TABLE OF CONTENTS

Tables

TABLE OF CONTENTS

Figures

7.1 INTRODUCTION

7.1.1 Background

Figure 7-1 shows the flash card for Building Block 1.5, Land Use Changes to Reduce Island Subsidence.

Sacramento–San Joaquin River Delta (Delta) peat islands (or portions thereof) are subsiding at rates of up to 1 inch per year, which by 2100 is estimated to lead to subsidence of more than 9 feet in some locations (Figure 7-2). When this continued subsidence occurs near levees, it increases the hydrostatic pressure on levees, which increases the risk of levee failure and future maintenance costs to avoid this increased risk and results in increased damage and repair costs due to more breaches. Continued subsidence is also increasing the "gulp," or accommodation space, within an island—the volume that would fill with water after a levee breach. It is this volume or gulp that has the biggest influence on Delta water salinity during a catastrophic levee breach and creates the greatest risk for all water users (including both Delta area users and urban and rural water contractors that receive exports from the Delta).

The large-scale construction of wetlands on deeply subsided Delta peat islands presents an opportunity to reverse subsidence, reduce the island gulp and the impacts associated with water salinity, and sequester atmospheric carbon that may be sold into the Greenhouse Cap and Trade efforts. Wetlands also provide wildlife habitat for a variety of threatened and endangered species and reduce the nutrient load in Delta waters, which improves the health of the Delta and the San Francisco Estuary.

Despite the many environmental benefits of wetland restoration, several undesirable consequences can also result from the same processes that help sequester carbon in wetlands. The consequences of most significant concern are (1) production of greenhouse gases, which offsets the benefits of carbon sequestration; (2) production of dissolved organic carbon (DOC), which (if discharged from the wetland) may cause problems in drinking water treatment processes; and (3) production of methylmercury (MeHg), which may affect wildlife within the wetland or cause ecological and human health problems if discharged into Delta waters.

Since 1997, the United States Geological Survey has operated a 15-acre experimental wetland on Twitchell Island to demonstrate that wetland plants can be used to halt and reverse subsidence. This base of knowledge forms the technical foundation for design and implementation of carbon sequestration projects on Delta peat islands. This base of knowledge also provides confidence that the potential exists to successfully meet the goals of sequestering carbon and reversing subsidence while minimizing adverse consequences (Figure 7-3).

7.1.2 Purpose and Scope of Building Block

The purpose of this building block is to estimate the costs, reduction in risks, and other benefits associated with constructing wetlands on Delta peat islands. All changes in costs and benefits are assessed relative to the project base case, which is "business as usual," that is, continued levee maintenance and agricultural production.

7.1.3 Objective and Approach

This building block has been developed from a range of literature, including the Phase 2 Carbon Sequestration Report (URS/JBA 2007g) and the findings from the work at the Twitchell Island demonstration site. This building block is a high-level assessment that builds on existing knowledge to provide objective information to decision makers.

The approach and specific objectives of this building block are to:

- Identify a number of islands where large-scale carbon sequestration could be implemented (see Section 7.1.4)
- Develop the conceptual design and discuss values, benefits, and constraints (see Section 7.2)
- Quantify the initial capital and ongoing operation and maintenance costs associated with carbon sequestration on these islands (see Section 7.3)
- Assess direct or indirect reductions in risk associated with carbon sequestration (see Section 7.4)
- Compare the costs and benefits of carbon sequestration and make recommendations on the merit of this building block (see Section 7.5)

7.1.4 Selection of Sites

In selecting potential Delta islands on which to implement carbon sequestration, the islands where the potential benefits would be greatest and the constraints (costs) associated with land use change would be least were identified. A three-step process was used to select islands:

- Step 1: Identify those islands where subsidence[1] and island likelihood of flooding are greatest
- Step 2: Identify those islands where disruption to infrastructure and agricultural production are least
- Step 3: Identify those islands where the variation in island elevation is least.

Each of these steps is described in greater detail below.

7.1.4.1 Step 1

In the Phase 1 Subsidence Technical Memorandum (URS/JBA 2007d), mean rates of subsidence were estimated for each of the Delta Islands. These data were used to predict the levels of subsidence for 2100 that are shown in Figure 7-2.

The predicted subsidence data were multiplied by the frequency of island flooding to create a score used to prioritize islands for wetland establishment to sequester carbon. A decision was made to focus the selection of sites on those islands where the subsidence likelihood of flooding score was equal to or greater than 0.08. A total of 20 islands were short-listed, as shown in Table 7-1.

[1] Subsidence is the downward movement of land surface (ranging from 0 to almost 1 in/yr [see the Subsidence Technical Memorandum (URS and JBA 2007d)]).

7.1.4.2 Step 2

The second filtering step in identifying target islands for carbon sequestration was based on infrastructure and agricultural production asset values.

Infrastructure asset values (including roads, houses, and utilities) were obtained from the Impact to Infrastructure Technical Memorandum (URS/JBA 2007f) for each island. Land use and estimates of annual crop revenues were used to determine the capitalized value of agricultural production for each island. When taken together, these data provided a measure of the cost or extent of disruption associated with implementing carbon sequestration.

Islands were excluded when the combined value of infrastructure assets and agricultural production was greater than $40 million (annual equivalent value of approximately $3 million, discounted at 6 percent over 30 years). The eleven islands that remained are shown in Table 7-2.

7.1.4.3 Step 3

The greatest plant growth rates are achieved where the depth of inundation is maintained within an optimal range (1 to 2 feet). Where island surface elevations vary significantly, vegetation biomass production will be low and/or the costs to reduce this elevation variance will be high. Therefore, it can be hypothesized that islands should be prioritized according to those where the variance in surface elevation is least. The seven islands with the least variation about the mean that were selected for assessment are shown in Table 7-3.

7.2 CONCEPTUAL DEVELOPMENT OF IMPROVEMENT

7.2.1 Analysis Criteria and Basis of Design

Carbon is removed from the atmosphere by wetlands when atmospheric carbon dioxide (CO_2) is photosynthetically transformed into plant biomass. Some portion of the carbon is later returned to the atmosphere (as CO_2 and methane) when plant biomass is decomposed by microorganisms. In most terrestrial ecosystems, the amount of photosynthetically fixed carbon equals the loss to the atmosphere through decomposition plus that stored in the biomass. However, in wetland systems the conditions may be such that decomposition is dramatically slowed, minimizing the loss of carbon back to the atmosphere. This condition makes wetlands ideal biological carbon sinks.

A carbon sequestration effort consists of two components: (1) re-establishing wetlands to slow peat decomposition rates and halt further subsidence, and (2) accreting plant biomass in the re-established wetlands to reverse subsidence. The change in subsidence that is relevant here is the net change that will occur for the newly constructed wetlands (biomass accretion) relative to the previous land use (peat decomposition).

Wetlands must produce plant biomass at a faster rate than the biomass is decomposed to achieve long-term carbon sequestration. Several biological, chemical, and physical attributes have been linked to high accretion rates of plant biomass in wetlands and thus to sequestration. The important operational variables are those that isolate the plant biomass from the atmosphere and slow decomposition rates, resulting in acceleration of residual plant material. These variables include:

- Amount of oxygen and the temperature are important because limiting oxygen and lowering temperatures slow the degradation of plant material.
- Plant species and chemical composition are important because the physical and chemical composition of plant tissues can slow rates of degradation by months to years.
- Plant community structure is an important characteristic because some wetland plants (such as rhizomatous species) form dense litter mats, which consume oxygen and shield the underlying litter from decomposition.
- Nutrient availability is important for biomass production. The macro- and micro-nutrients necessary for sustained plant growth are usually replete in Delta surface waters.

