AN ABSTRACT OF THE THESIS OF

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(Name) (Degree) (Major)

Date thesis is presented June 9, 1965

Title DIGITAL SIMULATION OF A LOAD-PEAKED GENERATING STATION LOCATED IN A TIDAL ESTUARY

Abstract approved [redacted]
(Major professor)

This simulation is a modelfor a tidal power-peaking plant that can be used to determine the electrical peaking generation for a given set of conditions.

The simulation internally contains a tide producing function for a specific year, the hydraulic characteristics of the plant, and the plant's machines' characteristics. The operator submits an expected load profile curve for some day, the date for that curve, and the state of the estuary some time previous to the time of the expected load.

The operator can then select an operating mode and its net results from one of the six possible operating modes predicted by the computer. These states include various use combinations of a full or empty estuary, with or without the use of pumping operation to attain a greater head.

The simulation can be run on an individual day basis or on a consecutive daily basis.

This was programmed for an IBM 1620 computer with 40k digits of storage. This program uses approximately 38k digits of storage.

DIGITAL SIMULATION OF A LOAD-PEAKING GENERATION STATION LOCATED IN A TIDAL ESTUARY

by

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A THESIS

submitted to

OREGON STATE UNIVERSITY

in partial fulfillment of
the requirements for the
degree of

MASTER OF SCIENCE

June 1966

APPROVED:

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Date thesis is presented June 9, 1965

Typed by Carol Baker

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DIGITAL SIMULATION OF A LOAD-PEAKING GENERATING STATION LOCATED IN A TIDAL ESTUARY

I. INTRODUCTION

The use of tidal energy for electrical power generation represents the utilization of a natural resource not currently exploited by utility systems. Such a facility becomes more useful to the utility company when the peak-load generating capacity of this type of plant can be forecasted for any one day in a year.

One manner by which this capacity can be forecasted is by the use of a simulation on a digital computer. This thesis will concern itself with the development of a digital simulation as a tool that can be used to predict the capability of this facility.

As a means of verification, partial characteristics of the Rance Estuary in France and the generating facility located there have been used in the preparation of this model. The term "partial" is used because some of the physical data were not obtainable from the French authorities. This necessitated some assumptions regarding the missing data.

II. SYSTEM DESCRIPTION

The simulation system is represented in Figure 1. This figure represents the various interconnections among the models which make up the simulation system. The supervisory and decision routine is not classified as a "model", but is the controlling program that directs the information flow and the use of each model.

The discussion of the development of each of the components of Figure 1 follow.

Tide Model

The tide generation of this model is accomplished by summing the Fourier sine coefficients that reproduce the tidal action of the sea at the point of interest. Figure 2 illustrates a logic flow diagram for this model.

The determination of the magnitude of the coefficients was accomplished by trial and error. The periods of these coefficients are those from which the tidal forces are derived (5, p. 550). These are;

Principle lunar with period = 12. 42 hours
Principle solar with period = 12. 00 hours
Larger lunar elliptic with period = 12. 66 hours
Luni-solar with period = 11. 97 hours
Lunar fortnightly with period = 327. 86 hours
Lunar monthly with period = 661. 30 hours
Solar semi-annual with period = 2191. 43 hours

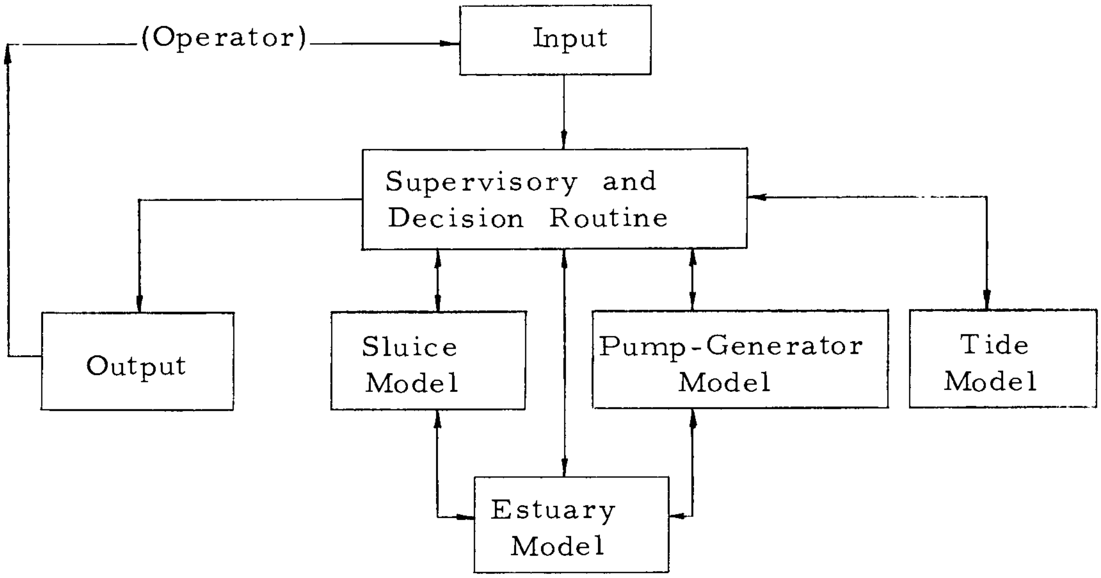

Figure 1. Overall system flow diagram of data exchange between models.

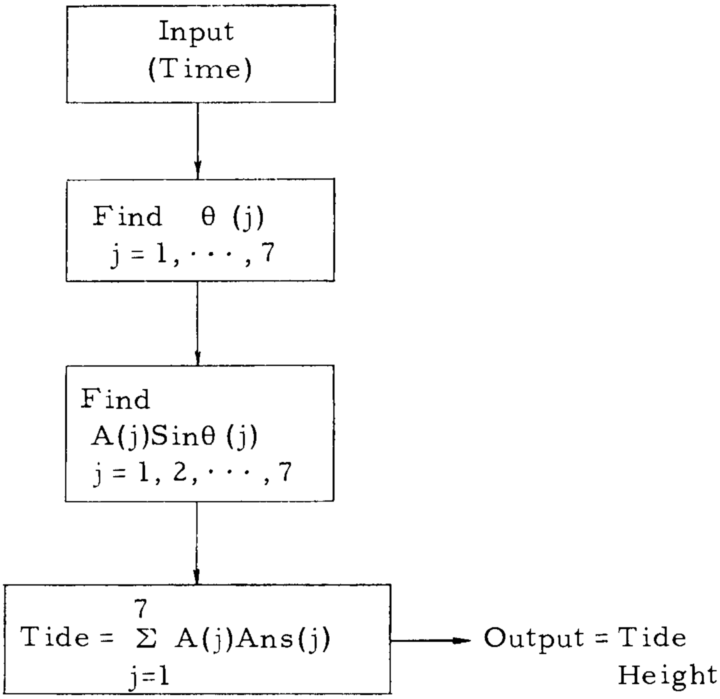

Figure 2. Flow diagram for tide model.

The coefficients for these various frequencies were varied by trial and error methods until the amplitude of the simulated tide nearly equalled, to within ±0.01 of a meter, that of the tides at Saint Malo in France (4). Eleven terms of the sine expansion series were required to maintain the accuracy of each of the trigonometric functions to ± 0.0001.

The model is capable of reproducing tidal data for a simulated time of one year. The input value of time for this model is referenced to the number of hours, to the nearest tenth of an hour, from January first at midnight. Any particular year can be simulated by creating the proper phase shift in each Fourier term by adding or subtracting the appropriate number of hours from the input value of time. In this thesis, a zero phase shift was used since no particular year was being simulated. The coefficients pertaining to the Fourier terms used in this model are as follows;

Principle lunar with amplitude = 4.575 meters
Principle solar with amplitude = 0.338 meters
Larger lunar elliptic with amplitude = 0.594 meters
Luni-solar with amplitude = 0.169 meters
Lunar fortnightly with amplitude = 0.529 meters
Lunar monthly with amplitude = 0.279 meters
Solar semi-monthly with amplitude = 0.246 meters

Estuary Model

This model determines the elevation of the water surface in the estuary as a function of the volume stored. Likewise, the volume stored can be determined from the height of the estuary.

This model could be constructed as a table from which the corresponding values of volume and height could be extracted. However, for the Rance Estuary, sufficient data[1] was available from which approximate mathematical relations could be derived. Figure 3 illustrates the hydraulic characteristics of the estuary.

The volume profile appeared to be parabolic in nature. A plot of the data on log-log paper indicated that Figure 3 could be represented by three exponential equations. One exponential equation for ranges of tidal height from two to five meters. A straight line equation resulted for values of tidal heights less than two meters because the exponent was evaluated as unity.

Starting with the initial values of exponents from a log-log plot, the exponents were adjusted until the results generated matched the given curve. The results are equations (1) and (2) as shown below.

$$V = \begin{cases} (10.48)(0.5H)^{1.0} & \text{for } 0 \leq H < 2 \\ (10.48)(0.5H)^{1.3797} & \text{for } 2 \leq H < 5 \\ (37.10(0.2H)^{1.6106} & \text{for } 5 \leq H < 13 \end{cases} \qquad (1)$$

[1] The original curve sent by Électricité De France to the author was not suitable for direct reproduction in this paper.

