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Intake Systems for Desalting Plants

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FOREWORD

This is one of a continuing series of reports designed to present accounts of progress in saline water conversion and the economics of its application. Such data are expected to contribute to the long-range development of economical processes applicable to low-cost demineralization of sea and other saline water.

Except for minor editing, the data herein are as contained in a report submitted by the contractor. The data and conclusions given in the report are essentially those of the contractor and are not necessarily endorsed by the Department of the Interior.

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SECTION I. INTRODUCTION

The ocean constitutes, by far, the largest source of feed water for desalination plants as well as for process and industrial uses. What appears to be a simple process - supplying seawater to the plant - is one of the leading causes for seawater desalination plant shutdowns according to OSW R and D Report No. 512. Failure to observe and incorporate in the design some of the basic engineering principles affecting seawater intake systems has, many times, been the reason for the failures. The intent of this contractual effort has been to study the particular engineering aspects of seawater intake systems for desalination plants and in this report to present them in such a way that they can be used to supplement standard engineering principles so that seawater intake systems can be built economically and operated dependably.

The contractual objectives involved the following specific tasks:

1. Identify and evaluate technical data essential to sound engineering and operation of a seawater intake, such as source water properties and quality, ground geology, coast line stability, currents, waves and tides, meteorological data, plant and animal life.

2. Identify and evaluate the principal materials of construction and evaluate them with respect to corrosion, erosion, durability, applicability, expected life and relative cost. Describe means for extending their useful life by means of coatings, additives, impregnations and cathodic protection.

3. Describe the type and nature of fouling organisms and outline methods of prevention.

4. Identify the trash and debris that might require removal, describe the equipment that would be needed, and outline means of disposal.

5. Identify and evaluate those factors necessary to make a sound selection of type of intake and site location.

6. Identify and evaluate those factors involved in the design of seawater intakes that must be carefully considered in the planning stages of a desalting plant.

7. Provide outline designs of a 20-MGD and a 100-MGD seawater intake for each of the three basic types - lagoon type, pipe type and shore type - and describe the principal elements involved.

8. Make capital and operating cost estimates for each of the designs.

9. Suggest study areas.

SECTION II. SUMMARY AND CONCLUSIONS

The contractual objectives culminating in a report covering the engineering aspects of seawater intake systems have been accomplished as set forth in the introduction. The fundamentals of seawater properties, oceanographic principles, materials selection, fouling and boring control and trash removal have been studied and organized to form a basis, together with extensive operating experience, for the selection, design and costing of the three basic types of intakes - lagoon, pipe and shore types - for 20-MGD and 100-MGD capacities in representative geographical locations to illustrate the respective designs.

Five areas where additional study would be of significant value became evident during the study, namely, in the fields of fouling control, materials of construction, infiltration gallery intakes, pipe installation in the surf zone and prediction of erosion.

Specific conclusions that have been drawn from the study are:

1. Fouling is the greatest problem area. The types and extent of fouling are unpredictable. Control methods are costly and the results to be expected are uncertain.

2. Concrete and steel are the preferred basic materials of construction. However, careful attention must be given in design and construction to their susceptability to corrosion and erosion if serious problems and costs are to be avoided.

3. Coatings and cathodic protection can greatly extend the life of steel and some alloys, but only when properly applied and used.

4. The largest single factor influencing selection of type of intake is the nature of the site, particularly the nature of the bottom materials and the slope of the ocean bottom.

5. In general, costs of construction and operation for the three types of intakes are, from lowest to highest: lagoon type, shore type and pipe type.

6. Capital and operating costs for supplying seawater to the pumps for the specified capacities and recovery factor are shown in Table II-I.

TABLE II-I

SUMMARY OF CAPITAL AND OPERATING COSTS

	Intake Type					
	Lagoon		Pipe		Shore	
	20 MGD	100 MGD	20 MGD	100 MGD	20 MGD	100 MGD
Capital Cost, $	255,600	402,000	1,283,500	1,651,500	141,900	267,500
Annual Operating Cost, $/Yr.	56,689	97,269	129,036	187,821	32,177	67,382
* Unit Cost, $/1000 Gal. Product	0.018	0.0059	0.039	0.0114	0.0098	0.0041

Note: Included in lagoon type intake costs are extra features for hurricane protection. Without these, the costs would be slightly less than for the shore type.

*Based on Recovery Factor = 0.50. For example a 20 MGD intake is required for 10 MGD fresh water production.

SECTION III. MARINE DATA

Seawater intake structures are invariably confined to near-shore and onshore areas. Therefore, the marine data presented here will be confined to these areas. The vagaries of the ocean, the complexities of the multitude of forces acting upon it, the difficulties of measuring the individual forces as well as the imperfect understanding of the true nature of many of the forces all too often enable only approximations to be made of their magnitude, direction and effect as they influence engineering considerations. Consequently, hard and fast rules cannot be set forth and engineering decisions must be tempered with mature engineering judgement.

A. Seawater - Physical Properties

Seawater is far more than just a solution of mineral ions. It may contain dissolved gases, a wide variety of organic substances and suspended matter, and living creatures, ranging from simple to complex. The concentration of dissolved substances will vary widely from place to place due to the diluting action of rivers, rain or melting ice, or it may be concentrated by evaporation.

The property of seawater generally used in defining it is the total amount of dissolved salts. The term used is "salinity". By definition, salinity is "the total amount of solid materials in grams contained in one kilogram of seawater when all the carbonate has been converted to oxide, the bromine and iodine replaced by chlorine, and all organic matter completely oxidized" (Sverdrup, Johnson, Fleming, 1942). Salinity can be quite accurately measured by commercially available direct-reading salinometers of the stem type.

While the salinity of mid-ocean seawater is generally around 35 parts per thousand (o/oo), in coastal areas it may vary from freshwater values in estuaries, to several times that of the standard mid-ocean value in lagoons where evaporation is in excess of precipitation. Seawater with a salinity of 35 o/oo is considered to be a standard concentration (concentration factor of 1.0).

Table III-I gives some of the important physical properties of waters, with concentration ratios varying from that of fresh water to four times normal seawater. The specific gravity of seawater is a nonlinear function of temperature. Figure III-1 gives the relationship between salinity, temperature and specific gravity within the ranges most likely to be encountered with seawater intakes. Figure III-2 gives some of the mechanical properties of salt water at sea level and atmospheric pressure.

TABLE III-I

PHYSICAL PROPERTIES OF SEAWATER AT 68°F

(McIlhenny and Zeitoun, 1969)

	Fresh Water	Concentration Ratio Seawaters					
	0	0.5	1.0	1.5	2.0	3.0	4.0
Density, lb./cu.ft.	62.3	-	63.9	-	65.2	67.3	69.0
Specific heat, (C_p), Btu./lb. °F	1.000	0.976	0.954	-	-	-	-
Thermal conductivity, Btu./(hr.)(ft.)(°F.)	0.345	-	0.338	-	0.332	0.327	-
Electrical conductivity, mhos./cm.	-	-	$4.9X10^{-2}$	-	-	-	-
Osmotic pressure, psi	-	-	315	-	680	1185	1780
Vapor pressure, psia	0.34	-	0.334	-	0.325	0.315	-
Boiling point rise, °F	-	-	1.23	-	2.67	4.25	-
Surface tension, dynes/cm.	72.7	-	73.5	-	74.3	75.0	75.85
Viscosity, lb./ft.hr.	2.4	-	-	2.57	-	2.85	-
O_2 solubility, ppm	9.2	8.2	7.15	-	-	-	-
N_2 solubility, cu.ft./1,000 cu.ft.	11.6	10.6	9.65	8.55	-	-	-

Figure III-1

CONVERSION OF APPARENT SPECIFIC GRAVITY TO SALINITY

(Coast and Geodetic Survey, 1942)

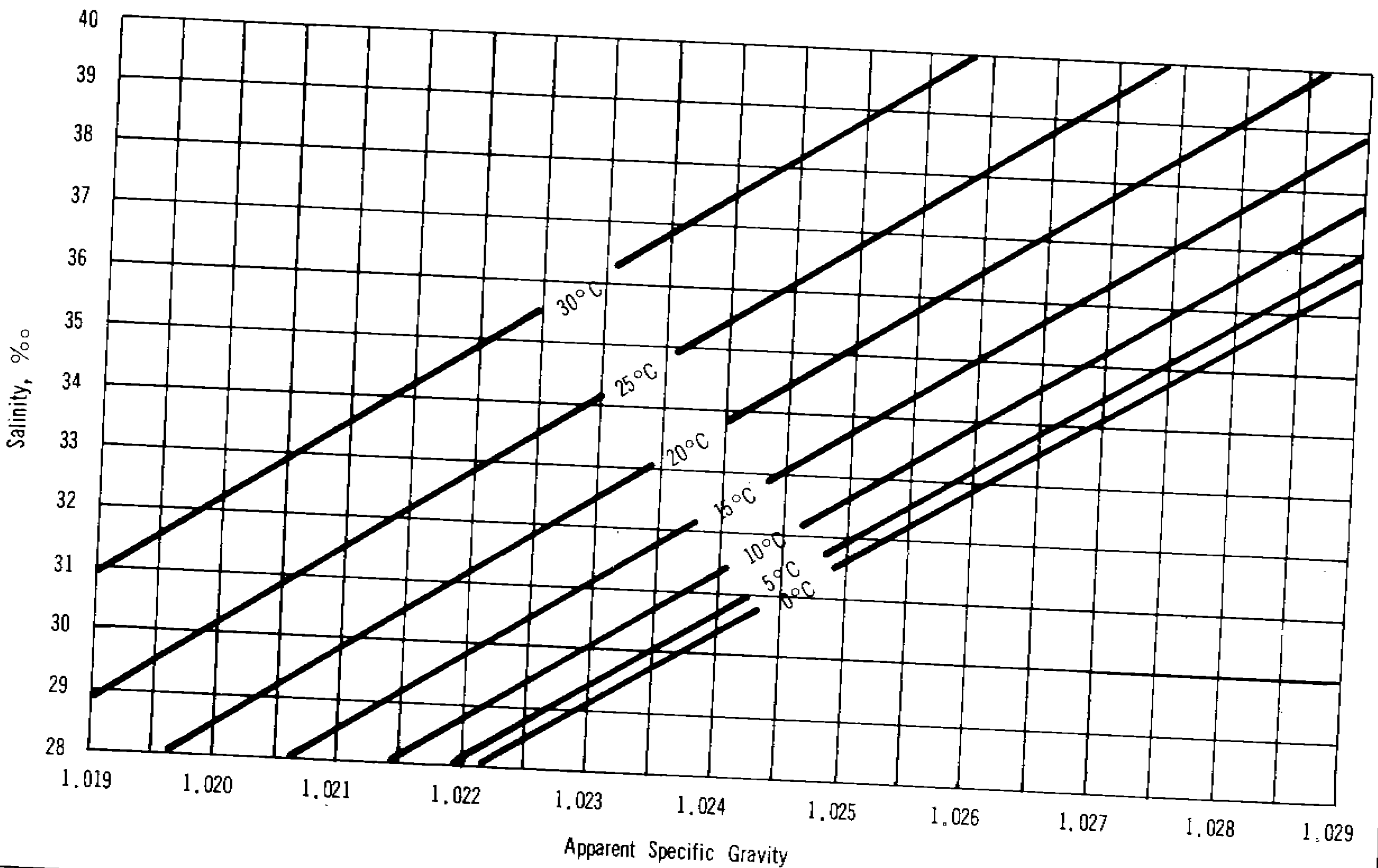
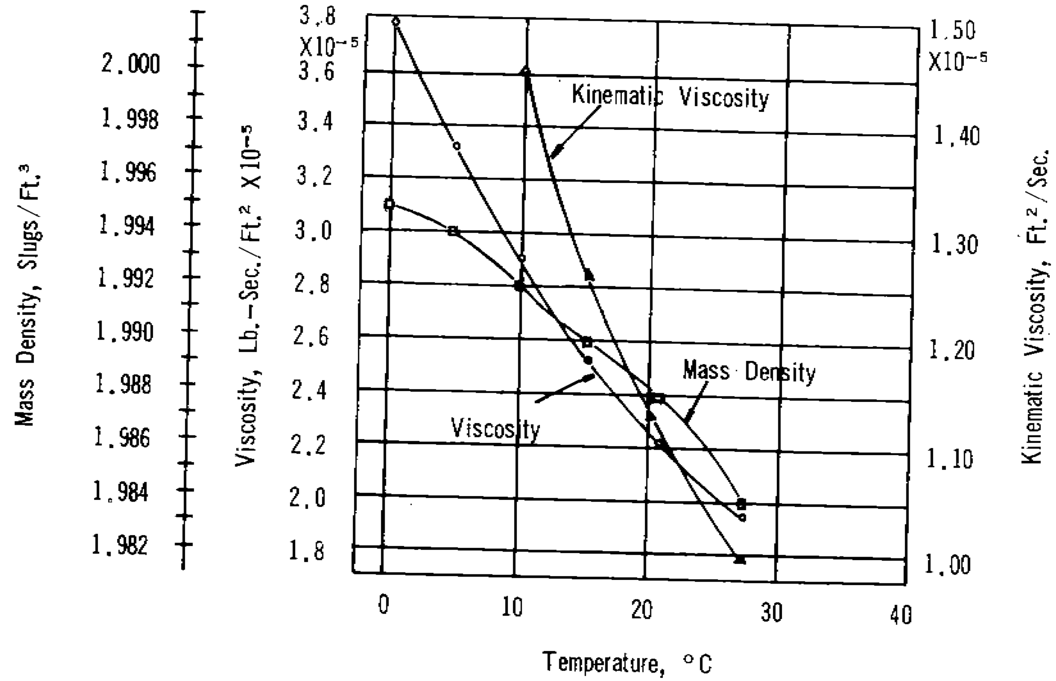


Figure III-2

MECHANICAL PROPERTIES OF SALT WATER

(Myers, Holm & McAllister, 1969)



Elevation : Sea Level

Pressure : Atmospheric

B. Seawater - Chemical Properties

Although some 77 chemical elements are present in seawater, 11 of the constituent ions make up over 99% of the total solutes. These 11 largely determine the chemistry of seawater and are chloride, sulfate, bicarbonate, bromide, fluoride, sodium, magnesium, calcium, potassium, strontium and boron. Some typical seawater analyses are shown in Table III-II. Seawater is alkaline, having a pH of from 7.8 to 8.3 unless modified by mixing with fresh water which is usually acidic. The carbonate system and undissociated boric acid act as a buffer to changes in the pH. Seawater in coastal areas also contains a large variety of dissolved organic compounds, although the total amount is low. The organic content is of great importance to marine life processes. Since all exposed surfaces in seawater are covered with a thin layer of organic materials, the corrosion rate of metals is greatly altered from what it would be if it were exposed directly to the ionic solution.

Seawater in coastal areas usually has a greater or lesser degree of turbidity. The particle size is small, ranging from 10 to 50 microns. Turbidity can cause erosion as well as corrosion, and in quiescent locations the suspensoids can settle out. Especially where dredging operations are carried out, high turbidity and troublesome operation can be expected.

Hydrogen sulfide is produced in seawater by the anaerobic bacterial reduction of the sulfate ion to furnish oxygen for metabolic processes. Hydrogen sulfide reduces the pH of seawater, thereby creating corrosive conditions, and the produced sulfides readily attack copper alloys. One caution that should be observed is the possible buildup of a lethal quantity of hydrogen sulfide in a pit or tank or other enclosed space in which deoxygenated seawater that contains organic material is present. Anaerobic conditions can be prevented by keeping seawater moving through the system.

C. Seawater - Desirable Qualities

Seawater along the shore or in lagoons where desalination plant intakes are likely to be located is subject to modification of its properties due to the influx of such materials as groundwater, river water, and the presence of waste products. It is further affected by the presence of a wide variety of marine life and foreign materials.

TABLE III-II

TYPICAL VARIATIONS IN PROPERTIES OF COASTAL WATERS
(McIlhenny and Zeitoun, 1969)

	Standard Seawater	Point Loma San Diego	Brazosport Harbor*	Raritan River New Jersey	South San Francisco
Total dissolved solids, ppm	35,000	33,400	36,250	24,000	-
Chloride, ppm	19,350	18,920	20,750	12,400	11,600
Sulfate, ppm	2,712	2,610	2,900	1,960	-
Bicarbonate, ppm	142	104	95	84	-
Bromide, ppm	67	66	71	-	-
Sodium, ppm	10,760	-	10,700	-	-
Magnesium, ppm	1,294	1,280	1,400	{ 4,000 as	-
Calcium, ppm	413	398	430	$CaCO^{3}$	-
Potassium, ppm	387	-	445	-	-
Strontium, ppm	8	-	7	-	-
pH	8.2	8.1	8.0	7.0	7.7

* Extreme conditions for total dissolved solids.

SECTION III. MARINE DATA

There are, in particular, three qualities of seawater which need to be considered in seawater intake location and design. These are temperature, salinity and foreign materials.

1. Temperature

For the distillation type of desalination plants, a cool seawater of constant temperature will make possible better operating efficiencies than a warm seawater, by extending the overall ΔT. For reverse osmosis or electrodialysis plants, on the other hand, a warm seawater is advantageous. Considerable water temperature differences may occur with depth, for instance, and advantage should be taken of this when sufficient advantage will result.

2. Salinity

For the distillation type of desalination plant, salinity makes little difference in plant efficiency. However, for reverse osmosis and electrodialysis plants, a less saline water is advantageous.

3. Foreign Materials

For all types of plants, foreign materials are detrimental, and a seawater free of such materials should always be sought. Careful selection of type of intake and location can often avoid much foreign material, but usually means for removing what material is contained with the seawater must be employed. The extent to which foreign material is removed is based on process considerations and cost.

D. <u>Forces on the Sea</u>

The sea is a restless, constantly moving mass of liquid contained in a basin of very irregular shape. Because of the ocean's tremendous size, it is subject to the influence of strong forces and can transmit the energy imparted to it for great distances. Under certain shore and bottom configurations as well as other major influences, the energy transmitted by the sea can be greatly concentrated at certain points or can be diffused and expended over wide areas. Seawater intakes, sooner or later, either constantly or intermittently, will be forced to receive some of the energy transmitted to the sea by the various forces which act upon it.

SECTION III. MARINE DATA

The forces acting on an intake structure must be recognized and understood sufficiently well so that the engineering of an intake will be competently done. Many of these forces and their energy transmission through seawater as a medium are only imperfectly understood. Many are complex and defy simple explanations and solutions. In this section, the general nature of these forces will be described and, as far as practicable, methods for their use in the engineering of intakes will be presented.

The principal forces acting upon the sea which influence the sea to the extent that they become significant in the engineering of intakes, are:

Forces	Effects
Winds	Wind waves Swells Currents Storm surges
Atmospheric pressure	Storm surges
Earth forces (seismic)	Tsunamis Seiches
Gravitational pull of sun and moon	Tides

E. Waves

Figure III-3 shows the various parts of an idealized wave. Ideally, the still water level is halfway between the wave crest and the wave trough, but actually it is somewhat below the median line due to peaking of the wave crest. The depth is the vertical distance from the still water level to the ocean bottom. The wave period is the time, in seconds, for two successive wave crests to pass a fixed point.

Waves are classified in several different ways. One classification is based upon the wave period. This is shown graphically in Figure III-4 in what is known as the ocean wave spectrum.

Beginning at the lower end of the spectrum and progressing upwards, the various waves and the range of their periods can be seen to be approximately as follows (Bascom, 1964):

Figure III-3

WAVE CHARACTERISTICS

(U.S. Army, C.E.R.C., 1966)

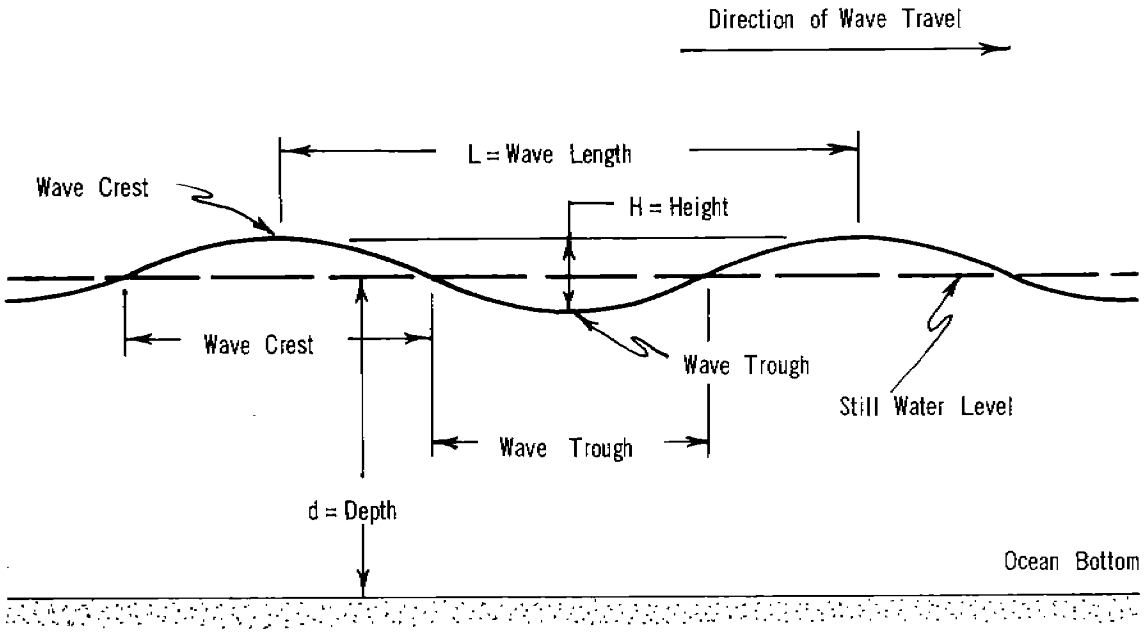
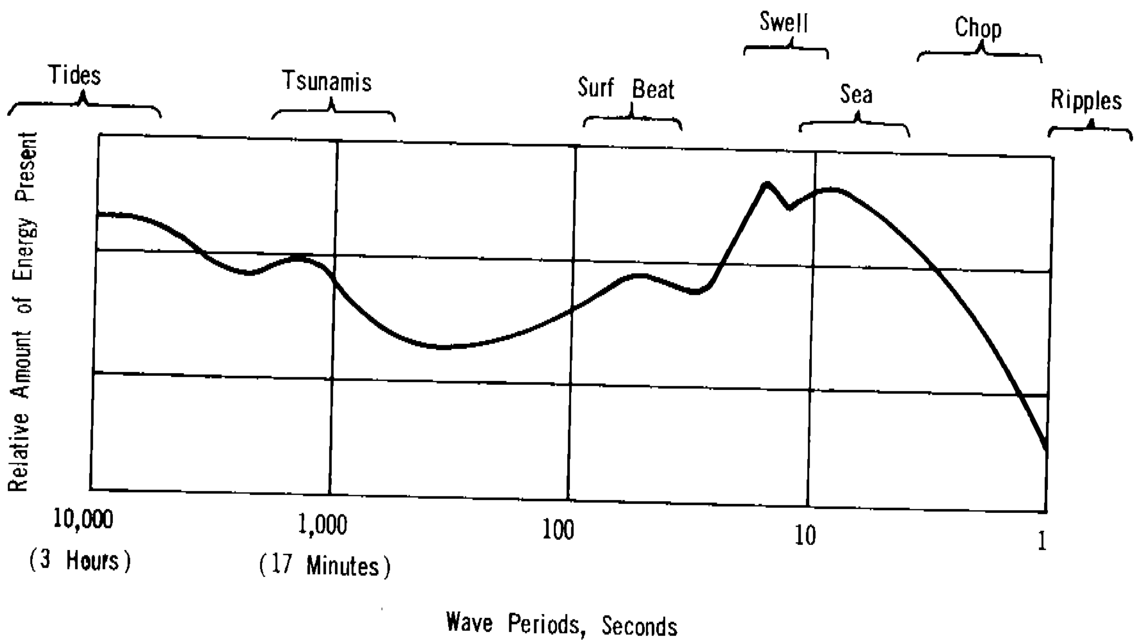


Figure III-4
THE OCEAN WAVE SPECTRUM
(Bascom, 1964)



Ripples	Fractional seconds
Wind chop	1 to 4 seconds
Fully developed seas	5 to 12 seconds
Surf beat	1 to 3 minutes
Tsunamis	10 to 20 minutes
Tides	12 to 24 hours

Waves may be classified as progressive or standing waves, depending upon their apparent movement, as forced or free waves, depending upon whether or not the generating forces are continuing to exert a significant influence, or as surface or long waves, depending upon whether or not the wave length is significantly affected by the water depth.

Ocean waves are not a pure mathematical shape. They are combinations of great numbers of small waves and must properly be dealt with on a statistical basis. However, an idealized wave can be visualized and can illustrate wave action so that it can be analyzed and applied to practice.

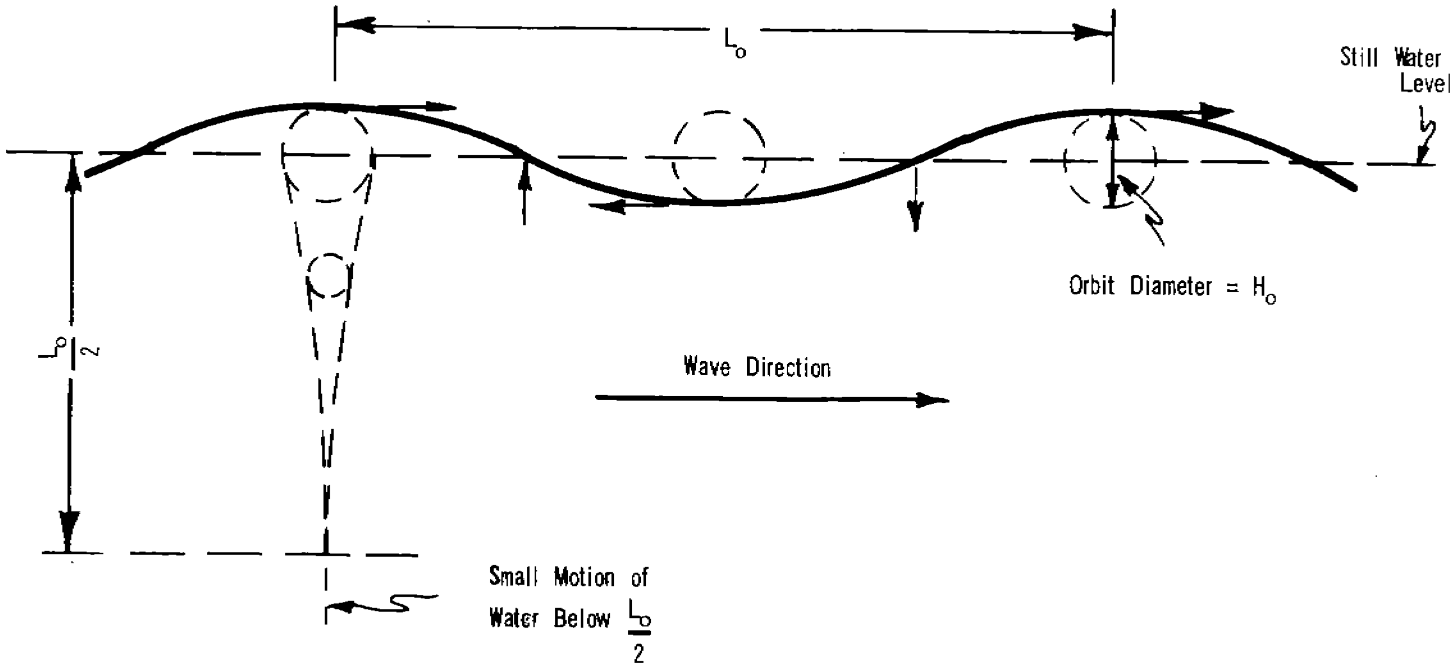
The direction of the orbital movement of water particles in different parts of a deep water wave is shown in Figure III-5. In general, the water particles trace an orbital path to a depth of approximately half the wave length. Although there may be some very slight particle movement below this depth, it is not significant to intake engineering. The water particles at the surface trace a circular path equal to the wave height. The particles further down trace smaller and smaller circles which gradually flatten out to ellipses with the long axis horizontal, finally tracing a horizontal line. At a depth of 1/9 the wave length, the diameter of the orbit is approximately half of that of the orbit of a surface particle. It can be seen that the particle motion decreases rapidly with depth.

The particles near the surface trace not a closed path but a very slightly progressing motion. This action is called mass transport. In itself, because it is so small, it can be considered negligible, but in the aggregate it does result in water movement.

Figure III—5

ORBITAL MOVEMENT OF WATER PARTICLES
OF A DEEP WATER WAVE

(U.S. Army, C.E.R.C., 1966)



In the idealized deep water wave, the surface form would be sinusoidal in shape. The wave length depends upon the wave period (though the wave height does not) and is equal to 5.12 times the square of the period.

It has been experimentally determined that a wave crest cannot assume a smaller included angle than 120° without breaking. In terms of wave height and wave length, the height cannot exceed one-seventh of the wave length without breaking, as shown in Figure III-6.

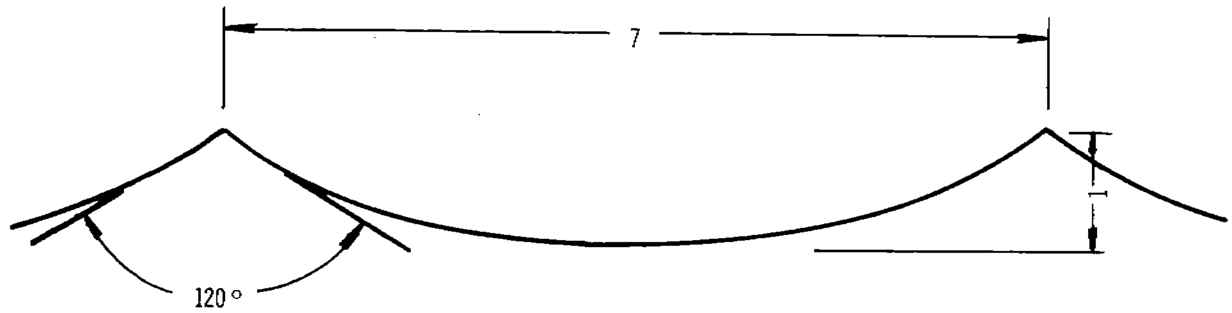
F. Wind Waves

Waves generated by wind, with one or two exceptions, transmit and release the most significant forces to which shore-type seawater intakes may be subjected. Exceptions are a tsunami or direct seismic activity transmitted through the ground on or in which the intake has been constructed.

If the wind direction remains constant and the wind velocity and distance over which the wind blows become great enough, the waves so formed will reach their limiting configuration in which the height to length ratio becomes 1:7. If the generating force continues to increase, the wave will break slightly, forming whitecaps. The resulting turbulence results in a certain amount of consolidation which then, in turn, results in the formation of longer waves. The longer waves, because of their ability to absorb the wind energy more efficiently, become predominant. It should be understood that, during this growth period, the waves do not grow uniformly in size. Waves of many sizes are involved at any one time and place during the growth of the sea as a close look at any sea surface will show.

The growth and size of wind generated waves in deep water are dependent upon three factors: velocity of the wind, duration of the wind and the length of the sea face, called the fetch, over which the wind blows. It can be readily seen that, for a given wind velocity and a very long fetch, the size of the wave is dependent upon the duration of the wind, while for a given wind and a very long wind duration, the size of the wave is dependent upon the length of the fetch. When the length of the fetch and the duration of the wind are both long and, for a given wind velocity, the waves are no longer increasing in size, the sea is then called a fully developed sea. It is the maximum which can be produced by a given wind velocity for essentially unlimited fetch and duration.

Figure III-6
MAXIMUM WAVE STEEPNESS
(Bascom, 1964)



SECTION III. MARINE DATA

A wind and sea scale for fully arisen seas is shown in Table III-III. Whole gale, storm and hurricane conditions seldom occur over durations and fetches shown as required to produce the fully developed seas for these classes. This scale is presented only to give a description and data of the nature and size of fully developed seas to be experienced with different wind velocities in deep water.

Because of the variation in wave heights under any given set of conditions, it has been found necessary to establish groupings for such wave heights. The term most generally used is significant wave height. This is the average of the highest one-third of the waves and is often denoted by the symbols H_s or H-1/3 or H_3. The average of the highest one-tenth of the waves is often denoted by the symbols H-1/10 or H_{10}. The average of the highest one percent of the waves is denoted H_1. The following approximate relationships then hold:

$$H_{10} \approx 1.27\ H_s$$

$$H_1 \approx 1.67\ H_s$$

Figure III-7 gives a wave spectrum for fully arisen seas caused by winds of twenty, thirty and forty knots. The area under each curve represents the total energy for that particular wave. The abscissa is the wave frequency or the reciprocal of the wave period. It can be seen that higher winds create a more pronounced peaking of energy and an increase in the wave period. An important consideration is that the wave energy is proportional to the square of the wave height. The wave heights for the twenty, thirty and forty knot winds can be obtained from Table III-III.

Wind waves generated in shallow water where the d/L_o ratio is less than 0.5 are modified from those generated in deep water. The effect of the bottom on shallow water wave generation will be covered later in this report.

Very practical and detailed methods for determining the size of deepwater and shallow water waves that might be anticipated are given in pages 1-50 and pages 50-62, respectively, in the U. S. Army Coastal Engineering Research Center Technical Report No. 4, "Shore Protection, Planning and Design", 1966. This excellent work is an invaluable guide in the engineering of coastal structures and should, by all means, be referred to in the engineering of seawater intakes.

TABLE III – III

WIND AND SEA SCALE FOR FULLY ARISEN SEA

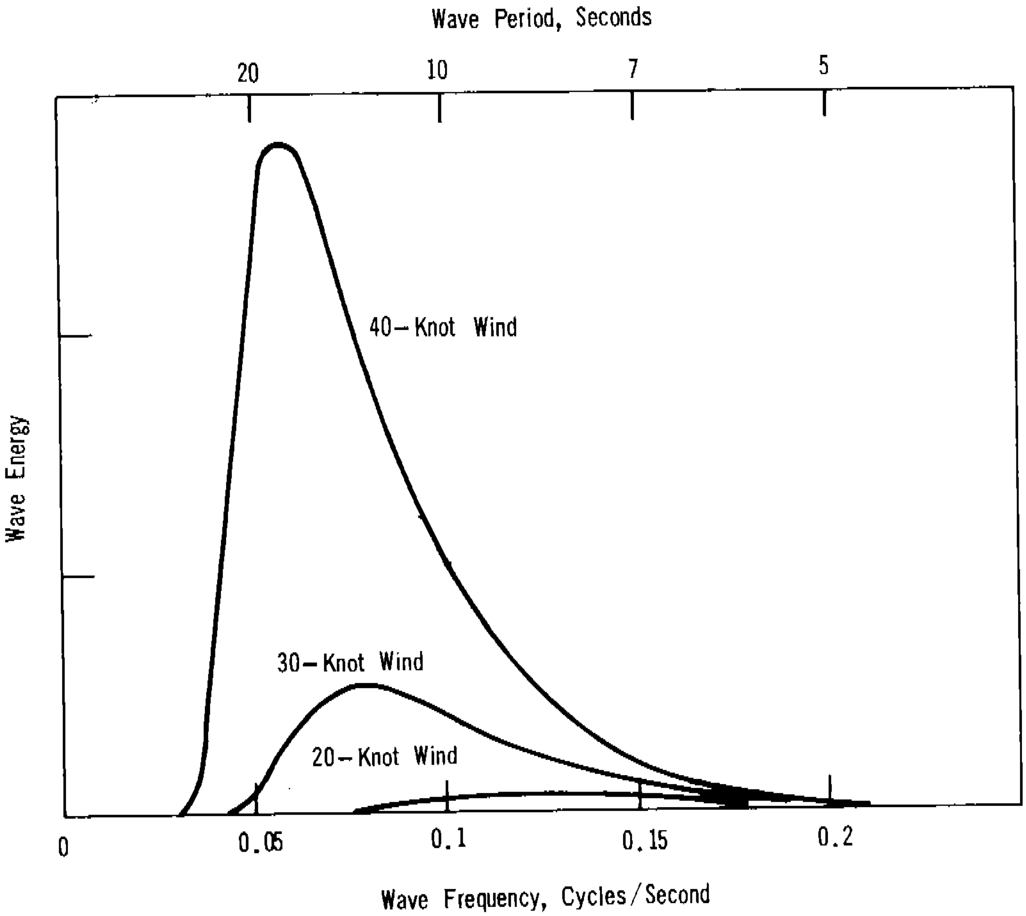
(U.S. Army, C.E.R.C., 1966)

SEA – GENERAL: SEA STATE	SEA – GENERAL: DESCRIPTION	WIND: (BEAUFORT) WIND FORCE	WIND: DESCRIPTION	WIND: RANGE (KNOTS)	WIND: WIND VELOCITY (KNOTS)	SEA: WAVE HEIGHT FEET: AVERAGE	SEA: WAVE HEIGHT FEET: SIGNIFICANT	SEA: WAVE HEIGHT FEET: AVERAGE 1/10 HIGHEST	SEA: SIGNIFICANT RANGE OF PERIODS (SECONDS)	SEA: T_{MAX} PERIOD OF MAXIMUM ENERGY OF SPECTRUM	SEA: T AVERAGE PERIOD	SEA: λ AVERAGE WAVE LENGTH	SEA: MINIMUM FETCH (NAUTICAL MILES)	SEA: MINIMUM DURATION (HOURS)
	Sea like a mirror.	0	Calm	< 1	0	0	0	0	-	-	-	-	-	-
0	Ripples with the appearance of scales are formed, but without foam crests.	1	Light Airs	1-3	2	0.05	0.08	0.10	≤1.2 sec	0.7	0.5	10 in	5	18 min
1	Small wavelets, short but pronounced crests have a glassy appearance, but do not break.	2	Light Breeze	4-6	5	0.18	0.29	0.37	0.4-2.8	2.0	1.4	6.7 ft	8	39 min
	Large wavelets, crests begin to break. Foam of glassy appearance. Perhaps scattered white horses.	3	Gentle Breeze	7-10	8.5	0.6	1.0	1.2	0.8-5.0	3.4	2.4	20	9.8	1.7 hrs
					10	0.88	1.4	1.8	1.0-6.0	4	2.9	27	10	2.4
2	Small waves, becoming larger; fairly frequent white horses.	4	Moderate Breeze	11-16	12	1.4	2.2	2.8	1.0-7.0	4.8	3.4	40	18	3.8
					13.5	1.8	2.9	3.7	1.4-7.6	5.4	3.9	52	24	4.8
3					14	2.0	3.3	4.2	1.5-7.8	5.6	4.0	59	28	5.2
					16	2.9	4.6	5.8	2.0-8.8	6.5	4.6	71	40	6.6
	Moderate waves, taking a more pronounced long form; many white horses are formed. (Chance of some spray)	5	Fresh Breeze	17-21	18	3.8	6.1	7.8	2.5-10.0	7.2	5.1	90	55	8.3
4					19	4.3	6.9	8.7	2.8-10.6	7.7	5.4	99	65	9.2
					20	5.0	8.0	10	3.0-11.1	8.1	5.7	111	75	10
5	Large waves begin to form; the white foam crests are more extensive everywhere. (Probably some spray)	6	Strong Breeze*	22-27	22	6.4	10	13	3.4-12.2	8.9	6.3	134	100	12
					24	7.9	12	16	3.7-13.5	9.7	6.8	160	130	14
					24.5	8.2	13	17	3.8-13.6	9.9	7.0	164	140	15
6					26	9.6	15	20	4.0-14.5	10.5	7.4	188	180	17
	Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind. (Spindrift begins to be seen)	7	Moderate Gale	28-33	28	11	18	23	4.5-15.5	11.3	7.9	212	230	20
					30	14	22	28	4.7-16.7	12.1	8.6	250	280	23
					30.5	14	23	29	4.8-17.0	12.4	8.7	258	290	24
					32	16	26	33	5.0-17.5	12.9	9.1	285	340	27
7	Moderately high waves of greater length; edges of crests break into spindrift. The foam is blown in well-marked streaks along the direction of the wind. Spray affects visibility.	8	Fresh Gale	34-40	34	19	30	38	5.5-18.5	13.6	9.7	322	420	30
					36	21	35	44	5.8-19.7	14.5	10.3	363	500	34
					37	23	37	46.7	6.0-20.5	14.9	10.5	376	530	37
					38	25	40	50	6.2-20.8	15.4	10.7	392	600	38
					40	28	45	58	6.5-21.7	16.1	11.4	444	710	42
8	High waves. Dense streaks of foam along the direction of the wind. Sea begins to roll. Visibility affected.	9	Strong Gale	41-47	42	31	50	64	7.0-23	17.0	12.0	492	830	47
					44	36	58	73	7.0-24.2	17.7	12.5	534	960	52
					46	40	64	81	7.0-25	18.6	13.1	590	1110	57
	Very high waves with long overhanging crests. The resulting foam is in great patches and is blown in dense white streaks along the direction of the wind. On the whole, the surface of the sea takes on a white appearance. The rolling of the sea becomes heavy and shock-like. Visibility affected.	10	Whole Gale	48-55	48	44	71	90	7.5-26	19.4	13.8	650	1250	63
					50	49	78	99	7.5-27	20.2	14.3	700	1420	69
					51.5	52	83	106	8.0-28.2	20.8	14.7	736	1560	73
9					52	54	87	110	8.0-28.5	21.0	14.8	750	1610	75
					54	59	95	121	8.0-29.5	21.8	15.4	810	1800	81
	Exceptionally high waves. Sea completely covered with long white patches of foam lying in direction of wind. Everywhere edges of wave crests are blown into froth. Visibility affected.	11	Storm	56-63	56	64	103	130	8.5-31	22.6	16.3	910	2100	88
					59.5	73	116	148	10.0-32	24	17.0	985	2500	101
	Air filled with foam and spray. Sea white with driving spray; visibility very seriously affected.	12	Hurricane	64-71	>64	>80	>128	>164	10.0-(35)	(26)	(18)			

Figure III-7

WAVE SPECTRUM FOR FULLY ARISEN SEAS

(Bascom, 1964)



Likewise, methods for hurricane wave height determination are given in pages 104-114 of the same technical report. Figure III-8 shows the hurricane zones established by the U. S. Weather Bureau which can be used as a guide in determining hurricane design parameters.

Because of the detailed explanation and the large amount of data contained in the C.E.R.C. report regarding the forecasting of deepwater and shallow water waves, no attempt will be made to repeat this material herein other than to say that such forecasts are based upon the use of synoptic surface weather charts, the location of land masses, and the configuration of the ocean bottom and depth.

G. Swell

When wind generated waves move out of the area of generation, they may travel for thousands of miles in deep water, utilizing the energy stored in them and losing very little of this energy until moving into shallow water. With the wind force gone, the wave crests become more rounded and the entire wave form approaches that of a sine curve. These waves are called swell. Their period is usually from six to sixteen seconds, although occasionally it is longer. Table III-IV gives some of the characteristics of swell in deep water. One characteristic of swell is that the actual overall velocity is only half that which would normally be the case with an individual wave of the same velocity.

H. Storm Surges

Violent storms with their high winds not only create waves but also "drag" some water with them. This phenomenon is known as a storm surge, a storm tide, or wind setup. Storms may also be accompanied by atmospheric pressure differences between a low pressure area and adjoining or surrounding high pressure areas, resulting in a lowering or a raising of the normal still water level. Any wave action would, of course, be superimposed upon the resulting still water level. Perhaps the most notable example was the Galveston, Texas, catastrophe of 1900. A hurricane with winds of 120 miles per hour was producing 25-foot high waves. The accompanying storm surge raised the water level 15 feet above the normal 2-foot tidal range, so that waves were reaching a level 40 feet above normal high tide, with disastrous results.

