Design of Seawater Intake Facilities for Solar Salt Plants

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ABSTRACT

For a solar sea salt plant, adequate quantities of undiluted seawater year-round can be ensured by proper survey and design of intake facilities. For this purpose, the topography of the coast and tidal and salinity variations are to be studied to determine the type of facility required. Various types of arrangements like tidal reservoirs and pumping stations, direct pumping from the sea with jetty-mounted rigid pipelines or flexible suction lines laid on the sea bed are described. A procedure for selection of the facility to suit the site conditions is outlined.

INTRODUCTION

Several factors are to be considered to determine the productive capacity of a solar sea salt plant and design an optimum layout. More important among these are:

1. Availability of land, extent, contours and topography
2. Soil conditions
3. Meteorological conditions
4. Availability of seawater and its salinity
5. Susceptibility of the area to storm water flooding.

Having collected these data it is necessary to design a seawater intake system that can be set up with minimum capital investment and operating cost.

CHOICE OF LOCATION

The first step in the design of a solar sea salt plant is to locate a point of intake where continuous and abundant supply of undiluted seawater is available throughout the dry season. The intake into the project area could be

(a) by tidal action through gates/pipes
(b) by pumping from a backwater or tidal creek that is constantly replenished from the sea
(c) by pumping from the main sea.

The location chosen will obviously be one where salinity is maximum, availability of seawater is abundant and where advantage can be taken of tidal inflow to the maximum extent possible.

ESTIMATION OF QUANTITY OF SEAWATER REQUIRED

The yield potential of the area is first determined, based upon recorded fresh water evaporation data. Since evaporation rates of brines at different densities is not normally available for the particular project location, a reasonable assumption has to be made regarding the density—evaporation rate relationship. Normally, it is assumed that the evaporation rate at salt point is about 35–40% that of fresh water. To illustrate with an example, suppose the average net fresh water evaporation rate for the dry season in a particular project area is 1000 mm. The corresponding salt point evaporation rate would be around 400 mm. The overall average brine evaporation rate could be assumed to be around 800 mm because the weaker brines (whose evaporation rate is closer to that of fresh water) cover a major portion of the evaporation area. This means that per hectare of evaporation area, 8,000 cubic metres (or tonnes) of fresh water are evaporated during one dry season. Assuming a seawater intake density of 3° Be (specific gravity 1.023) with a NaCl content of 2.7%, 97 grams of water is to be evaporated to produce 2.7 grams of salt. Assuming a salt recovery of 75% and a seepage loss of 30% through the system, 62 tonnes of seawater is to be evaporated to produce one tonne of salt.

If the annual water evaporation is 8,000 tonnes/hectare, the corresponding yield should therefore be $\frac{8{,}000}{62} = 129$ tonnes/hectare. Once the yield is known, the total annual production of the project area can be estimated.

The seawater requirement per tonne of salt depends upon

1. intake seawater density
2. seepage rate of the project area
3. non-productive dead storage brine quantity (in cases where the brines are not preserved during the wet season owing to incursion of rainwater into the project area).

As is well known, the intake seawater density is a very significant factor in determining the requirement. For instance, if the quantity of seawater required to produce one tonne of salt is 100 cubic metres at 3° Be, it would correspond to 150 cubic metres at 2° Be and 300 cubic metres at 1° Be. Table I illustrates the exponential rise in seawater requirement with decrease in salinity.

Normally, for undiluted seawater at 3–3.5° Be, the theoretical norm is 35–40 cubic metres per tonne of salt. However, allowing for seepage losses, salt recovery efficiency and dead storage (where applicable) actual requirements vary over a wide range between 100 and 200 cubic metres/tonne.

Once the seawater requirements per tonne are estimated, the annual requirement can be estimated. As an example, suppose the seawater requirement is 150 cubic metres/tonne, for an annual production capacity of 100,000 tonnes the total requirement is 150 × 100,000 = 15 million cubic metres.

Suppose this quantity has to be drawn/pumped in over a period of 150 days, the daily intake capacity would be 100,000 cubic metres.

TABLE 1

Volume of Seawater Requirements at Various Salinities to Produce One Tonne of Salt

Intake seawater density (°Be)	Vol. required to produce 1M³ 25°Be (litres)	Vol. required assuming 25% percolation loss (litres)	Vol. required to produce 1 tonne of salt assuming 70% recovery (litres)
1.0	31250	41667	238,000
1.5	20833	27777	158,706
2.0	15625	20833	119,016
2.5	12500	16677	95,290
3.0	10416	13883	79,331

DESIGN OF A TIDAL INTAKE FACILITY

Where land contour levels permit and tidal fluctuations are favourable, maximum advantage should be taken of tidal inflow and pumping should be resorted to at as late a stage in the evaporation system as possible. However, tidal inflow is not continuous and can be drawn in only during high tide periods. Daily tidal variation can be subject to one of the following cycles:

- diurnal
- semi diurnal
- mixed.

