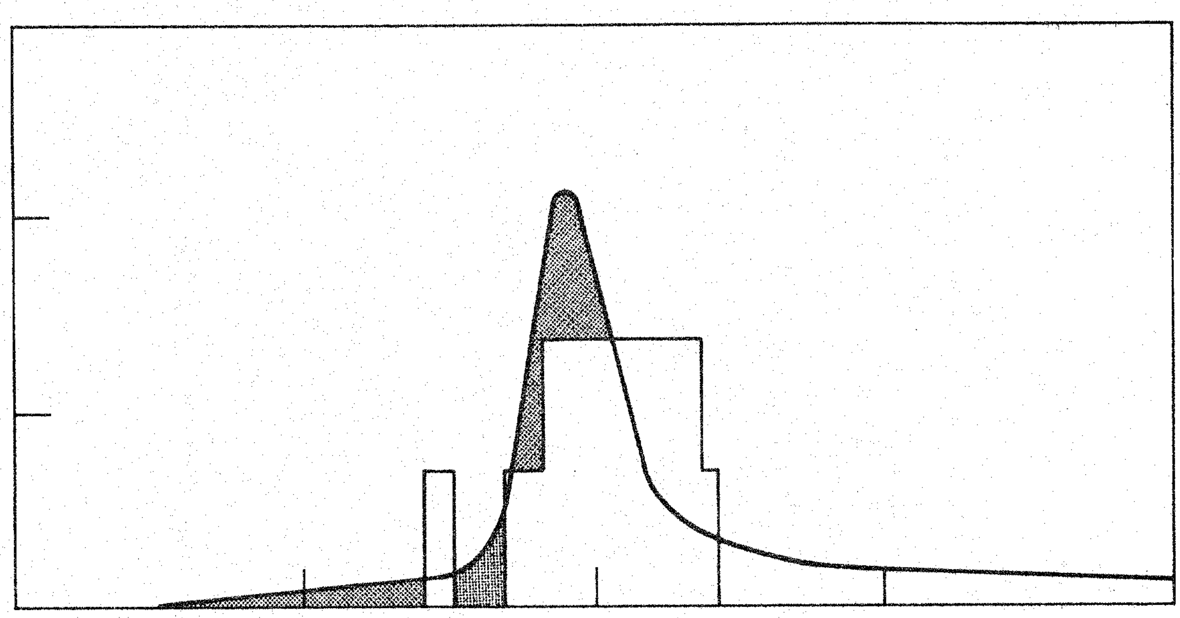
FHWA-EPD-86-119

Hydraulic Design of Stormwater Pumping Stations Using Programable Calculators

Texas Instruments
TI-59
Calculator Design
Series No. 5

U.S. Department of Transportation
Federal Highway Administration



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LIST OF SYMBOLS

Symbol	Units	Description
		Part I
A_1, A_2	sq ft	Area of water surface
D	ft	Depth of water stored in pipe or basin
d	ft	Depth of flow in pipe or basin
L	ft	Wetted length of pipe
M	sq ft	Area of midsection
Q	cfs	Rate of flow
S	ft/ft	Slope of storage basin or pipe
v	fps	Velocity of flow
V	ft^3	Storage volume
		Part II
a	ft	One-half of the chord length of the circular segment forming the base of an ungula
B	ft	Width of box conduit
b	ft	Depth of circular segment forming the base of an ungula
D	ft	Inside diameter of pipe
h		Heigth of ungula
H	ft	The total height of the trapezoidal basin
H	ft	Height of box conduit
ΔH	ft	Height increment
I	cfs	Inflow
$I_{(\Sigma T - T.I.)}$		Inflow at beginning of time increment
$I(\Sigma T)$		Inflow at end of time increment
$\overline{I}$		Average inflow for time increment
ΣLS	ft/ft	Sum of side slopes of a trapezoidal basin in the length direction
L_t	ft	Length of the floor of a trapezoidal basin
L	ft	Length of pipe
n	none	Number of height increments
O	cfs	Outflow
O_1	cfs	Outflow at beginning of time increment
R_w	ft	Radius of cylindrical wet well
S	ft^3	Storage used in the reservoir
S_o	ft/ft	Slope of pipe or conduit
ΔS		Change in storage during a time increment
$\Sigma\Delta S$		Cumulative storage

LIST OF SYMBOLS

Symbol	Units	Description
		Part II (Continued)
T	minutes	Time
$\Sigma\Delta T$	none	A counting variable, used by the calculator program E to keep track of number of iterations which have been performed
ΔT	seconds	Time increment (present in program to 60 seconds)
ΣT		Elapsed time in integral number of time intervals
T.I.		Time interval in whole minutes. Set by program user
V	ft^3	Volume
ΣWS	ft/ft	Sum of side slopes of a trapezoidal basin width direction
W_t	ft	Width of the floor of a trapezoidal basin
W	ft	Water Surface Elevation
ϕ	radians	One half of interior angle measuring circular segment forming the base of an ungula

Part I Discussion of Pumping Station Design Procedures

1.0 Introduction

In most localities, storm water pumping stations only operate for a relatively short period of time during a year. This means that a substantial capital investment must sit idle for long periods of time. Therefore, the design and operation of storm water pumping stations provides a most promising opportunity for cost reduction. Potential savings are even more promising in areas where storms are less frequent.

The merits of providng storage to reduce peak pumping rates of pumping stations have long been recognized by engineers. To control the costs of storm water projects, engineers are now examining potential saving much more closely. In order to achieve meaningful cost reductions, savings must be accomplished in both the construction cost, and the maintenance and operations cost areas.

Initial costs can be reduced by providing storage to reduce the peak pumping rate. This will produce savings in the cost of the pump, pump motor, and instrumentation; additional savings can be achieved by reducing the size of piping and valves. Substantial savings can occur if the number of pumps is reduced. These savings will be offset by the cost of providing storage; however, in many cases, a net savings will occur if the storage can be provided at a low cost.

Maintenance and operation costs can be lowered by reducing the fixed electrical charge assessed by most electrical utilities. This charge is basically for the electrical capacity that the utility must maintain to service the pumping station and is usually proportional to the horsepower of the station. Since horsepower is directly proportional to the pumping rate, any reduction in the pumping rate will be reflected in the fixed electrical charge.

Analyzing the effect of storage on reducing the pumping rate using manual calculations is a tedious, time consuming procedure. There are a wide range of storage and pumping rate combinations that will provide an adequate design. Due to time constraints, engineers usually only investigate the more obvious combinations. The purpose of this publication is to provide a collection of programmable calculator programs that will quickly analyze the problem, thus allowing engineers to investigate numerous combinations of storage and pumping rates.

2.0 Development of a Mass Curve Routing Procedure

The merits of using storage to reduce peak flows have been discussed in the previous section. A generalized case is selected for illustration because the actual pumping station case may be complicated by the varying pumping rates and discontinuities as the pumps turn on and off. This is shown in Figure 1.

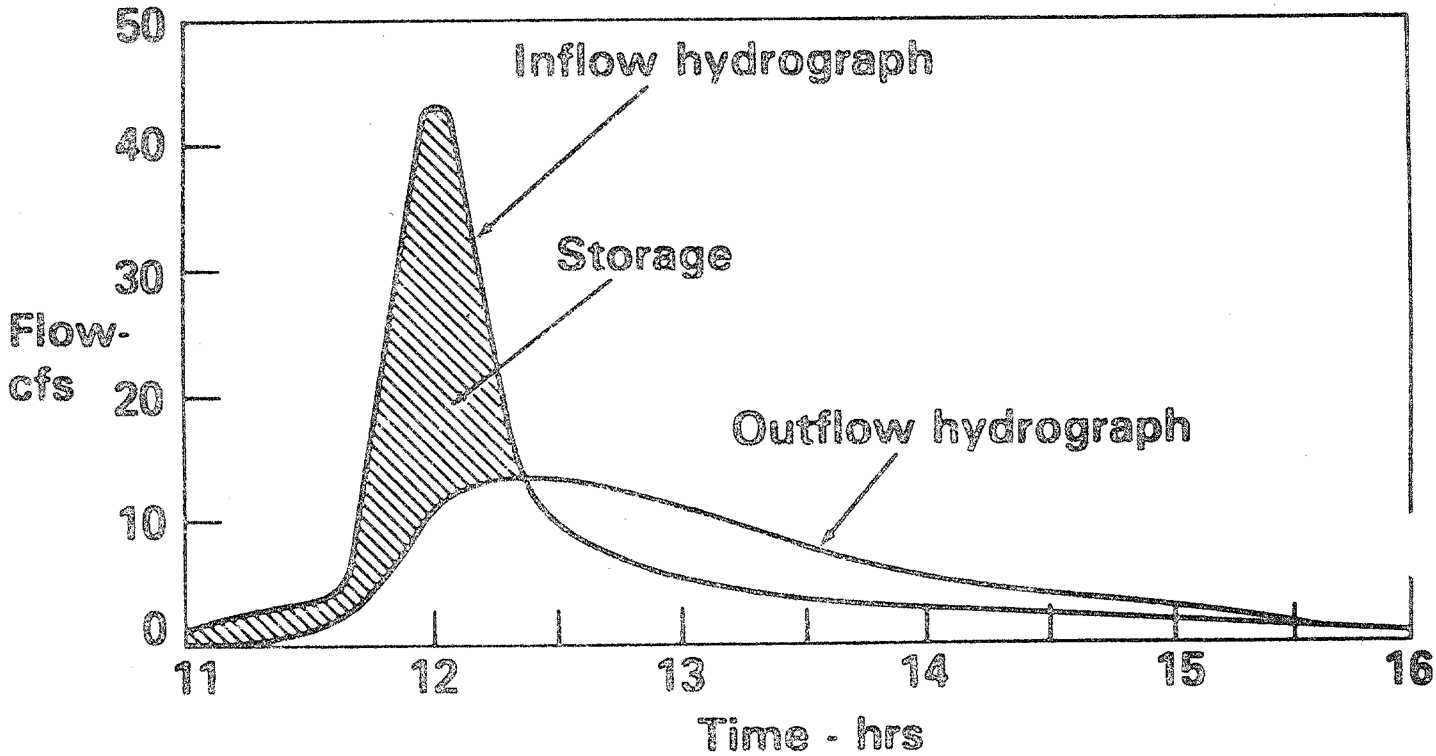


Figure 1. Use of Storage to Reduce Peak Flow Rate

The shaded area between the curves represents the volume of stormwater that must be stored to reduce the peak flow rate. Storage exists in natural channels, storm drain systems, constructed basins or forebays, and in storage boxes. Engineers must be able to identify and analyze the effect of storage on the discharge rates from the pump station.

Designers must establish the interrelationship between three separate components. First, the inflow hydrograph must be determined for the contributing watershed. Second, the volumetric storage capability of the storage facility must be identified. Third, the stage-discharge curve of the pumps must be determined. Once these three components have been established, a mass curve routing procedure can be used to analyze the problem. This routing procedure will be developed in the following sections.

An example problem is utilized to illustrate the development of the routing procedure; the inflow hydrograph used for this example problem is depicted in Figure 2.

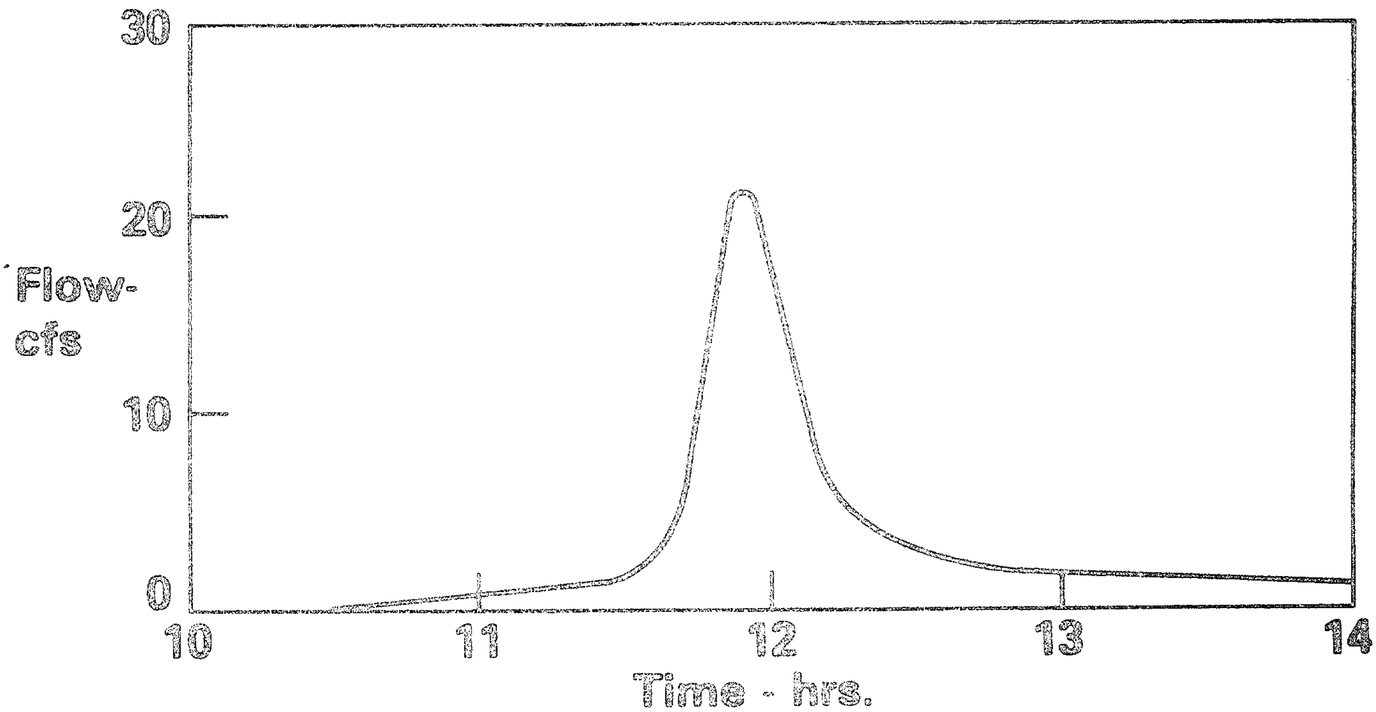


Figure 2. Inflow Hydrograph for Example Problem

3.0 Estimating Required Storage and Pumping Rates

Because of the complex relationship between the variables of pumping rates, storage, and pump on-off settings, a trial and error approach is usually necessary for estimating the pumping rates and storage required for a balanced design. There is a wide range of combinations that will produce an adequate design. A desirable goal is to maximize storage capacity so as to minimize pumping capacity.

Some approximation is necessary to produce the first trial design. One approach is shown in Figure 3.