Figure III-8

HURRICANE ZONES FOR ATLANTIC AND GULF COASTS

(U.S. Army, C.E.R.C., 1966)

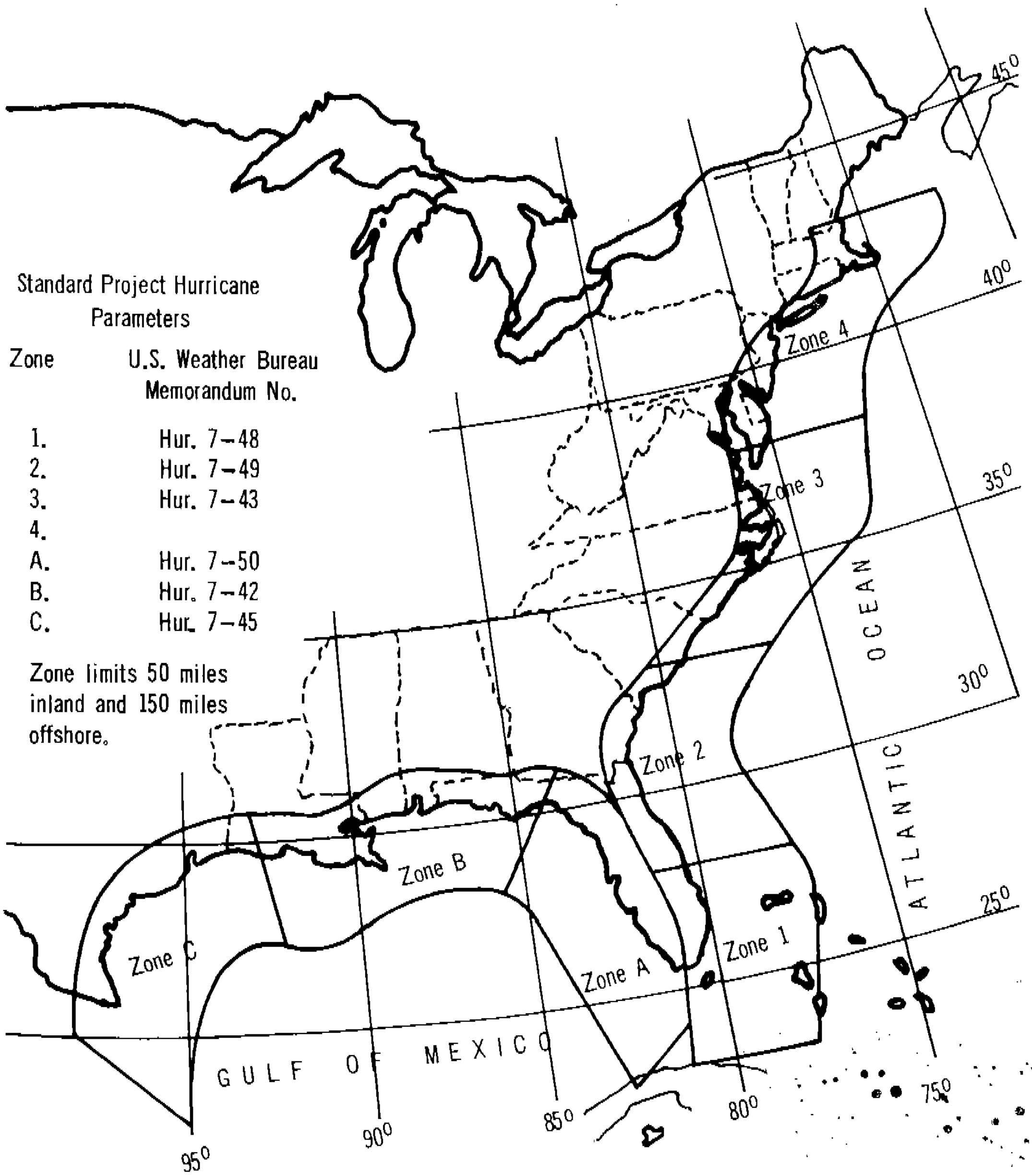


TABLE III-IV

APPROXIMATE LENGTHS AND VELOCITIES OF SINUSOIDAL SWELL IN DEEP WATER

(Bascom, 1964)

Period in seconds	Wave length, feet	Velocity, feet/sec.	Approximate velocity, miles/hr.	Water depth, feet
6	184	30.5	21	92
8	326	40.6	28	163
10	512	51.0	35	256
12	738	61.0	42	369
14	1000	71.5	49	500
16	1310	82.0	56	655

Note: The final column, d/L = 0.5, is the depth at which each becomes a shallow water wave.

SECTION III. MARINE DATA

I. Tsunamis

Waves created by underwater seismic activity are commonly misnamed tidal waves. They are more properly called tsunamis or seismic sea waves. Such waves can be caused by several phenomena such as by underwater faulting in the earth's crust, by an underwater volcanic eruption or by an underwater landslide.

Tsunamis have very long periods, varying from perhaps 12 minutes to almost 60 minutes. This would make them shallow water waves. The deep water wave heights are low, usually less than two feet. However, their heights when they reach shore can be many, many times the deep water height due to "the offshore characteristics of the waves, diffraction, the slope and configuration of the shore, and resonance" (Wiegel, 1964). Some have exceeded 100 feet.

The determination of design conditions for protection against tsunamis can only be based upon statistical data and upon anticipated future seismic activity. In areas where tsunamis are infrequent or nonexistent, as determined by historical records and by geological predictions, they can be eliminated as a part of the design criteria. On the other hand, where tsunamis have occurred fairly frequently and their size is significant, they should be included in the design criteria. Tsunamis are rare on the Atlantic and Gulf Coasts of the United States and are probably not important on the Pacific Coast except where the shoreline configuration might tend to amplify the wave force. Tsunamis are probably more a matter of site selection than a design consideration for United States Coasts, except for Hawaii and Alaska.

J. Tides

Tides are the longest of all the ocean waves, having a length of half the circumference of the earth and a period of 12 hours and 25 minutes. They are the result primarily of the gravitational forces exerted by the sun and the moon on the water together with the centrifugal force of the earth and moon and the earth and sun as rotating systems. The rise and fall of the water is generally called the tide while the horizontal movement of the water is termed the tidal current. The crest of the wave is high tide while the trough is low tide.

The greater force is exerted by the earth-moon system and the lesser force by the earth-sun system because of the sun's much greater distance. At new and full moon the effects of the moon and sun forces are additive and produce the higher tides which are called spring tides, while at first and last quarters of the moon the effects are offsetting, producing lower high and higher low tides, called neap tides. In the case of the moon, there is a 20 percent increase in the tidal range from the mean range, when the mocn is at perigee, and a 20 percent decrease at apogee. In addition to the effects of changes in longitude and declination of the sun and moon, many other influences modify or amplify these forces. The multiplicity of influencing factors makes the theoretical determination of tidal levels and periods extremely complex and impractical. Measurements, refined by theory, provide most of the practically useable data.

Tides on some shores, including the U. S. Atlantic, occur twice a day with roughly equal heights. These are called semidiurnal tides. Tides occur only once a day on some shores. These are called diurnal tides. On still other shores, including the U. S. Pacific, the tides are mixed. The heights of the alternate high and low tides are significantly different. Figure III-9 illustrates these three types of tides.

Tides may vary greatly along a shoreline because of the configuration of the shoreline. The Bay of Fundy is a well-known example of a funnel-shaped bay which, because of its peculiar configuration, amplifies the wave energy and produces a much higher tide than would otherwise be the case. The tides here rise to over 40 feet whereas only some 200 miles south at Portland, Maine, the mean tidal range is in the order of nine feet and at Woods Hole, Massachusetts, 150 miles further south, the mean tidal range is approximately two feet.

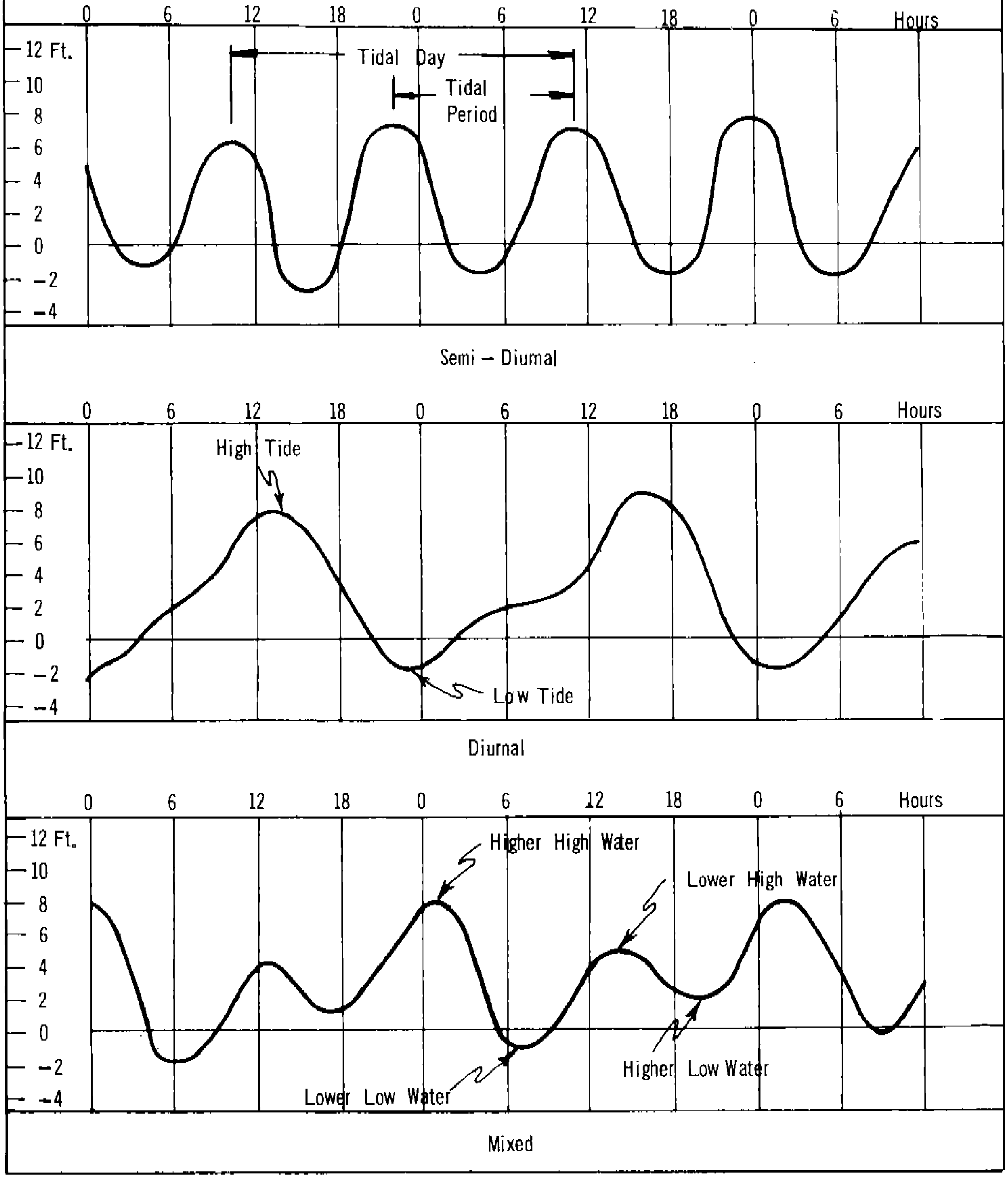
Associated with the rising and falling of the tide is a horizontal movement of water known as the tidal current. This is of particular importance on coasts and, as mentioned previously, is greatly influenced by the coastal configuration. A rising tide is referred to as flooding and a falling tide is known as ebbing. During those times when there is no current flow, the water condition is known as slack.

It is necessary to base tidal measurements upon a datum plane. The datum plane used varies from country to country. In the U. S., the Coast and Geodetic Survey has used mean

Figure III-9

TYPES OF TIDES

(U.S. Army, C.E.R.C., 1966)



low water as the datum plane for the Atlantic Coast and mean lower low water for the Pacific Coast. Another datum plane sometimes used on topographic maps is mean sea level. Definitions for the various water levels encountered during the tidal cycle are as follows (U. S. Army C.E.R.C., 1966):

HIGH TIDE, HIGH WATER (HW) - The maximum height reached by each rising tide.

HIGHER HIGH WATER (HHW) - The higher of the two high waters of any tidal day. The single high water occurring daily during periods when the tide is diurnal is considered to be higher high water.

HIGHER LOW WATER (HLW) - The higher of two low waters of any tidal day.

LOWER HIGH WATER (LHW) - The lower of the two high waters of any tidal day.

LOWER LOW WATER (LLW) - The lower of the two low waters of any tidal day. The single low water occurring daily during periods when the tide is diurnal is considered to be a lower low water.

LOW TIDE, LOW WATER (LW) - The minimum height reached by each falling tide. See TIDE.

MEAN HIGHER HIGH WATER (MHHW) - The average height of the higher high waters over a 19-year period. For shorter periods of observation, corrections are applied to eliminate known variations and reduce the result to the equivalent of a mean 19-year value.

MEAN HIGH WATER (MHW) - The average height of the high waters over a 19-year period. For shorter periods of observations, corrections are applied to eliminate known variations and reduce the results to the equivalent of a mean 19-year value. All high water heights are included in the average where the type of tide is either semidiurnal or mixed. Only the higher high water heights are included in the average where the type of tide is diurnal. So determined, mean high water in the latter case is the same as mean higher high water.

Figure III-12
RIP CURRENT

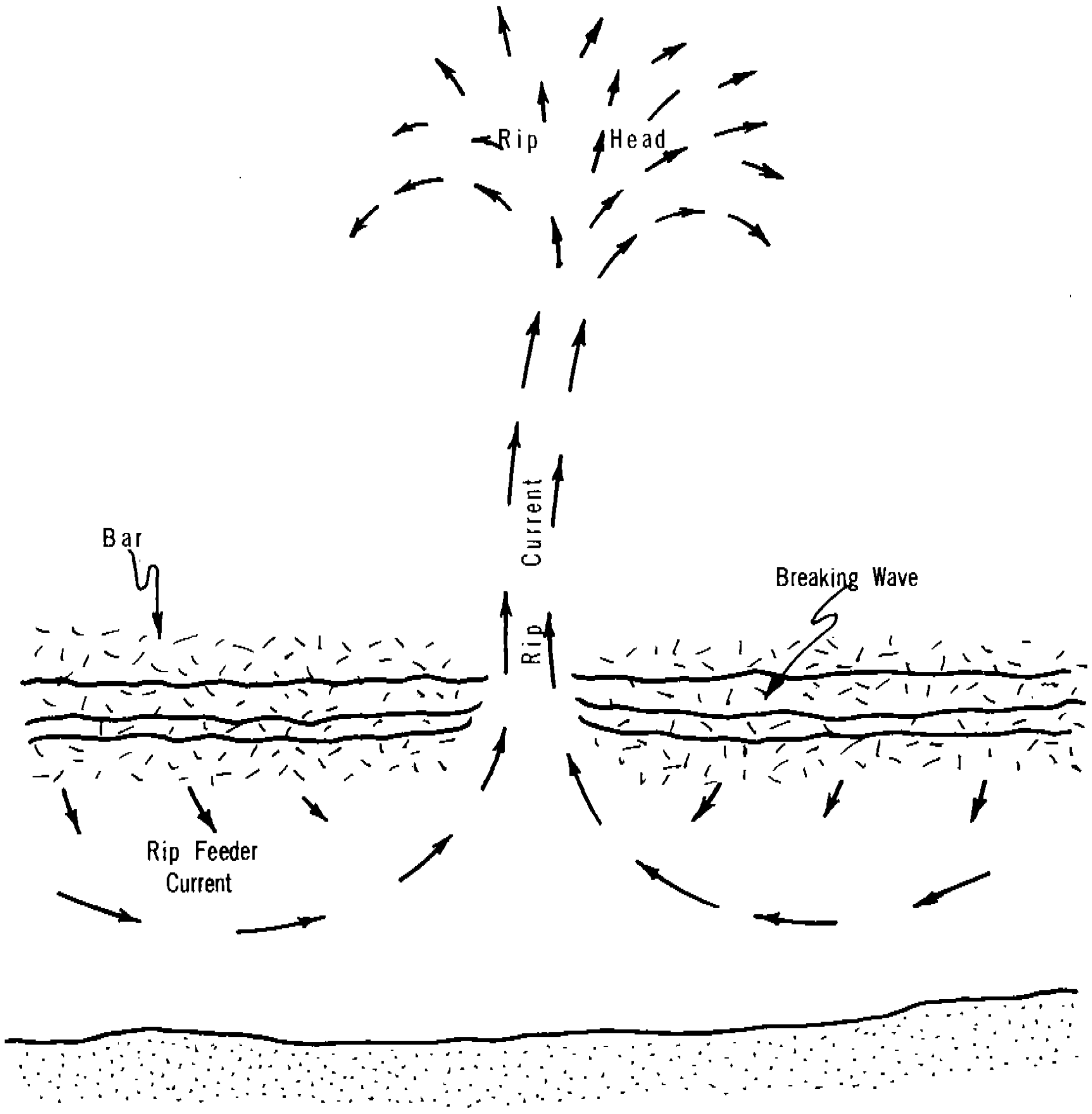
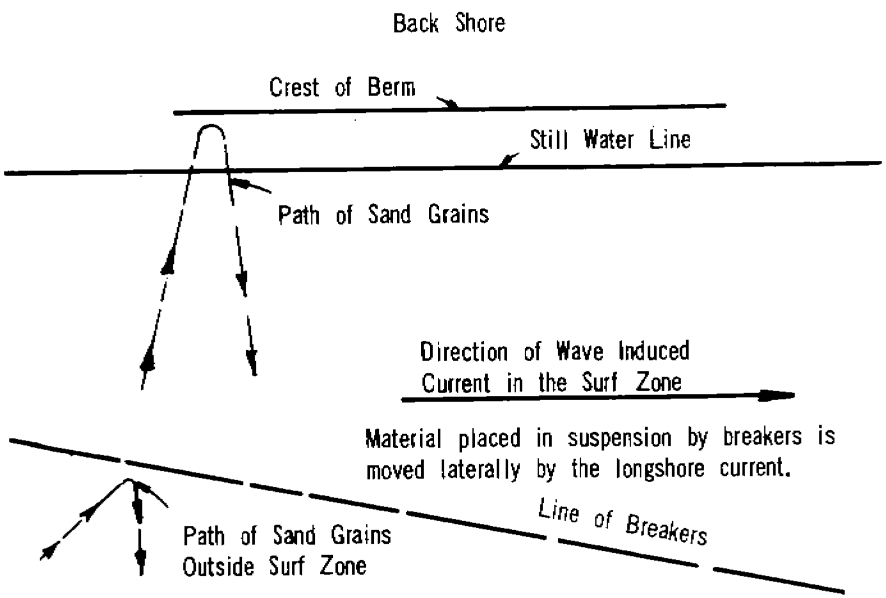


Figure III-13

LONGSHORE MOVEMENT OF LITTORAL DRIFT

(U.S. Army, C.E.R.C., 1966)



Bed load moves up or down coast in a zigzag pattern. Movement in all three zones illustrated is in a direction and at a rate dependent on the longshore component of wave energy.

There are several methods of drawing refraction diagrams; all begin with an accurate contour chart of the bottom configuration out to a depth of half the longest wave that will be considered. Then the period and direction of the waves to be diagrammed must be selected. The practicing coastal engineer will prepare diagrams for waves of many periods and directions, but usually he will also make a statistical wave hindcast. That is, he will make estimates of wave heights and periods based on historic weather maps to obtain statistics on what waves have arrived in the past and are likely to arrive in the future. One of these waves is likely to be predominant, and he will start with it - on much of the U. S. West Coast it is often a twelve-second wave from the northwest. Now he proceeds by drawing a straight line representing a wave front in deep water, or using another method, a wave ray (perpendicular to the wave front) that shows the direction of wave advance. In the wave-front method it is customary to calculate the new, somewhat reduced wave length for each contour depth and to use these to step off the advance of the wave front. The resulting diagram shows the successive positions of the wave front at time intervals equal to the period. As the wave slows down the wave fronts get closer and closer together.

A more detailed explanation of methods for preparing wave refraction diagrams is given in pages 63-72 in the U. S. Army Coastal Engineering Research Center Technical Report No. 4, "Shore Protection, Planning and Design".

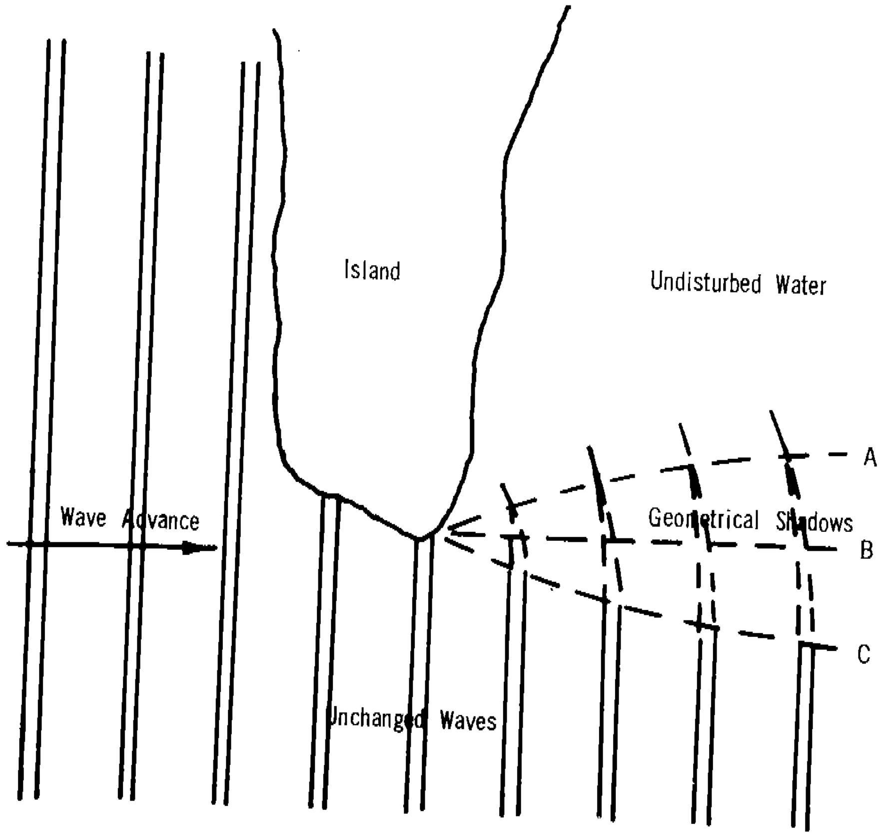
S. Wave Diffraction

Diffraction of a wave is the phenomenon in which a train of waves is interrupted by a barrier such as a breakwater. As a result, a portion of the wave energy moves laterally along the wave crest into the lee side of the barrier, as shown in Figure III-16. Diffraction is distinctly different from refraction. If the movement of a train of waves past a barrier is also affected by bottom friction, the result will be a combination of diffraction and refraction.

T. Littoral Transport

The movement of sand and other material along the shore in the nearshore zone is termed littoral transport. Waves and currents are the principal forces moving this material. One of three conditions always exists along any given stretch of beach - the beach is aggrading, or it is stable, or it is eroding. When a beach is aggrading, materials may

Figure III – 16
WAVE DIFFRACTION
(Bascom, 1964)



Wave Height at C = 1.0
Wave Height at B = 0.5
Wave Height at A = 0.1

originate by transport from adjacent areas, by materials brought down by streams or by erosion of coastal formations. Usually, however, the major source of incoming material along a seacoast for an aggrading beach is material (littoral drift) from an adjacent area. Actual sources and quantities from the various sources are difficult to determine with accuracy.

Although the mechanics of littoral transport are not well understood, it can be said that three general types of transport are involved. Along the foreshore, material is moved along the shore in a zigzag manner by waves approaching the shore at an angle and then by the backrush leaving the shore at an angle. In the surf zone, material is moved by the turbulent action of the waves which put the material into suspension and by the longshore currents which move the suspended material along. Along the bottom of the surf zone and seaward of the surf zone for a greater or lesser distance, movement may be by sliding, rolling and saltation which is caused by oscillation of passing waves. Bottom movement may take place in depths exceeding 100 feet. The three types of movement are shown in Figure III-13. Velocities necessary to move sand of various sizes is shown in Figure III-17. The coarser grains of sand are found shoreward and the finer grains of sand seaward. This gradation of sand is referred to as slope sorting.

The movement of sand grains may be measured by coating typical sand grains with a very thin film of suitable radioactive tracer. The direction and distance of movement can be detected by the use of ultraviolet light on the fluorescent film or by the use of a nuclear detector.

The U. S. Army Coastal Engineering Research Center gives a much more detailed description of the littoral process (U. S. Army C.E.R.C., 1966). In this report, it is stated that "the direction of littoral transport at any one time can generally be determined by observation of shore configuration in the vicinity of existing structures". This is probably the most reliable of several methods but observation should be over a period sufficiently long to account for a complete seasonal cycle.

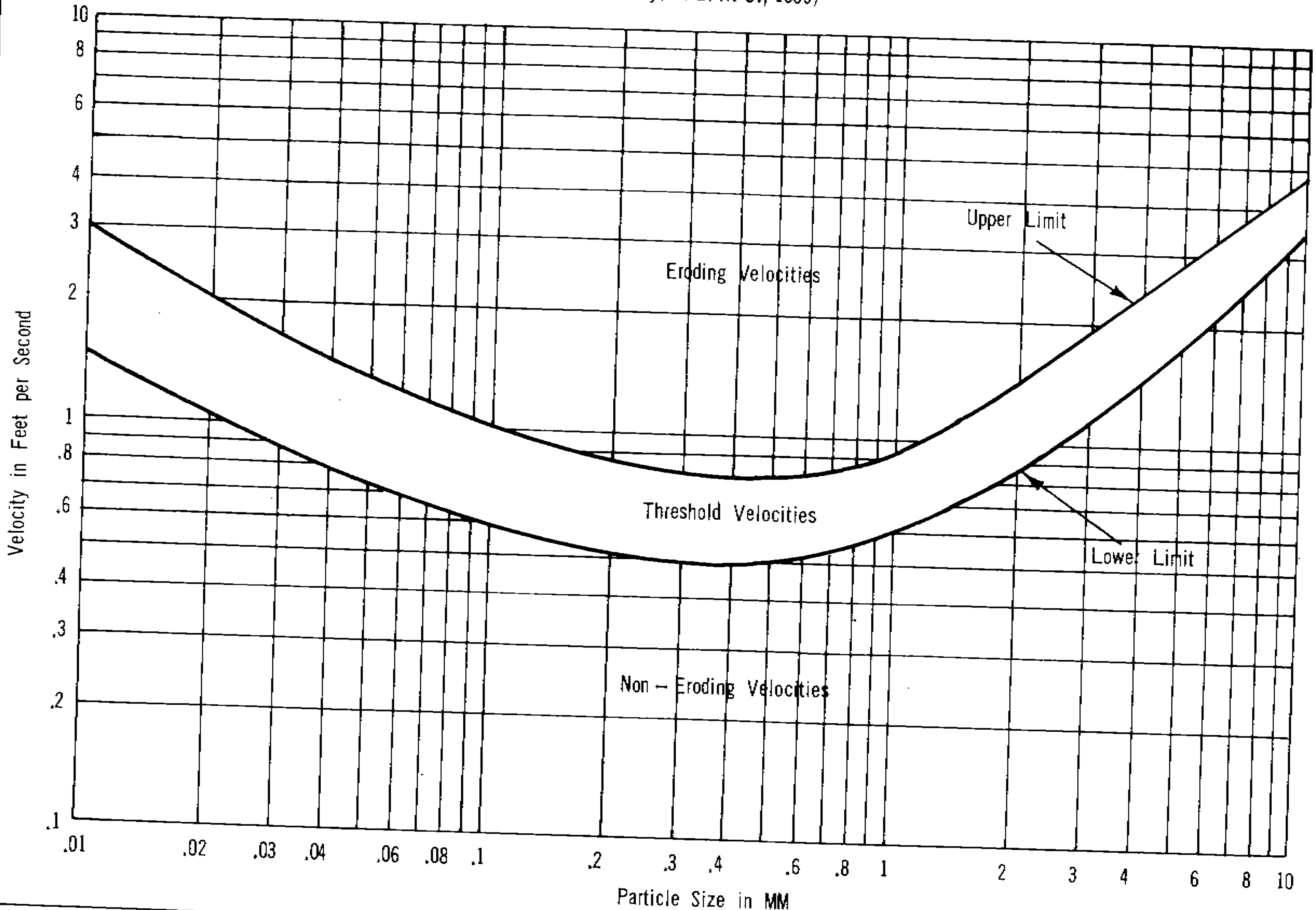
U. Plant and Animal Life

The animal organisms that cause difficulty in intake systems are those that float, the zooplankton, the ones that swim, the nekton, and in some instances the bottom dwellers or

Figure III – 17

MEAN VELOCITIES REQUIRED TO ERODE SAND

(U. S. Army, C. E. R. C., 1966)



benthic organisms. Various kinds of algae make up the major portion of the marine plant life, but it is the brown algae, phylum Phaeophyta, that have sufficient mass to make a problem for the intake systems.

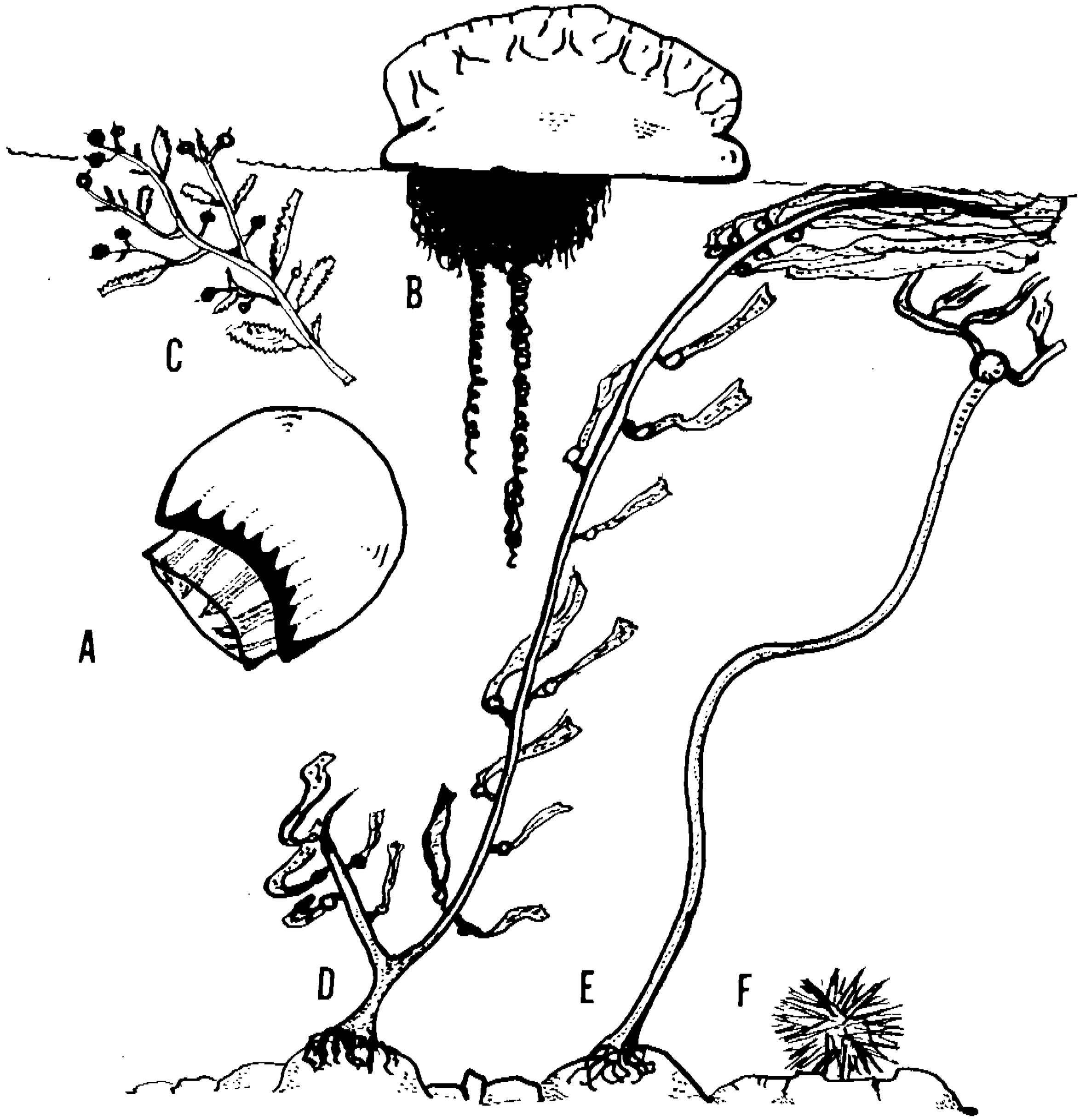
One might look at a calm ocean scene and see quiet and clear water and assume that there would be few problems in taking in large amounts of salt water from such an area, but a change in weather, or a change in season could bring a great number of floating animals such as large jellyfish or a mass of floating seaweeds washed upon the shore and these could present a problem. Plant and animal life that can come into an intake system will vary with the season and geographic location. Problems will vary for a bay, canal, or shore location that are in the same area. An example of the difference would be that for an open shore location of a seawater intake system there would be times when masses of seaweed may come in in large amounts; and in contrast, an intake system in a bay would run into problems with various kinds of small marine life, such as shrimp or young crabs, coming in with the intake water in large numbers.

Seaweeds of the Atlantic and Gulf Coasts

The open shores of the Gulf of Mexico and the Atlantic are sandy and relatively shallow, and they are not an ideal habitat for marine algae. Occasionally great windrows of algae will be washed ashore. The algae may have washed from nearby bay areas, where it can grow in more sheltered waters, or it may have washed in from the open sea. The commonest brown algae of the warm waters of the Gulf and south Atlantic is Sargassum; it is also known as "gulfweed". It is a plant 1 to 3 feet long with stems bearing leaf-like appendages and spherical bladders, as shown in Figure III-18, illustration C. It is quite tough and does not disintegrate readily. Gulfweed has a wide distribution in warm waters and has been well known for a long time. There is one portion of the Atlantic, south of Bermuda, where it grows in great profusion, known as the Sargasso Sea. Gulfweed grows without attachment and can vegetatively reproduce while floating in the sea. The species Sargassum fluitans and Sargassum natans are strictly pelagic (Humm and Caylor, 1957). In the spring and summer, currents and winds deposit gulfweed on the shore, but not in sufficient amounts to be a problem. However, in the case of a storm or hurricane, it can occur in such amounts as to create an operating problem in intake systems that pull in surface water.

Figure III – 18

TROUBLESOME PLANT AND ANIMAL LIFE



Atlantic and Gulf Coast

A. Cabbagehead jellyfish, Stomolophus meleagris

B. Portuguese man – of – war, Physalia physalia

C. Gulfweed, Sargassum

Pacific Coast

D. Giant kelp, Macrocystis pyrifera

E. Elk kelp, Pelagophycus porra

F. Giant red sea urchin, Strongylocentrotus franciscanus

There is another marine plant that can present problems; it is commonly known as "turtle grass". The scientific name of this plant is Thalassia diplanthera. It is not an algae but an angiosperm or "higher" plant. Turtle grass grows in the shallow sandy shores along the west coast of Florida and it is an important plant in bay and estuary systems along the entire Gulf Coast (Odum, 1967). It is most abundant between Cedar Keys to Pensacola, in Biscayne Bay and marine waters of the Miami area. Turtle grass leaves support a dense and varied crop of algae, both microscopic and macroscopic, and this could present a problem for a seawater intake system. Some of the forms of red algae as Hypnea musciformis grow to a fairly large size and then break loose and pile up in great windrows on the shore. This has been reported for Biscayne Bay (Humm, 1964). Also, the turtle grass is a fine habitat for various marine organisms such as crabs, shrimp, and small fish that might be swept in with the current of an intake system (O'Gowen and Wacasey, 1967). Off the southwest coast of Florida, there is a mud and shell substrate that is suitable for the turtle grass, and also for certain of the marine algae. There are actually 164 varieties described for this area. Some of these exist in tangled mats which can be washed loose by storms or strong currents and thrown up on the shore (Dawes et al, 1967). Most of these seaweeds grow in shallow waters from the intertidal zone down to about 30 or 40 meters. In clear tropical or subtropical waters some of them may occur at ten times this depth.

The southern tip of Florida represents a different ecological area for plants and animals. One of the greatest mangrove swamps of the world has developed along the southern coast of Florida. It extends from the Florida keys around the southern tip of the mainland and north along the Gulf Coast through the Ten Thousand Islands. Mangroves do not represent a particular plant, but it is a term used for all woody plants that can exist along the shallow tidal areas (McConnaughey, 1970). Within this complex of plants, there are many small animals such as crabs, snails, clams and other invertebrates which could flow into a saltwater intake system with the water.

Where there is a rocky substrate along the north Atlantic shores there are a number of brown algae of sufficient size to cause problems in seawater intake systems if they are washed ashore. Examples of this are the rock weed, Fucus, which is an olive-green brown algae that has a tough leathery flattened appearance with numerous air vesicles, and bladder wrack, Ascophyllum, which is a dominant member of algae communities. The dominant sea grass of the North Atlantic is the "grass wrack" or Zostrea marina. It helps to stabilize the bottom of bays, estuaries and river mouths, and also provides a good environment for cod, scallops, and crabs. Zostrea occurs in protected areas, and the many small animals that live in this environment could get into seawater intake systems.

Marine algae could create occasional operating problems in seawater intake systems located on Atlantic and Gulf Coasts. However, these plants usually have air bladders so that they float. An intake system that did not take in surface water could avoid much of the algae.

Marine Animals

There are a number of different kinds of animals that could create operating problems if they flow into the seawater intake systems with the intake water. These animals come from three major categories of marine life: the plankton, the nekton, and the benthic animals. Zooplankton is a term applied to the communities of floating, drifting animals carried about primarily by movements of the water rather than by their own swimming activity, but this does include the large jellyfish. Those larger animals that control the direction and speed of their own movements constitute the nekton. Organisms that live on or near the bottom are known as benthic animals.

Zooplankton of the Atlantic and Gulf Coasts

Various jellyfish are of sufficient size and number to cause operating problems in a salt water intake system. These animals are all in phylum Coelenterata. The particular jellyfish that has proven to provide the greatest problem on the northwest Gulf Coast is commonly known as the "cabbagehead". The scientific name is Stomolophus meleagris. This is a large jellyfish measuring as much as 18 inches in diameter. It resembles a large mushroom as can be seen in Figure III-18, illustration A. It is an order of jellyfish that do not have any tentacles. They have a body that is made of a very tough gelatinous substance. There are groups of nematocysts or sting cells scattered on the surface. The fact that they are large, tough, and occur seasonally in great numbers is what makes them an occasional operating problem as they flow into the intake systems at The Dow Chemical Company plant at Freeport, Texas. There are times when these animals are present in such numbers on the intake screens that men have to be employed to pull them off. They occur in large numbers even though the saltwater intake system is located on a canal and the water passes through a skimmer gate. The cabbagehead jellyfish can swim by rhythmic pulses of its large bell, either at the surface or below. This makes it possible for this animal, without benefit of eyes or brain, to go around or under a barrier.

Stomolophus, the "cabbagehead", is very well known along the Texas Coast and other areas of tropical and subtropical waters. In a tide trap collection experiment that was conducted for one year at the Institute of Marine Science at Port Aransas, Texas, it was found that the cabbagehead jellyfish was by far the most prominent animal in the tide trap collections. The peaks for collecting the cabbagehead were seasonal; one occurred in April and May and one in October (Copeland, 1965). The cabbagehead jellyfish may present more of a problem when intake systems are located in bays or canals, because they have a tendency to move through passes or inlets and accumulate in large numbers in such areas. However, the cabbagehead was an occasional problem to the operation of the seawater intake system of the Ethyl-Dow plant on the North Carolina Coast, and the intake was located on the open shore.

The life cycle of an animal such as Stomolophus is complex. There is an intermediate stage when the animal is an attached polyp and develops little buds that break off and form the "jellyfish" that we are familiar with. This intermediate attached stage is probably located in a tropical area where there are caves or stones for them to attach to. The adult feeds on small plankton which it catches with nematocysts located on the mouth arms. The cabbagehead jellyfish is found along the entire Gulf Coast and the south Atlantic Coast, and it could constitute an operating problem in a seawater intake system in any of those areas.

The common jellyfish of the Atlantic Coast, Aurelia aurita, can become as large as 10 inches in diameter. It can occur in great numbers, and it does have a fairly tough center, so it could become a problem if a large number were taken into an intake system. These animals are prevalent from Greenland to the West Indies. Also, they have long tentacles which have many sting cells, or nematocysts. Off the coast of New England there is a very large jellyfish, Cynea capillata. It may attain a diameter of 8 feet, however most are not over three feet. The tentacles, bearing nematocysts, are 75 feet long. Just a few of these animals taken into an intake could present a problem. All of these jellyfish are able to swim underneath the water or on the surface and that makes it possible for them to get into various kinds of intake systems (McConnaughey, 1970).

There is another animal that is common along the Gulf Coast and the south Atlantic Coast that is commonly called a "jellyfish", but it is in a different group. This is the Portuguese man-of-war, Physalia physalia. They look like bright blue oblong balloons riding the surf. Actually these animals are a colonial form in which several types of individuals are united, as shown in Figure III-18, illustration B. They cannot swim but drift only on the surface of the water. There are some muscles in the float of this animal so that it can change the direction it is going as the wind blows it along. Fishing tentacles, up to 75 feet in length, trail below the surface and catch large fish, which are then surrounded by the digestive tentacles. The Portuguese man-of-war would present a problem in the operation of an intake system only if surface waters were being taken in. If some of these Portuguese man-of-war do get on the intake screens and attempts are made to remove them, it must be remembered that the stinging capacity of the long tentacles of these animals is retained after the tentacles and the animal are separated. There are a number of other jellyfish-like animals that are present in the Gulf and Atlantic waters, but to be considered an operating problem in seawater intake systems they have to be fairly large in mass, and also occur in very large numbers. The few species that fall in this category have been discussed.

Nekton of the Atlantic and Gulf Coasts

There are a large number of animals classified as nekton that use the bays as nursery grounds. Consequently, there are times during the year when there are mass movements of these animals into or out of the bays. An intake system on or near a pass or bay could be affected by them. A good example of this is the shrimp. There are several kinds of shrimp common to warm Gulf and Atlantic waters: brown shrimp, Penaeus aztecus, the pink shrimp, Penaeus duorarum, and the white shrimp, Penaeus setiferus. During the months of May, June, July and August the brown shrimp may be moving from the bays out into the Gulf (Copeland, 1965). Such mass movements of animals give an opportunity for them to be caught in an intake system, particularly since these systems can create a noticeable current. The pink shrimp are known to move through the passes from April through September. At The Dow Chemical Company plant at Freeport, Texas, there are several "runs" of shrimp a year and the intake screens get overloaded, and have to be cleared by hand.

Another animal that lives in the bays and moves out into the Gulf is the common bay squid, Lilliguncula brevis. During the fall and spring these animals are moving through the passes along the Gulf, and if they were near a seawater intake they could possibly be swept on into the screens. The squid has the ability to swim rapidly and powerfully, and so it is not as vulnerable as some animals, such as the shrimp, which are not particularly strong swimmers.

Another group of animals that are frequently found in bays and estuaries of the Gulf and Atlantic are the crabs. They are classified as benthic animals. Many of these are the genus Callinectes. The most common is the blue crab, Callinectes sapidus. There are many of the juveniles of these crabs in the bays. They are agile and can readily get by most barriers. The young could be swept into an intake system, and once they are on the screens they are hard to remove. It would be unusual for them to become very much of an operating hazard though.

Fish of the Atlantic and Gulf Coasts

Experience at The Dow Chemical Company plant at Freeport, Texas, has shown that fish get into intake systems, but not in large enough numbers to be a problem. On one occasion there was a "run" of an unidentified fish that created an operating problem and occasionally there are large numbers of flounder, Paralichthys lethostigma, on the intake screens. The kinds of fish that will get into an intake system are those that are frequently found along the shore or in the bays. Examples are: the catfish, Bagre marius, the bay anchovies, Anchove mitchilli, the Atlantic croaker, Micropogon undalatus, the pinfish, Lagodon rhomboide, and the mullet, Mugil cephalus.