The overall objective of the carbon sequestration project is to maximize plant biomass accretion; minimize discharge of greenhouse gases, MeHg, and DOC; and sequester CO_2 from the atmosphere. However, as shown in Figure 7-4, the interconnectedness of each biochemical process makes achieving the objective extremely complex. Nevertheless, the results of previous research suggest that it is possible to manage wetland processes to achieve a net benefit.

The key design criteria that can be used to achieve the project objectives are:

- Ponding depth
- Planting and seeding
- Nutrients

Each of these criteria is discussed further below.

7.2.1.1 Ponding Depth

Water depth management influences the species, density, and the production/decomposition of biomass within a constructed wetland. The optimal depth for bulrush (*Scirpus* spp.) biomass production is 6 inches, and depths greater than this are thought to reduce plant decomposition (Miller 2007). Therefore, the optimal ponding depth for carbon sequestration is thought to be between 6 and 18 inches (currently being tested).

To achieve an optimal ponding depth on Delta islands, the island in question could be:

- Leveled by removing soil from high areas (“cut”) and depositing soil in low areas (“fill”)
- Filled with soil imported from other areas[2]
- Managed to minimize the need for cut and fill, so that in the short term a smaller surface area would be inundated (Using this approach the island may accrete and reverse subsidence over time.)

7.2.1.2 Planting and Seeding

The goal of planting and seeding is to introduce a local propagation source to accelerate establishment of targeted native wetland species. The findings from Twitchell Island indicate

[2] For instance, it has been estimated that an isolated conveyance facility could produce 9,000,000 cubic yards of available fill.

that emergent marsh vegetation first colonized to the south and southeast, where prevailing winter winds congregated seeds and vegetative propagules. Thus, in establishing wetlands, desirable plants species should be installed upwind in shallow water to make efficient use of natural dispersal. It is thought that planting 5 percent of an area is sufficient to establish broad, sparse cover within 12 months.

7.2.1.3 Nutrients

One of the important benefits of wetland re-establishment can be the removal of nutrients from surface waters, either by uptake into plant biomass or conversion of nitrate to nitrogen gas (e.g., denitrification) under the same anaerobic conditions that promote biomass preservation. However, carbon storage and nutrient supply can be antagonistic under some circumstances. For example, the accretion of plant biomass can immobilize essential nutrients required for new growth. Incomplete denitrification may result in production of greenhouse gases and organic chemicals that are problematic for water treatment. Perhaps most important, in many environments nutrients stimulate decomposition, thereby reducing the amount of carbon sequestered. These interactions have not been well quantified in the literature, and the balance has important implications with regard to management practices and carbon sequestration success.

7.2.2 Analysis Results and Design Layouts

7.2.2.1 Subsidence Reversal

As mentioned previously, the subsidence reversal process consists of two components: (1) re-establishing wetlands to slow peat decomposition rates and halt further subsidence, and (2) accreting plant biomass in the re-established wetland to reverse subsidence.

Under existing land uses, the mean long-term rate of subsidence for Delta peat islands is estimated at up to 1.0 inch per year. With carbon sequestration on the Twitchell Island ponds, rates of accretion have been estimated at between 0 to 3.6 inches per year,[3] with an average of around 1.6 inches per year (Miller 2007). Therefore, the overall difference in subsidence is estimated at 2.6 inches per year or 130 inches (10.8 feet) in 50 years.

7.2.2.2 Impact on Levee Fragility

Subsidence of organic soils (and sea-level rise) increases hydraulic gradients across levees to drainage ditches, which increases seepage through and under levees. Levee stability is affected by ongoing subsidence because an ongoing need exists to deepen drainage ditches to maintain an aerated root zone for agriculture. Commonly, drainage ditches are adjacent to levees on the perimeter of islands.

Efforts to halt or reverse subsidence in areas adjacent to levees (the zone of influence) will reduce future increases in the hydrostatic pressure on levees, which will in turn contribute to a reduction in future increases in the rate of levee breaches or the cost of maintenance.

[3] Estimated average using 7.5 years of data from Twitchell Island ponds.

7.2.2.3 Impact on Salinity Intrusion

When a levee breach occurs, the volume of water that floods an island depends on the future amount of island subsidence. Under current land uses, subsidence is estimated to result in a 35 percent increase in island volume by 2050 and 67 percent by 2100 (URS/JBA 2007d). The salinity of water that floods a breached island depends on the season and the island's location in the Delta. Catastrophic levee breaches increase the water salinity in the Delta, and this increase is larger if the breach occurs in summer than if it occurs in winter. As subsidence continues, the gulp increases and the time to restore equilibrium increases.

Efforts to reverse subsidence will reduce the volume of saline water flowing from San Francisco Bay into the Delta and therefore reduce the duration and intensity of the economic and ecological impacts associated with increased salinity intrusion.

7.2.2.4 Change in Greenhouse Gases

Carbon sequestration will lead to changes in the production of greenhouse gases (GHGs), which can be used to produce carbon credits. The production of GHGs, including CO_2 and $MH_{4,}$ results in the warming of the earth's atmosphere, which contributes to "climate change."

CO_2e is the internationally recognized way of expressing the amount of global warming of a particular greenhouse gas in terms of the amount of CO_2 required to achieve the same warming effect over 100 years. Methane has 23 times the global warming potential of carbon dioxide, and nitrous oxide has approximately 300 times the potential. So, for example, 1 kilogram (kg) of methane has the global warming potential of 23 kg of CO_2.

Under current ditched and drained conditions, aerobic decomposition of Delta island peat soils releases CO_2 to the atmosphere, and the island subsides. However, in waterlogged conditions (anaerobic) decomposition is slowed (Figure 7-5).

The change in GHG production is measured as the increased storage or removal of CO_2 by biological processes under baseline conditions (cropland or pastureland) compared with the carbon sequestration wetland.

The Greenhouse Gas Protocol was used to assess the change in CO_2 emissions between baseline conditions and the carbon sequestration site. The assumptions made in this assessment were based on findings on Twitchell Island (Miller et al. undated). The following assumptions were made:

- The release of CO_2 under the baseline conditions (based on long-term subsidence of 1 inch per year) is estimated at 3.71 metric tons of CO_2e per acre per year.
- The storage of CO_2 within a wetland (based on long-term accretion of 1.6 inches per year) is estimated at 3.56 metric tons of CO_2e per acre per year.
- The release of CO_2 within a wetland due to decomposition of organic matter is estimated at 0.85 metric tons of CO_2e per acre per year.
- The release of MH_4 within a wetland is estimated at 0.08 metric tons of MH_4 per acre per year, which is equivalent to 2.32 metric tons of CO_2 per acre per year.

Therefore, the estimate of carbon sequestered is equal to 4.09 metric tons of CO_2e per year (measured as 3.56 + 3.71 – 2.32 – 0.85).

Note that the release of nitrous oxide (NO_2) was not measured during the research at Twitchell Island. Given that 1 kg of NO_2 is equal to 310 CO_2e, any release of NO_2 would have considerable impacts on the calculation of carbon credits.

7.2.3 Geometric Description of Improvement

7.2.3.1 Existing Conditions

Each of the islands being considered for carbon sequestration is predominately privately owned. The islands are primarily used for agricultural production (54 percent of the total area), with the main agricultural land uses field crops (67 percent) and grain (26 percent) production. Some vineyards are present on Mandeville Island. The two islands that are not identified as having any agricultural production are Bradford Island and Medford Island (Table 7-4).

The infrastructure assets of each of the islands were assessed. Information was obtained for roads, bridges, oil and gas facilities, and dwellings (Table 7-5).

The islands with the fewest infrastructure assets will cause the least social disruption given implementation of carbon sequestration. These islands are Mandeville Island, Medford Island, and Venice Island. The substantial oil and gas assets and family housing on Twitchell and Bradford Islands may make them less desirable for carbon sequestration.