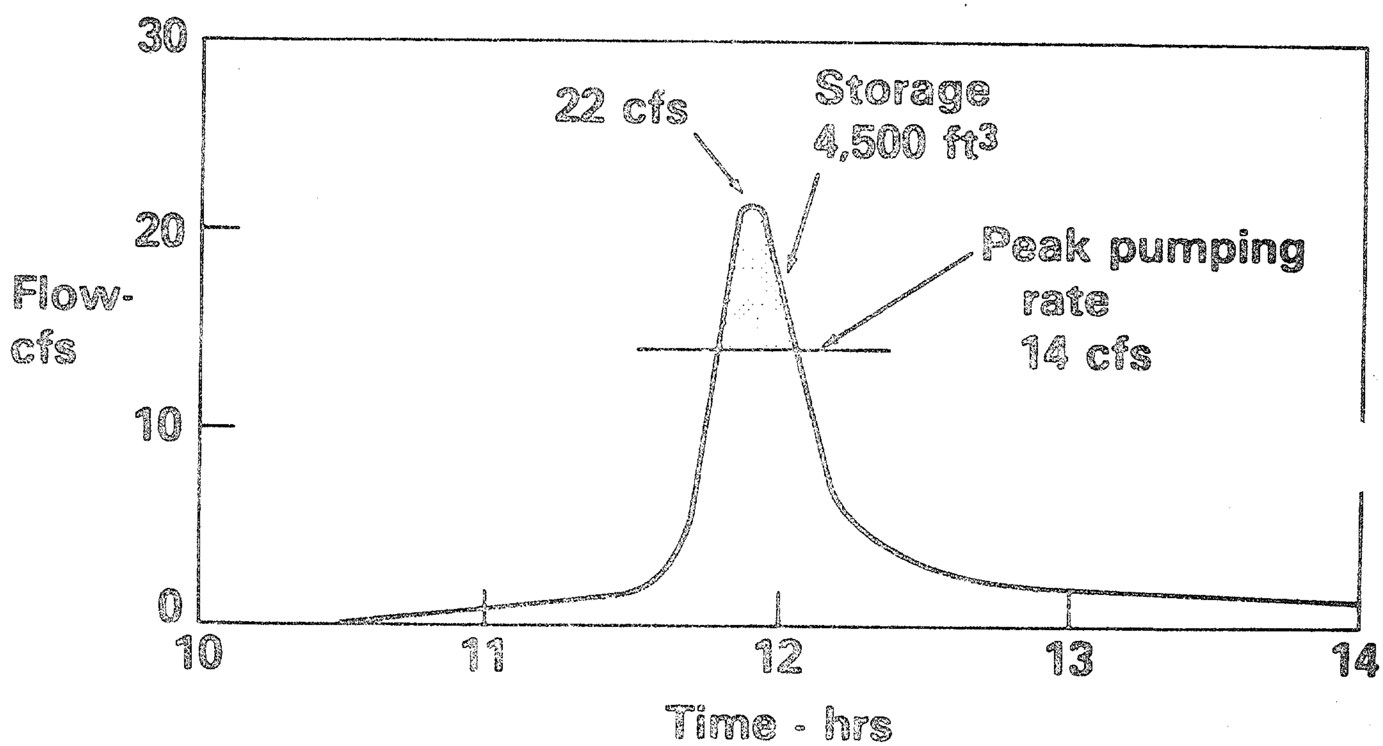


Figure 3. Estimating Required Storage

In this approach, the peak pumping rate is assigned and a horizontal line representing the peak rate is drawn across the top of the hydrograph. THE SHADED AREA ABOVE THE PEAK PUMPING RATE REPRESENTS THE VOLUME OF STORAGE REQUIRED ABOVE THE LAST PUMP-ON ELEVATION.

The number of pumps and their respective pumping rates are selected along with the pump on-off settings, and the storage basin's trial dimensions are assigned to produce the required volume of storage, represented by the shaded area in Figure 3, above the last pump-on elevation.

For the example problem, a peak pumping rate of 14 cfs was assigned; this will be accomplished by two 7 cfs pumps. The pumping rate is plotted as a horizontal line, and the shaded area is measured, determining the required volume (4,500 ft^3) above the last pump-on elevation.

4.0 Stage-Storage Relationship

Engineers have a wide range of tools available to them for providing the necessary storage at a pumping station. Earth basins either natural or constructed are the most cost-effective; however, at most highway pumping stations the storm water must be stored underground. This can be accomplished by oversizing the storm drain or providing a concrete storage box.

Routing procedures require that a stage-storage relationship be developed. This is accomplished by calculating the available volume of water for storage at uniform vertical intervals. Usually, the stage-storage curve is developed using 0.25 to 0.50 foot intervals.

4.1 Natural Earth Basins

Storage provided by irregular natural terrain is calculated by determining the area of horizontal planes associated with the vertical intervals. The areas of adjacent planes are averaged and multiplied by the vertical increment to determine an incremental volume. Starting at the bottom of the basin, the volumes are summed to obtain the stage-storage curve.

4.2 Trapezoidal Basins

The stage-storage curve can be calculated for a trapezoidal basin using the prismoidal formula:

$$V = \frac{D}{6}(A_1 + A_2 + 4M)$$

where:

V = Volume of basin at a given depth, ft^3

D = Depth of basin, ft

A_1 = Area of water surface, sq ft

A_2 = Area of base, sq ft

M = Area of midsection, sq ft

The volumes associated with the assigned depths are calculated and plotted to obtain the stage-storage curve.

A special case occurs when the basin is square (pyramid); the volume of the basin is calculated using the frustum of a pyramid equation:

$$V = \frac{D}{3} \left(A_1 + A_2 + (A_1 A_2)^{1/2}\right)$$

where:

V = Volume of a basin at a given depth, ft^3

D = Depth of basin, ft

A_1 = Area of water surface, sq ft

A_2 = Area of base, sq ft

4.3 Storm Drains

Whenever the pump start elevation is above the invert of the storm drain, the storm drain will perform more as a storage basin than a conveyance vehicle. By oversizing the storm drain, a true storage basin can be created to provide a meaningful reduction in pumping rates. One length of pipe could be designed to act as a storage basin, or the storage zone could be extended into several lengths of the storm drainage system.

The volumes for establishing the stage-storage curve can be calculated using the prismoidal formula:

$$V = \frac{L}{6} (A_1 + A_2 + 4M)$$

where:

V = Volume of water in pipe, ft^3

L = Wetted length of pipe, ft

A_1 = Wetted cross sectional area of lower end of pipe, sq ft

A_2 = Wetted cross sectional area of upper end of pipe, sq ft

M = Wetted cross sectional area of midsection of pipe, sq ft

Relative area-depth curves or tables for the particular storm drain shape must be consulted to determine the cross sectional areas. An FHWA report[1] provides relative area-depth tables for various cross sectional shapes.

If the pipe is circular, a special case exists, and the volume can be calculated using the ungula of a cone formula as discussed in calculator program section.

4.4 Storage Boxes

Underground storage boxes would most likely be rectangular reinforced concrete boxes. The volumes at the various stages can be calculated using a combination of formulas for regular prisms and triangular wedges.

Example Problem

In the example problem, a 520-ft long, 48" circular concrete pipe with a 0.40 percent slope is provided as a storage pipe as shown in Figure 4; a 21-ft diameter wet-well is also provided. The storage volumes for the respective elevations are tabulated in Table 1, and the stage-storage curve is plotted in Figure 5.

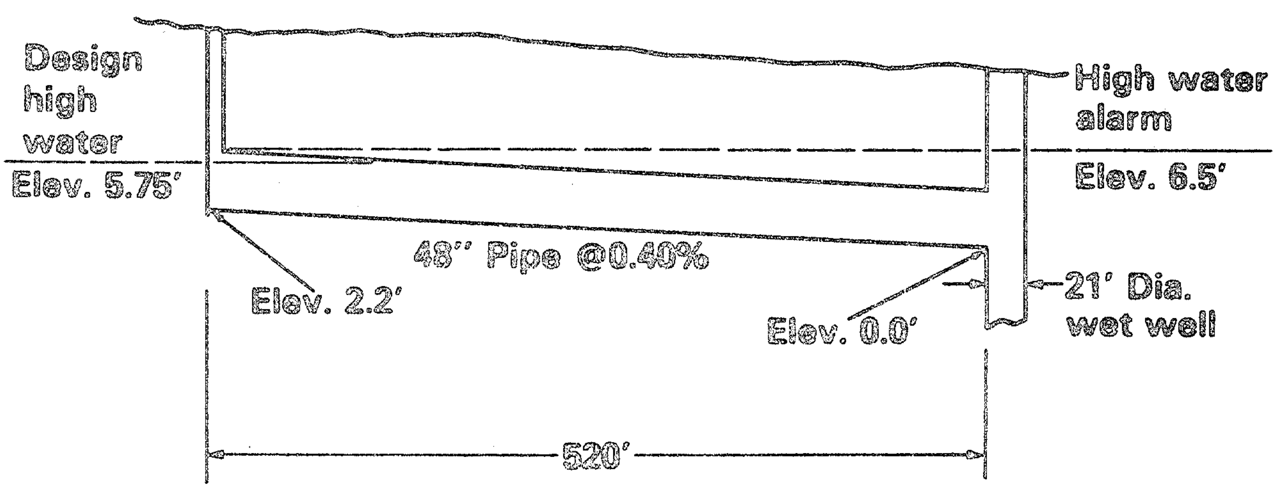


Figure 4. Storage Pipe Sketch

[1] Zelensky, P. N., Computation of Uniform and Nonuniform Flow in Presmatic Conduits, 1972, Federal Highway Administration, Office of Research and Development, Washington, D.C. 20590.

The storage volumes for the respective elevations are tabulated in Table 1, and the stage-storage curve is plotted in Figure 5.

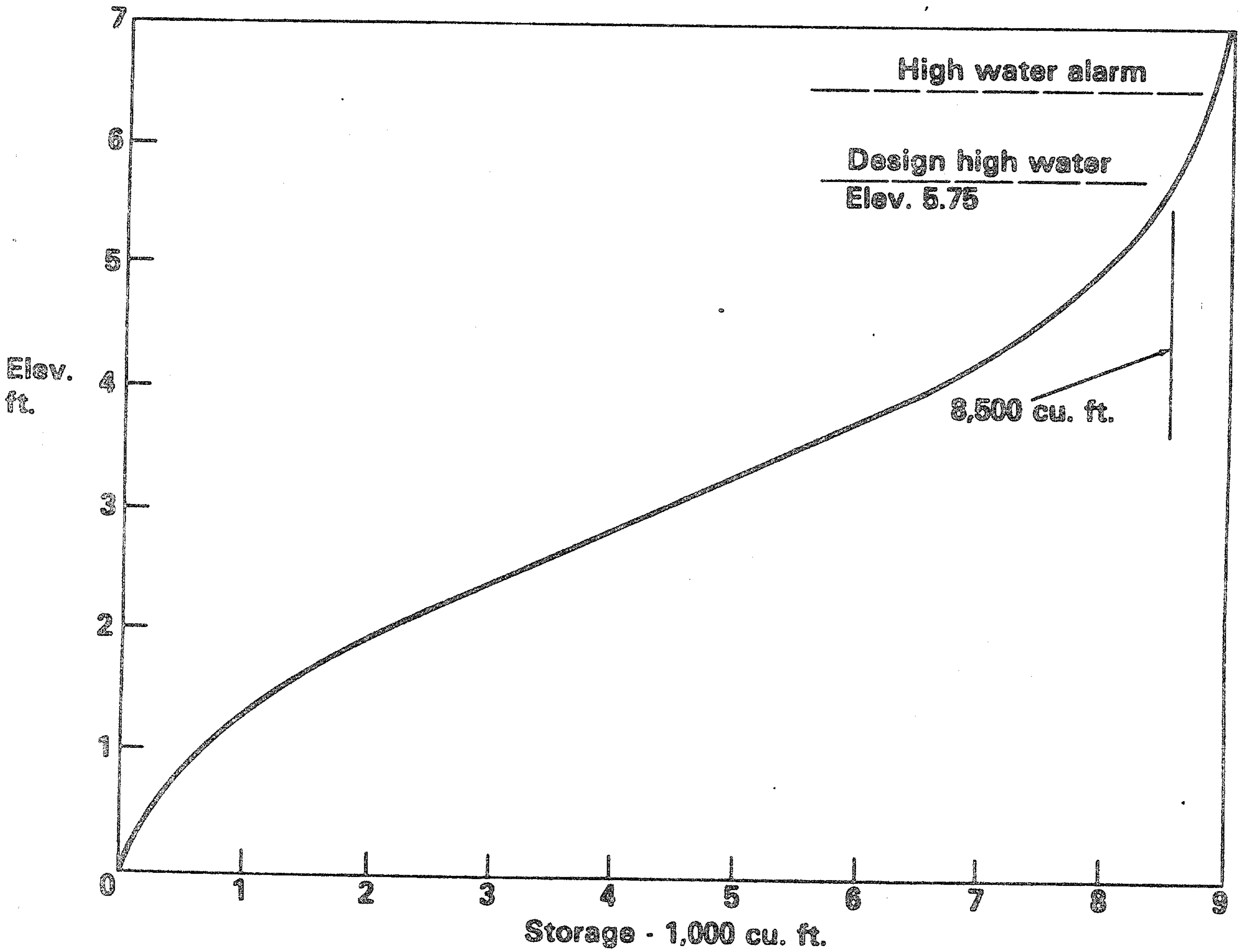


Figure 5. Stage-Storage Curve

Elevation (ft)	Pipe* (ft^3)	Wet Well (ft^3)	Total (ft^3)
0.0	0	0	0
0.5	45	173	218
1.0	251	346	597
1.5	672	519	1,191
2.0	1,333	692	2,025
2.5	2,213	866	3,079
3.0	3,187	1,039	4,226
3.5	4,168	1,212	5,380
4.0	5,072	1,385	6,457
4.5	5,773	1,559	7,332
5.0	6,230	1,732	7,962
5.5	6,468	1,905	8,373
6.0	6,534	2,078	8,612
6.5	6,534	2,251	8,785
7.0	6,534	2,424	8,958

Table 1 Stage-Storage Tabulation 48" Pipe @ 0.40 Percent - 21' Diameter Wet Well

*Computed by formula for ungular sections as explained in Part II of this publication.

5.0 Stage-Discharge Relationship

Mass curve routing procedures require that a stage-discharge relationship be established. For the example problem the following stage-discharge relationship was developed:

	Pump-Start Elevation	Pump-Stop Elevation
Pump No. 1 (7 cfs)	2.0	0.0
Pump No. 2 (7 cfs)	3.0	1.0

Figure 6 diagrams the pumping arrangement.