There is another way in which fish might be a problem in the intake systems, and that is, if there is a "fish kill". Fish can be killed in the Gulf and along the Atlantic Coast by a number of conditions, and when they are dead they often float. If the intake system is constructed so that surface water is taken in, then these dead fish of various sizes and shapes could become a problem. Fish kills are relatively common along the northern Gulf waters in the winter. Fish are caught in the bays and estuaries when a norther comes, and if they are in shallow pools that cool very quickly, it results in the death of the fish. These fish will eventually wash out of the bays and may wash ashore, because of the longshore current. Any sudden drop in temperature during the winter, particularly during the low tide, signals the possibility for a fish kill in the bays and estuaries of the Gulf (Gunter and Hall, 1963).

Another cause of mass fish deaths is one that is not so easily anticipated. This is the "red tide". In the Gulf, particularly the southwest Florida Coast and Texas Coast, there will be "blooms" of a dinoflagellate, a unicellular algae, in the plankton. It may be one of at least two possible species: Gonyaulax monilata or Gynodinium breve. These organisms are present in the water plankton most of the time. What causes them to grow to such numbers that the water appears red is not really known. The poison of dinoflagellate is a neurotoxin that kills the fish and some invertebrates. There have been frequent reports of the "red tide" along the western Florida Coast in the 1950's and 1960's and for the northern Gulf. The appearance of the red tide does not necessarily mean there will be a great fish kill, but often this is the result. Millions of fish can die. Since the number of fish that are killed is so great, many problems result with the pollution of beaches and bay areas. There have been a number of theories proposed to explain the bloom, but it seems not one but several factors are involved (Rounsfell and Dragovich, 1966).

Along the Gulf Coast there are other causes of mass mortality of fish, such as the sudden influx of fresh water into the estuary situation after a heavy rainfall, or the development of extreme salinities in an enclosed area. The Laguna Madre of the south Texas Coast sometimes becomes quite saline and a fish kill results.

In summary, there are a number of different kinds of plants and animals in the Gulf and Atlantic coastal waters that could cause operating problems if they came into the intake system with the intake water. Many of these problems could be avoided if the surface water is not taken into the system. Practical experience on the Texas Coast at The Dow Chemical Company plant shows that of all the plants and animals that might be a problem the biggest nuisance is the large cabbagehead jellyfish. The cabbagehead swims below the surface so it can get by almost any barrier, and then it is readily swept in by the currents of an intake system. It would be a problem to contend with in most intake systems.

Seaweeds of the Pacific Coast

The marine ecology of the Pacific Coast is quite different from that of the Atlantic and Gulf Coasts. The temperature of the water off the California Coast is cooler than expected due to upwellings of deep water near shore. The geology differs; there are many instances of rocky substrate in the intertidal region. The emphasis in this discussion will be on the southern California Coast. The best known seaweed along the Pacific Coast is the kelp. There are many species of kelp, but the ones considered here are the ones that are common to southern California. The giant kelp of southern California is *Macrocystis pyrifera*. *Macrocystis* grows to lengths of 200 feet, and the coastal beds lie in depths ranging from 25 feet to 90 feet. The plant anchors to the bottom by a root-like structure, the "holdfast". The fronds, or the main central structure, are composed of vine-like surfaces (laminae). A specialized blade at the upper end creates new blades by splitting off sections of its surface. Elongation occurs through the entire length of the stipe, and the buoyancy of the pneumatocysts keeps the frond oriented vertically until it reaches the surface, where it extends horizontally to form a canopy. Four or five months are required for the frond to develop to maturity and the total life span is six months. The life span of the entire plant, however, may be years since it constantly replaces senile fronds with new growth (North, 1967).

The kelp beds furnish a very important ecological environment for numerous fish, invertebrates and other algae. A kelp bed may be as large as eight square miles, and it appears as an underwater forest to a person with scuba gear. The kelp beds have been harvested commercially for a long time. Algin, a food emulsifier, is extracted from the kelp. State regulations allow cutting no deeper than 4 feet beneath the surface to prevent damage to the reproductive blades located at the base. The harvesters remove a substantial portion of the mature fronds, and a certain fraction of the plant's ability for photosynthesis is lost. However, this may permit more sunlight to get down to the smaller young plants and help their growth. Obviously, such a practice of cutting the kelp is going to release various torn fragments, floats and old fronds into the water, and provide a possible problem for an intake system.

Actually, there are a number of problems that may arise if an intake system is in or near the area of kelp beds. Maintaining a system anywhere near the kelp beds, where it would be necessary for divers to work with it, would be hazardous to the divers, since deaths have occurred when divers have become entangled in the kelp. The numerous fish and invertebrates that make up a kelp community could get in the intake system. The operation of an intake system located on a bay or sandy shore some distance from the kelp beds could be affected by the presence of this large seaweed, because during storms the great fronds are torn loose and thrown up on the beach in windrows. The material of the seaweed is very tough and very large and would make a serious problem if it were to come into an intake system. Primarily, most of the material from the kelp beds would float, but some of it will be flowing in the currents underneath the surface and get into an intake system that way. Sea urchins "graze" on kelp and there are times when the sea urchins move through the kelp beds in large numbers. They cut the kelp plants off near the holdfasts with the result that the kelp is washed upon the shore and the kelp bed is denuded (Clarke and Neushal, 1967). Any seawater intake system located along the southern California Coast would certainly have to take into consideration the location of the nearest kelp beds and the longshore currents to try to get the minimum amount of the very large and very troublesome fronds and floats which are shown in Figure III-18, illustration D.

There are numerous other algae in the kelp beds and also different kinds of kelp. Another giant kelp is the "elk" kelp, <u>Pelagophycus porra</u>. This kelp is seen frequently on the beaches. It has a tremendously long stem (up to 120 feet) ending in a large spherical float from which two rows of long flattened fronds branch out, as shown in Figure III-18, illustration E. Obviously, algae such as this could present a real problem if it were to float into an intake system. A little closer into shore are the brown algae known as the laminarians, and these are very broad leaf plants 3 or 4 feet in length. They can be torn loose during storms and accumulate on the beaches with the kelp in a considerable mass.

<u>Zooplankton of the Pacific Coast</u>

There are several species of the Pacific Coast zooplankton that could create operating problems if they were to flow into the intake system in any number. The cabbagehead jellyfish was described for the Gulf and Atlantic Coasts. It has also been recorded as occurring in large numbers in San Diego Bay, so it must be considered a potential nuisance on the Pacific Coast. The jellyfish Aurelia aurelia can occur in very large numbers. It was described in the previous section on the Atlantic and Gulf Coasts. Occasional storms will drive great numbers of Velella ashore along the California Coast. These "jellyfish-like" animals have a transparent triangular sail on which their colonial system is organized. The sail averages 3 to 4 inches in diameter and serves to keep the animal moving, if there is just a slight breeze. Because of the sail, which is almost plastic-like in quality, mass numbers could cause a problem, but they only float. So they would have to come in with surface water. This is in contrast to the cabbagehead and other jellyfish that have been previously described, because they can move up and down in the water and get by various barriers in the water.

Benthos of the Pacific Coast

There are three sea urchins that are associated with the kelp beds: Strongylocentrotus purpuratus, Strongylocentrotus franciscanus, and Lytechinus anamensis. These urchins can occur in great numbers. Whether it is a population "explosion" or invasion is not known. There can be as many as 100 urchins per square yard. They move across the kelp bed like an army. Once the kelp is destroyed the sea urchins can live off the fat stored in their body, or if they are in a region of a sewage outfall they can absorb the nutrients from the water. So, they could pose a problem if great numbers of these animals were to come into an intake system. They would be very hard animals to remove from the screens, because the spines would anchor them. The largest of these sea urchins, S. franciscanus, can have a diameter up to 7 inches (Clarke and Neushal, 1967).

Fish of the Pacific Coast

There are, of course, numerous fish in the intertidal areas along the Pacific Coast. Those that are associated with the kelp community are: the sheephead, Pumelometopon pulchrum, the senorita, Oxyjulis californica, the blacksmith, Chromis punctipinnis, and the kelp bass, Paralabrax clathratus, and there are flounder, catfish and rays in the bays. Any of these could come into an intake system, but probably not in sufficient numbers to be an operating problem. However, there is the very well known little fish, the grunion, which comes ashore in great numbers in the breeding season. During the spring from March to June, the grunion (Leuresthes tenuis) come ashore (southern California) with the highest tide to spawn in the sand. A seawater intake system near a sandy shore where the grunion comes in could have problems with fish during the March to June high tides (McConnaughey, 1970).

The "red tide" occurs in southern California waters as well as the Gulf. The species of dinoflagellate is *Gonyaulax polyhedra*. Recent red tide outbreaks have left millions of fish floating in bays and harbors, and this would present a real problem to an intake system not far off shore or in a bay.

V. Sources of Data

Preliminary engineering investigations of a general nature may be performed by an engineer using readily obtainable data and information. The agencies listed below can furnish much valuable information.

Coast and Geodetic Survey
Environmental Science Services Administration
U. S. Department of Commerce
6010 Executive Boulevard
Rockville, Maryland 20852
Telephone: (301) 496-8177

- Tide and current tables
- Tidal current charts for some locations
- Tidal bench mark data
- Surface water temperature and density
- Coastal currents
- Bathymetric charts
- Nautical charts (show nature and form of coast water depths, etc.)
- United States earthquakes

Weather Bureau
Environmental Science Services Administration
U. S. Department of Commerce
6010 Executive Boulevard
Rockville, Maryland 20852
Telephone: (301) 496-8177

- Synoptic weather charts
- Rainfall records
- Air temperature records
- Wind and hurricane data
- Other weather data

SECTION III. MARINE DATA

Geological Survey
U. S. Department of the Interior
Washington, D. C. 20240
Telephone: (202) 343-4579

Nearshore bottom geology maps
Topographic maps
Geologic maps

U. S. Naval Oceanographic Office
732 N. Washington Street
Alexandria, Virginia 22314
Telephone: (703) 695-6002

Bathymetric charts
Hydrographic (nautical) charts
Current data

National Oceanographic Data Center
Second and M Streets, SE.
Washington, D. C. 20390
Telephone: (202) 698-3700

Large collection of bathymetric, temperature, salinity, depth, surface current, biological and bottom sample data.

Office of the Chief of Engineers
U. S. Department of the Army
Washington, D. C. 20024
Telephone: (202) 697-7408

or

District Engineer in charge of the locality in which the proposed structure lies.

Shoreline changes

In addition to data which can be furnished by the above listed agencies, those sources normally used in making engineering investigations should, of course, be used. Not to be overlooked are interviews with long-time residents of the area and references to newspaper files and other records of the area. Valuable information as to magnitude of storms, coast line changes and similar related data can often be discovered.

SECTION III. MARINE DATA

Site investigations for an ocean intake which will form the basis for a decision involving actual plant location and the gathering, measuring and analyzing of the oceanographical engineering data which will be used in the engineering and design of the intake structure should be performed only by those thoroughly trained and qualified. This is a technical field of its own and one in which a multiplicity of variables, many imperfectly understood, must be considered in relation to each other. Failure to properly consider all pertinent data can result in unnecessary costs, structural failures, subsequent corrective work and excessive maintenance, as experience has shown time and time again.

The measurements necessary to establish, with an acceptable degree of certainty, such factors as current directions and velocities and surface and bottom water temperatures usually must cover a year's time in order to account for tidal and seasonal variations. The measurement of current directions and velocities is particularly complicated because of the complexity of forces acting upon and tending to modify each other. Furthermore, there are a wide range of instruments and methods for measuring currents, many quite sophisticated, all with their strong points and weaknesses and limits of error. Experienced judgement is needed to correlate all of this into useable and dependable data for the engineering of an intake structure.

This is not to mean that a project engineer will accept such expert technical assistance unquestioningly, for he still has responsibility for the project. However, he should be satisfied that a thoroughly competent and complete job of the oceanographic investigation has been performed and he can then make other decisions and perform the engineering design on a sound basis.

SECTION IV. MATERIALS

The materials used in seawater intake construction are relatively few in number and are among the most basic and widely used. However, different chemical and physical conditions prevail in seawater than those normally encountered on dry land. Consequently, the unusual conditions in marine uses must be recognized and understood if the materials of construction are to be used so as to provide economical and dependable operation.

A. Concrete

Concrete is one of the most widely used building materials in the world and one of the most durable. In a desalination plant intake system, concrete may be utilized for jetties, for canal linings, for pier supports and structure, for intake pumphouse building, for intake pipes and pump basins, and for such auxiliary features as sidewalks, roads, parking areas and handrails.

Concrete consists of a mixture of cement, sand, crushed rock aggregate and water, and usually reinforcing steel. The components are carefully proportioned and thoroughly mixed to insure complete contact of the cement paste with all surfaces of the sand and aggregate, and then poured into forms where the concrete begins to harden or "set".

Concrete has a number of advantages that make it useful as a construction material for intake structures. It has excellent compressive strength, in the range of 2,000 to 6,000 psi. Its rather poor tensile strength (200 to 600 psi) can be compensated for by incorporating reinforcing steel bars in the design which provide tensile strength to the member. Concrete has good resistance to abrasion and impact and to fire, weathering, and marine borers. It is a relatively economical building material whose heavy weight and high specific gravity are an advantage in the stability of coastal structures.

Concrete must be carefully cured after its original set if it is to develop its full structural strength. The curing process involves retarding the loss of water through evaporation by keeping the concrete moist or by covering with impermeable coverings for a period of several days.

There are several causes of deterioration in concrete which, acting singly or in combination, can result in the spalling, cracking or wearing away of the concrete surface, exposing the reinforcing steel to weathering and reducing the structural cross-section of the member. These include:

Alternate cycles of freezing and thawing

Corrosion of the reinforcing steel

Expansion cracking

Sulfate corrosion

Each of the causes of deterioration can be compensated for and prevented by careful design and control.

Dry concrete is not subject to deterioration from freezing and thawing. Moist concrete may be damaged by this weathering process unless proper steps are taken. In addition to protecting the green concrete from freezing temperatures, the use of an air-entrainment process which produces a large number of very tiny (from 0.001 to 0.01 inch) air bubbles closely spaced together through the concrete paste will prevent damage by freezing.

Air entrainment can be produced by either or both of two methods. The first is the addition of an air-entraining admixture, consisting of a complex amino compound or a rosin, usually placed directly into the mixer. The amount is small--only a few hundredths of one percent by weight. The second method is the use of an air-entraining Portland cement conforming to ASTM C226, "Tentative Specifications for Air-Entraining Additions".

Air entrainment causes a slight reduction in the strength of concrete. It also improves its workability, making possible the reduction of the water and sand content of the concrete, with a resultant compensating increase in design strength. Air entrainment, in addition to protecting the concrete from freezing and thawing cycles, improves its watertightness and reduces the segregation of aggregates. Air entrainment should be used for all reinforced construction exposed to salt spray or submerged in seawater.

Perhaps the most significant cause of deterioration of concrete in the marine environment is the corrosion of reinforcing steel (Wakeman et al, 1957). Concrete protects the steel from corrosion by excluding water, air and carbon dioxide and by providing a highly alkaline environment which facilitates the formation of a thin protective surface oxide film on the steel. When steel corrodes in reinforced concrete, the corrosion products occupy a larger volume than the original steel. Pressure is exerted in excess of the strength of the concrete and the concrete cracks.

In permanent, deeply submerged reinforced concrete in seawater, where dissolved oxygen and carbon dioxide concentrations are very low, reinforcement corrosion does not occur. The most severe conditions for reinforcement corrosion exist where the structure is alternately wetted by seawater or salt spray. The entire tidal zone, from 2 feet above high water to 2 feet below low water, is especially vulnerable.

The best prevention of reinforcement corrosion is the exclusion of moisture from the steel. An adequate cover of dense, relatively impermeable concrete is sufficient to protect the steel. At least 3 inches of cover is recommended over steel reinforcement and a minimum of 4 inches at corners. The concrete mix should be carefully designed with at least 7 sacks of cement per cubic yard, and a water-cement ratio of not more than 5-1/2 gallons of water per sack (including moisture on the aggregates). Air entrainment further promotes the watertightness of concrete. Between 3 and 6% entrained air is recommended. Metal chairs, if used for the support of steel reinforcement, should not extend to the surface of the concrete. Plastic chairs are superior to metal ones. Dissimilar metals should not be used. A sulfate-resistant Portland cement is recommended. Careful attention must be given to construction joints with adequate preparation of the exposed concrete surface before pouring so that moisture is not admitted through cracks to the reinforcing steel. High frequency mechanical vibrators used to vibrate the concrete in place permit the use of a stiffer concrete mix with lower water-cement ratio and gives greater watertightness. Vibrators also improve bonding between the cement paste and the steel, but should not be over-used in air-entrained concrete. Hot dip galvanized reinforcing steel is sometimes recommended as a means of reducing corrosion. Evidence indicates that the bond between galvanized steel and concrete is at least as good or better than between carbon steel and concrete.

Another general cause of deterioration in concrete is due to a group of reactive situations involving the concrete aggregate. Crushed stone aggregates are not necessarily inert materials. Many of the minerals present in the different types of rock are reactive and participate in chemical reactions with the mixing water, with water in the soil, and with the cement in the concrete. Sometimes aggregates contain foreign materials, contaminants which cause deterioration. Although there are many rock materials which undergo chemical reactions in concrete, not all the chemical reactions are harmful to the durability of the concrete. It is generally those reactions which cause expansion, that are damaging.

The alkali-silica reaction is an example. The aggregate rock may react with alkali in the cement in the mixing water or in the soil to produce an expansive concrete. The appearance of concrete which has been damaged by the alkali-silica reaction is called "pattern" or "map" cracking, resulting in exudation of cement gel through pores or cracks to form hard beads on the surface, and sometimes "popouts".

The easiest way to avoid the alkali-silica reaction is to use only aggregates which are non-reactive. However, this may not be economically feasible. Limiting the amount of alkali available for the reaction also can be accomplished by using a cement with an alkali content limited to 0.6% (as Na_2O). Seawater must not be used as mixing water under this condition, nor should fresh water containing an appreciable amount of alkali. The third method of preventing an alkali-silica expansive reaction is the addition of pozzolan cement. The natural pozzolans, such as calcined opaline shales and diatomites of high fineness, are more effective in preventing expansion than artificial materials such as blast-furnace slag or fly ash.

There are other causes of deterioration in concrete. Some chemicals in solution attack concrete, such as strong acids, the chlorides and nitrates of ammonia, magnesium, aluminum and iron, and some dissolved gases. Most of these are not normally encountered in the marine environment, except for the occurrence of industrial wastes. Sulfate solutions are potentially harmful to concrete, but the presence of chlorides, as in sea water, minimizes or inhibits the expansion of concrete in contact with sulfate solutions. Resistance to deterioration by dissolved chemicals is greater in dense, impermeable concrete. Limiting the amount of tricalcium aluminate (C_3A) in the cement is effective in increasing the resistance of concrete in seawater to sulfate attack. Type V Portland cement having a maximum C_3A content of 5% is usually specified for marine construction. Where the cost of Type V is high, Type II cement, which is moderately sulfate-resisting, might be substituted. In some parts of the country, Type I cement has the same sulfate resisting properties as Types II and V.

Concrete can be placed underwater. The plastic mix is conveyed through the water in a vertical pipe called a tremie. The pipe is kept filled and the bottom is kept below the surface of the soft concrete already in place so that contact with the water is limited to the exposed surface. Concrete may also be placed under water by bottom dump bucket.

Although concrete is fairly resistant to abrasion, it can be damaged by erosion and cavitation. A strong current carrying sand or gravel can wear away the surface of the concrete and expose the aggregate. Careful selection of aggregate for its resistance to abrasion can halt this form of deterioration from proceeding too far. On the other hand, the wear that occurs from cavitation when the velocity of water exceeds about 40 feet per second can only be prevented by careful design to avoid excessive flow velocities.

Some instances of damage to concrete structures in seawater have been reported as having been caused by boring clams. Investigation of such instances usually shows the concrete to have been merely a weak mortar or a soft concrete with no resistant aggregate. Marine borers are not a threat to structural grade concrete (Woods, 1968).

The Los Angeles Harbor Department has adopted a practice of increasing the watertightness of concrete piling by impregnating with asphalt. Vacuum-pressure methods are used, similar to those used to pressure-impregnate timber piles. Piles are dried at high temperature, placed in an asphalt bath, and subjected to a pressure of 150 psi. After a few hours at carefully controlled temperature and pressure, the pile is removed from the bath and cooled. Penetration of the asphalt by this method varies from 3/4 inch to 2-1/2 inches. Examination of piles treated by this technique shows no moisture penetration and no deterioration after many years of exposure.

B. Wood

Timber has a number of advantageous properties as a seawater construction material. It is strong, economical, readily processed, and workable into structural shapes and frames.

It is available in most parts of the world. It is not subject to corrosion. Wood also has some drawbacks for marine uses. It is vulnerable to decay, to boring insects and to fire. Its susceptability to marine borers in submerged applications is discussed in Section V. In intake systems the uses of timber will likely be limited to sheeting and shoring in the construction phase and to walkways, bulkheads, timber pile foundations and skimmer barriers in the finished installation.

Fungus is a prominent cause of deterioration in wood that is not submerged. The fungi are widely distributed geographically. The two types of action of fungi are those which stain or discolor the wood without serious damage, and those which result in actual wood destruction. Since they often occur together, the staining or discoloration may serve as an indication of damaging fungus attack or at least that favorable conditions exist for fungus activity. The submerged portion of timbers is generally considered to be safe from fungus decay, but there is some indication that fungi may possibly contribute to borer damage by favorably conditioning the wood surface for their attachment and entrance. There is even some suggestion that marine fungi may be a source of food for the larval stages of some borers (Bureau of Yards and Docks, 1965).

Fungi require a suitable food supply, moisture, oxygen and a favorable temperature range to grow. They can survive wide ranges of temperature, but their maximum activity occurs in the range between 70° and 90°F. At low temperatures their activity is suspended. A high temperature of 120° to 135°F with high humidity for a two-weeks' period is reported to kill 100% of the organisms, but the timber can again become "reinfected". Pressure creosote treatment which is adequate for marine borer protection is sufficient to prevent fungus damage. Ventilation of wood structures to keep them dry is effective in forestalling fungus decay. Design details which avoid moisture-trapping joints and connections also help prevent decay.

Insect damage to wood structures can be rapid. The principal insect enemies are the powder-post and similar beetles, drywood and subterranean termites. Of these, the termites found in all parts of the world are the most destructive. The subterranean termites maintain their colonies in the soil and enter wood that is in direct contact with the soil. They require a highly humid atmosphere and cannot survive in dry air. To reach untreated wood that is not in contact with the soil, they are able to build mud tunnels across the surface of concrete or treated wood, maintaining the required humid atmosphere inside the tunnel. Prevention of damage by subterranean termites includes such measures as saturating the soil with an insecticide and treating the wood with a preservative. Attention to design details such as providing a protective metal shield on foundation piers, avoiding wood in contact with the soil, or eliminating wood by using concrete or masonry construction are also important. The notion that salt air at the waterfront deters termites is fallacious. Subterranean termites have been known to penetrate sheets of lead, aluminum, rubber and plastics in their search for cellulose materials.

Non-subterranean termites, including the dry-wood termite, are not confined to a high-humidity atmosphere but can endure exposure to the open air and are thus more difficult to control. They are found in the tropics, and in the U.S., are confined to a narrow coastal strip from Virginia south to Florida and along the Gulf Coast and in Southern California. Preservative-treated wood is partly effective against non-subterranean termites.

The other boring insects include several species of the powder-post beetle, or Lyctus, the old house borer or Hylotrupes, and the wharf borer, which is usually associated with decay fungi and moisture. The best known control of these damaging insects seems to be pressure impregnation with a preservative (Beal, 1953).

Immersed in seawater, wood is subject to attack by a variety of marine borers. When properly impregnated with one of a number of materials, wood can be made to last for many years.

Pressure impregnation with creosote is the most widely-used treatment and gives reasonably effective protection against marine borers. However, the useful life of creosote treatment can be quite variable, depending upon type of borer activity and temperature of the seawater. For above-water situations, both in air and in contact with the ground, there are impregnation treatments with other chemicals than creosote which give resistance to decay, resistance to boring insects, and in some cases fire-retardant properties. These chemicals are water-soluble salts or mixtures of salts of heavy metals such as arsenic, chromium, copper and zinc, dissolved in water or in a solution of an acid or base (Bureau of Yards and Docks, 1965). Careful selection of the chemical to be used must include consideration of the planned use of the treated wood, because some of them leach from the wood readily, and other are corrosive to metals in contact with the wood. A list of some of these water-borne preservatives and fire-retardant formulations, together with some of the associated Federal Specifications, is shown in Table IV-I. Registered trade names are indicated with an asterisk. Wood impregnated with some salts can be used immersed in seawater as well as above-water. An outstanding example is a single test pile treated with a modified chromated copper arsenate installed in seawater in North Carolina. The pile is still in service after 19 years and appears to have both successfully resisted all borer attacks and accumulated remarkably little fouling.

Fire-retardant chemicals which may also be used for impregnating include ammonium phosphate, borax, boric acid, ammonium sulfate, zinc and various proprietary formulations (Greathouse and Wessel, 1953). Other steps which may be taken to prevent or minimize fire damage to marine timber structures are to encase timber piles in steel pipe above the mid-tide line and to grout in the annular space. Good housekeeping by eliminating floating inflammable materials under or adjacent to a structure is also a preventive technique. Floating oil, a frequent waterfront contaminant, is a serious fire hazard which cannot be excluded by normal mechanical means, but must be cleaned up by skimmer apparatus.

One technique which has been used successfully for extending the life of creosoted wood piles partially damaged by borers can also be used for new piles. The creosoted pile is covered with a sheathing of polyvinyl chloride which is held in place with nylon or titanium nails. The sheathing must extend down into the bottom material a sufficient distance to effect a seal. It is believed that the life of such a pile would be equal to the life of the PVC sheathing. Bands of 90-10 copper-nickel alloy, while normally exhibiting long life in seawater, cannot be used successfully to hold the sheathing in place. This is apparently due to the generation of hydrogen sulfide which will diffuse through the PVC and destroy the 90-10 copper-nickel bands in something like 10 years. A great deal of experience in this technique has been gained in the Los Angeles harbor area, where borers suddenly appeared in places not previously subject to borer attack.

TABLE IV-I

WATER-BORNE PRESERVATIVES, OIL-BORNE PRESERVATIVES AND FIRE-RETARDANT FORMULATIONS

(from AWPA Standard, 1970)

Water-Borne Preservatives	Service
Acid Copper Chromate (ACC) (Celcure*)	Atmosphere. Protects against insects and decay. CCA's may also protect against marine borers.
Ammoniacal Copper Arsenite (ACA) (Chemonite*)	
Chromated Copper Arsenate, Type A (CCA-Type A) (Erdalith*, Greensalt*, Langwood*, Wolman Salts* CCA)	
Chromated Copper Arsenate, Type B (CCA-Type B) (Boliden* CCA, Osmose K-33*)	
Chromated Copper Arsenate, Type C (CCA-Type C)	
Chromated Zinc Chloride (CZC)	
Copperized Chromated Zinc Arsenate (CuCZA) (Copperized Boliden Salts*)	
Fluor Chrome Arsenate Phenol, Type A (FCAP-Type A) (Tanalith, Wolman Salts* FCAP)	
Fluor Chrome Arsenate Phenol, Type B (FCAP-Type B) (Osmosalts*, Osmosar*)	
Fire-Retardant Formulations	
Type A, Chromated Zinc Chloride	Atmosphere.
Type B, Chromated Zinc Chloride (FR)*	
Type C, Minalith*	
Type D, Pyresote*	

* Reg. U.S. Pat. Off.

Table IV-I (Continued:

Oil-Borne Preservatives	Service
Pentachlorophenol	Atmosphere.
Copper Naphthenate	Not for
Solubilized Copper-8-Quinolinolate	immersion.

A number of woods are used in timber construction of waterfront facilities because they possess a degree of natural resistance to marine borers or to decay in above-water construction, in addition to the requirement of hardness and strength. Perhaps the best known of these naturally-resistant species is the greenheart, a product of the north coast of South America. This wood is extremely hard and durable. Its resistance to teredo attack is apparently due to an alkaloid material present in the wood.

C. Iron and Steel

Iron and steel share with concrete the role of being the major construction materials for intake facilities. If it were not for their tendency to corrode, they would be the metal of choice for most marine applications. Iron and its alloys lie rather far up the list of metals in the galvanic series in seawater. When coupled with more noble metals, the alloys of iron show increased corrosion but the corrosion performance of these materials is improved by protective coatings and by cathodic protection.

Cast Iron

The corrosion rate of cast iron is rather variable. In general, the rate of corrosion of cast iron is two to three times that of carbon steel in the submerged situation, and there is a greater tendency toward pitting. In a marine atmosphere, the corrosion rate is less than that of unalloyed steel.

Spheroidal graphite cast iron, also called ductile cast iron, is used for valve bodies and petroleum piping exposed to salt spray or occasional immersion. Addition of more than 12% nickel, or enough nickel plus copper to achieve an austenitic structure, produces alloyed austenitic cast irons, the "Ni-Resist" family, possessing exceptional resistance to salt atmospheres, and greater ductility than ordinary iron. These are coming into use for valve bodies and pump casings, as well as for parts of traveling screens. An additional 3% of chromium gives resistance to cavitation and erosion corrosion.

Wrought Iron

The corrosion resistance of wrought iron in conditions of alternate immersion is a little greater than mild steel, but the cost of the material makes it uneconomically expensive for marine construction.

SECTION IV. MATERIALS

Steel

Steel has many properties which make it a nearly ideal material for construction. It is easily handled, fabricated, cut and joined. It is available in a great variety of shapes. It has excellent mechanical strength and resistance to decay, to insects, to marine boring organisms, to fire and to abrasion. It is widely used in construction of intake facilities in the form of sheet piles, bearing piles, structural shapes, reinforcing bars and for equipment such as traveling screens. Sometimes steel is used in conjunction with concrete. Steel sheet piles, after being driven, are sometimes encased in concrete from the submerged zone to the top, for rigidity and corrosion resistance. Concrete-filled steel pipe is used for offshore marine platforms and other construction units. Steel is used almost universally for reinforcement of concrete construction. Steel pipe is often coated, inside and outside, with concrete for strength, corrosion resistance and added weight.

The drawback in the use of steel in marine applications is its tendency to corrode. The corrosion rate of ordinary steel sheet piles in the several vertical zones of seawater exposure varies greatly. The corrosion rate in seawater increases greatly as the velocity increases, as shown in Figure IV-1. Because of its position in the galvanic series, plain carbon steel suffers accelerated corrosion when it is in contact with all copper alloys, nickel alloys, and even low alloy steels and stainless steel. Contact with aluminum, cadmium, magnesium and zinc alloys gives protection to steel by corroding preferentially.

Corrosion of Steel

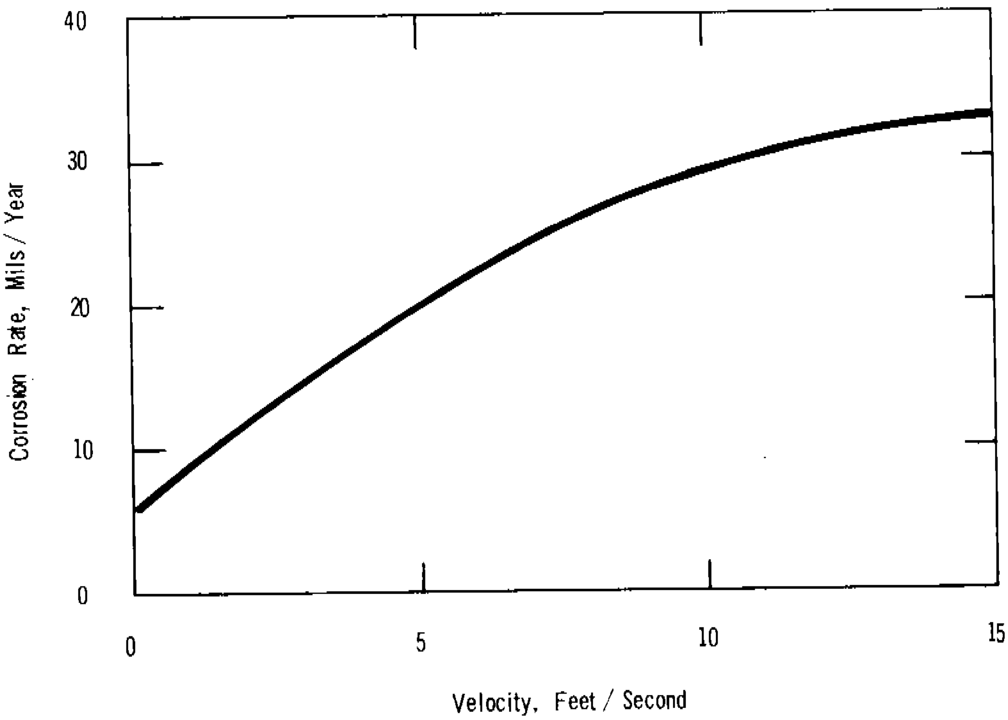
In general, it can be said that the rate of corrosion of steel in seawater is largely governed by the oxygen content of the seawater. Other factors of importance are temperature, velocity, erosion and kind and amount of pollution. The presence of dissimilar metals electrically connected and the use of coatings, both of which may be intentionally or unintentionally applied, are also important factors influencing the rate of corrosion.

Five rather distinct environmental zones influence the rate of corrosion of steel piling. These are shown in Figure IV-2. The average or typical corrosion rates of steel piling in the five different zones is also shown in Figure IV-2.

Figure IV – 1

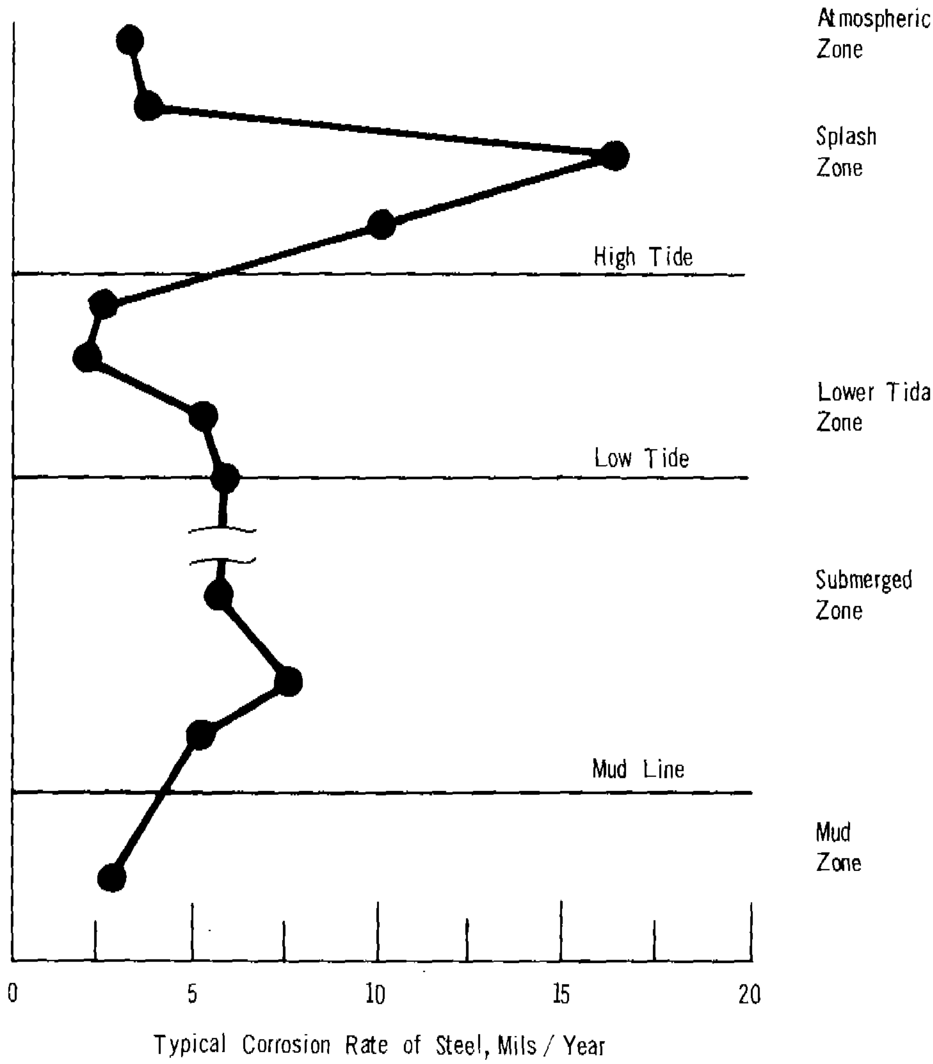
EFFECT OF SEAWATER VELOCITY ON CORROSION OF STEEL

(Tuthill and Schillmoller, 1966)



Temperature: Ambient
Exposure: 38 Days

Figure IV – 2
TYPICAL CORROSION RATES OF STEEL IN SEAWATER
(Tuthill and Schillmoller, 1966)



The atmospheric zone is above the level at which any significant amount of seawater splash will be encountered. The corrosion rate of steel in the atmosphere is a direct function of the rate at which the ferrous corrosion product is removed from the barrier film of rust, whether through leaching or washing or spalling. The tighter and denser the barrier film, the less is the leaching and spalling and, consequently, the rate of corrosion.

The splash zone is, as its name implies, the zone subject to intermittent wetting of the piling by the high oxygen content seawater. It extends roughly from mean tide level to the highest splash line. The thin film of seawater in almost constant combination with the oxygen in the air greatly accelerates corrosion. From Figure IV-2 it can be seen that the corrosion rate in the splash zone is several times greater than when continuously immersed in seawater.

The lower tidal zone exhibits the least corrosion of any of the five zones. Steel in this area, where the seawater is highly aerated, becomes cathodic to the adjacent submerged steel where the oxygen content is less, so it is protected by a degree of cathodic protection. The degree of protection is increased when the submerged surfaces are covered with fouling growth which shields the steel surface from oxygen.

In the submerged zone, the rate of corrosion is a function principally of the rate of diffusion of oxygen through the layers of rust and fouling organisms to the steel. However, pollution can greatly accelerate corrosion in this area, depending upon the nature of the pollutants. Temperature and tidal velocity have essentially no effect on the rate of corrosion in this area.

In the mud zone at the mud line, the rate of corrosion may increase due to the generation of additional concentration cells and sulfur compounds caused by marine organisms. Below the mud line the rate of corrosion is very low, due to the lower availability of oxygen and the relatively undisturbed nature of the barrier films.

The velocity of seawater past the surface has a large effect upon the rate of corrosion. A small motion as by a wave or current may reduce the rate of corrosion by making the environment more uniform. A larger motion reduces the thin film of water at the steel/water interface, thus permitting the seawater corrosives to contact the steel more readily.

Higher seawater velocities may also strip away the barrier film on steel (and copper base alloys, although stainless type alloys become more protective), thus exposing the steel surface to the corrosives in the seawater.

The maximum corrosion can normally be expected in the splash zone unless corrosive pollutants are present, in which case the maximum corrosion rate can be expected in the submerged zone, even exceeding that in the splash zone.

Low Alloy Steel

Low alloy steel, containing less than 5% of alloying additions, has a corrosion rate which may be less than that of mild steel. Tests of steel sheet piles show corrosion rates to be about the same in the submerged zone, but in the splash zone and in the atmospheric zone the corrosion rate of the low alloy steel often is substantially less than that of mild steel. Apparently the protective barrier film of corrosion products which forms at the exposed metal surface is made less permeable by the addition of small amounts of nickel and copper. Protective coatings perform better on the low alloy steels. Mariner steel is a low alloy steel which is available in sheet pile sections. The low alloy steels are stronger but more costly.

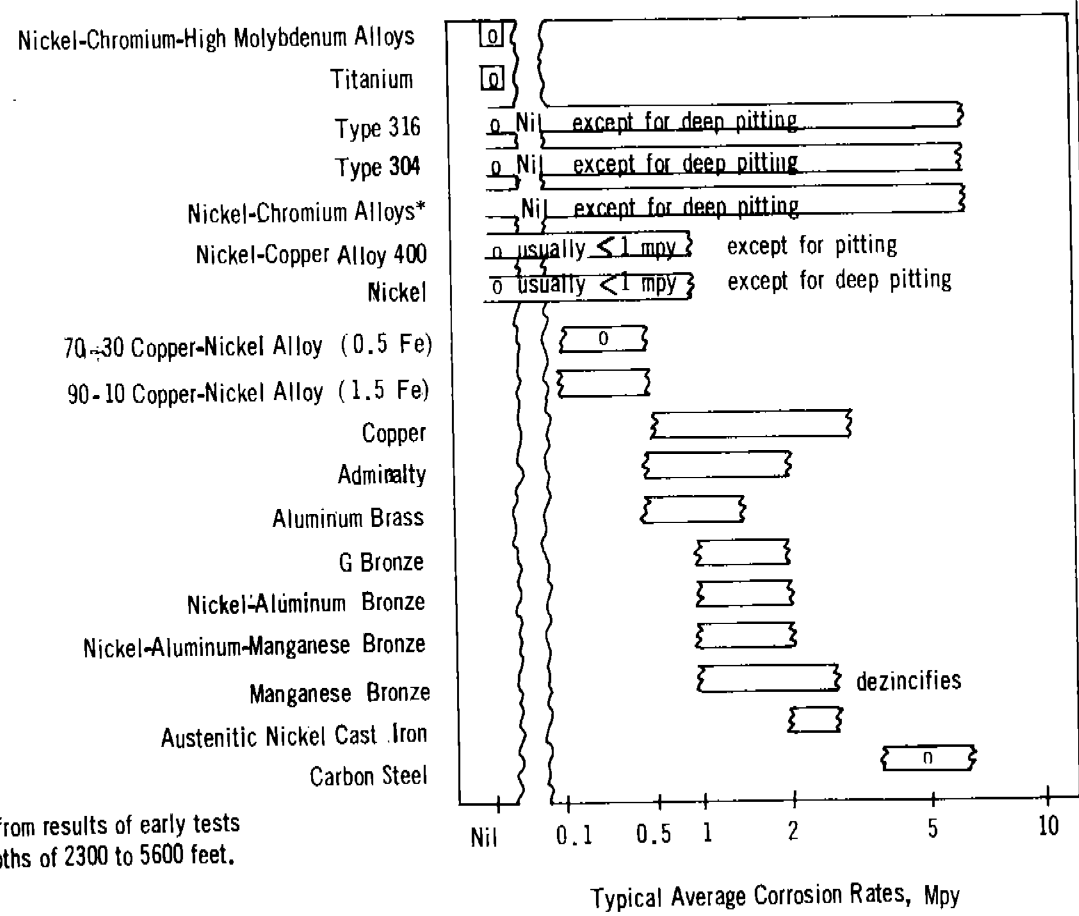
Stainless Steel

Stainless steel is an alloy of iron containing nickel and chromium and sometimes small amounts of other alloying elements. In general, the stainless steels have significant corrosion advantage over the carbon steels. To realize these advantages, the metal must be kept clean and free of extraneous particles such as sand and silt. In addition, the metal must have an ample supply of oxygen. When these factors are ignored, serious problems such as crevice corrosion, oxygen concentration cells and pitting will result. Particular places to watch for these problems are at flanged joints, under fasteners and similar very confined spaces. Cathodic protection will prevent most of these problems. The Type 300 series stainless steel is generally more suitable for cold seawater service than the Type 400 series. Figure IV-3 shows typical average corrosion rates immersed in quiet seawater for stainless steels as well as other alloys and metals. The stainless steels and some others show deep pitting but otherwise little or no corrosion. In piping, tubing and vessels this can be serious, but in general

Figure IV-3

GENERAL WASTING OF METALS IMMERSED IN QUIET SEAWATER

(Tuthill and Schillmoller, 1966)



o Data from results of early tests at depths of 2300 to 5600 feet.

*Nickel-chromium alloys designate a family of nickel base alloys with substantial chromium contents with or without other alloying elements all of which, except those with high molybdenum contents, have related seawater corrosion characteristics.

Velocity = <2 FPS

structural use this may not be particularly significant since the basic structural strength is essentially maintained. The pitting is usually well dispersed and may affect only from 1 to 9% of the surface area.

