their solubility products (Table 3-2 in Chapter 3). The maximum bittern salinity achievable in the Bay Area is around 447 ppt (36 °Be), and is limited by a combination of rainfall and evaporation rates in the Bay Area (Ransom, personal communication).

Because the byproduct of solar salt production can have both a solid and dissolved phase and it includes the water in which the ions and salts are dissolved, the term bittern becomes ambiguous and may not mean the same thing to everyone. **Bittern is defined**

Table 10-1. The fate of bittern ions during solar salt production

Ion	Sea Water Concentration (%)	Percent Allocation of Ions into Different Pond Types and Physical States[1] — Precipitate Form[2] — Evaporators Ponds — Stage 1 (%)	Stage 2 (%)	Crystallizer Ponds (%)	Bittern at 36°Be (%)	Dissolved Form[3] (%)
Mg	0.1313				30±	70±
Na	1.0708			95±1	5±	0±
SO_4	0.2692		33±		23±	44±
K	0.0387					100±
Cl	1.9352			79±1	4±	17±
Br	0.0066					100±
Ca	0.0419	12±	88±			0±
CO_3	0.0072	100±				0±

1 *Assumes final salinity of bittern is 36 °Be.*

2 *See Appendix D for mass balance analyses.*

3 *Based upon a salt production rate of 40 tons per acre per year (Ver Planck 1958)*

as the liquid bittern (which consists of bittern ions and salts dissolved in a water matrix) and the solid bittern (precipitated salts that reside on pond bottoms) (Table 10-3 and Figure 10-1).

The bittern liquid can be 11 to 12.5 times more saline than sea water, and several studies have shown that bittern causes toxicity to aquatic species. The elevated salinity affects osmo-regulation (Hansen and Associates 1993), and several studies have found ion imbalance to cause toxicity. Ion imbalance toxicity can occur at both high and low salinity levels (Pillard *et al*. 2000, Mount *et al*. 1997, Goodfellow *et al*. 2000). Bittern toxicity is discussed further in Section 7.1.

10.2 Estimates of Bittern Production Rates

In order to gain a sense of how much bittern may be stockpiled at the Cargill salt ponds (Section 10.3), it is necessary to know the production rate of bittern. Unfortunately, discrepancies exist amongst reported bittern production rate. Cargill has offered its estimate of bittern production rates, which is nearly 7 times less than estimates of its predecessor, Leslie Salt Company (see Section 10.2.1). To resolve this discrepancy, we used a mass balance analytical approach to develop new estimates of the bittern production rate at the Cargill salt ponds (Section 10.2.2 and Appendix D).

10.2.1 Previous Estimates

Cargill Estimates. Cargill estimates that 0.15 tons of bittern are produced per ton of salt harvested (Ransom, personal communications). We assume that this estimate is for bittern at the most concentrated level achievable in the Bay Area, 447 ppt (36 °Be).

Leslie Salt Estimates. In a report for the Leslie Salt Company on proposed bittern discharge into San Francisco Bay, CDM (1972) estimated that each ton of salt produced resulted in one ton of bittern. The report does not mention the salinity level. The Leslie Salt Company estimated that approximately 180 million gallons of bittern (at 32 °Be) was produced for every 925,000 tons of salt (Refuge records). This production rate corresponds to just over one ton of bittern for every ton of salt produced. These estimates are in line with historical estimates of bittern production (Ver Planck 1958).

10.2.2 New Estimate Based on Mass Balance Analyses

We have calculated a new estimate of bittern production rates, using a mass balance approach, in order to help investigate and resolve some of the inconsistencies between the two estimates given in the previous section. Assumptions used in these calculations are described in Table 10-4, and Appendix D provides the calculations. Table 10-5 presents the results of the mass balance calculations for bittern production at the Cargill salt ponds.

Several conclusions are evident from Table 10-5. Evaporation, and the resulting salinity (ion concentration) determine the volume of bittern produced and the speciation of bittern ions and salts. For instance, at a lower salinity (30 °Be; 369 ppt), all the ions are in the liquid phase, and the bittern volume is approximately three percent of the original brine solution and mass balance calculations predict 1-1.4 tons of bittern produced per ton of salt harvested. At a higher salinity (32 °Be; 395 ppt), the bittern volume decreases by approximately 45 percent due to ongoing evaporation to about 1.6 percent of the original brine volume and mass balance calculations predict 0.6 tons of bittern from each ton of salt harvested. A ten percent increase in salinity accompanies this volumetric reduction. At a still higher salinity (36 °Be; 447 ppt) the volume of bittern produced is

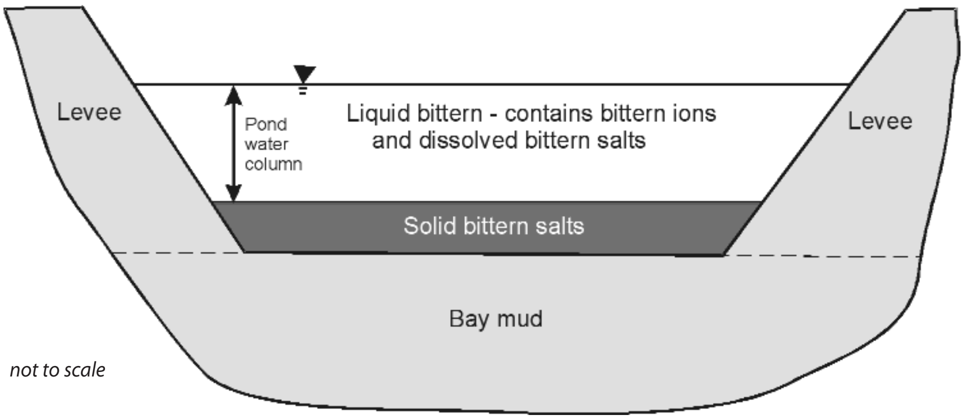
Table 10-2. Typical bittern ionic composition at 32 °Be (395 ppt) for Mediterranean Sea water

Ion	Concentration (%)
Cl^-	19.52
Br^-	1.2
SO_4^{2-}	6.93
Na^+	5.12
K^+	1.3
Mg^{2+}	5.55
Total	**39.62**

1 *Based upon bittern from Mediterranean Sea water. Ionic concentrations will be somewhat different for Bay water.*

2 *Source: Ver Planck (1958).*

Figure 10-1. Bittern pond vertical structure schematic



reduced further through evaporation, decreasing to approximately 0.6 tons of bittern produced for each ton of salt harvested.

The estimate of 0.6 tons of bittern produced for each ton of salt harvested is 40 percent below historical estimates (Ver Planck 1958, CDM 1972, Refuge records), and is due entirely to further concentration of the bittern through evaporation. Thus, mass balance analyses show that historical bittern production rate estimates may be too high given the bittern "strengthening" that occurs from evaporation. However, these same calculations do not support the bittern production estimates provided by Cargill of 0.15 tons bittern per ton of salt produced, and in fact are about four times higher, even at the highest salinity level achievable in the Bay Area.

The discrepancy in bittern production rates may be related to the definition of bittern, which was discussed in Section 10.1. For example, it is possible that Cargill is only including the solid phase in its definition of bittern. Alternatively, it is possible that Cargill is only including the ions and salts (and not the water) in its definition of bittern. However, an accurate calculation of bittern byproducts requires quantifying all of the components of bittern, including the solids (precipitated salts) and the liquid (dissolved salts and ions in a water matrix). Additionally, it is important to remember that even though the mass (and volume) of bittern is decreased as the bittern salinity increases through evaporation, conservation of mass requires that the total amount of salts and ions remains unchanged. This result has significant implications for the eventual disposal of the bittern (Section 10.4).

Table 10-6 expands upon the information presented in summary form in Table 10-5. Specifically, Table 10-6 illustrates the relationship between bittern ions in solution and bittern ions as precipitate, at different levels of salinity, and the relationship of the liquid bittern ions and salts to the water matrix in which these ions and salts are dissolved.

Several conclusions can be drawn from Table 10-6. First, at 30 to 32 °Be, all bittern ions and salts are in dissolved form. Second, while the bittern volume (and mass) decreases with increasing salinity, the total mass of bittern ions and salts remains constant. At 36 °Be, the same amount of bittern ions and salts are present, but these ions

Table 10-3. Definitions of bittern and its components

Term	Definition	Comments
Total bittern by-product	Combination of liquid and solid bittern.	Represents the complete bittern by-products, including all the liquid (bittern ions and salts dissolved in water matrix) and solid (precipitated salts) phases.
Total liquid bittern	Residual liquid brine from solar salt production. Includes bittern ions, dissolved salts and water.	Evaporation further concentrates bittern after removal from crystallizer ponds. As bittern becomes more concentrated and volume is reduced, salinity increases and further salt precipitation occurs. Thus, salts are further removed from the bittern, which leads to a change in concentration and distribution of the ions.
Bittern ions	Ions found in bittern. These ions include potassium, magnesium, bromide, chloride, sulfate, sodium, and chloride.	Ion concentration is controlled by the original brine (e.g., bay water, sea water) and the amount of ions removed from the brine through precipitation. Ions form the bittern salts, and the concentrations of the ions and dissolved salts are controlled by equilibrium relationships. Bittern ions occur in the liquid phase only; they combine into bittern salts when they precipitate into the solid phase on pond bottoms.
Bittern salts	Salts that exist in the bittern. These salts include magnesium sulfate, magnesium chloride, potassium chloride, and magnesium bromide.	Salts can be either dissolved (liquid phase) or precipitated (solid phase). Precipitated salts form deposits on pond beds and may not be included when discussing bittern as a byproduct. Sodium chloride is found in bittern, but may be excluded because it is the desired harvestable product.
Bittern solids	Bittern salts that have precipitated.	Bittern solids found primarily on bittern pond bottoms.

Table 10-4. Assumptions used to develop mass balance calculations for bittern production in the South Bay salt ponds

Assumptions		Reference
1	Optimum salt production per acre is 40 tons per acre.	Ver Planck (1958)
2	38.25 Tons of bay water required to produce one ton of salt.	Ver Planck (1958)
3	Based upon NaCl analyses, average Bay water salt concentrations input to the salt ponds can be approximated by sea water salt concentrations. Thus, in developing a mass balance from Ver Planck's (1958) hydrologic balance (Assumption 2), the original brine is assumed to be sea water.	Ver Planck (1958), Clark (1924)
4	Crystallizer salinity is operated at approximately 30 – 32 °Be.	Ver Planck (1958), Ransom (personal communication), Refuge Notes
5	Percent removal of sodium and chloride ions in the crystallizers is based upon achieving optimal salt production of 40 tons per acre.	Ver Planck (1958)
6	Bay water major ion concentrations (e.g., Na, Cl, SO_4, K, Mg, Ca, CO_3) have same relative distribution to sea water.	CDM (1972), Table 10-2
7	Percent sodium chloride and magnesium sulfate removal within the bittern ponds is estimated from chemical analyses of bittern from the South Bay salt ponds at a salinity of 36 °Be. Ionic concentrations measured are assumed to be typical of bittern at that salinity.	CDM (1972)
8	Bittern at 30 °Be is 3 percent of the original brine volume.	Ver Planck (1958)
9	Bittern at 32 °Be is 1.62 percent of the original brine volume.	Ver Planck (1958)
10	Bittern at 36 °Be is determined to be approximately 1.1 percent of the original brine volume based upon total dissolved solids analyses of the bittern by CDM (1972) in combination with mass balance analyses of salt removal in the crystallizers and previous ponds.	CDM (1972) and mass balance analyses results
11	Approximately 100 percent of the gypsum is removed prior to crystallizer ponds.	Ver Planck (1958)
12	Maximized desalting pond efficiencies assumes that approximately 100 percent of the sodium chloride precipitating in the desalting ponds can be recovered in the crystallizers when those salts are dissolved in brine and the brine recycled through the system.	
13	Maximum salinity achievable in the bittern ponds is 36 °Be based on Bay Area rainfall and solar evaporation conditions.	Ransom (personal communication)
14	Magnesium sulfate is the next salt to precipitate after sodium chloride. Magnesium sulfate and sodium chloride are the primary salts precipitating in the bittern ponds as the bittern becomes more concentrated.	Ver Planck (1958)
15	Potassium and bromide remain dissolved in the bittern up to 36 °Be and do not precipitate as salts.	Ver Planck (1958)
16	Magnesium chloride remains dissolved in the bittern up to 36 °Be.	Ver Planck (1958)
17	Approximately 25,000 acres are actively used for salt production based upon the maximum salt production rate of Ver Planck (1958) and the amount of salt produced as reported by Cargill.	Ver Planck (1958), Cargill (2000a), Map 1
18	Magnesium sulfate and other bittern salts only negligibly precipitate from solution at salinities below 30 – 32 °Be.	Ver Planck (1958)

and salts are now divided between the dissolved (liquid) and precipitate (solid) phases, with approximately one third in the precipitated phase and two thirds in the dissolved phase. These changes occur concurrent with a decrease in the bittern liquid volume.

10.3 Estimates of On-Site Bittern Storage

From a restoration perspective, it is important to know how much total bittern by-product is stored within the South Bay salt pond complex. We first examined available historical and current information regarding bittern storage, marketing, and discharge (Section 10.3.1), and then we calculated a new estimate of the amount and thickness of stored bittern based on the estimated time of storage, the annual bittern production rates calculated in the previous section (Section 10.2.2), and the total area of bittern storage ponds (Map 5).

Table 10-5. Estimated total bittern by-product per ton of salt harvested

Scenario	Bittern Phase	Salinity (ppt)	Salinity (°Be)	Bittern produced[1] Lower (tons)	Bittern produced[1] Upper (tons)
Discharge from Crystallizer[2]	Liquid	369	30	1.0	1.4
	Liquid	395	32	0.8	0.9
Concentrating in Bittern Storage and Desalting Ponds[3]	Liquid & solid	447	36	0.6	0.6

1 Based on two analyses: mass balance and concentration conversions. Calculations are shown in Appendix D.

2 Bittern production values shown represent discharge of bittern from crystallizers at salinity value shown.

3 Bittern production values shown represent bittern as it concentrates in the bittern storage and desalting ponds.

10.3.1 History of Bittern Stockpiling and Marketing

Chapter 3 discusses bittern production, handling and storage, with cessation of bittern sales to FMC in 1968 and the passage and implementation of the federal Clean Water Act and State Porter-Cologne Water Quality Control Act in the early 1970s that ended unregulated bittern discharge to the Bay being pertinent here. These actions marked the beginning of long-term on-site bittern storage in bittern ponds. Cargill currently markets some bittern for dust suppressants and de-icers, although this appears to be a recent development. How much they market for these purposes and for how long these markets have been open to Cargill is not clear. Estimates of the bittern market range from a small amount (Ransom, personal communication) to the volume of liquid bittern produced annually (Cargill 2001a). Thus, it appears that most of the bittern produced since 1972 has been stored within the South Bay salt pond complex.

Bittern desalting and storage ponds are shown in Map 5. Bittern storage ponds include 270 acres in Redwood City and 780 acres in Newark. Bittern desalting ponds include 110 acres in Redwood City and 450 acres in Newark.

Two changes in bittern handling and storage have occurred over the last 30 years (Ransom, personal communication). Cargill has been investigating

Table 10-6. Estimated amount of bittern generated during salt production

Salinity ppt	Salinity °Be	Bittern Phase	Total Bittern Production[1,2] Tons/Ac/Yr Lower[4]	Total Bittern Production[1,2] Tons/Ac/Yr Upper[4]	Total Bittern Production[1,2] Tons/Ton of Salt Produced Lower[4]	Total Bittern Production[1,2] Tons/Ton of Salt Produced Upper[4]	Bittern Ions and Salts[3] Tons/Ac/Yr	Bittern Ions and Salts[3] Tons/Ton of Salt Produced	Water Production Tons/Ac/Yr Lower[4]	Water Production Tons/Ac/Yr Upper[4]	Water Production Tons/Ton of Salt Produced Lower[4]	Water Production Tons/Ton of Salt Produced Upper[4]
BITTERN WITHDRAWN FROM CRYSTALLIZERS — LOWER SALINITY LEVEL ESTIMATE[1,5]												
369	30	Total	39.2	56.2	1.0	1.4	11.5	0.3	27.7	44.7	0.7	1.1
		Liquid (dissolved bittern ions and salts)	39.2	56.2	1.0	1.4	11.5	0.3	27.7	44.7	0.7	1.1
		Solid (precipitated salts)	0.0	0.0	0.0	0.0	0.0	0.0	NA	NA	NA	NA
BITTERN WITHDRAWN FROM CRYSTALLIZERS — HIGHER SALINITY LEVEL ESTIMATE												
395	32	Total	30.9	37.2	0.8	0.9	11.5	0.3	19.4	25.7	0.5	0.6
		Liquid (dissolved bittern ions and salts)	30.9	37.2	0.8	0.9	11.5	0.3	19.4	25.7	0.5	0.6
		Solid (precipitated salts)	0.0	0.0	0.0	0.0	0.0	0.0	NA	NA	NA	NA
BITTERN SUPPLIED TO BITTERN DESALTING PONDS PRIOR TO ADDITIONAL SODIUM CHLORIDE RECOVERY												
447	36	Total	25.4	26.0	0.6	0.7	11.5	0.3	13.9	14.5	0.3	0.4
		Liquid (dissolved bittern ions and salts)	21.3	21.9	0.5	0.5	7.4	0.2	13.9	14.5	0.3	0.4
		Solid (precipitated salts)	4.1	4.1	0.1	0.1	4.1	0.1	NA	NA	NA	NA

1 Assume sodium chloride is harvested and bittern removed from crystallizers at 32 °Be.

2 Assumes a salt production rate of 40 tons per acre per year.

3 This mass excludes water in which liquid bittern ions and salts are dissolved.

4 Upper and lower ranges depends upon calculation method used. See Appendix D.

5 Assumes magnesium sulfate precipitation negligible until a salinity of 32 °Be achieved.

Table 10-7. Estimated bittern accumulation over 30-year production period

Description[1]		Units	Total Bittern[2]		Location[3] Newark		Redwood City	
			Lower[4]	Upper[4]	Lower[4]	Upper[4]	Lower[4]	Upper[4]
Bittern storage area		Acres	1,050	1,050	780	780	270	270
BITTERN LIQUID AT 36 °BE[1]								
A	Dissolved bittern salts and ions	Million of tons	5.5	5.5	4.1	4.1	1.4	1.4
B	Water matrix	Million of tons	10.4	10.9	7.7	8.1	2.7	2.8
C	**Total bittern liquid = A + B**	**Million of Tons**	**15.9**	**16.4**	**11.9**	**12.2**	**4.1**	**4.2**
		Acre-Ft	8,828	9,093	6,558	6,755	2,270	2,338
		Millions of gallons	2,877	2,963	2,137	2,201	740	762
		Tons per acre	15,194	15,650	11,287	11,626	3,907	4,024
BITTERN SOLIDS AT 36 °BE								
D	Precipitated bittern salts	**Million of tons**	**3.1**	**3.1**	**2.3**	**2.3**	**0.8**	**0.8**
		Tons per acre	2,924	2,924	2,172	2,172	752	752
TOTAL BITTERN BY-PRODUCT = BITTERN LIQUID + BITTERN SOLIDS								
E	Total = C + D	**Million of tons**	**19**	**19.5**	**14.1**	**14.5**	**4.9**	**5**
		Tons per acre	18,118	18,574	8,730	8,927	3,022	3,090

1 Assumes bittern is stored at 36 °Be.

2 Assumes 40 tons of salt produced per acre and 25,000 production acres.

3 Estimated storage per site based on relative areas of bittern ponds (Map 5) and assuming same storage depths.

4 Lower and upper refer to range of estimates of bittern accumulation.

markets for bittern since at least the mid-1980s (Jean Takekawa, personal communication). Current bittern commercial applications include de-icer (Hydro Melt™), a de-icer amendment that improves the flowability and performance of salt in de-icing roads (ClearLane™), and a dust suppressant for unpaved roads (Dust-Off®) (Cargill 2001a). Cargill de-icer and dust suppressant products have been geographically limited to California and nearby states (e.g., Arizona and Nevada) historically because magnesium sulfate precipitates from solution at cold temperatures, making transport to more distant markets infeasible. However, recent improvements in processing the bittern to remove sulfates, and thus eliminating this problem, has expanded the market geographically.

The April 2001 "Bay's Edge" newsletter produced by Cargill (2001a) states that the volume of the bittern market equals the amount of liquid bittern it produces each year though no specific timetable on when this market was fully developed is provided. However, the desulfating process used to broaden the geographic markets is new, coming on line in October 2000 (Cargill 2001a). Thus, the improved bittern market is presumed to coincide with the advent of this desulfating process in late 2000. These products recover at least a portion of the magnesium ions and associated anions from solution. However, it does not appear to recover the other remaining ions in solution and does not address the precipitated bittern salts that result from the salt production process. Cargill states that with this recent technological improvement, they can market the annual volume of liquid bittern produced (which is about two thirds of the total bittern mass produced annually). This improvement translates into slowing the growth of the stockpiled bittern but it does nothing to reduce the size of the existing bittern stockpile.

The second change in bittern handling has been to improve the salt production efficiency. Cargill operates desalting ponds, which are handling ponds used to process bittern before it is stored onsite (Ransom, personal communication). Maps from the 1970s also show "bittern desalting ponds" but those ponds are currently used for brine evaporation. The current desalting ponds are essentially temporary bittern storage ponds used to "strengthen" or make the bittern more concentrated. Sodium chloride and magnesium sulfate both precipitate from solution between 395 and 447 ppt (32 – 36 °Be). Cargill stores bittern in the desalting ponds from the time it is discharged from the crystallizers until it reaches a salinity around 36 °Be, at which time it is pumped to the bittern ponds for on-site storage. An impure salt composed of magnesium sulfate and sodium chloride precipitates on the beds of the desalting ponds. On approximately one- to two-year intervals, these ponds are flooded with Bay water to dissolve those salts and that water is then sent back to the pickle ponds (Ransom, personal communication). Thus, the sodium chloride precipitated in the desalting ponds is recovered back to the brine for harvest in the crystallizers. This operational change is relatively recent and has led to a reduction in new bittern production (Ransom, personal communications). Cargill has not provided information on when this practice began nor exactly how much the improvement has reduced the annual contribution to the bittern stockpile.

10.3.2 New Mass Balance Estimate of On-Site Storage

The amount of total bittern byproduct (liquids and solids) varies with the salinity of the stored bittern, due to changes in liquid volume. The amount of dilution water in the bittern byproduct varies seasonally with winter rainfall and summer evaporation. In contrast,

Table 10-8. Estimated thickness of bittern stored in the 1,050 acres of bittern ponds

Bittern Phase	Description	Thickness(ft) [1,2]	
		Lower	Upper
Liquid phase	Dissolved bittern ions and salts in water matrix	8.4	8.7
Solid phase	Precipitated bittern salts	0.8	0.8

1 Current thickness from accumulation over a 30-year period.

2 Bittern pond locations shown in Map 5.

the amount of bittern ions and salts remains constant regardless of salinity. The net maximum salinity that can be achieved in the San Francisco Bay Area is approximately 447 ppt (36 °Be) and bittern at the Cargill salt ponds is stored at this salinity (Ransom, personal communication). For the purposes of this mass balance estimate and subsequent calculations for bittern disposal (Section 10.4), we use the amount of bittern stored at this salinity.

Table 10-7 provides mass balance estimates of the amount of bittern byproduct at 36 °Be. We have previously estimated that Cargill has 1,050 acres of bittern ponds (see locations in Map 5). We estimate approximately 19-20 million tons of total bittern byproduct (liquids and solids) is currently being stored in these ponds from salt production over the last 30 years. Approximately 14 million tons is stored at Newark and the remaining 5 million tons is stored at Redwood City.

Bittern byproduct at 36 °Be is approximately 84% liquid form (which includes water and dissolved ions and salts) and 16% solid form (which includes precipitated salts on and in the pond bottom sediments; see Figure 10-1). The 19-20 million tons (rounded numbers) of bittern byproduct represents approximately 8.4-8.7 feet of bittern liquid over the 1,050 acres of bittern ponds, with an additional 0.8 foot of precipitated bittern salts on the pond bottom (Table 10-8 and Figure 10-1).

10.4 Bittern Pond Desalination Water Volumes

As this chapter introduced, the bittern issue has both short-term and long-term implications. The short-term issues relate to the current negotiations between the state and federal agencies and Cargill for land acquisition. It is our understanding that Cargill has agreed to remove all of the bittern from the Redwood City ponds and transfer it to Newark. In this context, the short-term issues relate to Cargill's ability to move all the bittern to the Newark ponds and return the Redwood City ponds to a salinity level where the ponds can be opened to tidal action without adverse water quality and environmental consequences. The long-term issues relate to the need to dispose of the bittern once salt production ceases. Cargill's mineral rights agreement for the Refuge-owned lands, where the Newark ponds are located, does not obligate Cargill to clean up any of these ponds upon termination of salt production. Much of the current bittern storage is in the Newark ponds, and the remainder of the bittern stockpile will be transferred to the Newark ponds as part of the land acquisition agreement current being negotiated. Consequently, now is the time, within the current negotiations, to ensure that Cargill and not the public has the future obligation for full bittern remediation throughout the entire South Bay salt pond complex.

In this section, we use mass balance and pond flushing models to estimate the total volume of water necessary to desalinate the bittern ponds. As part of the acquisition negotiations, it is important that Cargill incorporate the full water volume from desalinating the Redwood City bittern ponds into its brine stream and/or obtain regulatory authorization from the RWQCB for discharge into San Francisco Bay. This topic is organized into three sections:

- Removing bittern from the ponds (desalination) (Section 10.4.1)
- Defining the basis for establishing acceptable salinity discharge levels to South San Francisco Bay if discharge is to be considered (Section 10.4.2)
- The process and time necessary to dilute and discharge bittern back to the bay (Section 10.4.3).

Table 10-9. Methods to desalinate the bittern ponds

Method	Description	Overview of Characteristics
Push Method	Pushes wash water through the bittern ponds to flush the dissolved and precipitated salts. Discharges outflow into dilution ponds where final 100:1 dilution achieved.	• Operates as a CFSTR • Outflow decreases in salinity over time. • Initial dilution occurs in bittern pond with continuous inflow. • Outflow salinity decreases over time as bittern removal progresses; final 100:1 dilution ratio reached with less water in dilution ponds.
Pull Method	Slowly discharges bittern liquid from bittern pond into dilution ponds. Once bulk of bittern liquid removed, introduces wash water into bittern ponds to dissolve precipitated bittern. Wash water then discharged to dilution ponds. This latter part of the process is similar to the "push" method.	• Can operate as a CFSTR or under batch flow conditions. • Salinity characteristics of outflow will be consistent for much of desalination process as the first batches will primarily remove bittern liquid. • First batches will require 100:1 dilution entirely within dilution ponds. • Once this method begins to dissolve and remove precipitated salts, process begins to replicate the "push" method. • Dilution of these later batches will occur in bittern and dilution ponds.

Table 10-10. Operating characteristics for typical bittern pond

Parameter	Value
Initial pond salinity, $C_{pond,t0}$	447 ppt or 36 °Be
Evaporative rate	4.1 ft/y
Liquid bittern depth	8.7 ft
Intake water salinity C_{inflow}	20-30 ppt
Accumulated total liquid bittern (ions, salt, water)[1]	15,700 tons of salt/ac
Accumulated precipitated bittern salts	3,000 tons of salt/ac

1 Represents high estimate for total liquid bittern range of 15,200 – 15,700 tons of salt per acre

10.4.1 Desalinating Bittern Ponds with the "Push" Method

This discussion of bittern pond desalination logistics closely follows that presented in Chapter 9 for the evaporator ponds. Bittern ponds are the most difficult to desalinate because of the accumulation of precipitated bittern salts atop the pond bottom sediments.

The "Push" and "Pull" Methods of Bittern Pond Flushing

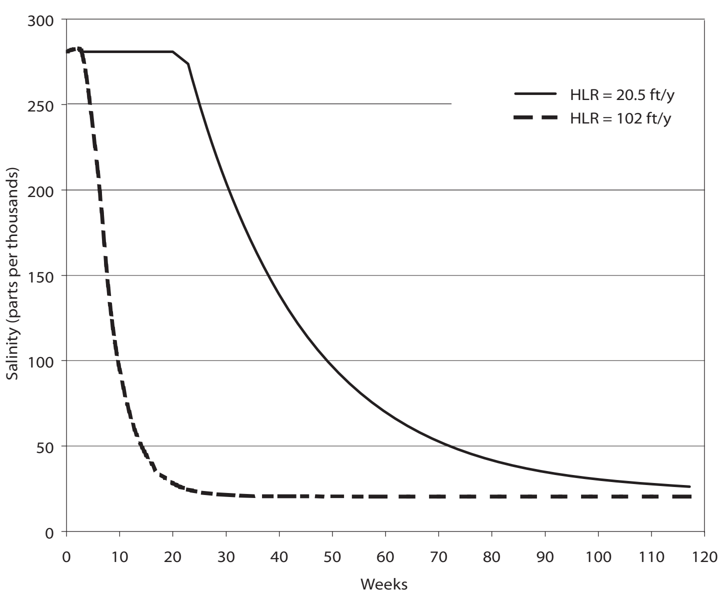
Fundamentally, there are two methods to desalinate the bittern ponds, which we define as the "push" and the "pull" methods (Table 10-9). Under both methods, an effective bittern dilution of 100:1 is achieved (see Chapter 7 for basis of this dilution ratio). The basic difference between the push and pull methods is at what point in the process this dilution takes place. In the push method, dilution primarily occurs within the bittern pond, while the pull method carries out most of its dilution in separate dilution ponds.

The push method outlined here operates the bittern ponds as Continuous Flow Stir Tank Reactors (CFSTRs) and the bittern pond operation and performance can be based upon the CFSTR model used commonly in the engineering field to analyze water and wastewater treatment facilities. The pull method may operate under several scenarios, though it is most likely to operate under batch flow conditions. Each method has it advantages and disadvantages though both should be able to desalinate the bittern ponds. Which method would be best to use will depend upon the characteristics of a given pond such as levee height and integrity, pump needs, and proximity to the Bay and sloughs.

In this section we have focused on the "push" method because the CFSTR model provides a convenient framework for considering the effects of both the dissolved and precipitated salts on outflow salinity and is helpful in understanding the kinetics involved in the desalinating process.

In the bittern ponds, desalination is complicated by the salt accumulation on pond bottom sediments. During desalination, solubility relationships and the resulting dissolution of precipitated salts maintain high salinity levels in the water column until the precipitated salts are depleted through dissolution. Following the discussion presented in Chapter 9 for evaporator ponds, we discuss desalination of bittern desalting and storage ponds in the context of a hypothetical example pond (Table 10-10). In this example, the bittern pond has a salinity of 447 ppt (36°Be). Bay water for flushing the system is assumed to be at 20-30 ppt, which is typical of the South Bay (SFEI 2001). Bittern depth is 8.7 ft with 3,000 tons of precipitated bittern salts per acre and 15,700 tons of liquid bittern per acre (Table 10-7).

Figure 10-2. Typical bittern pond desalination time as a function of hydraulic loading rates



1 Calculations and assumptions are presented in Appendix F. Assume precipitate bittern salt thickness of 8.7 ft.

2 HLR = hydraulic loading rate (see Section 9.1 for definition).

3 Water column salinity drops to about 280 ppt within 1-2 days; that initial decline not shown here in order to maximize representation of the long-term changes in salinity levels.

Figure 10-2 presents the temporal trends of salinity reduction for bittern pond flush water (Table 10-10). Under the two scenarios shown (e.g., two pumping rates), water is pumped continuously through the bittern pond and water levels are maintained at a fixed height. A full presentation and discussion of the calculations for this approximation are presented in Appendix F. Two different hydraulic loading rates (HLRs) are used for this model, 20 feet per year and 100 feet per year. At the 8.7 ft operating depth, this corresponds to hydraulic retention times (HRTs) of 135 days and 27 days, respectively. Roughly five pond volumes of additional water are used in this example to desalinate the bittern ponds.

During desalination, pond and outflow salinity decrease from over 440 ppt to near 280 ppt in one to two days with salt concentrations in the sediments being the main factor determining salinity concentrations in waters flushing through the ponds. At salinities near 280 ppt, levels stabilize as salts dissolve from the sediments and solubility relationships determine surface water salinity. Salinity levels are the same in the pond and its outflow. At an HLR of 20 feet per year, this occurs for approximately 20 weeks (Figure 10-2). At the higher HLR, this period occurs over 4 weeks. This time period is determined by the total mass of bittern salts accumulated in the sediments of the

Table 10-11. Estimated water volumes to desalinate bittern ponds without dilution for bay discharge

Plant	Area[1] (Acres)	Water volume required to desalinate ponds[2,3,4,5,6] (Millions of tons)	(Billions of gallons)	(Acre feet)
Redwood City	270	12.7	3.0	9,084
Newark	780	36.7	8.6	26,243
Total	1,050	49.4	11.5	35,327

1 Pond areas are calculated from Map 5.

2 Desalination characteristics based upon CFSTR model, calculations in Appendix F and described by Figure 10-2.

3 Only includes water to desalinate bittern pond; excludes additional water needed for dilution prior to Bay discharge.

4 Average salinity during desalination is calculated as 140 ppt.

5 Total volume needed is amount to dissolve bittern salts from sediment and 3 HRTs to flush liquid bittern.

6 Bittern pond characteristics based upon calculations in Appendix F.

bittern ponds and the rate the salts dissolve from the sediments. After the salts have washed from the sediments, outflow salinity decreases exponentially (Figure 10-2) as it did for the lower salinity ponds, asymptotically approaching Bay background salinity levels (Figure 9-1 in Chapter 9). Under the scenario of a HLR of 20 feet per year, the entire desalination process for the bittern pond is estimated at 1.5 years (Figure 10-2). At the higher HLR, the process is completed in about 20 weeks (0.4 year). In both cases, the same total water volume is required (roughly five pond volumes) and the rate of flushing determines the time required. However, at HLRs below a certain threshold level, the required volume of water to flush the bittern ponds would increase as evaporation will become a more critical factor. Additionally, if HLRs are too low, then equilibrium outflow concentrations at the completion of flushing will be too high.

Estimating Water Volumes Needed to Desalinate Bittern Ponds with the "Push" Method

This desalination process produces a considerable volume of water simply to move the bittern out of the bittern ponds. For the Redwood City bittern ponds, this water presumably will be returned to Cargill's Newark production stream and/or discharge to the bay under RWQCB regulatory authorization. This disposal option has the effect simply of relocating the bittern. Ultimately, however, this bittern and "wash water" will require removal from the South Bay salt pond complex. Bay discharge is the most feasible approach and it requires the RWQCB to establish environmentally sound discharge requirements (see Section 10.4.2). Considerably greater volumes of water will be needed to dilute the removed bittern and wash water before bay discharge (see Section 10.4.3).

Figure 10-2 shows that desalinating the bittern ponds will require a very extended time. Desalination time could take as little as 20 weeks with hydraulic loading rates well in excess of current operational levels, or as long as 1.5 years. The water volume generated during desalination of the Redwood City bittern ponds is in excess of the volume discussed for diluting the evaporator ponds (Section 9.2) and may provide a significant feed stream into the Cargill system. For instance, approximately 780 acres of bittern ponds are in the Newark system and 270 acres are in the Redwood City system. With an average salinity of 140 ppt during the flushing period, our mass balance estimates indicate **approximately 12.7 million tons (3 billion gallons) of water are needed to flush the Redwood City bittern pond complex** (Table 10-11). This estimate equals about 21% of the 61 million tons of bay water used annually for salt production in the South Bay salt ponds, but this flushing water will have a salinity level seven times higher. Because of the ionic imbalance of these brines, accepting the bittern and the wash water from the Redwood City ponds is a considerable commitment from Cargill in which some costs may be recovered through the incremental harvest of sodium chloride from the bittern stream.

At some point in the future, it is possible that Cargill will cease salt production altogether in the Bay Area. At that time, the bittern stockpile may no longer be a problem if a viable, sustainable and large market for the bittern has been found. Without that market, however, bittern will again become an issue. Cargill's current market size estimate for bittern (Cargill 2001a) is too small to deplete any of the stockpiled bittern while salt production continues. At current stockpile levels in Newark and Redwood City, we estimate that a total of 49.4 million tons (11.5 billion gallons) of water will be required to desalinate the bittern ponds and their sediments (Table 10-11). This volume assumes constant flushing of the Bay water through bittern ponds but excludes the additional water necessary to dilute the bittern and wash water prior to bay discharge (see Section 10.4.3).

The 11.5 billion gallons of Bay water used to desalinate all the bittern ponds assumes that bittern is reprocessed and not discharged. If discharge is necessary, additional dilution will be required to eliminate toxicity concerns. Issues affecting bittern dilution for Bay discharge are discussed in the following section.

10.4.2 Defining Acceptable Salinity Discharge Limits to the Bay

In order to address the bittern disposal issue, an important question to answer is what are the acceptable salinity discharge limits to the Bay?

In assessing acceptable discharge limits, two issues arise: salinity and specific ion toxicity. Based upon toxicity analyses, the limiting factor for dilution of bittern and wash water used to flush the bittern ponds is not likely to be salinity but rather specific ion toxicity. Salinity discharge levels have been discussed previously (Section 9.2) and are likely similar when applied to bittern discharge. Precipitation of ions from solution into pond sediments selectively removes certain ions and results in an ion imbalance in the remaining surface water. Several studies have found ion imbalance to cause toxicity in aquatic species that can occur at both high and

Table 10-12. Estimated water volumes to dilute bittern for bay discharge

Plant	Area (Acres)	Bittern Pond Volume[3] (Millions of tons)	Bittern Pond Volume[3] (Billions of gallons)	Bittern Pond Volume[3] (Acre feet)	Total bay water needed to dilute bittern for bay discharge[1,2] (Millions of tons)	Total bay water needed to dilute bittern for bay discharge[1,2] (Billions of gallons)	Total bay water needed to dilute bittern for bay discharge[1,2] (Acre feet)
Redwood City	270	4.2	0.8	2,339	376	88	268,947
Newark	780	12.2	2.2	6,756	1,087	253	776,959
Total	1050	16.4	3.0	9,095	1,463	341	1,045,906

1 See notes from Table 10-11. Stockpiled amount is upper estimate from Table 10-7.

2 Assumes 100:1 dilution ratio plus 15% additional for operational inefficiencies.

3 Assumes bittern liquid depth of 8.7 ft (See Table 10-10).

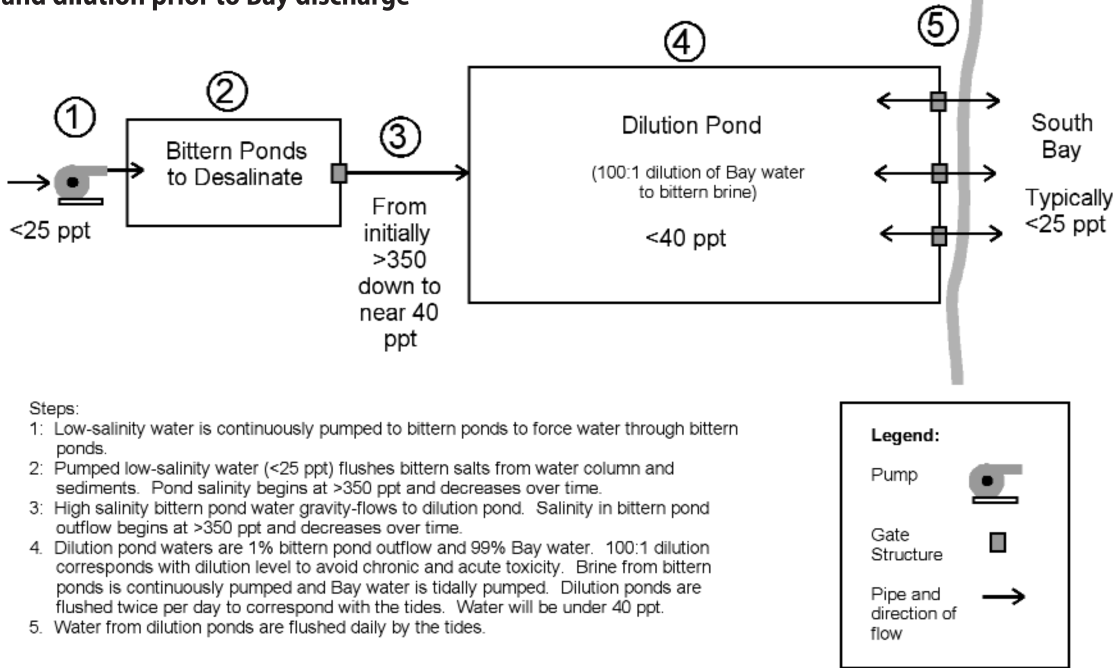
low salinity levels (Pillard *et al.* 2000, Mount *et al.* 1997, Goodfellow *et al.* 2000). Several studies using chronic and acute toxicity tests have provided similar recommendations with regard to discharge of the bittern. All these studies recommend a 100:1 dilution of bittern to avoid toxicity (Hansen and Associates 1993, CDM 1972, Marine Bioassay Laboratories 1986). Table 7-1 presents toxicity information on bittern (Hansen and Associates 1993). Similar dilutions are suggested for hypersaline brine as well.

10.4.3 Discharging Removed Bittern to South San Francisco Bay

The simplest method to estimate the total water required if discharge to the Bay is desired is to use the volume of bittern liquid that has entered the bittern ponds over the last 30 years. This bittern liquid is assumed to have a salinity of 32 °Be went Cargill removes it from the crystallizer ponds, would have all salts in their dissolved form, and represents the amount of bittern liquid requiring a 100:1 dilution under ideal conditions. Over the last 30 years, approximately 19-20 million tons of bittern have been stored in the bittern ponds (Table 10-7). At a 100:1 dilution and assuming an additional 15% for inefficiencies, approximately 1.5 billion tons (341 billion gallons) of water will be required to desalinate the bittern ponds and sufficiently dilute the outflow for direct discharge to the Bay (Table 10-12). This values seems a reasonable estimate, as approximately 1.8 billion tons of Bay water were required for salt production during the 30 years during which this stockpiling occurred.

To discuss the logistics of bittern dilution and bay discharge, we present a scenario similar to that used for diluting flushed waters from the evaporator ponds (Figure 10-3). For the bittern ponds, the 100:1 dilution of the bittern necessitates that the dilution pond areas be larger than the bittern pond areas. Several tide gates allow good tidal exchange into the dilution pond in which bittern is pumped or gravity fed. Because dilution of the bittern will be required to minimize toxicity effects, the process will be limited by the area of dilution ponds available to provide sufficient area for the dilution to occur. Table 10-13 presents estimates of the time required to desalinate the bittern ponds and discharge the diluted water to the Bay. For these estimates we have assumed an average tidal exchange rate of approximately 3 feet per day, that a total of 341 billion gallons of water will be required (see Table 10-12), and that dilution rates will not be limited by pumping bittern pond outflows but by the tidal exchange available to the dilution pond. More time will be

Figure 10-3. Conceptual design for bittern pond desalination and dilution prior to Bay discharge



required if bittern pond outflow is a limiting factor, if more water is required, or if less tidal exchange is available. The estimated time depends upon the available area of dilution ponds. At an area ratio of one acre of dilution ponds to one acre of bittern ponds, approximately 1.5 years will be required to flush a given bittern pond. At higher ratios, that time is decreased. For instance at a 5:1 ratio, approximately 4 months is estimated for dilution and discharge.

Table 10-13. Estimated time required to dilute and discharge bittern ponds

Assumed tidal exchange[1] (Feet per day)	Dilution pond area ratio[2]	Time to desalinate and flush[3,4,5,6] (Years)	(Days)
3	1:1	0.91	332
3	2:1	0.45	166
3	5:1	0.18	66

1 Assumes average tidal exchange available at the bittern ponds is 4 feet per day and that in practice, only 75% tidal efficiency will be achieved. Thus, calculations are based upon a tidal exchange of 3 feet per day.

2 Dilution pond area ratio represents the area of dilution ponds to bittern ponds.

3 See Table 10-12 for needed water volumes.

4 Estimate is for each pond set desalinated at a given time. If bittern ponds are desalinated in steps, the time shown represents the time necessary to dilute each set of bittern ponds.

5 Assumes that bittern pond flush water provided at sufficient rate into dilution ponds.

6 Assumes water column fully mixed and that density stratification does not occur.

The total time to dilute all the bittern pond flush water to acceptable Bay discharge salinities will depend upon the number of ponds flushed concurrently, which will be limited largely by the amount of area available for dilution ponds. For instance, if the amount of space for dilution ponds at Redwood City requires that bittern ponds be desalinated in two steps, with some desalinated first and the remainder desalinated at a later date, than two flushing cycles will be required and the amount of time to desalinate the entire bittern pond complex at Redwood City would be twice the time predicted in Table 10-13. Thus, Table 10-13 represents the amount of time necessary to desalinate a given bittern pond set. The number of ponds and acreage of that set is limited by the available area for dilution ponds.

10.5 Conclusions Regarding Bittern Disposal Negotiations

Assessing constraints associated with bittern requires both short-term and long-term considerations. In the short term, constraints pertain to the current negotiations between Cargill and the state and federal governments. In the long term, bittern storage and disposal will become critical and pertinent issues if Cargill abandons salt production operations in the Bay Area entirely and it has not marketed the entire bittern stockpile.

10.5.1 Short Term Considerations - Current Negotiations

It is our understanding that the parties have agreed that Cargill will transfer "all bittern" currently stored in the Redwood City Plant to the Newark Plant via its trans-Bay pipeline (see Map 5) (Barroll, Moore, Kolar, personal communications). What has not been publicly disclosed is the definition of bittern incorporated into the acquisition negotiations. In order to ensure that the state and federal governments are not liable for a large amount of byproducts from the Cargill salt operation now or in the future, the final purchase agreement must include the total bittern byproduct in Redwood City (liquids and solids) and a commitment from Cargill to take full responsibility over the long term for bittern in Newark. According to our estimates for Redwood City, the short-term commitment includes the following:

- Removal of all Redwood City liquid bittern (4.1-4.2 million tons/740-762 million gallons; Table 10-7)
- Full desalination of the bittern pond sediment (0.8 million tons; Table 10-7)
- Transfer of all hypersaline brine (flush or wash water) generated from this desalination process (12.7 million tons/3 billion gallons; Table 10-11).

The purchase agreement should spell out Cargill's responsibilities with regard to removing, diluting, and storing all bittern and associated desalination water, because both materials will impact interim and long-term salt pond management. These materials will also impact the necessity and characteristics of salinity discharge standards and the timeframe under which restoration can realistically be achieved. Without clear distinctions between liquid bittern, precipitated bittern salts, and hypersaline wash water, the exact responsibilities, roles, and expectations for each party cannot be defined. It is critical that the state avoid a repeat of the mistakes made in the North Bay with regard to bittern (see Chapter 7 for details on the North Bay bittern experience).

10.5.2 Longer Term Considerations and Concerns

We estimate that over the past 30 years, Cargill has produced 19-20 million tons of total bittern (at 36 °Be) (Table 10-7). We believe that the current market for bittern is relatively small compared with the historical quantities currently stored on-site, and therefore this amount will require disposal. Because the costs of physically disposing of the bittern are relatively high, we assume that the preferred method of bittern disposal will be pond desalination, bittern dilution and subsequent discharge to the Bay.

Ecological restoration of the entire South Bay salt pond complex is predicted to take roughly 120 years (99 years for the smaller Cargill proposed sale area; see Tables 8-3 and 8-4 in Chapter 8), given South Bay sediment dynamics, available sediment supply, and the absence of dredged sediment reuse. (Chapter 8 has more information on sediment dynamics, sediment supply, and methods to raise salt pond elevations.) Over that time period, Cargill may cease all salt production in the Bay Area. If Cargill ceases its operations in the South Bay, the bittern issue must be revisited. If a large, sustainable, and viable bittern market has not developed, the bittern issues we face in the future will be the same as those posed today: toxicity, discharge, and disposal (Hansen and Associates 1993, FlowScience 1994, CDM 1972, Marine Bioassay Laboratories 1986).

Cargill's assurances that it will take all bittern from the Redwood City Plant as part of the current purchase negotiations does not lessen long-term concerns regarding bittern disposal unless a sustainable market exists. Bittern has historically been sold for a variety of purposes, including its most recent uses as a de-icer and dust suppressant. Thus, given certain economic scenarios, it has value. But in the absence of a sustainable market, bittern constitutes a waste product that will require careful and costly attention. Cargill's considerable economic investment to make bittern more marketable and to develop that market clearly implies that there is sufficient bittern supplies to satisfy that market for many years to come. In other words, even with new bittern markets, it will take many years to remove all the stockpiled bittern via market sales.

Consequently, we believe it important that the current negotiations incorporate a commitment by Cargill to accept full responsibility for all bittern over the long term. Most Newark bittern storage is on Refuge-owned lands. The 1979 operating agreement (see Appendix B) under which Cargill produces salt on Refuge property does not obligate Cargill to clean up the bittern or any other problems upon its termination of salt production. That deficiency should be addressed within the current negotiations otherwise the public may be stuck with a significant bill as has been the case with the North Bay salt ponds (see Chapter 7).

10.5.3 Estimated Costs for Dilution of Bittern Ponds

Flow Science (1994) estimated costs to dilute the North Bay salt ponds for various discharge scenarios. It is beyond the scope of this report to develop a precise estimate for the South Bay but we present ballpark estimates for dilution of the South Bay ponds based upon the North Bay analysis. We have adjusted the estimate for a 3.5% annual inflation, a 20% increase in energy costs, a longer period of stockpiling and a 20% contingency. Adjusting FlowScience (1994) estimates results in predicted costs of approximately $1,200 to $23,000 per acre of bittern ponds. These per-acre costs translate into a range of $0.3 to $6.2 million for Redwood City and $0.9 to $18 million for Newark to desalinate the South Bay bittern ponds to salinity levels acceptable for Bay discharge under RWQCB permit.

Chapter 11.
Restoration Opportunities

Chapter 11.
Restoration Opportunities

The existing conditions of the South Bay salt ponds and the various restoration constraints discussed in Chapters 3 through 10 define the basis for restoration opportunities. This chapter describes how these conditions help to establish the opportunities for ecological restoration in the South Bay salt ponds.

11.1 Biological Opportunities

The fundamental purpose of wetland restoration is to improve the ecological function of the San Francisco Estuary to benefit the numerous fish, wildlife, and plant species that depend on these estuarine resources. In this context, the biological opportunities include expanding existing populations of target species and providing the necessary habitat to improve diversity and richness of native species. The Endangered Species Act prioritizes recovery of federally listed species and provides guidelines for defining this opportunity.

Restoration of the South Bay ecosystem, specifically the salt pond complex, has been a focus for many years among environmentalists, local, state, and federal regulatory and resource agencies, scientists, and the community. Most entities agree that increasing the total amount of tidal marsh to provide habitat for endangered species is the highest priority. It is also recognized that shallow, open water habitat should be incorporated into any proposed restoration design to maintain the existing habitat functions for shorebird and waterfowl species that have become dependent upon the South Bay salt ponds. Restoration of the salt pond complex presents an opportunity to enhance ecological function in the South Bay while addressing the need to balance conservation of existing wildlife resources.

The primary opportunity—as well as the primary difficulty—in restoring the South Bay salt pond complex is the area's vast size and the many overlapping jurisdictions. These jurisdictions include cities, counties, flood control districts, and other state and federal entities. Stakeholder involvement in the restoration process will require long review periods and compromise. However, the opportunity to focus many people's attention on South Bay ecology will help to identify community needs and emphasize the value of our natural resources. We must recognize that the Bay-Delta Estuary's resources are part of our community identity. By protecting and enhancing these resources, the community helps to ensure the health of an ecologically rich and diverse region. Successful implementation of a plan to restore this ecosystem adjacent to an urban center is a unique opportunity to inspire other communities to follow the South Bay's model of conservation, participation, and coexistence.

Biological opportunities include but are not limited to:

- **Increasing total amount of special status species habitats,** primarily tidal marsh habitat for marsh-dependent special status species as mandated by federal, state, and local plans and legislation.
- **Creating contiguous bands of habitat** to facilitate colonization of what are now habitat islands. Contiguous bands would result in more viable populations of endangered species through higher recruitment among young adults and juveniles seeking new territories and breeding opportunities.
- **Creating large blocks of habitat** to facilitate protection of wildlife from upland-based predators such as the red fox.
- **Enhancing some existing salt pond habitat** through water level management, predator control, vegetation control, and creation of artificial islands. Enhancement will benefit special status wildlife and wintering birds that use the ponds in their current configuration.
- **Identifying and evaluating methods to buffer sensitive wildlife and plant populations** from human encroachment, development, and predators while simultaneously identifying suitable public access locations and designs.
- **Establishing habitat features critical to species' survival** during extreme high tides or other seasonal fluctuations. Many habitat requirements for marsh-dependent species have already been identified with no significant opportunities for implementation.
- **Removing rip-rap shoreline protection** that harbors rats and other predators and displaces high marsh habitat. Replacing rip-rap with gently sloping vegetated shelves provide habitat for rare plants and protect shorelines by dissipating wave energy.
- **Improving, removing, or relocating the existing 38 dredge locks** should be considered in the restoration design. Use of the existing dredge locks, which allow access to the salt ponds, currently represent the main impacts to wildlife in the salt pond system.
- **Developing a systematic approach to monitoring** the existing and restored habitats over a long period to allow for refinement of management goals and species requirements beyond what is currently known. Monitoring during early phases will help to identify successful restoration measures.
- **Prioritizing and funding efforts to address predators and invasive species** on a regional level; existing isolated efforts have limited effectiveness.
- **Establishing a connection between tidal marsh habitats and adjacent habitats**, including watersheds and treatment plants, to create ecologically valuable ecotones and necessary buffers between habitats and other land uses.

- **Upgrading or improving existing infrastructure and access required for maintenance.** These changes could help to reduce wildlife disturbance. Project development could include negotiations with public and private entities with jurisdiction over infrastructure such as PG&E towers, roadways, and flood-control channels. Replacing traditional methods with more ecologically sensitive methods could be accomplished through the permit process.
- **Restoring historic geomorphic features** such as channels and sloughs where possible.
- **Incorporating public access** and restricted areas for wildlife viewing.
- **Increasing awareness of the value of Bay ecosystems** among public and private entities in order to increase support for these resources in the future.

11.2 Geomorphic and Engineering Opportunities

The geomorphic conditions of the salt ponds form the underlying basis on which the numerous ecological opportunities can be achieved. These opportunities include varied pond topography, preserved antecedent channel networks, habitat value of the crystallizer ponds, and potential for wastewater reuse.

11.2.1 Varied Pond Topography

The varied elevations of the salt ponds and the fact that many ponds have experienced little subsidence and are at or near intertidal marsh elevations provides several opportunities. These opportunities are summarized below.

Obtain early ecological benefits by restoring the highest elevation ponds first. Vegetation colonization in the higher ponds could occur with relatively little, if any, sedimentation. Vegetative cover and food resources (e.g., invertebrates) provide the foundation for use of the restored wetlands by target wildlife species.

Utilize the variation in topography as a factor when determining phasing options for salt pond restoration. For a variety of reasons, it is unlikely that all ponds will be restored to tidal action at the same time. Therefore, resource managers will need to prioritize which areas to restore first and which to restore in later phases. For example, it might make sense to target the highest and lowest elevation ponds first. The highest ponds provide rapid benefits. The lowest ponds require large amounts of sedimentation, so starting the process early returns those ponds to marsh conditions as soon as possible.

Varied baseline topography provides considerable and varied ecological functions. Other restoration projects have taught us that interim conditions—conditions existing from the time tides are reintroduced to the emergence of "final" tidal marsh equilibrium conditions—can provide varied and significant ecological functions unique from that provided by tidal marsh. For example, a deeply subsided salt pond progresses from a tidal lagoon to a low intertidal mudflat to a high intertidal mudflat before becoming vegetated and fully channelized. During this evolution, the site provides dabbling and diving duck habitat that transforms into and coexists with wading bird and probing shorebird habitat. Fish use also changes over time, especially as invertebrate forage resources colonize these areas.

Concurrently restoring ponds of different elevations provides the widest range of interim ecological functions dispersed geographically around the South Bay. Restoring ponds of varying elevations concurrently creates habitat at different evolutionary stages early in the restoration effort. These different stages would last for many years until equilibrium tidal marsh conditions are reached. This approach benefits the greatest variety of species in the shortest amount of time. It also allows the greatest opportunity for adaptive management. By monitoring the different evolutionary stages simultaneously, early feedback on restoration techniques is possible. Changes necessary to optimize the restoration outcome can be recognized and made early in the process, rather than waiting many years.

11.2.2 Preserved Antecedent Channel Networks

A fundamental component of any tidal marsh is its channel network system. Channels are the conduits through which tidal waters circulate, transporting sediment, nutrients, organic matter, and wildlife. Channels also provide important habitat within the tidal marsh.