7.2.3.2 Site Layout

The conceptual plan for implementing carbon sequestration projects would convert an entire island to a constructed wetland. Under this conceptual plan, it is assumed that all existing land uses would be terminated and assets (roads, buildings, and utilities) would be abandoned.

Existing siphons will be utilized to supply water to the wetlands. It is assumed that sufficient siphons of suitable condition exist for this to occur and that the existing siphons do not need refurbishment.

Some access levees may need to be constructed within the islands to allow for ongoing maintenance and monitoring of the wetland. Also, some costs are assumed for constructing sheds to store equipment and other maintenance materials.

7.2.3.3 Grading Plan

The elevation of each Delta island was obtained from a Geographic Information System topographical elevation layer (Interferometric Synthetic Aperture Radar [IFSAR]; see USACE 2000a). The area of each island was assessed in 1-foot intervals between minus 28 and plus 35 feet (North American Vertical Datum of 1988 [NAVD88]). From this assessment, an estimate was made of the volume of soil required to reduce the variation in island elevation to within 2 feet across 90 percent of the island. The volume of cut required to fill each of the islands is shown in Table 7-6.

The volume of cut varies between 4 million and 10 million cubic yards (CY). The volume of soil required per unit area was least on Venice Island, followed by Mandeville Island and Webb Tract.

Preliminary estimates suggest that the Isolated Conveyance Facility could produce 9,000,000 CY of fill.[4] This volume of soil would be sufficient to level only about 40 percent of Venice Island or 77 percent of Medford Island.

Alternatively, 9,000,000 CY of soil can be thought of as equivalent to 1 foot of soil on approximately 5,600 acres of land.

7.2.4 Description of Values, Benefits, and Constraints

The benefits and constraints of this building block include:

- A reduction in the production of GHGs (and associated carbon credits)
- The provision of ecosystem habitat for improved biodiversity
- An increase in recreational use of the islands
- A reduction in future risks associated with levee failure[5]
- An improvement in water quality
- A loss in agricultural production
- Increased costs to protect infrastructure assets
- Social disruption

7.2.4.1 Benefits

Carbon Sequestration

A key benefit of carbon sequestration on the islands will be the ability to have a net accretion of carbon. In Section 7.2.2.4, the net accretion of carbon or carbon credits was estimated at 4.09 metric tons of CO_2e per acre.[6] The carbon credits generated by each island are shown in Table 7-7.

With the passing of Assembly Bill 32, the California legislature has agreed to a statewide reduction in GHG emissions equivalent to the statewide GHG emissions levels in 1990 (to be achieved by 2020). The bill authorizes the California Air Resources Board to develop appropriate regulations and establish a mandatory reporting system to track and monitor global warming emissions levels. Policies to reduce carbon emissions are likely to include market-based compliance mechanisms, such as greenhouse gas emissions exchanges, banking, credits, and other transactions.

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[4] The costs to transport this volume of soil may make it cost prohibitive to use.

[5] Reducing subsidence does not eliminate the current accommodation space and thus does not reduce current risks. It simply reduces future increases in subsidence and accommodation space increases.

[6] The California Climate Action registry has developed a forest project protocol to define a certifiable approach for quantifying carbon credits. Our estimates of reduced GHG emissions are based on the use of this protocol for Twitchell Island.

One such mechanism, carbon credits, is a tradable permit scheme that has been established around the world as a way of regulating GHG production. For a tradable permit scheme to function efficiently, the market for carbon credits needs to have both willing buyers and sellers. For there to be willing buyers, governments will need to regulate current polluters such that there is a financial incentive to change behavior. Where both buyers and sellers exist, carbon credits will have a monetary value and lead to behavioral change.

Recent evidence suggests that governments are setting GHG emissions at levels too high to create demand; hence, current prices ($5–$10 per ton of CO_2e) for carbon credits are well below those the Stern Report suggested are required ($30–$50 per ton of CO_2e) to stabilize GHG emissions.

A functioning carbon market has the potential to provide additional income to farmers and offset the economic and social impacts caused by retirement of agricultural lands from production. Based on a carbon price of $10 and $30 per CO_2e, the additional income for landowners is equal to $40 and $125 per acre. The additional revenue per island is shown in Table 7-8.

Improved Biodiversity

Managed marshes for carbon sequestration may create habitat for a number of listed species in the Delta and may allow farmers to use the land for mitigation credits. The managed marshes are freshwater to brackish emergent wetlands on islands in the Delta that have relatively shallow depths and discharge minimal flow to the Delta. The habitat value of these marshes for several listed species is dependent on spatial heterogeneity of the habitat and the development of riparian and ecotone to upland habitat.

Tules (*Scirpus* spp.) may provide nesting and foraging habitat for colonial nesting tricolored blackbirds (California Department of Fish and Game Species of Concern). Dabbling migratory waterfowl may use shallow open areas for resting and foraging. Deeper open water (4–5 feet), which may result from the variable topography of a flooded island, may benefit diving ducks. Many species would benefit from the riparian habitat that may colonize the interface between upland and wetland. These species might include Sanford's arrowhead (California Native Plant Society [CNPS] 1B.2) and the giant garter snake (California and federal threatened species), though the islands for carbon sequestration are at the southern edge of the giant garter snake range. The addition of rock piles to the upland vegetation in the interior of the levee would provide crevices for giant garter snakes to hide, increasing the value of the habitat for the species. California hibiscus (CNPS 2) may be planted along the flooded upland portion. Riparian vegetation will colonize the edges of the marsh, including sandbar willows, cottonwoods, and potentially arroyo willows, which may benefit some resident and migrating passerine bird species and raptors. Reduction of human activity on an island may result in use of riparian trees for Swainson hawk nests (federal species of concern, California threatened species). Also, heron and egret rookeries may become established in riparian stands.

Recreation

Recreational use of the islands could increase with carbon sequestration, to include activities such as bird watching and duck hunting. These activities could provide an additional revenue stream for landowners.

Estimates of willingness to pay by hunters for the right to shoot ducks on wetlands in the Suisun Marsh are likely to be in the range $15 to $100 per hunting day.[7] In assessing the likely number of hunting days for a particular island, the draft Context Memorandum: Recreation (Delta Vision Blue Ribbon Task Force 2007) was consulted. The information showed that for private clubs in the Suisun Marsh area, about 60,000 waterfowl recreation user-days occurred during the 2006 season.[8] If we consider that these clubs cover approximately 60,000 acres, then this level of hunting can be thought of as 1 waterfowl recreation user-day per acre.[9]

At a conservative estimate of $15 to $100 per recreation user day, the potential per acre revenue is $15 to $100. However, where wetlands are managed for duck hunting, capital costs will be incurred to establish an area as a duck hunting site, and ongoing operations and maintenance costs will reduce the earning capacity of the land. Annual operation and maintenance costs are estimated at $15–$20 per acre[10] (note: costs are reflective of 1976 values).

Water Quality

Carbon sequestration improves water quality in two ways: by removing the load of nutrients from the Delta waterways and by minimizing the release of nutrient-laden drainage water back to the Delta waterways (from agricultural land under the base case).

The economic value of this improvement in water quality can be measured in terms of:

- The reduced occurrence of potentially toxic algal blooms
- Improvements in overall river health
- Reduced treatment costs to remove pollutants from urban water supplies

Limited data exist to quantify these values to the extent they will be changed by carbon sequestration.

A potential water quality risk of carbon sequestration is the cycling and methylation of mercury and the production of reactive dissolved organic material. Mercury is a ubiquitous contaminant that is toxic to humans and wildlife. These water quality risks will be managed by preventing the discharge of drainage water back into the Delta.