Contact with stainless steel increases the corrosion of cast iron, steel, and alloys of aluminum, zinc and magnesium. Dissimilar metal contact with metals which are cathodic to the stainless steels should, of course, be avoided, unless the stainless steel is cathodically protected itself.

Stainless steel may be joined by welding. Bolting and rivetting are to be avoided where possible because they permit the formation of crevices which encourage crevice corrosion, unless cathodically protected. Where crevices must be permitted without cathodic protection, they should be caulked with sealants but there are not many suitable materials. Greases with zinc oxide have been used with limited success.

Stainless steels are particularly useful as fasteners in traveling screens.

D. Non-Ferrous Metals and Alloys

Non-ferrous metals and alloys often have distinct properties which make them highly desirable for various specific applications in intake construction and equipment. However, their cost is generally such as to make them prohibitively costly for large-scale use.

Aluminum

Aluminum and aluminum alloys are used successfully in many marine structures. The metal is light and strong, having a yield strength of 30,000 psi in the low strength alloys to a range of 55,000 to 70,000 psi in the high strength alloys. Aluminum alloys must be used with care in their selection and design, however, because they are susceptible to pitting, galvanic and several other types of corrosion. Connections with other metals must be avoided because of the high electrochemical potentials of all its alloys. Low strength alloys can be welded, but high strength alloys present difficulties. Aluminum is alloyed with other metals to make a highly efficient sacrificial anode for protecting steel structures.

Nickel Base Alloys

Nickel alone in still seawater corrodes by pitting as much as 50 mils per year. Alloyed with other metals such as copper, molybdenum or chromium, it develops outstanding corrosion resistance. One alloy, nickel-molybdenum-chromium alloy C (59% Ni, 16% Mo, 16% Cr, 5% Fe, 4% W) called Hastelloy C, is apparently essentially inert to marine corrosion, even at high velocities. Another with outstanding resistance to pitting and crevice corrosion is Inconel (60% Ni, 21.5% Cr, 9% Mo, 5% Fe, 3.5% Cb plus Ta), used in wire rope, tubing and sheet metal. Monel, a nickel-copper alloy (66% Ni, 32% Cu, 1% Fe, 1% Mn) has excellent corrosion resistance at high velocity. In moving seawater its corrosion rate is about 1 mil per year, but under stagnant conditions, pitting may occur in an amount as great as 50 mils per year or more, and it is susceptible to crevice corrosion. In an intake system, monel might be chosen for many of the parts of the traveling screen installation such as nuts, bolts, screws, and the screen wire and frames. For applications requiring higher strength, a heavy duty version of monel is nickel-copper-aluminum alloy K-500. This alloy finds use in pump shafts, valve stems and fasteners, and might be selected for chain rollers and guides in a traveling screen installation as well as for the screen wire. One type of monel, the S-type, has 4% Si, which makes it a very hard and strong casting alloy. It is able to resist wear under corrosive conditions, even where no lubrication can be provided. It has a tensile strength of about 75,000 psi, which can be increased by cold-working to about 130,000 psi. Several other nickel base alloys have application where corrosion resistance and high strength are desired.

Titanium

Titanium and many of its alloys are believed to be practically inert to all forms of corrosion in seawater, but some of its alloys have been found to be susceptible to rapid stress corrosion fatigue and cracking in seawater, and to crevice corrosion. Cathodic protection does not seem to offer any protective safeguard against this stress-corrosion cracking in titanium alloys.

Copper

Copper has good resistance to corrosion in stagnant or slowly moving seawater. Its corrosion rate is about 1 mil per year, evenly and without pitting. If pollutants are present in the seawater, the corrosion rate may be substantially higher. Normally small amounts of arsenic (1/2 to 1%), oxygen, and phosphorus are added for better electrical and mechanical properties. The addition has little effect on corrosion performance. Copper is used to some extent in piping. Its drawback in seawater service is its rapidly diminishing resistance to corrosion as the velocity increases above 3 to 4 feet per second. Copper's ease of manipulation, however, makes it useful for air and oil tubing and for such things as bellows and expansion joints.

For hundreds of years copper has been used as sheathing for wooden ships because of its toxic effect on fouling organisms. The slow corrosion of a copper surface releases copper ions into solution and effectively prevents fouling. Anti-fouling paints include copper oxide in the paint film which dissolves into the seawater, furnishing toxic copper ions.

Copper Base Alloys

The copper base alloys can be roughly divided into brasses, bronzes and copper-nickel alloys.

Brass is essentially an alloy of copper and zinc, with only a small amount of other alloying elements. Its use in seawater intake systems is limited to only minor or secondary applications.

Bronze is historically an alloy of copper and tin, but today such elements as phosphorous, aluminum, iron, nickel, manganese, silicon and even zinc are added as alloying constituents to impart certain desired properties. Generally, the bronzes stand up well in seawater service. Their use in seawater intake systems is principally as pump impellers, valve bodies, shaft bushings and similar specialty items.

The copper-nickel and the copper-nickel-iron alloys provide excellent resistance to corrosion by seawater but, because of their cost, are used only for special applications in seawater intake systems. The 90-10 copper-nickel alloy releases copper to seawater at a rate sufficient to provide a good degree of fouling control and still at a reasonably low rate, probably less than 1 mil per year. It would appear to have a potential as an anti-fouling liner for intake pipes.

E. Stone

Stone is a construction material used since ancient times, for marine construction. Stone is used in breakwaters, jetties and causeways because of its low cost, great weight, strength and durability. Crushed rock is used as granular fill material behind bulkheads, in cellular cofferdams, and as an aggregate in concrete construction.

A typical rock-mound breakwater or jetty is trapezoidal in cross-section with different classes of rock placed in different layers. The lowest class of rock, the smallest, is used as the core, being a quarry residue or even a dredged material. The highest class, by size, is the cap rock, placed in the outer layer, particularly where it must resist being dislodged by the forces of the heaviest storm waves. Class A stone may be specified to have a weight anywhere from 2 to 30 tons, depending on the design of the breakwater. The size is a function of the height of wave and the slope of the face. It may be placed on both faces of the breakwater down to the bottom, or it may be placed only on the seaward side and extending from the top to several feet below low water. Class A rock is usually selected quarry rock. It is carefully placed and closely fitted on the breakwater slope. An intermediate layer or layers of armor rock may be included in the design, having the function of keeping the smaller inner layer material in place under wave forces.

The properties of rock to be used for a breakwater or jetty are strength, durability and toughness or wear resistance. Additional properties are required of rock or crushed stone which is to be used for concrete aggregate. All three of the major geological classifications of stone contain rocks which are suitable for jetty construction. Table IV-II gives the classification and average physical properties of rocks. The thermal coefficient of expansion of the rock is not an important factor in its suitability for jetty construction, but in some locations it must be resistant to freezing and thawing disintegration.

There are other types of design for breakwaters, groins and jetties than the rubble mound construction. These make use of a variety of materials, design features and construction techniques. Groins and jetties may be constructed of round timber piles and timber sheet piling, of steel sheet pile of various sections, of steel sheet pile cells filled with

TABLE IV-II

CLASSIFICATION AND AVERAGE PHYSICAL PROPERTIES OF ROCKS

(Severinghaus, 1960)

Group	Type	Rock	S.G.	Weight/Ft³	Deval Toughness (French Coefficient)
Igneous	Intrusive	Granite	2.6	167	11
		Syenite	2.7	171	15
		Diorite	2.8	179	17
		Gabbro	2.9	185	14
		Peridotite	2.9	182	11
	Extrusive	Rhyolite	2.5	159	19
		Trachyte	2.7	170	24
		Andesite	2.6	166	18
		Basalt	2.8	177	18
		Diabase	2.9	186	22
Sedimentary	Calcareous	Limestone	2.6	165	9
		Dolomite	2.7	170	9
	Siliceous	Sandstone	2.6	165	10
		Chert	2.5	159	12
Metamorphic	Foliated	Gneiss	2.7	172	10
		Schist	2.8	180	13
		Amphibolite	3.0	188	9
	Non-foliated	Quartzite	2.7	169	18
		Marble	2.7	173	6

granular material, of prestressed concrete sheet piles and even of sand-asphalt mixture. Excellent design and construction data and details are found in a publication by the U. S. Army Coastal Engineering Research Center, "Shore Protection, Planning and Design", Report No. 4 (1966). Armor units for breakwater construction are precast of concrete in areas where an adequate supply of suitable rock is not readily available. The precast shapes may be rectangular concrete blocks, or they may be shapes which afford considerable interlocking such as the tetrapod, the tribar, or the quadripod.

F. Plastics

Plastic materials are available as films, sheets, screen-cloth and as extruded shapes such as pipe and tubing. The development of glass fiber reinforcement for plastic materials has vastly increased the applicability of plastic materials as chemically inert, non-corroding substitutes for metals in service at temperatures below 250°F.

Polyvinyl chloride (PVC) has been used for 8 years as the screen material in traveling screens in one seawater intake system. The operators are enthusiastic about its performance, reporting negligible maintenance and no corrosion. At least one major manufacturer of traveling screens will now furnish PVC screen mesh as standard equipment. Its freedom from corrosion in seawater, together with its non-conductive property, thus making it independent of galvanic action, would seem to make it a superior material for this purpose. Its structural strength has been shown to be ample.

Fiberglass-reinforced plastic (FRP) made of corrosion-resistant plastic resins, such as polyvinyl ester resin, with fiberglass reinforcing is now being used regularly as the material of construction for housings for traveling screens. Its inertness in marine atmospheres, as well as its non-conductivity, makes it a long-lasting, relatively maintenance-free material for this purpose. It can also be used as piping material for screen washing systems and other seawater piping systems. It can readily withstand the temperature and pressures normally encountered in seawater intake systems.

Fiberglass-reinforced plastic (epoxy) pipe was used successfully by the U. S. Air Force at Eniwetok Atoll as a floating underwater pipeline through which liquid fuel from tankers could be conveyed to shore storage facilities. It was reported that there was a build-up of marine growth on the pipe but that it "can easily be wiped off by hand" (Young and Whitaker, 1969).

FRP pipe is light in weight and thus can be easily transported and handled. Joining is fast and repairs can be made quickly and easily.

High-density polyethylene has been used as intake pipe material for some years in Europe and is now gaining some acceptance in the United States. Various features of this pipe are presented in Sub-Section G.

Considerable work is being done towards the development of plastics which can be used satisfactorily as structural members. Considering the several highly advantageous properties of many plastics, particularly their excellent corrosion resistance to seawater and their electrical nonconductivity, these materials would appear to hold promise of wider applications in seawater intake systems, eventually fulfilling many structural requirements now being met by metals.

G. Intake Pipes

The most widely used material for underwater ocean intake pipelines of large diameter is reinforced concrete. Some installations are still in use after sixty years of satisfactory service. Many improvements in the design and fabrication of concrete pipe have been made over this time. Specialized fabricating equipment makes possible careful control over the quality of the finished pipe and design mixes are closely controlled to produce a dense, strong concrete.

The older method of reinforcement used longitudinal steel bars and spirally wound wire. The new method, which has largely replaced the older, uses a steel cylinder of thin gauge metal and a spirally wound, pretensioned, high tensile strength wire. In the smaller diameters, up to 48 inches, the steel cylinder is lined on the inside with a centrifugally cast dense concrete layer. The core of the cylinder and concrete is steam cured, and then wound with the high tensile strength wire under carefully controlled tension and spacing. A dense cement mortar is mechanically impacted around the outside of the core to a thickness of 1 inch to protect the reinforcing steel. In the larger diameters, up to 144 inches, the metal cylinder is embedded in the concrete by pouring in vertical molds, forming a concrete lining inside and outside the cylinder. This constitutes the core of the finished pipe. The molds are mechanically vibrated at high frequency during pouring to produce a dense, high strength concrete. The core is removed from the molds and steam or water cured. It is then wound with the pretensioned wire and mortar is sprayed on the outside to a thickness of 1 inch to protect the reinforcing. Typical pipe sections and joints are shown in Figure IX-14.

Pipe sections are normally cast in 16-foot lengths and may be welded together in manufacturing to produce 32-foot lengths. The welded joint is then covered with concrete for protection. Pipe joints are of the bell and spigot type. A steel spigot ring or a steel bell ring is welded onto the end of each pipe cylinder before casting, and lined with concrete on its interior or exterior surface as appropriate. An O-ring rubber gasket is incorporated into the joint for a watertight seal. A joint assembly harness is provided for the purpose of underwater assembly of the pipe. Two lugs are anchored in each end of the pipe, diametrically opposite each other on the horizontal centerline. The pipe is lowered carefully into the construction trench so that the lugs are positioned to match the lugs on the pipe previously laid. A diver guides the flare of the bell of the pipe being laid around the spigot of the installed pipe, runs the draw bolt through each pair of lugs, and draws the joint snugly home by taking up on the nut of each bolt. Both nuts are then backed off a few turns to permit flexibility in the joint. The purpose of the joint assembly harness is not for anchoring the pipe together but only for pulling the joint together while laying the pipe. The joints in the finished pipelines are prevented from pulling apart by the backfill. The finished pipeline can be designed for carrying pressures up to 150 psi, although as an intake, the pipeline may be expected to operate under a slight negative pressure head.

Steel pipe is available in any standard diameter, any gauge thickness and any length. It has great strength and resistance to impact and abrasion. Pipe sections can be joined by a number of methods, the most usual being electric arc welding.

For use in seawater intake pipelines, steel pipe has disadvantages which must be carefully considered. It must be protected from seawater corrosion both outside and inside.

Experience with seawater flowing in unprotected steel pipes has indicated an average service life of roughly eight years. With protection, the life of the pipe can be extended. Protective coatings are effective in extending the life, but probably cannot be counted on to give full protection for 30 years in flowing seawater. It is believed that it may be feasible to protect the surface of the steel from corrosion using a combination of a protective coating plus sacrificial aluminum type anodes fastened at intervals to the inside and the outside of the pipe to provide cathodic protection to any uncoated portion of the surface.

Two plastic materials used for pipes which deserve to be considered for seawater intake pipelines are: filament-wound fiberglass reinforced epoxy (FRP) and high-density polyethylene. Both of these materials are in use as pipe material in corrosive environments, both are free from corrosion in seawater, and both are available in fairly large sizes. Both materials are resistant to borer attack in seawater and to fungus. While marine fouling organisms can attach and grow on these plastics, it is reported that attachment is not as tenacious as to other basic construction materials.

Fiberglass reinforced epoxy pipe (FRP) is a two-component material, light in weight, strong, and corrosion-resistant, suitable at temperatures up to 250°F. FRP pipe is available in pipe diameters up to 72 inches. Its glassy-smooth surface permits pipe sizing on the basis of a high design value of Hazen-Williams coefficient C of 150.

The abrasion resistance of FRP pipe is not great. It can be easily cut with a saw. In an intake installation, careful attention should be given to bedding and backfill material to insure that they are free from rocks and large granular material.

Sections of pipe are joined by adhesive bonding with a sleeve coupling. The pipe ends are sanded to roughen the surface, epoxy adhesive applied to the ends of the pipe and inside of the coupling, and the pipe ends pressed together inside the coupling to bond. Several hours are allowed for the adhesive to cure.

High-density polyethylene pipe is sometimes used for marine intakes and outfalls. The pipe is available in sizes up to 48 inches in diameter with a standard length of 48 feet.

SECTION V. FOULING AND BORING

Fouling in seawater can be a problem of equal magnitude with that of corrosion. Fouling organisms are almost universal in their distribution in seawater, being more prevalent in warmer waters. Fouling organisms consist of many different types and any one fouling community may include dozens of different individual species. The prediction of species that might be encountered at a particular location is difficult and quantitative control measures are even more difficult to establish. Means of controlling fouling should be carefully considered in the design of any seawater intake system.

Boring organisms are generally confined to timbers. Although wood will probably be used only in limited amounts in the submerged portions of intake structures, it is important to understand the problems generated by boring organisms and how they may be controlled.

A. Nature of Fouling

Fouling is the growth of marine plants and animals on the surfaces of submerged objects. The term "fouling" is usually applied to situations in which the growth is harmful. Biological fouling causes many problems in seawater intakes and to other portions of seawater desalting plants as well.

Fouling growths can occur on the insides of intake pipes, reducing their effective diameters and increasing friction head loss to such an extent that flow velocities and quantities may be seriously reduced. Sometimes the flow is stopped completely, resulting in shutdown of equipment. As fouling organisms grow rapidly in an intake, the clumps of shells may be torn loose by the force of the flow and carried through the pipe to points where they may clog pump intakes, plug condenser tubes, block valves, and impede the flow through screens. In power plants, entire turbogenerator units have had to be shut down to clean out condenser tubes as frequently as two and three times a day (Dobson, 1946) with attendant loss of production and increased expense. For example, the Carmarthen Bay Power Station in Wales experienced a heavy growth of mussels and acorn barnacles around the main intake within three months of commissioning. After nine months the turbine unit had to be shut down for daily cleaning. After fourteen months of operation the entire plant was shut down and 100 tons of marine growth, chiefly mussels, was removed manually (James, 1967). One New England power station removed 266 tons of marine growth in one year. In another power station, the bottom of an intake tunnel 6 feet by 10 feet was covered with a 3 to 6-foot depth of dead shells (Dobson, 1946). An 18-inch diameter cast iron line in a South Carolina power plant was reduced to an effective diameter of 6 inches in just 12 months by a growth of scallops (Pectin), a less-frequently-encountered fouling organism.

Fouling can also cause damage in ways other than clogging. Bacteria and algae can foul heat exchange tubes by forming a slime layer which retards flow and reduces heat transfer efficiency. In one plant, the task of manual removal of smelly marine growths was so disagreeable that workers balked and a labor problem developed. Bacterial slimes, especially of the sulfate-reducing type, can cause corrosion on ferrous metal surfaces. Barnacles can cause serious pitting of the surface of monel, stainless steel and nickel (Brooks, 1968).

B. Fouling Organisms

Many different species of marine organisms are found in fouling communities. In an extensive study, "Marine Fouling and its Prevention", by the Woods Hole Oceanographic Institution (1952), more than 2200 species were listed as being observed in such locations as ships, test panels, buoys, submarine cables, wrecks, lightships, ropes and dock gates. The more common fouling organisms listed by Anderson and Richards (1966) are:

Plants	(Algae and Slimes)
Sea Mosses	(Hydroids)
Sea Anemones	(Metridium)
Barnacles	(Balanus)
Mussels	(Mytilus)

In addition, tunicates, tubeworms and bryozoans can contribute very significantly to fouling. Marine plants and sea mosses are easier to control, while sea anemones, barnacles and, particularly, mussels are more resistant to most control techniques.

One type of fouling organisms typified by barnacles, plants and sea mosses, are sessile, that is, not capable of relocating once they have become attached. A second type, exemplified by anemones and mussels, are able to make some further locomotion after they become attached. All of these common fouling organisms enter the intake system as very small embryos.

They have only a short span of time in which to become attached to some surface, the time varying from a few hours to several weeks, depending upon the species.

Following attachment, the organisms begin to develop a protective coating. Before this coating has developed, the embryo is more sensitive and vulnerable to unfavorable conditions such as changes in water temperature, dissolved oxygen level, salinity, food supply and to the presence of toxic substances. Control methods are thus more likely to be effective and less costly when directed at this period of the life cycle of the organism. Therefore, a knowledge of the life cycle and the breeding seasons of the potential fouling organisms is required for the prudent selection of a technique and schedule of fouling control at any chosen site. In Figure V-1 is shown the common fouling organisms encountered at several typical locations. Also indicated is the season when fouling can be expected to occur.

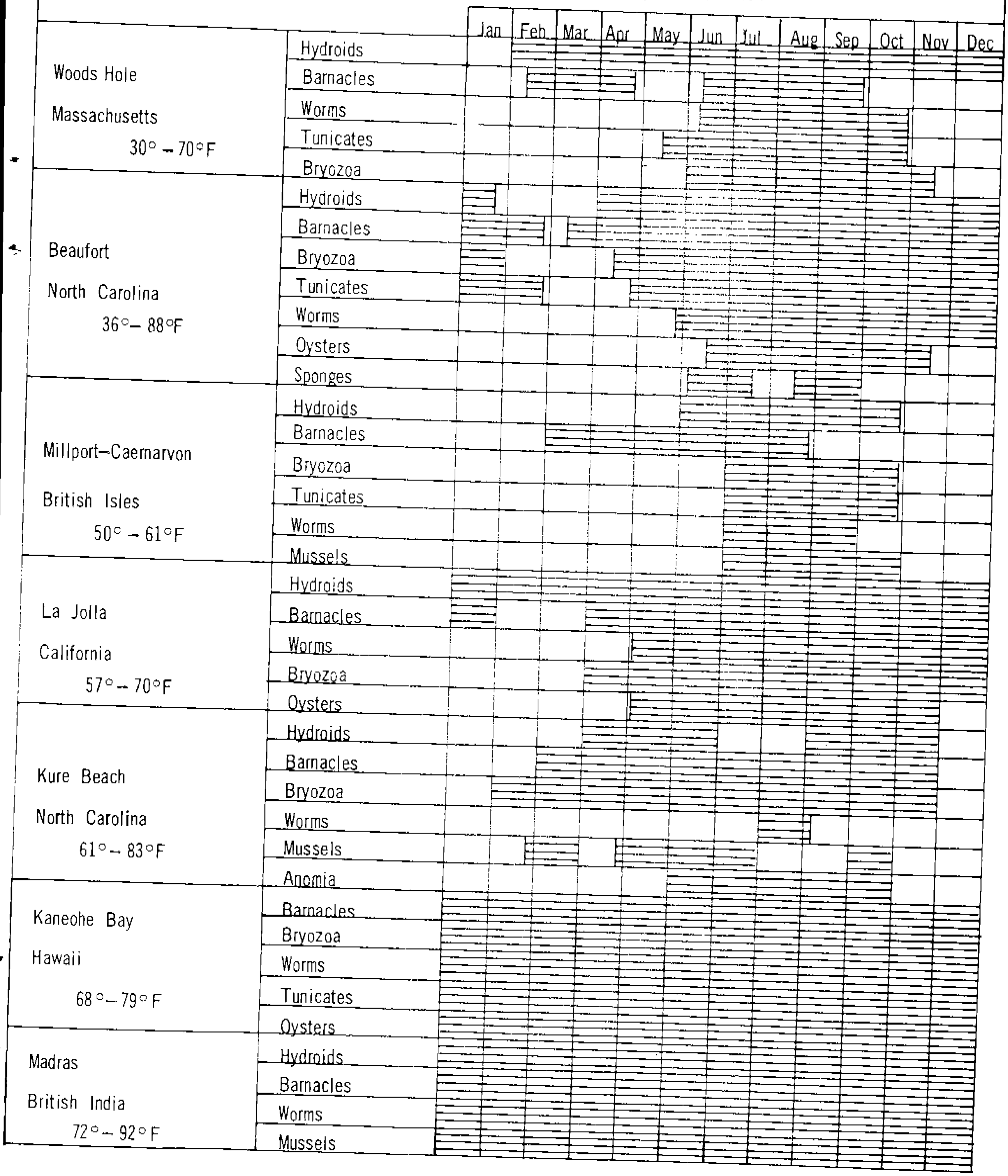
Among the commonly found fouling organisms in intake systems, the most plentiful and probably the most difficult to control is the common mussel. The worst offender is, probably, the edible black mussel, Mytilus edulis, sometimes called the bay mussel. It is widely distributed, being found on the Atlantic Coasts of Europe and the United States, and also on the Pacific Coast of North America. Other common species of mussels often encountered in intakes are the sea mussel of the Pacific Coast, Mytilus californicus, and other species, such as Mytilopsis leucophaeta, Brachydontes exustus, Brachydontes recurvus and Modiolus, the horse mussel (Clapp, 1950).

The black mussel is a wedge-shaped bivalve with a life cycle typical of many fouling organisms. It is pointed at the hinge and rounded at the trailing end, of a black or dark brown color and with indistinct curves around the shell. It is a common shell of rocky coasts of the northeastern United States and a populous inhabitant of the intertidal zone. The shell ranges up to about 4 inches in length and about 1-1/2 inches in width.

The two sexes are separate, but a single individual may change its sex from one year to the next. Eggs and sperm are discharged at the same time by nearby individuals, and the eggs are quickly fertilized in the open water. The female is very prolific, discharging on the average 5 to 12 million eggs; release of as many as 25 million has been

Figure V-1

FOULING PERIODS IN VARIOUS HARBORS (Dobson, 1946)



observed. Larval development is rapid after fertilization, and at the end of 5 hours the ciliated embryo is completely free-swimming. In 24 hours it is a very active swimmer, and it has usually attached to some hard surface by the end of 44 hours. The embryo mussel forms a single elementary shell, the prodissoconch, which completely covers the organism by the end of the 69th hour (Dobson, 1946). The larval mussel is still able, at this stage in its life cycle, to detach itself and swim rapidly or to crawl snail-like on surfaces. Later, the embryo forms a bivalve shell, the dissoconch, fastening this to the surface with a number of strong, clear threads called byssus threads. It is still capable of locomotion, and if threatened by unfavorable conditions such as inadequate food supply, low dissolved oxygen or chemical irritation, may break off the byssus threads which fasten it and crawl to a new location. Some species of mussels prefer light while others grow faster in darkness and migrate toward these preferences.

The mussel feeds by forcing water through the digestive tract by rapid vibration of the cilia on the mantle. Suspended solid food particles in the water adhere to the mucous surfaces in the digestive tract where digestive juices dissolve and assimilate the nutritive portions. The remainder is expelled as fecal pellets. The food of the mussel is believed to be mostly living microscopic diatoms and algae, although it is indicated that it can also survive on decaying animal and vegetable material as well. Mussels thrive in areas polluted by domestic sewage, provided there is sufficient dissolved oxygen in the water.

The growth rate of Mytilus is very rapid. It is estimated that under ideal conditions of food supply and circulation a pint of the microscopic embryo or spat could develop in six months into 500 tons of adult mussels (Anderson and Richards, 1966). It grows more rapidly in areas where circulation assures it an adequate food supply. Growth rates in the wave zone have been observed as high as three times the growth rate in deeper, more quiescent waters. Flow velocities in intake tunnels permit mussel growth to occur at a rate many times that in the natural habitat (Dobson, 1946).

The spawning season for the edible mussel varies roughly with latitude, or, more correctly, with water temperature. In the cooler waters off of the New England Coast, mussels do not spawn during the winter months, while in warmer waters further south embryo are produced and survive throughout the entire year (Anderson and Richards, 1966).

Many marine molluscs are adapted for living in the between-tide area where they may be exposed to hot sun and open air during a portion of the tidal period. They possess strong shells and powerful muscles capable of shutting the shells quickly and tightly when unfavorable conditions are sensed. Thus, they are able to isolate themselves from the hostile environment for periods of as much as 72 hours. After an extended period of closure, the mussel will open the shell very slightly and "drink" cautiously to sense if conditions are again favorable. This ability and behavioral pattern make the mussel very difficult to control and must be considered in the selection of control techniques.

Since mussels are the most resistant type of fouling organism, methods which are adequate in the control of mussels will almost certainly assure control of the less resistant fouling organisms. It must be pointed out that fouling communities are composed of a variety of different organisms and will take on additional characteristics distinct from any individual members, although the general character will usually approach that of the dominant organism. Many free living animals will be found as a part of the fouling community.

Algae are aquatic plants. They contain chlorophyll, can manufacture their own foods and do not usually, because of the requirement for sufficient light, foul dark or shaded surfaces. Most, but not all, algae are world-wide in distribution. They are generally classified as to their predominant color - blue-green, green, red, or brown algae.

The microscopic fouling organisms which produce, or are associated with, slimes include bacteria, diatoms, protozoa and rotifers (Woods Hole, 1952). Organic and inorganic particulates suspended in seawater also become incorporated in the film. The bacteria which form the slimes are present throughout the year and in numbers dependent upon the available organic matter, temperature and amount of pollution. Diatoms are microscopic plants suspended in the water or attached to underwater objects. Protozoa are single-celled animals which do not produce slime films themselves but live in or on slime films produced by bacteria or diatoms. If the conditions are proper they may grow rapidly and constitute a significant portion of the fouling load. Rotifers are narrowly distributed and seldom a problem.

Hydroids live in colonies. A colony will start with the attachment of a single individual to a submerged object. Through repeated budding and growth the colony will continue to grow until it reaches its mature size. Hydroid fouling will reach both a maximum thickness and a maximum density.

Sea anemones are single polyps, which are more developed than the hydroids, attached to a surface by a basal disc. Metridium, a common form found on both coasts of America, has a stubby, rubbery body with a large number of short tentacles. It may constitute a considerable part of the fouling load.

Barnacles are encased in hard, calcareous shells and are attached to submerged or periodically wetted surfaces by a permanent, tenacious cement. The goose barnacle is held to the surface by a muscular stalk. Upon dying, the stalk decays and the goose barnacle will float free and be carried through the intake.

Tunicates, found as fouling growths, either grow singly as soft, sack-like individuals or as colonies. A protective coat of tough material, similar to a tunic, covers the exterior, hence its name. Colonies are groups of individuals growing together as jelly-like masses. Each colony will have individuals of all ages from the young to the dying.

Tube worms, or serpulid worms (Annelids), are characterized by tough white calcareous protective tubes laid out in a most contorted pattern. Under proper conditions tube worms can accumulate in large masses, becoming so extensive as to resemble coral. Tube worms, where they occur, are very troublesome and can plug tubes and narrow channels in a relatively short time. A wide variety of free-living annelid worms may live in fouling communities, among which are scaleworms and the clam-worm.

C. Methods of Controlling Fouling

A number of potentially workable methods of controlling fouling in intake systems, either by preventing the setting of embryo farms or by killing the adult forms of the fouling organisms, have been either used or suggested. These are:

1. An increase in temperature
2. An increase or decrease in salinity
3. Removal of dissolved oxygen
4. Maintenance of adequate water velocities
5. Use of protective toxic coatings
6. Use of toxic materials such as copper base alloys
7. Filtering the water
8. Treating with acid
9. Treating with poisons (chlorine is the usual choice)

Of the methods used or proposed, the ones which have been usually adopted in general practice are increasing the temperature and chlorination. Adequate water velocity has been used with mixed success and the use of 90-10 copper-nickel shows promise. The other methods, though not widely used for fouling control in seawater intakes, may be of value in certain situations. A combination of several of these methods may often be used to advantage.

Control by Increasing Temperature

This is one of the earliest methods used by power stations. The flow direction in the intake and outfall is reversed and some cooling water recirculated until the discharge flow through the intake is heated somewhat above 100°F. The extent of control of the fouling population depends upon the organism, the exposure time, and the temperature.

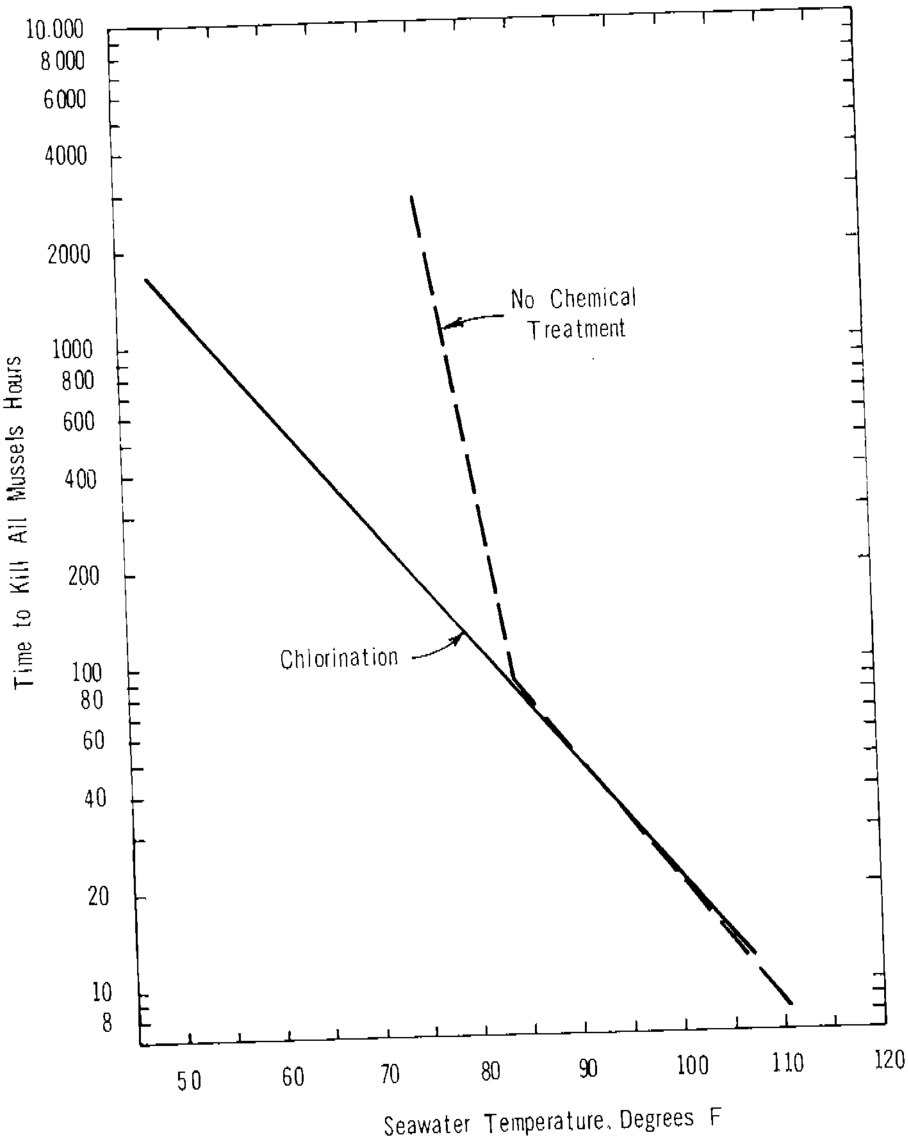
As an example, thermal treatment has been satisfactorily used for the control of marine fouling at the Southern California Edison steam power station at Redondo, California (Chadwick et al, 1950). The water temperature in the intake was raised to 102°F for a 4-hour period every 10 days to 3 weeks. Test panels in pipes remained clean for a year, whereas a 6 to 8-inch growth of mussels was found on some surfaces not exposed to the full heat treatment. During the period of treatment, the vacuum would drop approximately 1 inch of mercury. The operating cost of this treatment was estimated at $800 per year for two 66,000-kw turbine generators.

White (1950) reported the effectiveness of thermal treatment in the control of fouling by *M. edulis*, both by temperature elevation alone and in conjunction with chlorination. Figure V-2 shows the exposure time required for complete kill of the mussels at any test temperature, with and without chemical treatment. The results are applicable for the conditions encountered at Lynn Harbor, Massachusetts, and

Figure V - 2

COMPARATIVE TIME FOR KILLING SHELLED MUSSELS· CONTINUOUS TREATMENT

White, 1950)



All Mussels from Lynn Harbor

are considered representative of what could be expected at other locations with different ambient temperatures. The temperatures and exposure times are higher than those reported at Redondo (Chadwick et al, 1950).

Control by Change of Salinity

Fresh water has been used since ancient times to eliminate marine growth from fouled surfaces by mariners who would run their ships up fresh water streams to loosen the ship's fouling load. The method has drawbacks as a practical control method. A source of fresh or low salinity brackish water to the seawater desalination plant is not always available. Some fouling organisms are capable of surviving wide ranges in salinity and the sudden killing of a large part of the fouling population can cause the breaking loose of clusters of shells and debris to constitute an operating problem in the plant.

Control by Removing Dissolved Oxygen

This method will eliminate many fouling species. Others, including certain molluscs, are capable of obtaining oxygen from the chemical breakdown of organic compounds and thus can survive anaerobic conditions. Both chemical and mechanical removal of dissolved oxygen are expensive, and increasing concern over control of pollution may dictate that waste effluents contain dissolved oxygen, even if this requires supplemental aeration.

Control by Maintaining High Water Velocity

A surface velocity of 1 foot per second is sufficient to minimize the setting of mussel and barnacle larvae on smooth metal surfaces. However, this requires much higher average velocities to maintain the desired surface velocity. As far as is known, the relationship between surface roughness, pipe diameter, average velocity and type of fouling organism has never been established. In one case, an average velocity of 7.3 feet per second in 60-inch concrete pipe has prevented fouling for five years. However, no seawater was permitted to stand in the pipe when it was not in operation. Mussels which have already formed on the inside of pipes have been removed by flushing velocities of 13-1/2 feet per second applied for one hour a week (Dobson, 1946). Catch basins and strainers must be interposed to catch the debris produced. The pumping costs in plants employing large volumes of seawater flow would make this control method rather costly.

SECTION V. FOULING AND BORING

Present techniques for protection of waterfront structures involve consideration of many factors. Techniques which are effective at one location may be useless at another. Short term tests with exposed panels may be inadequate to show the long term effectiveness of a protective treatment being considered.

The selection of the correct treatment process is not simple. Current practice consists of either impregnation with creosote or another preservative, to deny borer access by sheathing, jacketing, or surrounding with fill. A combination is sometimes used. Protective coatings have wide application for the protection of ship hulls and underwater surfaces but are less appropriate for intake structures because the coating generally requires replacement every few years.

A sheathing of PVC or treated fabric is effective for pile protection, but it has low resistance to abrasion and tearing. Any small break from driving the pile or from subsequent sand and gravel scour or mechanical impact is sufficient to admit the larvae of borer organisms.

Metal sheathing has been tried in a variety of forms with mild success. The use of metal sheathing on ships dates back many hundreds of years when thin lead sheets were nailed to the hull to protect against worms. Piles must be carefully prepared before sheathing with sheet metal by removing all knots and projections and smoothing the surface, then coating with burlap or asphalt-saturated felt. The metal is nailed tightly over this layer. Copper, zinc and Muntz metal have been used for sheathing, but each has some objectionable failing.

Metal armor is not much used today, having been by-passed in favor of encasement in concrete. The concrete encasement may be poured, using forms, or it may be shot directly on the wood piles in a process similar to gunite. Usually there is some kind of steel reinforcement. Some of the poured concrete techniques may be applied in place and are suitable for repair and protection of existing damaged piles.

The trend in concrete jacketing is toward application of the jacket before driving. In addition to borer protection, concrete encasement provides a stiffer construction and affords fire protection as well.

Creosoting has become the most commonly practiced method of wood treatment to prevent damage by marine borers. Actually, marine borers are not excluded by creosoted timber. They still attack, but at a slower rate. Creosoting also affords protection against destructive fungi and termites as well.

The average life expectancy of treated timber piles in the Gulf of Mexico, the Caribbean and in Pacific Islands is eight to ten years. In cooler waters, marine borer activity is less violent and longer useful life may be expected. In San Francisco Bay, a life of 15 to 25 years is estimated, and in San Pedro the expectation is 20 to 30 years. At Gulfport, Mississippi, the life expectancy in years is considered to be approximately equal to the creosote retention in pounds per cubic foot.

Several methods are used for the application of creosote, with varying degrees of protection against marine borers. The wood may be treated in-place, applying the creosote by brush, grease gun, swab or trowel. This application produces no penetration of the creosote and is not suitable for submerged timber. It is useful, however, for field treatment of treated piles where holes have been bored, ends cut off, or minor spots damaged such as those resulting in handling. The dip and soak treatment involves submerging the complete timber, or the cut ends of a previously treated timber, in creosote for a period of 2 to 24 hours, allowing it to soak up the preservative. Surface penetration is slight, but end-grain penetration may be considerable. The treatment may be enhanced by alternately dipping in hot and cold solutions. In the hot bath, air and water vapor in the wood expand and some is driven out of the timber. In the cold bath, a contraction and slight vacuum draw the preservative into the surface layers. This treatment gives inadequate penetration for submerged timber.

Pressure treatment uses both heat and pressure to force preservative into the wood so that more of it is retained, sufficient to give good protection against marine borers. Large metal cylinders are used by commercial wood preservers capable of applying pressures up to 250 psi and temperatures of 220°F. A comparison of the types of treatment methods is given in Table V-I.

Other preservatives are used in wood preservation but are not normally suitable for submerged timber. They may be applied

SECTION VI. TRASH REMOVAL

An alternate to a skimmer barrier is a submerged inlet which is inherent with the pipe type intake and which can readily be designed into the lagoon and shore type intakes as shown in Section IX.

Trash Racks

When a skimmer barrier or a submerged inlet is provided, the next point of trash removal is the trash rack. This would generally be located ahead of the traveling screens in the pump basin, as shown in Figure VI-1. Should a skimmer barrier not be provided, it might be advantageous to locate the trash rack at the inlet, immediately ahead of the submerged opening for the lagoon and shore type intakes.

The trash rack, also called a bar screen, is a bar rack or grate, usually of steel, as shown in Figure VI-2. Bars are generally spaced from 2 to 4 inches apart and installed with the bars in a vertical or inclined position. They serve the purpose of removing larger solid floating objects, larger marine animals and the larger marine plants. Trash racks may be cleaned manually if the amount of trash is small or mechanically if the amount of trash is large.

Traveling Screens

After passing through the trash racks, the water should be screened by powered traveling screens. Figure VI-3 illustrates a typical traveling screen. They may be operated automatically, being activated when a control device detects a pre-determined difference in water level across the screens. They may also be operated manually, by push-buttom, if desired, although this is generally not recommended. Screen mesh may vary from 1/8-inch to 1-inch openings; a 3/8-inch opening screen is widely used and seems to be quite effective.

With small to medium tidal differences, the traveling screens are best placed ahead of the pumps. However, with large tidal differences, traveling screens of less height can be provided, at a lower cost, by placing them downstream from the pumps where the water depth can be held constant.

Some solid non-floating materials may settle out in the trash rack and traveling screen basin. The amount should be small and can be removed by a suction pump.

