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of Engineers



**DREDGING OPERATIONS TECHNICAL  
SUPPORT PROGRAM**

MISCELLANEOUS PAPER D-88-3

**PLANNING-LEVEL COST ESTIMATES OF  
DREDGED MATERIAL CONTAINMENT  
ISLANDS IN NEW YORK HARBOR**

by

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## PREFACE

This report presents planning-level cost estimates for construction and operation of three types of containment islands, one of which will possibly be located in one of three locations in the Lower New York Bay. Estimates are given as merely "order of magnitude" values based on typical unit costs and assumed area and cross-section configurations.

This report was prepared in response to a request for assistance from the Dredging Operations Technical Support (DOTS) Program by the US Army Engineer District (USAED), New York. DOTS is funded by the Office, Chief of Engineers, through the Water Resources Support Center, Dredging Division (WRSC-D). DOTS is managed through the Environmental Effects of Dredging Programs (EEDP) of the Environmental Laboratory (EL) of the US Army Engineer Waterways Experiment Station (WES). Dr. Robert M. Engler was EEDP Manager, and Mr. Thomas R. Patin was DOTS Coordinator. The work was monitored by Mr. David B. Mathis, WRSC-D. Support for report publication was provided by the USAED, New York, under Intra-Army Order No. NYD 88-01(C).

The study was conducted by the Water Resources Engineering Group (WREG), Environmental Engineering Division (EED), EL, WES, under the direction of Dr. Thomas M. Walski (formerly of WREG). Support for developing the design and cost-estimating assumptions was obtained from various individuals from the Hydraulics Laboratory and Geotechnical Laboratory, WES. Points of contact in the USAED, New York, were Ms. Carol A. Coch, Project Manager, and Mr. John F. Tavolaro, Chief, Water Quality Compliance Section.

This report was written principally by Dr. Walski. Mr. Thomas E. Schaefer, Jr., WREG, assisted in the report writing, calculations, and preparation. The report was edited by Ms. Lee T. Byrne, Information Products Division, Information Technology Laboratory. Messrs. T. Neil McLellan and Clifford L. Truitt, both formerly of WREG, and Dr. F. Douglas Shields, WREG, served as technical reviewers. The study was performed under the direct supervision of Dr. Michael R. Palermo, former Chief, WREG, and Dr. Paul R. Schroeder, Acting Chief, WREG; and under the general supervision of Dr. Raymond L. Montgomery, Chief, EED, and Dr. John Harrison, Chief, EL.

COL Dwayne G. Lee, CE, was Commander and Director of WES. Technical Director was Dr. Robert W. Whalin.

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CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
acres	4,046.873	square metres
cubic feet	0.02831685	cubic metres
cubic yards	0.7645549	cubic metres
feet	0.3048	metres
gallons	3.785412	cubic decimetres
miles (US statute)	1.609347	kilometres
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
square feet	0.09290304	square metres
square yards	0.8361274	square metres
tons (2,000 pounds, mass)	907.1847	kilograms
yards	0.9144	metres

PLANNING-LEVEL COST ESTIMATES OF DREDGED MATERIAL  
CONTAINMENT ISLANDS IN NEW YORK HARBOR

PART I: INTRODUCTION

Purpose

1. The New York District (NYD) Corps of Engineers is considering construction of a dredged material containment island to receive contaminated dredged material from several dredging sites in the New York/New Jersey Harbor area (Figure 1). This report provides planning-level cost estimates for three types of containment islands for three locations in Lower New York Bay. Costs are expressed in 1985 dollars throughout the report; however, a conversion factor for May 1987 dollars is provided in each cost summary table.

Scope and General Assumptions

2. Since no plans, specifications, or engineering data are available for the actual design of the proposed islands, the estimates contained in this report are merely "order of magnitude" values. The approach has been based primarily on typical unit costs applied to material quantity estimates taken from hypothetical sections and assumed configurations. While this may be the only reasonable approach for such preliminary estimates, the associated limitations cannot be overemphasized. Construction techniques for some of the options considered are at best unrefined, and estimates based primarily on material prices (even "in place") may not be entirely representative of actual construction costs. Marine construction costs, in general, are affected to a greater degree by variabilities in site conditions, weather, marine traffic, and equipment demands.

3. For each alternative considered, construction material quantities required to construct the island are determined, and expected unit prices are presented. The costs for the islands are then calculated. Next, alternative levels of effluent treatment are proposed, and costs are determined. Finally, costs per unit of storage volume in the islands are determined for each

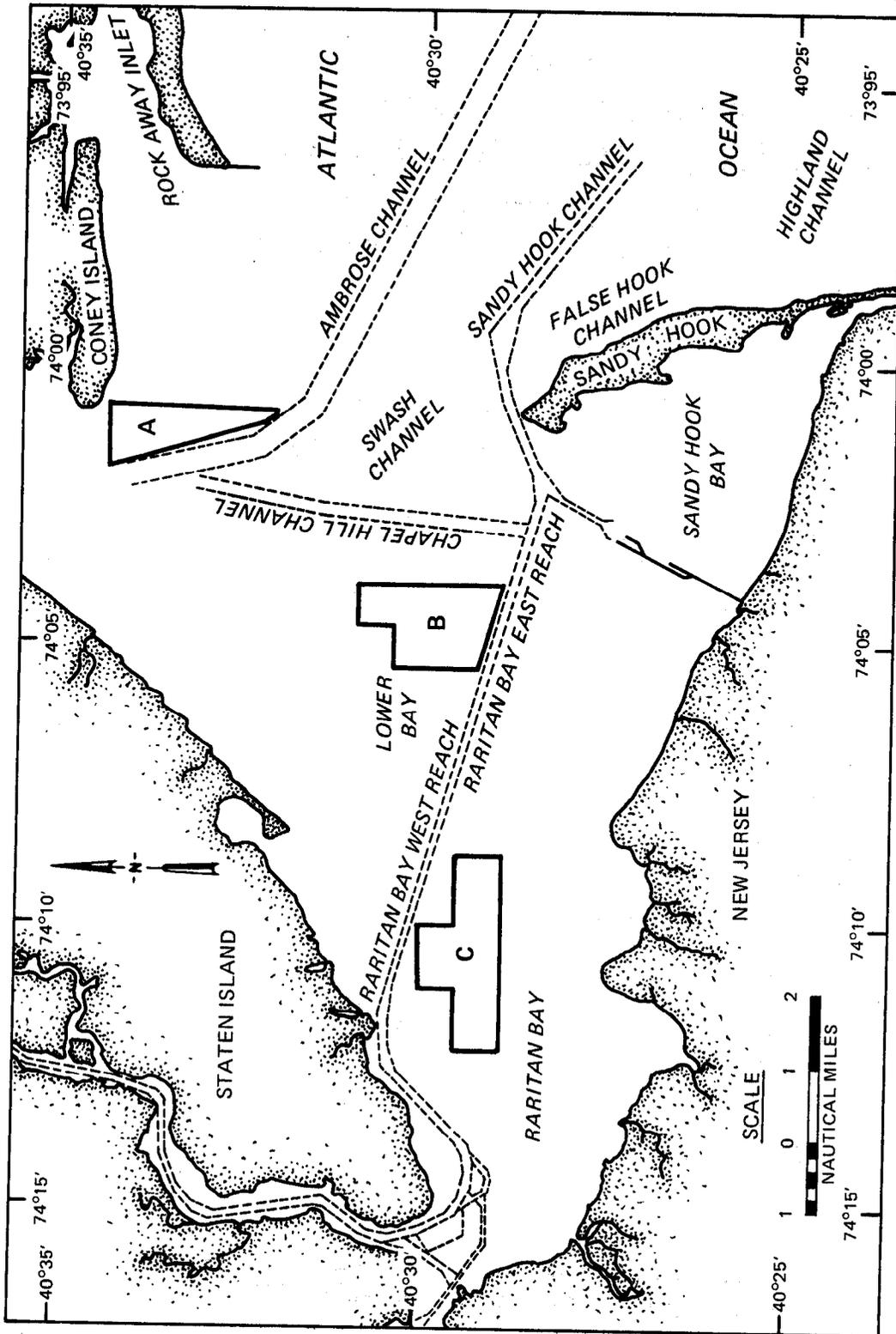


Figure 1. Index map of the study area in the Lower Bay, New York Harbor (to convert US nautical miles to kilometres, multiply by 1.852)

alternative. An extracted summary of each of these principal costs is presented in Table 1 (values in Table 1 are in May 1987 dollars).

Table 1  
Summary of Planning-Level Cost Estimates for Containment  
Islands in Lower New York Bay (1987 Dollars\*)

<u>Parameter</u>	<u>Sand Dike</u>			<u>Rock Dike</u>	<u>Sheet Pile Cofferdam</u>
	<u>Site A</u>	<u>Site B</u>	<u>Site C</u>		
Total costs ( $10^6$ \$) (design, construction, maintenance)	153	186	219	486	278
Treatment costs ( $10^6$ \$) (Level 3)	9.0	9.0	9.0	9.0	9.0
Storage volume ( $10^6$ yd**)	6.6	6.6	6.6	22.7	28.2
Unit storage costs (\$/yd <sup>3</sup> ) w/o treatment	23.1	28.4	33.6	21.4	9.9
w/treatment	24.2	29.4	34.7	21.8	10.2

\* Costs calculated throughout this report were multiplied by 1.05 for May 1987 dollars.

\*\* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 4.

## PART II: CONTAINMENT ISLAND ALTERNATIVES

### Dikes and Volumes

4. Three different dike designs were investigated for containment islands in Lower New York Harbor: sheet pile cofferdams, rock and sand dikes, and sand dikes. Artists' conceptions of the sheet pile cofferdams and sand dikes during operation of the sites are shown in Figures 2a and 2b. In the following section, the volumes of construction material in the dikes, the storage capacity in the containment island, and the surface area of the containment island that potentially must be lined are calculated.

5. Based on information provided by Ms. Carol A. Coch of the NYD,\* the dikes are to be constructed in 20 ft of water and will rise to 25 ft (msl) above the water. They will be filled to an elevation of 15 ft above sea level (msl). The entire area will occupy 500 acres as measured from the outside toe of each dike. An oval shape will be used to minimize interactions with currents. This shape was based on suggestions from the Hydraulics Laboratory, US Army Engineer Waterways Experiment Station (WES). Three sites are considered:

- a. A--East Bank (off East Bank and Coney Island).
- b. B--West Bank (Lower Bay west to Chapel Hill Channel).
- c. C--East Raritan Bay (Raritan Bay below Seguine Point).

