Chapter 3D. Affected Environment and Environmental Consequences - Flood Control

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SUMMARY

This chapter describes flood control features of the DW project alternatives and identifies impacts of the alternatives on levee reliability and flood control on the DW project islands. Key flood control issues discussed are reliability of interior and exterior levees around the DW project islands, seepage impacts on neighboring islands, and effects of wind and wave erosion on levees.

Features and programs incorporated into Alternatives 1, 2, and 3 would limit potential flood control impacts to less-than-significant levels. Less-than-significant impacts are the potential for seepage from reservoir islands to adjacent islands, wind and wave erosion on reservoir islands, and erosion of levee toe berms at new facilities on the reservoir islands. No significant impacts are projected to occur under Alternative 1, 2, or 3.

In general, the levee buttressing and maintenance program proposed by DW for Alternative 1, 2, or 3 would have several beneficial impacts. It would increase the long-term stability of perimeter levees on the DW project islands, decrease the potential for levee failure during seismic activity, reduce the cumulative flooding hazard in the Delta, and reduce long-term public costs for levee maintenance and repair around the reservoir islands. By decelerating the rate of subsidence relative to existing conditions on the habitat islands, implementing Alternative 1 or 2 would improve long-term levee stability on the habitat islands by slowing levee deterioration that results from subsidence.

Because the rate of subsidence would increase under the No-Project Alternative, levee stability would decline over time and the potential for seepage and for levee failure during seismic activity would increase. The cumulative risk of levee failure would increase under the No-Project Alternative. The perimeter levees could be substantially buttressed and improved to increase long-term levee stability.

INTRODUCTION

This chapter assesses potential impacts of the DW project alternatives on DW island levee reliability and flood control in the Delta. The discussion in this chapter includes several terms that may not be familiar to all readers. The following are definitions of key terms as they are used in this EIR/EIS:

- **Buttress**. An exterior pier, often sloped, used to steady a structure by providing greater resistance to lateral forces to prevent buckling. See also "toe berm".
- **Toe berm**. The section projecting at the base of a dam, levee, or retaining wall.
- **Levee crest**. The top of a levee.
- **Borrow area**. An excavated area or pit created by the removal of earth material to be used as fill in a different location.
- **Subsidence**. A local or regional sinking of the ground. In the Delta, this results primarily from peat soil being converted into gas.
- **Settlement**. The sinking of surface material as a result of compaction of soils or sediment caused by an increase in the weight of overlying deposits or by pressure resulting from earth movements.
- **Seismicity**. The frequency, intensity, and distribution of earthquake activity in a given area.

- **Liquefaction**. The process in which soil loses cohesion when subject to seismic activity (i.e., shaking).

- **Seepage**. A slow movement of water through permeable soils caused by increases in the hydraulic head (see below).

- **Piezometer**. A sandpipe monitoring well used to measure the depth to the groundwater surface in the aquifer.

- **Hydraulic head**. The pressure created by water within a given volume.

- **Hydrostatic pressure**. The pressure of water at a given depth due to the weight of the fluid above it.

AFFECTED ENVIRONMENT

This section describes levee and flood conditions on the DW project islands. Information for this section is based, in part, on information collected for the 1990 draft EIR/EIS. Where conditions have not changed, this information has been used. Descriptions of levee and flood conditions have been updated using more recent information from DWR; the Bay-Delta Oversight Council; and DW's geotechnical engineers, Harding Lawson Associates (HLA) and Hultgren Geotechnical Engineers, where appropriate.

Sources of Information

Information on levees and flood control in the Delta and on the DW project islands was collected from reports by DWR, the Bay-Delta Oversight Council, and DW's engineering consultants. Local reclamation district engineers and consulting engineers were also contacted for further information. Appendix D1 is an annotated list of geotechnical reports prepared for the DW project and consulted for much of the information in this chapter.

Delta Levee Stability

History of Delta Levees

Prior to reclamation for agriculture, the Delta was a tidally influenced marshland. Reclamation began in 1850 and involved the use of extensive levee systems, internal drainage networks, and pumps. In 1861, the California Legislature created a state commission to manage reclamation projects. In 1868, the responsibility for reclamation was given to landowners and their reclamation districts, and Delta island reclamation began on a large scale.

Between 1871 and 1879, most of the Delta islands were enclosed by levee systems. By the late 1870s, steam-powered dredges were being used to build levees, and between 1880 and 1916, most of the Delta marshes were reclaimed (DWR 1982). By the mid-1940s, the Delta had been completely transformed from a tidal wetland to a series of channels separated by islands protected by levees.

Delta Levee System

The Delta levee system initially served to control island flooding. Today the levees are necessary to prevent inundation of island interiors during normal runoff and tidal cycles because island interiors have been lowered by extensive soil subsidence. Subsidence is the lowering of the interior land level primarily as a result of microbial decomposition, topsoil erosion, and oxidation of the islands' peat soils. Delta lands have historically subsided at rates that are among the highest in the world. The land surface of some Delta islands is subsiding at a rate of 2-3 inches per year (U.S. Soil Conservation Service [SCS] 1989). Levees that were originally built 2 or 3 feet above ground level must now be maintained, in many cases, at heights of over 20 feet above ground level as a result of interior island subsidence (DWR 1982, 1988; Bay-Delta Oversight Council 1993).

Before reclamation, the surface elevations of the Delta soils were approximately at sea level. Therefore, the difference between sea level and existing elevations of the island interiors represents the magnitude of subsidence that has taken place on each island since reclamation began. The lowest surface elevations of Bacon and Bouldin Islands and Holland and Webb Tracts are -20.3, -19.9, -17.9, and -20.5 feet relative to mean sea level, respectively (Northpoint Engineers 1988).

Delta Levee Failure Mechanisms

More than 100 Delta island levee failures have occurred since the early 1890s (DWR 1982). Figure 3D-1 shows the 15 Delta islands that have flooded since 1967. Levee failures occur as a consequence of overtopping or levee instability.

Overtopping occurs when the crest of the levee is lower than the water level. Overtopping can occur not only as a result of floodflows, but also as a consequence of high tides and wind (Bay-Delta Oversight Council 1993). Factors contributing to levee instability include seepage, settlement, erosion, subsidence, and seismicity. These factors are described below.

Seepage. Water seeping through or beneath levees contributes to erosion problems and subsequent levee instability. Sandy levees are especially susceptible to seepage erosion and the resulting formation of "pipes" (large voids) in the levee material. (Bay-Delta Oversight Council 1993). Regional and project-specific seepage conditions are described below.

Seepage of water from waterways or adjacent islands is a major concern of Delta land users. The amount of seepage that occurs is controlled by the permeability of soils, length of the seepage path, and height of the hydraulic head (i.e., the pressure created by water within a given volume). The problem is worsened in the Delta by the decline in the level of peat soils, which increases the hydraulic head between channel water surfaces and the islands, and by the presence of permeable subsurface sand layers. Seepage has been reported to increase after flooding of an adjacent island and to cease after the flooded island has been drained (DWR 1982, HLA 1989).

Under existing conditions, seepage fluctuates with exterior channel water levels; dredging episodes in exterior channels; and variations in farming practices, such as weed control, flooding adjacent to levees, or lowering of interior water levels. Seepage varies from island to island and within individual islands as a function of soil conditions and levee conditions. Site-specific information on groundwater conditions on the DW islands and neighboring islands is now being collected by HLA and Hultgren Geotechnical Engineers under contract to DW to give an indication of existing seepage through the aquifer. Results of groundwater monitoring to date have been published in three reports (see Appendix D1, "Annotated List of Geotechnical Reports Prepared for the Delta Wetlands Project").

Water seeps onto Delta islands by two primary routes: high seepage passes through or immediately beneath levee embankments, and deep seepage passes through permeable materials below the peat that underlies most levee embankments. High seepage is not transmitted from flooded islands to adjacent islands and is addressed by individual reclamation districts as it occurs. Subsurface sand layers provide the primary conduits for deep seepage. These layers may permit the seepage to travel from a flooded island to an adjacent island. If clay is present under channels between islands, or if it overlies sand layers, the permeability of the seepage path and resultant seepage are greatly reduced.

Settlement. The construction of Delta levees over soft foundation materials has caused ongoing consolidation of levee material and levee settlement. Delta islands are subject to levee cracking, seepage, and instability of varying degrees because of differential settlement and the composition of the levee soils. The levees are raised periodically to compensate for settlement. The process of raising levees increases the load on the underlying materials, causing more settlement, and the cycle repeats itself. Levees commonly settle at various rates, which depend on factors such as the nature of underlying material and the length of time since the levee crest was last raised with additional fill (HLA 1989).

Wind and Wave Erosion. Levee exterior (waterside) slopes are subject to varying erosional effects of channel flows, tidal action (which can cause water levels in some channels to vary by as much as 4 feet daily), wind-generated waves, and boat wakes. To counter erosion, riprap (rock) may be placed on a levee, or a berm may be placed as a buffer in front of the levee. Although vegetation can contribute to piping problems, it is generally desirable as another tool in controlling erosion. (Bay-Delta Oversight Council 1993.)

Subsidence. Subsidence (i.e., lowering of the land surface) results primarily from peat soil being converted into a gas. Many Delta islands are composed of peat soils that decompose when exposed to oxygen and higher temperatures, a process that is accelerated by agricultural activity (Bay-Delta Oversight Council 1993).

Seismicity. Faults are considered active if they have moved at least once during the last 11,000 years. Active faults that have the potential to produce earthquake effects on Delta levees exist (DWR 1982). None of the Delta levee failures are known to have been the direct result of an earthquake. However, an earthquake could potentially cause levee failures through lateral deformation, settlement, or liquefaction because Delta levees are founded on sand, silt, clay, and peat that, when saturated, generally lose strength under seismic acceleration.

The height differential between the top of existing levees and island interior bottoms is gradually increasing because of subsidence. This growing differential increases levee vulnerability to earthquake effects because hydrostatic pressure (i.e., the pressure of water at a given depth due to the weight of the fluid above it) becomes greater relative to the resisting forces of the levees and foundation soils.

DWR has an emergency plan to protect Delta water supplies in the event that levees are damaged by an earthquake. The plan calls for cessation of pumping in the south Delta, release of water from upstream reservoirs, use of Clifton Court Forebay as a temporary supply, and rapid repair of damaged levees (Argent 1988).

DW Project Islands

Levee Failure. Since 1932, two DW project islands, Holland and Webb Tracts, have flooded as a result of levee overtopping or stability failure. Using levee data from 1974, the Corps calculated the statistical frequency of levee failure resulting from overtopping or levee instability on Delta islands, based on the assumption that no major rehabilitation work would be done (Table 3D-1). The Corps predicted that Bouldin Island would experience levee failure more than 18 times in 100 years, or an average of once every 5.5 years under existing conditions. The Corps predicted that levees on Bacon Island, Holland Tract, and Webb Tract would fail once every 11-24 years under existing conditions. (DWR 1982.)

Seepage. The DW project islands and adjacent islands experience seepage problems of varying degrees under existing conditions. Existing levees will continue to have at least some high seepage caused by the high hydraulic heads between exterior water surfaces and interior island bottoms. Site-specific data on seepage in the DW project area indicate that water levels in sand aquifers are within a few feet of the interior elevations of the islands (HLA 1992a).

Current agricultural land use practices (see Chapter 3I, "Land Use and Agriculture") on many Delta islands lower groundwater levels and accelerate subsidence in peat material at or near the island surfaces. Because of continued subsidence, associated increases in levee heights, and corresponding hydrostatic pressures, seepage is expected to increase over time in the DW project island interiors under existing conditions.

HLA, under contract to DW, issued questionnaires pertaining to seepage on Delta islands to reclamation engineers in 1988. Although most of the information collected was not specific, results indicated that all islands adjacent to DW project islands have some problem with seepage, subsidence, or ground settlement. District engineers reported no seepage on many islands after flooding events on adjacent islands. However, some islands have reported increases in seepage after such flooding (HLA 1991, Holmes pers. comm.).