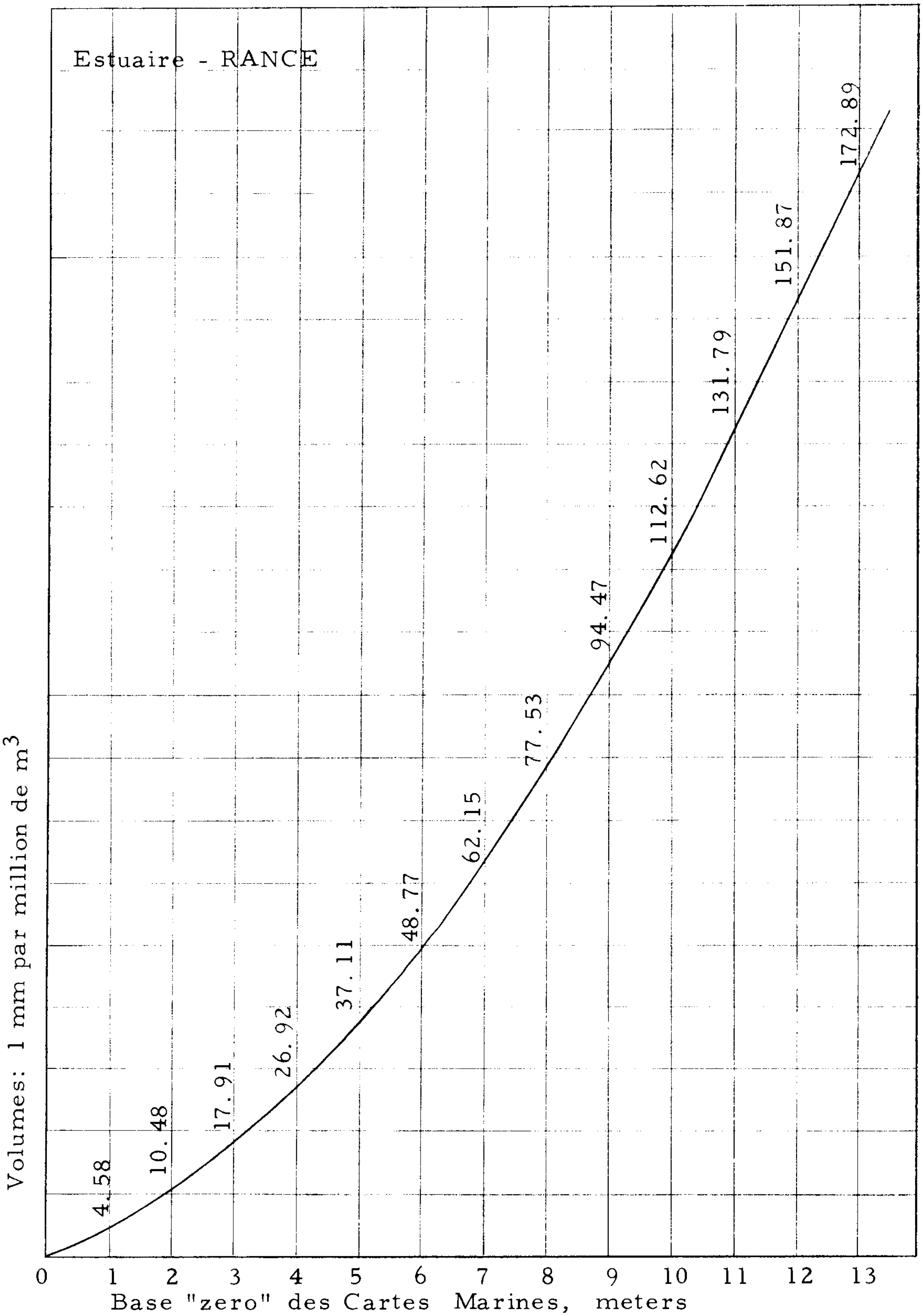

Figure 3. Estuary volume as a function of estuary water elevation.

$$H = \begin{cases} 2\left(\frac{V}{10.48}\right)^{1.0} & \text{for} \quad 0 \le V < 10.48 \\ 2\left(\frac{V}{10.48}\right)^{0.7250} & \text{for} \quad 10.48 \le V < 37.10 \\ 5\left(\frac{V}{37.10}\right)^{0.6210} & \text{for} \quad 37.10 \le V \le 172.89 \end{cases} \qquad (2)$$

A series approximation was then constructed to reduce these mathematical relations to a form [2] that the computer could use. The series relations are shown in equations (3) and (4).

$$x^A = 1 + A\ell n(x) + \left(\frac{A\,\ell n(x)}{2!}\right)^2 + \left(\frac{A\,\ell n(x)}{3!}\right)^3 + \cdots \qquad (3)$$

$$\text{where} \quad \ell n(x) = 2\left[\frac{x-1}{x+1} + 1/3\left(\frac{x-1}{x+1}\right)^3 + 1/5\left(\frac{x-1}{x+1}\right)^5 + \cdots\right] \qquad (4)$$

where $x > 0$

Figure 4 illustrates the flow diagram of this logic calculation. The series approximation is continued until the additional terms have no effect on the tolerance limits. In this case, the estuary water surface elevation is calculated to ± 0.01 meters and the stored value to ± 0.01 mega cubic meters.

This simulation model could also contain an additive figure for fresh water flow as a function of time into the estuary. In this particular case, the river flow is negligible compared to the tidal flow.

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[2] Digital computers add, subtract, multiply and divide. Subroutines have to be developed for more complex relations.

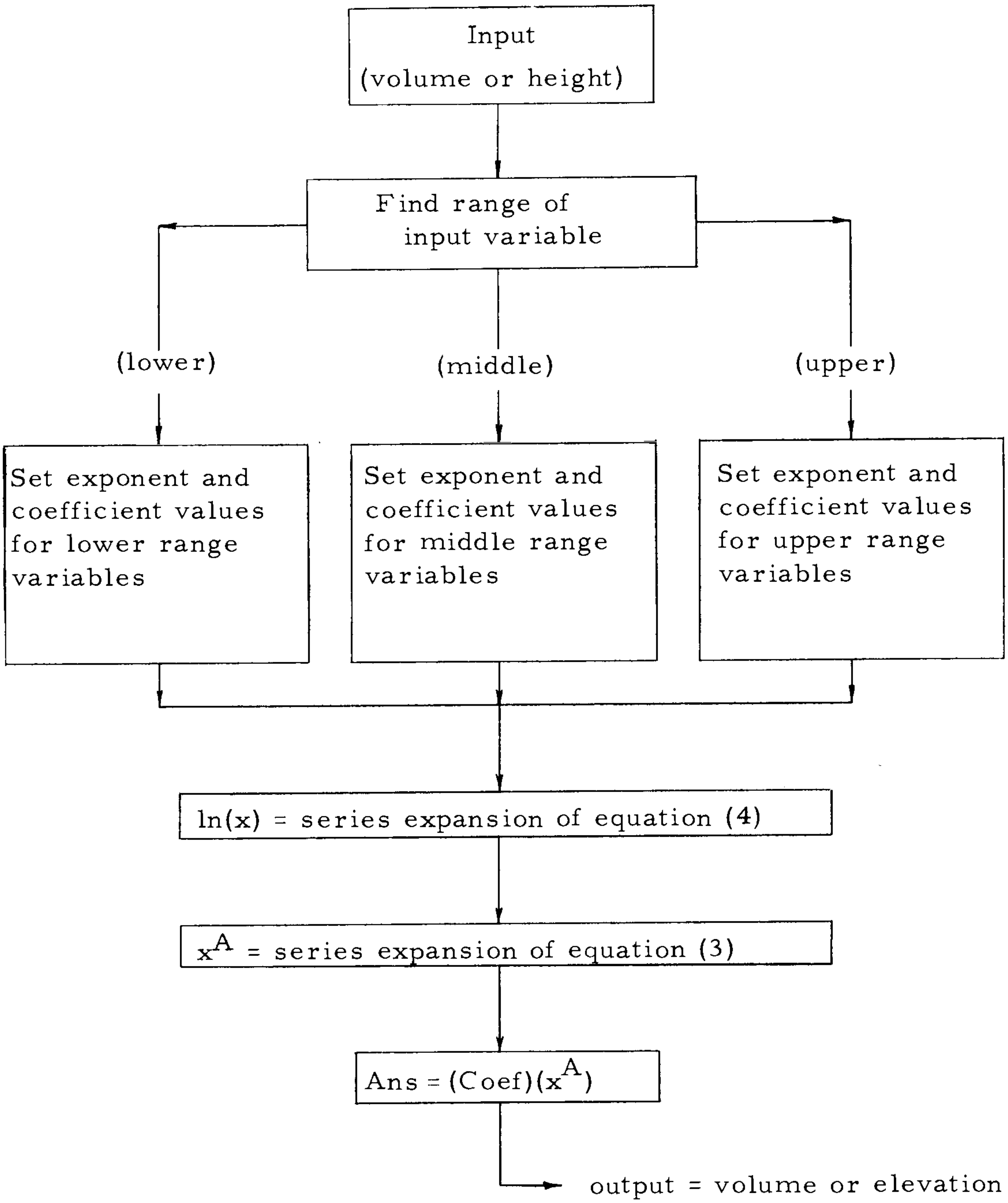

Figure 4. Flow diagram for the estuary model.

An input to this model of estuary elevation produces an output of estuary volume, and vice versa.

Pump-Generator

This model contains the relations of head, flow, and power, any one of which can be expressed as a function of the other two. Because of the interrelations of these parameters, this model becomes well suited to a "table-look-up" method rather than the use of mathematical equations.

Since the turbines engineered for this tidal facility can generate and pump in both directions, four tables of operating characteristics are required. A programmed register contains the information that directs the model to extract information from the proper table.

In this model, the stored information is power, expressed in megawatts. The values of head (difference between estuary and tidal elevations) and fluid flow are used to determine the address of the tabular quantity, power.

The model can be entered with a given head, a given flow, and/or a given power restriction. The model output will contain those parameters not specified. If all three are specified, the model will verify whether or not the point is a valid operating condition. Figure 5 is the flow diagram for this model.