Figure VI-2
TYPICAL TRASH RACK INSTALLATION
(Courtesy FMC/Link-Belt)

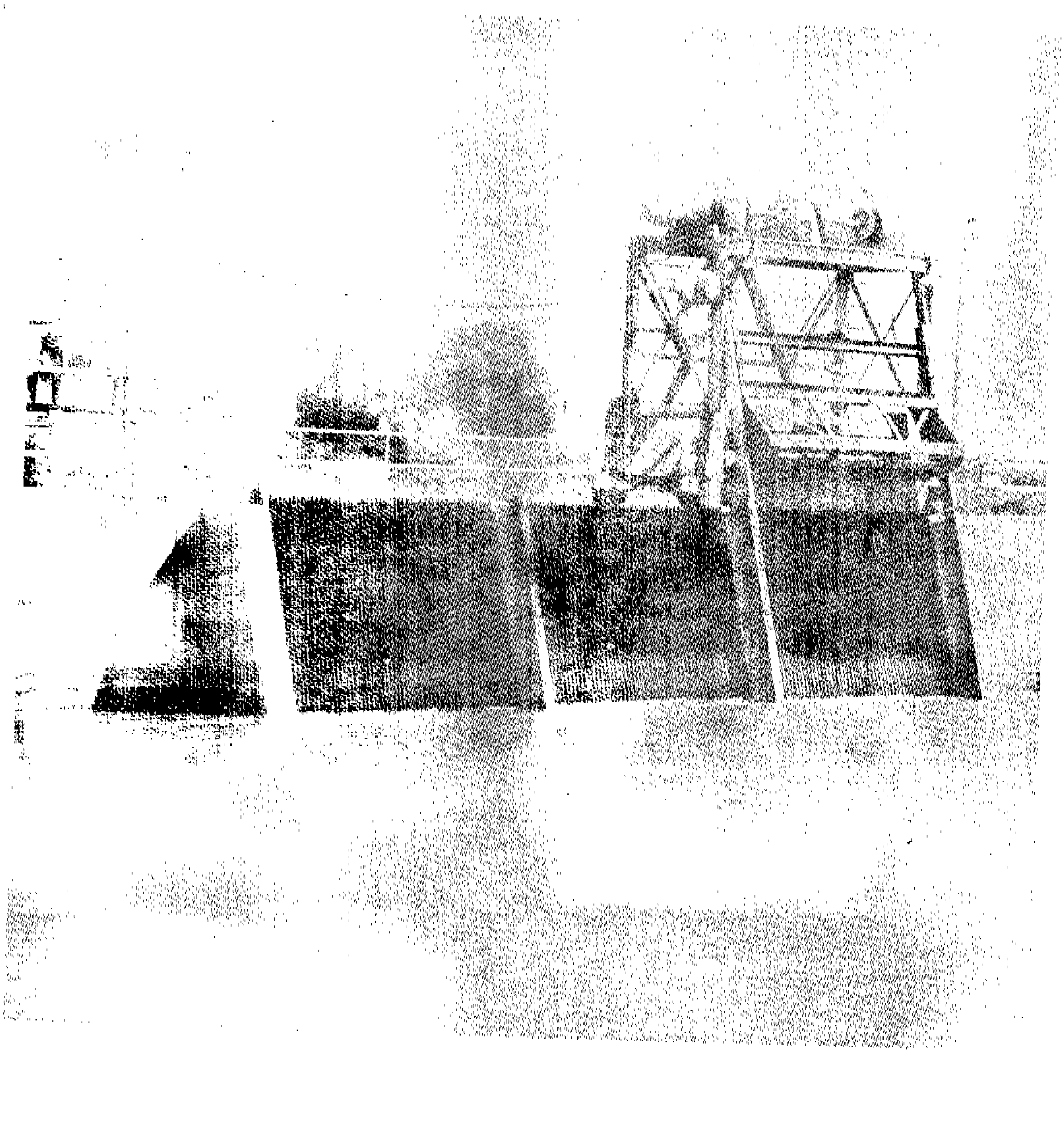
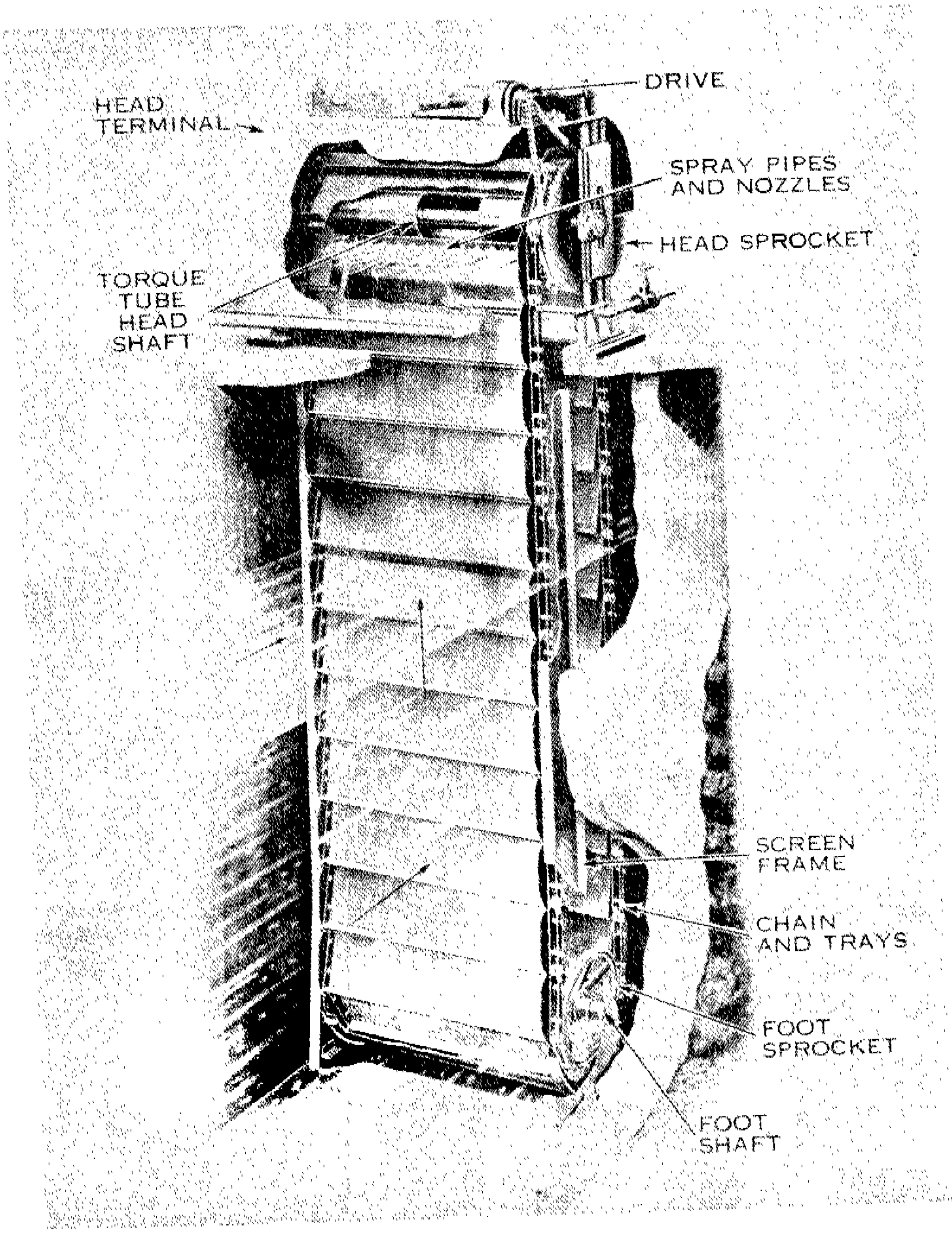


Figure VI-3

TYPICAL TRAVELING SCREEN

(Courtesy FMC/Link-Belt)



C. Trash Removal Equipment

Unusual conditions must be adequately provided for by the application of sound engineering judgement. Economic factors will also require design changes. The corrosive nature of seawater makes the selection of materials and certain design details very important. Section IV should be used to supplement the selection of materials made in this section.

Skimmer Barrier

A skimmer barrier may be a fixed structure or it may be a floating log boom type. When used as a firewall, it should be built of non-flammable materials. When fire is not a factor, construction could be of treated wood. The forces acting against the skimmer barrier structure are only the normal wind and wave forces since the head drop across the barrier is insignificant and the current velocity is low. Added to these, however, may be forces exerted by a barge or boat which might float into it. Where possible, a skimmer barrier can best be located where the prevailing currents would tend to sweep away the waste material which might wash up against it.

Trash Racks

Trash racks are generally constructed with bars of carbon steel, typically 3/8-inch by 2-inch to 1/2-inch by 4-inch, oriented edgewise to the water flow, with a spacing between bars from 2 to 4 inches. The optimum velocity of water through the trash racks has been found to lie in the range of from 1 to 2-1/2 feet per second. Trash racks constructed of a suitable alloy material would be more resistant to seawater corrosion than carbon steel, plain or coated, but the higher cost is generally not justified.

Trash racks should be designed to withstand the largest differential head pressure which might be foreseen. Racks should be designed for easy removal by portable crane for maintenance and replacement.

Unless trash loading is expected to be high or rack area very large, removal of trash can be done manually using a long-handled rake. Where conditions warrant commercially designed mechanical trash rakes can be installed. Even when the initial decision is to clean the racks manually, it would be wise to design and build the racks and basin so that a standard manufacturer's trash rack could be readily installed later if needed.

SECTION VI. TRASH REMOVAL

A differential pressure indicator and alarm should be installed to sound an alarm at a preset pressure differential (about 4 inches to 6 inches of water head). A differential pressure timed controller can be provided to start the mechanical trash rake and shut it off after a predetermined period of operation or when the head loss returns to normal.

Cathodic protection, of either the anodic or impressed current type, would be beneficial where plain or coated carbon steel construction is used.

Traveling Screens

Traveling screens (Figure VI-3) are designed to remove finer materials that pass the trash racks. Traveling screens are manufactured by several firms. It is recommended that these firms be consulted because of their experience in this field and the substantial amount of design data that they can provide.

Rotary screens and disc screens can operate effectively only where the water level is relatively constant. Because of the considerable variation in water level to be expected at a seawater intake, the trend is away from these types of screens and towards traveling screens.

As trash carried by the water loads the screen mesh, it is necessary to remove the screen from the water in order to unload the trash and at the same time to present a fresh, unloaded screen surface to the flowing water. This is accomplished by breaking the screens into a series of screen panels traveling on an endless chain. Each screen frame fits closely to its neighbor and to the boundaries of the water channel in which it moves so that all of the water must flow through the screen mesh. Trash and marine life in the water lodge on the screens while they are on the way upward, out of the water.

Accumulated trash on the screen mesh and on the lifting lips is washed by a 50 to 80 psi water spray into a sluiceway that flows into a trash collection basket usually located in a concrete pit equipped with a drain. The flush water, minus its trash and marine life, will then flow back into the pump basin.

Traveling screens should always be provided as multiple units so that, in the event one unit is down for servicing, as solutions in oil or solutions in water, or in the form of a gel, grease or emulsion. The oil-borne preservatives include organic and metal-organic chemicals, such as pentachlorophenol, and copper naphthenate. Water-borne preservatives are salts or mixtures of salts of heavy metals, such as arsenic, chromium, copper and zinc. In at least one instance, a wood pile impregnated with chromated copper arsenate appears to have successfully prevented borer attack for 19 years, and, at the same time, essentially eliminated fouling.

Several guidelines are available to the planner who is considering protective treatment of timber piles. NavDocks MO-312, the "Handbook of Wood Preservation", published by the Navy Department, contains detailed information on preservatives, treatment methods and the principles of selection.

SECTION VI. TRASH REMOVAL

Trash, in the broader sense of the word, is used in this report to denote both marine life and inanimate objects of a size sufficient to cause blockage of any portion of the overall plant system. Seawater will contain varying amounts of many different kinds of trash, depending upon the marine life present, the effect of currents, the seasons of the year, and other factors. Careful attention to site location can minimize the amount and types of trash which might enter an intake system drawing from open water but it is virtually impossible to eliminate all trash by this means. Therefore, equipment for the removal of trash from the intake water is an important part of an intake system.

A. Nature of Trash

For the purpose of seawater intake consideration, trash may be classified in five broad groups:

- Solid floating objects
- Solid non-floating materials
- Liquid floating wastes
- Marine animals
- Marine plants

Each group has certain characteristics which influence the type of equipment best suited to remove it.

Solid Floating Objects

Objects comprising this group may consist of almost anything that floats, and the sources of such objects are almost limitless. They may come from far-away shores, such as the Japanese fishing net floats which are carried by the Japanese current to the Pacific Coast of the United States. Pieces of a damaged or broken-up ship, as well as its cargo and other floating objects and refuse dumped by ships at sea may float in to shore. Eroded or flood-washed land may supply trees, branches, bushes and weeds and grass. People make their contribution through the disposal of such solids as plastic containers and foamed packing materials. The sea itself casts up its dead animal life. Illustrative of the wide variety of solid floating objects that may enter an intake are the following:

Logs	Dead animals
Lumber	Dead fish
Trees	Plastic containers

- Bushes
- Boxes
- Bottles
- Barrels
- Driftwood
- Weeds
- Grass
- Plastic drinking cups
- Small boats
- Fishing net floats
- Cans
- Sticks
- Flotsam and jetsam

Solid Non-Floating Materials

These materials consist principally of sand, small stones, shells and occasionally small metallic objects. They move by rolling along the bottom or by saltation under the influence of currents and turbulence.

Liquid Floating Wastes

These wastes generally consist of oil or other floating immiscible liquids. While increasingly tighter controls are being exercised over the release, accidental or otherwise, of these wastes, they do occur occasionally and can constitute a real problem in an intake.

Marine Animals

In this group are the many kinds of marine organisms described in Section III. With the exception of crabs and a few other animals which move along the bottom, these animals swim or float and can propel themselves through the water at various rates of speed. Occasionally, for short periods of time, large numbers of shrimp or jellyfish will be picked up by the screening system. When this occurs, and without a suitable screening and removal system, a plant would be quickly shut down.

Marine Plants

Many kinds of sea plants of many shapes and sizes can be troublesome in intakes. In certain seasons or after a storm, marine plants may become free-floating in large quantities. Obviously, means must be provided for their removal in the event they enter an intake. Care in the selection of the intake opening location may make it possible to avoid much trouble from an influx of substantial amounts of such plant life, although some will probably be encountered from time to time in many locations.

SECTION VI. TRASH REMOVAL

B. Elements of Trash Removal

When obtaining the marine data needed in preparing the design criteria for a seawater intake system, a determination of the types and amounts of trash likely to be encountered must not be overlooked. The presence or absence of certain types of trash could have a major influence upon the type of intake system to be selected as well as upon the specific types and design features of the trash removal equipment best suited for the location chosen. At best, such a determination of the types and amounts of trash likely to be encountered may be only approximate. Small amounts of trash constantly enter any intake system, but it is only occasionally, and usually for short periods of time, that any substantial amounts enter. It is for these relatively short, high trash volume periods that equipment must be designed.

Trash removal should take place progressively, starting with the seawater inlet. Three means for removing trash are often used. These are, in the order in which the seawater passes through the intake system:

A skimmer barrier or submerged inlet,
One or more trash racks and,
Traveling screens

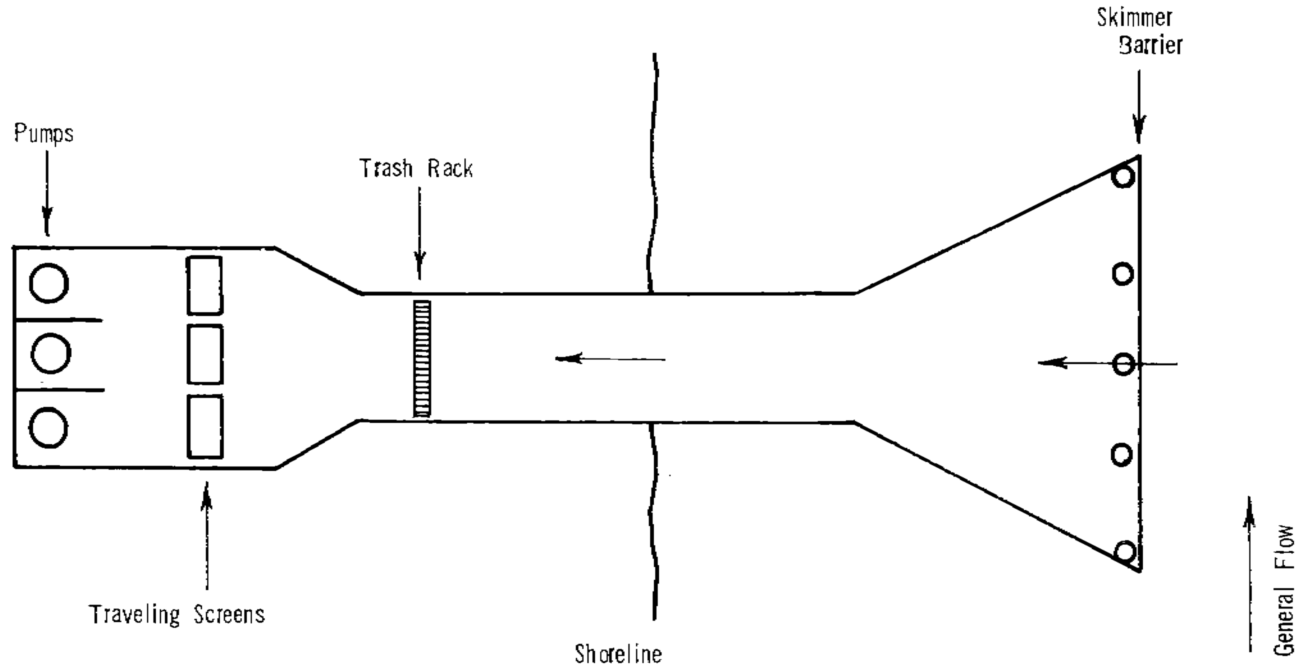
Skimmer Barrier or Submerged Inlet

In Figure VI-1 is shown, schematically, a typical lagoon type intake arrangement which illustrates the locations of the three points of trash removal.

A skimmer barrier is essentially a firewall and/or a physical barrier across the entrance to an intake system when an open channel is used as the means for conveying water to the pump basin. To accomplish its purpose, it must extend above the highest high water line a short distance and below the lowest low water line a short distance. It will prevent solid floating objects and liquid floating wastes from entering the intake system and is of particular value in preventing flammable floating liquids from entering the pump basin where their ignition could damage the equipment in the pump basin. It will also serve as a physical barrier to the damaging effects of a boat or barge that might get out of control.

Figure VI – 1

SCHEMATIC OF TYPICAL LAGOON TYPE INTAKE



SECTION VI. TRASH REMOVAL

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The trash rack, also called a bar screen, is a bar rack or grate, usually of steel, as shown in Figure VI-2. Bars are generally spaced from 2 to 4 inches apart and installed with the bars in a vertical or inclined position. They serve the purpose of removing larger solid floating objects, larger marine animals and the larger marine plants. Trash racks may be cleaned manually if the amount of trash is small or mechanically if the amount of trash is large.

Traveling Screens

After passing through the trash racks, the water should be screened by powered traveling screens. Figure VI-3 illustrates a typical traveling screen. They may be operated automatically, being activated when a control device detects a pre-determined difference in water level across the screens. They may also be operated manually, by push-buttom, if desired, although this is generally not recommended. Screen mesh may vary from 1/8-inch to 1-inch openings; a 3/8-inch opening screen is widely used and seems to be quite effective.

With small to medium tidal differences, the traveling screens are best placed ahead of the pumps. However, with large tidal differences, traveling screens of less height can be provided, at a lower cost, by placing them downstream from the pumps where the water depth can be held constant.

Some solid non-floating materials may settle out in the trash rack and traveling screen basin. The amount should be small and can be removed by a suction pump.

at least one other unit is operable. They should be set in place so that they can be readily lifted by portable crane for maintenance when needed. It is preferable that all screens at any one intake be of the same size to facilitate maintenance, minimize maintenance costs, and permit some degree of interchangeability.

The detailed procedures involved in the selection of a traveling screen are fully covered by the manufacturers of such equipment. They require that the maximum flow of seawater to be handled, the optimum or desired number of screens, the maximum, minimum and average water depths, the desired wire mesh, velocity through the mesh, and space limitations, all be known.

The selection of the size of a traveling screen must be such as to allow maximum design flow at the lowest water level anticipated. The operating platform must be above the highest high water anticipated. In some cases, it might be wise to provide room in the basin for an additional screen to be provided at some later date. As a rule, a relatively wide, shallow screen will be less costly than a narrow, deep screen.

Screen efficiencies must be carefully considered in calculating water flows. Tables of efficiencies are available from the screen manufacturers. Determination of power requirements involves a number of individual loads: chain joints, screen frames rubbing in guides, dead weight of chain and screen frames as well as their loadings, the effect of rusted surfaces, wedging of trash between screen frames, chain and main frame, uneven flow distribution, and others. Starting torque may be high and motors are often selected on the basis of starting torque requirements.

Single speed or dual speed drives may be selected, depending upon the amount and extent of trash loading. For relatively moderate to heavy loadings a screen speed of 10 feet per minute should be ample. However, for very occasional heavy loadings which may be experienced at coastal installations, a dual speed drive may be advantageous. The higher speed would handle a correspondingly larger amount of trash for the relatively short time periods involved, whereas the lower speed would be used to run the screens continuously for normal or light loadings, or for a set time period each day. The lower speed would also be of advantage when lubricating the screen carrier chains. High speed operation during very heavy loading periods will clear the trash faster than at low speed, thus returning the head differential to normal in less time. Dual speeds of 10 and 2-1/2 feet per minute and 20 and 5 feet per minute are useful combinations.

One combination of materials that has performed well and should be capable of giving 5 to 7 years service life before significant maintenance would be required is:

Main frame:	Carbon steel, structural grade, coated with self-priming coal tar epoxy
Basket frames:	Carbon steel, structural grade, coated with self-priming coal tar epoxy
Screen mesh:	PVC (or 304 SS or 316 SS or monel)
Backup bar for screen mesh:	304 SS (or 316 SS or monel)
Bolts and nuts:	Monel
Main carrier chain:	17-4 PH with 416 SS heat treated pins, bushings and rollers
Wear bar on structural frame performing as chain track:	304 SS
Foot wheel shaft (fixed):	304 SS
Foot wheel sprocket:	Type D-2 ni-resist or nickel aluminum bronze
Bushing:	Ryertex (impregnated plastic)
Head shaft:	304 SS
Head sprocket (fixed to shaft):	Cast semi-steel, coated with self-priming coal tar epoxy (design for easy replacement)

Removable inserts for sprocket:	17-4 PH or 416 SS heat treated (17-4 PH not to be used with rectified impressed current cathodic protection but okay with sacrificial anodes)
Bearing:	Cast steel in bronze bushing
Housing:	Fiberglass reinforced polyester

Cathodic protection is beneficial when stainless steel or monel screen mesh is used. Aluminum or zinc anodes both should perform well to prevent the excessive corrosion that might otherwise result due to galvanic action between the screen mesh and any bare portions of carbon steel.

PVC screen has been in use for eight years on one installation and has performed very satisfactorily. Its use is generally recommended since it appears to have good structural strength and is essentially free from seawater corrosion.

Any material passing through the traveling screens will be small. If it will cause difficulties in process or other equipment, it must be removed by settling or filtration, or both. The extent to which fine screening or filtering is indicated must be determined by the design requirements of the process equipment.

Wash water pumps should be wired to start automatically with the traveling screens. The following construction has given good service:

Casing:	Fine grained cast iron epoxy lined (epoxy lining must be competently done)
Impeller:	Cast stainless steel, 19-9 extra low carbon
Shaft:	K monel
Piping:	Mild steel, long radius bends, velocities <7 fps (for 9-year life), or fiberglass reinforced plastic properly supported for longer life

Spray nozzles: Monel

Pump suction should be taken downstream from the traveling screens so as to take screened water which has been chlorinated.

Diversion Screens

Diversion of the marine animals back to their natural environment, a promising approach to this problem, was conceived in 1965 and is still in the developmental stage. To accomplish this, a horizontally traveling screen is interposed at an oblique angle in the path of the flowing intake water. The main stream flows through the screen. The fish, other marine animals and trash are gently pushed to one side by the traveling screen and into a diversion channel that flows back to the environment. This is illustrated in Figure VI-4.

Advantages claimed are:

1. Impingement of the fish on the horizontally moving screen is much more gentle than that which occurs against a vertically moving screen interposed at 90° to the path of the intake water. Many animals sustain injuries from this direct impact or from their struggles to free themselves from the lifting vanes on the screens or in the process of being flushed off into the sluiceway.

2. Non-swimming forms such as eggs and juvenile fish can be safely collected on the screen and then released into the by-pass channel.

3. Tests have confirmed high efficiency of deflection and survival of the live marine animals in the intake stream to the diversion channel.

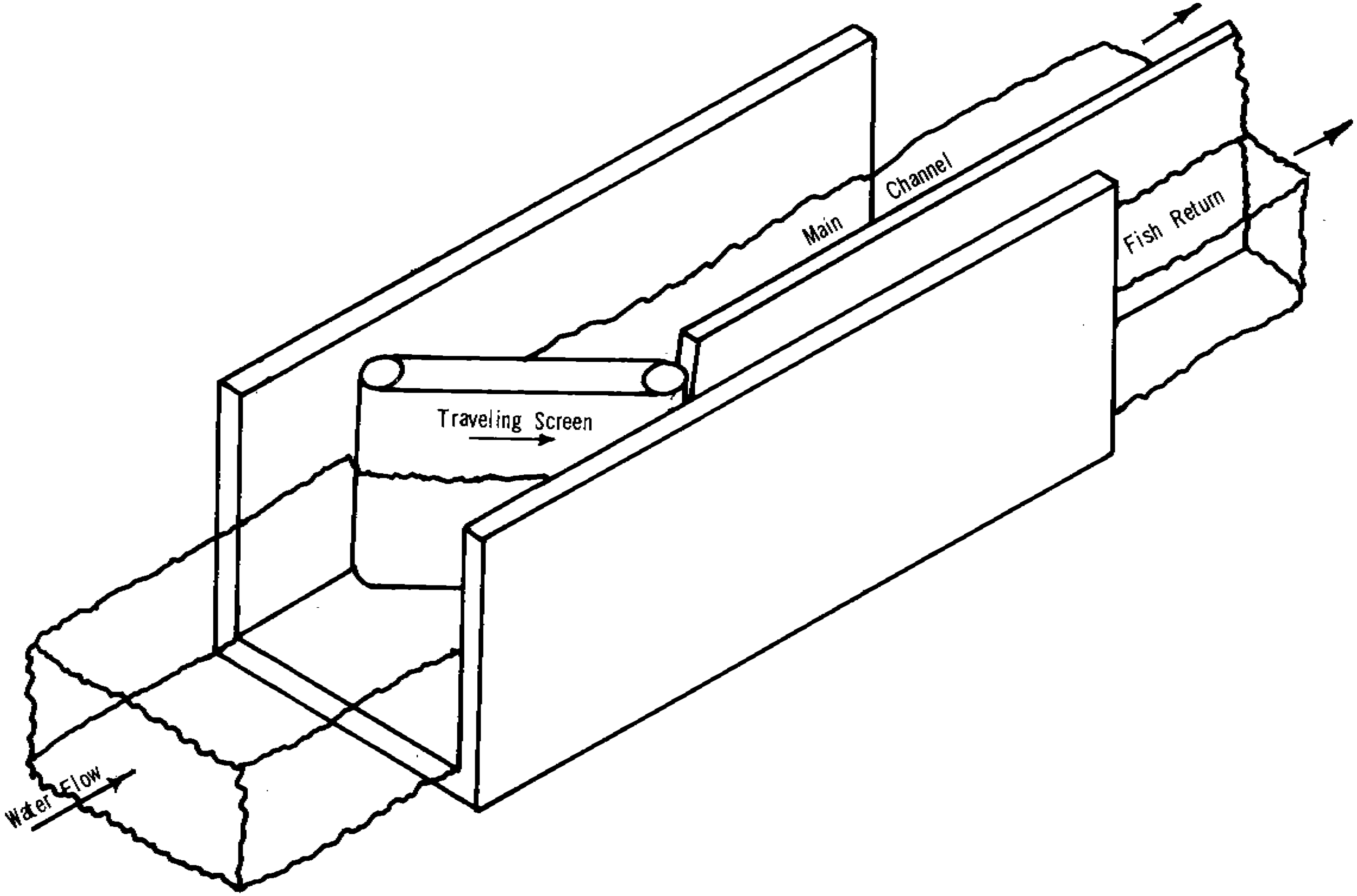
Unfortunately not all of the problems connected with the use of horizontally traveling screens have been solved and they are not presently offered as standard items by the major manufacturers.

D. Trash Disposal

Trash removed from the trash racks and traveling screens is usually sluiced away and collected in bins or wire baskets provided with carrying lugs to enable a specially adapted

Figure VI – 4

EXPERIMENTAL HORIZONTAL TRAVELING SCREEN



truck to latch on, transport and dump the container at a suitable disposal point. The ultimate disposal is usually by burial.

During the time the basket is filling, odor and flies are troublesome. These can often be controlled by keeping the contents of the basket wet with a fine water spray.

Live marine animals caught on the screens include only a small percentage of edible fish. Live, healthy fish are almost certainly too few in number to justify the cost of identifying and separating them.

Fish shredders have occasionally been used to cut up the trash collected in the baskets. These machines may be specially built for the job or they may consist of an ordinary hammer mill equipped with cutting knives. The mill cuts all trash fed into small bits and the carrying water then conducts the cut-up product to some point where it flows into a waste stream. Such a discharge may be a pollutant and local or federal regulations may prevent such a waste stream from being discharged. The use of this method of disposal should be carefully considered from all viewpoints before it is adopted.

SECTION VII. INTAKE SELECTION

Site selection for a desalination plant involves consideration of many of the factors normally involved in the site selection of an industrial or similar type facility. Engineering, economic, legal, aesthetic and similar factors are important. It is not the purpose of this report to present all the factors which must be analyzed and assessed for the total desalination plant, but rather to set forth those factors peculiar to seawater intakes which must be included in the total analysis and assessment of the desalination plant and which will influence the decision.

A. Types of Intakes

The three basic types of seawater intakes are:

Lagoon type
Pipe type
Shore type

Each of these is shown schematically in Figure VII-1 and in more detail in the engineering drawings shown in Section IX.

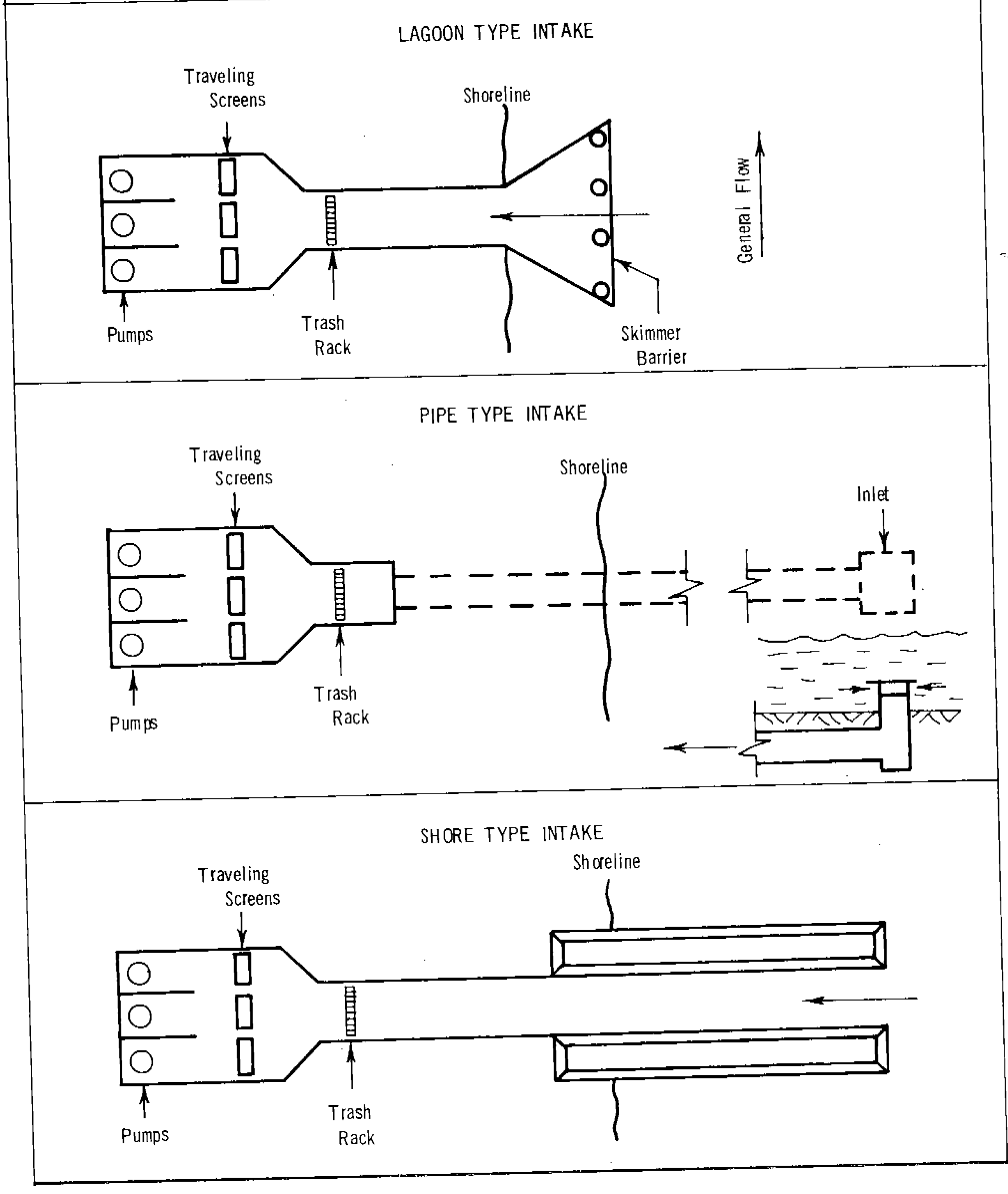
A fourth type, the well type, is not included in the scope of this report. Its use in supplying any substantial quantity of seawater has been quite limited and several serious problems, such as the generation of hydrogen sulfide, which are difficult to predict and equally difficult to correct, introduce a considerable degree of uncertainty. Of course, where it clearly can be used without trouble, the well type has several major advantages, such as providing essentially complete freedom from fouling, marine life, other trash and sand. It provides essentially filtered water and, with modifications to the well concept of withdrawal, would appear to have a definite potential.

Lagoon Type Intake

The lagoon type intake is characterized by a location on a lagoon, canal, waterway, bay, sound, or similar body of water free from the direct influence of ocean or gulf waves and surf. The channel between the inlet and the pump basin can be relatively short. In the pump basin, the seawater passes through a fixed bar trash rack and then through traveling screens, before entering the pump suctions. Where tides are excessive, the traveling screens could advantageously be placed downstream from the pumps, avoiding the