In many salt ponds with antecedent channel networks, overall elevations have subsided. Under a restoration scenario that allows natural sedimentation to raise these ponds back to tidal marsh height, the antecedent channel network will exert a strong and generally desirable influence on the channel network formation (see Section 5.3). Even where several feet of sedimentation is needed, channel networks can persist vertically as the pond bottom rises during natural sedimentation, thereby "imprinting" themselves into the restored marsh geomorphology. In contrast, if fill is placed in the ponds to augment the sediment deficit, the antecedent channel network could be partially or wholly lost. Under these conditions, the channels would be buried under fill unless the channels are somehow isolated from fill placement.

In most, if not all, cases it will be ecologically desirable to promote channel formation based on the antecedent channel network. Consequently, we would recommend little or no fill placement in ponds except perhaps the most subsided ponds located along the southern shore from Mountain View to San Jose (see Map 9). (See Table 5-2 in Chapter 5 for the anticipated depths of needed sedimentation.) Where fill is used, existing channels should be isolated from fill placement. For most South Bay salt ponds, utilizing the channel networks in restoration planning will promote rapid progress toward ecological goals and provide a diversity of habitats during the interim restoration period.

11.2.3 Restoration of Crystallizer Ponds

Crystallizer ponds are ready-made pannes suitable for shorebird nesting and roosting habitat that need comparatively little modifications. The crystallizer ponds address ecological needs for a variety of species, especially the threatened western snowy plover, and they can be incorporated into early-phase restoration efforts.

11.2.4 Reuse of Treated Wastewater

Effluent from the San Jose/Santa Clara Water Pollution Control Plant (SCWPCP) represents a large, daily freshwater source that never existed historically. This discharge has converted extensive tracts of tidal salt marsh in the southern reaches of the South Bay to tidal brackish and tidal freshwater marsh. Using effluent in the desalination process could improve South Bay water quality.

The SCWPCP has a nominal capacity of 167 million gallons per day or 7,800 acre-feet per year. Under its current NPDES permit, San Jose can discharge up to 120 million gallons per day (RWQCB 1990). The salt production ponds utilize approximately 44,000 acre-feet per year. Thus, effluent from the SCWPCP constitutes approximately 20 percent of the Bay water used for South Bay salt production. This represents a large water source that may be leveraged for salinity reduction in decommissioned ponds and for bittern dilution. Lower salinity water used for desalination allows shorter hydraulic retention times and lower effluent levels following desalination. See Chapter 9 for more information on this subject. Wastewater discharges also originate from the cities of Sunnyvale and Palo Alto (see Map 12). Though smaller in volume than San Jose's discharge, these flows could prove useful in pond desalination and bittern dilution.

A potential problem associated with using effluent as a water source for the salt ponds is the potential for creating a nuisance algae and odor problem from elevated nutrient levels. (See Section 6.6 for more information on algae and odor problems.) Additionally, infrastructure costs could be high for moving the effluent to areas where it is needed.

Part IV.

Planning for the Acquisition and Beyond

Chapter 12.

Review of the Cargill Proposals

Chapter 12.
Review of the Cargill Proposals

Cargill has recently proposed to consolidate its operations and "decommission" nearly two-thirds of its land (roughly 16,000 acres) from salt production and to sell its lands and salt production rights to the U.S. Fish and Wildlife Service. Making such vast lands available for ecological restoration is a significant step in returning the Bay to a healthy, self-sustaining ecosystem. This proposal reflects the decreasing economic viability of the solar salt production business in general and in an urban setting like the San Francisco bay area in particular. In this chapter we examine Cargill's proposal, current acquisition negotiations including recent proposals to reduce the sale area and price, and how it merges with the regional need for wetland restoration.

Cargill has made two proposals for public land acquisition: it made a preliminary evaluation in 1999 that it never pursued (to decommission 87 percent of its South Bay production area) and it made a formal offer in 2000 (to decommission 61 percent of its South Bay production area) that is currently being negotiated. These two proposals are discussed in detail in Section 12.1, along with some more recent negotiations that may lead to acquisition of an area somewhat smaller than the 2000 proposal. We provide rough total restoration cost estimates in Section 12.2. Lastly, in Section 12.3 we discuss the environmental implications of Cargill's system "re-engineering" now underway in its remaining salt production facilities to improve current operating efficiency and to accommodate production on fewer acres.

12.1 Cargill Sale Proposals

In October 2000, Cargill released its proposal for public acquisition of approximately 16,000 acres of its South Bay salt production ponds and production rights (Cargill 2000c). In this section we summarize the current acquisition negotiations with the State and federal governments and the substance of Cargill's past and current proposals.

The acreage of the sale area includes the South Bay salt ponds, the remaining Napa River salt ponds not sold to the State in 1994, and submerged tidelands in the South Bay. The acreage figures we provide here are based on production pond areas as provided in the San Francisco Estuary EcoAtlas (SFEI 1998) and they exclude the Napa River and submerged lands.

Cargill owns only 56 percent of the ponds it currently uses for salt production. The federal government owns the remaining 44 percent, which are part of the Don Edwards National Wildlife Refuge and managed by the U.S. Fish and Wildlife Service (see Map 2). Cargill sold these lands to the federal government in the 1970s. On the federally-owned portion, Cargill retains only mineral rights for salt production and it operates under a 1979 agreement with the USFWS (see Chapter 3 and Appendix B).

This section examines several aspects of the acquisition proposals with an emphasis on the current proposal being negotiated:

- 2000 Cargill Sale Proposal (Section 12.1.1)
- Appraisals (Section 12.1.2)
- July 2001 reduced scale proposal (Section 12.1.3)
- 1999 preliminary Cargill proposal (Section 12.1.4)
- Proposed purchase price (Section 12.1.5)
- What the public gets for $300 million (Section 12.1.6)
- What Cargill gains in addition to $300 million (Section 12.1.7)
- Precedent for future restoration acquisitions (Section 12.1.8)
- What the current negotiations should include (Section 12.1.9)

12.1.1 2000 Cargill Sale Proposal

Under the current proposal, Cargill would reduce its salt pond production acreage from 26,190 acres to 10,310 acres and make the remaining 15,880 acres available for wildlife habitat (of which the Refuge already owns 25 percent). The publicly discussed acquisition price is $300 million (cited in several newspaper articles in the fall of 2000). This acquisition would include the 15,880 acres of South Bay salt production ponds plus a reported 600 acres of submerged tidelands in the South Bay and 1,400 acres of salt ponds along the Napa River, for a total of about 18,000 acres in the acquisition.

Cargill's reduced operations would be conducted on lands owned mostly by the Refuge (73 percent of the total acreage after the sale versus 44 percent currently). Cargill's annual salt production would drop from its current 1,000,000 tons (about 40 tons per acre) to 500,000 tons (about 50 tons per acre). Cargill would increase per-acre yield through improved pond operational efficiency and modified salt harvest practices in the crystallizer ponds (Cargill 2000a and 2000c). Cargill has reported it expects future production of 600,000 tons of salt annually with 12,000 production acres, or a 50-ton per acre yield (Cargill 2000c). We have revised the annual production to 500,000 tons because the Bay Area EcoAtlas GIS data (SFEI 1998) indicates retained lands are about 2,000 acres less than Cargill has announced.

The acquisition is reported to include removal of bittern and hypersaline brine from the decommissioned ponds (Barroll, Moore, and Kolar, personal communications). Cargill has already begun facility improvements to pump the Redwood City bittern and brine to Newark (Section 12.2). Cargill reportedly has committed to storing at least some of the transferred bittern on Cargill-owned property (though where is not known) rather than using the Refuge-owned Ponds 12 and 13 in Newark Plant #2 (see Map 5). Thus, Cargill will be converting some evaporator ponds in the Newark Plant #2 into bittern storage ponds.

The areas subject to current negotiations (and also included in the 1999 preliminary proposal) are shown on Map 3 and include the following:

- **Cargill sells land and salt production rights on 11,940 acres of salt production ponds it owns.** This acreage represents 46 percent of the total South Bay salt pond area and 81 percent of the pond area that Cargill owns. Areas include all of Baumberg, Redwood City, and Alviso Plant ponds owned by Cargill, except for a 20-acre portion of Redwood City Pond 10 (being sold for marina development).
- **Cargill sells salt production rights on 3,920 acres of salt production ponds owned by the Refuge.** This acreage represents an additional 15 percent of the total South Bay salt pond area, bringing the total percent of pond area removed from production to 61 percent. This acreage also represents 34 percent of the pond area that the Refuge owns and Cargill uses for salt production. This area includes all of Redwood City and Alviso ponds owned by the Refuge.
- **Cargill retains operation of the two large bittern ponds in Newark owned by the Refuge.** These two bittern ponds total 670 acres, or 3 percent of the total South Bay salt pond area, and 6 percent of the lands owned by the Refuge.
- **Cargill retains operations on the 2,800 acres of production and crystallizer ponds it owns in Newark.** This acreage represents 11 percent of the total South Bay salt pond area and 19 percent of the pond area that Cargill owns.
- **Cargill sells a 20-acre corner of Redwood City Pond 10 for Marina Development.** Cargill has removed the northern corner of this pond from the sale area in order to accommodate a marina development. Pond 10 is a bittern storage pond, and the Refuge reports that Cargill plans to transfer the bittern in this pond to Cargill-owned lands in Newark (Kolar, personal communication).

12.1.2 Appraisals

The federal government and Cargill commenced independent property appraisals in 2000. The negotiating parties use the results of these appraisals to form the basis of the sale price, with federal law providing directive on linking purchase price to appraised value. The results of these appraisals are not disclosed to the public without consent of both parties, which has not occurred at the time of publication of this report.

The recent appraisal process has reportedly arrived at total property values in excess of $300 million. Cargill has recently committed to donating (in the form of a tax deduction) any appraised value above $300 million (Ransom, personal communication). Funding sources are expected to include the State and federal governments and perhaps private foundations. Because of the tax deduction that the Cargill corporation will receive from the donation, the actual cost to the government would increase, via lost corporate taxes, by an amount dependent on the size of the donation.

Appraisals consider property value in the context of "highest and best use." Consequently, the single most important factor in appraising the Cargill properties is the potential for development. The Clean Water Act and the Rivers and Harbors Act regulate development on areas identified as being "Waters of the United States." Development on jurisdictional wetlands and waters is very difficult and the "highest and best uses" of such areas are wildlife habitat and compatible activities, not development. The salt pond system was constructed mostly if not entirely on historic tidal marshlands and adjacent seasonal wetland areas and is largely subject to federal jurisdiction. However, jurisdiction over portions of the Cargill salt pond system remains an open question; Cargill has long argued that certain areas, such as the crystallizers, are not jurisdictional and the USACE and USEPA have not made final determinations.

In light of this debate over jurisdiction, it is likely that a considerable portion of the appraised value comes from the relatively small areas where jurisdiction is not definitive. These areas likely include the Redwood City crystallizer ponds (470 acres) and perhaps some additional lands in Redwood City. Given the extremely high value of developable lands in Silicon Valley (easily in excess of $1 million per acre), it is very conceivable that these areas represent a bulk of the total appraised value.

12.1.3 The July 2001 Reduced-Scale Proposal

In late July 2001, local media announced that Senator Dianne Feinstein is trying to salvage the negotiations by focusing the acquisition on a smaller area (13,000 to 15,000 acres, down from about 18,000 acres) for a significantly reduced sale price ($100 million) (San Francisco Chronicle, 2001; San Jose Mercury News, 2001). The need for salvaging the deal is that it appears politically unlikely that Congress will approve all federal funds necessary at the $300 million price tag. While this proposal occurred very late in preparing this Feasibility Analysis, we nonetheless can provide some points for consideration of such an approach.

Outcome of the Recent Appraisals

The previous section describes the recent appraisal process and the tentative outcome (not yet finalized by Cargill and the USFWS) that the appraised value is over $300 million and that Cargill will donate any value above that amount.

Areas Likely to Be Eliminated from the Purchase

Between 3,000 and 5,000 acres would be removed from the acquisition, based on information in the recent media accounts (San Francisco Chronicle; San Jose Mercury). The Redwood City crystallizer ponds, a clear candidate for high-value lands based on perceived development potential, account for only 470 acres. The entire remaining Cargill-owned ponds in the Redwood City plant total about 1,800 acres. Napa River ponds total about 1,400 acres (Cargill 2000c). Since the $300 million proposal includes sale of Cargill land and salt production rights on Refuge lands, the latest proposal could also include retention of production rights on Refuge ponds. We have requested information from Cargill regarding which areas it might keep under this latest proposal; Cargill has yet to provide that information.

Need for Scientifically Based Jurisdictional Determination

As part of the latest negotiations, unpublished accounts have suggested that the deal may include a negotiated final settlement of the jurisdictional issue in favor of Cargill on lands that Cargill has long maintained are not jurisdictional. We can recommend that any such settlements be based upon an unbiased, technically sound, and field based jurisdictional determination in accordance with current delineation protocol (USACE 1987).

Need for Disclosure of Latest Proposal Terms

In order for the public to understand the full scope of the latest proposal in terms of how it affects land use controls on the entire South Bay salt pond complex, the federal government should disclose this information to the public. The salt ponds are a major regional, national and international resource and the future of such a vast amount of land must be decided in full view of the public, not behind closed doors.

12.1.4 The 1999 Preliminary Proposal

Cargill developed an earlier proposal to carry out ecological restoration on most of the South Bay salt ponds. In the fall of 1999, Cargill evaluated two restoration strategies involving nearly 23,000 acres of its South Bay salt production ponds (Wildlands *et al*. 1999). Although Cargill never offered this as a formal proposal, it represents Cargill's first detailed examination of its salt pond complex from the perspective of ecological restoration.

The key difference between the 1999 and 2000 proposals is that the 1999 proposal also included decommissioning an additional 6,840 acres of Refuge-owned salt ponds. This additional acreage represents 26 percent of the total South Bay salt pond area and 60 percent of the Refuge-owned ponds. Ponds included in the 1999 proposal only (see Map 3) included the entire Newark #1 plant and Ponds 1 through 6 of the Newark #2 plant. Of notable importance, Ponds 1 to 3 in Newark Plant #2 (also referred to as Mowry ponds 1 to 3), which total 1,520 acres, are some of the easiest to restore within the entire South Bay salt pond complex (see Map 14). These three ponds represent 57 percent of the total acreage of ponds identified as "high feasibility for restoration" (see Map 14, Chapter 13, and Appendix C). They represent the most significant wildlife enhancement opportunities in the entire South Bay salt pond complex yet they are being withheld from the current round of public acquisition.

12.1.5 Proposed Purchase Price

Cargill has been widely quoted in the newspapers as expecting $300 million for the sale of land and mineral rights described above. Because Cargill's offer mixes land ownership with mineral rights, it is not possible to define the per-acre land cost unless one can determine the value of the mineral rights for salt production. It is beyond the scope of this document to investigate the monetary values of mineral rights. The reader must clearly understand that the federal government already owns 25 percent of the land Cargill is offering to "sell." The U.S. Fish and Wildlife Service and Cargill have recently completed independent real estate appraisals and are currently in the process of reviewing and negotiating based on the two appraisals (see Section 12.1.2). Cargill has stated publicly that it will donate any appraised value in excess of $300 million, and both Cargill and the USFWS have stated that the appraisals are well above that value.

12.1.6 Relative Restoration Costs After Paying $300 Million

By far the greatest distinction between what ponds Cargill is offering and what ponds Cargill is retaining is the relative ease and cost of restoration and the ability of pond restoration to meet regional ecological recovery goals. Included with Cargill's offer is 100 percent of the highly subsided salt ponds, totaling 5,580 acres (35 percent of the total acreage proposed for acquisition and restoration). These are located from Mountain View to San Jose (see Map 9). Because of considerable subsidence, these ponds have an enormous sediment deficit, and they therefore present the greatest challenge for tidal marsh restoration (see Chapter 8). In addition, these ponds have the tallest levees from base to crest (see Section 5.6) and thus have the most costly levee maintenance requirements if they are retained as managed open water for shorebirds and waterfowl. Elevations are relatively close to tidal marsh height in all the ponds Cargill retains (see Maps 3 and 9). In other words, the public gets all of the salt ponds that carry the highest price tag for restoration to tidal marsh or management as open water habitats, and nearly all the ponds Cargill keeps carry the lowest price tag for restoration.

12.1.7 Benefits to Cargill in Addition to $300 Million

Cargill receives several benefits in addition to money.

First, they have retained some of the easiest to restore salt ponds in the entire system. The vast lands in the Newark #1 and #2 plants that Cargill plans to keep in production are all relatively close to intertidal elevations (see Map 9) and we have identified most of them as relatively easy to restore to tidal marsh (see Map 14).

Second, Cargill is retaining the ecologically important and potentially highly valuable Newark crystallizer ponds. The crystallizer ponds are a contentious issue with respect to the presence or absence of federal Clean Water Act jurisdiction; lack of jurisdiction makes the crystallizers subject to development and thus extremely valuable. In contrast, crystallizers are readily modified to provide excellent seasonally ponded panne habitat for Western Snowy Plovers and other species. We estimate that at least 240 acres of these crystallizer ponds will not be needed once reduced salt production rates are reached.

Third, Cargill eliminates a considerable property tax liability by selling 81 percent of the salt production ponds it owns and retaining operations largely on Refuge lands. After the sale, Cargill will own only 27 percent of its production lands instead of the 56 percent they currently own. Although we have not researched Cargill's annual property tax costs, we can make some reasonable estimates. Were the approximately 12,000 acres that Cargill is offering to sell (see Map 3) really worth the $300 million it wants for them — and this assumes salt production rights have no monetary value — this land would be worth about $25,000 per acre. This estimate is probably too high and well above its current land assessments. Cargill currently owns about 15,000 acres of salt ponds, so, if we use this inflated land value, Cargill's current holdings are worth $375 million. At a 1 percent annual property tax rate, Cargill would currently be paying $3.75 million annually for taxes. If we lower the per-acre value 80 percent to $5,000 per acre, Cargill's current annual tax bill would be $750,000. Now sell off 81 percent of those lands and do not reassess the value of the remaining lands, and Cargill's tax bill drops by $600,000 per year at the $5,000 per acre value, and $3 million per year at the $25,000 per acre value. In either case, Cargill's property taxes drop considerably.

Fourth, Cargill increases the future value of the remaining property it owns in Newark. By setting a precedent for high land costs now, when Cargill decides to cease salt production altogether in the region (which is only a matter of time), the purchase price of the remaining lands would, presumably, have to be at least the price set with the current acquisition. Cargill believes that much of its Newark lands, especially the 865 acres of crystallizer ponds, are not subject to federal wetland jurisdiction, and therefore have development potential. This makes the value of those lands on the order of $1 million per acre.

12.1.8 Precedent for Future Restoration Land Acquisition Costs

One of the most significant adverse consequences for regional ecological restoration efforts is the effect this acquisition could have on the costs of other suitable restoration lands, including Cargill's retained properties in Newark. Land costs are often the greatest single cost of wetland restoration in the San Francisco Estuary. Even values in the $5,000 per acre range quickly become an obstacle.

Averaging the $300 million across the 19,000 acres proposed for sale (including South Bay salt ponds, South Bay tidelands, and Napa River salt ponds) and assuming no value for salt production rights yields a per-acre land cost of about $15,800. In contrast, the July 2001 proposal by Senator Feinstein (see Section 12.1.3) of $100 million for 13,000 to 15,000 acres yields a per-acre land cost of $6,700 to $7,700 depending on the total acreage included in the new proposal. This difference in per-acre land value can have significant influence on future acquisition efforts.

12.1.9 Items that Should Be Included as Part of Current Acquisition

The transfer of ownership and control of salt production ponds brings with it many costly liabilities, as has been demonstrated by the North Bay salt ponds (see Chapter 7). These liabilities include: bittern; hypersaline brine; levee maintenance; water control structure maintenance; operational requirements to avoid excessive salt concentration in the absence of salt production; and flood protection. Under the range of desalination procedures described in Chapter 9, these responsibilities will also include considerable quantities of hypersaline wash water used to flush salts from the ponds.

Bittern

Cargill is reported to be negotiating with the Refuge to transfer to Newark the bittern currently stored at Redwood City. Cargill has recently made system modifications to facilitate this transfer (see Section 12.2). So long as Cargill continues to operate the Newark plants, this bittern remains the concern of Cargill. But when Cargill ceases salt production altogether, the ultimate disposition of bittern must be addressed. (See Chapter 10 for further discussion of bittern.)

Concentrated Brine

Transfer of hypersaline brine into Cargill's production stream is not guaranteed at this time. Cargill has expressed willingness to take these brines because they have economic value. Still to be negotiated is the salinity cutoff level determining what Cargill takes and what remains behind. Given the recommendation for a maximum pond salinity under wildlife management of nominal increases over bay water (see Chapter 9), it is imperative that Cargill remove brines in excess of this salinity from transferred ponds into its production stream.

Hypersaline Desalination Wash Water

This topic has not been reported in acquisition negotiations. Will Cargill also take the concentrated brines generated from desalinating the decommissioned salt ponds? An additional 50 million gallons of water could be generated over 3 to 8 years, depending on the desalination strategy (see Section 9.3). This volume is about 125 percent of Cargill's current annual total intake of Bay water.

Ongoing Operations and Maintenance Costs

Responsibilities for the remaining operations and maintenance items must be addressed in the acquisition negotiations currently under way. As these costs will be considerable (see Chapter 14), planning is essential to avoid management responsibilities falling onto the Refuge without adequate resources, as happened to the CDFG in the North Bay salt ponds (see Chapter 7 for more details).

12.2 Restoration Cost Estimates for 2000 Cargill Proposal

The total costs of restoring all or a portion of the South Bay salt pond complex comprises several distinct components. Based on the stated acquisition price ($300 million) for the 15,880-acre Cargill proposed sale area and cost estimates derived here and elsewhere in this report, we have calculated rough estimates of total restoration costs for the proposed acquisition area. Section 12.2.1 describes the components of the cost estimate and Section 12.2.2 presents the results of those estimates. Because there is so much uncertainty in actual costs of each component, we offer "low" and "high" cost estimates. These cost estimates address the "mudflat-sustainable" natural sedimentation restoration approach and the range of dredged sediment reuse restoration approaches discussed in Chapter 8.

12.2.1 Components of the Cost Estimate

We have identified eight distinct components that together comprise the total restoration cost estimates. For some of components, we have worked with single-value cost estimates (e.g., a fixed purchase price) while for others we have provided a range of costs that we estimate span the "low" to "high" spectrum. All estimates are in 2001 dollars.

1. **Purchase**. We have used a fixed-price amount of $300 million for acquisition of 16,000 acres offered by Cargill. These costs occur at the beginning of the process.
2. **Planning**. We have used a fixed-price amount of $10 million for planning the wetland restoration, long-term management, and monitoring program. We assume these costs are spread evenly over the first five years following acquisition.
3. **Operations and Maintenance during Planning.** We have used an O&M range of $284 to $686 per acre (Table 14-5 in Chapter 14) for the five-year planning period, or about $23 million for the "low" estimate and $55 million for the "high" estimate.
4. **Construction**. We have used a construction cost range of $1,500 to $5,000 per acre (Chapter 13) for the two-thirds of the ponds to be restored to tidal marsh (rounded to 11,000 acres for this analysis), or about $17 million for the "low" estimate and $56 million for the "high" estimate. For the natural sedimentation approach, we estimate that these costs would occur periodically over a roughly 70-year implementation period.

Table 12-1. Estimated total restoration and management costs for Cargill proposed sale area, 2001 dollars

Description	Natural Sedimentation Low[1]		Natural Sedimentation High[2]		Dredged Sediment Low[1]		Dredged Sediment High[2]	
	Cost ($M)	Duration	Cost ($M)	Duration	Cost ($M)	Duration	Cost ($M)	Duration
Planning and Design	10	5 yr	10	5 yr	10	5 yr	10	5 yr
O&M During Planning	23	5 yr	55	5 yr	23	5 yr	55	5 yr
Construction[3]	17	~70 yr	56	~70 yr	17	39 yr	56	39 yr
Monitoring[3]	60	40 yr	120	40 yr	60	40 yr	120	40 yr
Permanent O&M, 1/3 Area	142	99 yr	343	99 yr	142	99 yr	343	99 yr
Interim O&M, 2/3 Area[4,5]	156	99 yr	377	99 yr	62	39 yr	151	39 yr
Dredged Sediment Reuse Incremental	-	NA	-	NA	-	38 yr	361	38 yr
Subtotal	**408**		**961**		**314**		**1,095**	
Purchase	300	Initial	300	Initial	300	Initial	300	Initial
Total	**708**		**1,261**		**614**		**1,395**	

1 Low scenarios use lowest estimate cost per category or best case estimate.

2 High scenarios use highest cost per category or worst case estimate.

3 Construction costs exclude dredged sediment reuse-related costs.

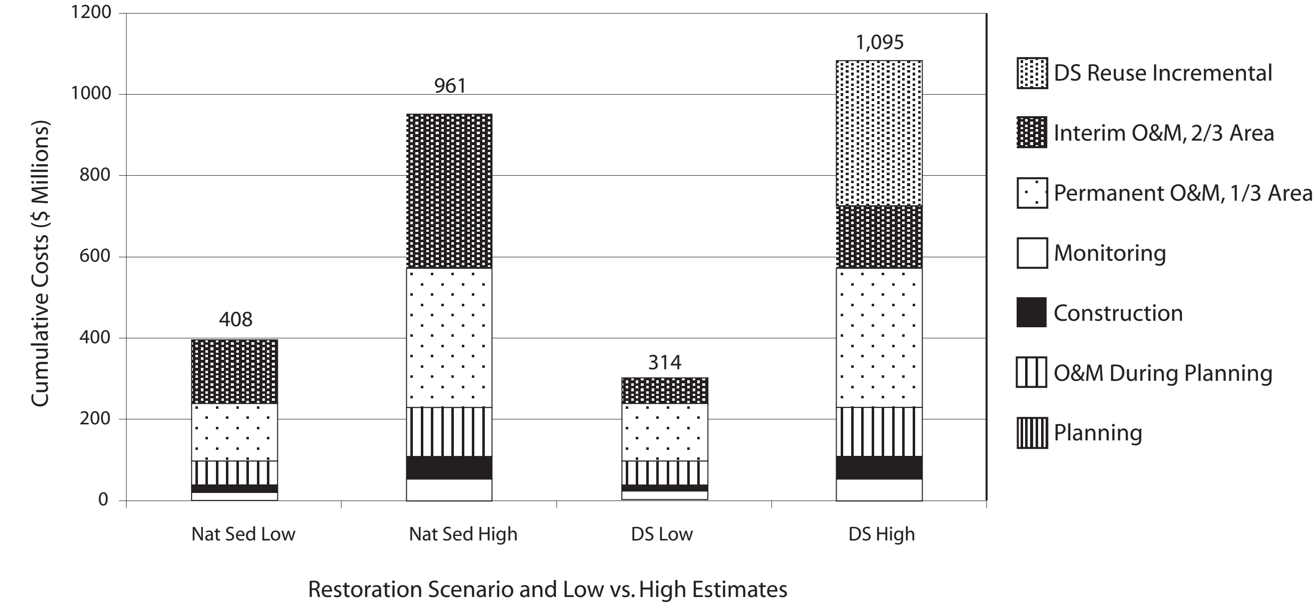
4 Dredged sediment low: interim O&M period minimizes duration and annual cost; no incremental dredged sediment reuse costs.

5 Dredged sediment high: interim O&M period corresponds to costliest dredged sediment reuse (least O&M time) and maximum O&M costs; maximize incremental dredged sediment reuse costs. This combination yields highest overall estimated dredged sediment reuse costs.

5. **Monitoring.** We have used a monitoring cost range of $1.5 to $3 million per year to extend over a total of 40 years, or $60 million for the "low" estimate and $120 million for the "high" estimate. Wildlands (1999) used a $2 million per year estimate. The 40-year time period will be unprecedented in wetland restoration monitoring but is a reasonable guess based on the extended time period necessary to implement the entire restoration effort. In reality annual costs may rise and fall depending on where the overall restoration effort is at in any given year, and this 40-year estimate should reflect a dispersal of the same total costs over a longer total period.
6. **Permanent Operations and Maintenance for Ponds Retained as Shallow Open Water.** Permanent O&M applies to water control infrastructure and levees for those ponds being retained in perpetuity as shallow open water habitats. These ponds will total about one-third the acquisition area, or about 5,000 acres. Permanent O&M costs have the same per acre range as for O&M during planning, or $284 to $686 per acre (Table 14-5 in Chapter 14). For the planning horizon, we have used 99 years, which corresponds to the time estimate for mudflat-sustainable natural sedimentation to restore tidal marsh. This time period allows us to compare natural sedimentation to dredged sediment reuse on a time-equivalent basis. Over this time period, the total costs would be about $142 million for the "low" estimate and $343 million for the "high" estimate. Permanent O&M costs, however, will continue in perpetuity beyond that 99-year time frame.
7. **Interim Operations and Maintenance for Ponds Restored to Tidal Marsh.** For those ponds being restored to tidal marsh, the full suite of O&M activities applies for the interim period prior to their restoration. After restoring tidal action, O&M reduces to levee maintenance only which continues until marsh vegetation is well established to provide levee erosion protection. These ponds will total about two-thirds the acquisition area, or about 11,000 acres. The per-acre cost range remains the same as above, $284 to $686 per acre (Table 14-5 in Chapter 14), with the number of acres declining to zero over time as restored ponds become established tidal marsh. Because tidal marsh restoration must be phased over many decades to avoid scouring mudflats, this time period is quite extended. To account for the decline to zero O&M over time, we average the initial costs with the final costs to arrive at a per-year cost range of $142 to $343 per acre; we use those values to estimate total interim O&M costs. This approach also integrates the levee maintenance-only component of the O&M costs.

   For the natural sedimentation approach, we assume 99 years (though it might end somewhat sooner), which translates into $156 million for the "low" estimate and $377 million for the "high" estimate. For the dredged sediment reuse restoration approach, restoration will be completed more rapidly and thus interim O&M will end sooner depending on how much dredged sediment is used. For the low-cost estimate, we used the shortest time period, 39 years, in conjunction with the lowest per-acre cost, which translates to $62 million. For the high-cost estimate, we used the highest per-acre cost and again a 39-year period. We used the 39-year period instead of the longest 51-year maintenance period we calculated because the shorter time corresponds to the more costly DM reuse approach (Table 8-4). This approach corresponds to the highest overall dredged sediment reuse options (Chapter 8) and thus provides a "realistic" combined upper cost estimate. This "high" estimate is $151 million.

Figure 12-1. Estimated total restoration and management costs for 16,000-acre Cargill proposed sale area, excluding acquisition, 2001 dollars



8. **Dredged Sediment Reuse Incremental Costs.** Salt pond restoration sponsors under current dredged sediment reuse programs in the San Francisco Estuary would be required to pay 100% of the incremental cost beyond that for ocean disposal (Chapter 8). These cost estimates include all costs directly related to dredged sediment reuse, such as transport, offloading, and placement. General wetland restoration and monitoring costs, even where dredged sediment is used, are accounted for under those headings. The "lowest" incremental cost is $0, or wetland restoration is the same cost to dredgers as is ocean disposal. The "highest" incremental cost is $361 million, which applies the highest per-cubic-yard incremental cost ($10/yard) with the greatest total dredged sediment reuse volume we evaluated (36.1 million cubic yards).

Figure 12-2. Annual restoration and management costs for Cargill proposed sale area, excluding acquisition, 2001 dollars

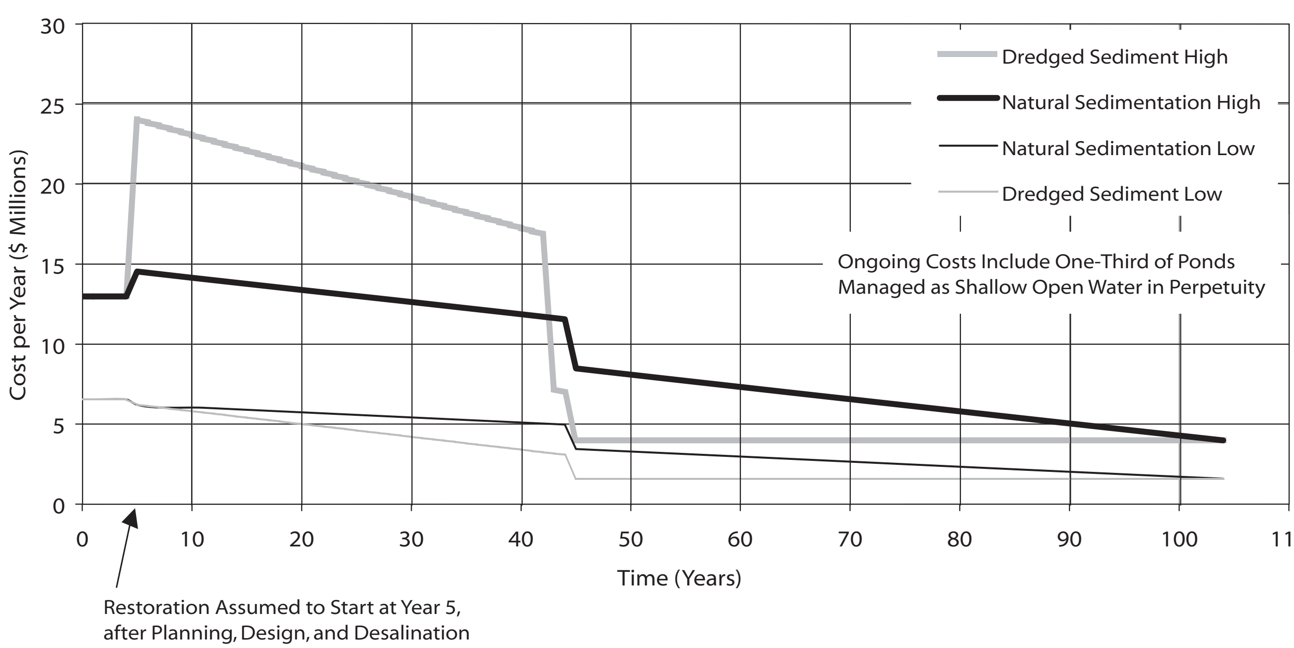
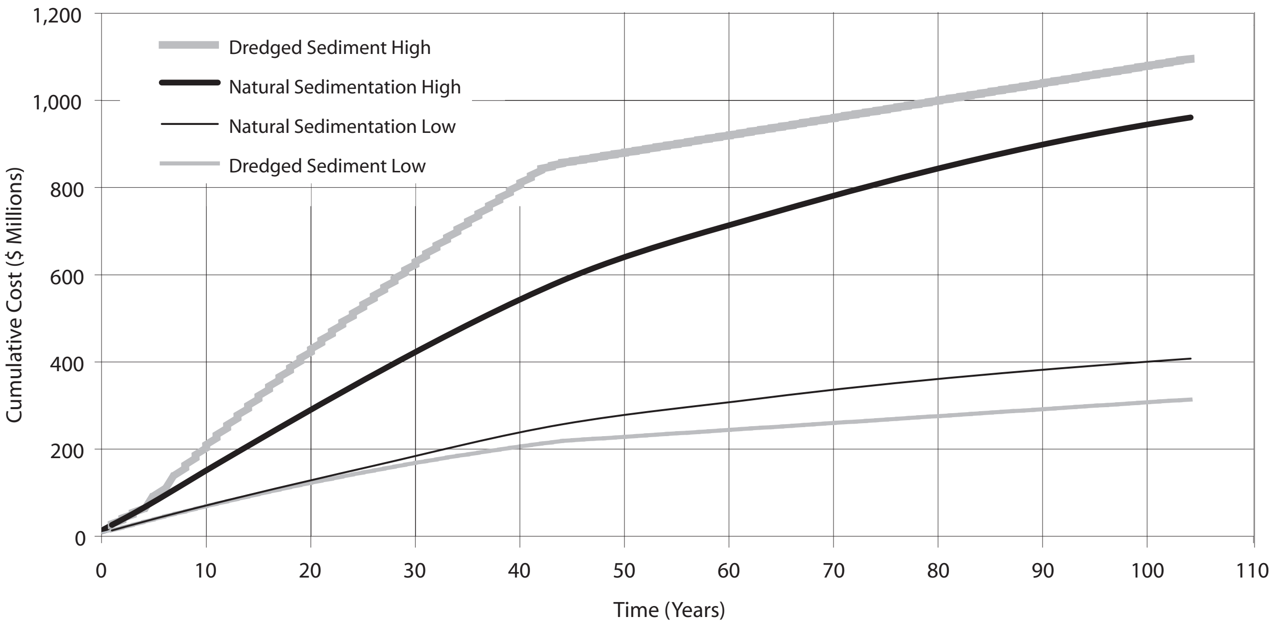


Figure 12-3. Cumulative restoration and management costs for Cargill proposed sale area, excluding acquisition, 2001 dollars



12.2.2 Estimated Range of Total Restoration Costs for Cargill Proposed Sale Area

Table 12-1 presents the total cost estimate ranges for the "mudflat sustainable" natural sediment approach and the dredged sediment reuse approach. Figure 12-1 shows total costs, Figure 12-2 breaks these down as per-year costs for the restoration period, and Figure 12-3 shows how these annual costs accumulate over the restoration period to equal the totals shown in Figure 12-1. All values shown are in 2001 dollars. Data are presented in Appendix G.

12.3 System Modifications to Re-Engineer for a Smaller Cargill System

Cargill began anticipating changes to its salt production system in early 2000 (if not earlier) while preparing the proposals described in the preceding sections. The purpose of these proposed actions is to modify its South Bay salt production complex to achieve three goals: (1) decommission approximately 16,000 acres salt production ponds as part of the anticipated acquisition; (2) improve production efficiency on the remaining 10,000 acres of salt production ponds (Cargill 2001a); and (3) improve efficiency for the existing production system (Douglas, personal communication). Some of the modifications were made in 2000 (see Map 5; Cargill 2000b) and many are planned for 2001 construction (Cargill 2001b). This section describes these system modifications (Section 12.3.1), the ecological significance of these modifications and subsequent pond management to Mowry Ponds 1 to 3 (Section 12.3.2) and to the remainder of the salt pond system (Section 12.3.3), and the possible economic significance of excess crystallizer capacity in Newark (Section 12.3.4).

12.3.1 Proposed and Constructed System Modifications

In anticipation of the sale, Cargill plans to improve its production efficiencies to "…become more flexible, cost efficient, and more effective in producing high quality brines to support a sustainable tonnage for harvest each year" (Cargill 2000b). Cargill has identified two operational objectives as critical to modifying the system for continued production on fewer acres (Cargill 2000b, 2001a):

1. ***The ability to move concentrated brines east from the Redwood City plant to the Newark #2 plant.*** In the past, brines have only been moved west to Redwood City. A benefit of this modification is Cargill's ability to move all the bittern stored in the Redwood City plant across the bay to the Newark #2 plant.
2. ***The ability to ensure efficient brine transfer such that concentrated brine production remains at full capacity***. In the past, brine transfer has been operated primarily for salt production with some flexibility for wildlife resource management. Cargill's proposed action would reduce that flexibility relative to current levels. Cargill states that improved brine transfer ability enhances their flexibility by allowing more control over water management (Douglas, personal communication).

To accomplish these modifications, Cargill has proposed or already undertaken numerous actions (Cargill 2000c, 2001a, 2001b) as described below. Many of the descriptions below include statements of purpose; many of these statements come directly from the Cargill literature cited and some come from inferences we have made through a process of reverse engineering.

Newark #1 Plant Construction in 2000 (Cargill 2001b)

- **New levee gaps.** Cargill excavated several new 25-foot gaps in internal levees within Newark Plant #1 to force more highly concentrated brines south toward the final evaporation ponds. These gaps were excavated on the levee between Ponds 3A and 4A (four gaps); between Ponds 4 and 5 (two gaps); between Ponds 6 and 7 (four gaps); and between Ponds 8 and 9 (four gaps).
- **New levee.** Cargill constructed a new, 1,800-foot levee within Pond 4A from the southeast corner of Pond 3A south to the main east-west levee between Ponds 4A and 7.
- **Larger pipes and gates.** Cargill increased the size of the pipes and gates in Ponds 7 and 9 to increase brine flow.
- **Provide all-weather pump access.** Cargill widened the access road to "Big Dan" pump between Ponds 4B and 9 to permit all-weather access.

Newark #2 Plant Construction in 2000 (Cargill 2001b)

- **Improve brine flow between ponds 4 and 5.** Cargill installed a new pipe and gate between these ponds.
- **Improve existing Mowry siphon capacity.** Cargill removed sedimentation from dredge lock at Pond 7 to improve bay water volume for the bay water pump to the Mowry siphon pump.
- **Improve flow from crystallizers to bittern ponds.** Cargill enlarged an existing siphon, installed an additional siphon across Plummer Slough, and constructed a new pump platform at the western end of the deep storage ditch in the FMC pond area.
- **Relocate pump discharge point.** Cargill extended the discharge pipe from "Green Hornet #2" pump by 1,100 feet, to relocate its discharge point.

Redwood City Plant Construction in 2000 (Cargill 2001b)

- **Convert Pond 1 to Intake Pond.** Cargill installed up to two 60-inch intake pipes and trash racks at Redwood City Pond 1 so this pond can take in Bay water directly. This pond is not shown on any available maps as having been used previously as an intake pond. The intake water would be used to dilute the stored bittern for easier pumping to the East Bay (see Map 5).
- **Reconstruct pump platform in Pond SF2.** Cargill reconstructed a pump platform in Redwood City Pond SF2 at the discharge end of the trans-Bay pipeline. A pump will be installed at a later date. The new arrangement will facilitate bittern and brine transfer from Redwood City to Newark.

Newark #1 and #2 Plants Proposed Construction for 2001 (Cargill 2001a, 2001b)

- **New siphon across Mowry Slough connecting Plant 2 pond 1 to pipeline from Plant 1.** Cargill proposes to construct a new siphon across Mowry Slough. This new connection will allow them to redirect brine flow in the new, smaller salt production system relative to the brine flow path used for decades (see Map 5). This change could have significant adverse effects and is discussed further in Section 12.2.2 below.
- **Larger siphon across Newark Slough connecting Plant 1 ponds 1 and 2.** Cargill proposes to replace the old, 48-inch siphon between Ponds 1 and 2 just south of the Dumbarton Bridge east approach with a larger, 72-inch siphon across Newark Slough. The larger siphon will allow better movement and control of brines and bittern, and will enable bittern and brine transfer from Redwood City to Newark. Two pipelines may be constructed, one for brines and one for bittern.
- **New pipeline to Newark crystallizers atop levees in Plants 1 and 2.** Cargill proposes to construct 5 miles of new pipeline connecting from the trans-bay pipeline output next to the Dumbarton Bridge to the Newark crystallizers. This pipeline will allow Redwood City bittern and brines to be placed directly into the crystallizers to reduce total bittern quantity by removing additional sodium chloride before sending the bittern on to long-term storage.
- **New channel connecting Plant 2 ponds 5 and 6.** Cargill proposes to construct a new channel connecting these ponds at the landward end of Albrae Slough. The new channel will provide dredge access and eliminate a dredge lock, but it would also improve brine flow considerably for future reduced-scale salt production.
- **New siphon across Albrae Slough connecting Plant 2 ponds 3 and 4.** Cargill proposes to construct a new, 48-inch siphon to connect these ponds as part of the brine flow redirection (see Map 5).

Redwood City Plant Proposed Construction for 2001 (Cargill 2001a)

- **Improve SF2 transmission capacity.** Cargill proposes to dredge a brine ditch leading to the reconstructed pump platform. This enlarged ditch will facilitate bittern and brine transfer from Redwood City to Newark. During the interim period when the San Francisco Public Utilities Commission is cleaning up lead-contaminated soils in Pond SF-1, these brines will be moved in a temporary pipeline that connects to the pump station.

12.3.2 Potential Impacts to Mowry Ponds 1, 2 and 3 After Re-Engineering

One of two potentially significant adverse environmental impacts of Cargill's proposed system re-engineering is a degradation of wildlife values and future restoration potential of Mowry Ponds 1, 2 and 3 within the Newark #2 Plant complex. The degradation is caused by conversion of these lower salinity intake ponds to higher salinity concentrator ponds (see Map 5). Cargill states two purposes of this altered brine flow: (1) move Redwood City bittern and brine to Newark, and (2) support improved efficiencies in the re-engineered solar salt system (Cargill 2001a).

These three ponds comprise about 1,500 acres. Mowry Pond 1 is an intake pond, with the intake water used primarily to provide additional gravity head to move concentrated brines from the Alviso plant northwest to the Newark crystallizer ponds (Douglas, personal communication). Its salinity varies according to frequency of intake and duration of standing water. Mowry Ponds 1 through 3 are also used at times to store concentrated Alviso brines when crystallizer capacity precludes continued movement of the Alviso brines (Douglas, personal communication). Consequently, Cargill states that salinity in these three ponds varies up to roughly 100 ppt.

The key difference that these ponds will experience under the new brine flow path is that they will become later-stage evaporator ponds for brine originating in Plant 1. Map 5 shows the future brine flow path under a reduced-acreage salt production system, a scenario Cargill has confirmed as viable (Douglas, personal communication). Cargill may or may not continue to use the existing intake into Mowry Pond 1. What makes the increase in salinity a concern for these three ponds is that they will shift from Stage 1 to Stage 2 evaporator ponds, with the distinction being salinities in Stage 2 ponds are high enough to allow gypsum precipitation. All three ponds are relatively high elevation (Map 9), do not have gypsum layers (Map 7) and contain few constraints for restoration. Were gypsum to be deposited on these ponds, then their future restoration feasibility could diminish.

These three ponds are targeted by the resource agencies as the highest restoration priority for recovery of several special status species (see Chapter 4). These ponds are currently used by a number of shorebird and waterfowl species at most if not all times of the year. Pond elevations are within one foot of local mean high water, meaning they could return relatively quickly to vegetated tidal marsh after restoration of tidal action. Little additional efforts would be needed for their restoration.

The impact of reduced restoration potential is significant because nearly every biologist in the region views these three ponds in particular as amongst the most important to restore to tidal marsh at the earliest possible opportunity. Not only that, they represent more than half of the "easy to restore" salt ponds in the South Bay (see Map 14). If their restoration potential is degraded through conversion to high salinity, then very little acreage of South Bay salt ponds could be restored with relative ease.

12.3.3 Potential Reduced Wildlife Function of Remaining Salt Ponds After Re-Engineering

The second potentially significant adverse environmental impacts of Cargill's proposed system re-engineering is a degradation of wildlife values within much of the remaining 10,000-acre production complex. This degradation would be caused by new water and salinity management to improve production efficiency that may come at the expense of wildlife management flexibility.

In anticipation of the acquisition, Cargill plans to improve its production efficiencies to "…become more flexible, cost efficient, and more effective in producing high quality brines to support a sustainable tonnage for harvest each year" (Cargill 2000c). Cargill has identified two elements as critical to modifying the system for continued production on fewer acres: (1) shifting brines from Redwood City to Newark, and (2) the ability to ensure higher salinity evaporation ponds remain full at all times so that concentrated brine production remains at full capacity.

From an ecological perspective, it is the objective to "remain full at all times" that will degrade the ecological functions of the retained salt ponds in two important ways. First, by keeping ponds as full as possible at all times, the variability in water depth that is integral to shorebird and waterfowl use of the ponds will largely disappear. Consequently, only those species able to exploit the greater water depths will continue to find value in the salt ponds. Second, the internal islands and berm and levee slopes that are variably exposed as water levels are adjusted throughout the pond system will reduce in size. These areas are the primary nesting habitat for several species, most notably the western snowy plover. Because that particular species has protection under the federal endangered species act, Cargill will retain obligations to provide suitable nesting habitat for that species. But for the many other species without endangered species act protection, Cargill will have no obligation to manage for nesting habitat.

Such fundamental changes to the water level (and thus the salinity) regime of the smaller production system following acquisition was never anticipated in the CEQA/NEPA compliance for the Corps and BCDC permits, nor in the permits themselves. The presence of special status species and the overall importance of the South Bay salt ponds to shorebirds and waterfowl necessitate a new CEQA/NEPA compliance review and new permits.

Cargill has stated that it believes the re-engineering will improve wildlife management flexibility by providing increased control over water level management (Douglas, personal communication). While it may be the case that the system modifications will allow greater control relative to pre-modification conditions, one cannot equate opportunity with action. In other words, while Cargill could manage more effectively for wildlife benefits, they are under no obligation to act accordingly except in cases where the Endangered Species Act requires certain actions. Further, since Cargill's primary focus is to produce salt as efficiently as possible, system management is inherently keyed to production efficiency not wildlife management.

12.3.4 Reduced Need for Newark Crystallizer Ponds with Smaller System

By making about 16,000 acres of salt production ponds available for restoration, Cargill will eventually have excess crystallizer pond capacity in Newark. Currently, Cargill harvests about 700,000 tons of salt annually from Newark and an additional 300,000 tons at Redwood City (Cargill web site). Cargill predicts a reduced annual production of 600,000 tons, harvested from the 865 acres of crystallizers at Newark only, after it ceases production on the 16,000 acres converted to wildlife habitat. We estimate annual production may be closer to 500,000 tons based on Bay Area EcoAtlas (SFEI 1998) GIS acreage calculations. The reduced salt production volume should free up the need for at least 240 of the 865 acres of Newark crystallizers once the new production volumes are reached. At current real estate values in the East Bay, these lands might sell for $1 million per acre if they are not subject to federal Clean Water Act jurisdiction, a contested issue. These ponds could yield Cargill an additional $240 million or more.

Crystallizer ponds are the most easily restored and managed lands for Western snowy plover nesting, California least tern foraging, shorebird roosting, and habitat for the endemic rare insect western Tanarthrus beetle. The loss of these crystallizer ponds to development, especially on such a scale, would severely hamper recovery efforts for these species.

Chapter 13.

Restoration Feasibility and Two Case Studies

Chapter 13.
Restoration Feasibility and Two Case Studies

In this chapter we seek to provide the reader with an integrated understanding of the relative feasibility of restoring each South Bay salt pond to tidal marsh and from that provide a range of restoration cost estimates reflecting "easy" and "difficult" to restore ponds. To accomplish this goal, first we integrate information presented throughout the previous chapters into a feasibility determination – stated as "high", "medium", and "low" – for restoring each South Bay salt pond to tidal marsh in order to provide a landscape-scale understanding of the complexity facing restoration planners (Section 13.1).

From the restoration feasibility determination we then select small groups of contiguous ponds from the "high" and "low" feasibility categories and develop case studies of restoring the selected ponds to tidal marsh. The first case study examines "high" feasibility ponds that are relatively "easy" to restore because of few site constraints requiring comparatively little construction activities to restore tidal action (Section 13.2). These ponds have the highest likelihood of meeting ecological goals in a cost-effective and rapid manner. The second case study examines "low" feasibility ponds that are relatively "difficult" to restore because a variety of constraints mandate a complicated restoration design, relatively expensive construction activities, and ultimately pose serious challenges to the achievement of ecological goals in a timely and cost-effective manner (Section 13.3). Each case study outlines principal design considerations, presents a simple conceptual design, and concludes with a rough construction cost estimate. The "low" feasibility case study also considers dredged sediment reuse; see Chapter 8 for a thorough discussion of the issues surrounding dredged sediment reuse.

We use several abbreviations throughout this chapter. Refer to the list of abbreviations at the beginning of this report for their definitions.

13.1 Restoration Feasibility

The feasibility of restoring each of the South Bay salt ponds to tidal marsh derives directly from all the data presented throughout this report. These data include the extensive physical, chemical, and biological information for the South Bay salt ponds (Chapters 2 through 6), the lessons learned from the Napa River salt pond restoration effort (Chapter 7), the options for resolving the sediment deficit problem (Chapter 8), and the ability to restore groups of adjacent ponds.

Nearly every pond has its strengths and weaknesses for tidal marsh restoration suitability. Each of these attributes carries with it a value judgment and some objective measure about its relative importance. Arriving at a classification for each pond requires considering the full range of subjective and objective measures. To arrive at the classification for each pond we show in Map 14, we used all data throughout this report along with our own best professional judgement. We recognize that others might reach different conclusions with these same data; therefore, we have included the entire GIS database as Appendix C for others to use and arrive at their own conclusions. This database underlies all the maps presented in this report. Further, the reader must understand that the reasons for classification of each pond are site-specific and thus differ between ponds. Therefore, all ponds within a single classification do not share the identical reasons for their classification.

The scope of this feasibility analysis did not include obtaining the detailed site-specific information necessary for a thorough restoration feasibility analysis on a pond-by-pond basis. A thorough analysis would require more information, such as: the details of infrastructure items and their easements, including underground utilities, pipelines, and storm drains; flood storage requirements and other land use controls; current occupation of existing habitats by special status species; the presence of historic and archaeological artifacts and sites; and the presence of toxic contaminants.

13.1.1 Feasibility Criteria

Restoration feasibility integrates costly restoration activities, major impediments to restoration, and the ecological opportunities and constraints each pond presents.

Restoration Elements with Major Cost Implications

- PG&E towers that must have the concrete footings increased in height to protect against higher water levels. In some cases, the towers themselves may need to be raised to maintain minimum line clearance from the ground.
- Underground utilities that cannot be abandoned and that lie at elevations that interfere with unrestricted tidal exchange.
- Flood control levees that are expensive to build and maintain.
- Water controls structures that must be operated and maintained in perpetuity.

Major Impediments to Restoration

- Significant subsidence that has created a large sediment deficit and high cost for levee maintenance – at least in the interim.
- Gypsum layers combined with high elevation.
- Proximity to wastewater treatment plant discharges that reduce tidal water salinity and tend to create brackish rather than salt marsh.
- Proximity to ground zero of *Spartina alterniflora* invasion, at least until control efforts show some measure of success.
- Existing use of ponds by shorebirds, waterfowl, and other species that are dependent on non-tidal marsh habitats within the salt pond complex.

Major Ecological Opportunities

- Proximity to existing marsh for colonization and creating continuity between existing habitats.
- Target areas for endangered species recovery efforts.
- Ability to create large tracts of tidal marsh with the least construction costs.

13.1.2 High Feasibility Ponds

A high feasibility pond requires minimal work to restore tidal marsh and it provides considerable ecological benefits. Pond elevations are relatively high so that marsh vegetation can establish itself quickly. A tidal source is readily available. A largely intact antecedent channel network is present to promote adequate tidal circulation. The location is well suited for rapid colonization by target plant, fish and wildlife species. The area is targeted as important for endangered species recovery efforts. The ponds are comparatively remote from exotic species invasions. These criteria define ponds where all that is needed is modest levee adjustment, borrow ditch closure, and excavation of a pilot channel through outboard marsh before breaching the levee.

These criteria yield a total of 8 ponds representing 2,690 acres (10% of total salt pond area; Map 14):

- **Mowry Slough Ponds (Newark #2 Plant Ponds 1, 2 and 3).** These ponds total about 1,520 acres and would be restored together. Raising or reconstructing a single, roughly _-mile flood control levee at the northeast side of Pond 3 is the primary construction need along with levee breaches. Pond 3 does have 24 PG&E overhead transmission towers. However, since these towers have concrete foundations and sufficient line clearance, they probably would require no work as part of tidal marsh restoration. These three ponds, part of the Refuge, have long been targeted by resource managers as the highest restoration priority of the entire South Bay salt pond complex. These ponds are not included in the Cargill proposed sale area.
- **Coyote Creek (Alviso Plant Ponds A17 and A21).** These ponds total about 280 acres. Each would be restored separately. They are largely absent of any constraints, are at relatively high elevation, and are close to existing wetlands; this combination of factors could contribute to rapid establishment of tidal marsh functions in these ponds.
- **Redwood City Ponds (Redwood City Plant Ponds 1, 2, and 4).** These ponds total about 890 acres. Ponds 1 and 2 would be restored together. Pond 4 would be a stand-alone project or restored with the adjacent medium-feasibility ponds (Ponds 3 and 5). They are largely absent of any constraints, are at relatively high elevation, and are close to existing wetlands; this combination of factors could contribute to rapid establishment of tidal marsh functions in these ponds.

13.1.3 Medium Feasibility Ponds

We have identified 13,240 acres of ponds as medium feasibility. These ponds are distributed throughout the entire salt pond complex (Map 14) and include 2,690 acres that would be rated as high feasibility except for their location close to the center of the South Bay *Spartina alterniflora* invasion (see Section 12.1.5 below and Chapter 4).

13.1.4 Low Feasibility Ponds

A low feasibility pond requires considerable work to restore tidal marsh and presents challenges that may question their ability to provide desired ecological functions. These ponds typically face one or more constraints: construction of new flood control levees; the relatively long time of natural sedimentation and/or the high cost of dredged sediment reuse to restore intertidal elevations in subsided ponds; infrastructure that would interfere with unrestricted tidal exchange; and residual high salinities in pond sediments.