Diurnal tides have one high and one low during each lunar day. Semi-diurnal tides (which are common for most unobstructed coasts of the world) have two nearly equal high waters and two nearly equal low waters each lunar day. Mixed tides have two quite unequal high waters and two unequal low waters during a lunar day.

Further, the highs of high waters and the lows of low waters vary from day to day during a lunar month and during the course of a solar year. The highest high waters and the lowest low waters (spring tides) occur shortly after full moon and new moon. The lowest high waters and the highest low waters (neap tides) occur shortly after the first and third quarters of the moon. During the year, springs and neaps change: the highest spring and neap tides occur near the spring (March 21) and autumn equinoxes (September 22) and the lowest near the summer (June 22) and winter solstices (December 22).

The range of tides varies considerably from a few cms to as much as 12 metres. The presence of bays or estuaries could affect tides in varying degrees by delaying and/or prolonging the tide. Silted foreshores could affect the tides by limiting the low water mark but adhering to the high tide level.

Tidal variations are recorded by automatic tidal gauges. In addition, the contours of an area subject to tidal inundation have to be plotted in detail on the same datum as the tidal observations.

In order to design a seawater tidal intake system, the following data should be obtained:

1. Tide tables and tidal curves showing the variations for the full intake period
2. A reservoir level storage volume curve
3. The rate of intake flow required into the reservoir that will feed the salt works. Intake requirements vary with pond evaporation rate and will be higher during peak summer. The intake pipes must be designed to take care of the peak summer requirement.

As an illustrative example we assume a daily semi-diurnal tidal variation at spring tide, as shown in Figure 1, and a daily tidal variation at neap tide, as shown in Figure 2. We also show a tide variation over a lunar month, as in Figure 3. First, the minimum water level in the reservoir is plotted on the tidal curve and stage storage curve (Figure 4). This is the point at which the tidal gate will open. A minimum level of 6.1 M is assumed and marked in Figures 1, 2 & 4.