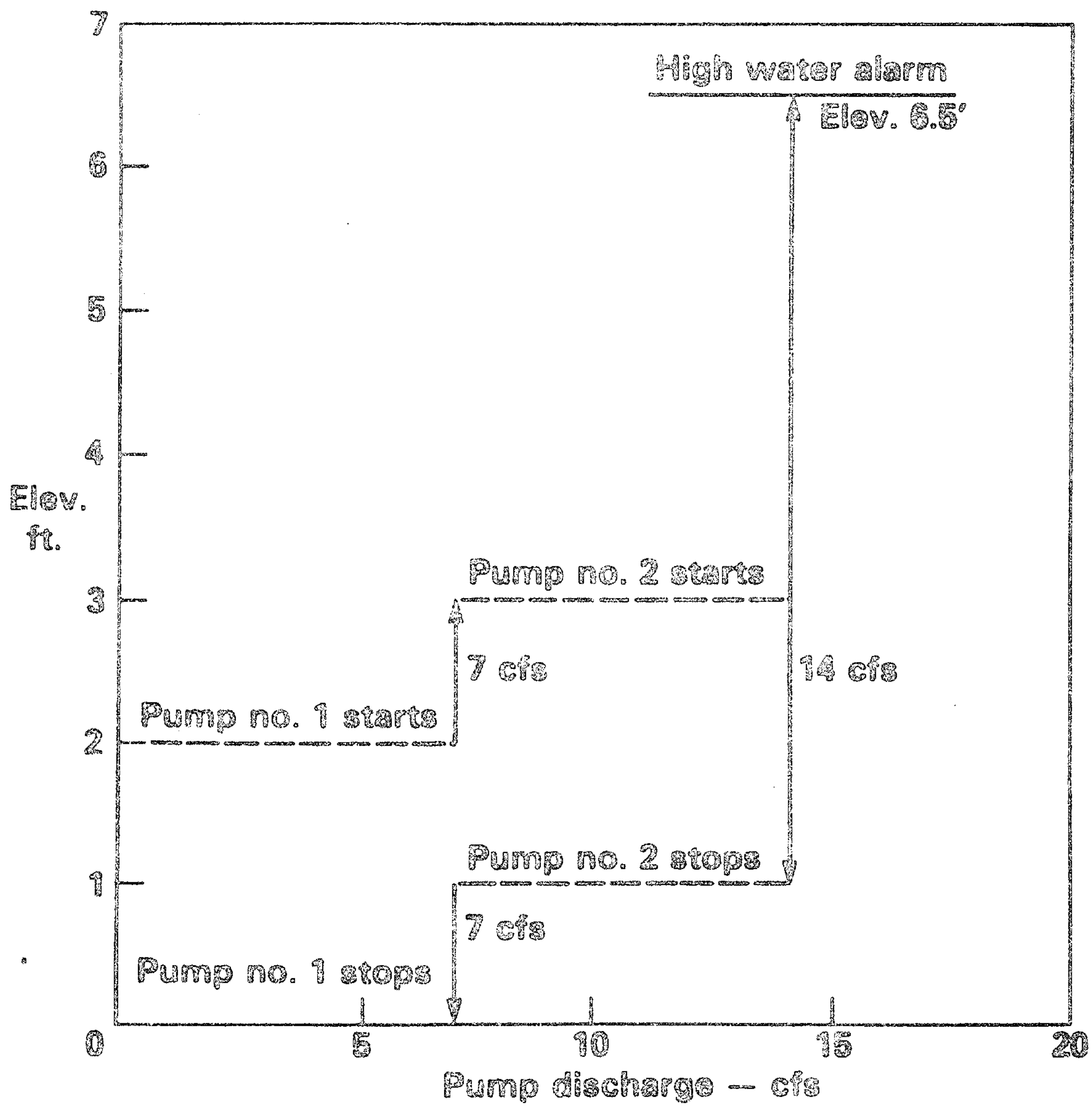


Figure 6. Stage-Discharge Curve

This stage-discharge relationship is based on three design criteria assumptions: (a) Pump No. 1 stops at Elevation 0.0, (b) 2-ft pumping range, and (c) 1-ft difference in elevation between pump starts.

Since pumping station design is basically a trial and error approach; this pumping arrangement should be considered as the first attempt.

6.0 Inflow Mass Curve

To obtain an inflow mass curve, the inflow rates at the limits of a time increment are averaged and multiplied by the time increment to obtain an incremental volume. These incremental volumes are then summed to obtain a cumulative inflow and plotted against time to create an inflow mass curve.

The inflow hydrograph (Figure 2) for the example problem is summed in Table 2 and plotted in Figure 7 as the inflow mass curve.

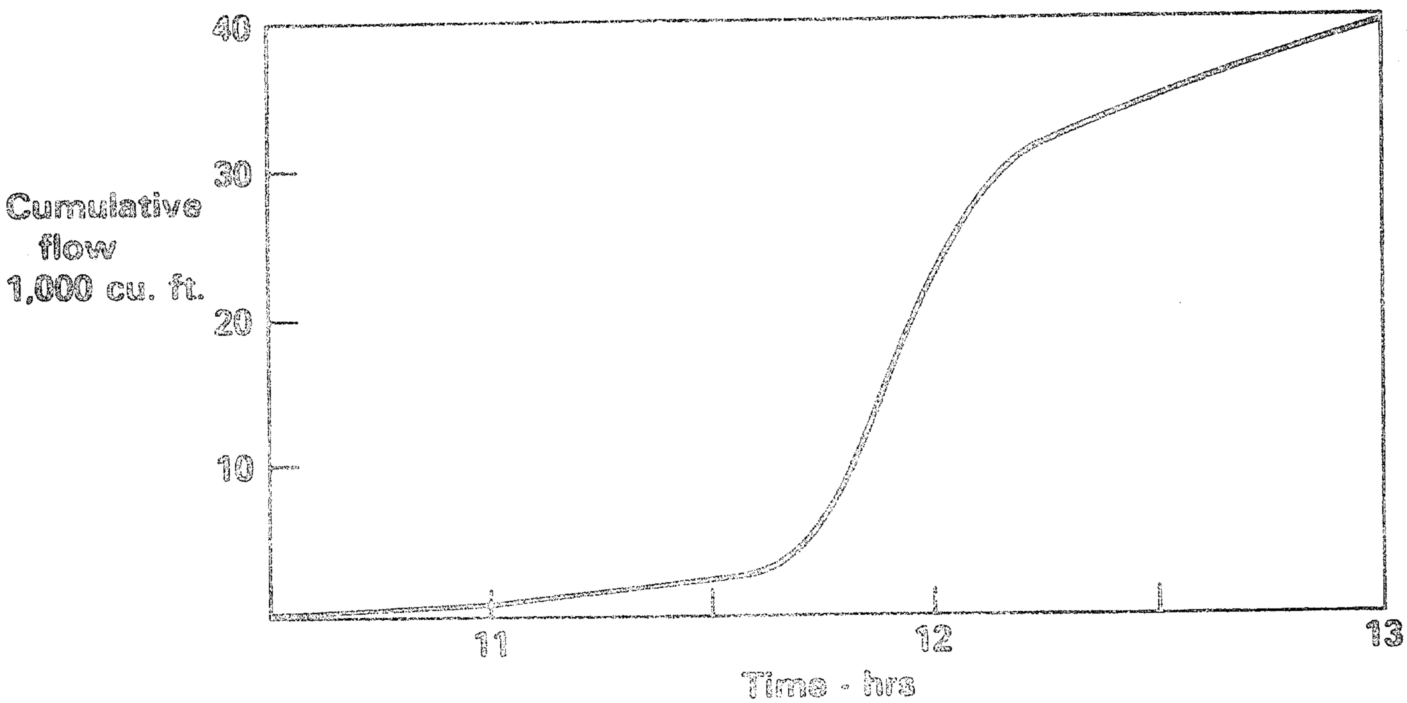


Figure 7. Inflow Mass Curve

Time	Inflow (cfs)	Average Inflow (cfs)	Time Increment (sec)	Incremental Flow (ft^3)	Cumulative Flow (f^3)
10:30	0				0
		.05	300	15	
35	.1		"		15
		.15	"	45	
40	.2		"		60
		.25	"	75	
45	.3		"		135
		.35	"	105	
50	.4		"		240
		.45	"	135	
55	.5		"		375
		.55	"	165	
11:00	.6		"		540
		.65	"	195	
05	.7		"		735
		.75	"	225	
10	.8		"		960
		.85	"	255	
15	.9		"		1,215
		.95	"	285	
20	1.0		"		1,500
		1.05	"	315	
25	1.1		"		1,815
		1.15	"	345	
30	1.2		"		2,160
		1.85	"	550	
35	2.5		"		2,710
		3.5	"	1,050	
40	4.5		"		3,760
		8.0	"	2,400	
11:45	11.5		300		6,160

Table 2 Development of Inflow Mass Curve

Time	Inflow (cfs)	Average Inflow (cfs)	Time Increment (sec)	Incremental Flow (ft^3)	Cumulative Flow (ft^3)
11:45	11.5				6,160
		15.2	300	4560	
50	19.0		"		10,720
		20.2	"	6060	
55	21.5		"		16,780
		19.2	"	5760	
12:00	17.0		"		22,540
		14.5	"	4350	
05	12.0		"		26,890
		9.2	"	2760	
10	6.5		"		29,650
		5.8	"	1740	
15	5.0		"		31,390
		4.5	"	1350	
20	4.0		"		32,740
		3.8	"	1140	
25	3.5		"		33,880
		3.4	"	1020	
30	3.3		"		34,900
		3.0	"	900	
35	2.7		"		35,800
		2.6	"	780	
40	2.5		"		36,580
		2.4	"	720	
45	2.3		"		37,300
		2.2	"	660	
50	2.1		"		37,960
		2.05	"	620	
55	2.0		"		38,580
		1.95	"	580	
13:00	1.9		300		39,160

7.0 Mass Curve Routing

After the three components, inflow hydrograph, stage-storage relationship and stage-discharge relationship have been determined, a graphical mass curve routing procedure can be used. In actual design practice, the inflow hydrograph, which is developed by an acceptable hydrologic method is a fixed design component; however, the storage and pumping discharge rates are variable. The designer may wish to assign a pumping discharge rate based on environmental or downstream capacity considerations. The required storage is then determined by various trials of the routing procedure.

As the stormwater flows into the storage basin, it will accumulate until the first pump-start elevation is reached. The first pump is activated and if the inflow rate is greater than the pump rate, the stormwater will continue to accumulate until the elevation of the second pump-start is reached. As the inflow rate decreases, the pumps will shut off at their respective pump-stop elevations.

These conditions are modeled in the mass curve diagram by establishing the point at which the cumulative flow curve has reached the storage volume associated with the first pump-start elevation. This storage volume (2025 ft^3) (Figure 5) is represented by the vertical distance between the cumulative flow curve and the base line as shown in Figure 8. A vertical storage line is drawn at this point since it establishes the time at which the first pump starts.

The pump discharge line is drawn from the intersection of the vertical storage line and the base line upwards towards the right; the slope of this line is equal to the discharge rate of the pump. The pump discharge curve represents the cumulative discharge from the storage basin, while the vertical distance between the inflow mass curve and the pump discharge curve represents the amount of storm water stored in the basin.

If the rate of inflow is greater than the pump capacity, the inflow mass curve and the pump discharge curve will continue to diverge until the volume of water in storage is equal to the storage (4,226 ft^3) associated with the second pump-start elevation. At this point the second pump starts, and the slope of the pump discharge line is increased to equal the combined pumping rate.

The procedure continues until peak storage conditions are reached. At some point on the inflow mass curve the inflow rate will decrease, and the slope of the inflow mass curve will flatten. To determine the maximum amount of storage required, a line is drawn parallel to the pump dischage curve tangent to the inflow mass curve as shown in Figure 8. The vertical distance between the lines represents the maximum amount of storage required.

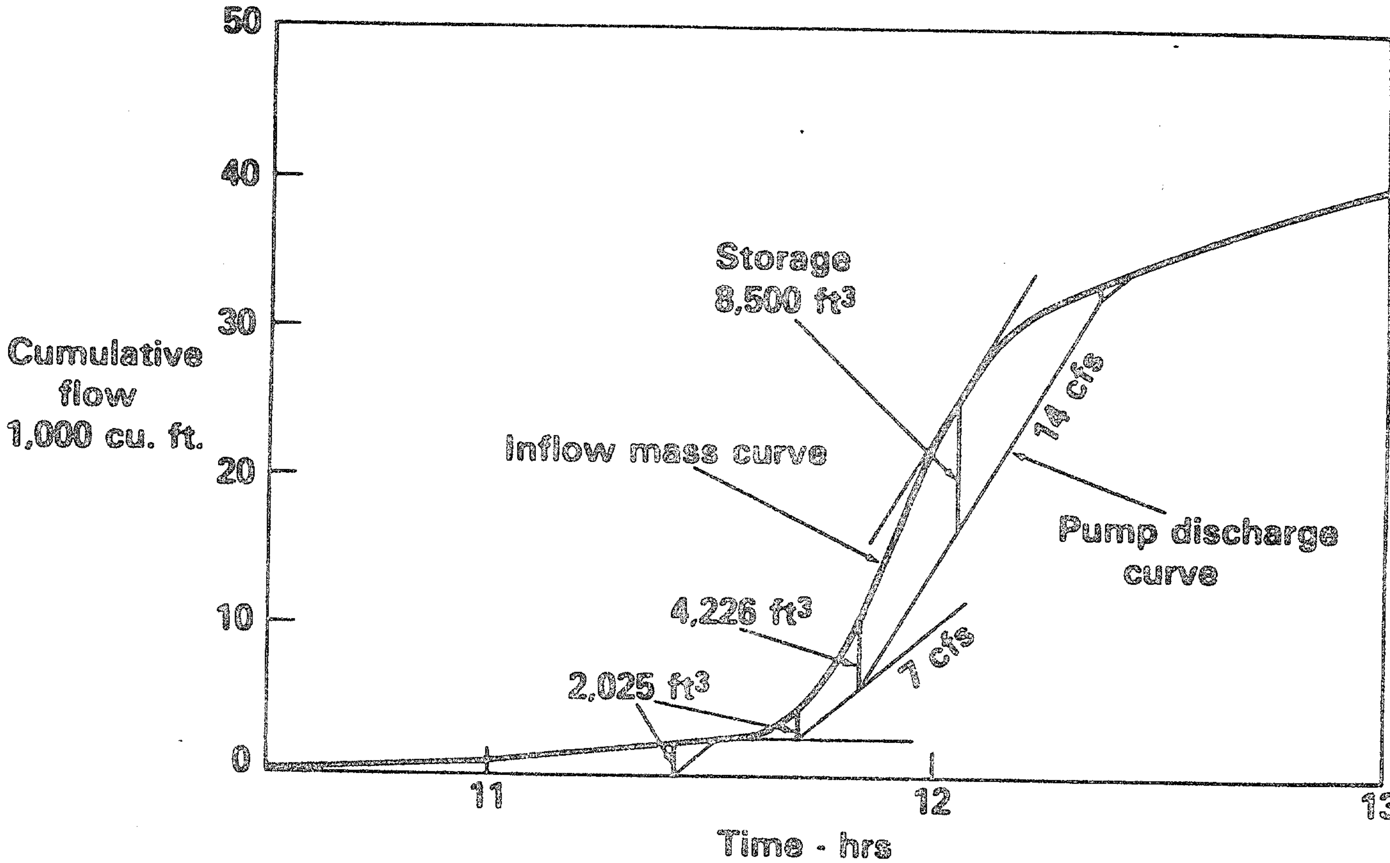


Figure 8. Mass Curve Routing Diagram

The routing procedure continues until the pump discharge curve intersects the inflow mass curve. At this point the storage basin has been completely emptied, and a pumping cycle completed. As the storm recedes, the pumps will cycle to discharge the remaining runoff.

In developing the pump discharge curve, the engineer should remember that the pump's performance curve is quite sensitive to changes in head and that the static head will fluctuate as the water level in the storage basin fluctuates. The designer should also recognize that the pump discharge rate represents an average pumping rate.