These criteria yield a total of 40 evaporator ponds and all the crystallizer ponds, representing 8,430 acres (32% of total salt pond area; see Map 14) that would be relatively difficult to restore to tidal marsh.

- **Subsided Ponds (Alviso Plant A2E, A3W, A8, A12, and A13).** These five ponds total 2,140 acres. They represent a sediment deficit of about 24 million cubic yards (22% of estimated total sediment deficit of all South Bay salt ponds combined). All but Pond A8 would require extensive flood control levee improvements (Map 11). Ponds A2E, A3W, and A8 are used heavily by numerous bird species. Pond A8 has overhead electrical distribution lines that, because of subsidence, might need upgrading. Pond A8 has underground electrical lines apparently located in the levee dividing it from Pond A5 to the west. Providing tidal exchange to these ponds is difficult – especially to A8, A12 and A13 –because they are so far removed from the bay up tributary channels.
- **Crystallizer Ponds (Newark and Redwood City).** The crystallizer ponds total 1,340 acres. These ponds are not well suited for restoration to tidal marsh for several reasons. All have been closely graded, resulting in loss of the antecedent channel network; therefore, new tidal channels would have to be excavated. Most of the Newark crystallizer ponds are located above the historic margins of the bay and are remote from tidal action, so achieving tidal exchange may not be possible. The Redwood City crystallizer ponds would require flood control improvements around their entire western and southern boundaries. All the crystallizer ponds are optimally suited for enhancement as salt panne habitat consisting of seasonal ponding and little vegetative cover (see Section 2.3).
- **Baumberg Ponds (several in Baumberg Plant).** These ponds total 2,280 acres. Tidal restoration would be difficult because these ponds are either far removed from tidal exchange (Map 10); located at a high elevation and coated with a gypsum layer (Pond 8A; Map 13); or constrained by the proximity of the invasive Spartina alterniflora. Tidal exchange constraints may ease if the planned Eden Landing restoration project is constructed (see Map 1).
- **Newark Dumbarton Bridge Approach South Side (Newark #1 Plant, Pond 2 and unnumbered pond).** These two ponds total 320 acres. They would have extensive flood control problems for the approach to the Dumbarton Bridge. Present bird use is extensive. The ponds have a gypsum layer combined with relatively high elevation. A number of overhead electrical transmission lines (Map 12) may constrain restoration to tidal marsh.
- **Fremont Interior Ponds (Newark #2 Plant Ponds 5 and 6, and Alviso Plant Pond A22).** These three ponds total 1,140 acres.

These ponds would present significant flood control risks (Map 11). They are far removed from the tides (Map 10). They have a gypsum layer combined with relatively high elevation (Map 13). They have a number of overhead electrical transmission lines that may present challenges to tidal restoration (Map 12). Pond A22 has the East Bay Dischargers Authority force main on its upland side, which may pose a constraint.

- **Small Redwood City Ponds (Redwood City Plant Ponds S5 and two unnumbered ponds)**. These ponds total 50 acres. They are relatively removed from the tides. They would require extensive flood control enhancements for a relatively small acreage of wetland creation. They may be restorable in association with adjacent ponds.
- **Bittern Ponds (Redwood City Ponds 8E, 9, 9A, and 10 and Newark #2 Ponds 12, 13 and FMC 1-6).** These ponds total 1,160 acres. They contain bittern salts in both liquid and solid form and the underlying pond sediments are hypersaline (see Section 3.2.4 and Chapter 10). Cargill has stated its intent to remove the bittern from Redwood City as part of the acquisition currently under negotiation. Without public disclosure of the terms of the acquisition as they apply to bittern removal, we cannot assess the effectiveness of Cargill's removal action relative to eliminating all residual salts. Were Cargill to remove all the bittern, including liquids, solids, and salt in the pond sediments, then these ponds would rise to medium or high restoration feasibility.

13.1.5 The *Spartina alterniflora* Constraint

We have "down-graded" by one level the restoration feasibility classification of several ponds between the San Mateo and Dumbarton bridges because of the currently uncontrolled invasion of existing tidal marshes and adjacent by the plant species *Spartina alterniflora* (see Map 14). Control of this invasive species is currently the subject of a multi-agency task force, but no satisfactory control measure has been identified to date and species range continues to expand (Ayers and Strong 2002, Smith *et al.* 2002). Consequently, several resource managers have suggested that tidal marsh restoration on ponds in this portion of the South Bay be implemented in later phases of overall system restoration, in order to give more time for control efforts to be developed and implemented or, if control fails altogether, to evaluate the ecological implications of restoration more fully.

We have identified a total of 3,420 acres of ponds subject to this downgrade. Of this total, 2,690 acres (79%) would be classified as high feasibility in the absence of the S. alterniflora problem. As noted above in Section 13.1.2 and shown in Map 14, we have identified only 2,690 acres as high feasibility. Absent the S. alterniflora constraint, the high feasibility acreage would double from 10 to 20 percent of the total area of the South Bay salt pond complex. Spartina alterniflora presents a major challenge to achieving tidal marsh restoration goals quickly and cost effectively.

13.2 Case Study 1: Restoring High Feasibility Salt Ponds to Tidal Marsh

For the first case study, we examined what would be involved to restore high feasibility salt ponds to tidal marsh. This section describes the principal considerations, conceptual restoration plan, and a rough construction cost estimate for such a scenario. For this case study we selected Redwood City Ponds 1 and 2, which total 590 acres (Map 14), for the following reasons:

- Importance of their location for recovering tidal marsh-dependent plant and wildlife species.
- Little need for flood control improvements.
- Small degree of subsidence.
- Few infrastructure constraints.

Table 13-1. High feasibility case study site summary information

Description	Area[1] (ac)	Average Elevation[2] (ft NGVD)	Distance to MHHW (ft)	PG&E Towers (no.)
Ponds				
Redwood City 1	446	2.0	2.3	4
Redwood City 2	141	1.9	2.4	8
Total	587			12
Tidal Datums[3]				
MHHW		4.3	0	
MHW		3.7	0.6	
MTL		0.4	3.9	
MLW		-2.9	7.2	
MLLW		-4.1	8.4	
Perimeter Elevations[4]				
External levees		10	-5.3	
Internal levees		7	-2.3	

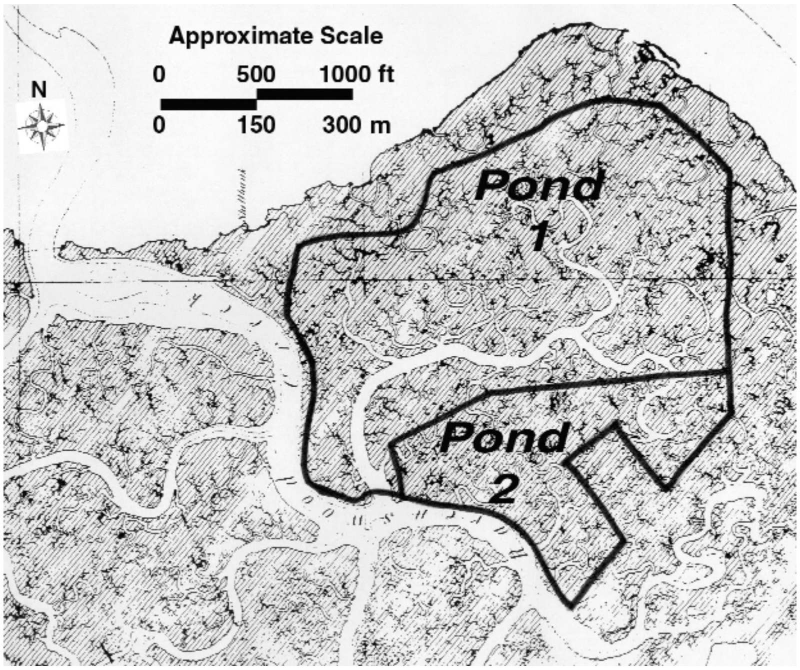
1 *Pond areas derived from Bay Area EcoAtlas (SFEI 1998).*

2 *Pond elevations from Wildlands* et al. *(1999)*

3 *Tidal datums for NOS station 941-4509, NOS (2000)*

4 *Perimeter elevations from Fremont Engineers (1999) and USACE (1988)*

Figure 13-1. United States Coast and Geodetic Survey 1857 T-Sheet historic conditions map for Redwood City Ponds 1 and 2



1 The location of modern pond boundaries is approximate.

2 The USCGS base map is not georeferenced.

- Close proximity to existing tidal marshes, which facilitates plant and animal colonization.
- Ability to retain water level management in upstream salt ponds.
- Probable availability of these two ponds because they are within the current Cargill proposed sale area. (Were it not for this constraint, we would have selected the Mowry Ponds 1, 2 and 3; however, these ponds are not included in the current acquisition negotiations.) However, recent 2002 negotiations may exclude part or all of Redwood City, so these ponds may not remain within the acquisition area.

13.2.1 Principal Design Considerations

A number of design considerations are incorporated into the conceptual restoration design presented in the following section. Each of these considerations is discussed below.

Existing Underground Utility Lines

These lines provide power to the pump on the west side of Ravenswood Slough at the border between Ponds 3 and 4 (Map 12). The underground line is presumably within the footprint of western levee. The line appears to become overhead across Ravenswood Slough to the pump on the west side of the slough. The pump at the border of Ponds 3 and 4 is used to move brine west toward the crystallizer ponds during normal salt production. This pump will no longer be needed once salt production ends and Cargill has completed transfer of bittern and brine to Newark.

Existing PG&E Overhead Transmission Line Towers

There are four towers in Pond 1 and eight towers in Pond 2 (one of which is on the levee dividing the two ponds). These towers are assumed to have adequate concrete footings and line sag clearance so no action is needed to modify them.

Existing Elevations

Table 13-1 lists site elevations, local tidal datums, and levee heights.

Flood Protection

Along the south border alongside the Dumbarton Bridge approach east to Moseley Tract, the upland edge of Pond 2 is high ground (Wildlands *et al.* 1999; see Map 11). We assume these data are correct and that no flood protection is needed along this portion of ponds. Along the southeast border with the Moseley Tract, flood protection needs depend on what happens with the Moseley Tract itself. The Moseley tract is targeted for tidal marsh restoration by the City of San Jose as mitigation for its treatment plant discharge freshwater impacts (Van Keuren, personal communication). If the elevation of the frontage road is inadequate, San Jose or Caltrans will address this constraint separately. If the Moseley project is built, it will resolve flood control issues along the frontage road. The levee between Ponds 1-2 and the Moseley tract would no longer be needed because there would be tidal marsh restoration on both sides. If the Moseley project is not built, a flood protection levee must be provided on the small portion of the Pond 2 levee at the southeast corner near frontage road. The levee between Pond 1 and the Moseley Tract remains necessary, and therefore must be maintained.

Interior Levee Dividing Ponds 1 and 2

This levee served to separate the ponds for salt production. Under restoration, this interior levee will no longer be needed. The design would lower its elevation to upland ecotone and construct gaps to reduce predator access.

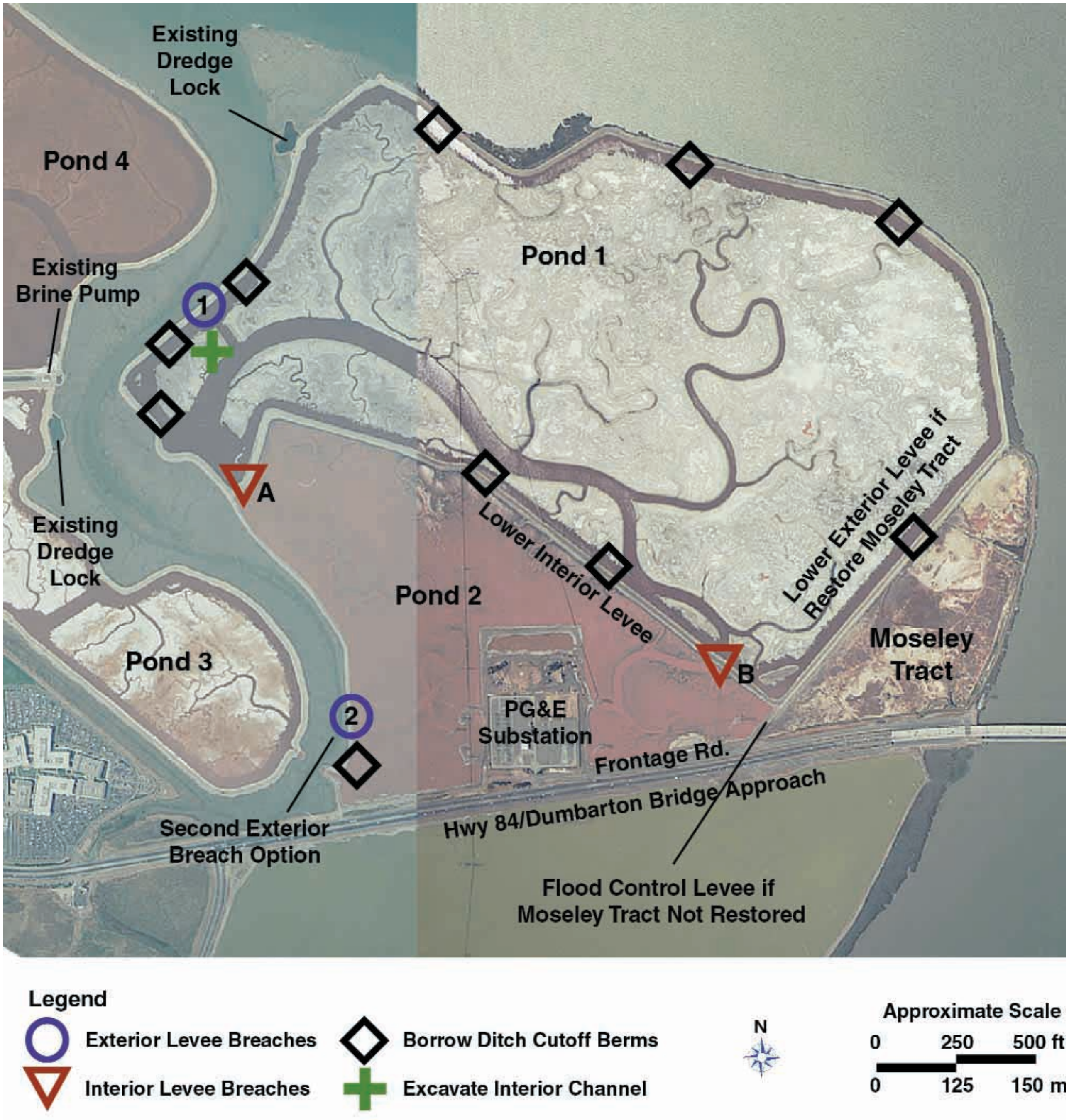
Existing Borrow Ditches

These ditches are found alongside interior and exterior levees in both ponds. The concern is that they can capture tidal flows when tidal marsh is restored. A solution is to construct "cutoff berms" and "training berms" at strategic locations (Orr *et al.* 2001). These berms would be the width of the ditch and approximately 100 feet in length. The basis for this approach is the recently designed and constructed Cooley Landing Tidal Marsh Restoration Project located in Palo Alto. This approach has not been applied previously. It is too soon to determine if it is successful, but it appears reasonable. We therefore utilize it in this case study.

Locations and Sizing of Levee Breaches

The goal in tidal marsh restoration is always to rely upon historic conditions as the design template whenever possible. Often times those conditions have been altered irreversibly. Historic conditions at ponds 1 and 2 (Figure 13-1) fortunately have carried forward in several regards and we have incorporated them into the conceptual restoration design to the extent possible (Figure 13-2). The main channel in Pond 1 was approximately 120 feet wide. We identified breach width from historic and antecedent channel networks and

Figure 13-2. Existing conditions and conceptual restoration plan at high-feasibility Redwood City Ponds 1 and 2



from existing tidal channel sizing models (PWA 1995, Collins 1991). We accounted for the larger initial tidal prism due to pond subsidence. The tidal prism will decrease over time as the marsh plain elevation builds naturally.

13.2.2 Conceptual Restoration Plan

There are two alternative restoration plans for the high feasibility ponds. The difference between the two alternatives is how to address the levee separating the Moseley Tract from the two salt ponds. Which plan is needed depends on whether or not the adjacent Moseley Tract is restored to tidal marsh. Both designs are presented in Figure 13-2.

Exterior Levee Breaches

Exterior levee breaches are the same for both alternatives. The breaches provide unrestricted tidal exchange to both ponds and promote use of the using antecedent channel network. Exterior levee breaches are proposed at two locations:

- **Breach 1** : into Pond 1 on Ravenswood Slough near its mouth.
    - Top width: 150 ft.
    - Invert elevation: -7.7 ft NGVD/-5.0 ft NAVD/-3.6 ft MLLW.
    - Side slopes: 3 to 1.
    - Bottom width: 80 ft.

- **Breach 2**: into Pond 2 on Ravenswood Slough near its head. This breach may be optional depending on whether the breach into Pond 1 combined with opening of the interior levee and use of the borrow ditches provides sufficient tidal exchange into Pond 2.
  - Top width: 60 ft.
  - Invert elevation: -1.7 ft NGVD/+1.0 ft NAVD /+2.4 ft MLLW.
  - Side slopes: 3 to 1.
  - Bottom width: 24 ft.

Interior Levee Breaches

Interior levee breaches are the same for both alternatives. The breaches provide unrestricted tidal exchange to Pond 2 via Pond 1, utilizing the antecedent channel network to the extent possible. These breaches have the added benefit of creating a large "island" that will reduce predator access to the interior of the restored marsh. Interior levee breaches are proposed at two locations:

- **Breach A**: west end of pond boundary at borrow ditch.
  - Top width: 100 ft.
  - Invert elevation: -4.7 ft NGVD/-2.0 ft NAVD /-0.6 ft MLLW.
  - Side slopes: 2 to 1.
  - Bottom width: 60 ft.

Table 13-2. Rough estimated construction costs for high feasibility restoration case study

Item	Description	Quantity	Units	Unit Price	Cost
ALTERNATIVE 1: MOSELEY TRACT RESTORED BY OTHERS					
1	Mobilization and demobilization	1	LS	100,000	$ 100,000
2	Exterior breaches, cut	4,000	CY	20	80,000
3	Interior breaches, cut	2,000	CY	20	40,000
4	Lower interior levee, cut	2,000	CY	10	20,000
5	Lower Moseley levee, cut	1,000	CY	10	10,000
6	Widen inside of breach, cut	5,000	CY	10	50,000
7	Cut-off berms, 10, fill	15,000	CY	20	300,000
8	Abandon underground electrical	1	LS	25,000	25,000
	Subtotal				625,000
	20% Contingency				125,000
	Total				**$ 750,000**
ALTERNATIVE 2: MOSELEY TRACT NOT RESTORED					
1	Mobilization and demobilization	1	LS	100,000	$ 100,000
2	Exterior breaches, cut	4,000	CY	20	80,000
3	Interior breaches, cut	2,000	CY	20	40,000
4	Lower interior levee, cut	2,000	CY	10	20,000
5	Widen inside of breach, cut	5,000	CY	10	50,000
6	Raise flood control levee, fill	500	CY	10	5,000
7	Cut-off berms, 10, fill	15,000	CY	20	300,000
8	Abandon underground electrical	1	LS	25,000	25,000
9	Maintain flood control levees1	1,250	LF	100	125,000
	Subtotal				745,000
	20% Contingency				149,000
	Total				**$ 894,000**

1 Flood control levee maintenance assumes 10 maintenance events over a 50-year planning horizon at a unit cost of $10 per linear foot per event.

2 LS = lump sum; CY = cubic yard; LF = linear foot

- **Breach B:** east end of pond boundary at block in antecedent channel.
    - Top width: 60 ft.
    - Invert elevation: -2.7 ft NGVD/0.0 ft NAVD /+1.4 ft MLLW.
    - Side slopes: 2 to 1.
    - Bottom width: 45 ft.

Widen Interior Channel Adjacent to Breach

Both alternatives include widening the existing channel located just inside the breach into Pond 1. The channel cross section would match that of the adjacent levee breach and be designed to provide unrestricted daily tidal exchange.

Lowering the Interior Levee between Ponds 1 and 2

Lowering this internal levee is optional but desirable and is included in both alternatives. The lowered levee creates upland ecotone as refuge for tidal marsh species and the new gaps reduce predator access. Estimated levee lowering includes:

- Total length of levee to be lowered: 1,600 ft.
- Existing elevation: assumed 7 ft NGVD.
- Target elevation: about 1 ft above local MHHW.

Lowering the Levee between Moseley Tract and Ponds 1 and 2

Lowering this eastern perimeter levee is optional under the alternative in which the Moseley Tract is restored to tidal marsh by other entities. If the Moseley Tract is not restored and thus the flood control issues along that segment of the frontage road are not resolved, this levee must remain in place and be maintained. Specific aspects of levee lowering include:

- Total length of levee to be lowered: 850 ft.
- Existing elevation: assumed 10 ft NGVD.
- Target elevation: about 1 ft above local MHHW.

Borrow Ditch Cutoff Berms

Borrow ditch cutoff berms are intended to block the existing borrow ditches from capturing tidal flows and to prevent the establishment of a naturalistic tidal channel network. A total of 10 borrow ditch cutoff berms are anticipated (see Figure 13-2).

13.2.3 High Feasibility Restoration Construction Cost Estimate

This estimate considers the major costs to construct each of the two restoration alternatives for the high-feasibility case study. Costs not included are those needed for planning, environmental review and permitting, long-term monitoring, and interim management during restoration planning. The only long-term maintenance costs considered are flood control levee maintenance under the second alternative in which the adjacent Moseley Tract is not restored to tidal marsh. Table 13-2 summarizes the estimated construction costs. These costs are $750,000 and $894,000, respectively, for each of the two alternatives. For this 590-acre restoration, the associated range in construction costs is $1,270 to $1,515 per acre. The total restoration costs estimated in Section 12.2 for the Cargill proposed sale area utilize these values as the "low" cost option.

13.3 Case Study 2: Restoring Low Feasibility Salt Ponds to Tidal Marsh

For the second case study, we examined what would be involved to restore low feasibility salt ponds to tidal marsh. This section describes the principal considerations, conceptual restoration plan, and a rough construction cost estimate for such a scenario. For this case study we selected a group of five ponds: Alviso Plant Ponds A2E, A3N, A3W, B1 and B2 in Sunnyvale, which total 1,450 acres (see Map 14). We have selected these ponds for the following reasons:

- **Extensive subsidence requires:**
    - many years of natural sedimentation until elevations are suitable for tidal marsh establishment, with the possibility that wind-generated waves may resuspend sediment and extend this time line for many years;
    - or dredged sediment placement to raise site elevations closer but not up to target tidal marsh elevation so that the time period of natural sedimentation and marsh establishment is considerably reduced;
    - and much greater maintenance on flood control levees due to greater water depths and taller levees from base to crest.
- **Extensive flood control improvements** are needed to protect adjacent uplands.
- **A large number of overhead electrical PG&E towers** would probably require upgrades for proper protection against tidal waters.
- **It is more difficult to provide tidal access** due to distance from the Bay.
- The probable availability of these five ponds because they are within the current Cargill acquisition area.

Not all five ponds are classified here as "low" feasibility for restoration to tidal marsh (see Map 14). We initially considered for this case study Pond A3W only. A comparison of flood control levee improvements needed to isolate pond A3W from all its surroundings (4,100 linear feet of levee for 610 acres of marsh) versus levee improvements for the entire cluster of ponds (3,700 linear feet of levee for 1,450 acres of marsh) suggested an economy of scale could be achieved by restoring all five ponds together. An alternative design for these five ponds that is not evaluated in this report is to make a bayward band of tidal marsh consisting of Ponds B1, A3N, and the northern end of B2. Ponds A2E, A3W, and the bulk of B2 would then be managed in perpetuity as open water.

13.3.1 Principal Design Considerations

A number of design considerations are incorporated into the conceptual restoration design presented in the following section. Each of these considerations is discussed below.

Deep Subsidence

The most fundamental issue for these ponds is the deep subsidence of all these ponds and the associated sediment deficit to restore tidal marsh plain elevations. These ponds have subsided between about 4 and 8 feet below local MHHW and have a combined sediment deficit to MHHW of 16.2 MCY (Table 13-3). Once opened to tidal action, these ponds become a large sediment sink into which naturally circulating sediment in the shallow South Bay

Table 13-3. Low feasibility case study site summary information

Description	Area[1] (ac)	Average Elevation[2] (ft NGVD)	Sediment Deficit[3] Distance to MHHW (ft)	Sediment Deficit[3] to MHHW (mcy)	Sediment Deficit[3] to1.5 ft <MHHW (mcy)	PG&E Towers (no.)
Ponds						
Alviso A2E	315	-3	7.7	3.9	3.2	0
Alviso A3N	185	-1.4	6.1	1.8	1.4	7
Alviso A3W	606	-3.2	7.9	7.7	6.3	7
Alviso B1	158	-1.3	6	1.5	1.1	16
Alviso B2	186	0.5	4.2	1.3	0.8	4
Total	**1,450**			**16.2**	**12.7**	**34**
Tidal Datums[4]						
MHHW		4.7	0			
MHW		4.1	0.6			
MTL		0.5	4.2			
MLW		-3.1	7.8			
MLLW		-4.3	9			
Perimeter Elevations[5]						
External levees		10	-5.3			
Internal levees		7	-2.3			
Upland edges		7	-2.3			

1 *Pond areas derived from Bay Area EcoAtlas (SFEI 1998).*

2 *Pond elevations from Wildlands* et al. *(1999)*

3 *Sediment deficit calculated as area times depth.*

4 *Tidal datums for NOS station 941-4575, NOS (1990)*

5 *Perimeter elevations from Fremont Engineers (1999) and USACE (1988)*

waters will settle. This deficit translates into 15% of the grand total sediment deficit for the entire South Bay salt pond complex, and 18% of the Cargill proposed sale area (see Chapter 8). There are two approaches to address this constraint for restoring tidal marsh:

- **Mudflat-Sustainable Natural Sedimentation Approach.** In this approach, pond elevations rise through accretion of naturally deposited sediments. These sediments derive largely from the shallow South Bay mudflats, which are externally replenished at a slow rate relative to the sediment demand of accreting salt ponds. Maintaining topographic equilibrium on the mudflats (i.e., preserving the mudflats as critical habitat) mandates a slow opening of these ponds. Their 16.2 MCY deficit represents 27 years of external sediment input to the South Bay (see Chapter 8). During this time flood control levees will require regular maintenance (see below). Were these ponds opened too rapidly, it is reasonable to assume some drop in mudflat elevation would occur for a number of years, followed by a return to higher elevations with a lot of variability throughout.
- **Dredged Sediment Reuse Approach.** In this approach, sediment dredged from the San Francisco Estuary is placed in the ponds up to some elevation below equilibrium marsh plain elevations (we use 1.5 ft below MHHW). Following sediment placement the ponds would be opened to tidal action at which time natural sedimentation would fill the remaining sediment deficit. Dredged sediment would account for 12.7 MCY (Table 13-3), leaving 3.5 MCY for natural sedimentation to provide the complete sediment deficit. That smaller remaining deficit represents 6 years of external sediment input into the South Bay, a far shorter period for flood control levee maintenance. Tidal action can be restored to ponds sequentially as each reaches its placement capacity.

Using dredged sediment in these ponds may be appropriate to raise pond heights closer to intertidal marsh elevation. Dredged sediment reuse would shorten the time for marsh establishment. Other projects around the Estuary have taught us the lesson that target elevations for dredged sediment are best kept below local MHW (Pond 3 in Union City, Faber Tract in Palo Alto, Muzzi Marsh in Marin, Sonoma Baylands in Sonoma County, and the proposed Hamilton-Bel Marin Keys and Montezuma projects). Filling low allows natural sedimentation to provide the upper layer of the restored marsh. It also optimizes channel formation and plant establishment. These projects have also demonstrated that dredged sediment can be used judiciously to construct high marsh.

Locations and Sizing of Levee Breaches

The goal is to provide unrestricted tidal exchange and, where an antecedent channel network is present, promote its re-establishment. The 1857 map of the area (Figure 13-3) shows that portions of these ponds were shallow mudflat and possibly subtidal channels rather than intertidal marshlands. We drew upon historic conditions to guide the restoration template to the extent possible. We identified breach width from antecedent channel networks and from existing tidal channel sizing models (PWA 1995, Collins 1991). We accounted for the considerably larger initial tidal prism as due to pond subsidence; the tidal prism will decrease over time as the marsh plain elevation builds through natural processes.

Flood Protection

According to Wildlands *et al.* (1999), the upland edges of ponds A2E, A3W, and B2 are not at flood protection heights (see Map 11). We assumed these data are correct and that raising existing internal levees to flood protection heights is needed along this portion of ponds for a total distance of approximately 3,700 feet. The adjacent uplands of Santa Clara County have subsided considerably due to regional groundwater withdrawal, with reported subsidence up to 13 ft in the region (USACE 1988). Once tidal action is restored, these new levees will require regular maintenance until marsh vegetation becomes well established and periodically thereafter. Because these would be comparatively large levees, their construction and maintenance costs per unit distance are expected to be amongst the highest of the entire South Bay salt pond complex. The more rapidly marsh elevations restore, the shorter the maintenance period for these raised levees will be. These ponds are all included in the Cargill proposed sale area.

Existing PG&E Overhead Transmission Line Towers

There are a total of 34 towers in these five ponds. We assumed that in these subsided ponds the concrete footings are of insufficient height and that line sag clearance would be too low for restored tidal elevations. If these assumptions are correct at least in part, then some or all 34 towers would need to be raised and fitted with taller concrete footings.

Interior Levees Dividing Ponds 1 and 2

These levees would not be needed for restoration. Therefore, the levee elevations would be lowered to upland ecotone and gaps constructed to reduce predator access.

Existing Borrow Ditches

These ditches are found alongside interior and exterior levees in all ponds. The concern is that they capture tidal flows when the ponds are restored to tidal marsh. A solution is to construct "cutoff berms" and "training berms" at strategic locations (Orr *et al.* 2001). Cutoff berms are the width of the ditch and are approximately 100 feet in length. The basis for this approach is the recently designed and constructed Cooley Landing Tidal Marsh Restoration Project in Palo Alto. This approach has not been applied previously. It is too soon to determine if it is successful, but it appears reasonable. We have utilized it in this case study.

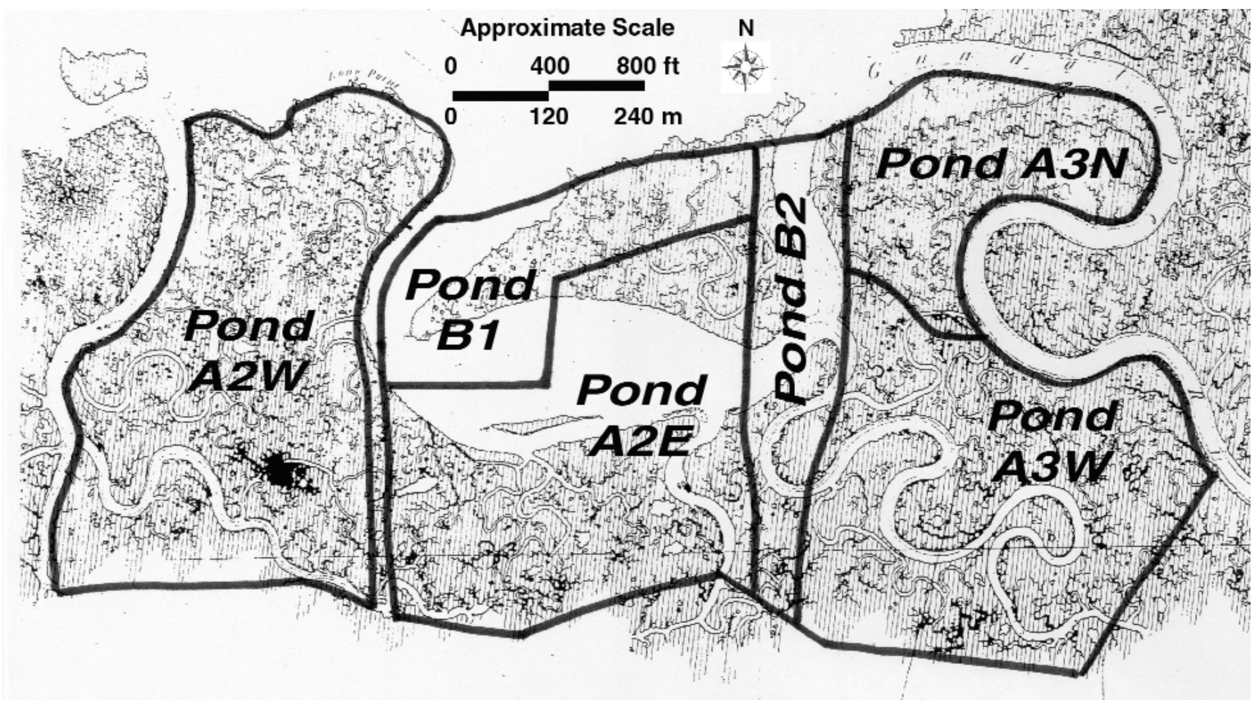
13.3.2 Conceptual Restoration Plan

Several construction elements are included for the low feasibility ponds. The basic design elements are shown in Figure 13-4.

We consider two basic design alternatives:

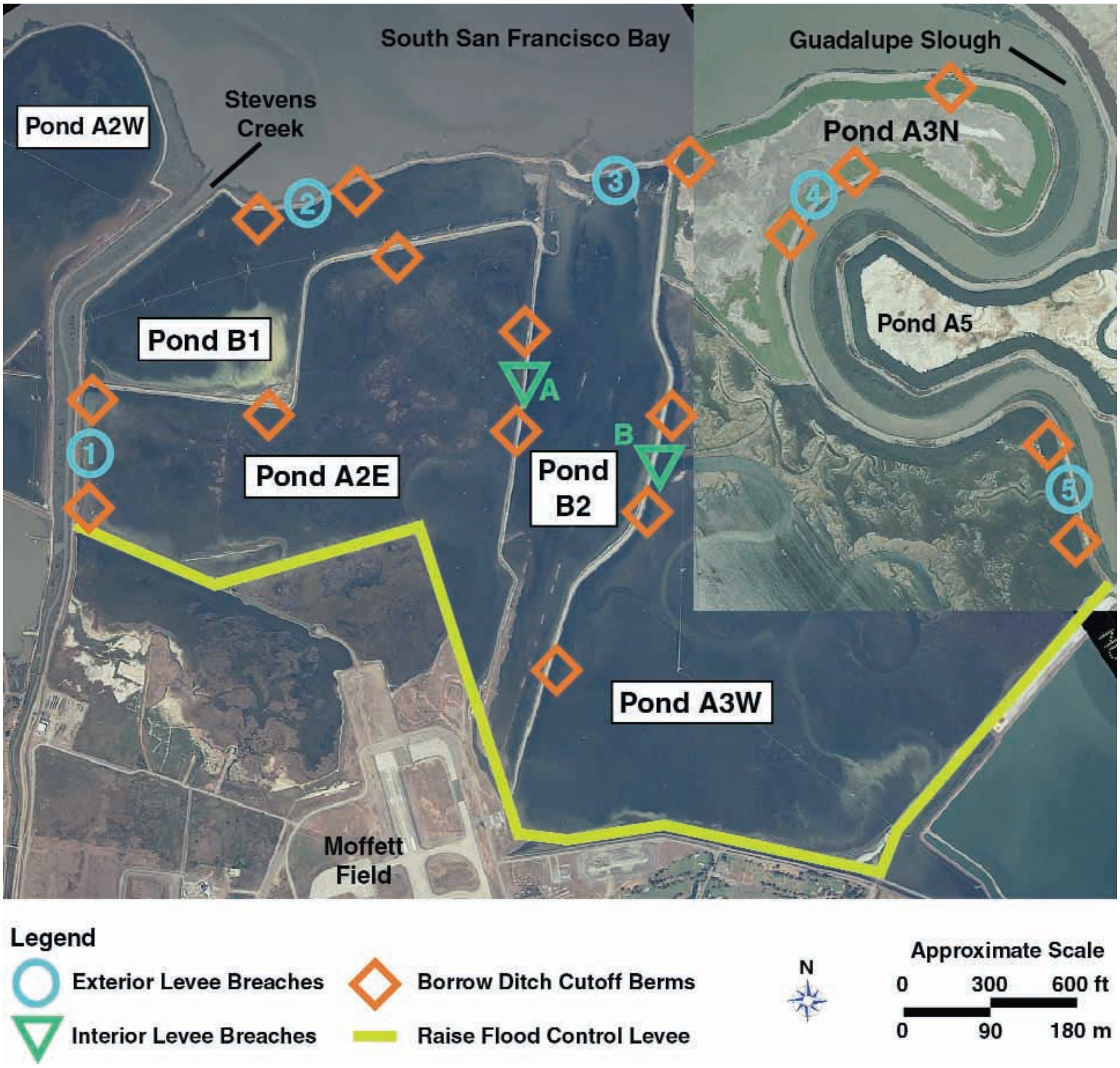
- **Alternative 1: Natural Sedimentation**. This alternative relies on natural sedimentation to raise the ponds back to intertidal marsh elevation. Estimated accumulation thickness ranges from 4.2 to 7.7 feet (Table 13-3).

Figure 13-3. United States Coast and Geodetic Survey 1857 T-Sheet historic conditions map for Alviso Ponds A2E, A3N, A3W, B1, and B2



1 The USCGS base map is not georeferenced.

Figure 13-4. Existing conditions and restoration elements at Alviso Ponds A2E, A3N, A3W, B1, and B2



- **Alternative 2: Dredged Sediment Reuse.** This alternative reuses clean dredged sediment to raise site grades closer to the equilibrium marsh elevation and natural sedimentation to provide the upper marsh layer. Under this alternative, 12.7 MCY of dredged sediment would be placed up to 1.5 ft below local MHHW (Table 13-3).

Exterior Levee Breaches

Exterior levee breaches provide the openings for unrestricted tidal exchange to all ponds. Breaches are located to promote use of the antecedent channel networks present in each pond to the extent possible if the networks are present. Exterior levee breaches are proposed at five locations.

- Breach 1: into Pond A2E on Stevens Creek.
- Breach 2: into Pond B1 on South San Francisco Bay.
- Breach 3: into Pond B2 on South San Francisco Bay.
- Breach 4: into Pond A3N on Guadalupe Slough.
- Breach 5: into Pond A3W on Guadalupe Slough.

Two Interior Levee Breaches

Interior levee breaches would be included to provide additional tidal connection to the interior areas of the pond cluster. Interior breaches have the added benefit of creating "islands" that will reduce predator access to the interior of the restored marsh. Interior levee breaches are proposed at two locations.

- Breach A: west side of Pond B2 into Pond A2E.
- Breach B: east side of Pond B2 into Pond A3W.

Lowering interior levees

Lowering interior levees creates upland ecotone as refuge for tidal marsh species and constructing gaps in these levees reduces predator access. The total length of the levee to be lowered is 7,000 feet. The existing elevation is assumed to be 7 ft NGVD. The target elevation is about 1 ft above local MHHW.

Table 13-4. Rough estimated construction costs for low feasibility restoration case study

Item	Description	Quantity	Units	Unit Price	Cost
ALTERNATIVE 1: NO DREDGED SEDIMENT PLACEMENT					
1	Engineering design	1	LS	250,000	$ 250,000
2	Mobilization and demobilization	1	LS	250,000	250,000
3	Exterior breaches, cut	15,000	CY	20	300,000
4	Interior breaches, cut	4,500	CY	20	90,000
5	Lower interior levee, cut	7,000	CY	10	70,000
6	New flood control levee, fill	15,000	CY	15	225,000
7	Cut-off berms, 17, fill	25,500	CY	20	510,000
8	Maintain flood control levees1	4,000	LF	200	800,000
9	Reinforce overhead PG&E towers	34	LS	100,000	3,400,000
	Subtotal				5,895,000
	20% Contingency				1,179,000
	Total				**$ 7,074,000**
ALTERNATIVE 2: USE DREDGED SEDIMENT TO RAISE GRADES[2]					
1	Engineering design	1	LS	500,000	$ 500,000
2	Mobilization and demobilization	1	LS	250,000	250,000
3	Exterior breaches, cut	15,000	CY	20	300,000
4	Interior breaches, cut	4,500	CY	20	90,000
5	Lower interior levee, cut	7,000	CY	10	70,000
6	New flood control levee	15,000	CY	15	225,000
7	Cut-off berms, 17, fill	25,500	CY	20	510,000
8	Maintain flood control levees1	4,000	LF	200	800,000
9	Reinforce overhead PG&E	34	LS	100,000	3,400,000
	Subtotal Before Dredged Sediment Costs				**$ 6,145,000**
10A	Incremental dredged sediment reuse, low	12,500,000	CY	0	0
	Subtotal Alternative 2A				6,145,000
	20% Contingency				1,229,000
	Total, Alternative 2A				**$ 7,374,000**
10B	Incremental dredged sediment reuse, high	12,500,000	CY	10	125,000,000
	Subtotal Alternative 2B				131,145,000
	20% Contingency				26,229,000
	Total, Alternative 2B				**$157,374,000**

1 Flood control levee maintenance assumes 20 maintenance events over a 50-year planning horizon, at $10 per linear foot per event.

2 Dredged sediment costs per cubic yard are the incremental costs above that for ocean disposal (see Section 8.4). Alternative 2A uses the low end estimated incremental cost and Alternative 2B uses the high end estimated incremental cost.
LS = lump sum; CY = cubic yard; LF = linear foot; PG&E = Pacific Gas & Electric Company.

Raising Flood Control Levees

The existing levees entire southern boundary of these salt ponds needs to be raised to necessary flood control elevations (Figure 13-4). The total length of levee to be raised is 3,700 feet and we have estimated 15,000 cubic yards of soil would be needed for this effort.

Cutoff Berms

Cutoff berms are intended to block the existing borrow ditches from capturing tidal flows, thus preventing the establishment of a natural tidal channel network. A total of 17 borrow ditch cutoff berms are anticipated (see Figure 13-4).

Dredged Sediment Reuse

The dredged sediment reuse scenario follows that presented in Chapter 8, namely that the ponds would be filled to 1.5 ft below local MHHW. This placement elevation equates to 12.7 MCY (Table 13-3). Dredged sediment offloading, distribution, and placement approaches are described in Chapter 8.

13.3.3 Low Feasibility Restoration Construction Cost Estimate

This estimate considers the major costs to construct each of the two restoration alternatives for the low-feasibility case study: one with and one without dredged sediment reuse. Costs not included are those needed for planning, environmental review and permitting, long-term monitoring, and interim management during restoration planning. The only long-term maintenance costs considered are flood control levee maintenance. Table 13-4 summarizes the estimated construction costs. These costs are $7.1 and $157.4 million, respectively, for each of the two alternatives. For this 1,450-acre restoration, the associated range in construction costs is **$4,900 acre for natural sedimentation and between $5,100 to $110,000 per acre for dredged sediment reuse.** The total restoration costs estimated in Section 12.2 for the Cargill proposed sale area utilize this natural sedimentation value as the "high" cost option.

Chapter 14

Estimated Operations and Maintenance Costs

Chapter 14

Estimated Operations and Maintenance Costs

The South Bay salt pond system functions in its current state only through costly operations and maintenance (O&M) activities that Cargill carries out continuously. These O&M activities include levee maintenance, water management, equipment and structure repair and replacement, and compliance with regulatory requirements. All these activities must continue after public acquisition of the South Bay salt ponds in part or in whole. Though the underlying objectives may change to wildlife management from salt production, the types of activities will remain essentially the same. The Don Edwards San Francisco Bay National Wildlife Refuge (Refuge) should anticipate continuing costs at least equivalent to those currently required for salt production. Inadequate funding of these same types of O&M activities in North Bay salt ponds has complicated restoration efforts and compromised existing and target wildlife management efforts.

In this chapter we develop a cost estimate for the anticipated O&M activities for the South Bay salt ponds. We express the results as a range intended to bracket the uncertainties in making such an estimate. We have based our estimates on data from the North Bay salt pond restoration effort, from the study Cargill commissioned to examine South Bay salt pond restoration (Wildlands et al.1999), and from data about resource management costs at other wildlife Refuges in California.

Operations and maintenance needs for acquired South Bay salt ponds will fall into three distinct categories. First, all acquired ponds will require the full range of O&M activities from acquisition to the initiation of tidal marsh restoration activities. We term this period "initial" O&M. Second, the roughly one-third of acquired ponds that are anticipated to be retained as shallow open water habitat will require the full range of O&M activities in perpetuity. We term this period "permanent" O&M. Finally, the roughly two-thirds of acquired ponds planned for tidal marsh restoration will require the full range of O&M activities until they are opened to tidal action, after which time the main activity required will be levee maintenance that can stop only when marsh vegetation is well established to provide levee erosion protection. We term this final category "interim" O&M.

Section 14.1 identifies the costs associated with each of the specific O&M activities that will be required. Section 14.2 examines comparable budgets from other wildlife refuges in California. Section 14.3 compiles the information from the two previous sections into our preliminary South Bay operations and maintenance budget estimate. We then use these final costs to develop a total acquisition and restoration cost estimate for the 16,000-acre portion of the South Bay salt ponds that Cargill offered for public acquisition in 2000 and about which acquisition negotiations are ongoing.

14.1 Identifying Costs for Operation and Maintenance Items

Several sources have been used to identify the primary O&M needs and to develop the accompanying costs. Much of this information is based upon the California Department of Fish and Game (CDFG) experience in restoring the former North Bay salt ponds. These ponds are very similar to the South Bay ponds, as they share a common history of salt production and ownership. We have also considered the examples of the Refuge and comparable projects discussed by Wildlands et al. (1999) as well as other outside sources (Peer Consultants, personal communication; Brown and Caldwell 1999). Many of the same O&M needs are anticipated in the South Bay. We discuss, identify and estimate O&M costs for the South Bay in the context of all of these information sources, focusing on the primary O&M items:

- Water management (Section 14.1.1)
- Levee maintenance (Section 14.1.2)
- Equipment and water control structure maintenance (Section 14.1.3)
- Bittern handling (Section 14.1.4)
- Regulatory requirements (Section 14.1.5)
- Contingency allowance (Section 14.1.6)

14.1.1 Water Management

Water management is the highest O&M cost in the Napa Salt Ponds, and it is badly under-funded (Huffman, personal communication; Chapter 7). Historically, Cargill spent over $300,000 annually for moving water through the 7,000 acres of salt ponds in the North Bay, $43 per acre. CDFG currently budgets only $60,000 annually to the these ponds for all purposes and most of these funds are used for moving water. If the entire $60,000 is used for moving water, the current water management budget is only about 20% of the historic Cargill water management budget. The resulting water management is inadequate and has degraded the ponds' ecological value as well as increased the costs of specific water management tasks as detailed in Chapter 7.

Several factors will affect water management costs in North Bay ponds as well as the South Bay salt ponds if restored. Current energy problems in California are expected to increase water management costs. Cargill planned during 2001 to increase its water management budget for retained ponds by 50 to 100% (Huffman, personal communication). Since the summer of 2001, energy prices have largely stabilized, although California has been stuck with $43 billion in long-term energy contracts negotiated at the height of the energy crisis (San Jose Mercury News 2002). Projections by the California Energy Commission for the next 10 years predict that prices for the most part will be relatively stable

(CEC 2002). Thus, we conclude that energy cost increases will be lower than those predicted by Cargill and instead estimate that energy prices will be 20% higher than in the past. This value accounts for higher prices today than those before the energy crisis, considers California's long-term energy contracts, and considers that the spot market and regulatory decisions by FERC, the State Legislature, the Governor and the California Public Utilities Commission could influence future energy pricing (CEC 2002). Future water management costs for the South Bay salt ponds are thus estimated at $52 per acre annually, or an annual total of $1.35 million dollars for the 26,000 acre complex.

Another factor affecting water management costs will be the amount of water needed for pumping on a per acre basis. Pumping volumes will differ between operational scenarios. For instance, during desalination and maintenance of low salinity levels, water management demands for the salt ponds will be much higher than those required by Cargill for salt production. Under salt production, only source water for the brine is introduced into the system and that brine is pumped throughout the system as it becomes more saline. We estimate that Cargill pumps an amount of water into the system at an hydraulic loading rate of approximately 1.9 feet per year, the average evaporation rate predicted for the salt pond complex (Table A-1 in Appendix A). Under desalination and salinity maintenance as described in Chapter 9, water is initially flushed through the ponds to desalinate the ponds and then water is added in sufficient volume to prevent salt from concentrating as a result of evaporation. Salinity discharge limits will ultimately determine the amount of water needed during desalination. To achieve outflow salinity levels near background Bay levels, we estimate a hydraulic loading rate of approximately 20 feet per year, a rate ten times higher than that required for salt production (see Chapter 9). A lower rate, such as 8 feet per year will also desalinate the ponds though outflow salinity levels will be relatively high and may not meet RWQCB requirements. This loading rate is about 4 times higher than that needed for salt production. Decisions regarding acceptable salinity levels and thus hydraulic loading rates will require direction from the RWQCB. In any case, we estimate that 4 to 10 times more water will be required than for salt production and this increase will raise pumping costs considerably.

Two factors will reduce pumping costs. First, brine used for salt production is heavier than bay water due to salinity-driven density changes. Our calculations estimate that for the salt pond complex, brine, on average, is 10% heavier than bay intake water. Because pump horsepower is directly related to weight pumped, bay water should be, on average, 10% cheaper to pump than brine on a volumetric basis. Second, the relative amount of tidal pumping to mechanical pumping may increase as the system is changed from concentrating brine to maintaining low salinity conditions. The relative amount of tidal pumping might increase because of greater flexibility for accepting water both seasonally and spatially, maintaining greater head and more gravitational flow by allowing greater tidal range, and by changing flow paths from their current configuration. There is, however, insufficient information to assess this factor quantitatively.

From all these considerations, we estimate that pumping costs will be much higher than for salt production to maintain low salinity conditions. Factoring in a 20% increase in energy use, a 10% decrease in mass and flows 4 to 10 times greater, we estimate that pumping costs will be 4.3 to 10.8 times higher. Using the $52 per acre pumping cost estimate derived above, we estimate **$220 – $560 per acre annually.** We use this estimate later in calculating total annual O&M costs. This estimate assumes that current infrastructure is used during the desalination process, as it is in the North Bay.

Table 14-1. South Bay levee lengths and funding responsibilities

Type of levee	Description	Length (miles)	Current Funding
External	Levees that are the primary flood control levees on the bayfront. They are maintained to tidal flood protection heights.	80	Cargill
Internal	Levees that divide salt ponds and provide no flood protection. Therefore, they are maintained at lower heights.	76	Cargill
Public	Flood control levees maintained to tidal flood protection heights.	17	Public agencies
Upland unprotected	Most inland levees that separate salt ponds from adjacent land uses. Flood protection depends entirely upon external or publicly maintained levees located elsewhere.	21	Cargill
No data	Levees located around Newark #2 plant. No data to categorize these levees	26	Cargill
Total levees requiring ongoing maintenance		**220**	
High Ground	An area where existing features adjacent to the salt ponds are above tidal flooding heights.	13[1]	Cargill

1 High ground boundaries to salt ponds require no levee maintenance and thus their distances are not included as levee.

Sources: Wildlands et al. *(1999); See Map 11 and Table 5-3 in Chapter 5.*

14.1.2 Levee Maintenance

North Bay levees are typically 7 to 9 feet above mean sea level, with slopes ranging from 2:1 to 3:1. These levees are effective for salt pond operation but too steep to provide desired ecological functions (see Chapter 2). Ultimately for the final restoration where levees are required, less steep slopes are recommended to provide for both flood control and ecological function. In the interim, levees and their associated costs should be similar to costs for salt pond operation.

Currently, CDFG spends about $8 per foot per year for maintenance on the levees it can repair (Huffman, Wyckoff, personal communications). However, CDFG cannot keep up with levee repair needs in the North Bay salt ponds for two main reasons: equipment and scheduling limitations. CDFG uses drag lines and excavators for levee repair as opposed to a floating dredge as used by Cargill in the South Bay. Erosion attacks the levees on the inside and outside. Without a floating dredge, many levees are inaccessible for repair. Scheduling limitations also restrict repair activities. Levees cannot be repaired during the rainy season (approximately December through April) nor during periods when it can endanger clapper rail habitat (February through September) (Huffman, personal communication). Thus, repair is essentially restricted to October and November with equipment only able to access certain levee areas.

When levee access is restricted, levee repairs by CDFG are estimated at $10 per foot (Huffman, personal communication). This levee repair cost is similar to Cargill's in the South Bay. Cargill maintains their levees by topping them with sediment excavated from levee-parallel borrow ditches inside the salt pond (Chapter 3); disking and grading the levees approximately every two to three years after topping; and grading the levees and constructing chokers prior to the next round of maintenance (BCDC 1995). These estimates are on the low end of those presented by Wildlands et al.(1999) of $10 to $27 per foot annually. Wildlands et al. (1999) based its estimate on total levee length. In the South Bay, there are approximately 220 miles of levees – external, internal, upland unprotected, and publicly maintained (Map 11 and Table 14-1). Cargill maintains approximately 10 linear miles of its levees each year (WRA 1994). Thus, we estimate that Cargill spends approximately $530,000 to $1.4 million annually on levee maintenance. Using the simplifying assumption that the levee distance to pond area ratio is fairly uniform throughout the South Bay salt pond complex (which is a questionable assumption), these annual costs translate into **$20 to $54 per acre.** We use this estimate later in calculating total annual O&M costs.

14.1.3 Equipment and Water Control Structure Maintenance

This category includes pumps, weirs, piping, siphons, gates, and fish screens, and accompanying electrical and control systems used to move water through the pond complex. Much of the equipment in the North Bay is 50 years old and at the end of its design life (Huffman, personal communication). Although salt production continues in the South Bay, the equipment used there is not much newer. A 30-year design life is typical for major equipment in water treatment systems (Peer Consultants, personal communication; Brown and Caldwell 1999). However, 20 years is the design life for equipment installed in the North Bay former salt ponds (Huffman, personal communication). Future South Bay salt pond equipment costs are expected to reflect the increased maintenance and associated replacement costs for equipment near the end of its design life.

Pumps

The typical reconditioning cost for a 100-horse power (HP) pump is $25,000 (Huffman, personal communication). New pumps of similar capacity are estimated to cost $30,000 to $35,000 each. Pump reconditioning is expected to be required every 5 to 10 years, so each pump of similar capacity requires an annual O&M cost of $2,500 to $7,000 depending upon servicing frequency and pump design.

The South Bay salt pond complex has about 30 pumps that. From Cargill (1999) maintenance information, we estimate that approximately 4 pumps are for intake, 20 are for pumping hypersaline brine internally through the system, and 6 are for pumping bittern, pickle, and other services (Table 14-2). In the North Bay, one 75 HP and one 100 HP provide intake water to the 7,000 acres of former salt production ponds, averaging one intake pump per 3,500 acres. The 26,000 acres of South Bay salt production ponds contain approximately 1 intake pump for every 6,500 acres, so we have assumed that these pumps are of the larger size used in the North Bay (approximately 100 HP). We also assume that the pumps for pushing brine internally through the system are of similar size because brine is pumped relatively frequently during the salt production to move it through the process and it is heavier than Bay water. The remaining pumps (e.g., pickle, bittern, drain water) are estimated at approximately half the capacity and horsepower of the inflow pumps because the volumes of liquid pumped are much less. For all pumps considered, we expect an average pump size to be between 75 and 100 HP.

Our estimate of the pump O&M costs in the South Bay is based on North Bay information. We estimate an annual O&M budget for each South Bay pump to be $2,500 – 7,500. For the 30 pumps, this comes to $75,000 to $225,000 annually for pump O&M. Standardizing these costs on an acreage basis yields annual pump O&M costs of $3 to $9 per acre.

Table 14-2. Cargill South Bay pumping stations

Function	Estimated Number of Pumps	Estimated Size of Pumps
Intake water[1]	4	~100 HP
Move hypersaline brine[2]	20	~75 – 100 HP
Move bittern and Pickle[3]	5	~25-50 HP
Other[3]	1	~25-50 HP

1 *We assumed the capacity of inflow pumps is similar to that in the North Bay. The North Bay system had a similar number of inflow pumps per acre of salt pond.*

2 *Internal pumps are required to pump the brine throughout the system.*

3 *Bittern, pickle, and other pumps move much smaller but heavier volumes of liquid. We estimate these pumps need to be half the size of inflow and hypersaline brine pumps.*

Water Control Structures

Other water control structures include gates, water boxes, fish screens, siphons, pipes, and trash racks. For pipe and gate repair at an intake station, Huffman (personal communication) estimated the cost of a 72-inch replacement gate to be $75,000, and its accompanying 70-foot long 84-inch diameter pipe at over $100,000, bringing total replacement costs, including labor, close to $200,000. In the North Bay, fish screens are being considered at intake locations to minimize the risks of "taking" endangered fish species. Fish screens are expensive as they are constructed with stainless steel mesh and are self-cleaning. Thus they increase replacement costs by two to three times. Until recently, there were four intake gates in the South Bay salt ponds. Replacement costs for these gates are expected to be similar to those reported for the North Bay. Huffman (personal communication) assumed a 20-year design life because the system is very corrosive. Whether fish screens will be necessary in the South Bay is not determined; far fewer special status fish species utilize the South Bay relative to the North Bay.

