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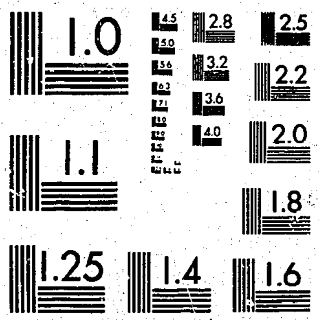

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GR-78-3

WATER CONSTRAINT AND PREDICTION ALGORITHMS FOR YELLOWTAIL POWERPLANT AND AFTERBAY DAM

April 1978

Electric Power Branch
Division of Research
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16. ABSTRACT

The operation of the computer algorithm used to detect constraints on the water system at Yellowtail Dam and Powerplant, Mont., including the afterbay dam, is explained. The algorithm is also shown in flow chart form. In addition, the two segments of the algorithm which allow the powerplant operator to predict water system conditions are discussed. The first segment will allow for Yellowtail Afterbay Reservoir level predictions up to 10 hours in advance. The second segment predicts the permissible time of operation of the four generators at given loads before an afterbay level limit is exceeded.

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a. DESCRIPTORS-- / *computer applications/ *algorithms/ computer programming/ digital systems/ water management (applied)/ afterbays/ *scheduling/ *reservoir operation/ computer models/ river forecasting/ river regulation/ river flow/ drawdown/ electric power demand/ peaking capacities/ water supply forecasting/ computer programs/ mathematical models

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by
Steven C. Stitt

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ACKNOWLEDGMENT

Mr. W. B. Gish of the Electric Power Branch contributed a great deal to the design of the water constraint and prediction algorithms. Mr. Del Adams, Project Manager; Mr. Harold Hergenrider, Operations and Maintenance Chief; and Mr. Toby Rodewald, Operations Foreman; all of the Yellowtail Project Office, supplied information and actual data used during simulation tests.

CONTENTS

FIGURES

FIGURES—Continued

INTRODUCTION

A water constraint system is necessary in the operation of a complex water system (in this case consisting of a dam and reservoir, powerplant, and afterbay reservoir) to assure that limits on upstream and downstream water levels are not exceeded. Some type of system must be employed to monitor these levels and to operate the generators and the gates and valves controlling the flow of water in such a manner as to maintain the levels within desired limits. The principles of the water control and constraint system may be executed in several different ways. Water control may be done manually. Some of the control may be performed by a hardwired system using water-level detectors and some type of indication device (strip charts, annunciators). A third method is to use a computer to control functions such as loading of generators (generator load and voltage algorithms are described in a companion report) and actuating spillway gates or outlet valves. The computer may also be used to perform the water constraint function. This report describes a system for monitoring water constraints to interact with both the powerplant operator and the load control programs. The river control is assumed automatic and is controlled by a special river control algorithm operating in the same computer.

The Yellowtail Unit is part of the Pick-Sloan Missouri Basin Program and consists of Yellowtail Dam and Bighorn Lake, the powerplant, the switchyard, and Yellowtail Afterbay Dam and Reservoir. See figure 1.

Yellowtail Dam is located near the mouth of Bighorn Canyon on the Bighorn River, about 34 kilometers (21 mi) due north of the Montana-Wyoming State line and 72 km (45 mi) southwest of Hardin, Mont. The powerplant is located immediately downstream from the dam and houses four 65 789 kV•A (kilovolt ampere) generating units, giving a total plant capacity of 250 megawatts. The afterbay dam is located about 3.6 km (2-1/4 mi) downstream from Yellowtail dam. It was constructed to provide a uniform daily discharge to the Bighorn River, level the peaking power discharges from the powerplant, and provide for the water requirements of the Bighorn Canal.

The proposed PPGC (Powerplant Generation Controller) for the Yellowtail Powerplant will be a minicomputer-based system. This system will allow the plant operator [via a CRT (cathode ray tube) screen at the powerplant] to monitor the status of the powerplant, control generator load and voltage for the four generators, and control the discharge of water to the Bighorn River and the Bighorn Canal at the afterbay dam.

The PPGC will also have a communication link to the PSCC (Power System Control Computer) at Watertown, S. Dak. This computer will be programed to maintain and schedule load for the Upper Missouri power system. It will be capable of controlling the plant load at Yellowtail along with other powerplants in the Upper Missouri Region.

The AGC (Automatic Generation Control) program in the PPGC at Yellowtail is required to operate within the water system limits already existing at the plant. The water constraint portion of the algorithm is designed to perform that function. Periodic checks are made to ensure that the level limits on Bighorn Lake, the afterbay reservoir, the Bighorn River, and the Bighorn Canal have not been exceeded. The algorithm will activate an alarm if any of these limits are exceeded. Also, if the afterbay reservoir has exceeded level limits, the algorithm will not allow the AGC system to continue changing the load on the powerplant in such a way as to cause the afterbay to further exceed the limit.

At Yellowtail, these water constraints may have a day-to-day effect on the plant loading. To control the plant load, the plant operator must have some means of predicting when the water limits will be reached. Also, in emergency power system loading situations where full plant capacity is needed, the operator will need to predict how long the plant can operate before a water constraint is reached. The predictor portion of the algorithm performs these tasks.

CONCLUSIONS

The water constraint and prediction algorithm proposed for the Yellowtail Powerplant provides for detection of maximum and minimum level constraints for the afterbay reservoir, the Bighorn River, and the Bighorn Canal. The algorithm also provides for detection of maximum rate of level-change constraints, which include forebay level drawdown, and river level rates during ice-free conditions, ice-formation conditions, and ice-cover conditions.

The algorithm allows the powerplant operator to perform two prediction functions: the afterbay level for 10 hours in advance, and the amount of time available before the afterbay will exceed level limits. The algorithm uses a closed-loop-corrected water model to perform these predictions.

APPLICATIONS

The algorithm as outlined applies directly to the Yellowtail Unit. The water model used by the algorithm is unique to Yellowtail because of the afterbay reservoir. The water model predicts maximum and minimum constraints for the afterbay reservoir level. Therefore, the principles of prediction used in the algorithm would be applicable only to other projects which have an afterbay reservoir. However, the concepts of water constraint detection used by the algorithm could be applied to any water project.

The algorithm may also be adapted to operate in a central dispatch computer such as the Watertown PSCC. The required water levels, gate positions, and generator outputs would have to be telemetered to the PSCC.

ALGORITHM CONCEPTS

Load Constraint

The main purpose of the Yellowtail water algorithm is to constrain the plant load controller from causing the afterbay reservoir to exceed high and low elevation limits. In one day of operation, the afterbay at Yellowtail can vary as much as 8.2 meters (27 ft) between minimum and maximum elevations. The algorithm will detect when either limit has been reached. When the maximum limit is encountered, the algorithm provides alarms to the operator and sets a flag to the AGC to stop the generator loads from increasing. When a minimum limit is found, the algorithm again alarms and sets a flag to stop the generator load from decreasing. The algorithm will detect and alarm to the operator other exceeded limits such as: excessive forebay level drawdown rate, river level maximum and minimum elevations, excessive river level rates of change, and canal maximum and minimum elevations.

Afterbay Level Scheduler

The algorithm will also aid the operator by predicting the water conditions at the plant for 10 hours in advance. The operator can enter a 10-hour plant loading schedule and determine whether this schedule would cause the afterbay to exceed level limits at any point during the schedule period. If he finds that the loading schedule will cause the afterbay to go to limits, he can adjust his loading schedule and rerun the prediction until he finds a schedule that will work. In this way he can know the capability of the plant.

The operator may create any type of conditions for the water system over a 10-hour period and obtain a prediction of the level of the afterbay in 1-hour increments for that 10-hour period. For example, he may enter a 10-hour schedule for the total plant load (10 data entries, one for each hour), and then he may assume all other water conditions remain constant at present actual values (gate positions, river elevation, canal elevation). With this information, the algorithm will generate an afterbay level schedule. If at any time the algorithm predicts the afterbay to be exceeding a limit, an alarm message is displayed. In addition to plant load, the operator has the option to enter several other plant conditions for other predictions. He may enter different gate positions, forebay elevation, or canal elevation to be used by the predictor. He may also enter a 10-hour river elevation schedule. The algorithm will also use the next 10 hours of scheduled plant load as indicated by the Watertown area control computer for the 10-hour load schedule, if it is available. In all instances, the algorithm predicts what the afterbay level will do over the next 10-hour period, given the conditions entered by the operator through a CRT display.

Time to Limit Prediction

Another portion of the algorithm will allow the operator to predict how much time he has to run the plant at a certain load before an afterbay limit is exceeded. The operator may enter any total plant load to make the prediction. He may also enter values for forebay elevation, gate positions, and the canal elevation. However, the river elevation is always taken as the present actual value. This portion of the algorithm is intended for short-term time predictions of less than 5 hours where more accuracy is desired. The longer time-oriented predictions can be made with the 10-hour scheduler previously described. The algorithm also indicates the operation time to an afterbay limit for normal plant capacity and emergency plant capacity. The maximum or minimum type of limit encountered is also shown.

INTERFACE

Executive

The flow charts of the Water Constraint algorithm are found in figures 2 through 10 of this report. Figure 2 defines some of the standard symbols used within the flow charts. The interface requirements for the water algorithm are shown in figure 3. Figures 4 through 10 show the processes of the algorithm in flow chart form. Appendix A gives an alphabetical list of all the variables used in the algorithm flow charts, with a brief definition of what each variable represents. The algorithm is made up of three separate programs in order to accomplish the three different tasks outlined above (Load Constraint, Afterbay Level Schedule, Time to Limit Predictor). The Water Constraint program must be called on a periodic basis by the "Executive" (see fig. 3). The timing of this call is not critical. The maximum time between calls depends upon the water system. It should be called often enough that changes in the water system can be detected accurately. A calling time ranging from every 5 to 15 minutes would be acceptable at Yellowtail. The Executive must also supply the Water Constraint program with the actual computer time. When a power-up occurs, the Executive must not call the Water Constraint until the operator has initialized the computer time. A flag, "power-up predictor," must be set by the Executive to indicate a power-up has occurred.

Buffers

All the programs use a buffer system to isolate the running program from the data base (see fig. 3). The programs use buffered data so that they can be interrupted during their operation without affecting the data being used during that particular pass. Buffers are required for hardware input, software (format) inputs and outputs, and alarm outputs.

CRT Formats

The operation and layout of the CRT formats that support the algorithm are shown on figures 11 through 20. The CRT formats proposed for the PPGC at Yellowtail employ a "question and answer" method on the bottom three lines of the formats to operate them. Figure 11 shows the general flow of the "questions and answers" used by each format. The computer supplies the first question in the control tree area (bottom three lines) of the format. When the operator wishes to change the format, he responds to the question in order to direct the computer to a certain area of the format. The computer continues to "ask" questions, with the operator supplying the answers until the particular quantity to be changed has been determined. The particular questions (first question, second question, etc.) and the possible operator answers for each question are shown following each of the CRT layout drawings. For example, figure 12 shows the layout for the time and water substitution format. The figure also shows the definitions for each quantity on the format. Figures 13 and 14 show the particular questions and answers to be used to enter the operator changeable quantities on that format.

This method of CRT operation is slower than other methods such as using a light pen or joy stick for cursor positioning. However, the faster methods require more sophisticated and expensive CRT equipment and software.

There are four formats required to support the algorithm. First, an alarm format is required (see alarm buffer on fig. 3). The three other formats are: the Time and Water Substitution format as shown on figure 12, the Water Predictor format shown on figure 17, and the Load Time Limit predictor shown on figure 15.

Hardware Inputs

The hardware inputs required by the algorithm are shown in figure 3. All water flows in the system must be calculated. So, all gate and valve positions, levels, and unit loads must be supplied to the algorithm. Some quantities may be operator entered. For example, the spillway gate and outlet works valve positions are entered by the operator via the Time and Water Substitution format (fig. 12). There are no transducers monitoring those gate and valve positions. However, the accuracy of the algorithm relies on the accuracy of those inputs. Thus, the operator must be sure he makes a new entry whenever a gate or valve position is changed.

Calibration System

A calibration system is necessary to calibrate the algorithm. Data quantities must be able to be displayed and changed by this system. The calibration system consists of a CRT format to be designed by the system supplier and eight channels of D/A (digital to analog) converters. The format will allow examination and changing any memory cell containing data. Also the scaling, offsets, and data addresses used in the D/A converter system should be controlled by the format. The D/A outputs will be used to drive an eight-channel strip chart recorder. This system permits the display of trends for various inputs and outputs of the model predictor system and the adjustment of constants within the model for best operation.

DESCRIPTION OF ALGORITHM OPERATION

Each of the three programs in the water algorithm use either or both of the routines MODEL and WCON. The operation of these routines will be described first, followed by an explanation of how the three programs use these routines to accomplish their different tasks.

MODEL–The routine MODEL contains all of the equations for turbine discharge, spillway discharge, outlet works discharge, river discharge, and canal discharge. These equations were created using curve-fitting techniques from design and test curves. All of these are used to model the Yellowtail Afterbay Reservoir. Given all of the water levels, gate positions, and unit loads, the total water discharge either into or out of the afterbay can be calculated. See figure 21 for a simplified diagram of the MODEL routine. The MODEL routine is always supplied with a value of time for prediction. Given this time and the total discharge calculation, the routine predicts what the afterbay volume will be after that time has expired–assuming the discharge is constant. An equation is used to convert that afterbay volume to a predicted afterbay level.

WCON–The routine WCON searches for afterbay and river constraints that are being exceeded. Maximum and minimum limits on the afterbay, river, and canal are checked. Also, a 30-minute prediction for the afterbay level is made from its present rate of change. If this prediction exceeds a limit, the operator receives an alarm, giving him some indication of an approaching limit.

The particular water constraints which are currently applicable at Yellowtail are shown in appendix B. In addition to these constraints, the WCON routine also checks the canal for minimum and maximum levels. These limits are not specified and can be set to any desired value by the computer programmer. The level constraints for the afterbay and the river change according to the seasons (irrigation and nonirrigation). Also, the river rate-of-change constraints change with different ice conditions (ice-free, ice-cover, and ice formation or breakup). The operator enters the season and the ice conditions via the time and water substitution format (fig. 12) so the algorithm can apply the correct constraints.