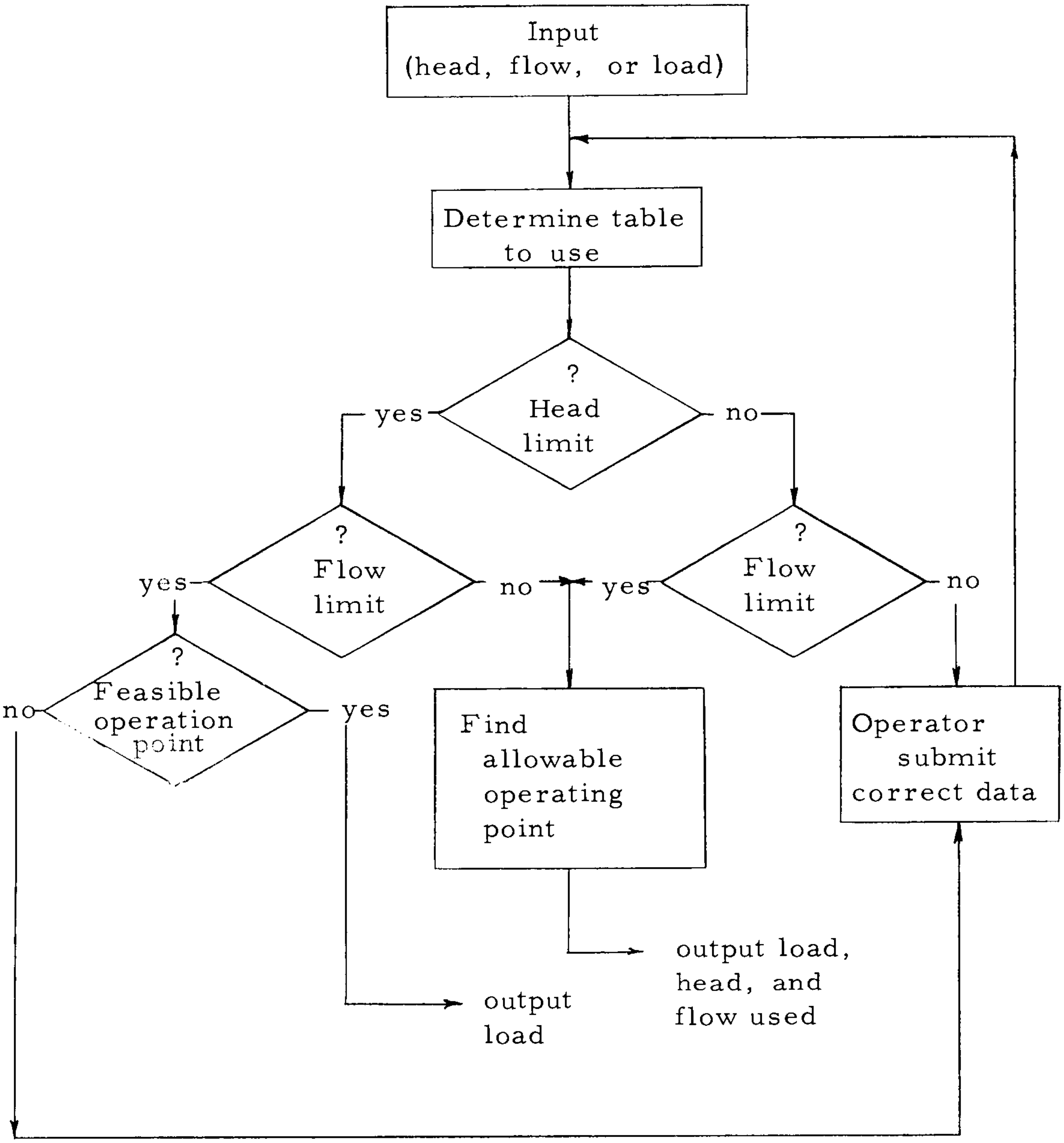

Figure 5. Flow diagram for simulating the machine steady-state characteristics.

A typical type of operation would be to specify an existing head situation and a maximum load restriction. The model output would then contain the flow used. This flow would then be summed over the time interval and the number of units being utilized to obtain the total discharge volume. The estuary fluid elevation is then evaluated, and the tide elevation recalculated. A new head is specified and resubmitted to the model at the next time interval.

The values of power stored in the table are at discrete intervals corresponding to one half meters of head and five units of flow in cubic meters per second. The values for the input or output parameters, however, do not have to be on these discrete points. The model will linearly interpolate between parameter values, thus establishing parameter values on a continuum.

Tolerances maintained in this simulation model are ± 0.01 meters of head, ± 1. cubic meters per second of flow, and ± 0.01 megawatts of power. The machine characteristic values were calculated by using the operational efficiency curves of a prototype machine for the Rance Tidal Project (1). Using several known operating values as pivot points (2), the operating characteristics were modified to fit the machines in the Rance Tidal Project. Figures 6 and 7 illustrate the calculated family of power curves.

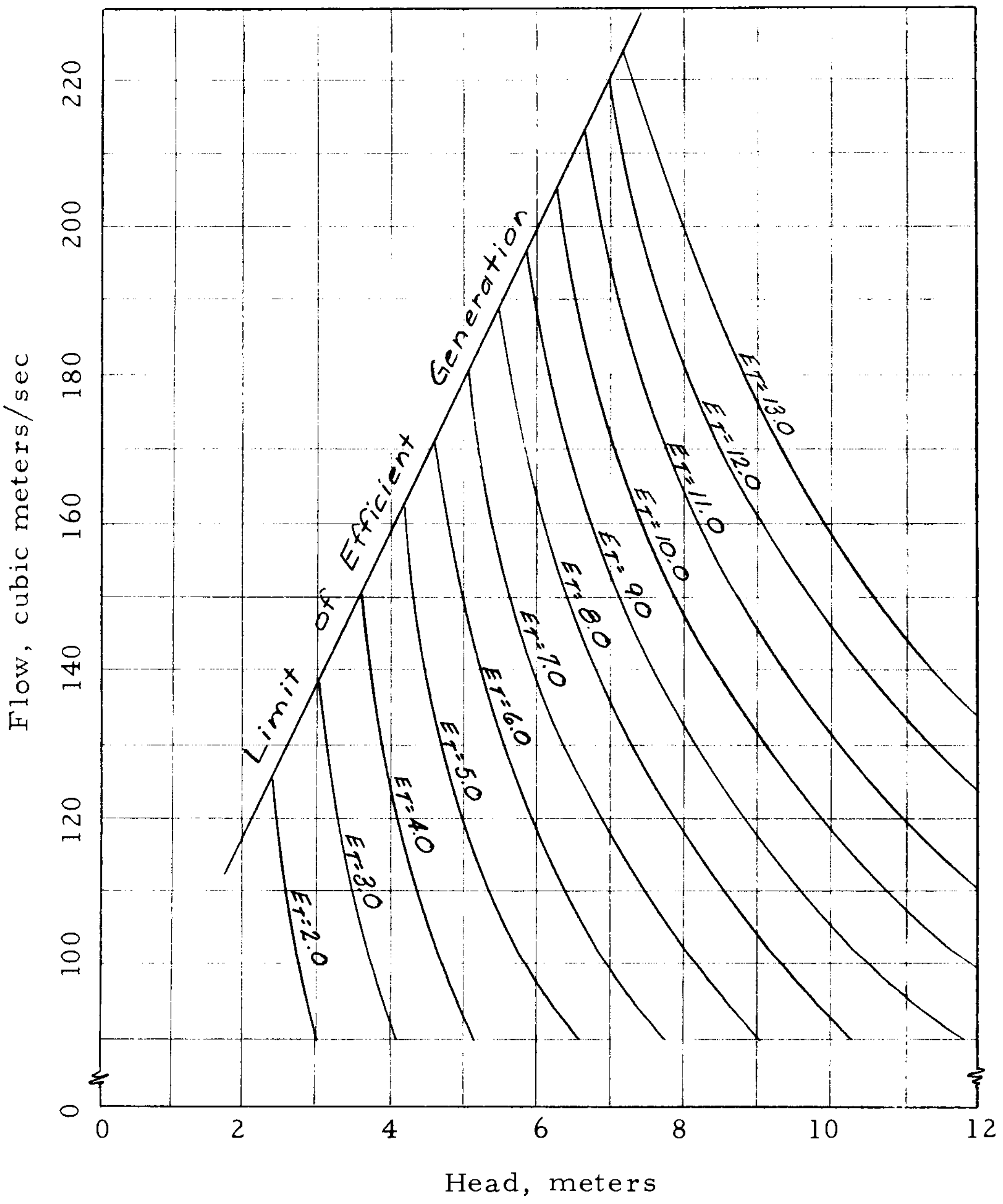

Figure 6a. Machine characteristics for generator operation with fluid flow from estuary to sea. E_T is power generated in megawatts.

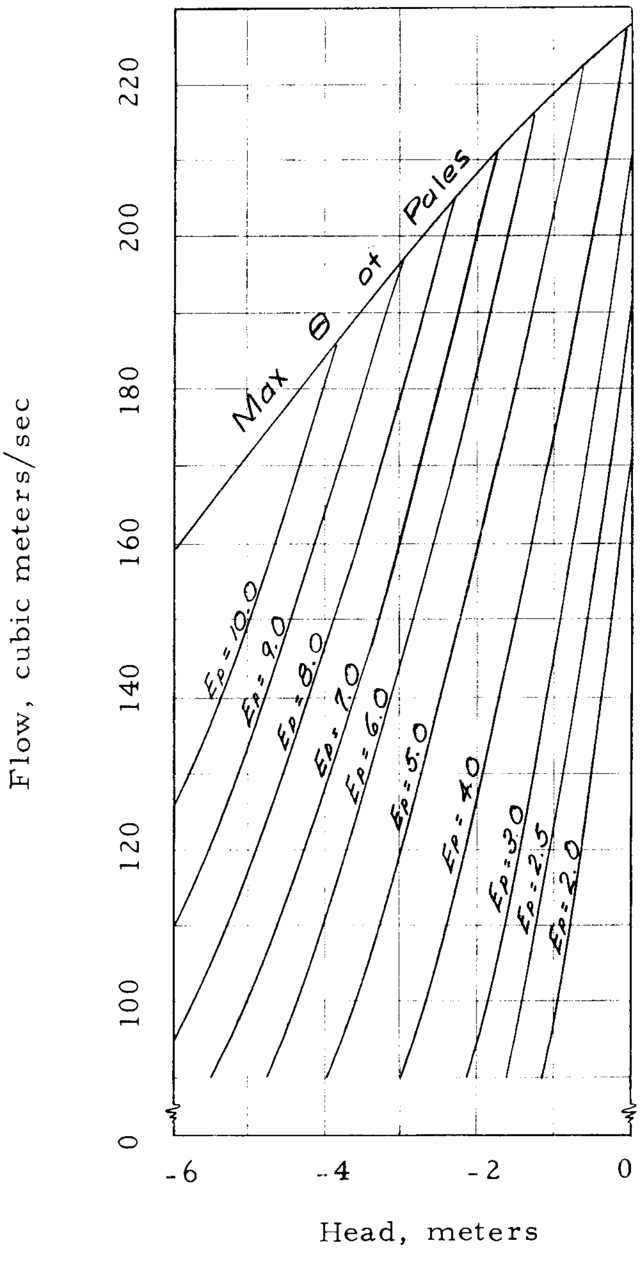

Figure 6b. Machine characteristics for pump operation with fluid flow from estuary to sea. E_p is power consumed in megawatts.

