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ERMINAL ISLAND SEWAGE TREATMENT
LANT OUTFALL, LOS ANGELES HARBOR,
CALIFORNIA

Hydraulic Model Investigation

by

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Proposed relocations of the Terminal Island Treatment Plant outfall in Los Angeles Harbor were tested in a physical hydraulic model of Los Angeles and Long Beach Harbors, California. The model, with length scales of 1:100 vertically and 1:400 horizontally, reproduced proposed plans of harbor modifications that included dredging and landfill in Los Angeles Harbor and dredging and construction of an oil loading pier in Long Beach Harbor. Five potential locations of the outfall were tested for conditions of a mean tidal
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20. **ABSTRACT (Continued)**

range, a modeled effluent representing a prototype effluent of 10 ppt and 76°F discharging into receiving water of 34 ppt and 60°F. The model effluent was dyed red and photographed as it moved through the harbors. Outfall locations along the face of the proposed Los Angeles phase I landfill produced a plume that generally followed an eastward curving path toward the breakwater, passing out through Angel's Gate with ebb phase flows. During flood phase flows some dye moved back northward toward the outfall location. One location, near the western edge of the proposed landfill, showed an instability in direction of plume travel, moving westward at times. Tests of two locations were performed with a possible phase II landfill installed in the model. These tests showed that the outfall location behind the island produced a buildup of dye in that area, whereas a location on the southern (ocean) side of the island permitted dye to readily escape from the harbors via Angel's Gate.

degrees

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PREFACE

This study was performed at the U. S. Army Engineer Waterways Experiment Station (WES) with funding provided by the City of Los Angeles, California, under terms of WES Agreement 75-5 as amended. The Los Angeles and Long Beach Harbors model was constructed with funds provided by the U. S. Army Engineer District, Los Angeles.

Personnel of the WES Hydraulics Laboratory performed the work described herein during the period July-October 1978 under the direction of Mr. H. B. Simmons, Chief of the Hydraulics Laboratory; Mr. F. A. Herrmann, Assistant Chief of the Hydraulics Laboratory; Mr. R. A. Sager, Chief of the Estuaries Division; Dr. R. W. Whalin, Chief of the Wave Dynamics Division; and Mr. G. M. Fisackerly, Chief of the Harbor Entrance Branch. Mr. W. H. McAnally, Jr., was Project Engineer, and Mr. J. T. Hilbun was Senior Engineering Technician. Mr. McAnally prepared this report. The invaluable advice and assistance of Mr. M. J. Trawle is gratefully acknowledged.

Project monitors for the City of Los Angeles were Messrs. C. S. Todd and J. E. Batey of the City Engineer's Office.

Commander and Director of WES during the course of this study was COL John L. Cannon, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. Customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
gallons per day	3.785412	cubic decimetres per day
inches	25.4	millimetres
miles (U. S. statute)	1.609344	kilometres
square feet	0.09290304	square metres
square miles (U. S. statute)	2.589988	square kilometres

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C = (5/9) (F - 32). To obtain Kelvin (K) readings, use: K = (5/9)(F - 32) + 273.15.

TERMINAL ISLAND SEWAGE TREATMENT PLANT OUTFALL

LOS ANGELES HARBOR, CALIFORNIA

Hydraulic Model Investigation

PART I: INTRODUCTION

Objectives

1. The purpose of the tests described herein was to show behavior of the effluent plume from proposed locations of the Terminal Island Sewage Treatment Plant outfall in Los Angeles Harbor.

Background

2. The Corps of Engineers plans a dredging and landfill project in Los Angeles Harbor. The proposed landfill configuration covers the area where the outfall from the City of Los Angeles' Terminal Island Sewage Treatment Plant currently lies; therefore relocation of the outfall is required. Previous model tests were conducted for discharge of the treatment plant effluent in the proposed LNG (liquified natural gas) facility slip adjacent to Fish Harbor. Subsequently, plans for the proposed LNG facility in Los Angeles Harbor were abandoned and the landfill configuration was altered accordingly. The tests described herein were then requested for alternate outfall locations.

PART II: SAN PEDRO BAY

3. San Pedro Bay is formed by the curvature and indentation of the southern California coastline (Figure 1). Sheltered to the west by Point Fermin, the bay is open to the south and southeast except for the slight protection offered by Catalina Island. Originally an open bay, the protection afforded by its orientation has been augmented by an 8-mile-long* breakwater extending from Point Fermin eastward to near Seal Beach (Figure 2).

4. The breakwater consists of three sections. The San Pedro breakwater (oldest of the three) is 11,000 ft long and extends from the shoreline east of Point Fermin to Angel's Gate, which is the navigation opening for Los Angeles Harbor and is 2,100 ft wide. The Middle breakwater is 18,500 ft long and extends from Angel's Gate to Queen's Gate, which is the navigation opening for Long Beach Harbor and is 1,800 ft wide. The Long Beach breakwater is the third section of the breakwater and extends 13,350 ft due east of Queen's Gate.

5. The San Pedro breakwater is of rubble-mound construction with a cap of granite blocks to an elevation of 14 ft above mean lower low water (mllw). The Middle and Long Beach breakwaters are of rubble-mound construction, but unlike the San Pedro section have sand cores (impermeable for all practical purposes) to elevations of -26 and -24 ft mllw, respectively.

6. Tides experienced in San Pedro Bay are of the mixed type (two unequal tides per day). The mean tidal range is 3.8 ft and the mean diurnal (mean higher high to mean lower low) range is 5.4 ft. The maximum astronomical tide range is about 10 ft. Tidal datum is mllw which is 2.8 ft below mean sea level.

7. Despite ample tide ranges, currents in the bay are rather weak with normal maximum current velocities of approximately 1 fps. Wind-induced surface currents can be of the same order of magnitude as those generated by tides, depending upon wind speed and duration.

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 4.