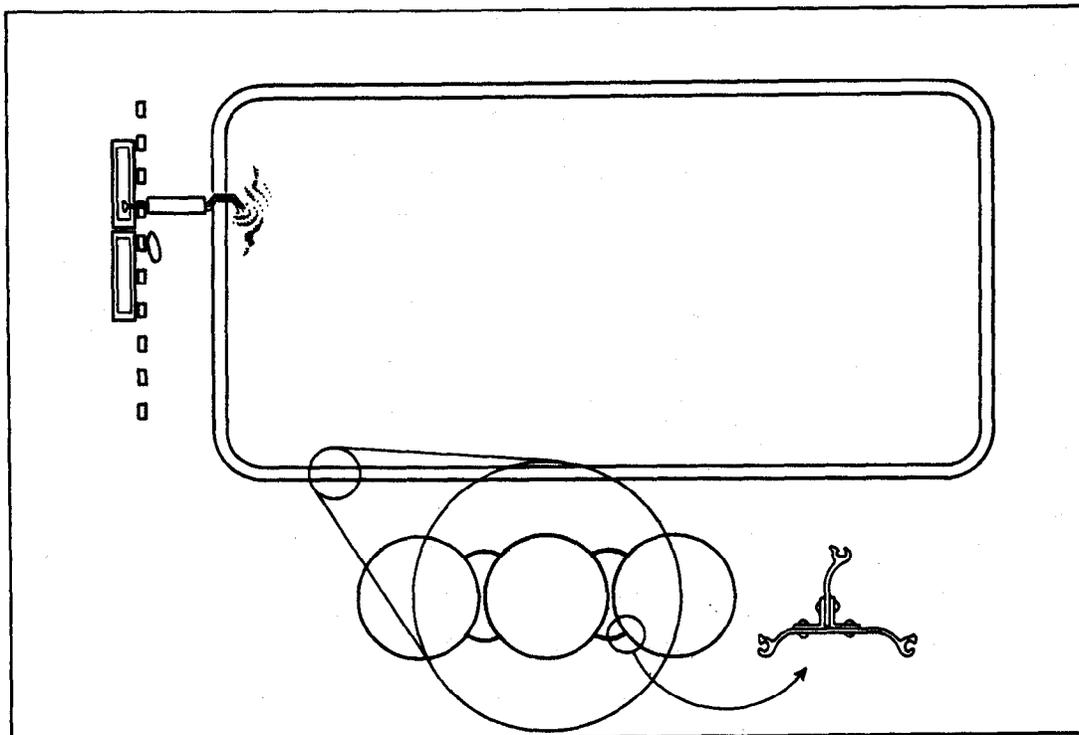
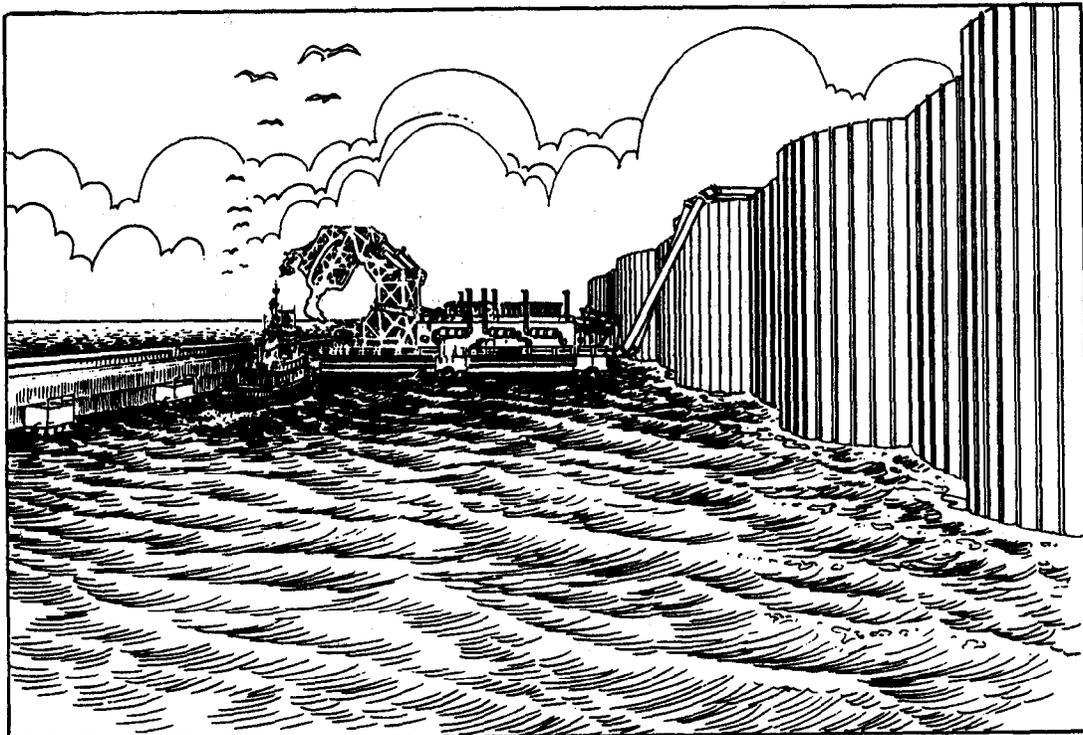
The sites shown in Figure 1 were taken from Bokuniewicz and Fray (1979). For the cofferdam and rock alternatives, the costs should be similar for all sites. For the dredged sand dikes, the costs should be lowest for Site A, higher for B, and highest for C because of the distance the sand must be transported.

#### Sand dikes

6. The sand dikes can be dredged in place from the coarsest sands that can be found in the harbor. For planning purposes, it is estimated that the slope of the dikes below the waterline will be roughly 1 on 30; above the waterline the slope will be 1 on 8. The weight of the sand dikes should displace an estimated 15-ft-thick layer of the existing bottom material. The

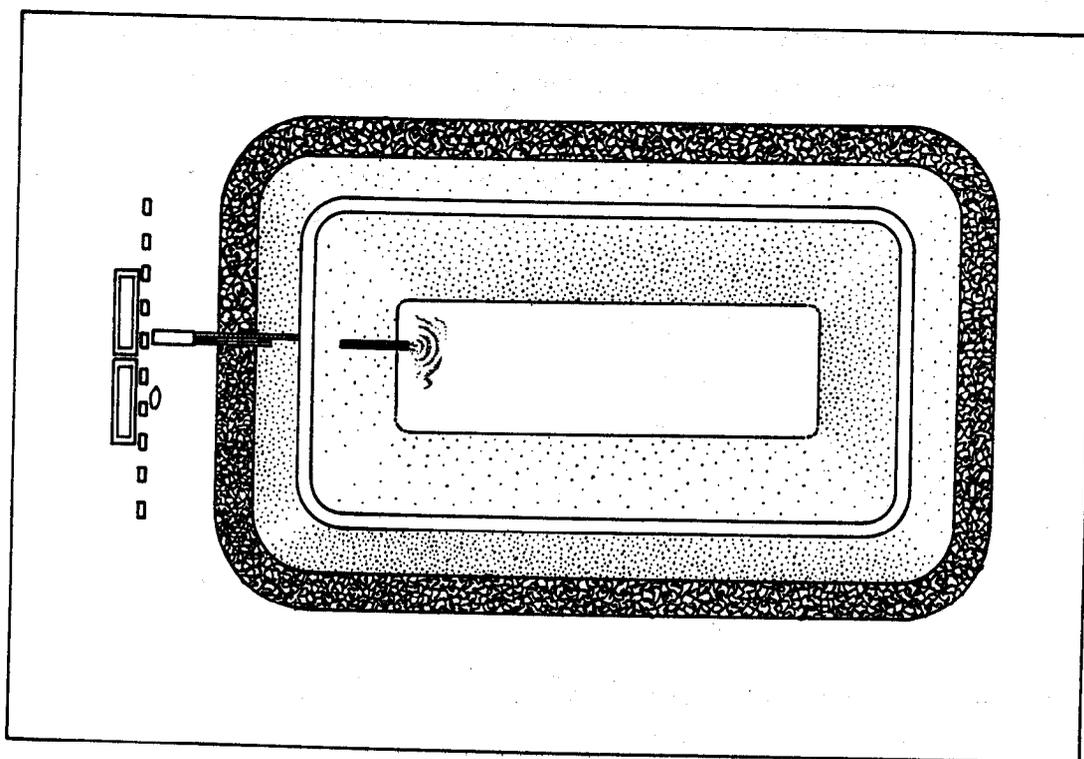
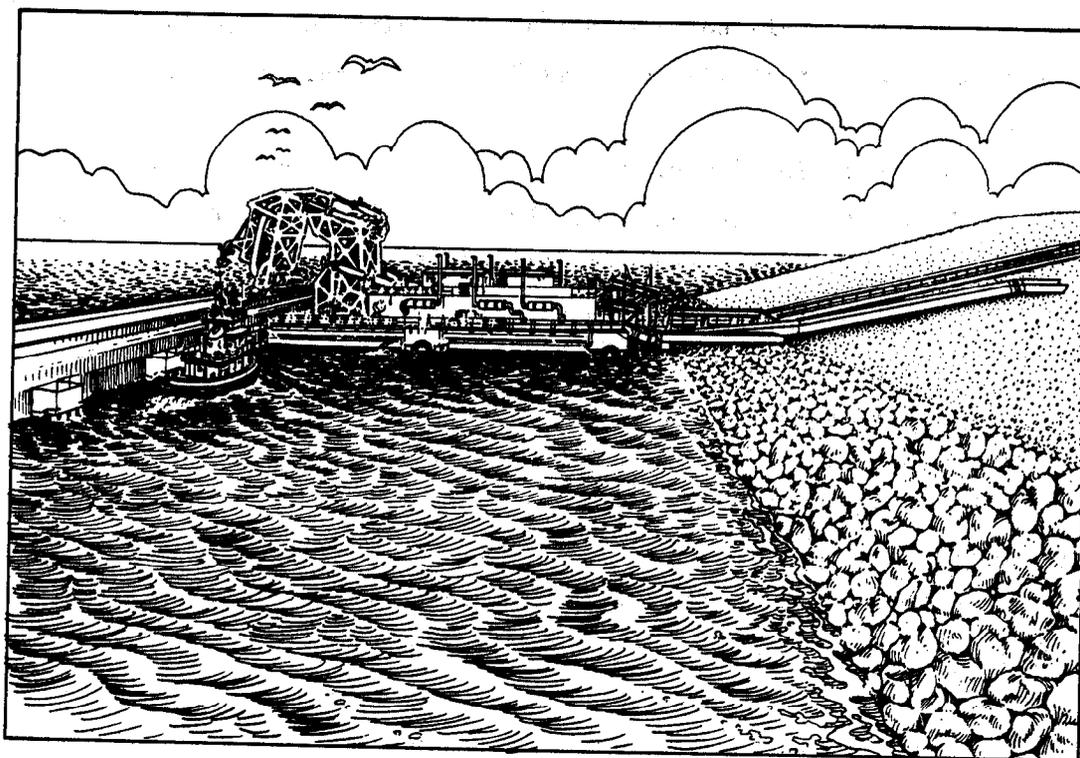
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\* Personal Communication, February 1985, Ms. Carol A. Coch, Project Manager, NYD, New York.



a. Sheet pile cofferdam

Figure 2. Sheet pile cofferdams and sand dikes during operation of the sites (Continued)



b. Sand dikes

Figure 2. (Concluded)

value of 1 on 30 is likely to be conservative. With adequate protection from waves, steeper slopes that will decrease costs and increase storage volume may possibly be designed.

7. A cross-sectional view of the sand dike is shown in Figure 3 and in Appendix A (Figure A1) along with detailed calculations of volume of material required per length of dike, which is 44,050 ft<sup>3</sup> sand/ft dike length. The length of the dike along the dike center line is 12,800 ft, which results in total volume of sand required of 20.9 million yd<sup>3</sup>.

8. Scour protection. It is assumed that both the inside and outside faces of the sand dike will require armoring to reduce the effects of wave action, currents, and storm surges. For estimating purposes, the armoring material is taken to be randomly placed quarried stone having a unit weight of 162 lb/ft<sup>3</sup> and a constructed porosity of 40 percent. The actual design of the armor layer(s) is dependent on the unspecified values of several factors including wave heights, periods, storm surge elevations, and the hydrodynamic effects associated with nearby ship traffic. In any case, the riprap will at least cover the above-water portion of the dike slope (the 1 on 8 section) and extend some distance outward on the submerged slope to protect against toe scour. However, small variations in the above design variables can result in large, nonlinear changes in the required armor design.

9. For example, a 3-ft design wave on the exterior of the dike requires individual rock weights in the range of 60 to 80 lb (two layer system, minimum single layer thickness of 1 ft) and coverage of the submerged slope to a water depth of 3 ft or approximately 90 to 100 slope ft waterward. A 5-ft design wave height suggests weights more on the order of 300 lb and coverage of twice the area of submerged slope. Also, interior and exterior faces must be treated differently, not only because of different forces, but because of the

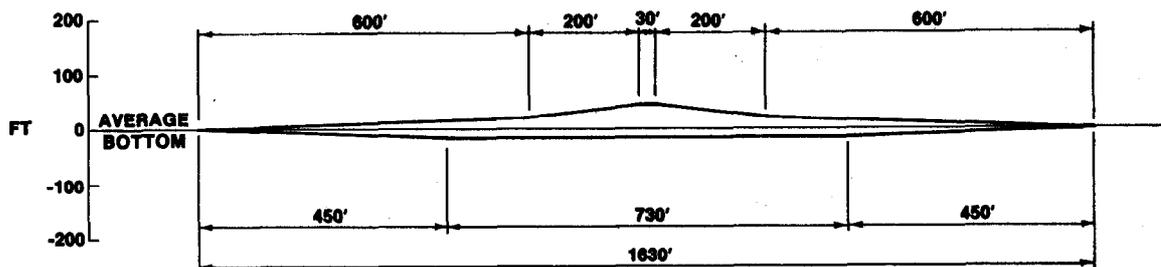


Figure 3. Cross-sectional view of sand dike

potential use of a liner on the interior. However, in order to proceed with the estimate, an arbitrary assumption has been made that the riprap is to be placed only on the 1 on 8 portion of the slope and that the same design is used inside and outside. An estimated area of riprap coverage is 6,961,000 ft<sup>2</sup> (see Appendix A). This assumption is not conservative, and the resulting estimates may be somewhat low for this item. The riprap required is

$$(6,961,000 \text{ ft}^2)(2 \text{ ft})(1 - 0.4)(162 \text{ lb/ft}^3) \left( \frac{\text{tons}}{2,000 \text{ lb}} \right) \\ = 676,700 \text{ tons of riprap} \quad (1)$$

10. The inside of the containment island should be covered with a synthetic liner or a thick layer of impermeable soil to below the top of the dredged material. Calculations in Appendix A indicate that 185 acres of liner will be required. Figure 4 is a plan view of the containment area.