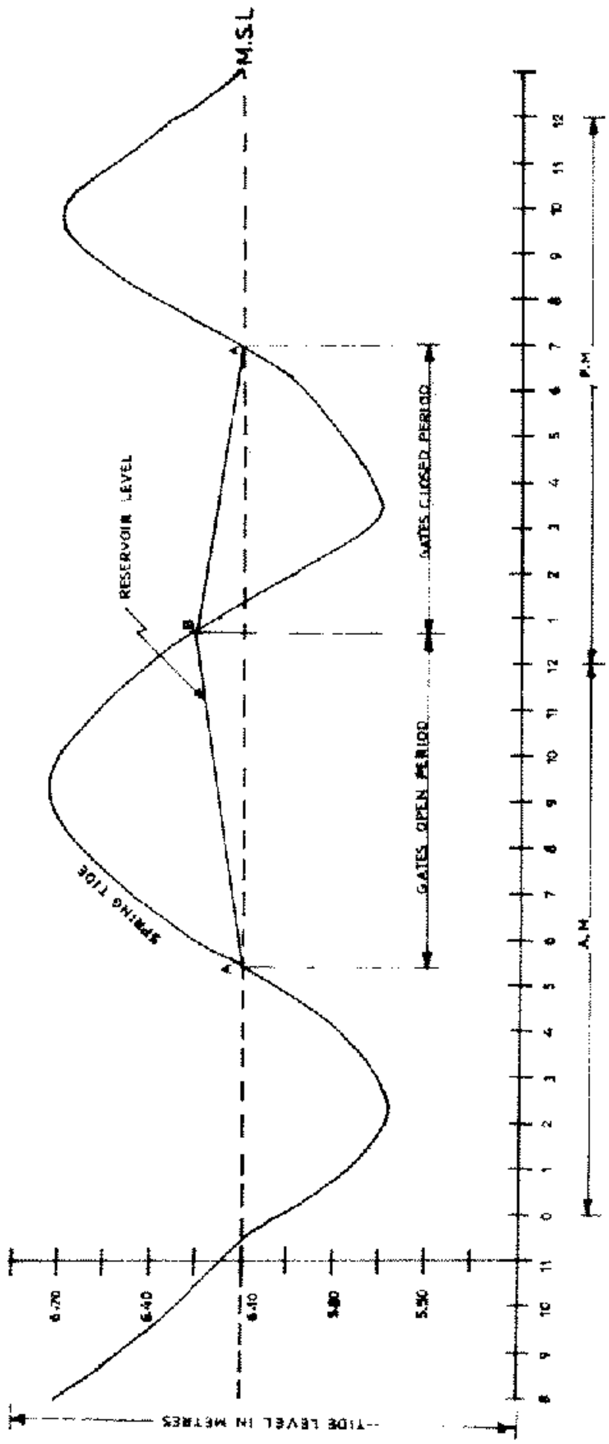

Figure 1. Tide Curve of Spring Tide

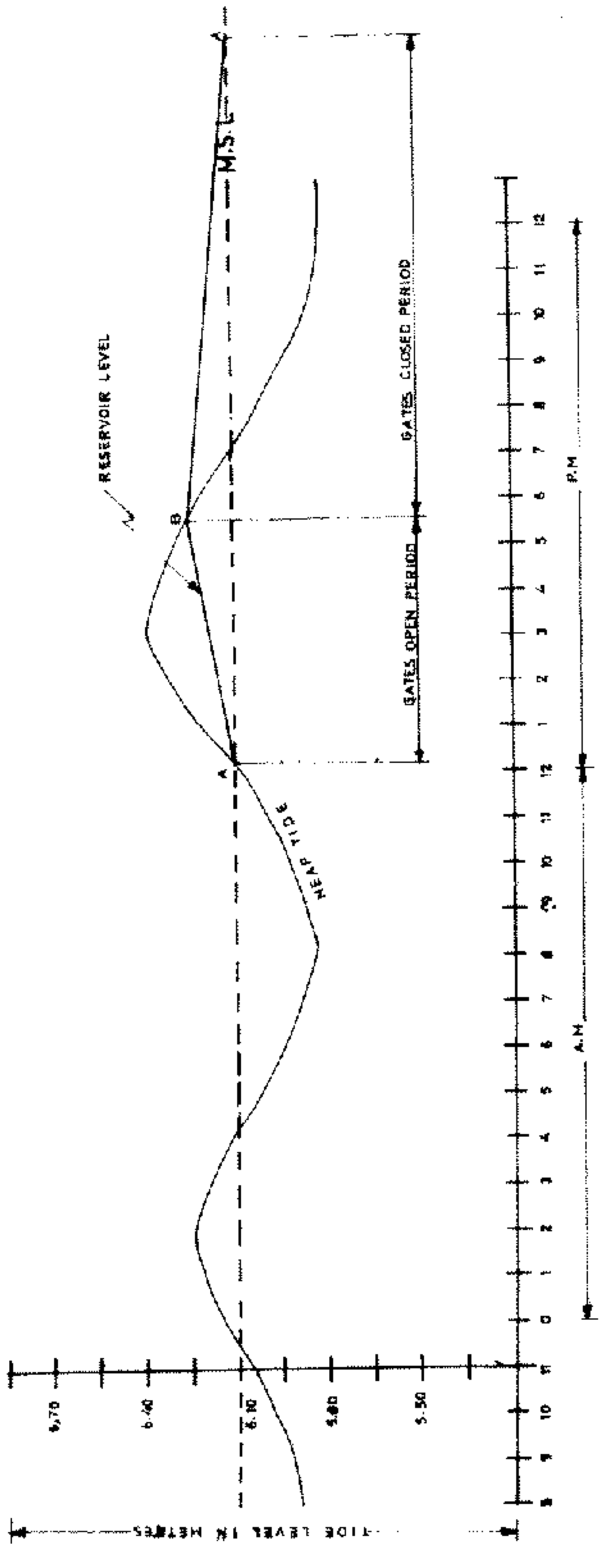

Figure 2. Tide Curve of Neap Tide

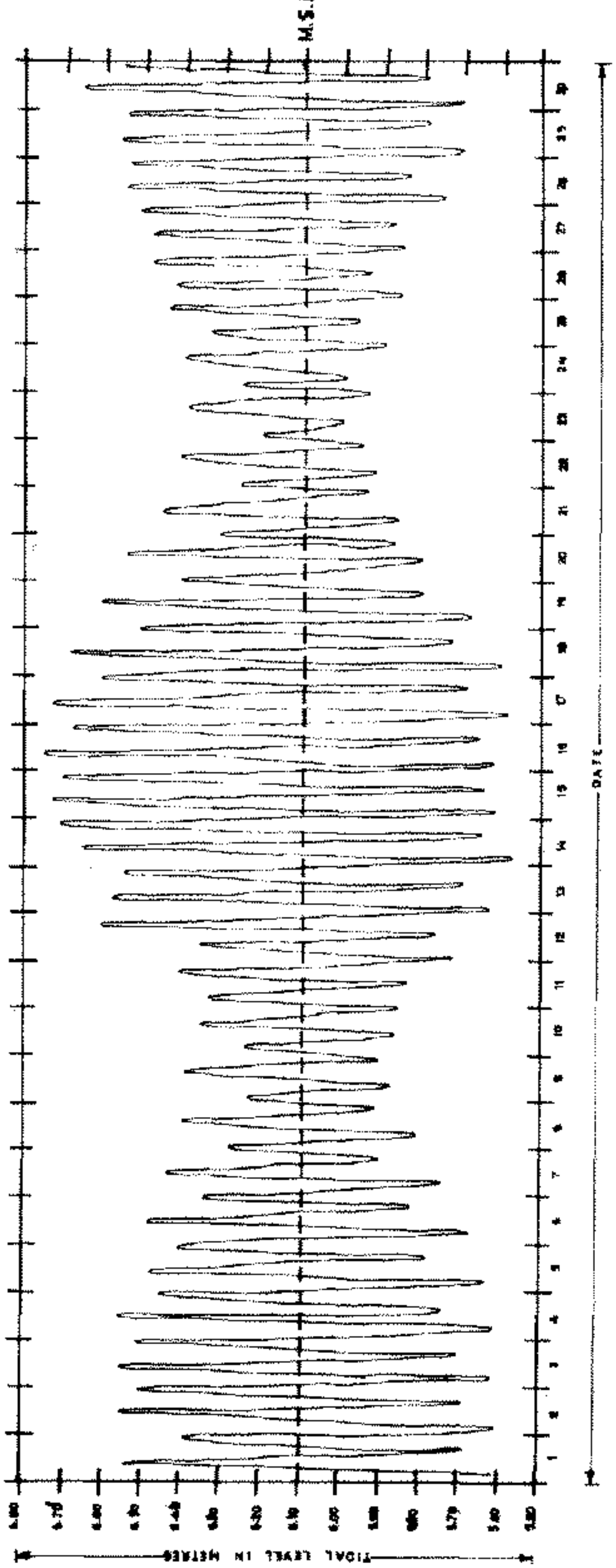

Figure 3. Tidal Variation During a One-Month Period

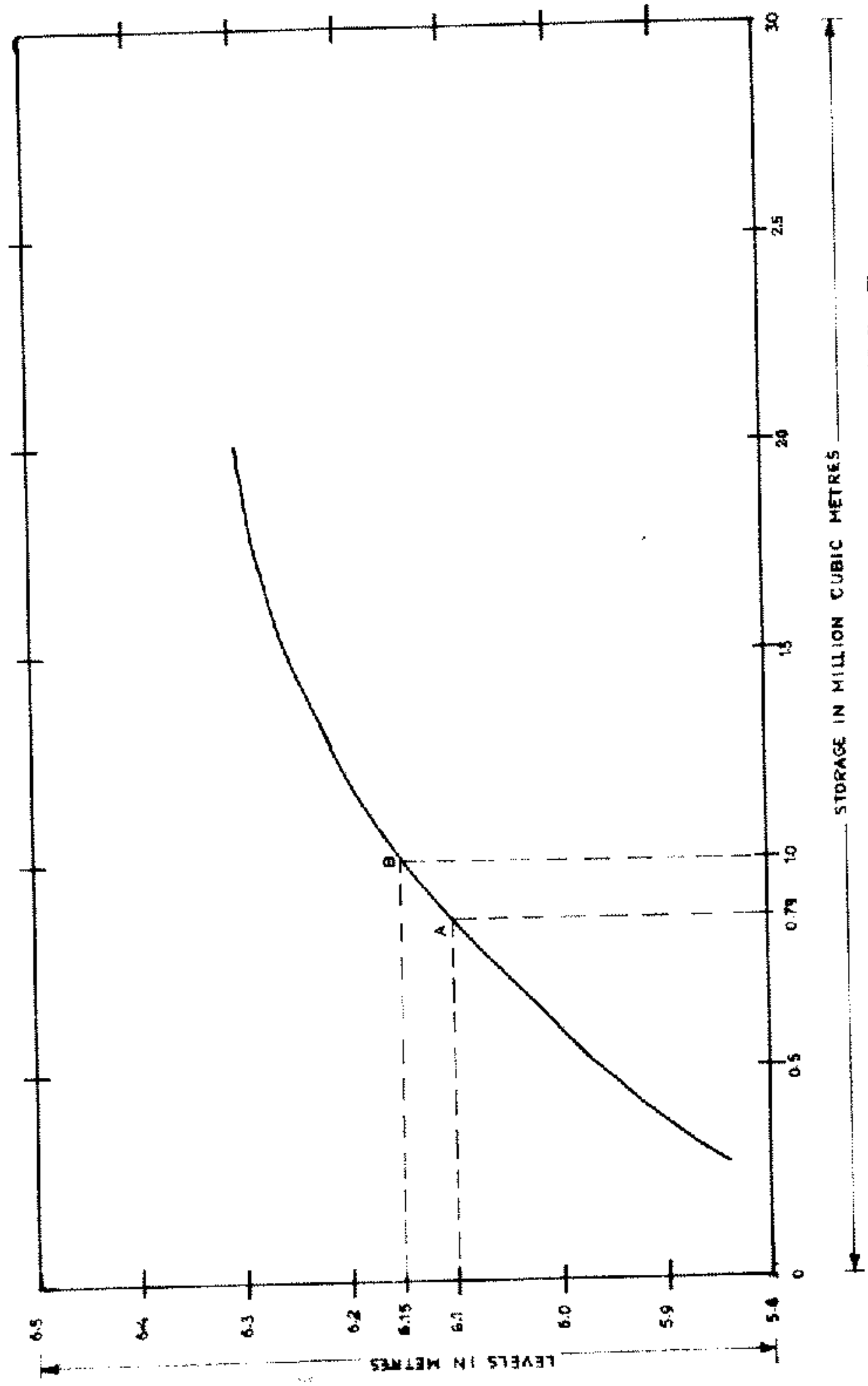

Figure 4. Stage-Storage Curve for a Tidal Reservoir of 400 Hectares with 11 Tidal Inflow Pipes

Suppose, the reservoir area is 400 hectares and it is required that the reservoir must feed a pump of capacity 30,000 litres per minute continuously:

Volume of tidal inflow required into the reservoir

$$\frac{(30000 \times 60 \times 24)\ \text{cubic M. per day}}{1000}$$

$$+ (400 \times 10^{4}[\text{m}^2/\ \text{hectare}] \times 10\ [\text{mm evap/day}])$$

$$\times 10^{-3} = 83200\ \text{cubic metres.}$$

The total quantity required during a 14-day period is 1,164,800 cubic metres.