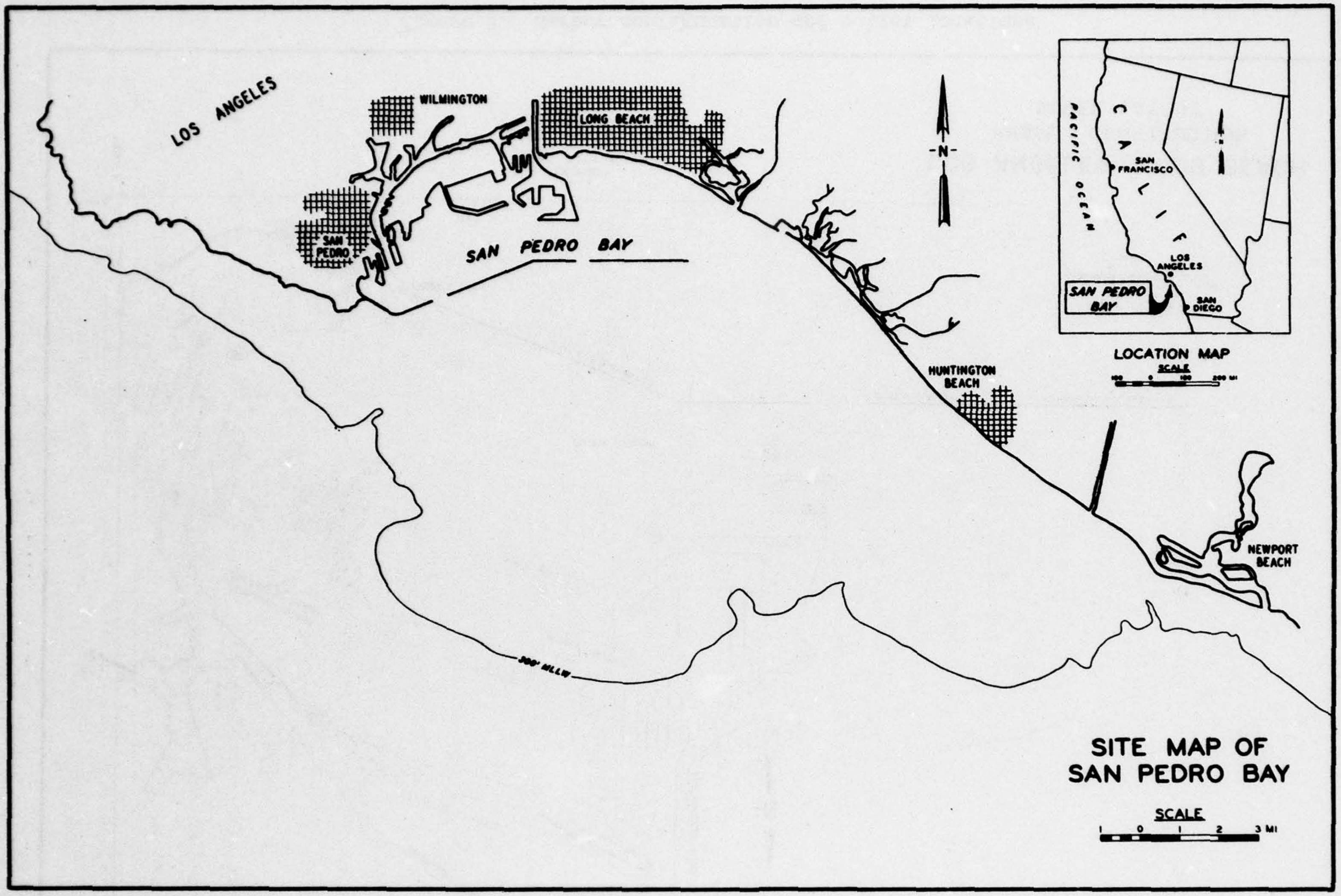

Figure 1. Site map

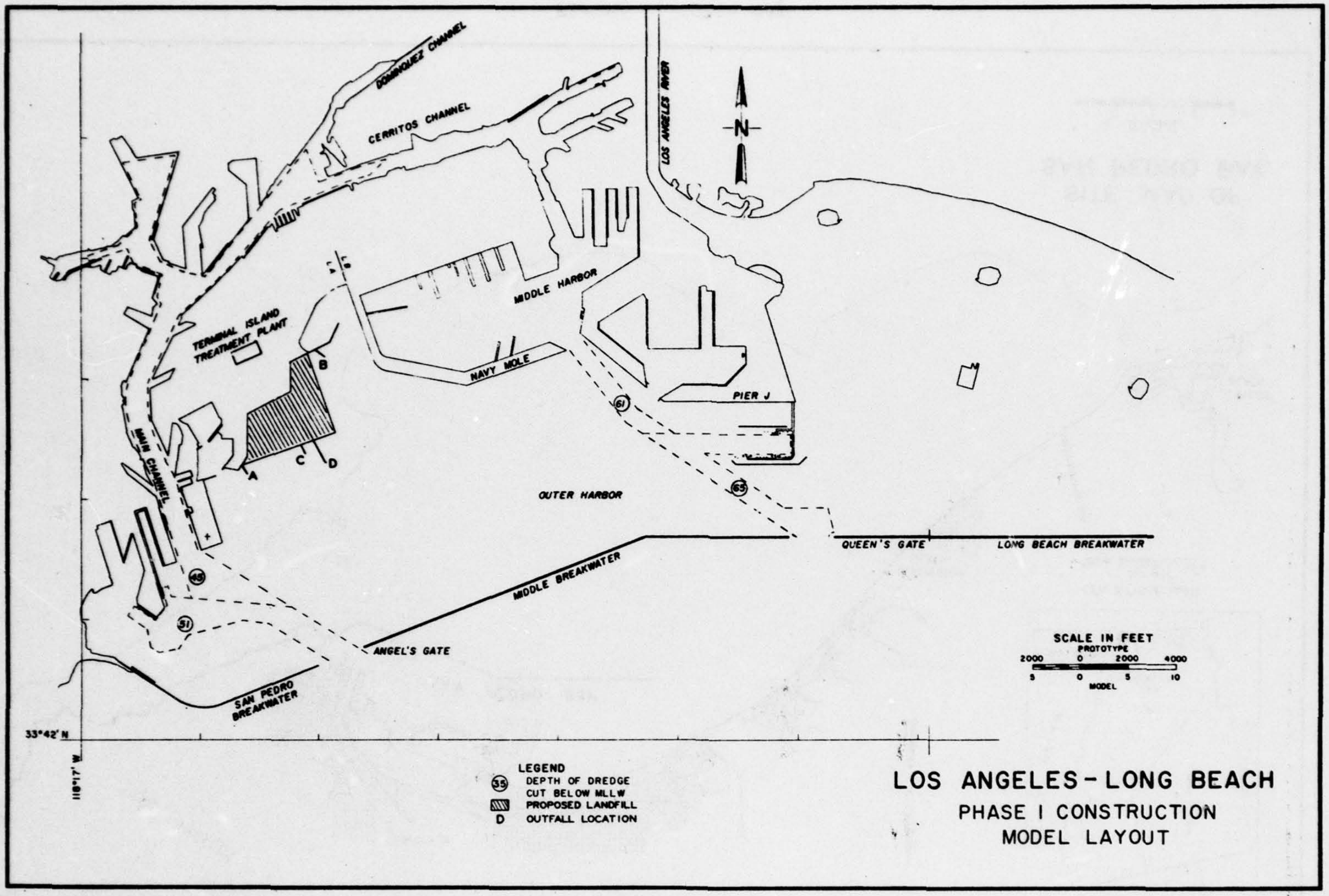

Figure 2. Harbor configuration and outlet locations

8. Freshwater discharges into the harbors are limited to intermittent storm runoff (principally in Dominquez Channel and the Los Angeles River) and a few freshwater effluents. Lack of significant freshwater inflow results in essentially uniform salinities in the harbors. Salinity of the bay water is very close to that of the surrounding coastal waters, which averages about 33 to 34 ppt total salts. Following heavy rains, individual basins may experience storm runoff that results in a low-salinity surface layer; however, these conditions are relatively rare and do not persist.

9. Thermal stratification is encountered in San Pedro Bay, ranging from mild seasonal temperature gradients to strong gradients due to cooling water