11. Volumetric storage. The volumetric storage available within the sand dikes as calculated in Appendix A is  $6.6 \times 10^6 \text{ yd}^3$  from the existing sea bottom to 15 ft above sea level (msl). Figure 5 is a profile of the storage volume in the site and how it is affected by the toe of the dike.

12. The mild slopes required for the sand dikes result in the center line of the dikes being located 815 ft from the outside perimeter of the 500-acre area. Similarly, much of the inside of the area is filled with the toe of the dike. If it is possible to define the 500-acre area as being measured from within the center line of the dikes, the available storage volume will increase by roughly a factor of 3 while the dike length, and hence cost, will increase by only about 50 percent.

#### Rock dike

13. The second type of dike is rock-with-sand fill. It will be built with a 1 on 3 slope to a height of 45 ft after a bottom displacement of 15 ft (Figure 6). Calculations in Appendix B indicate that 10,125 ft<sup>3</sup> of rock are required per foot of dike length, and the total center line dike length will be 17,000 ft. The total weight of rock required can be given for a constructed porosity of 40 percent and unit density of 162 lb/ft<sup>3</sup> by

$$(17,000 \text{ ft})(10,125 \text{ ft}^3)(1 - 0.4)(162 \text{ lb/ft}^3) \left( \frac{\text{tons}}{2,000 \text{ lb}} \right) \\ = 8.36 \times 10^6 \text{ tons} \quad (2)$$

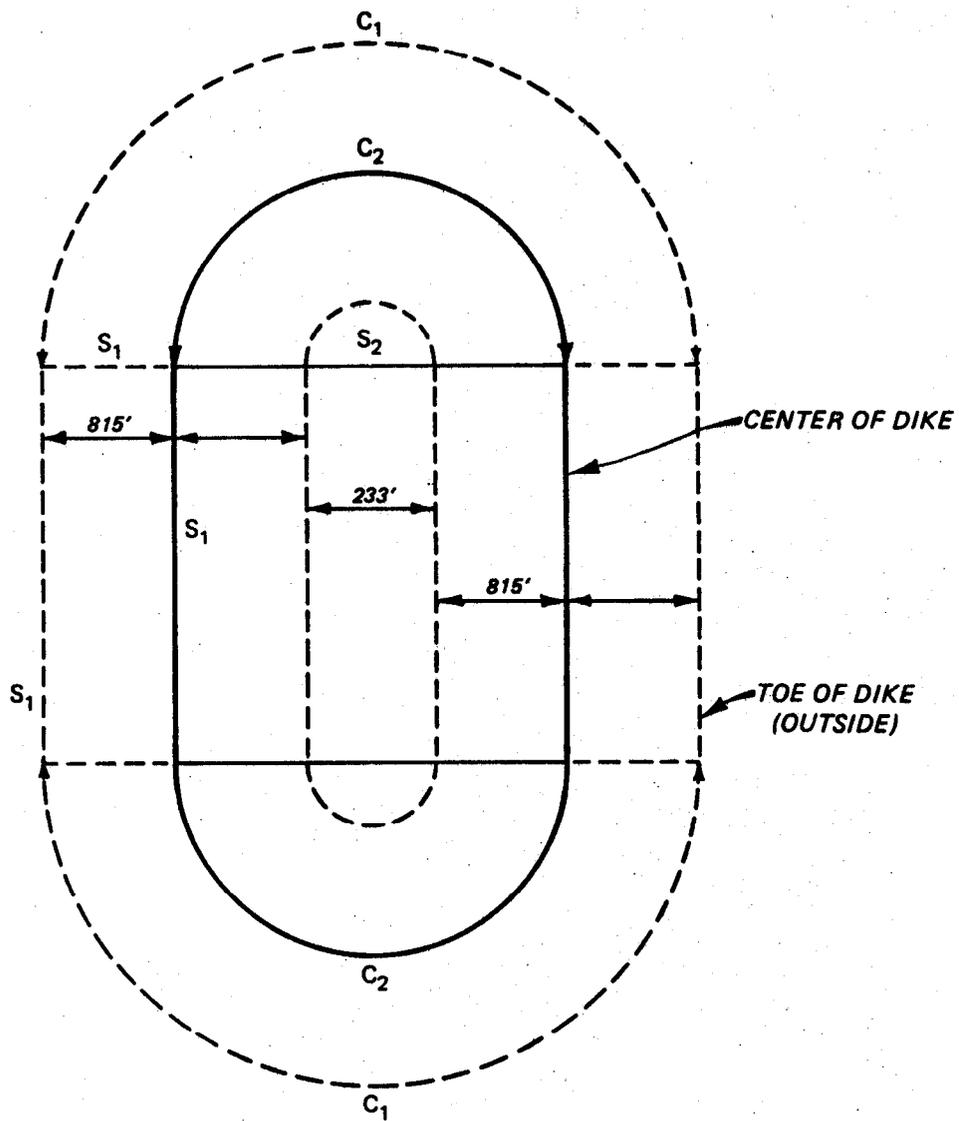


Figure 4. Plan view of containment island with sand dikes

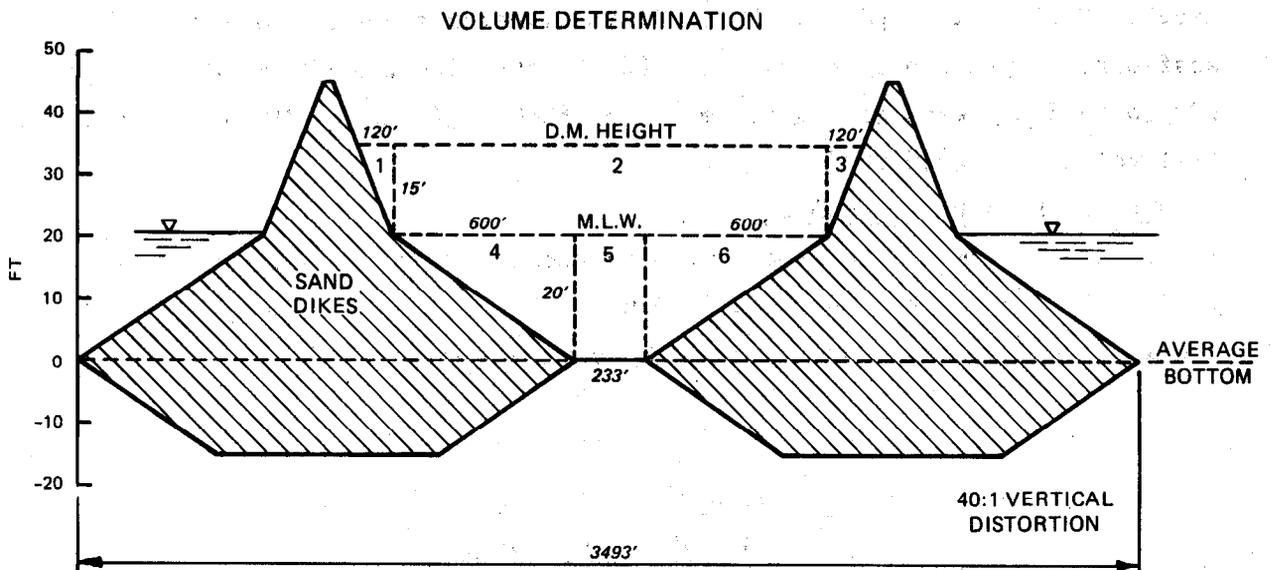


Figure 5. Storage volume determination for sand dikes

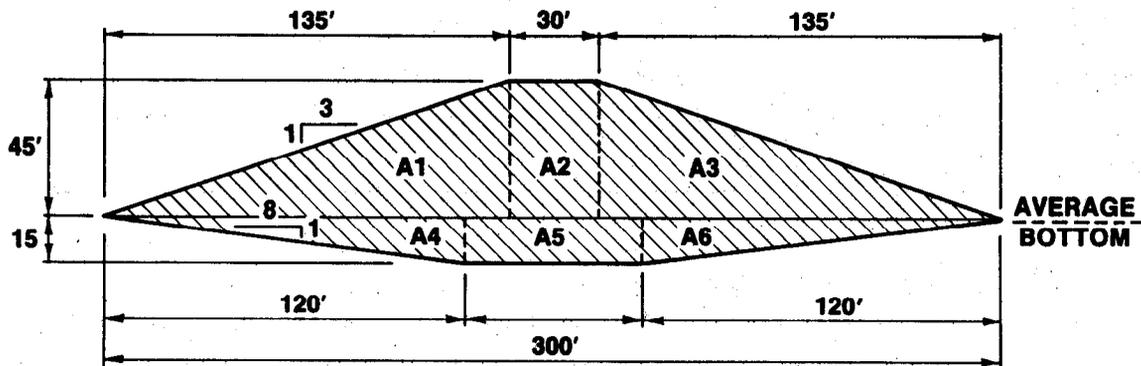


Figure 6. Cross-sectional view of rock dike

14. The inside face of the dike will be covered with filter stone, which will in turn be covered by an impermeable liner. The area of liner to cover the face of the dike and the bottom is 425 acres, as calculated in Appendix B. The storage volume of the rock dike island as calculated in Appendix B is  $22.7 \times 10^6 \text{ yd}^3$  if the material is placed from the existing sea bottom to 15 ft above sea level (msl).

#### Sheet pile cofferdam

15. A dike made up of sand-filled sheet pile cofferdams will be 25 ft above mean sea level and will penetrate into the bottom to a depth of 20 ft. The area to be lined is calculated in Appendix C as 515 acres. The area will hold  $28.2 \times 10^6 \text{ yd}^3$  of material from the sea bottom to 15 ft above mean sea

level. Cells will typically be 30 ft in diameter and rise 45 ft above the seafloor. Given a perimeter of 18,000 ft, the dike will be made of roughly 600 cofferdams, each with a volume of 31,808 ft<sup>3</sup> (1,200 yd<sup>3</sup>) for a total sand fill volume of 720,000 yd<sup>3</sup>.

Summary of required quantities

16. The amounts of rock and sand required for the sand, rock, and cofferdam dikes are given in Table 2 along with the area of liner required and the internal storage capacity of each type of construction.

Table 2  
Summary of Construction Material Quantities  
and Volumes for Storage

<u>Parameter</u>	<u>Sand Dike</u>	<u>Rock Dike</u>	<u>Sheet Pile Cofferdam</u>
Sand (10 <sup>6</sup> yd <sup>3</sup> )	20.9	--	0.7
Rock (10 <sup>3</sup> tons)	677	8,365	--
Liner (acres)	185	425	515
Storage volume (10 <sup>6</sup> yd <sup>3</sup> )	6.6	22.7	28.2

Storage versus dredging volumes

17. The storage volume described in the preceding section refers to the actual volume available in the containment area between the sea bottom and the height to which material is to be placed (i.e. 15 ft above msl). It is not equal to the in situ volume of material dredged or the bin (or hopper) volume transported to the site. The in situ and bin volumes should be fairly similar if clamshell or dragline dredges are used. However, water must be added to the bin to enable the material to be pumped into the containment area. This increases the volume added to the area by roughly a factor of 2.