The annual O&M costs of routine maintenance for siphons, pipes, trash racks, and water boxes is difficult to estimate. Thirty to 50 repairs to Cargill pipes and gates are made annually (Cargill 2000b). Cargill's costs probably include excavation, recompaction, labor (e.g., foremen, equipment operators, and electricians), and associated regulatory compliance work (Cargill 2000b, Wildlands et al. 1999). Without further information from Cargill and given the magnitude of the repairs shown in the annual maintenance reports (Cargill 2000b), we assume these costs as twice those associated with pump repairs, or $150,000 to $450,000 annually. Standardizing these costs on an acreage basis yields annual pump O&M costs of $6 to $17 per acre.

14.1.4 Bittern Management

Operating and maintenance costs associated with bittern include the prevention of discharge to open waters, pumping heavy bittern, and replacing corroded equipment. If Cargill does commit to handling and relocating the bittern from transferred properties (Moore, personal communications; Barroll, personal communications), then we assume all O&M costs associated with bittern will be borne by Cargill.

14.1.5 Endangered Species and Regulatory Requirements

Protecting endangered species and their habitat can double O&M costs (Wyckoff, personal communication). Much of this cost is indirectly associated with restricting and limiting activities or equipment on necessary O&M activities (e.g., levee repair, water management). There are also direct costs such as permitting. Permits from the U.S. Army Corps of Engineers are required for each project, and each permit costs about $2,000 (Wyckoff, personal communication). Every O&M action that is taken once a system is running is a considered a separate project. Some of these regulatory costs may be negotiated and reduced by grouping activities together when applying for permits. In the Refuge, hands-on management of salt production costs $87 per acre annually; this cost includes $29 per acre for permitting oversight (Wildlands et al.1999). Cargill spends approximately $58 per acre annually (Wildlands et al.1999).

14.1.6 Contingency Allowance

Wildlands (1999) used a 15% contingency allowance in predicting capital costs, but no contingency when estimating O&M costs. However, for all restoration work in the salt ponds, conditions atypical of upland and urban work will be encountered. Atypical constraints such as weather, tides, endangered species requirements, permits, and difficult access will limit the rate at which work progresses. The U.S. Army Corps of Engineers typically underestimates O&M work in the North Bay, so CDFG recommends a contingency of 20% or more (Wyckoff, personal communication). For this report, we have used a 20% contingency on levee maintenance, equipment repairs and monitoring. We have not used a contingency on water management costs or permitting.

14.2 Comparable Projects

For comparable projects, we have considered the former salt ponds in the North Bay, the Refuge, and other projects presented in Wildlands et al. (1999). Wildlands also presents data from 17 state and federal wetland-wildlife areas within California.

14.2.1 Budget Needs in the North Bay

The primary budget costs in the North Bay are for water management and levee maintenance. Though the current budget for the 7,000 acres of former salt ponds in the North Bay is $60,000, CDFG estimates that proper water management of that system alone requires approximately $500,000 (Huffman, personal communication). This estimate is based upon Cargill's budget for water management when the ponds were used for salt production (Section 14.1.1) and the estimated increase due to higher current and future electrical costs. This $500,000 budget would provide the funds necessary to keep the ponds wet and eliminate the ecosystem degradation that is occurring because of the currently under-funded water management needs. Under a desalination regime in which low salinity levels are achieved and maintained, CDFG estimates water management costs could increase up to $1 million dollars annually (Huffman, personal communication). Given the condition

Table 14-3. Operations and maintenance budget for 7,000 acres of North Bay salt ponds

	Estimated minimum cost to keep ponds wet ($)		Desired budget for desalination ($)	
Description	**Per year**	**Per acre per year**	**Per year**	**Per acre per year**
Water Management	500,000	71	1,000,000	143
Equipment and Levee Maintenance	60,000	8.6	1,000,000	143
Total	**560,000**	**80**	**2,000,000**	**286**

Table 14-4. Annual operations and maintenance budgets for selected state and federal refuges in California

Wildlife Area	Acreage	Cost per acre ($)
Tehama	46,895	4.86
Butte Valley	13,392	19.52
Ash Creek	13,897	20.71
Oroville/Spencerville	11,871	31.13
Grizzly Island	12,491	50.69
Upper Butte Basin	9,208	56.44
Shasta Valley	4,657	56.93
San Francisco NWR	35,653	58.38
Mendota	11,802	58.73
Honey Lake	7,366	59.57
North Grasslands	6,335	63.66
Sacramento NWR	31,000	80.65
Gray Lodge	8,341	97.80
Los Banos	6,130	114.77
Imperial	5,883	147.89
Tijuana NWR	8,138	151.76
Tijuana NWR (DPR)	900	522.22
Median		**58.73**
Upper Quartile (75%)		**50.69**
Lower Quartile (25%)		**97.80**

of the levees and the age of the equipment, annual O&M costs beyond those required for water management could be as high as an additional $1 million dollars. Table 14-3 shows two North Bay budgets based upon our discussions with the CDFG: a minimum budget to keep ponds wet and predicted budget needs to desalinate the ponds. The budgets range from $80 - $286 per acre. The higher amount would provide sufficient water to desalinate the system and maintain low salinity levels; repair old equipment; and address deteriorating levees. The budget does not include any monitoring costs.

14.2.2 Refuge Budget

It costs approximately $87 per acre annually to manage the Refuge. About one-third of this cost is devoted to compliance with permitting requirements and regulations. During a period of interim management leading to restoration, higher water flows would be required to desalinate ponds and maintain lower salinities (Chapter 9), so the attendant cost would be substantially higher.

14.2.3 State and Federal Wetland and Wildlife Refuges

Wildlands *et al.* (1999) has presented a list of O&M costs for comparable projects. The annual median cost is $58 per acre. The range is from a lower quartile of $51 per acre annually to an upper quartile of $98 per acre annually.

14.3 A Preliminary South Bay Operations and Maintenance Budget

Our estimate does not differentiate between costs to Cargill and costs to the Refuge, except for bittern. Based upon information in Sections 14.1 and 14.2, we have developed a cost estimate for interim management of the 26,000-acre South Bay salt ponds based upon certain assumptions:

- Sufficient water is provided to desalinate the ponds and maintain acceptable outflow salinity levels.
- Water is provided for desalination based upon current infrastructure of the South Bay salt ponds, as in the North Bay. Alternative water flows that take greater advantage of tidal flows should reduce water management costs.
- A 20% contingency is applied to selected maintenance activities to account for the atypical construction and operating environments associated with the salt ponds. The contingency does not apply to water management or regulatory issues.
- Ten miles of levees are maintained annually. While there are different levee types, the range of costs is probably sufficient to meet O&M requirements for all levee types.
- Pumps in the South Bay are equivalent to pumps in the North Bay, with reconditioning required every 5 to 10 years.
- Cost of maintaining or replacing remaining water control structures is twice that for pumps due to the costs for excavation equipment and labor.
- Bittern costs are fully covered by Cargill.
- An additional $29 per acre is added for meeting regulatory requirements, based on Wildlands *et al.* (1999).

Results

Based upon these assumptions and the information presented earlier, we estimate an annual O&M budget between $7.4 and $17.8 million dollars for the entire 26,000 acre South Bay salt pond complex. When standardized by acres, the estimated O&M costs are $284 to $686 per acre annually (Table 14-5). These O&M costs apply to the entire salt pond complex at the outset during restoration planning and design, which we assume lasts five years. After that period, these same O&M costs (adjusted for future inflation) apply in perpetuity to the one-third of the total complex retained as shallow open water habitats. For the two-thirds restored to tidal marsh, these costs would phase out over time as tidal action is returned to each pond, which we assumes happens gradually to avoid scouring sediments from the South Bay mudflats (see Chapter 8). As each pond is restored to the tides, its O&M needs drop to levee maintenance and associated regulatory costs only, which continues until marsh vegetation is well established. We assume that all other O&M categories no longer apply after restoring tidal action.

Table 14-5. Estimated operations and maintenance costs for South Bay salt ponds

	Unit Cost ($)		Unit		Minimum Cost ($)		Maximum Cost ($)	
Item	**Min**	**Max**	**Type**	**Amount**	**Total**	**Per Acre**	**Total**	**Per Acre**
Water Management	220	560	acre	26,000	5,720,000	220	14,560,000	560
Levee Maintenance	10	27	LF1	53,000	530,000	20.4	1,431,000	55.0
Equipment and Water Control Structures								
Pumps	75,000	225,000	yr	1	75,000	2.9	225,000	8.7
Other[2]	150,000	450,000	yr	1	150,000	5.8	450,000	17.3
Bittern Management[3]	NA	NA	NA	NA	NA		NA	
Endangered Species and Regulatory Requirements	29	29	acre	26,000	754,000	29.0	754,000	29.0
Subtotal					7,229,000	278	17,420,000	670
Contingency[4]	20	20	%		151,000	5.8	421,200	16.2
Total[5]					**7,380,000**	**284**	**17,841,200**	**686**

1 Levee maintenance shown as cost per linear foot maintained; total based on 10-mile annual estimate (WRA 1994).

2 Gates, water boxes, fish screens, siphons, pipes, and trash racks.

3 Cargill assumed to bear all costs associated with bittern management.

4 Contingency applies to levee maintenance, equipment repairs, and monitoring. Does not apply to water management or permitting.

5 Total per-acre cost ranges calculated here are used in Chapter 12 for overall salt pond restoration cost estimates.

Discussion

The most comparable site for estimating O&M costs is the North Bay salt ponds. CDFG estimates that $286 per acre is needed annually during the interim restoration period of the North Bay salt ponds (Table 14-3).

Thus, our lower end estimate for the South Bay salt ponds is generally in line with North Bay estimates when equivalent tasks are considered. We present a cost range, and our higher estimate is probably within a reasonable uncertainty. For reasons described above, we speculate that achieving O&M goals in the South Bay salt ponds will require a greater effort than that for CDFG's North Bay salt ponds. Until the flow regime of the system can be changed greatly, we believe the South Bay O&M estimate represents a credible effort to meets goals of preventing a decrease in ecological function in the system and provide sufficient resources to desalinate the system in the short term and maintain low salinity levels over the long term.

This estimate is much higher than current Refuge costs or those of projects cited by Wildlands et al. (1999) as comparable. These "comparable" projects are likely not truly comparable. None of those examples require the high costs of desalination and maintenance of low salinity waters. We estimate those water management costs alone to be $220 - $560 per acre annually, or more than 75% of total O&M costs. Subtracting out this important and substantial item would reduce O&M costs to $64 - $126 per acre annually, which is more representative of O&M costs for the refuges listed in Table 14-4.

Conclusions

This estimate of operations and maintenance costs highlights three important considerations. First, it identifies the importance of creating a comprehensive budget for long-term restoration of the salt ponds that accounts for interim and in-perpetuity management. These costs are substantial; they range from $284 to $686 per acre per year, or from $7.4 to $17.8 million annually for the entire 26,000-acre South Bay salt pond complex and $4.5 to $11 million annually for the 16,000-acre Cargill proposed sale area (Table 14-5). (In Chapter 12 we combine these results with the other components of total restoration costs to calculate the full cost for the Cargill proposed sale area.) Results from the North Bay salt pond restoration show that inadequate funding for O&M purposes can lead to deteriorated ecosystem health, create more obstacles to restoration, and delay restoration progress, thus incurring even more costs via extended maintenance needs. The South Bay has the added element of substantial flood protection levees being part of the pond complex. Were those levees to fail due to under-funded maintenance needs, substantial portions of the South Bay that lie below sea level could be flooded (see Chapter 5). For all these reasons, it is important that the current acquisition negotiations anticipate these O&M costs and incorporate financial mechanisms that ensure the Refuge receives the necessary budget in perpetuity.

Second, this O&M cost estimate offers insight into ways in which overall salt pond restoration costs can be minimized. We know that the very high cost of water management comprises more than 75% of all O&M costs (Table 14-5) and that total O&M costs make up about 40% to 60% of the total restoration costs (Table 12-1 in Chapter 12). Consequently, proactively managing the duration and spatial extent for which water management will need to be conducted will have a significant influence on total costs. Water management needs remain in perpetuity for all ponds not being restored to tidal marsh and are not needed for any pond restored to tidal marsh. Therefore, the total restoration costs will be affected primarily by how quickly ponds can be restored to tidal marsh and secondarily by selection of specific ponds for restoration versus retention as shallow open water habitats and total area restored versus retained. The massive sediment deficit that the South Bay salt ponds represent (Chapter 5) combined with the need to avoid scouring South Bay mudflats (Chapter 8) fundamentally constrains the rate of tidal marsh restoration and thus elimination of water management needs. Using dredged sediment to make up a portion of this sediment deficit is one strategy that would reduce duration of interim O&M costs. Adaptive management might also prove useful in that monitoring mudflat conditions closely could yield improved understanding of the sediment sink—mudflat scour relationship which could be used for subsequent restoration planning.

Finally, these O&M cost estimates inform our policy decisions regarding relative amounts of ponds restored to tidal marsh versus retained as managed shallow open water habitats. The Goals Project (1999) recommended a roughly two-thirds/one-third split and the ecological basis for this recommend is clear (Chapter 4). The estimated O&M costs provide a price tag for achieving that ecological goal.

Part V.
Conclusions

Chapter 15.
Conclusions and Recommendations

Chapter 15.

Conclusions and Recommendations

The Cargill Salt Corporation produces about 1 million tons of common salt annually from its 26,190-acre South San Francisco Bay salt pond complex. Cargill owns 14,760 acres (56%) of these salt ponds. The Don Edwards San Francisco Bay National Wildlife Refuge owns the remaining 11,430 acres (44%), which it acquired in the 1970s (see Map 2). As part of that sale, Cargill (then Leslie Salt) retained the mineral rights for salt production on all these lands.

Nearly the entire South Bay salt pond complex (97% total area) consists of former tidal marshlands diked for decades. Only about 670 acres (3%), representing about three quarters of the Newark crystallizer ponds (see Map 5), were built outside the tidal marshlands on the adjacent grassland/vernal pool complexes. The historical condition affects the extent of current federal regulatory jurisdiction under the Clean Water Act and Rivers and Harbors Act. Jurisdiction, in turn, can affect the property value of the salt ponds through its restrictions on development and thus acquisition negotiations.

A long-established and worthy goal of the regional resource management community has been to acquire the entire South Bay salt pond complex and restore it to its pre-existing tidal marsh condition. Two actions have taken place in the past few years that may bring this goal to fruition and which serve as the impetus for this Feasibility Analysis. First, the San Francisco International Airport has been evaluating salt pond restoration (in part or in whole) as mitigation for its proposed runway extension project. Second, in 2000 Cargill formally offered to sell about 16,000 acres plus 600 acres of South Bay tidelands and another 1,400 acres along the Napa River to the state and federal governments for $300 million. Those 16,000 acres include 12,000 acres Cargill owns and mineral rights on 4,000 acres the Refuge owns. Negotiations have been ongoing since 2000, and a smaller deal for $100 million representing 13,000 to 15,000 acres may soon be reached that may or may not involve SFO mitigation funds.

In negotiating with Cargill and other entities, resource managers will need to understand not only the short-term goals of acquiring property but also the long-term goal of sustainable restoration and management. Restoration, especially along the scale of the South Bay salt ponds, is a process and not an event. The complexity of this process crosses many scales. Most basically, each restoration site must undergo a number of changes to transform from the current salt pond condition to the ultimate goal for that site whether it be tidal marsh, ponds, pannes or some combination. Some of the important issues and challenges facing resource managers and planners that will affect the rate at which salt ponds can be restored to tidal marsh include: proximity to colonizing plants and animals, initial site elevations creating sediment deficits, sediment supply and dredged sediment availability, bittern and hypersaline brine removal and pond desalination, restoration and ongoing operations and maintenance costs, containing invasive species, protecting existing biological resources, and decreasing survival pressures on the many special status species that utilize tidal marsh and salt ponds. These issues have implications on a broad spatial scale and a long temporal scale, one of the most significant of which is resolving the sediment deficit with scouring ecologically important South Bay mudflats. Restoration does not mean that today it is a salt pond and the day after breaching a levee we have a vegetated, natural marsh.

This Feasibility Analysis examined the suite of issues relevant to restoring tidal marsh on the entire 26,000-acre South Bay salt pond complex as well as the smaller 16,000-acre Cargill proposed sale area. The analysis integrates all the information obtained into a pond-by-pond restoration feasibility determination and a set of overall recommendations. This conclusion chapter summarizes the seven key conclusions that we believe affect the acquisition and restoration planning most strongly (Section 15.1) and it describes a variety of other pertinent considerations (Section 15.2).

15.1 Seven Key Conclusions Summarized

From all the material we evaluated and people we talked with in preparing this Feasibility Analysis, we have identified seven key conclusions that we believe are the most salient to negotiating a purchase and planning the restoration of all or a portion of the South Bay salt pond complex. Although we support acquisition and restoration fully, addressing the challenges summarized in these seven key conclusions will require careful planning and thoughtful action to achieve the desired environmental and ecological benefits in a cost effective manner. The important message from these analyses is that a long-term commitment will be required to realize the benefits of salt pond purchase and restoration.

15.1.1 Mix Tidal Marsh Restoration and Shallow Open Water Management

Promoting recovery of federally listed species and species of concern should be a primary consideration in restoration planning and implementation. To accommodate conflicting ecological requirement between many of these species, an overall restoration plan should include about one-third of the salt ponds retained as managed shallow open water areas and two-thirds restored to tidal marsh. Tidal marsh represents the historical condition for nearly all the salt ponds and their loss is directly responsible for declines in numerous plant, fish and wildlife species around which a broad consensus exists for their recovery. Shallow open water, historically less common in the South Bay and currently provided almost entirely by the salt ponds, supports a thriving bird community around which a broad consensus also exists for its protection. Several threatened and endangered species depend on and/or utilize both ecosystem types. Reconciling these competing goals translates into retaining about one-third of the South Bay salt ponds as managed shallow open water habitats and restoring the remainder to tidal marsh. This approach is consistent with recommendations originally put forth by the Goals Project as well as goals to promote recovery of special status species as stated in the two draft U.S. Fish and Wildlife recovery plans applicable to the South Bay (Western Snowy Plover and Tidal Marsh Ecosystems). How these goals are accomplished in the context of ongoing Cargill operations presents a complex challenge for restoration planners. Though based clearly in conservation needs, permanently maintaining one-third of the salt ponds as shallow open water habitats will require a long-term O&M funding commitment that would not be necessary were all ponds restored to tidal marsh. Thus, the resource management community must understand and accept the permanent costs associated with meeting its conservation goals as well as the consequences of failing to meet those funding needs (see Key Conclusion #4 in Section 15.1.4).

15.1.2 Resolve Sediment Deficit with Phased Restoration and/or Dredged Sediment Reuse

A very large sediment deficit exists for restoring tidal marsh elevations on subsided salt ponds that will require restoration phasing over many decades and/or dredged sediment reuse in order to protect South Bay mudflats. Subsidence is a common feature of San Francisco Estuary diked baylands. Most of the salt ponds from Mountain View to San Jose (the "Alviso Plant") have subsided from 6 to 8 feet below marsh height due to groundwater pumping ongoing through the 1960s. Surrounding uplands in the South Bay have subsided even more, up to 13 feet in some places. Most of the remaining salt ponds have subsided from 1 to 4 feet below marsh height.

We estimate this subsidence to represent a sediment deficit of about 108 million cubic yards (MCY) to restore tidal marsh elevations for the entire 26,000-acre South Bay salt pond complex and about 89 MCY for the 16,000-acre Cargill proposed sale area. The actual deficit will be less according to how many and which ponds are retained as managed shallow open water (or retained for salt production). Meeting this sediment deficit *without scouring the ecologically important South Bay mudflats* will require one of two approaches: (1) phase restoration over many decades to match sediment demand with the rate at which sediment naturally enters the South Bay (estimated by others at about 0.9 MCY per year), or (2) partially fill ponds with clean dredged sediment. We estimate the first option would require about 120 years to restore two-thirds of the entire South Bay salt pond complex and 99 years for two-thirds of the smaller Cargill proposed sale area. Dredged sediment reuse can reduce these time frames to as short as 56 years and 39 years for the full complex and Cargill proposed sale area, respectively, depending on the rate of dredged sediment availability. These time periods could be reduced further if greater quantities of dredged sediment could be made available more rapidly. Dredged sediment, however, has economic consequences that must be considered; these are discussed next.

15.1.3 Dredged Sediment Reuse May Be Desirable and Economically Competitive

Our cost estimate ranges for "natural sedimentation" and "dredged sediment reuse" restoration approaches overlap considerably, suggesting that dredged sediment may be economically competitive. Further, dredged sediment reuse can speed the overall period of restoration, thereby achieving ecological goals decades sooner. A fundamental aspect of salt pond restoration is that the sediment supply to offset the sediment deficit (see Section 15.1.2 above) cannot, as a matter of natural resource protection, come at the expense of South Bay mudflats. Our estimates indicate that the "mudflat-sustainable" natural sedimentation restoration approach will require on the order of 120 years to restore two-thirds of the total salt pond complex to tidal marsh and 100 years for two-thirds of the smaller Cargill proposed sale area ponds. The dredged sediment reuse options we evaluated reduced that time frame to 56-72 years and 39-51 years for the total salt pond complex and the Cargill proposed sale area, respectively. The range in years reflects different amounts of dredged sediment reuse that could be considered. These time periods could be shortened further if suitable dredged sediment were available more rapidly than we assumed for our analyses. Because total restoration costs include interim and ongoing O&M costs, more rapid restoration shortens the duration of the more costly interim O&M and thus reduces costs further. Additionally, accelerated restoration efforts, if well planned, will also achieve the environmental and ecological benefits sooner. These benefits have not been estimated though their consideration is critical in developing any accurate cost-benefit analyses that considers using dredged sediment.

Our rough cost estimate for the "mudflat-sustainable" natural sedimentation approach consists entirely of interim and permanent O&M and comes in at $621 million to $1.49 billion for restoring two-thirds of the total South Bay salt pond complex (or about 18,000 acres). For the 16,000-acre Cargill proposed sale area, those costs span a range of $315 to $764 million. For dredged sediment reuse, we considered three scenarios reflecting variable quantities of dredged sediment. Though dredged sediment reuse has considerable up-front costs, it gains a vital economic benefit – it reduces the time period over which costly interim O&M is necessary. To calculate these costs, we used a suite of assumptions including that restoration sponsors would be responsible only for the incremental costs of dredged sediment reuse not normally paid for by dredging projects. Dredged sediment reuse cost estimates range from $457 to $1.48 billion for the full salt pond complex and $222 to $899 million for the Cargill proposed sale area. In other words, dredged sediment has the potential to be a very effective and economically competitive approach to restoring the South Bay salt ponds. In practice, the single greatest issue is dredged sediment availability, as competition now exists for reusing dredged sediment for wetland restoration (e.g., Montezuma and Hamilton-Bel Marin Keys).

15.1.4 Account for All the Bittern and Hypersaline Brine in the Short and Long Term

The current acquisition negotiations need to include requirement for full bittern and hypersaline brine removal from the Redwood City ponds included in the Cargill proposed sale area and a formulation of a binding plan for Cargill's long-term disposition of bittern and

hypersaline brines stored in Newark. Bittern is the hypersaline byproduct of solar salt production. Bittern occurs in both a liquid and solid state and consists of naturally occurring minerals in bay water minus the commercially harvested common salt and some other salts that solidify within the pond system as part of evaporation (mainly gypsum). Bittern is thus distinguished from bay water by a salinity level over ten times higher and by its ionic imbalance, both of which make it toxic to aquatic organisms. Hypersaline brines are the concentrated bay waters that arise from salt production prior to salt harvesting and from any efforts to "clean" bittern and other high-salinity ponds during pond decommissioning. Three specific issues require incorporation into current acquisition negotiations.

Bittern Definition Must Include All Components of Bittern in Acquisition Negotiations

Considerably different estimates of the ongoing bittern production rates exist that we believe stem in part from varying definitions of bittern. Cargill currently estimates it produces 0.15 million tons of bittern annually. Leslie Salt, Cargill's predecessor, estimated 1 million tons annually. Resolving this disparity is critical to ensure that bittern in all its forms are properly removed from Redwood City as part of acquisition so that the public does not take on this costly liability as it did with the North Bay salt ponds in the 1990s. **Bittern is defined as the total liquid bittern, including dissolved ions and salts and the water in which they are dissolved, plus the precipitated bittern salts that have deposited on bittern pond bottoms.** Using this definition and assuming that Cargill stores bittern at the highest salinity possible in the region (dictated by rainfall and solar evaporation), our new mass balance analysis estimates an annual bittern production rate of about 0.6 million tons. We believe that Cargill's estimate of 0.15 million tons is too low to account for all forms of bittern regardless of storage salinity and liquid or solid phase and that Leslie's estimate of 1 million tons is too high because it failed to account for evaporative concentration in the bittern storage ponds.

Acquisition Should Provide Plan for Hypersaline Brines

Hypersaline brines are the concentrated bay waters that arise from salt production prior to salt harvesting and from post-acquisition efforts to "clean" (i.e., desalinate) bittern and other high-salinity ponds. Hypersaline brines pose similar toxicity issues to that of bittern, though at reduced levels of significance since their ionic imbalance is less than bittern. Negotiations should clearly define responsibilities, terms and conditions for the disposition of these brines. The volume produced will depend upon the desalination method and the initial salinity level of ponds being desalinated and could be an additional one to two volumes in addition to what is currently within a pond. Because of its very large volume, transferring brine into Cargill's salt production stream at a rate that is economically and logistically feasible while meeting state and federal restoration goals will require close coordination between Cargill and the resource management agencies.

Provide a Long-Term Plan for Existing Stockpiled Bittern Disposition

In the early 1970s, the federal Clean Water Act and the state Porter-Cologne Water Quality Act ended unregulated bittern discharge to the Bay. Since that time, the available market for bittern has been relatively minor. Consequently, Cargill has stockpiled roughly 30 years of bittern at Redwood City and Newark. We have estimated that stockpile to be about 19-20 million tons of bittern. It is our understanding that all the bittern stockpiled in Redwood City will be transferred to Newark. Most of Cargill's Newark-stored bittern is located in Ponds 12 and 13 in Newark Plant #2; these ponds are owned by the Refuge. Transfer of the Redwood City bittern to Newark may require converting additional ponds to bittern storage, and whether these additional ponds would be on Cargill or Refuge property is to be determined as part of the acquisition.

The 1979 operating agreement under which Cargill exercises it mineral rights on Refuge-owned salt ponds places Cargill under no obligation to clean up bittern or any other problems it has created on these publicly-owned lands. Solar salt production in the highly urbanized San Francisco Estuary may not be an economical operation in the long-term as suggested by Cargill's current efforts to reduce local salt production and increase production efficiencies. Over the anticipated period for sustainable restoration, it seems likely that Cargill will cease salt production altogether. **Thus, current acquisition negotiations are the forum to establish clear Cargill responsibility for long-term disposition of all bittern, including the existing stockpiles and all future bittern production.** The State of California has learned the hard way from the Napa River salt ponds just how difficult and costly bittern remediation can be. Cargill has currently undertaken efforts to reduce bittern volumes through reprocessing bittern in the salt production process and creating and enlarging commercial markets for bittern.

15.1.5 Commit to Immediate and Long-Term Operations, Maintenance and Monitoring

Immediate and long-term ongoing operations, maintenance and monitoring funds are essential to achieve ecological goals and protect against levee failures that could flood locally large segments of the South Bay. These funds represent a need for long-term political and fiscal commitment by local, state and federal agencies. Securing these funds may be more important and difficult than the initial purchasing of the property. Beyond the first step in restoration (acquisition), it will be essential to maintain hundreds of water control structures and some significant portion of the 234 miles of levees enclosing the salt ponds. Adaptive management will provide the best approach for ensuring a successful restoration program that will take decades to complete. Monitoring data are the essential information resource for adaptive management and therefore monitoring should be adequately funded throughout the restoration effort.

Water Control Structures Provide the Means for Wildlife Management in Retained Ponds

Pond water levels, salinity and water quality are all essential elements for wildlife management in the salt ponds. These parameters are governed largely by the amount and rate of water exchange between ponds and the South Bay. Numerous pumps, pipes, gates, and related infrastructure are necessary to carry out any water management. Therefore, inadequately maintaining water control structures could compromise ecological goals and provide the potential for water quality problems (i.e., unintended "salt production" leading to hypersaline brines and gypsum deposition).

Flood Protection Levees Protect Subsided South Bay Uplands

Cargill currently maintains a total of 21 miles of levees that separate salt ponds from adjacent upland land uses and another 180 miles bayward of these levees, some of which provide flood control protection remotely. Public agencies maintain another 17 miles of levees enclosing the salt ponds. Inadequate levee maintenance could lead to failures potentially flooding extensive areas of the South Bay that lie below sea level.

Estimated Operations and Maintenance Activities and Costs

O&M activities will vary according to the phase of overall restoration and the target ecosystem types being managed. We have divided the restoration effort into three phases: initial planning and design, interim management of ponds targeted for tidal marsh restoration, and permanent management of ponds retained as shallow open water habitats. The full range of O&M activities that will required for most of these phases includes water management, levee maintenance, water control structure maintenance, and meeting regulatory act requirements. We estimate annual O&M costs (in 2001 dollars) for all these activities to range between $284 and $686 per acre. These costs translate to $4.5 to $11 million total annually for the 16,000-acre Cargill proposed sale area (a slightly reduced version of which is currently being negotiated) and $7.4 to $17.8 million total annually for the entire salt pond complex. Annual costs will decline over time as described next. All O&M funds would need to go to the Don Edwards San Francisco Bay National Wildlife Refuge, the entity expected to own and be responsible for all the acquired salt ponds. Actual O&M costs will depend also on which ponds are restored to tidal marsh and which are retained as open water, as levee maintenance costs will vary depending on the nature of individual levees.

Initial planning and design period. During the initial planning and design period, which we assume last five years, we expect that full O&M activities and funds will be required for all purchased properties. For the 16,000-acre Cargill proposed sale area, initial O&M will cost somewhere between $23 and $55 million total. For the entire 26,000-acre South Bay salt pond complex, these costs would be $37 to $89 million.

Interim management of ponds restored to tidal marsh. During the extended period over which two-thirds of the pond acreage would be restored to tidal marsh, O&M activities and costs will gradually decline. At the outset, the full range of O&M activities would be required. Once a pond is restored to tidal marsh, only levee maintenance would be required and we assume that ends once marsh vegetation becomes well established for levee erosion protection. For two-thirds of the Cargill proposed sale area, these O&M costs will be somewhere between $156 and $357 million for the longer implementation time required by the natural sedimentation approach and $62 to $151 million for a shorter period associated with dredged sediment reuse.

Permanent management of ponds retained as shallow open water habitats. The one-third of pond acreage retained as shallow open water habitat will require the full range of O&M activities and costs in perpetuity. For the Cargill proposed sale area, these costs will be between $1.4 and $3.4 million annually. These costs would be $2.3 to $5.5 million annually for the entire salt pond complex.

Monitoring

Monitoring funds will also be required and are likely necessary shortly after acquisition. We estimate that monitoring will cost $1.5 to $3.0 million dollars annually for the 16,000-acre Cargill proposed sale area and will extend over a 40-year period and perhaps longer. We would anticipate that actual monitoring costs will rise and fall from one year to the next, so this 40-year estimate should approximate those total costs. Total costs over those 40 years would range between $60 and $120 million, in 2001 dollars.

15.1.6 Restoration Planning Needs to Consider the Many Pressures on Biological Resources

During the restoration process, many environmental and economic pressures will threaten existing biological resources and thus are important considerations in acquisition and restoration planning. We have identified three topics of particular concern: increased importance to wildlife of remaining salt production ponds, dynamics of wildlife use of South Bay salt ponds, and the invasive eastern cordgrass, Spartina alterniflora.

Increased Importance of Remaining Salt Production Ponds

Converting two-thirds of salt ponds to tidal marsh (regardless whether of the entire salt pond complex or the smaller Cargill proposed sale area) will increase the importance of the remaining salt ponds for species that rely on shallow open water environments. The situation becomes more complex in the context of Cargill retaining salt production on a reduced area consisting of Newark #1 and #2 plants, which comprise about 10,000 acres. Cargill recently began a series of modifications to those plants intended to increase production efficiency by about 25% in anticipation of public acquisition. Historically, conflicts exist between salt production and wildlife management on existing Refuge-owned ponds in Newark #1 and #2 plants. Although these conflicts have diminished in recent years, Cargill's higher salt production expectations and the inherent need to optimize the salt production process could lead to less flexibility for pond operations in an ecologically friendly manner. Some of these modifications have, however, improved wildlife conditions by providing more ponding in certain areas that were previously difficult to keep flooded adequately.

Dynamic Ecological Resources

Wildlife resource use of the South Bay salt ponds is best characterized by its dynamics. Variability in pond environmental conditions occur from interannual climate differences as well as Cargill operations. Wildlife continually adjust their use of any particular salt pond in response to these varying conditions. Therefore, throughout the restoration planning and implementation effort, it will be important for restoration planners to have current information. These information needs emphasize the role of ongoing monitoring, within an Adaptive Management framework, to provide data on species recovery and decline that can be used to adjust restoration planning and goals as the process moves forward.

Spartina alterniflora

The invasive *Spartina alterniflora*, an aggressive eastern cordgrass, diminishes marsh habitat functions relative to the native cordgrass, S. foliosa. No current controls effectively prevent *S. alterniflora* spread once it has become established. It is particularly problematic in the East Bay between the San Mateo and Dumbarton bridges. Restoring ponds close to existing stands of *S. alterniflora* should be undertaken cautiously until more research into and demonstration of its control has been completed.

15.1.7 Buyer Beware of Differential Restoration Feasibility

Not all ponds can be restored with equal ease. The current Cargill proposed sale area contains many of the most difficult and costly to restore ponds while retaining most of the easiest and least costly to restore ponds under Cargill control. Restoration costs for a given pond depend upon many factors but are most impacted by the degree of subsidence. The feasibility of restoring any given salt pond to tidal marsh varies according to a variety of site-specific factors as well as how surrounding ponds are treated. Thus, which ponds the public buys and which ponds Cargill retains in salt production have tremendous economic and ecological ramifications for all parties. Using a suite of biological, physical, and chemical criteria, we reached the following conclusions about restoration feasibility: 2,690 acres (10 percent total area) are high feasibility, 13,240 acres (51 percent total area) are medium feasibility, 8,430 acres (32 percent total area) are low feasibility, and 1,830 acres (7 percent total area) we had insufficient data to make a determination. Without dredged sediment reuse, we estimate per-acre restoration costs to be approximately $1,500 versus $5,000 for high and low feasibility ponds, respectively.

Most of the "high feasibility" ponds are not part of the Cargill proposed sale area. As it currently stands, Cargill is selling the public the most costly ponds to manage and restore, especially the deeply subsided Alviso ponds, and retaining the most easily restored ponds. Of the 108 MCY estimated sediment deficit for the total salt pond complex, those ponds Cargill has offered for public acquisition represent 89 MCY or 82% of that total deficit. Further, under the range of possible dredged sediment reuse options we evaluated, virtually all that sediment is needed only in the ponds Cargill is currently offering the public. Only under the maximum reuse scenario would ponds currently not part of the proposed acquisition be considered for dredged sediment reuse, and those ponds account for only 4 MCY of 58 MCY under that scenario.

In addition to these economic ramifications, this arrangement has ecological consequences. Most of the "high feasibility" ponds are represented by just three salt ponds – Mowry 1, 2 and 3 in Alameda County. These three ponds have long been targeted for restoration because of their particular suitability to yield tremendous ecological recovery benefits. Because they are easily restored and have undergone minimal subsidence, those benefits could be reached with a minimum of cost and in comparatively short time periods. Their exclusion from the acquisition poses an important constraint on achieving ecological recovery goals for the San Francisco Estuary.

15.2 Other Considerations and Recommendations

Along with the key findings presented in the previous section, we have identified numerous other issues that warrant highlighting here. These other issues have fewer and more manageable implications than the key findings. We have divided these into four areas:

- Ecological Considerations (Section 15.2.1)
- Physical Considerations (Section 15.2.2)
- Environmental Chemistry Considerations (Section 15.2.3)
- Economic and Logistical Considerations (Section 15.2.4)

15.2.1 Ecological Considerations

- **Salt ponds to be operated in perpetuity as open water habitat should have a salinity level less than 140 ppt to optimize habitat for shorebirds and preclude additional gypsum precipitation.** Salinity levels in ponds should be varied to promote different biotic communities and increase wildlife diversity. Maintaining salt ponds at variable salinity levels below 140 ppt will provide ecological benefits by providing good habitat conditions for a variety of invertebrates that have different optimum salinity requirements. Invertebrates provide an important dietary component of migrating shorebirds and waterfowl.
- **Levees represent artificial boundaries and should not constrain restoration planning.** There is no magic to the location of the existing pond boundaries. Levees were constructed decades ago based on ownership boundaries, ease of construction, and solar salt production needs. They do not bind us in the location of future restoration areas. Moving boundaries increases costs, but ecological benefits can outweigh costs. In some cases, it may be imperative to adjust boundaries. The draft USFWS Tidal Marsh Ecosystem Recovery Plan considers these boundaries adjustable.
- **Tidal marsh and managed shallow open water should be dispersed geographically throughout the South Bay salt ponds.** Species that utilize each of these ecosystem types occur throughout the South Bay and the optimal recovery strategy is to disperse these habitats spatially. The challenge for restoration planners in the context of ongoing Cargill salt production in Newark Plants #1 and #2 is to integrate the ecological functions of those ongoing production ponds into a regional restoration strategy.
- **Salt panne habitat for western snowy plover roosting and breeding is most easily achieved on crystallizer ponds.** These seasonally ponded areas are unvegetated, flat, hypersaline, and ideal for snowy plover habitat. Restoring panne habitat from salt ponds requires far more effort and expense.

15.2.2 Physical Considerations

- **Gypsum layers will hinder tidal marsh establishment on one 310-acre pond in Baumberg and could hinder establishment on another 2,140 acres elsewhere throughout the South Bay salt pond complex.** Gypsum is present on about 6300 acres of salt ponds at an estimated thickness of nearly 2 inches. Gypsum forms a hard, cement-like coating that can impede plant colonization and tidal slough channel formation. At lower elevations, gypsum is not expected to be a problem but in higher elevation ponds it could interfere with marsh establishment.
- **Ease of providing a tidal connection should be considered in determining whether ponds are restored to tidal marsh or retained as shallow open water habitats.** Restoring tidal action or managing pond levels with tidal exchange requires a physical link to the bay, either directly or through adjacent ponds. Many ponds are enclosed entirely by other salt ponds

or are far upstream small tidal sloughs from the bay. These constraints on tidal exchange will need to be considered carefully in restoration planning. In addition to possible direct connections, Cargill has a variety of gates and pipes that link salt ponds together and this plumbing system should be exploited to the maximum extent practicable.

- **Further research should be undertaken to define the sediment deficit problem more precisely.** We have been able to estimate the sediment deficit magnitude from recent yet fairly generalized salt pond topographic data and place that deficit in context of current knowledge about South Bay sediment dynamics. We have predicted that too rapid of salt pond restoration to tidal action is likely to scour sediment from the South Bay mudflats, which would cause significant adverse environmental impacts to wildlife resources that utilize those mudflats. It will be essential for restoration planning to define these issues far more quantitatively. There are three topics that we believe would aid such a planning effort: (1) improve our understanding of South Bay sediment dynamics and budgets, (2) generate accurate bathymetric maps of the South Bay to provide a baseline against which to evaluate future changes, and (3) improve our numerical modeling capabilities to provide more accurate predictions at resolutions important biologically in an intertidal environment. Organizations such as the USGS and Stanford University have made progress in these areas, but a concerted, well-funded research program is warranted.

15.2.3 Environmental Chemistry Considerations

- **Maintaining ponds during an interim period in a low salinity condition may increase nuisance algae and odor problems.** Nuisance alga and hydrogen sulfide production has historically been a problem in low salinity pond. During the interim restoration period when ponds are flushed and lower salinity levels are maintained, nuisance algae could become a greater problem given that ponds are relatively shallow, warm and have good light attenuation, conditions that favor algae blooms.
- **Salt ponds sediments should have few contaminants. Most water quality differences between salt ponds and adjacent bay waters will be transitory once tidal flow resumes.** Salt pond sediments are likely to have lower concentrations of PCBs, DDT, chlordanes, mercury and trace elements than nearby tidal marshes because of severely muted tidal flows and very low sedimentation rates. Any water quality differences such as salinity, nutrients, water temperature, DO and pH are likely to be transitory, disappearing once tidal flows resume.

15.2.4 Economic and Logistical Considerations

- **It may be advantageous for all parties to retain salt production on some ponds for an interim period following public acquisition.** The public presumably becomes responsible for pond operations and maintenance costs following acquisition and decommissioning from salt production. Many factors will limit the time at which any given pond can be restored to tidal marsh, most notably the sediment deficit constraint. Consequently, a comprehensive plan should be formulated whereby Cargill continues salt production on some ponds following acquisition while other acquired ponds are converted wholly to interim or permanent management as shallow open water habitats. Such an approach maintains higher salt production levels for Cargill and reduces public expenditures for O&M.
- **Negotiations with Cargill to acquire more ponds should be continued.** Cargill should be encouraged to consider selling additional ponds, as it considered with its preliminary 1999 proposal. One year prior to the current proposal being negotiated, Cargill considered releasing nearly 7,000 acres more for restoration, including all of Newark #1 Plant and roughly half of Newark #2 Plant. The USFWS Tidal Marsh Ecosystem Recovery Plan targets Newark #2 Plant ponds 1, 2 and 3 between Mowry Slough and Coyote Creek as the highest priority ponds for tidal marsh restoration in the entire South Bay. These ponds are not optimal intake ponds for Cargill's salt production system because they are far south where salinities are lower and more pumping is required. In all cases, the economics to both the government and Cargill should be considered in the rate ponds are released for restoration. Releasing ponds at a rate that exceeds realistic restoration efforts will burden the government with unnecessary long-term O&M expenditures and reduce Cargill efficiencies.
- **Cargill will have roughly 240 acres of excess crystallizer capacity in Newark once salt production drops to its post-sale and post-desalination levels.** Cargill has always maintained that these areas are not subject to federal wetlands jurisdiction and therefore they can be developed. At current real estate prices, these crystallizers could be worth more than $1 million per acre. Conversely, the crystallizers are targeted by regional ecological recovery efforts as prime salt panne habitat easily managed and restored for Snowy Plover nesting, least tern foraging, and seasonal shorebird use.

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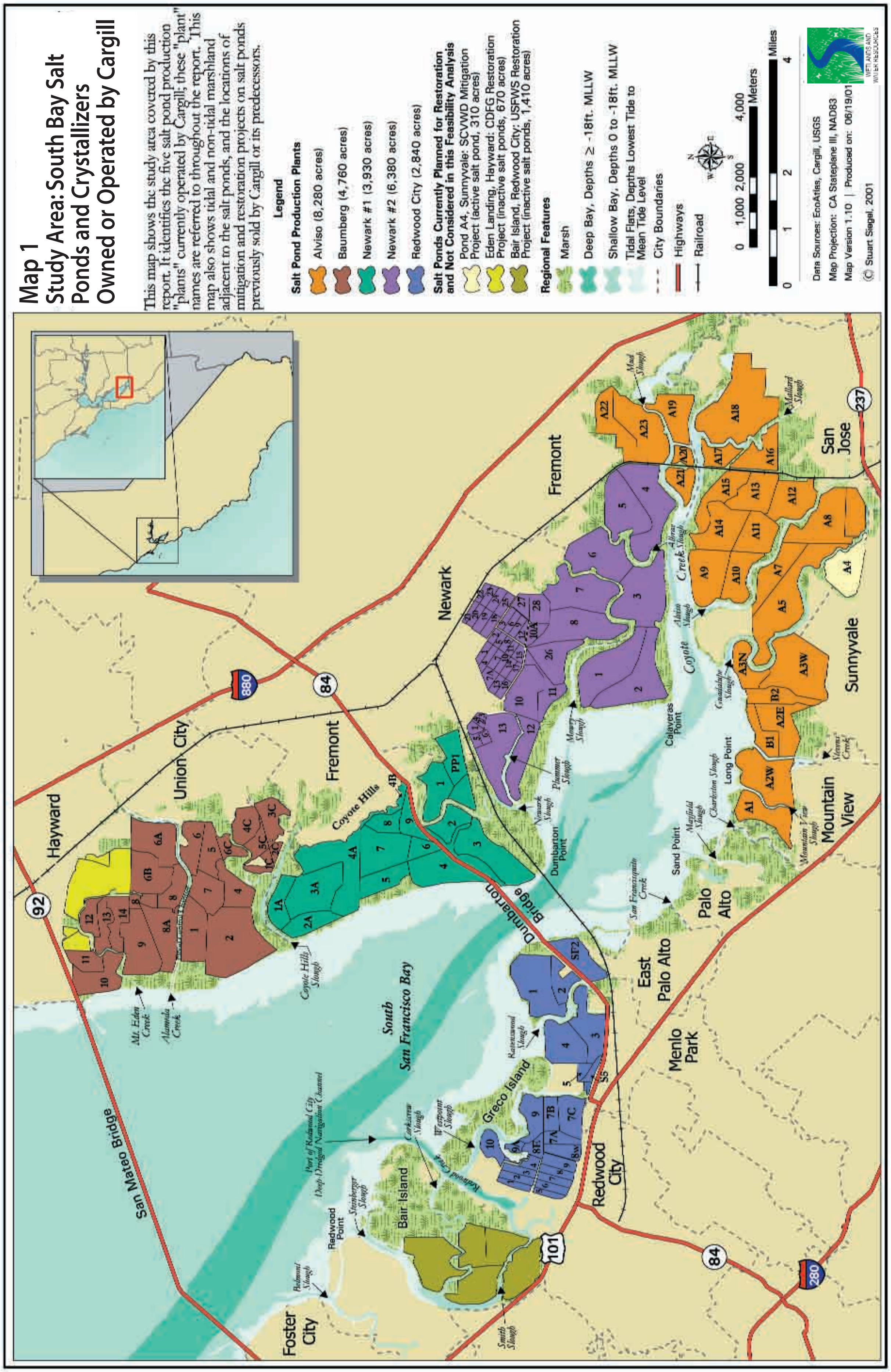
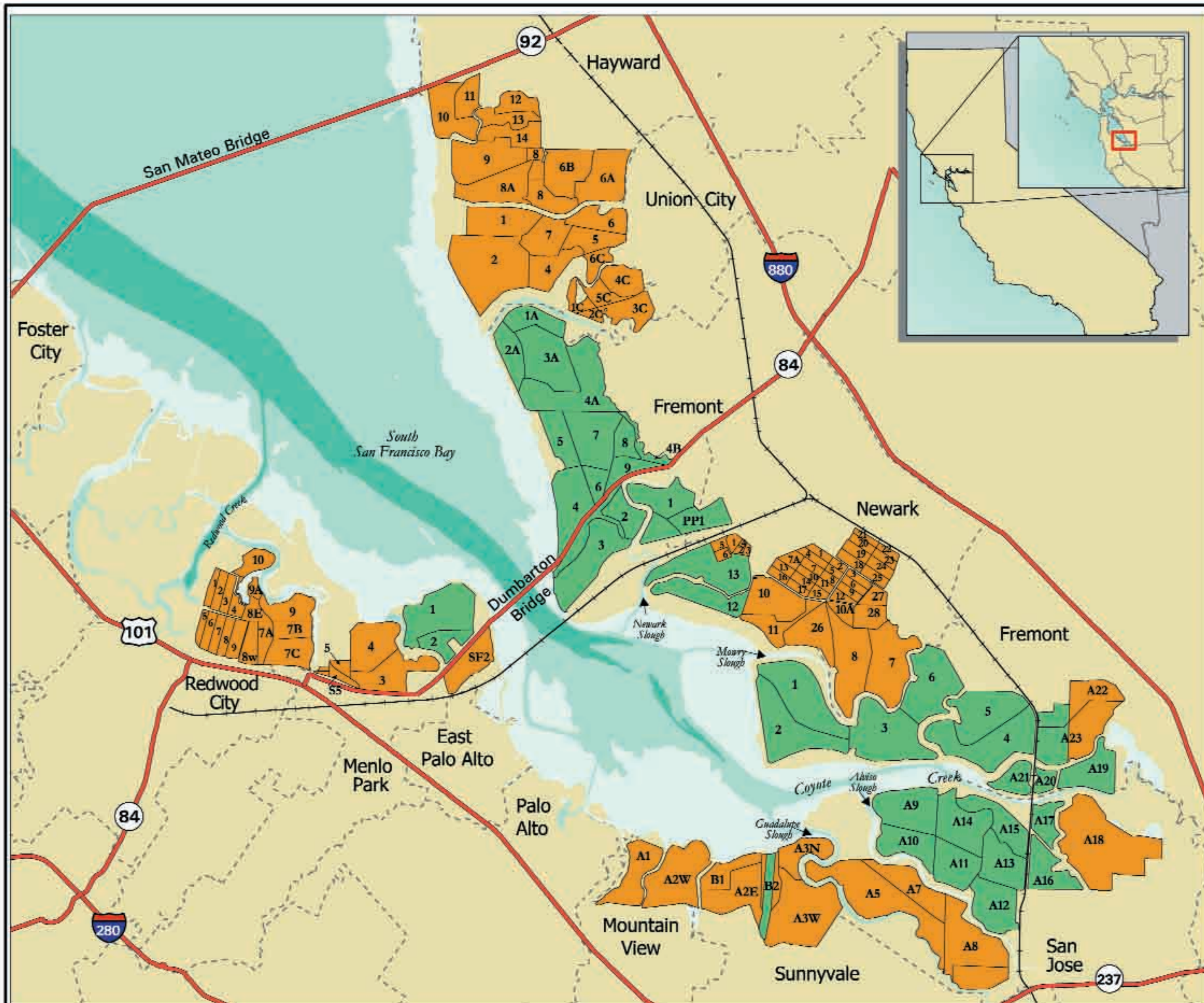
Map Atlas


Map 1
Study Area: South Bay Salt Ponds and Crystallizers Owned or Operated by Cargill
This map shows the study area covered by this report. It identifies the five salt pond production "plants" currently operated by Cargill; these "plant" names are referred to throughout the report. This map also shows tidal and non-tidal marshland adjacent to the salt ponds, and the locations of mitigation and restoration projects on salt ponds previously sold by Cargill or its predecessors.
Legend
Salt Pond Production Plants
Alviso (8,280 acres)
Baumberg (4,760 acres)
Newark #1 (3,930 acres)
Newark #2 (6,380 acres)
Redwood City (2,840 acres)
Salt Ponds Currently Planned for Restoration and Not Considered in this Feasibility Analysis
Pond A4, Sunnyvale: SCVWD Mitigation Project (active salt pond, 310 acres)
Eden Landing, Hayward: CDFG Restoration Project (inactive salt ponds, 670 acres)
Bair Island, Redwood City: USFWS Restoration Project (inactive salt ponds, 1,410 acres)
Regional Features
Marsh
Deep Bay, Depths ≥ -18ft. MLLW
Shallow Bay, Depths 0 to -18ft. MLLW
Tidal Flats, Depths Lowest Tide to Mean Tide Level
City Boundaries
Highways
Railroad
0 1,000 2,000 4,000 Meters
0 1 2 4 Miles
Data Sources: EcoAtlas, Cargill, USGS
Map Projection: CA Stateplane III, NAD83
Map Version 1.10 | Produced on: 06/19/01
© Stuart Siegel, 2001
Hayward
Union City
Fremont
Newark
San Jose
Sunnyvale
Mountain View
Palo Alto
East Palo Alto
Menlo Park
Redwood City
Foster City
South San Francisco Bay
San Mateo Bridge
Dumbarton Bridge
Bair Island
Greco Island
Coyote Hills
Dumbarton Point
Sand Point
Long Point
Calaveras Point
Redwood Point

Map 2



Map 2
Land Ownership of Operating South Bay Salt Ponds

This map identifies land ownership of the South Bay salt ponds considered in this feasibility analysis. Note that Cargill produces salt on about 11,430 acres of publicly owned salt ponds. Cargill retained mineral rights for these lands under the 1979 purchase agreement that helped establish the Don Edwards San Francisco Bay National Wildlife Refuge.

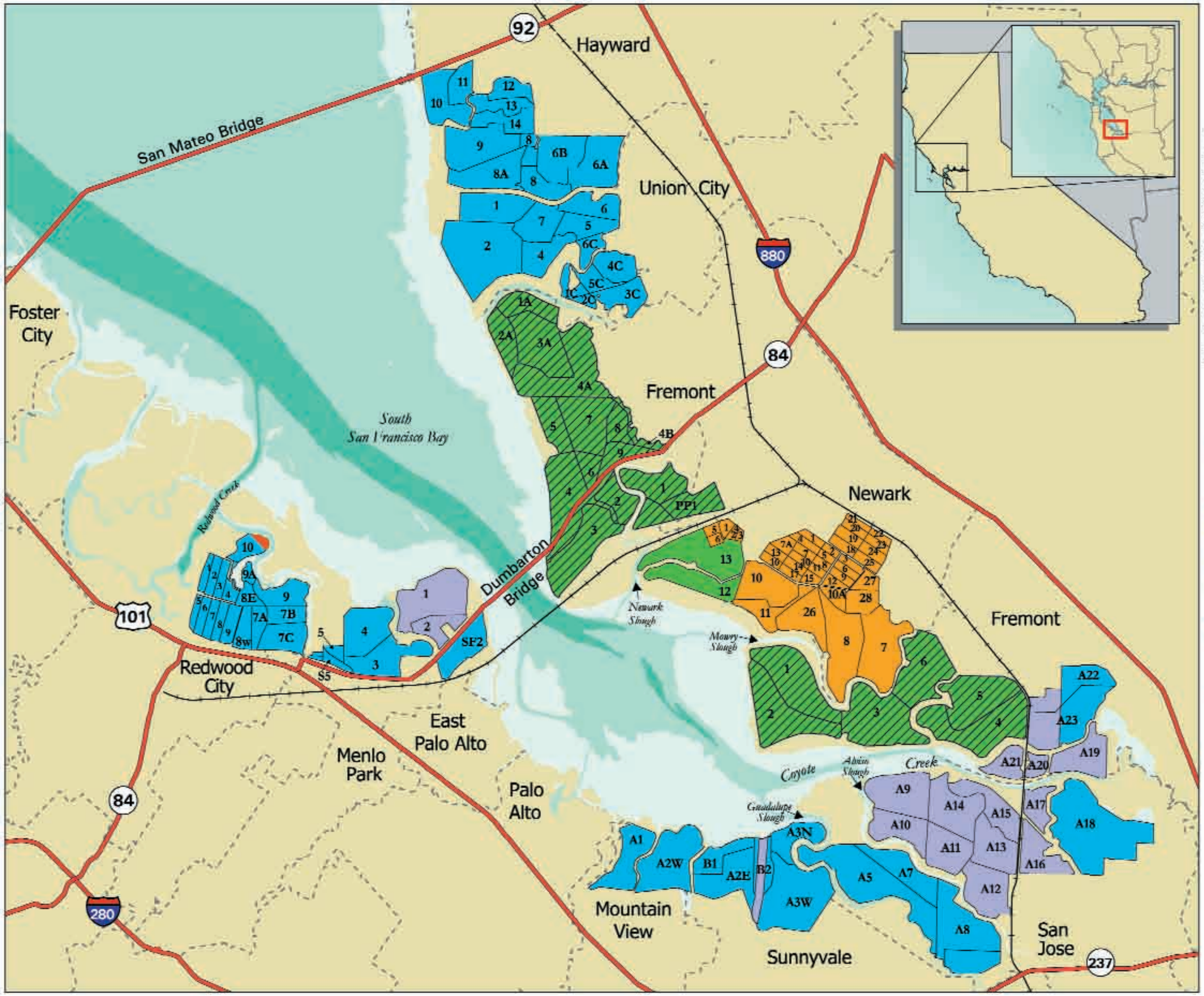
Legend

- Owned and Operated by Cargill (14,760 acres)
- Owned by Don Edwards San Francisco Bay National Wildlife Refuge, operated by Cargill for salt production (11,430 acres)
- City Boundaries
- Highways
- Railroad

0 1,000 2,000 4,000 Meters

0 1 2 4 Miles

Data Sources: EcoAtlas, Cargill, USGS
Map Projection: CA Stateplane III, NAD83
Map Version 1.7 | Produced on: 03/30/01



Map 3
Areas Cargill Proposed for Sale, 1999 and 2000

This map shows the two proposals Cargill has made to sell its lands and/or mineral rights for habitat restoration. In 1999, Cargill proposed 22,720 acres (87%) for restoration and 3,470 acres (13%) retained in salt production. In 2000, Cargill proposed 15,880 acres (61%) for restoration and 10,310 acres (39%) retained in salt production. The differing 6,840 acres are Refuge lands previously designated for habitat restoration but currently proposed for continued salt production. Note also that 3,920 acres (25%) of Cargill's current "lands for sale" are public lands on which Cargill holds only the mineral rights for salt production.