In developing the pump discharge curve, the engineer should remember that the pump's performance curve is quite sensitive to changes in head and that the static head will fluctuate as the water level in the storage basin fluctuates. The designer should also recognize that the pump discharge rate represents an average pumping rate.

In the example problem two 7 cfs pumps are provided. The pumping conditions are as follows:

	Pump-Start Elevation	Pump-Stop Elevation
Pump No. 1 (7 cfs)	2.0 (2,025)	0.0 (0)
Pump No. 2 (7 cfs)	3.0 (4,226)	1.0 (597)

The numbers in parenthesis are the storage volumes (ft^3) associated with the respective elevations.

As depicted in Figure 8, Pump No. 1 is activated when the cumulative flow fills the storage basin to elevation 2.0 (2,025 ft^3). The pump discharge curve is drawn from the base line at a rate of 7 cfs. Since the rate of discharge is greater than the inflow rate, the basin will quickly empty, and Pump No. 1 will shut off. The pump discharge curve will be horizontal because there is no pumped discharge until the inflow builds up to the Pump No. 1 start elevation again.

Pump No. 1 comes on again as the inflow build up. Since the inflow rate is greater than the discharge rate the curves will diverge until the available storage (4,226 ft^3) is reached at Pump No. 2 start elevation. The combined discharge rate is plotted, and a line is drawn parallel to the discharge curve through the point of tangency of the inflow mass curve to determine the maximum amount of storage required as shown in Figure 8. The vertical distance between the lines represents the maximum amount of storage required (8,500 ft^3).

The peak storage conditions have now been reached, and storage decreases. The routing continues until the two curves intersect, at which time the basin will have emptied. Pump No. 2 will shut off when the storage volume is equal to the volume (597 ft^3) associated with the Pump No. 2 stop elevation (1.0 ft); Pump No. 1 will shut off when the storage pipe has been emptied at Pump No. 1 stop elevation (0.0). Subsequent inflows will cause the pumps to cycle as the storm flow recedes; this additional cycling was not shown for simplicity.

The design is adequate since the available storage at the high water alarm is 8,785 ft^3. High water design conditions are plotted on the stage-storage curve (Figure 5) for reference.

In the final design, fine tuning of the mass curve routing procedure can occur after the pumps have been selected. For example, if two equal pumps are selected, the pumping rate when only one pump is pumping most likely would be greater than one-half of the combined rate due to head losses in the piping system. Another refinement can be made for the condition when all of the pumps have come on line and peak pumping conditions have been reached. The pump discharge curve can be adjusted to reflect changes in the pumping caused by changes in the static head. However, it is noted that these refinements do not act on the side of safety.

8.0 Discussion

Pumping Design

The designer now has a complete design that allows the problem to be studied in-depth. The peak rate of runoff has been reduced from 22 cfs, the inflow hydrograph peak, to 14 cfs, the maximum pump discharge rate. A reduction of 46.5 percent is accomplished by providing 8,500 ft^3 of storage. This is only one possible design option. The designer may wish to reduce the pumping rate further by providing more storage, and additional combinations of pump discharge and storage can be considered.

It is important that the designer visualize what is happening during the peak design period. To aid in this process, the pump discharge curve developed in Figure 8 can be superimposed on the design inflow hydrograph (Figure 2), as shown in Figure 9, to obtain another picture of the routing process.

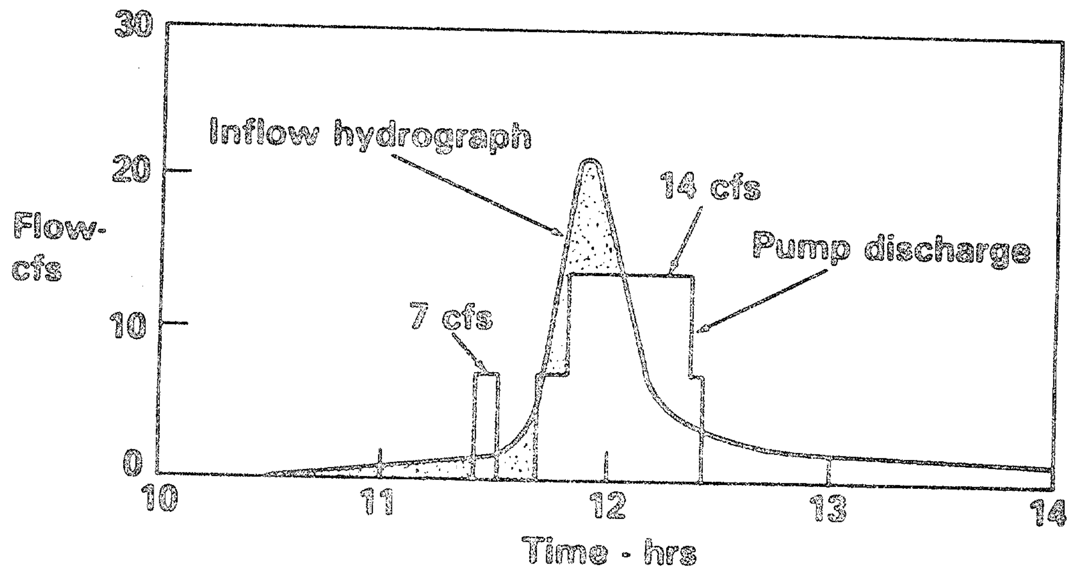


Figure 9. Pump Discharges

The shaded area between the curves represents storm water that is going into storage. Again, pump cycling at the end of the storm has been omitted in order to simplify the illustration.

To complete the design, the designer should investigate more frequent storms (2-10 yr. recurrence interval) to evaluate pumping cycles during these storms. Less frequent storms (100-yr. recurrence interval) should also be investigated to determine the amount of flooding that will occur.

Sediment Problems

Handling of sediment remains a difficult problem in pumping station design. Mechanical engineers prefer that as much sediment as possible be deposited in the storage boxes and wet well to minimize wear on the pumps while maintenance engineers prefer that the sediment be passed through the system so that the station is as maintenance-free as possible. While both of these goals may have merit, they are at cross-purposes, and some trade-off must be obtained.

Since the velocity in the storage pipe is quite low (1-2 fps) sediment will tend to settle out in the storage pipe. Some engineers recommend a relatively steep slope of 1-2 percent to pass the sediment into the wet well. As a general statement, the steeper the grade, the better the sediment removal; however the steeper grade may cause the station wet well to be driven deeper into the ground, increasing its cost. A steep grade may also limit the length of pipe that would otherwise be available for storage.

It is difficult to analyze flow and sediment conditions in the storage pipe; one approach would be to investigate the "flushing case." Design publications recommend a minimum velocity of 3 fps when the pipes are flowing full; however, in the pumping station case, the pumping rates determine the pipe velocity. For the "flushing case," it is assumed that all main pumps have stopped and that the inflow rate is one-half of the smallest pumping rate to insure pump cycling. The slope of the storage pipe is then selected to provide a velocity of at least 3 fps. The flushing case for the example problem is shown in Figure 10.

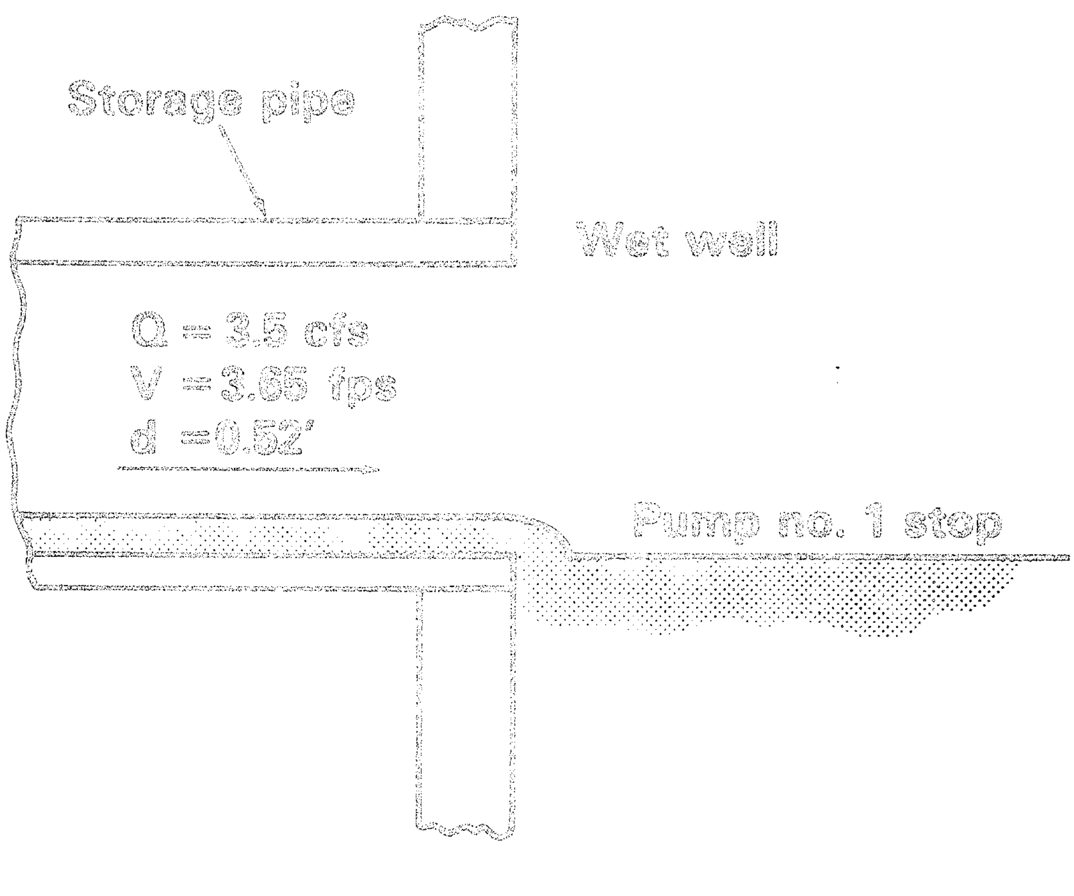


Figure 10. Flushing Conditions for Storage Pipe

The selection of the storage pipe size and slope is an important element in the trail and error design procedure. Table 3 provides design slopes of various sized concrete pipe that will produce a velocity of 3 fps when flowing at a depth of D/8. While this criteria is quite rigorous, the resulting slopes for the larger pipes are still quite flat. If the storage pipe is depressed or isolated from the upstream storm drainage, a minimum pipe grade of 0.35 percent is suggested to prevent low spots in the pipe.

In summary, the storage pipe and wet well should be designed to handle sediment; however, the pumping system should be designed to carry sediment-laden storm water in case sediment removal does not occur in the wet well.

Pipe Size (Inches)	Pipe Slope ft/ft
24	.0083
27	.0071
30	.0062
33	.0054
36	.0048
42	.0039
48	.0033
54	.0028
60	.0024
66	.0021
72	.0019
78	.00172
84	.00156
90	.00142
96	.00130

Table 3 Trial Slopes for Flushing Concrete Pipe (3 fps, 1/8 full-flow, n = 0.013)

Part II Pumping Station Analysis and Design Using a Programable Calculator

1.0 Introduction

The calculator programs presented here will assist the engineer in the preliminary design and analysis of typical pumping stations used in highway applications. Such pumping stations can be generalized as having a storage reservoir and two or more pumps which start and stop at preset water surface elevations. These calculator programs can be applied to any pumping station fitting this general description.

The design or analysis of pumping stations using these calculator programs is accomplished in three steps. The first step is to determine the stage-storage relationship for the storage reservoir. The second step is to assign the pumping rates and the start/stop elevations for the pumps. The third and final step is to route an inflow hydrograph through the pumping station and analyze its performance. These three steps may be repeated, changing various parameters, to arrive at a pumping station design which achieves the best compromise between storage and pumping characteristics for a given inflow hydrograph. Because the calculator programs allow a much more rapid analysis of a given pumping station than is possible using hand or graphical techniques, the engineer should achieve better designs in less time by using these programs.

The general aspects of pumping station design and analysis have been presented in part I of this publication. Part II presents a method of analysis using the Texas Instrument TI-59 programable calculator with a PC-100 printer. The programs presented have been written for this particular calculator. However, the equations used to describe the pumping station performance are general in nature, and could be programed on another calculator. With this in mind the programs have been thoroughly flowcharted and the algorithms explained in detail to facilitate the users understanding of the programs as well as to aid in programing this method of analysis on a different calculator.

Part II consists of 7 sections, including the introduction. Section 2 presents a general description of the procedure used to analyze the performance of a typical pumping station. Each of the three steps in the procedure is described in a general way to aquaint the reader with the concepts used. Section 3 presents a general description of the calculator programs, what each program accomplishes and how it fits into the overall analysis. Section 4 contains detailed user instructions. A step-by-step procedure is outlined on how the required information is entered for each program and what the resulting outputs mean. Section 5 presents four detailed example problems which illustrate the use of these calculator programs for the analysis of typical pumping stations. A summary of program limitations, of which all users of these programs should be aware, is presented in Section 6. Section 7 presents a detailed description of each of the programs. The equations used in each program are presented and explained. Each program is flowcharted and explained in detail.

2.0 General Description of Analysis Procedure

As stated in the introduction, a typical pumping station consists of a storage reservoir and two or more pumps which may start and stop at different water surface elevations. The analysis of a typical pumping station is done in three parts. Part one is the determination of the stage-storage relationship for the storage reservoir. Part two is the assignment of the pumping rate and the start/stop elevation for each of the pumps. Part three is the routing of an inflow hydrograph through the pumping station and an analysis of its performance.

The storage reservoir for a typical pumping station may consist of the station wet well plus a network of oversized pipes and boxes. The station wet well may be cylindrical or rectangular. The storage reservoir may consist of a rectangular basin with variable side slopes, similar to an inverted truncated pyramid or it may consist of a natural depression or some other irregular volume. In any case, the first step in an analysis of a pumping station is to adequately define the stage-storage relationship of the reservoir. This is a tedious process when done by hand or graphical methods. The first group of programs, discussed in Section 3, are used to perform the necessary calculations to adequately define the stage-storage relationship for any of the reservoirs mentioned above, except for the irregular reservoir. The stage-storage relationship for an irregular reservoir must be determined by other methods and then entered into the calculator. This is not a severe limitation because these types of reservoirs are used infrequently. The manner in which these programs are used to determine the stage-storage relationship is described briefly here and in much greater detail in Section 7.

Briefly, the total reservoir height, i.e. the top elevation minus the bottom elevation, is divided into twenty (20) increments. For each reservoir component (wet well, feeder pipe, etc.), the volume corresponding to each reservoir height increment is computed. The stage-storage relationship for each reservoir component is computed separately and these are added together to arrive at the total or cumulative reservoir stage-storage relationship. This total reservoir stage-storage relationship is used in subsequent calculations for the analysis of the pumping station performance.

The next step in the analysis procedure is the assignment of the pumping rates and the start/stop elevations for each of the pumps. The calculator programs have the capability of handling up to six (6) pumps. The pumping rate, the start elevation and the stop elevation for each pump is specified by the user. The way in which the calculator program determines when a particular pump is on or off is described here briefly and is described in much greater detail in a later section. Each pump is assigned a number, the pump which starts first (i.e. has the lowest turn on elevation) is assigned number one (1), the next pump to start is assigned number two (2), etc.