18. Much of the additional water is released by the material during settling and consolidation. The amount of water released (i.e., amount by which the volume of material decreases) is highly dependent on how the site is managed. In later sections, a bin concentration of suspended solids is taken as 400 g/l while the final concentration is 600 g/l. This is only a rough estimate used in order to gain an appreciation for life of the site. Modeling

work is required to evaluate the effect of alternative management schemes on site life.

### Unit Prices

19. The quantities determined in the previous section can be multiplied by unit prices to determine costs. Unit prices for some major items are given in the following sections, plus a description of contingency, engineering and design (E&D), and supervision and administration (S&A) costs.

#### Sand

20. Sand to construct dikes and fill cofferdams is available in the vicinity of site A. The grain size of the sand ranges from medium to fine, and the sand is hence marginally acceptable for dike construction. Studies will need to be conducted to locate the coarsest sand available in the area for dike construction. Material can be hydraulically dredged and placed. Unit cost should be roughly  $\$2/\text{yd}^3$ .

21. For Sites B and C, material will need to be transported 5 and 10 miles respectively and will thus require booster pumping. Unit prices of  $\$3/\text{yd}^3$  and  $\$4/\text{yd}^3$  should be used for these sites based on cost data for operating hydraulic dredges in other districts.

#### Rock

22. The costs of rock quarrying, hauling, and placing are fairly uncertain because of the lack of quarry near the proposed islands. In some cost estimates for an earlier New York containment island (Telecopy from C. Coch), a cost of  $\$20/\text{ton}$  was used. To correct for inflation and uncertainty,  $\$30/\text{ton}$  will be used in this study.

#### Sheet pile cofferdam

23. Costs for nearshore sheet pile cofferdam construction of  $\$5,400/\text{ft}$  for a 60-ft dike were provided to C. Coch by D. Quinn of the New England Division\* based on a report by Sasaki Associates, 1984. Extrapolating the height to 65 or 70 ft to allow for penetration into the bottom gives a unit price of  $\$6,000/\text{ft}$  along the center line.

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\* Personal Communication, February 1985, Mr. Dick Quinn, New England Division, to Ms. Carol A. Coch, NYD, New York.

### Cover

24. Assuming a cover thickness of 3 ft and the fact that cover material can be dredged locally for  $\$2/\text{yd}^3$ , final cover of the sites should cost  $\$10,000/\text{acre}$ . However, the cover will not be required until the end of the project life, so the present worth of cover cost will be negligible compared with other costs.

### Liners

25. No data could be found on placing of a synthetic liner underwater. Chicago District did line an upland disposal area at a cost of  $\$12.34/\text{yd}^2$ . Allowing for considerably higher installation costs for placing a much larger liner in a marine environment, a cost of  $\$18/\text{yd}^2$  ( $\$88,000/\text{acre}$ ) will be used.

### Unloading facility

26. The cost of  $\$16$  million for an unloading facility as provided by C. Coch appears reasonable for this level of estimating and will be constant for all alternatives.

### Maintenance

27. A present worth of maintenance costs of  $\$16$  million as used by C. Coch appears reasonable for these estimates.

### Contingencies

28. A contingency of 25 percent will be used for island construction as recommended by Engineer Manual (EM) 1110-2-1301 (Office, Chief of Engineers 1980) for planning studies. Because of the uncertainty involved with constructing treatment facilities on an island and difficult access to the site, treatment costs will have a contingency of 50 percent.

### E&D and S&A

29. Allowances of 12 percent for E&D will be made because this will be a unique facility. Six percent for S&A will be used.

### Summary of unit prices

30. Unit prices and other cost factors to be used in this analysis are listed in Table 3.

### Island Costs

31. Combining the quantities required for island creation and the unit prices presented in the previous section gives the cost estimates listed in

Table 3  
Summary of Unit Prices and Other Cost Factors\*

<u>Cost Item</u>	<u>Unit Prices/ Cost Factors</u>
Sand (Site A)	\$2/yd <sup>3</sup>
Sand (Site B)	\$3/yd <sup>3</sup>
Sand (Site C)	\$4/yd <sup>3</sup>
Rock	\$30/ton
Sheet pile cofferdam	\$6,000/ft
Liner	\$88,000/acre
Unloading facility	\$16,000,000
Present worth maintenance	\$16,000,000
Contingencies (island)	25%
Contingencies (treatment)	50%
E&D	12%
S&I	6%

\* Multiply by 1.05 for May 1987 dollars.

Table 4. The final costs do not include the effluent treatment that is described in later sections.

32. From Table 4, it appears that the rock dike is too costly. The sand dike at Site A is least costly, but it has considerably less storage volume than the sheet pile cofferdam. In a later section, the island and treatment costs are combined to give unit costs for comparisons.

#### Determining Treatment Capacity

33. The solids balance for material placed in the island is given below and is shown in Figure 7.

$$Q_1 C_1 + Q_2 C_2 = Q_3 C_3 + Q_4 C_4 \quad (3)$$

Table 4  
Island Cost Summary (10<sup>6</sup>\$)\*

Cost Item	Sand Dike			Rock Dike	Sheet Pile Cofferdam
	Site A	Site B	Site C		
Sand	42	63	84	--	--
Rock	20	20	20	250	--
Cofferdam	--	--	--	--	108
Liner	16	16	16	37	45
Unloading facility	16	16	16	16	16
Subtotal	94	115	136	303	169
Contingency	<u>19</u>	<u>24</u>	<u>30</u>	<u>76</u>	<u>42</u>
Construction cost	113	139	166	379	211
E&D	11	15	18	45	25
S&A	<u>6</u>	<u>7</u>	<u>9</u>	<u>23</u>	<u>13</u>
Total first cost	130	161	193	447	249
Maintenance	<u>16</u>	<u>16</u>	<u>16</u>	<u>16</u>	<u>16</u>
Total cost	146	177	209	463	265

\* Multiply by 1.05 for May 1987 dollars.

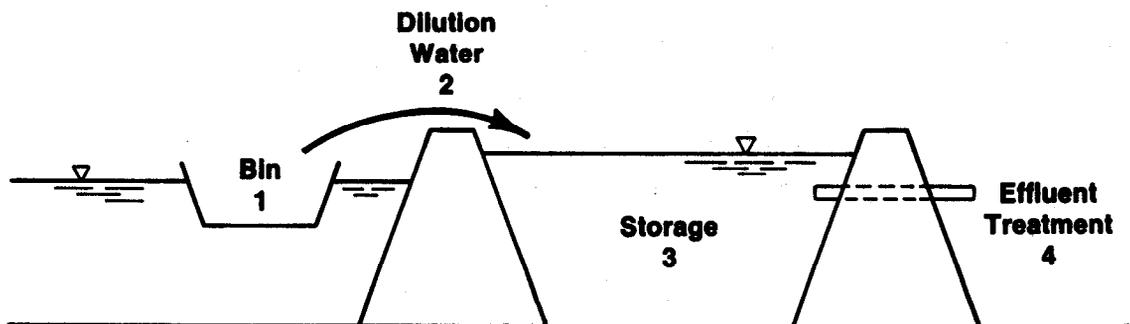


Figure 7. Solids balance

where

Q = volumetric flow rate, yd<sup>3</sup>/year

C = concentration, g/l

1 = bin

2 = dilution water

3 = contents of containment island  
 4 = discharge to treatment  
 $C_1 = 400 \text{ g/l}^*$   
 $C_3 = 600 \text{ g/l}^{**}$   
 $C_2 = C_4 = 0 \text{ g/l}$

$$Q_1 + Q_2 = Q_3 + Q_4 \quad (4)$$

Substituting for  $C_1$  in Equation 3 gives

$$Q_3 = 0.667Q_1 \quad (5)$$

$Q_1$  will have to be diluted with an equal volume of water to be pumpable; therefore,

$$Q_2 = Q_1 \quad (6)$$

Substituting Equations 5 and 6 into Equation 4 and solving for  $Q_4$  gives

$$Q_4 = 1.33 Q_1 \quad (7)$$

Since  $Q_1 = 169,000 \times 4 \text{ yd}^3/\text{year}^*$

$$Q_4 = 900,000 \text{ yd}^3/\text{year} = 2,500 \text{ yd}^3/\text{day} \quad (8)$$

Converting to gallons per day

$$Q_4 = 500,000 \text{ gpd} \quad (9)$$

$Q_4$  is the average flow that must be treated. Dredging activity will fluctuate throughout the year, but the ponded levels can be allowed to fluctuate to

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\* Personal Communication, February 1985, Ms. Carol A. Coch, Project Manager NYD, New York.

\*\* Personal Communication, Dr. Michael R. Palermo and Ms. Marian Poindexter, Environmental Engineering Division, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

maintain a fairly constant flow from the site. However, treatment equipment should be sized to handle a peak flow of twice average flow; therefore, a capacity of 1 mgd will be used for treatment equipment.

#### Approximate Filling Rates

34. If  $Q_4 = 900,000 \text{ yd}^3/\text{year}$ ,  $Q_3 = 450,000 \text{ yd}^3/\text{year}$ . This is a rough approximation of the rate of filling of the area. The sheet pile cofferdam will therefore fill in

$$\frac{28.2}{0.45} = 62 \text{ years} \quad (10)$$

while the sand dike area will fill in

$$\frac{6.62}{0.45} = 14.7 \text{ years} \quad (11)$$

It should be possible to extend the life of these sites with good management. Management techniques should include dewatering and trenching to promote desiccation and thus additional consolidation. More precise modeling that accounts for evaporation, consolidation, and drainage is required to better quantify the design life.

#### Treatment Costs

35. An overall layout of the containment island is shown in Figure 8 and a profile is shown in Figure 9. The details of the layout depend on the precise processes selected. The following levels of treatment are considered:

- a. Level 1. Coagulation and settling in polishing lagoon (basin that after chemical treatment promotes flocculation and settling to better clarify the effluent).
- b. Level 2. Filtration and chlorination.
- c. Level 3. Activated carbon.

36. Some of the above levels of treatment (settling, carbon adsorption) will remove a significant fraction of dissolved materials. Additional removal

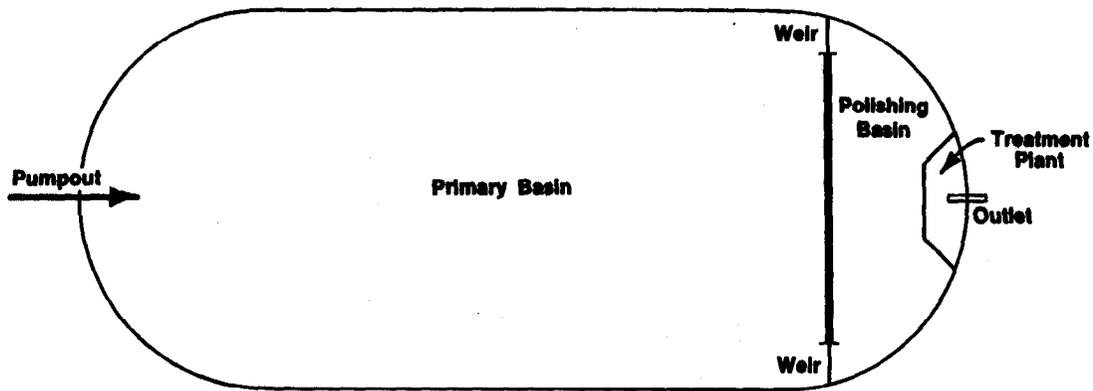


Figure 8. Plan view of island with treatment

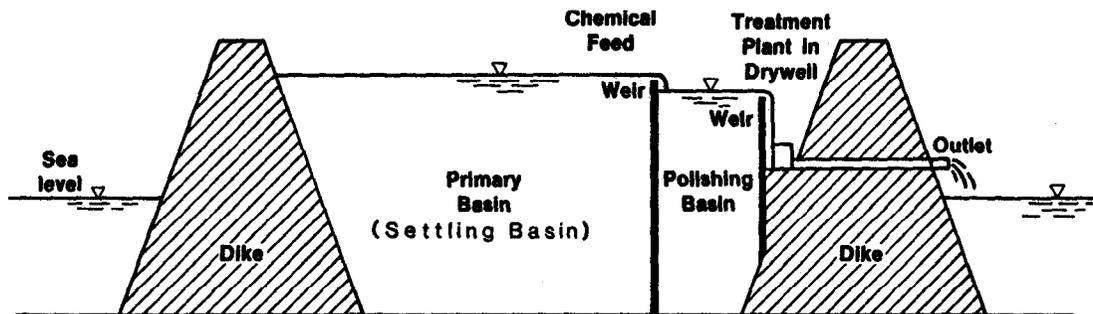


Figure 9. Island profile with treatment

will not only be extremely expensive but impractical in salt water since methods that remove all dissolved material, such as distillation, reverse osmosis, or electrodialysis, must be used. Reverse osmosis is the most likely process for removal of dissolved material. It will result in a drinking water quality effluent. The energy use for such removal is high, and energy will be very expensive on the containment island. Such processes are also highly susceptible to fouling and scaling. The present worth of such a process will be on the order of \$20 million. If specific ions are a problem, additional work may identify methods to selectively remove only those ions (e.g. ion exchange). Any sludge generated in treatment will be returned to the polishing lagoons.