HLA has been collecting baseline groundwater data from 34 piezometers since 1989 on islands adjacent to the DW islands. As seepage through the deep aquifer increases and decreases, groundwater levels within the aquifer will rise and fall accordingly. Thus, measuring preproject and during-project groundwater levels provides the most reliable indicator of changes in seepage through the aquifer (see Appendix D1 for an annotated bibliography of reports prepared by HLA since 1989 for the DW project).

Settlement. Typical levees on Delta islands consist of a layer of fill, about 10 feet thick, composed mostly of sand with some peat and clay. The fill is underlain by peat and soft clay, which in turn is typically underlain by sand, silt, and clay (HLA 1989). The peat and soft clay foundation materials are highly compressible and create continual settlement problems for Delta island levees, including the proposed project levees.

Wind and Wave Erosion. The DW project islands are subject to varying erosional effects from wind-generated waves, channel flows, and tidal action. Exterior levee slopes on the DW project islands are constructed with erosion control material (e.g., riprap) to counter wind and wave erosion.

Subsidence. If current DW agricultural practices continue, the surfaces of the DW islands will decline roughly 6-10 feet over the next 50 years, assuming peat layers are at least 10 feet thick (HLA 1989). Table 3D-2 shows DWR's (1982) estimates of projected island bottom subsidence in 50 years. Island bottom elevations below sea level are predicted to subside 16-18 feet between 1982 and 2032. If the existing levees are maintained and built to greater heights to compensate for the subsidence, hydrostatic pressures on the DW project levees would increase and greatly increase the risk of seepage and levee failure.

Seismicity. No active faults are known to pass beneath the DW project islands, although the islands are within the zones of influence of several active faults. The major active fault systems and their distances west of Webb Tract are the Concord-Green Valley (22 miles), Calaveras (27 miles), Hayward (37 miles), Rodgers Creek (43 miles), San Andreas (54 miles), and Vacaville/ Winters (26 miles) fault systems (HLA 1989). The Midland fault passes near the western edges of Holland and Webb Tracts but is not considered to be active (DWR 1982).

Flood Control System

Existing System in the Delta

Levee systems throughout the Delta are either federal "project levees" or "nonproject levees". Project levees within the Delta are maintained to federal Corps standards by the State of California or by local landowners under state supervision. Nonproject levees are defined as levees constructed and maintained by local landowners and reclamation districts and constitute about 65% of levees in the Delta flood control system (DWR 1982). Federal and state agencies have no jurisdiction over nonproject levees and cannot require maintenance of these levees. Maintenance of nonproject levees is largely financed by landowners to widely ranging and less stringent standards than are applied to project levees.

Nonproject levees are maintained, repaired, and upgraded by local reclamation districts according to the state's Flood Hazard Mitigation Plan for the Delta. The Delta Flood Protection Act of 1988 increased the financial assistance to Delta reclamation districts responsible for maintaining nonproject levees. The Delta Flood Protection Act authorized $12 million annually through 1998-1999, with the money to be split between supplementing local revenues and funding special levee projects in the western Delta and flood protection for Walnut Grove and Thornton. The Delta Flood Protection Act also focused on protecting and enhancing the fish, plant, and wildlife resources of the Delta. Under the Delta Flood Protection Act, no project receiving funding from the act can result in a net long-term loss of riparian, fishery, or wildlife habitat, and a DFG finding to that effect must be issued before funds are disbursed.

Financing of the Levee System

Costs of maintaining and repairing the levee system in the Delta are substantial (DWR 1982, 1993). State and local governments have invested millions of dollars in the past 10 years to maintain and repair eroded levees. In some instances, the expenditures exceeded the appraised value of the island or tract being protected. The average annual cost of levee maintenance on nonproject levees in the Delta ranged from $3,000 to $165,000 per levee mile, averaging $11,800 per levee mile between 1981-1991 (DWR 1993).

Beginning in 1988, state cost-sharing was increased to 75% of costs exceeding $1,000 per mile under the Delta Levee Rehabilitation Act of 1988. Under the 75% cost-share proportion established by the Delta Levee Rehabilitation Act, the state cost could increase to approximately $170,000 per year, or $8.5 million over 50 years if projected based on experience from 1981-1991. This cost is approximately twice current costs.

The Delta Flood Protection Act provided $60 million over a 10-year period to control subsidence and rehabilitate levees on eight western Delta islands. Subsidence makes levees more difficult to maintain because of greater hydrostatic pressure and is most directly controlled through elimination of agricultural cultivation of peat soils. (DWR 1988.)

Local Reclamation Districts

Landowners throughout the Delta, including those on the DW project islands, have organized into local reclamation districts to reclaim and protect lands from overflow. Generally, each landowner has one vote per $1 of assessed value of taxable land and improvements. Typically, each district is governed by a board of three trustees. The districts finance levee maintenance work by assessments on protected landowners.

Flood Control System for the DW Project Islands

Existing System. The four DW project islands are completely bounded by nonproject levees. On Webb Tract, the nonproject levee along the San Joaquin River on the north side of the island borders the Stockton ship channel and is classified as a "direct agreement" levee. The Port of Stockton has assured the federal government that this and other direct agreement levees will be maintained. The federal government will repair damage to this levee resulting from wave wash from large ships (DWR 1982).

Financing. During 1980-1986, over $36 million of federal, state, and local reclamation district money was spent on emergency levee repairs on the DW project islands (Table 3D-3). Approximately 85% of this money was spent on Holland and Webb Tracts, where major levee breaks occurred in 1980. During 1981-1986, $1,362,000 was spent on levee maintenance work on the four DW project islands (Table 3D-3). Approximately 40% of this maintenance cost was reimbursed by the state under the Delta Levee Maintenance Subventions Program. During this period, up to 50% of maintenance costs exceeding $1,000 per mile of nonproject levees was reimbursable under the subventions program.

Emergency repair and maintenance costs for nonproject levees on the DW project islands totaled about $37 million over the periods shown in Table 3D-3. Of this total, approximately 95% was state or federal public money; only about 5% was raised by reclamation districts through assessments of landowners within their jurisdiction. As part of the Delta Flood Protection Act West Delta Islands Program to meet the water quality objectives for the Delta, Holland and Webb Tracts can receive funding for subsidence control and levee rehabilitation.

Local Reclamation Districts

Bacon Island. Levees on Bacon Island are maintained by Reclamation District No. 2028. The reclamation district engineer inspects the island levees in spring and fall or when levee problems are reported by the local landowners. The district engineer generally specifies, supervises, and coordinates any required levee repair or rehabilitation. Levee maintenance can be performed by the reclamation district at any time during the year and can include vegetation control, road maintenance, and the raising of levees that have subsided (Sinnock pers. comm.). The materials used for levee reconstruction on Bacon Island have been primarily dredged from adjoining channels.

The levees are maintained to reclamation district standards requiring top widths of 20 feet, exterior levee slopes of 2:1, and interior slopes of 4:1 (Sinnock pers. comm.). The minimum top width prescribed in DWR Bulletin 192-82 (DWR 1990) and Corps bulletins is 16 feet, but accepted practice in the Delta is to require 20-foot top widths to allow equipment maneuvers and car passage.

Webb Tract. Webb Tract levees are maintained by Reclamation District No. 2026. The levees are inspected approximately twice each year by the reclamation district engineer or more often in response to local alert. The reclamation district engineer specifies, supervises, and coordinates levee rehabilitation work. The reclamation district and landowners maintain all levees, including those along the Stockton ship channel, where bank protection against wave wash is under federal jurisdiction (Kjeldsen pers. comm.). The materials used for levee reconstruction on Webb Tract were primarily dredged from adjoining channels. Borrow areas were developed on Webb Tract in 1990 and have since been used as the primary source of fill material to improve the levees. The levees are maintained to local reclamation district standards with top widths of 20 feet, exterior levee slopes of 2:1, and interior slopes of 4:1 (Sinnock pers. comm.).

Flood waters rushing through a levee breach on January 18, 1980, created the blowout pond on the east end of Webb Tract. The Corps emergency pumps were moved to Webb Tract after being removed from Holland Tract in May 1980. The Corps removed its emergency pumps and turned over the island to the local reclamation district in mid-December 1980; the district then began rehabilitating its own pumps for final drawdown. Water was not drawn down below the island bottom until February 1981 (Kjeldsen pers. comm.).

Bouldin Island. Bouldin Island levees are maintained by Reclamation District No. 756. The reclamation district engineer specifies, supervises, and coordinates any levee rehabilitation work and generally inspects the levees approximately three times each year. Materials used for levee reconstruction on Bouldin Island were a combination of dredged soils from adjoining channels and imported material from other sources. Borrow areas were developed on Bouldin Island in 1990 and have since been used as the primary source of fill material to improve the levees. Levees are maintained to local reclamation district standards of top widths of 20 feet, exterior levee slopes of 2:1, and interior slopes of 4:1. (Wright pers. comm.)

Holland Tract. Holland Tract levees are maintained by Reclamation District No. 2025 according to the same maintenance procedures and standards as those previously discussed for Bouldin Island. Materials used for levee reconstruction on Holland Tract were a combination of dredged soils from adjoining channels and imported material from other sources. (Wright pers. comm.) Borrow areas were developed on Holland Tract in 1990 and have since been used as the primary source of fill material to improve the levees.

The levee on the northern tip of Holland Tract breached on January 18, 1980. Flood waters scoured out the blowout pond now present at that location. The Corps installed emergency pumps after the breach; the pumps operated until April 25, 1980, when dismantling began. The surface water level was drawn down to the island bottom by May 5, 1980 (Wright pers. comm.).

IMPACT ASSESSMENT METHODOLOGY

Analytical Approach and Impact Mechanisms

Impacts on levee reliability and flood control were evaluated through comparison of the levee improvement design for the DW project alternatives with conditions studied, based primarily on results of the preliminary geotechnical investigations by DW's consultants, HLA (1989) and Moffatt & Nichol (1988).

The geotechnical studies included field investigations, monitoring, modeling, and levee stability analyses for the DW project islands. Potential effects on levee stability and the flood risk that could exist during project construction or operation were identified. HLA assisted DW in development of project design and operation measures that would reduce or eliminate those potential effects. DW incorporated these measures into design of the DW project alternatives. Therefore, the DW project includes measures that avoid or reduce significant impacts relative to flood control. Appendix D1 is an annotated bibliography of the geotechnical studies performed for this project.

The impact analysis for flood control impacts is based on the preliminary levee design described below. The levee stability analysis assumes the maximum levee cross section described below. Variation from the preliminary design may require supplemental levee stability analysis, and if results of the new analysis differ significantly from the existing results, supplemental environmental review may be required prior to final levee design approval.

There is a potential of some level of continuing subsidence on the DW project islands, even with the cessation of farming activities. As a result, the water storage capacity of the reservoir islands could increase in future years. The rate of subsidence, however, would be substantially less than under existing conditions. Reduced rates of subsidence and increased water storage capacity on the reservoir islands would not be expected to substantially increase or decrease levee stability analyzed in this chapter.

Criteria for Determining Impact Significance

An alternative is considered to have a significant impact on flood control if it would:

- decrease levee stability on the DW project islands during project construction,
- substantially decrease regional supplies of levee material,
- decrease long-term levee stability on the DW project islands below long-term stability under existing conditions, or
- increase risk of cumulative levee failure and flooding in the project vicinity.

An alternative is considered to have a beneficial impact on flood control if it would increase long-term levee stability on the DW project islands or reduce the cumulative risk of levee failure in the project vicinity.

IMPACTS AND MITIGATION MEASURES OF ALTERNATIVE 1

Alternative 1 involves storage of water on Bacon Island and Webb Tract (reservoir islands) and management of Bouldin Island and Holland Tract (habitat islands) primarily for wetlands and wildlife habitat. The reservoir islands would be managed primarily for water storage, with wildlife habitat and recreation constituting secondary uses. The impacts of Alternative 1 on flood control in the project area are described below. Impacts on flood control under Alternative 1 are considered either less than significant or beneficial because the project includes measures that avoid potential impacts or reduce them to a less-than-significant level.