Starting with the highest pump number, the turn on elevation is entered into the calculator. The calculator determines which reservoir height increment corresponds to the turn on elevation for the pump. This information is stored for future use. The turn off elevation is entered next for the highest pump number. The calculator determines which reservoir height increment corresponds to the pump turning off and stores this information for future use. The pumping rate for the highest number of pump is entered next and this is also stored for future use. Once these three pump parameters have been entered for the highest pump number the parameters for the next lower pump number are entered in the same order.

This sequence is repeated until the three pump parameters, i.e., turn on elevation, turn off elevation and pumping rate, have been entered for all pumps. This completes step two of the analysis procedure.

Step three, the final step, of the analysis procedure involves routing an inflow hydrograph through the pumping station. The calculator performs this routing by using a slightly modified form of the standard Storage-Routing Equation. The details of the routing procedure are explained Section 7 and are only briefly described here. The first part of step three is to enter the time interval between inflow hydrograph ordinates (i.e. successive inflow values). This is used to calculate the average inflow for each time interval and to keep track of the cumulative time once the inflow hydrograph begins. After the time interval value has been entered, the inflow values for each successive time interval are entered, beginning with time equal to zero. For each inflow value entered, the calculator will compute the cumulative value of storage used in the storage reservoir. This value of storage is then used to determine the water surface elevation in the storage reservoir. The calculator then determines the current outflow value by comparing the current storage value with the pump-storage relationship developed in step two above. Each of these values time, inflow, storage, water surface elevation, and outflow are printed by the calculator for each successive time interval. The complete inflow hydrograph is routed through the pumping station by entering each successive inflow value until the outflow from the pumping station is zero, or the storage reservoir has been exceeded.

3.0 General Description of Programs

The seven separate, but interdependent, calculator programs presented will enable the engineer to analyze a typical pumping station in less time than required by hand methods. Each of these seven programs will be described in general terms in this section. A more detailed description is contained in Section 7. Each separate program has a unique label which serves to identify it and also serves to access the program when using the calculator.

The first part of the analysis of a pumping station is the determination of the stage-storage relationship for the storage reservoir. As mentioned in Section 2, the storage reservoir can be rather simple or it can be quite complex. As a result, the programs used to determine this stage-storage relationship must be flexible. They must be able to calculate the stage-storage relationship for many different reservoir configurations. For this reason, five of the seven programs described deal with the determination of the stage-storage relationship for various types of storage reservoirs.

The most common configuration of storage reservoir used for a typical highway pumping station is the station wet well with a system of pipes feeding into it. It is often desirable to oversize these feeder pipes, or to use box conduits in lieu of pipes, to achieve larger values of storage within the reservoir. The first three programs described are used to determine the stage-storage relationship for this typical configuration. These three programs are Program Label A, Program Label B, and Program Label C.

Program Label A is used to define the stage-storage relationship for the station wet well. It is also used to enter the top and bottom elevations of the total storage reservoir. Program Label A can also be used to determine the stage-storage relationship for a trapezoidal basin, occasionally used as a reservoir component. This will be discussed in more detail later in this section. Program Label A is accessed by pressing the label A button on the TI-59 calculator (assuming the proper programs have been loaded into the calculator). Once Program Label A has been accessed the top elevation and then the bottom elevation of the storage reservoir are entered. The program subtracts these two elevations and divides the result by 20. This determines the reservoir height increment. For each height increment a data storage register is set aside (Registers 1 thru 21). The cumulative stage-storage relationship for the reservoir will be stored in these data registers. The next step in the execution of program Label A is to identify the type of wet well used in the pumping station, either rectangular or cylindrical. If the wet well is cylindrical, the radius of the wet well is then entered. The program will then calculate the cumulative storage for the wet well for each of the 20 reservoir height increments, starting at the bottom elevation of the reservoir and continuing until all 20 height increments have been accounted for. These values are stored in data registers 1 through 21. If the wet well is rectangular, the length and width of the wet well are entered. The values of the sums of the side slopes in both the length and width directions are entered next. These will be zero when the wet well has vertical walls. These values are needed when a trapezoidal basin is used as a component of the storage reservoir, as discussed later. Once all the parameters for the rectangular basin have been entered, the program then calculates the cumulative storage for the wet well for each of the 20 reservoir height increments, as described above for the cylindrical wet well. Once the stage-storage relationship for the wet well has been determined, the contributions to the total reservoir stage-storage relationship of the other reservoir component, the feeder pipes, must be determined. This is accomplished by Program Label B and Program Label C.

Before proceeding with the discussion of Program Label B and Program Label C, there is another use of program Label A which was mentioned above. Occasionally it is feasible to excavate a trapezoidal basin, similar to an inverted truncated pyramid, and use this as the pumping station wet well. This is handled in the same manner as described above for the rectangular wet well. The only difference is that the sum of the basin side slopes, in both the length and width directions is not equal to zero.

<u>Program Label B</u> is used to calculate the stage-storage relationship for any circular pipes feeding into the wet well. These pipes may be of any diameter, any length, or on any slope. (Horizontal pipes must be approximately by very small but finite slopes, 1×10^{-6} as an example.) As long as the downstream invert elevation of the pipe is below the top elevation of the reservoir, the pipe will contribute some volume to the cumulative stage-storage relationship of the reservoir. Program Label B is accessed by pressing the Label B button on the TI-59 calculator (assuming the proper programs have been loaded into the calculator). Once Program Label B has been accessed the parameters describing the feeder pipe are entered. These are the pipe diameter, the pipe slope, the pipe length, and the downstream invert elevation. Once the pipe parameters have been entered, the program determines which reservoir height increment corresponds to the pipe invert. This in turn allows the program to add the additional storage contributed by the feeder pipe to the proper data registers. The additional storage for the feeder pipe is then calculated and placed in the appropriate data registers. If there are more pipes contributing to the total reservoir volume these are accounted for by repeated use of Program Label B. This program is run for each contributing pipe. If the reservoir consists of simply the station wet well and circular feeder pipes, the total stage-storage relationship for the reservoir has been computed. If the feeder pipes also consist of box conduits then Program Label C must also be used.

<u>Program Label C</u> is used to calculate the stage-storage relationship for any box conduits feeding into the wet well. These boxes may be of any width, any height, any length or on any slope.* As long as the downstream invert elevation of the box is below the top elevation of the reservoir, the box will contribute some volume to the cumulative stage-storage relationship of the storage reservoir. Program Label C is accessed by pressing the Label C

*Horizontal boxes must be approximated by very small but finite slopes, 1×10^{-6} as an example.

button on the TI-59 Calculator (assuming the proper programs have been loaded into the calculator). Once program Label C has been accessed the parameters describing the box conduit are entered. These are the box height, the box slope, the box length, the box width and the downstream invert elevation. As described above for the circular pipes, the calculator then determines which height increment corresponds to the box invert and adds the calculated volumes to the appropriate data registers. If there are more boxes contributing to the total reservoir volume these are accounted for by repeated use of Program Label C. If the reservoir components consist of only the wet well and the feeder pipes, then once Programs Label A, Label B and Label C have been executed, the complete stage-storage relationship for the pumping station reservoir has been defined. The stage-storage relationship will be used by other programs, as described below, to analyze the pumping station performance.

Occasionally it is convenient to utilize a natural depression or some other reservoir as the storage resevoir for the pumping station. It might also be that the performance of a pumping station with a reservoir of known stage-storage relationship is to be analyzed. In either case, the stage-storage relationship for the reservoir is known before hand. Program Label A' is used in this instance to enter a known stage-storage relationship for the storage reservoir. Program Label A' is accessed by pressing the button labeled A' on the TI-59 calculator (assuming the proper program has been loaded into the calculator). Once Program Label A' has been accessed the top elevation of the reservoir and then the bottom elevation of the reservoir are entered into the calculator. The calculator determines the value of the reservoir height increment, as described in Program A, and stores this value for use in subsequent calculations. The known stage-storage relationship for the reservoir is entered next. Sequential volumes, numbered zero (0) through twenty (20) are entered into the calculator. Volume zero is asociated with the bottom elevation of the reservoir and volume twenty is associated with the top elevation of the reservoir. Intervening volumes are associated with intervening increments of reservoir height. This is simply a stage-storage curve, where the total stage of the reservoir is divided into twenty equal increments. Once the stage-storage relationship for the known reservoir has been entered, if there are other components which add storage to the reservoir, such as feeder pipes or boxes, then these may be accounted for by using Program Label B or Program Label C as described previously. Once the stage-storage relationship for the reservoir is complete the performance of the pumping station may be evaluated by subsequent programs, as described later in this section.

The programs described above are used to calculate a stage-storage relationship for a typical storage reservoir. It is often useful to record the stage-storage relationship for later use. This is done by using Program Label E'. Once the stage-storage relationship has been computed Program Label E' may be used to list the stage-storage relationship. Program Label E' is accessed by pressing the label E' button on the TI-59 calculator. Once this has been done the calculator will list the volumes associated with the twenty equal reservoir height increments. This is especially useful if a particular pumping station reservoir will be used in several designs. The stage-storage relationship need be calculated only once and then for subsequent analyses the stage-storage relationship may be entered into the calculator using Program Label A'.

The second part of the analysis of a pumping station is to assign the number of pumps, the pumping rate for each pump, and the start/stop elevation for each pump. This is accomplished by using Program Label D. Program Label D is accessed by pressing the Label D button on the TI-59 calculator. This program will handle up to six pumps of any discharge. The first parameter entered after accessing program Label D, is the number of pumps. In order to keep track of these pumps the calculator assigns each pump a number. The pump with the highest start elevation is assigned the highest number. Starting with the highest pump number the following pump parameters are entered for each pump: the start or turn on elevation, the stop or turn off elevation, and the pumping rate. These three parameters are entered for each pump, in turn, starting with the highest number of pump and finishing with pump number one. The way in which the calculator program stores this pump information for future use is described here briefly. This is described in greater detail in Section 6.

The program compares the start elevation entered for the highest number pump and determines the reservoir height increment with which it corresponds. The program then stores this pump "on" information for future use by adding .1 to the values of storage associated with that height increment and all higher height increments. The program then examines the stop elevation entered for the highest number pump and determines the height increment with which it corresponds. The program then stores this pump "off" information by adding .01 to the values of storage associated with that height increment and all higher height increments. The program then stores the value of the pumping rate for the highest number of pump in a designated data storage register. This sequence of operations is repeated for each of the pumps up to a maximum number of six pumps. Once all three pumps parameters have been entered for each of the pumps, the pump information has been assigned and a storage vs. pumping rate relationship has been determined. Part two of the pumping station analysis is then complete.

The third and final part of the analysis of a pumping station is the routing of an inflow hydrograph through the pumping station and an analysis of its performance. This is accomplished by using Program Label E, the seventh and final program to be described in this section. Program Label E is accessed by pressing the button labeled E on the TI-59 calculator. The first data entered, once Program Label E has been accessed, is the time interval, to the nearest whole minute (fractional portions of a minute such as 2.5 minutes or 3.3 minutes are not allowed). This time interval value is stored in a dedicated data storage register and is used in subsequent calculations. The successive inflow values for the inflow hydrograph are entered next, beginning with the inflow associated with time equal to zero. For each inflow value entered, the programs will print the appropriate value for the following: cumulative time, the value of inflow entered, the current value of storage used in the reservoir, the water surface elevation associated with the current storage, and finally the outflow value at the end of the time interval. The methods to used compute these values are described here briefly and are described in greater detail in Section 7.

For each inflow value entered the calculator computes the average inflow for the time interval. With this average infow and the outflow computed for the previous time increment the calculator computes the change in storage. The current value of storage is then computed and printed. The water surface elevation associated with the current value of storage is then computed and is printed. Finally, the current value of storage is compared with the pump-storage relationship developed in part two of the analysis. This determines the outflow value at the end of the time increment. This value is printed and is also used in subsequent calculations. This sequence of operations is repeated for each inflow value entered. The analysis of a pumping station for a given infow hydrograph is complete when the outflow has decreased to zero (all pumps have turned off). The printed tape produced by the PC-100 printer provides a complete record of the performance of the pumping station. The maximum storage required, the maximum water surface elevation and the sequencing of the pumps is recorded for analysis. This completes the analysis of the pumping station.

4.0 User Instructions

This section explains in detail the data required by each of the seven calculator programs, and also explains how the program user inputs this data. This section also describes the prompting messages which are printed on the paper tape to tell the user what data is required and when to enter it. This section is organized into three parts, parallelling the analysis of the pumping station. The first part describes how the five programs associated with defining the storage reservoir are used. The second part describes how the program associated with the pumps is used. The third and final part describes how the routing program is used. These descriptions assume a working knowledge of the calculator and printer.

The five programs used to determine the stage-storage relationship for the pumping station storage reservoir are contained on two sets of magnetic cards. Programs Label A, Label A', and Label E' are contained on the first set of magnetic cards. Programs Label B, Label C, and Label E' are contained on the second set of cards. Program Label E' is contained on each set of cards to allow the user to list the stage-storage relationship for any reservoir without having to load an extra set of magnetic cards into the calculator. Each set consists of two cards. The first card contains the calculator program instructions on banks 1 and 2. The second card contains the appropriate data and alpha-numeric codes on banks 3 and 4. Programs Label A and Label A' will be described first. Programs Label B, Label C, and Label E' will then be described.

Program Label A

Program Label A is used to calculate the stage-storage relationship for the pumping station wet well.

Program Label A is contained on the first set of magnetic cards. These two magnetic cards must be read into the TI-59 calculator before program Label A can be accessed.*

Program Label A is accessed by pressing the button labeled A on the TI-59 calculator.

Once Program Label A has been accessed the message "TOP ELEVATION?" will be printed and the calculator will halt operation. The top elevation of the storage reservoir is input by the user and then the R/S button is pressed.

*The publication package contains a listing of the programs and data register contents. These must be transfered to magnetic cards. (Appendix)

The calculator then prints the message, "BOTTOM ELEV.?" and halts operation. The bottom elevation of the storage reservoir is input by the user and then the R/S button is pressed.

The calculator will then print the message, "RECT.=0, CYL.=1", and halt operation.

If the pumping station wet well is cylindrical the user enters the number 1 and then presses the R/S button.

If the pumping station wet well is rectangular then the user enters the number 0 and presses the R/S button.

For a cylindrical wet well, after the number 1 has been entered and the R/S button pressed, the calculator will print the message, "RADIUS?" and halt operation.

The user then enters the value of the radius of the cylindrical wet well in feet and presses the R/S button.

The calculator will then calculate the stage-storage relationship for 20 equal height increments, from the bottom elevation to the top elevation specified. These volumes are stored in data registers 1 through 21.

When the calculator has completed these calculations the paper tape will advance and the calculator will halt operation.

For the rectangular wet well, after the number 0 has been entered into the calculator and the R/S button pressed, the calculator will print the message, "BASIN LENGTH?", and then halt operation.

The user then enters the length of the rectangular wet well and presses the R/S button.