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[7] According to the California Department of Fish and Game License and Review Branch, a Type-A one-day entry permit for the 2006/2007 waterfowl season costs $14.75, which we rounded to $15.00. In a May 5, 2005, *Western Farm Press* article, "Sacramento Valley Rice Growers Winter Flood, Ducks Keep Coming," Harry Cline stated that duck club hunters are "willing to pay as little as $1,500 to as much as $5,000 or more per person per season."

[8] In the June 12, 2007, Context Memorandum: Recreation, Pat Graham and Steve Chappell of the Suisun Resource Conservation District estimated that the 158 duck clubs of the Suisun Marsh were open an average of 3 days a week, 13 weeks a year (i.e., 39 hunting days a season). Graham and Chappell then multiplied this by an assumed number of hunters a day (10) for each of the 158 duck clubs in Suisun Marsh. The resulting value was 61,620 recreation user-days per year for the duck clubs in Suisun Marsh.

[9] Of the 85,000 acres of habitat land in Suisun Marsh, the state owns 10,487 acres. Duck clubs, which own most of Suisun Marsh's waterfowl habitat, own approximately 70,000 acres.

[10] San Francisco Bay Conservation and Development Commission, Suisun Marsh Protection Plan (December 1976). Accessed: August 3, 2007. http://www.bcdc.ca.gov/index.php.

7.2.4.2 Constraints

Loss of Agricultural Production

A significant constraint to carbon sequestration will be the value of agriculture foregone where an island is changed to a wetland. The economic value of this lost production can be measured as the area of different land uses multiplied by the net value (income less variable costs) of production on this land use. For the land uses shown in Table 7-4, if we assume that net annual value of lost agricultural production is equal to 65 percent[11] of income (Table 7-9), the value of lost agricultural production within each island is shown in Table 7-10.

Increased Costs to Protect Infrastructure Assets

In developing the conceptual design for each island, it has been assumed that the island and the assets on each island (see Table 7-5) would be abandoned. Hence, no increased cost to protect infrastructure has been assumed except for the building blocks considered in this report.

Social/Transaction Costs

Where substantial land use change is to occur, and where people and their livelihoods are affected, considerable social costs can be assumed to occur. It is beyond the scope of this building block to assess the magnitude of these social costs. However, we can state that where the number of family dwellings is the greatest, the social costs are also likely to be the greatest.

Continued operation of an island as a carbon sequestration site is likely to involve considerable transaction costs (willingness to accept compensation for foregone income and costs to relocate). Given the cultural values associated with the Delta in its use for agricultural production, much community angst is also likely to exist regarding any change in land use.

Where an island is converted for carbon sequestration, institutional arrangements will need to be changed (for example, land use covenants would be needed) to protect any investment made.

7.3 COST ESTIMATE

7.3.1 Construction Considerations

The following list provides the basis for the conceptual-level construction cost estimate (Table 7-11). The assumptions used are conceptual in nature. The cost estimate associated with this conceptual design is for planning purposes only.

- **Clearing and grubbing.** Clearing and grubbing are to be conducted using track-mounted or low-ground-pressure vehicles and are to occur across all but the high areas (estimated at 10 percent of an island) that will be retained. The unit cost was estimated at $1,200 per acre.
- **Excavation.** Excavation and grading are to be conducted using track-mounted or low-ground-pressure vehicles, such as graders and backhoes. Total earthwork quantities are

[11] This value is a "rule of thumb" rather than being representative of any one industry.

shown in Table 7-6. For this preliminary cost estimate, the earthwork costs have been determined assuming that an entire island is leveled to within 2 feet. An alternative but un-priced design would be to use terrace levees to define and grade separate flat marsh plain areas. The unit cost for cut and fill was estimated at $7 per CY.

- **Siphon refurbishment.** It is assumed that siphons do not need to be refurbished. However, a detailed siphon analysis should be completed before project design.
- **Supply water system.** In some cases, earthwork may be necessary to convey water to all areas of an island. Shallow earthen channels may be necessary and existing channels may be able to be used. However, no costs are assumed for the preliminary cost estimate.
- **Planting.** Plugs are assumed to be sown on only 5 percent of the island. The remaining area is assumed to revegetate naturally. The unit cost of planting is estimated based on 1,300 plants per acre at $8 per plant to collect, transport, and install.
- **Haul road.** The estimated cost to construct a temporary access haul route is $500,000 per island.
- **Contingencies.** The cost assumed is 30 percent of the construction cost.
- **Other.** Administration, design, and contract management are estimated at 30 percent of construction plus contingencies.

7.3.2 Cost Estimate Tables (with Variations)

7.3.2.1 Capital Cost

As mentioned in Section 7.2.4.2, considerable social and transaction costs are likely to be involved with any carbon sequestration project. These costs, whether compensation for lost agricultural production or capital costs to purchase land, have not been assessed within this cost estimate.

The construction costs for each island are shown in Table 7-11.

The construction costs were least for Medford Island, at $30 million, and greatest for Webb Tract, at over $130 million. The island with the least cost per acre is Venice Island.

The most substantial costs are those associated with the earthwork required to level islands. As mentioned previously (Section 7.3.1), an alternative approach would be to minimize earthwork and allow islands to naturally level over time. The time that it would take for this to occur has not been assessed.

7.3.2.2 Operation, Maintenance, and Monitoring Cost

Operations have been estimated at 0.2 full-time equivalents at $80,000 per island per year. Maintenance (including monitoring) costs have been estimated at 0.5 percent of capital costs per year. The annual and capitalized cost (net present value at 6 percent over 30 years) for each island is shown in Table 7-12.

7.4 RISK REDUCTION ESTIMATE

7.4.1 Direct Risk Reduction

From a risk-reduction perspective, carbon sequestration offers the opportunity to:

- Reduce the on-island consequences of levee failures (since lands are converted from their present use),
- Reduce the increase in accommodation space, thus reducing salinity intrusion in the future in the event of levee failures. This reduction will in turn contribute to a reduction in water export impacts for events involving multiple levee failures.
- By reducing subsidence, future increases in hydrostatic pressures on Delta levees will be reduced or maintenance costs will be reduced. However, this benefit does not reduce the present risk (the current hydrostatic pressures and risk of levee failure).

These risk reduction benefits are discussed in the following subsections.

7.4.2 Potential Indirect Risk Reductions in the Context of the Scenarios

Carbon sequestration results in a net accretion of carbon, which has two substantial effects on the risks associated with a Delta island breach. An indirect benefit of subsidence reduction is the future growth in island accommodation space, which in turn reduces the salinity intrusion into the Delta in the event of levee failure. This benefit is realized for scenarios involving multiple island failures, such as during a seismic event. By reducing salinity intrusion during these scenarios, the adverse consequences for all water users (including both in-Delta and exports to urban and rural contractors) are reduced. The estimated change in rates of subsidence with and without carbon sequestration is shown in Table 7-13.

For all seven short-listed islands, the total surface area is about 24,000 acres, and therefore with carbon sequestration the change in gulp for 2050 is estimated at 260,000 acre-feet (measured as 24,000 times 10.8). This change in volume with and without the project subsidence is shown in Table 7-14.

If carbon sequestration is implemented on all short-listed islands, the change in island gulp is a 40 percent improvement on the “without project” scenario. Future subsidence with carbon sequestration is reduced from 35 percent of the current situation to 21 percent. It is estimated that 50 years will be sufficient for Bradford Island and Holland Tract to reduce their accommodation space (gulp) to zero, and Mandeville and Venice islands will take at least 100 years.

Although estimates of subsidence have been made for 2100, we have chosen not to include these statistics in Table 7-14, as the rates of long-term accretion remain uncertain. Also, with discounting, the value of any reduction in risk beyond 30–50 years will be marginal at best.