Assuming that the tidal inflow will be through a number of parallel high density polyethylene pipes, the flow through each pipe of 300 mm diameter on the spring and neap tide days is estimated as set out in Tables 2 & 3. The flow rate for a given head and pipe diameter and length for a pipe with a tidal flap gate is determined from the equations:

$$H = \frac{V^2}{2g}(1 + K_e + K_p L + K_g)$$

where

H is the total head
K_e is the entrance loss coefficient
K_p is the friction coefficient
L is the length of the pipe
A is the area of cross section
v is the velocity of flow
K_g is the gate loss coefficient.

TABLE 2

Estimation of Tidal Inflow Through a 300-mm-Diameter Pipe on Spring Tide Day

Time	Head (metres)	Average head (metres)	Flow rate (cu.M/sec)	Inflow volume (cu.M)
5 am	0			
		0.09	0.1025	369
6 am	0.18			
		0.20	0.1831	659
7 am	0.40			
		0.49	0.2380	857
8 am	0.58			
		0.61	0.2657	956
9 am	0.64			
		0.64	0.2716	978
10 am	0.64			
		0.59	0.2623	944
11 am	0.54			
		0.47	0.2339	842
12 noon	0.40			
		0.26	0.1729	623
1 pm	0.12			
		0.06	0.0837	302
1:30 pm	0			
				6530
7 pm	0			
		0.20	0.1514	545
8 pm	0.39			
		0.47	0.2339	842
9 pm	0.55			
		0.55	0.2521	907
10 pm	0.55			
		0.51	0.2413	869
11 pm	0.46			
		0.34	0.1972	710
12 pm	0.21			
		0.11	0.1109	399
1 am	0			
				4272

TABLE 3

Estimation of Tidal Inflow Through a 300-mm-Diameter Pipe on Neap Tide Day

Time	Head (metres)	Average head (metres)	Flow rate (cu.M/sec)	Inflow volume (cu.M)
11 pm	0			
		0.03	0.0602	217
12 am	0.06			
		0.09	0.1029	370
1 am	0.12			
		0.11	0.1232	444
2 am	0.14			
		0.11	0.1110	400
3 am	0.07			
		0.04	0.0677	244
4 am	0			
				1675
12 noon	0			
		0.06	0.0839	302
1 pm	0.12			
		0.18	0.1455	524
2 pm	0.24			
		0.27	0.1760	634
3 pm	0.29			
		0.28	0.1814	653
4 pm	0.27			
		0.23	0.1624	585
5 pm	0.18			
		0.14	0.1259	453
6 pm	0.09			
		0.05	0.0731	263
7 pm	0			
				3414

Standard head vs discharge charts prepared from computer solutions are available for pipes of varying diameters and lengths.