The forebay level drawdown and river level rate of change is checked by using software filters. This technique is necessary because of the long rate-limit times. For example, the forebay limit on drawdown is 1 meter in any 24-hour period. The computer storage capability is insufficient to store 24 hours' worth of data taken at 10-minute increments (the interval necessary for this limit to be constantly checked); therefore, software filters are used to detect these limits. The derivation of one of these filters is shown in figure 22. Figure 22A shows the Laplace form for the filter, with time domain sketches shown for a constant increasing level rate. Figure 22B is a simplification of the Laplace form so it can be used to create a digital filter. Figure 22C shows the digital form used by the computer and the equations used by the forebay-level filter. The filtered rate outputs of these software filters contain the time information necessary to detect different rate limits. Given the filter time constant, the output of the filter will indicate how long the level has been changing at a certain rate.

Water Constraint–The Water Constraint program is called by the computer Executive approximately every 10 minutes. The program sets up and calls the MODEL routine, setting the prediction time for 10 minutes. Every time the Water Constraint program is called, it determines whether the predicted value for the afterbay level made by MODEL on the last pass (10 minutes earlier) is equal to the actual level. The MODEL routine is then continually corrected in a proportional fashion according to the error in its prediction. The Water Constraint program also calls the WCON routine. Any flags set by WCON are used to set the necessary alarms and stop allocation flags.

Water Predictor–The Water Predictor program is called by the Water Predictor format which the operator is using to run the 10-hour scheduler with. Whenever the operator has set up the water conditions he wants the program to use in making the 10-hour afterbay level schedule, he executes the Water Predictor. The program then calls the MODEL routine, setting the prediction time for 1 hour. It also calls WCON to check for limit conditions exceeded by any of the predicted quantities. This process is repeated 10 times in order to create the 10-hour afterbay schedule.

Load Time Limit–The Load Time Limit operates in much the same way as the Water Predictor described above. The Load Time Limit program is executed by the Load Time Limit format which the operator is using to create the water conditions he wants the program to use. When the program is executed, it in turn calls the MODEL routine, setting the prediction time for 12 minutes. However, the Load Time Limit does not call the WCON routine. It simply checks the predicted afterbay level for an exceeded limit. The program keeps executing the process in a loop until a limit is exceeded or it has iterated through 10 hours of prediction time. If it has not found a limit for 10 hours in advance, it terminates.

SIMULATION

The Water Constraint portion of the algorithm was tested using actual water-level charts and power charts supplied by the Yellowtail Project Office. Input data necessary to run the program for a 24-hour period was used. The afterbay level generated by the MODEL routine (variable ALNEW) agreed to within 5 percent of the actual afterbay level recorded for that period. This result is very good considering the inherent errors of the water model used. The actual discharge curves used for turbine discharge, spillway discharge, river discharge, etc., have a certain degree of error. Also, the curve-fitting techniques used to formulate discharge equations induce error.

The software filters used to detect level-rate constraints were also tested. For the shorter time constants of up to 3 hours, rate changes to be detected in a 3-hour period or less, the filter accurately (within 10 percent) alarmed the rate limits. For the longer time constants, the filter accuracy decreased (up to approximately 25 percent) and would detect falsely on fluctuations in the level. However, since these filters are used only for alarm purposes, the inaccuracy during level fluctuations is acceptable and in some cases may be desirable.

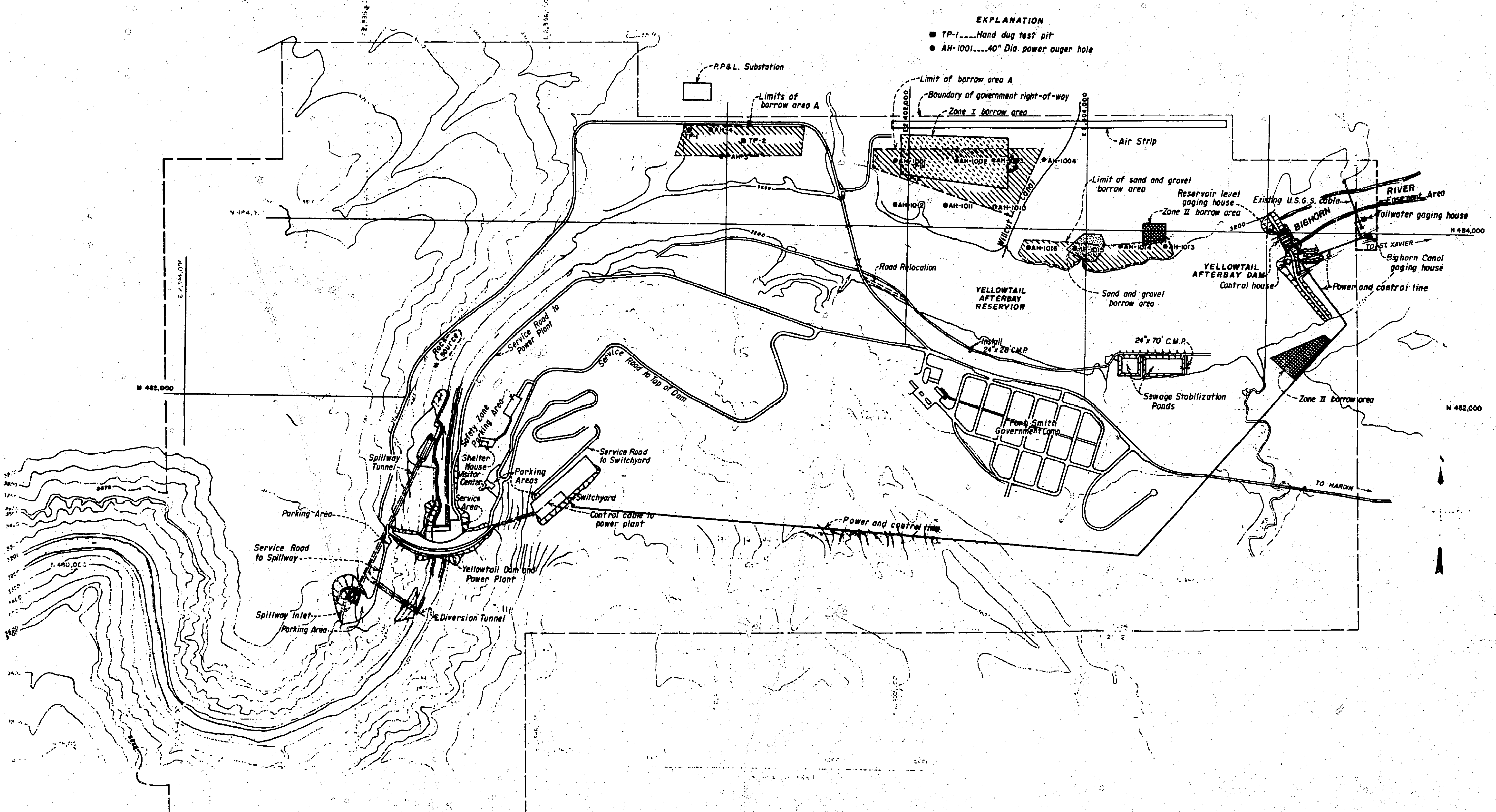
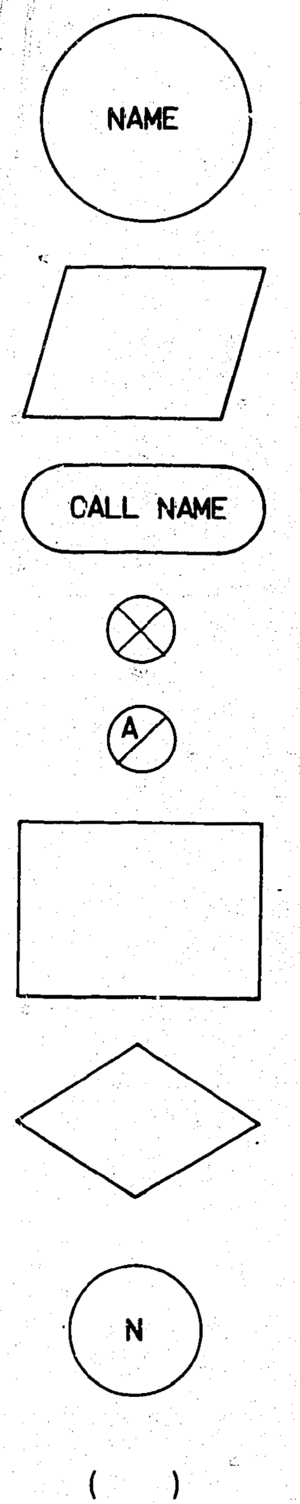


Figure 1.-Yellowtail Unit vicinity map. Drawing 459-D-1093

DRAWING SYMBOLS



- START OF SUBROUTINE
- DATA INPUT AND OUTPUT
- SUBROUTINE CALL
- SUBROUTINE RETURN OR EXIT
- INDICATES AN ALARM MUST BE SET
- OPERATION MUST TAKE PLACE
- DECISION MUST BE MADE
- SUBROUTINE FLOW IS CONTINUED ELSE WHERE WITH AN IDENTICAL LETTER
- INDICATES DEFINED VARIABLE ON FORMAT AND CONTROL TREE DRAWINGS

MATHEMATICAL SYMBOLS

+	ADDITION
−	SUBTRACTION
*	MULTIPLICATION
**	EXPONENT
/	DIVISION
$(\ )^2$	SQUARE
←	REPLACEMENT
SET	REPLACE WITH I
CLEAR	REPLACE WITH O
NAME	VALUE OF "NAME" FOR THE PRESENT PASS
$\sum_{GI}^{GN}$	SUMMATION OF THE VARIABLE FOR GENERATORS GI TO GN
⌉ NAME=X	DO THE SUMMATION ONLY WHEN THE VARIABLE "NAME" EQUALS X FOR THE GENERATORS SPECIFIED IN THE SUMMATION

DECISION SYMBOLS

=	EQUIVALENT
>	GREATER THAN
<	LESS THAN
≥	GREATER THAN OR EQUAL
≤	LESS THAN OR EQUAL
≠	NOT EQUAL
+	POSITIVE
−	NEGATIVE
| |	ABSOLUTE VALUE
SET	VARIABLE EQUAL TO I
CLEAR	VARIABLE EQUAL TO O
OR	LOGICAL INCLUSIVE OR
AND	LOGICAL AND

Figure 2.–General algorithm flow chart definitions. Drawing 459-D-2491

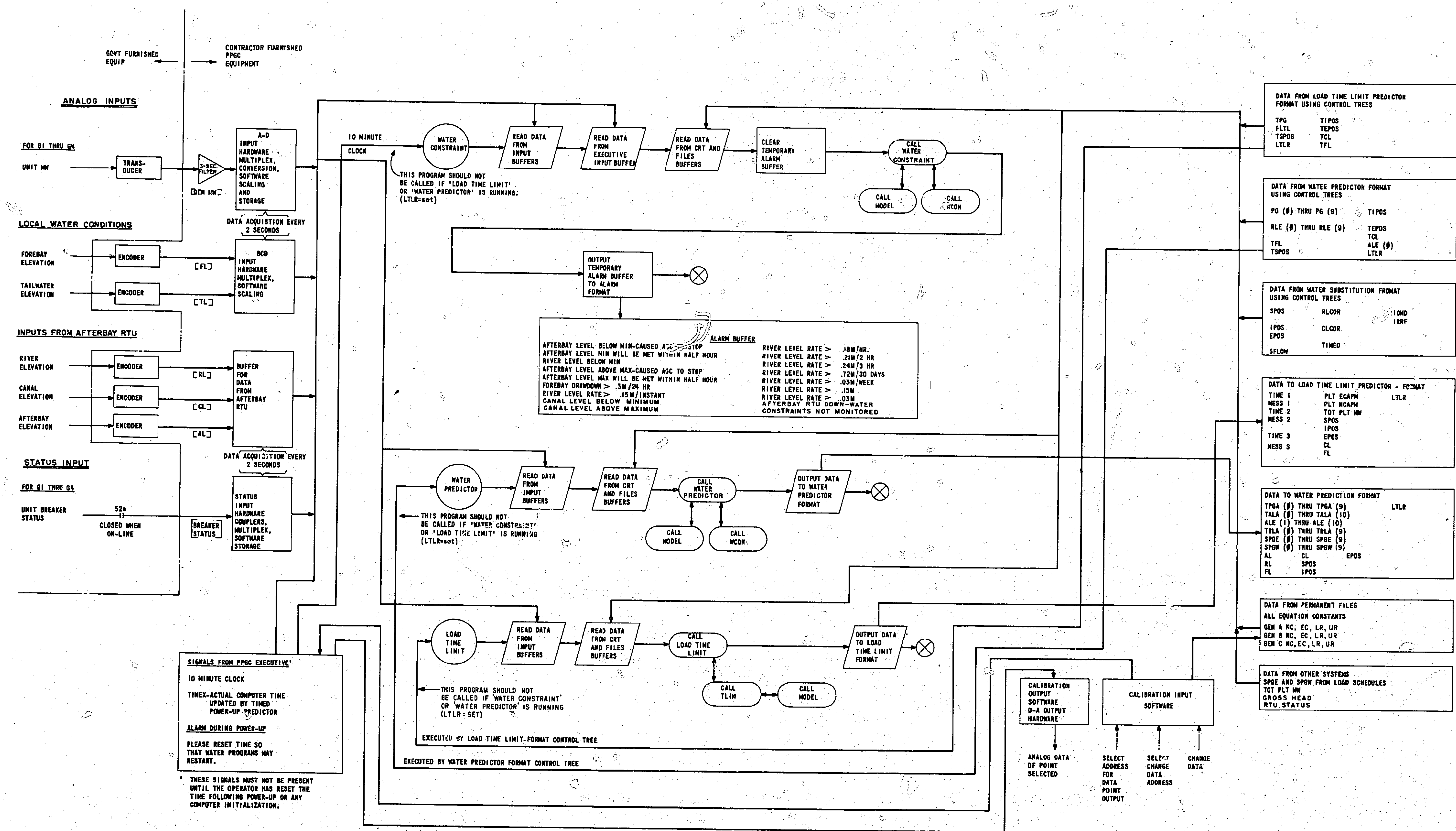
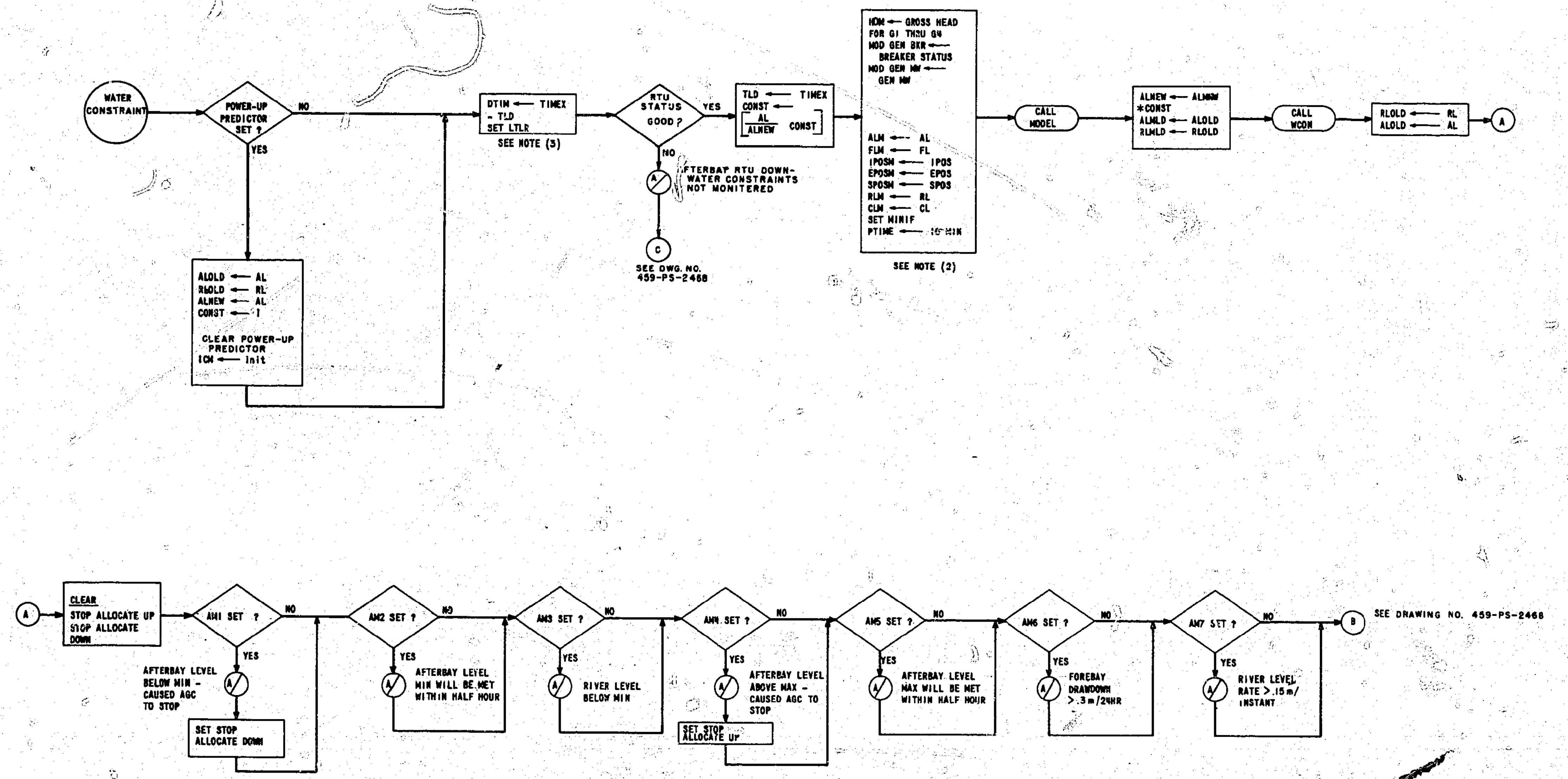