discharges. Ambient surface temperatures average about 55°F in winter , 68°F in summer, and 62°F on an annual basis. At -20 ft mllw, the corresponding averages are 55°F, 64°F, and 60°F. Monthly variations in water temperature are shown in Table 1.

PART III: THE PHYSICAL MODEL

Description

10. The U. S. Army Engineer Waterways Experiment Station (WES) physical hydraulic model reproduces San Pedro Bay and a portion of the Pacific Ocean surrounding it (Figure 3). The model limits encompass the coastline from approximately 2 miles northwest of Point Fermin southeastward to Huntington Beach. The offshore bathymetry is reproduced out

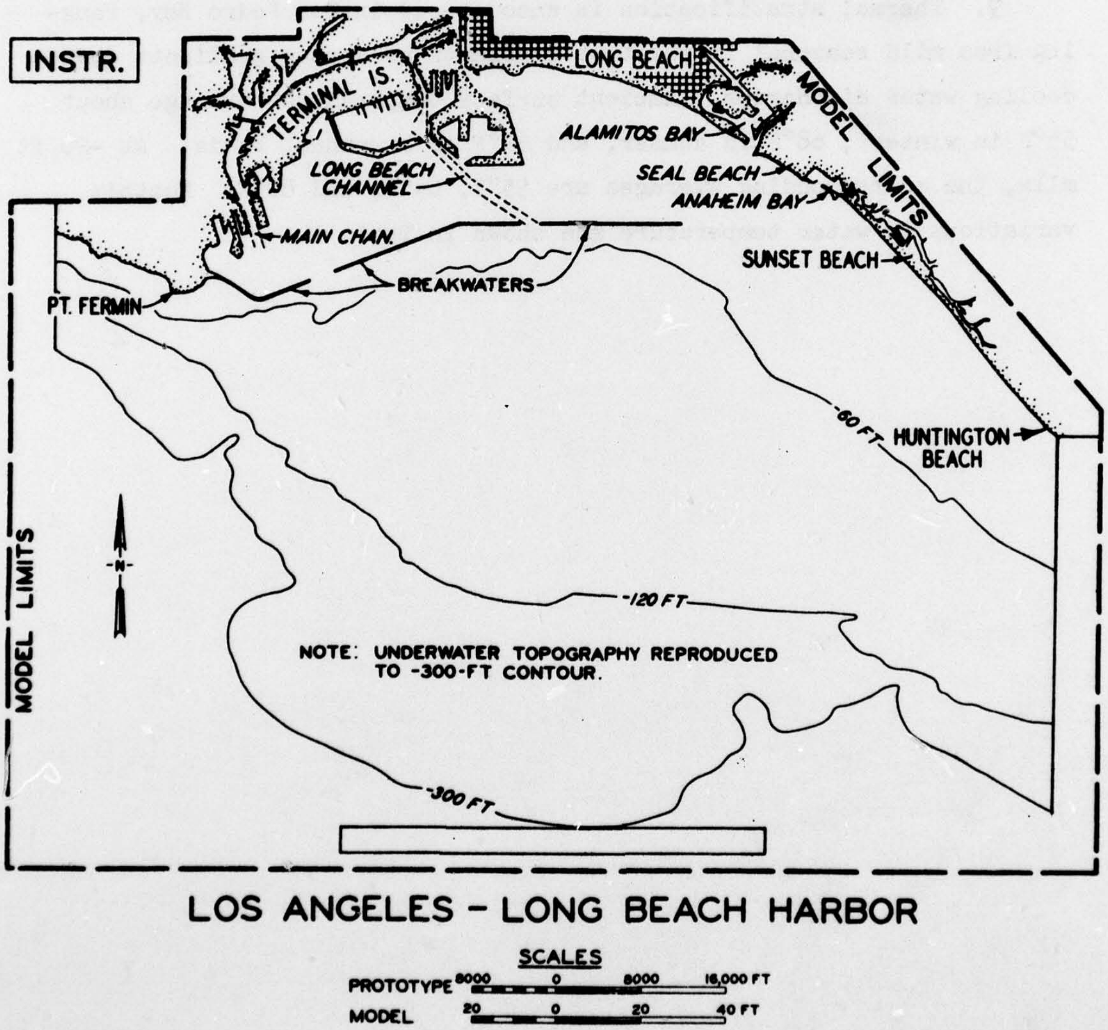

Figure 3. Model limits

to the -300 ft contour, but the model extends beyond the -300 ft contour to provide room for wave and tide generators. The 44,000 sq ft of the model represents about 253 square miles of prototype area.

