FIGURES

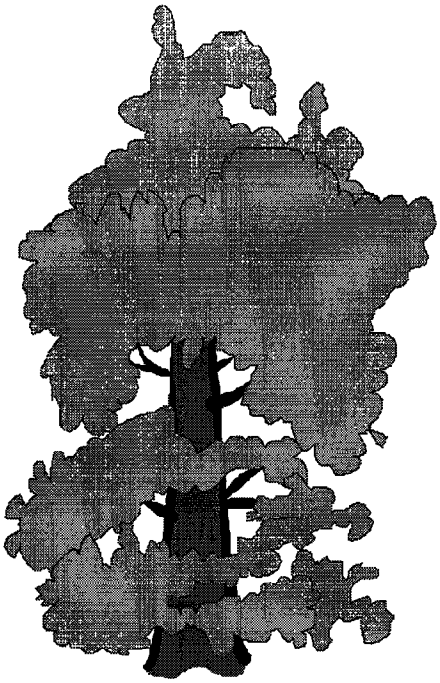


Figure 5

Possible Strategies for Levee and Habitat Improvements

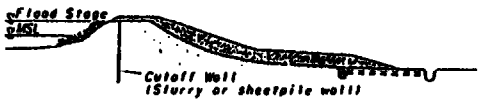
LEVEE IMPROVEMENT EXAMPLES	PURPOSE	APPLICABLE AREAS	POSITIVES	NEGATIVES
 A. Placement of Fill on Levee Crown and Landside Slope in Firm Mineral Soil Foundation Areas	o Increases freeboard and flood protection. o Increases landside slope stability. o Lengthens seepage path.	Firm foundation areas, generally located in outer fringes of Delta and on old stream channels filled with mineral soils.	a. Levee structural stability is improved. b. Levee improvements stay within general footprint of existing levee and drain ditch. c. Relatively easily maintained as a flood control levee. d. Provides small increase in seismic stability.	a. Requires import of mineral soil. b. Represents a significant cost. c. Provides no environmental enhancement. d. Provides no significant increase in seismic stability. e. Addition of fill may result in short-term instability and/or cracking if levee/foundation system is weak.
 B. Placement of Fill on Levee Crown and Landside Slope, Together with Landside Berm in Soft Foundation Areas	o Increases freeboard and flood protection. o Increases landside slope stability. o Lengthens seepage path. o Placement of berm accounts for soft foundation.	Most areas of Delta, but especially applicable in areas where soft foundation material exists.	a. Levee structural stability is improved. b. Relatively easily maintained as a flood control levee. c. Provides limited increase in seismic stability.	a. Requires significant import of mineral soil. b. Represents a significant cost. c. Provides no environmental enhancement. d. Provides only slight increase in seismic stability. e. Addition of fill may result in short-term instability and/or cracking if staged-construction is not used. f. Seepage system may need to be modified. g. Infringes on inboard farm land or habitat areas.
 C. Placement of Fill on Levee Crown, on Landside Slope, and in Landside Berm in Soft Foundation Areas - Together with Seepage Cutoff Wall (Slurry or Sheetpile Wall	o Increases freeboard and flood protection. o Increases landside slope stability. o Significantly lengthens seepage path. stops concentrated seepage areas. o Placement of berm accounts for soft foundation.	Areas of the Delta where both soft foundation materials and significant, concentrated seepage problems exist.	a. Levee structural stability is improved. b. Provides significant improvement in control of seepage problems in levee. c. Relatively easily maintained as a flood control levee. d. May provide moderate improvement in seismic stability of levee if water levels inboard of cutoff wall are greatly reduced within levee (reduces amount of possible liquefaction).	a. Requires significant import of mineral soil. b. Placement of fill represents a significant cost. c. Construction of cutoff wall represents a major cost. d. Provides no environmental enhancement. e. Levee and foundation may still be unstable during earthquake loading. f. Addition of fill may result in short-term instability and/or cracking if staged-construction is not used. g. Construction of cutoff wall may result in hydraulic fracturing and/or levee cracking if not carried out carefully. h. Lowered ground water inboard of wall may result in differential settlement and cracking. i. Seepage system may need to be modified.

Figure 5 cont.