Figure 3.–Water Constraint algorithm–interface definition. Drawing 459-PS-2466



NOTES

1) THE VARIABLE 'TLD' SHALL BE SET = Φ AT INITIAL LOAD OF THE SYSTEM. IT SHALL NOT BE CHANGED ON POWER UP INITIALIZATION.

2) THE VARIABLES 'IPOS', 'EPOS', AND 'SPOS' SHALL BE SET = Φ AT INITIAL LOAD OF THE SYSTEM. THEY SHALL NOT BE CHANGED ON POWER-UP INITIALIZATION.

3) THE FLAG 'LTLR' WHEN SET WILL KEEP THE EXECUTIVE FROM CALLING ANY OF THE OTHER WATER PREDICTOR ROUTINES

Figure 4.–Water Constraint algorithm–Water Constraint routine. Drawing 459-PS-2467

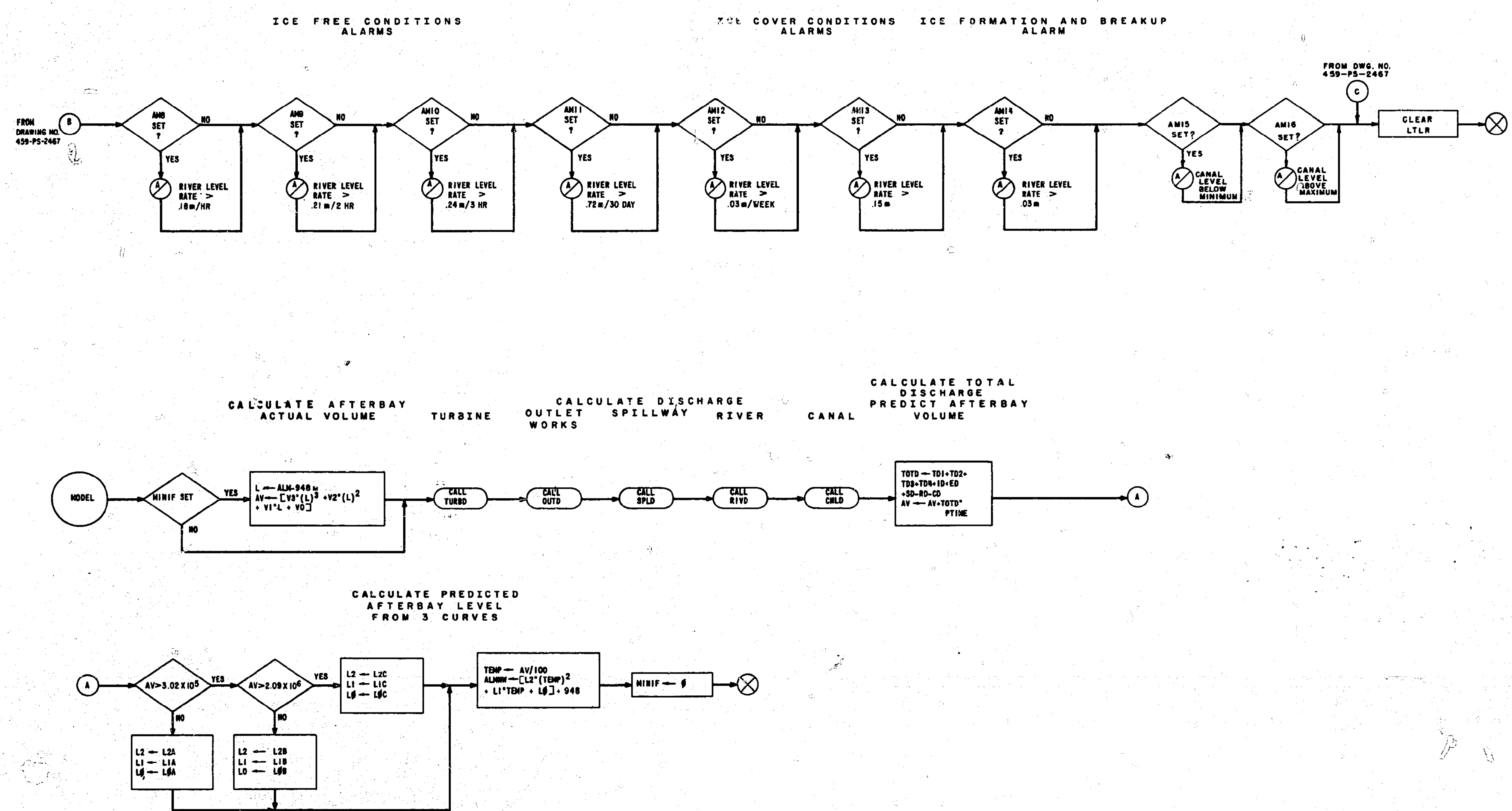


Figure 5.–Water Constraint algorithm–Water Constraint and MODEL routines. Drawing 459-D-2468

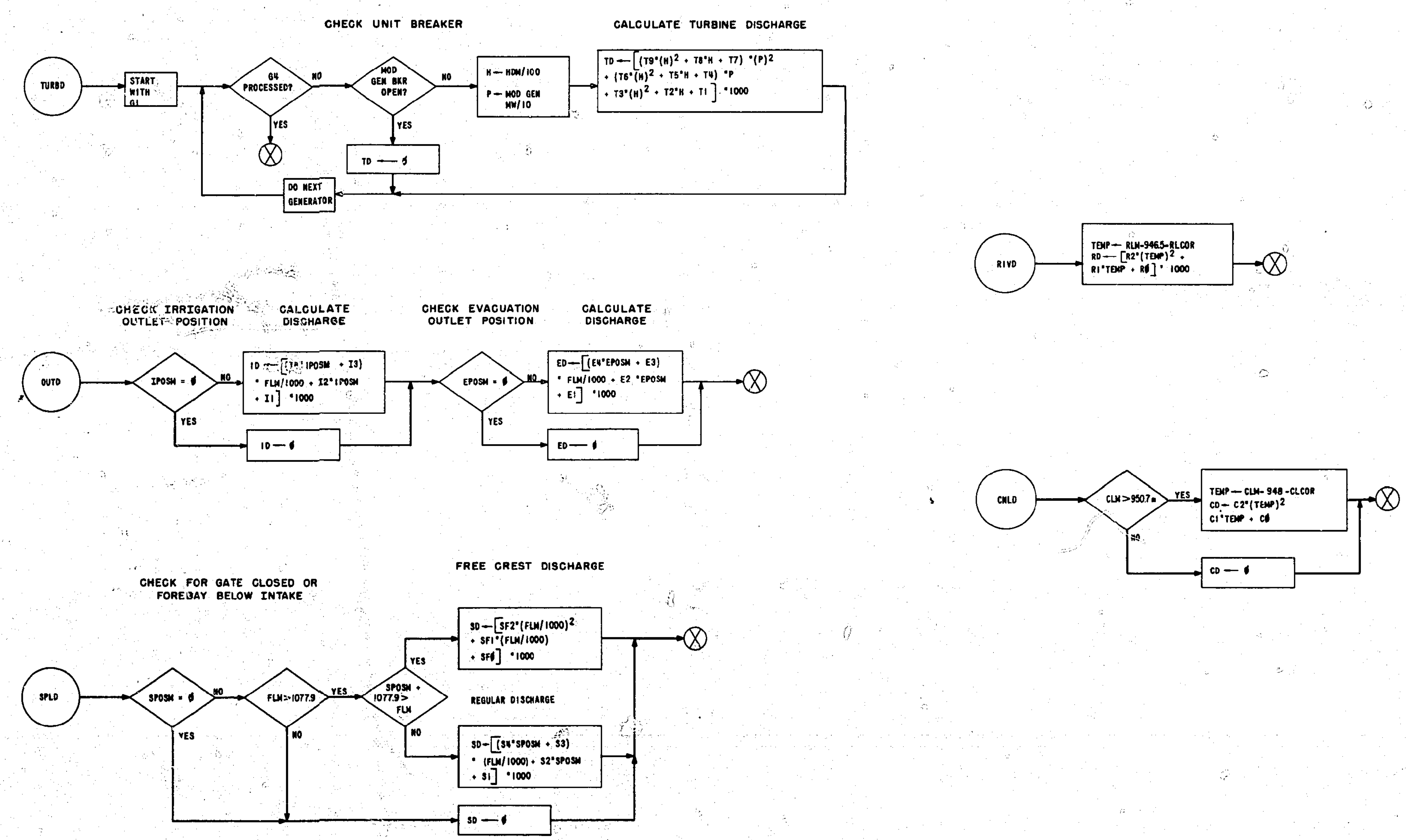


Figure 6.–Water Constraint algorithm–discharge calculation routines. Drawing 459-PS-2469