Flood Control Features

Bacon Island and Webb Tract

The exterior levees of the DW reservoir islands, Bacon Island and Webb Tract, would be improved to bear the stresses and erosion potential of interior island water storage and drawdown. Water would be stored on the islands to a maximum elevation of 6 feet above sea level. This storage elevation is subject to a number of constraints, including, but not limited to, water availability, seepage monitoring, and DSOD regulations. The DW project's design, construction, monitoring, and maintenance measures to address flood control are detailed below.

Levee Design. Under Alternative 1, the exterior levees of the reservoir islands would be improved. A typical improved levee would have a 2:1 exterior (waterside) slope, a crest about 22 feet wide (including the thickness of erosion protection on the interior slope) at an elevation of about +9 feet, a 3:1 or steeper initial interior

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slope down to an elevation near -3 feet, and wide toe berms to buttress the levee. Alternatively, the interior slope may be inclined at about 5:1 and be without toe berms. Figure 3D-2 shows examples of potential initial levee improvements on levees with a 3:1 existing interior slope. The initial levee crest would be constructed approximately 8 feet wider than the long-term planned width (22 feet) to accommodate settlement and to allow for future levee raising. (HLA 1993.) The new slopes would meet or exceed criteria for Delta levees outlined in DWR Bulletin 192-82.

During final design, the range of existing conditions, including various existing slope inclinations and thickness of peat, would be checked. Each levee section with a different soil condition or levee geometry may require a slightly different toe berm thickness and slope. During final design, consideration will be given to steepening the upper portion of the interior slopes to inclinations of between 2:1 and 2.5:1. A slightly steeper slope may reduce the amount of new fill required and limit both settlement and the potential for cracking.

Erosion Protection in Levee Design. The interior slopes of perimeter levees would be protected from erosion by conventional rock revetment similar to existing exterior slopes or other conventional systems, such as soil cement or a high-density polyethylene liner. The erosion protection would be sized to withstand design storms with a 50-year return period (Moffatt & Nichol 1988). There exists only a 2% chance of a 50-year severe wind event occurring in any year.

Moffatt & Nichol Engineers, in its September 1988 report to DW, gave a preliminary assessment of the effect of winds and waves on levees. For final levee design, Moffatt & Nichol will evaluate the expected waves along each section of the interior levees of the reservoir islands, considering fetch, angle of incidence, wind speed and duration, and depth of reservoir. Riprap or other suitable erosion protection measures will be sized for each section of interior levee slope based on these studies. In areas where final design studies indicate that wave splash and runup could potentially erode the levee crest if it is unprotected, the levee crest would be hardened or the erosion-protection facing would be extended up as a splash berm. Frequent monitoring of levee conditions conducted during and after the construction phase of the DW project is described below.

Project Features to Control Seepage. Interceptor wells would be installed in the exterior levees of the reservoir islands in those locations where substantial seepage to adjacent islands is predicted to occur (Figure 3D-3). The system would not be installed along non-critical sections of levee, such as the south side of Webb Tract bordering Franks Tract. The interceptor wells would be installed prior to diversions of water to the islands and filling of the reservoirs. As the reservoirs are filled, water would be pumped from the interceptor wells into the reservoirs. The interceptor wells would be pumped sufficiently to maintain the hydraulic heads at distances of 500-1,000 feet from the project island perimeters (i.e., beneath levees of adjacent islands) within existing conditions as determined by the results of background seepage monitoring described below.

Because of the potential for increased seepage to adjacent islands, DW has undertaken an extensive program to document existing locations and amounts of seepage. DW, working with the Central Delta Water Agency, formed a Seepage Review Committee representing reclamation districts and their district engineers on islands surrounding the DW project islands. Committee members reviewed their records on historical seepage problem areas to suggest monitoring locations.

Identified purposes of the Seepage Review Committee are to:

- provide a line of communication from DW to reclamation districts on adjacent islands and the Central Delta Water Agency through district engineers;
- inform the reclamation district engineers about significant technical issues that could affect the adjacent islands; and
- review and provide comments on DW's proposed plan and findings related to seepage issues to DW, reclamation districts, and the Central Delta Water Agency.

HLA, under contract to DW, designed and implemented a groundwater monitoring program to document preproject seepage patterns. By January 1992, 34 piezometers had been installed on 17 islands in the Delta (HLA 1992b). Currently, Hultgren Geotechnical Engineers is continuing to monitor 30 piezometers. Two monitoring wells on Webb Tract have been damaged beyond use, and two on McDonald Island are no longer monitored because they are influenced by a relief well demonstration project (described below) and are not believed representative of background conditions. Piezometers have been installed vertically through levee crowns at boring depths ranging from 36 feet below ground surface to approximately 135 feet below ground surface. Water levels are measured weekly to monitor hydraulic head in the sand aquifer. To supplement weekly manual measurements, automated data acquisition devices have been used continuously for 1-2 weeks in individual piezometers to record piezometric conditions as affected by tides and flood stages (HLA 1992b).

Groundwater monitoring has shown that tidal fluctuations in nearby Delta channels affect groundwater levels in baseline piezometers. Daily groundwater fluctuations in individual piezometers range from 0.5 foot to 3 feet (HLA 1992b).

Seepage Monitoring Program. A seepage monitoring program would be implemented to provide early detection of seepage problems caused by the project. Seepage monitoring would use the piezometer readings on islands adjacent to the reservoir islands, infrared aerial photography, weir monitoring, visual inspection, and other methods as appropriate. The seepage monitoring program would quantify and document seepage impacts as the basis for appropriate mitigation and compensation measures. Diversions of water onto the DW project islands would continue only if seepage to adjacent and neighboring islands does not increase beyond existing conditions or if increases can be effectively mitigated.

Piezometer Monitoring. To monitor seepage caused by project operations, daily mean water levels for individual piezometers and groups of three or more piezometers on islands adjacent to DW project islands would be compared with seepage performance standards described below. In addition to the 34 baseline piezometers, additional piezometers are proposed for locations 1 or more miles from perimeters of the DW project islands to determine variations in groundwater levels that are not attributable to the project (HLA 1992a).

Recommended locations of the proposed piezometers for Alternative 1 are shown in Figure 3D-3. A piezometer spacing of 1,500 feet to 2,000 feet on neighboring islands would closely monitor a continuous aquifer that underlies both a DW project island and a neighboring island. A minimum spacing of 1,000 feet would be used for critical seepage risk locations, and a maximum spacing of about 4,000 feet would be used in other areas. The spacing of monitoring piezometers will be influenced by the character of the underlying aquifer and the distance from the DW reservoir island.

Cooperation from neighboring reclamation districts and landowners would be needed for DW to install monitoring piezometers and periodically access them to download data from the devices. If, for some reason, an adjacent reclamation district or landowner would not allow piezometers to be placed over a long stretch of levee on their property, DW would place several piezometers on the DW reservoir island levees to monitor groundwater levels. Based on that information, DW would maintain the average groundwater level beneath the reservoir levee near historical levels.

Pressure transducers (instruments that detect fluid pressure and produce electrical signals related to the pressure) connected to electronic data loggers (to record the electronic signals) will be installed in each piezometer at least 1 year before the first project filling. The data loggers will be programmed to measure groundwater levels at least once per hour, and the readings will be averaged to compute a daily mean for each piezometer (HLA 1992a). Water level measurements taken concurrently in sloughs and rivers near the DW project islands also will be recorded.

Seepage Performance Standards. HLA, under contract to DW, has developed the following recommended performance standards to be used during filling and water storage periods to determine net increases in seepage caused by the DW project (HLA 1992a). The recommended seepage performance standards have been approved by the Seepage Review Committee. The seepage performance standard for individual piezometers is 1 foot above two standard deviations of the previous year's background groundwater data for that location; the standard for a group of three or more piezometers is 0.25 foot above two standard deviations of the previous year's data for that group. These standards would be evaluated by comparison with data collected from background seepage monitoring activities. Using this comparison, net seepage increases caused by the project could be detected within approximately 1 week (Hultgren pers. comm.).

Hypothetical patterns of seepage relative to performance standards for individual piezometers are presented graphically in Figure 3D-4. This figure illustrates three scenarios: no seepage increase (Case I), a seepage increase that is not attributable to the project (Case II), and a seepage increase that is caused by the project (Case III). Mean water levels in individual piezometers surpass the seepage performance standard in Case II; however, mean water levels in background piezometers show a corresponding increase, indicating a regional seepage increase not caused by the project (Figure 3D-4). The seepage increase in individual piezometers in Case III is attributable to the project because background piezometers do not show a corresponding increase (Figure 3D-4).

Final seepage performance standards will be set by SWRCB in consultation with the local reclamation districts governing adjacent islands, the technical review group described below, and DWR.

Evaluation of Monitoring Information. DW is working toward the continuation of a technical review group, similar to the Seepage Review Committee, to work with DW and its engineers to jointly evaluate any seepage increases caused by the project and cooperatively review appropriate corrective actions. During diversions, DW will submit biweekly reports describing the results of seepage monitoring to the technical review group, SWRCB, and DWR. If seepage exceeds performance standards, additional diversions of water would be halted, the technical review team would be informed, and remedial actions described below would be implemented. The committee would be informed and DW would implement one or more of the seepage control measures described below. Water diversions would not be restored until seepage monitoring indicated that seepage levels are not exceeding the performance standards. DW will also submit quarterly seepage reports summarizing the results of ongoing seepage monitoring.

Remedial Measures to Control Seepage. If seepage monitoring detects seepage caused by the project that exceeds the seepage performance standards, DW would undertake appropriate measures to reduce the seepage to preproject levels. These measures may consist of installing additional interceptor wells or other available measures described below.

One potential method for controlling seepage is implementation of a relief well program. A relief well is a well that drains a pervious soil layer to relieve seepage. A relief well program for Alternative 1 would consist of relief wells installed at regular spacings near the toes of existing levees on neighboring islands. Discharge elevations for the relief well system would be set to maintain water levels within historical levels to control subsidence rates. (HLA 1992a.)

The effectiveness of relief wells in controlling seepage was tested in the McDonald Island drawdown demonstration study, conducted by HLA under contract to DW (HLA 1990a). This investigation sought to demonstrate that groundwater head in a sand aquifer can be lowered using a groundwater relief well system and that such a system is a viable option for controlling seepage caused or increased by the proposed project. Results from the McDonald Island drawdown demonstration indicate that dewatering was effective in controlling essentially all seepage through the sand aquifer into the island and that a gravity flow relief system can control hydraulic head in the sand aquifer within a desired range by adjusting the discharge head level (HLA 1990a, b).

Relief wells would provide neighboring reclamation districts and landowners with benefits unrelated to the DW project. In addition to providing valuable reclamation capabilities on neighboring islands, relief wells can reduce the risk of levee instability as subsidence continues (HLA 1992a).

The effect that increased seepage may have on levee stability can also be offset through construction of toe berms with an internal drainage system on neighboring islands. Berm construction would depend on the agreement of the affected landowner and the reclamation district. Other measures may be more feasible where an agreement cannot be reached.

Other technically feasible seepage control measures include lowering the design pool elevation on the DW reservoir islands, developing wetland easements adjacent to levees on neighboring islands, purchasing farmlands affected by increased seepage, constructing a combination of seep and interior ditches and increasing pumping rates, installing clay blankets, and installing impervious cutoff walls through project island levees.

Siphon and Pump Station Erosion Control Measures. Facilities needed for the proposed water storage operations include intake siphons to divert water into the island interiors and pump stations to discharge the stored water from the islands. A new intake siphon complex and a new discharge pumping station would be constructed on the reservoir islands. (See locations in Chapter 2, Figures 2-2, 2-3, 2-7, and 2-8).

Because flow velocities could cause erosion at the interior toes of the newly reconstructed levees, expansion chambers are proposed for the siphon outlets and pump outlets (see siphon and pump designs in Appendix 2, Figures 2-2 and 2-5). These chambers would dissipate exit flow energies, decrease the exit velocities onto the island interiors, and prevent erosion to the interior levee toes.

The outlets from the proposed pump stations would discharge underwater on the channel side of the levees. The discharge velocities from the pump outlets would not exceed 5 feet per second when water is entering the Delta channels. Exit velocities would be reduced to this level by an expansion chamber fitted to the end of each discharge pipe. Additionally, rock riprap would be placed around the outlets where necessary to protect the embankments and dissipate energy. Velocities at the intake ends of the siphons would not cause erosion to the exterior channel sides of the levee embankments.