The calculator will then print the message "BASIN WIDTH?", and halt operation.

The user enters the width of the rectangular wet well and presses the R/S button.

The calculator prints the message, " Σ LENGTH SLOPES" and halts operation.

For a rectangular wet well which has vertical walls the user enters zero and then presses the R/S button.

The calculator then prints the message, " Σ WIDTH SLOPES" and halts operation.

For a rectangular wet well which has vertical walls the user enters zero and presses the R/S button.

The calculator will then compute the stage-storage relationship for 20 equal height increments, from the bottom elevation to the top elevation specified. These volumes are stored in data registers 1 through 21.

When the calculator has computed these calculations the paper tape will advance and the calculator will halt operation.

The stage-storage relationship for the pumping station wet well has been calculated and the additional storage provided by the other components of the storage reservoir may now be calculated. This is done by using Programs Label B and Label C.

Before continuing to explain the use of Programs Label B and Label C, there is one more point to be addressed for Program Label A. As discussed in Sections 2 and 3, Program Label A may also be used to compute the stage-storage relationship for a rectangular basin with sloping walls, similar to an inverted truncated pyramid. This type of storage basin is sometimes used where it is economically feasible. In such cases, the stage-storage relationship for the basin may be computed by using Program Label A as described above for a rectangular basin. In this case, however, the sum of the side slopes will not be zero, and the appropriate values for the sum of the side slopes in both the length and width directions must be entered. This is discussed in greater detail in Section 7.

As mentioned above, Programs Label B and Label C are used to determine the additional storage provided by the other components of the storage reservoir, namely the feeder pipes or boxes. Program Label B is used to determine the additional storage provided by circular pipes, while Program Label C is used to determine the additional storage provided by box conduits. Each program's use will be described in detail below.

Program Label B

Program Label B is used to calculate the additional storage provided by circular pipes which feed into the pumping station wet well.

Program Label B is contained on the second set of magnetic cards. These two magnetic cards must be read into the TI-59 calculator before Program Label B can be accessed.*

*This publication package contains a listing of these programs and data register contents. This must be transfered to magnetic cards.

Program Label B is accessed by pressing the button labeled B on the TI-59 calculator.

Once Program Label B has been accessed the calculator will print the message, "DIAMETER" on the paper tape and halt operation.

The user must then enter the diameter in feet of the circular pipe and press the R/S button.

The calculator will then print the message, "SLOPE" and halt operation.

The user enters the slope of the pipe in feet per foot and presses the R/S button. (Horizontal pipes must be approximated by a very small but finite slope, 1×10^{-6} as an example.)

The calculator then prints the message,"LENGTH" and halts operation.

The user then enters the length of the pipe in feet and presses the R/S button.

The calculator then prints the message, "INVT. ELEV." and halts operation.

The user then enters the invert elevation of the end of the pipe closest to the pumping station wet well, and then presses the R/S button.

The calculator will then compute the additional storage provided by the pipe and allocate this to the correct reservoir height increments. Once these computations are complete the calculator will advance the paper tape and halt operation.

If there are additional pipes which feed into the pumping station wet well and if their downstream invert elevation is below the top elevation of the reservoir then these pipes will provide additional storage. The additional storage provided by each pipe is accounted for by repeating the use of Program Label B for each pipe as described above.

Program Label C

As mentioned previously Program Label C is used to compute the additional storage provided by box conduits which feed into the pumping station wet well.

Program Label C is contained on the second set of magnetic cards. These two magnetic cards must be read into the TI-59 calculator before Program Label C can be accessed.*

*This publication package contains a listing of these programs and data register contents. Thse must be tranfered to magnetic cards.

Program Label C is accessed by pressing the button labeled C on the TI-59 calculator.

Once Program Label C has been accessed the calculator will print the message "BOX HEIGHT" and halt operation.

The user then enters the height of the box conduit in feet and presses the R/S button.

The calculator then prints the message, "SLOPE" and halts operation.

The user enters the value of the slope of the box conduit, in feet per foot and presses the R/S button. (Horizontal boxes must be approximated by a very small but finite slope, 1×10^{-6} as an example.)

The calculator then prints the message, "BOX LENGTH" and halts operation.

The user enters the length of the box conduit in feet and presses the R/S button.

The calculator then prints the message, "BOX WIDTH" and halts operation.

The user enters the width of the box conduit in feet and presses the R/S button.

The calculator then prints the message, "INVT. ELEV." and halts operation

The user then enters the invert elevation of the downstream end of the box conduit, and presses the R/S button.

The calculator then computes the additional storage provided by the box conduit and allocates this storage to the correct reservoir height increments. Once these computations are complete the calculator will advance the paper tape and halt operation.

If there are additional box conduits which feed into the pumping station wet well and if their downsteam invert elevation is below the top elevation of the reservoir, then these boxes will provide additional storage. The additional storage provided by each box conduit is accounted for by repeating the use of Program Label C for each box as described above.

Programs Label A, Label B and Label C are used to calculate the stage-storage relationship for the majority of storage reservoirs used in typical highway pumping stations. As discussed in Sections 2 and 3, an irregular reservoir is used occasionally. The irregular shape of the reservoir precludes the use of simple geometric shapes to adequately describe its stage-storage relationship. The stage-storage relationship for such a reservoir must be determined by other means, such as the planimeter method. Once the stage-storage relationship for any reservoir has been determined, and placed in the appropriate data registers, it may be analyzed using the programs described in this publication. Program Label A' is used to place a predetermined stage-storage relationship into the appropriate data registers. The use of Program Label A' is described below.

Program Label A'

As mentioned above, Program Label A' is used to enter a predetermined stage-storage relationship for any reservoir.

Program Label A' is contained an the first set of magnetic cards. These two magnetic cards must be read into the TI-59 calculator before program Label A' can be accessed.*

Program Label A' is accessed by pressing the button labeled A'. This requires the keystrokes 2nd A' on the TI-59 calculator.

Once Program Label A' has been accessed the calculator will print the message, "TOP ELEVATION?" and halt operation.

The user then enters the top elevation of the reservoir and presses the R/S button.

The calculator then prints the message, "BOTTOM ELEVATION?" and halts operation.

The user then enters the bottom elevation of the reservoir and presses the R/S button.

The calculator will then print the message "VOLUME (0)?" and halt operation.

The user then enters the volume associated with the bottom elevation of the reservoir. This is often zero, but occasionally there is a sump or some other feature which must be accounted for. After entering the volume the user then presses the R/S button.

The calculator will then print the message, "VOLUME (1)?" and halt operation.

The user then enters the volume associated with the first height increment above the bottom of the reservoir and presses the R/S button.

The calculator will request the volume associated with each of the twenty equal reservoir height increments in the same manner as described above. The user must enter the appropriate volume and then press the R/S button after each entry.

After the twenty (20) volumes describing the stage-storage relationship for the reservoir have been entered, the calculator will advance the paper tape and halt operation.

*This publication package contains a listing of the programs and the data register contents. These must be transfered to magnetic cards.

Once a stage-storage relationship for a reservoir has been determined by Programs Label A, Label B, and Label C it is frequently desirable to make a record of the total stage-storage relationship for future use. Program Label E' is used to list the stage-storage relationship stored in data registers 1 through 21.

Program Label E'

As mentioned above, program Label E' is used to list the stage-storage relationship computed by other programs.

Program Label E' is contained on both magnetic card set one and magnetic card set two. Either set of two cards must be read into the TI-59 calculator before Program Label E' can be accessed.*

Program Label E' is accessed by pressing the button labeled E' on the TI-59 calculator. This requires the keystrokes 2nd E'.

Once Program Label E' has been accessed, the calculator will print the twenty volumes associated with the twenty equal reservoir height increments and then halt operation.

The five programs used for the determination of the stage-storage relationship of the pumping station reservoir have been described above. There are two additional programs which must be discussed. These are Program Label D and Program Label E.

As discussed in Sections 2 and 3, Program Label D is used in part two of the pumping station analysis which consists of the assignment of the pumping rates and start/stop elevations for each of the pumps.

Program Label D

As discussed previously Program Label D is used to input the appropriate pump data into the calculator.

Program Label D is contained on a single magnetic card. (Program No. 3) This magnetic card must be read into the calculator before Program Label D can be accessed.*

*This publication package contains a listing of these programs and data register contents. These must be transfered to magnetic cards.

Program Label D is accessed by pressing the button labeled D on the TI-59 calculator.

Once Program Label D has been accessed the calculator will print the message, "NO. OF PUMPS?" and halt operation.

The user then enters the number of pumps which will be used in the pumping station. (NOTE: Due to memory size restrictions in the calculator the number of pumps must be held to a maximum of six.) After entering the number of pumps the user then presses the R/S button.

The calculator then prints the message, "ON ELEV., PUMP 6" or 5 (whatever the number of pumps enters in the previous step was). As discussed in Section 3, the calculator will assign a number to each of the pumps. The pump with the highest start elevation will be the pump with the highest number. All pumps with a lower number must have a start elevation which is less than or equal to the start elevation of the pump with a higher number. After printing the message the calculator will halt operation.

The user then enters the start or on elevation for the highest number pump and presses the R/S button.

The calculator will then print the message, "OFF ELEV. PUMP 6" or 5 (whatever the number of pumps entered in the first step was).

As was the case for the start elevation, the stop elevation for the higher number pumps must be greater than or equal to the stop elevation for lower number pumps. This may be summarized by, the first on must be the last off. Once the off elevation for the highest number pump has been entered the user presses the R/S button.

The calculator will then print the message, "PUMPING RATE" and halt operation.

The user then enters the pumping rate in cubic feet per second (cfs) for the highest number pump and presses the R/S button.

The calculator then prints the message, "ON ELEV., PUMP 5" or 4 (one less than the highest number pump) and halts operation.

The user enters the on elevation for the pump (this elevation must be less than or equal to the elevation entered for the previous pump), and then presses the R/S button.

The calculator then prints the message, "OFF ELEV., PUMP 5" or 4 (one less than the highest number pump) and then halts operation.

The user then enters the appropriate off elevation (this elevation must be less than the off elevation entered for the higher number pump) and then presses the R/S button.

The calculator then prints the message, "PUMPING RATE" and halts operation.

The user enters the appropriate pumping rate in cfs and presses the R/S button.

The sequence of operations described above continues until all pumps have been discribed for. Once all the appropriate pump parameters have been entered the calculator will advance the paper tape and halt operation.

The second part of the pumping station analysis is now complete.

As discussed in Sections 2 and 3, Program Label E is used to perform the final part of the pumping station analysis. This is the routing of an inflow hydrograph through the pumping station.

Program Label E

Program Label E is contained on the fourth set of magnetic cards. These two magnetic cards must be read into the calculator before Program Label E can be accessed*.

Program Label E is accessed by pressing the button labeled E on the TI-59 calculator.

Once Program Label E has been accessed the calculator will print the message, "INTERVAL?" and halt operation.

The user then enters the time interval (in whole minutes) used between successive values of the inflow hydrograph ordinates. The inflow hydrograph must be described by a succession of inflow values each corresponding to a successive value of time. The difference between each successive time value is the time interval entered above. Once the time interval has been entered the user then presses the R/S button.

*This publication package contains a listing of the programs and the data register contents. These must be transferred to magnetic cards.

The calculator will then print a list of messages which define the symbols used to identify the outputs which Program label E prints for each inflow value entered. These are:

TIME = T

INFLOW = I

STORAGE = S

WATER SURFACE ELEV. = W

OUTFLOW = O

After printing this list of messages the calculator will advance the paper tape and print the message, " 0.00 = T" and halt operation.

The user then enters the inflow hydrograph value associated with the time equal to zero. This is most often also equal to zero. After entering the inflow value the user presses the R/S button.

The calculator will then print the value of inflow entered in the step above along with the label, "=I". The calculator will then compute the value of storage used to store the initial inflow, if any, and print this value along with the label, "=S". The calculator then computes the value of the water surface elevation which corresponds to this storage. The calculator then prints this value of the water surface elevation along with the label, "=W". The calculator then determines if any pumps have turned on or off by comparing the value of storage computed above with the storage-pump relationship developed by Program Label D. If any pumps have turned on or off the calculator will then compute the outflow value associated with the pumps which are turned on and print this value along with the label, "=O." The calculator will then advance the paper tape, print the value of the next time increment along with the label, "=T" and halt operation.

The user then enters the inflow value corresponding to the value of time printed by the calculator and presses the R/S button.

The calculator will then repeat the sequence of operations described above and print the appropriate values of inflow (I), storage (S), water surface elevation (W) and outflow (O). The calculator then prints the next sequential time value and halts operation.

This process is repeated for each sequential inflow hydrograph value until the performance of the pumping station has been adequately defined. If all that is desired is the peak storage requirements then the analysis may be terminated once the value of storage computed by the calculator has reached a maximum. If a complete analysis of the pumping station, including outflow rates and turn on/turn off times for each pump is needed then the appropriate values of inflow are entered until the entire inflow hydrograph has been accounted for. Additional values of zero inflow are entered, for subsequent time increments once the inflow hydrograph has ceased until the storage within the reservoir has been depleted or the outflow drops to zero. A complete and detailed analysis of the pumping station is contained on the paper tape.

If at any time the storage capacity of the reservoir is exceeded, the calculator will print the message, "BASIN EXCEEDED" and halt operation.

By using the seven programs, as described in this section, a complete analysis of a typical pumping station can be performed quickly and accurately. The actual application of these programs in the analysis of typical highway pumping stations is described in the next section, Section 5, dealing with example problems.

SUMMARY OF PROGRAMS

PROGRAM SET 1

LABEL A - Calculates the stage-storage relationship for the pumping station wet well. This program is valid for circular or rectangular wet wells and trapezoidal basins.

LABEL A' - Used to enter a predetermined stage-storage relationship for any reservoir.

LABEL E' - Used to list the stage-storage relationship computed by other programs.

PROGRAM SET 2

LABEL B - Calculates the stage-storage relationship for circular pipes feeding into the wet well.

LABEL C - Calculates the stage-storage relationship for box conduits feeding into the wet well.

LABEL E' - Used to list the stage-storage relationship computed by other programs.

PROGRAM SET 3

LABEL D - Used for input of pump parameters.

PROGRAM SET 4

LABEL E - This program is used for routing the infl hydrograph through the pumping station.

5.0 Example Problems

This section presents four examples of the design and analysis of pumping stations using the calculator programs described in Sections 1 through 4.

The first example problem analyzes the performance of the simple pumping station presented in part 1 of this publication. The reader may then compare the results of the analysis using the calculator programs with those obtained by a graphical method, as presented in Part 1.

The second example problem analyzes the performance of a more typical highway pumping station. This pumping station contains a rectangular wet well, a box conduit and circular feeder pipes.

The third example problem presents a pumping station with an excavated trapezoidal wet well.

The fourth, and final, example problem presents a pumping station utilizing an irregular reservoir.

The reader is encouraged to work out the example problems as they are presented to gain experience in the use of the calculator programs.

The calculator printouts for each example is included directly following the example for the readers' reference.