Level 1: Coagulation and settling

37. Effluent from the primary basin can be treated to remove additional fine-grained material by adding polymer to the effluent at the weir connecting the basin to a second smaller basin called a polishing basin. The construction costs for this include the sheet pile wall separating the basins and the

chemical feed equipment. Operating costs include polymer, labor, and a small cost for pumping energy.

38. Since the difference in heads between the two basins will be small, a single sheet pile wall between the basins can be constructed to enclose approximately a 5-acre area that will serve as the polishing lagoon. Assuming the area is a circle with the main dike forming half of the circle, the length of the wall will vary depending on the type of containment area (sand or cofferdam) but should be approximately 1,000 ft. Special treatment to prevent leakage between the basins must be provided. The sheetpiling will need to be roughly 60 ft long, since it will be 35 ft from pond bottom to the top and should be embedded at least 25 ft (and braced) to avoid overturning. This gives a vertical area of  $60,000 \text{ ft}^2$ . No cost data could be found for placing such exposed sections of sheet piling, especially in open water. Therefore, some cost data from the Means Square Foot Costs (Strychaz 1983) were extrapolated to give  $\$40/\text{ft}^2$ . This yields a cost of  $\$2.4$  million.

39. Chemical feed and storage equipment to treat 1 mgd will depend on the dosage required and should cost only on the order of  $\$30,000$  based on data from Hansen, Gumerman, and Culp (1979). A small chemical storage and feed building should cost  $\$40,000$ . Data by Morgan, Walski, and Corey (1984) indicate that polymer costs on the order of  $\$2/\text{lb}$ , and dosages of  $5 \text{ mg}/\ell$  are typical. This gives a feed rate based on average flow of

$$(5 \text{ mg}/\ell)(8.34 \text{ lb}/\text{gal})(0.5 \text{ mgd}) = 20.8 \text{ lb}/\text{day} \quad (12)$$

or

$$(\$2/\text{lb})(20.8 \text{ lb}/\text{day})(365 \text{ day}/\text{yr}) = \$15,220/\text{year} \quad (13)$$

The present worth of this cost over 50 years at an interest rate of 10 percent is

$$(\$15,220/\text{year})(9.915) = \$151,000 \quad (14)$$

Operating and maintenance (O&M) labor plus process and building energy should cost roughly  $\$10,000/\text{year}$ , which results in a present worth  $\$100,000$ .

40. Summing the present worth of the components gives

<u>Component</u>	<u>10<sup>6</sup>\$</u>
Dikes	2.40
Feed equipment	0.07
Chemicals	0.15
Labor	<u>0.10</u>
Total	2.72

Applying the contingency factor gives  $\$4.08 \times 10^6$ .

41. Because of the high salinity of the material, it may not be necessary to use flocculation to achieve water of low suspended solids. Lab testing is required to see if this level of treatment is necessary before the basin is built.

#### Level 2: Filtration and chlorination

42. Because of the reasonably small flow to be treated, it is possible to use a package gravity filtration plant to filter and chlorinate the water. Some existing standard designs should be adequate. Since it is not the intent of this plant to produce potable water, fairly coarse sand can be used in the filters. After filtration, oxidation of metals by the chlorine should be negligible. The primary operational problem is providing adequate head to force water through the filter without needing additional pumping. This should be possible if the plant is placed in a dry well with an area of about 3,000 ft<sup>2</sup> at approximately sea level, as shown in Figure 9.

43. Costs for package filtration plants are taken from Hansen, Gumerman, and Culp (1979) as \$0.8 million. O&M costs, which include building and process energy and labor, should be on the order of \$80,000/year, which results in a present worth of \$0.8 million.

<u>Component</u>	<u>10<sup>6</sup>\$</u>
Construction	0.8
O&M (present worth)	<u>0.8</u>
Total	1.6

#### Level 3: Carbon adsorption

44. Carbon adsorption can remove dissolved organic chemicals from water. A detailed pilot study would be required to identify the required loading rate and detention time. Using cost data from Hansen, Gumerman, and

Culp (1979), a 7.5-min detention, a carbon loading rate of 1 gpm/ft<sup>3</sup>, 5-ft bed depth, and hydraulic loading rate of 5 gpm/ft<sup>2</sup>, the construction cost should be on the order of \$300,000. Labor and energy costs should be on the order of \$20,000/year or a present worth of \$200,000. Spent carbon will be disposed of in the primary settling basin. The plant should use on the order of 50 tons of granular activated carbon per year, which should cost on the order of \$100,000/year with a present worth of \$1,000,000.

45. The cost summary for the third level of treatment is

<u>Component</u>	<u>10<sup>6</sup>\$</u>
Construction	0.20
O&M	0.20
Carbon	<u>1.00</u>
Total	1.40

Total treatment costs

46. The costs for each level of treatment are summarized below. Level 2 treatment should not be used unless preceded by Level 1, unless, as mentioned, earlier lab testing indicates that it is possible to directly filter the effluent from the primary basin.

<u>Level</u>	<u>Cost in 10<sup>6</sup>\$*</u>		
	<u>Cost for Level</u>	<u>Cost w/50% Contingency</u>	<u>Cumulative Cost</u>
1 (settle)	2.7	4.1	4.1
2 (filter)	1.6	2.4	6.5
3 (carbon)	1.4	2.1	8.6

\* Multiply by 1.05 for May 1987 dollars.

Similarly, Level 3 should not be used without Level 2. Comparing the treatment costs with island construction costs, it becomes clear that treatment will be a fairly minor cost. Extensive treatability testing will of course be required to determine if the loading rates used are appropriate for the material.

## Unit Storage Costs

47. Dividing the total costs by the storage volume gives the unit costs listed in Table 5.

Table 5  
Unit Costs for Storage (\$/yd<sup>3</sup>)\*

<u>Dike Type</u>	<u>Without Treatment</u>	<u>With Treatment</u>
Sand dikes		
Site A	22.1	23.4
Site B	26.8	28.1
Site C	31.7	33.0
Rock dikes	20.4	20.8
Sheet pile cofferdam	9.4	9.7

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\* Multiply by 1.05 for May 1987 dollars.

### PART III: SUMMARY

48. Table 5 indicates that a sheet pile cofferdam island will have the lowest unit cost. This is due to the fact that it can be built vertically whereas sand dikes must have a fairly mild slope. Sand dikes will become much more attractive if the 500-acre island is defined along the center line of the dike instead of the outside toe of the dike.

49. The sand dikes have the lowest initial cost, which may make them attractive if financing construction becomes crucial. They may also be more aesthetically pleasing than cofferdams.

50. Additional work must be performed on suitability of sand in the harbor for island construction, methods to prevent leakage from sites, long-term consolidation of material and treatability of the material after it settles in the primary basin. Note that unit costs are based on volumetric storage, and additional work must be done to define the relationship between volume in storage and both in situ and hopper bin volume, which are of more interest to dredgers.

51. Since this site will hold contaminated material, leak prevention is a major concern. Because of the fairly steep slope on the rock dike and vertical slope on the sheet pile cofferdam, it will be difficult to place liners to prevent leakage from these sites. Since there will be 15 ft of head driving material through any cracks or pores, special attention to the interlocking of cofferdam sections will be required to prevent leakage. Because of the milder slopes, it should be easier to prevent leakage from the sand dikes using synthetic liners.

52. Site A appears to be more attractive based on costs for sand dikes. It may also be less costly because it is closer to the dredging sites, which should reduce dredging costs.

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## APPENDIX A: CALCULATION OF QUANTITIES FOR SAND DIKE ISLAND

1. This appendix presents the procedures and calculations used to determine design quantities for the sand dike containment island. Quantities calculated include:

- a. Sand dike cross-sectional area.
- b. Length along dike center.
- c. Volume of sand for dike construction.
- d. Storage volume available in the island.
- e. Liner area.
- f. Riprap area.

### Sand Dike Cross-Sectional Area

2. Component areas (A1-A9) of the sand dike cross section shown as Figure A1 are calculated below and then summed to determine the total cross-sectional area of the sand dike.

#### Component areas

$$\begin{aligned} \text{A1: } A1 &= 1/2(200 \text{ ft})(25 \text{ ft}) \\ &= 2,500 \text{ ft}^2 \end{aligned}$$

$$\begin{aligned} \text{A2: } A2 &= 30 \text{ ft}(25 \text{ ft}) \\ &= 750 \text{ ft}^2 \end{aligned}$$

$$\begin{aligned} \text{A3: } A3 &= A1 \text{ (by symmetry)} \\ &= 2,500 \text{ ft}^2 \end{aligned}$$

$$\begin{aligned} \text{A4: } A4 &= 1/2(600 \text{ ft})(20 \text{ ft}) \\ &= 6,000 \text{ ft}^2 \end{aligned}$$

$$\begin{aligned} \text{A5: } A5 &= (430 \text{ ft})(20 \text{ ft}) \\ &= 8,600 \text{ ft}^2 \end{aligned}$$

$$\begin{aligned} \text{A6: } A6 &= A4 \text{ (by symmetry)} \\ &= 6,000 \text{ ft}^2 \end{aligned}$$

$$\begin{aligned} \text{A7: } A7 &= 1/2(450 \text{ ft})(15 \text{ ft}) \\ &= 3,375 \text{ ft}^2 \end{aligned}$$

$$\begin{aligned} \text{A8: } A8 &= (730 \text{ ft})(15 \text{ ft}) \\ &= 10,950 \text{ ft}^2 \end{aligned}$$

$$\begin{aligned} \text{A9: } A9 &= A7 \text{ (by symmetry)} \\ &= 3,375 \text{ ft}^2 \end{aligned}$$