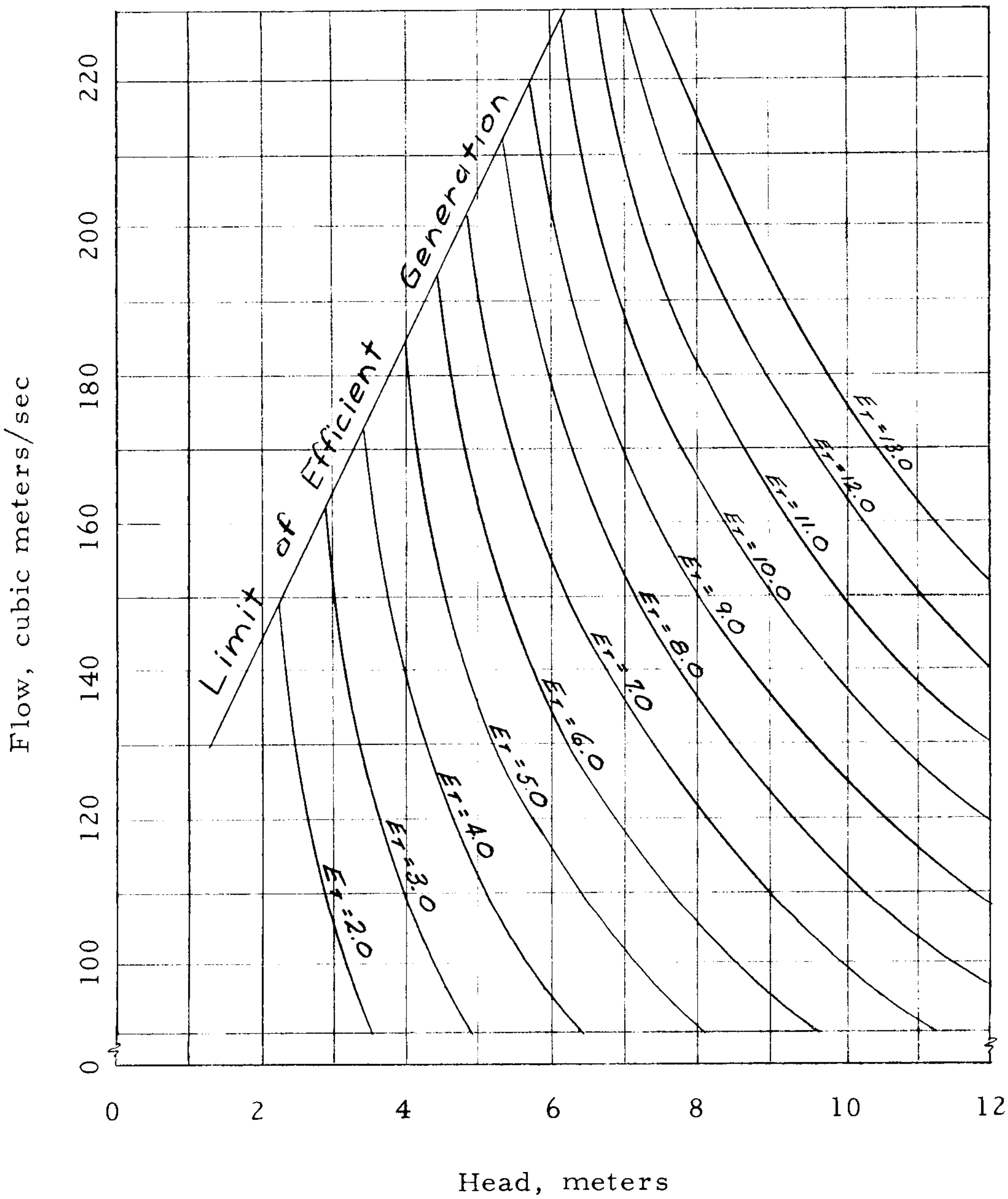

Figure 7a. Machine characteristics for generator operation with fluid flow from sea to estuary. E_T is power generated in megawatts.

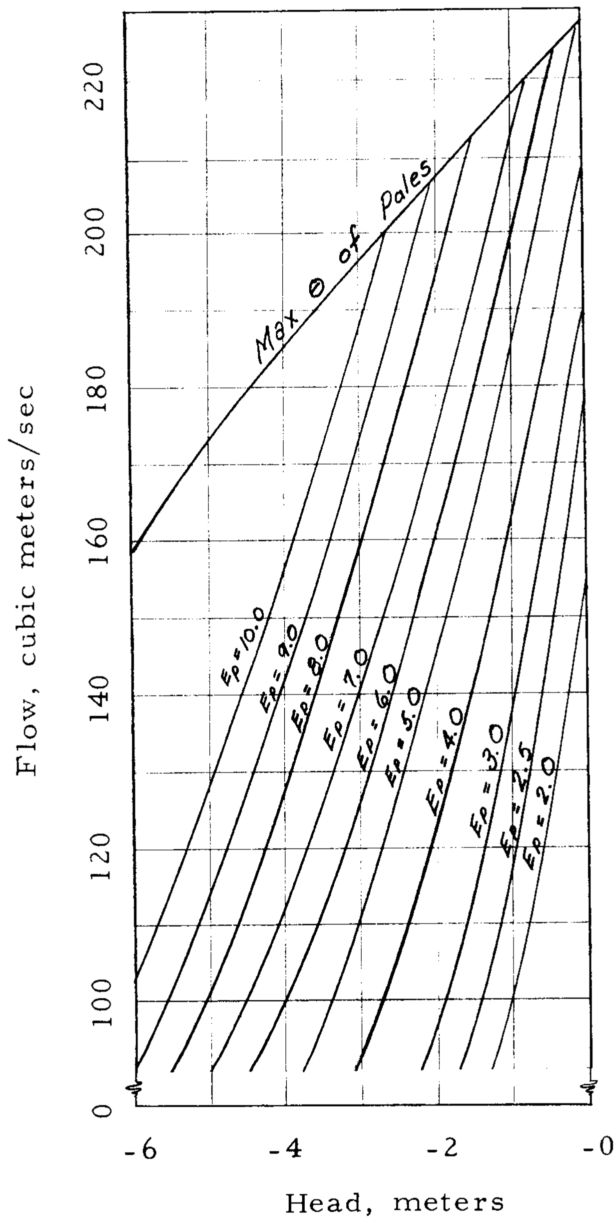

Figure 7b. Machine characteristics for pump operation with fluid flow from sea to estuary. E_p is power consumed in megawatts.

Sluice Model

The model describes the hydraulic operation of the project during those times water is passed through the dam when neither pumping nor generating are taking place. This particular model can be represented by a mathematical relation. Figure 9 on page 26 illustrates a cross section of one of the six sluice gates used in the simulated model.

However, some assumptions were used to simplify the relations. One is that the sluice gate will open to the height of the down stream fluid elevation, provided that this height is under plus six meters of elevation. This is the maximum opening the gates can obtain. In this range of down stream elevations, no hydraluic jump is permitted. Thus, flow under the gate is a function of head and opening of the gate. If a hydraulic jump was permitted, a greater flow would occur than without one. The simulation uses the lower flow calculation.

When the down stream elevation is above the gate opening, a hydraulic jump could occur, creating some energy loss. However, it is more likely that the hydraulic jump will be submerged and a flow condition will exist like the one illustrated in Figure 9 on page 26. Assuming no loss at the sluice gate opening, the Bernoulli energy relation produces the following flow equation (3, p. 155-6).

$$Q^2 = 2g(A+h)^2(HE - H) \tag{5}$$

Upon utilization of the momentum equation and conservation of mass relations the energy head loss equation becomes (Ibid.)

$$\Delta H_e = \frac{(\mathcal{V}_A - \mathcal{V}_H)^2}{2g} - \frac{(H - h_2)^2}{2(H+h)} \tag{6}$$

Upon incorporating this head loss relation into the energy equation (Appendix I) the following expression represents the flow equation for fluid through the sluice gates.

$$Q^2 = \left[2g(A+h)^2\right] \left[\frac{(H+h)^2}{(H+h)^2 + (H-A)^2}\right] \left[(HE - H) + \frac{(HE - H)^2}{4(H+h)}\right] \tag{7}$$

For the case when $H \leq 6.0$ meters, $A = H$ and equation (7) reduces to equation (5).

Inputs to this simulation model are the elevations of the tide and estuary. The output is the flow of water in cubic meters per second per unit width. Fluid flow is positive for flow into the estuary and negative for flow out of it.

Input

The operator submits a forecasted system load profile for some day, the date of the submitted profile, and the state of the estuary at some specific time previous to the load profile. The load profile contains data at every two tenths of an hour starting from seven A. M. through to seven P. M. This is assuming that load peaking will not be required during the evening hours. For this simulation, the range of values for each data point is from a value at 0.00 megawatt to a value of 999.99 megawatts. For values larger than this, it is possible to change the format for reading the load profile into the computer.