7.5 FINDINGS AND CONCLUSIONS

7.5.1 Findings

This assessment of the costs, reduction in risks, and other benefits associated with constructing wetlands on Delta peat islands has found the following:

- Wetlands can be used successfully to reverse subsidence on Delta peat islands where ponding depth and plant species are optimized.
- The elevation of Delta islands typically varies by about 2 feet about the mean. Therefore, island earthwork to reduce this variability and achieve an optimal ponding depth is substantial.
- Conceptual estimates for construction costs are typically \$20,000 to \$27,000 per acre, and the cost for earthwork constitutes about 85 percent of these costs. Opportunities exist to reduce this cost by changing land use practices and allowing islands to naturally level over time, or alternatively by using natural island contours to achieve optimal ponding depths on separate island segments.
- The benefits of carbon sequestration include improved biodiversity, subsidence reversal, and reduction in greenhouse gases.
  - Carbon sequestration sites will provide important habitat for endangered flora and fauna species throughout the Delta.
  - The net change in subsidence per island is estimated at 10.8 feet over 50 years (2.6 inches per year)
  - The net reduction in greenhouse gas generation is estimated at about 4 metric tons of CO_2e per acre per year.
- The constraints to carbon sequestration include the loss of agricultural production on islands and increased costs to protect infrastructure. The value of agricultural production foregone across all islands is estimated at \$2.5 million per year.
- Reductions in the direct and indirect risks associated with a catastrophic levee breach event include reduced on-island economic consequences in the event of levee failure, and reduced salinity intrusion due to a reduced island volume (gulp). Given that the benefits of carbon sequestration will be increasingly realized through time, the temporal elements of this risk reduction need to be quantified.
- Considerable social and transaction costs are likely to be involved with any carbon sequestration project. These costs, whether compensation for lost agricultural production or capital costs to purchase land, have not been assessed within this cost estimate.
- Much uncertainty remains with regard to long-term carbon accretion rates, changes in greenhouse gas emissions, and the potential risks associated with MeHg and DOC.
- The economic viability of carbon sequestration is very dependent on the value attributed to carbon credits. If a market develops at \$30 per CO_2e, sequestration revenues may be adequate to cover annual operation and maintenance costs or to replace the foregone net revenue of the displaced agriculture. Higher revenue would be needed to do both.

7.5.2 Conclusions and Recommendations

Carbon sequestration has been shown to successfully reverse subsidence and result in a net accretion of organic carbon over time. These preliminary analyses are encouraging. However, much more needs to be known about how this accretion will reduce the risk consequences associated with catastrophic levee breaches over time. This contribution of benefit may justify capital costs and a deficiency in annual revenues.

Tables

Table 7-1 Short-Listed Islands for Carbon Sequestration (Where Subsidence and Island Flooding Frequency Are Greatest)

ID	Island Name	Predicted Subsidence (feet/50 years)	Island Flooding Frequency	Score[1]	Area (acres)
150	Venice Island	3.97	0.07	0.29	3,156
4	Webb Tract	3.81	0.05	0.21	5,519
16	Palm Tract	3.63	0.05	0.19	2,520
5	Empire Tract	3.69	0.04	0.16	3,677
17	Jones Tract-Upper and Lower	3.13	0.05	0.16	12,205
15	Bacon Island	3.83	0.04	0.15	5,586
13	Holland Tract	2.79	0.05	0.14	4,286
11	Quimby Island	3.79	0.04	0.14	783
174	Staten Island	3.41	0.04	0.13	9,094
6	Bradford Island	3.31	0.04	0.13	2,153
87	Terminous Tract	3.18	0.04	0.13	10,387
68	Little Egbert Tract	1.25	0.09	0.12	3,248
144	Mandeville Island	3.05	0.04	0.11	5,246
9	Jersey Island	2.24	0.05	0.10	3,499
63	Tyler Island	2.44	0.04	0.10	8,987
1007	Brannan-Andrus Island	1.56	0.05	0.08	12,690
152	Medford Island	2.69	0.03	0.08	1,176
176	Brack Tract	1.20	0.07	0.08	5,354
10	Bethel Island	1.95	0.04	0.08	3,460
179	Twitchell Island	2.58	0.03	0.08	3,583

[1] Selection Score = Subsidence * Frequency of Flooding

Table 7-2 Potential Islands for Carbon Sequestration (Where Subsidence and Island Flooding Frequency are Greatest and Asset Values are Minimized)

ID	Island Name	Score[1]	Asset Value ($0,000)	Area (acres)
150	Venice Island	0.29	32,502	3,156
4	Webb Tract	0.21	25,936	5,519
16	Palm Tract	0.19	37,532	2,520
13	Holland Tract	0.14	22,230	4,286
11	Quimby Island	0.14	4,422	783
6	Bradford Island	0.13	21,630	2,153
68	Little Egbert Tract	0.12	36,758	3,248
144	Mandeville Island	0.11	31,130	5,246
9	Jersey Island	0.10	29,805	3,499
152	Medford Island	0.08	8,559	1,176
179	Twitchell Island	0.08	37,062	3,583

[1] Selection Score = Subsidence * Frequency of Flooding

Table 7-3 Islands Selected for Assessment

ID	Island	Area (acres)	Weighted Mean depth (feet)	Weighted Standard Error of the Mean (feet)
150	Venice Island	3,156	-14.1	0.86
4	Webb Tract	5,519	-11.8	0.78
13	Holland Tract	4,286	-7	0.95
6	Bradford Island	2,153	-6.2	0.71
144	Mandeville Island	5,246	-13.1	0.86
152	Medford Island	1,176	-9.0	0.91
179	Twitchell Island	3,583	-10.3	0.80

Sources: Interferometric Synthetic Aperture Radar (IFSAR) topographical dataset (USACE 2000a), NAVD88.

Table 7-4 Agricultural Land Use on Potential Islands for Carbon Sequestration

URS_ID	Name	Total Area Acres	Agricultural Land Use (acres)					
			Alfalfa	Field Crops	Grain	Orchards	Truck	Vineyards
150	Venice Island	3,156	0	2,752	0	0	6	0
4	Webb Tract	5,519	0	2,620	1,814	0	0	0
13	Holland Tract	4,286	82	540	443	0	0	0
6	Bradford Island	2,153	0	0	0	0	0	0
144	Mandeville Island	5,246	42	1,379	663	0	4	226
152	Medford Island	1,176	0	0	0	0	0	0
179	Twitchell Island	3,583	486	1,908	705	14	0	0
Total		25,119	609	9,198	3,625	14	10	226

Table 7-5 Infrastructure Assets on Potential Islands for Carbon Sequestration

URS_ID	Name	Minor Roads (miles)	Hwy Bridge (no.)	Oil – gas wells (no.)	Gas Fields (acres)	Gas Pipelines (miles)	Dwellings–family (no.)	Dwellings–other (no.)
150	Venice Island	13	0	4	0	0.0	0	2
4	Webb Tract	0	0	19	83	0.2	1	0
13	Holland Tract	10	1	11	0	0.0	12	4
6	Bradford Island	11	0	22	0	1.4	27	10
144	Mandeville Island	5	0	10	0	0.0	0	0
152	Medford Island	5	0	0	0	0.0	0	1
179	Twitchell Island	5	0	54	2,199	1.7	24	31

Table 7-6 Estimated Earthwork Required for Each Island Assuming an Overall 2-Foot Variation in Elevation

URS_ID	Island Name	Area (acres)	Earthwork (cubic yards)	Ratio (soil volume/area/1,000)
150	Venice Island	3,156	4,475,000	1.42
4	Webb Tract	5,519	9,866,000	1.79
13	Holland Tract	4,286	8,852,000	2.07
6	Bradford Island	2,153	4,177,000	1.94
144	Mandeville Island	5,246	8,852,000	1.69
152	Medford Island	1,176	2,173,000	1.85
179	Twitchell Island	3,583	5,992,000	1.67
Total		25,119	44,387,000	