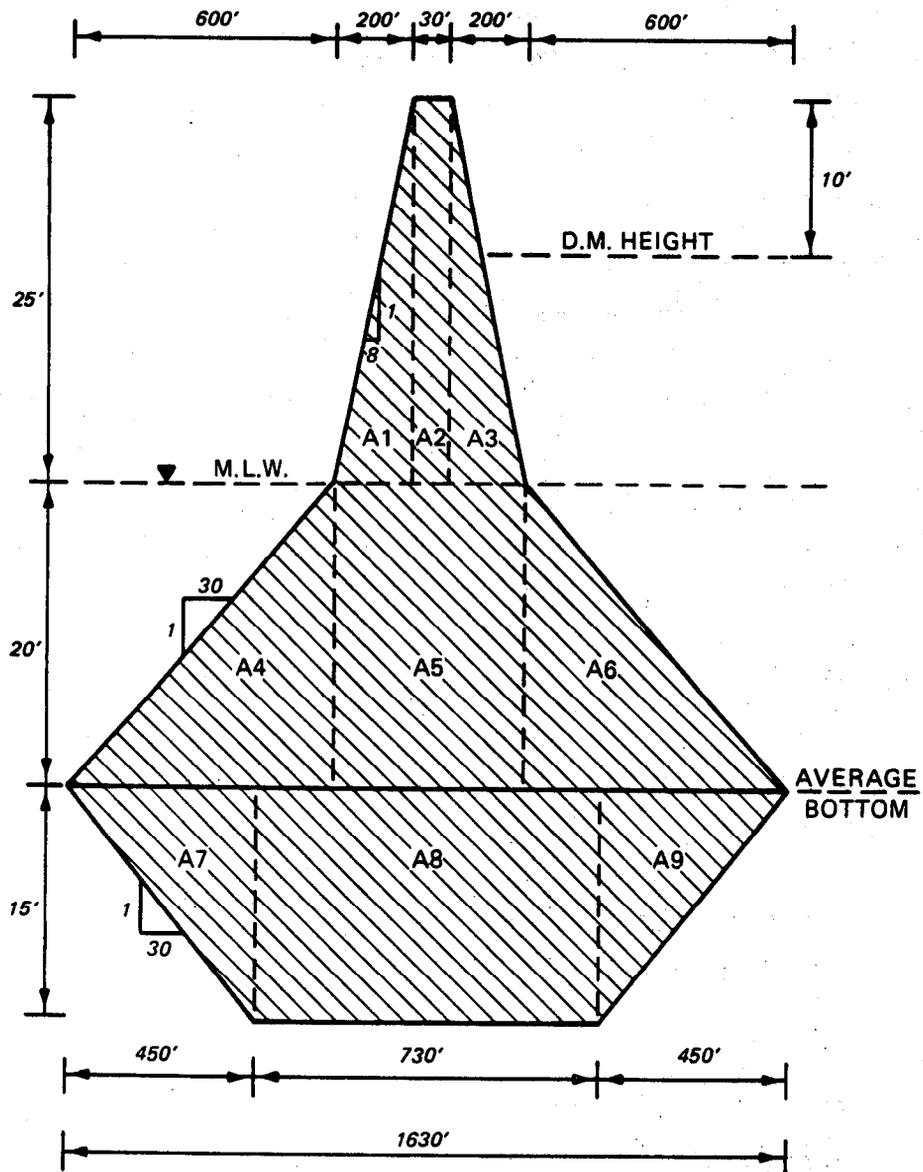


Figure A1. Sand dike cross section

Total area

$$\text{Total} = \sum_{i=1}^9 A_i$$

$$\text{Total} = 44,050 \text{ ft}^2$$

Length Along Dike Center

3. The length along the sand dike center is calculated below. This length consists of the arc sections  $C_2$  and straight sections  $S_1$ , as labeled on Figure A2.

Straight section length:  $S_1$

$$\begin{aligned} \text{Area} &= S_1^2 + 2 \left[ \frac{\pi \left( \frac{S_1}{2} \right)}{2} \right]^2 \\ &= S_1^2 + \pi \left( \frac{S_1}{2} \right)^2 \end{aligned}$$

$$\text{Area} = 500 \text{ acres} = 21,780,000 \text{ ft}^2 \text{ (assumed maximum area for island)}$$

$$21,780,000 \text{ ft}^2 = S_1^2 + \frac{\pi}{4} S_1^2$$

$$21,780,000 \text{ ft}^2 = \left(1 + \frac{\pi}{4}\right) S_1^2$$

$$S_1^2 = 12,198,960 \text{ ft}^2$$

$$S_1 = 3,493 \text{ ft}$$

Arc length:  $C_2$

$$S_2 = S_1 - 2(815 \text{ ft}) = 1,863 \text{ ft}$$

$$C_2 = 1/2(2\pi r)$$

$$= \pi \left( \frac{S_2}{2} \right)$$

$$= \pi \left( \frac{1,863}{2} \right)$$

$$C_2 = 2,926 \text{ ft}$$

Total dike length

$$\text{Total} = 2S_1 + 2C_2$$

$$= 2(3,493) + 2(2,926)$$

$$= 12,837 \text{ ft}$$

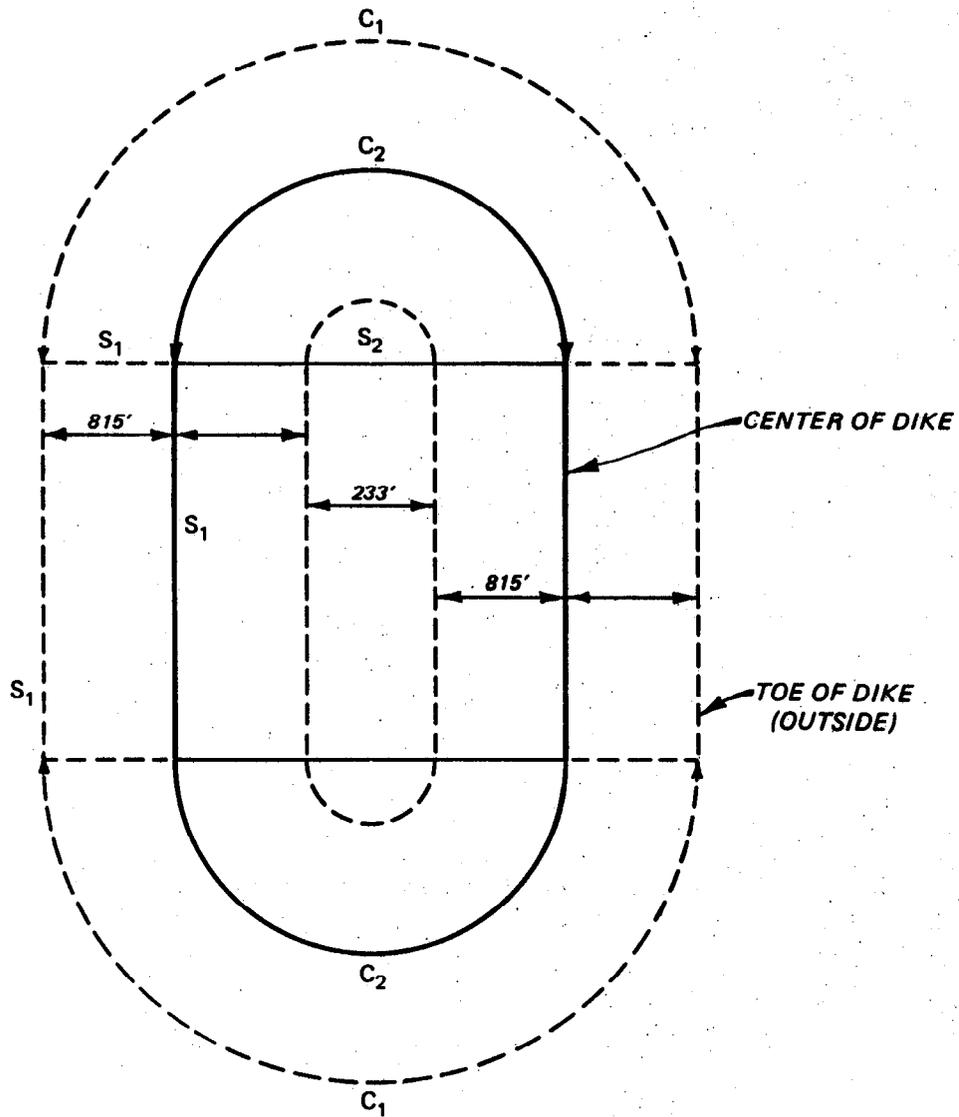


Figure A2. Plan view of containment area with sand dikes

Volume of Sand for Dike Construction

4. The volume of sand required for the dike can now be estimated as follows:

$$\begin{aligned}
 \text{Volume} &= \text{total dike length} \times \text{cross-sectional area} \\
 &= 12,837 \text{ ft} \times \frac{44,050 \text{ ft}^2}{27} \\
 &= 20,943,706 \text{ yd}^3
 \end{aligned}$$

## Storage Volume of Island

5. The available storage volume of the sand dike containment island for the given configuration (Figure A3) is calculated on the following pages.

6. Component cross-sectional areas (1-6) as shown in Figure A4 are calculated as follows. A total cross-sectional area is thus obtained for Section 1A of Figure A3; the storage volume is also determined for that section. The storage volumes for Sections 2A and 2B are also calculated.

### Section 1A: Component cross-sectional areas

$$\begin{aligned}\text{Section 1: } A &= 1/2(120 \text{ ft}) 15 \text{ ft} \\ &= 900 \text{ ft}^2\end{aligned}$$

$$\begin{aligned}\text{Section 2: } A &= (1,433 \text{ ft}) 15 \text{ ft} \\ &= 21,495 \text{ ft}^2\end{aligned}$$

$$\begin{aligned}\text{Section 3: } 1 \text{ and } 3 \text{ (symmetric)} \\ &= 900 \text{ ft}^2\end{aligned}$$

$$\begin{aligned}\text{Section 4: } A &= 1/2(600 \text{ ft}) 20 \text{ ft} \\ &= 6,000 \text{ ft}^2\end{aligned}$$

$$\begin{aligned}\text{Section 5: } A &= (233 \text{ ft}) 20 \text{ ft} \\ &= 4,660 \text{ ft}^2\end{aligned}$$

$$\begin{aligned}\text{Section 6: } 4 \text{ and } 6 \text{ (symmetric)} \\ A &= 6,000 \text{ ft}^2\end{aligned}$$

### Total area

$$\begin{aligned}A_{\text{total}} &= [2(900) + 2(6,000) + 21,495 + 4,660] \text{ ft}^2 \\ &= 39,955 \text{ ft}^2\end{aligned}$$

### Volume Section 1A

$$\begin{aligned}V_1 &= 39,955 \text{ ft}^2 \times \frac{3,493 \text{ ft}}{27} \\ &= 5,168,993 \text{ yd}^3\end{aligned}$$

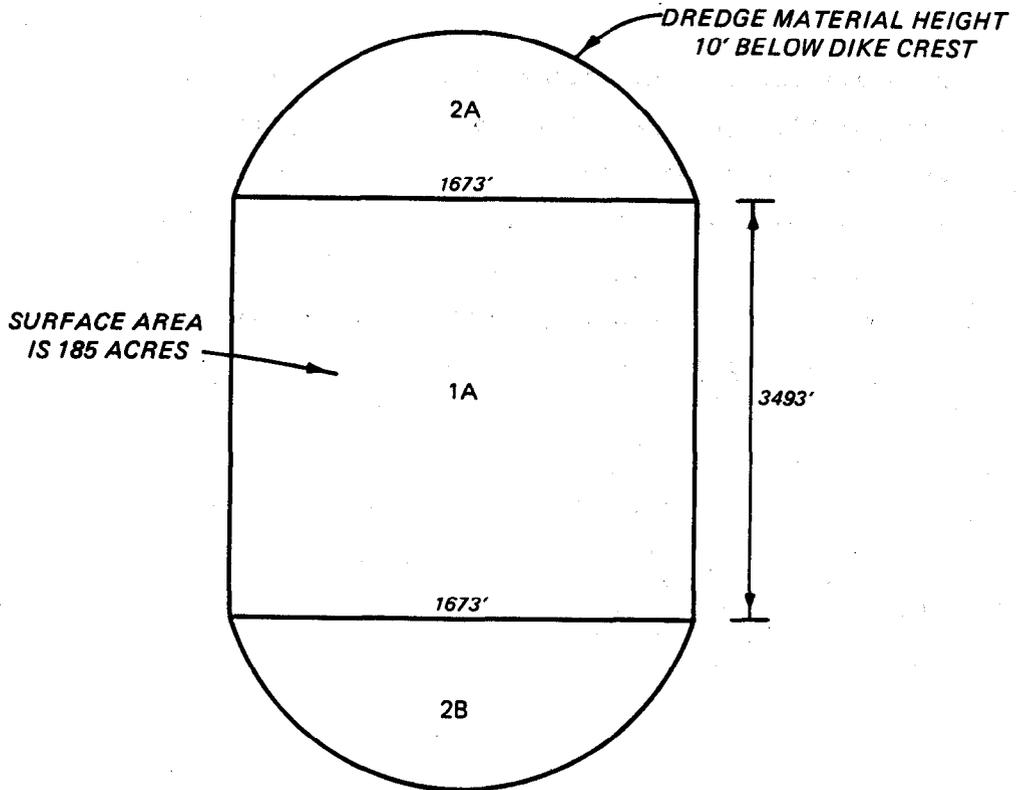
### Volume Sections 2A and B, Part 1

$$\text{Volume of cylinder} = \pi r^2 h$$

where

$$h = \text{height} = 15 \text{ ft}$$

$$r = \text{radius} = \frac{\text{diam @ } h = 7.5 \text{ ft}}{2} = \frac{1,553}{2} = 776.5 \text{ ft}$$