The operator may elect to continue the simulation based on the result of the previous day. To do so, he selects one of the possible operating modes [3] submitted by the computer for that day. The computer then proceeds to determine possible modes for the next day.

Supervisory and Decision Routine

This routine establishes the guide lines for the operation of the component parts of the simulation. The basic criterion in this routine is that the required peaking operation will start at some level of power and generate all load above this level relative to the load profile. The simulation determines the level of power and the time generation will commence. The reference level will vary as a function of

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[3] These modes to be discussed in more detail later.

the submitted load profile and tidal conditions of the date for which a load curve is submitted. Figure 8 illustrates the logic flow for this routine.

The simulator creates six possible operating modes. The first three specify that the estuary will be as full as possible prior to the expected load reference. The first mode is without using pumping. The second is with pumping. The third mode is with pumping and any excess generation possible after the load reference has been satisfied, but no generation after seven P. M.

The last three modes of operation are like the first three modes except that the estuary is specified to be as low as possible prior to the expected load. The difference among these last three modes being operation without pumping, with pumping, and excess generation up to seven P. M. The results of these six runs can be compared on the basis of the net megawatt hours of energy produced.

Output

The output from the simulated runs are graphs, and digital net energy sums for the six operating modes. The elevations of the estuary and tide are plotted as functions of time. Whenever generation or pumping is being conducted, cross hatching occurs between these two levels. The forecasted load curve and load reference level are also plotted as functions of time. Cross hatching occurs during

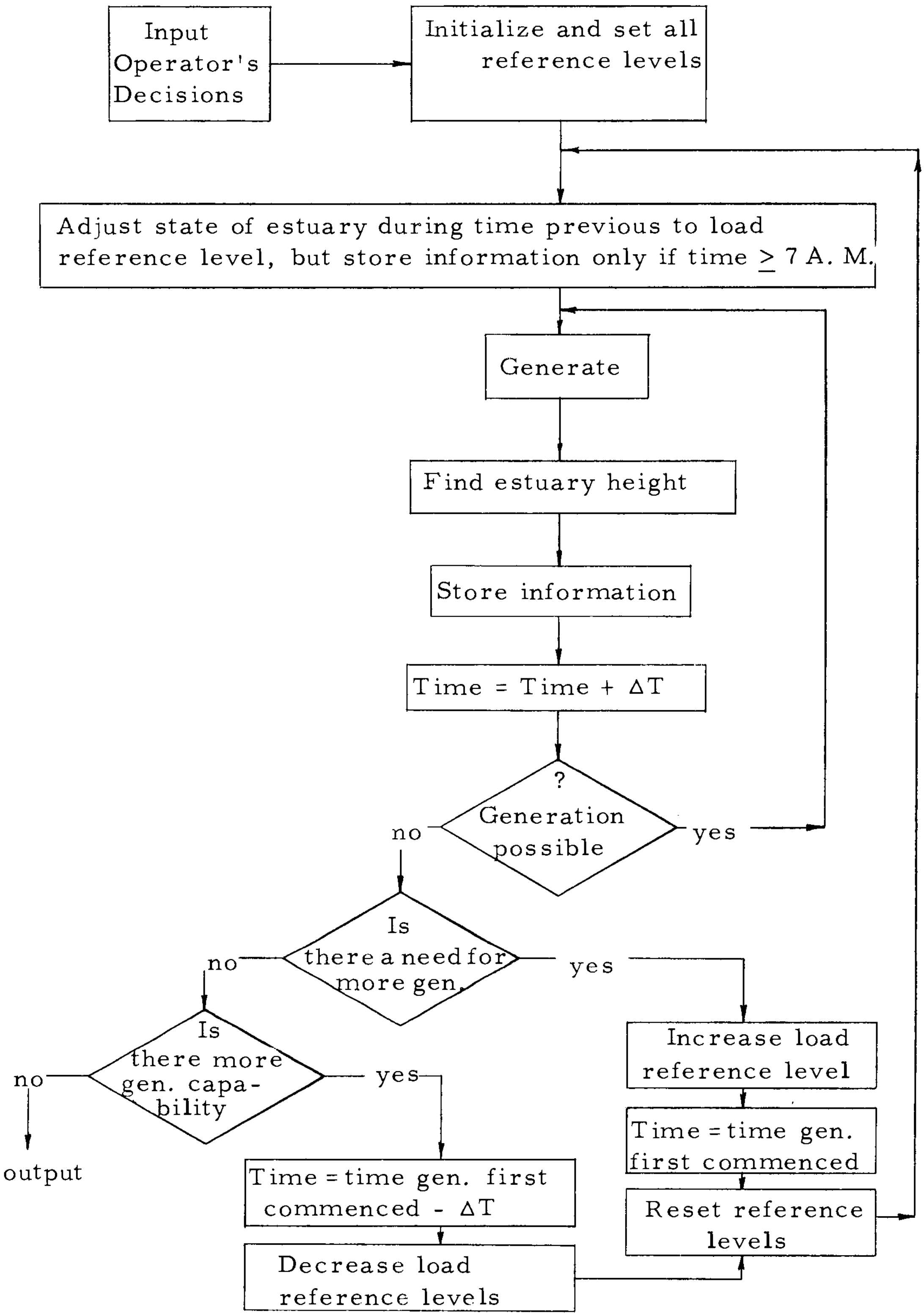

Figure 8. Flow diagram of supervisory and decision routine.

generation and pumping cycles.

Results in the form of net energy generated, and energy consumed in pumping are represented by summed values. The time generation commenced for each mode is also submitted to the operator.

III. COMMENT ON THE SIMULATION

Computer Source Deck Language

The simulation program was written for an IBM 1620 computer with 40k core storage locations. The language used was SPS. This language was used in order to conserve space and running time. Program debugging and correction was greatly facilitated with SPS as compared to the FORTRAN language. Approximately 38000 core storage locations are used by this present program.

Restrictions on the Programmed Simulation

It was specified that the curve of the load profile was to be for a duration of only 12 hours starting at seven in the morning. This is not a physical restriction as far as the computer is concerned. In order to expand this time range, 24 more bits of core storage per delta time unit will need to be reserved. There is available space to do this. However, 61 data-time points (seven A. M. to, and including seven P. M. at two tenths of an hour interval as a delta time unit) conveniently fit the perforated paper upon which the output was placed.

By forcing the computer to branch to location 00402, the computer will read in the table values, on cards, used in the pump-generation simulation model. It was stated that this model used four tables. However, only three are actually loaded. The same table for the generation characteristics is used for fluid flow from the basin to the sea and for fluid flow from the sea to the basin. Different values of flow and head for the same data point in the table are obtained by an address modification factor that is determined by the operating mode.

The permissible operating head range for pumping is from zero to four meters. The prototype from which the table values were calculated had an engineered maximum restriction of six meters. Due to core storage restrictions the six meter figure was reduced to four meters under the assumption that this reduction would not materially effect the simulation. An estimated 3500 storage locations were saved by this reduction and by "packing" program statements into the blank matrix field areas.

The table values for the generators were restricted to a minimum head of two meters to a maximum head of twelve meters. The upper and lower limits were determined as the limits of efficient or conservative generation.

The steady-state surface slope for water flowing down stream was found to be about 0.01 meters per mile of estuary length (Appendix II). This was for a high value of flow which was rarely used. Therefore, the calculation for this phenomenon was neglected in determining the effective head to pumps and generators.

IV. PREDICTION OF PEAKING CAPACITY

The simulation predicts the peaking capacity in each of the six modes of operation specified by the supervisory and decision routine. A sample of this predicted capacity is illustrated on the chart in Appendix III on page 33. The chart is a visual display of the peaking capacity of the facility.

From this display, an operator will be able to know the end results of manual plant operation if he follows any one of the possible modes as if they were operating specifications. The end conditions from plant operation can then be specified as initial conditions for the next day's operation. This enables the computer to determine six possible modes of operation for the next day's choice of peaking operation.

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APPENDIX

APPENDIX I. SLUICE GATE DERIVATION

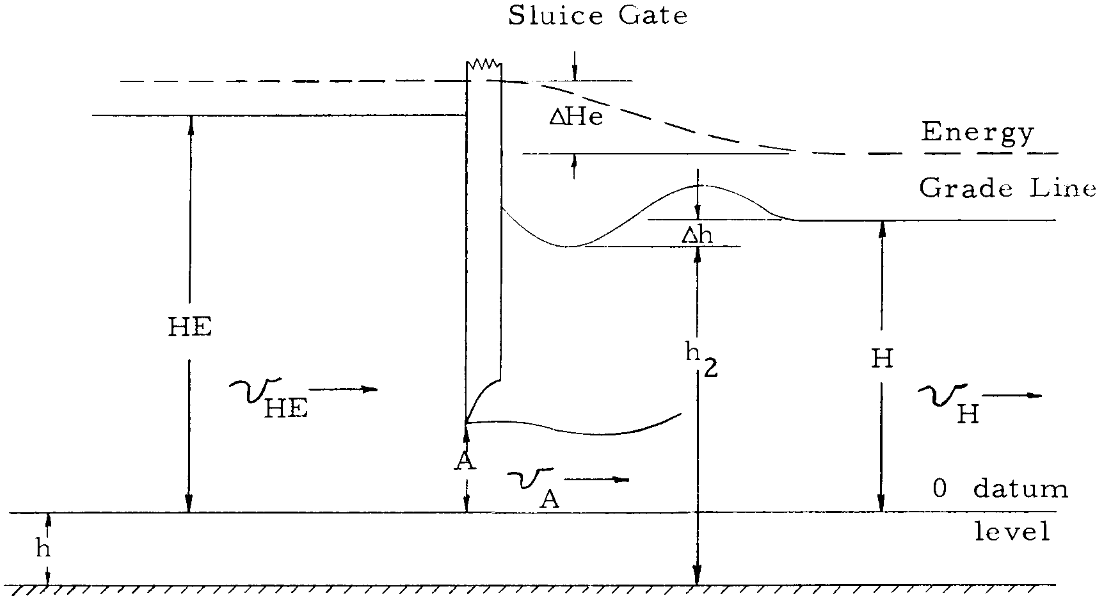


Figure 9. Pictorial representation of a sluice gate in the structure located in a tidal estuary.