Construction Techniques. Placing levee construction materials on soft or poorly consolidated foundation soils can lead to rapid compression, slumping, and ground heave. To control these problems during construction, the toe berm fill will be started prior to fill being placed on the slopes or levee crest. After the toe berm has been installed, the slope and crest fills may be completed. The first fill placement would be no more than 5 feet thick on peat or clay substrates and no greater than 8 feet thick on sand substrate. These placement limits would allow pore pressures in foundation materials to dissipate and would permit monitoring of the existing levees with piezometers as construction proceeds (HLA 1989).

Peat foundation materials are expected to consolidate and pore pressures are expected to dissipate quickly after the first placement of fill (HLA 1989). The fill on the crest would be allowed to remain in place as long as possible prior to placement of the road surface; this will allow some settlement and minor grading to occur prior to completion of the levee road.

The second placement could be possible within a few months of the first. As the peat foundation material consolidates, permeability and rates of pore pressure dissipation would decline, and the interval between fill placements may increase. On clay or clayey peat materials, pore pressure would dissipate more slowly, and many months may be needed between fill placements (HLA 1989).

DW constructed a levee test section (a section of levee built to determine its stability characteristics) on Bouldin Island away from existing levees. The test section was brought to failure so that strength and behavior of foundation materials could be evaluated. The test section was constructed using conventional construction equipment (i.e., scrapers). Fill was placed until failure occurred, while measures of pore pressure, shear strength, and settlement were made. Strength of foundation materials was determined through back-calculation of the stresses when failure occurs and then evaluation of lateral deformation, cracking, and settlement. Results from the test section will be used during the final design phase for the DW project to determine safe rates of levee construction. Results of the test on Bouldin Island are described in the Wilkerson Dam report (HLA 1992b).

Construction Monitoring. DW engineers would monitor rates of settlement, consolidation, and strength gain during the levee reconstruction process. Piezometers and other equipment used to determine settlement (e.g., settlement plates and slope inclinometers) would be installed prior to construction near existing levees where they are unlikely to be damaged by construction activity. If monitoring detects levee stability problems, construction would be halted until the problem is corrected or compensated for through modification of designs or procedures.

Sources of Levee Materials. Materials needed to improve the existing levees would be obtained primarily from sand deposits within the interiors of the islands. Some peat may also be mixed with sand dredged for reconstructing the levees. Analyses performed on 66 sand samples from the island interiors indicated that sands on all project islands are suitable for use as levee fill (HLA 1989).

Supplies of suitable sand deposits for levee construction exist on all the DW project islands (HLA 1989). Sand frequently lies beneath layers of soft peat approximately 10-15 feet deep, which must first be removed from the borrow areas. The borrow pits would generally be more than 400 feet inward from the top of a levee to avoid structural impacts on the levee and at least 2, 000 feet inward from the final toe of an improved levee where seepage restrictions are required.

It is anticipated that rock revetment would be quarried from either the Dutra-McNeer quarry or the Basalt quarry of Syar Industries. Both of these quarry operations are presently ongoing. Riprap material would be barged from the quarry to the construction site (see Chapter 3L, "Traffic"). Levee construction under Alternative 1 would require approximately 470,000 tons of rock for Bacon Island and 405,000 tons of rock for Webb Tract (Forkel pers. comm.).

Postconstruction Monitoring and Maintenance. Reconstructed exterior levees would be maintained for the life of the project. Maintenance activities for the reservoir island levees and their erosion protection would include the following measures.

- DW will conduct a weekly inspection of the levees to check for surface erosion, slumping, tension cracking, damaged erosion protection, seepage, and encroaching vegetation. Results of weekly monitoring inspections would be submitted to the governing local reclamation district and DWR for review and to SWRCB for permit compliance.
- If weekly inspections indicate erosion, cracking, or seepage problems, DW will implement corrective actions, including, but not limited to, placement of fill material; placement or installation of erosion protection material; reshaping

or grading of fill material; herbicide application; selective burning; and/or installation of relief wells, toe berms on adjacent islands, or other seepage control measures described below.

- Tall grasses, brush, and/or trees will be kept cleared from the levee crest, slope, and stability berm.

- Areas of erosion will be repaired through replenishment the protective cover as needed.

- The road surface will be regraded and/or patched as required for all-weather accessibility.

- Levee profile surveys will be conducted by DW annually for the first 5 years of operation and triannually thereafter. Results of levee profile surveys will be submitted to DWR, SWRCB, and the Corps for review.

- The levee crest will be raised by the addition of fill to maintain the crest at or above DWR Bulletin 192-82 criteria, additional erosion protection will be placed to protect the added fill, and the all-weather road surface will be reestablished after the fill is placed.

Wave Erosion Protection, Monitoring, and Maintenance Program. A weekly visual inspection of levees would be conducted by DW to ensure that erosion protection materials are not eroded beyond 50-year storm design criteria. Results of visual inspections would be included in DW's quarterly report to the local reclamation districts and DWR. If visual monitoring indicates that erosion is occurring more rapidly than anticipated during design analysis, corrective action will be taken immediately. Corrective actions include, but are not limited to, installing wave protection barriers, increasing erosion protection placement, and/or lowering reservoir water levels (HLA 1992c). Appropriate corrective action to ensure protection of the levee crest will be determined in the field based on conditions encountered.

Bouldin Island and Holland Tract

Under Alternative 1, Bouldin Island and most of Holland Tract (3,014 acres) would be devoted to wildlife habitat. On the habitat islands, the existing levee system would be improved to meet state-recommended standards for Delta levees identified in DWR Bulletin 192-82. The interior slope faces and toe berms of the perimeter levees would be planted with grass to resist erosion from rainfall and would be maintained in a manner similar to current practices. Levee tops would be modified to accommodate construction and operation of recreation facilities. The recreation facilities would be constructed on a raised pile foundation interior of the center line of the levees and would not require levee improvements beyond those currently required. Routine maintenance activities on perimeter levees would not differ from current practices and would include, but are not limited to, placement of fill material and gravel, reshaping of fill material, grading, discing, mowing, selective burning, rodent control, and installation of rock revetment.

Changes in Flood Control Conditions

Bacon Island and Webb Tract

Settlement during Construction. DW's proposed material placement procedures, use of the levee test section, and construction monitoring program would contribute to adequate levee reliability. Levee stability analyses by HLA (1989) calculated safety factors during construction of the proposed DW levee improvements. Adequate safety factors were calculated if lifts of fill did not exceed 5 feet until sufficient time was allowed for consolidation and strength gain in foundation materials. As proposed, levee reconstruction on the DW project islands would be staged over several years to allow time for consolidation of foundation materials. Therefore, reconstruction of reservoir island levees would not affect levee stability during construction.

Settlement and Long-Term Levee Stability. Reconstruction of levees by DW would cause compression of substrates and settlement of the new levees. Extent of settlement would vary both with thickness of fill and with peat thickness below the fill.

HLA estimated depths of settlement resulting from fill placement in an area directly underlain by 20 feet of peat. If fill is added up to an elevation of 15 feet above the initial ground surface and then is continuously placed as the ground settles (keeping the surface of the fill 15 feet above the original ground elevation), 15 feet of settlement is predicted. This condition will result in the thicknesses of the underlying peat compressing from 20 feet to 5 feet. The total thickness of the fill will be 30 feet: the initial 15 feet of fill thickness plus another 15 feet placed over time to maintain the top elevation of the fill as the fill mass settles. (HLA 1989, Hultgren pers. comm.) Approximately one-half of the estimated settlement would occur within 2-3 months after fill placement, one-quarter of the settlement would occur within 3 years, and the remaining one-quarter would occur over the next 30-50 years (HLA 1989). Figure 3D-5 shows examples of settlement of initial fill (the initial fill profile is shown in Figure 3D-2) and the additional fill required to raise the levee crest.

Differential settlement can create tensions in the soil, resulting in cracks parallel to the existing levee. Cracking may also occur where the reconstructed levee joins with an existing levee, where levees cross subsurface peat or clay-filled channels, or where new interior levees abut existing levees. These factors differ for each site on the DW project islands and would be investigated in detail before construction begins and before settlement monitoring locations are chosen. Monitoring and maintenance on levees as described above would quickly detect any cracking problems and replenish fill material where cracking occurs.

Differential settlement caused by levee reconstruction may also affect existing levees. Any cracking of the existing levees caused by levee reconstruction would be mitigated by placement of sand against the inside of the existing levees. Movement of soil from levee cracks or water seeping through cracks would be slowed by the fill and would be monitored for subsequent maintenance needs, including placement of additional fill or implementation of erosion control measures.

Stability analyses by HLA (1993) calculated that under Alternative 1, levee reconstruction would increase the factor of safety for levee stability 14%-28% (depending on levee slope design) over existing conditions. The inward (toward island interior) factor of safety would increase immediately after construction and continue to increase as the peat foundations consolidate and gain strength under the weight of new fill. The outward (toward Delta channels) factor of safety would decrease about 10% when the reservoir is full, but the margin of safety would still be greater than that computed for existing conditions. There is a slight decrease in the factor of safety calculated for the exterior levee slope when the reservoir is full because the island would be filled to 6 feet above the channel water levels. However, the consequence of a levee breach would be much less when the island reservoir is full or partially full than when the island is empty, as it is now, because improved DW project levees are more likely to minimize the size of a levee breach if one occurs and because the hydraulic head between the channel water level and reservoir water level (approximately 6 feet) would be less than the existing head between the channel water level and island interiors (16-18 feet) (HLA 1993). Therefore, the existing conditions pose a higher risk to levee stability than the levee configurations under Alternative 1.

In conclusion, levee settlement or instability is not predicted to adversely affect levee reliability because the proposed initial placement of fill would be staged over several years until sufficient levee heights are reached, and because the proposed annual maintenance program would replenish the levee slopes with new fill to compensate for settlement. Any diminishing of levee height or cracking would be corrected annually. Levee stability analysis indicates that implementing Alternative 1 would improve levee stability and safety factors on the reservoir islands.

Seepage. Dredging of material for improvements to the levees would cause exposure of subsurface sand deposits on the reservoir island interiors. Under proposed water storage operations, such exposed areas would be subject to up to 24 feet of hydraulic head. Such exposure of sand deposits has the potential to permit seepage beneath the DW project levees to adjacent islands.

An engineering model (SEEP) was used by HLA (1989) to analyze seepage potential of water storage on Webb Tract across Fishermans Cut to Bradford Island. This location was identified as being particularly sensitive because of the short seepage distance across Fishermans Cut. Fixed hydraulic levels were tested under a range of permeability conditions of soil materials to determine the effect of flooding and exposed borrow pit excavation. The model indicated that both hydraulic heads and seepage levels in sands on Bradford Island would increase as a result of flooding of Webb Tract. This analysis assumed a water storage elevation of +4 feet based on a previous project description; however, the currently proposed water storage level of +6 feet would not alter the results of the study (Tillis pers. comm.). Seepage levels would still increase on Bradford Island as a result of the proposed +6 feet water storage under Alternative 1.

Alternative 1 incorporates an interceptor well system to control seepage to adjacent islands and a seepage monitoring system described above under "Flood Control Features". The monitoring system would verify that seepage on adjacent islands is controlled at or below existing conditions and would detect the need for additional seepage control measures to be implemented. A measurable seepage performance standard based on background monitoring data to determine existing seepage conditions would be used to trigger the implementation of additional seepage control measures. Therefore, Alternative 1 would control seepage at existing conditions or would improve seepage conditions.

Wind and Wave Erosion. The proposed flooding of reservoir islands could result in wind and wave erosion of the interior levee slopes because of the long wind fetch across the islands and the water depths during water storage. Prolonged removal of levee slope material by wave erosion of the interior levee slopes could eventually affect levee reliability. Interior slopes of perimeter levees would be constructed with erosion control material (rock revetment or riprap) similar to that used on exterior levee slopes.