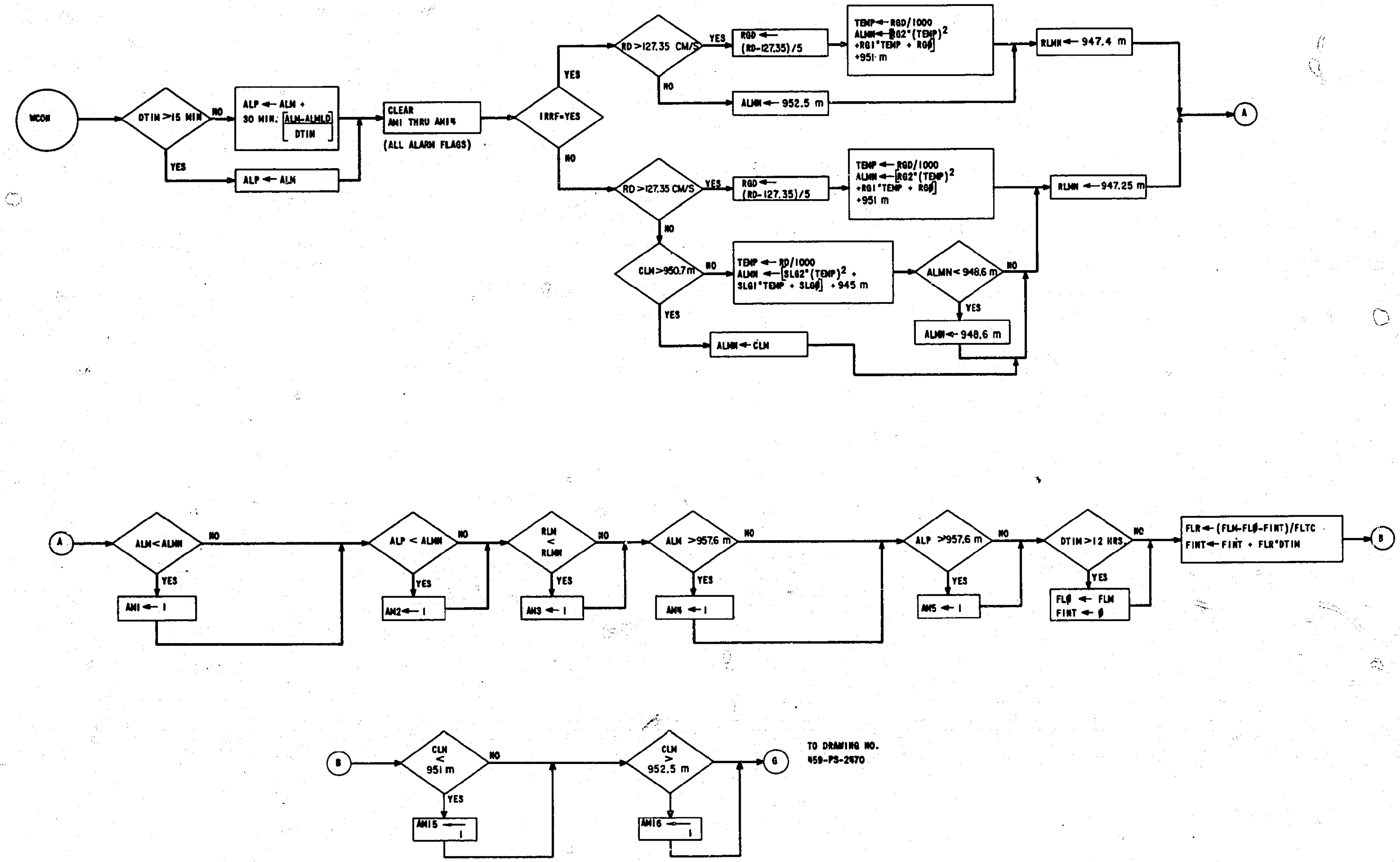


Figure 7.–Water Constraint algorithm–WCON routine. Drawing 459-PS-2470

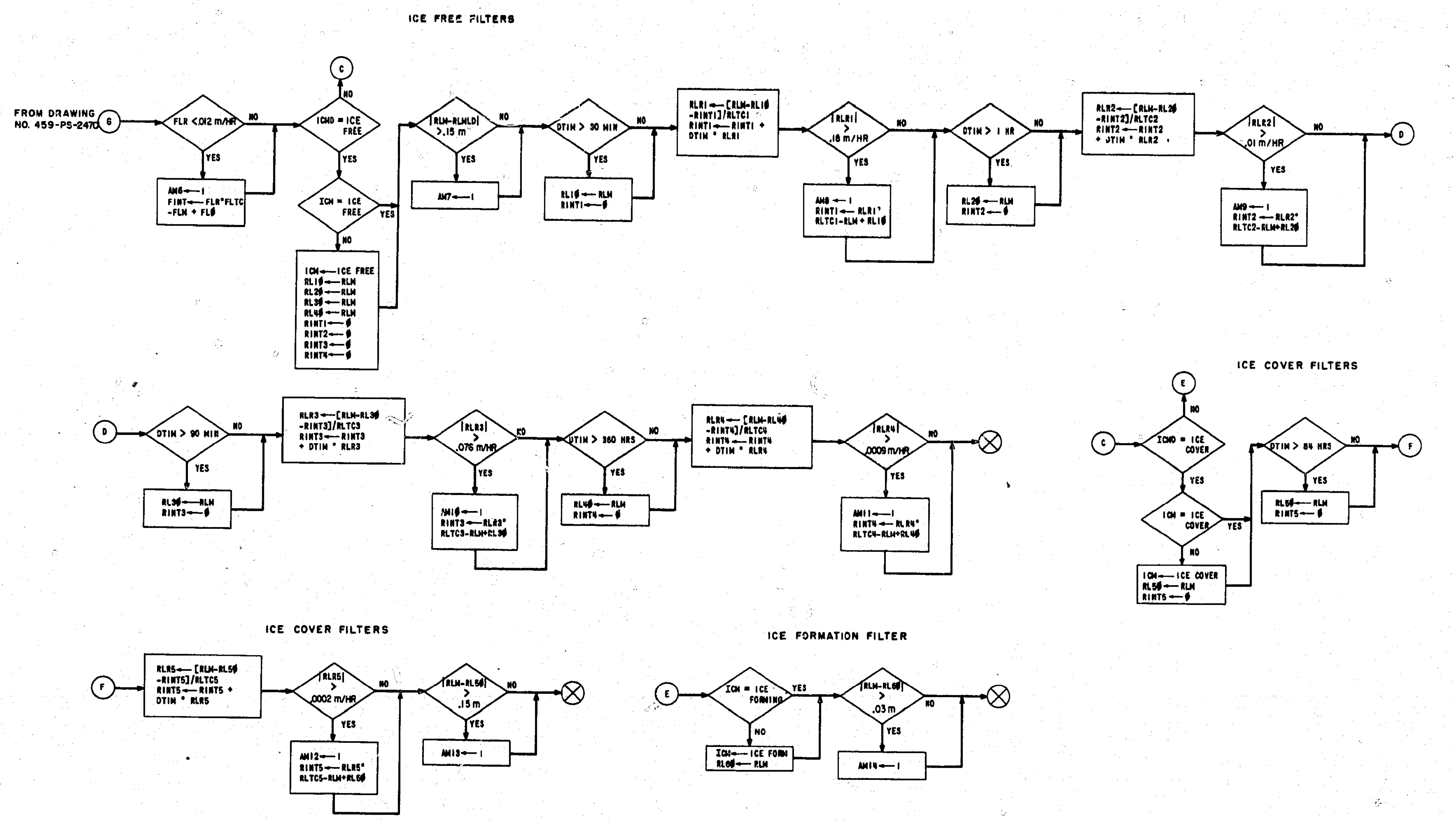


Figure 8.–Water Constraint algorithm–WCON routine. Drawing 459-PS-2471

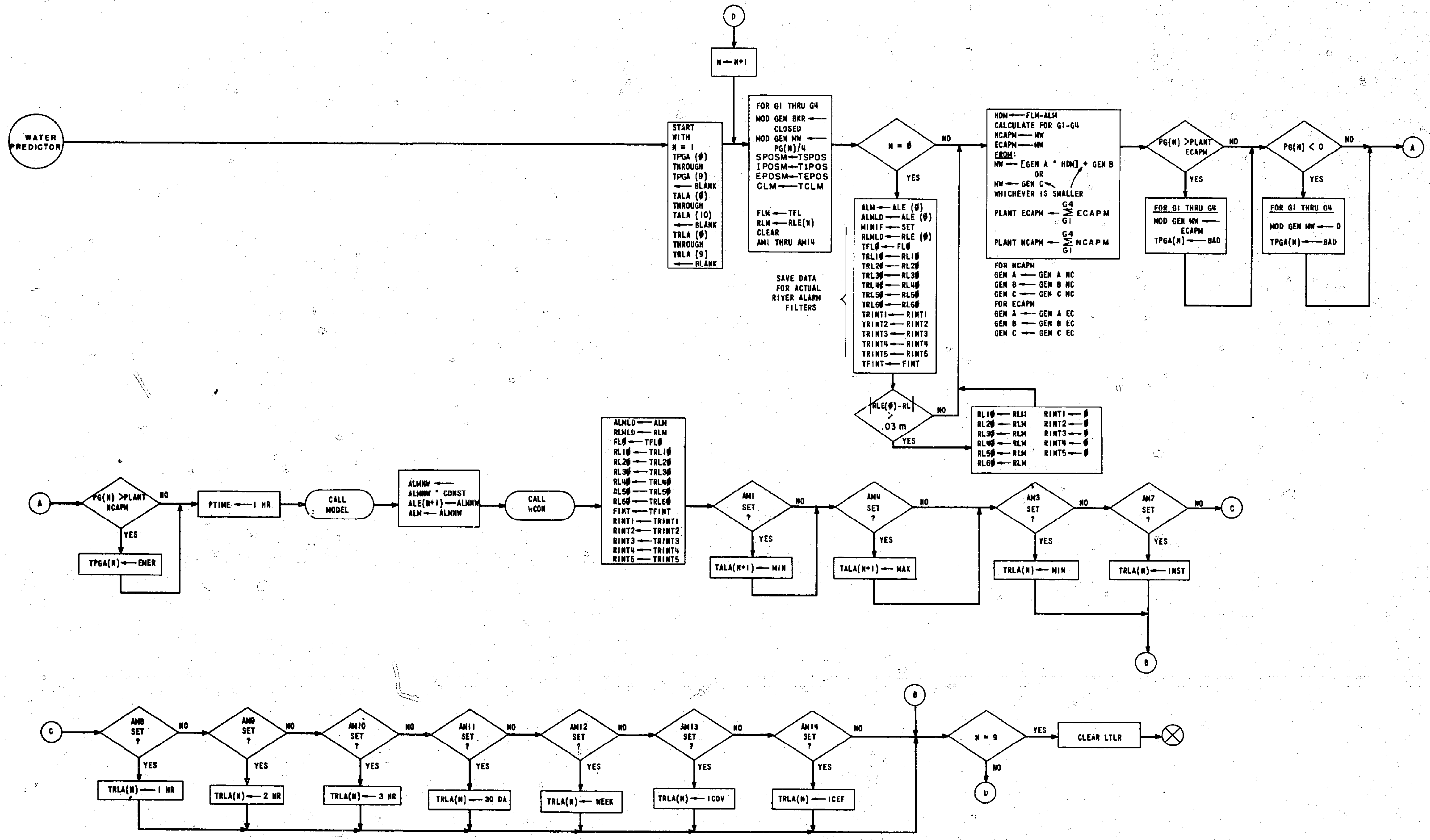


Figure 9.–Water Constraint algorithm–Water Predictor routine. Drawing 459-PS-2472

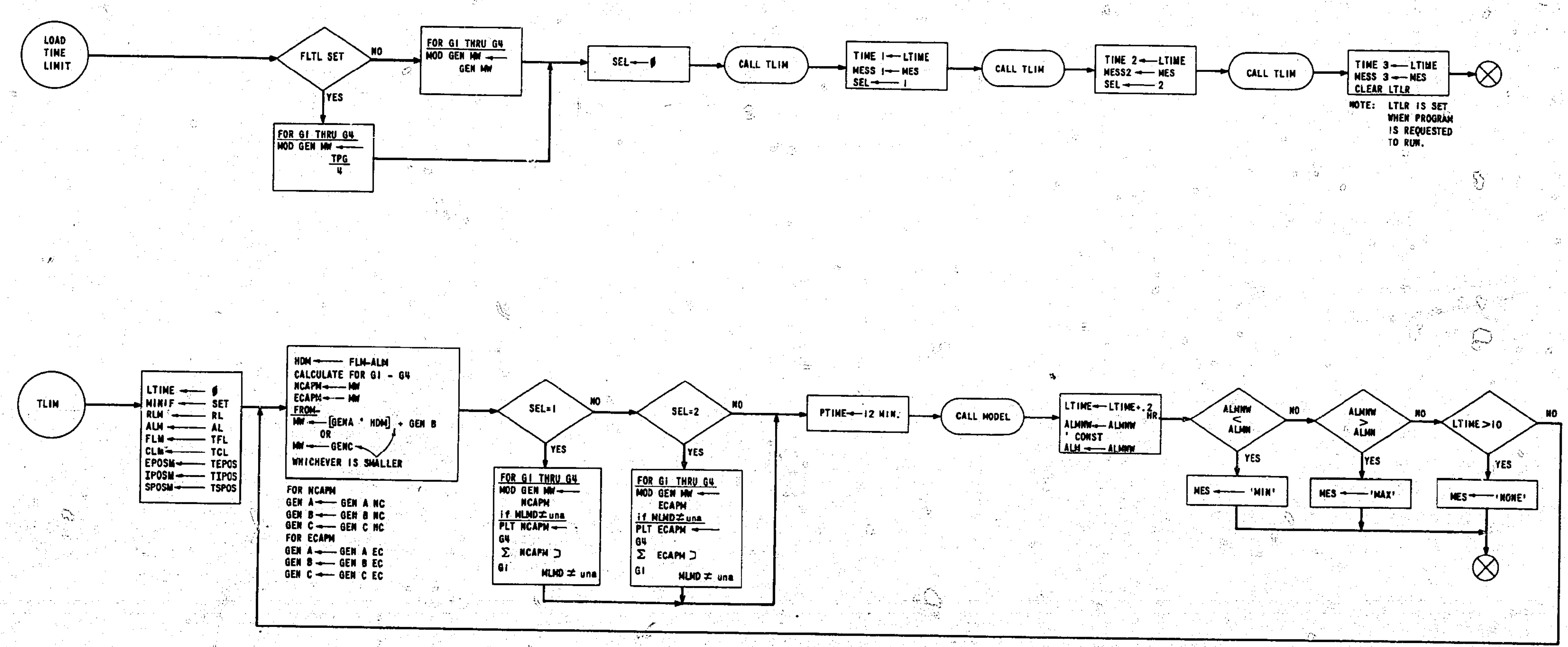


Figure 10.–Water Constraint algorithm–Load Time Limit and TLIM routines. Drawing 459-PS-2473