Possible Strategies for Levee and Habitat Improvements

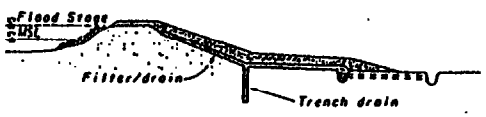
LEVEE IMPROVEMENT EXAMPLES	PURPOSE	APPLICABLE AREAS	POSITIVES	NEGATIVES
 D. Placement of Fill on Levee Crown, on Landside Slope, and in Landside Berm in <u>Soft</u> Foundation Areas - Together with <u>Filter/Drain System</u> on Landside Slope.	o Increases freeboard and flood protection. o Increases landside slope stability. o Lengthens seepage path, stabilizes concentrated leaks and prevents piping erosion. o Placement of berm accounts for soft foundation.	Areas of the Delta where both soft foundation materials and significant, concentrated seepage or settlement and cracking problems exist.	a. Levee structural stability is improved. b. Provides significant improvement in control of seepage problems in levee. c. May prevent piping erosion associated with both flood events and moderate earthquake-induced settlement and cracking.	a. Requires significant import of mineral soil. b. Placement of fill represents a significant cost. c. Construction of filter/drain represents additional cost. d. Provides no environmental enhancement. e. Levee and foundation may still be unstable during earthquake loading. f. Addition of fill may result in short-term instability and/or cracking if staged-construction is not used. g. Seepage system may need to be modified. h. Seepage and filter/drain system may need to be maintained. i. Infringes on inboard farm land or habitat areas.
 E. Placement of Fill on Levee Crown, on Landside Slope, and in Landside Berm in <u>Soft</u> Foundation Areas - Together with <u>Filter/Drain System</u> on Landside Slope and Toe Drain	o Increases freeboard and flood protection. o Increases landside slope stability. o Lengthens seepage path, stabilizes concentrated leaks and prevents piping erosion through both levee and foundation. o Placement of berm accounts for soft foundation.	Areas of the Delta where both soft foundation materials and significant, concentrated seepage or settlement and cracking problems exist. Particularly suited where piping erosion problems exist within levee foundation.	a. Levee structural stability is improved. b. Provides significant improvement in control of seepage problems in levee <u>and foundation</u>. c. May prevent piping erosion associated with both flood events and moderate earth quake-induced settlement and cracking.	a. Requires significant import of mineral soil. b. Placement of fill represents a significant cost. c. Construction of filter/drain on both slope and in trench represents additional cost. d. Provides no environmental enhancement. e. Levee and foundation may still be unstable during earthquake loading. f. Addition of fill may result in short-term instability and/or cracking if staged-construction is not used. g. Construction of drain trench may cause levee distress or seepage problems if not carried out carefully. h. Seepage system may need to be modified. i. Seepage and filter/drain system may need to be maintained. j. Infringes on inboard farm land or habitat areas.

Figure 5 cont.