Legend

Ponds Common to 1999 and 2000 Proposals

- Cargill Sells Land and Mineral Rights (11,940 acres)
- Cargill Sells Mineral Rights on Refuge Land (3,920 acres)
- Cargill Retains Production on Refuge Land (670 acres)
- Cargill Retains Production on Cargill Land (2,800 acres)
- Cargill Sells to Marina Developer (20 acres)

Ponds Different between 1999 and 2000 Proposals

- Cargill Retains Production on Refuge Lands in 2000 Proposal and Sells Mineral Rights in 1999 Proposal (6,840 acres)

City Boundaries
Highways
Railroad

0 1,000 2,000 4,000 Meters
0 1 2 4 Miles

Data Sources: EcoAtlas, Cargill, USGS
Map Projection: CA Stateplane III, NAD83
Map Version 1.10 | Produced on: 04/28/01

Bay Plan Policies and Commission Suggestions

Bay Plan Policies

1. If not needed for salt production, ponds west of Coyote Hills should be acquired as permanent wildlife area.
2. **Dumbarton Bridge** - Design proposed high-level bridge to have slim profile and minimum supporting structure and to enable motorists to see Bay and shoreline. Approaches should provide for fishing and wildlife observation. Toll plaza site under study.
3. **Dumbarton Point Waterfront Park** (proposed) - Boundaries to be determined. Water-oriented uses only. Some fill may be needed.
4. **Newark Slough to Coyote Creek** - Protect harbor seal nursey and hauling grounds. No direct public access.
5. **Newby Island** - Provide levee access for wildlife observation.
6. **Alviso Slough** - Widen and strengthen levees for public access and occasional picnic areas. Some fill may be needed.
7. If not needed for sewage treatment purposes, oxidation ponds should be acquired as permanent wildlife area.
8. **Moffett Naval Air Station** - If and when not needed by Navy, site should be evaluated for commercial airport by regional airport system study. (Moffett NAS not within BCDC permit jurisdiction.)
9. If not needed for salt production, ponds north of Moffett Field should be reserved for possible airport expansion.
10. If not needed for salt production, ponds between Stevens Creek and Charleston Slough should be added to North County Shoreline Park Complex as recreation lakes or wildlife areas.
11. **South Bay** - Preserve valuable wildlife habitat and develop recreational boating. Some fill and dredging may be needed. Parts of Bay and salt ponds may be acquired as permanent wildlife areas.
12. If not needed for salt production, pond between Cooley Landing and railroad bridge should be developed for recreational use. Expand Cooley Landing marina northward.

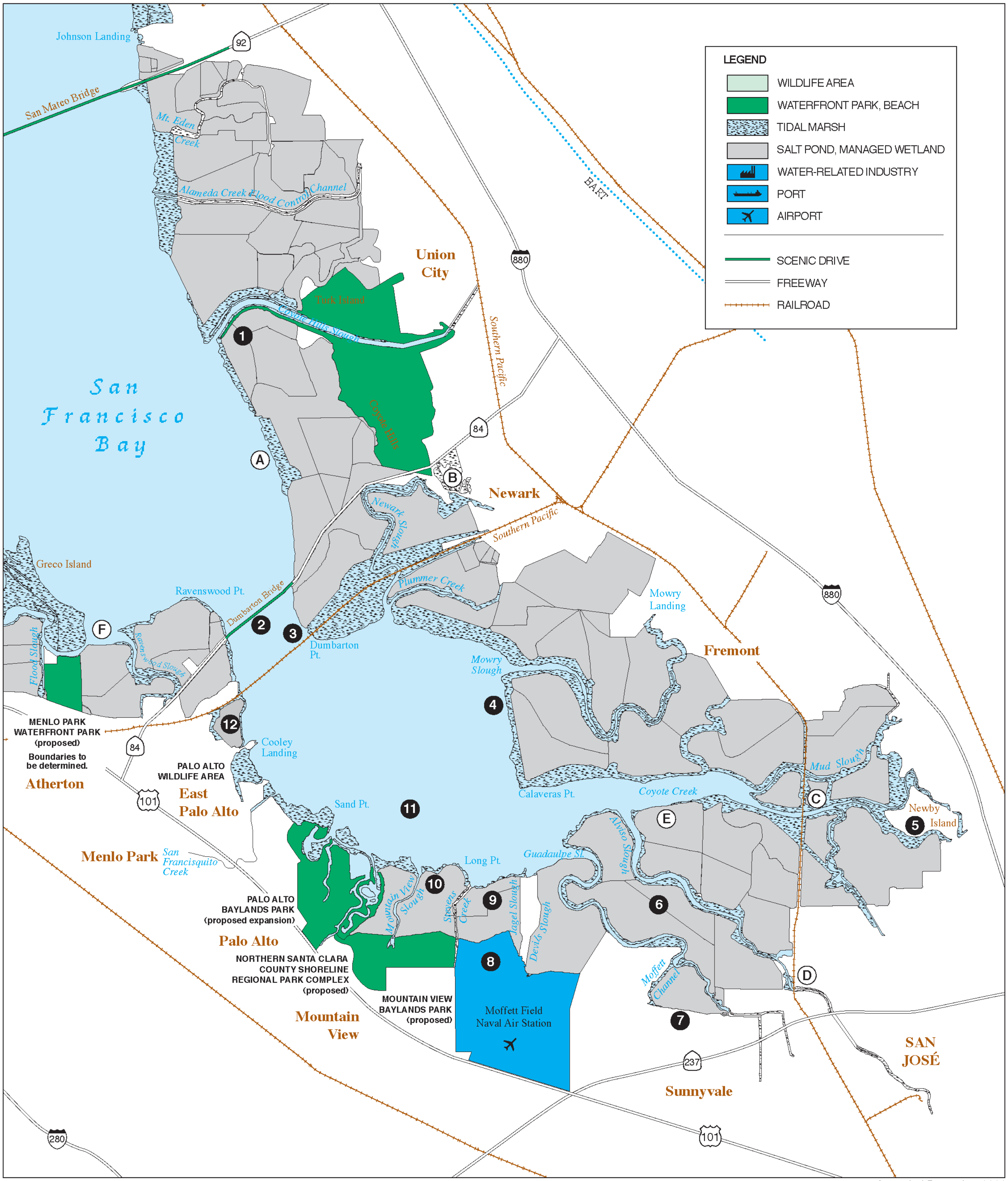
Commission Suggestions

- (A) Breach dikes and return area to Bay.
- (B) Possible aquatic park.
- (C) Drawbridge - Possible park.
- (D) Alviso-San Jose - Prepare prcise plan and development program for waterfront area. Expand boating and commercial recreation facilities, provide continuous public access to slough frontage.
- (E) If not needed for salt production, deep ponds near Alviso Slough may be developed as controlled-level recreation lake. Shallow ponds near Coyote Creek have high wildlife value, should be excluded from intensive use area.
- (F) Possible shallow-draft port.
- (G) Westpoint, Ravenswood, and Flood Sloughs - If flood control project is needed, develop controlled-level recreation lake at mouth of sloughs.

WETLANDS AND WATER RESOURCES

Map 4 - Notes
BCDC Bay Plan Map 7

March 2002 | **Project No.1040**



San Francisco Bay Conservation and Development Commission

Amended December 2000

1 .5 0 1 MILE

1 .5 0 1 KILOMETER

NORTH

WETLANDS AND WATER RESOURCES

Map 4
BCDC Bay Plan Map 7

March 2002

Project No.1040

Map 5
South Bay Salt Pond Operations

This map shows existing salt production facilities, system modifications Cargill made in 2000, and system modifications Cargill proposes should be made for interim management of the 15,880 acres currently under negotiations (see Map 3). Most of these data from published Cargill maintenance reports and maps, 1996-2001. Generalized brine flow path interpreted from variety of data sources; Cargill does not provide operations information.

Legend

Existing Conditions

- Intake Pond (2,120 acres)
- Gravity Intake
- Pump Intake
- Bittern Desalting Ponds (110 acres Redwood City and 450 acres Newark #2)
- Bittern (waste) Ponds (1,050 acres)
- Crystallizer Ponds (1,340 acres)
- Generalized Brine Flow Path
- Evaporation Ponds

Changes Made to Redwood City Plant in 2000

- New Intake Pond: Dilution Water for Bittern and Brine Transfer to Newark (450 acres)
- New Gravity Intake

Cargill Proposed Changes After Sell Portion of Salt Pond Complex

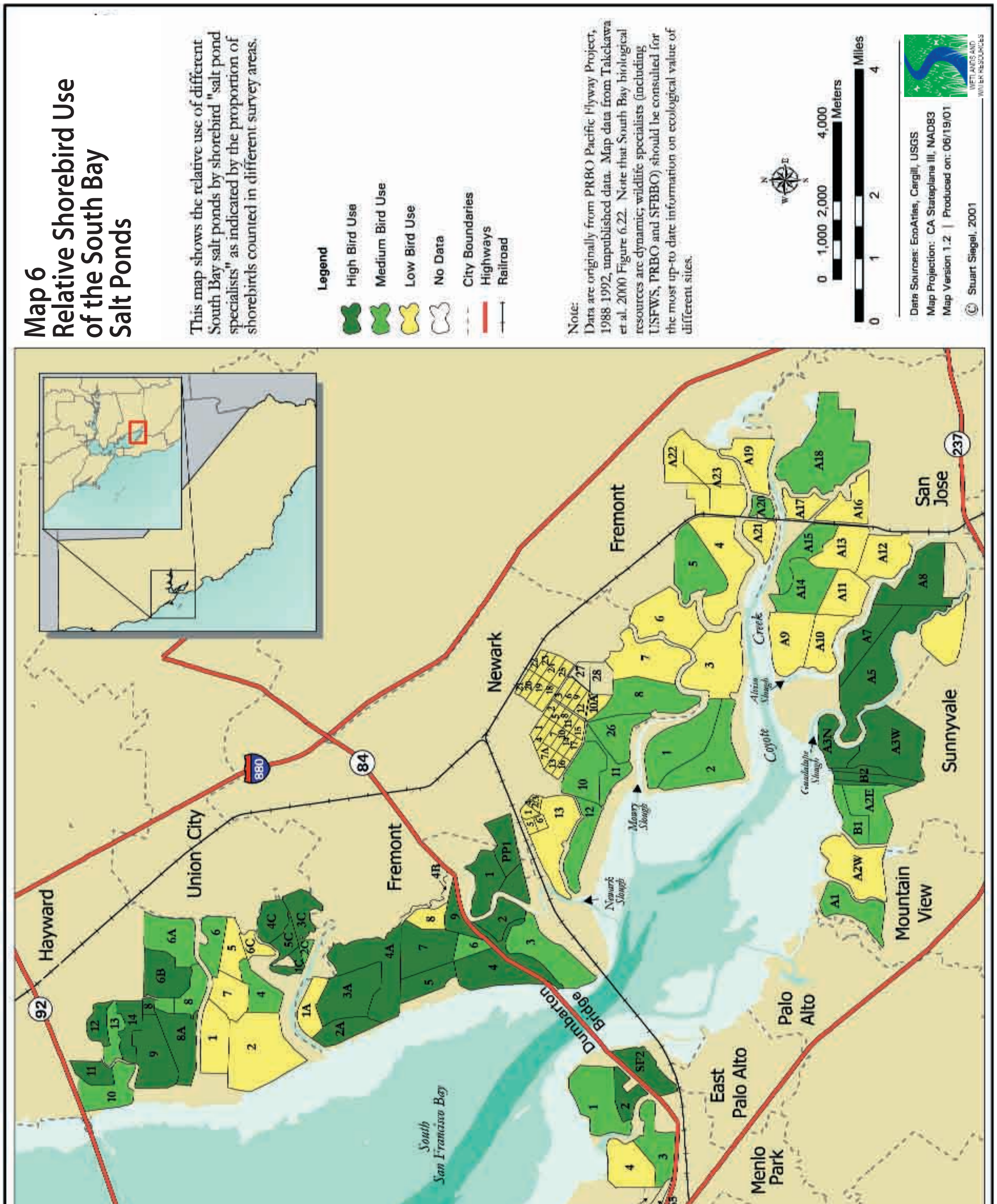
- New Intake Ponds for Interim Management (1,910 acres)
- New Generalized Brine Flow Path
- City Boundaries
- Highways
- Railroad

0 1,000 2,000 4,000 Meters

0 1 2 4 Miles

Data Sources: EcoAtlas, Cargill, USGS
Map Projection: CA Stateplane III, NAD83
Map Version 1.4 | Produced on: 06/19/01

WETLANDS AND WATER RESOURCES


Map 6
Relative Shorebird Use of the South Bay Salt Ponds
This map shows the relative use of different South Bay salt ponds by shorebird "salt pond specialists" as indicated by the proportion of shorebirds counted in different survey areas.
Legend
High Bird Use
Medium Bird Use
Low Bird Use
No Data
City Boundaries
Highways
Railroad
Note:
Data are originally from PRBO Pacific Flyway Project, 1988-1992, unpublished data. Map data from Takekawa et al. 2000 Figure 6.22. Note that South Bay biological resources are dynamic; wildlife specialists (including USFWS, PRBO and SFBBO) should be consulted for the most up-to date information on ecological value of different sites.
0 1,000 2,000 4,000 Meters
0 1 2 4 Miles
Data Sources: EcoAtlas, Cargill, USGS
Map Projection: CA Stateplane III, NAD83
Map Version 1.2 | Produced on: 06/19/01
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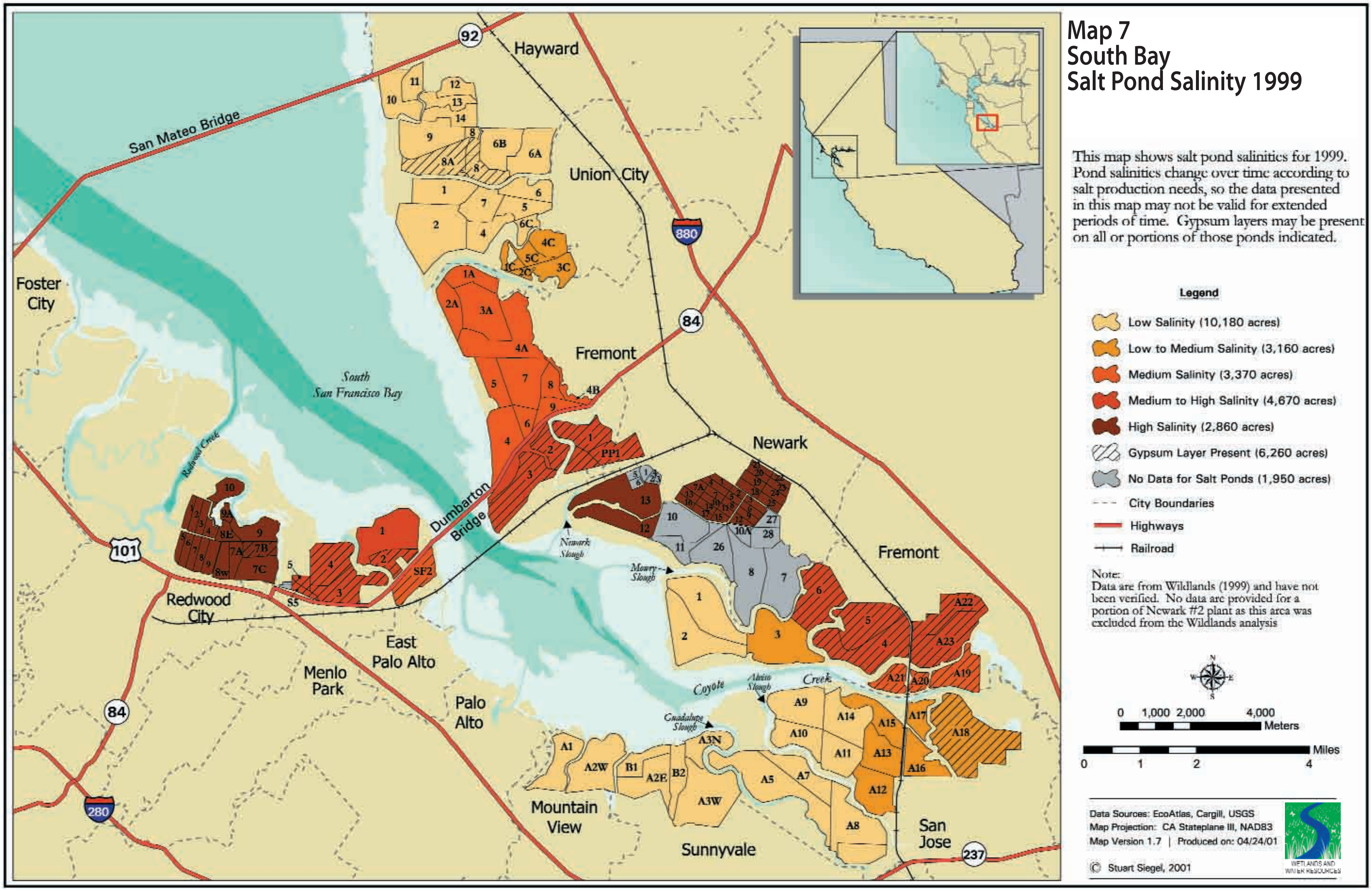
Hayward
Union City
Fremont
Newark
San Jose
Sunnyvale
Mountain View
Palo Alto
East Palo Alto
Menlo Park
Redwood City
Foster City
San Mateo Bridge
Dumbarton Bridge
South San Francisco Bay
Coyote Creek
Newark Slough
Mowry Slough
Alviso Slough
Guadalupe Slough
92
880
84
101
280
237

Map 6

167


Map 7
South Bay
Salt Pond Salinity 1999
This map shows salt pond salinities for 1999. Pond salinities change over time according to salt production needs, so the data presented in this map may not be valid for extended periods of time. Gypsum layers may be present on all or portions of those ponds indicated.
Legend
Low Salinity (10,180 acres)
Low to Medium Salinity (3,160 acres)
Medium Salinity (3,370 acres)
Medium to High Salinity (4,670 acres)
High Salinity (2,860 acres)
Gypsum Layer Present (6,260 acres)
No Data for Salt Ponds (1,950 acres)
City Boundaries
Highways
Railroad
Note:
Data are from Wildlands (1999) and have not been verified. No data are provided for a portion of Newark #2 plant as this area was excluded from the Wildlands analysis
0 1,000 2,000 4,000 Meters
0 1 2 4 Miles
Data Sources: EcoAtlas, Cargill, USGS
Map Projection: CA Stateplane III, NAD83
Map Version 1.7 | Produced on: 04/24/01
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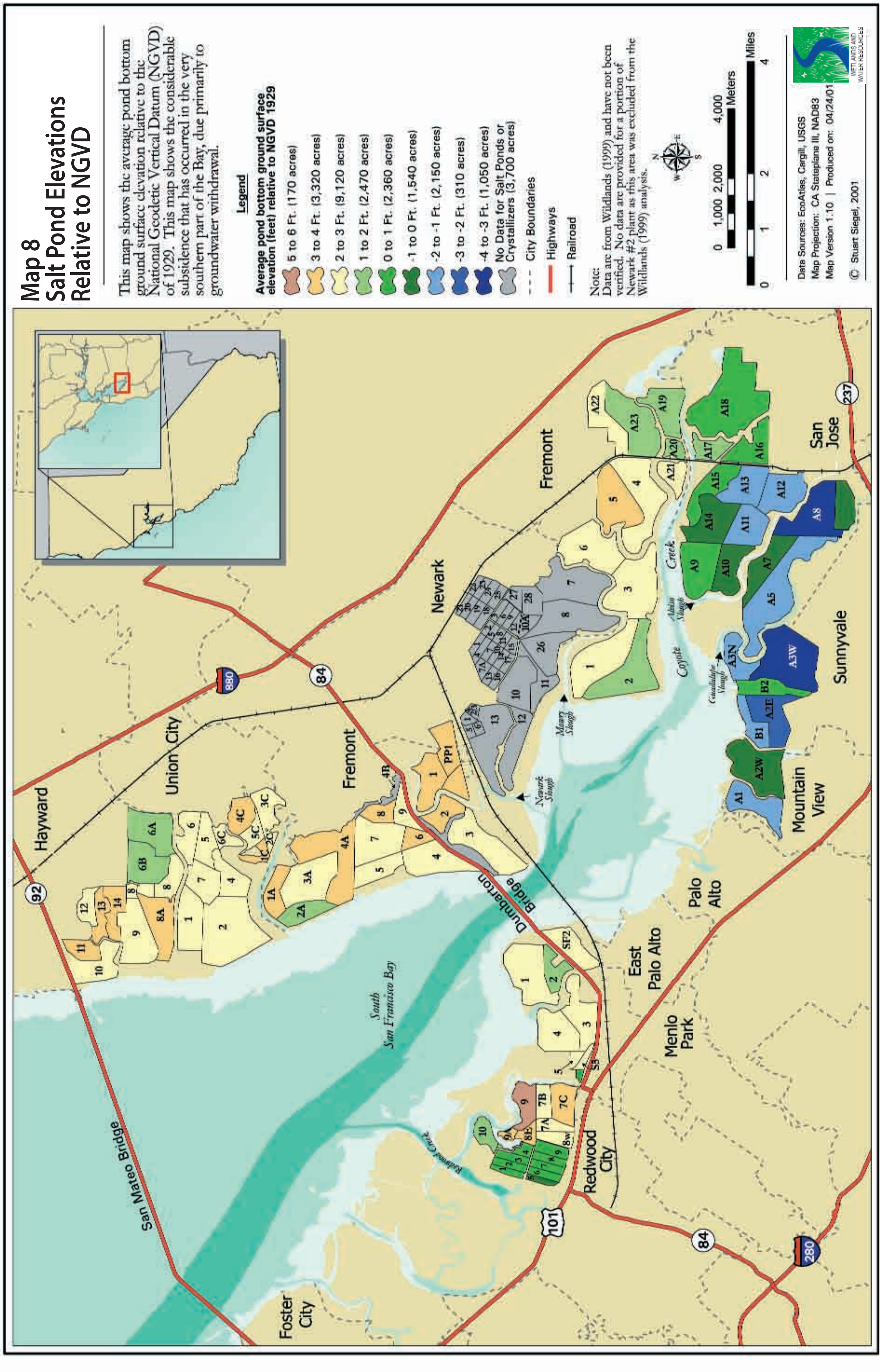
WETLANDS AND WATER RESOURCES
Hayward
Union City
Fremont
Newark
Foster City
Redwood City
Menlo Park
East Palo Alto
Palo Alto
Mountain View
Sunnyvale
San Jose
San Mateo Bridge
Dumbarton Bridge
South San Francisco Bay
Redwood Creek
Newark Slough
Mowry Slough
Alviso Slough
Guadalupe Slough
Coyote Creek



Map 8
Salt Pond Elevations Relative to NGVD
This map shows the average pond bottom ground surface elevation relative to the National Geodetic Vertical Datum (NGVD) of 1929. This map shows the considerable subsidence that has occurred in the very southern part of the Bay, due primarily to groundwater withdrawal.
Legend
Average pond bottom ground surface elevation (feet) relative to NGVD 1929
5 to 6 Ft. (170 acres)
3 to 4 Ft. (3,320 acres)
2 to 3 Ft. (9,120 acres)
1 to 2 Ft. (2,470 acres)
0 to 1 Ft. (2,360 acres)
-1 to 0 Ft. (1,540 acres)
-2 to -1 Ft. (2,150 acres)
-3 to -2 Ft. (310 acres)
-4 to -3 Ft. (1,050 acres)
No Data for Salt Ponds or Crystallizers (3,700 acres)
City Boundaries
Highways
Railroad
Note:
Data are from Wildlands (1999) and have not been verified. No data are provided for a portion of Newark #2 plant as this area was excluded from the Wildlands (1999) analysis.
0 1,000 2,000 4,000 Meters
0 1 2 4 Miles
Data Sources: EcoAtlas, Cargill, USGS
Map Projection: CA Stateplane III, NAD83
Map Version 1.10 | Produced on: 04/24/01
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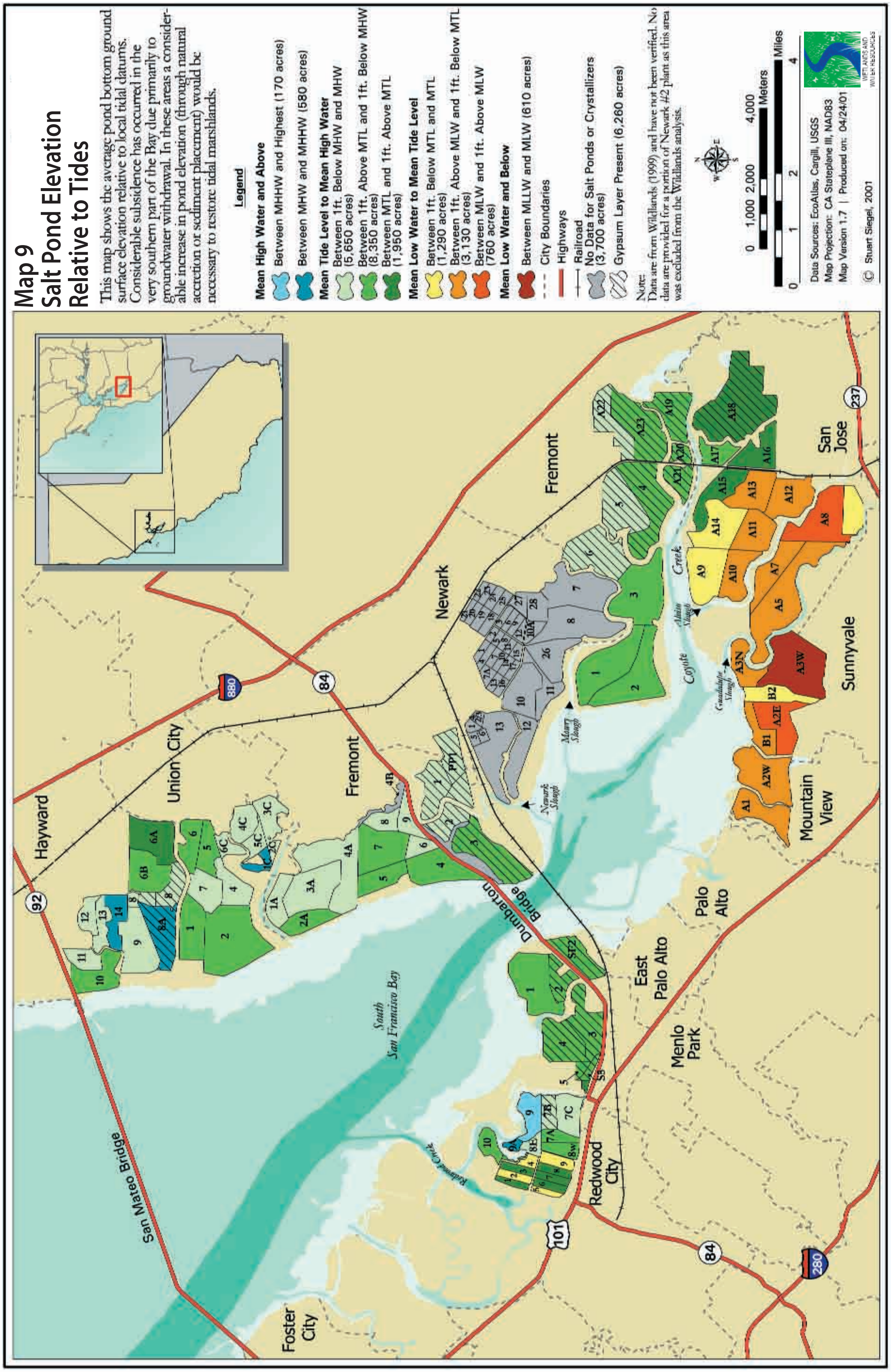
Hayward
Union City
Fremont
Newark
San Jose
Sunnyvale
Mountain View
Palo Alto
East Palo Alto
Menlo Park
Redwood City
Foster City
San Mateo Bridge
Dumbarton Bridge
South San Francisco Bay
Newark Slough
Mowry Slough
Coyote Creek
Alviso Slough
Guadalupe Slough

Map 8

169


Map 9
Salt Pond Elevation
Relative to Tides
This map shows the average pond bottom ground surface elevation relative to local tidal datums. Considerable subsidence has occurred in the very southern part of the Bay due primarily to groundwater withdrawal. In these areas a considerable increase in pond elevation (through natural accretion or sediment placement) would be necessary to restore tidal marshlands.
Legend
Mean High Water and Above
Between MHHW and Highest (170 acres)
Between MHW and MHHW (580 acres)
Mean Tide Level to Mean High Water
Between 1ft. Below MHW and MHW (5,650 acres)
Between 1ft. Above MTL and 1ft. Below MHW (8,350 acres)
Between MTL and 1ft. Above MTL (1,950 acres)
Mean Low Water to Mean Tide Level
Between 1ft. Below MTL and MTL (1,290 acres)
Between 1ft. Above MLW and 1ft. Below MTL (3,130 acres)
Between MLW and 1ft. Above MLW (760 acres)
Mean Low Water and Below
Between MLLW and MLW (610 acres)
City Boundaries
Highways
Railroad
No Data for Salt Ponds or Crystallizers (3,700 acres)
Gypsum Layer Present (6,260 acres)
Note:
Data are from Wildlands (1999) and have not been verified. No data are provided for a portion of Newark #2 plant as this area was excluded from the Wildlands analysis.
0 1,000 2,000 4,000 Meters
0 1 2 4 Miles
Data Sources: EcoAtlas, Cargill, USGS
Map Projection: CA Stateplane III, NAD83
Map Version 1.7 | Produced on: 04/24/01
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WETLANDS AND WATER RESOURCES
San Mateo Bridge
Hayward
Union City
Fremont
Newark
Fremont
San Jose
Sunnyvale
Mountain View
Palo Alto
East Palo Alto
Menlo Park
Redwood City
Foster City
Dumbarton Bridge
South San Francisco Bay
Coyote Creek
Newark Slough
Mowry Slough
Alviso Slough
Guadalupe Slough
Redwood Creek
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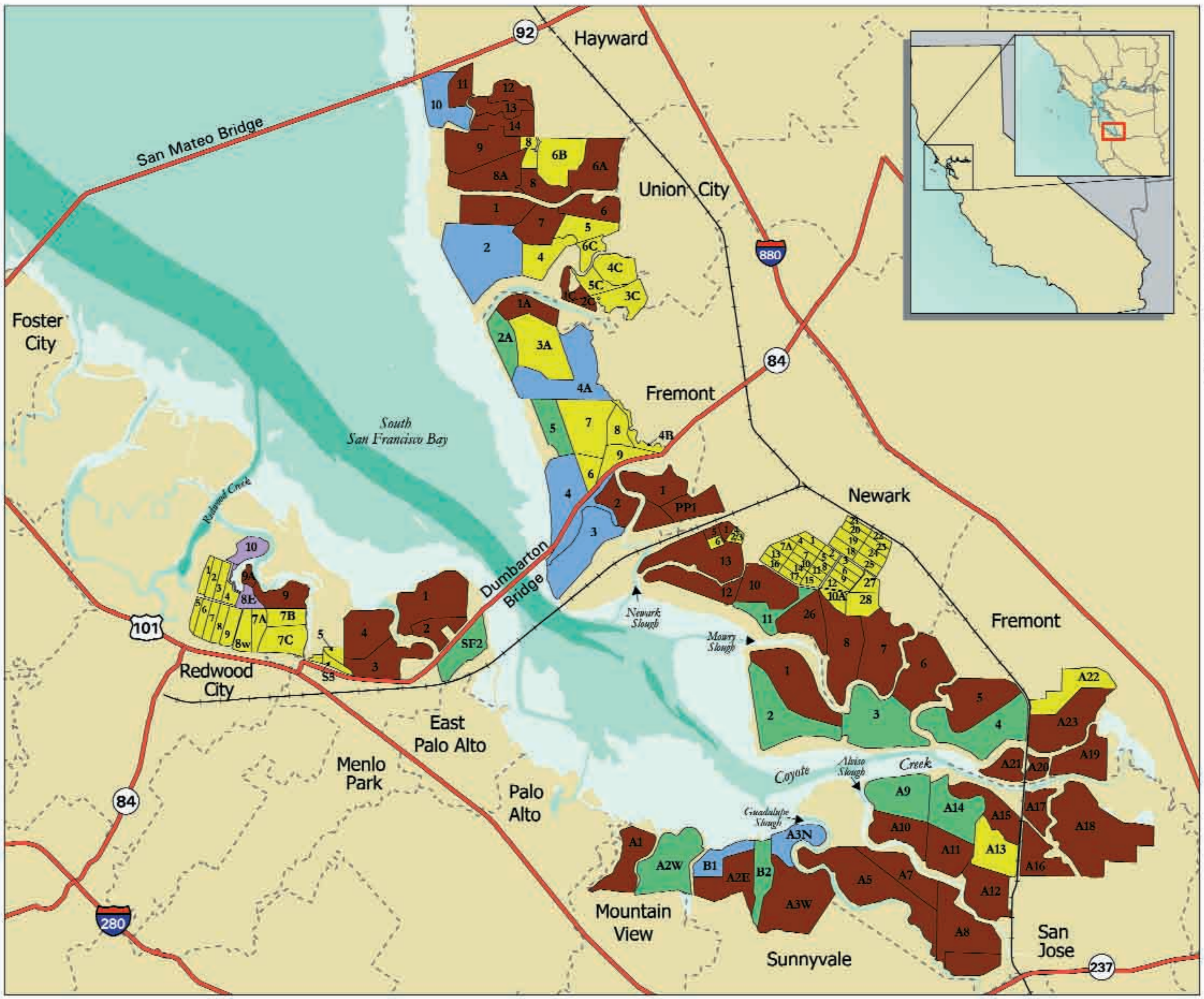


Map 10
Potential Hydrologic Connections to Tides

This map identifies how tidal action might be restored to the salt ponds as part of tidal marsh restoration. Ponds with an open bay edge are the easiest to provide tidal action. Ponds with tidal connections along tributary channels can be more difficult to provide tidal action, depending on the size of the tributary channel. Ponds with no tidal connection require bringing tidal action through an adjacent pond. Tidal marsh outboard of the ponds constrains restoration because new channels need to be created across these marshes (through natural erosion and/or mechanical excavation) and this marsh loss can have adverse impacts to wildlife.

Legend

Relatively Easy to Provide Tidal Connection
- Open Bay Edge, no Marsh (2,780 acres)
- Open Bay Edge, Marsh (3,680 acres)

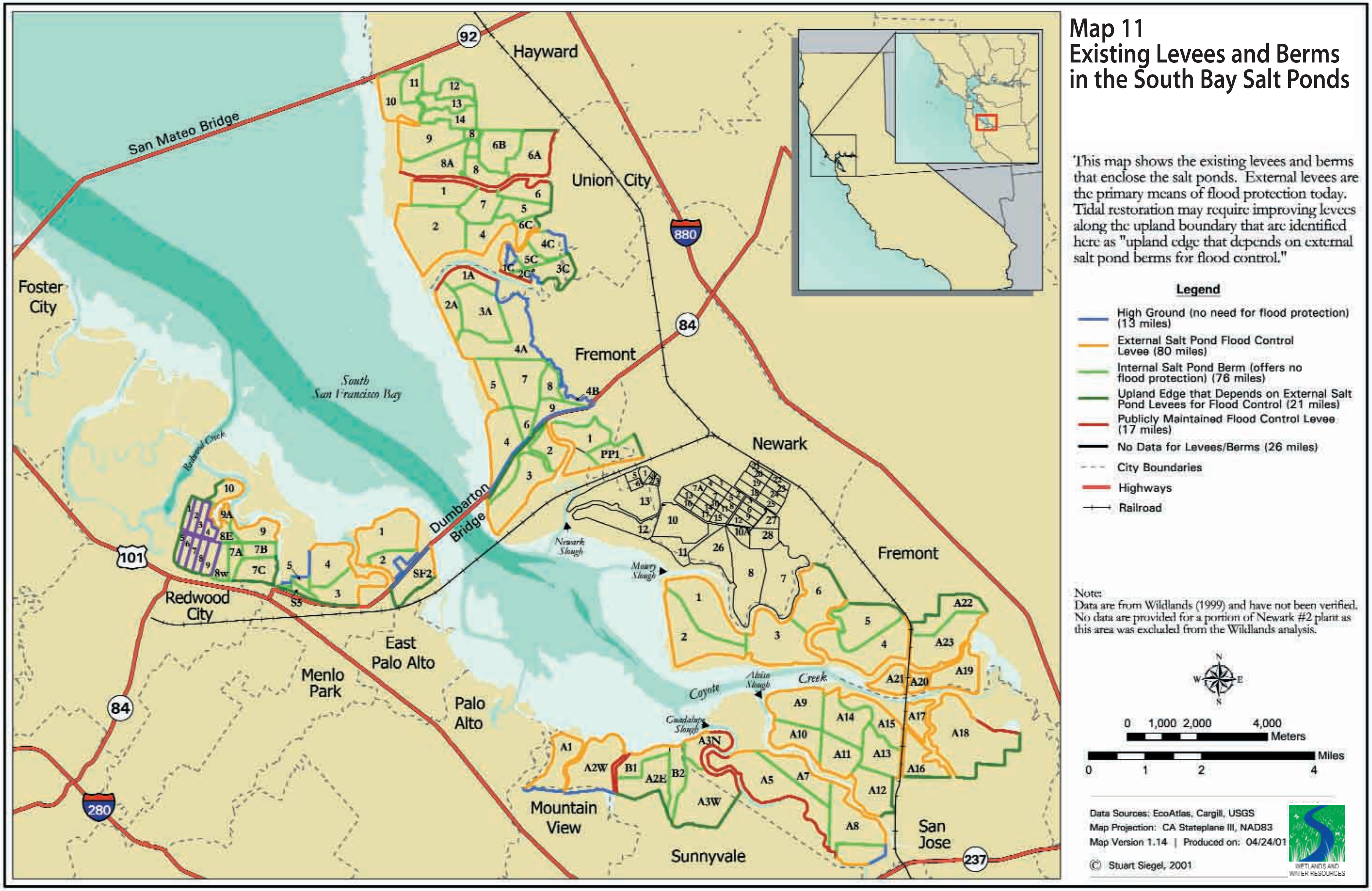
Ease of Tidal Connection Depends on Size of Channel
- Tributary Channel, no Marsh (180 acres)
- Tributary Channel, Marsh (14,330 acres)

Most Difficult to Provide Tidal Connection
- No Tidal Edge (5,220 acres)
- City Boundaries
- Highways
- Railroad

Note:
Where more than one tidal connection is possible, the more likely option is identified in this map.

0 1,000 2,000 4,000 Meters
0 1 2 4 Miles

Data Sources: EcoAtlas, Cargill, USGS
Map Projection: CA Stateplane III, NAD83
Map Version 1.4 | Produced on: 06/19/01


Map 11
Existing Levees and Berms in the South Bay Salt Ponds
This map shows the existing levees and berms that enclose the salt ponds. External levees are the primary means of flood protection today. Tidal restoration may require improving levees along the upland boundary that are identified here as "upland edge that depends on external salt pond berms for flood control."
Legend
High Ground (no need for flood protection) (13 miles)
External Salt Pond Flood Control Levee (80 miles)
Internal Salt Pond Berm (offers no flood protection) (76 miles)
Upland Edge that Depends on External Salt Pond Levees for Flood Control (21 miles)
Publicly Maintained Flood Control Levee (17 miles)
No Data for Levees/Berms (26 miles)
City Boundaries
Highways
Railroad
Note:
Data are from Wildlands (1999) and have not been verified. No data are provided for a portion of Newark #2 plant as this area was excluded from the Wildlands analysis.
0 1,000 2,000 4,000 Meters
0 1 2 4 Miles
Data Sources: EcoAtlas, Cargill, USGS
Map Projection: CA Stateplane III, NAD83
Map Version 1.14 | Produced on: 04/24/01
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San Mateo Bridge
Hayward
Union City
Fremont
Newark
Foster City
Redwood City
East Palo Alto
Menlo Park
Palo Alto
Mountain View
Sunnyvale
San Jose
Dumbarton Bridge
South San Francisco Bay
Redwood Creek
Newark Slough
Mowry Slough
Alviso Slough
Coyote Creek
Guadalupe Slough
92
880
84
101
280
237

Map 12
Infrastructure Potentially Affecting the South Bay Salt Ponds

This map shows the major physical infrastructure elements that affect the South Bay salt ponds. Not researched or shown but potentially present are underground pipelines and associated facilities for petroleum, natural gas, telephone, fiber obtic, storm water, etc. There are no sewer outfalls in the east bay south of the San Mateo Bridge; all east bay sewer discharges north of San Jose are pumped north through the East Bay Dischargers Authority pipeline to the outfall in San Leandro.

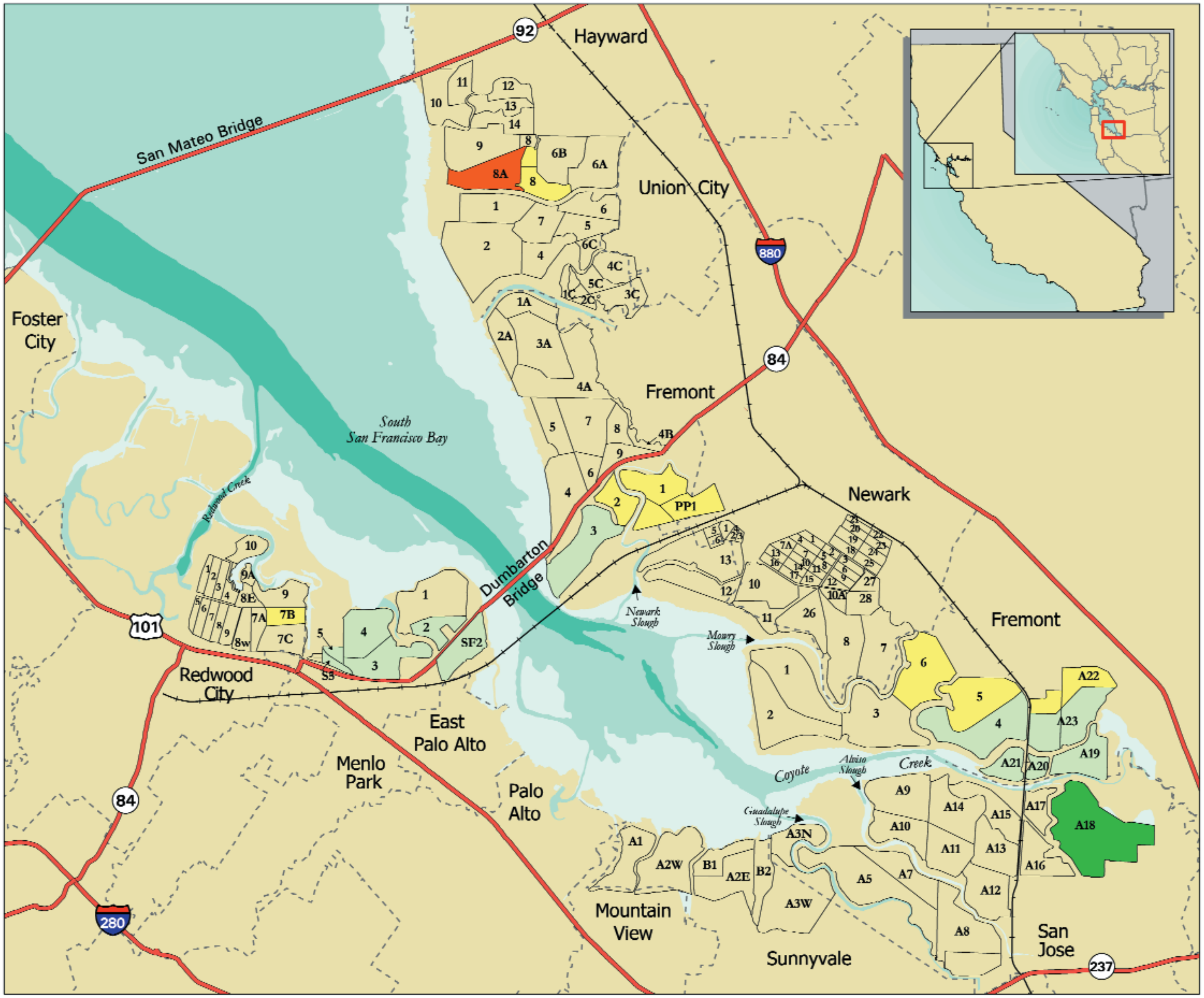
Legend

- Industrial Outfall Location
- Sewer Outfall Locations
- Sewer Force Mains
- Hetch Hetchy Aqueduct
- Overhead Power Transmission Lines
- Underground Distribution Line
- Railroad
- Highways

Note:
The PG&E overhead and underground electrical transmission and distribution line data are from a 1999 PG&E facilities map. The East Bay super sewer force main data are from the EIR for its construction. The Sunnyvale and South Bayside System Authority force main and outfall data are provided by those entities. San Jose outfall data are from RWQCB, 1995.

0 1,000 2,000 4,000 Meters
0 1 2 4 Miles

Data Sources: EcoAtlas, Cargill, USGS, EBDA, PG&E, SBSA, RWQCB
Map Projection: CA Stateplane III, NAD83
Map Version 1.5 | Produced on: 06/19/01



Map 13 Gypsum Constraints with Salt Pond Elevation

This map shows the constraint that gypsum layers may present for tidal marsh restoration as a function of pond bottom elevation. The higher the pond elevation, the greater potential that the gypsum will interfere with plant colonization and channel formation. Unknown is whether gypsum would interfere with subsurface water movements in any ecologically significant manner, a topic little studied in tidal wetlands.

Legend

Gypsum Likely to Interfere with Tidal Marsh Restoration

- Between MHW and MHHW (310 acres)

Gypsum Could Interfere with Tidal Marsh Restoration

- Between 1ft. Below MHW and MHW (2,140 acres)

Gypsum Less Likely to Interfere with Tidal Marsh Restoration

- Between 1ft. Above MTL and 1ft. Below MHW (2,950 acres)
- Between MTL and 1ft. Above MTL (860 acres)

City Boundaries

Highways

Railroad

0 1,000 2,000 4,000 Meters

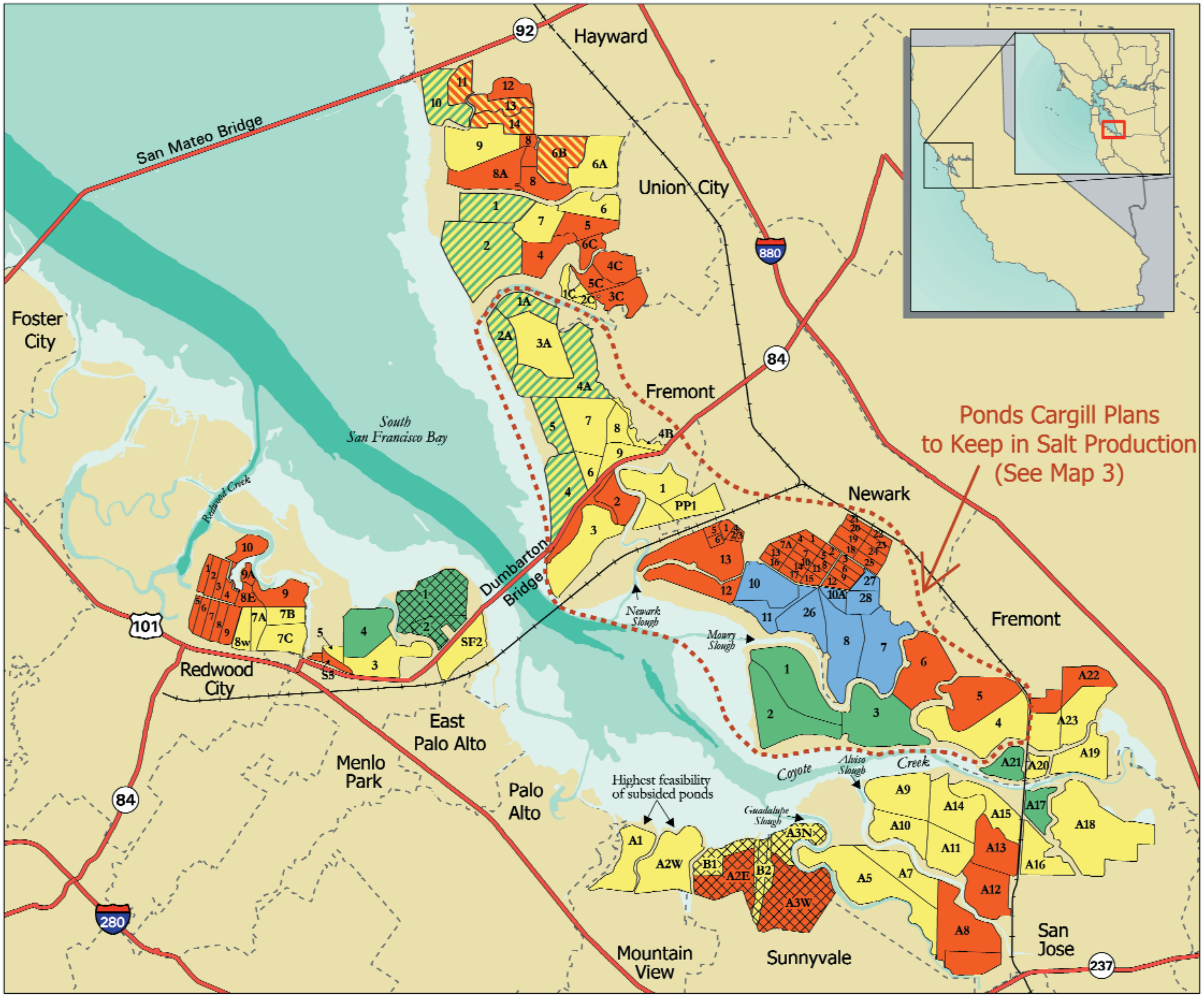
0 1 2 4 Miles

Data Sources: EcoAtlas, Cargill, USGS
Map Projection: CA Stateplane III, NAD83
Map Version 1.5 | Produced on: 06/19/01

WETLANDS AND WATER RESOURCES

Map 14
Relative Feasibility of Restoring the South Bay Salt Ponds to Tidal Marsh

This map shows the integrated analysis of relative feasibility of restoring every salt pond to tidal marsh (portions of Newark #2 plant with insufficient data not included in the analysis). Relative feasibility considers elevation, tidal connection, flood hazards, existing bird use, salinity, infrastructure, gypsum, *Spartina alterniflora*, and overall evaluation of the entire salt pond complex. Designations shown here are inherently subjective and each pond has different and site-specific reasons for its classification. In several cases we assume clusters of ponds would be restored as a means to reduce overall flood hazard protection needs relative to restored acreage.



Legend

- High Feasibility (2,690 acres)
- Medium Feasibility (10,550 acres)
- Low Feasibility (7,700 acres)
- Medium Feasibility; Would Increase to High Feasibility if no *Spartina alterniflora* Problem (2,690 acres)
- Low Feasibility; Would Increase to Medium Feasibility if no *Spartina alterniflora* Problem (730 acres)
- Ponds Selected for Case Study (2,040 acres)
- Insufficient Data to Determine Feasibility (1,830 acres)
- City Boundaries
- Highways
- Railroad

0 1,000 2,000 4,000 Meters

0 1 2 4 Miles

Data Sources: EcoAtlas, Cargill, USGS
Map Projection: CA Stateplane III, NAD83
Map Version 1.5 | Produced on: 06/19/01

WETLANDS AND WATER RESOURCES

Appendices

Appendix A

Dependence of Evaporation Rates on Salinity and Water Temperatures

Appendix A: Dependence of Evaporation Rates on Salinity and Water Temperature

Evaporation rates are a rate limiting parameter for solar salt production. Ultimately, the rate that salt is precipitated from solution fundamentally depends upon the rate the water is withdrawn from the system. This rate depends upon both evaporation and precipitation. Precipitation to the solar salt production pond system is climate driven and therefore cannot be managed. Thus, evaporation is the remaining variable that can be managed to control water loss from the solar salt production system.

Evaporation depends upon many variables including wind speed, saturation vapor pressure, relative humidity, air temperature and solar radiation (Brutsaert 1982, Penman 1948). In freshwater systems (specific gravity = 1.00), saturation vapor pressure does not vary and thus only local climatic variables cause evaporation rates to vary. For instance, Oroud (1995) calculated that for a hypothetical freshwater lake in the region of the Dead Sea, evaporation would vary seasonally from 0.065 m (0.21 ft) in January to about 0.3 m (0.98 ft) during July. Mean annual evaporation was calculated as 2.1 m y^{-1} (6.9 ft y^{-1}).

Ver Planck (1958) estimated that net evaporation ranged from 34 to 43 in per year (2.83 – 3.9 feet annually). With area rainfall in the range of 10 to 22 inches annually, gross evaporation rates are likely around 55 inches per year or 4.6 ft annually. Evapotranspiration rates ranging from 3.96 to 4.17 feet annually measured around the estuary (CIMIS: Brentwood, Morgan Hill, San Jose). Lafleur (1990) and Brutsaert (1982) have found that evapotranspiration is approximately 70 – 100% that of evaporation. Assuming that evapotranspiration rates are about 85% of evaporation rates, CIMIS data can be used to predict evaporation rates of 4.6 – 4.9 feet annually. Thus, evaporation rates in the Bay Area are on the order of 70% those of rates recorded near the Dead Sea.

In saline waters, salinity and water density greatly affect the saturation vapor pressure and this affects evaporation rates (Salhorta *et al.* 1985). As salinity increases, saturation vapor pressure increases, the vapor pressure gradient between the water and air decreases, and the evaporation rate decreases (Stanhill 1994). Thus, whereas Oroud (1995) predicted annual evaporation rates of 2.1 m yr^{-1} for a freshwater lake (SG = 1.00), annual evaporation rates were only a quarter of that at 0.58 m y^{-1} (1.9 ft y^{-1}) for a saline lake with a SG = 1.34. Evaporation rates were not only affected annually but seasonally as well ranging from only 0.000 m in January to 0.145 m (0.48 ft) in July.

Stanhill (1994) developed an empirical relationship between annual evaporation and surface density in the Dead Sea:

$$E = 4.701 - 2.926D \qquad \text{(Eq. A-1)}$$

where E = evaporation rate (m y^{-1}) and D = water density (g cm^{-1}). This relationship described 98% of the variation between evaporation rates measured in the Dead Sea and corresponding water densities. Salhotra *et al.* (1985) demonstrated this same linear relationship seasonally.

In the crystallizer ponds, salt crusts form and deposit to the sediments. In these ponds, evaporation rates may be further reduced than just by the increase in salinity alone. Fujiyasu and Fahey (2000) showed that in systems in which salt crusts formed, evaporation was further reduced by increased surface reflectivity and an increased surface resistance to moisture transfer.

Cargill achieves salinity in the bittern ponds of 36 °Be at which point brine concentration from evaporation essentially ceases (Ransom, personal communication). Essentially, at this point, evaporation

equals precipitation and no water is further removed from the brine. Precipitation in the South Bay is approximately 15 to 20 inches annually depending upon the location around the Bay Area (WRCC 2000). From the above discussion, the reduction in evaporation is likely do to a combination of:

- Reduction in evaporation from salinity increases
- Decrease in evaporation by increased surface reflectivity
- Increased surface resistance to moisture transfer.