The erosion control measures, erosion monitoring program, and levee maintenance measures described above under "Flood Control Features" would be implemented as part of Alternative 1. Perimeter levees would be inspected weekly, and any potential erosion problems would be reported and would trigger maintenance measures, which could include placement of additional rock revetment, replenishment of fill, or lowering of pool elevations.

Slope Slippage during Drawdown of Stored Water. If levee soils remain saturated while external water pressure is removed, as could occur during drawdown of the reservoirs, the levee slope could become unstable. The rate of drawdown would be slow enough to allow substantial drainage of the relatively permeable slope materials (Tillis and Hultgren pers. comms.). Drawdown is considered rapid if a water level is lowered faster than the soil's ability to drain; in this case, the weight of saturated soil exceeds the stabilizing effect of water pressure against the levee embankment, which can result in slope slippage. Based on a discharge rate of 4,000 cfs, the reservoir drawdown rate could be as fast as 18 inches per day at the higher reservoir stages (Hultgren pers. comm.). This drawdown rate would not be considered rapid from this perspective (Tillis and Hultgren pers. comms.). Therefore, the possibility of slope failure during drawdown would be minimal under Alternative 1. Any interior slope slippage following drawdown would be corrected during maintenance replenishment of fill material. DW's proposed drawdown schedule would not threaten levee stability during drawdown of stored water.

Erosion at Siphon and Pump Stations. High-velocity water releases at siphon and pump stations could erode levee materials. Operation of the proposed siphon and pump stations would not cause substantial levee toe erosion on interior or exterior levee slopes because the stations will be equipped with expansion chambers, which reduce flow velocities through dissipation, and rock revetment will be placed in the interiors of the islands to minimize erosion potential of the levee toe surfaces at the siphon and pump stations.

Project-Induced Seismic Activity. Although deep well water injection and reservoir flooding have been associated with triggering earthquakes, there is no evidence to support that theory in the Delta area. The presence of the Sacramento and San Joaquin Rivers and the existing flooding of Franks Tract have not increased seismic activity in the region. Creating reservoirs on Bacon Island and Webb Tract would not be likely to increase seismic risk in the Delta region.

Liquefaction and Levee Movement during Seismic Activity. The two predominant risks to Delta levees during earthquakes are liquefaction (loss of soil cohesion when subject to shaking) of poorly consolidated sands beneath levees and damage caused by movement of levees under seismic acceleration. The materials used for levee reconstruction could be subject to liquefaction resulting from seismic acceleration; however, both these risks would be reduced by the proposed buttressing of the DW project island levees. Soil borings indicate that some of the sand layers beneath the peat on the DW project islands have a potential for liquefaction, but levee reconstruction and island flooding would probably not increase nor decrease the potential for liquefaction and levee failure (HLA 1989). Because the proposed levees are broader than the existing levees and broader levees distribute seismic effects over a larger area, total levee failure caused by substrate liquefaction would be less likely with the proposed levees than with the existing levees. The buttressed project levees would have much greater mass than existing levees and may be less vulnerable to failure from seismic acceleration. The level of potential risk of levee movement under seismic shaking may be somewhat lower than many existing levels because levee stability would increase under Alternative 1.

An earthquake powerful enough to cause failure of project levees would likely destroy many of the existing weaker levees on neighboring islands. Even if they failed under seismic activity, project levees would be likely to offer some protection against wind-generated wave erosion. DW project levees would probably be more intact and more easily repaired following a breach than would other Delta levees. Thus, Alternative 1 would likely produce an overall benefit in levee protection under seismic activity.

Levee Fill Availability. Sources of suitable levee reconstruction material are located on the DW project islands or in existing quarries in the region. Borrow quantities for Alternative 1 are shown in Table 3D-4. It is unlikely that levee construction and improvement under Alternative 1 would deplete regional supplies of levee materials.

Bouldin Island and Holland Tract

Habitat management on Bouldin Island and Holland Tract would not decrease levee stability or require substantial amounts of levee material during project construction. A habitat type defined as "borrow pond" is included in the HMP (Appendix G3, "Habitat Management Plan for the Delta Wetlands Habitat Islands") and will provide a source of adequate borrow material for initial construction under the project. Borrow ponds would be managed similarly to lake habitat but may be deeper than the proposed lakes and would be occasionally disturbed to facilitate extraction of borrow for long-term maintenance of the project. Any future borrow excavation for levee maintenance outside these areas would be subject to review by the HMP oversight team, but overall, habitat management on these islands would not impair long-term levee maintenance activities.

Habitat management would slow the rate of subsidence on these islands relative to subsidence rates under existing agricultural use. Therefore, implementation of Alternative 1 would increase long-term levee stability on habitat islands by decreasing subsidence.

Summary of Project Impacts and Recommended Mitigation Measures

Impact D-1: Increase in Long-Term Levee Stability on Reservoir Islands. Implementation of Alternative 1 would increase levee stability on the reservoir islands. Levee stability analyses conducted by HLA (1989, 1993) indicate that improvements to perimeter levees (e.g., widening and fill placement) on reservoir islands would more than offset decreases in stability that could result from island flooding. Therefore, this impact is considered beneficial.

Mitigation. No mitigation is required.

Impact D-2: Potential for Seepage from Reservoir Islands to Adjacent Islands. Implementation of Alternative 1 could increase the potential for seepage beneath the DW island levees to adjacent islands during project operation. Dredging of material from the reservoir island interiors for improvements to perimeter levees could expose subsurface sand deposits, which could result in increased hydraulic heads between adjacent islands and the reservoir islands when they are filled. The proposed project seepage monitoring and control measures that are detailed above would control seepage at or below existing conditions. Therefore, this impact is considered less than significant.

This impact conclusion is based on three elements provided by DW and its geotechnical consultant, HLA, and described above under "Flood Control Features":

- a measurable seepage performance standard,
- a feasible monitoring program to determine whether the performance standard is met, and
- a feasible mitigation program that would be implemented if the performance standard is exceeded during project operations.

SWRCB will develop terms and conditions attached to any water right permit granted to DW for Alternative 1. Conditions relevant to the seepage issue will ensure that seepage control measures and monitoring are continued through the life of the project and that mitigation measures to correct any seepage problems attributable to project operations are implemented when monitoring indicates a need for such measures. DW could divert water and operate the project only if these conditions were satisfied.

Mitigation. No additional mitigation is required.

Impact D-3: Potential for Wind and Wave Erosion on Reservoir Islands. Implementation of Alternative 1 could result in wind and wave erosion of the interior levee slopes of perimeter levees on reservoir islands because of the long wind fetch across the islands and the water depths during water storage. Interior slopes of the levees would be constructed with rock revetment to prevent erosion of the interior levee slopes. The erosion control design measures, erosion monitoring program, and levee maintenance measures described above would be implemented under Alternative 1. Therefore, this impact is considered less than significant.

Mitigation. No additional mitigation is required.

Impact D-4: Potential for Erosion of Levee Toe Berms at Pump Stations and Siphon Stations on Reservoir Islands. Implementation of Alternative 1 would not cause substantial levee toe erosion at siphon and pump stations on interior or exterior levee slopes. Pump and siphon units will be equipped with expansion chambers, which reduce flow through dissipation, and routine inspection and maintenance of the levees would identify any erosion problems and include implementing erosion control measures as needed. Therefore, this impact is considered less than significant.

Mitigation. No mitigation is required.

Impact D-5: Decrease in Potential for Levee Failure on DW Project Islands during Seismic Activity. Implementation of Alternative 1 would require strengthening and reconstructing perimeter levees on reservoir islands and improving perimeter levees on habitat islands. Existing levees on reservoir islands would be buttressed and broadened, and levees on habitat islands would be improved to meet DWR's recommended standards for Delta levees. These improvements would increase long-term levee stability; the overall risk of levee failure caused by earthquakes would be less than under existing conditions. Therefore, this impact is considered beneficial.

Mitigation. No mitigation is required.

Impact D-6: Increase in Long-Term Levee Stability on Habitat Islands. Implementation of Alternative 1 would slow the rate of subsidence on Bouldin Island and Holland Tract relative to subsidence rates under existing agricultural use. Decreased subsidence contributes to increased long-term levee stability on habitat islands. Therefore, this impact is considered beneficial.

Mitigation. No mitigation is required.

IMPACTS AND MITIGATION MEASURES OF ALTERNATIVE 2

Impacts and mitigation measures of Alternative 2 are the same as those of Alternative 1.

IMPACTS AND MITIGATION MEASURES OF ALTERNATIVE 3

Alternative 3 involves storage of water on Bacon Island, Webb Tract, Bouldin Island, and Holland Tract, with secondary uses for wildlife habitat and recreation. The portion of Bouldin Island north of SR 12 would be managed as a wildlife habitat area and would not be used for water storage. The impacts of Alternative 3 on flood control in the project area are described below. Impacts on flood control under Alternative 3 are considered less than significant or beneficial because the project includes measures that avoid impacts or reduce potential impacts to a less-than-significant level.

Flood Control Features

The exterior levees of the four DW project islands would be reconstructed as described for levee reconstruction on Webb Tract and Bacon Island under Alternative 1. The design, construction, monitoring, and maintenance measures for reservoir island perimeter levees for Alternative 3 would be as described for Alternative 1.

Alternative 3 would require interior levees to be constructed around several parcels not owned by DW: the two marina sites at the south edge of Holland Tract, and across Bouldin Island on the southern and northern sides of SR 12. The interior levee on the south side of SR 12 would be designed and constructed in accordance with standards of DWR's DSOD. Interior levee designs have been submitted to DSOD for review and approval (Hultgren pers. comm.). The levee on the southern side of SR 12 on Bouldin Island is described in Chapter 3E, "Utilities and Highways", and in Appendix E1, "Design and Construction of Wilkerson Dam South of SR 12 on Bouldin Island".

The methods of fill placement and staged construction for interior levees would be similar to those described for the exterior levees, except that fill would be compacted to DSOD standards. The DSOD levees would be protected from wind and wave erosion on the water side with a method of slope protection, potentially a high-density polyethylene surface or placement of riprap.

The DSOD levee on Bouldin Island may require a longer construction period than all other elements of the project. Borrow material from the island would be used for interior levee construction. An estimated 8,900,000 cubic yards of borrow material would be needed for the DSOD levee construction (Table 3D-5).

Changes in Flood Control Conditions

Bacon Island, Webb Tract, Bouldin Island, and Holland Tract

Settlement during Construction. Settlement impacts on the reservoir islands under Alternative 3 would be similar to those described above for reservoir islands under Alternative 1. Stability analysis (HLA 1989) indicates that levee reconstruction on the DW islands would allow time for consolidation of foundation materials and would not affect levee stability during construction.

Interior Levees. The toe of the proposed interior levee along the southern side of SR 12 across Bouldin Island would be set back from the highway to protect the roadbed from settlement problems caused by the new levee (HLA 1989). DWR's DSOD must approve the final design of this interior levee (see Chapter 3E and Appendix E1 for further detail regarding the proposed DSOD levee).

Given that DSOD must approve the design and construction of these interior levees, no increase in flooding hazard or decrease in public safety is expected to occur during project operation.

Settlement and Long-Term Levee Stability. Long-term levee stability impacts on Alternative 3 reservoir islands would be similar to those described for the two reservoir islands under Alternative 1. Levee stability analyses (HLA 1989, 1993) indicate that initial and final perimeter levee conditions would increase levee stability on the project islands.

Seepage. The seepage mitigation, monitoring, and control program under Alternative 3 would control seepage impacts at or below existing conditions as described for Alternative 1 but would be expanded to include Bouldin Island and Holland Tract.

Under Alternative 3, 142 more piezometers would be installed on neighboring islands than would be installed under Alternative 1. Figure 3D-6 shows the proposed interceptor well system and seepage monitoring system for Alternative 3.

Wind and Wave Erosion. The erosion control measures, erosion monitoring program, and levee maintenance measures described for Alternative 1 would be implemented as part of Alternative 3. Alternative 3 would require approximately 470,000 tons, 405,000 tons, 385,000 tons, and 400,000 tons of rock for levee improvements on Bacon Island, Webb Tract, Bouldin Island, and Holland Tract, respectively (Forkel pers. comm.). Potential erosion effects would be monitored weekly, and proposed maintenance measures would be implemented to maintain levees at conditions equal to or better than existing conditions.