Table 7-7 Carbon Credits Generated at Equilibrium for Short-Listed Delta Islands

			Carbon Credits (t CO_2e/yr) at Sustainable Growing Density		
URS_ID	**Island Name**	**Total Area (acres)**	**Low**	**Average**	**High**
150	Venice Island	3,156	6,569	11,627	16,685
4	Webb Tract	5,519	11,488	20,332	29,177
13	Holland Tract	4,286	8,921	15,790	22,659
6	Bradford Island	2,153	4,481	7,932	11,382
144	Mandeville Island	5,246	10,919	19,327	27,734
152	Medford Island	1,176	2,448	4,332	6,217
179	Twitchell Island	3,583	7,458	13,200	18,942
	Total:	25,119	52,284	92.540	132,796

Table 7-8 Revenue Earned Through the Production of Carbon Credits

URS_ID	Island Name	Average Carbon Credits	Price for Carbon Credits ($/$CO_2$e) $10	Price for Carbon Credits ($/$CO_2$e) $30
150	Venice Island	11,627	$116,269	$348,807
4	Webb Tract	20,332	$203,324	$609,971
13	Holland Tract	15,790	$157,899	$473,697
6	Bradford Island	7,932	$79,318	$237,954
144	Mandeville Island	19,327	$193,266	$579,798
152	Medford Island	4,332	$43,325	$129,974
179	Twitchell Island	13,200	$132,000	$396,000
		Total:	$925,401	$2,776,201

Table 7-9 Estimated Net Value of Agricultural Production ($/acre)

Land Use	Revenue ($/acre)	Variable Costs (65% revenue)	Net Value ($/acre)
Alfalfa	800	520	280
Field crops	500	325	175
Grain	300	195	105
Orchards	5,900	3,835	2,065
Processing vegetables	2,900	1,885	1,015
Vineyards	4,200	2,730	1,470

Table 7-10 Estimated Value of Agricultural Production Foregone

URS_ID	Island Name	Area (acres)	Agricultural Production Foregone ($0,000)	
			Annual ($/year)	Capitalized Value NPV (6% over 30 years)
150	Venice Island	3,156	$488	$6,718
4	Webb Tract	5,519	$649	$8,932
13	Holland Tract	4,286	$164	$2,255
6	Bradford Island	2,153	$0	$0
144	Mandeville Island	5,246	$659	$9,071
152	Medford Island	1,176	$0	$0
179	Twitchell Island	3,583	$574	$7,899
		25,119	$2,534	$34,875

NPV = net present value

Table 7-11 Conceptual-Level Construction Cost Estimate for Short-Listed Islands

	Venice Island	Webb Tract	Holland Tract	Bradford Island	Mandeville Island	Medford Island	Twitchell Island
PRELIMINARY							
TEMPORARY ACCESS AND HAUL ROUTE CONSTRUCTION	$500,000	$500,000	$500,000	$500,000	$500,000	$500,000	$500,000
CLEARING AND GRUBBING	$3,408,480	$5,960,520	$4,628,880	$2,325,240	$5,665,680	$1,270,080	$3,869,640
EARTHWORK							
CELL BOTTOM EXCAVATION AND FILL (300' HAUL)	$31,325,000	$69,062,000	$61,964,000	$29,239,000	$61,964,000	$15,211,000	$41,944,000
WATER SUPPLY DISTRIBUTION SYSTEM							
SIPHON PIPE AND STRUCTURE REFURBISHMENT	$0	$0	$0	$0	$0	$0	$0
PLANTING & SEEDING							
PLUGS (5%)	$1,660,351	$2,903,510	$2,254,837	$1,132,679	$2,759,886	$618,686	$1,884,993
SUBTOTAL	$36,893,831	$78,426,030	$69,347,717	$33,196,919	$70,889,566	$17,599,766	$48,198,633
OTHER							
CONTINGENCIES (30%)	$11,068,149	$23,527,809	$20,804,315	$9,959,076	$21,266,870	$5,279,930	$14,459,590
TOTAL CONSTUCTION	$47,961,980	$101,953,839	$90,152,032	$43,155,995	$92,156,436	$22,879,696	$62,658,223
ADMINISTRATION (10%)	$4,796,198	$10,195,384	$9,015,203	$4,315,600	$9,215,644	$2,287,970	$6,265,822
DESIGN/ENGINEERING (8%)	$3,836,958	$8,156,307	$7,212,163	$3,452,480	$7,372,515	$1,830,376	$5,012,658
CONSTRUCTION MANAGEMENT (5%)	$5,755,438	$12,234,461	$10,818,244	$5,178,719	$11,058,772	$2,745,563	$7,518,987
TOTAL COST	$62,350,574	$132,539,991	$117,197,641	$56,102,794	$119,803,367	$29,743,604	$81,455,690
TOTAL COST PER ACRE	$19,756	$24,015	$27,344	$26,058	$22,837	$25,292	$22,734

Table 7-12 Operation and Maintenance Cost Estimate for Short-Listed Islands

	Venice Island	Webb Tract	Holland Tract	Bradford Island	Mandeville Island	Medford Island	Twitchell Island
Annual Costs							
Operations	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000	$16,000
Maintenance	$240,460	$510,419	$451,410	$216,430	$461,432	$115,048	$313,941
Subtotal	$256,460	$526,419	$467,410	$232,430	$477,432	$131,048	$329,941
Net Present Value	$3,530,127	$7,246,071	$6,433,822	$3,199,359	$6,571,773	$1,803,860	$4,541,584

Table 7-13 Change in Subsidence with Carbon Sequestration

	Change in subsidence	
	Per Year (inches)	**Over 50 years (feet)**
Without carbon sequestration	-1.0	-4.16
With carbon sequestration	1.6	6.67
Net change (with – without)	**2.6**	**10.83**

Table 7-14 Island Subsidence With and Without Carbon Sequestration

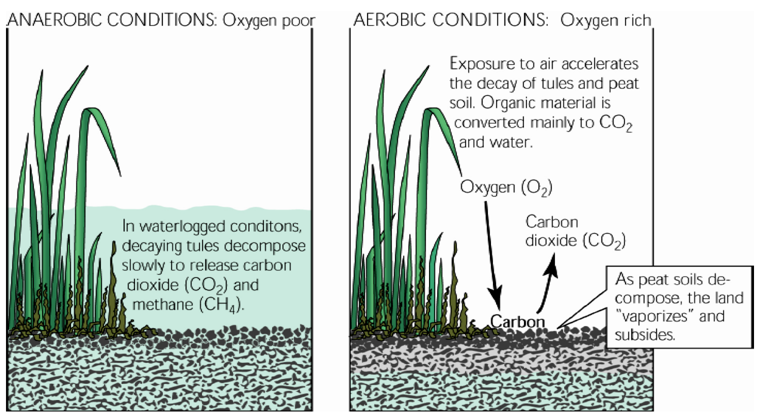
Years	Without Carbon Sequestration (Do-Nothing Scenario)		With Carbon Sequestration	
	Mean Estimate (acre-feet)	Percent Change	Mean Estimate (acre-feet)	Percent Change
1998	1,893,500		1,893,500	
2050	2,556,500	35%	2,295,302	21%

Source: URS/JBA 2007b.

Figures

Objectives Managed flooding of islands to halt and reverse subsidence and potentially provide carbon credits.