11. The downcoast embayments such as Alamitos Bay, Anaheim Bay, and Bolsa Bay are correctly reproduced in plan, but water depths within the bays were estimated to expedite construction. This permitted proper reproduction of approximate tidal volumes in the embayments so that their gross effects upon the system are included; however, it does not permit detailed studies within these bays unless they are reconstructed to the precise existing bathymetry. Should such studies be desired, it would be a relatively easy modification to perform.

12. The model was constructed of concrete to linear scales of 1:100 vertically and 1:400 horizontally, which resulted in the following model-to-prototype scales, based on the Froudian relations, for the harbor circulation and tidal flushing tests:

Vertical length	1:100
Horizontal length	1:400
Surface area	1:160,000
Velocity	1:10
Time	1:40

13. The model breakwaters were designed to correctly reproduce the wave transmission and reflection characteristics of the prototype breakwater. Two-dimensional wave flume tests were conducted to determine the proper model rock size scale for the basin oscillation study (model wave periods = 0.5 to 10 sec), which was found to be approximately the same as the vertical length scale of 1:100. The impermeable core of the breakwater was reproduced in the model; however, in the tidal circulation tests, it was necessary to seal the breakwater with an additional amount of plastic sheeting (up to the -26 ft mllw level) to simulate correct transmission for the tidal periods.

14. Major piers, wharves, and quays within the harbors were built in the model to reproduce their effects upon the flow. Piles are simulated by 1/16- and 1/32-in.-diam brass rods.

15. The model was operated completely with fresh water since the relatively homogeneous salinity of the bay waters does not lead to significant ambient density stratification.

16. The model has been verified to satisfactorily reproduce astronomical tidal elevations at 13 locations, tidal currents at 5 ranges, and overall circulation in the outer harbors for existing conditions and a spring range tide (McAnally 1975,* 1977**). Phenomena not modeled in the circulation tests include wind waves, longshore currents, oceanic currents, wind-induced currents, wind-induced setup, barometric water-surface elevation changes, and stratification caused by natural temperature changes or natural salinity variations. It is estimated that all these phenomena are relatively unimportant to the overall mean circulation in the harbors complex. Wind-induced surface currents can and probably do sometimes make substantial alteration in the surface currents; however, their effect on the volume transports and gross harbor circulation and flushing is probably relatively small. Thus it is felt that model results satisfactorily depict relative alterations to the overall circulation and flushing of the harbors.

Appurtenant Equipment

17. Tides were produced in the model by a WES-designed automatic tide generator system illustrated in Figure 4. Operation of the system is described in Figure 5. The program cam used in this model as the primary input to the control system was made of a laminated-plastic-cotton-cloth board. Two adjustable steel cams were used to modify any portion of the tide for which a change was desired.

18. The open-ended circular prototype discharge pipes were

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* W. H. McAnally, Jr., "Los Angeles and Long Beach Harbors Model Study: Tidal Verification and Base Circulation Tests," Technical Report H-75-4, Report 5, Sep 1975, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

** W. H. McAnally, Jr., "Physical Model of San Pedro Bay Tidal Circulation," PORTS 77, 1977, American Society of Civil Engineers, New York, NY.

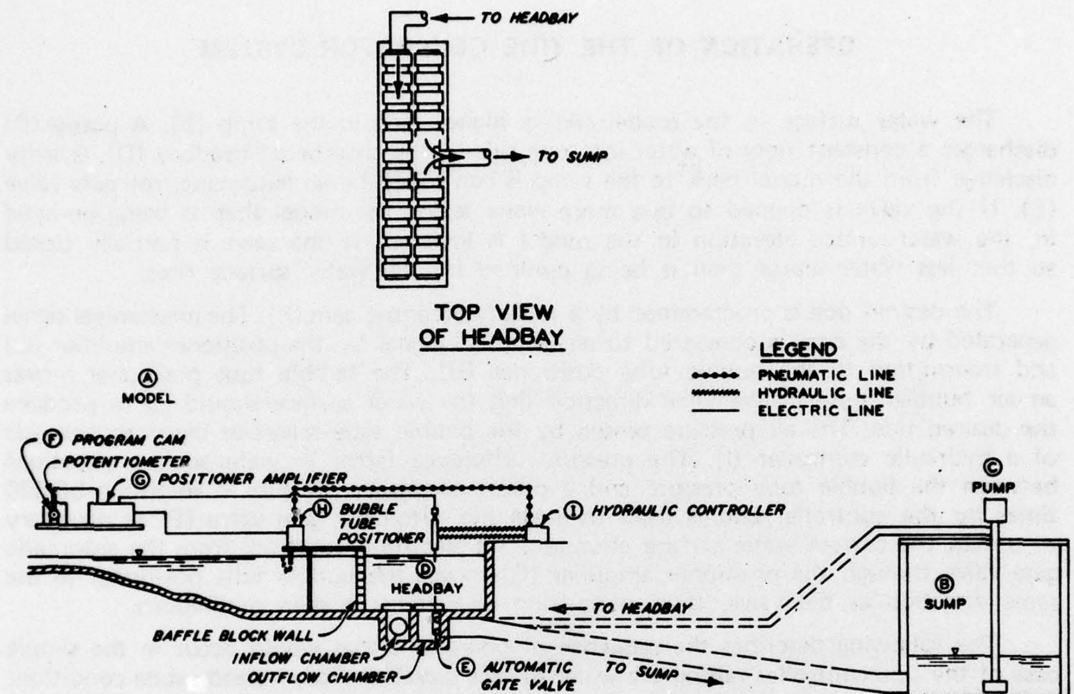

Figure 4. Tide generator system

reproduced in the model by rectangular slots (in the end of the pipes) whose vertical dimension was the prototype pipe's diameter multiplied by the vertical length scale ratio. Slot width was such that the effluent's exit velocity was scaled according to the Froude law. For a model to prototype ratio of the density difference ratio (difference between effluent and ambient water density divided by ambient density) of one, the model exit densimetric Froude number is equal to that of the prototype. Using these criteria, the 48-in.-diam pipe at locations A, C, D, and E (see Figure 2) was modeled by a 0.48-in.-high and 0.0078-in.-wide slot, and the 39-in. pipe at location B was modeled by a 0.39-in.-high by 0.0064-in.-wide slot.