Liquefaction and Levee Movement during Seismic Activity. As described for reservoir islands under Alternative 1, improved levees would decrease liquefaction effects of seismic shaking and may be less vulnerable to failure from seismic acceleration than existing levees.

Levee Fill Availability. As under Alternative 1, sources of suitable levee reconstruction material are adequate for Alternative 3 and are located on the DW project islands or in existing quarries in the region. Borrow quantities proposed for Alternative 3 are shown in Table 3D-5.

Summary of Project Impacts and Recommended Mitigation Measures

Impact D-7: Increase in Long-Term Levee Stability on Reservoir Islands. This impact is described above under Impact D-1. This impact is considered beneficial.

Mitigation. No mitigation is required.

Impact D-8: Potential for Seepage from Reservoir Islands to Adjacent Islands. This impact is described above under Impact D-2. This impact is considered less than significant.

Mitigation. No mitigation is required.

Impact D-9: Potential for Wind and Wave Erosion on Reservoir Islands. This impact is described above under Impact D-3. This impact is considered less than significant.

Mitigation. No mitigation is required.

Impact D-10: Potential for Erosion of Levee Toe Berms at Pump Stations and Siphon Stations on Reservoir Islands. This impact is described above under Impact D-4. This impact is considered less than significant.

Mitigation. No mitigation is required.

Impact D-11: Decrease in Potential for Levee Failure on DW Project Islands during Seismic Activity. This impact is described above under Impact D-5. This impact is considered beneficial.

Mitigation. No mitigation is required.

IMPACTS AND MITIGATION MEASURES OF THE NO-PROJECT ALTERNATIVE

The project applicant would not be required to implement mitigation measures if the No-Project Alternative were selected by the lead agencies. However, mitigation measures are presented for impacts of the No-Project Alternative to provide information to the reviewing agencies regarding the measures that would reduce impacts if the project applicant implemented a project that required no federal or state agency approvals. This information would allow the reviewing agencies to make a more realistic comparison of the DW project alternatives, including implementation of recommended mitigation measures, with the No-Project Alternative.

Flood Control Features

Levee maintenance and operation under the No-Project Alternative would be the same as existing routine maintenance procedures.

Changes in Flood Control Conditions

Bacon Island, Webb Tract, Bouldin Island, and Holland Tract

Settlement and Long-Term Levee Stability. Under the No-Project Alternative, which would consist of intensified agricultural operations on the project islands, the DW island interiors would subside an additional 6-10 feet over the next 40 years (HLA 1989). Levee heights would increase as the island interiors subside. Long-term stability analyses indicate that levee reliability would decrease below existing conditions under the No-Project Alternative.

Seepage. The loss of peat through subsidence and oxidation could lead to greater infiltration and increased seepage onto the island. Seepage under the No-Project Alternative would exceed existing conditions.

Wind and Wave Erosion. Wind and wave erosion under No-Project conditions would be similar to existing erosion. The No-Project Alternative would not increase erosion on the DW project island levees.

Liquefaction and Levee Movement during Seismic Activity. Because the No-Project Alternative would decrease levee stability compared with existing conditions, the risk of seismically induced levee failures would increase.

Summary of Project Impacts and Recommended Mitigation Measures

Decrease in Long-Term Levee Stability. Implementation of the No-Project Alternative would result in increased levee heights on the DW project islands as the island interiors subside. Long-term levee stability analyses indicate that levee reliability would decrease under the No-Project Alternative. Implementing the following measure would reduce this effect of the No-Project Alternative.

Buttress Perimeter Levees. The perimeter levees of the DW project islands could be substantially buttressed to increase levee stability under the No-Project Alternative. The need for improvements to those levees over time would be evaluated by the local reclamation districts.

Increase in Potential for Seepage onto Project Islands. Implementation of the No-Project Alternative would cause the loss of peat through subsidence and oxidation on DW project islands, which could lead to greater infiltration and increased seepage onto the DW project islands.

Increase in Potential for Levee Failure during Seismic Activity. Implementation of the No-Project Alternative would decrease long-term levee stability, which would increase the potential for seismically induced levee failures.

CUMULATIVE IMPACTS

Cumulative impacts are the result of the incremental impacts of the proposed action when added to other past, present, and reasonably foreseeable future actions. The following sections consider only those impacts that may contribute cumulatively to impacts on flood control on the Delta islands.

Cumulative Impacts, Including Impacts of Alternative 1

Cumulative Flood Hazard

Under DW's proposed levee reconstruction and maintenance program, the potential for levees to fail on the DW project islands would be lower than under existing conditions. Therefore, the cumulative flood hazard for adjacent islands when Webb Tract and Bacon Island are filled with stored water would not exceed present hazards. In fact, Alternative 1 would be likely to reduce cumulative flood hazard in the Delta by increasing levee safety on these islands.

Impact D-12: Decrease in Cumulative Flood Hazard in the Delta. Implementation of Alternative 1 would likely reduce the cumulative risk of flooding in the Delta. Under Alternative 1, levee safety on the DW islands would increase; therefore, the cumulative safety of levees in the Delta would increase. This impact is considered beneficial.

Mitigation. No mitigation is required.

Financing of the Levee System

Implementation of Alternative 1 would reduce the need for public financing of maintenance and repair work on the levee systems around the DW project islands. DW would continue to seek reimbursement for maintenance work on the channel sides of exterior levees. During the early 1980s, public financing of this work on the four islands exceeded $36 million, or about $5.5 million each year. Alternative 1 would have a substantial fiscal benefit at the state and federal levels. Savings would result from the project because the risk of levee failure would be reduced, the cost of project-specific maintenance and rehabilitation work on the levees above state or federal standards would be borne entirely by DW, and the cost of reclamation would be much lower than in the case of existing Delta levees because much of the routine levee maintenance would not fall within the state or federal cost-sharing programs.

Impact D-13: Decrease in the Need for Public Financing of Levee Maintenance and Repair on the DW Project Islands. Implementation of Alternative 1 would likely reduce the need for public financing of levee maintenance and repair on the DW project islands. Savings at the state and federal level would result from project implementation because the risk of levee failure would be reduced, so the cost of reclamation would be much lower than in the case of existing levees. This impact is considered beneficial.

Mitigation. No mitigation is required.

Cumulative Impacts, Including Impacts of Alternative 2

The cumulative impacts of this alternative would be the same as those described for Alternative 1.

Cumulative Impacts, Including Impacts of Alternative 3

Under the Alternative 3 levee reconstruction and maintenance program, the potential for levees to fail on the project islands would be lower than under existing conditions. Therefore, this alternative would likely reduce cumulative flood hazard in the Delta. Similar to Alternative 1, Alternative 3 would also reduce the need for public financing of maintenance and repair work on the levee systems around the DW islands.

Cumulative Impacts, Including Impacts of the No-Project Alternative

By decreasing levee reliability below existing conditions over time, the No-Project Alternative could increase the cumulative risk of levee failure in the Delta. The risk to levee stability on the DW project islands under the No-Project Alternative would be primarily a result of accelerated subsidence of the island bottoms caused by increased agricultural production over time. Repair work on the levees over time would be the responsibility of DW because the islands are surrounded by nonproject levees.

Increase in Cumulative Risk of Levee Failure in the Delta. By decreasing levee reliability below existing conditions over time, the No-Project Alternative could increase the risk of cumulative levee failure in the Delta. Implementing the following measure would reduce this cumulative effect.

Buttress Perimeter Levees. The perimeter levees of the DW project islands could be substantially buttressed to increase levee stability under the No-Project Alternative. The need for improvements to those levees over time would be evaluated by the local reclamation districts.

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Table 3D-1. Historic Flooding and Predicted Statistical Frequency of Levee Failures on the DW Project Islands

Island	Years of Levee Failure Since 1932	Predicted Failures per 100 Years		
		Under Existing Conditions	After 20 Years	After 40 Years
Bacon Island	None	5.63	7.25	8.77
Webb Tract	1950, 1980	8.81	9.29	9.29
Bouldin Island	None	18.25	18.25	18.25
Holland Tract	1980	4.17	5.68	7.89

Source: DWR 1982.

Table 3D-2. Predicted Future Subsidence on the DW Project Islands

Island	Subsidence since Reclamation (feet)	Estimated Maximum Thickness of Organic Soils (feet)	Estimated Future Rate of Subsidence (inches/year)	Predicted Additional Subsidence in Next 50 Years[a] (feet)	Predicted Island Bottom Elevation by 2032[b] (feet)
Bacon Island	18	18	3.0	13	-31
Webb Tract	18	33	3.0	13	-31
Bouldin Island	17	31	3.0	13	-30
Holland Tract	16	24	3.0	13	-29

[a] Base year is 1982; therefore, this table shows estimates of subsidence between 1982 and 2032.

[b] Predicted island bottom elevation is sum of "Subsidence since Reclamation" and "Predicted Additional Subsidence in Next 50 Years". Elevation is in relation to mean sea level.

Source: DWR 1982.

Table 3D-3. Expenditures for Emergency Levee Repairs (1980-1986) and Levee Maintenance (1981-1986) on the DW Project Islands ($1,000)

Island (Reclamation District No.)	Nonproject Levee Mileage	Emergency Expenditures (1980-1986)				Maintenance Expenditures (1981-1986)			Combined Expenditures		
		Federal[a]	State[b]	Local District	Total	State[c]	Local District	Total	Public	Local District	Total Expenditures
Bacon Island (2028)	14.3	467	259	74	800	354	482	836	1,080	556	1,636
Webb Tract (2026)	12.8	14,537	6,846	582	21,965	12	25	37	21,395	607	22,002
Bouldin Island (756)	18.0	2,350	2,103	288	4,741	118	221	339	4,571	509	5,080
Holland Tract (2025)	10.9	6,655	1,837	177	8,669	59	91	150	8,551	268	8,819
Total	56.0	24,009	11,045	1,121	36,175	543	819	1,362	35,597	1,940	37,537

[a] Federal emergency expenditures through the Federal Emergency Management Agency (FEMA).

[b] State emergency expenditures under the Natural Disaster Assistance Act (NDAA).

[c] State maintenance expenditures under the Delta Levee Maintenance Subventions Program.

Source: DWR 1993.

Table 3D-4. Assumed Borrow Site Requirements for Alternatives 1 and 2

	Borrow Quantity (cubic yards)	Borrow Site Configuration		
		Depth (feet)	Total Area (acres)	Average Size (acres)
Perimeter levees				
Bacon Island	330,000	5	41	10
Webb Tract	410,000	5	51	10
Bouldin Island	1,830,000	10	113	10
Holland Tract	250,000	5	31	10
Inner levees				
Bacon Island	160,000	5	20	10
Webb Tract	600,000	5	74	10
Bouldin Island	400,000	5	50	10
Holland Tract	200,000	5	25	10
Total levee borrow				
Bacon Island	490,000	5	61	10
Webb Tract	1,010,000	5	125	10
Bouldin Island	2,230,000	5 or 10	163	10
Holland Tract	450,000	5	56	10

Source: Forkel pers. comm.

Table 3D-5. Assumed Borrow Site Requirements for Alternative 3

	Borrow Quantity (cubic yards)	Borrow Site Configuration		
		Depth (feet)	Total Area (acres)	Average Size (acres)
Perimeter levees				
Bacon Island	330,000	5	41	10
Webb Tract	410,000	5	51	10
Bouldin Island	1,830,000	10	113	10
Holland Tract	250,000	5	31	10
Inner levees				
Bacon Island	160,000	5	20	10
Webb Tract	600,000	5	74	10
Bouldin Island	400,000	5	50	10
Holland Tract	200,000	5	25	10
DSOD levee borrow				
Bouldin Island	8,900,000	30	184	184
Total levee borrow				
Bacon Island	490,000	5	61	10
Webb Tract	1,010,000	5	125	10
Bouldin Island	11,130,000	5, 10, or 30	347	10
Holland Tract	450,000	5	56	10

Source: Forkel pers. comm.