Using Bernoulli's equation for the conservation of energy and the conservation of mass relations, the above diagram can be described as (3, p. 155-6)

$$\frac{v_{HE}^{2}}{2g} + HE + h = \frac{v_{A}^{2}}{2g} + H + \Delta HE$$

where $v_{HE} \approx 0$

$$\Delta HE = \frac{(v_A - v_H)^2}{2g} - \frac{(H - h_2)^2}{2(H+h)}$$

$$Q = v_A(A+h) = v_H(H+h)$$

The relation describing h_2 as a function of Q, HE, and H is very complicated and is normally approached by an empirical method. Since data were not readily available for this type of sluice gate, an assumption about the submerged hydraulic jump was made. Δh was formulated to be equal to one-half of the head difference, or

$$\Delta h = 1/2\,(HE - H)$$

This means that

$$h_2 = \frac{3H - HE}{2} + h$$

Upon substitution of the above relations back into the original energy equation and equating the $\mathcal{V}_A$ term to the other relations

$$\frac{Q^2}{2g(A+h)^2} = (HE - H) - \frac{\left(\frac{Q}{A+h} - \frac{Q}{H+h}\right)^2}{2g} + \frac{\left(H - \frac{3H-HE}{2}\right)^2}{2(H+h)}$$

Transferring all Q's to the left-hand side

$$\frac{Q^2}{2g(A+h)^2}\left(1 + \frac{(H-A)^2}{(H+h)^2}\right) = (HE - H) + \frac{(HE - H)^2}{4(H+h)}$$

Solving for Q^2

$$Q^2 = \left[2g(A+h)^2\right]\left[\frac{(H+h)^2}{(H+h)^2 + (H - A)^2}\right]\left[(HE - H) + \frac{(HE-H)^2}{4(H+h)}\right]$$

For cases when $H < HE$, the above is rearranged so that the symbols of H and HE interchange.

APPENDIX II. TAIL-WATER RISE CALCULATION

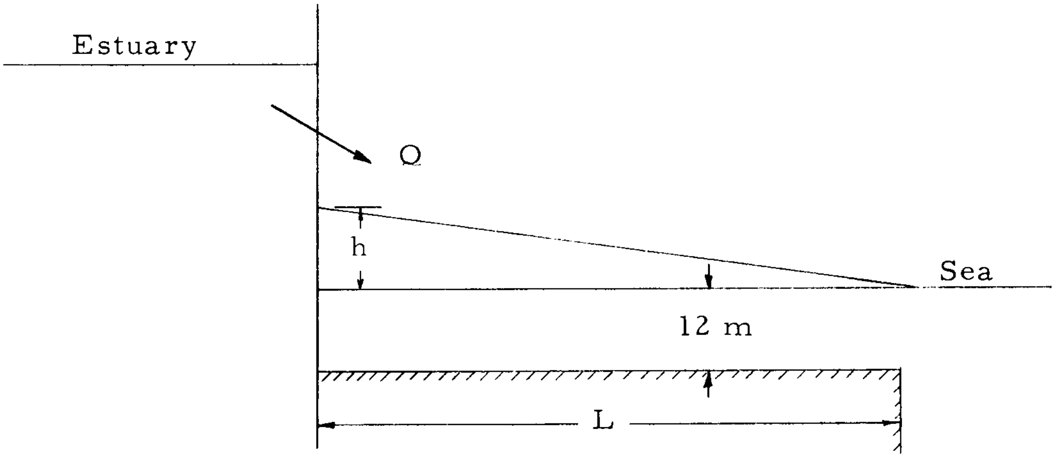


Figure 10. Tail-water rise needed to maintain a steady-state flow to the sea.

In order to determine the head at the dam site, the amount of tail-water rise, h, as a function of flow, Q, is needed. Assuming a flow of 300 cubic meters per second per machine

$$\text{Total } Q = 24 \text{ units} \times 300\ m^3/\text{sec-units} = 7200\ m^3/\text{sec}$$

The Rance Estuary's tidal basin at low-low tide has a configuration of:

Cross Sectional Area

$$= (12 \text{ mtr depth}) \times (600 \text{ mtr width})$$

$$= 7200 \text{ mtr}^2$$

$$\text{celerity} \doteq \sqrt{(g)(\text{depth})}$$

$$= [(9.8)(12)]^{1/2} = 10.85 \text{ meters/sec}$$

$$= 2.5 \text{ miles/min}$$

Hydraulic radius, R_h = Cross sectional area/wetted perimeter

$$= 7200 \text{ mtr}^2/(600 + 24)$$

$$= 11.5 \text{ mtr}$$

Resonant wave length ($1/4\ \lambda$)

$$1/4\ \lambda = 1/4\ CT$$

where T = tidal period, in seconds

C = celerity

$$1/4\lambda = (0.25)(10.85)(12.5)(3600)$$

$$= 122,500 \text{ mtr}$$

Since the length of the estuary, L, is about 1700 meters, resonance will not occur.

Using Chezy-Manning equation for the slope of the surface of the water in a channel at steady state conditions, Q becomes

$$Q = (1.49/n) A R_h^{2/3} S_o^{1/2}$$

where $S_o = h/L$

n = boundary roughness factor

Upon rearranging

$$h = \left(\frac{Qn}{1.49}\right)^2 \frac{L}{A^2 R_h^{4/3}}$$

if $Q = 7200$

$n = 0.02$

L = unit length of 1 mi

$$h = \left(\frac{144}{1.49}\right)^2 \frac{161,000 \text{ cm/mi}}{(52 \times 10^6)(26)}$$

$$= 1.07 \text{ cm/mi}$$

This value is low enough that it will be neglected in head calculations.

APPENDIX III. MODE CHARTS

The charts on page 33 illustrate the possible modes of operation for peak-load generation for May 1, 19xx. The initial condition which produced these charts was a specified input of estuary elevation equal to 6.65 meters at midnight of the morning of May 1.

For modes one through three, it is assumed that the operator manipulates the plant such that the estuary would be as full as possible. Modes four through six assumes that the estuary will be as low as possible.

The data specified for this sample has a tidal configuration such that peak-load generation is possible only for operating specifications compatible with modes one through three. Mode four was an infeasible peak-load operation because there was not a sufficient head to permit generation. The addition of pumping, mode five, did not add sufficient head to allow load-peaking. However, mode six shows that off-peak generation was possible. On the other hand, off-peak load generation was not possible for mode three.

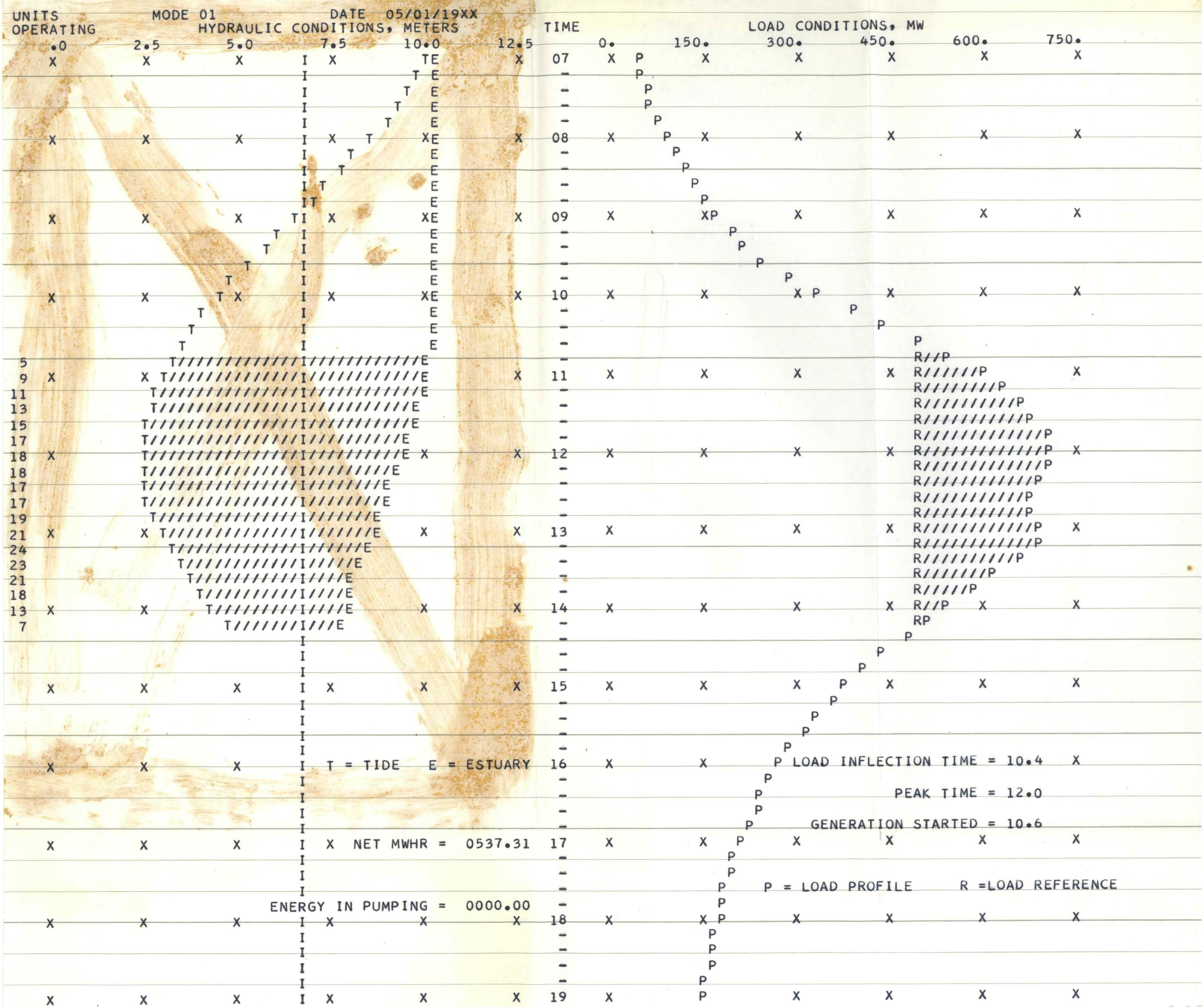
It should be noted that for modes two and three, the system load was increased above the expected profile because of the added load for pumping.