In estimating evaporation rates in the Cargill salt ponds, annual evaporation rates will depend upon salinity and a relationship similar to that for Equation A-1 is expected. However, two differences between the systems will modify the relationship. First, though evaporation depends upon specific gravity, it also has been found to depend upon the specific ions in solution. Salhotra *et al.* (1985) found that Dead Sea water had evaporation rates that were slightly higher than concentrated Mediterranean Sea Water rates with the same salinity. From our analyses, the differences in ion concentrations caused salinity to vary between the two water sources (at the same salinity) by about 5 – 10%. Second, the climatic differences between the areas affect evaporation rates. This is evidenced by the differences in freshwater evaporation rates. Assuming from Ver Planck (1958) that average gross evaporation rates in the Bay Area are 4.75 feet annually, then Bay Area evaporation rates are approximately 70% of those measured in the near the Dead Sea. Thus, to empirically approximately evaporation rates in the South Bay salt ponds, Equation A-1 can be modified such that:

$$E = K(4.701 - 2.926D) = 3.291 - 2.048D \qquad \text{(Eq. A-2)}$$

where K is defined as the ratio between Bay Area and Dead Sea freshwater evaporation rates and is approximately 70%.

Figure A-1 shows the predicted evaporation rates for different salinity levels in the South Bay Salt Production Ponds. Based upon the salt production model provided by Ver Planck, evaporation rates can be predicted for the solar salt pond complex with each pond representing 10% of the total salt production pond area (Table A-1). From that analysis, average gross evaporation rates for the salt ponds are approximately 3.3 ft y^{-1} and average net evaporation rates is 1.9 ft y^{-1}. This value is in rough agreement information from Ver Planck (1958) on maximum salt production rates in the Bay Area. Ver Planck (1958) estimated that maximum salt production was 40 tons ac^{-1} y^{-1} and that production rate required 1,530 tons ac^{-1} y^{-1} of water at 0.224 lbs of salt per gallon. This is roughly equivalent to seawater at 0.228 lbs of salt per gallon. However, more recent data shows that Bay Water is on the order of 20 ppt (SG = 1.022). At this concentration, approximately 2100 tons ac^{-1} y^{-1} of water would be required or 1.5 ft y^{-1}. This is about 20% less than predicted net evaporation rates and is reasonable given the assumptions and uncertainty in this analysis.

Because the salt production ponds are saline systems, there are certain manipulations that will affect evaporation rates. Shifting the average salinity of the system will affect evaporation rates. By shifting the average salinity downward, evaporation rates will increase. By shifting average salinity upwards, the evaporation rates will decrease. A downward shift in salinity would occur if unusually high volumes of input water were introduced for any given year.

A second method to alter evaporation rates may be through manipulating water temperatures. In saline systems, as water temperature increases, surface vapor pressure of the water surface increases causing an increased vapor pressure gradient with the overlying air (Stanhill 1994). This increased gradient in turn causes an increase in evaporation rates. As waters become more saline, their water temperature naturally increases. Salhotra showed that as water increased in salinity from around 6 to 27 °Be, water temperature increases by around 3 to 5 °C (5 to 9 °F) depending upon the time of year. Water temperatures can also be increased by operating ponds shallower (Bachand 1996). Higher evaporation rates correspond to higher water temperatures (Stanhill 1994). Thus, in more saline ponds, it may be possible to increase evaporation rates by operating the ponds shallower.

Figure A-1. Changes in evaporation with increasing salinity.

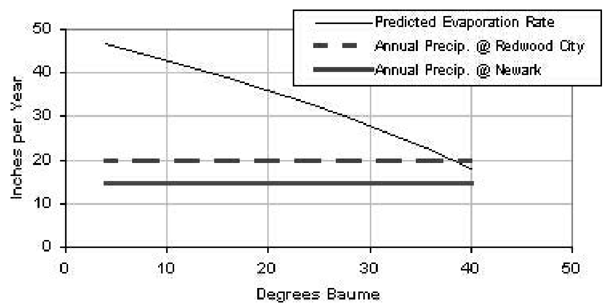


Table A-1. Predicted evaporation rates for the solar salt pond complex.

Pond No.	Salinity Be	Gross Evap in/y	Precipitation in/y	Net Evap. in/y
1	3	47.21	17.35	29.87
2	4	46.63	17.35	29.28
3	5	46.22	17.35	28.87
4	8	44.21	17.35	26.86
5	10	42.69	17.35	25.34
6	13	41.04	17.35	23.70
7	17	38.21	17.35	20.86
8	21	35.34	17.35	17.99
9	26	31.63	17.35	14.28
10	29	28.76	17.35	11.41
Average		40.19	17.35	22.85

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Table A-1. Effect of ion characteristics of water (Salhotra)

S.G. g/cm	Mean evap mm/d	m/y	intercept	slope	R^2
Dead Sea water:					
1.16	5.37	1.96005	8.75	-5.85	1.00
1.233	4.2	1.533			
Mediterranean water:					
1.037	6.16	2.2484	4.60	-2.26	0.96
1.153	5.57	2.03305			
1.186	5.18	1.8907			
Combined					
1.16	5.37	1.96005	5.77	-3.32	0.85
1.233	4.2	1.533			
1.037	6.16	2.2484			
1.153	5.57	2.03305			
1.186	5.18	1.8907			

Empirical Dead Sea Evaporation	Intercept	4.701	2.926
Bay Area Correction			0.7
Empirical Bay Area Evaporation		3.2907	2.0482

$$E = 4.701 - 2.926D$$

Table A-2. Bay area Evaporation rate predictions

E m/y	E ft/y	in/y	Salinity Be	SG	g/L	Precipitation Newark	RC
1.18	3.89	46.63	4	1.03	31	14.66	20.03
1.12	3.68	44.21	8	1.06	83	14.66	20.03
1.06	3.47	41.64	12	1.09	135	14.66	20.03
0.99	3.24	38.92	16	1.12	187	14.66	20.03
0.91	3.00	36.01	20	1.16	239	14.66	20.03
0.84	2.74	32.92	24	1.20	291	14.66	20.03
0.75	2.47	29.62	28	1.24	343	14.66	20.03
0.66	2.17	26.08	32	1.28	395	14.66	20.03
0.57	1.86	22.28	36	1.33	447	14.66	20.03
0.46	1.52	18.20	40	1.38	473	14.66	20.03

Table A-3. Average Evaporation Rate for Complex based upon Ver Planck 10 pond model

Pond No.	Salinity Be	Salinity SG	Gross Evap m/y	Gross Evap ft/y	Gross Evap in/y	Precipitati in/y	Net Evap. in/y
1	3.2	1.02	1.20	3.92	47.10	17.35	29.75
2	4	1.03	1.18	3.89	46.63	17.35	29.28
3	4.7	1.03	1.17	3.85	46.22	17.35	28.87
4	8	1.06	1.12	3.68	44.21	17.35	26.86
5	10.4	1.08	1.08	3.56	42.69	17.35	25.34
6	12.9	1.10	1.04	3.42	41.04	17.35	23.70
7	17	1.13	0.97	3.18	38.21	17.35	20.86
8	20.9	1.17	0.90	2.94	35.34	17.35	17.99
9	25.6	1.21	0.80	2.64	31.63	17.35	14.28
10	29	1.25	0.73	2.40	28.76	17.35	11.41
	32	1.28	0.66	2.17	26.08	17.35	8.74
	36	1.33	0.57	1.86	22.28	17.35	4.94
Average				3.35	40.18	17.35	22.84

Table A-4. Hydrologic Mass Balance

	ton/ac/y	lbs/ac/y	cu ft/ac/y	ft/y	in/y	ppt	Be	SG	tons of salt	lbs salts/gal	lbs NaCl/gal	tons salt/acre
Sea Water	1,530	3,060,000	47,605	1.09	13.11	35	4.3	1.0306	53.55	0.292	0.227	41.6
Bay Water	2,434	4,868,182	76,274	1.75	21.01	22	3.3	1.0233	53.55	0.183	0.143	41.6

Appendix B

1979 USFWS - Leslie Salt Company Agreement on Salt Production on Refuge Lands

THIS AGREEMENT is made and entered into this 29th day of June, 1979, by and between THE UNITED STATES FISH AND WILDLIFE SERVICE (hereinafter called "the United States"), and LESLIE SALT CO., a Delaware corporation (hereinafter called "Leslie").

RECITALS

WHEREAS, the Declaration of Taking dated June 30, 1977, covering certain lands of Leslie described in Exhibit A ("the Property") to be included within the San Francisco Bay National Wildlife Refuge ("the Refuge"), excepted and reserved to Leslie certain rights, privileges, and easements ("Leslie's Reserved Rights"), title to which remained in Leslie; and

WHEREAS, said Declaration of Taking was amended twice to modify the land descriptions and to revise the estate; and

WHEREAS, the United States and Leslie believe that the Refuge and Leslie's operations are compatible and capable of existing together on the property; and

WHEREAS, the United States and Leslie desire, by this Agreement, to protect the Refuge and to establish procedures and remedies for review of decisions made by the United States in managing the Refuge which adversely affect Leslie's Reserved Rights and for assuring compensation or other remedies provided by law to Leslie for damage to its Reserved Rights and for payment to Leslie of additional costs of operation which may be caused by Refuge activities, as provided by this Agreement.

NOW THEREFORE, the United States and Leslie, in an effort to more clearly define their respective rights and responsibilities, do hereby acknowledge and agree:

1. Leslie and the United States agree that Leslie's activities and operations on the Property shall conform to, and be governed by, the rules and regulations prescribed from time to time by the Secretary of the Interior or his authorized agent, the Director of the Fish and Wildlife Service, and restrictions established by the Refuge Manager (the "Manager"), but only to the extent such rules, regulations, and restrictions are consistent with Leslie's exercise of its Reserved Rights.

Should the United States, its agents, designees and permittees take any action which interferes with or otherwise adversely affects Leslie's Reserved Rights then Leslie shall be entitled to compensation and other remedies as provided by law and this agreement, on account of impairment, interference with, or the taking of Leslie's Reserved Rights.

2(a) The United States agrees that Refuge activities will not be exercised in a manner that will diminish Leslie's Reserved Rights. The United States shall enforce regulations covering the safety and conduct of Refuge employees, agents, contractors, members of the public, and all other persons (except employees or invitees of Leslie), while on the Property with the express or tacit permission of the United States. It is recognized by and between the United States and Leslie that such persons shall be present on the Property at the sole invitation, and for the sole benefit, of the United States, and Leslie shall have no responsibility to ensure the safety or regulate the conduct of such persons. The United States shall also make reasonable efforts to prevent entry of trespassers upon and remove

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trespassers from the Property.

(b) It is recognized that various pumps, siphons, pipelines, fences, piers, wharves, weirs, gates, pump houses and other fixtures, equipment, and structures owned by Leslie and used in connection with Leslie's Reserved Rights will be maintained upon the Property by Leslie, and that such fixtures, equipment, and structures or those which may be constructed in the future are susceptible to damage and, along with various other conditions existing on the Property, constitute a potential hazard. In recognition of such facts, it is agreed that the United States, at its expense, shall construct and maintain protective devices for all such fixtures, equipment, and structures or conditions located in intensive public use areas and public use areas which may either present hazards to, or be susceptible to damage by, the employees, agents, contractors, and invitees of the United States. The United States shall maintain such devices at its expense.

(c) The United States shall also provide posting and patrols in an effort to protect said facilities.

(d) The public shall not be permitted to conduct equestrian activities or operate any motor-driven vehicle, machine, or motor-driven boat on, or in, any dikes, levees, roads, paths, or ponds in areas defined in Paragraph 7 as public use areas or closed areas, except by mutual agreement between the Manager and Leslie. The United States agrees to enforce regulations to prohibit such use. Furthermore, the United States agrees to regulate the parking, traffic flow, and other uses of motor-driven vehicles and machines and motor-driven boats in areas defined in Paragraph 7 as intensive public use areas so that such uses will not interfere

with Leslie's Reserved Rights.

3. All water control and other fixtures, equipment, and structures, other than dikes, levees, roads or paths, existing or hereinafter constructed by Leslie on the Property, associated with Leslie's Reserved Rights, such as pumps, siphons, pipelines, pump stations, nets, traps, posts, piers, wharves, weirs, gates, and tide gates, shall, unless otherwise herein provided, be the sole property of Leslie. However, piers, wharves, and other structures designed to permit or facilitate travel and forming an integral part of, or extension of, dikes, levees, roads, or paths, shall be treated the same as dikes, levees, roads, and paths for purposes of use and maintenance. Leslie shall give thirty (30) days' written notice to the Manager prior to the location of new fixtures, equipment, or structures, or the relocation of any existing fixtures, equipment, or structures, constructed by Leslie on the Property. Said fixtures, equipment, and structures shall be subject to the approval of the United States as to location, which approval shall not unreasonably be withheld, provided that Leslie shall have the right to compensation for damages to its operations or additional costs of operation sustained as a result of the disapproval or other action of the United States under this provision.

If Leslie's interest should for any reason terminate in whole, or in part, Leslie shall have the right, but not the obligation, after thirty (30) days' written notice to the Manager, to remove any fixtures, equipment, or structures within a reasonable time following such notice.

Leslie shall not leave any dikes or levees in a breached condition as a result of such removal nor leave any substantial holes or pits in any dikes or levees as a result of such removal. Any fixtures, equipment, or structures not removed within a reasonable time shall be deemed abandoned. However, the United States shall have the option, exercisable upon notice to Leslie within thirty (30) days after receiving the notice, to purchase any such fixtures, equipment, or structures at their then-prevailing fair market value.

4. The total salt pond acreage within the Property existing as of June 30, 1977, shall not be increased, nor shall land within the Property not part of a salt pond on June 30, 1977 be converted to salt pond use or bittern storage use, nor shall salt ponds within the Property be converted into crystallizers, without the written approval of the Manager.

5. The United States, in the management of the Refuge, and Leslie, in its operations with respect to its Reserved Rights, agree that they shall take all reasonable actions, consistent with their respective interests and rights in the Property as provided herein, to protect the interest and rights of the other in the Property.

The United States, its agents and contractors, may harvest and sell brine shrimp and bait fish produced from the Property, as well as other biological products the control of which is not necessary or desirable for the exercise of Leslie's Reserved Rights. The United States will not, without the written consent of Leslie, confer any

other private economic use, or right of access for such use, upon any third party.

6. Leslie may voluntarily terminate all or a portion of its right, privilege and easement in all or any portion of the Property at any time by executing and delivering to the United States a quitclaim deed of the interest to be terminated. Within a reasonable period following such termination Leslie may, but is not obligated to, remove any and all fixtures, equipment, and structures constructed by Leslie on the Property, unless said fixtures, equipment, and structures shall have been abandoned or are to be purchased by the United States under the option contained in Paragraph 3. It is mutually agreed that any termination under this section shall not create any rights in Leslie to benefits under the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970 (84 Stat. 1894, 42 USC Section 4601, et seq.).

7. Leslie shall have the right, but not the obligation, to perform such maintenance, repair, and construction work on the Property as Leslie believes is necessary or desirable for enjoyment of its Reserved Rights, at such standards as Leslie believes appropriate for protection of its Reserved Rights. Subject to the limitations of Paragraph 4, said work shall include, but is not limited to, the maintenance, construction, removal, or relocation of exterior dikes and levees, and dikes and levees not affected by tidal action, or other improvements, in accordance with an annual schedule of work delivered to the Manager by April 15 of each year covering Leslie's succeeding fiscal year, commencing June 1 and ending May 31, which shall specifically describe such item of work, its location, and the period within

which such item of work will be performed. The Manager may require that Leslie modify an item of work or provide for a different period of time within which such work may be performed if such work or the scheduling thereof would be materially injurious to Refuge purposes; provided, however, that the Manager shall notify Leslie of any such modifications within thirty (30) days of his receipt of Leslie's annual schedule of work and provided further that the United States shall bear any additional costs resulting from such modifications.

The United States shall, as early in each year as possible, provide Leslie with its annual schedule of work for the succeeding year.

Leslie shall also have the right, but not the obligation, to perform emergency repair work necessary for dike or levee rupture repair, dike or levee failure prevention, pump repair, gate repair, or to correct any other condition posing imminent threat to Leslie's operations, property, or Reserved Rights. Whenever Leslie elects to undertake such emergency work, Leslie shall immediately notify the Manager and shall take all reasonable measures requested by the Manager in carrying out such emergency work to prevent harm to wildlife or to Refuge activities or improvements.

Work not included in the annual schedule of work and other than emergency repair work may be performed by Leslie upon written approval by the Manager, which approval will not unreasonably be withheld. Such approval shall be granted or denied within thirty (30) days following receipt of a request by Leslie.

Leslie shall not be required to bear the expense of construction or maintenance of improvements and/or structures to the extent caused by use of the Property by the United States.

Leslie shall not be required to perform work made necessary by the activities of the United States or requested by the United States, unless Leslie and the United States shall first have agreed in writing on the amount and the time and method of payment of compensation for same.

The United States shall, for the purpose of determining maintenance obligations, classify dikes, levees, roads and paths, or portions thereof, into one of the following categories: (1) closed areas; (2) public use areas; and (3) intensive public use areas. The United States may reclassify any portion of the dikes, levees, roads and paths from one category to another category by giving written notice to Leslie of such reclassification and reclassification shall be effective as of the date thereafter designated in the written notice given to Leslie, subject to the following conditions:

(a) An "intensive public use area" which is reclassified a "public use area" or a "closed area" shall be returned by the United States to its original condition (as of June 30, 1977). For the purpose of determining maintenance obligations, it will be deemed an "intensive public use area" for two full Leslie fiscal years following the Leslie fiscal year in which it is reclassified and returned to its original condition.

(b) An area classified as a "public use area" which is reclassified as a "closed area" will, for the purpose of determining maintenance obligations, be deemed a public use area for two full Leslie fiscal years following the Leslie fiscal year in which it is reclassified.

"Closed areas" shall be those areas closed to public use with access only for Refuge management, including research and the commercial harvesting of brine shrimp and bait fish. The United States will not be liable for paying any increase in cost incurred by Leslie in maintaining and repairing any dikes, levees, roads or paths within "closed" areas except to the extent use of said dikes, levees, roads or paths in the management and operation of the Refuge, including research and the commercial harvesting of brine shrimp and bait fish, increases Leslie's maintenance and repair costs.

"Intensive public use areas" shall be those areas in which the activities of the United States or the public utilize vehicles (including multiple-unit vehicles) on any dike, levee, road, or path with gross weight in excess of 4,000 pounds, or impose an intensive use which threatens the stability, safety, or function of any such dike, levee, road, or path, or results in substantially increased maintenance costs of any dike, levee, road, or path. Such activities shall include, but not be limited to, use of any dikes, levees, roads, or paths, on a regular basis, where the public is transported by motorized vehicle but shall not include infrequent use by vehicles (including multiple unit vehicles), with gross weight in excess of 4,000 pounds, where prior written notice is given to Leslie. The United States shall maintain and repair all dikes, levees, roads or paths in such areas.

All areas not classified as either "closed" or "intensive public use" are "public use areas". Prior to August 1 each year the United States shall pay to Leslie the amount actually expended for maintenance and repair by Leslie within the "public use" areas during the preceding Leslie fiscal year, less the normal level of maintenance and repair costs, plus ten percent (10%) of the difference for administration. Said amount due Leslie from the United States shall be diminished each year by the cumulative amount, if any, (plus ten percent (10%) of the difference) by which Leslie's actual maintenance and repair expenses during the preceding two Leslie fiscal years are less than Leslie's normal level of maintenance and repair costs for said two preceding Leslie fiscal years.

The normal level of maintenance and repair costs for dikes, levees, roads and paths within "public use" areas shall be calculated as (i) the average annual maintenance and repair costs for all dikes, levees, roads and paths incurred by Leslie during the ten-year period ended December 31, 1977, on the Property; multiplied by (iia) the total linear feet of dikes and levees on the Property minus the linear feet of dikes and levees contained in "closed" and "intensive use" areas divided by (iib) the total linear feet of dikes and levees on the Property (for purposes of this calculation an area classified as "public use" during any portion of a Leslie fiscal year shall be regarded as a "public use" are for the entire Leslie fiscal year); adjusted for (iii) a reasonable cost index for comparable San Francisco Bay Area maintenance activities adjusted annually from a base year of 1977.

The term "maintenance and repair" as used in this section shall include, but not be limited to:

(1) all activities necessary to maintain the elevation of the top of the dikes and levees above the plane of highest tidal action.

(2) all activities necessary to repair a breach or failure of any dike, or levee, including the rebuilding of any portion of a dike or levee which has breached or failed.

(3) all activities necessary to alleviate a threat of breach or failure of any dike or levee.

(4) the placement of rip-rap or other dike erosion control devices on the bayward side of exterior dikes.

(5) the grading, and replacement of gravel, on the surface of roads and paths, including the re-establishment of graded road surfaces on dikes or levees which have been maintained or repaired as set forth above.

(6) the repair or replacement of bridges, intakes, and brine flow and other structures which have been damaged by traffic on roads and paths.

The term "maintenance and repair" shall not include activities necessitated by a major cataclysm of nature such as an earthquake, cyclone, typhoon or other event of comparable magnitude. Furthermore, the term maintenance and repair shall not include any upgrading in size or quality of the levees, dikes, roads and paths above the condition in which they have been historically maintained.

The responsibility of the United States and

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Leslie for the cost of repairs to dikes, levees, roads, or paths damaged by the independent acts of third parties shall be determined by the applicable law and not by this agreement.

Leslie, in reserving the right to maintain and repair all dikes, levees, roads and paths shall have the right to remove or alter any improvement and/or structure placed thereon by the United States if it is reasonably necessary to do so in maintaining and repairing the dikes, levees, roads and paths for the protection of Leslie's Reserved Rights. Any additional cost incurred by Leslie in removing or altering said United States improvement and/or structure shall be paid by the United States. Where removal or alteration is required, Leslie shall, except in an emergency, give the United States prior notice and a reasonable period of time to remove or alter the improvement and/or structure before Leslie takes such action.

The United States shall have the right to construct and maintain on the Property improvements and/or structures for Refuge purposes, provided that the United States shall give written notice to Leslie prior to the commencement of construction describing the location and extent of such improvements and/or structures; that the United States shall be responsible for all costs of construction and maintenance of said improvements and structures; and provided that said improvements and structures shall not adversely effect the stability, safety, or function of any dike, levee, road, or path and shall not otherwise interfere with Leslie's enjoyment of its Reserved Rights. If, notwithstanding the foregoing, such construction

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or maintenance does so affect the stability, safety, or function of said dikes, levees, roads, or paths or otherwise interferes with Leslie's Reserved Rights, the United States shall immediately take such action as shall be required to remedy said adverse effect or remove said interference.

Leslie will make available to the United States, at stock piles designated by Leslie, at Leslie's acquisition cost if any, any rip-rap needed in connection with such maintenance which shall be available to Leslie and not reasonably required for Leslie's operations.

8. It shall be the responsibility of Leslie to obtain all permits and approvals of agencies required for its salt-producing operation. Where the law requires the landowner to join in a permit application, the Refuge Manager will consent and join in the application to the extent not in conflict with other governmental purposes and the Refuge Manager will not unreasonably withhold such consent.

9. The United States acknowledges and agrees that Leslie shall have the right to introduce San Francisco Bay waters or brine into its salt pond system within the Property at the present points of entry or at such other points of entry as may reasonably be necessary or desirable for the enjoyment and use by Leslie of its Reserved Rights. Leslie may introduce or pump waters or brine from one salt pond to another within or without the Property, conduct brine across the Property, and alter (subject to the provisions of Paragraphs 4 and 10) the size or configuration or sequence of use of individual salt ponds during the entire cycle of evaporation prior to the harvesting of salt, and control the biological or other characteristics of salt

ponds where necessary or desirable for the production of salt.

10. It is understood that changes in the salinity and sequence of use of the various salt ponds occur from time to time in the maintenance and operation of the overall salt pond system. Leslie agrees that it will not make changes from the normal range of practice in the solar salt making business in the salinity, or sequence of use, of the salt ponds without giving the United States thirty (30) days' written notice of the change, together with the reasons the change is required.

It is understood and agreed between Leslie and United States that a reversal by Leslie of brine flow from Leslie's Redwood City system across San Francisco Bay and the incorporation of that flow into the flow of brine leading to Leslie's Newark plant is anticipated in the future. It is understood and agreed that said reversal is and will be regarded by United States and Leslie as being within the normal range of practice by Leslie.

11. The United States will provide access to Leslie, its employees, agents, and designees, and will permit Leslie to admit and deploy such equipment and materials upon the Property as are necessary or appropriate for Leslie's full use and enjoyment of its Reserved Rights.

12. Leslie shall have the right to store bittern on Tract 108 as long as Leslie deems it necessary to do so. In the event that Leslie utilizes the bittern processing and storage area on Tract 108 to its full capacity, the United States agrees that Leslie shall have the interim right to store bittern in any other salt ponds Leslie may select (1)

until such time as a bittern disposal system is in operation; or (2) during any period in which a bittern disposal system is not permitted or not operational. When a bittern disposal system is put into operation, the ponds being utilized for bittern storage, other than those required for storage in the bittern disposal system, will resume their salt pond function as part of the salt production system. The bittern disposal system shall have the capacity to dispose of all bittern generated by the South San Francisco Bay salt production of Leslie. In selecting any bittern storage area in addition to Tract 108 Leslie will consult with the Refuge Manager to seek the Manager's advice as to whether a proposed storage site will have adverse effects on the Refuge that could be avoided or mitigated by choosing an alternate site for bittern storage. The decision as to the location of additional bittern storage areas shall be made by Leslie except that Leslie will not unreasonably reject alternate sites identified by the Manager.

13. Leslie, its successors or assigns, may appeal any decision or action by the United States or its representatives directly to the Director of the Fish and Wildlife Service in Washington, D.C., who shall render a decision in writing within fifteen (15) days of receipt of said appeal. The Director's decision shall constitute final agency action for purposes of judicial review. Leslie shall have the right to seek equitable relief in Federal district court, pending the outcome of administrative procedures and judicial review thereof.

Judicial review of administrative procedures shall be in the United States District Court. If Leslie is

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seeking compensation in monetary damages, jurisdiction shall be in an appropriate federal court.

It is hereby expressly understood and agreed that the respective interests of Leslie and the United States are property interests and nothing contained herein shall be construed to limit either party's remedies to those available in ordinary contract claims.

Resort by Leslie to the appeal procedures provided herein shall be without prejudice to the right of Leslie to pursue any remedies afforded by law or equity that would otherwise be available to Leslie, including without limitation, the rights to enforce Leslie's Reserved Rights, to obtain just compensation for the taking of its property, or to obtain damages for noncompliance by the United States with this Agreement.

14. Nothing in this Agreement or the Declaration of Taking shall be construed as conferring the right on the United States to change or enlarge its use of the Property in a manner which shall restrict the use and enjoyment by Leslie of its Reserved Rights or to increase Leslie's cost of operations carried out on the Property, determined in accordance with generally accepted accounting principles consistently applied, or deprive Leslie of any of its Reserved Rights without the payment of additional compensation to Leslie. The United States accordingly acknowledges and agrees that neither entry by Leslie into this Agreement, nor the terms of acquisition by the United States of the Property, shall be construed as a waiver by Leslie, either express or to be implied by law, of: (1) any of its Reserved Rights in the Property, and the enforcement thereof;

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(2) the right to claim damages for the taking of the Property, or severance damages in connection with such taking, on account of a taking in addition to that for which Leslie previously received compensation; and (3) any other remedies afforded by law.

15. Notices under this Agreement shall be by certified mail to the party to whom the notice is being given as hereinafter provided or by actual delivery of such notice to such party and any such notice shall be deemed given when so deposited in the mail or so actually delivered.

Notice to the Manager, San Francisco Bay National Wildlife Refuge, shall be addressed:

Refuge Manager
San Francisco Bay National Wildlife Refuge
3849 Peralta Boulevard, Suite D
Fremont, California 94536

Notice to Leslie shall be addressed:

President
Leslie Salt Co.
7200 Central Avenue
Newark, California 94560

Either party may from time to time change the address which it desires to be used and upon written notice to the other party such changed address shall be inserted herein in place of the address above stated.

16. Leslie shall have the right to transfer all or any part of the interest that it possesses under this agreement and/or in and to its Reserved Rights. Any compensation paid to Leslie for such transfer shall be the sole property of Leslie.

17. All the terms and provisions of this Agreement shall be binding upon and inure to the benefit of the

parties hereto and their respective successors and assigns.

18. Nothing contained in this Agreement shall constitute a waiver of compliance with federal laws.

19. Nothing contained in this Agreement shall be construed as a waiver by either party of their rights to any other remedies afforded by law.

20. Neither the estate reserved to Leslie nor this agreement shall preclude the parties from entering into written modifications, or other written agreements, in a form acceptable for recording, without modifying the judgment to be entered in this action, and the United States is not precluded from enlarging its estate by such written agreement with Leslie, or by condemnation in the future, provided it is authorized by law to do so.

21. Any commitment by the United States set forth herein for the payment of funds to Leslie is subject to the availability of funds; provided, however, that the United States Fish and Wildlife Service will make every effort to secure an adequate appropriation of funds from Congress each fiscal year to cover the expected payments to Leslie set forth in this Agreement and, in the event that adequate funds are not available to cover any payment under the Agreement, the Service will make every effort to secure a supplemental appropriation.

IN WITNESS WHEREOF, the parties hereto have caused this instrument to be duly executed this 29th day of June, 1979.

UNITED STATES FISH AND WILDLIFE SERVICE

By William H. Meyer
Acting Regional Director William H. Meyer

LESLIE SALT CO.

By [signature]

Appendix C

Geographic Information System (GIS) Data

Appendix C. South Bay Salt Pond GIS Data

Production Plant	Pond Number	Pond Area[1]	Pond Elev[2]	Local mhhw[3]	NOS Station[3]	Pond Distance to mhhw[4]	Pond Void Space to mhhw[5]	Pond Perimeter	Bittern Storage Ponds	Bittern De-Salting Ponds	Pond Owner	Pond NGVD Elev Group
		acres	ft ngvd	ft ngvd	no.	ft	cy	m				
Map 1			Table 5-2	Table 5-2	Table 5-2	Table 5-2	Table 5-2		Map 5	Map 5	Map 2	Map 8
SALT PONDS												
Alviso	a1	285	-1.94	4.70	941-4575	6.64	3,052,197	5,734			cargill	g-2--1
Alviso	a2e	315	-3.00	4.70	941-4575	7.70	3,911,410	6,121			cargill	h-3--2
Alviso	a2w	457	-0.91	4.70	941-4575	5.61	4,139,584	6,183			cargill	f-1-0
Alviso	a3n	185	-1.45	4.70	941-4575	6.15	1,839,664	4,437			cargill	g-2--1
Alviso	a3w	606	-3.19	4.70	941-4575	7.89	7,711,402	6,913			cargill	i-4--3
Alviso	a5	661	-1.94	4.70	941-4575	6.64	7,084,466	11,130			cargill	g-2--1
Alviso	a7	269	-0.77	4.70	941-4575	5.47	2,378,458	5,871			cargill	f-1-0
Alviso	a8	444	-3.38	4.70	941-4575	8.08	5,794,576	7,116			cargill	i-4--3
Alviso	a8-south	175	**-0.50**	4.70	941-4575	5.20	1,470,672	3,640			cargill	f-1-0
Alviso	a9	372	**0.50**	4.70	941-4575	4.20	2,519,752	5,001			refuge	e0-1
Alviso	a10	253	-0.84	4.70	941-4575	5.54	2,262,034	4,864			refuge	f-1-0
Alviso	a11	268	-1.78	4.70	941-4575	6.48	2,804,240	4,148			refuge	g-2--1
Alviso	a12	314	-1.95	4.11	941-4561	6.06	3,068,939	4,707			refuge	g-2--1
Alviso	a13	283	-1.09	4.11	941-4561	5.20	2,371,850	4,574			refuge	g-2--1
Alviso	a14	351	-0.06	4.70	941-4575	4.76	2,695,369	5,486			refuge	f-1-0
Alviso	a15	252	0.67	4.11	941-4561	3.44	1,397,854	5,714			refuge	e0-1
Alviso	a16	241	0.55	4.11	941-4561	3.56	1,381,530	5,224			refuge	e0-1
Alviso	a17	136	1.13	4.11	941-4561	2.98	655,430	3,590			refuge	d1-2
Alviso	a18	856	0.49	4.11	941-4561	3.62	4,997,174	8,861			cargill	e0-1
Alviso	a19	276	1.76	4.11	941-4561	2.35	1,047,444	5,024			refuge	d1-2
Alviso	a20	67	1.78	4.11	941-4561	2.33	251,033	2,178			refuge	d1-2
Alviso	a21	142	2.31	4.11	941-4561	1.80	413,378	3,294			refuge	c2-3
Alviso	a22	184	2.95	4.11	941-4561	1.16	343,988	4,265			cargill	c2-3
Alviso	a22	89	2.95	4.11	941-4561	1.16	167,401	2,648			refuge	c2-3
Alviso	a23	275	1.15	4.11	941-4561	2.96	1,311,791	4,922			cargill	d1-2
Alviso	a23	180	1.15	4.11	941-4561	2.96	858,531	3,495			refuge	d1-2
Alviso	b1	158	-1.29	4.70	941-4575	5.99	1,525,288	4,336			cargill	g-2--1
Alviso	b2	51	0.50	4.70	941-4575	4.20	344,912	3,145			cargill	e0-1
Alviso	b2	108	0.50	4.70	941-4575	4.20	729,427	4,643			refuge	e0-1
Alviso	b2	28	0.50	4.70	941-4575	4.20	187,856	2,937			cargill	e0-1
Baumberg	1	297	2.16	3.98	941-4637	1.82	872,663	4,816			cargill	c2-3
Baumberg	1c	65	3.71	3.98	941-4637	0.27	28,508	3,175			cargill	b3-4
Baumberg	2	692	2.11	3.98	941-4637	1.87	2,087,442	6,854			cargill	c2-3
Baumberg	2c	32	2.74	3.98	941-4637	1.24	64,155	1,732			cargill	c2-3
Baumberg	3c	180	2.94	3.98	941-4637	1.04	301,396	4,529			cargill	c2-3
Baumberg	4	202	2.91	3.98	941-4637	1.07	348,781	4,347			cargill	c2-3
Baumberg	4c	168	3.16	3.98	941-4637	0.82	222,044	3,172			cargill	b3-4
Baumberg	5	172	2.38	3.98	941-4637	1.60	443,386	4,170			cargill	c2-3
Baumberg	5c	96	2.95	3.98	941-4637	1.03	159,241	3,830			cargill	c2-3
Baumberg	6	183	2.35	3.98	941-4637	1.63	481,593	4,281			cargill	c2-3
Baumberg	6a	329	1.07	3.98	941-4637	2.91	1,544,651	5,183			cargill	d1-2
Baumberg	6b	293	1.65	3.98	941-4637	2.33	1,102,628	4,615			cargill	d1-2
Baumberg	6c	85	2.76	3.98	941-4637	1.22	166,631	2,870			cargill	c2-3
Baumberg	7	217	2.51	3.98	941-4637	1.47	515,370	3,874			cargill	c2-3
Baumberg	8	156	2.75	3.98	941-4637	1.23	309,057	3,858			cargill	c2-3
Baumberg	8a	310	3.95	3.98	941-4637			5,907			cargill	b3-4
Baumberg	8-middle	42	2.75	3.98	941-4637	1.23	83,905	1,739			cargill	c2-3
Baumberg	8-north	31	2.75	3.98	941-4637	1.23	62,227	1,477			cargill	c2-3
Baumberg	9	386	2.83	3.98	941-4637	1.15	716,125	5,540			cargill	c2-3
Baumberg	10	269	2.34	3.98	941-4637	1.64	711,703	5,374			cargill	c2-3
Baumberg	11	128	3.01	3.98	941-4637	0.97	199,825	3,134			cargill	b3-4
Baumberg	12	117	2.89	3.98	941-4637	1.09	206,524	3,298			cargill	c2-3
Baumberg	13	134	3.30	3.98	941-4637	0.68	147,303	4,272			cargill	b3-4
Baumberg	14	172	3.71	3.98	941-4637	0.27	74,766	4,682			cargill	b3-4
Newark 1	1	242	3.11	4.40	941-4506	1.29	504,091	4,622			refuge	b3-4
Newark 1	1a	173	3.15	4.40	941-4506	1.25	349,511	4,018			refuge	b3-4
Newark 1	1-south	105	3.11	4.40	941-4506	1.29	218,283	2,864			refuge	b3-4
Newark 1	2	162	3.07	4.40	941-4506	1.33	347,576	3,818			refuge	b3-4
Newark 1	2a	176	1.67	4.34	941-4509	2.67	759,887	4,036			refuge	d1-2
Newark 1	3	433	2.64	4.34	941-4509	1.70	1,186,647	6,731			refuge	c2-3
Newark 1	3a	417	2.85	4.40	941-4506	1.55	1,041,912	5,504			refuge	c2-3
Newark 1	4	347	2.64	4.34	941-4509	1.70	950,568	5,869			refuge	c2-3
Newark 1	4a	546	3.08	4.40	941-4506	1.32	1,162,562	9,101			refuge	b3-4
Newark 1	4b	71		4.40	941-4506	4.40		5,021			refuge	
Newark 1	5	196	2.61	4.34	941-4509	1.73	546,670	4,110			refuge	c2-3
Newark 1	6	98	3.22	4.40	941-4506	1.18	185,909	2,860			refuge	b3-4
Newark 1	7	375	2.67	4.40	941-4506	1.73	1,047,380	5,168			refuge	c2-3
Newark 1	8	115	3.11	4.40	941-4506	1.29	239,009	3,067			refuge	b3-4

Appendix C. South Bay Salt Pond GIS Data

Production Plant	Pond Number	Pond Area[1]	Pond Elev[2]	Local mhhw[3]	NOS Station[3]	Pond Distance to mhhw[4]	Pond Void Space to mhhw[5]	Pond Perimeter	Bittern Storage Ponds	Bittern De-Salting Ponds	Pond Owner	Pond NGVD Elev Group
		acres	ft ngvd	ft ngvd	no.	ft	cy	m				
Map 1			Table 5-2	Table 5-2	Table 5-2	Table 5-2	Table 5-2		Map 5	Map 5	Map 2	Map 8
Newark 1	9	130	2.84	4.40	941-4506	1.56	326,346	4,575			refuge	c2-3
Newark 1	db approach	153		4.40	941-4506	4.40		7,869			refuge	
Newark 1	PP1	195	3.11	4.40	941-4506	1.29	406,551	4,128			refuge	b3-4
Newark 2	1	496	2.55	4.43	941-4519	1.88	1,505,595	6,678			refuge	c2-3
Newark 2	2	484	1.88	4.43	941-4519	2.55	1,990,933	7,644			refuge	d1-2
Newark 2	3	543	2.28	4.70	941-4575	2.42	2,119,778	6,897			refuge	c2-3
Newark 2	4	522	2.27	4.70	941-4575	2.43	2,046,818	8,190			refuge	c2-3
Newark 2	5	416	3.25	4.70	941-4575	1.45	972,775	6,008			refuge	b3-4
Newark 2	6	448	2.83	4.43	941-4519	1.60	1,157,667	6,179			refuge	c2-3
Newark 2	7	446		4.43	941-4519			6,426			cargill	
Newark 2	8	437		4.43	941-4519			6,902			cargill	
Newark 2	10	295		4.40	941-4506			4,792		yes	cargill	
Newark 2	10a	61		4.43	941-4519			2,221			cargill	
Newark 2	11	157		4.43	941-4519			5,782		yes	cargill	
Newark 2	12	256		4.40	941-4506			5,972	yes		refuge	
Newark 2	13	415		4.40	941-4506			7,229	yes		refuge	
Newark 2	26	253		4.43	941-4519			4,898			cargill	
Newark 2	27	63		4.43	941-4519			2,282			cargill	
Newark 2	28	115		4.43	941-4519			2,758			cargill	
Newark 2	FMC-1	29		4.40	941-4506			1,346	yes		cargill	
Newark 2	FMC-2	11		4.40	941-4506			852	yes		cargill	
Newark 2	FMC-3	12		4.40	941-4506			921	yes		cargill	
Newark 2	FMC-4	7		4.40	941-4506			664	yes		cargill	
Newark 2	FMC-5	28		4.40	941-4506			1,881	yes		cargill	
Newark 2	FMC-6	24		4.40	941-4506			1,265	yes		cargill	
Redwood City	1	446	2.03	4.34	941-4509	2.31	1,661,837	6,077			refuge	c2-3
Redwood City	2	141	1.89	4.34	941-4509	2.45	558,765	4,258			refuge	d1-2
Redwood City	3	296	2.05	4.34	941-4509	2.29	1,095,453	6,061			cargill	c2-3
Redwood City	4	307	2.12	4.34	941-4509	2.22	1,098,443	4,434			cargill	c2-3
Redwood City	5	35	2.45	4.34	941-4509	1.89	108,003	1,644			cargill	c2-3
Redwood City	7a	81	2.10	4.05	941-4501	1.95	256,351	2,714			cargill	c2-3
Redwood City	7b	104	2.99	4.05	941-4501	1.06	177,524	2,863			cargill	c2-3
Redwood City	7c	191	3.00	4.05	941-4501	1.05	323,245	3,725			cargill	b3-4
Redwood City	8e	65	3.01	4.05	941-4501	1.04	109,652	2,346	yes		cargill	b3-4
Redwood City	8w	95	2.40	4.05	941-4501	1.65	252,180	2,845			cargill	c2-3
Redwood City	9	171	5.07	4.05	941-4501			4,098	yes		cargill	a5-6
Redwood City	9a	32	3.50	4.05	941-4501	0.55	28,820	1,574	yes		cargill	b3-4
Redwood City	10	103	1.85	4.05	941-4501	2.20	365,621	2,852		yes	cargill	d1-2
Redwood City	MISC-1	9		4.05	941-4501			1,957		yes	cargill	d1-2
Redwood City	MISC-2	6		4.05	941-4501			841			cargill	e0-1
Redwood City	MISC-3	8		4.05	941-4501			913			cargill	e0-1
Redwood City	s5	38	2.45	4.05	941-4501	1.60	98,680	2,249			cargill	c2-3
Redwood City	sf2	239	2.13	4.05	941-4501	1.92	741,567	4,591			cargill	c2-3
CRYSTALLIZERS												
Newark 2	1	31		4.43	941-4519			1,760			cargill	
Newark 2	2	22		4.43	941-4519			1,288			cargill	
Newark 2	3	32		4.43	941-4519			1,743			cargill	
Newark 2	4	39		4.43	941-4519			2,029			cargill	
Newark 2	5	22		4.43	941-4519			1,291			cargill	
Newark 2	6	34		4.43	941-4519			1,771			cargill	
Newark 2	7	33		4.43	941-4519			1,630			cargill	
Newark 2	7a	43		4.43	941-4519			1,752			cargill	
Newark 2	8	24		4.43	941-4519			1,341			cargill	
Newark 2	9	34		4.43	941-4519			1,741			cargill	
Newark 2	10	29		4.43	941-4519			1,574			cargill	
Newark 2	11	23		4.43	941-4519			1,312			cargill	
Newark 2	12	32		4.43	941-4519			1,746			cargill	
Newark 2	13	32		4.43	941-4519			1,576			cargill	
Newark 2	14	34		4.43	941-4519			1,651			cargill	
Newark 2	15	32		4.43	941-4519			1,488			cargill	
Newark 2	16	30		4.43	941-4519			1,546			cargill	
Newark 2	17	30		4.43	941-4519			1,592			cargill	
Newark 2	18	46		4.43	941-4519			1,947			cargill	
Newark 2	19	48		4.43	941-4519			1,972			cargill	
Newark 2	20	36		4.43	941-4519			1,812			cargill	
Newark 2	21	25		4.43	941-4519			1,697			cargill	
Newark 2	22	26		4.43	941-4519			1,574			cargill	
Newark 2	23	35		4.43	941-4519			1,769			cargill	

Appendix C. South Bay Salt Pond GIS Data

Production Plant	Pond Number	Pond Tide Elevation Group	Gypsum Layer	Potential Hydrologic Regime	Pond Salinity	Cargill 2000 Plan
Map 1		Map 9	Maps 7 and 13	Map 10	Map 7	Map 3
SALT PONDS						
Alviso	a1	g-Between 1ft. < MTL and 1ft. > MLW		tributary channel, marsh	low	sells land and minerals
Alviso	a2e	h-Between 1ft. > MLW and MLW		tributary channel, marsh	low	sells land and minerals
Alviso	a2w	g-Between 1ft. < MTL and 1ft. > MLW		open bay edge, marsh	low	sells land and minerals
Alviso	a3n	g-Between 1ft. < MTL and 1ft. > MLW		open bay edge, no marsh	low	sells land and minerals
Alviso	a3w	i-MLLW-MLW		tributary channel, marsh	low	sells land and minerals
Alviso	a5	g-Between 1ft. < MTL and 1ft. > MLW		tributary channel, marsh	low	sells land and minerals
Alviso	a7	g-Between 1ft. < MTL and 1ft. > MLW		tributary channel, marsh	low	sells land and minerals
Alviso	a8	h-Between 1ft. > MLW and MLW		tributary channel, marsh	low	sells land and minerals
Alviso	a8-south	f-Between MTL and 1ft. < MTL		tributary channel, marsh	low	sells land and minerals
Alviso	a9	f-Between MTL and 1ft. < MTL		open bay edge, marsh	low	cargill sells minerals
Alviso	a10	g-Between 1ft. < MTL and 1ft. > MLW		tributary channel, marsh	low	cargill sells minerals
Alviso	a11	g-Between 1ft. < MTL and 1ft. > MLW		tributary channel, marsh	low	cargill sells minerals
Alviso	a12	g-Between 1ft. < MTL and 1ft. > MLW		tributary channel, marsh	low-medium	cargill sells minerals
Alviso	a13	g-Between 1ft. < MTL and 1ft. > MLW		no tidal edge	low-medium	cargill sells minerals
Alviso	a14	f-Between MTL and 1ft. < MTL		open bay edge, marsh	low	cargill sells minerals
Alviso	a15	e-Between 1ft. > MTL and MTL		tributary channel, marsh	low-medium	cargill sells minerals
Alviso	a16	e-Between 1ft. > MTL and MTL		tributary channel, marsh	low-medium	cargill sells minerals
Alviso	a17	d-Between 1ft. < MHW and 1ft. > MTL		tributary channel, marsh	low-medium	cargill sells minerals
Alviso	a18	e-Between 1ft. > MTL and MTL	yes	tributary channel, marsh	low-medium	sells land and minerals
Alviso	a19	d-Between 1ft. < MHW and 1ft. > MTL	yes	tributary channel, marsh	medium	cargill sells minerals
Alviso	a20	d-Between 1ft. < MHW and 1ft. > MTL	yes	tributary channel, marsh	medium	cargill sells minerals
Alviso	a21	d-Between 1ft. < MHW and 1ft. > MTL	yes	tributary channel, marsh	medium	cargill sells minerals
Alviso	a22	c-Between MHW and 1ft. < MHW	yes	no tidal edge	medium-high	sells land and minerals
Alviso	a22	c-Between MHW and 1ft. < MHW	yes	no tidal edge	medium-high	cargill sells minerals
Alviso	a23	d-Between 1ft. < MHW and 1ft. > MTL	yes	tributary channel, marsh	medium-high	sells land and minerals
Alviso	a23	d-Between 1ft. < MHW and 1ft. > MTL	yes	tributary channel, marsh	medium-high	cargill sells minerals
Alviso	b1	g-Between 1ft. < MTL and 1ft. > MLW		open bay edge, no marsh	low	sells land and minerals
Alviso	b2	f-Between MTL and 1ft. < MTL		open bay edge, marsh	low	sells land and minerals
Alviso	b2	f-Between MTL and 1ft. < MTL		open bay edge, marsh	low	cargill sells minerals
Alviso	b2	f-Between MTL and 1ft. < MTL		open bay edge, marsh	low	sells land and minerals
Baumberg	1	d-Between 1ft. < MHW and 1ft. > MTL		tributary channel, marsh	low	sells land and minerals
Baumberg	1c	b-MHW-MHHW		tributary channel, marsh	low-medium	sells land and minerals
Baumberg	2	d-Between 1ft. < MHW and 1ft. > MTL		open bay edge, no marsh	low	sells land and minerals
Baumberg	2c	c-Between MHW and 1ft. < MHW		tributary channel, marsh	low-medium	sells land and minerals
Baumberg	3c	c-Between MHW and 1ft. < MHW		no tidal edge	low-medium	sells land and minerals
Baumberg	4	c-Between MHW and 1ft. < MHW		no tidal edge	low	sells land and minerals
Baumberg	4c	c-Between MHW and 1ft. < MHW		no tidal edge	low-medium	sells land and minerals
Baumberg	5	d-Between 1ft. < MHW and 1ft. > MTL		no tidal edge	low	sells land and minerals
Baumberg	5c	c-Between MHW and 1ft. < MHW		no tidal edge	low-medium	sells land and minerals
Baumberg	6	d-Between 1ft. < MHW and 1ft. > MTL		tributary channel, marsh	low	sells land and minerals
Baumberg	6a	e-Between 1ft. > MTL and MTL		tributary channel, marsh	low	sells land and minerals
Baumberg	6b	d-Between 1ft. < MHW and 1ft. > MTL		no tidal edge	low	sells land and minerals
Baumberg	6c	c-Between MHW and 1ft. < MHW		no tidal edge	low	sells land and minerals
Baumberg	7	c-Between MHW and 1ft. < MHW		tributary channel, marsh	low	sells land and minerals
Baumberg	8	c-Between MHW and 1ft. < MHW	yes	tributary channel, marsh	low	sells land and minerals
Baumberg	8a	b-MHW-MHHW	yes	tributary channel, marsh	low	sells land and minerals
Baumberg	8-middle	c-Between MHW and 1ft. < MHW	yes	no tidal edge	low	sells land and minerals
Baumberg	8-north	c-Between MHW and 1ft. < MHW		no tidal edge	low	sells land and minerals
Baumberg	9	c-Between MHW and 1ft. < MHW		tributary channel, marsh	low	sells land and minerals
Baumberg	10	d-Between 1ft. < MHW and 1ft. > MTL		open bay edge, no marsh	low	sells land and minerals
Baumberg	11	c-Between MHW and 1ft. < MHW		tributary channel, marsh	low	sells land and minerals
Baumberg	12	c-Between MHW and 1ft. < MHW		tributary channel, marsh	low	sells land and minerals
Baumberg	13	c-Between MHW and 1ft. < MHW		tributary channel, marsh	low	sells land and minerals
Baumberg	14	b-MHW-MHHW		tributary channel, marsh	low	sells land and minerals
Newark 1	1	c-Between MHW and 1ft. < MHW	yes	tributary channel, marsh	medium-high	retain prod and mineral rights
Newark 1	1a	c-Between MHW and 1ft. < MHW		tributary channel, marsh	medium	retain prod and mineral rights
Newark 1	1-south	c-Between MHW and 1ft. < MHW	yes	tributary channel, marsh	medium-high	retain prod and mineral rights
Newark 1	2	c-Between MHW and 1ft. < MHW	yes	tributary channel, marsh	medium-high	retain prod and mineral rights
Newark 1	2a	d-Between 1ft. < MHW and 1ft. > MTL		open bay edge, marsh	medium	retain prod and mineral rights
Newark 1	3	d-Between 1ft. < MHW and 1ft. > MTL	yes	open bay edge, no marsh	medium-high	retain prod and mineral rights
Newark 1	3a	c-Between MHW and 1ft. < MHW		no tidal edge	medium	retain prod and mineral rights
Newark 1	4	d-Between 1ft. < MHW and 1ft. > MTL		open bay edge, no marsh	medium	retain prod and mineral rights
Newark 1	4a	c-Between MHW and 1ft. < MHW		open bay edge, no marsh	medium	retain prod and mineral rights
Newark 1	4b	no-data		no tidal edge	medium	retain prod and mineral rights
Newark 1	5	d-Between 1ft. < MHW and 1ft. > MTL		open bay edge, marsh	medium	retain prod and mineral rights
Newark 1	6	c-Between MHW and 1ft. < MHW		no tidal edge	medium	retain prod and mineral rights
Newark 1	7	d-Between 1ft. < MHW and 1ft. > MTL		no tidal edge	medium	retain prod and mineral rights
Newark 1	8	c-Between MHW and 1ft. < MHW		no tidal edge	medium	retain prod and mineral rights

Appendix C. South Bay Salt Pond GIS Data

Production Plant	Pond Number	Pond Area[1]	Pond Elev[2]	Local mhhw[3]	NOS Station[3]	Pond Distance to mhhw[4]	Pond Void Space to mhhw[5]	Pond Perimeter	Bittern Storage Ponds	Bittern De-Salting Ponds	Pond Owner	Pond NGVD Elev Group
		acres	ft ngvd	ft ngvd	no.	ft	cy	m				
Map 1			Table 5-2	Table 5-2	Table 5-2	Table 5-2	Table 5-2		Map 5	Map 5	Map 2	Map 8
Newark 2	24	47		4.43	941-4519			1,955			cargill	
Newark 2	25	47		4.43	941-4519			1,976			cargill	
Redwood City	1	42	0.54	4.05	941-4501	3.51	235,167	2,264			cargill	0-1
Redwood City	2	56	0.33	4.05	941-4501	3.72	334,825	2,462			cargill	0-1
Redwood City	3	53	0.43	4.05	941-4501	3.62	312,180	2,406			cargill	0-1
Redwood City	4	39	0.13	4.05	941-4501	3.92	249,219	1,778			cargill	0-1
Redwood City	5	35	-0.20	4.05	941-4501	4.25	240,313	2,107			cargill	-1-0
Redwood City	6	55	0.58	4.05	941-4501	3.47	306,136	2,384			cargill	0-1
Redwood City	7	56	0.38	4.05	941-4501	3.67	330,231	2,449			cargill	0-1
Redwood City	8	57	0.53	4.05	941-4501	3.52	323,854	2,464			cargill	0-1
Redwood City	9	80	0.13	4.05	941-4501	3.92	508,855	2,606			cargill	0-1