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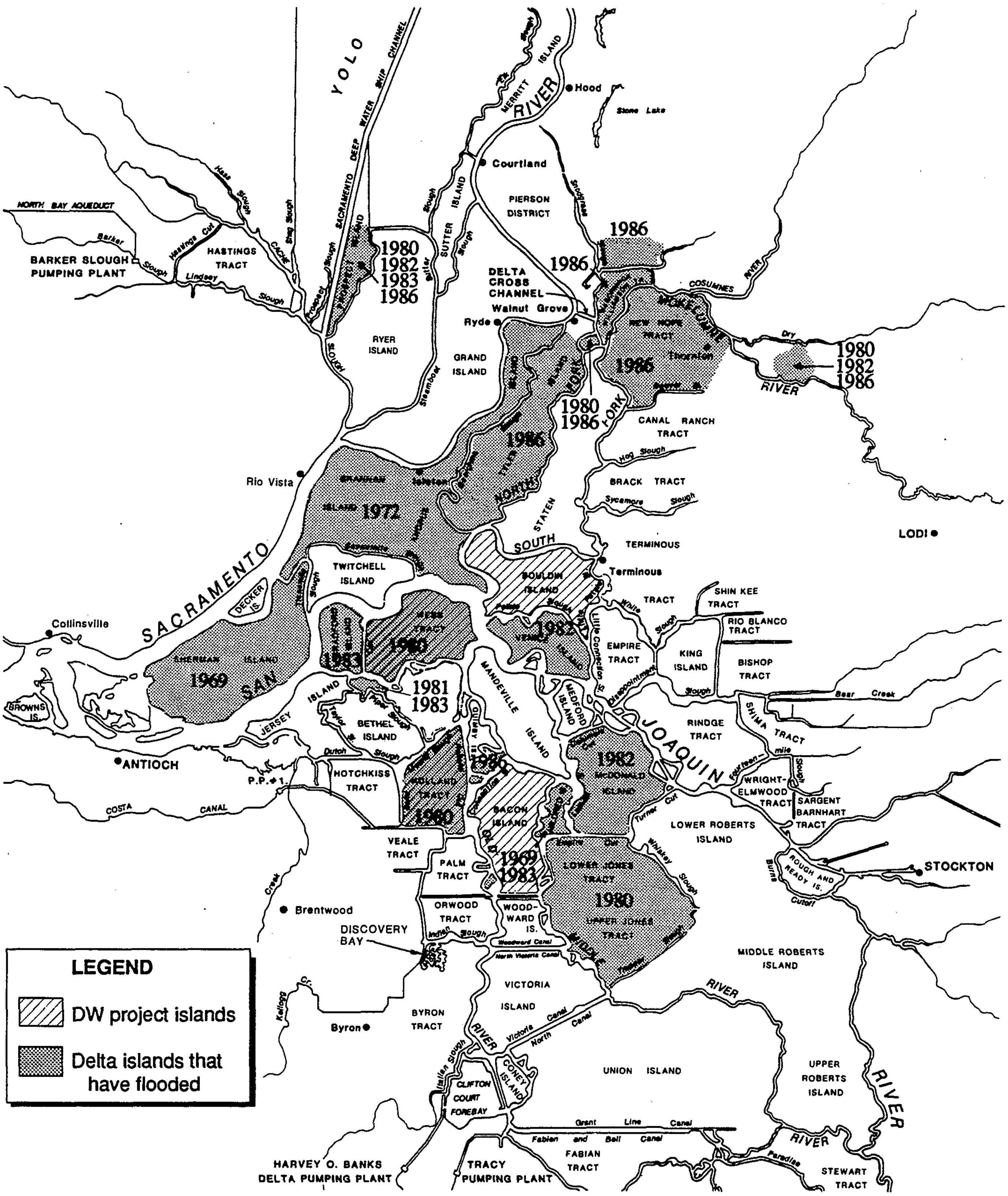
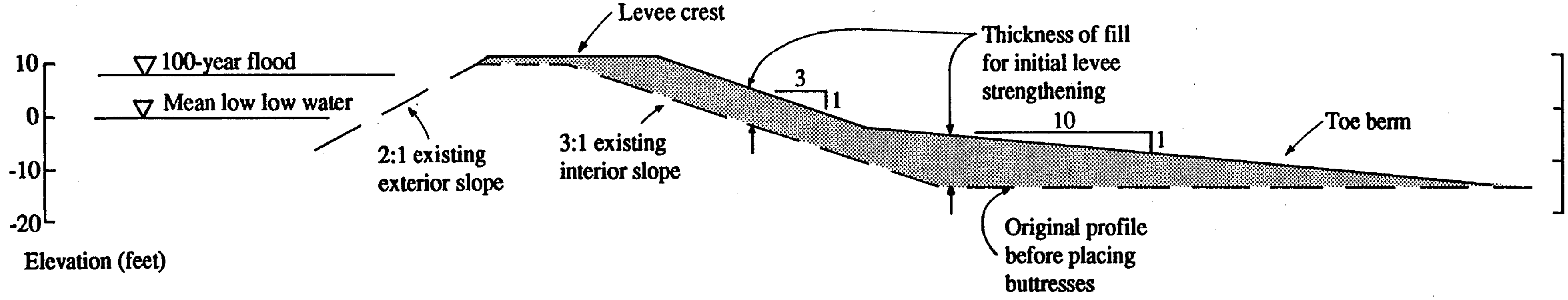


Source: California Department of Water Resources 1993.

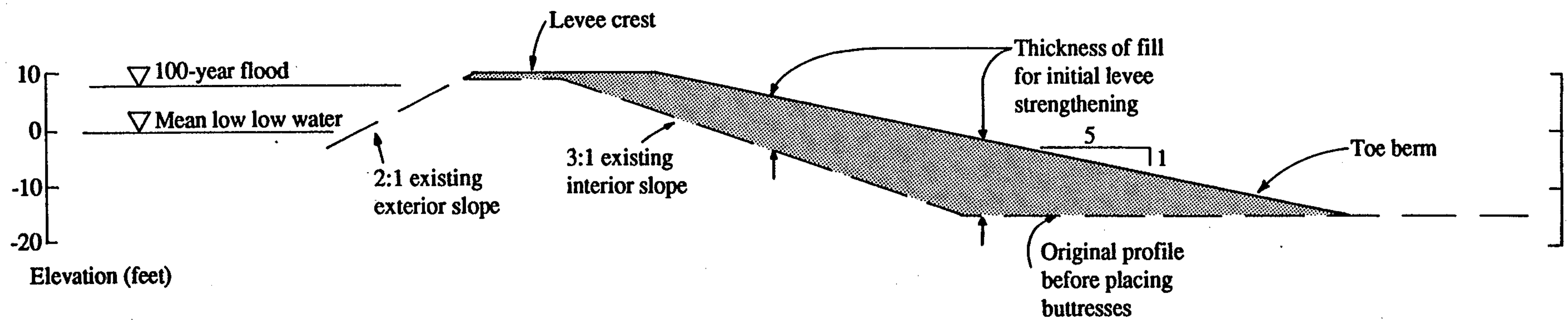
Figure 3D-1.
Recent Flooding on Delta Islands, 1967-1992

DELTA WETLANDS
PROJECT EIR/EIS
Prepared by: Jones & Stokes Associates

Example A: Broken-Slope Buttress



Example B: Constant-Slope Buttress



Source: Harding Lawson Associates 1993.

Figure 3D-2.
Examples of Initial Levee Strengthening on Reservoir Islands

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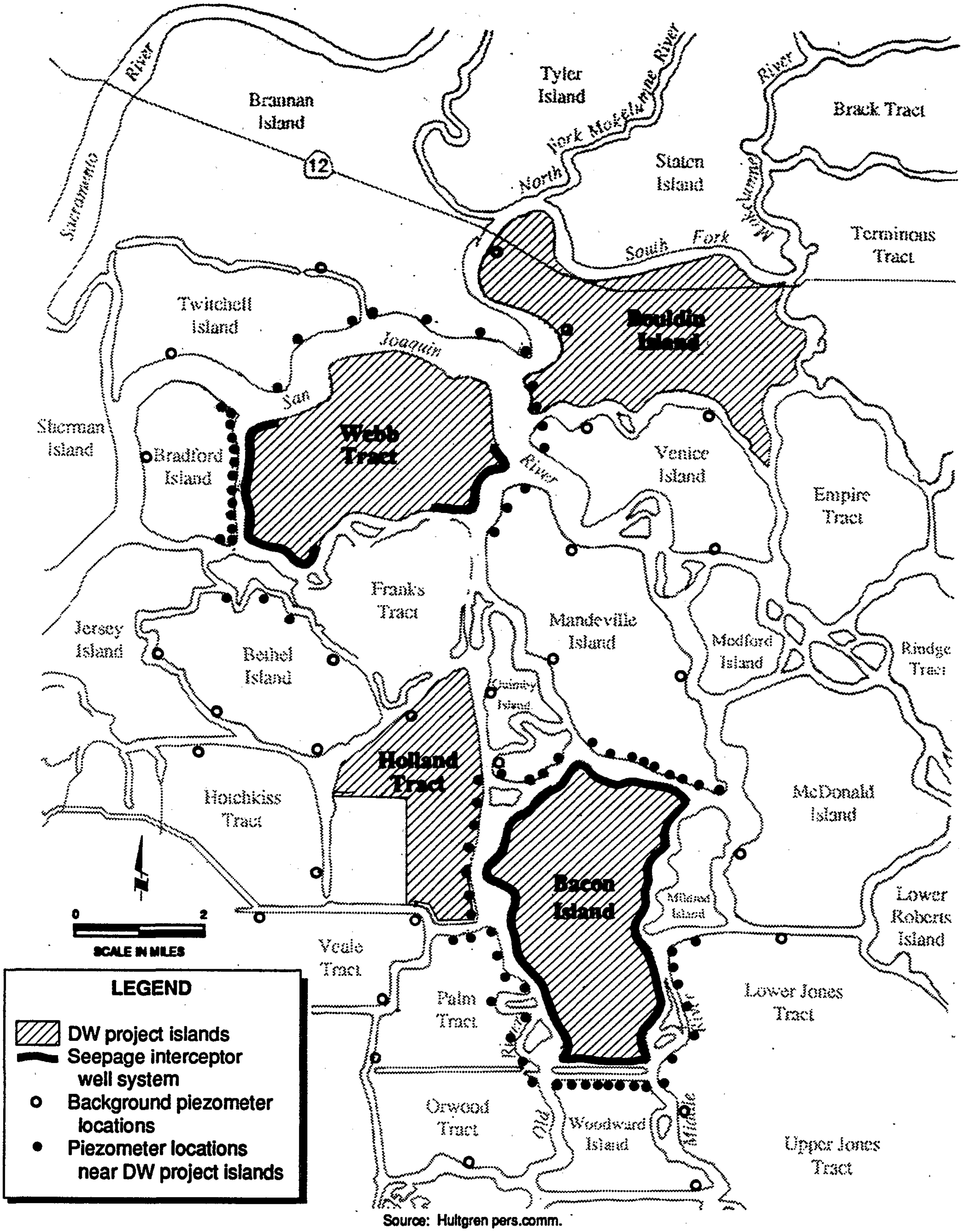

Figure 3D-3.
Seepage Interceptor Well System and Proposed Locations of Seepage Monitoring Piezometers for Alternatives 1 and 2