19. Water for model effluent was heated by an electrical resistance heating element mounted in the supply line. A flow-through bimetal thermometer was used to monitor temperature of water leaving the heater, and a laboratory thermistor measured discharge temperature at the outlet.

OPERATION OF THE TIDE GENERATOR SYSTEM

The water surface in the model (A) is higher than in the sump (B). A pump (C) discharges a constant flow of water into one side of the chambered headbay (D). Gravity discharge from the model back to the sump is controlled by an automatic, roll-gate valve (E). If the valve is opened so that more water leaves the model than is being pumped in, the water-surface elevation in the model is lowered. If the valve is partially closed so that less water leaves than is being pumped in, the water surface rises.

The desired tide is programmed by a radially eccentric cam (F). The mechanical signal generated by the cam is converted to an electrical signal by the positioner amplifier (G) and transmitted to the bubble tube positioner (H). The bubble tube positioner moves an air bubbler tube in the same direction that the water surface should go to produce the desired tide. The air pressure sensed by the bubble tube serves as input to one side of a hydraulic controller (I). The pressure difference (error in water-surface elevation) between the bubble tube pressure and a preset controller pressure is amplified 50,000 times by the controller and is used to move the automatic gate valve (E) as necessary to obtain the correct water-surface elevation. An electronic feedback from the automatic gate valve through the positioner amplifier (G) moves the bubble tube positioner in the same direction as the valve, thus minimizing undesirable system oscillations.

The following describes the sequence of operations that would occur in the simple case of the tide controller raising the water-surface elevation from a steady-state condition:

1. The program cam (F) indicates that the water surface is to rise 1 in. A potentiometer converts this mechanical signal to a voltage and transmits it to the positioner amplifier (G).
2. The positioner amplifier amplifies the signal and transmits it to the bubble tube positioner (H), which rises 1 in.
3. The air pressure in the bubble tube is reduced by its decreased submergence.
4. The differential between the bubble tube pressure and a preset pressure is converted to hydraulic pressure and amplified by the hydraulic controller (I).
5. The amplified hydraulic pressure differential activates a hydraulic pressure cylinder atop the automatic gate valve (E), causing it to close slightly.
6. The downward movement of the gate valve is converted to an electrical signal by another potentiometer, and the signal is transmitted back to the positioner amplifier (G).
7. The positioner amplifier causes the bubble tube positioner to move down a small amount and thus slows down the rate of gate valve closure.
8. The system continues to respond to the changing water-surface elevation until the desired 1-in. rise is accomplished.

Figure 5. Operation of the tide control system

20. Time-lapse motion pictures were taken with an Automax camera set at a 1-sec framing interval. Color slides were taken by a 35-mm SLR with automatic film advance. Both cameras were mounted 14 ft above the water surface just seaward of the breakwater. Model lighting was provided by thirty-four 1000-watt lamps at the model periphery. The model bed was painted light blue to provide sharp contrast with the red dye used in the model effluent.

PART IV: TESTS DESCRIPTION

21. Tests were conducted for the sewer outfall at the five locations shown in Figures 2 and 6. Locations A, B, C, and D were tested for the modified (June 1978) phase I harbor configuration shown in Figure 2. Modifications for this phase I plan consist of a 45-ft-deep channel in the Los Angeles Harbor main channel, a landfill east of Fish Harbor, a 65-ft-deep channel dredged to pier J from Queen's Gate, and a breakwater and piers adjacent to pier J in Long Beach Harbor. Two additional tests were performed using outfall locations D and E and additional landfill in Los Angeles Harbor that might be considered for phase II construction. In these tests temporary landfills were inserted as shown in Figure 6.

22. All tests were performed with a repetitive mean tide as shown in Figure 7. Other test conditions are listed in Table 2. Discharges of 30 and 15 mgd were tested at outfall location A and 30 mgd at all other locations. For the phase I configuration test of location D, the outfall extended 1000 ft beyond the landfill edge; whereas for the phase II configuration it was shortened to about 400 ft.

23. The model effluent in these tests contained a dye tracer to show the effluent path through the harbor. The dye is conservative and should not be viewed as a tracer for nonconservative constituents of the prototype effluent that may experience decay or transformation with time.

Design

24. Average monthly effluent and ambient water temperatures are shown in Table 1. The average temperature difference between effluent and receiving water is 16°F, corresponding to average temperatures of 76°F and 60°F, respectively. These temperatures, and salinities of 10 ppt and 34 ppt, were used to compute average water densities of 1.0047 g/cc and 1.0253 g/cc for the effluent and receiving waters, respectively. This difference in density was reproduced in the model by heating the effluent.