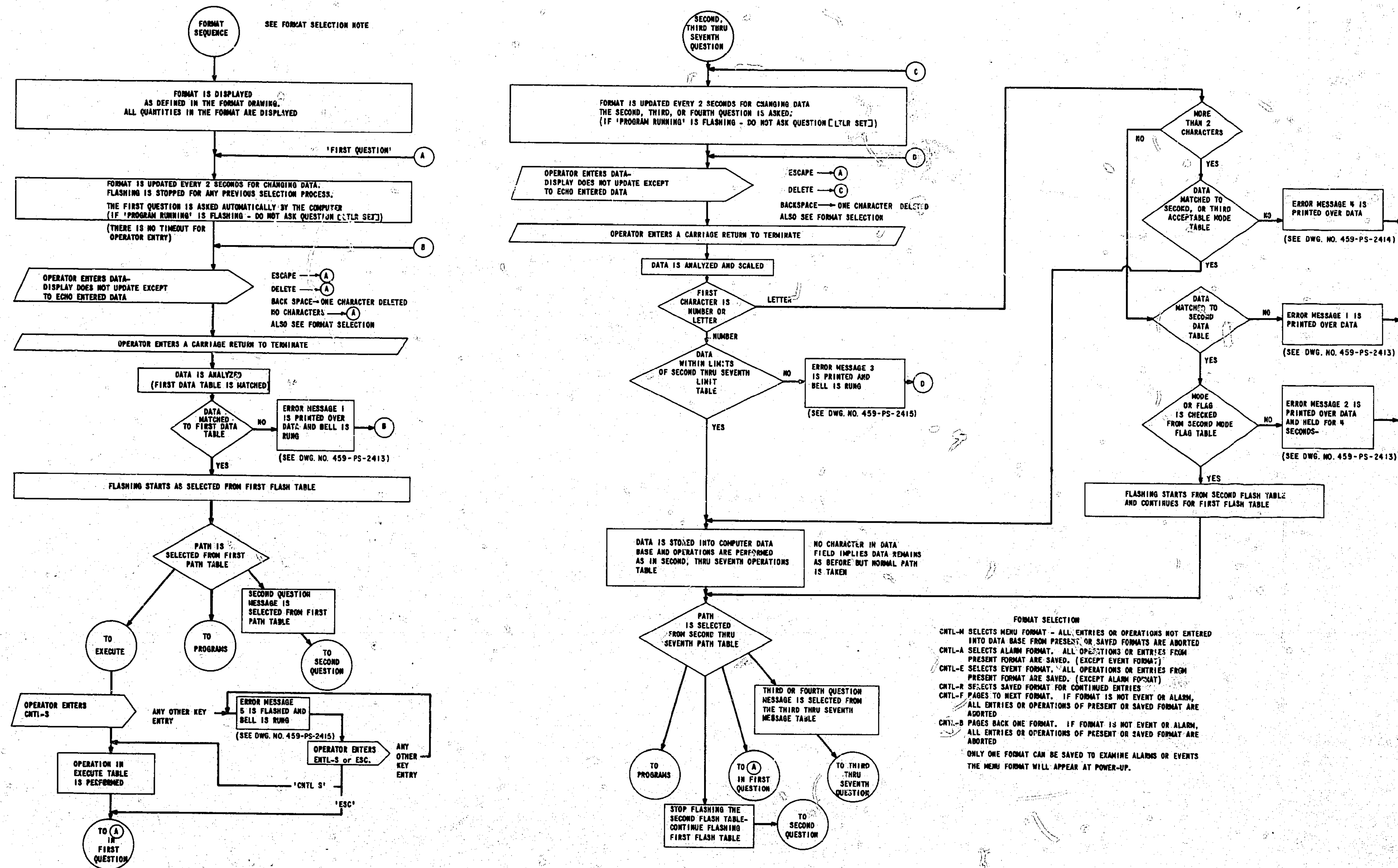


Figure 11.–CRT format general flow. Drawing 459-PS-2411

```
09/12/76  18:36:26  TIME AND  WATER SUBSTITUTION     PAGE 17   ALARM X
                 VALUE    VALUE                       LIMIT XX   EVENT
                 USED     MEASURED        SPILLWAY GATE POSITION   XX.X  M
    PLANT HEAD   XXX        XXX
                                          IRRIGATION OUTLET POS    XXX  %

                                          EVACUATION OUTLET POS    XXX  %
    RIVER ICE MODE    ICE XXXXXXXX
                                          SPRING FLOW              XXX   CM/S
    IRRIGATION SEASON       XXX
                                          RIVER CORRECTION        ±X.XX  M
    TIME     XX/XX/XX    XXXX:XX
                                          CANAL CORRECTION         X.XX  M

                                          DAILY  PRECIPITATION    XXX.X  MM




 -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
    BOTTOM  3  LINES  ARE  FOR   CONTROL  TREE
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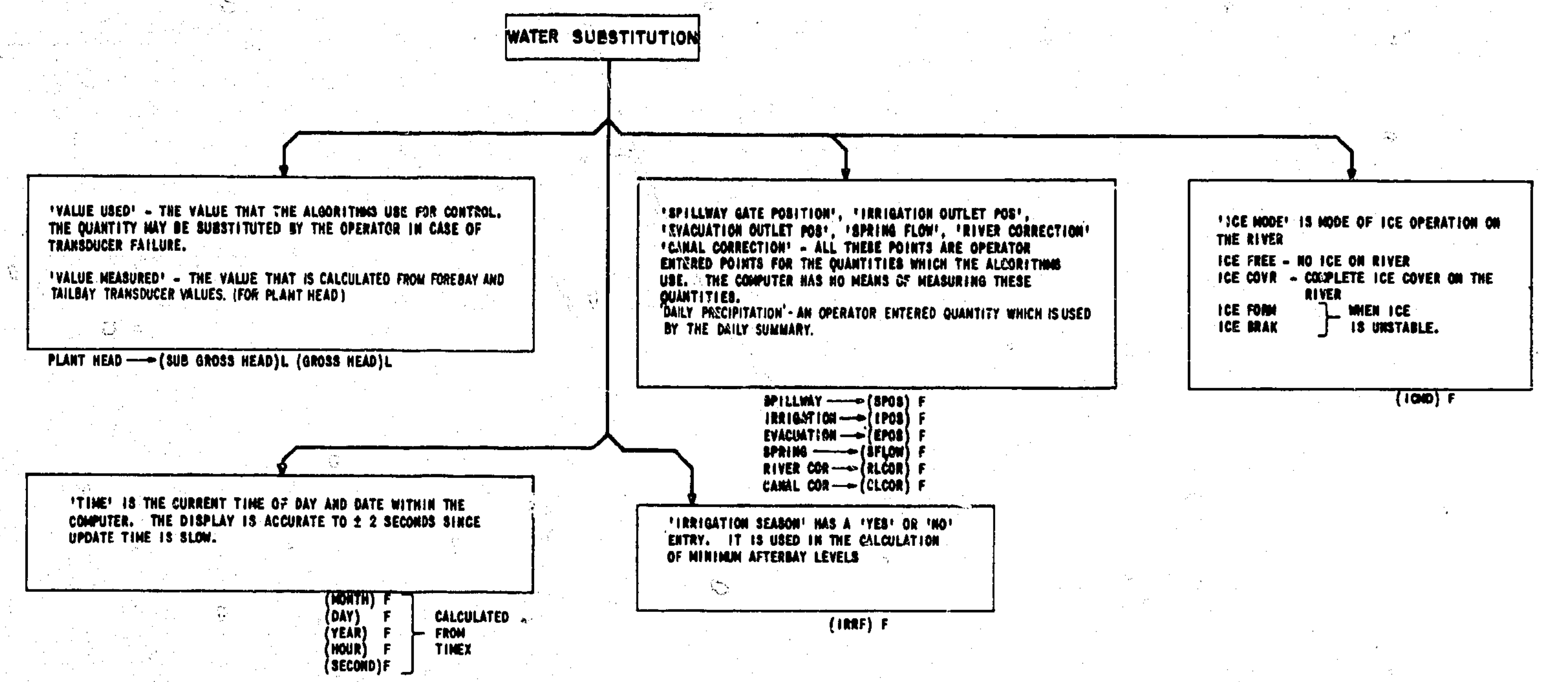


NOTES

L L Indicates data from load control. F Indicates data from format control tree only.

Figure 12.–Time And Water Substitution format layout. Drawing 459-PS-2423

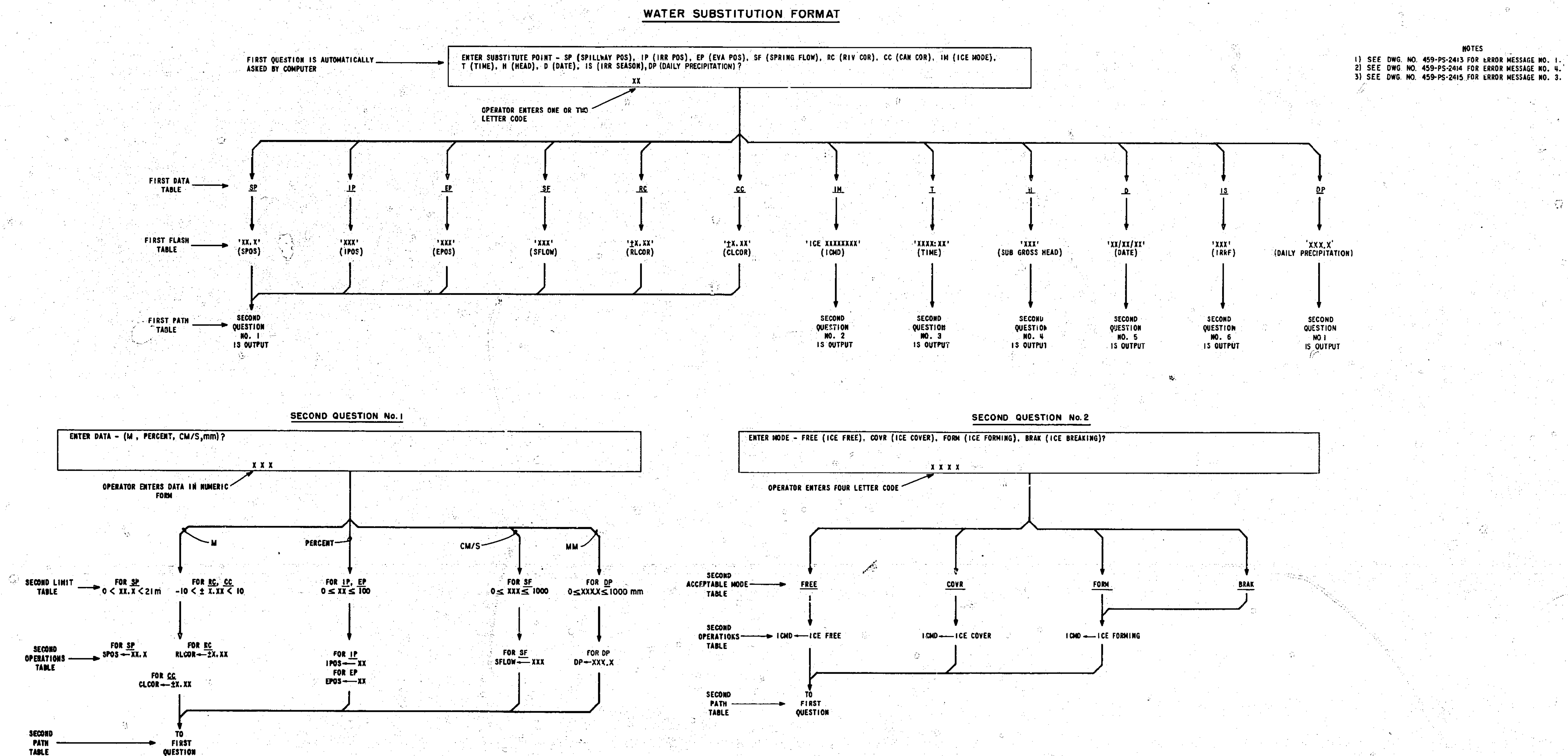


Figure 13.–Time And Water Substitution format control tree (sheet 1 of 2). Drawing 459-PS-2424

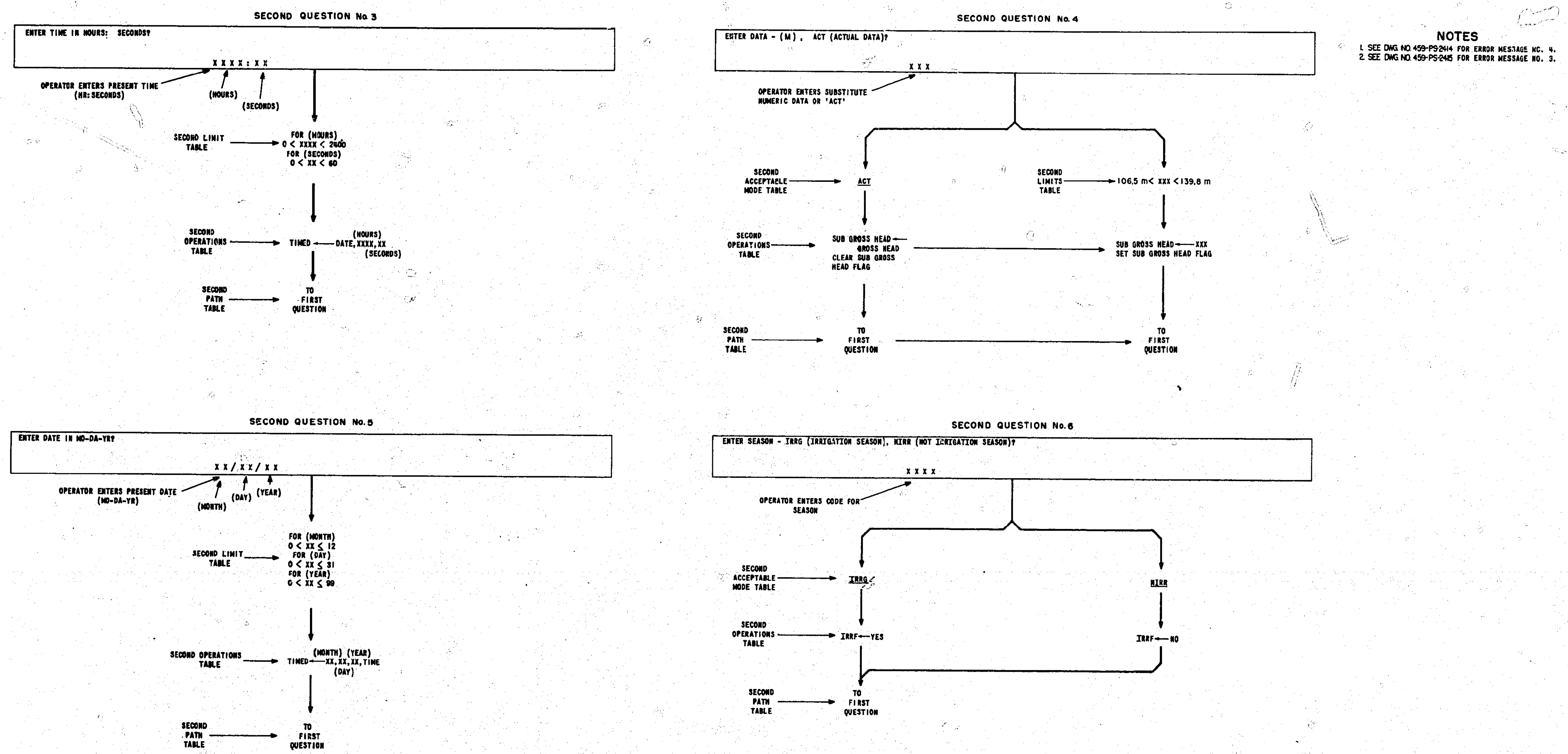


Figure 14.–Time And Water Substitution format control tree (sheet 2 of 2). Drawing 459-PS-2425

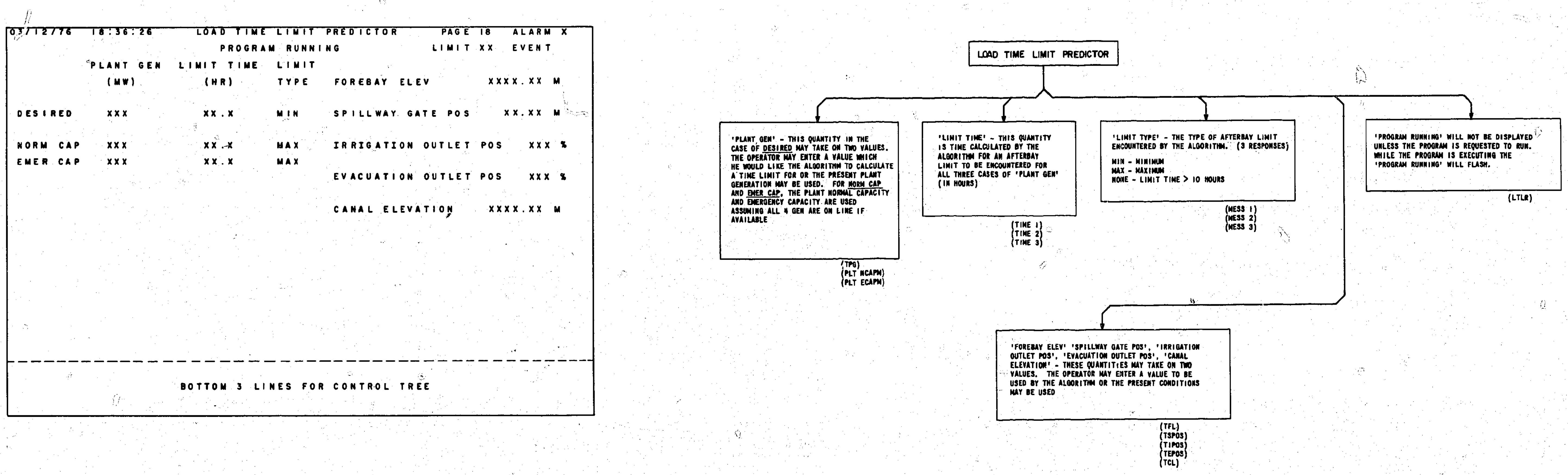


Figure 15.–Load Time Limit Predictor format layout. Drawing 459-PS-2426

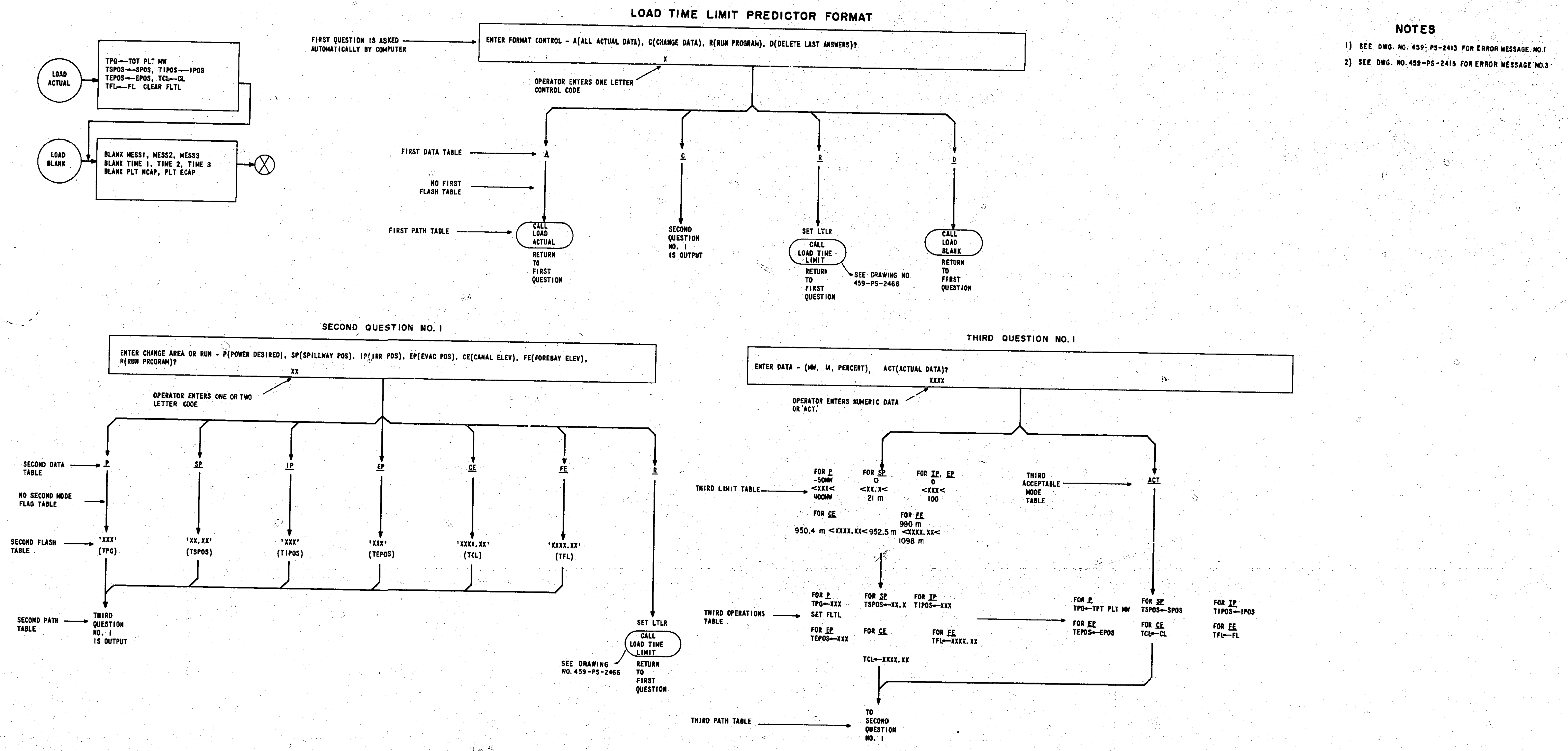


Figure 16.–Load Time Limit Predictor format control tree. Drawing 459-PS-2427

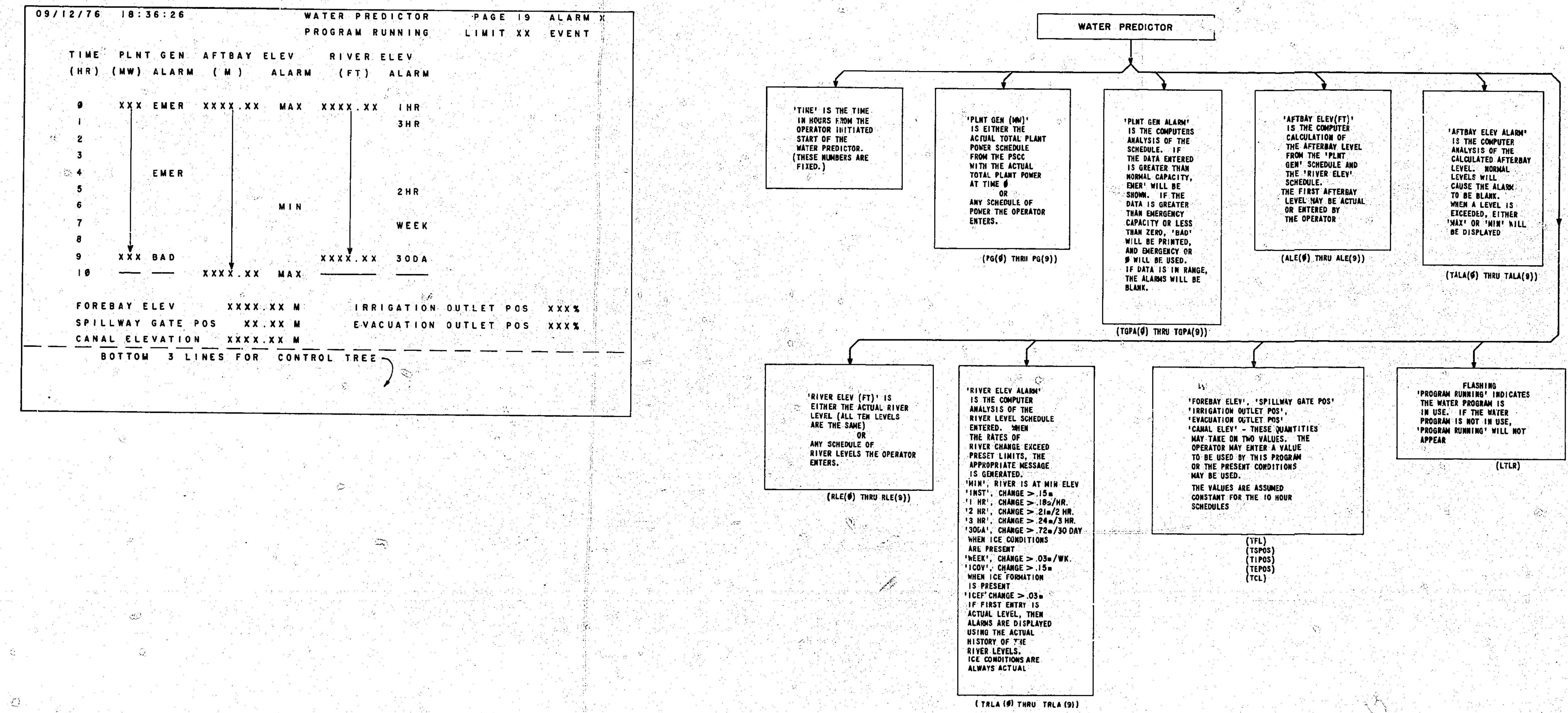


Figure 17.–Water Predictor format layout. Drawing 459-PS-2428

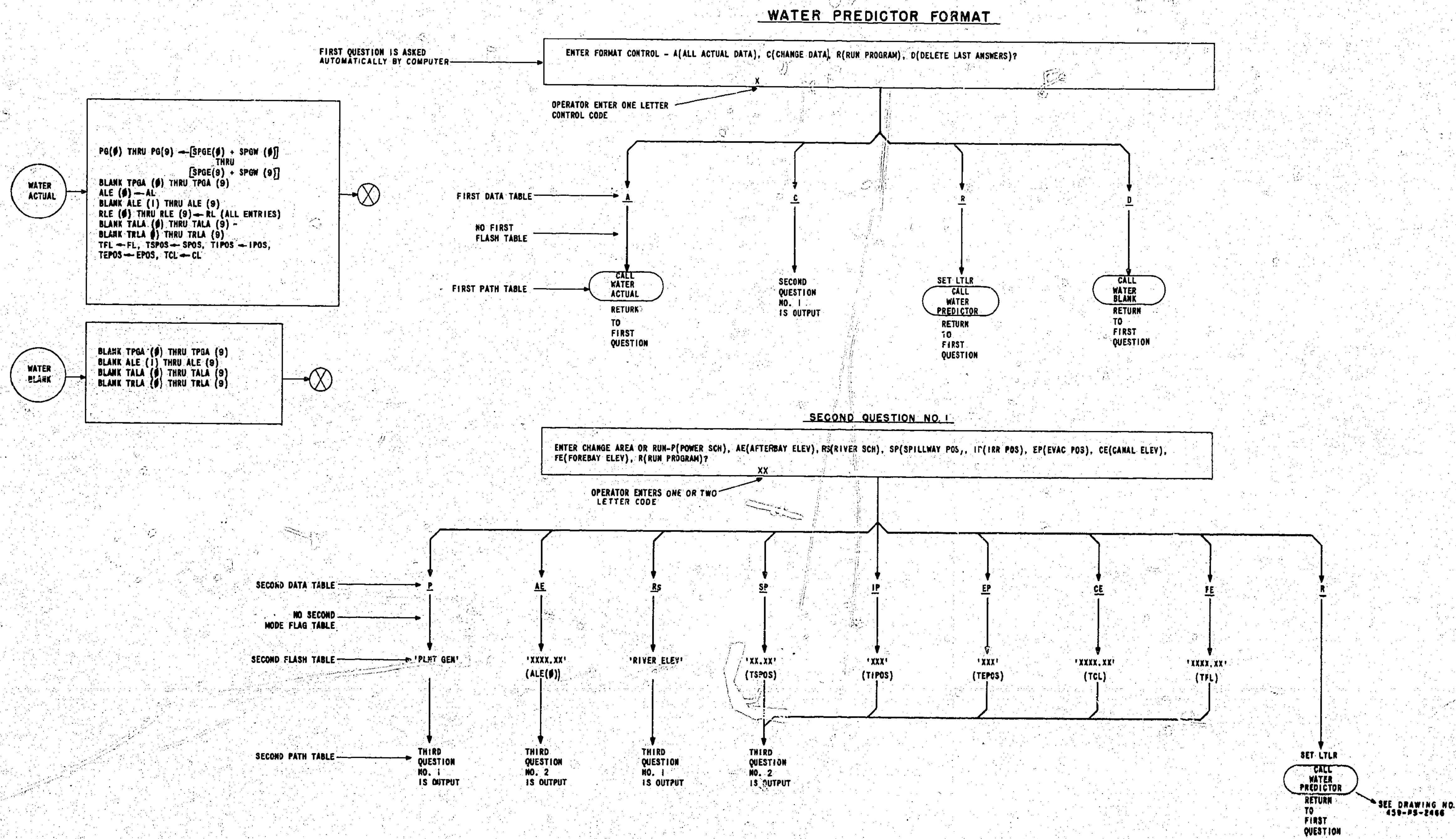
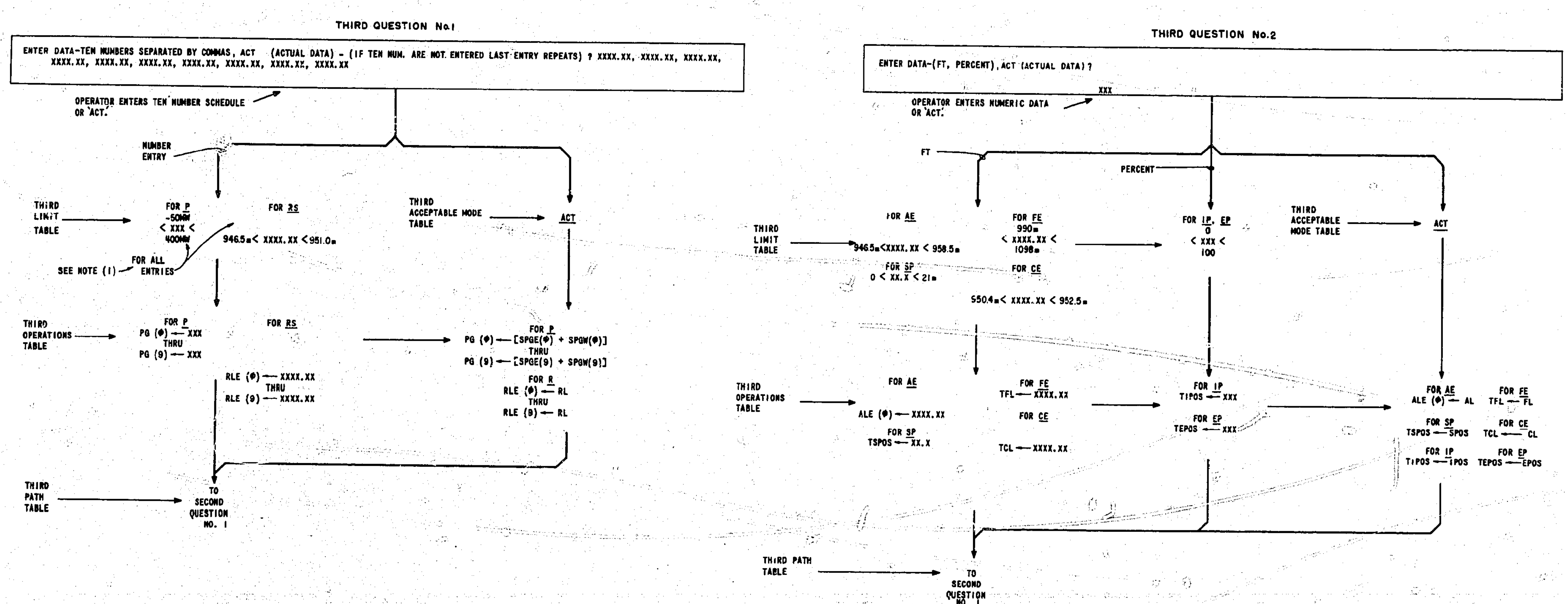


Figure 18.–Water Predictor format control tree (sheet 1 of 2). Drawing 459-PS-2429



NOTES

1) IF BLANK BETWEEN COMMAS OCCURS AS ENTRY, DO NOT ENTER NEW DATA FOR THAT VALUE. IF NOT ENOUGH ENTRIES WERE MADE, REPEAT LAST ENTRY FOR REMAINING ENTRIES. IF TOO MANY ENTRIES WERE MADE. IGNORE EXTRA ENTRIES.
2) SEE DWG. NO. 459-PS-2415 FOR ERROR MESSAGE NO. 3.

Figure 19.-Water Predictor format control tree (sheet 2 of 2). Drawing 459-PS-2430

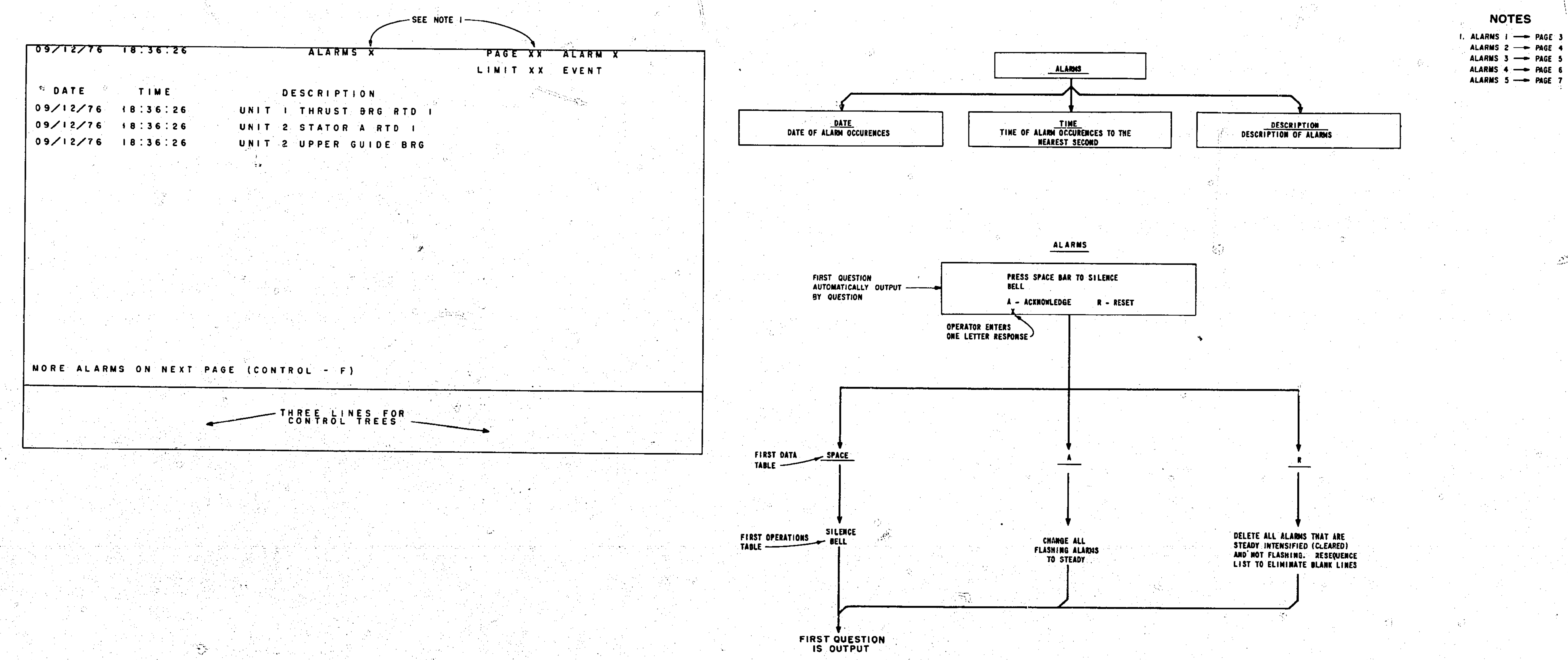


Figure 20.–Alarm format layout and control tree. Drawing 459-PS-2404

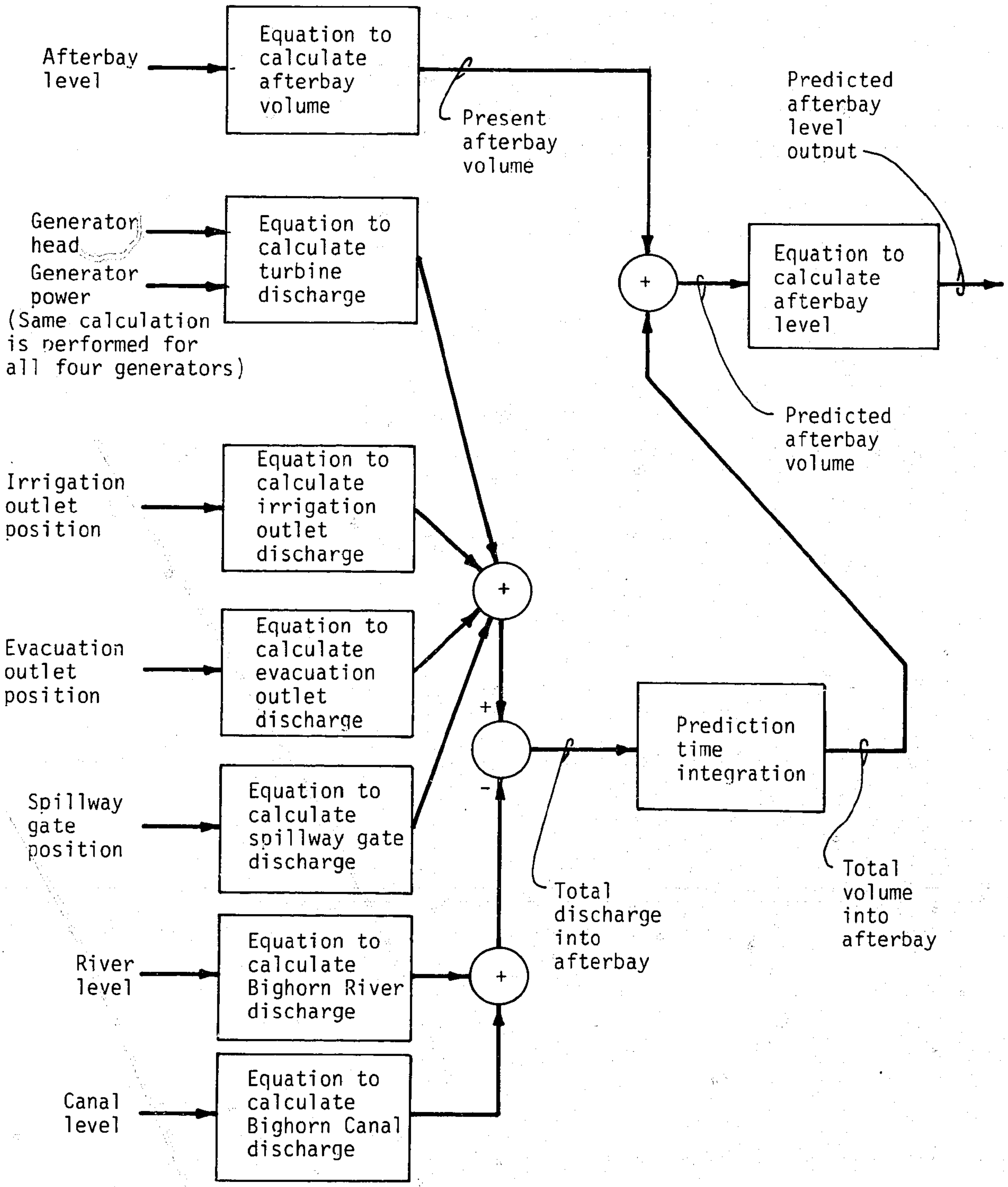
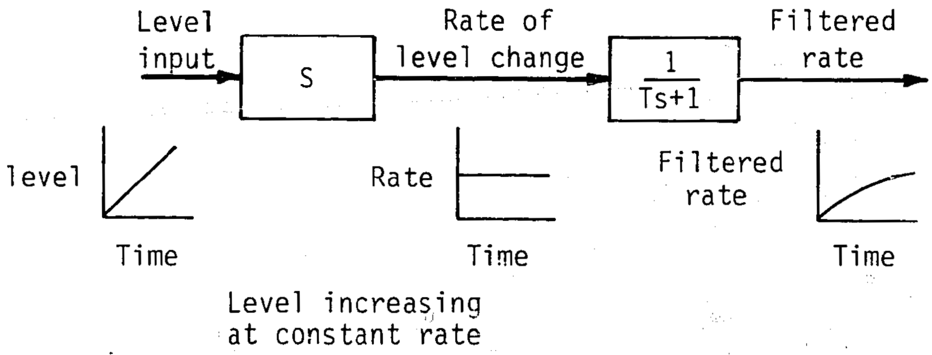
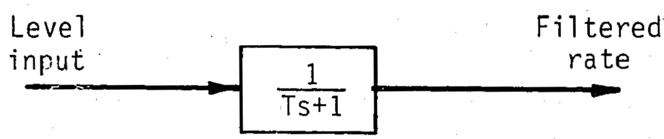


Figure 21.–Simplified flow of MODEL routine.



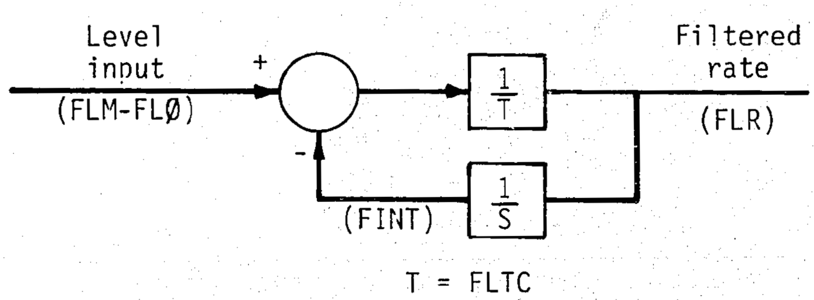
A - Laplace form



$$\text{Filtered rate} = \text{Level} \times \left[\frac{S}{Ts+1} \right] = \text{Level} \times \left[\frac{\frac{1}{T}}{1 + \frac{1}{Ts}} \right]$$

$$\text{Filtered rate} = \frac{1}{T} \left[\text{Level} - (\text{Filtered rate}) \times \frac{1}{s} \right]$$

B - Simplification of Laplace



FLR ← (FLM-FLØ-FINT)/FLTC
FINT ← FINT + (FLR X DTIM)

Time since last pass

Initialization
FLØ = FLM
FINT = Ø

C - Computer form with forebay level rate shown as example

Figure 22.–Derivation of rate filters.

APPENDIX A

FLOW CHART VARIABLE DEFINITIONS

APPENDIX A

FLOW CHART VARIABLE DEFINITIONS

AL	Transducer measured afterbay level (meters)
ALE (0)	Initial afterbay level for 10-hour scheduler. May be present actual value or operator entered (meters)
ALE (1) through ALE (10)	10-hour predicted afterbay level schedule (meters)
ALM	The afterbay level used by the MODEL routine (meters)
ALMLD	Afterbay level on the last pass used by WCON routine (meters)
ALMN	Afterbay minimum level calculated by WCON (meters)
ALMNW	Afterbay level predicted by MODEL routine (meters)
ALNEW	Corrected value for the predicted afterbay level (meters)
ALOLD	Value of the afterbay level for the last pass (meters)
ALP	30-minute afterbay level prediction by WCON (meters)
AM 1 through AM 16	Alarm flags set by the WCON routine
AV	Afterbay volume calculated by MODEL (cubic meters)

BREAKER STATUS	Status, open or closed, of the unit breaker