From Tables 2 & 3 it is seen that the following inflows are possible through each pipe. On the spring tide day,

		Inflow vol. (cu.M)
Gate Open	5 am to 1.30 pm (8.30 hours)	6530
Gate Open	7 pm to 1.00 am (6.00 hours)	4272
		10802

On the neap tide day

Gate Open	11 pm to 4 am (5 hours)	1675
Gate Open	12 noon to 7 pm (7 hours)	3414
		5089

Therefore the average inflow through one pipe for 14 days

$$\frac{(10802 + 5089) \times 14}{2} = 111237\ \text{cu.M}$$

Therefore, number of pipes required $= \dfrac{1164800}{111237} = 10.4$, (say 11 pipes).

Tidal gate structures are normally installed in slush and low-lying areas with the tidal pipes below mean sea level. Wooden tidal gates or sets of corrugated metal pipes (asbestos bonded), HDPE or FRP pipes are commonly used, fitted with one-way opening flap gates (Figure 5).

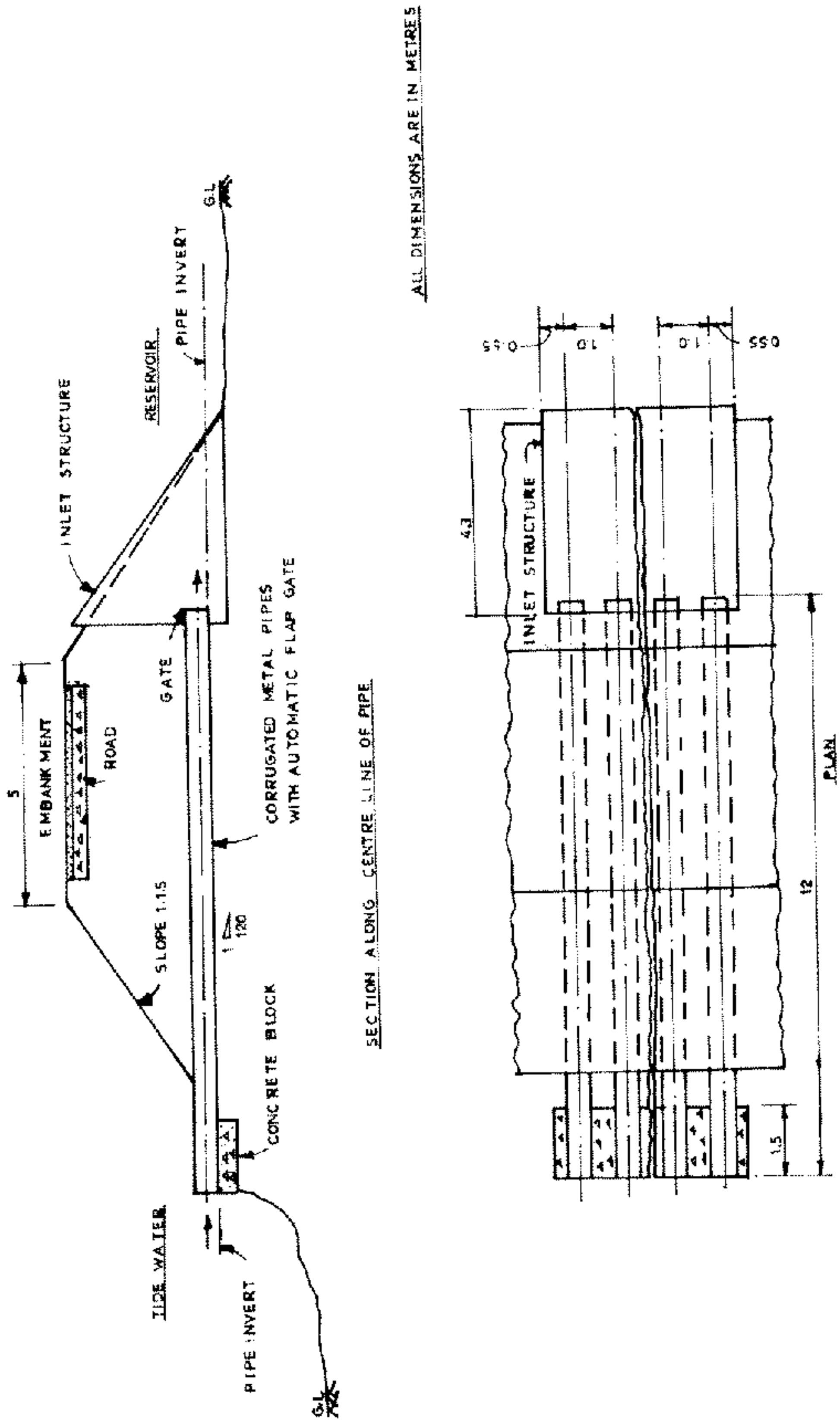

Figure 5. Typical Arrangement of Pipes with Tidal Flap Gates