SECTIONS 2A & 2B ARE VOLUMETRICALLY SIMILAR

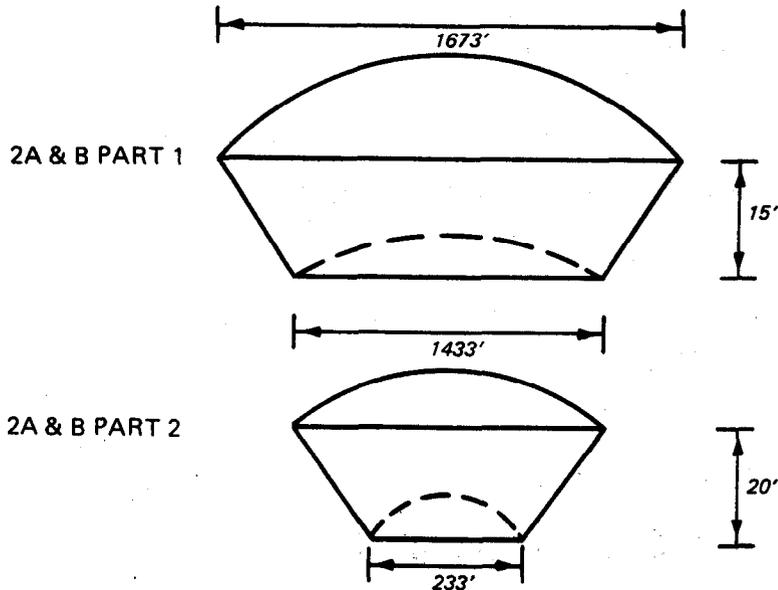


Figure A3. Area and section layout for storage volume determination (with sand dikes)

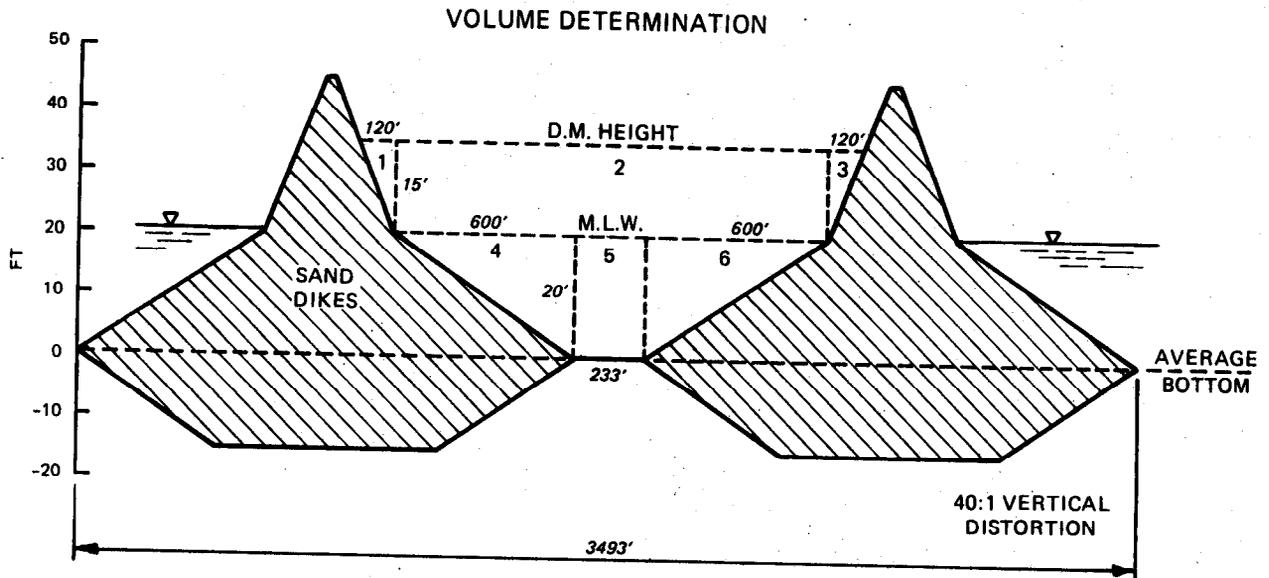


Figure A4. Storage volume determination for the sand dike containment island

$$v = \pi(776.5 \text{ ft})^2 \frac{15 \text{ ft}}{27}$$

$$v = 1,052,350 \text{ yd}^3$$

Volume Sections 2A and B, Part 2

where

$$h = 20 \text{ ft}$$

$$r = \frac{\text{diam @ } h = 10 \text{ ft}}{2} = \frac{833 \text{ ft}}{2} = 416.5 \text{ ft}$$

$$v = 403,688 \text{ yd}^3$$

Total volume with 10-ft free board

$$\text{Total volume} = 6,625,031 \text{ yd}^3$$

Liner Area Required

7. The liner area can be estimated from Figure A3 as the enclosed surface area at 10 ft below the dike crest.

$$\text{Area} = LW + \pi r^2$$

$$= 3,493 \text{ ft} (1,673 \text{ ft}) + \pi \left( \frac{1,673 \text{ ft}}{2} \right)^2$$

$$\text{Area} = 185 \text{ acres}$$

## Riprap Area

8. The riprap coverage area is calculated for the 1 on 8 inside and outside slopes from the dike crest to the 1 on 30 slope.

### Inside area of curved sections

$$\text{Area} = 2\pi \left( \frac{d_T + d_B}{2} \right) (S)$$

S = surface slope distance

$d_T$  and  $d_B$  = top and bottom section diameters respectively

$$S = \sqrt{(25^2 + 200^2)} = 202 \text{ ft}$$

$$\begin{aligned} A &= 2\pi \left( \frac{1,833 + 1,433}{2} \right) (202) \\ &= 2,072,609 \text{ ft}^2 \end{aligned}$$

### Inside and outside area of straight section

$$\begin{aligned} A &= 2[(3,493)(202)] \\ &= 1,408,000 \text{ ft}^2 \end{aligned}$$

### Total riprap area

9. Assuming equal inside and outside areas for the 1 on 8 dike section, a total riprap area can be estimated as follows:

$$\begin{aligned} \text{Total riprap area} &= 2(2,072,609 + 1,408,000) \text{ ft}^2 \\ &= 6,961,000 \text{ ft}^2 \end{aligned}$$

APPENDIX B: CALCULATION OF QUANTITIES FOR ROCK DIKE ISLAND

1. Estimates of design quantities for the rock dike island are calculated in this appendix. Estimates are given for the following:

- a. Rock dike cross-sectional area.
- b. Length along dike center.
- c. Volume of rock required for dike construction.
- d. Storage volume available.
- e. Liner area required.

Rock Dike Cross-Sectional Area

2. The total cross-sectional area of the rock dike is determined below from the summation of all component areas (A1-A6) of Figure B1.

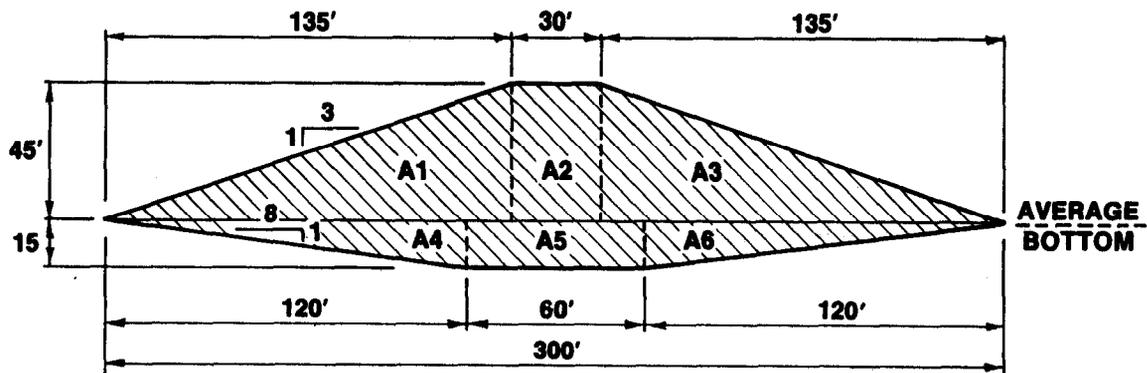


Figure B1. Rock dike cross section

Component areas

A1:  $A1 = 1/2(135 \text{ ft})(45 \text{ ft})$   
 $= 3,037.5 \text{ ft}^2$

A2:  $A2 = 30 \text{ ft} (45 \text{ ft})$   
 $= 1,350 \text{ ft}^2$

A3:  $A3 = A1$  (symmetric)  
 $= 3,037.5 \text{ ft}^2$

A4:  $A4 = 1/2(120 \text{ ft})(15 \text{ ft})$   
 $= 900 \text{ ft}^2$

A5:  $A5 = 60 \text{ ft} (15 \text{ ft})$   
 $= 900 \text{ ft}^2$

A6:  $A_6 = A_4$  (symmetric)  
 $= 900 \text{ ft}^2$

Total area

$A_{\text{total}} = A_1 + A_2 + A_3 + A_4 + A_5 + A_6$   
 $= 10,125 \text{ ft}^2$

Length Along Dike Center

3. The length along the rock dike center consists of the arc sections  $C_2$  and straight sections  $S_1$  as shown in Figure B2. The length is calculated as follows:

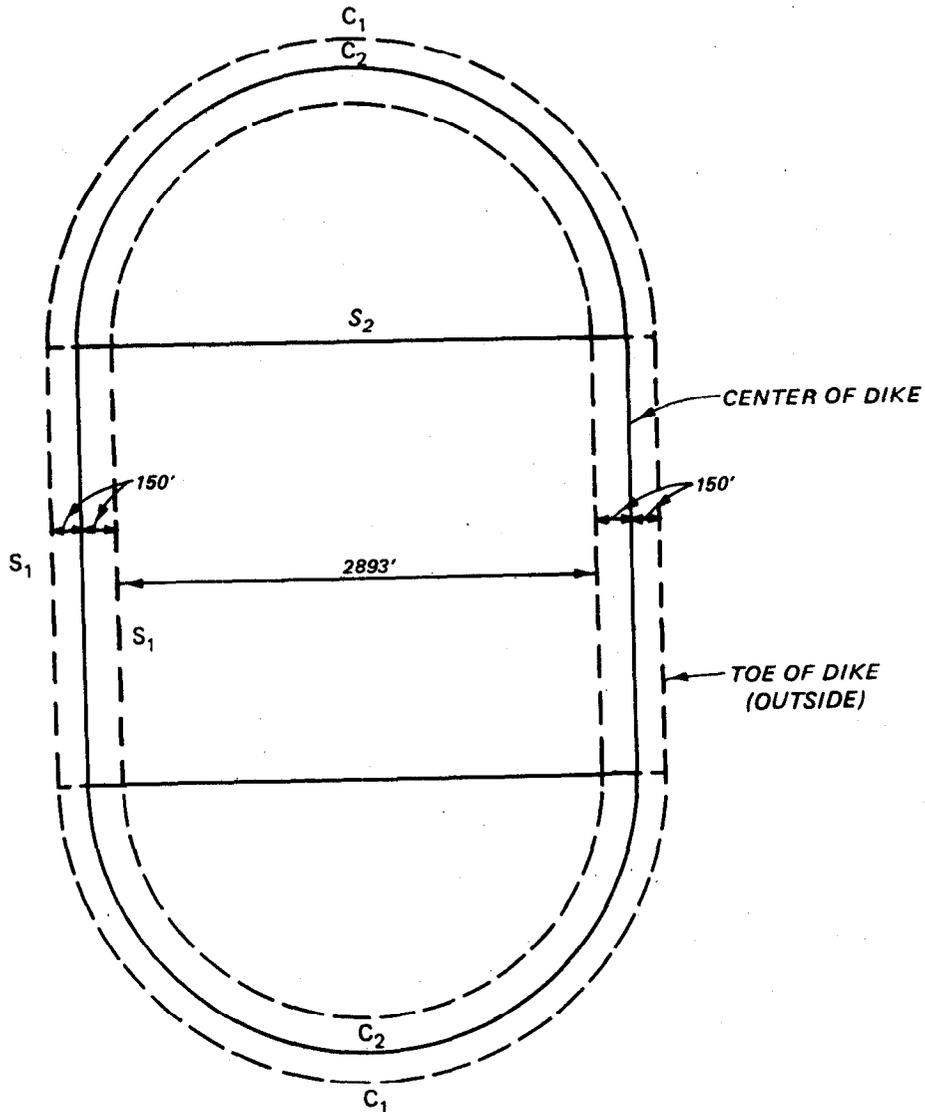


Figure B2. Plan view of rock dike containment island

### Straight section length

$$\begin{aligned}\text{Total} &= 2 \times 3,493 \text{ ft} \\ &= 6,986 \text{ ft}\end{aligned}$$