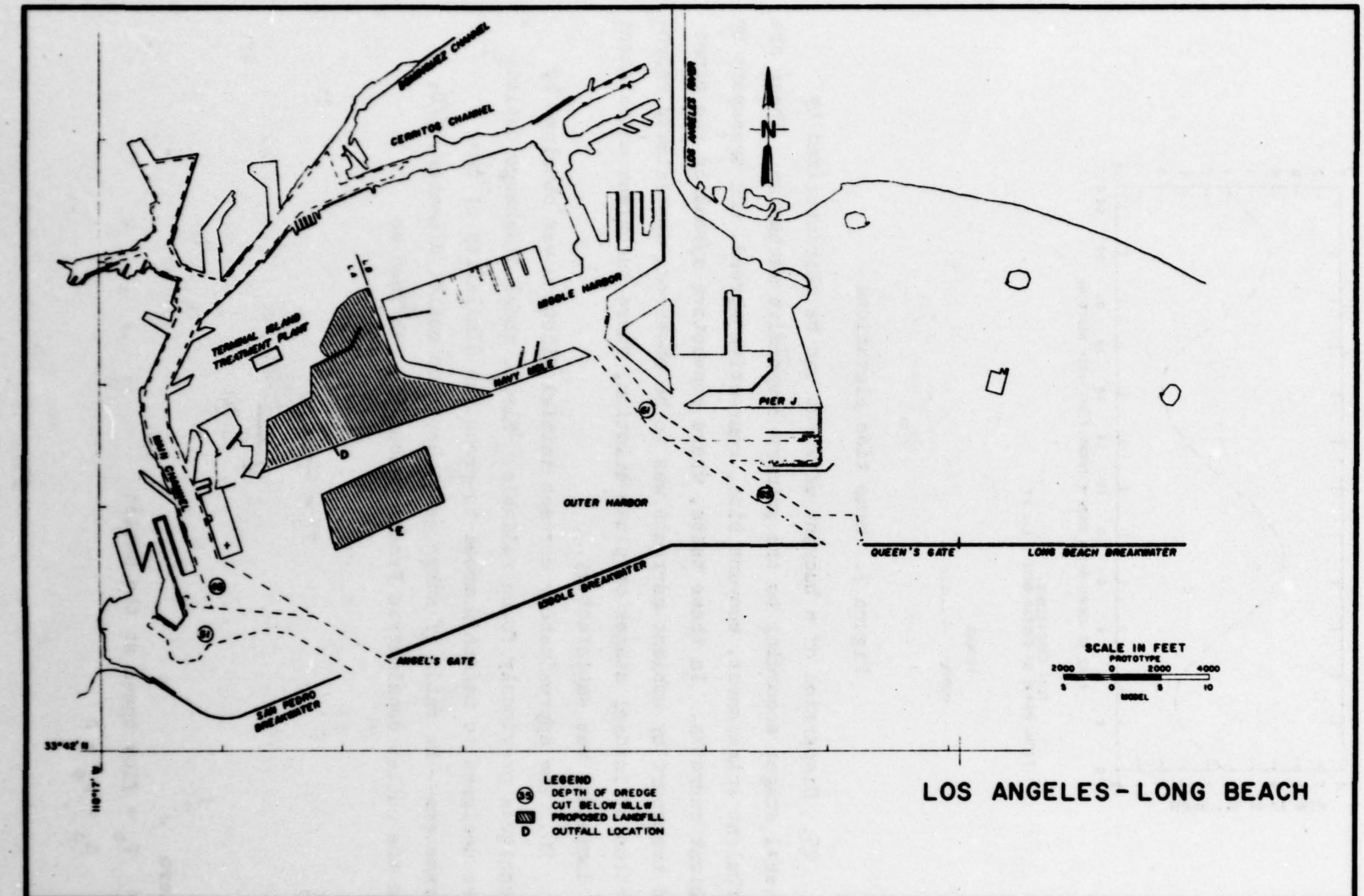

Figure 6. Phase II landfill configuration and outfall locations

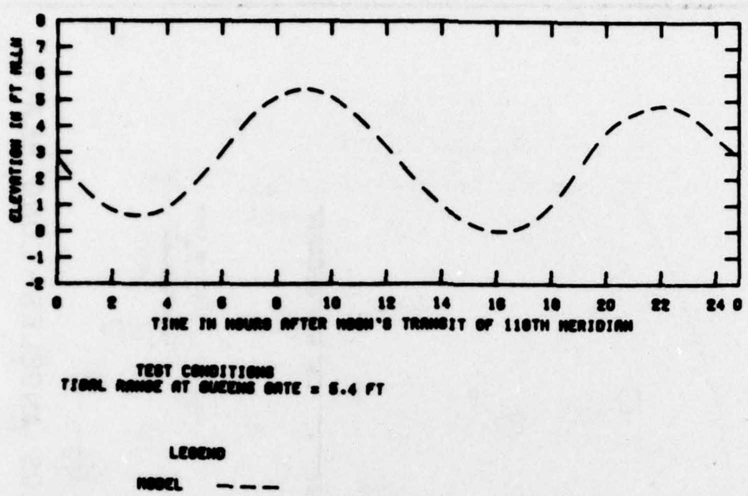

Figure 7. Mean tide elevations

25. Dispersion of a buoyant effluent can be characterized by several stages according to the primary dispersive mechanism. These are turbulent entrainment, buoyant rise, convective spread, and transport by ambient currents. In these tests, where convective spread of the plume and transport by ambient currents was to be observed, approximate reproduction of initial stages of plume dilution, where turbulent entrainment is dominant, was satisfactory.

26. The approximately correct initial dilution was obtained by techniques previously found reliable. First, model discharge outlets were designed to maintain model-to-prototype similarity of two parameters--the ratio of submergence depth to outlet diameter, Y/D, and the outlet densimetric Froude number (F'_o) defined as

$$F'_o = \frac{V_o}{\sqrt{\frac{\Delta_\rho g D}{\rho}}}$$

where

V_o = flow speed at the outlet

$\Delta_\rho = \rho_e - \rho$

ρ_e = effluent density

ρ = ambient water density

g = acceleration due to gravity

D = outlet diameter (or characteristic dimension)

Similarity of these parameters in the distorted-scale model was achieved by use of rectangular slot outlets (described in paragraph 18).

27. Even with similarity of these parameters, a distorted-scale model does not properly reproduce the three-dimensional turbulent entrainment that is the primary dilution mechanism in initial development of the plume. Therefore, effluent dilution up to the point of the surface boil was predicted analytically by use of published experimental results for dilution of horizontal round jets in shallow water (Partheniades et al., 1973*); then outlet pipe geometry in the model was adjusted from the original design until the calculated dilution was achieved. Results of the analysis and test conditions are shown in Table 2. Adjustment of the outlet pipe geometry consisted of widening the slots and raising the pipes slightly above the model bed.