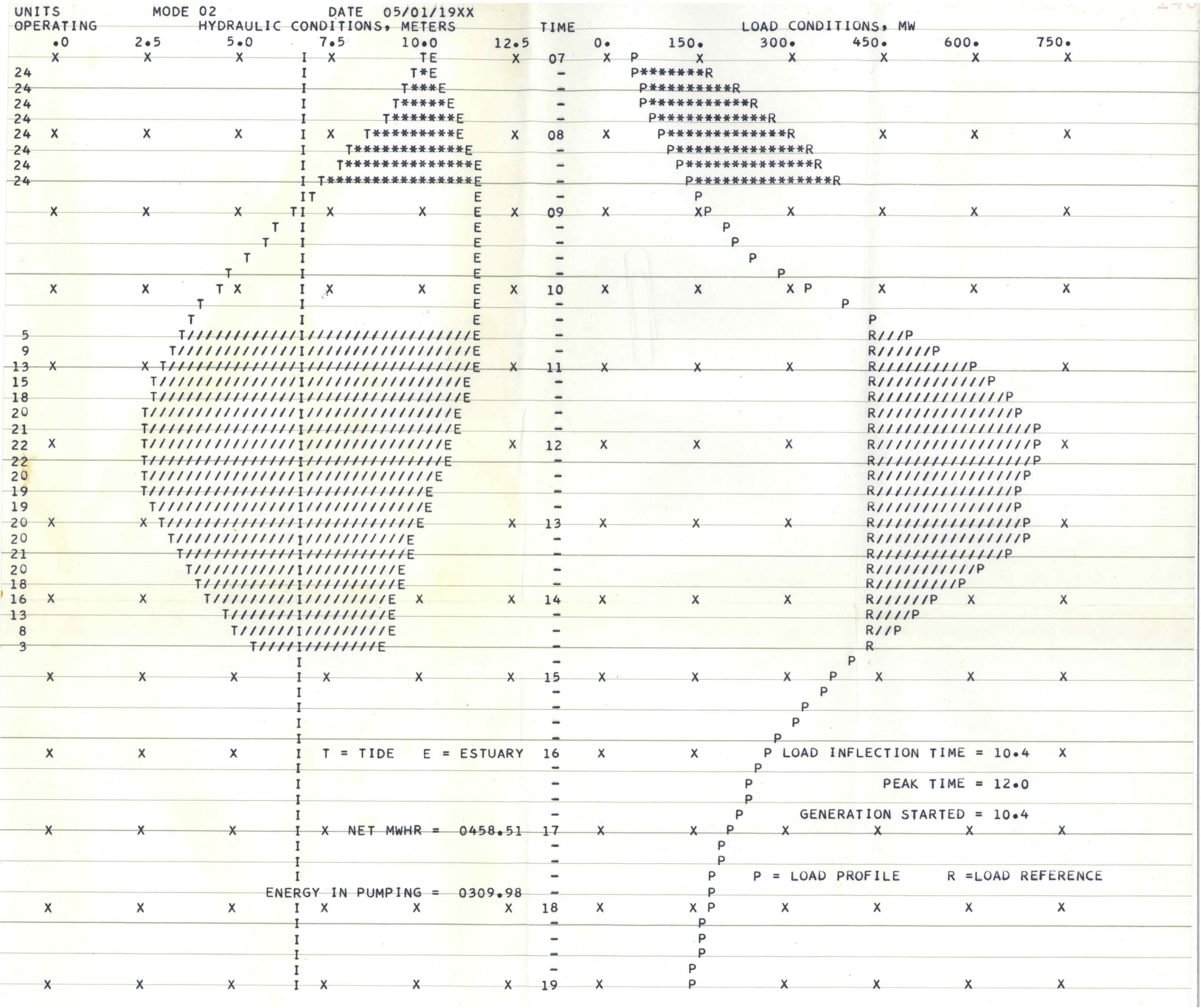
The extreme left-hand edge of the charts contain the number of pump-generator units being utilized during each time interval to perform the required operation.

Symbols which are not self defined on the charts are as follows: "I" represents mean tide level which is 6.65 meters of fluid elevation; Cross hatching with stars, "*", represents a pumping operation while cross hatching with slashes, "/", represents a generating operation; "X"'s represent scale markers as defined at the top of each page.

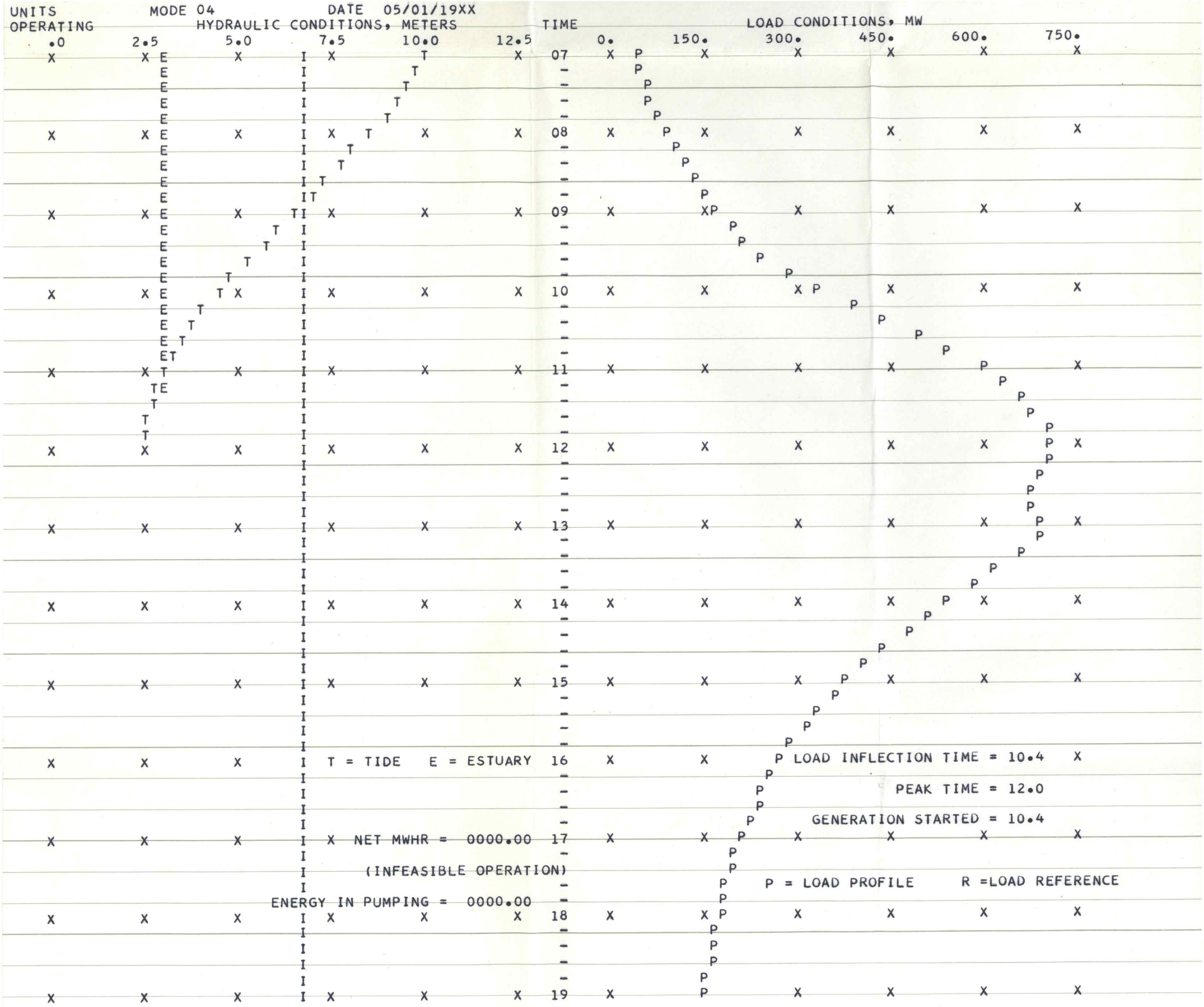
The load profile is a representative one. It is not intended to represent any particular system load profile.