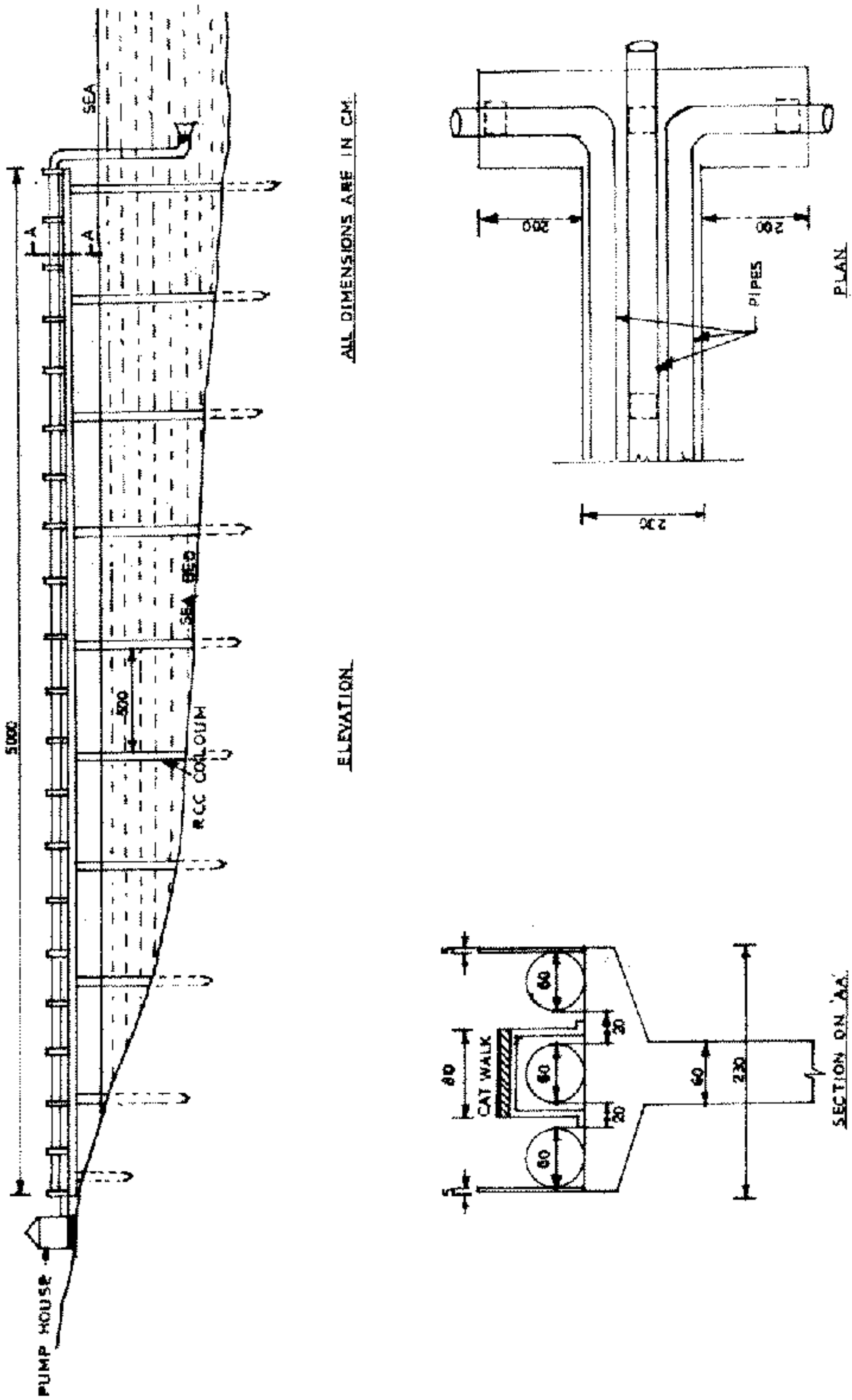

Figure 6. Arrangement of Pipes on Jetty for Direct Pumping from the Sea

Where tidal inflow is inadequate, it has to be supplemented by pumping. Propeller and mixed flow pumps are commonly used for this application.

PUMPED INTAKE

Where pumping is involved it must be known whether the water is to be drawn from a tidal backwater or creek or directly from the sea. In the case of pumping from a tidal backwater or creek it must be ascertained whether the link between the backwater and the sea would replenish at the rate at which the brine is being drawn. In certain areas, the sea mouths tend to close owing to sand accumulation (caused by littoral drift) in the peak of summer, choking supply. These phenomena must be studied. Pumping from tidal backwaters generally requires less capital investment and should be resorted to wherever possible.