Figure VII – 1

TYPES OF SEAWATER INTAKE SYSTEMS



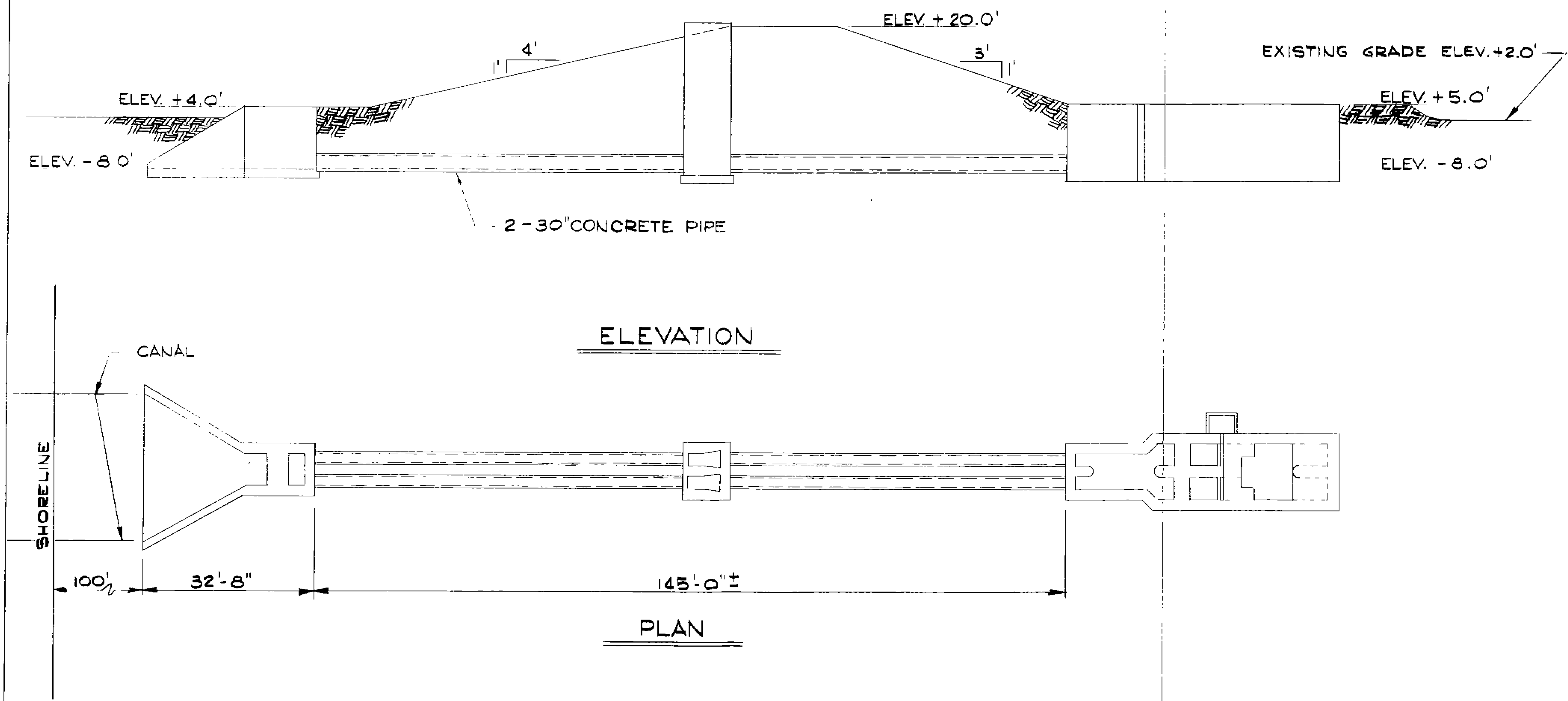


FIGURE IX-1

LAGOON INTAKE - 20 MGD
PLAN AND ELEVATION

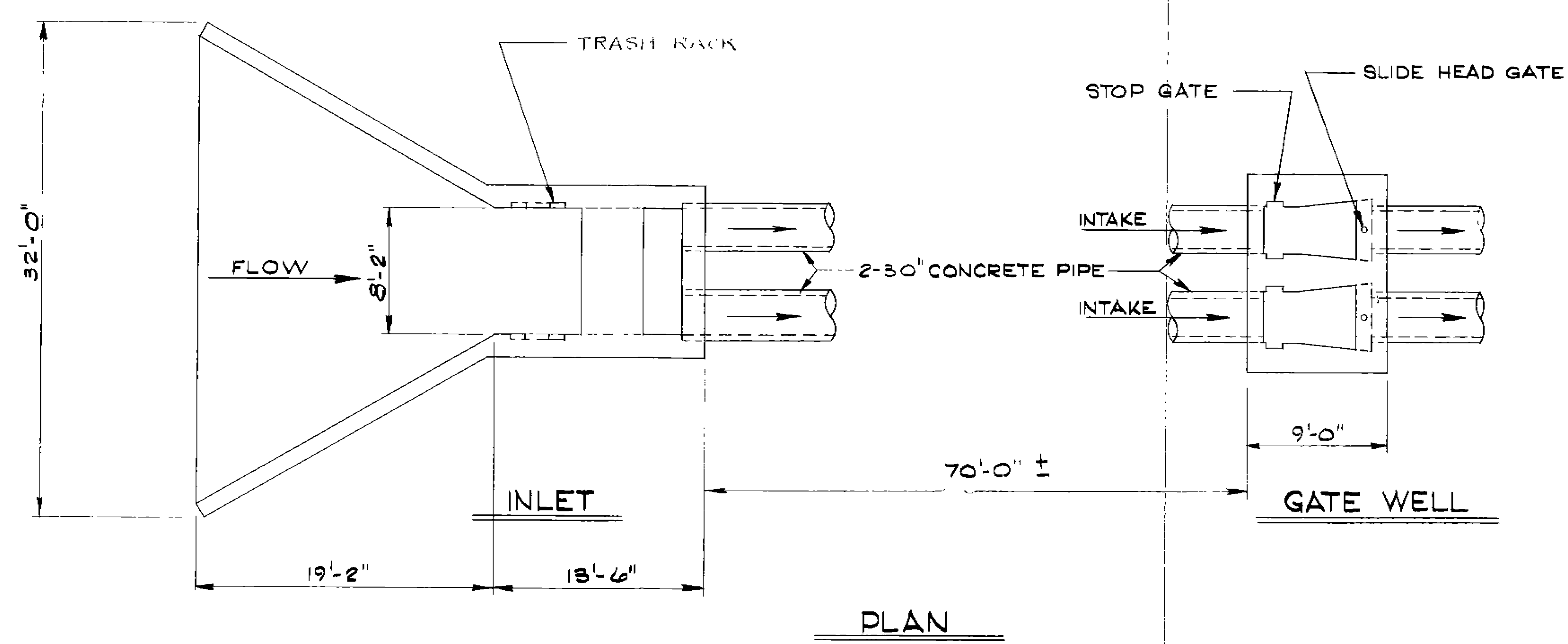


FIGURE IX - 2
LAGOON INTAKE - 20 MGD
PLAN VIEW OF INLET
AND GATE WELL

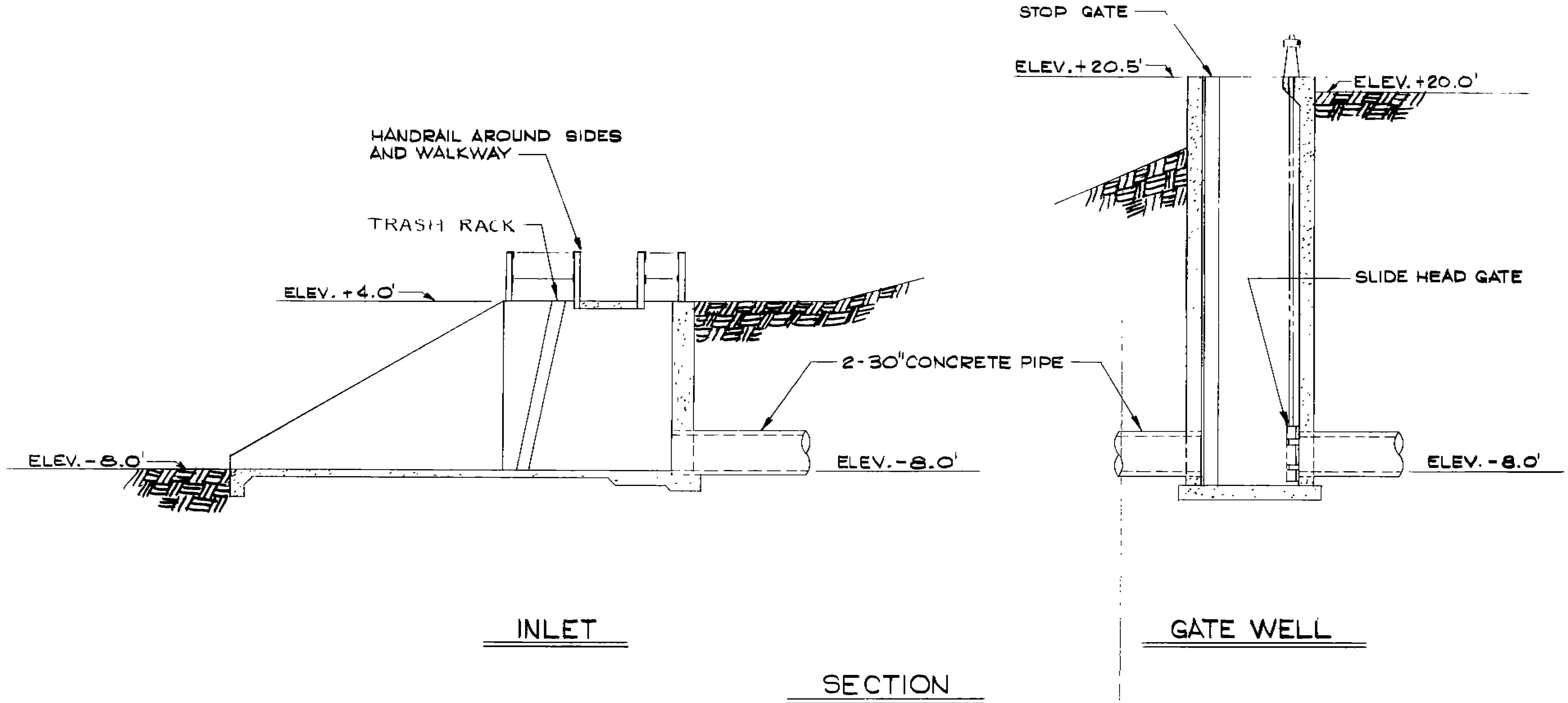


FIGURE IX - 3

LAGOON INTAKE - 20 MGD
SECT. ELEV. OF INLET
AND GATE WELL

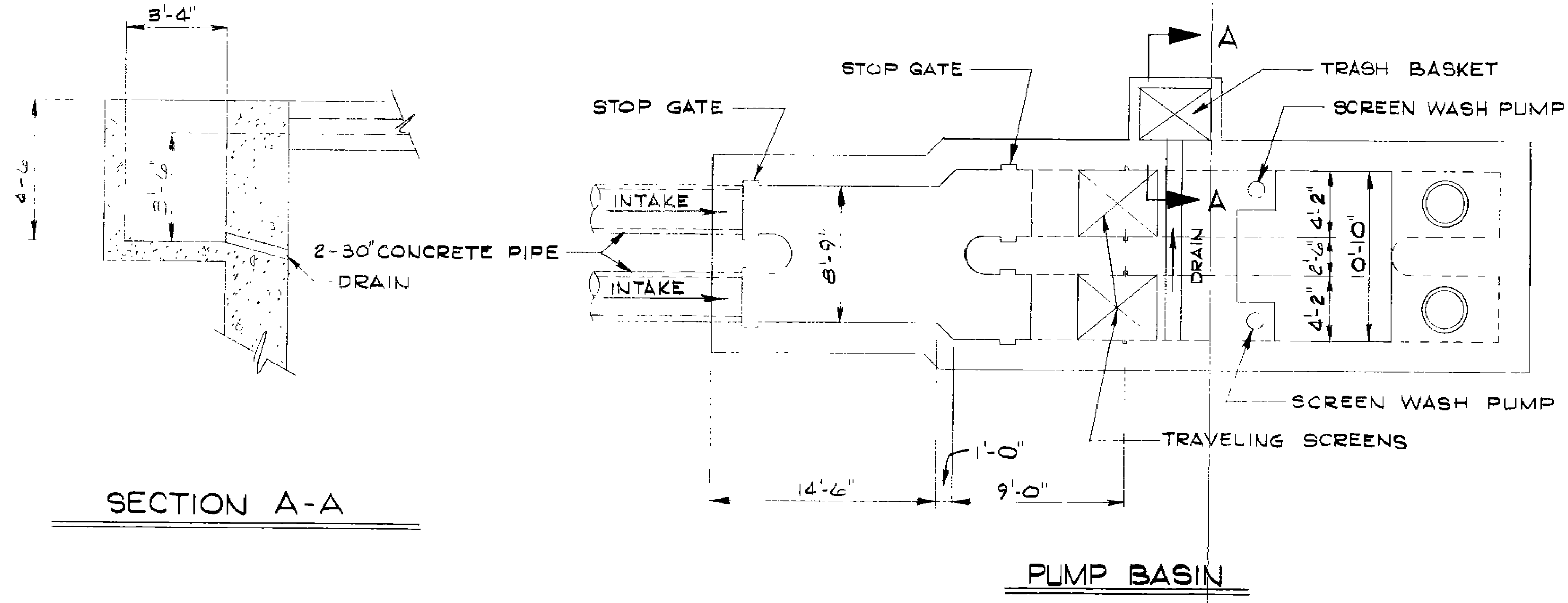


FIGURE IX - 4

LAGOON INTAKE - 20 MGD
PLAN VIEW OF PUMP BASIN

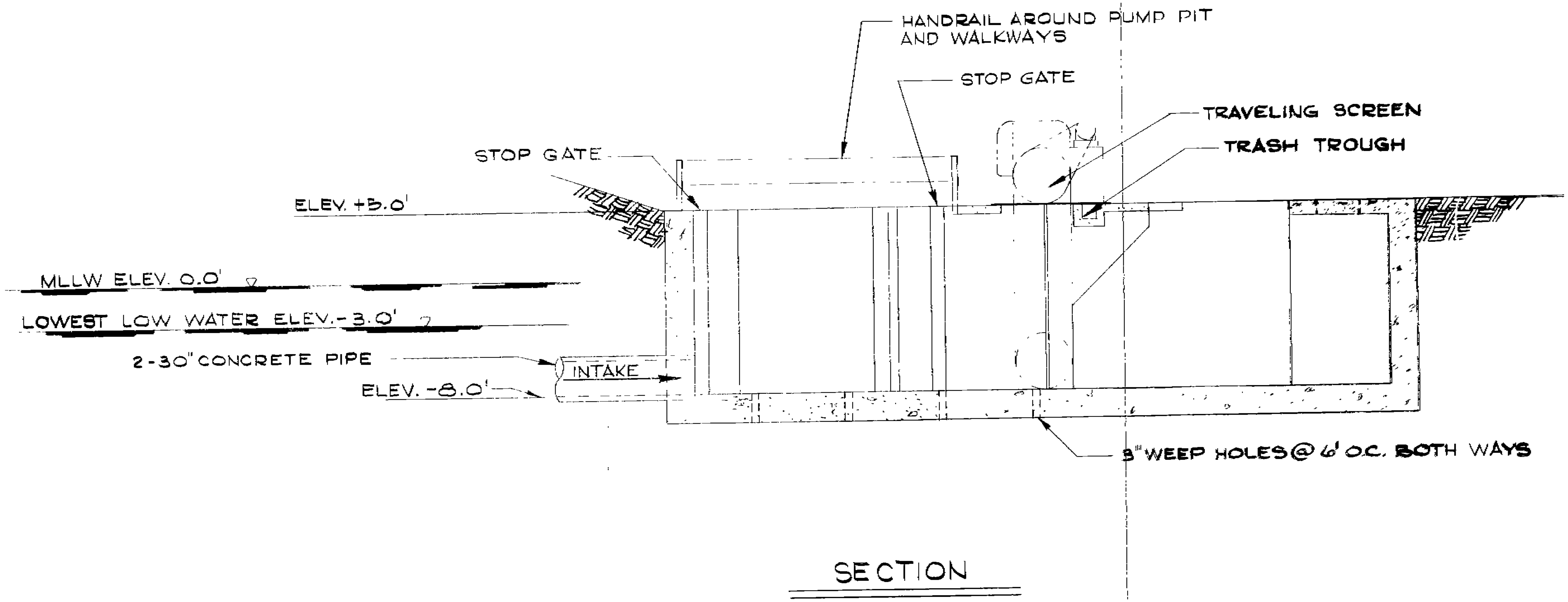


FIGURE IX - 5

LAGOON INTAKE - 20 MGD
SECT. ELEV. OF PUMP BASIN

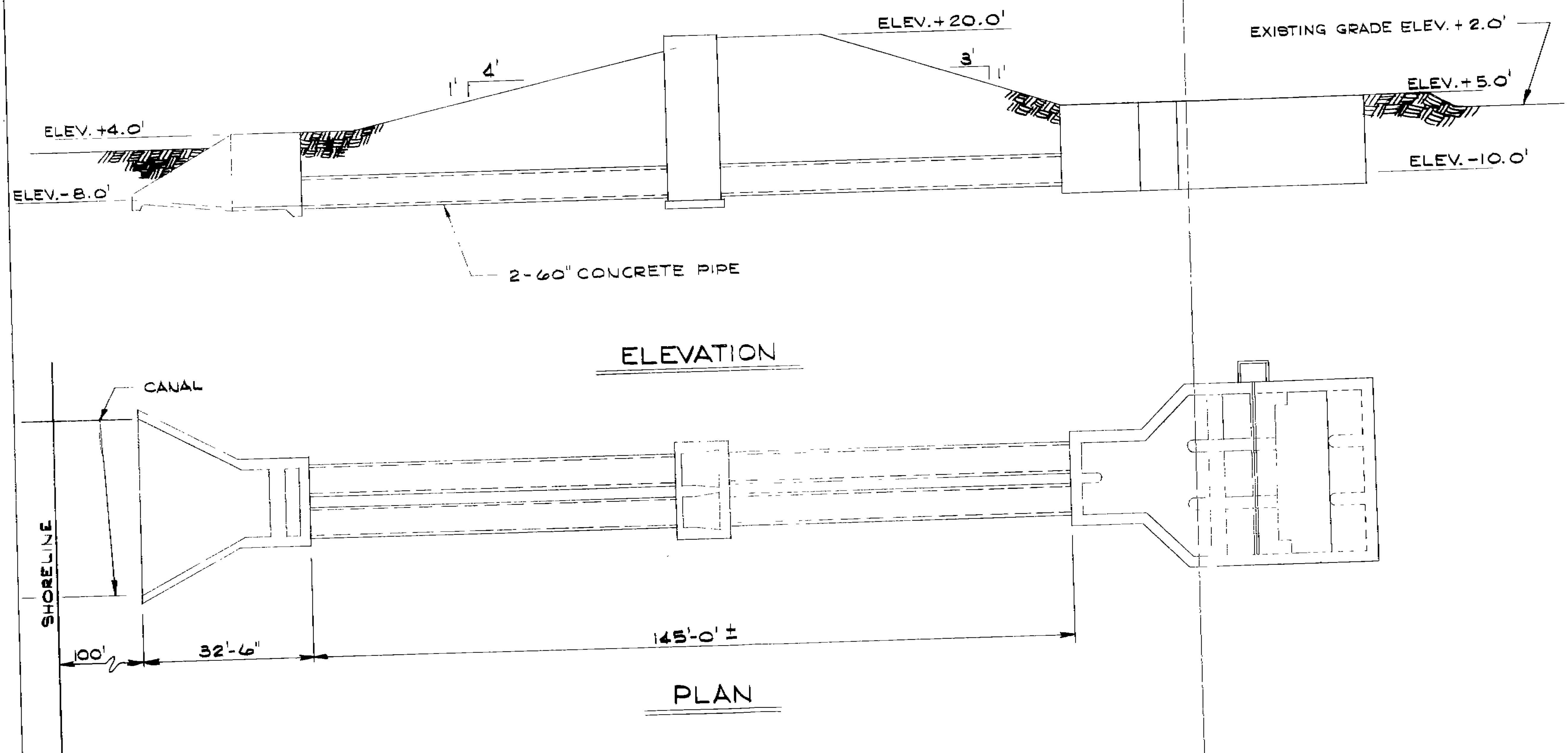


FIGURE IX-6
LAGOON INTAKE - 100 MGD
PLAN AND ELEVATION

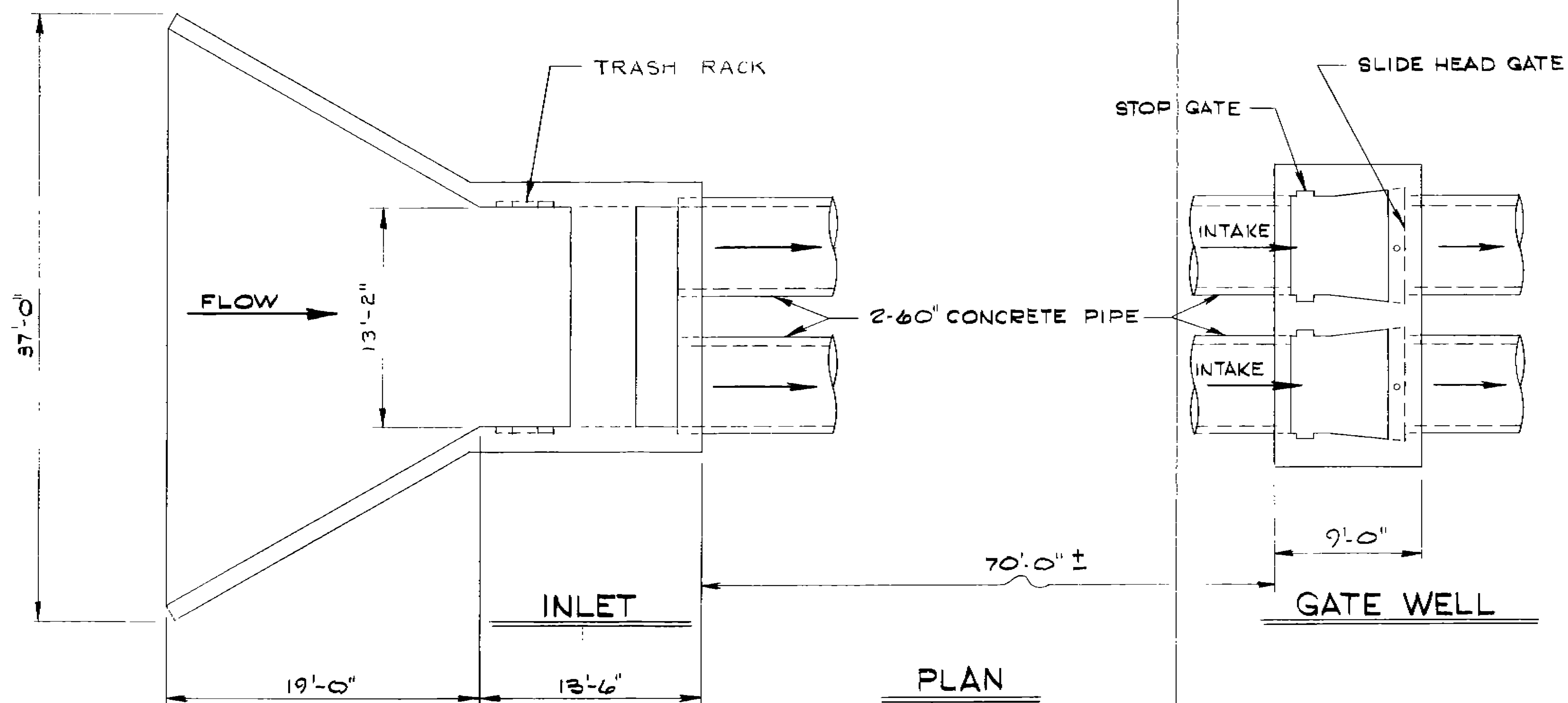


FIGURE IX - 7

LAGOON INTAKE - 100 MGD
PLAN VIEW OF INLET
AND GATE WELL

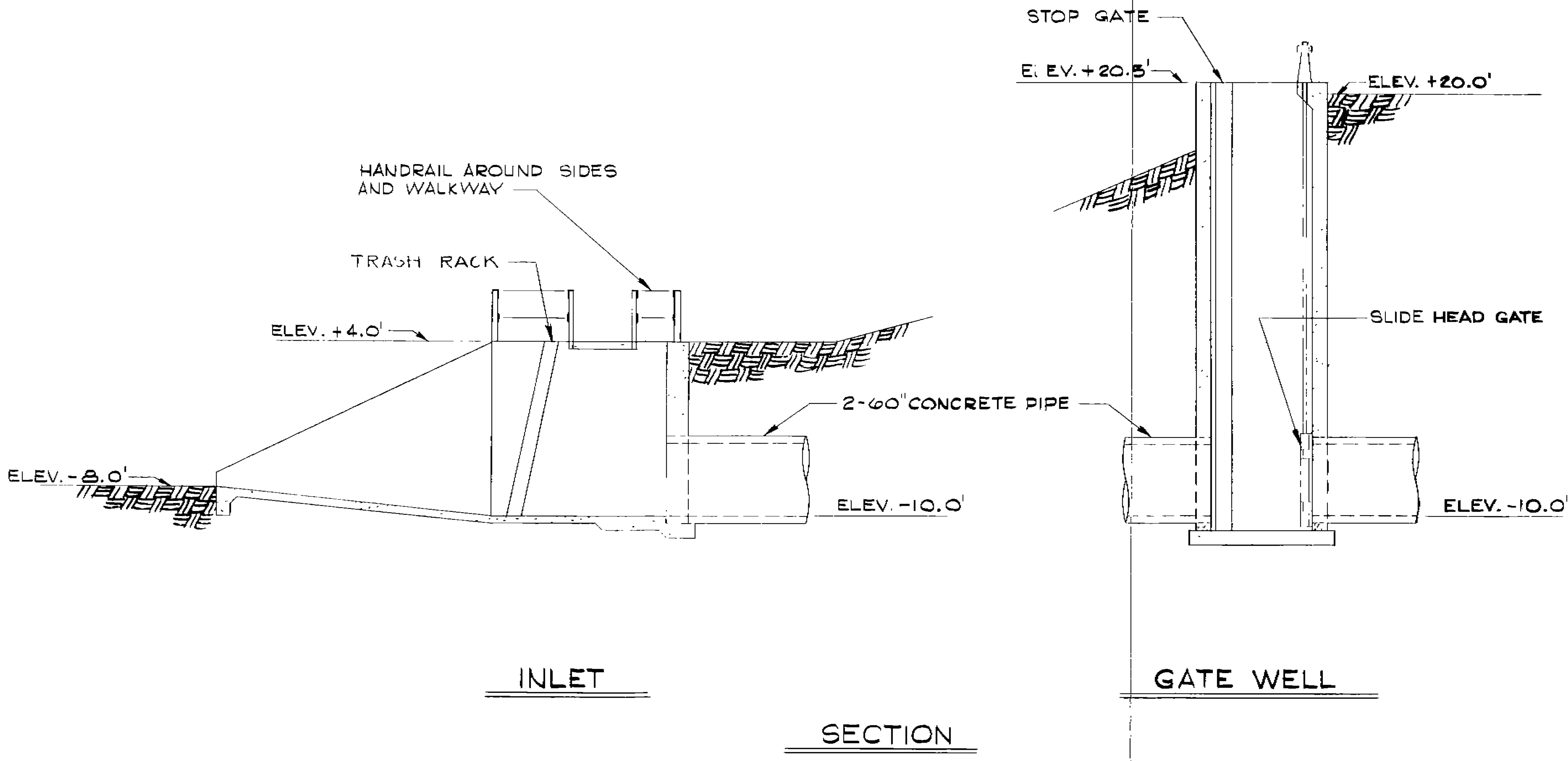
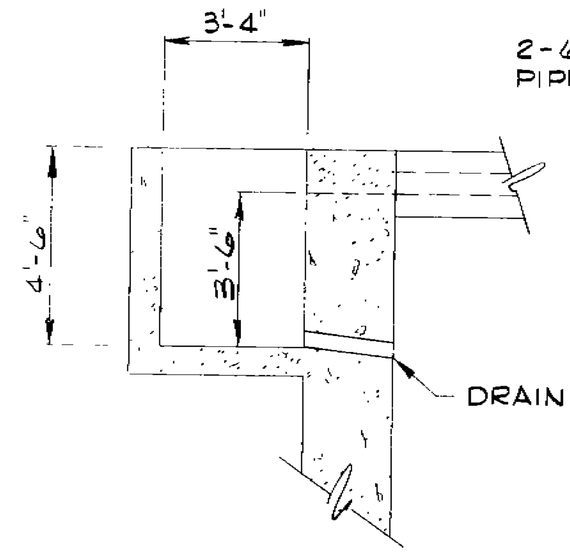
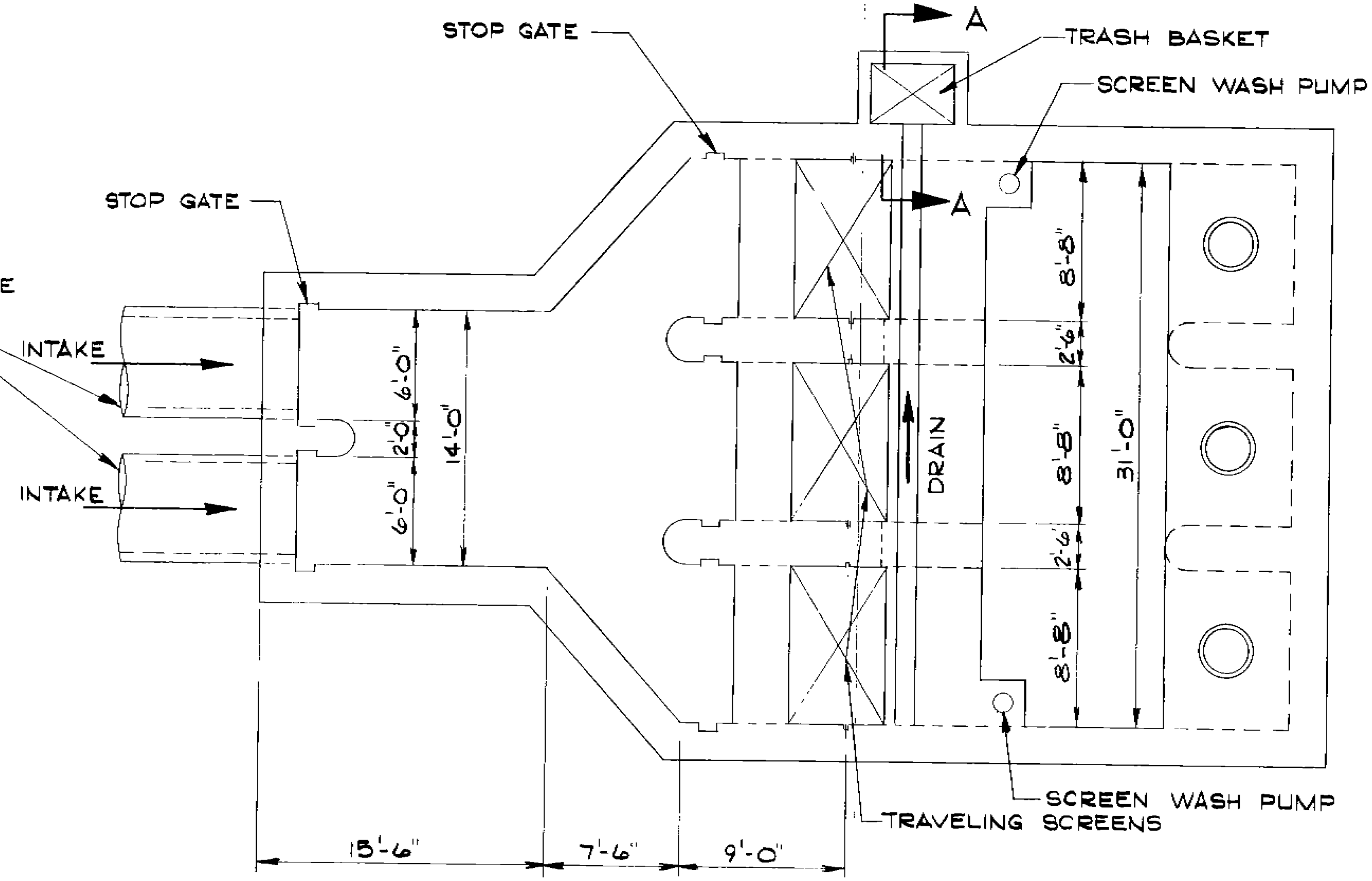


FIGURE IX-8

LAGOON INTAKE - 100 MGD
SECT. ELEV. OF INLET
AND GATE WELL



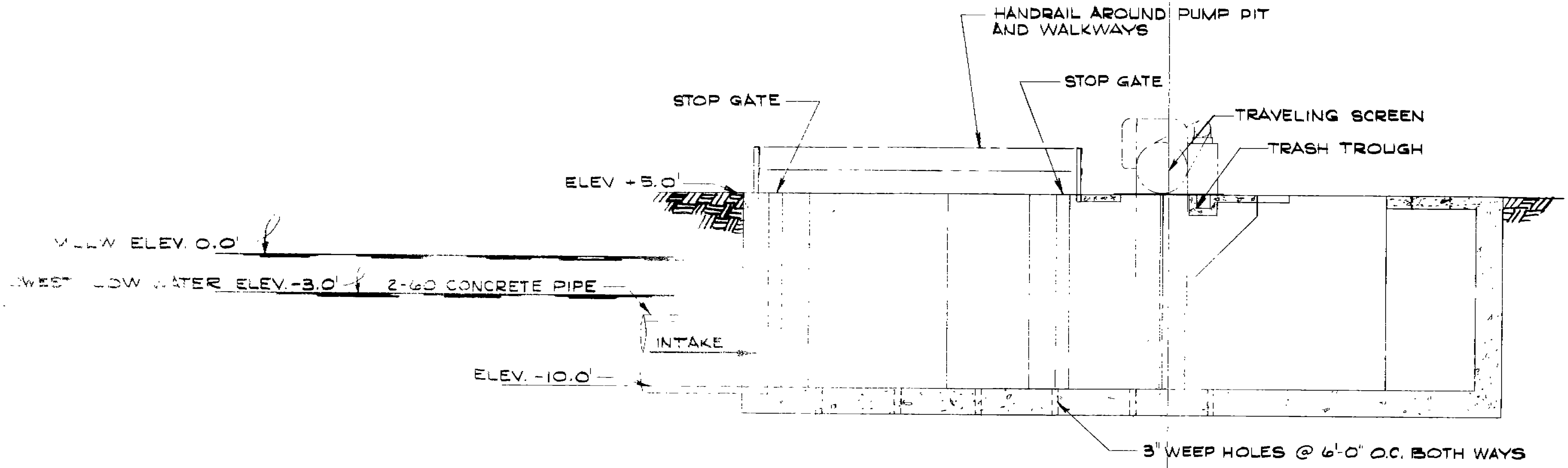
SECTION A-A



PUMP BASIN

FIGURE IX - 9

LAGOON INTAKE-100 MGD
PLAN VIEW OF PUMP BASIN



PUMP BASIN

FIGURE IX - 10

LAGOON INTAKE - 100 MGD
SECT. ELEV. OF PUMP BASIN

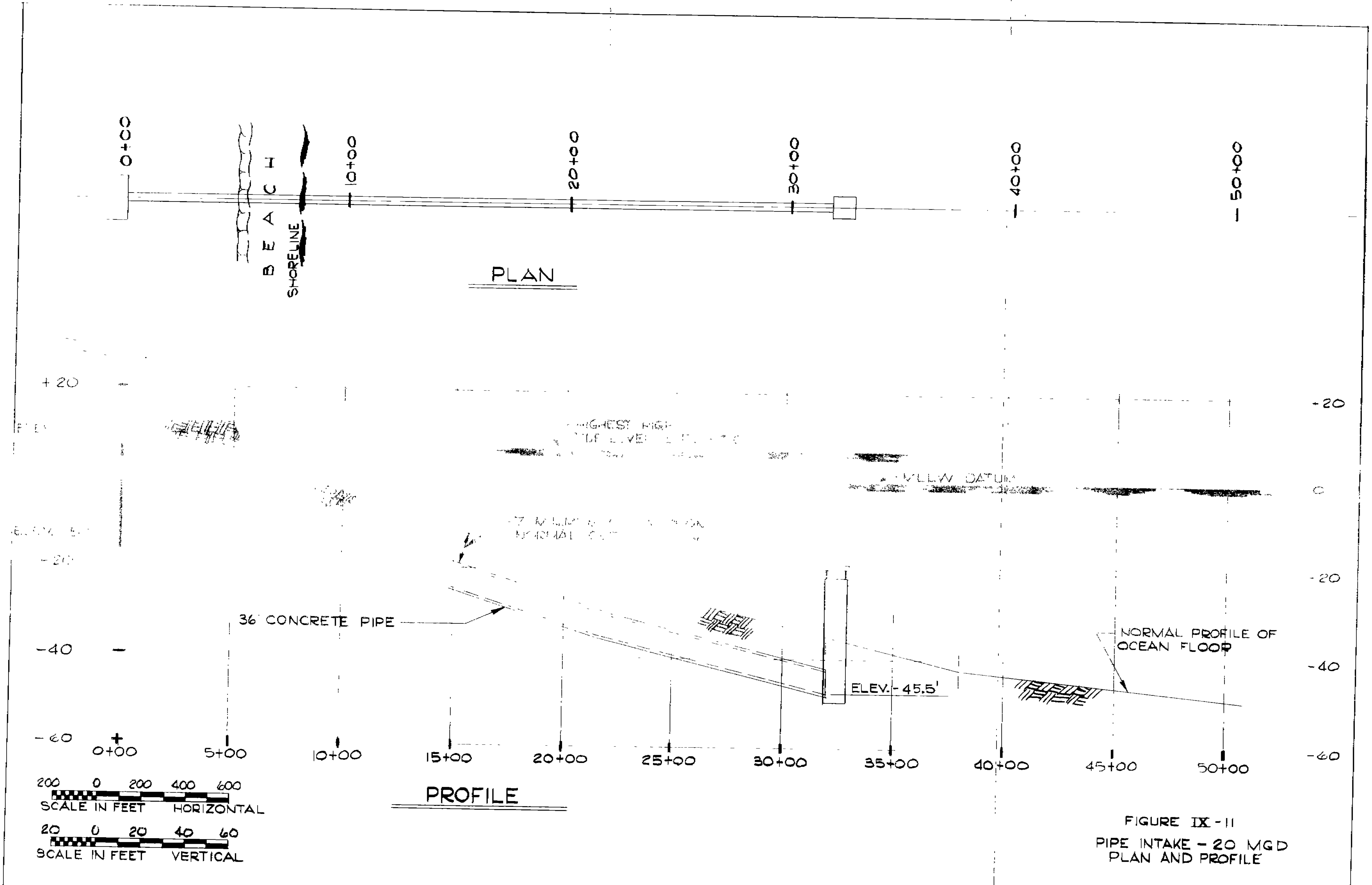
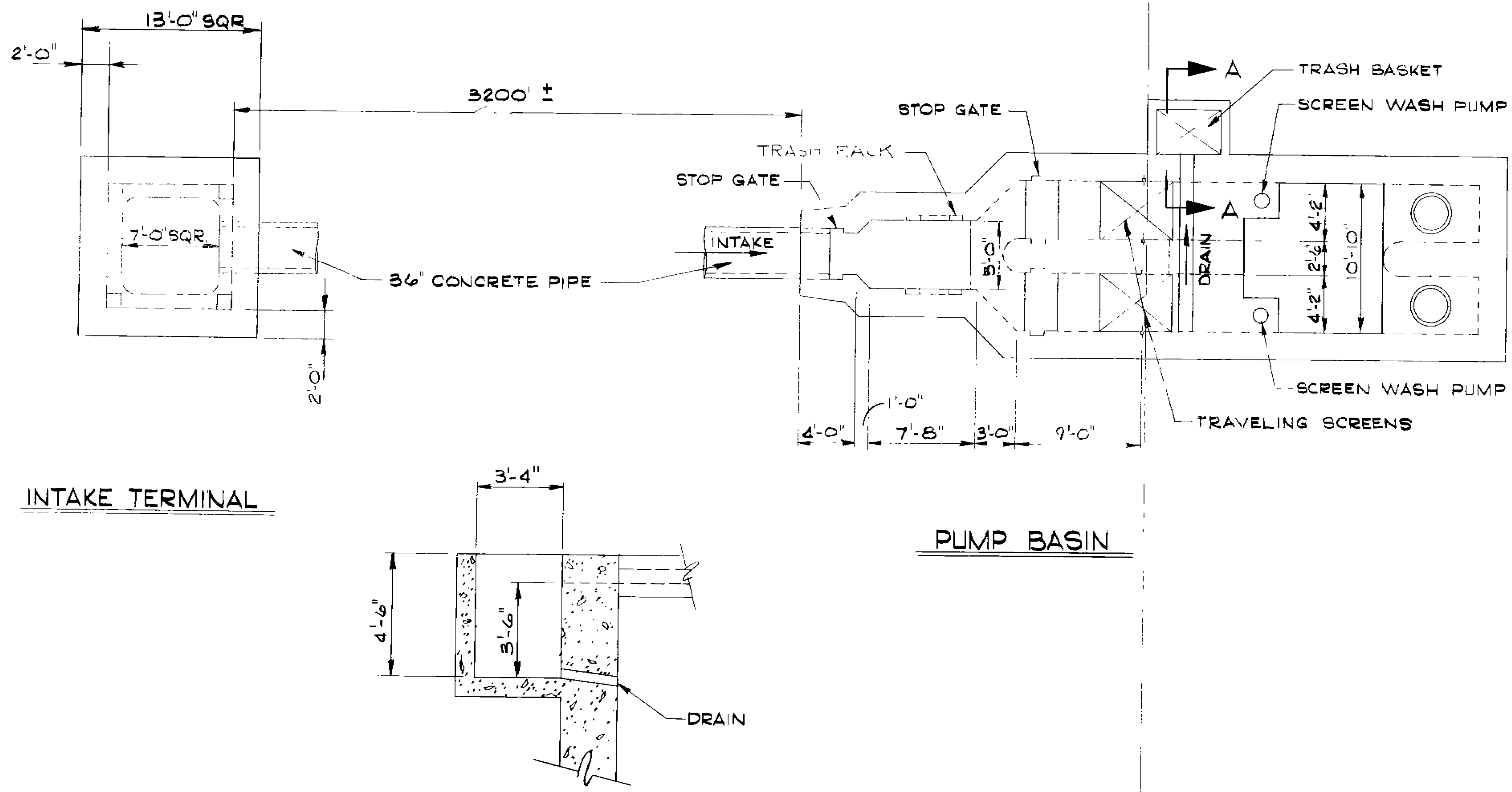


FIGURE IX-11
PIPE INTAKE – 20 MGD
PLAN AND PROFILE



SECTION A-A

FIGURE IX-12

PIPE INTAKE – 20 MGD
PLAN VIEW OF PUMP BASIN
AND INTAKE TERMINAL

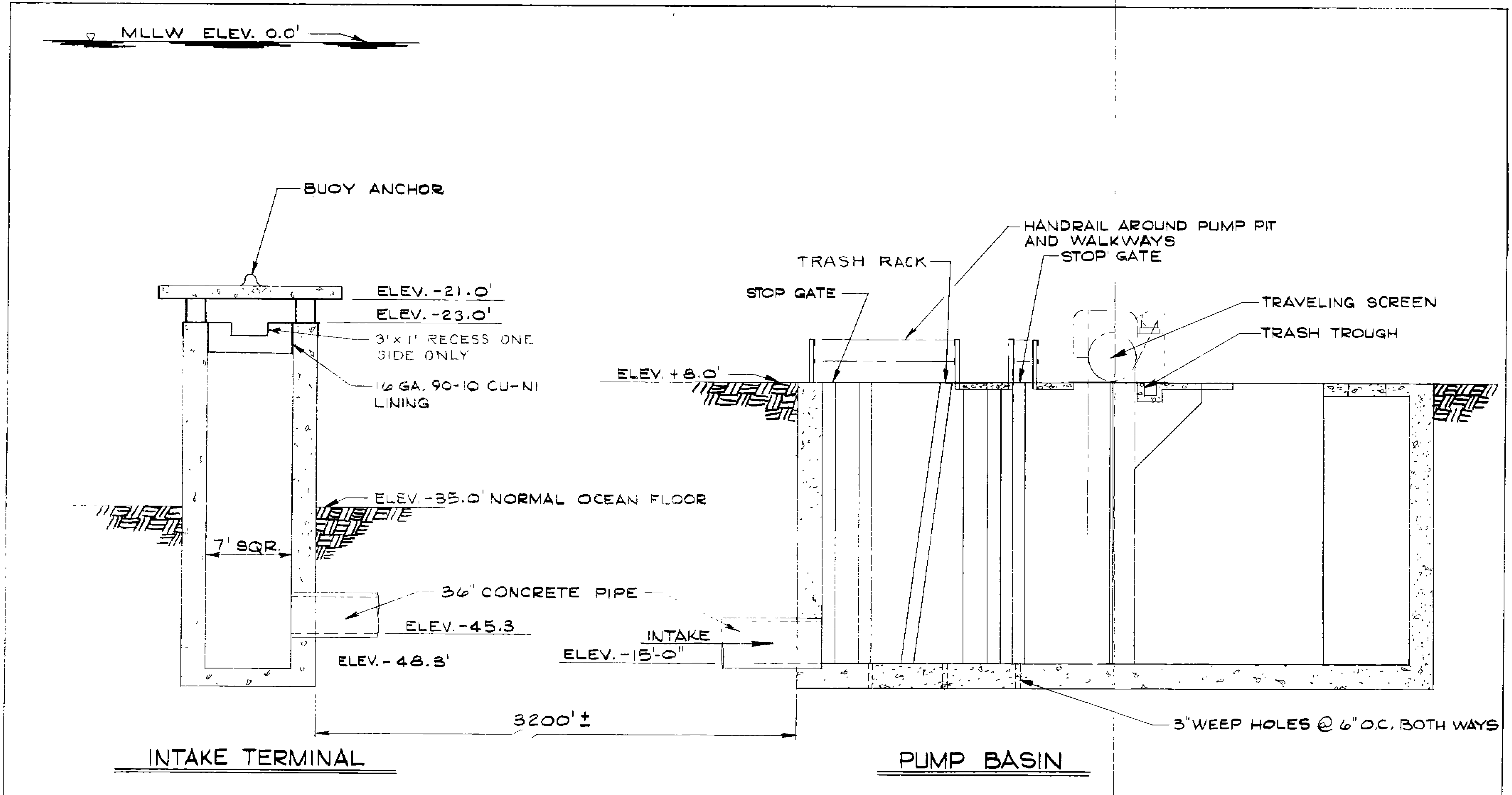
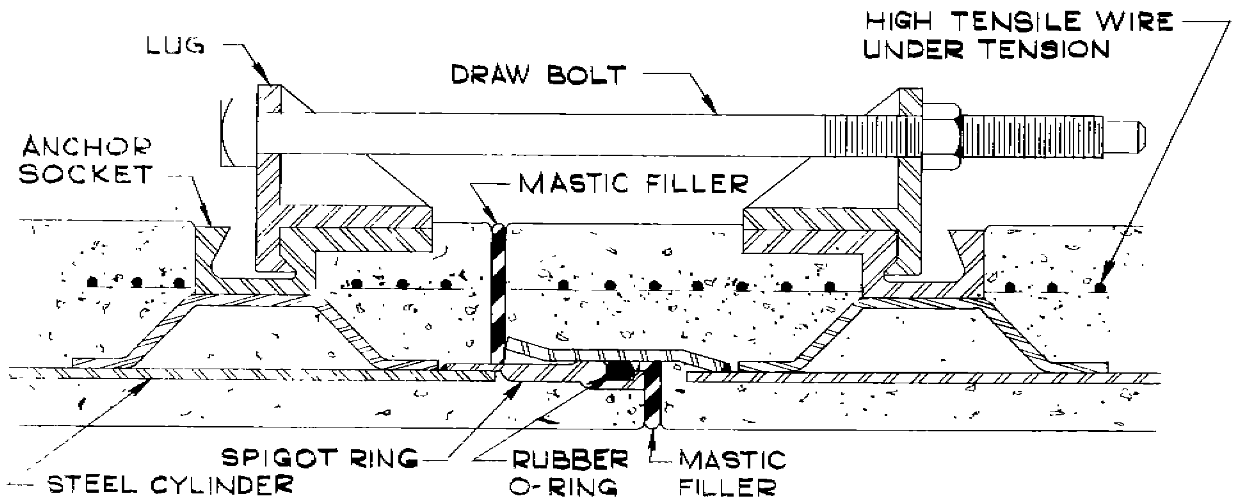
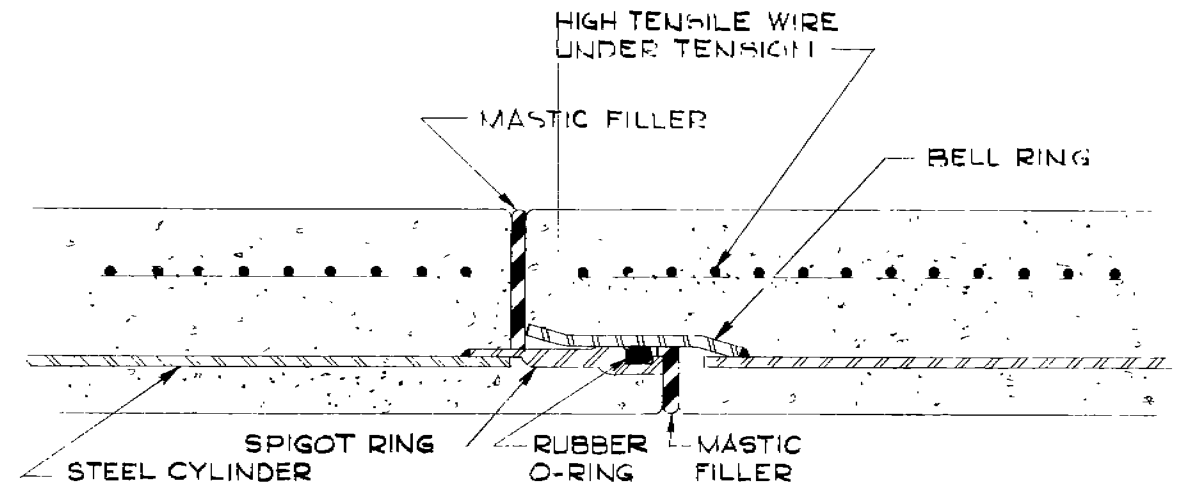