Possible Strategies for Levee and Habitat Improvements

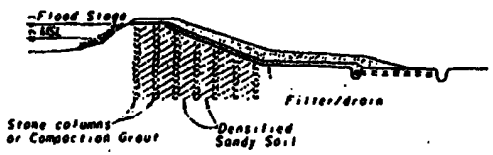
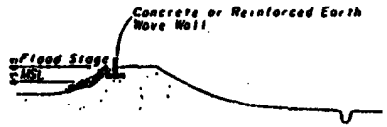
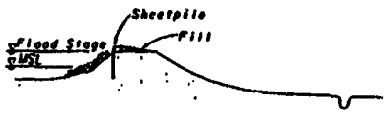
LEVEE IMPROVEMENT EXAMPLES	PURPOSE	APPLICABLE AREAS	POSITIVES	NEGATIVES
 F. Placement of Fill on Levee Crown, on Landside Slope, and in Landside Berm in Soft Foundation Areas - Together with Filter/Drain System on Landside Slope. Densification of Levee and Foundation Soils Using Vibroreplacment (Stone Columns) or Compaction Grouting.	o Increases freeboard and flood protection. o Increases landside slope stability. o Lengthens seepage path, stabilizes concentrated leaks and prevents piping erosion through levee. o Placement of berm accounts for soft foundation. o Densification of levee and foundation soils prevents/limits earthquake-induced liquefaction.	Areas of the Delta where both soft foundation materials and liquefiable materials exist within levee and/or levee foundation.	a. Levee structural stability is improved. b. Provides significant improvement in control of seepage problems in levee. c. Densification reduces amount of slumping and cracking which may occur during an earthquake. Filter/drain may prevent piping erosion following an earthquake (and flood events).	a. Requires significant import of mineral soil. b. Placement of fill represents a significant cost. c. Construction of filter/drain represents additional cost. d. Densification represents a major cost. e. Provides no environmental enhancement. f. Addition of fill may result in short-term instability and/or cracking if staged-construction is not used. g. Densification construction may cause levee distress or seepage problems if not carried out carefully. h. Seepage system may need to be modified. i. Seepage and filter/drain system may need to be maintained. j. Infringes on inboard farm land or habitat areas.
 G. Construction of Concrete Wave Wall on Levee Crown	o Provides wave protection during high tides and flood events (Probably only an interim measure).	Areas of the Delta where levee freeboard is of immediate concern.	a. Provides wave protection. b. Relatively inexpensive. c. Can be constructed relatively quickly.	a. Provides no significant improvement in: - overall freeboard. - structural stability. - seepage control. - piping erosion. - seismic stability. b. Provides no environmental enhancement.
 H. Construction of Sheetpile Wave Wall on Levee Crown	o Provides wave protection during high tides and flood events (Probably only an interim measure).	Areas of the Delta where levee freeboard is of immediate concern.	a. Provides wave protection. b. Relatively inexpensive. c. Can be constructed relatively quickly.	a. Provides no significant improvement in: - overall freeboard. - structural stability. - seepage control. - piping erosion. - seismic stability. b. Requires limited import of fill. c. Provides no environmental enhancement. d. Installation of sheetpile wall may result in cracking of levee if not carried out with care.

Figure 5 cont.

Possible Strategies for Levee and Habitat Improvements

LEVEE IMPROVEMENT EXAMPLES	PURPOSE	APPLICABLE AREAS	POSITIVES	NEGATIVES
 I. Maintenance of Vegetation on Existing Levee Slopes	• Provides reasonable on-site growth and regrowth of vegetation while maintaining safety, access, and inspectability of levees.	Most areas in the Delta, but impact on levee stability must be first evaluated on a site by site basis. Waterside vegetation must be integrated with wave protection systems such as riprap to prevent major levee erosion.	a. Limited waterside vegetation provides some riparian and shaded aquatic habitat. b. Limited waterside vegetation provides some wave protection for levee. c. Grass vegetation provides erosion control for surface runoff. d. Preservation of existing trees provides valuable riparian habitat.	a. If Engineer's guidance not followed and vegetation becomes overgrown, there - Vegetation limits access for inspection, maintenance, and flood fighting. - Vegetation encourages burrowing rodents. - Downing of trees during storms causes damage to levees due to fallen root balls pulling out chunks of the levee. - *Tree roots can also eventually provide a* seepage path through levee when they decay. b. Cannot be implemented on Federal levees. c. Because levees require continual maintenance and remediation, some developed habitats need to be covered over with stabilizing berms.
 J. Placement of Fill on Levee Crown and Landside Slope, Together with Landside Berm in Soft Foundation Areas. Creation of Waterside Berm at Mean Sea Level to Create Waterside Wetland Habitat.	• Increases freeboard and flood protection. • Increases landside slope stability. • Lengthens seepage path. • Placement of berm accounts for soft foundation. • Provides Waterside Wetland Habitat.	Areas of Delta where soft foundation material exists and where waterside slope is not steep (deep). Cannot be used where channel capacity is severely limited.	a. Levee structural stability is improved. b. Relatively easily maintained as a flood control levee. c. Provides limited increase in seismic stability. d. Provides valuable Waterside Wetland Habitat (Waterside fill may limit seepage and improve waterside slope stability).	a. Requires major import of mineral soil. b. Placement of landside fill represents a significant cost. c. Placement of waterside fill represents a significant cost. d. Provides only limited increase in seismic stability. e. Limits channel capacity. f. Addition of fill may result in short-term instability and/or cracking if staged-construction is not used. g. *Dredging may be needed on waterside.* h. Seepage system may need to be modified.
 K. Placement of Fill on Levee Crown and Landside Slope, Together with Landside Berm in Soft Foundation Areas. Creation of Waterside Berm above Mean Sea Level to Create Waterside Riparian Habitat.	• Increases freeboard and flood protection. • Increases landside slope stability. • Lengthens seepage path. • Placement of berm accounts for soft foundation. • Provides Waterside Riparian Habitat.	Areas of Delta where soft foundation material exists, and where waterside slope is not steep (deep). Cannot be used where channel capacity us severely limited.	a. Levee structural stability is improved. b. Relatively easily maintained as a flood control levee. c. Provides limited increase in seismic stability. d. Provides valuable Waterside Riparian Habitat (Waterside fill may limit seepage and improve waterside slope stability).	a. Requires major import of mineral soil. b. Placement of landside fill represents a significant cost. c. Placement of waterside fill represents a significant cost. d. Provides only limited increase in seismic stability. e. Limits channel capacity. f. Addition of fill may result in short-term instability and/or cracking if staged-construction is not used. g. Dredging may be needed on waterside. h. Seepage system may need to be modified.