Halt Subsidence
Establish tule wetlands

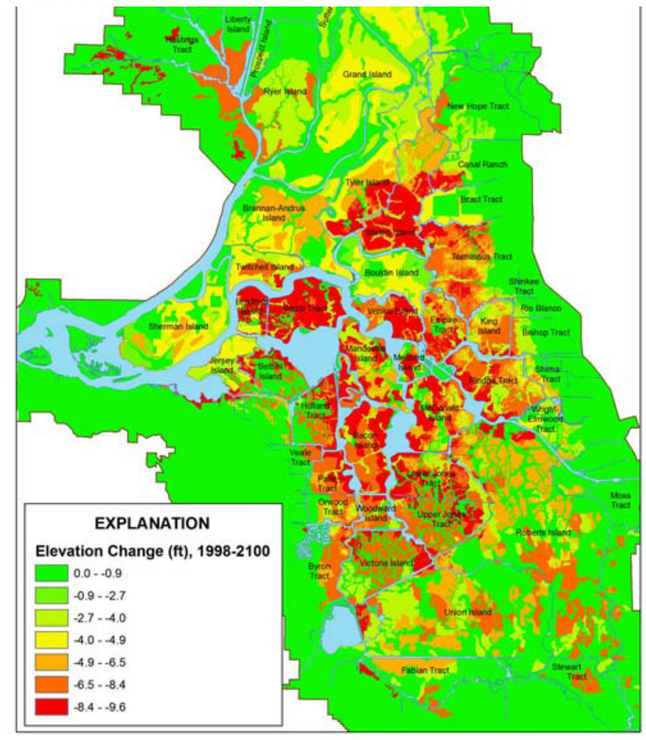


Reverse subsidence
Vegetation matter accumulated over 8 years

- Twitchell Island ponds show increases of 1.6 inches/year in addition to preventing subsidence of ~1 inch/year
- Predicted change in net subsidence of 11 feet by 2050

Photographs courtesy of Roger Fujii (USGS)

Carbon Sequestration Sites
Predicted subsidence for 2100



Twitchell Island carbon sequestration pilot project ponds

Potential Islands for Implementation
Islands were identified where subsidence and levee fragility were greatest and the value of infrastructure and agricultural production was least. These islands were:

- Venice Island (3,156 acres)
- Webb Tract (5,519 acres)
- Holland Tract (4,286 acres)
- Bradford Island (2,153 acres)
- Mandeville Island (5,246 acres)
- Medford Island (1,176 acres)
- Twitchell Island (3,583 acres)

Project Benefits

- The key benefits of subsidence reversal include:
  - Reduced likelihood of levee breach in future years (improved levee fragility), and
  - Reduced salinity intrusion in future years due to a reduced island gulp.
- Other benefits of carbon sequestration include improved biodiversity, a reduction in greenhouse gases, and reduced costs for levee maintenance.
  - Carbon sequestration sites will provide important habitat for endangered flora and fauna species throughout the Delta (duck-hunting, recreation).
  - The net reduction in greenhouse gas generation is estimated at about 4 metric tons of CO_2e per acre per year.

Project Constraints

- The constraints to carbon sequestration include the loss of agricultural production on islands and increased costs to protect infrastructure.
- Social and transaction costs associated with land use change

Project Findings

- Wetlands can be used successfully to reverse subsidence on Delta peat islands where ponding depth and plant species are optimized.
- The elevation of any Delta island typically varies by about 2 feet about the mean. Therefore island earthwork to reduce this variability and achieve an optimal ponding depth is substantial.

Project Costs

- Total conceptual cost estimate for seven islands (including earthwork for leveling) is a capital cost of $60M and an annual cost of $6.2M.
- Opportunities exist to reduce this cost by changing land use practices and allowing islands to naturally level over time, or alternatively by using natural island contours to achieve optimal ponding depths on separate island segments.
- Revenue from carbon credits may partially offset annual operating costs