Example Problem 1

This pumping station design is the same as that presented in Part 1 of this publication. The pumping station storage reservoir consists of 21 foot diameter (10.5 ft radius) wet well and 520 feet of 48 inch (4 ft.) circular concrete pipe on a 0.4 percent (0.004 ft/ft) slope. The invert elevation is 0.0 ft. There are two pumps with the following parameters:

Pump Number	Pumping Rate	On (Start) Elev.	Off (Stop) Elev.
1	7 cfs	2.0	0.0
2	7 cfs	3.0	1.0

The maximum water surface elevation within the reservoir is specified as 6.5 feet. The bottom elevation of the reservoir is specified as 0.0 feet.

The inflow hydrograph is presented in Figure 2 of Part 1 and is also presented on the following page in a tabular format with the time interval of 5 minutes.

Example 1. Inflow Hydrograph Data

Time (min.)	Inflow (cfs)	Time (min.)	Inflow (cfs)
0	0.0	75	11.5
5	0.1	80	19.0
10	0.2	85	21.5
15	0.3	90	17.0
20	0.4	95	12.0
25	0.5	100	6.5
30	0.6	105	5.0
35	0.7	110	4.0
40	0.8	115	3.5
45	0.9	120	3.3
50	1.0	125	2.7
55	1.1	130	2.5
60	1.2	135	2.3
65	2.5	140	2.1
70	4.5	145	2.0
		150	1.9

Using the calculator programs presented, analyze the performance of this pumping station.

°Step 1. Stage-storage relationship for reservoir

The stage-storage relationship for the cylindrical wet well is determined as described in Section 4, using Program Label A.

The additional storage provided by the 48-inch feeder pipe is determined using Program Label B, as described in Section 4.

A record of the complete stage-storage relationship for the reservoir is desired so Program Label E' is run. The results are summarized below:

Elevation (ft)	Height Increment	Storage (ft^3)	Elevation (ft)	Height Increment	Storage (ft^3)
0.0	0	0	3.575	11	5549
0.325	1	127	3.900	12	6253
0.650	2	312	4.225	13	6881
0.975	3	573	4.550	14	7404
1.300	4	926	4.875	15	7826
1.625	5	1376	5.200	16	8151
1.950	6	1931	5.525	17	8388
2.275	7	2585	5.850	18	8553
2.600	8	3303	6.175	19	8672
2.925	9	4052	6.50	20	8785
3.250	10	4807			

°Step 2. Assignment of pump parameters

The various pump parameters are entered by using Program Label D, as described in Section 4.

The parameters are summarized below:

Pump Number 2	On Elevation	3.0 ft
Pump Number 2	Off Elevation	1.0 ft
Pumping Rate		7.0 cfs
Pump Number 1	On Elevation	2.0 ft
Pump Number 1	Off Elevation	0.0 ft
Pumping Rate		7.0 cfs

°Step 3. Routing inflow hydrograph through pumping station

The inflow hydrograph is routed through the pumping station using Program Label E as described in Section 4. The results of this routing are summarized in Figure 1.

It is interesting to compare the results of the analysis using the calculator programs and the result obtained using graphical methods, as presented in Part 1 of this publication. The peak storage requirements as determined by the graphical method, was 8,500 cubic feet. The peak storage requirement, as determined by the calculator programs was 8,067 cubic feet. The 8,067 cubic feet is a more accurate answer. A very rigorous sequence of calculations (not shown) determined that the actual peak storage requirement is 7900 cubic feet.

The calculator program predicted the peak storage required within 2 percent. The graphical method predicted the peak storage required within 8 percent. The larger error in the graphical method is due to the difficulty in scaling small values of storage. The error in the calculator method is due to the descrete time increment of one minute used in calculations as well as rounding errors for the pump start/stop elevations.

The latter source of error may be eliminated by assigning the pump start/stop elevations so that they correspond exactly with a reservoir height increment. This degree of refinement is only warranted for the most detailed of analyses.

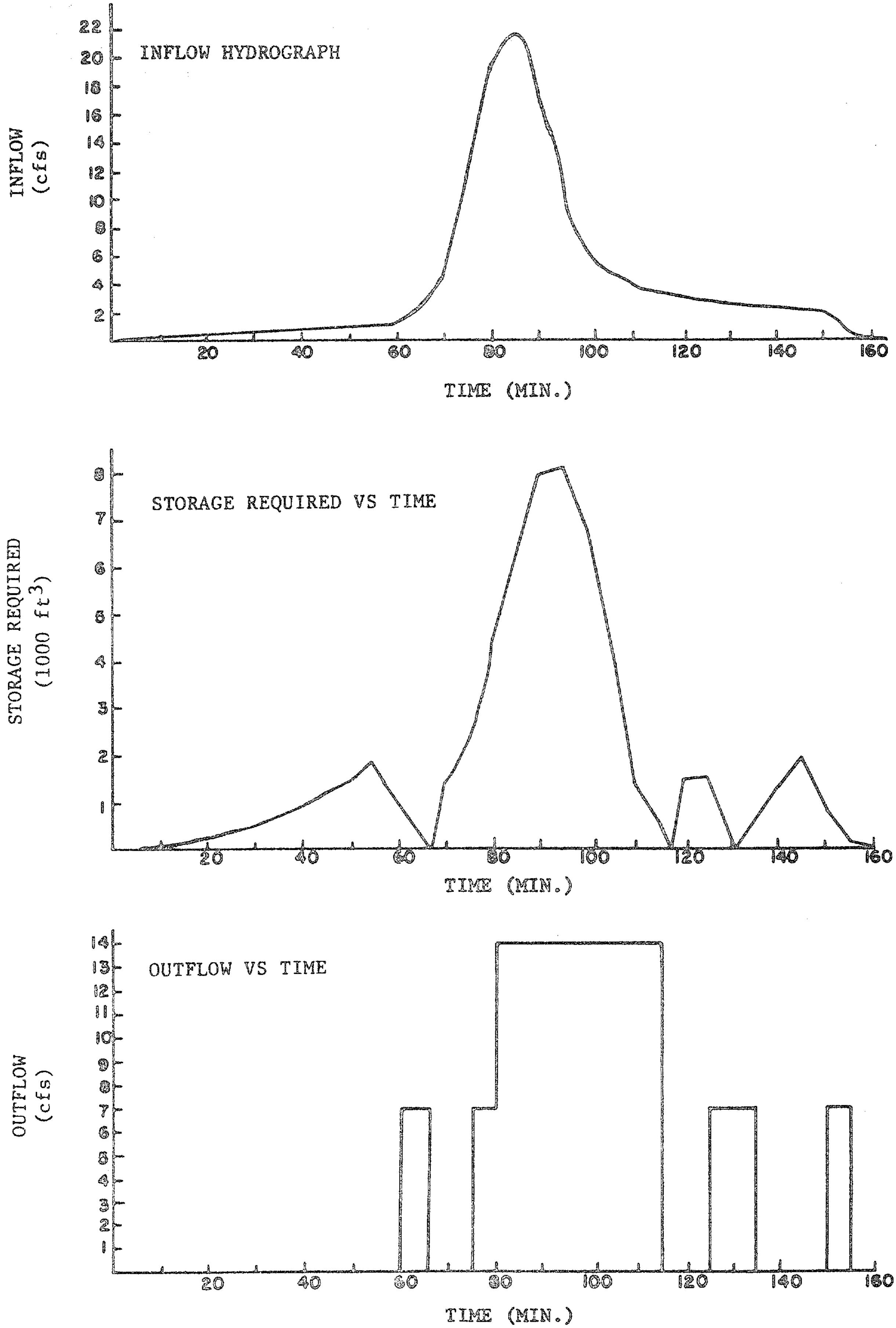


FIGURE 1 SUMMARY OF RESULTS FOR EXAMPLE PROBLEM No. 1

EXAMPLE PROBLEM NUMBER 1

```
TOP ELEVATION?
        6.5
BOTTOM ELEV.?
          0.
RECT.=0, CYL.=1
          1.
RADIUS?
       10.5


DIAMETER
          4.
     SLOPE
      0.004
    LENGTH
       520.
INVT.ELEV.
          0.
```

```
NO. OF PUMPS?
           2.
 ON EL., PUMP 2
           3.

OFF EL., PUMP 2
           1.

PUMPING RATE
           7.
 ON EL., PUMP 1
           2.

OFF EL., PUMP 1
           0.

PUMPING RATE
           7.
```

```
   INTERVAL?
      5.

ENTER INFLOW WHEN
 PROMPTED BY TIME

       TIME = T
     INFLOW = I
    STORAGE = S
    W.S.EL. = W
    OUTFLOW = O

    0.00      = T
    0.00      = I
    0.00      = S
    0.00      = W
    0.00      = O

    5.00      = T
    0.10      = I
   15.00      = S
    0.04      = W
    0.00      = O

   10.00      = T
    0.20      = I
   60.00      = S
    0.15      = W
    0.00      = O

   15.00      = T
    0.30      = I
  135.00      = S
    0.34      = W
    0.00      = O

   20.00      = T
    0.40      = I
  240.00      = S
    0.52      = W
    0.00      = O

   25.00      = T
    0.50      = I
  375.00      = S
    0.73      = W
    0.00      = O

   30.00      = T
    0.60      = I
  540.00      = S
    0.93      = W
    0.00      = O
```

35.00 = T
0.70 = I
735.00 = S
1.12 = W
0.00 = D

40.00 = T
0.80 = I
960.00 = S
1.32 = W
0.00 = D

45.00 = T
0.90 = I
1215.00 = S
1.51 = W
0.00 = D

50.00 = T
1.00 = I
1500.00 = S
1.70 = W
0.00 = D

55.00 = T
1.10 = I
1815.00 = S
1.88 = W
0.00 = D

60.00 = T
1.20 = I
900.00 = S
1.28 = W
7.00 = D

65.00 = T
2.50 = I
222.00 = S
0.49 = W
0.00 = D

70.00 = T
4.50 = I
1272.00 = S
1.55 = W
0.00 = D

75.00 = T
11.50 = I
2412.00 = S
2.19 = W
7.00 = D

80.00 = T
19.00 = I
4467.00 = S
3.10 = W
14.00 = D

85.00 = T
21.50 = I
6342.00 = S
3.95 = W
14.00 = D

90.00 = T
17.00 = I
7917.00 = S
4.97 = W
14.00 = D

95.00 = T
12.00 = I
8067.00 = S
5.12 = W
14.00 = D

100.00 = T
6.50 = I
6642.00 = S
4.10 = W
14.00 = D

105.00 = T
5.00 = I
4167.00 = S
2.97 = W
14.00 = D

110.00 = T
4.00 = I
1317.00 = S
1.58 = W
14.00 = D

115.00 = T
3.50 = I
450.00 = S
0.82 = W
0.00 = D

120.00 = T
3.30 = I
1470.00 = S
1.68 = W
0.00 = D

125.00 = T
2.70 = I
1530.00 = S
1.72 = W
7.00 = D

130.00 = T
2.50 = I
210.00 = S
0.47 = W
7.00 = D

135.00 = T
2.30 = I
576.00 = S
0.98 = W
0.00 = D

140.00 = T
2.10 = I
1236.00 = S
1.52 = W
0.00 = D

145.00 = T
2.00 = I
1851.00 = S
1.90 = W
0.00 = D

150.00 = T
1.90 = I
756.00 = S
1.14 = W
7.00 = D

155.00 = T
0.00 = I
114.00 = S
0.29 = W
0.00 = D

160.00 = T

Example Probem 2

A new 4-lane divided arterial is being designed in an urban area. Because of right-of-way restrictions and other factors it has been decided that a depressed section is preferable. At one location along the alignment, the arterial passes under an existing railroad bridge. Clearance requirements dictate a long sag vertical curve. The only feasible means of draining this section of the highway is to pump the stormwater out of the sag.

It is desirable to use the smallest pumping rate feasible, in order to reduce the initial cost of the pumping station and to reduce stand-by electrical charges. This means that within the limited right-of-way available, storage must be provided in order to reduce the pumping rates to a minimum.

The goal is to provide a combination of storage and low pumping rates which minimizes the overall annual cost of the pumping station. A thorough economic analysis, evaluating various combinations of storage and pumping rates, is beyond the scope of this publication.

This example problem will demonstrate how various pumping rates may be evaluated for a given reservoir configuration.

For the pumping station layout shown in Figure 2 determine the minimum acceptable pumping rate, given the inflow hydrograph listed in Step 3.

°Step 1. Stage-storage relationship for reservoir

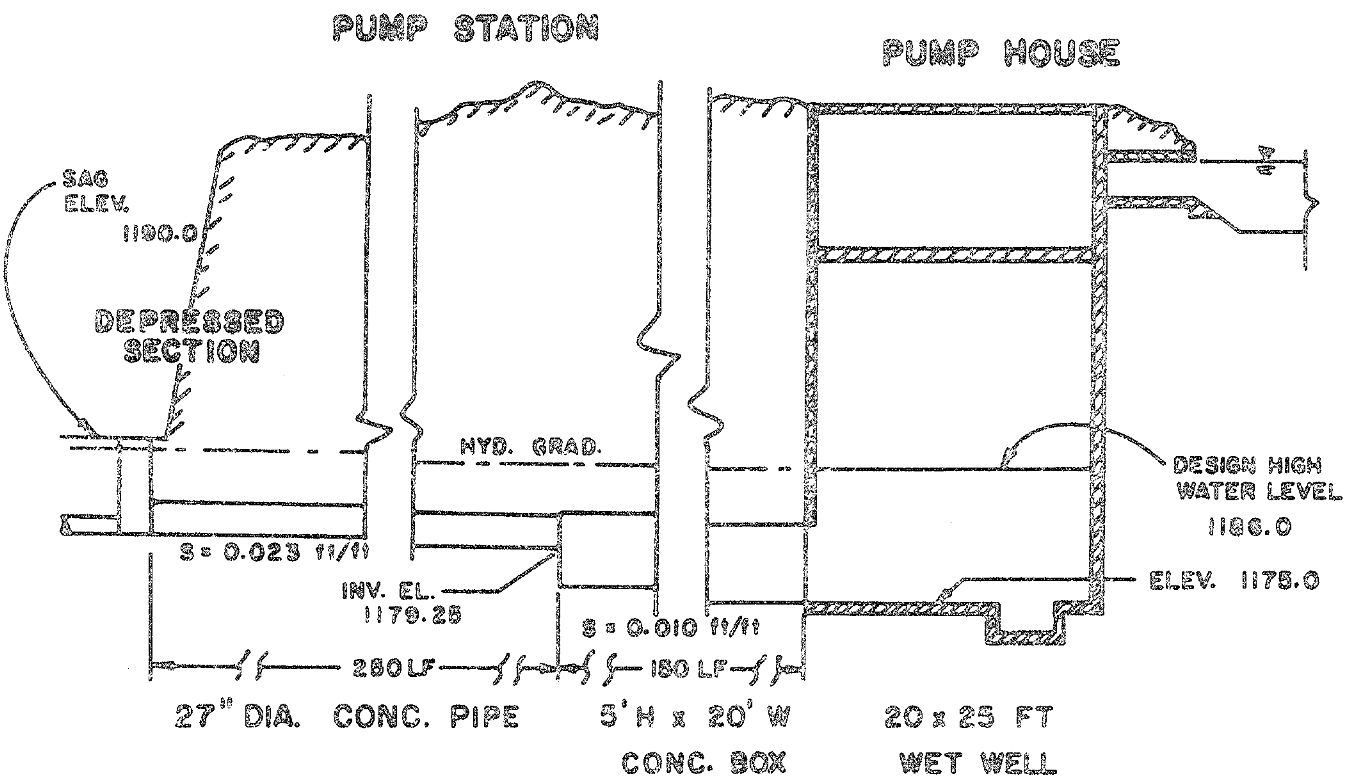
The reservoir for this pumping station consists of 3 components:
The 20 X 25 foot pumping station wet well, 150 linear feet of box conduit (5 feet high by 20 feet wide), and 250 linear feet of 27 inch diameter reinforced concrete pipe.