Procedure

28. Each of the tests followed this procedure: model tides were generated for about 2 hr (three tidal cycles) to obtain stable circulation conditions in the harbors; then heated water was discharged through the outlet for about an additional 1-1/2 hr to permit development of the spreading plume. At the next zero hour of the tidal cycle (Figure 7), filming began and red dye was added to the hot-water discharge. Time-lapse motion pictures (one frame per second) and color slides were taken of the outer harbor area from a vantage point above and seaward of the breakwater. Numerals in the field of view showed the number of elapsed tidal cycles and a clock showed elapsed model time. Small foam chips

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* E. Partheniades, B. C. Beechly, and J. Yen, "Near-Field Temperature Distribution in Shallow Waters due to Submerged Heated Water Jets," Proceedings, Fifteenth Congress of the International Association for Hydraulic Research, Vol 2, p 137, 1973.

floating on the water showed surface current patterns. Each test (except one) lasted at least seven *tidal cycles of* 24.84 *hr* (*prototype*) each, with time-lapse photography of cycles 1-3 and 5-7. Cycle 4 was omitted so that the camera could be reloaded. Dye injection was continuous throughout each test.

PART V: RESULTS

29. Data from these tests consisted of notes on observed plume behavior and photographic documentation described in paragraph 28. The following paragraphs describe plume behavior as observed during the tests.

Location A

30 mgd flow rate

30. During the first cycle of injection the dye plume moved south and west toward Main Channel, then southward to Angel's Gate, reaching the San Pedro breakwater at about hour 16 of the first cycle. By the end of the cycle a circular dye cloud occupied the area between the Main Channel and San Pedro breakwater.

31. Midway through cycle 2 the dye plume changed direction from its initial path, moving northeastward toward the Navy Mole in Long Beach Harbor. At the mole, it turned to the southeast and traveled in a broad arc toward and along the Middle breakwater. The plume front reached Angel's Gate early in cycle 3, was turned northward by flood phase currents, and began to spiral back toward the outfall. Before reaching the outfall area it was drawn seaward by ebb currents carrying a portion of the plume through Angel's Gate. This transport pattern followed a large clockwise gyre that was observed in model base circulation tests (McAnally 1975*).

32. The transport pattern described above persisted for cycles 3-8, with the primary dye path being a very large semicircular arc from the outfall eastward to the Navy Mole, southward to the Middle breakwater, and westward to Angel's Gate. Small patches of dye occasionally drifted eastward toward pier J and westward toward the San Pedro breakwater.

33. During the first cycle, some dye entered Fish Harbor, but after the plume changed direction in cycle 2 most of the dye was flushed

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* See footnote on page 12.

out. At the end of seven cycles a very light trace of dye was observed in Fish Harbor. At about cycle 6 a small quantity of dye entered the seaplane anchorage just east of the treatment plant.

34. No significant change was observed in dye movement during cycle 7 so the test was ended at the start of cycle 8. After the change in direction during cycle 2, no tendency to return to the first cycle path was observed.

15 mgd flow rate

35. For the 15 mgd test at location A the model and heated effluent were operated for 4 and 3 hours, respectively, before testing began to ensure that start-up transients were eliminated. Test duration was 11 tidal cycles.

36. During the first two cycles, the plume followed the same eastern arc path of the latter part of the previous test, with the initial dye front passing out through Angel's Gate in slightly less than one tidal cycle. However, at about hour 4 of cycle 3 the plume reversed direction and began moving southward toward the San Pedro breakwater as it had done during the first cycle of the 30 mgd test. Some dye intruded a short distance up Main Channel; a circular cloud of dye formed inside the San Pedro breakwater.

37. At about hour 9 of cycle 5 the dye plume reversed direction again, returning to the eastern route through the Long Beach Outer Harbor. By cycle 7 the pattern of dye coverage in the outer harbor was very similar to that observed in the 30 mgd test.

38. Filming ended after cycle 7 but the test was continued through cycle 11 because of the observed variation in the plume paths to the breakwater. After the reversal to the eastern path in cycle 5, the dye plume consistently followed it through cycle 11, showing no tendency to move westward from the outfall. Close observation showed that flood phase surface currents from Angel's Gate flowed northward toward the outfall, splitting into a very large clockwise gyre to the east of the outfall and a smaller counterclockwise gyre west of the outfall. The direction that the plume took seemed to be determined by which gyre captured it. Small oscillations in the location at which the gyres split appeared to have caused the instability.

Location B

39. The test at outfall location B lasted 10 tidal cycles. For about the first half tidal cycle of dye injection the dye spread to nearly cover the area between the proposed landfill and the Navy Mole. Following higher high water the dye cloud began moving eastward parallel to the Long Beach entrance channel. The dye cloud reached the proposed pier J breakwater at the end of cycle 1. By midcycle 2 the area between the Navy Mole and the proposed landfill was completely covered with dye and intrusion into the seaplane anchorage had begun.

40. During subsequent cycles the dye plume exhibited the following behavior: during ebb phases the plume moved eastward, hugging the Navy Mole, turned south at about pier J, and moved toward the Middle breakwater. At the breakwater the dye cloud split, with some going out Queen's Gate and some moving westward along the breakwater toward Angel's Gate. Some of that passing through Angel's Gate was pushed northwestward by flood currents until it reached the proposed landfill in Los Angeles Harbor where some of the dye turned eastward to close the circle. Some dye was occasionally pushed farther westward toward the Los Angeles Main Channel. Traces of dye were observed in Long Beach Middle Harbor beginning about cycle 3.

Location C

41. Outfall location C was clearly in the clockwise gyre that moved the dye in the eastern path observed for locations A and B. It demonstrated no tendency for the plume to move directly westward from the discharge point.

42. During the first cycle of dye injection, a portion of the plume entered the sheltered area just east of the proposed Los Angeles landfill. By the end of cycle 3 the dye had reached the rear of that area and isolated patches were observed in Long Beach Middle Harbor.

43. The plume path followed the large clockwise arc described for location A except that during flood phase currents, the plume appeared

to move farther toward pier J than in tests of location A. The path to the breakwater more nearly resembled that of location B.

Location D

Phase I harbor configuration

44. Outfall location D placed the effluent plume well out into the clockwise gyre previously described. The plume's path was similar to that of locations A and C except that the arc was smaller and did not extend quite as far eastward. Dye in significant quantity did not enter the area between the Los Angeles landfill and the Navy Mole until cycle 3. During the test, no dye was observed in Long Beach Middle Harbor.