Figure 5 cont.

Possible Strategies for Levee and Habitat Improvements

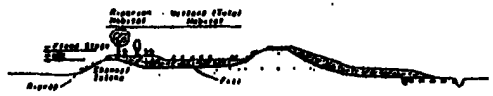
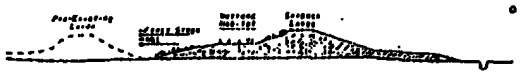
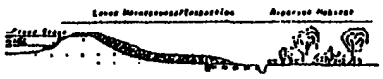
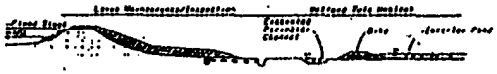
LEVEE IMPROVEMENT EXAMPLES	PURPOSE	APPLICABLE AREAS	POSITIVES	NEGATIVES
 L. Placement of Fill on Levee Crown and Landside Slope, Together with Landside Berm in Soft Foundation Areas. Placement of Fill between Channel Island and Levee to Create Waterside Wetland and Riparian Habitat.	o Increases freeboard and flood protection. o Increases landside slope stability. o Lengthens seepage path. o Placement of berm accounts for soft foundation. o Provides Waterside Riparian and Wetland Habitat.	Areas of Delta where soft foundation material exists, and where channel islands and channel between island levee is not too deep. Cannot be used where channel capacity is severely limited.	a. Levee structural stability is improved. b. Relatively easily maintained as a flood control levee. c. Provides limited increase in seismic stability. d. Provides valuable Waterside Riparian and Wetland Habitat (Waterside fill may limit seepage and improve waterside slope stability).	a. Requires major import of mineral soil. b. Placement of landside fill represents a significant cost. c. Placement of waterside fill represents a significant cost. d. Provides only limited increase in seismic stability. e. Limits channel capacity. f. Addition of fill may result in short-term instability and/or cracking if staged-construction is not used. g. Dredging may be needed on waterside. h. Seepage system may need to be modified. i. Channel island requires protection.
 M. Placement of Fill on Levee Crown and Landside Slope. Together with Landside Berm in Soft Foundation Areas. Placement of Sand Beach on Waterside Slope to Create Recreation Area.	o Increases freeboard and flood protection. o Increases landside slope stability. o Lengthens seepage path. o Placement of berm accounts for soft foundation. o Provides Recreation Area.	Areas of Delta where soft foundation material exists, and where waterside slope is not too steep (deep). Cannot be used where channel capacity is severely limited.	a. Levee structural stability is improved. b. Relatively easily maintained as a flood control levee. c. Provides limited increase in seismic stability. d. Provides valuable Waterside Recreation Area. (Waterside fill may limit seepage and improve waterside slope stability.)	a. Requires major import of mineral soil. b. Placement of landside fill represents a significant cost. c. Placement of waterside sandy fill represents a significant cost. d. Provides only limited increase in seismic stability. e. Limits channel capacity. f. Addition of fill may result in short-term instability and/or cracking if staged-construction is not used. g. Dredging may be needed on waterside. h. Seepage system may need to be modified. i. Beach area requires maintenance.
 N. Partial Setback of Levee to Create Waterside Riparian Habitat, Placement of Fill on Levee Crown and Landside Slope. Slope, Together with Landside Berm in Soft Foundation Areas.	o Increases freeboard and flood protection. o Increases overall slope stability. o Lengthens seepage path. o Placement of berm accounts for soft foundation. o Provides Waterside Riparian Habitat.	All areas of Delta, but especially applicable in areas where soft foundation material exists.	a. Levee structural stability is improved. b. Relatively easily maintained as a flood control levee. c. Provides limited increase in seismic stability. d. Lengthens seepage path.	a. Requires significant import of mineral soil. b. Fill placement and cost associated with levee setback greater than simply raising levee crown and adding berm. c. Provides only limited increase in seismic stability. d. Addition of fill likely to result in short-term instability and/or cracking if staged-construction is not used. e. Seepage system may need to be modified. f. Infringes on inboard farm land or habitat areas.