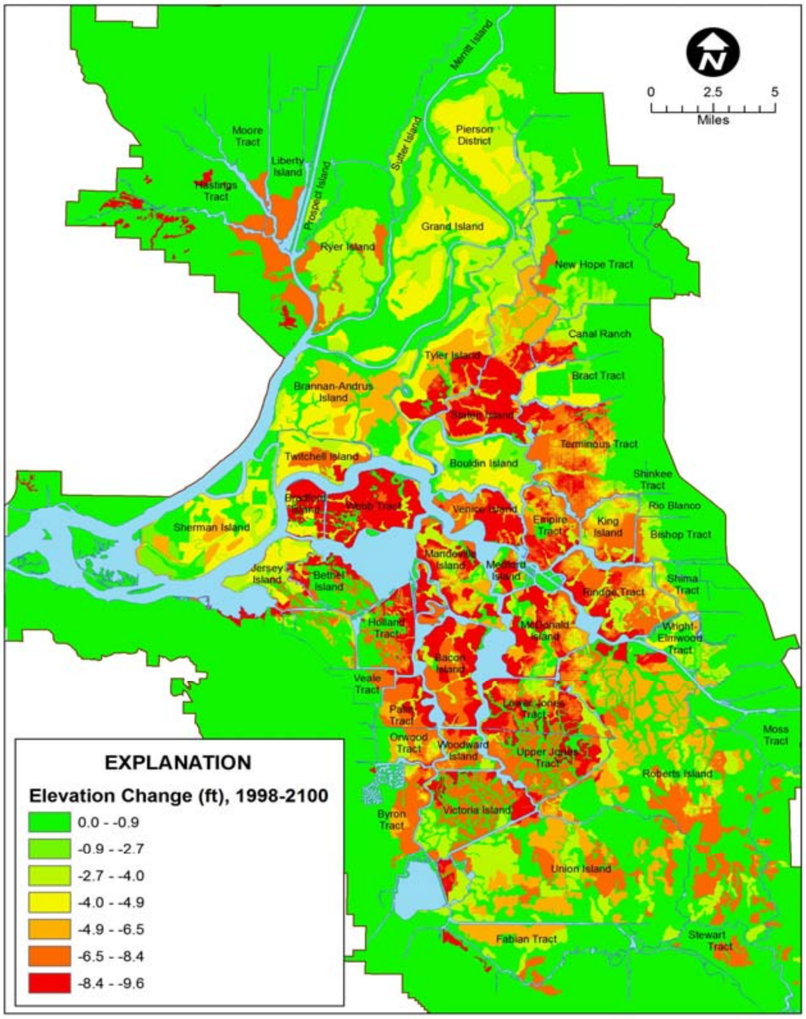


Figure 7-2 Predicted Subsidence in the Delta for 2100

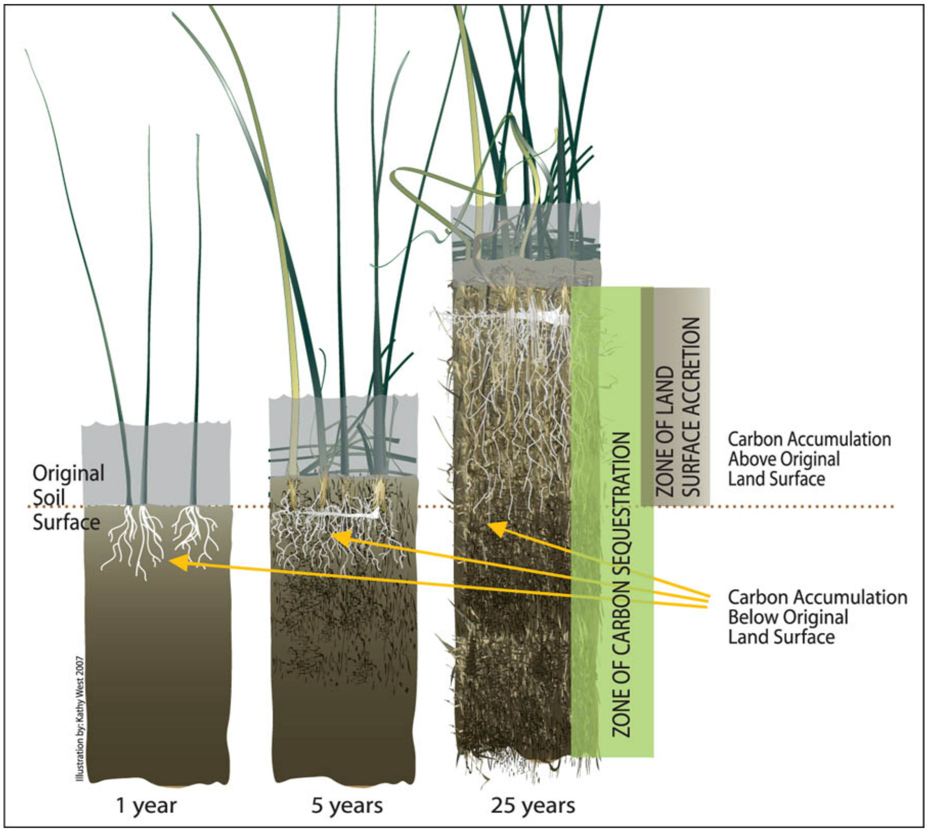


Figure 7-3 Carbon Accumulation over Time in a Continuously Flooded Wetland

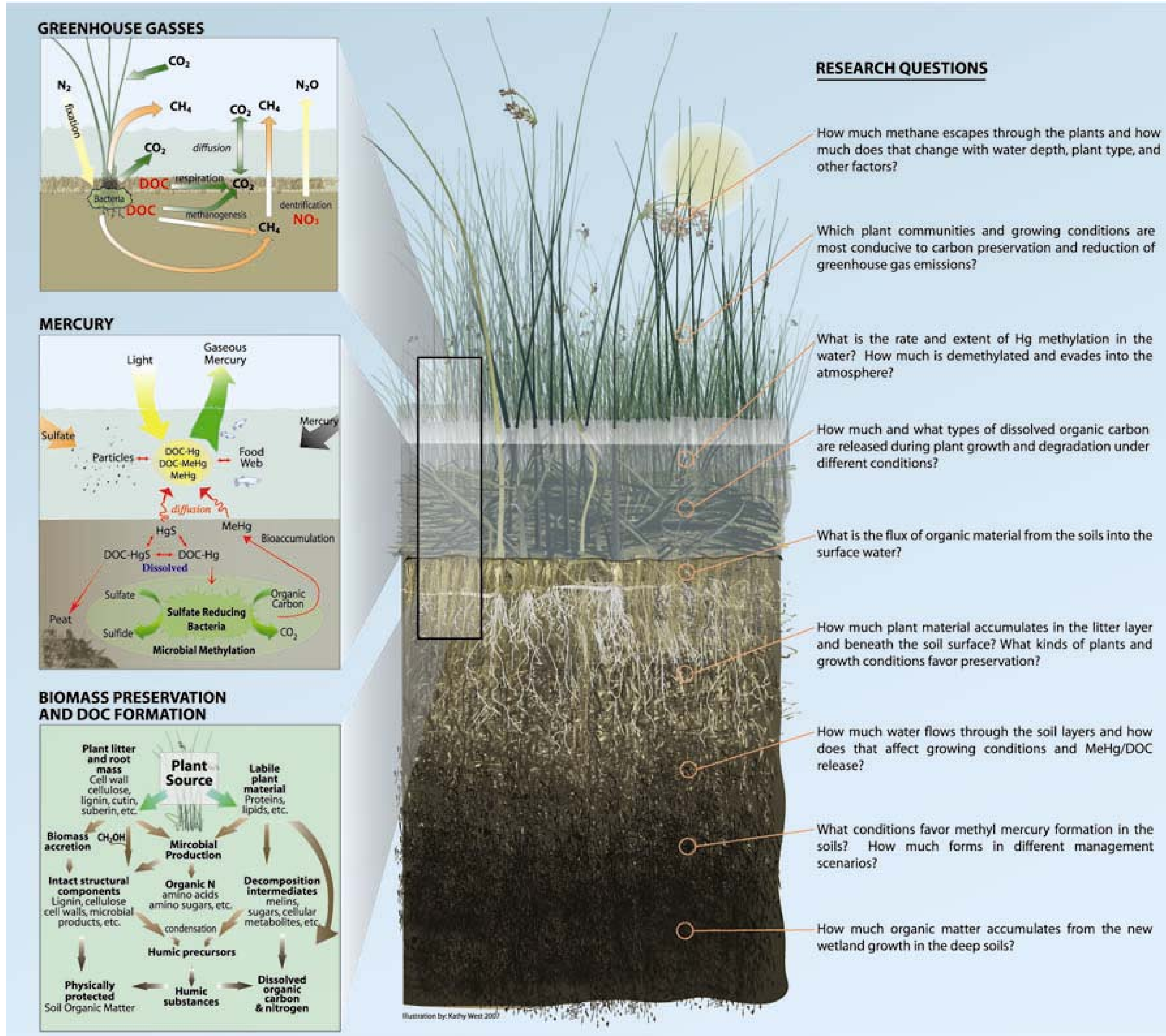


Figure 7-4 Biochemical Processes in Wetlands

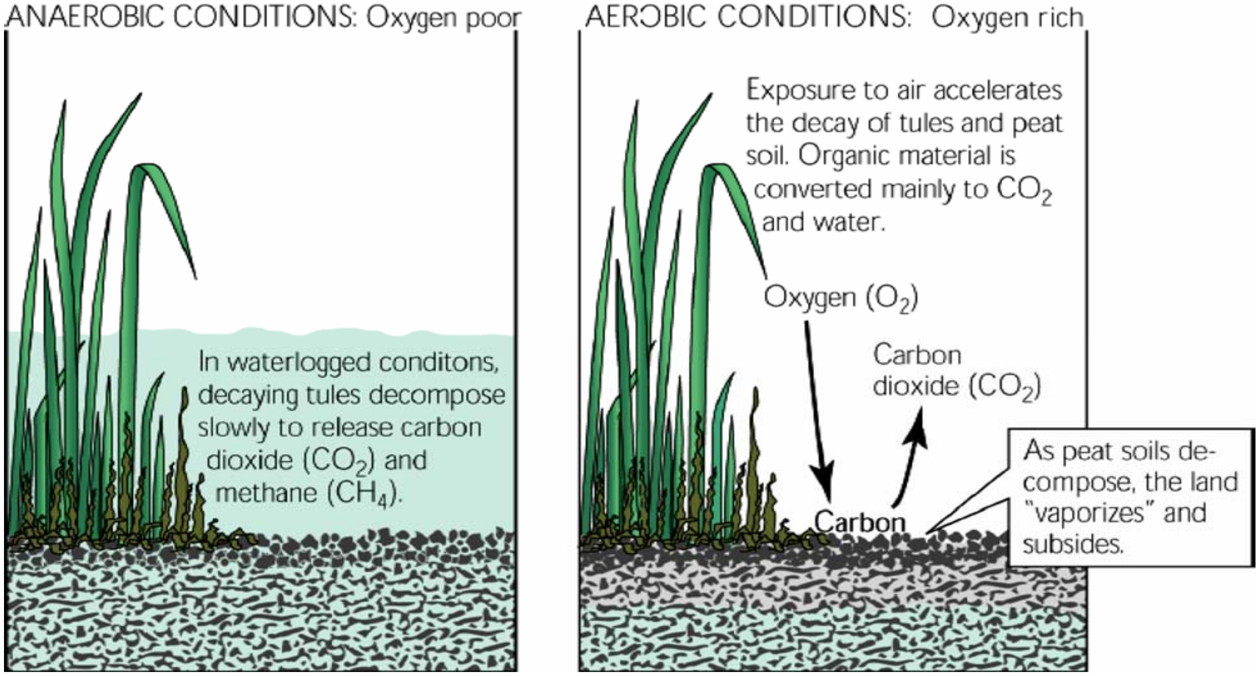


Figure 7-5 Decomposition of Organic Matter Under Aerobic and Anaerobic (Flooded) Conditions