C2, C1, C0	Equation constants to calculate Bighorn Canal water discharge. C0 = 22.21; C1 = –18.88; C2 = 3.9
CD	Bighorn Canal discharge calculated by MODEL (cubic meters per second)
CL	Transducer-measured Bighorn Canal elevation (meters)
CLCOR	The correction factor used to calculate canal discharge (meters)
CLM	The Bighorn Canal elevation used by MODEL (meters)
CONST	Correction constant used to correct model
DTIM	Time since last pass of algorithm
E4, E3, E2, E1	Constants for calculating evacuation outlet discharge. E4 = 0.53; E3 = 0.028; E2 = –0.45; E1 = –0.025
ECAPM	Calculated unit emergency capacity (megawatts)
ED	Evacuation outlet discharge (cubic meters per second)
EPOS	Evacuation outlet position (operator entered) (percent open)
EPOSM	Evacuation outlet position used by the MODEL routine (percent open)

FINT	Forebay level integration
FL	Transducer-measured forebay level (meters)
FL0	Initial forebay level value used for integration (meters)
FLM	Forebay level used by MODEL routine (meters)
FLR	Filtered forebay level rate of change (meters per minute)
FLTC	Forebay level filter time constant (minutes)
FLTL	Flag to indicate to "Load Time Limit" that plant load is being entered by the operator
GEN A, GEN B, GEN C	Constants used to calculate unit capacities
GEN A EC, GEN B EC, GEN C EC	Constants used to calculate unit emergency capacities.
GEN A NC, GEN B NC, GEN C NC	Constants used to calculate unit normal capacities
GEN MW	Transducer-measured unit power (megawatts)
H	Constant used in turbine discharge calculation
HDM	Plant head used by MODEL routine (meters)

I4, I3, I2, I1	Constants used to calculate irrigation outlet discharge. I4 = 0.57; I3 = 7.5×10^{-3}; I2 = –0.489; I1 = -6.2×10^{-3}
ICM	Water system ice mode (operator-entered)
ICMD	Water system ice mode used by the operator display equipment
ID	Irrigation outlet discharge (cubic meters per second)
IPOS	Irrigation outlet position (operator-entered) (percent open)
IPOSM	Irrigation outlet position used by MODEL routine (percent open)
IRRF	Flag to indicate irrigation or nonirrigation season
L	Constant used to calculate afterbay volume
L2, L1, L0	Constants used to calculate predicted afterbay level
L2A, L1A, L0A	Constants used to calculate predicted afterbay level. L2A = 3.4×10^{-7}; L1A = 1.46×10^{-3}; L0A = –0.24
L2B, L1B, L0B	Constants used to calculate predicted afterbay level. L2B = -3.9×10^{-9}; L1B = 2.6×10^{-4}; L0B = 2.712
L2C, L1C, L0C	Constants used to calculate predicted afterbay level. L2C = -9.8×10^{-10}; L1C = 2.08×10^{-4}; L0C = 3.12

LTIME	Time prediction made by "Load Time Limit"
LTLR	Flag used to keep any of three main programs from executing at same time.
MES	Contains limit message code for "Load Time Limit"
MESS1	Limit message code for entered plant load
MESS2	Limit message code for normal plant capacity
MESS3	Limit message code for emergency plant capacity
MINIF	Initialize flag for the MODEL routine
MOD GEN BKR	Unit Breaker Status used by MODEL routine
N	Counter for 10-hour schedule predictor
NCAPM	Unit normal capacity used by predictors (megawatts)
P	Constant used to calculate turbine discharge
PG (0) through PG (9)	10-hour total plant generation schedule used by "Water Predictor"
PLANT ECAPM	Total plant emergency capacity used by MODEL routine (megawatts)
PLANT NCAPM	Total plant normal capacity used by the MODEL routine (megawatts)

POWER-UP PREDICTOR	Power-up flag for algorithm
PTIME	Prediction time used by MODEL routine
R2, R1, R0	Constants used to calculate river discharge. R2 = 0.058; R1 = –0.047; R0 = 0.02
RD	Calculated Bighorn River discharge (cubic meters per second)
RG2, RG1, RG0	Constants used to calculate afterbay level minimum from radial gate discharge. RG2 = –0.018; RG1 = 0.458; RG0 = 3.02
RGD	Calculated radial gate discharge (cubic meters per second)
RINT1 through RINT5	River level integrations
RL	Transducer-measured river level (meters)
RL10 through RL60	Initial river level used for integrations (meters)
RLCOR	River level correction factor used in calculating river discharge (meters)
RLE (0) through RLE (9)	10-hour river level schedule used by the "Water Predictor" (meters)
RLM	Bighorn River level used by the MODEL routine (meters)

RLMLD	River level for the previous pass as used by the WCON routine (meters)