Appendix C. South Bay Salt Pond GIS Data

Production Plant	Pond Number	Pond Tide Elevation Group	Gypsum Layer	Potential Hydrologic Regime	Pond Salinity	Cargill 2000 Plan
Map 1		Map 9	Maps 7 and 13	Map 10	Map 7	Map 3
Newark 1	9	c-Between MHW and 1ft. < MHW		no tidal edge	medium	retain prod and mineral rights
Newark 1	db approach	no-data		open bay edge, no marsh	medium-high	retain prod and mineral rights
Newark 1	PP1	c-Between MHW and 1ft. < MHW	yes	tributary channel, marsh	medium-high	retain prod and mineral rights
Newark 2	1	d-Between 1ft. < MHW and 1ft. > MTL		tributary channel, marsh	low	retain prod and mineral rights
Newark 2	2	d-Between 1ft. < MHW and 1ft. > MTL		open bay edge, marsh	low	retain prod and mineral rights
Newark 2	3	d-Between 1ft. < MHW and 1ft. > MTL		open bay edge, marsh	low-medium	retain prod and mineral rights
Newark 2	4	d-Between 1ft. < MHW and 1ft. > MTL	yes	open bay edge, marsh	medium-high	retain prod and mineral rights
Newark 2	5	c-Between MHW and 1ft. < MHW	yes	tributary channel, marsh	medium-high	retain prod and mineral rights
Newark 2	6	c-Between MHW and 1ft. < MHW	yes	tributary channel, marsh	medium-high	retain prod and mineral rights
Newark 2	7	no-data		tributary channel, marsh	no data	retains production
Newark 2	8	no-data		tributary channel, marsh	no data	retains production
Newark 2	10	no-data		tributary channel, marsh	no data	retains production
Newark 2	10a	no-data		no tidal edge	no data	retains production
Newark 2	11	no-data		open bay edge, marsh	no data	retains production
Newark 2	12	no-data		tributary channel, marsh	sal-high	retain prod on refuge land
Newark 2	13	no-data		tributary channel, marsh	sal-high	retain prod on refuge land
Newark 2	26	no-data		tributary channel, marsh	no data	retains production
Newark 2	27	no-data		no tidal edge	no data	retains production
Newark 2	28	no-data		no tidal edge	no data	retains production
Newark 2	FMC-1	no-data		tributary channel, marsh	no data	retains production
Newark 2	FMC-2	no-data		no tidal edge	no data	retains production
Newark 2	FMC-3	no-data		no tidal edge	no data	retains production
Newark 2	FMC-4	no-data		no tidal edge	no data	retains production
Newark 2	FMC-5	no-data		tributary channel, marsh	no data	retains production
Newark 2	FMC-6	no-data		no tidal edge	no data	retains production
Redwood City	1	d-Between 1ft. < MHW and 1ft. > MTL		tributary channel, marsh	medium-high	cargill sells minerals
Redwood City	2	d-Between 1ft. < MHW and 1ft. > MTL	yes	tributary channel, marsh	medium-high	cargill sells minerals
Redwood City	3	d-Between 1ft. < MHW and 1ft. > MTL	yes	tributary channel, marsh	medium-high	sells land and minerals
Redwood City	4	d-Between 1ft. < MHW and 1ft. > MTL	yes	tributary channel, marsh	medium-high	sells land and minerals
Redwood City	5	d-Between 1ft. < MHW and 1ft. > MTL	yes	no tidal edge	medium-high	sells land and minerals
Redwood City	7a	d-Between 1ft. < MHW and 1ft. > MTL		no tidal edge	sal-high	sells land and minerals
Redwood City	7b	c-Between MHW and 1ft. < MHW	yes	no tidal edge	sal-high	sells land and minerals
Redwood City	7c	c-Between MHW and 1ft. < MHW		no tidal edge	sal-high	sells land and minerals
Redwood City	8e	c-Between MHW and 1ft. < MHW		tributary channel, no mar	sal-high	sells land and minerals
Redwood City	8w	d-Between 1ft. < MHW and 1ft. > MTL		no tidal edge	sal-high	sells land and minerals
Redwood City	9	a-MHHW-Highest		tributary channel, marsh	sal-high	sells land and minerals
Redwood City	9a	b-MHW-MHHW		tributary channel, marsh	sal-high	sells land and minerals
Redwood City	10	d-Between 1ft. < MHW and 1ft. > MTL		tributary channel, no mar	sal-high	sells land and minerals
Redwood City	MISC-1	d-Between 1ft. < MHW and 1ft. > MTL		tributary channel, no mar	sal-high	sells land and minerals
Redwood City	MISC-2	e-Between 1ft. > MTL and MTL		no tidal edge	no data	sells land and minerals
Redwood City	MISC-3	e-Between 1ft. > MTL and MTL		no tidal edge	no data	sells land and minerals
Redwood City	s5	d-Between 1ft. < MHW and 1ft. > MTL	yes	no tidal edge	medium-high	sells land and minerals
Redwood City	sf2	d-Between 1ft. < MHW and 1ft. > MTL	yes	open bay edge, marsh	medium	sells land and minerals
CRYSTALLIZERS						
Newark 2	1	no-data		no tidal edge	sal-high	retains production
Newark 2	2	no-data		no tidal edge	sal-high	retains production
Newark 2	3	no-data		no tidal edge	sal-high	retains production
Newark 2	4	no-data		no tidal edge	sal-high	retains production
Newark 2	5	no-data		no tidal edge	sal-high	retains production
Newark 2	6	no-data		no tidal edge	sal-high	retains production
Newark 2	7	no-data		no tidal edge	sal-high	retains production
Newark 2	7a	no-data		no tidal edge	sal-high	retains production
Newark 2	8	no-data		no tidal edge	sal-high	retains production
Newark 2	9	no-data		no tidal edge	sal-high	retains production
Newark 2	10	no-data		no tidal edge	sal-high	retains production
Newark 2	11	no-data		no tidal edge	sal-high	retains production
Newark 2	12	no-data		no tidal edge	sal-high	retains production
Newark 2	13	no-data		no tidal edge	sal-high	retains production
Newark 2	14	no-data		no tidal edge	sal-high	retains production
Newark 2	15	no-data		no tidal edge	sal-high	retains production
Newark 2	16	no-data		no tidal edge	sal-high	retains production
Newark 2	17	no-data		no tidal edge	sal-high	retains production
Newark 2	18	no-data		no tidal edge	sal-high	retains production
Newark 2	19	no-data		no tidal edge	sal-high	retains production
Newark 2	20	no-data		no tidal edge	sal-high	retains production
Newark 2	21	no-data		no tidal edge	sal-high	retains production
Newark 2	22	no-data		no tidal edge	sal-high	retains production
Newark 2	23	no-data		no tidal edge	sal-high	retains production

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Appendix C GIS Data (2-27sws).xls

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Appendix C. South Bay Salt Pond GIS Data

Production Plant	Pond Number	Pond Tide Elevation Group	Gypsum Layer	Potential Hydrologic Regime	Pond Salinity	Cargill 2000 Plan
Map 1		Map 9	Maps 7 and 13	Map 10	Map 7	Map 3
Newark 2	24	no-data		no tidal edge	sal-high	retains production
Newark 2	25	no-data		no tidal edge	sal-high	retains production
Redwood City	1	e-Between 1ft. > MTL and MTL		no tidal edge	sal-high	sells land and minerals
Redwood City	2	f-Between MTL and 1ft. < MTL		no tidal edge	sal-high	sells land and minerals
Redwood City	3	e-Between 1ft. > MTL and MTL		no tidal edge	sal-high	sells land and minerals
Redwood City	4	f-Between MTL and 1ft. < MTL		no tidal edge	sal-high	sells land and minerals
Redwood City	5	f-Between MTL and 1ft. < MTL		no tidal edge	sal-high	sells land and minerals
Redwood City	6	e-Between 1ft. > MTL and MTL		no tidal edge	sal-high	sells land and minerals
Redwood City	7	e-Between 1ft. > MTL and MTL		no tidal edge	sal-high	sells land and minerals
Redwood City	8	e-Between 1ft. > MTL and MTL		no tidal edge	sal-high	sells land and minerals
Redwood City	9	f-Between MTL and 1ft. < MTL		no tidal edge	sal-high	sells land and minerals

Appendix C. South Bay Salt Pond GIS Data

Production Plant	Pond Number	Relative Restoration Feasibility[5]								
Map 1		Elev	Tides	Flood	Bird Use	Salinity	Infrastructure	Gypsum	Determination Map 14	Notes
SALT PONDS										
Alviso	a1	M	M	H	M	H	M		M	1 of 2 good subsided ponds
Alviso	a2e	L	M	L	M	H	M		L	
Alviso	a2w	M	H	H	H	H	M		M	2 of 2 good subsided ponds
Alviso	a3n	M	H	M	L	H	L-M		M	
Alviso	a3w	L	M	L	L	H	M		L	
Alviso	a5	H	M	M	L	H	H		M	Sunnyvale freshwater discharge
Alviso	a7	M	M	M	L	H	H		M	
Alviso	a8	L	L-M	H	L	H	L-M		L	
Alviso	a8-south	M	L-M	H		H	M		L	
Alviso	a9	M	H	L	L	H	L-M		M	underground electrical, flood
Alviso	a10	M	M	L	H	H	H		M	
Alviso	a11	M	M	L	H	H	H		M	
Alviso	a12	M	L-M	L	H	H	H		L	
Alviso	a13	M	L-M	L	H	H	H		L	
Alviso	a14	M	M	L	M	H	L		M	
Alviso	a15	H	M	L	M	H	L		M	
Alviso	a16	H	L-M	L	H	H	H		M	
Alviso	a17	H	M	H	H	H	H		H	
Alviso	a18	H	M	L	M	H	M	M	M	
Alviso	a19	H	M	H	H	M	L	L-M	M	San Jose freshwater discharge
Alviso	a20	H	M	H	M	M	L	L-M	M	San Jose freshwater discharge
Alviso	a21	H	H	H	H	M	H	L-M	H	
Alviso	a22	H	L-M	L	H	M	L	L-M	L	
Alviso	a22	H	L-M	L	H	M	L		L	
Alviso	a23	H	M	L	H	M	M		M	
Alviso	a23	H	M	L	H	M	M		M	
Alviso	b1	M	H	M	M	H	M		M	
Alviso	b2	M	H	L	L	H	M		M	
Alviso	b2	M	H	L	L	H	M		M	
Alviso	b2	M	H	L	L	H	M		M	
Baumberg	1	H	M	M	H	H	M		M-H	w/o S. alterniflora, increase to H
Baumberg	1c	H	M	H	L	H	M-H		M	
Baumberg	2	H	H	M	H	H	H		M-H	w/o S. alterniflora, increase to H
Baumberg	2c	H	M	M	M	H	M-H		M	
Baumberg	3c	H	L	L	L	H	M-H		L	
Baumberg	4	H	L	M	M	H	H		L	
Baumberg	4c	H	L	M	L	H	M-H		L	
Baumberg	5	H	L	M	H	H	H		L	
Baumberg	5c	H	L	M	L	H	M-H		L	
Baumberg	6	H	M	M	M	H	M		M	
Baumberg	6a	H	M	M	M	H	M		M	
Baumberg	6b	H	L	M	L	H	H		L-M	w/o S. alterniflora, increase to M
Baumberg	6c	H	L	M	H	H	M-H		L	
Baumberg	7	H	M	M	H	H	M		M	
Baumberg	8	H	M	M	M	H	H	L-M	L	
Baumberg	8a	H	M-H	M	L	H	H	L	L	
Baumberg	8-middle	H	L	M	M	H	H	L-M	L	
Baumberg	8-north	H	L	M	L	H	H		L	
Baumberg	9	H	M	M	L	H	H		M	
Baumberg	10	H	H	M	M	H	H		M-H	w/o S. alterniflora, increase to H
Baumberg	11	H	L	L	L	H	H		L-M	w/o S. alterniflora, increase to M
Baumberg	12	H	L	L	L	H	L-M		L	
Baumberg	13	H	L	M	M	H	L-M		L-M	w/o S. alterniflora, increase to M
Baumberg	14	H	L	M	L	H	H		L-M	w/o S. alterniflora, increase to M
Newark 1	1	H	M	H	L	M	H	L-M	M	
Newark 1	1a	H	H	H	H	H	H		M-H	w/o S. alterniflora, increase to H
Newark 1	1-south	H	M	H	L	M	H	L-M	M	
Newark 1	2	H	M	L	L	M	H	L-M	L	flood hazard
Newark 1	2a	H	H	H	L	H	H		M-H	w/o S. alterniflora, increase to H
Newark 1	3	H	H	L	M	M	M	M	M	
Newark 1	3a	H	L	H	L	H	H		M	
Newark 1	4	H	H	H	L	H	H		M-H	w/o S. alterniflora, increase to H
Newark 1	4a	H	H	H	L	H	H		M-H	w/o S. alterniflora, increase to H
Newark 1	4b	H	L	H		H	H		M	
Newark 1	5	H	M	H	L	H	H		M-H	w/o S. alterniflora, increase to H
Newark 1	6	H	L	H	M	H	H		M	
Newark 1	7	H	L	H	L	H	H		M	
Newark 1	8	H	L	H	H	H	H		M	

Appendix C. South Bay Salt Pond GIS Data

Production Plant	Pond Number	Relative Restoration Feasibility[5]								
Map 1		Elev	Tides	Flood	Bird Use	Salinity	Infrastructure	Gypsum	Determination Map 14	Notes
Newark 1	9	H	L	H	L	H	H		M	
Newark 1	db approach	H	M	L	L	M	M		L	flood hazard
Newark 1	PP1	H	L	M-H	L	M	H	L-M	M	
Newark 2	1	H	M	H	M	H	H		H	
Newark 2	2	H	H	H	M	H	H		H	
Newark 2	3	H	H	H	H	H	H		H	
Newark 2	4	H	H	M	H	M	H	M	M	
Newark 2	5	H	L	M	M	M	H	L-M	L	Gypsum in high elev pond
Newark 2	6	H	M	M	H	M	H	L-M	L	Gypsum in high elev pond
Newark 2	7		M		H	L-M	H			Insufficient data
Newark 2	8		M		M	L-M	H			Insufficient data
Newark 2	10		L-M		M	L-M	M			Insufficient data
Newark 2	10a		L		L	L-M	H			Insufficient data
Newark 2	11		M-H		M	L-M	H			Insufficient data
Newark 2	12		M-H		M	L	H		L	Bittern
Newark 2	13		M-H		H	L	H		L	Bittern
Newark 2	26		M-H		M	L-M	H			Insufficient data
Newark 2	27		L			L-M	H			Insufficient data
Newark 2	28		L			L-M	H			Insufficient data
Newark 2	FMC-1		L-M		H	L	H		L	Bittern
Newark 2	FMC-2		L		H	L	H		L	Bittern
Newark 2	FMC-3		L		H	L	H		L	Bittern
Newark 2	FMC-4		L-M		H	L	H		L	Bittern
Newark 2	FMC-5		L-M		H	L	H		L	Bittern
Newark 2	FMC-6		L		H	L	H		L	Bittern
Redwood City	1	H	H	H	M	M-H	M-H		H	Summer 2001 plover nesting
Redwood City	2	H	M	H	L	M-H	M	M	H	Summer 2001 plover nesting
Redwood City	3	H	M	M	M	M-H	H	M	M	
Redwood City	4	H	H	M	H	M-H	H	M	H	
Redwood City	5	H	L	M		M-H	H	M	M	
Redwood City	7a	H	L	M		M	H		M	
Redwood City	7b	H	L	M		M	H	L-M	M	
Redwood City	7c	H	L	L		M	H		M	
Redwood City	8e	H	H	M		M	H		M	
Redwood City	8w	H	L	M		M	H		M	
Redwood City	9	H	M	M		M	H		L	Bittern
Redwood City	9a	H	H	H		M	H		L	Bittern
Redwood City	10	H	H	M		M	H		L	Bittern, flood hazard
Redwood City	MISC-1	H	H	M		M	H		L	
Redwood City	MISC-2	H	L	M			H		L	
Redwood City	MISC-3	H	L	M			H		L	
Redwood City	s5	H	L	M		M-H	H	M	L	
Redwood City	sf2	H	H	L	L	H	H	M	M	
CRYSTALLIZERS										
Newark 2	1		L		M	L	H		L	Plover, tern, shorebirds
Newark 2	2		L		M	L	H		L	Plover, tern, shorebirds
Newark 2	3		L		M	L	H		L	Plover, tern, shorebirds
Newark 2	4		L		M	L	H		L	Plover, tern, shorebirds
Newark 2	5		L		M	L	H		L	Plover, tern, shorebirds
Newark 2	6		L		M	L	H		L	Plover, tern, shorebirds
Newark 2	7		L		M	L	H		L	Plover, tern, shorebirds
Newark 2	7a		L		M	L	H		L	Plover, tern, shorebirds
Newark 2	8		L		M	L	H		L	Plover, tern, shorebirds
Newark 2	9		L		M	L	H		L	Plover, tern, shorebirds
Newark 2	10		L		M	L	H		L	Plover, tern, shorebirds
Newark 2	11		L		M	L	H		L	Plover, tern, shorebirds
Newark 2	12		L		M	L	H		L	Plover, tern, shorebirds
Newark 2	13		L		M	L	H		L	Plover, tern, shorebirds
Newark 2	14		L		M	L	H		L	Plover, tern, shorebirds
Newark 2	15		L		M	L	H		L	Plover, tern, shorebirds
Newark 2	16		L		M	L	H		L	Plover, tern, shorebirds
Newark 2	17		L		M	L	H		L	Plover, tern, shorebirds
Newark 2	18		L		M	L	M		L	Plover, tern, shorebirds
Newark 2	19		L		M	L	M		L	Plover, tern, shorebirds
Newark 2	20		L		M	L	H		L	Plover, tern, shorebirds
Newark 2	21		L		M	L	L		L	Plover, tern, shorebirds
Newark 2	22		L		M	L	L		L	Plover, tern, shorebirds
Newark 2	23		L		M	L	H		L	Plover, tern, shorebirds

Appendix C. South Bay Salt Pond GIS Data

Production Plant	Pond Number	Relative Restoration Feasibility[6]								
Map 1		Elev	Tides	Flood	Bird Use	Salinity	Infrastructure	Gypsum	Determination Map 14	Notes
Newark 2	24		L		M	L	M		L	Plover, tern, shorebirds
Newark 2	25		L		M	L	M		L	Plover, tern, shorebirds
Redwood City	1	H	L	L		L	H		L	Graded
Redwood City	2	M	L	M		L	H		L	Graded
Redwood City	3	H	M	M		L	H		L	Graded
Redwood City	4	M	M	M		L	H		L	Graded
Redwood City	5	M	L	L		L	H		L	Graded
Redwood City	6	H	L	M		L	H		L	Graded
Redwood City	7	H	L	M		L	H		L	Graded
Redwood City	8	H	L	M		L	H		L	Graded
Redwood City	9	M	L	M		L	H		L	Graded

Notes:
1. Pond area and perimeter from EcoAtlas v.1.50b4, SFEI (2000).
2. Pond elevation data from Wildlands (1999).
3. Applicable National Ocean Service station and local MHHW from Wildlands (1999).
4. Distance to MHHW = Local MHHW - existing pond elevation.
5. Void space to MHHW = pond area x distance to MHHW.
6. Relative restoration feasibility subjective classfication of each attribute based on data throughout report. Significance and conditions of each attribute subject to change at any time for many reasons.

Appendix D

Salt Mass Balance

Appendix. D Salt Mass Balance

Table D-4. Determining bittern water quality characteristics as measured in SF (CDM 1972)

Source		Bay Water[1]	1:1 Bittern to Bay water[1]	Bittern[2]
	Be			36 deg Be[3]
TDS	ppT	30.6	240	449.4
Cl	ppT	17	158	299
SO4	ppT	2.4	21	39.6
Na	ppT	7.5	5.5	3.5
Ca	ppT	0.38	0.45	0.52

1. CDM (1972)
2. Calculated from bay water and diluted bittern
3. From Hanson paper relating TDS to Baume and SG

Table D-5. Calculation of Annual Bittern production and removal of precipitates

	Composition of Sea Water[4]	Volume (L)	Mass	
	% conc.	L of original brine	g/L	tons/ac
Mg	0.1313	1.0000	1.313	2.01
Na	1.0708	1.0000	10.708	16.38
SO4	0.2692	1.0000	2.692	4.12
K	0.0387	1.0000	0.387	0.59
Cl	1.9352	1.0000	19.352	29.61
Br	0.0066	1.0000	0.066	0.10
Ca	0.0419	1.0000	0.419	0.64
CO3	0.0072	1.0000	0.072	0.11
Total	3.50		35.009	53.56

From Planck (1958): (38.25 tons of Bay water per ton of salt produced) x (40 tons of salt produced per acre) = 1,530 tons bay water per acre per year.

Appendix. D Salt Mass Balance

Table D-1. General Information

Molecular Weights	
Mg	54.938
Na	22.98977
So4	96.056
CO3	60.0092
K	39.098
Cl	34.453
Fe	55.84
O	15.999
Ca	40.08
Br	79.904

Table D-2. Bittern chemical composition

Assumptions and Notes

1 Bittern compostion from Ver Planck (1958)
2 Assumes bittern at 30 Be

Salinity Measures			
Be	32	36	
SG	1.283185841	1.330275229	
TDS	395	447	*From Hansen paper relating TDS to Baume and SG
Concentration	0.0162	0.01	

Table D-3. Determination of Bay Water dilution: Is Bay Water Simply Sea Water Diluted with Fresh?

For the purpose of calculating bittern one need a reasonable expression of Bay water ion concentrations.
This analyses determines if Sea Water is OK for the ionic balance and loading.

Source		Bay Water[1]	SeaWater[2]	Dilution
TDS	ppT	30.6	35	0.874285714
Cl	ppT	17	19.35	0.878552972
SO4	ppT	2.4	26.92	0.089153046
Na	ppT	7.5	10.7	0.700934579
Ca	ppT	0.38	0.419	0.906921241

Bay Water in this analyses is approximately 89% seawater and the rest is freshwater. Sodium is a bit low.

1. From CDM Bay Water Analyses
2. Clarke 1924 in Ver Planck (1958)

Conclusion: Assume that Sea Water is a good approximation of Bay water for the purpose of determining salt and bittern production.

Appendix. D Salt Mass Balance

Table D-5. Calculation of Annual Bittern production and removal of precipitates (continued)

	CaCO3 removal to evaporator ponds CaCO3 to evaporator		Gypsum removal to evaporators			Salt removal in crystallizers		
	g/L	tons/ac	g/L	tons/ac	% removed	% removal	g/L	tons/ac
Mg								
Na						97.7	10.462	16.01
SO4			0.889	1.36	33.0			
K								
Cl						81.0	15.679	23.99
Br								
Ca	0.05	0.074	0.371	0.57	88.5			
CO3	0.0720	0.110						
Total	0.120	0.184	1.260	1.93			26.141	40.00

Estimated for salt production of 40 tons/ac

Salt production (40 tons/ac max per Ver Planck (1958) for water amount used

g/L of original brine

g/L as measured in the Bittern (CDM 1972)

Table D-5. Calculation of Annual Bittern production and removal of precipitates (continued)

	Bittern Characteristics											
	30 - 32 Be			36 Be[2]								
	Dissolved salts in bittern			Precipitated salts			Remaining Dissolved ions			WQ[3]	% original
	g/L orig brine	tons/ac	g/L bittern	% removal	g/L	tons/ac	g/L	tons/ac	% remaining	g/L[3]	brine vol
Mg	1.313	2.01	63.16	59.7	0.784	1.20	0.529	0.81	40.3		
Na	0.246	0.38	11.82	85.0	0.209	0.32	0.037	0.06	0.3	3.5	1.05
SO4	1.803	2.76	86.74	76.0	1.370	2.10	0.433	0.66	16.1	39.6	1.09
K	0.387	0.59	18.62				0.387	0.59	100.0		
Cl	3.673	5.62	176.69	Note 1	Note 1	0.48	3.360	5.14	17.4	299.0	1.12
Br	0.066	0.10	3.17				0.066	0.10	100.0		
Ca	0.000	0.00	0.00				0.000	0.00	0.0		
CO3	0.000	0.00	0.00				0.000	0.00	0.0		
Total	7.488	11.46	360.21		2.676	4.09	4.812	7.36		447.0	1.08

Notes
1. Removal rate estimated from CDM water quality data (1972)
2. 32 deg baume assumes no removal of sulfate and a production of 40 tons/acre of sodium chloride
3. CDM water quality data
4. Clarke (1924) in Ver Planck (1958)
5. Magnesium sulfate precipitates to sediments

Appendix. D Salt Mass Balance

Tables D-6 and D-7 are used to calculate liquid bittern production rates and amount stockpiled using two different methods.

Table D-6. Calculation of Liquid Bittern (water + dissolved bittern ions and salts) Stockpiled

Salinity	deg Be	30	32	36
Information				
Total salt pond area	ac	25,000	25,000	25,000
Period of stockpiling	yr	30	30	30
Specific Gravity	SG	1.26	1.28	1.33
Calculations				
Liquid Bittern Conc	ppt as g/L	369	395	447
	g/kg	293	308	336
	%	0.293	0.308	0.336
Production of dissolved bittern salts and ions[1]	tons/ac/y	**11.5**	**11.5**	**7.4**
Water Matrix	tons/ac/y	27.7	25.8	14.5
Total liquid bittern production rates[2]	tons/ac/y	**39.1**	**37.2**	**21.9**
	ft/y	0.02	0.02	0.01
Total Liquid Bittern Stockpiled[2]	million tons	**29.4**	**27.9**	**16.4**
	tons/ac	**27,962**	**26,583**	**15,650**
	ac-ft	**17,141**	**16,013**	**9,093**

Notes
1. Dissolved bittern salts and ion production rates are from Table D-5. Same rates used for salinity at 30 and 32 deg Be.
2. Liquid bittern includes dissolved salts and ions and water. Stockpiling assumes markets for bittern over the last 30 years has been minor. Assumes 25,000 salt production area.

Table D-7. Calculations of Liquid Bittern Stockpiled on site from water used and bittern production on Site from Concentration and SG

Salinity	deg Be	30	32	36	
Information					
Liquid Bittern WQ	g/L	369	395	447	
Bittern as % of original solution[1]	%	3.0	1.6	1.1	
Specific Gravity	SG	1.26	1.28	1.33	
Weight of pure water	lbs/gal	8.34	8.34	8.34	
Weight of seawater	lbs/gal	8.59	8.59	8.59	
Calculations					
Seawater required for salt production	tons/ac/yr	1,530	1,530	1,530	Ver Planck (1958)
	million lbs/ac/yr	3.06	3.06	3.06	
	gallons/ac/yr	356,305	356,305	356,305	input, volumetric
Total liquid bittern production rates[2]	gallons/ac/yr	10,689	5,772	3,836	output, volumetric,
	ac-ft/ac/y (ft/y)	0.033	0.018	0.012	seems 100% ions and salts
	lbs/ac/yr	112,377	61,757	42,543	
	tons/ac/yr	**56.2**	**30.9**	**21.3**	
Liquid Bittern stockpiled[3]	million tons	**42.1**	**23.2**	**16.0**	
	tons/ac	**40134**	**22056**	**15194**	
	ac-ft	24603	13286	8828	

Conclusions from Table D-6 and D-7

1. Estimates at 36 deg Be are roughly equivalent for both methods. Calculation validates methods used in Tables D-7 and D-6 for calculating liquid bittern production **as well as underlying mass balance calculations used in Table D-5.**
2. Estimates for liquid bittern production calculated in Table D-7 bracket calculations in Table D-6. This is expected as Table D-6 relies on Table D-5. Mass balance calculatic in Table D-5 are for an estimated salinity range of 30 - 32 deg Be.

Table D-8. Estimates of Total Bittern production rates.

Salinity	Production						Ratio of Bittern to salt production	
	Liquid		Dissolved salts and ions	Precipitate	Total Bittern			
deg Be	Lower Tons/ac/y	Upper Tons/ac/y	Tons/ac/y	Tons/ac/y	Lower Tons/ac/y	Upper Tons/ac/y	Lower %	Upper %
30	39.1	56.2	11.5	0.0	39.1	56.2	0.98	1.40
32	30.9	37.2	11.5	0.0	30.9	37.2	0.77	0.93
36	21.3	21.9	7.4	4.1	25.4	26.0	0.63	0.65
Stockpiled for Entire Salt Pond Complex over 30 year period								
deg Be	Lower Tons x 10[6]	Upper Tons x 10[6]	Tons x 10[6]	Tons x 10[6]	Lower Tons x 10[6]	Upper Tons x 10[6]		
30	29.4	42.1	8.6	0.0	29.4	42.1		
32	23.2	27.9	8.6	0.0	23.2	27.9		
36	16.0	16.4	5.5	3.1	19.0	19.5		

Appendix. D Salt Mass Balance

Table D-9. Estimated Total bittern by-product per ton of salt harvested.

Scenario	Bittern Phase	Salinity (ppt)	Salinity (°Be)	Bittern produced[1] Lower (tons)	Bittern produced[1] Upper (tons)
Discharge from crystallizer[2]	Liquid	369	30	0.98	1.40
	Liquid	395	32	0.77	0.93
Concentrating in Bittern Storage and Desalting	Liquid and solid	447	36	0.63	0.65

Notes:
[1] Based on two analyses: mass balance and concentration conversions. Calculations are shown in Appendix D.
[2] Bittern production values shown represent discharge of bittern from crystallizers at salinity value shown.
[3] Bittern production values shown represent bittern as it concentrates in the bittern storage and desalting ponds.

Table D-10. Estimated amount of bittern ions and salts generated during salt production.

Salinity		Bittern Phase	Total Bittern Production[1,2]				Bittern Ions and Salts[3]		Water Production			
ppt	deg Be		tons/ac/yr		tons/ton of salt produced		tons/ac/y	tons/ton of salt produced	tons/ac/yr		tons/ton of salt produced	
			Lower	Upper	Lower	Upper			Lower	Upper	Lower	Upper
Bittern withdrawn from crystallizers -- lower salinity level estimate[1,4]												
369	30	Total	39.1	56.2	0.98	1.40	11.5	0.286409	27.7	44.7	0.692248	1.12
		Liquid (dissolved bittern ions and salts)	39.1	56.2	0.98	1.40	11.46	0.286409	27.69	44.73	0.692248	1.12
		Solid (precipitated salts)	0	0	0.00	0.00	0.0	0	NA	NA	NA	NA
Bittern withdrawn from crystallizers -- higher salinity level estimate												
395	32	Total	30.9	37.2	0.77	0.93	11.5	0.286409	19.4	25.8	0.485558	0.64
		Liquid (dissolved bittern ions and salts)	30.9	37.2	0.77	0.93	11.5	0.286409	19.42	25.76	0.485558	0.64
		Solid (precipitated salts)	0	0	0.00	0.00	0.0	0	NA	NA	NA	NA
Bittern supplied to bittern desalting ponds prior to additional sodium chloride recovery												
447	36	Total	25.4	26.0	0.63	0.65	11.5	0.286409	13.9	14.5	0.347736	0.36
		Liquid (dissolved bittern ions and salts)	21.3	21.9	0.53	0.55	7.4	0.1840527	13.91	14.55	0.347736	0.36
		Solid (precipitated salts)	4.1	4.1	0.10	0.10	4.1	0.1023563	NA	NA	NA	NA

Notes:
1. Assume sodium chloride is harvested and bittern removed from crystallizers at 32 deg Baume.
2. Assumes a salt production rate of 40 tons per acre per year.
3. This mass excludes water in which liquid bittern ions and salts are dissolved.
4. Assumes magnesium sulfate precipitation negligible until a salinity of 32 deg Baume achieved.
5. Assumes additional sodium chloride is recoverable from bittern desalting ponds.

Table D-11. Bittern storage at different plants

Description[1]		Units	Total[2] Lower	Total[2] Upper	Location[3] Newark Lower	Newark Upper	Redwood City Lower	Redwood City Upper
Bittern storage area		Acres	1,050	1,050	780	780	270	270
Bittern liquid at 36 deg Be[1]								
A	Dissolved bittern salts and ions	Million of tons	5.5	5.5	4.1	4.1	1.4	1.4
B	Water matrix	Million of tons	10.4	10.9	7.7	8.1	2.7	2.8
C	**Total bittern liquid = A + B**	Million Tons	16.0	16.4	11.9	12.2	4.1	4.2
		Acre-Ft	8,828	9,093	6,558	6,755	2,270	2,338
		Millions of gallons	2,877	2,963	2,137	2,201	740	762
		Tons per acre	15,194	15,650	11,287	11,626	3,907	4,024
Bittern solids at 36 deg Be								
D	Precipitated bittern salts	Million of tons	**3.1**	**3.1**	**2.3**	**2.3**	**0.8**	**0.8**
		Tons per acre	2,924	2,924	2,172	2,172	752	752
Total Bittern By-Product = bittern liquid + bittern solids								
E	Total = C + D	Million of tons	**19.0**	**19.5**	**14.1**	**14.5**	**4.9**	**5.0**
		Tons per acre	18,118	18,574	8,730	8,927	3,022	3,090

Appendix. D Salt Mass Balance

Notes
1. Assumes bittern is stored at 36 degrees Baume.
2. Assumes 40 tons of salt produced per acre and 25,000 production acres.
3. Estimated storage per site is based on relative areas of bittern ponds at each plant (Map 5).

Table D-12. Thickness of precipitated bittern salts at 36 deg Be

Salt	Mass produced annually (tons/ac)	Specific Gravity	Density (lb/ft^3)	Mass stored over 30 year period (tons/ac)	(lbs/ft^2)	Thickness (ft)	(in)
$MgSO_4$	3.30	2.66	166				
NaCl	0.80	2.17	135				
Total	4.09	2.56	160	2924	134	**0.8**	10

Appendix E

Natural Sedimentation Assumptions

Appendix E. Natural Sedimentation Assumptions

We used three scenarios to estimate the time necessary to reach tidal marsh plain elevations on two thirds of the entire South Bay salt pond complex (approximately 18,000 acres). The differences between the three scenarios are the rates of projected sea level rise (1.3 and 2.0 millimeters per year) and the areas requiring "maintenance" sediment deposition (mudflat only or marsh plus mudflat). Descriptions of the three scenarios follow.

Scenario 1: Salt Pond Accumulation and Mudflat Maintenance

- Sea level rise projected at 1.3 millimeters per year.
- 72 million cubic yards of sediment needed for 18,000 acres of salt ponds.
- Sediment deposition maintains restored salt pond elevations in light of projected sea level rise.
- Sediment deposition maintains intertidal mudflat elevations in light of projected sea level rise. Total acreage of 15,000 acres (Goals Project 1999).
- Internal organic matter accumulation (i.e., vascular plant production) maintains tidal marsh elevations in light of projected sea level rise. Total acreage of 10,000 acres (Goals Project 1999).

Scenario 2: Salt Pond Accumulation and Tidal Marsh and Mudflat Maintenance

- Sea level rise projected at 1.3 millimeters per year.
- 72 million cubic yards of sediment needed for 18,000 acres of salt ponds.
- Sediment deposition maintains restored salt pond elevations in light of projected sea level rise.
- Sediment deposition maintains intertidal mudflat *and* tidal marsh elevations in light of projected sea level rise. Total acreage of 25,000 acres (Goals Project).

Scenario 3: Salt Pond Accumulation and Tidal Marsh and Mudflat Maintenance

- Sea level rise projected at 2.0 millimeters per year.
- 72 million cubic yards of sediment needed for 18,000 acres of salt ponds.
- Sediment deposition maintains restored salt pond elevations in light of projected sea level rise.
- Sediment deposition maintains intertidal mudflat *and* tidal marsh elevations in light of projected sea level rise. Total acreage of 25,000 acres (Goals Project 1999).

We made six assumptions to assist us with this analysis. These assumptions are described below.

1. **Assumptions Regarding "Maintenance" Deposition.** The existing tidal marshes and mudflats need to maintain their elevations with respect to the tides over the long term under sea level rise in order to continue providing their ecological support functions. For tidal marshes, we consider two variations for maintaining these elevations. In Scenario 1, we assume that vascular plant growth will provide the necessary accumulation to maintain marsh elevations. In Scenarios 2 and 3, we assume that sediment deposition is necessary to maintain elevations. For tidal mudflats, we assume that sediment deposition is needed under all scenarios.
2. **Assumptions Regarding Sea Level Rise.** In Scenarios 1 and 2, we assume a sea level rise of 1.3 millimeters per year (Titus and Narayanan 1995). For Scenario 3, we use a higher rate of sea level rise corresponding with rates of 1.9 to 2.0 millimeters per year measured at San Diego, La Jolla, Newport, and Seattle.

3. **Assumptions Regarding Sediment Supply.** The calculations presented here use a constant rate of 0.89 million cubic yards of net sediment influx into the South Bay (Krone 1996). According to Schoellhamer (personal communication), this value is the best available today, although its accuracy is uncertain. Whether the rate would change over time is difficult to predict because it is influenced strongly by climate and land use practices.
4. **Assumptions Regarding Restoration Implementation.** For the purpose of simple calculations, we assume restoration starts at time zero. The purpose of this assumption is to consider advantages gained by spreading out restoration implementation to reduce the annual sediment demand, thereby, reducing the potential for sediment scouring from intertidal mudflats.
5. **Assumptions Regarding Sediment Accumulation.** Because the South Bay shows relatively high rates of sedimentation in the shallow margins (e.g., rapid sediment accumulation in local marinas and marsh restoration projects), we assume that sedimentation rates in restored salt ponds will be similar to these regional rates. Therefore, sedimentation to marsh plain elevations would occur in a five to ten year timeframe for higher elevation salt ponds. For the more subsided ponds, sedimentation would occur in a ten to twenty year timeframe. These values are approximate. This assumption is not used in the calculations, but rather in the interpretation of the results relative to sediment scouring of the mudflats.
6. **Assumptions Regarding Sediment Source.** The calculations presented here assume that 100 percent of the sediment supplied to the restored salt ponds comes from a net influx of sediments into the South Bay. The purpose of this assumption is to test the demand for sediment from other sources given the anticipated rate of sediment accumulation. In other words, a low net sediment influx into the South Bay equates to a sediment demand from other sources, not a low sedimentation rate in restored salt ponds.

Given the purpose of this analysis and the assumptions stated above, the results are expected to yield one of three outcomes. These outcomes are fundamental to how salt pond restoration is implemented in an environmentally sound manner.

1. **Relatively low likelihood of scouring mudflats.** If the calculations show rapid (e.g., 20 years) return of marsh plain elevations in the restored salt ponds, then one can conclude that the net sediment influx into the South Bay would provide a sufficient sediment source. The mudflats would probably not be scoured to any significant degree.

2. **Intermediate likelihood of scouring mudflats.** If the calculations show moderate (e.g., 50 years) return of marsh plain elevations in restored salt ponds, then one can conclude that, under a natural sedimentation design approach, the mudflats will experience some degree of scour unless restoration implementation is spread out over a longer timeframe.

3. **Relatively high likelihood of scouring mudflats.** If the calculations show slow (e.g., 100 years) return of marsh plain elevations in the restored salt ponds, then one can conclude that, under a natural sedimentation design approach, sediment is likely to be drawn from mudflats to make up the sediment deficit and maintain sedimentation rates. Therefore, restoration implementation must spread out over many decades or utilize dredged material to avoid mudflat scour.

Appendix F

Desalinating Low and High Salinity Ponds

Appendix F: Desalinating Low and High Salinity Ponds

This appendix models the "push" method of pond desalination described in Chapter 10. The purpose of modeling this desalination method is to understand the fate and halite (common salt) and gypsum. An important goal during the transition period between salt production and restoration will be desalinating water and sediments in the salt ponds. Many factors can potentially affect this process including source water and hydraulic loading rates (HLRs). Actions to manage the ponds during this process will affect not only the water and sediment salinity but also other salt pond characteristics such as the formed gypsum layers in 30 – 40% of the production pond area. To understand the processes better, we have used a mass balance approach to model pond desalination when low salinity water is continuously pumped into a pond. This method has been defined in Chapter 10 as the "Push Method" and application of this method underlies many of the conclusions reached in Chapters 9 and 10. For these models, we have made several assumptions and these are listed in Table F-1.

Figure F-1 presents the simple hydrologic and mass balance models for the salt production ponds. These models assume conservation of mass. In other words, water entering the ponds must exit the ponds through infiltration, evaporation, evapotranspiration or surface outflow. This example can also be applied to the different elements entering and exiting the ponds. For instance, during salt production, all sodium entering the system must either precipitate to the pond bed or flow from the system.

The hydrologic or water balance can be described as:

$$Q_{Inflow} = Q_{Outflow} + Q_{evaporation}$$ **Equation F- 1**

where

Q_{inflow} = the surface water flow into each pond
$Q_{outflow}$ = the surface water flow from each pond, and
$Q_{evaporation}$ = net evaporation losses.

Net evaporation losses are discussed in Appendix A and are the difference between gross evaporation rates and precipitation. In this model, evapotranspiration is considered negligible due to the relative scarcity of emergent macrophytes in the salt ponds. This model assumes that each salt pond is a continuously mixed system or a continuous-flow stirred tank reactor (CFSTR).

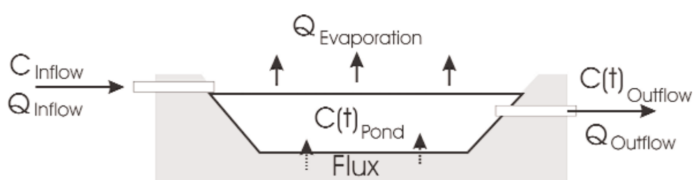


Figure F-1. Hydrologic and Mass Balance Model for Salt Ponds

Table F-1. Assumptions for salt concentration under constant water level Management and no flushing

No.	Description
1	Each pond can be modeled as a CFSTR (Continuous-Flow Stirred Tank Reactor).
2	A net evaporation rate of 30 in y^{-1} has been assumed based on the analysis in Appendix A. This net evaporation rate is representative of lower salinity ponds, although it overestimates rates for higher salinity ponds. Because lower salinity ponds form such a large area of the complex and because salinity levels as ponds approach lower salinity conditions are those that most affect discharge, this assumption seems to meet the needs of this simple analysis.
3	Inflow concentrations are constant
4	Bay water is used as a dilution source and a salinity of 20 ppt is assumed reasonably representative of Bay water. Lower salinity source water will require less flush water to maintain low salinity levels in a given pond. Higher salinity source water will require more flush water.
5	Different water densities between Bay water and salt pond water negligibly affect the results. Assumed that wind and temporal mixing in combination with pond operation provide adequate mixing.
6	Formed gypsum and salt layers are homogeneous and generally free of other material such as organic matter or Bay sediments.
7	Conservation of mass. All mass in and out of the model can be accounted for.
8	Have used published literature values for gypsum dissolution rates.
9	Have used published literature values for halite dissolution rates. Have used these same relationships to approximate bittern dilution rates.
10	Analysis ignores seasonal effects such as variable precipitation, evaporation and salinity levels during the year. Desalination is assumed to be sufficiently long-term to justify this approach. Desalination efforts can be optimized by considering seasonal differences in climate and water quality.

Using this model, the mass balance for water quality parameters can be described by:

$$mass_{Inflow} = mass_{Outflow} + mass_{stored} + \Delta mass_{time}$$ **Equation F- 2**

which can be further defined as:

$$Q_{Inflow} C_{Inflow} = Q_{Outflow} C_{Outflow} - Flux \bullet Area_{Bed} + \frac{\Delta C(t)_{Pond}}{\Delta t} \bullet Area_{Bed} \bullet h$$

Equation F- 3

where

C_{inflow} = the inflow concentration of the given water quality parameter,
$C_{outflow}$ = the outflow concentration of a given water quality parameter,

Flux = the flux of the parameter into the sediments through diffusion or precipitation,
$Area_{Bed}$ = the bed area of the pond,
C_{pond} = the parameter concentration in the pond itself, and
h = water depth.

To understand how salinity varies with different management regimes, we present operation of the salt ponds under two scenarios:

- Water level maintenance
- Desalination

Water level maintenance is similar to operation during salt production and is also similar to the operational mode in the North Bay where insufficient funds have been available for water management. In this analysis, we assess the effects of these two different management regimes on pond salinity, pond sediment salt concentrations and gypsum.

F-1. Scenario One: Water Level Maintenance

Under this scenario, water levels are maintained to prevent ponds from drying out. This is the minimum water that should be available to the system. Any thing less will lead to ponds drying out with the concomitant increase in salinity, decrease in pH and reduction in habitat value (DeYeager, 2000; Huffman, 2001).

There is no discharge from the ponds under this strategy as water only leaves through evaporation:

$$Q_{Inflow} = Q_{evaporation} = HLR \bullet Area_{Bed} \qquad \textbf{Equation F- 4}$$

HLR is defined as the hydraulic loading rate (e.g. cm d^{-1}, in y^{-1}).

F-1.1. Effects on Salt Concentrations

Operating the ponds under this scenario is similar to the operating protocols for concentrating salt. Whether salt will continue to concentrate depends largely on the source water and the operational water depth. Under this scenario, the salinity mass balance equation (Equation F-3) becomes:

$$Q_{Inflow}C_{Inflow} = -Flux \bullet Area_{Bed} + \frac{\Delta C(t)_{Pond}}{\Delta t} \bullet Area_{Bed} \bullet h \qquad \textbf{Equation F- 5}$$

In ponds such as the evaporator ponds and the pickle ponds, there is essentially no salt precipitation or flux from the water column. For these ponds, Equation F - 5 becomes:

$$Q_{Inflow}C_{Inflow} = \frac{\Delta C(t)_{Pond}}{\Delta t} \bullet Area_{Bed} \bullet h \qquad \textbf{Equation F- 6}$$

By rearranging Equation F - 6, the salt concentration can be described as:

$$\frac{\Delta C(t)_{Pond}}{\Delta t} = \frac{Q_{Inflow}C_{Inflow}}{Area_{Bed} \bullet h} \qquad \textbf{Equation F- 7}$$

which can then be solved to show that:

$$C(t)_{Pond} = \frac{Q_{Inflow}C_{Inflow}}{Area_{Bed} \bullet h}t + C_{Pond,t0} = \frac{HLR}{h} \bullet C_{Inflow}t + C_{Pond,t0} = \frac{C_{Inflow}}{HRT}t + C_{Pond,t0}$$

where:

$C_{pond,t0}$ = initial concentration of water quality parameter at the beginning of pond maintenance activities,
HLR = the hydraulic loading rate (e.g. cm d^{-1}, in y^{-1}), and
HRT = hydraulic retention time.

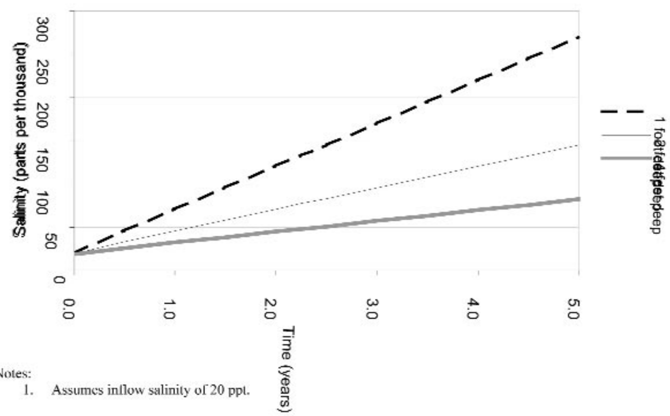
This relationship shown in Equation F - 8 is valid until a salinity level is achieved at which time salts precipitate. This begins to occur at the salinity of pickle ponds (312 ppt, 25.6 Be). Under this relationship, pond salinity does not achieve a steady state condition but instead increases over time. Ultimately, the steady state condition that would be achieved is the precipitation of salts and the formation of bittern.

From Equation F - 8, three parameters essentially control the salt concentrating process:

- The water depth (h)
- The inflow concentration C_{inflow}
- The time (t) during which the ponds are operated in this manner

Hydraulic loading rate and the initial pond salinity also affect the pond salt concentrations although those variables cannot be operationally adjusted. Under this scenario, HLR equals the evaporation rate and the initial pond concentration is the pond concentration when this management scenario was implemented.

Thus from a pond management perspective, there are two methods to control the rate at which salinity increases under this operating scenario: water level and inflow salinity levels. Figure F – 2 shows that for higher inflow salinity levels, pond salinity increases more rapidly because of the higher salt loading to the pond. Thus, selection of low salinity source waters is one method to limit the rate ponds become more saline over time. However, lower salinity water may be more expensive, especially if it is pumped. To offset evaporative losses, a seasonal HLR of approximately 2.5 ft y^{-1} would be needed. For 25,000 acres, this requires an annual average fresh or storm water flow of approximately 62.5 acre-ft y^{-1} or 39 gpm.



Notes:
1. Assumes inflow salinity of 20 ppt.

Figure F-3. Changes in pond salinity over time for different water depths.

F-1.2. Effects on Gypsum

Under this management scenario, gypsum will begin to settle out over time. Settling is consistent with the salt production process. Gypsum begins to form at a salinity level of 147 ppt (12.9 °Be). For a two-foot deep pond with an inflow concentration of 20 ppt (typical of the Bay), gypsum would begin to form after about 5 years (Figure F - 3). For a four-foot depth, the time would be doubled. For ponds in which a gypsum layer was evident at the initiation of water level management, the layer would persist as the pond water increased in salinity.

F-2. Scenario Two: Flushing and Desalination

Under flushing and desalination, inflow exceeds evaporative rate. In our model, inflow enters at a constant rate in order to flush salts from water and sediments, with surface water salinity eventually approaching Bay water levels (Figure F - 1).

F-2.1. Low Salinity Ponds

In low salinity ponds, sodium chloride has not precipitated to the sediments. Equation F - 3 becomes:

$$Q_{Inflow}C_{Inflow} = Q_{Outflow}C_{Outflow} + \frac{\Delta C(t)_{Pond}}{\Delta t} \bullet Area_{Bed} \bullet h$$ **Equation F- 9**

Negligible sodium chloride concentrations in the sediments make flux negligible. This equation can be solved such that:

$$C(t)_{Outflow} = \left(C_{Pond,t0} - \frac{Q_{Inflow}C_{Inflow}}{Q_{Outflow}}\right)e^{\left(t/_{HRT}\right)} + \frac{Q_{Inflow}C_{Inflow}}{Q_{Outflow}},$$ **Equation F- 10**

and rearranges to yield:

$$C(t)_{Outflow} = C_{Pond,t0}e^{\left(t/_{HRT}\right)} + \left(\frac{Q_{Inflow}C_{Inflow}}{Q_{Outflow}}\right)\left(1-e^{\left(t/_{HRT}\right)}\right) = C_{Pond,t0}e^{\left(t/_{HRT}\right)} + C_{Inflow}\left(\frac{1}{1-r}\right)\left(1-e^{\left(t/_{HRT}\right)}\right)$$ **Equation F- 11**

where

$$r = \frac{Q_{evaporation}}{Q_{Inflow}}$$ **Equation F- 12**

Equation F - 11 can be presented in two parts such that

$$C(t)_{Outflow} = C(t)_{Outflow,1} + C(t)_{Outflow,2}$$ **Equation F- 13**

where

$$C(t)_{Outflow,1} = \left(C_{Pond,t0}\right)e^{-\left(t/_{HRT}\right)}$$ **Equation F- 14**

and

$$C(t)_{Outflow,2} = C_{Inflow}\left(\frac{1}{1-r}\right)\left(1-e^{-\left(t/_{HRT}\right)}\right)$$ **Equation F- 15**

F-2.2.1. Effects on Pond Salinity and Its Outflow

The first term $C(t)_{Outflow,1}$ describes the effects of the initial pond water on outflow concentrations. Essentially, as low salinity water is introduced, it dilutes the higher salinity water within the pond over time. The second term $C(t)_{Outflow,2}$ describes the effects of evaporation on the pond outflow salinity levels. As desalination occurs, evaporation still occurs and continues to concentrates salts. Thus, the first process causes a decrease in salinity and the second causes an increase.

Table F-2 presents hypothetical initial conditions for the pond. In this hypothetical 1.5-foot deep pond, the initial salt concentration before flushing begins is 140 ppt.

Figure F-4 combines the two terms and presents changes in outflow concentrations for different HLRs. The lowest HLR of 8.2 ft y^{-1} corresponds with a 67 day HRT for a 1.5 ft deep pond and is a little over three times net evaporation rates. The highest HLR of 410 ft y^{-1} corresponds with a 1.3 day HRT and is 2 orders of magnitude greater than net evaporation rates. The intermediate HLR of 21 ft y^{-1} corresponds with a 26 day HRT.

Table F-2. Hypothetical initial conditions for pond desalination.

Parameter	Value
$C_{pond,t0}$	140 ppt
Net evaporative rate	2.5 ft y^{-1}
Water depth	1.5 ft
C_{inflow}	20 ppt

Initially, the portion of the outflow attributed to flushing the pond is 140 ppt. As the pond water is displaced from the pond, some portion of the pond outflow is the initial high salinity pond water and some portion the low salinity inflow water. As desalination continues, the portion of outflow attributed to low salinity inflow water increases. Salinity decreases in the outflow thus correspond to a relationship between period during which flushing has occurred and the operational HRT for the given pond. Table F-3 shows this relationship. In general, after one HRT, the outflow salinity for a pond is approximately one third its initial levels. For a HLR of 21 ft y^{-1}, this corresponds with a 4 week time period. After 3 HRTs, concentrations are approximately 5% of original pond concentrations, a nearly steady state salinity level.

The relationship described in Table F-3 generally describes the changes in outflow salinity for all HLRs except for low HLRs. At high HLRs (and correspondingly high flows), evaporation rates negligibly affect pond outflow concentrations. Essentially, too much water is passing through for evaporative salt concentration to be much of a factor. However, as HLRs decrease, evaporation effects become increasingly important, as shown in Figure F-4. At the lowest HLR shown, which is approximately three times net evaporation rate, the outflow concentration approaches 40 ppt. The outflow is twice as concentrated than the inflow at this low HLR and therefore twice as concentrated as background levels in the Bay. At higher HLRs, from five times the evaporative rate (21 ft y^{-1}) to one hundred times the evaporative rate (410 ft y^{-1}), the outflow concentration approaches a range of 20 to 25 ppt. The steady state outflow concentration is independent of the initial pond concentration and only depends upon the inflow water salinity.

Table F-3. Initial pond flushing over time for pond desalination.

t/HRT	Percent initial pond water remaining in outflow
0	100
1	36.8
2	13.5
3	5.0
4	1.8

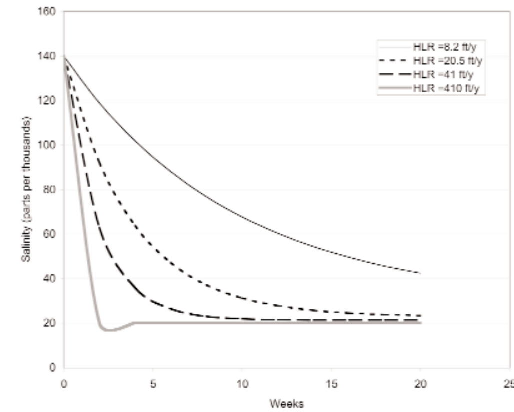


Figure F-4. Flushing of initial pond water.

F-2.1.2.Effects on Gypsum

Gypsum has accumulated in approximately 30 – 40% of the salt production pond area. We have assumed in this study that the gypsum has not evenly precipitated and thus we have assumed that approximately 30% of the salt production ponds have significant gypsum accumulation. Gypsum forms a relatively hard surface and if it is persistent could potentially affect slough formations and vegetation colonization. Gypsum likely does not pose a problem if it dissolves or is unevenly interspersed throughout the organic soils. However, if it forms a consolidated and uniform layer, than the gypsum layer will likely affect the restoration rate and its characteristics.

Gypsum precipitates in ponds with salinity between 150 - 375 ppt. During flushing and desalination, salinity will have dropped below that level after one HRT. At that point, equilibrium relationships suggest gypsum will dissolve. However, kinetics may not favor dissolution.

Figure F - 5 models the flux of gypsum from sediments. Assuming steady state conditions, a mass balance equation describing the process is:

$$Mass = Flux \bullet Area \bullet time = Q_{outflow} \bullet C \bullet time \qquad \textbf{Equation F- 16}$$

Under optimal production, an estimated 8.6 tons ac^{-1} y^{-1} of gypsum has accumulated over time in the higher salinity ponds and this rate is assumed for 30% of the total salt production pond area. For a 50 years production period, this equals 1.64 inches of gypsum or 430 tons ac^{-1}. Raines and Dewers (1997) used gypsum blocks to measure *in situ* gypsum dissolution rates of 0.1 – 2.0 x 10^{-5} mol cm^{-2} h^{-1} (67.2 – 1334 tons ac^{-1} y^{-1}). James *et al.* (1981) measured *in situ* rates of 1.5 x 10-5 mol cm^{-2} h^{-1} (1000 tons ac^{-1} y^{-1}). Actual dissolution rates in the salt ponds will likely differ to some degree from these rates because of several factors:

- Gypsum density in the sediments,
- Water exchange rates with gypsum layers,
- Surface flow velocities, and
- Water chemistry including salinity and trace metal concentrations.

However, these dissolution rates are likely a reasonable estimate for this analysis.

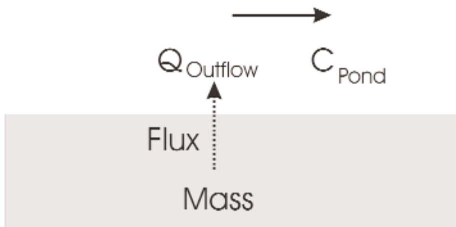


Figure F-5. Flux of gypsum from the sediments.

Table F-4 estimates dissolution rates and dissolution times. For lower dissolution rates, the estimated time to dissolve a 50-year accumulation of gypsum is approximately 6 years. For higher dissolution rates, the estimated time is around 4 months. This assumes that the gypsum has formed a hard and fairly homogeneous surface in the ponds in which gypsum has accumulated. These are estimated times and should be used only as guidelines until more data and information are available. We believe the main factor affecting dissolution rates in this system will be flow velocities (Raines and Dewers 1997), given the relative uniform pond characteristics. James *et al.* (1981) found that *in situ* dissolution rates in quiescent areas were an order of magnitude less than those in rapid flow areas (greater than 1 m s^{-1}). Salinity may also have a large effect on gypsum dissolution though that effect will likely be only most evident during the first HRT of flushing when salinity may still be quite elevated. Therefore, in areas experiencing highest flow velocities such as slough areas and zones affected by tidal influence, the gypsum layer is expected to dissolve over a period of months. In areas in which water is much more quiescent, such as marsh areas remote from the slough, gypsum dissolution is predicted to occur over a period of years. In these areas, marsh topography and vegetation colonization may be adversely impacted by this gypsum layer.

Two other variables need also be considered when assessing or predicting the effects of gypsum. First, in areas where the marsh has subsided, bay sediment will likely accrete relatively quickly over the existing pond bed. For low elevation ponds with existing gypsum layers, the gypsum will likely become buried under sediment deposits as the pond accretes. With a layer of bay mud topping the buried gypsum layer, marsh plants may be able to colonize the marsh effectively and the gypsum layer may be inconsequential.

Table F-4. Time for dissolution of gypsum.

Gypsum accumulation over time	Dissolution rate	Time	
Tons ac-1	Tons ac^{-1} y^{-1}	Years	Days
423	67.2	6.3	2300

423	1334	0.32	117

Notes:
1. Gypsum accumulation is estimated for a 50-year discharge period assuming maximum salt production rates.
2. Dissolution rates shown are estimated minimum and maximum rates estimated from the literature.

Another variable is saturation state. In marsh areas where the ponds dry out, the gypsum layer will likely persist for the longest period. Gypsum cannot dissolve without water. It is reasonable to assume that in slough areas and zones affected by tidal influence the gypsum layer will dissolve over a period of a month to a few months. In areas with more quiescent water, the gypsum layer if a hard consolidated surface will take on the order of years to dissolve from the sediment into the water column.