Where backwaters are not available or are inadequate to meet the project requirements, direct pumping from the sea has to be resorted to. There are, in general, two ways to do this:

(a) by running the suction pipe along a jetty and then turning it vertically down (Figure 6)
(b) by running a flexible suction line along the sea bed connected to a concrete suction block (Figure 7).

The actual pumping capacity required can be computed as follows:

Suppose the daily pumping requirement is estimated to be 10,000 cubic metres. Assuming pumping for 20 hours, the capacity required would be

$$\frac{10{,}000}{20 \times 60} = 8.3 \text{ cubic metres/min.}$$

Normally about 30% standby capacity is provided to take care of breakdowns, etc. Therefore, the pumping capacity would be 11 cubic metres/min.

Pump specifications. Vertical turbine (propeller) or mixed flow pumps are generally recommended for the high volume low head application of seawater pumping. Materials of construction are cast iron for the body with open Niresist impellers. Motors are totally enclosed and fan-cooled. The pumps are primed by use of vacuum pumps with the delivery valve closed. After the pump casing is filled with water, the pump is started and the valve opened slowly. Pumps can discharge either into the atmosphere or into a submerged tank.

PREVENTION OF SAND BAR FORMATION

Along certain coastlines, there is a continuous littoral sand drift. At estuaries, during the wet season, upland

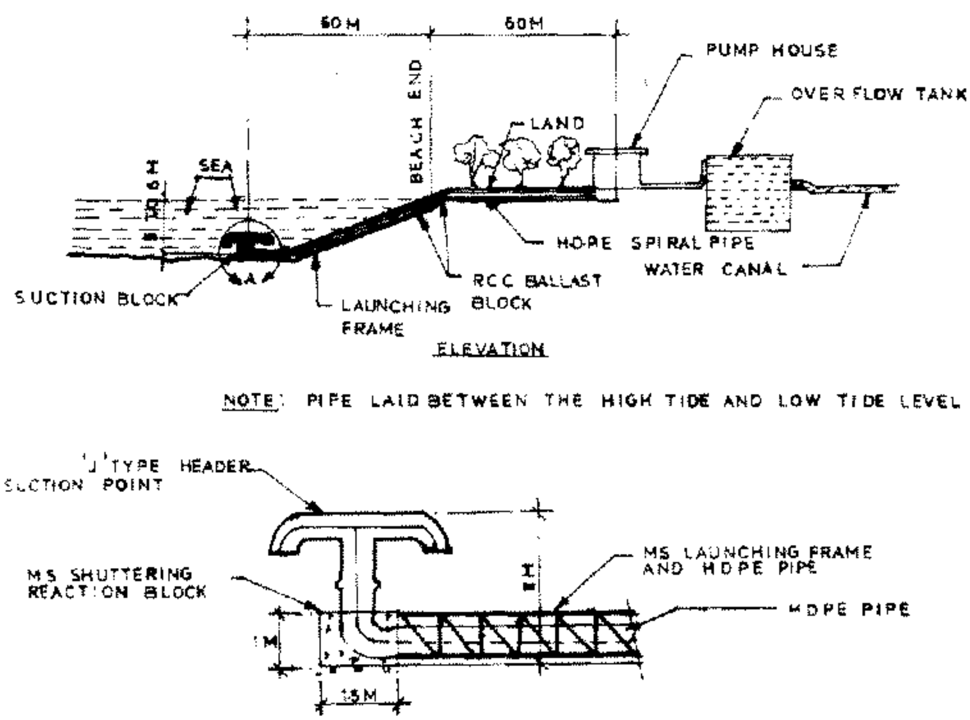

Figure 7. Flexible Pipes on Ocean Floor for Direct Pumping from the Sea

storm water continuously drains into the sea, preserving an open sea mouth. However, as summer advances and upstream flow ceases, littoral sand begins to accumulate along the shore, forming a 'bar' and eventually cutting off the backwater from the sea. A salt works drawing its brine from the backwater faces brine scarcity at a time when it needs it most. The solution to the problem would be direct pumping from the sea or construction of a groyne perpendicular to the coastline and adjacent to the sea mouth and between the mouth and the direction of sand drift. The groyne normally extends into the sea for a distance of 100–150 metres, depending upon the nature and extent of sand drift, and succeeds in blocking sand accumulation at the sea mouth and maintaining the mouth open.

SUMMARY

By a careful study of the contour levels of a solar salt plant site and the relative tidal variations, a system of gravity/pumped intake can be designed at minimum capital and operating cost.

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