RLMN	Minimum river level used by WCON routine (meters)
RLOLD	Value of the river level for last pass of algorithm (meters)
RLR1 through RLR5	River level filtered change rates (meters per minute)
RLTC1 through RLTC5	River level filter time constants (minutes)
RTU STATUS	Status, either up or down, of the afterbay dam RTU
S4, S3, S2, S1	Constants for calculating spillway discharge. S4 = 2.8; S3 = 2.03; S2 = –2.51; S1 = –2.16
SD	Calculated spillway discharge (cubic meters per second)
SEL	Flag to indicate time limit calculations for entered plant load, normal plant capacity, and emergency plant capacity
SF2, SF1, SF0	Constants to calculate free-crest spillway discharge. SF2 = 3.98×10^3; SF1 = -8.5×10^3; SF0 = 4.5×10^3
SFLOW	Spring flow into afterbay (operator-entered) (cubic meters per second)

SLG2, SLG1, SLG0	Constants used to calculate afterbay level minimum from sluice gate discharge. SLG2 = 65.93; SLG1 = 42.5; SLG0 = 2.29
SPGE(1) through SPGE(9)	Total plant generation scheduled to the east (next 10 hours) (megawatts)
SPGW(1) through SPGW(9)	Total plant generation scheduled to the west (next 10 hours) (megawatts)
SPOS	Spillway gate position (operator-entered) (percent open)
SPOSM	Spillway gate position used by the MODEL routine (percent open)
STOP ALLOCATE DOWN	Flag to AGC to stop load decreases
STOP ALLOCATION UP	Flag to AGC to stop load increases
T1 through T9	Constants used to calculate turbine discharge. T9 = 0.0025; T8 = –0.0073; T7 = 0.0055; T6 = –0.0047; T5 = 0.0088; T4 = 0.0018; T3 = 0.0085; T2 = –0.022; T1 = 0.020
TALA(0) through TALA(10)	Afterbay alarm message outputs

RLMLD	River level for the previous pass as used by the WCON routine (meters)
RLMN	Minimum river level used by WCON routine (meters)
RLOLD	Value of the river level for last pass of algorithm (meters)
RLR1 through RLR5	River level filtered change rates (meters per minute)
RLTC1 through RLTC5	River level filter time constants (minutes)
RTU STATUS	Status, either up or down, of the afterbay dam RTU
S4, S3, S2, S1	Constants for calculating spillway discharge. S4 = 2.8; S3 = 2.03; S2 = –2.51; S1 = –2.16
SD	Calculated spillway discharge (cubic meters per second)
SEL	Flag to indicate time limit calculations for entered plant load, normal plant capacity, and emergency plant capacity
SF2, SF1, SF0	Constants to calculate free-crest spillway discharge. SF2 = 3.98×10^3; SF1 = -8.5×10^3; SF0 = 4.5×10^3
SFLOW	Spring flow into afterbay (operator-entered) (cubic meters per second)

SLG2, SLG1, SLG0	Constants used to calculate afterbay level minimum from sluice gate discharge. SLG2 = 65.93; SLG1 = 42.5; SLG0 = 2.29
SPGE(1) through SPGE(9)	Total plant generation scheduled to the east (next 10 hours) (megawatts)
SPGW(1) through SPGW(9)	Total plant generation scheduled to the west (next 10 hours) (megawatts)
SPOS	Spillway gate position (operator-entered) (percent open)
SPOSM	Spillway gate position used by the MODEL routine (percent open)
STOP ALLOCATE DOWN	Flag to AGC to stop load decreases
STOP ALLOCATION UP	Flag to AGC to stop load increases
T1 through T9	Constants used to calculate turbine discharge. T9 = 0.0025; T8 = –0.0073; T7 = 0.0055; T6 = –0.0047; T5 = 0.0088; T4 = 0.0018; T3 = 0.0085; T2 = –0.022; T1 = 0.020
TALA(0) through TALA(10)	Afterbay alarm message outputs

TCL	Bighorn Canal elevation used by the prediction programs (meters)
TD1 through TD4	Turbine discharge calculated for units 1 through 4 by MODEL routine (cubic meters per second)
TEMP	A temporary storage variable
TEPOS	Evacuation outlet position used by prediction programs (percent open)
TFINT	Temporary storage for variable FINT
TFL	Forebay level used by prediction programs (meters)
TFL0	Temporary storage for variable FL0
TIME 1	Predicted time to afterbay limit for total plant generation entered by operator (calculated by "Load Time Limit")
TIME 2	Predicted time to afterbay limit for normal plant capacity (calculated by "Load Time Limit")
TIME 3	Predicted time to afterbay limit for emergency plant capacity (calculated by "Load Time Limit")
TIMED	Computer time initialization variable entered by operator on power-up

TIMEX	Actual computer time from executive