### Arc length

$$\begin{aligned}\text{Total} &= 2\pi r ; r = \frac{S_2}{2} \\ &= 2\pi \left( \frac{3,193 \text{ ft}}{2} \right) \\ &= 10,031 \text{ ft}\end{aligned}$$

### Total dike length

$$\begin{aligned}6,986 \text{ ft} + 10,031 \text{ ft} &= 17,017 \text{ ft} \\ \text{Total dike} &= 17,017 \text{ ft}\end{aligned}$$

### Volume of Rock for Dike Construction

4. The volume of rock required for the dike is calculated as follows:

Volume = total dike length  $\times$  cross-sectional area

$$\begin{aligned}&= 17,017 \text{ ft} \times \frac{10,125 \text{ ft}^2}{27} \\ &= 6,381,375 \text{ yd}^3\end{aligned}$$

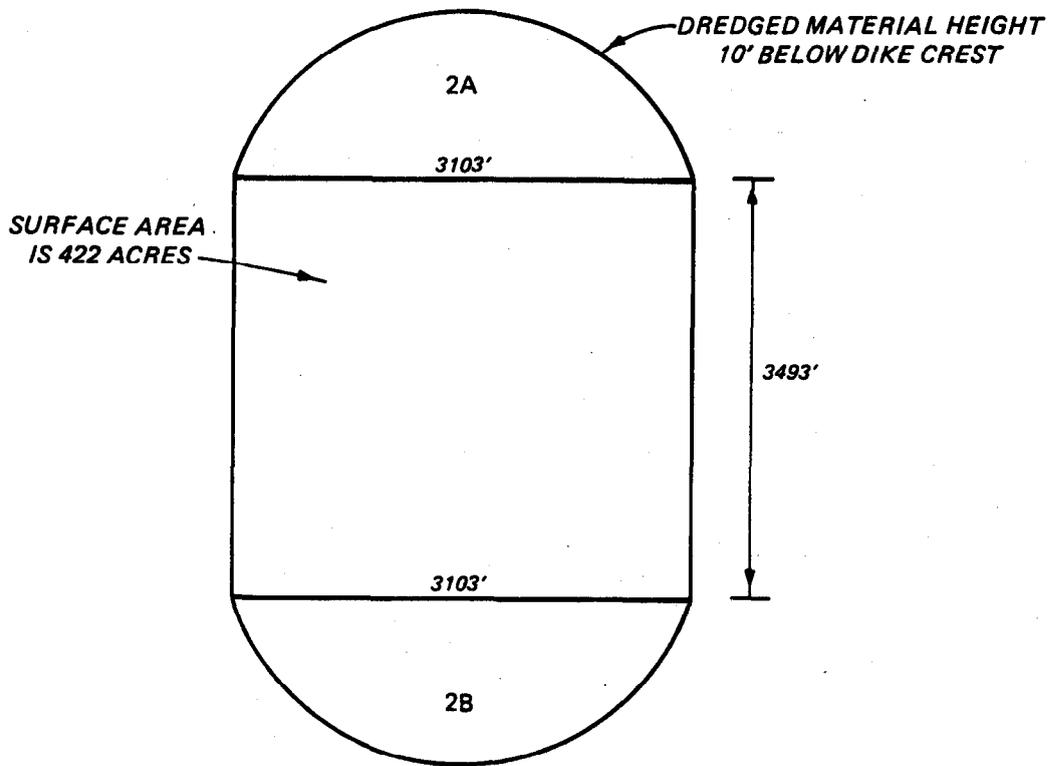
### Storage Volume of Island

5. The available storage volume of the rock dike containment island for the given configuration (Figure B3) is calculated as follows:

6. Component cross-sectional areas (A1, A2, and A3) as shown in Figure B4 are calculated below. These areas are summed for a total area; a volume for Section 1 (so labeled on Figure B3) is then calculated. Volumes for Sections 2A and 2B are also calculated.

#### Section 1: Component cross-sectional areas

$$\begin{aligned}\text{A1: } A1 &= 1/2 bh \\ &= 1/2(105 \text{ ft}) 35 \text{ ft} \\ &= 1,837.5 \text{ ft}^2 \\ \text{A2: } A2 &= bh \\ &= 2,892.7 \text{ ft} (35 \text{ ft}) \\ &= 101,244.5 \text{ ft}^2\end{aligned}$$



SECTIONS 2A & 2B ARE VOLUMETRICALLY SIMILAR

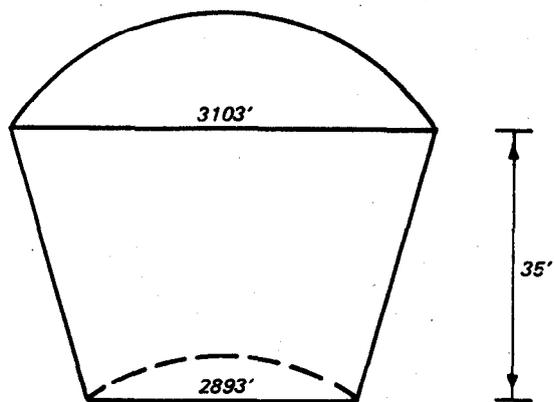


Figure B3. Area and section layout for storage volume determination (with rock dikes)

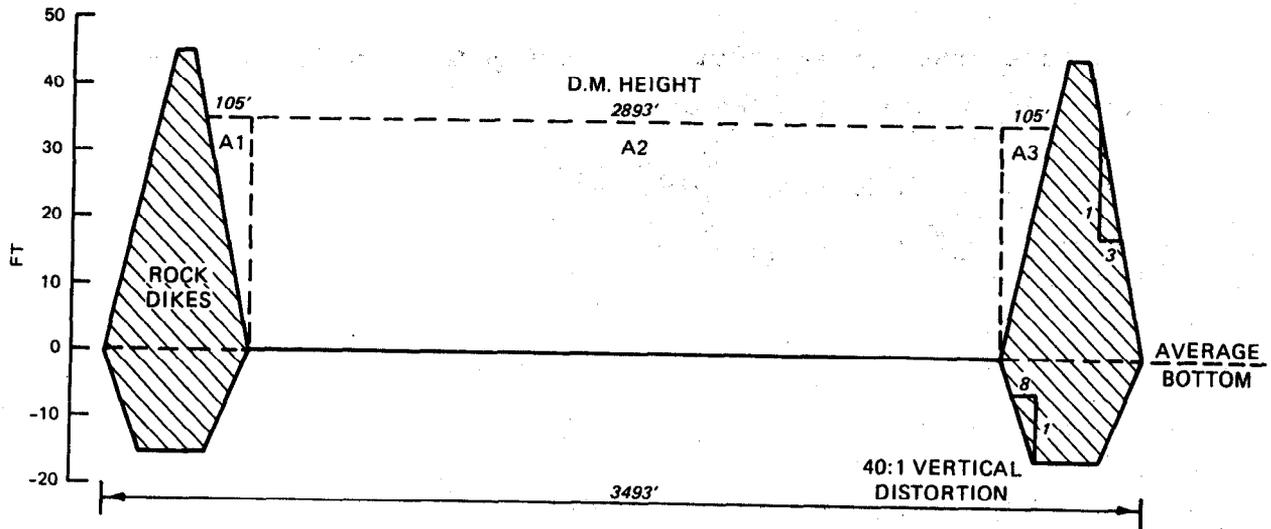


Figure B4. Storage volume determination for the rock dike containment island

$$\begin{aligned} A3: A3 &= A1 \text{ (symmetric)} \\ &= 1,837.5 \text{ ft}^2 \end{aligned}$$

Total area

$$\begin{aligned} \text{Total} &= A1 + A2 + A3 \\ &= 104,920 \text{ ft}^2 \end{aligned}$$

Volume Section 1

$$v = 104,920 \text{ ft}^2 \times \frac{3,493 \text{ ft}}{27}$$

$$v_1 = 13,573,540 \text{ yd}^3$$

Volume Sections 2A and 2B

$$\text{Volume} = \pi r^2 h$$

where

$$h = \text{height} = 35 \text{ ft}$$

$$r = \text{radius} = \frac{\text{diam @ } h = 17.5 \text{ ft}}{2} = \frac{2,998}{2} = 1,499 \text{ ft}$$

$$v = 9.15 \times 10^6 \text{ yd}^3$$

Total volume with 10-ft free board

$$\text{Total volume} = 22.75 \times 10^6 \text{ yd}^3$$

### Liner Area Required

7. The liner area can be estimated from Figure B3 as the enclosed surface area at 10 ft below the dike crest.

$$\begin{aligned} \text{Area} &= 3,493 \text{ ft} (3,103 \text{ ft}) + \pi \left( \frac{3,103 \text{ ft}}{2} \right)^2 \\ &= 18.4 \times 10^6 \text{ ft}^2 \text{ or } 425 \text{ acres} \end{aligned}$$

## APPENDIX C: CALCULATION OF QUANTITIES FOR SHEET PILE COFFERDAM ISLAND

1. Design quantities are estimated for the sheet pile cofferdam island. These quantities include:

- a. Length along dike.
- b. Storage volume available.
- c. Liner area.

### Length Along Dike

2. The length along this dike can be estimated from the outside boundary (or Toe of Dike-Outside) for the sand dike given in Figure A2 of Appendix A. This boundary will enclose an area of approximately 500 acres. The length is determined as follows:

Straight section length:  $S_1$

$$S_1 = 3,493 \text{ ft (as calculated in Appendix A)}$$

$$\text{Total } S_1 = 2(3,493) = 6,986 \text{ ft}$$

Arc section length

$$\text{Arc} = 2\pi r$$

$$= 2\pi \left( \frac{3,493}{2} \right)$$

$$= 10,973 \text{ ft}$$

Total dike length

$$\text{Total} = 6,986 + 10,973$$

$$= 17,959 \text{ ft}$$

### Storage Volume Available

3. The storage volume of the sheet pile cofferdam island to 10 ft below the dike crest can be calculated as follows:

$$\text{Volume} = Lwh + \pi r^2 h$$

$$= \frac{3,493 \text{ ft} (3,493 \text{ ft}) 35 \text{ ft} + \pi \left( \frac{3,493 \text{ ft}}{2} \right)^2 35 \text{ ft}}{27}$$

$$= 28,238,169 \text{ yd}^3$$

## Liner Area

4. The bottom surface liner area will be approximately 500 acres. Accounting for the area up and around the dike walls, an estimated 515 acres of liner will be needed. Estimates were obtained as follows:

### Average bottom surface

$$\begin{aligned} A &= LW + \pi r^2 \\ &= \frac{(3,493 \text{ ft}) 3,493 \text{ ft} + \pi \left(\frac{3,493 \text{ ft}}{2}\right)^2}{43,560} \\ &= 500 \text{ acres} \end{aligned}$$

### Side planes of dike

$$\begin{aligned} A &= 2Lh + 2\pi rh \\ &= \frac{2(3,493 \text{ ft})(35 \text{ ft}) + 2\pi \left(\frac{3,493 \text{ ft}}{2}\right) 35 \text{ ft}}{43,560} \\ &= 15 \text{ acres} \end{aligned}$$

### Total liner

$$\begin{aligned} \text{Total} &= 500 + 15 \\ &= 515 \text{ acres} \end{aligned}$$