FIGURE IX -13

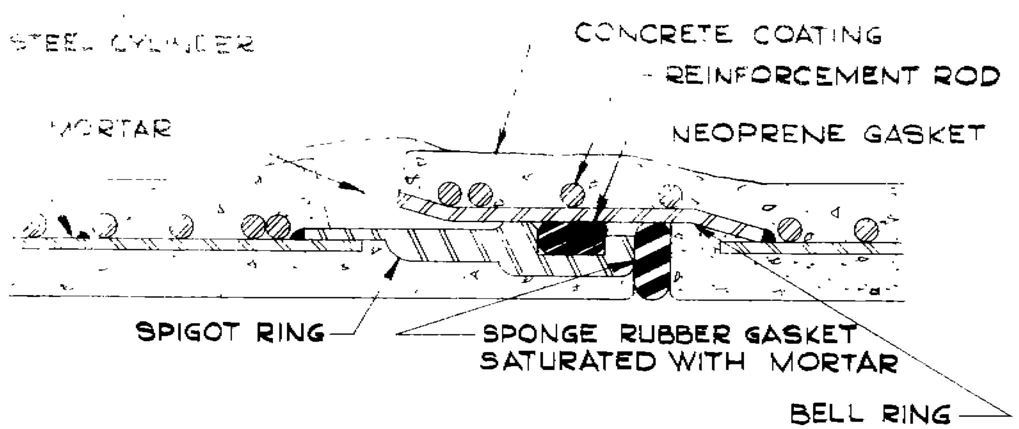
PIPE INTAKE – 20 MGD
SECT. ELEV. OF PUMP BASIN
AND INTAKE TERMINAL



TYPICAL SUBAQUEOUS JOINT
PRESTRESSED CONCRETE EMBEDDED CYLINDER PIPE
FOR 36" & 72" PIPE



TYPICAL ONSHORE JOINT
PRESTRESSED CONCRETE EMBEDDED CYLINDER PIPE
FOR 60" & 72" PIPE



TYPICAL ONSHORE JOINT
PRETENSIONED CONCRETE CYLINDER PIPE
FOR 30" & 36" PIPE

FIGURE IX-14

PIPE INTAKE
TYPICAL JOINT DETAILS

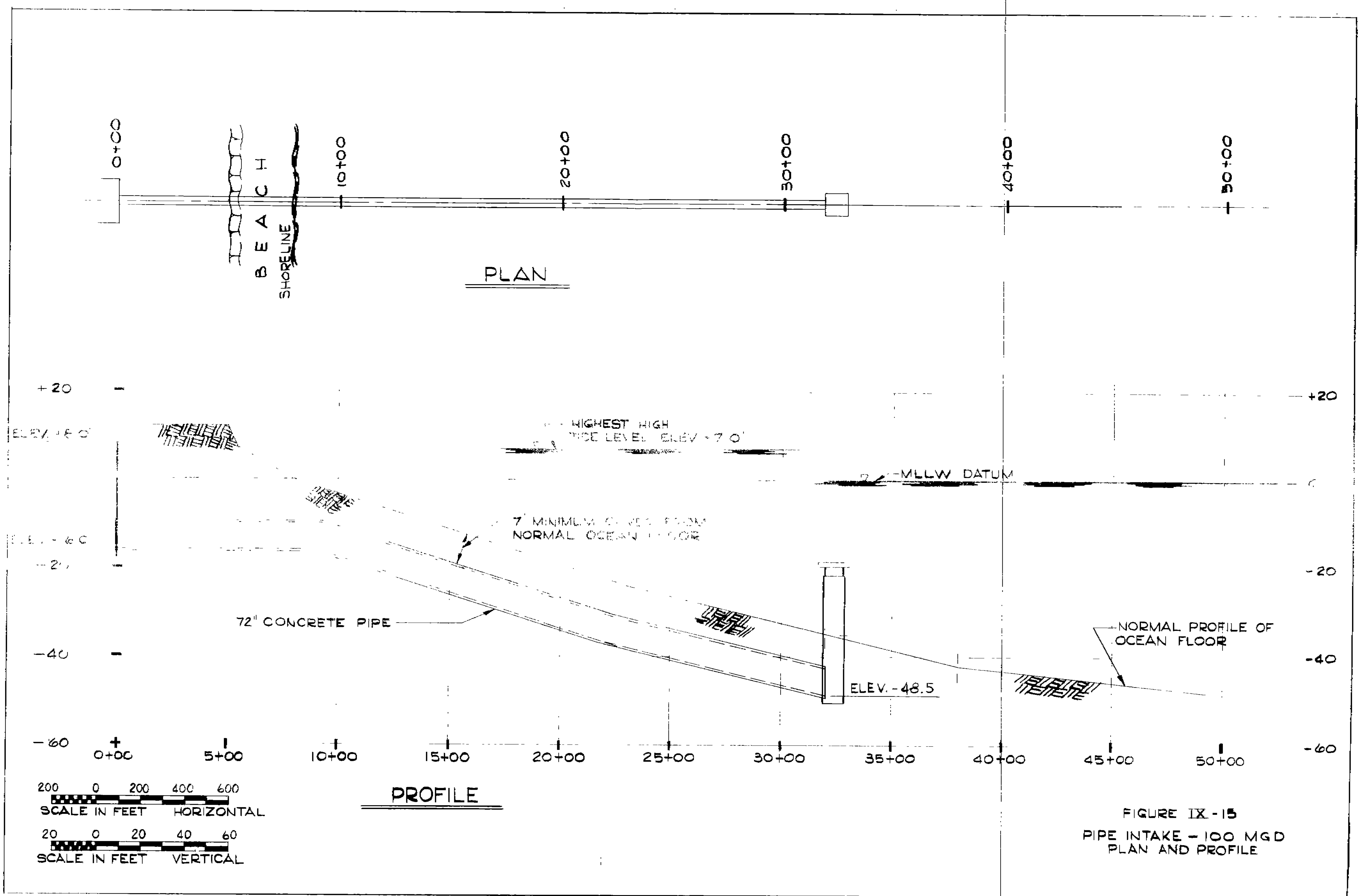


FIGURE IX-15

PIPE INTAKE – 100 MGD
PLAN AND PROFILE

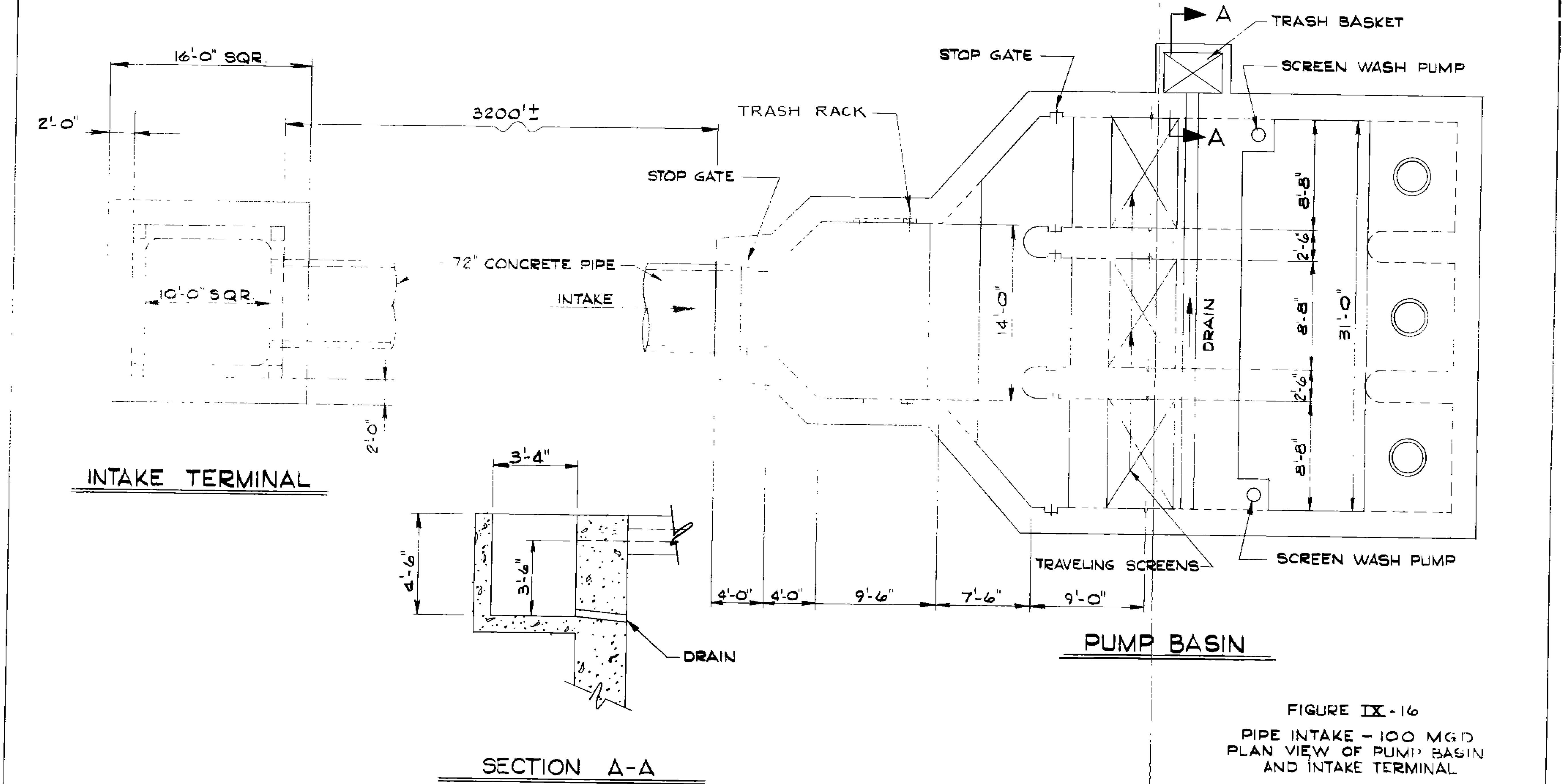


FIGURE IX-16
PIPE INTAKE – 100 MGD
PLAN VIEW OF PUMP BASIN
AND INTAKE TERMINAL

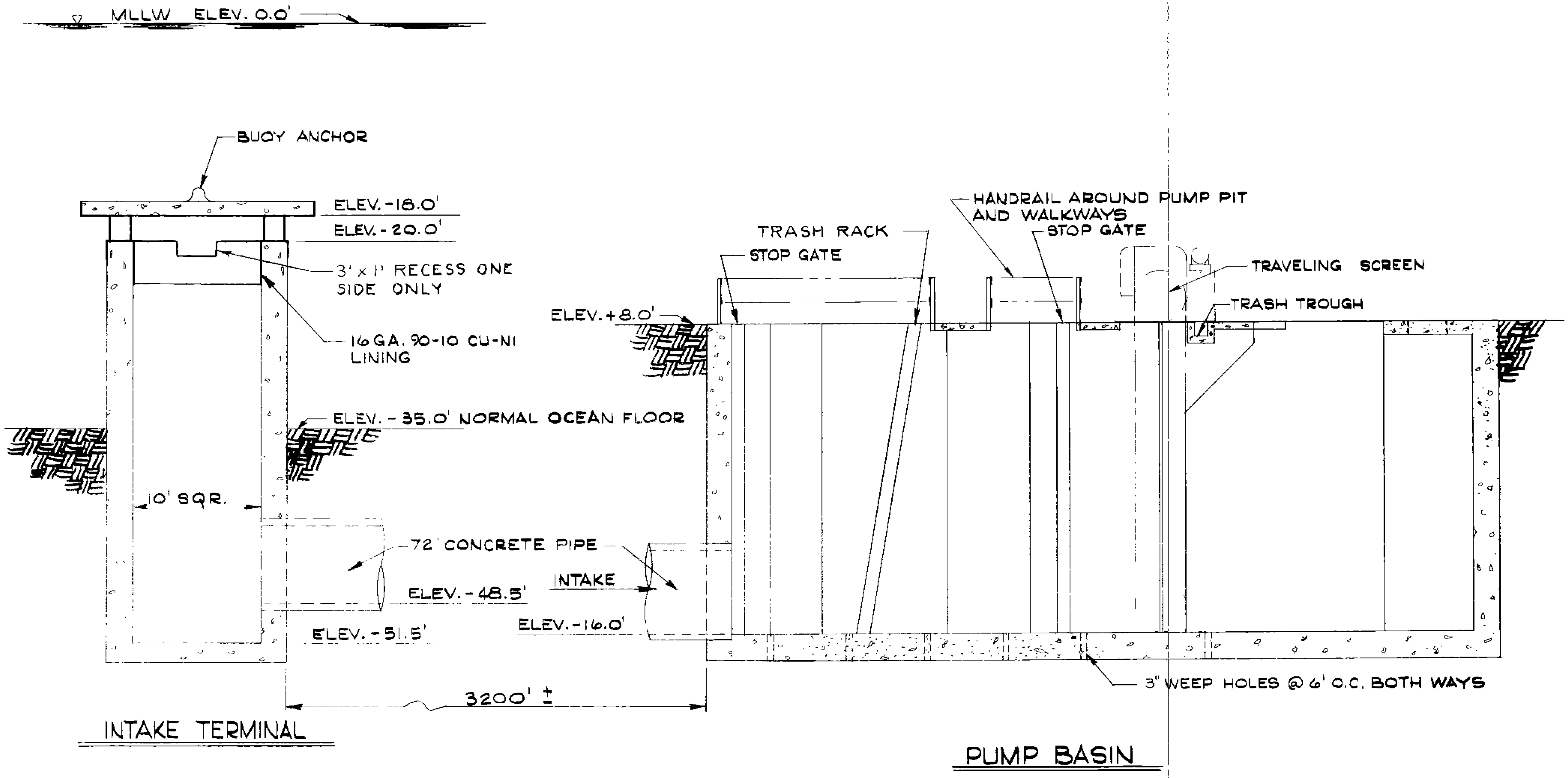


FIGURE IX-17

PIPE INTAKE - 100 MGD
SECT. ELEV. OF PUMP BASIN
AND INTAKE TERMINAL

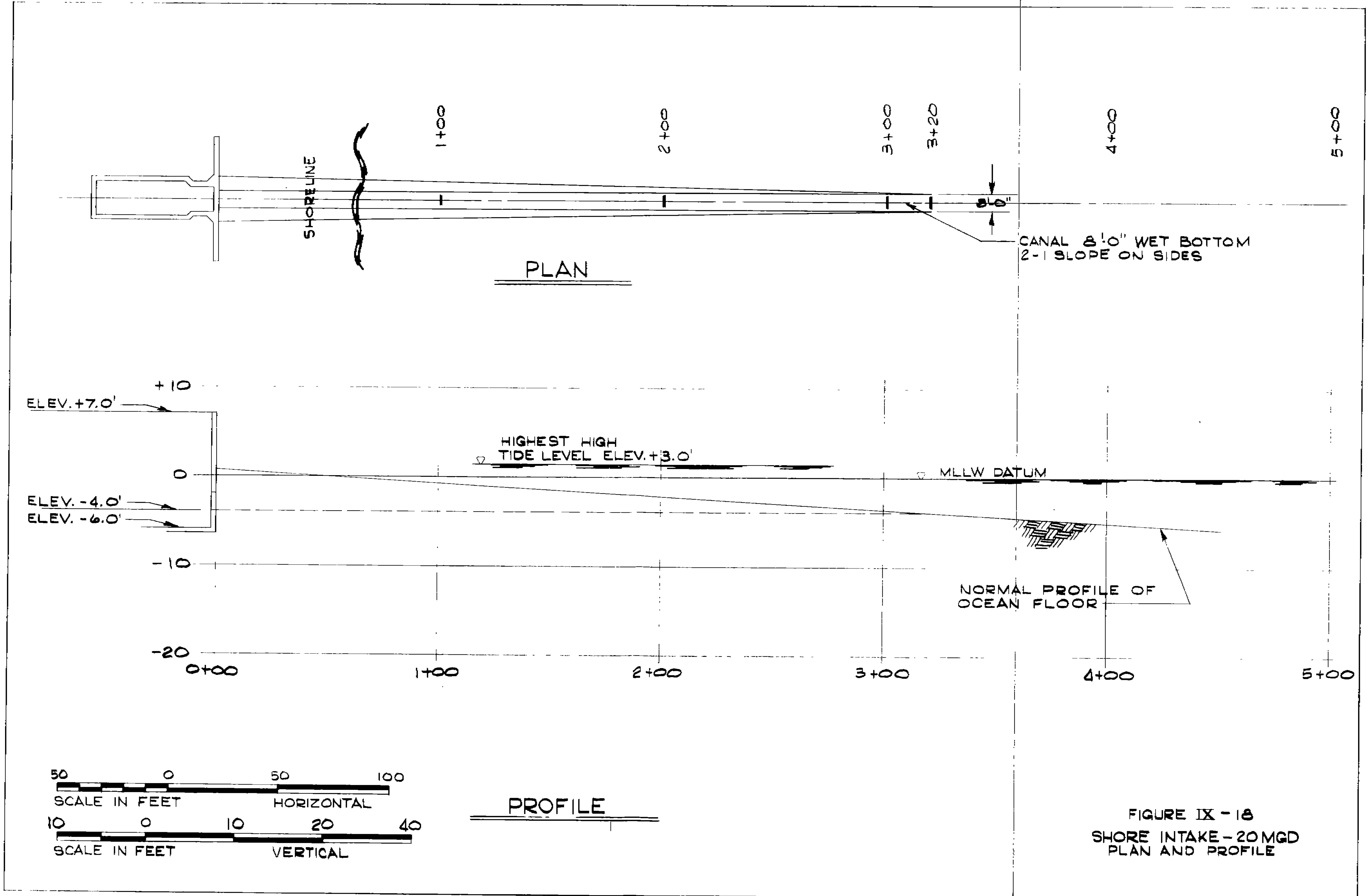


FIGURE IX - 18
SHORE INTAKE - 20 MGD
PLAN AND PROFILE

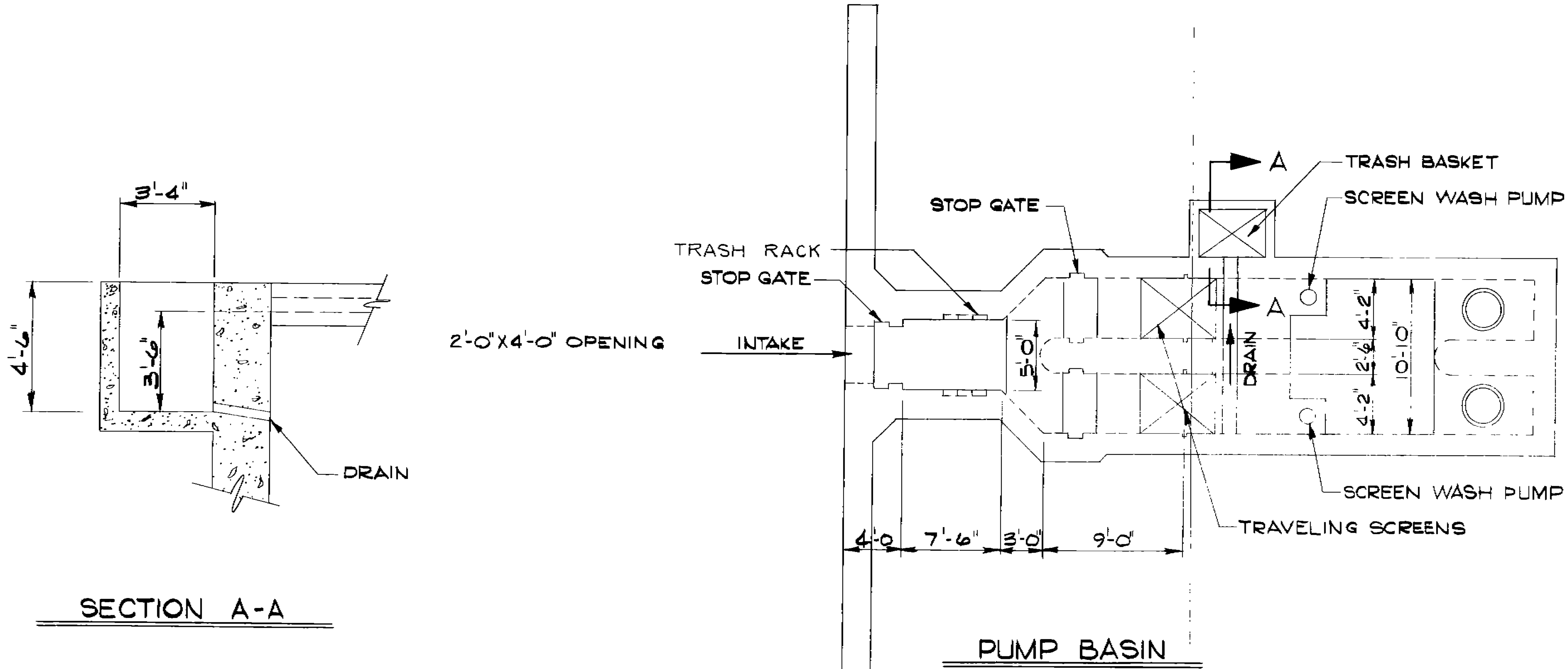


FIGURE IX-19

SHORE INTAKE-20 MGD
PLAN VIEW OF PUMP BASIN

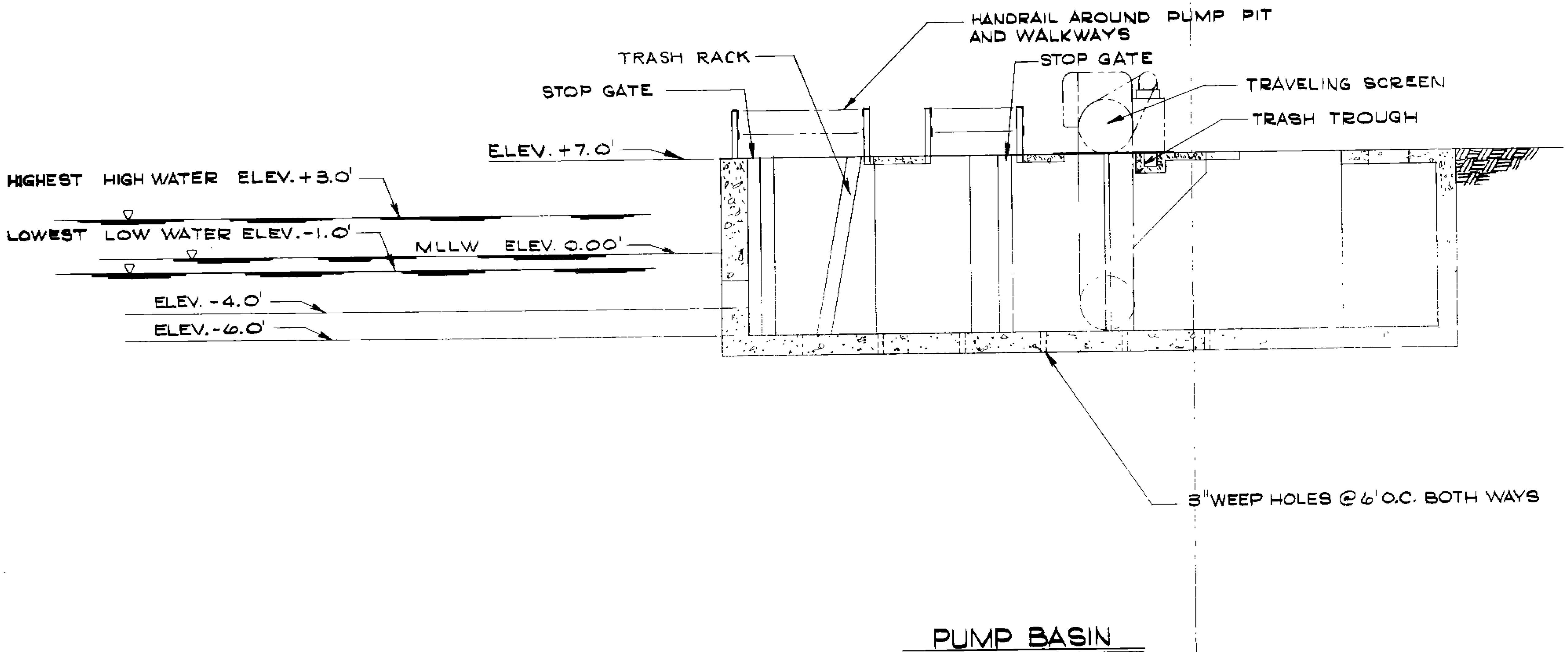


FIGURE IX - 20
SHORE INTAKE - 20 MGD
SECT. ELEV. OF PUMP BASIN

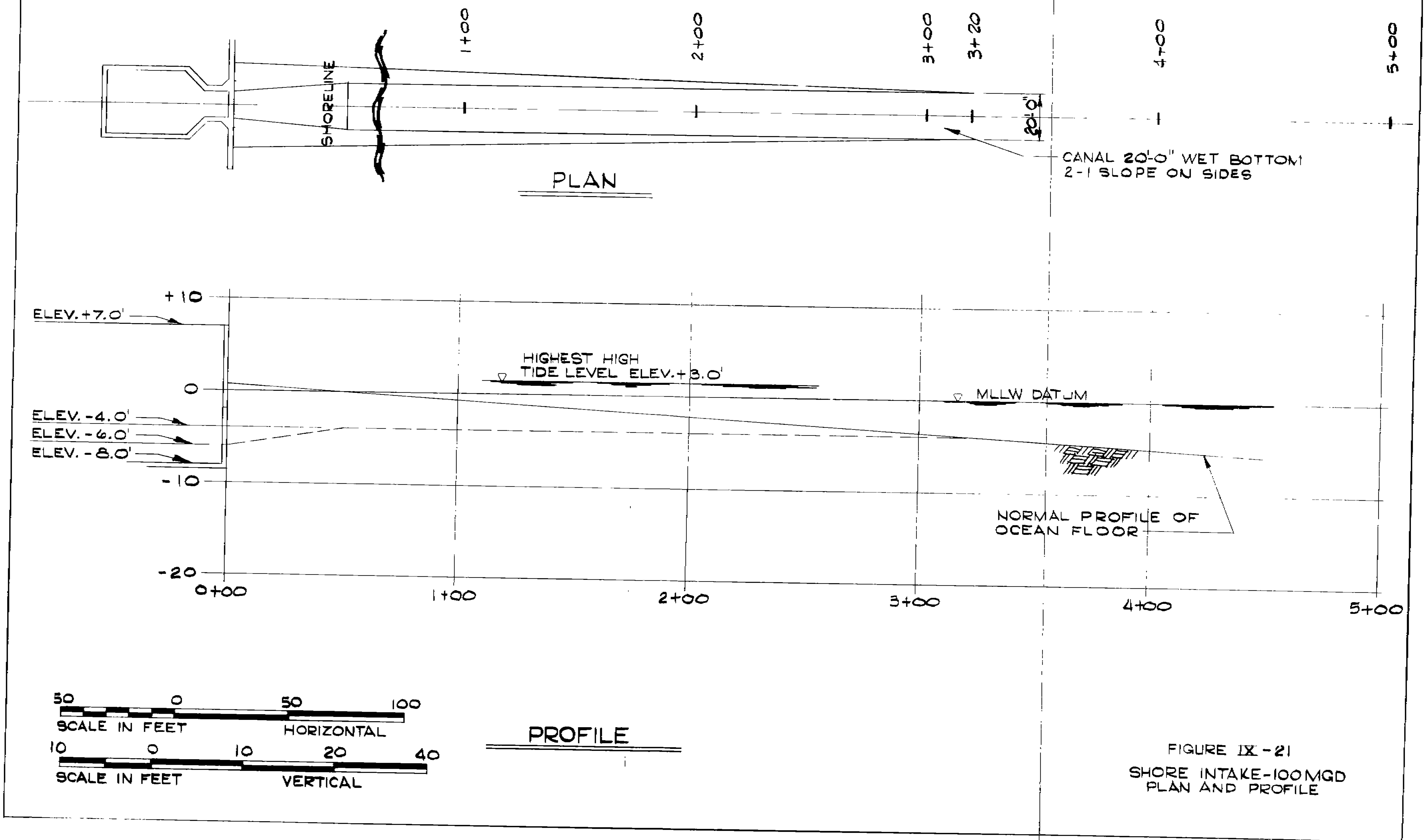


FIGURE IX-21

SHORE INTAKE-100 MGD
PLAN AND PROFILE

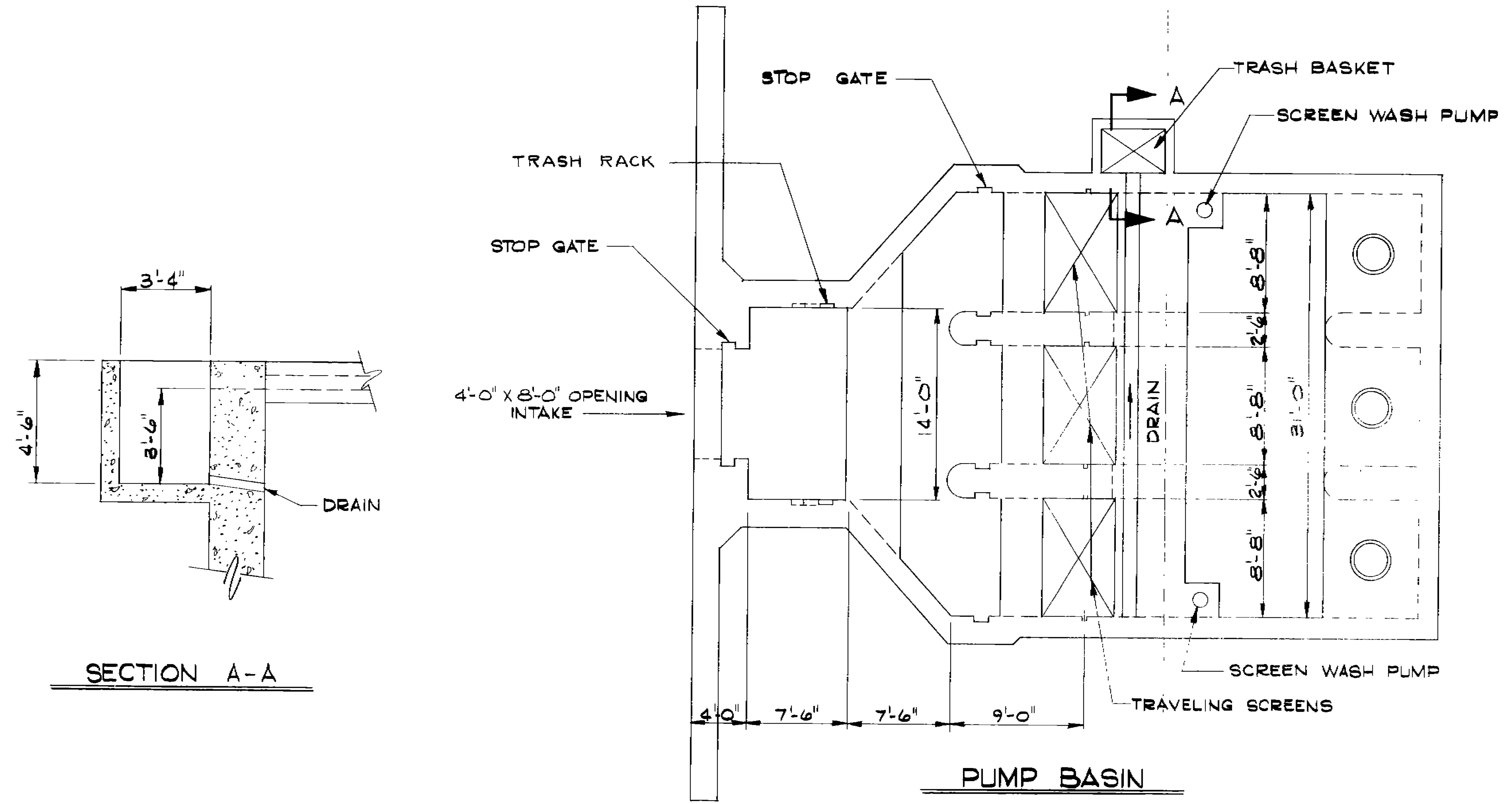
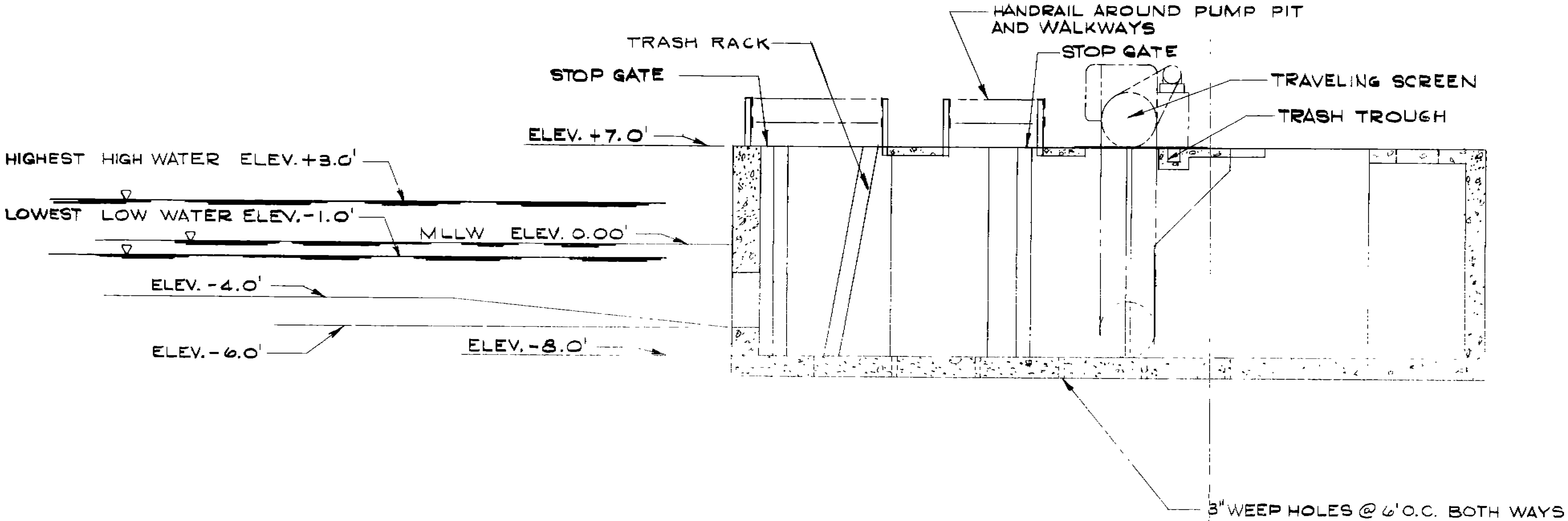


FIGURE IX-22
SHORE INTAKE-100 MGD
PLAN VIEW OF PUMP BASIN



PUMP BASIN

FIGURE IX - 23
SHORE INTAKE - 100 MGD
SECT. ELEV. OF PUMP BASIN

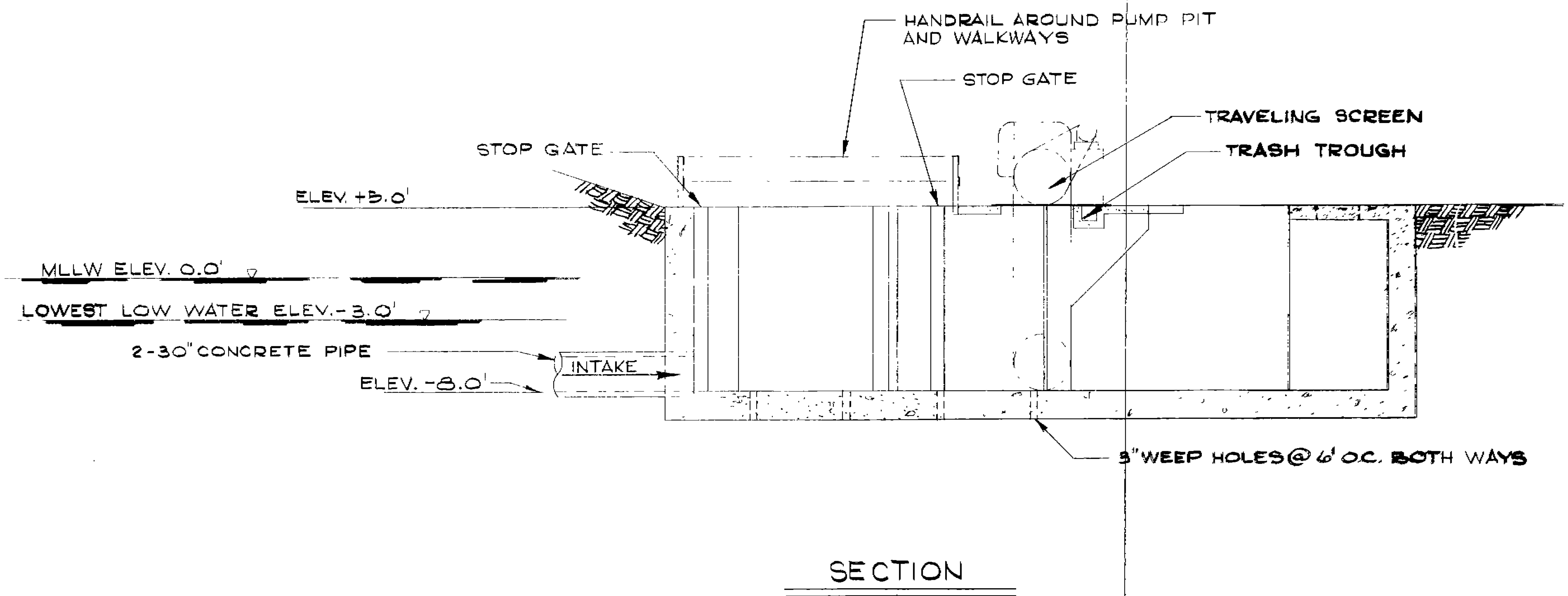


FIGURE IX - 5

LAGOON INTAKE - 20 MGD
SECT. ELEV. OF PUMP BASIN

need for long vertical screens. Because of its simplicity, this is basically the least costly generally and the most satisfactory.

Pipe Type Intake

The pipe type intake withdraws water from the ocean a substantial distance from the shore, generally beyond the surf zone where sand transport and bottom erosion are minimal, and conveys it through, usually, a single pipe to the pump basin. Here it passes through a fixed bar trash rack and then through traveling screens, before entering the pump suctions. The pipe from inlet to pump basin is usually buried at a sufficient depth in the bottom to prevent wave or current erosion from exposing the pipe. This type intake is often used where a sand bottom exists.

Shore Type Intake

The shore type intake withdraws water from the surf zone or otherwise close to the shore. The short offshore channel through which the seawater flows through the surf zone to the pump basin may be formed by two parallel jetties if the bottom material is of gravel or cobbles of such size that a stable channel cannot be maintained without jetty protection, or it may be cut in the bottom rock if the bottom is of bedrock or large cobble. This type intake gives serious problems with sand when used where sand is present, so it should generally be confined to locations where the bottom is rocky rather than sandy or silty.

Modified Types of Intakes

The three basic intake types described above may be modified for unusual situations, but the basic principles still apply. For instance, an offshore artificial island could be constructed and the desalination plant and pump units located there, while the fresh water is pumped to shore for distribution. This has been suggested in an engineering and economic feasibility study of a combined nuclear power plant and desalination plant prepared by the Bechtel Corporation in 1965 for The Metropolitan Water District of Southern California, the Office of Saline Water of the United States Department of the Interior, and the United States Atomic Energy Commission. A pipe type intake could be located to advantage in a lagoon, under certain conditions.

B. General Factors Influencing Intake Selection

As a general rule, the lagoon type intake should be used where the geography of the area permits and is particularly indicated in areas like the Texas Gulf Coast where the gulf bottom is silty and shallow for great distances from the shoreline. The presence of barrier islands as well as lagoons and waterways provides opportunity for locating a lagoon type intake.

The pipe type intake is indicated where the geography of the area does not permit the lagoon type and where the ocean bottom is sandy. The shore type intake is suitable where the geography of the area does not permit the lagoon type and where the ocean bottom is rocky rather than sandy.

Silt Bottom

The problem of silt is not one which can be solved by an intake design, although low inlet velocities can often avoid silt problems. The bottom is likely to be silty in a bay or estuary where there is no surf, where wave action is usually gentle, and where there are no strong currents because silt, consisting chiefly of weathered rock fragments or products of chemical disintegration, with a particle size ranging from 1/16 mm down to colloidal, has a low settling velocity. Particles at the larger end of the size range may settle as rapidly as 8 inches per minute, while smaller size particles may take many times that long to settle and are readily resuspended by even slight eddy currents. The silt usually comes from rivers or streams or other land runoff. Seawater with silt in suspension may be encountered in areas with sand or rock bottoms. During times of low rainfall and calm weather, the silt carried in suspension in the seawater may settle to the bottom and the water becomes clear.

An intake located in water with a silty bottom should be designed with a low approach velocity to avoid the pickup of additional silt through resuspension. Either the pipe type or the lagoon type inlet is suitable for this type of location. Neither type can eliminate the silty material already carried in suspension in the water which comes into the intake. If silt removal is necessary to the satisfactory operation of the desalination process, supplementary equipment such as large gravity sedimentation basins, with or without chemical flocculation, would be required.

Sand Bottom

Sand should be no problem with a lagoon type intake designed for sufficiently low approach velocities, nor should it be a problem with a properly designed and located pipe type intake. However, with a shore type intake, sand would be placed in suspension by the surf and moved along the bottom in such quantities as to create a major problem. It is unlikely that intake approach velocities could be maintained sufficiently low as to prevent significant sand movement without frequent deepening of the channel.

Rock Bottom

The lagoon type and shore type intake lend themselves well to installation on a rock bottom. The pipe type intake would have to be bedded below the rock surface or suitably anchored to withstand storm damages, a costly operation in either case.

Fouling

All three types of intakes would be subject to fouling growths, depending upon the types of fouling organisms present in the water. However, the pipe type intake has a considerably larger area of exposure in the pipe itself. While necessary steps should be incorporated in the design for the control of fouling, should such steps fail, for some reason or other, fouling could be far more serious inside the pipe than with the other two types of intakes. Fouling could be fairly readily removed from trash racks and traveling screens, but it could be removed only with difficulty from a pipe.

Liquid Floating Wastes

Such wastes could be readily prevented from entering a lagoon type intake by the installation of a skimmer barrier at the entrance to the intake, or by providing a submerged opening ahead of the pump basin. The pipe type intake with a properly located submerged inlet in deeper water should be inherently free from such wastes. However, the shore type intake, though it should be provided with a submerged opening, might still allow some floating liquid wastes to enter the intake system. Such wastes could tend to dead-end at the submerged opening wall and build up in depth while, at the same time, being subject to some agitation and possible mixing due to the wave action. The type of floating wastes which might be anticipated should be determined prior to design, if possible, so that their nature can be determined and suitable means provided for preventing their entrance.

Solid Floating Wastes

Such wastes can be prevented from entering a lagoon type intake by the same means as outlined for liquid floating wastes. Likewise, pipe type intakes should be inherently free of solid floating wastes. On the other hand, the shore type intake can be subject to a build-up of such wastes, necessitating removal as required.

Marine Life

The pipe type intake, with its inlet located in relatively deep water a good distance below the surface, and with a velocity cap to direct incoming water to enter with a horizontal velocity, is probably the most free from marine life. Marine plants tend to either live on the bottom if the water is clear and shallow or float on the surface. Crawling marine life remains on the bottom. Swimming marine life, particularly fish, can detect and avoid a horizontal current produced by the velocity cap, whereas they seem unable to detect a vertical current. The lagoon type intake is inherently free of that marine life that will not enter a lagoon or waterway. However, some types are present, and must be prevented from entering the system.

A waterway, for instance, may have a specific troublesome type of marine life. One specific instance is the occasional influx of large numbers of Stomolophus, a jelly-fish (commonly called cabbageheads) for a short period once or twice a year along the southern Texas coast.

Aesthetic Value

Where aesthetic value is important, as with a beach frequented by people, both the lagoon type and the shore type are obviously visible. Access along the beach would require a walkway or a bridge over the intake channel unless a pipe were installed. The pipe type intake, with the pipe buried, gives no evidence of its presence except by a marker buoy out in the ocean over the inlet. The pump basin could be located a suitable distance back from the beach.

SECTION VII. INTAKE SELECTION

Shore Erosion

The lagoon type intake can be designed to prevent erosion of the shore due to tidal or other currents. The buried pipe of the pipe type intake has no influence upon shore erosion. However, the shore type, particularly if constructed with jetties, could have a serious effect upon an erodable shore, resulting in the loss of expensive real estate and resulting law suits. Even short jetties can have an effect upon beach erosion far out of proportion to the distance they extend beyond the shore line.

Storms

The lagoon type intake is inherently protected from the direct effect of storm waves, whereas the shore type intake is exposed to the forces of a storm. The pipe type intake, if properly designed and built, should be largely immune from storm action.

Tides

All three types of intakes are subjected to tides. However, the lagoon type intake, when located in bays or similar bodies of water with certain configurations, might experience unusually large tides or tidal currents. These should be carefully determined before design proceeds.

Damage from Seismic Disturbances

The lagoon and shore type intakes, being relatively compact systems, should stand only a remote chance of being directly affected by a surface fault. However, the pipe type intake, having a much more extended configuration, would stand a greater chance of possible damage to the buried pipe. In areas of earthquake potential, a careful study and decision should be made as to the possibility of damage from a seismic disturbance.

Separation of Intake and Outfall

An intake cannot be located without consideration of the flow of effluent from the plant outfall. The direction of flow of currents should be carefully studied and the intake and outfall located in such relation to each other that no significant inflow of effluent will result. With the lagoon type intake, especially when located on a barrier island, such as Padre Island off the southern coast of Texas, the outfall can easily be located on the sea side of the island, thus practically assuring separation of intake water and effluent. When the intake is located on a waterway, the predominant direction of flow can usually be determined and the outfall located a sufficient distance downstream to preclude any possibility of recirculation. However, waterway or lagoon currents may be of a reversing nature, thus complicating the locating of an outfall so as to avoid recirculation. With the pipe type intake and a pipe type outfall, a very careful study of current flow must be made to locate the intake and outfall at the proper points to avoid recirculation. With the shore type intake and a pipe type outfall, a greater separation distance is inherent and should result in little or no recirculation if careful current studies have been made.

Navigation Hazards

Lagoon type intakes can be damaged by barges or ships. A skimmer barrier can ward off such vessels and prevent damage to the intake system. A pipe type intake, with the pipe buried at a sufficient depth, should be free from damage from ship anchors. A buoy marking the location of the inlet structure should be observed by marine vessels. The shore type intake, being in the surf zone, should not be subject to damage from marine vessels which normally keep clear of this area.

Capital Cost

As a general rule, the lagoon type intake is fundamentally the simplest and least expensive of the three systems, as can be seen from Section X. The pipe type intake, because of the length of buried pipe involved, is the most expensive.

Operating Cost

Operating costs for the lagoon type and shore type intakes should be reasonably comparable. Head loss from inlet to pump suction would be similar in each case. Costs for the removal of trash might increase the cost of operation of the shore type intake over that of the lagoon type by a small amount. Pumping costs for the pipe type intake would be higher by the additional amount of head lost by the seawater in flowing through the submerged pipe.

Future Expansion

The lagoon type intake with an open channel to the pump basin, and the shore type, also with an open, relatively short channel, would almost undoubtedly have such low velocities that additional pump and screening capacity could be added without causing any significant additional head loss in flow along the channel. However, unless the buried pipe in the pipe type intake were initially sized for additional capacity, a significant increase in head loss would result from attempts to increase the flow through the pipe, thus limiting any great increase in capacity without the installation of another intake pipe.

Dependability

The lagoon type intake could probably be considered the least likely to experience problems of a type or magnitude which would result in shutdown. Its simplicity of concept, relative freedom from trash and relative ease of maintenance and operation make this type of intake particularly dependable for continuous, economical operation. The pipe type intake has a considerable length of buried pipe which could be subject to damage or fouling. Therefore, this type would rank somewhat lower in dependability. However, with careful operation, dependability can be reasonably assured.

The shore type installation has the added potential problem of occasional large amounts of trash. The pipe type intake is probably the least susceptible to trash, with its inlet a sufficient distance above the bottom to prevent bottom-moving trash from entering, its inlet a sufficient distance below the surface to prevent floating trash from entering, and with a velocity cap to prevent fish from entering.

A brief evaluation summary of the above factors is shown in Table VII-I.