Figure 5 cont.

Possible Strategies for Levee and Habitat Improvements

LEVEE IMPROVEMENT EXAMPLES	PURPOSE	APPLICABLE AREAS	POSITIVES	NEGATIVES
 O. Complete Setback of Levee to Improve Channel Capacity, Improve Levee Structural Stability and Provide Waterside Wetland Habitat.	o Increases channel capacity. o Improves levee stability. o Provides Waterside Wetland Habitat.	Many areas of Delta, but possibly not in areas where very thick layers of soft foundation material may make creation of new setback levees infeasible.	a. Increases channel capacity and improves flood control. b. New levee would be an engineered fill and would not liquefy during seismic events. c. Provides Waterside Wetland Habitat.	a. Requires major import of mineral soil. b. Fill placement and cost associated with levee setback greater than simply raising levee crown and adding berm. c. Foundation liquefaction could still cause failure during future earthquake. d. New levee fill likely to result in short-term instability and/or cracking if staged-construction is not used. This could temporarily make new levee less reliable than existing levee. e. Significantly infringes on inboard farm land or habitat areas.
 P. Placement of Fill on Levee Crown and Landside Slope, Together with Landside Berm in Soft Foundation Areas. Creation of Landside Riparian Habitat.	o Increases freeboard and flood protection. o Increases landside slope stability. o Lengthens seepage path. o Placement of berm accounts for soft foundation. o Provides Landside Riparian Habitat.	All areas of Delta, but especially applicable in areas where soft foundation material exists.	a. Levee structural stability is improved. b. Relatively easily maintained as a flood control levee. c. Provides limited increase in seismic stability. d. Provides Landside Riparian Habitat. e. Reduces subsidence near levee by not tilling land in habitat area.	a. Requires significant import of mineral soil. b. Represents a significant cost. c. Provides only slight increase in seismic stability. d. Addition of fill may result in short-term instability and/or cracking if staged-construction is not used. e. Seepage system may need to be modified. f. Significantly infringes on inboard farm land and requires some land to be taken out of agricultural production.
 Q. Placement of Fill on Levee Crown and Landside Slope, Together with Landside Berm in Soft Foundation Areas. Creation of Inboard Ponds and Waterfilled Perimeter Ditches for Landside Wetland Habitat.	o Increases freeboard and flood protection. o Increases landside slope stability. o Lengthens seepage path. o Placement of berm accounts for soft foundation. o Provides Landside Wetland Habitat.	All areas of Delta, but especially applicable in areas where soft foundation material exists and significant inland subsidence is occurring.	a. Levee structural stability is improved. b. Relatively easily maintained as a flood control levee. c. Provides limited increase in seismic stability. d. Provides Landside Wetland Habitat. e. Reduces subsidence near levee by keeping organic soils saturated.	a. Requires significant import of mineral soil. b. Represents a significant cost. c. Provides only slight increase in seismic stability. d. Addition of fill may result in short-term instability and/or cracking if staged-construction is not used. e. Seepage system may need to be modified. f. Significantly infringes on inboard farm land and requires some land to be taken out of agricultural production. g. Inland pond and dike systems require maintenance.