TIPOS	Irrigation outlet position used by prediction programs (percent open)
TL	Transducer-measured tailwater elevation (meters)
TLD	Time of last pass of water predictor
TOTD	Total discharge into the afterbay (calculated by MODEL routine) (cubic meters per second)
TOT PLT MW	Total plant load as calculated by the AGC system (megawatts)
TPG	Total plant generation used by "Load Time Limit" routine (megawatts)
TPGA(0) through TPGA(9)	Alarm messages for plant generation schedule entries
TRINT 1 through TRINT 5	Temporary storage for variables RINT 1 through RINT 5
TRL 10 through TRL 60	Temporary storage for variables RL 10 through RL 60
TRLA(0) through TRLA(9)	Alarm messages for entered 10-hour river level schedule

TSPOS	Spillway gate position used by prediction programs (percent open)
V0 through V3	Constants used to calculate afterbay volume given afterbay level. V3 = –1370.5; V2 = 6.96×10^4; V1 = -1.22×10^5; V0 = 4.3×10^4

APPENDIX B

WATER CONSTRAINTS FOR THE YELLOWTAIL UNIT

APPENDIX B

WATER CONSTRAINTS FOR THE YELLOWTAIL UNIT
(Data as of July 1976)

I. Bighorn River Level Rate Constraints

A. For ice-free conditions:

(1) Change greater than 0.15 m at any instant.

(2) Change greater than 0.18 m during any hour.

(3) Change greater than 0.21 m during any 2-hour period

(4) Change greater than 0.24 m during any 3-hour period.

(5) Change greater than 0.73 m during any 30-day period.

B. For ice-cover conditions:

(1) Change greater than 0.15 m during complete time.

(2) Change greater than 0.03 m during any week.

C. For ice-formation or breakup conditions:

(1) Change greater than 0.03 m during complete time.

II. Bighorn Lake Constraint

(1) Drawdown greater than 0.3 m during any 24-hour period.

III. Bighorn River Level Constraints

A. During irrigation season:

(1) Minimum level 962.56 m (discharge of 33.98 m^3/s).

B. During nonirrigation season:

(1) Minimum level 962.41 m (discharge of 28.32 m^3/s).

IV. Afterbay Reservoir Level Constraints

A. During irrigation season:

(1) Minimum elevation 967.74 m.

(2) Maximum elevation 972.92 m.

B. During nonirrigation season:

(1) Minimum elevation 963.78 m.

(2) Maximum elevation 972.92 m.

GPO 847-849

ABSTRACT

The operation of the computer algorithm used to detect constraints on the water system at Yellowtail Dam and Powerplant, Mont., including the afterbay dam, is explained. The algorithm is also shown in flow chart form. In addition, the two segments of the algorithm which allow the powerplant operator to predict water system conditions are discussed. The first segment will allow for Yellowtail Afterbay Reservoir level predictions up to 10 hours in advance. The second segment predicts the permissible time of operation of the four generators at given loads before an afterbay level limit is exceeded.

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The operation of the computer algorithm used to detect constraints on the water system at Yellowtail Dam and Powerplant, Mont., including the afterbay dam, is explained. The algorithm is also shown in flow chart form. In addition, the two segments of the algorithm which allow the powerplant operator to predict water system conditions are discussed. The first segment will allow for Yellowtail Afterbay Reservoir level predictions up to 10 hours in advance. The second segment predicts the permissible time of operation of the four generators at given loads before an afterbay level limit is exceeded.

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GR-78-3
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Bur Reclam Rep GR-78-3, Div Res, Apr 1978. Bureau of Reclamation, Denver, 72 p., 22 fig, 2 app.

DESCRIPTORS–/ *computer applications/ *algorithms/ computer programming/ digital systems/ water management (applied)/ afterbays/ *scheduling/ *reservoir operation/ computer models/ river forecasting/ river regulation/ river flow/ drawdown/ electric power demand/ peaking capacities/ water supply forecasting/ computer programs/ mathematical models
IDENTIFIERS–/ minicomputers/ Yellowtail Dam, Mont./ Yellowtail Powerplant, Mont./ Yellowtail Afterbay Dam/ Pick-Sloan Missouri Basin Program

COSATI Field/Group: 13B COWRR 1302

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