C. Advantages and Disadvantages of Intake Types

Lagoon Type Intake

Advantages:

Excellent where solid floating wastes are present

TABLE VII-I

EVALUATION OF INTAKE TYPES
AGAINST CERTAIN FACTORS

Factor	Lagoon Type	Pipe Type	Shore Type
Silt bottom	Good	Good	Poor
Sand bottom	Good	Good	Poor
Rock bottom	Good	Costly	Good
Fouling	Potential	Higher potential	Potential
Liquid floating wastes	Good	Excellent	Fair
Solid floating wastes	Excellent	Excellent	Fair
Marine life	Very good	Excellent	Good to fair
Aesthetic value	Poor	Good	Poor
Shore erosion	None	None	Serious potential
Storms	Protected	Exposed	Exposed
Tides	Normal to abnormal	Normal	Normal
Damage from seismic disturbances	Remote	Possible	Remote
Separation of intake and outfall	Excellent	Fair to good	Good
Navigation hazards	Potential	Slight potential	None
Capital cost	Lowest	Highest	Medium

Table VII-I (Continued):

Factor	Lagoon Type	Pipe Type	Shore Type
Operating cost	Lowest	Highest	Medium
Future expansion	Good	Fair	Good
Dependability	Very good	Good	Good

Excellent where complete separation of intake and outfall is desired

Lowest capital cost

Lowest operating cost

High degree of dependability of uninterrupted operation

Disadvantages:

Aesthetic value is poor

Pipe Type Intake

Advantages:

Excellent where liquid floating wastes are present

Excellent where solid floating wastes are present

Excellent where marine life is present

Aesthetic value is excellent

Disadvantages:

Costly with rock bottoms

Subject to possible damage by seismic disturbances

Highest capital cost

Somewhat higher operating costs

Limited for future increased capacity

Shore Type Intake

Advantages:

Lower capital cost where rocky bottom exists

Normal operating cost

Disadvantages:

Poor with silty situations

Poor with sand bottom sites

Aesthetic value is poor

Shore erosion potential is serious unless shore is not subject to erosion

SECTION VIII. GENERAL CONSIDERATIONS

In the early stages of planning for a seawater intake for a desalination plant, there are certain broad, general considerations not covered specifically in previous sections of this report.

A. Site Location

The general site location will usually be dictated by the basic requirements for the production of fresh water from a desalination plant for a community or industry. Factors often unrelated to water supply may be overruling considerations in establishing the general location. In addition to all of the usual site factors which must be considered are those peculiar to seawater intakes.

Seawater Qualities

Three qualities of seawater may have a major influence in determining the specific site for a seawater intake. These are temperature, salinity and foreign materials.

For a distillation type desalination plant, a cool seawater is desirable. Temperature studies of the source water body will show where the coolest water is available.

Salinity is of no appreciable effect to a distillation type desalination plant. With reverse osmosis and electrodialysis plants, however, the lower the salinity the higher the recovery.

Foreign material of all kinds such as floating debris, marine life, floating wastes, sand and others are detrimental. Areas of heavy concentrations of foreign materials should be avoided insofar as practical.

Industry

Present or future industrial plants usually have or will have discharge streams that, even though within legal limits, will contain small amounts of waste materials. Desalination intakes should be of a type and located insofar as possible to minimize the inclusion of industrial wastes with the intake seawater.

Power Plants

Ocean shore power plants use substantial quantities of seawater for cooling purposes. The effluent water is usually warm and may contain some dissolved copper. Power plant outfalls should be avoided when a desalting intake location is chosen.

Commercial Fishing

The locations of commercial fishing grounds, oyster beds and other commercial marine life areas should be determined. Cognizance should be taken of the rights of fishermen to these areas and of any beneficial or harmful effects of an intake on their operations. In commercial fishing areas, care should be exercised in design to avoid exposed underwater pipelines and projecting portions of the intake system on which nets and other fishing equipment might become snagged.

Kelp Harvesting

In some areas of the California coast, naturally growing kelp is commercially harvested. Due recognition should be given to this activity and these areas should be avoided, if at all possible.

Recreational Activities

Swimming, surfing, boating, sport fishing, scuba diving, strolling on the beach, and a wide range of other recreational activities may be actively engaged in along sections of a coast line. The recreational interests must be recognized.

Underwater Lines

The presence of underwater lines, such as electric power, communication and pipe, should be determined to assure compatability with their presence and to avoid interference.

Navigation

Barges, tugs, freighters and passenger ships may frequent waterways, lagoons or open water in which it might be desired to locate an intake. The operating patterns of such vessels, as well as the potential harm to the intake system that could result from an accident, such as a barge out of control, should be determined, and used, in selecting a site for an intake.

SECTION VIII. GENERAL CONSIDERATIONS

Dredging

Dredging operations may produce large amount of silt which will remain in suspension in the water for long periods of time. Where dredging operations are likely to be performed, the intake should, if possible, be located in consideration of the prevailing currents or flow of water so as to minimize or prevent the intake of such silt.

Outfall Considerations

A desalination plant using seawater as feed water will almost certainly discharge the effluent back into the source body of water. A knowledge of the prevailing water currents will make it possible to locate the outfall and inlet in relation to each other so as to prevent or minimize recirculation. Hydrographic models of the intake and outfall relationships are necessary for large plants and desirable for smaller plants to establish the expected flow patterns.

B. Sizing for Capacity

The pipe type intake is fairly limited in flexibility of operation at various capacities. To maintain freedom from sediment settling in the pipe, to provide an economically sized pipe, and to assist in preventing fouling, a reasonable velocity must be maintained. On the other hand, an excessive velocity in the pipe will result in increased pumping costs because of larger head loss. Open channels used with the lagoon and shore type intakes, being short, can provide greatly increased capacity without economically excessive head loss.

C. Economic Considerations

The usual economic considerations apply to intake systems the same as they do to the desalination plant and any other utility.

The cost of money initially must be compared with the predicted cost of money at the time plant increases may be needed. The cost of construction initially, together with labor productivity, must be compared with the cost of construction and labor productivity at the time plant increases are needed. The design life must be established.

D. Approvals

Any installation on the shore of the ocean, with the conflicting and competing uses, must meet the prescribed federal, state and local requirements, in detail, before construction is begun.

Governmental Approvals

The operator of a seawater desalination plant must consider the necessary review and approvals or permits before construction can begin. Generally, the waste discharge section of the plant will require a greater amount of review, and permits to discharge a waste must be obtained from appropriate agencies of both the federal government and the state.

The intake portion of the plant will require a permit from the U. S. Corps of Engineers if any portion of the intake structure stands in navigable water, whether inland or coastal. If the structure includes any hazard to navigation, it must be marked and lighted in a manner prescribed by the U. S. Coast Guard. This provision would apply to the types of intake which include jetties, breakwaters of log booms, and those which include underwater pipelines and intake terminals. If the structure includes jetties or breakwaters, it may affect the normal flow pattern of currents and sand transport and be subject to review by state and federal fish and game authorities for possible effect on wildlife. If there are underwater pipeline crossings, the approval of local navigation districts may be required. The state water quality control agency and the wildlife agencies may be involved if any dredging operations are proposed, such as to provide fill for grade raising or levee construction.

The application to the Corps of Engineers for a permit to construct a structure in United States waters should be made to the District Engineer in charge of the locality in which the work lies and should include drawings of the proposed structure, a profile of any pipeline involved, and a map showing the location of the proposed construction (C of E, 1968). In review, the Corps of Engineers coordinates for the site should be included in the application, using "x" and "y" coordinates for a bay or inland system, and latitude and longitude coordinates for any structure in the ocean or Gulf of Mexico. In reviewing the application, the

SECTION VIII. GENERAL CONSIDERATIONS

Corps of Engineers will consider such factors as the stability of the proposed structure and the location with respect to any designated dumping ground for wastes, designated danger or exclusion areas, fairways and anchorage areas. The location of structures or coastal works which have been proposed or authorized but not yet constructed will be considered in reviewing the permit application.

SECTION IX. INTAKE DESIGN

The intake designs presented in this section are what might be termed "outline designs". They are conceptual in nature and illustrate the elements comprising the intake systems from inlet point to and including the pump suction basin but excluding the pumps. These designs must not be construed as complete in detail but rather as illustrative of the principles and elements involved.

For each of the three types of intakes, outline designs have been made for a 20-MGD and a 100-MGD capacity. At a 50% recovery factor, these intakes would supply the feed water needed for desalination plants with fresh water capacities of 10 MGD and 50 MGD respectively. For all designs, a design life of 30 years has been assumed.

A. Lagoon Type Intake Design

Each principal element or feature of the lagoon type intake design will be briefly described so as to supplement the pictorial presentation shown on the drawings.

Site Conditions

The designs shown in Figures IX-1 through IX-10 are based on a location at Corpus Christi Pass on Padre Island, Texas. Although a thorough site investigation has not been made, conditions approximating those which are expected to be found have been assumed. The desalination plant is located on the western or inland side of the island, with the intake taking seawater from the Laguna Madre. The outfall will discharge into the Gulf of Mexico on the east side of the island. The soil is assumed to be sand and clay. The normal tidal range is 2 feet, with the lowest low water at 3 feet below mean lower low water.

Intake Channel

Because of the very shallow water depth of that portion of Laguna Madre adjacent to the chosen site, less than 2 feet and frequently less than 1/2 foot, a channel is required from the nearest deep water. The Intracoastal Waterway passes this location, the nearest point being some 10,000 feet to the north-northwest. A trapezoidal channel prism 9 feet deep with a bottom width of 20 feet and 3 on 1 side slopes will be dredged along the track of the old existing channel, now mostly silted up. Approximately 17,000 cubic yards need to be removed.

SECTION IX. INTAKE DESIGN

Inlet

A conventional flat-bottom transition with angled vertical side walls is employed for the change in flow where the seawater enters the two circular pipes from the dredged channel. The floor of the open end is 8 feet below MLLW. In the 20-MGD intake the floor is flat, while in the 100-MGD it slopes to the invert elevation of the pipes, 10 feet below MLLW. The width of the open end is 32 feet and 37 feet respectively. The side walls of the inlet are formed with sloping slots 4 inches deep by 12 inches wide to permit installation of the trash rack. A 6-inch concrete slab walkway across the top provides a platform for the operator to stand on while raking clean the trash racks. A wood handrail around the open sides of the intake is included.

Concrete has been selected as the material of construction for the inlet walls and floor. It will provide the needed degree of erosion resistance and a simple, rigid installation for the trash rack. Concrete will provide a solid headwall into which the two concrete pipe channels can be set and sealed. The concrete is expected to provide a 30-year life with essentially no maintenance.

Fouling growths in the inlet, the pipeline, the pump basin, and the remainder of the desalination plant will be controlled by chlorination, using either continuous or intermittent feed. A chlorine solution diffuser pipe (not shown on the drawings) is located in the inlet just ahead of the trash rack.

Hurricane Provisions

Because of the high incidence of hurricanes in the Gulf Coast, protection against the high waters and high winds associated with a hurricane is designed into the desalination plant. A protective levee is placed around the plant to a height of 20 feet above MLLW. A 20-foot roadway along the top permits vehicle passage. The inner face has a 3 on 1 slope and the outer face has a 4 on 1 slope. A levee height of 20 feet is selected on the basis of hurricane experience along the Gulf Coast. Levees on the western end of the Gulf are designed to this height, which includes the height of hurricane tide plus wave height plus runup. Additional construction is made necessary by the levee. A pipeline must be run under the levee to move the seawater to the pump basin, which is located inside the levee. An inlet (already described) at the seaward end of the pipeline and a valve gate well near the high point of the levee complete the seawater intake facility for this lagoon type intake.

Where hurricanes are not a hazard, the use of the pipelines through a protecting levee would not be required. Also, in many locations the lagoon would have adequate depth close to shore, and would not require dredging of an intake channel from deep water to the inlet. The above two features, however, were included in the design to illustrate conditions likely to be found along much of the Gulf Coast with shallow water and hurricane potential where the other types of intake designs might not be applicable. The additional cost for providing for these features causes the lagoon type example design to cost more than the shore type example, whereas at another location the lagoon type intake would normally be expected to cost less than a shore type intake of the same capacity.

Pipeline and Gate Well

Two concrete pipes are provided for the flow of seawater from the inlet to the pump basin. Each pipe is sized to carry the full design flow alone, in case one pipe is out of service. The 20-MGD intake has 30-inch diameter pipes which convey the seawater at 6.4 feet per second acting singly or 3.1 feet per second in tandem. The 100-MGD intake uses 60-inch pipes at a velocity of 7.9 feet per second singly or 4.0 feet per second in tandem.

To shut off the flow of seawater in case of hurricane tides, an electrically operated slide gate is provided in each of the pipelines, housed in a concrete gate well at the high point of the levee. Slots for stop gates are also provided in case it should be necessary to dewater that section of the pipeline to repair a slide gate.

Pump Basin

Concrete is selected as the material of construction for the pump basin. Steel sheet piling was considered, but was rejected because of the difficulty of maintaining fixed dimensions for equipment such as traveling screens, stop gates and pumps, and because of the special adaptor pieces which would be necessary. The pump basin is essentially a concrete box which contains the following features: a headwall with inlet port(s), traveling screens and their appurtenances, pump suction pits and foundations for the intake pumps. In the pipe type and shore type intakes the pump basin also contains the trash racks.

The pump basin is constructed with a sufficient bottom depth to provide no less than the minimum amount of water over the suction bell of the pumps recommended by the pump manufacturer, under the conditions of the lowest low tide that may be expected, and under the conditions of the maximum pumping rate. The width of the entrance portion of the pump basin is governed either by the width of the pipes or opening where seawater enters the basin, or by the required area of trash racks to limit the velocity of water flowing through to approximately 2 feet per second. The width of the pump end of the pump basin is determined either by the required width of the traveling screens or the width recommended by the pump manufacturer for the pump suction pit. The pump pit dimensions recommended by some manufacturers could in some cases require modification of the dimensions of the pump end of the pump basin from those shown in the sample designs.

The top elevation of the pump basin is based on the maximum high water which might be expected. The pump basin length is greater than that required for placement of equipment, so that the working room is adequate for a diver or maintenance worker to work on the pump pits, traveling screens, or other parts of the pump basin. The greater length also makes the placement of the galvanic anodes easier. These should be located at least 5 feet upstream and downstream from the traveling screens.

A vertical wall separates the traveling screens so that when one is removed from service, stop gates dropped into suitable vertical slots will divert the flow to the other screen or screens. Vertical walls also isolate each pump suction pit.

Working areas and walkways are provided by horizontal concrete slabs over the pump basin, around the traveling screens, around the pumps, and near the trash racks.

Traveling screens of the type discussed in Section VI are provided. At least two traveling screen units should be installed, of sufficient capacity that the plant can operate with one unit out of service.

SECTION IX. INTAKE DESIGN

Two seawater pumps take suction from the pump basin and deliver seawater through the spray nozzles against the moving screens during the wash cycle. The intake point is downstream of the screens, so that only chlorinated and filtered water is pumped. A pressure of 80 psi is recommended by the manufacturer. Pump motors are 25 horsepower for the 20-MGD intake and 40 for the 100-MGD.

A square concrete trash basket well is added to the side of the pump basin to act as a holder for the fish and other marine life washed from the traveling screens. A wire basket of slightly smaller dimensions sitting inside the well facilitates the removal of the accumulation. The material reaches the basket through a 1-foot wide sloping trash trough. Water drains from the well back into the pump basin through a 6-inch drain pipe.

Weep holes are provided in the floor of the pump basin to prevent buildup of uplift hydrostatic pressure underneath the basin.

Handrails are placed around all openings in the pump basin and in the inlet. The standard handrail is constructed of treated lumber, with 4 x 4 vertical posts topped by a 2 x 6 horizontal cap. Two 2 x 4's serve as horizontal rails, one at mid-height, and the other just under the cap. Where mechanical work is expected nearby, such as in the vicinity of pumps or traveling screens, a 1 x 6 toe board is added to prevent accidental loss of tools over the edge. Painted galvanized nails and galvanized bolts are used as fasteners.

B. Pipe Type Intake Design

Although many features of the pipe type intake are different from those of the lagoon type, the pump basins are similar except for the location of the trash racks.

Site Conditions

The designs shown in Figures IX-11 through IX-17 are based upon a hypothetical location such as is found along the California Coast. The site area is assumed to be part of a broad coastal shelf bordering the mainland. The predominant types of materials are sediments originating mostly from rivers and sea cliffs. The sediments consist mostly of quartz and feldspar sand, with occasional random, very thin lenses of clayey silts at 40 and 60 feet below MLLW. The sandy soils have ample bearing value for any normal loads which might be placed upon them by any of the intake structures. The beach and bottom profile is assumed to be as shown on the drawings. The prevailing surface current is 0.1 knot parallel to the shore, and the bottom current about the same. Maximum probable bottom erosion is assumed to be 5 feet. The elevation difference between MLLW and highest high tide is 7.0 feet. The design wave height for the maximum storm has been assumed at 27 feet, so that the water depth at point of breaking is about 35 feet below MLLW.

Intake Terminal

The intake terminal will be constructed of concrete, because of its durability in seawater and its weight. The intake terminal is located at a water depth of 35 feet below MLLW, a point beyond reasonable possibility of breaking wave damage and where sand movement should be small. The bottom of the inlet is placed at 12 feet above the ocean bottom and 23 feet below MLLW. This elevation is chosen so that it will be sufficiently high to prevent sand from entering and sufficiently below MLLW so that it will not be a hazard to navigation and so that floating trash will not enter.

The intake terminal is constructed on shore and floated into position where it is set on a suitable base. It is designed to have a sufficiently sound foundation so that it will not move or tip with respect to the intake pipe to which it is connected. The pipe seal at the intake terminal is made of a flexible material which will permit a small axial as well as lateral movement of the intake terminal with respect to the pipe without placing an excessive force on the pipe.

A velocity cap, or fish cap, marked by a buoy, is provided over the intake opening so that all seawater entering will do so in a horizontal direction. A 1-foot by 3-foot recess in one of the upper edges of the intake will afford a sufficiently large opening to admit a diver for inspection. The inlet, as shown in Figures IX-13 and IX-17, is lined with 16-gauge copper-nickel sheet to prevent fouling ahead of the chlorine diffusers.

Fouling in the pipeline will be controlled by chlorine injected into the intake terminal through an exterior bustle pipe and a series of equally-spaced diffuser pipes extending through the intake terminal walls. The discharge points are approximately 4 to 6 inches from the inside walls of the intake terminal, just below the metal liner. A chlorine solution will be produced by dissolving bulk chlorine in seawater to a concentration of 2,000 to 3,000 ppm. The solution will be pumped to the injection point with a Duraloy pump through a PVC line. The system is designed to furnish a maximum of 20 ppm chlorine in the intake seawater. During construction, the intake line, as it is progressively installed, should be protected from fouling buildup by slowly pumping seawater with about 0.5 ppm chlorine residual through it until the line is ready for operation.

Pipe Conduit

The conduit in which the seawater will flow from the intake terminal to the pump basin is constructed of concrete. Since the maximum erosion of the ocean bottom from a mean bottom line has been taken as 5 feet, actual buried depth of the top of the pipe has been taken as 7 feet. This will provide 2 feet as a factor of safety for the unforeseen contingency. Anchorage, other than burial, is not necessary. Since the line extends approximately a half mile offshore and is relatively inaccessible for maintenance, every effort should be made to provide an installation free from any defects which could cause significant maintenance or a shutdown. The pipe will be bedded in sand which will be jetted under and around the pipe while it is held in position. In the surf zone, temporary sheet piling will be used for the trench. Work will be performed from a temporary trestle. Beyond the surf zone, sheet piling will not be needed to form the trench walls, and work can be performed from a barge.

A 36-inch pipe is used for the 20-MGD capacity intake, and a 72-inch for the 100-MGD. The velocity of flow in the pipes is 4.3 and 5.5 feet per second, respectively. This is about the minimum consistent with economy in first cost, but it will permit some later increase in capacity at a higher velocity. The head loss at the two design capacities, with a coefficient of roughness of 100, and using the Hazen-Williams formula, is 8.4 and 5.7 respectively.

Pump Basin

The pump basin and its equipment are similar to that described for the lagoon type intake except that the trash rack will be located here, and the depth of floor below MLLW must be sufficient to allow for the head loss through the intake pipe.

Future Expansion

The great length of the intake pipe and the head loss characteristics limit the potential of this type of increased capacity.

C. Shore Type Intake Design

This type of intake differs from the pipe type intake only in the means for bringing water to the pump basin. It is generally similar to the lagoon type except that it takes water from the open ocean and, therefore, is exposed to wave action.

Site Conditions

The intake as designed is shown in Figures IX-18 through IX-23. A location along the northern coast of Oahu was selected as the site. The shore and ocean bottom are assumed as being consolidated sedimentary material. The water depth is 18 feet at a seaward distance of 900 feet, and 60 feet deep at 2,100 feet. MHHW is +1.9 feet, the highest high water is +3.0 feet, and the lowest low water is -1.0 feet, all measured from MLLW.

Intake Channel

A channel is dredged by blasting, from the pumping basin seaward to where a water depth of 4 feet is encountered. The channel is trapezoidal in cross-section, with a bottom width of 20 feet, a length of 320 feet, and side slopes of 2 on 1. The bottom of the channel is horizontal. The spoil material is removed by crane or dragline and placed along the shore.

Pump Basin

The pump basin is similar to that for the pipe type intake with a lesser bottom depth and a submerged intake opening. The submerged opening prevents floating wastes from entering, and the wall acts as a wave barrier. Chlorination is used for control of fouling, with injection ahead of the trash rack.

SECTION X. COSTS

Costs shown in this section should be taken as representative of what might be expected for the sizes and types of intakes described in Section IX. Although made from material takeoffs, the cost estimates do not have the degree of precision which would be the case if thorough site investigations had been made and detailed design drawings had been prepared.

A. Capital Costs

Included under capital costs are labor, materials, equipment, equipment rental, engineering, inspection, contractor's expenses and profit, contingency and interest on construction funds.

Channel Construction

Dredging for the channel for the lagoon type intake was based upon providing a 3000-foot channel 9 feet deep and 20 feet wide at the bottom, with side slopes of 3 on 1. The material was assumed to be sand and mud. The channel for the shore type intake was based upon providing a channel 320 feet long and 8 feet wide at the bottom, with 1 on 2 side slopes. Since the material was assumed to be consolidated granular material, blasting would be required.

Intake Terminal and Intake Pipe

The intake terminal for the pipe type intake was based on constructing it on shore, floating it to location, and then positioning and setting it on a suitable base. Temporary trestlework and steel sheet piling would have to be provided for dredging the trench and laying the pipe in the surf zone. The steel sheet piling would be used four times during the process by driving and pulling. Trench dimensions for the 100-MGD and the 20-MGD sizes were based on depths of 14 feet and 11 feet and widths of 20 feet and 17 feet, respectively. Beyond the surf zone, an open trench would be dredged. Backfill for the intake terminal and the pipe was based on jetting sand around and under the pipe and around the intake terminal. Removal and salvage of the trestle is included.

Pump Basins

The pump basins are shown to be constructed of poured concrete. Excavation for the lagoon type was assumed to be in clay with some sand. For the pipe type intake, excavation was assumed to be in sand, and for the shore type, the material was assumed to be consolidated granular material which would require blasting.

Equipment

Manufacturers' prices were used for such items of equipment as traveling screens, chlorinators and controllers, pumps and electrical equipment. Installation was estimated on the basis of the required labor and construction equipment.

Chlorination

Chlorination equipment was sized to provide a maximum dosage rate of 20 ppm, using manufacturer's standard equipment and controllers. A small building was provided to house the equipment.

General

The estimated costs of materials, labor and equipment rental were increased to yield final cost estimates equivalent to the costs to be expected from a competitive bid, lump sum construction contract. Material costs were increased 9% to cover taxes and contractor's fees, equipment rental costs were increased 5% to cover contractor's fees, and labor costs were increased 35% to cover contractor's overhead and fees. Capital cost estimates for the six design examples are shown in Tables X-I through X-VI.

To the estimated cost of construction were added a construction contingency of 10%, engineering at 10% of construction cost plus contingency, and interest on investment during construction which was computed on the basis of an assumed construction period of one year and an interest rate of 5% applied to a sum which increased over the construction period. The effective rate of interest on the increasing funds paid during the period was taken as equivalent to 2.5% of the estimated construction cost, contingency and engineering.

B. Annual Expenditure

The total annual expenditure is made up of the amortization of the capital cost, the estimated operation and maintenance costs, and interest on the working capital.

SECTION X. COSTS

TABLE X-I

COST ESTIMATE FOR 20-MGD LAGOON TYPE INTAKE

Item	Quantity	Units	Unit Cost	Total Item Cost	Totals
Pump Station					
Concrete	150	C.Y.	$ 115.00	$17,200	
Excavation	1000	C.Y.	0.90	900	
Backfill	500	C.Y.	1.60	800	
Handrail	450	B.F.	0.68	300	
Traveling Screens	2	Each	14,400.00	28,800	
Cathodic Protection	1	Lot	700.00	700	
Wash Pumps and Piping	1	Lot	7,000.00	7,000	
Electrical	1	Lot	3,600.00	3,600	
					$59,300
Inlet					
Concrete	55	C.Y.	122.00	6,700	
Excavation	500	C.Y.	0.80	400	
Backfill	300	C.Y.	0.33	100	
Handrail	300	B.F.	0.67	200	
Trash Rack	1	Each	600.00	600	
					8,000
Gate Structure & Pipe					
Concrete	64	C.Y.	158.00	10,100	
Excavation	3500	C.Y.	0.86	3,000	
Backfill	3400	C.Y.	1.59	5,400	
Handrail	200	B.F.	0.50	100	
30" Pipe	282	L.F.	10.60	3,000	
Slide Gates	2	Each	2,950.00	5,900	
Cathodic Protection	2	Each	100.00	200	
Electrical	1	Lot	1,200.00	1,200	
					28,900
Dredging	167,000	C.Y.	0.50	83,500	
					83,500

Table X-I (Continued):

Item	Quantity	Units	Unit Cost	Total Item Cost	Totals
Chlorination System					
Chlorinators, etc.	1	Unit	$22,700.00	$22,700	
Building	80	S.F.	20.00	1,600	
Pumps and Piping	1	Lot	1,000.00	1,000	
Electrical	1	Lot	1,100.00	1,100	
					$ 26,400
Total Construction Cost					$206,100
Construction Contingency at 10%				20,600	
Sub-Total					226,700
Engineering at 10%				22,700	
Sub-Total					249,400
Interest on Construction Money				6,200	
Total Capital Cost					$255,600

TABLE X-II

COST ESTIMATE FOR 100-MGD LAGOON TYPE INTAKE

Item	Quantity	Units	Unit Cost	Total Item Cost	Totals
Pump Station					
Concrete	385	C.Y.	$ 102.00	$39,500	
Excavation	2,500	C.Y.	0.68	1,700	
Backfill	1,800	C.Y.	1.55	2,800	
Handrail	900	B.F.	0.67	600	
Traveling Screens	3	Each	20,000.00	60,000	
Cathodic Protection	3	Each	500.00	1,500	
Wash Pumps and Piping	2	Each	4,250.00	8,500	
Electrical	1	L.S.	4,000.00	4,000	
					$118,600
Inlet					
Concrete	70	C.Y.	111.00	7,800	
Excavation	1,000	C.Y.	0.60	600	
Backfill	700	C.Y.	1.57	1,100	
Handrail	200	B.F.	0.50	100	
Trash Rack	1	Each	600.00	600	
					10,200
Gate Structure & Pipe					
Concrete	83	C.Y.	149.00	12,400	
Excavation	5,000	C.Y.	0.68	3,400	
Backfill	4,500	C.Y.	1.55	7,000	
Handrail	200	B.F.	0.50	100	
Pipe 60"	282	L.F.	49.60	14,000	
Slide Gate 60"	2	Each	5,700.00	11,400	
Cathodic Protection	2	Each	100.00	200	
Electrical	1	L.S.	1,300.00	1,300	
					49,800
Chlorination System					
Chlorinators and Controls	1	L.S.	50,000.00	50,000	
Building 20' X 20'	400	S.F.	15.00	6,000	

Table X-II (Continued):

Item	Quantity	Units	Unit Cost	Total Item Cost	Totals
Pumps and Piping	2	Each	$2,000.00	$ 4,000	
Electrical	1	L.S.	2,000.00	2,000	
					$ 62,000
Dredging	167,000	C.Y.	0.50	83,500	83,500
Total Construction Cost					$324,100
Construction Contingency at 10%				32,400	
Sub-Total					356,500
Engineering at 10%				35,700	
Sub-Total					392,200
Interest on Construction Money				9,800	
Total Capital Cost					$402,000

TABLE X-III

COST ESTIMATE FOR 20-MGD PIPE TYPE INTAKE

Item	Quantity	Units	Unit Cost	Total Item Cost	Totals
Pump Station					
Concrete	287	C.Y.	$ 109.00	$ 31,300	
Excavations & Wellpoints	1,100	C.Y.	9.20	10,100	
Backfill	500	C.Y.	0.60	300	
Temporary Sheet Piling	15,000	S.F.	2.50	37,500	
Handrail	650	B.F.	0.62	400	
Trash Rack	1	Each	600.00	600	
Traveling Screens	2	Each	17,450.00	34,900	
Cathodic Protection	2	Each	350.00	700	
Wash Pumps and Piping	2	Each	3,900.00	7,800	
Electrical	1	L.S.	4,800.00	4,800	
					$128,400
Intake Terminal					
Concrete	46	C.Y.	130.00	6,000	
Installation	1	L.S.	10,000.00	10,000	
Buoy	1	Each	900.00	900	
Cu-Ni Liner	950	Lb.	3.16	3,000	
					19,900
Pipe - Inland Section					
Excavation	4,500	C.Y.	1.55	7,000	
Pipe 36"	500	L.F.	38.40	19,200	
Backfill	4,500	C.Y.	0.51	2,300	
Temporary Sheet Piling	70,000	S.F.	2.50	175,000	
					203,500
Pipe - Surf Section					
Excavation	3,500	C.Y.	1.57	5,500	
Pipe 36"	800	L.F.	38.40	30,700	
Backfill	3,500	C.Y.	1.06	3,700	
Temporary Trestle	800	L.F.	200.00	160,000	
Temporary Sheet Piling	112,000	S.F.	2.50	280,000	
					479,900

Table X-III (Continued):

Item	Quantity	Units	Unit Cost	Total Item Cost	Totals
Pipe - Deepwater Section					
Dredge	23,000	C.Y.	$ 0.55	$ 12,700	
Pipe 36"	1,900	L.F.	58.70	111,300	
Dredge Backfill	34,500	C.Y.	0.55	19,000	
					$ 143,000
Chlorination System					
Chlorinators & Controls	1	L.S.	22,700.00	22,700	
Building 8' X 10'	80	S.F.	20.00	1,600	
Pumps	2	Each	1,500.00	3,000	
Pipeline 4"	3,200	L.F.	9.75	31,200	
Electrical	1	L.S.	1,700.00	1,700	
					60,200
Total Construction Cost					$1,034,900
Construction Contingency at 10%				103,500	
Sub-Total					1,138,400
Engineering at 10%				113,800	
Sub-Total					1,252,200
Interest on Construction Money				31,300	
Total Capital Cost					$1,283,500

TABLE X-IV

COST ESTIMATE FOR 100-MGD PIPE TYPE INTAKE

Item	Quantity	Units	Unit Cost	Total Item Cost	Totals
Pump Station					
Concrete	530	C.Y.	$ 105.00	$ 55,700	
Excavation & Wellpoints	2,400	C.Y.	9.20	22,100	
Backfill	600	C.Y.	0.67	400	
Temporary Sheet Piling	15,000	S.F.	2.50	37,500	
Handrail	3,300	B.F.	0.64	2,100	
Trash Rack	5,000	Lb.	0.31	1,600	
Traveling Screens	3	Each	23,900.00	71,700	
Cathodic Protection	3	Each	500.00	1,500	
Wash Pumps and Piping	2	Each	4,550.00	9,100	
Electrical	1	L.S.	4,800.00	4,800	
					$206,500
Intake Terminal					
Concrete	70	C.Y.	130.00	9,100	
Installation	1	L.S.	10,000.00	10,000	
Buoy	1	Each	900.00	900	
Cu-Ni Sheathing	1,870	Lb.	3.16	5,900	
					25,900
Pipe - Inland Section					
Excavation	6,000	C.Y.	1.58	9,500	
Pipe 72"	500	L.F.	91.00	45,500	
Backfill	6,000	C.Y.	0.52	3,100	
Temporary Sheet Piling	70,000	S.F.	2.50	175,000	
					233,100
Pipe - Surf Section					
Excavation	6,000	C.Y.	1.58	9,500	
Pipe 72"	800	L.F.	91.00	72,800	
Backfill	6,000	C.Y.	0.52	6,200	
Temporary Trestle	800	L.F.	200.00	160,000	

Table X-IV (Continued):

Item	Quantity	Units	Unit Cost	Total Item Cost	Totals
Temporary Sheet Piling	112,000	S.F.	$ 2.50	$280,000	
					$ 528,500
Pipe - Deepwater Section					
Dredge	36,000	C.Y.	0.55	19,800	
Pipe 72"	1,900	L.F.	111.00	210,900	
Dredge Backfill	54,000	C.Y.	0.55	29,700	
					260,400
Chlorination System					
Chlorinators & Controls	1	L.S.	50,000.00	50,000	
Building 20' X 20'	400	S.F.	15.00	6,000	
Pumps and Motors	4	Each	1,500.00	6,000	
Pipeline	3,200	L.F.	11.40	36,500	
Electrical	1	L.S.	4,500.00	4,500	
					103,000
Total Construction Cost					$1,357,400
Construction Contingency at 10%				135,700	
Sub-Total					1,493,100
Engineering at 10%				149,300	
Sub-Total					1,642,400
Interest on Construction Money				41,100	
Total Capital Cost					$1,683,500

TABLE X-V

COST ESTIMATE FOR 20-MGD SHORE TYPE INTAKE

Item	Quantity	Units	Unit Cost	Total Item Cost	Totals
Pump Station					
Concrete	200	C.Y.	$ 120.00	$24,000	
Excavate (Blast)	420	C.Y.	21.20	8,900	
Backfill	200	C.Y.	21.00	4,200	
Handrail	700	B.F.	0.62	400	
Trash Rack	1500	Lb.	0.40	600	
Traveling Screens	2	Each	14,750.00	29,500	
Cathodic Protection	2	Each	350.00	700	
Wash Pumps and Piping	2	Each	3,900.00	7,800	
Electrical	1	L.S.	4,800.00	4,800	
					$ 80,900
Channel					
Excavate (Blast)	250	C.Y.	28.50	7,100	
					7,100
Chlorination System					
Chlorinators & Controllers	1	L.S.	22,700.00	22,700	
Building 8' X 10'	80	S.F.	20.00	1,600	
Pump & Piping	1	Each	1,000.00	1,000	
Electrical	1	L.S.	1,100.00	1,100	
					26,400
Total Construction Cost					$114,400
Construction Contingency at 10%				11,400	
Sub-Total					125,800
Engineering at 10%				12,600	
Sub-Total					138,400
Interest on Construction Money				3,500	
Total Capital Cost					$141,900

TABLE X-VI

COST ESTIMATE FOR 100-MGD SHORE TYPE INTAKE

Item	Quantity	Units	Unit Cost	Total Item Cost	Totals
Pump Station					
Concrete	350	C.Y.	$ 106.00	$37,000	
Excavation (Blast)	1000	C.Y.	17.00	17,000	
Backfill	500	C.Y.	2.00	1,000	
Handrail	3400	B.F.	0.65	2,200	
Trash Rack	3400	Lb.	0.32	1,100	
Traveling Screens	3	Each	20,070.00	60,200	
Cathodic Protection	1	Lot	1,500.00	1,500	
Wash Pumps and Piping	1	Lot	9,100.00	9,100	
Electrical	1	Lot	4,800.00	4,800	
					$133,900
Chlorination System					
Chlorinators, etc.	1	Unit	50,000.00	50,000	
Building	400	S.F.	15.00	6,000	
Pumps and Piping	2	Each	1,500.00	3,000	
Electrical	1	L.S.	2,000.00	2,000	
					61,000
Channel					
Excavate	600	C.Y.	34.60	20,800	
					20,800
Total Construction Co					$215,700
Construction Contingency at 10%				21,600	
Sub-Total					237,300
Engineering at 10%				23,700	
Sub-Total					261,000
Interest on Construction Money				6,500	
Total Capital Cost					$267,500

SECTION X. COSTS

Amortization

To provide the funds for construction of the desalination plant, the sale of bonds was assumed, with a repayment period equal to the life expectancy of the plant. The bond life is thus 30 years, and the interest rate was taken as 5%. This required an annual payment of $65,051 for each $1,000 of bonded indebtedness.

Maintenance

Maintenance cost for the steel trash racks is estimated on the basis of complete replacement every ten years. The cost of material, fabrication and installation is included.

At five-year intervals, each traveling screen unit will be removed and overhauled mechanically, sandblasted and repainted. The estimated cost for each of the smaller units includes $1200 for sandblasting, painting and mechanical work, $300 for materials and parts, and four man-days for the rigging crew. The costs are proportionately higher in the larger screen units used in the 100-MGD intakes.

Maintenance of the cathodic protection system on the traveling screens consists of complete replacement of the sacrificial anodes every five years. The estimate includes provision of 600 pounds of aluminum type anode at $0.60 per pound and four man-days of labor, apportioned over a five-year period. For the larger size traveling screens, the cost is proportionately higher.

The estimates of costs to maintain the chlorination systems were made on the basis of conversation with representatives of chlorinator manufacturers.

The cost of maintaining the remaining items of fixed equipment, piping, structure and grounds is estimated on the basis of experience with similar structures.

Because of its inaccessibility to normal maintenance practice, the buried offshore pipeline was designed, and materials chosen, so that it would probably be free of maintenance requirements for the 30-year life of the facility. To prevent the growth of marine fouling communities on the interior of the pipe, a chlorination system would be installed and operated to produce a small positive chlorine residual in the seawater passing through the pipe.

SECTION X. COSTS

Some dredging to maintain the entrance channel to the lagoon type intake across the shallow bay is anticipated. The amount assumed is equivalent to one-fifth of the total channel volume each year.

Power Costs

The cost of electric power was estimated on the basis of the operating horsepower and the periods of operation. The unit cost of power used was taken at $0.008 per KWH.

Chlorine

The cost of chlorine was estimated at a unit cost of $0.06 per pound, delivered in ton cylinders for the 20-MGD intakes, and in tank car or trailer car lots for the 100-MGD plant. Chlorine usage was estimated on the basis of intermittent chlorination for two hours out of every twelve, using an applied dosage of 6 ppm.

Operator Labor

The labor costs for operation of the intake system were estimated on the basis of an hourly pay scale of $5.35 per hour. Payroll extras, estimated at 30%, are added to the hourly rate, and 30% of the hourly rate plus payroll extras is added for general and administrative overhead, giving an hourly estimated cost of $9.00 per hour. The traveling screens will receive one hour of operator attention each day, with provision for additional manpower of 30 man-days per year for the extra manpower needed whenever there is a period of heavy influx of sea life loading requiring continuous backwashing of the screens and manual removal of the trash. Operation of the chlorination system has been assumed as requiring one man-hour per day for the 20-MGD intake and three man-hours per day for the 100-MGD intake.

Trash Disposal

A winch truck is used to haul trash from the traveling screens to a land burial site. One-hour operation every two days is provided at an estimated cost of $20 per hour for truck and operator. The cost is proportionately higher for the 100-MGD intake.

SECTION X. COSTS

Taxes and Insurance

Taxes, or a payment in lieu of taxes, in the amount of 1.5% of the total capital cost of the plant, is included. The cost of insurance to protect against loss by fire or other damage, as well as possible damage from plant operation to adjacent property, is included as an annual cost of operation, in the amount of 0.25% of the total capital cost.

Total Working Capital

A revolving fund equal to two months of operating costs would be maintained to facilitate payments of expenditures. Interest on this working capital is computed at 5% on a 60-day basis. The resulting figure equals 0.822% of the total working capital and is added to the total working capital to determine the total annual operating costs.

Unit Cost

To serve as a basis of cost comparison with other elements of the desalination plant, the annual operating costs are converted to a unit cost on a product water basis. An annual production of 330 days is assumed. The plant recovery factor is taken as 50% (a feed-water input rate twice that of the product water rate).

Cost Summaries

The operating costs, on an annual basis, for the three intake types are shown in Table X-VII for the 20-MGD size, and in Table X-VIII for the 100-MGD size.

TABLE X-VII

CAPITAL AND OPERATING COSTS FOR 20-MGD INTAKES

Item	Intake Type: Lagoon	Pipe	Shore
Total Capital Cost, $	255,600	1,283,500	141,900
Amortization, $/Yr.	16,628	83,493	9,231
Maintenance, $/Yr.			
Trash Racks	72	36	34
Traveling Screens	720	720	720
Chlorinator	1,600	2,400	1,600
Cathodic Protection	148	136	136
Structural & Misc.	3,000	2,000	2,000
Dredging	16,700	———	———
Pipe Cleaning	150	1,000	———
Operation, $/Yr.			
Power	41	68	41
Chlorine	3,300	3,300	3,300
Operator	8,730	8,730	8,730
Trash Disposal	3,640	3,640	3,640
Taxes and Insurance, $/Yr.	4,473	22,461	2,483
Interest on Working Capital, $/Yr.	487	1,052	262
Total Annual Operating Cost, $/Yr.	59,689	129,036	32,177
Unit Cost, $/1000 Gal. Prod. at 0.5 R. F.	0.018	0.039	0.0098

TABLE X-VIII

CAPITAL AND OPERATING COSTS FOR 100-MGD INTAKES

Item	Intake Type		
	Lagoon	Pipe	Shore
Total Capital Cost, $	402,000	1,683,500	267,500
Amortization, $/Yr.	26,150	109,514	17,401
Maintenance, $/Yr.			
Trash Racks	84	93	66
Traveling Screens	1,510	1,510	1,510
Chlorinator	2,500	3,500	2,500
Cathodic Protection	310	286	286
Structural & Misc.	4,500	3,000	3,000
Dredging	16,700	—	—
Pipe Cleaning	300	1,300	—
Operation, $/Yr.			
Power	119	356	119
Chlorine	16,500	16,500	16,500
Operator	15,300	15,300	15,300
Trash Disposal	5,470	5,470	5,470
Taxes and Insurance, $/Yr.	7,033	29,461	4,681
Interest on Working Capital, $/Yr.	793	1,531	549
Total Annual Operating Cost, $/Yr.	97,269	187,821	67,382
Unit Cost, $/1000 Gal. Prod. at 0.5 R. F.	0.0059	0.0114	0.0041

SECTION XI. SUGGESTED STUDY AREAS

During the course of this study effort, it became apparent that there were several design and construction areas about which available data are incomplete.

A. Fouling Control

Conventional fouling control practices are likely to be costly in large intake systems. Relatively little appears to be known about the effectiveness of intermittent and periodic chlorination schedules and of the amount of halogen required. Other lesser known fouling control techniques not at present used in intakes are: the use of repellent coatings, of impregnated toxins, and of physiological interference with the attachment mechanisms.

B. Materials of Construction

Plastics, protected wood, and corrosion-resistant alloys are all potentially more useful in intake construction than present practice indicates.

Modern plastic materials have a wide range of properties, many of which are useful for seawater service. Greater use in spray nozzles, wash piping, structural members, screen frames and pump casings is indicated.

Wood is cheap and available and its use is now limited by its susceptibility to destruction by marine organisms. As new treatments are developed, the use of wood should be able to be satisfactorily increased.

Corrosion-resistant metal alloys have been used in specialized marine situations. Because they inherently possess a long useful life, they will probably be used in more situations where long life and lack of maintenance are economically dictated.

C. Infiltration Gallery Intakes

Several installations have used infiltration type intakes with mixed success. It is apparent that too little is known about the water transmissivity of nearshore soils and of the effects of oxygen depletion during seawater percolation. The designs appear to have merit for specialized locations, but little information now exists to enable confidence in the predicted performance of such an intake.

D. Pipe Installation in the Surf Zone

The cost of pipe installation through the surf zone is many times the cost of the pipe material alone, and several times the cost beyond the surf zone. The designs in this report are based on current practice, but it is believed that considerable cost reduction is possible with imaginative engineering and construction techniques.

E. Prediction of Erosion

More quantitative data are needed on the amount or extent of erosion resulting from the action of currents, waves and storms. Additional data would enable an engineer to predict with greater confidence the effects of bottom scour and storm erosion when designing pipe emplacement in the surf zone.

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