45. By the third cycle the dye plume had formed a large circle in the outer harbor. During ebb currents, the southwestern portion of the circle was carried out through Angel's Gate and during flood currents, dye near the gate was carried northward toward the outfall. The time required for dye to complete the circular path was about one tidal cycle. During flood phase currents of cycle 2, some of the northward moving dye entered the Main Channel and then moved south and along the San Pedro breakwater.

46. No continuing change in dye transport or distribution was observed after the fourth cycle, so the test was terminated in cycle 6.

Phase II landfill configuration

47. With the possible phase II landfill added to the model, the initial dye release moved very slowly eastward in the gap between the island landfill and Terminal Island fill (Figure 6). By the end of cycle 1, dye had reached the Navy Mole and covered the east end of the island fill. Small quantities of dye moved south of the island to be caught by the clockwise gyre (much reduced in size) and carried to Angel's Gate.

48. During cycle 3, the dye plume's edge entered Long Beach Middle Harbor. Late in that cycle some of the dye transported by the gyre south of the island was carried into the area north of the San Pedro breakwater.

Location E

49. During the first few hours of cycle 1, the dye plume from location E moved directly toward the Middle breakwater. Between hours 2 and 9 the plume front curled northward with flood currents until it almost reached the island fill, then ebb currents following hour 9 carried most of the plume out through Angel's Gate. Subsequent flood currents pushed the plume's eastern edge farther eastward into Long Beach Harbor. After the first cycle, dye caught in or near Angel's Gate as currents switched from ebb to flood was carried around the north side of the island fill and then along the Navy Mole. After four cycles some of the dye began to enter Long Beach Middle Harbor. After five cycles dye was observed along the San Pedro breakwater.

PART VI: DISCUSSION AND SUMMARY

49. These tests showed the path of a buoyant plume originating at several locations in Los Angeles Harbor. They also showed the approximate length of time for a conservative dye tracer in the model plume to reach selected points in the harbors. They did not represent the dispersion and decay of nonconservative constituents in the prototype effluent.

50. Outfall location A appeared to be in an area where flood phase tidal currents split into two opposite turning gyres. This caused the plume to have an unstable path, switching back and forth between the western gyre, which carried it toward the San Pedro breakwater, and the eastern gyre, which carried it in a circular path into Long Beach Harbor and then along the Middle breakwater to Angel's Gate. The eastern path appeared to be the dominant one. The plume's path was very similar for both the 30 and 15 mgd flow rates.

51. The plume from outfall location B followed an easterly path similar to that of location A, except that considerably more dye appeared in the area around location B and somewhat more entered Long Beach Middle Harbor.

52. Location C produced a plume that was very similar to that of location B, except for less accumulation in the area between the Los Angeles Harbor landfill and the Navy Mole.

53. The plume from location D followed the clockwise turning gyre as did those from locations B and C; but since it originated farther out in the flow, the plume described a somewhat shorter path to Angel's Gate and kept dye largely away from the enclosed basins of Long Beach Harbor. Most dye tracer not carried out through Angel's Gate traveled a circular path that returned to the area of the outfall in about one tidal cycle (24.84 hr).

54. Installation of the phase II landfill considerably altered the plume's behavior for a discharge at location D. Much of the dye was trapped between the landfill island in Los Angeles Harbor and pier J in Long Beach Harbor and required about one cycle to reach the Navy Mole.

55. Location E, tested with the possible phase II landfill installed in the model, formed a circular plume in a clockwise gyre between the landfill island and Middle breakwater. Most dye in the plume was carried out through Angel's Gate during ebb phase currents, but some dye was transported around the north side of the landfill and eastward from the landfill about two cycles after injection.

Table 1

Average Ambient Water and Effluent Temperatures, °F

Month	Average Temperature Outer Harbor at -20 ft mllw*	Average Effluent Temperature**	Difference of Average Temperatures
Jan	55	71	16
Feb	57	70	13
Mar	58	70	12
Apr	58	73	15
May	58	78	20
Jun	60	77	17
Jul	61	80	19
Aug	64	83	19
Sep	64	81	17
Oct	64	80	16
Nov	61	79	18
Dec	58	72	14
Average	60	76	16

* Hurst, W. C., and Whiteneck, L. L., 1974, "Draft Environmental Impact Report, Western LNG Terminal Company, Berth 308, Los Angeles Harbor," Port of Los Angeles, Los Angeles, Calif.

** Source, Los Angeles City Engineer's Office.

Table 2

Predicted Dilutions and Test Conditions

				Prototype				Model				
Test No.	Outfall Location	Harbor Configuration	Effluent Discharge Rate Prototype mgd	Y/D*	F'_o	Predicted Dilution at Surface	Predicted $\Delta\rho/\rho$ at Surface	Air Temp °F	Ambient Water Temp °F	Effluent Temp °F	Effluent Surface* Temp °F	Actual $\Delta\rho/\rho$ at Surface*
CM 6	A	Phase I	30	4.4	2.30	0.42	-0.008	76-84	75	160	123	-0.009
CM 7	A	Phase I	15	4.4	1.15	0.35	-0.007	76-82	74	160	118	-0.008
CM 8	B	Phase I	30	5.5	2.30	0.30	-0.006	74-76	74	160	113	-0.007
CM 9	C	Phase I	30	5.8	2.30	0.35	-0.007	76-84	73	159	115	-0.007
CM 10	D	Phase I	30	5.8	2.30	0.35	-0.007	78-92	68	157	111	-0.007
CM 12	D	Phase II landfill	30	5.8	2.30	0.35	-0.007	78-86	68	157	111	-0.007
CM 13	E	Phase II landfill	30	9.0	2.30	0.20	-0.004	78-85	60	155	90	-0.004

* Water-surface elevation at mean tide level.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

McAnally, William H
Terminal Island Sewage Treatment Plant outfall, Los Angeles Harbor, California; hydraulic model investigation / by William H. McAnally, Jr. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.
27, [2] p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; H-78-23)
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