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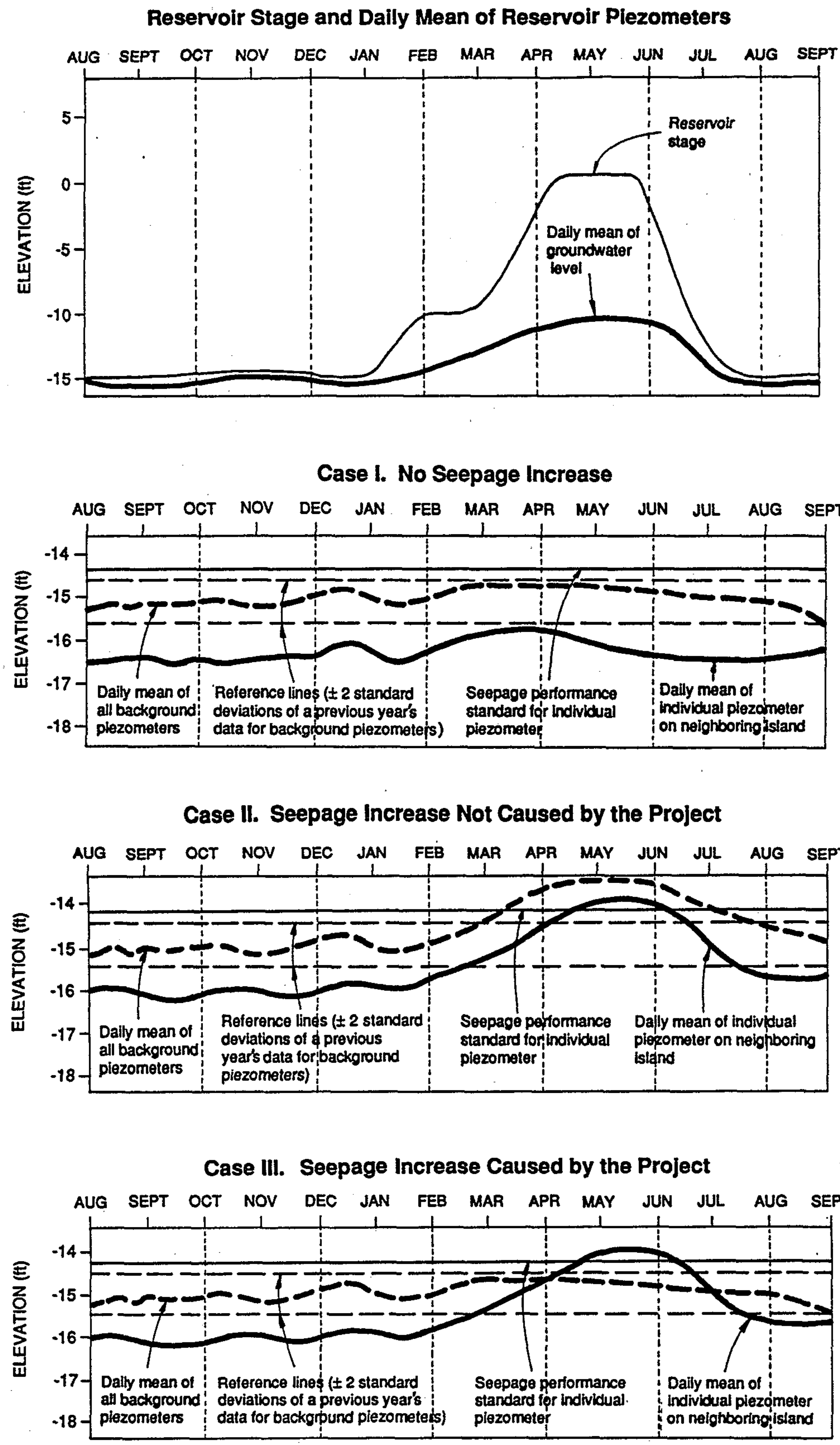

Figure 3D-4.
Hypothetical Patterns of Seepage Relative to Performance Standards

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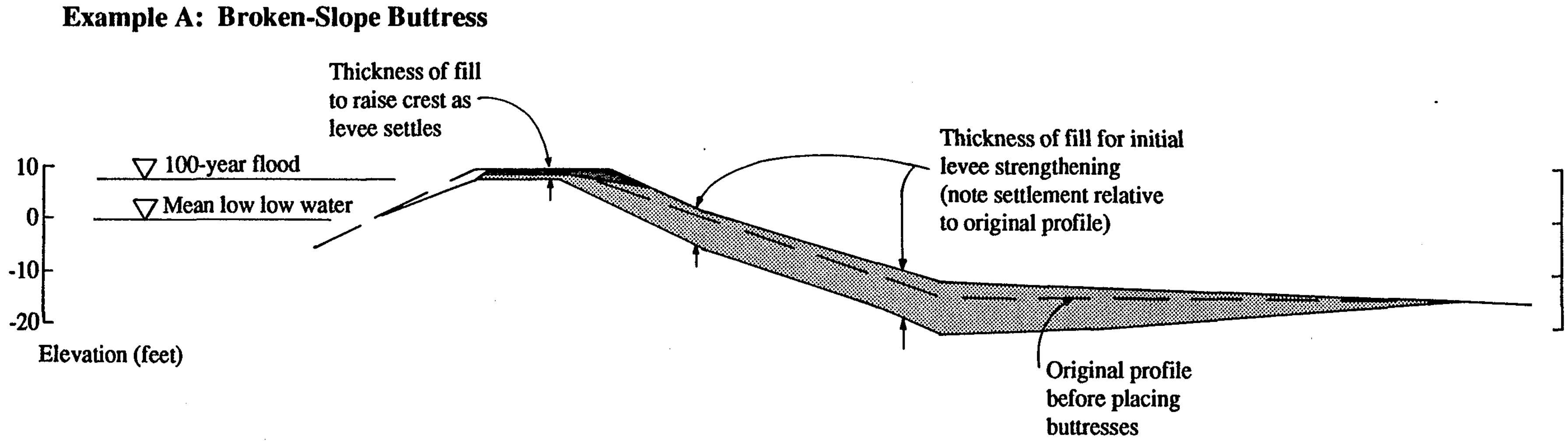
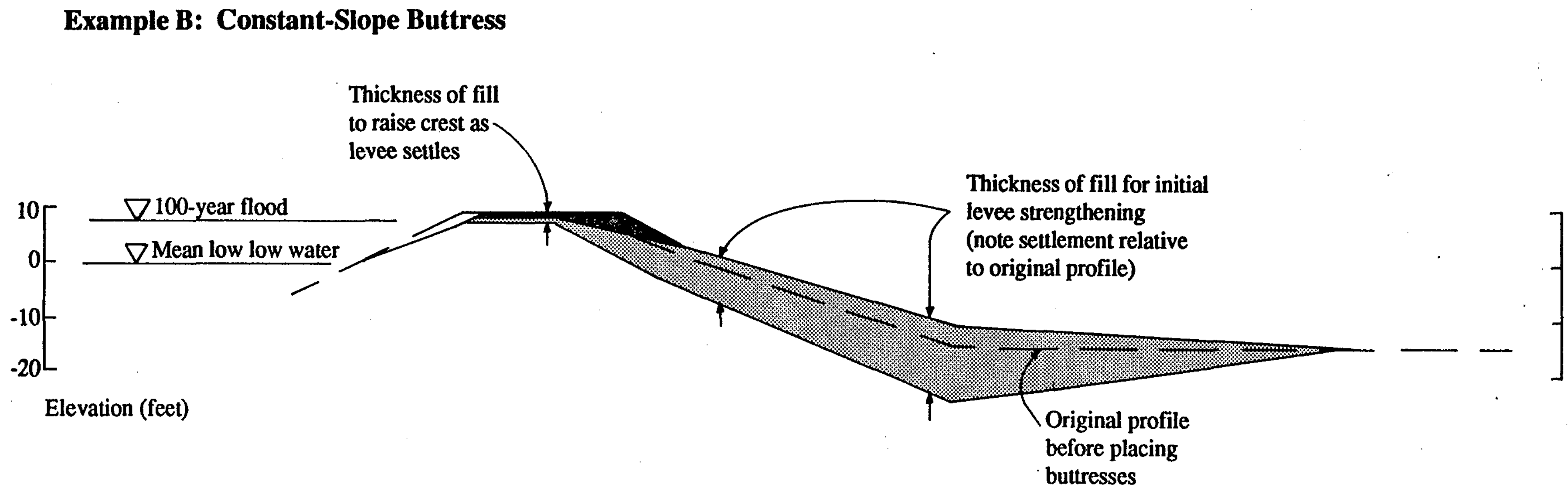
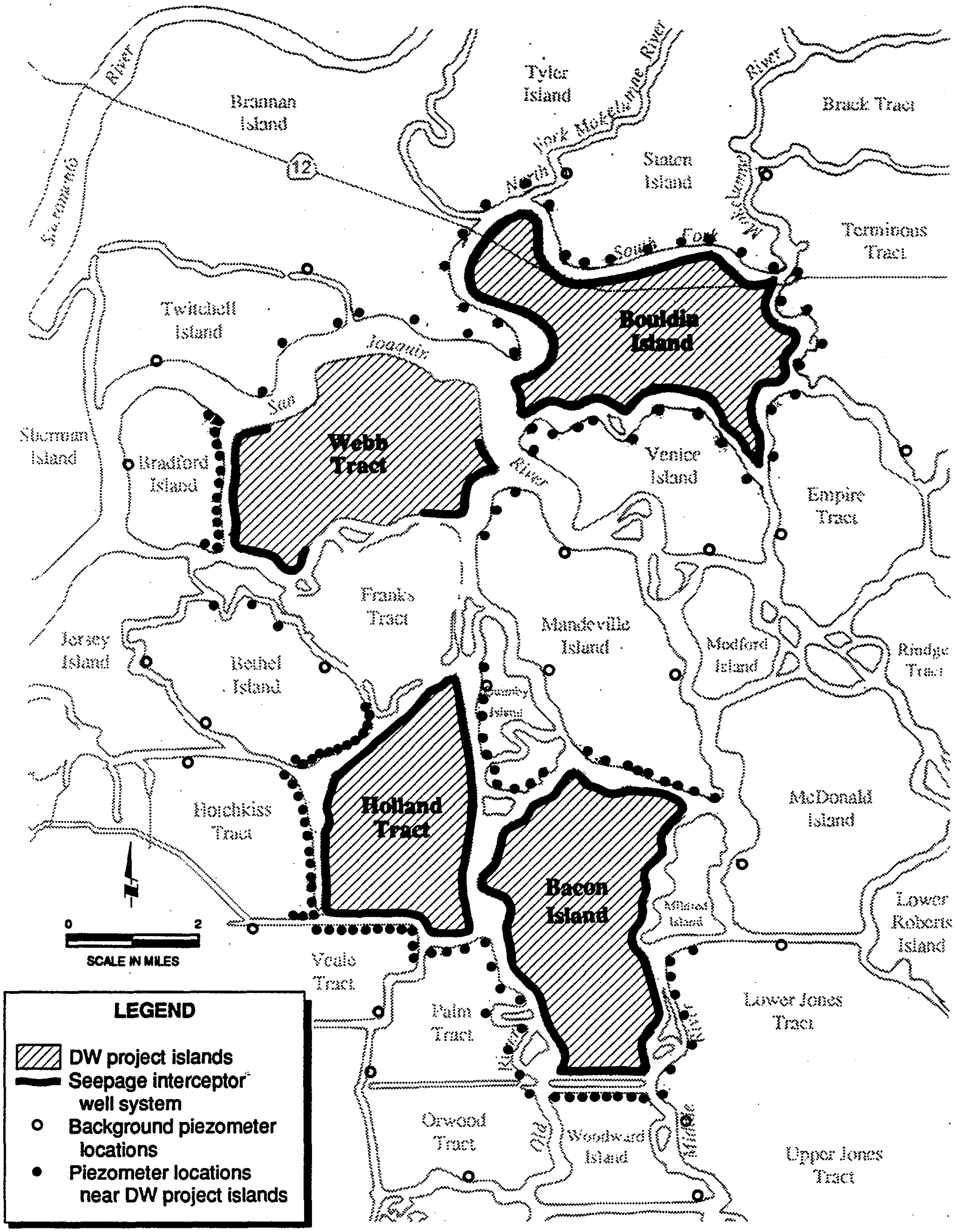




Source: Harding Lawson Associates 1993.

Figure 3D-5.
Examples of Settlement of Initial Fill and Rising Crest with Additional Fill

DELTA WETLANDS
PROJECT EIR/EIS
Prepared by: Jones & Stokes Associates



Source: Hultgren pers.comm.

Figure 3D-6.
Seepage Interceptor Well System and Proposed Locations of Seepage Monitoring Piezometers for Alternative 3

DELTA WETLANDS
PROJECT EIR/EIS
Prepared by: Jones & Stokes Associates