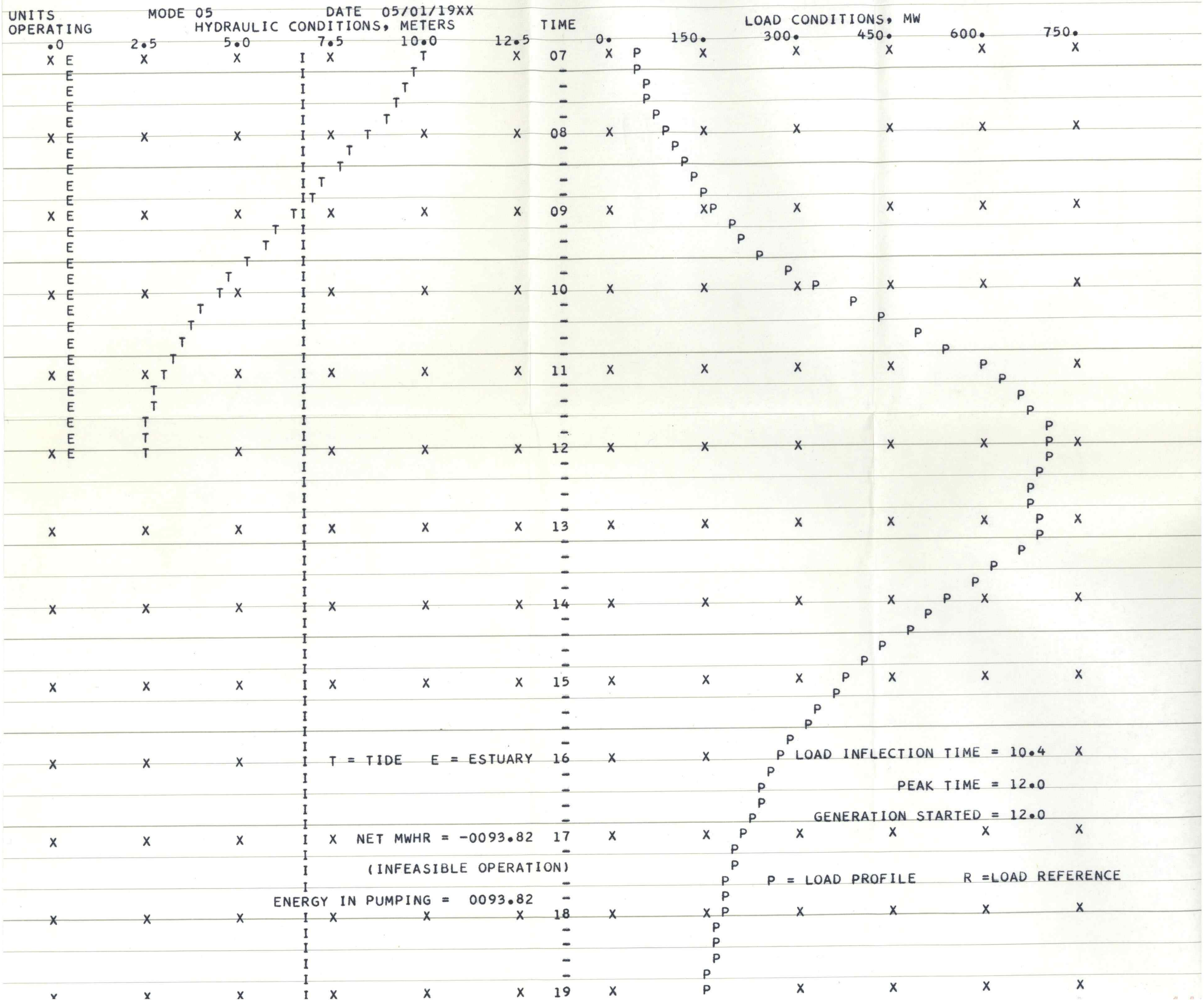
Figure 11. Mode Charts.


UNITS OPERATING
MODE 01
DATE 05/01/19XX
HYDRAULIC CONDITIONS, METERS
.0 2.5 5.0 7.5 10.0 12.5
TIME
LOAD CONDITIONS, MW
0. 150. 300. 450. 600. 750.
07 08 09 10 11 12 13 14 15 16 17 18 19
5 9 11 13 15 17 18 18 17 17 19 21 24 23 21 18 13 7
T = TIDE E = ESTUARY
NET MWHR = 0537.31
ENERGY IN PUMPING = 0000.00
LOAD INFLECTION TIME = 10.4
PEAK TIME = 12.0
GENERATION STARTED = 10.6
P = LOAD PROFILE
R =LOAD REFERENCE


UNITS OPERATING
MODE 02
DATE 05/01/19XX
HYDRAULIC CONDITIONS, METERS
TIME
LOAD CONDITIONS, MW
.0 2.5 5.0 7.5 10.0 12.5
0. 150. 300. 450. 600. 750.
07 08 09 10 11 12 13 14 15 16 17 18 19
T = TIDE E = ESTUARY
P LOAD INFLECTION TIME = 10.4
PEAK TIME = 12.0
GENERATION STARTED = 10.4
NET MWHR = 0458.51
ENERGY IN PUMPING = 0309.98
P = LOAD PROFILE R =LOAD REFERENCE

```
UNITS          MODE 03              DATE  05/01/19XX
OPERATING          HYDRAULIC CONDITIONS, METERS                 TIME              LOAD CONDITIONS, MW
  .0        2.5         5.0         7.5       10.0        12.5        0.      150.       300.       450.       600.       750.
   X         X           X        I  X          TE          X    07    X  P       X          X          X          X          X
24                                I           T*E                 -       P*******R
24                                I          T***E                -        P*********R
24                                I         T*****E               -        P***********R
24                                I        T*******E              -         P************R
24 X         X           X        I  X   T*********E        X    08    X      P*************R           X          X          X
24                                I    T***********E              -           P**************R
24                                I   T*************E             -            P**************R
24                                I T***************E             -             P**************R
                                  IT                E             -              P
   X         X           X      TI  X          X    E       X    09    X         XP          X          X          X          X
                              T I                   E             -                 P
                             T  I                   E             -                  P
                           T    I                   E             -                    P
                         T      I                   E             -                       P
   X.        X         T X      I  X           X    E       X    10    X          X          X P        X          X          X
                     T          I                   E             -                                P
                    T           I                   E             -                                  P
 5                 T////////////I///////////////////E             -                                  R///P
 9                T/////////////I///////////////////E             -                                  R//////P
13 X         X T////////////////I///////////////////E       X    11    X          X          X       R//////////P          X
15              T///////////////I//////////////////E              -                                  R////////////P
18              T///////////////I//////////////////E              -                                  R//////////////P
20             T////////////////I////////////////E                -                                  R///////////////P
21             T////////////////I////////////////E                -                                  R/////////////////P
22 X           T////////////////I///////////////E           X    12    X          X          X       R/////////////////P X
22             T////////////////I///////////////E                 -                                  R/////////////////P
20             T////////////////I/////////////E                   -                                  R////////////////P
19             T////////////////I////////////E                    -                                  R///////////////P
19              T///////////////I////////////E                    -                                  R///////////////P
20 X         X T////////////////I///////////E               X    13    X          X          X       R////////////////P    X
20                T/////////////I//////////E                      -                                  R////////////////P
21                 T////////////I//////////E                      -                                  R//////////////P
20                  T///////////I/////////E                       -                                  R////////////P
18                   T//////////I/////////E                       -                                  R/////////P
16 X         X         T////////I///////E   X               X    14    X          X          X       R//////P   X          X
13                       T//////I///////E                         -                                  R////P
 8                        T/////I///////E                         -                                  R//P
                           T    I       E                         -                                  P
                             T  I       E                         -                               P
   X         X           X   T  I  X    E   X               X    15    X          X          X   P    X          X          X
                                I       E                         -                             P
                                I T     E                         -                           P
                                I  T    E                         -                          P
                                I     T E                         -                        P
   X         X           X      I  T = TIDE    E = ESTUARY       16    X          X          P LOAD INFLECTION TIME = 10.4  X
                                I       T E                       -                     P
                                I        TE                       -                    P                   PEAK TIME = 12.0
                                I        ET                       -                    P
                                I        E T                      -                   P            GENERATION STARTED = 10.4
   X         X           X      I  X  NET MWHR =  0458.51        17    X          X  P       X          X          X          X
                                I          E  T                   -                  P
                                I           E  T                  -                  P
                                I           E  T                  -                 P    P = LOAD PROFILE      R =LOAD REFERENCE
                       ENERGY IN PUMPING =  0309.98               -                 P
   X         X           X      I  X         E  T           X    18    X          X P        X          X          X          X
                                I             E T                 -                P
                                I             E T                 -                P
                                I             E T                 -                P
                                I               T                 -               P
   X         X           X      I  X         X T            X    19    X          P          X          X          X          X
```


UNITS OPERATING
MODE 04
DATE 05/01/19XX
HYDRAULIC CONDITIONS, METERS
.0 2.5 5.0 7.5 10.0 12.5
TIME
07 08 09 10 11 12 13 14 15 16 17 18 19
LOAD CONDITIONS, MW
0. 150. 300. 450. 600. 750.
T = TIDE E = ESTUARY
LOAD INFLECTION TIME = 10.4
PEAK TIME = 12.0
GENERATION STARTED = 10.4
NET MWHR = 0000.00
(INFEASIBLE OPERATION)
ENERGY IN PUMPING = 0000.00
P = LOAD PROFILE
R =LOAD REFERENCE


UNITS OPERATING
MODE 05
DATE 05/01/19XX
HYDRAULIC CONDITIONS, METERS
.0 2.5 5.0 7.5 10.0 12.5
TIME
07 08 09 10 11 12 13 14 15 16 17 18 19
LOAD CONDITIONS, MW
0. 150. 300. 450. 600. 750.
T = TIDE E = ESTUARY
LOAD INFLECTION TIME = 10.4
PEAK TIME = 12.0
GENERATION STARTED = 12.0
NET MWHR = -0093.82
(INFEASIBLE OPERATION)
ENERGY IN PUMPING = 0093.82
P = LOAD PROFILE
R =LOAD REFERENCE


UNITS OPERATING
MODE 06
DATE 05/01/19XX
HYDRAULIC CONDITIONS, METERS
.0 2.5 5.0 7.5 10.0 12.5
TIME
07 08 09 10 11 12 13 14 15 16 17 18 19
LOAD CONDITIONS, MW
0. 150. 300. 450. 600. 750.
T = TIDE E = ESTUARY
NET MWHR = 0414.94
ENERGY IN PUMPING = 0093.82
EXCESS ENERGY = 0508.76
LOAD INFLECTION TIME = 10.4
PEAK TIME = 12.0
GENERATION STARTED = 12.0
P = LOAD PROFILE
R =LOAD REFERENCE