In summary, gypsum dissolution rates will vary throughout the ponds and this will likely result most from variations in flow velocity and saturation state. In slough areas or zones near tidal influence, gypsum dissolution rates are expected to occur over a period of months. In quiescent areas, gypsum dissolution will occur over a period of years. That period may be greatly extended in high marsh areas that are less frequently flooded. In these high marsh areas, gypsum is most likely to hinder channel formation and vegetation colonization.

F-2.2. High Salinity Ponds

High salinity ponds are defined as crystallizers, desalting ponds and bittern ponds. These ponds are differentiated from the low salinity ponds by the presence of precipitated salts. Of these three pond types, bittern ponds differ most from the other two because of the large amount of unharvested salts accumulated in their sediments. Crystallizer salt is harvested. Desalting ponds only store bittern for a few years and then are rinsed with pickle to dissolve the salts (Ransom, 2000).

Table F-5 presents hypothetical conditions for a bittern pond in this process. During modeling of desalination, both internal and external salt loads need to be considered. Equation F - 5 can be rearranged so that salt inputs to the ponds include salts from the inflows (external loading) and salts entering the water column from the sediments (internal loading):

$$Q_{Inflow} C_{Inflow} + Flux \bullet Area_{Bed} = \frac{\Delta C(t)_{Pond}}{\Delta t} \bullet Area_{Bed} \bullet h \quad \textbf{Equation F- 17}$$

In the bittern ponds, bittern first enters the ponds at a salinity of approximately 369 ppt (30 °Be) as discussed in Chapter 3. As bittern concentrates, bittern salts precipitate from solution. These salts likely form a layer of salt similar to that in the crystallizers. However, that salt is composed of salts less soluble than halite. Nonetheless, the bittern salts likely form a homogeneous layer that overlays the bay muds (Figure F -6).

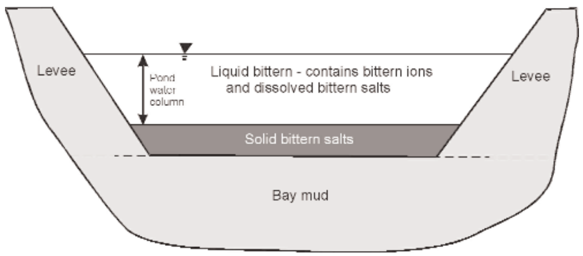


Figure F-6. Bittern pond schematic.
(Not to scale)

Table F - 5. Operating characteristics for "typical" bittern pond.

Parameter	Value
$C_{pond,t0}$	447 ppt
Evaporative rate	2.5 ft y^{-1}
Water depth	7.6 ft
C_{inflow}	20 ppt
Accumulated bittern salts	3,300 tons of salt ac^{-1}

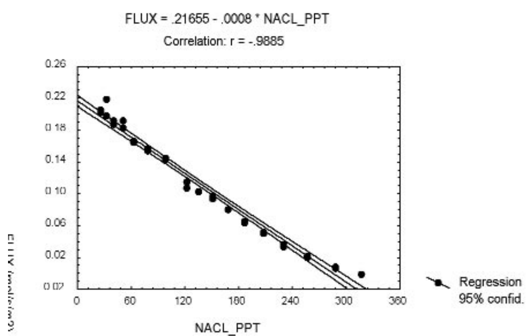


Figure F-7. Halite dissolution as a function of NaCl concentration. (Alkatton et al., 1997a)

The flux of bittern salts are assumed to be similar to that of halite (sodium chloride). The bittern salts are more soluble than halite and therefore this assumption is likely conservative, with the dissolution of bittern salts likely higher. From Alkatton *et al.* (1997), halite dissolution was found to be dependent upon sodium chloride concentrations (Figure F -7).

Assuming that bittern salts had similar dissolution rates as halite, total dissolved solids act as a reasonable surrogate for sodium chloride concentrations. Using *in situ* tests by Alkatton *et al.* (1997), which are fairly representative of rates that would occur here, we estimate the bittern salt dissolution rate as:

$$Flux = 0.21655 - 0.0008(TDS) \quad \textbf{Equation F- 18}$$

Solving the Equation F - 17 while incorporating the flux equation and while maintaining consistent units yields:

$$C(t)_{Outflow} = C_k e^{\,at} - \left(b/a\right) \quad \textbf{Equation F- 19}$$

where

C_k = constant required to set $C_{outflow}$ at time zero to initial pond concentration of approximately 320 ppt, In this solution "a" is defined by Equation F - 20:

$$a = \frac{HLR - Ev + 4583}{h} \quad \textbf{Equation F- 20}$$

and "b/a" is defined by Equation F - 21:

$$b/a = -\frac{HLR \bullet C(t)_{Outflow} + 1.313\times10^{6}}{HLR - Ev + 4583} \quad \textbf{Equation F- 21}$$

where

E_v = the net evaporative rate in ft y^{-1}.

As water is introduced into the bittern pond for flushing, bittern salts initially determine the pond and outflow salinity (Figure F - 8). Our mass balance analysis predicts that salinity decreases initially after flushing begins and then reaches a constant level near 280 ppt. This level is controlled by dissolution kinetics of the bittern salts from the sediments (Figure F - 8). Essentially, the flux of bittern salts is very rapid from the sediments and the pond salinity level is relatively independent of the wash water used (storm water, wastewater, fresh water or Bay water). The concentration is also on slightly affected by flow rates, HLRs or HRTs.

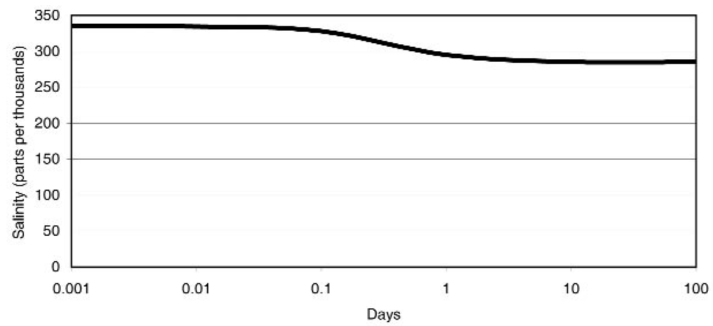


Figure F-8. Water column salinity during flushing of sediments of bittern salts.

Different amounts of time will be required to flush the sediments, depending upon the HLR. Although the outflow concentration is the same, the volume of water moving through the system is not. Higher HLRs and higher flow rates can move more salt out of the sediments, proportional to the flow rate. Thus, based upon sediment accumulation rates of bittern salts (Chapter 10), a HLR of 120 ft y^{-1} would wash the sediment of bittern salts in about 30 days whereas a HLR of 40 ft y^{-1} would take about 80 days (Figure F - 9).

After the sediments have been flushed of bittern salts, outflow salinity begins to decrease rapidly as it does for lower salinity ponds, asymptotically approaching salinity levels near background (Figure F-10). As with the low salinity ponds, the final achievable salinity is dependent upon flow rates. For HLRs above 20 ft y^{-1}, outflow salinity concentrations near background levels can be achieved. Thus, during the initial period of flushing, pond and outflow salinity are high as bittern salts are dissolved from the sediments and flush through the system. At a HLR of 20 ft y^{-1}, the amount of time to flush a bittern pond is estimated at 90 weeks.

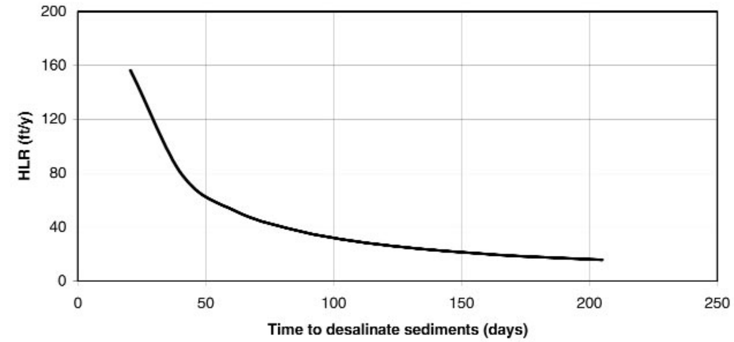


Figure F-9. Time to flush sediments of bittern salts as a function of HLR.

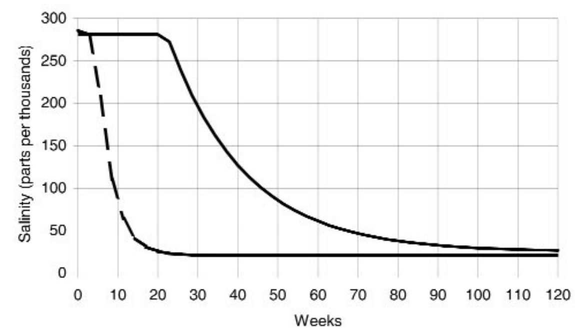


Figure F-10. Outflow salinity of bittern pond over time as pond is washed of dissolved and precipitated salts.

Appendix F: Mass Balance Spreadsheet

Scenario for Restoration Operations

1. Evaluating San Francisco Estuary typical salinities in during wet and dry season

From SFEI (1997)

Period/Month		PSU mean	min	max	mean/min	mean/max
Wet Season						
	Jan-94	16.8	0.1	28.6	168	0.59
	Apr-94	18.0	0.1	28.6	180	0.63
	Feb-95	6.5	0.1	16.3	93	0.40
	Apr-95	8.3	0.1	17.4	119	0.48
	Feb-96	8.5	0.1	22.4	121	0.38
	Apr-96	14.8	0.1	29.8	185	0.50
	Jan-97	3.4	0.1	11.7	68	0.29
	Apr-97	16.7	0.1	30.3	167	0.55
Wet Season Average		**11.6**	**0.1**	**23.1**	**138**	**0.48**
Dry season						
	Sep-93	22.2	0.1	29.7	247	0.75
	Aug-94	18.0	0.1	28.6	180	0.63
	Aug-95	15.5	0.3	27.6	62	0.56
	May-96	14.8	0.1	29.8	185	0.50
	Jul-96	16.9	0.1	29.2	282	0.58
	Aug-97	18.2	0.1	30.6	260	0.59
Dry Season Average		**17.6**	**0.1**	**29.3**	**203**	**0.60**
Dry/Wet		**1.5**	**1.4**	**1.3**		

Conclusions

1. **Wet season bay water is on average is 30 - 50% less saline than during the dry season depending upon location in the Bay**
2. **Mean bay concentration is generally two orders of magnitude greater than minimum concentrations**
3. **Mean bay concentration is approximately half maximum concentrations.**
4. **Salinity data is lower for the estuary rather than the South Bay because of data from the Sacramento River has much lower salinities than the South Bay**

2. Investigation of water level maintenance practices

Notes
1. Assumes year round salinity of 20 psu based on SFEI data from Dumbarton, South Bay and Coyote Ck.

Effects of Water Depth changes

Net Evaporation Rate 2.5

Water Depth (ft) years	Salinity for different water depths 1	2	4
0	20	20	20
0.5	45	32.5	26.25
1	70	45	32.5
1.5	95	57.5	38.75
2	120	70	45
2.5	145	82.5	51.25
3	170	95	57.5
3.5	195	107.5	63.75
4	220	120	70
4.5	245	132.5	76.25
5	270	145	82.5

Effects of various salinities
1. Assumes 2 ft water depth

Appendix F: Mass Balance Spreadsheet

2. Investigation of water level maintenance practices continued

Salinity	Pond salinity at different inflows salinity levels 0.5	10	20
0	0.5	10	20
0.5	0.8125	16.25	32.5
1	1.125	22.5	45
1.5	1.4375	28.75	57.5
2	1.75	35	70
2.5	2.0625	41.25	82.5
3	2.375	47.5	95
3.5	2.6875	53.75	107.5
4	3	60	120
4.5	3.3125	66.25	132.5
5	3.625	72.5	145

3. Desalination practices

Investigating desalination practices on water and sediment salt concentrations over time.

A. Evaporator Ponds, No acccumulation of salts in sediments

Notes
1. Effects of different HLR and HRTs
2. Assume that a maximum amount of time to flush the ponds is 4 months (January - April) which is an approximation of the rainy season. Therefore, there is approximately 120 days (17 weeks) in which high salinity water can be put out in the estuary. After that time, water should be at least below 60 psu in the ponds.
3. Includes Non-steady state flushing
4. No acccumulation of salts in the sediments

C_t: Flushing Ponds:

$$C(t)_{Outflow,1} = \left(C_{Pond,t0}\right)e^{-\left(t/_{HRT}\right)}$$

HLR	**ft/y**	**8.2**	**20.5**	**41**	**410**
HRT	**years**	**0.1829**	**0.0732**	**0.0366**	**0.0037**
HRT	**days**	**66.8**	**26.7**	**13.4**	**1.3**
Days since flushing began	**weeks**	**Salinity (ppt)**			
0	0	140.0	140.0	140.0	140.0
14	2	113.5	82.9	49.1	0.0
28	4	92.0	49.1	17.2	0.0
42	6	74.6	29.1	6.0	0.0
56	8	60.5	17.2	2.1	0.0
70	10	49.1	10.2	0.7	0.0
84	12	39.8	6.0	0.3	0.0
98	14	32.3	3.6	0.1	0.0
112	16	26.2	2.1	0.0	0.0
126	18	21.2	1.3	0.0	0.0
140	20	17.2	0.7	0.0	0.0

Specifications

Parameter	Value	Unit
Cpond,t0	140	ppt
Evap. rate	2.5	ft/y
depth	1.5	ft
C_{inflow}	20	ppt

Appendix F: Mass Balance Spreadsheet

C_2: Concentrating of inflow within the pond

$$C(t)_{Outflow} = C_k e^{-at} - \left(\frac{b}{a}\right)$$

Notes
1. As inflow water is pumped into ponds, it concentrates during its residence in the ponds
2. Rate at which pond salinity from inflow water achieves steady state is dependence upon water depth, inflow rates.

HLR			8.2	20.5	41	410
HRT	years		0.1829	0.0732	0.0366	0.0037
	days		66.8	26.7	13.4	1.3
R			0.30487805	0.1219512	0.06097561	0.0060976
days	weeks		Salinity			
0		0	0.0	0.0	0.0	0.0
14		2	5.4	9.3	13.8	20.1
28		4	9.9	14.8	18.7	20.1
42		6	13.4	18.1	20.4	20.1
56		8	16.3	20.0	21.0	20.1
70		10	18.7	21.1	21.2	20.1
84		12	20.6	21.8	21.3	20.1
98		14	22.1	22.2	21.3	20.1
112		16	23.4	22.4	21.3	20.1
126		18	24.4	22.6	21.3	20.1
140		20	25.2	22.7	21.3	20.1

$C_1 + C_2$

HLR			8.2	20.5	41	410
HRT	years		0.1829	0.0732	0.0366	0.0037
	days		66.8	26.7	13.4	1.3
R			0.30487805	0.1219512	0.06097561	0.0060976
days	weeks		Salinity			
0		0	140.0	140.0	140.0	140.0
14		2	119.0	92.2	62.9	20.1
28		4	101.9	63.9	35.9	20.1
42		6	88.1	47.1	26.4	20.1
56		8	76.9	37.2	23.1	20.1
70		10	67.8	31.3	21.9	20.1
84		12	60.4	27.8	21.5	20.1
98		14	54.4	25.8	21.4	20.1
112		16	49.6	24.5	21.3	20.1
126		18	45.6	23.8	21.3	20.1
140		20	42.4	23.4	21.3	20.1

Estimated time to dilute to 5% (3 HRTs)

in days

HLR	Depth (ft)			
ft y^{-1}	1	1.5	2	3
8.2	134	200	267	401
20.5	53	80	107	160
41	27	40	53	80
410	3	4	5	8

Appendix F: Mass Balance Spreadsheet

B. DILUTION IN CRYSTALLIZERS AND BITTERN PONDS

Notes
1. Effects of different HLR and HRTs
2. Assume that a maximum amount of time to flush the ponds is 4 months (January - April) which is an approximation of the rainy season. Therefore, there is approximately 120 days (17 weeks) in which high salinity water can be put out in the estuary. After that time, water should be at least below 60 psu in the ponds.
3. Includes Non-steady state flushing
4. Ponds defined by accumulation of salts in the sediments

1. General Design Specifications

Specifications		
Parameter	**Value**	
Cpond,t0	447	PPT
	36	deg Be
Evaporative rate	2.5	FT/Y
HLRinflow	20.5	FT/Y
Water depth	8.7	FT
Cin	20	ppt
HRT	0.424	years
	155	days
Annual salt storage		
Dissolved bittern stored	7.4	tons salt/ac y
	5	g ft/L/y
Evaporite bittern stored	4.1	tons salt/ac y
	3	g ft/L/y
Stockpiled storage		
Years of stockpiling	30	y
Bittern Pond acres	1050	acres
Production acres	25000	acres
Dissolved bittern stored	5285.714286	tons salt/BP-ac
	3885	g ft/L
Evaporite bittern stored	2928.571429	tons salt/BP-ac
	2153	g ft/L
Area	1050	acres

dissolution model:	
Non-steady state	
C	50
A	529
b/a	-285

2. Determination of outflow concentrations given dilution coefficients for halite.

Calculation of non-steady state outflow concentration from bittern ponds during dilution

days	Cout (ppt)	years
0.001	335	0.000
0.01	335	0.000
0.1	329	0.000
1	297	0.003
10	285	0.027
100	285	0.274
250	285	0.685

Notes
1. Calculated outflow concentration based upon dilution rates of halite from sediments.

Appendix F: Mass Balance Spreadsheet

3. Flushing bittern dissolved salts

Flushing Initial Trends	HLR	
	20.5 ft/y	102 ft/y
days	Salinity (ppt)	
1	284	273
31	237	115
62	199	56
92	168	34
123	142	26
153	121	22
184	103	21
214	89	21
244	77	21
275	67	21
305	59	21
336	53	21
366	48	21
396	43	21
427	39	21
457	37	21
488	34	21
518	32	21
549	30	21
579	29	21
609	28	21
640	27	21
670	26	21
701	26	21
731	25	21

Specification	HLR		Units
	20 ft/y	102 ft/y	
Parameter	Value		
Cin	20	20	
Cpond,t0	285	281	ppt
Evaporative rate	2.5	2.5	ft/y
HLRinflow	20.5	102	ft/y
Water depth	8.7	8.7	ft
HRT	0.4244	0.0853	y
	155	31	day
R	0.122	0.025	
Inflow	20	20	ppt

$$C(t)_{Outflow2} = C_{Inflow}\left(\frac{1}{1-r}\right)\left(1-e^{-\left(t/_{HRT}\right)}\right)$$

4. Estimation of time to flush bittern from sediments

Flow	HLR	C	A	B/a	Conc	time	
MGD	ft/y				mg/L	year	days
	20.5	50	529	-285	285	0.3681	134.3
	102.5	50	538	-281	281	0.0748	27.3
	205	50	550	-275	275	0.0382	13.9
	2050	50	762	-204	204	0.0051	1.9

Appendix F: Mass Balance Spreadsheet

5. Flushing bittern and sediments together

days	20.5 ft/y	102 ft/y	weeks
	Salinity (ppt)		
0	285	281	0.00
20	281	281	2.86
40	281	215	5.71
60	281	123	8.57
80	281	74	11.43
100	281	49	14.29
120	281	35	17.14
140	281	28	20.00
160	274	25	22.86
180	243	23	25.71
200	217	22	28.57
220	193	21	31.43
240	173	21	34.29
260	154	21	37.14
280	138	21	40.00
300	124	21	42.86
320	112	21	45.71
340	101	21	48.57
360	92	21	51.43
380	83	21	54.29
400	76	21	57.14
420	70	21	60.00
440	64	21	62.86
460	59	21	65.71
480	55	21	68.57
500	51	21	71.43
520	47	21	74.29
540	44	21	77.14
560	42	21	80.00
580	39	21	82.86
600	37	21	85.71
620	36	21	88.57
640	34	21	91.43
660	33	21	94.29
680	32	21	97.14
700	30	21	100.00
720	30	21	102.86
740	29	21	105.71
760	28	21	108.57
780	27	21	111.43
800	27	21	114.29
820	26	21	117.14
AVERAGE FOR 90 WKS	146	49	

6. Estimation of Total Water Volume

Note
1. Total Water volume is considered equivalent for all "high" HLRs (>20 ft/y) because evaporation effects are negligible
2. Total volume needed is amount to dissolve bittern salts from sediment and 3 HRTs to flush liquid bittern.

a	HLR	ft/y	20.5	
b	Liquid bittern depth	ft	8.7	From Table 1 in Section B
c	HRT	days	155	
d	Time to flush liquid bittern	days	465	3 HRTs
e	Time to flush bittern sediment	days	134	From Table 4 in Section B
f	Total time to flush pond	days	599	"f" + "e"; For a HLR of 20.5 ft/y
		years	1.6	
g	Bittern pond area	acres	1050	
h	Total volume needed	acre-ft	35327	"a" x "f" x "g"
		gal 10^9	11.51	
I	SG of seawater	SG	1.03	
j	Total weight needed	tons 10^6	49.43	

Appendix G

Annual Salt Pond Restoration and Management Estimated Costs

Table G-1. Mudflat-Sustainable Natural Sedimentation -- LOW Estimate (2001 Dollars)
16,000-Acre Cargill 2000 Proposed Sale Area

Year	Purchase ($M)	P&D ($M)	P&D-O&M ($M)	Constr ($M)	Monit ($M)	Perm O&M ($M)	Int O&M ($M)	Totals: Incremental ($M)	Totals: Cumulative ($M)
Init	300								
0	0	2	4.5			0	0	6.5	6.5
1	0	2	4.5			0	0	6.5	13.1
2	0	2	4.5			0	0	6.5	19.6
3	0	2	4.5			0	0	6.5	26.2
4	0	2	4.5			0	0	6.5	32.7
5	0	0	0	0.2	1.5	1.42	3.12	6.2	38.9
6	0	0	0	0.2	1.5	1.42	3.09	6.2	45.1
7	0	0	0	0.2	1.5	1.42	3.06	6.1	51.3
8	0	0	0	0.2	1.5	1.42	3.03	6.1	57.4
9	0	0	0	0.2	1.5	1.42	3.00	6.1	63.5
10	0	0	0	0.2	1.5	1.42	2.97	6.1	69.5
11	0	0	0	0.2	1.5	1.42	2.93	6.0	75.5
12	0	0	0	0.2	1.5	1.42	2.90	6.0	81.5
13	0	0	0	0.2	1.5	1.42	2.87	6.0	87.5
14	0	0	0	0.2	1.5	1.42	2.84	5.9	93.4
15	0	0	0	0.2	1.5	1.42	2.81	5.9	99.3
16	0	0	0	0.2	1.5	1.42	2.78	5.9	105.2
17	0	0	0	0.2	1.5	1.42	2.75	5.8	111.0
18	0	0	0	0.2	1.5	1.42	2.71	5.8	116.8
19	0	0	0	0.2	1.5	1.42	2.68	5.8	122.6
20	0	0	0	0.2	1.5	1.42	2.65	5.7	128.3
21	0	0	0	0.2	1.5	1.42	2.62	5.7	134.0
22	0	0	0	0.2	1.5	1.42	2.59	5.7	139.7
23	0	0	0	0.2	1.5	1.42	2.56	5.6	145.3
24	0	0	0	0.2	1.5	1.42	2.52	5.6	150.9
25	0	0	0	0.2	1.5	1.42	2.49	5.6	156.5
26	0	0	0	0.2	1.5	1.42	2.46	5.5	162.1
27	0	0	0	0.2	1.5	1.42	2.43	5.5	167.6
28	0	0	0	0.2	1.5	1.42	2.40	5.5	173.1
29	0	0	0	0.2	1.5	1.42	2.37	5.5	178.5
30	0	0	0	0.2	1.5	1.42	2.34	5.4	183.9
31	0	0	0	0.2	1.5	1.42	2.30	5.4	189.3
32	0	0	0	0.2	1.5	1.42	2.27	5.4	194.7
33	0	0	0	0.2	1.5	1.42	2.24	5.3	200.0
34	0	0	0	0.2	1.5	1.42	2.21	5.3	205.3
35	0	0	0	0.2	1.5	1.42	2.18	5.3	210.6
36	0	0	0	0.2	1.5	1.42	2.15	5.2	215.8
37	0	0	0	0.2	1.5	1.42	2.11	5.2	221.0
38	0	0	0	0.2	1.5	1.42	2.08	5.2	226.2
39	0	0	0	0.2	1.5	1.42	2.05	5.1	231.3
40	0	0	0	0.2	1.5	1.42	2.02	5.1	236.4
41	0	0	0	0.2	1.5	1.42	1.99	5.1	241.5
42	0	0	0	0.2	1.5	1.42	1.96	5.0	246.5
43	0	0	0	0.2	1.5	1.42	1.92	5.0	251.6
44	0	0	0	0.2	1.5	1.42	1.89	5.0	256.5
45	0	0	0	0.2	0	1.42	1.86	3.4	260.0
46	0	0	0	0.2	0	1.42	1.83	3.4	263.4
47	0	0	0	0.2	0	1.42	1.80	3.4	266.8
48	0	0	0	0.2	0	1.42	1.77	3.4	270.1
49	0	0	0	0.2	0	1.42	1.74	3.3	273.5
50	0	0	0	0.2	0	1.42	1.70	3.3	276.8
51	0	0	0	0.2	0	1.42	1.67	3.3	280.0
52	0	0	0	0.2	0	1.42	1.64	3.2	283.2

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Table G-1. Mudflat-Sustainable Natural Sedimentation -- LOW Estimate (2001 Dollars)
16,000-Acre Cargill 2000 Proposed Sale Area

Y	Purchase ($M)	P&D ($M)	P&D-O&M ($M)	Constr ($M)	Monit ($M)	Perm O&M ($M)	Int O&M ($M)	Totals: Incremental ($M)	Totals: Cumulative ($M)
53	0	0	0	0.2	0	1.42	1.61	3.2	286.4
54	0	0	0	0.2	0	1.42	1.58	3.2	289.6
55	0	0	0	0.2	0	1.42	1.55	3.1	292.7
56	0	0	0	0.2	0	1.42	1.51	3.1	295.8
57	0	0	0	0.2	0	1.42	1.48	3.1	298.9
58	0	0	0	0.2	0	1.42	1.45	3.0	301.9
59	0	0	0	0.2	0	1.42	1.42	3.0	304.9
60	0	0	0	0.2	0	1.42	1.39	3.0	307.9
61	0	0	0	0.2	0	1.42	1.36	2.9	310.9
62	0	0	0	0.2	0	1.42	1.33	2.9	313.8
63	0	0	0	0.2	0	1.42	1.29	2.9	316.7
64	0	0	0	0.2	0	1.42	1.26	2.8	319.5
65	0	0	0	0.2	0	1.42	1.23	2.8	322.3
66	0	0	0	0.2	0	1.42	1.20	2.8	325.1
67	0	0	0	0.2	0	1.42	1.17	2.8	327.9
68	0	0	0	0.2	0	1.42	1.14	2.7	330.6
69	0	0	0	0.2	0	1.42	1.10	2.7	333.3
70	0	0	0	0.2	0	1.42	1.07	2.7	335.9
71	0	0	0	0.2	0	1.42	1.04	2.6	338.6
72	0	0	0	0.2	0	1.42	1.01	2.6	341.2
73	0	0	0	0.2	0	1.42	0.98	2.6	343.7
74	0	0	0	0.2	0	1.42	0.95	2.5	346.3
75	0	0	0	0.2	0	1.42	0.92	2.5	348.8
76	0	0	0	0.2	0	1.42	0.88	2.5	351.2
77	0	0	0	0.2	0	1.42	0.85	2.4	353.7
78	0	0	0	0.2	0	1.42	0.82	2.4	356.1
79	0	0	0	0.2	0	1.42	0.79	2.4	358.5
80	0	0	0	0.2	0	1.42	0.76	2.3	360.8
81	0	0	0	0.2	0	1.42	0.73	2.3	363.1
82	0	0	0	0.2	0	1.42	0.69	2.3	365.4
83	0	0	0	0.2	0	1.42	0.66	2.2	367.6
84	0	0	0	0.2	0	1.42	0.63	2.2	369.9
85	0	0	0	0.2	0	1.42	0.60	2.2	372.0
86	0	0	0	0.2	0	1.42	0.57	2.2	374.2
87	0	0	0	0.2	0	1.42	0.54	2.1	376.3
88	0	0	0	0.2	0	1.42	0.50	2.1	378.4
89	0	0	0	0.2	0	1.42	0.47	2.1	380.5
90	0	0	0	0.2	0	1.42	0.44	2.0	382.5
91	0	0	0	0.2	0	1.42	0.41	2.0	384.5
92	0	0	0	0.2	0	1.42	0.38	2.0	386.5
93	0	0	0	0.2	0	1.42	0.35	1.9	388.4
94	0	0	0	0.2	0	1.42	0.32	1.9	390.3
95	0	0	0	0.2	0	1.42	0.28	1.9	392.2
96	0	0	0	0.2	0	1.42	0.25	1.8	394.0
97	0	0	0	0.2	0	1.42	0.22	1.8	395.8
98	0	0	0	0.2	0	1.42	0.19	1.8	397.6
99	0	0	0	0.2	0	1.42	0.16	1.7	399.3
100	0	0	0	0.2	0	1.42	0.13	1.7	401.1
101	0	0	0	0.2	0	1.42	0.09	1.7	402.7
102	0	0	0	0.2	0	1.42	0.06	1.6	404.4
103	0	0	0	0.2	0	1.42	0.03	1.6	406.0
104	0	0	0	0.2	0	1.42	0.00	1.6	407.6
TOTAL	0	10	23	17	60	142	156	408	408

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Table G-2. Mudflat-Sustainable Natural Sedimentation -- HIGH Estimate (2001 Dollars)
16,000-Acre Cargill 2000 Proposed Sale Area

Year	Purchase ($M)	P&D ($M)	P&D-O&M ($M)	Constr ($M)	Monit ($M)	Perm O&M ($M)	Int O&M ($M)	Totals: Incremental ($M)	Totals: Cumulative ($M)
Initial	300								
0	0	2	11			0	0	13.0	13.0
1	0	2	11			0	0	13.0	26.0
2	0	2	11			0	0	13.0	38.9
3	0	2	11			0	0	13.0	51.9
4	0	2	11			0	0	13.0	64.9
5	0	0	0	0.6	3.0	3.43	7.55	14.5	79.4
6	0	0	0	0.6	3.0	3.43	7.47	14.5	93.9
7	0	0	0	0.6	3.0	3.43	7.39	14.4	108.2
8	0	0	0	0.6	3.0	3.43	7.32	14.3	122.5
9	0	0	0	0.6	3.0	3.43	7.24	14.2	136.8
10	0	0	0	0.6	3.0	3.43	7.16	14.2	150.9
11	0	0	0	0.6	3.0	3.43	7.09	14.1	165.0
12	0	0	0	0.6	3.0	3.43	7.01	14.0	179.0
13	0	0	0	0.6	3.0	3.43	6.94	13.9	192.9
14	0	0	0	0.6	3.0	3.43	6.86	13.8	206.8
15	0	0	0	0.6	3.0	3.43	6.78	13.8	220.5
16	0	0	0	0.6	3.0	3.43	6.71	13.7	234.2
17	0	0	0	0.6	3.0	3.43	6.63	13.6	247.8
18	0	0	0	0.6	3.0	3.43	6.56	13.5	261.4
19	0	0	0	0.6	3.0	3.43	6.48	13.5	274.9
20	0	0	0	0.6	3.0	3.43	6.40	13.4	288.2
21	0	0	0	0.6	3.0	3.43	6.33	13.3	301.6
22	0	0	0	0.6	3.0	3.43	6.25	13.2	314.8
23	0	0	0	0.6	3.0	3.43	6.17	13.2	327.9
24	0	0	0	0.6	3.0	3.43	6.10	13.1	341.0
25	0	0	0	0.6	3.0	3.43	6.02	13.0	354.0
26	0	0	0	0.6	3.0	3.43	5.95	12.9	367.0
27	0	0	0	0.6	3.0	3.43	5.87	12.9	379.8
28	0	0	0	0.6	3.0	3.43	5.79	12.8	392.6
29	0	0	0	0.6	3.0	3.43	5.72	12.7	405.3
30	0	0	0	0.6	3.0	3.43	5.64	12.6	417.9
31	0	0	0	0.6	3.0	3.43	5.56	12.5	430.5
32	0	0	0	0.6	3.0	3.43	5.49	12.5	443.0
33	0	0	0	0.6	3.0	3.43	5.41	12.4	455.3
34	0	0	0	0.6	3.0	3.43	5.34	12.3	467.7
35	0	0	0	0.6	3.0	3.43	5.26	12.2	479.9
36	0	0	0	0.6	3.0	3.43	5.18	12.2	492.1
37	0	0	0	0.6	3.0	3.43	5.11	12.1	504.2
38	0	0	0	0.6	3.0	3.43	5.03	12.0	516.2
39	0	0	0	0.6	3.0	3.43	4.95	11.9	528.1
40	0	0	0	0.6	3.0	3.43	4.88	11.9	540.0
41	0	0	0	0.6	3.0	3.43	4.80	11.8	551.8
42	0	0	0	0.6	3.0	3.43	4.73	11.7	563.5
43	0	0	0	0.6	3.0	3.43	4.65	11.6	575.1
44	0	0	0	0.6	3.0	3.43	4.57	11.6	586.7
45	0	0	0	0.6	0	3.43	4.50	8.5	595.2
46	0	0	0	0.6	0	3.43	4.42	8.4	603.6
47	0	0	0	0.6	0	3.43	4.34	8.3	611.9
48	0	0	0	0.6	0	3.43	4.27	8.3	620.2
49	0	0	0	0.6	0	3.43	4.19	8.2	628.3
50	0	0	0	0.6	0	3.43	4.12	8.1	636.4
51	0	0	0	0.6	0	3.43	4.04	8.0	644.5
52	0	0	0	0.6	0	3.43	3.96	7.9	652.4
53	0	0	0	0.6	0	3.43	3.89	7.9	660.3

Table G-2. Mudflat-Sustainable Natural Sedimentation -- HIGH Estimate (2001 Dollars)
16,000-Acre Cargill 2000 Proposed Sale Area

Year	Purchase ($M)	P&D ($M)	P&D-O&M ($M)	Constr ($M)	Monit ($M)	Perm O&M ($M)	Int O&M ($M)	Totals: Incremental ($M)	Totals: Cumulative ($M)
54	0	0	0	0.6	0	3.43	3.81	7.8	668.1
55	0	0	0	0.6	0	3.43	3.73	7.7	675.8
56	0	0	0	0.6	0	3.43	3.66	7.6	683.5
57	0	0	0	0.6	0	3.43	3.58	7.6	691.0
58	0	0	0	0.6	0	3.43	3.51	7.5	698.5
59	0	0	0	0.6	0	3.43	3.43	7.4	705.9
60	0	0	0	0.6	0	3.43	3.35	7.3	713.3
61	0	0	0	0.6	0	3.43	3.28	7.3	720.5
62	0	0	0	0.6	0	3.43	3.20	7.2	727.7
63	0	0	0	0.6	0	3.43	3.13	7.1	734.8
64	0	0	0	0.6	0	3.43	3.05	7.0	741.9
65	0	0	0	0.6	0	3.43	2.97	7.0	748.8
66	0	0	0	0.6	0	3.43	2.90	6.9	755.7
67	0	0	0	0.6	0	3.43	2.82	6.8	762.5
68	0	0	0	0.6	0	3.43	2.74	6.7	769.2
69	0	0	0	0.6	0	3.43	2.67	6.7	775.9
70	0	0	0	0.6	0	3.43	2.59	6.6	782.5
71	0	0	0	0.6	0	3.43	2.52	6.5	789.0
72	0	0	0	0.6	0	3.43	2.44	6.4	795.4
73	0	0	0	0.6	0	3.43	2.36	6.3	801.7
74	0	0	0	0.6	0	3.43	2.29	6.3	808.0
75	0	0	0	0.6	0	3.43	2.21	6.2	814.2
76	0	0	0	0.6	0	3.43	2.13	6.1	820.3
77	0	0	0	0.6	0	3.43	2.06	6.0	826.4
78	0	0	0	0.6	0	3.43	1.98	6.0	832.3
79	0	0	0	0.6	0	3.43	1.91	5.9	838.2
80	0	0	0	0.6	0	3.43	1.83	5.8	844.0
81	0	0	0	0.6	0	3.43	1.75	5.7	849.8
82	0	0	0	0.6	0	3.43	1.68	5.7	855.4
83	0	0	0	0.6	0	3.43	1.60	5.6	861.0
84	0	0	0	0.6	0	3.43	1.52	5.5	866.5
85	0	0	0	0.6	0	3.43	1.45	5.4	872.0
86	0	0	0	0.6	0	3.43	1.37	5.4	877.3
87	0	0	0	0.6	0	3.43	1.30	5.3	882.6
88	0	0	0	0.6	0	3.43	1.22	5.2	887.8
89	0	0	0	0.6	0	3.43	1.14	5.1	892.9
90	0	0	0	0.6	0	3.43	1.07	5.1	898.0
91	0	0	0	0.6	0	3.43	0.99	5.0	903.0
92	0	0	0	0.6	0	3.43	0.91	4.9	907.9
93	0	0	0	0.6	0	3.43	0.84	4.8	912.7
94	0	0	0	0.6	0	3.43	0.76	4.7	917.4
95	0	0	0	0.6	0	3.43	0.69	4.7	922.1
96	0	0	0	0.6	0	3.43	0.61	4.6	926.7
97	0	0	0	0.6	0	3.43	0.53	4.5	931.2
98	0	0	0	0.6	0	3.43	0.46	4.4	935.7
99	0	0	0	0.6	0	3.43	0.38	4.4	940.0
100	0	0	0	0.6	0	3.43	0.30	4.3	944.3
101	0	0	0	0.6	0	3.43	0.23	4.2	948.6
102	0	0	0	0.6	0	3.43	0.15	4.1	952.7
103	0	0	0	0.6	0	3.43	0.08	4.1	956.7
104	0	0	0	0.6	0	3.43	0.00	4.0	960.7
TOTAL	0	10	55	56	120	343	377.3	961	961

Table G-3. Dredged Sediment Reuse -- LOW Estimate (2001 Dollars)
16,000-Acre Cargill 2000 Proposed Sale Area

Year	Purchase ($M)	P&D ($M)	P&D-O&M ($M)	Constr ($M)	Monit ($M)	Perm O&M ($M)	Int O&M ($M)	Incremental DS Reuse ($M)	Totals Incremental ($M)	Totals Cumulative ($M)
Initial	300									
0	0	2	4.5			0	0	0	6.5	7
1	0	2	4.5			0	0	0	6.5	13
2	0	2	4.5			0	0	0	6.5	20
3	0	2	4.5			0	0	0	6.5	26
4	0	2	4.5			0	0	0	6.5	33
5	0	0	0	0.2	1.5	1.42	3.12	0	6.2	39
6	0	0	0	0.2	1.5	1.42	3.0	0	6.1	45.1
7	0	0	0	0.2	1.5	1.42	3.0	0	6.1	51.1
8	0	0	0	0.2	1.5	1.42	2.9	0	6.0	57.1
9	0	0	0	0.2	1.5	1.42	2.8	0	5.9	63.0
10	0	0	0	0.2	1.5	1.42	2.7	0	5.8	68.8
11	0	0	0	0.2	1.5	1.42	2.6	0	5.7	74.5
12	0	0	0	0.2	1.5	1.42	2.6	0	5.6	80.2
13	0	0	0	0.2	1.5	1.42	2.5	0	5.6	85.7
14	0	0	0	0.2	1.5	1.42	2.4	0	5.5	91.2
15	0	0	0	0.2	1.5	1.42	2.3	0	5.4	96.6
16	0	0	0	0.2	1.5	1.42	2.2	0	5.3	102.0
17	0	0	0	0.2	1.5	1.42	2.2	0	5.2	107.2
18	0	0	0	0.2	1.5	1.42	2.1	0	5.2	112.4
19	0	0	0	0.2	1.5	1.42	2.0	0	5.1	117.5
20	0	0	0	0.2	1.5	1.42	1.9	0	5.0	122.5
21	0	0	0	0.2	1.5	1.42	1.8	0	4.9	127.4
22	0	0	0	0.2	1.5	1.42	1.8	0	4.8	132.3
23	0	0	0	0.2	1.5	1.42	1.7	0	4.8	137.0
24	0	0	0	0.2	1.5	1.42	1.6	0	4.7	141.7
25	0	0	0	0.2	1.5	1.42	1.5	0	4.6	146.3
26	0	0	0	0.2	1.5	1.42	1.4	0	4.5	150.9
27	0	0	0	0.2	1.5	1.42	1.4	0	4.4	155.3
28	0	0	0	0.2	1.5	1.42	1.3	0	4.4	159.7
29	0	0	0	0.2	1.5	1.42	1.2	0	4.3	164.0
30	0	0	0	0.2	1.5	1.42	1.1	0	4.2	168.2
31	0	0	0	0.2	1.5	1.42	1.0	0	4.1	172.3
32	0	0	0	0.2	1.5	1.42	1.0	0	4.0	176.3
33	0	0	0	0.2	1.5	1.42	0.9	0	4.0	180.3
34	0	0	0	0.2	1.5	1.42	0.8	0	3.9	184.2
35	0	0	0	0.2	1.5	1.42	0.7	0	3.8	188.0
36	0	0	0	0.2	1.5	1.42	0.6	0	3.7	191.7
37	0	0	0	0.2	1.5	1.42	0.6	0	3.6	195.4
38	0	0	0	0.2	1.5	1.42	0.5	0	3.6	198.9
39	0	0	0	0.2	1.5	1.42	0.4	0	3.5	202.4
40	0	0	0	0.2	1.5	1.42	0.3	0	3.4	205.8
41	0	0	0	0.2	1.5	1.42	0.2	0	3.3	209.2
42	0	0	0	0.2	1.5	1.42	0.2	0	3.2	212.4
43	0	0	0	0.2	1.5	1.42	0.1	0	3.2	215.6
44	0	0	0	0.2	1.5	1.42	0.0	0	3.1	218.7
45	0	0	0	0.2	0	1.42	0	0	1.6	220.3
46	0	0	0	0.2	0	1.42	0	0	1.6	221.8
47	0	0	0	0.2	0	1.42	0	0	1.6	223.4
48	0	0	0	0.2	0	1.42	0	0	1.6	225.0
49	0	0	0	0.2	0	1.42	0	0	1.6	226.6
50	0	0	0	0.2	0	1.42	0	0	1.6	228.2
51	0	0	0	0.2	0	1.42	0	0	1.6	229.8
52	0	0	0	0.2	0	1.42	0	0	1.6	231.4
53	0	0	0	0.2	0	1.42	0	0	1.6	232.9

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Table G-3. Dredged Sediment Reuse -- LOW Estimate (2001 Dollars)
16,000-Acre Cargill 2000 Proposed Sale Area

Year	Purchase ($M)	P&D ($M)	P&D-O&M ($M)	Constr ($M)	Monit ($M)	Perm O&M ($M)	Int O&M ($M)	Incremental DS Reuse ($M)	Totals Incremental ($M)	Totals Cumulative ($M)
54	0	0	0	0.2	0	1.42	0	0	1.6	234.5
55	0	0	0	0.2	0	1.42	0	0	1.6	236.1
56	0	0	0	0.2	0	1.42	0	0	1.6	237.7
57	0	0	0	0.2	0	1.42	0	0	1.6	239.3
58	0	0	0	0.2	0	1.42	0	0	1.6	240.9
59	0	0	0	0.2	0	1.42	0	0	1.6	242.5
60	0	0	0	0.2	0	1.42	0	0	1.6	244.1
61	0	0	0	0.2	0	1.42	0	0	1.6	245.6
62	0	0	0	0.2	0	1.42	0	0	1.6	247.2
63	0	0	0	0.2	0	1.42	0	0	1.6	248.8
64	0	0	0	0.2	0	1.42	0	0	1.6	250.4
65	0	0	0	0.2	0	1.42	0	0	1.6	252.0
66	0	0	0	0.2	0	1.42	0	0	1.6	253.6
67	0	0	0	0.2	0	1.42	0	0	1.6	255.2
68	0	0	0	0.2	0	1.42	0	0	1.6	256.7
69	0	0	0	0.2	0	1.42	0	0	1.6	258.3
70	0	0	0	0.2	0	1.42	0	0	1.6	259.9
71	0	0	0	0.2	0	1.42	0	0	1.6	261.5
72	0	0	0	0.2	0	1.42	0	0	1.6	263.1
73	0	0	0	0.2	0	1.42	0	0	1.6	264.7
74	0	0	0	0.2	0	1.42	0	0	1.6	266.3
75	0	0	0	0.2	0	1.42	0	0	1.6	267.9
76	0	0	0	0.2	0	1.42	0	0	1.6	269.4
77	0	0	0	0.2	0	1.42	0	0	1.6	271.0
78	0	0	0	0.2	0	1.42	0	0	1.6	272.6
79	0	0	0	0.2	0	1.42	0	0	1.6	274.2
80	0	0	0	0.2	0	1.42	0	0	1.6	275.8
81	0	0	0	0.2	0	1.42	0	0	1.6	277.4
82	0	0	0	0.2	0	1.42	0	0	1.6	279.0
83	0	0	0	0.2	0	1.42	0	0	1.6	280.5
84	0	0	0	0.2	0	1.42	0	0	1.6	282.1
85	0	0	0	0.2	0	1.42	0	0	1.6	283.7
86	0	0	0	0.2	0	1.42	0	0	1.6	285.3
87	0	0	0	0.2	0	1.42	0	0	1.6	286.9
88	0	0	0	0.2	0	1.42	0	0	1.6	288.5
89	0	0	0	0.2	0	1.42	0	0	1.6	290.1
90	0	0	0	0.2	0	1.42	0	0	1.6	291.7
91	0	0	0	0.2	0	1.42	0	0	1.6	293.2
92	0	0	0	0.2	0	1.42	0	0	1.6	294.8
93	0	0	0	0.2	0	1.42	0	0	1.6	296.4
94	0	0	0	0.2	0	1.42	0	0	1.6	298.0
95	0	0	0	0.2	0	1.42	0	0	1.6	299.6
96	0	0	0	0.2	0	1.42	0	0	1.6	301.2
97	0	0	0	0.2	0	1.42	0	0	1.6	302.8
98	0	0	0	0.2	0	1.42	0	0	1.6	304.3
99	0	0	0	0.2	0	1.42	0	0	1.6	305.9
100	0	0	0	0.2	0	1.42	0	0	1.6	307.5
101	0	0	0	0.2	0	1.42	0	0	1.6	309.1
102	0	0	0	0.2	0	1.42	0	0	1.6	310.7
103	0	0	0	0.2	0	1.42	0	0	1.6	312.3
104	0	0	0	0.2	0	1.42	0	0	1.6	313.9
TOTAl	0	10	22.72	17	60	142	62	0	314	314

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Table G-4. Dredged Sediment Reuse -- HIGH Estimate (2001 Dollars)
16,000-Acre Cargill 2000 Proposed Sale Area

Year	Purchase ($M)	P&D ($M)	P&D-O&M ($M)	Constr ($M)	Monit ($M)	Perm O&M ($M)	Int O&M ($M)	Incremental DS Reuse ($M)	Totals: Incremental ($M)	Totals: Cumulative ($M)
Initial	300									
0	0	2	11			0	0	0	13.0	13.0
1	0	2	11			0	0	0	13.0	26.0
2	0	2	11			0	0	0	13.0	39.0
3	0	2	11			0	0	0	13.0	52.0
4	0	2	11			0	0	0	13.0	65.0
5	0	0	0	0.6	3.0	3.43	7.5	9.5	24.0	89.0
6	0	0	0	0.6	3.0	3.43	7.4	9.5	23.8	112.9
7	0	0	0	0.6	3.0	3.43	7.2	9.5	23.6	136.5
8	0	0	0	0.6	3.0	3.43	7.0	9.5	23.5	160.0
9	0	0	0	0.6	3.0	3.43	6.8	9.5	23.3	183.2
10	0	0	0	0.6	3.0	3.43	6.6	9.5	23.1	206.3
11	0	0	0	0.6	3.0	3.43	6.4	9.5	22.9	229.2
12	0	0	0	0.6	3.0	3.43	6.2	9.5	22.7	251.8
13	0	0	0	0.6	3.0	3.43	6.0	9.5	22.5	274.3
14	0	0	0	0.6	3.0	3.43	5.8	9.5	22.3	296.6
15	0	0	0	0.6	3.0	3.43	5.6	9.5	22.1	318.7
16	0	0	0	0.6	3.0	3.43	5.4	9.5	21.9	340.6
17	0	0	0	0.6	3.0	3.43	5.2	9.5	21.7	362.3
18	0	0	0	0.6	3.0	3.43	5.0	9.5	21.5	383.8
19	0	0	0	0.6	3.0	3.43	4.8	9.5	21.3	405.2
20	0	0	0	0.6	3.0	3.43	4.6	9.5	21.1	426.3
21	0	0	0	0.6	3.0	3.43	4.5	9.5	20.9	447.2
22	0	0	0	0.6	3.0	3.43	4.3	9.5	20.7	468.0
23	0	0	0	0.6	3.0	3.43	4.1	9.5	20.5	488.5
24	0	0	0	0.6	3.0	3.43	3.9	9.5	20.4	508.9
25	0	0	0	0.6	3.0	3.43	3.7	9.5	20.2	529.0
26	0	0	0	0.6	3.0	3.43	3.5	9.5	20.0	549.0
27	0	0	0	0.6	3.0	3.43	3.3	9.5	19.8	568.8
28	0	0	0	0.6	3.0	3.43	3.1	9.5	19.6	588.4
29	0	0	0	0.6	3.0	3.43	2.9	9.5	19.4	607.7
30	0	0	0	0.6	3.0	3.43	2.7	9.5	19.2	626.9
31	0	0	0	0.6	3.0	3.43	2.5	9.5	19.0	645.9
32	0	0	0	0.6	3.0	3.43	2.3	9.5	18.8	664.7
33	0	0	0	0.6	3.0	3.43	2.1	9.5	18.6	683.4
34	0	0	0	0.6	3.0	3.43	1.9	9.5	18.4	701.8
35	0	0	0	0.6	3.0	3.43	1.7	9.5	18.2	720.0
36	0	0	0	0.6	3.0	3.43	1.5	9.5	18.0	738.0
37	0	0	0	0.6	3.0	3.43	1.4	9.5	17.8	755.9
38	0	0	0	0.6	3.0	3.43	1.2	9.5	17.6	773.5
39	0	0	0	0.6	3.0	3.43	1.0	9.5	17.5	791.0
40	0	0	0	0.6	3.0	3.43	0.8	9.5	17.3	808.2
41	0	0	0	0.6	3.0	3.43	0.6	9.5	17.1	825.3
42	0	0	0	0.6	3.0	3.43	0.4	9.5	16.9	842.2
43	0	0	0	0.6	3.0	3.43	0.2	0	7.2	849.4
44	0	0	0	0.6	3.0	3.43	0	0	7.0	856.3
45	0	0	0	0.6	0	3.43	0	0	4.0	860.3
46	0	0	0	0.6	0	3.43	0	0	4.0	864.3
47	0	0	0	0.6	0	3.43	0	0	4.0	868.3
48	0	0	0	0.6	0	3.43	0	0	4.0	872.3
49	0	0	0	0.6	0	3.43	0	0	4.0	876.3
50	0	0	0	0.6	0	3.43	0	0	4.0	880.3
51	0	0	0	0.6	0	3.43	0	0	4.0	884.2
52	0	0	0	0.6	0	3.43	0	0	4.0	888.2
53	0	0	0	0.6	0	3.43	0	0	4.0	892.2

Table G-4. Dredged Sediment Reuse -- HIGH Estimate (2001 Dollars)
16,000-Acre Cargill 2000 Proposed Sale Area

Year	Purchase ($M)	P&D ($M)	P&D-O&M ($M)	Constr ($M)	Monit ($M)	Perm O&M ($M)	Int O&M ($M)	Incremental DS Reuse ($M)	Totals: Incremental ($M)	Totals: Cumulative ($M)
54	0	0	0	0.6	0	3.43	0	0	4.0	896.2
55	0	0	0	0.6	0	3.43	0	0	4.0	900.2
56	0	0	0	0.6	0	3.43	0	0	4.0	904.2
57	0	0	0	0.6	0	3.43	0	0	4.0	908.2
58	0	0	0	0.6	0	3.43	0	0	4.0	912.1
59	0	0	0	0.6	0	3.43	0	0	4.0	916.1
60	0	0	0	0.6	0	3.43	0	0	4.0	920.1
61	0	0	0	0.6	0	3.43	0	0	4.0	924.1
62	0	0	0	0.6	0	3.43	0	0	4.0	928.1
63	0	0	0	0.6	0	3.43	0	0	4.0	932.1
64	0	0	0	0.6	0	3.43	0	0	4.0	936.1
65	0	0	0	0.6	0	3.43	0	0	4.0	940.0
66	0	0	0	0.6	0	3.43	0	0	4.0	944.0
67	0	0	0	0.6	0	3.43	0	0	4.0	948.0
68	0	0	0	0.6	0	3.43	0	0	4.0	952.0
69	0	0	0	0.6	0	3.43	0	0	4.0	956.0
70	0	0	0	0.6	0	3.43	0	0	4.0	960.0
71	0	0	0	0.6	0	3.43	0	0	4.0	964.0
72	0	0	0	0.6	0	3.43	0	0	4.0	967.9
73	0	0	0	0.6	0	3.43	0	0	4.0	971.9
74	0	0	0	0.6	0	3.43	0	0	4.0	975.9
75	0	0	0	0.6	0	3.43	0	0	4.0	979.9
76	0	0	0	0.6	0	3.43	0	0	4.0	983.9
77	0	0	0	0.6	0	3.43	0	0	4.0	987.9
78	0	0	0	0.6	0	3.43	0	0	4.0	991.9
79	0	0	0	0.6	0	3.43	0	0	4.0	995.8
80	0	0	0	0.6	0	3.43	0	0	4.0	999.8
81	0	0	0	0.6	0	3.43	0	0	4.0	1003.8
82	0	0	0	0.6	0	3.43	0	0	4.0	1007.8
83	0	0	0	0.6	0	3.43	0	0	4.0	1011.8
84	0	0	0	0.6	0	3.43	0	0	4.0	1015.8
85	0	0	0	0.6	0	3.43	0	0	4.0	1019.8
86	0	0	0	0.6	0	3.43	0	0	4.0	1023.7
87	0	0	0	0.6	0	3.43	0	0	4.0	1027.7
88	0	0	0	0.6	0	3.43	0	0	4.0	1031.7
89	0	0	0	0.6	0	3.43	0	0	4.0	1035.7
90	0	0	0	0.6	0	3.43	0	0	4.0	1039.7
91	0	0	0	0.6	0	3.43	0	0	4.0	1043.7
92	0	0	0	0.6	0	3.43	0	0	4.0	1047.6
93	0	0	0	0.6	0	3.43	0	0	4.0	1051.6
94	0	0	0	0.6	0	3.43	0	0	4.0	1055.6
95	0	0	0	0.6	0	3.43	0	0	4.0	1059.6
96	0	0	0	0.6	0	3.43	0	0	4.0	1063.6
97	0	0	0	0.6	0	3.43	0	0	4.0	1067.6
98	0	0	0	0.6	0	3.43	0	0	4.0	1071.6
99	0	0	0	0.6	0	3.43	0	0	4.0	1075.5
100	0	0	0	0.6	0	3.43	0	0	4.0	1079.5
101	0	0	0	0.6	0	3.43	0	0	4.0	1083.5
102	0	0	0	0.6	0	3.43	0	0	4.0	1087.5
103	0	0	0	0.6	0	3.43	0	0	4.0	1091.5
104	0	0	0	0.6	0	3.43	0	0	4.0	1095.5
TOTAL	0	10	55	56	120	343	151	361	1,095	1,095

Restoring Cargill Salt Company's 26,000 acres of South Bay salt ponds to tidal marsh has been a treasured goal for decades. Once restored, a wealth of biological resources will benefit. Now, a deal is close at hand to acquire and restore more than half these ponds. This unprecedented opportunity motivated this study.

Inside the reader will find a wealth of information about what it will take to restore these ponds to tidal marsh and what issues should be addressed as part of acquiring lands from Cargill.

Should the public acquire and restore these lands? Absolutely.

Should the public and Cargill get a fair deal? Absolutely.

Are restoration costs reasonable and in line with other national efforts, such as the $7.8 billion Florida Everglades restoration effort? Absolutely.

WETLANDS AND WATER RESOURCES

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