The stage-storage relationship for the pumping station wet well is determined by using Program Label A, as described in Section 4. The top elevation is set at 1,190 the elevation of the depressed section.

The additional storage provided by the box conduit is determined using Program Label C, as described in Section 4.

The additional storage provided by the pipe is determined using Program Label B, as described in Section 4.

A record of the complete stage-storage relationship for the reservoir is needed, so Program Label E' is used as described in Section 4.



NOT TO SCALE

FIGURE 2 LAYOUT OF PUMPING STATION FOR EXAMPLE PROBLEM No. 2

The complete stage-storage relationship is summarized below:

Elevation (ft)	Height Increment	Storage (ft^3)	Elevation (ft)	Height Increment	Storage (ft^3)
1175.00	0	0	1183.25	11	19,578
1175.75	1	937	1184.00	12	20,083
1176.50	2	3,000	1184.75	13	20,588
1177.25	3	5,625	1185.50	14	21,091
1178.00	4	8,250	1186.25	15	21,566
1178.75	5	10,875	1187.00	16	21,988
1179.50	6	13,500	1187.75	17	22,369
1180.25	7	16,077	1188.50	18	22,744
1181.00	8	17,830	1189.25	19	23,119
1181.75	9	18,569	1190.00	20	23,494
1182.50	10	19,074			

Note that this total reservoir height of 15 feet is higher than the design high water. Since we wish to evaluate the storage required for various pumping rates it is desirable to have the range of storages evaluated greater than the maximum allowable. The reason for this will become evident as the example problem continues.

°Step 2. <u>Assignment of pump parameters</u>

The pump start/stop elevations will remain constant for all different pumping rates evaluated. These are summarized below:

Pump Number	On Elevation	Off Elevation
2	1181.00	1178.00
1	1178.00	1175.50

The pumping rates will be varied in order to determine their effect upon peak storage requirements. An initial pumping rate of 3000 gallons per minute (6.68 cubic feet per second) is assigned for each pump.

The pump parameters summarized above are entered into the calculator using Program Label D as described in Section 4.

°Step 3. <u>Routing of inflow hydrograph through pumping station</u>

The inflow hydrograph is presented below:

Time (min.)	Inflow (cfs)	Time (min.)	Inflow (cfs)
0	0	50	9.6
5	2.0	55	7.2
10	5.0	60	5.0
15	10.0	65	4.0
20	15.0	70	3.0
25	21.5	75	3.0
30	19.7	80	2.0
35	15.6	85	1.0
40	14.8	90	0.0
45	11.5	95	0.0

This inflow hydrograph is routed through the pumping station using Program Label E as described in Section 4.

The peak storage required for a pumping rate of 3000 GPM is 18840 ft^3. The water surface elevation which corresponds to this storage is 1182.15 ft, which is below the design high water elevation of 1186.00 ft. This means that there is additional storage available and that a lower pumping rate is feasible.

The pumping rates for the pumps can be changed without reentering Program Label D. The pumping rates for each pump are stored in dedicated data storage register (as described in Section 6). These are:

Pump Number	Data Register
6	29
5	28
4	27
3	26
2	25
1	24

To change the pumping rate for pump number 2, simply store the new pumping rate in data register 25. To change the pumping rate for pump number 1, simply store the new pumping rate in data register 24.

A new pumping rate of 2500 GPM (5.57 cfs) is entered for both pump number 2 and pump number 1.

The same inflow hydrograph is routed through the pumping station using Program Label E.

The peak storage required for a pumping rate of 2500 GPM is 20774 ft^3, with a water surface elevation of 1185.03 ft. This is still below the design high water elevation.

The peak storage requirements for pumping rates of 2000 GPM (4.46 cfs) was also evaluated, following the same procedure. The required storage was 23393 ft^3 with a water surface elevation of 1189.80 ft.

The results of this analysis is presented in Figure 3.

By graphical interpolation the minimum acceptable pumping rate is determined to be 2,375 GPM (5.29 cfs) for the given inflow hydrograph. This is confirmed by running the 5.29 cfs rate and determining that the required storage is 21,375 ft^3 at elevation 1185.95 ft.

The complete printout for this example problem is contained at the end of this section.

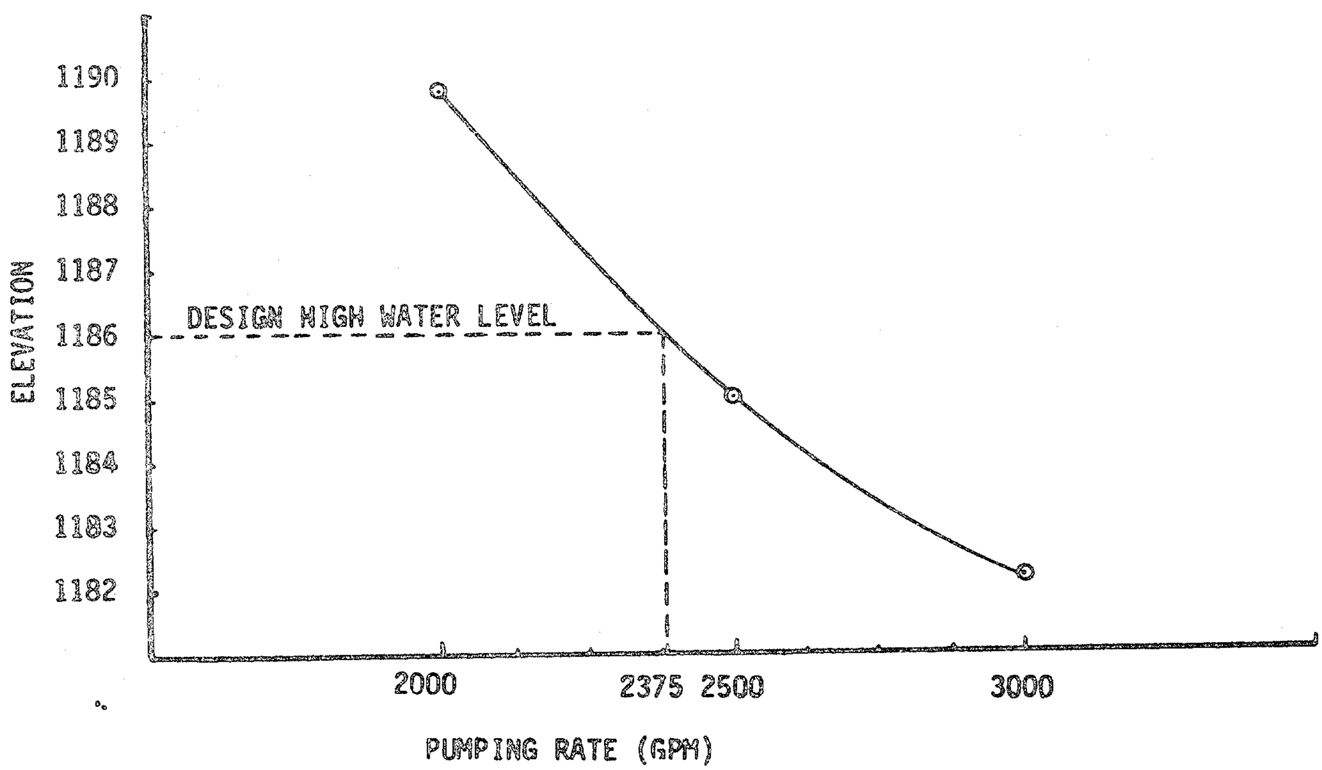


FIGURE 3. Pumping Rate Vs. Elevation for Example Problem No. 2

EXAMPLE PROBLEM NUMBER 2

```
TOP ELEVATION?
      1190.
BOTTOM ELEV.?
      1175.
RECT.=0; CYL.=1
         0.
BASIN LENGTH?
        25.
BASIN WIDTH?
        20.
Σ LENGTH SLOPES
         0.
Σ WIDTH SLOPES
         0.

         0.
       375.
       750.
      1125.
      1500.
      1875.
      2250.
      2625.
      3000.
      3375.
      3750.
      4125.
      4500.
      4875.
      5250.
      5625.
      6000.
      6375.
      6750.
      7125.
      7500.
```

```
BOX HEIGHT
          5.
   SLOPE
       0.01
BOX LENGTH
        150.
BOX WIDTH
         20.
INVT.ELEV.
       1175.

          0.
        937.
       3000.
       5625.
       8250.
      10875.
      13500.
      16062.
      17750.
      18375.
      18750.
      19125.
      19500.
      19875.
      20250.
      20625.
      21000.
      21375.
      21750.
      22125.
      22500.
```

```
DIAMETER
        2.25
   SLOPE
       0.023
  LENGTH
        250.
INVT.ELEV.
     1179.25

          0.
        937.
       3000.
       5625.
       8250.
      10875.
      13500.
      16077.
      17830.
      18569.
      19074.
      19578.
      20083.
      20588.
      21091.
      21566.
      21988.
      22369.
      22744.
      23119.
      23494.

NO. OF PUMPS?
          2.
 ON EL., PUMP 2
      1181.

OFF EL., PUMP 2
      1178.

PUMPING RATE
        6.68
 ON EL., PUMP 1
      1178.

OFF EL., PUMP 1
     1175.5

PUMPING RATE
        6.68
```

```
  INTERVAL?
       5.

ENTER INFLOW WHEN
 PROMPTED BY TIME

      TIME = T
    INFLOW = I
   STORAGE = S
   W.S.EL. = W
   OUTFLOW = O

      0.00     = T
      0.00     = I
      0.00     = S
   1175.00     = W
      0.00     = O

      5.00     = T
      2.00     = I
    300.00     = S
   1175.24     = W
      0.00     = O

     10.00     = T
      5.00     = I
   1350.00     = S
   1175.90     = W
      0.00     = O

     15.00     = T
     10.00     = I
   3600.00     = S
   1176.67     = W
      0.00     = O

     20.00     = T
     15.00     = I
   7350.00     = S
   1177.74     = W
      0.00     = O

     25.00     = T
     21.50     = I
  11221.80     = S
   1178.85     = W
      6.68     = O

     30.00     = T
     19.70     = I
  15397.80     = S
   1180.05     = W
      6.68     = O

     35.00     = T
     15.60     = I
  18288.00     = S
   1181.46     = W
     13.36     = O

     40.00     = T
     14.80     = I
  18840.00     = S
   1182.15     = W
     13.36     = O

     45.00     = T
     11.50     = I
  18777.00     = S
   1182.06     = W
     13.36     = O

     50.00     = T
      9.60     = I
  17934.00     = S
   1181.11     = W
     13.36     = O

     55.00     = T
```

```
   INTERVAL?
      5.

ENTER INFLOW WHEN
 PROMPTED BY TIME

      TIME = T
    INFLOW = I
   STORAGE = S
   W.S.EL. = W
   OUTFLOW = O

    0.00     = T
    0.00     = I
    0.00     = S
 1175.00     = W
    0.00     = O

    5.00     = T
    2.00     = I
  300.00     = S
 1175.24     = W
    0.00     = O

   10.00     = T
    5.00     = I
 1350.00     = S
 1175.90     = W
    0.00     = O

   15.00     = T
   10.00     = I
 3600.00     = S
 1176.67     = W
    0.00     = O

   20.00     = T
   15.00     = I
 7350.00     = S
 1177.74     = W
    0.00     = O

   25.00     = T
   21.50     = I
11488.20     = S
 1178.93     = W
    5.57     = O

   30.00     = T
   19.70     = I
15997.20     = S
 1180.23     = W
    5.57     = O

   35.00     = T
   15.60     = I
18952.80     = S
 1182.32     = W
   11.14     = O

   40.00     = T
   14.80     = I
20170.80     = S
 1184.13     = W
   11.14     = O

   45.00     = T
   11.50     = I
20773.80     = S
 1185.03     = W
   11.14     = O

   50.00     = T
    9.60     = I
20596.80     = S
 1184.76     = W
   11.14     = O

   55.00     = T
```

```
  INTERVAL?
     5.

ENTER INFLOW WHEN
 PROMPTED BY TIME

        TIME = T
      INFLOW = I
     STORAGE = S
     W.S.EL. = W
     OUTFLOW = O

     0.00    = T
     0.00    = I
     0.00    = S
  1175.00    = W
     0.00    = O

     5.00    = T
     2.00    = I
   300.00    = S
  1175.24    = W
     0.00    = O

    10.00    = T
     5.00    = I
  1350.00    = S
  1175.90    = W
     0.00    = O

    15.00    = T
    10.00    = I
  3600.00    = S
  1176.67    = W
     0.00    = O

    20.00    = T
    15.00    = I
  7350.00    = S
  1177.74    = W
     0.00    = O

    25.00    = T
    21.50    = I
 11754.60    = S
  1179.00    = W
     4.46    = O
```

```
    30.00    = T
    19.70    = I
 16596.60    = S
  1180.47    = W
     4.46    = O

    35.00    = T
    15.60    = I
 19750.80    = S
  1183.51    = W
     8.92    = O

    40.00    = T
    14.80    = I
 21634.80    = S
  1186.37    = W
     8.92    = O

    45.00    = T
    11.50    = I
 22903.80    = S
  1188.82    = W
     8.92    = O

    50.00    = T
     9.60    = I
 23392.80    = S
  1189.80    = W
     8.92    = O

    55.00    = T
     7.20    = I
 23236.80    = S
  1189.49    = W
     8.92    = O

    60.00    = T
```

```
INTERVAL?
      5.

ENTER INFLOW WHEN
 PROMPTED BY TIME

      TIME  = T
    INFLOW  = I
   STORAGE  = S
   W.S.EL.  = W
   OUTFLOW  = O

      0.00   = T
      0.00   = I
      0.00   = S
   1175.00   = W
      0.00   = O

      5.00   = T
      2.00   = I
    300.00   = S
   1175.24   = W
      0.00   = O

     10.00   = T
      5.00   = I
   1350.00   = S
   1175.90   = W
      0.00   = O

     15.00   = T
     10.00   = I
   3600.00   = S
   1176.67   = W
      0.00   = O

     20.00   = T
     15.00   = I
   7350.00   = S
   1177.74   = W
      0.00   = O

     25.00   = T
     21.50   = I
  11555.40   = S
   1178.94   = W
      5.29   = O

     30.00   = T
     19.70   = I
  16148.40   = S
   1180.28   = W
      5.29   = O

     35.00   = T
     15.60   = I
  19221.60   = S
   1182.72   = W
     10.58   = O

     40.00   = T
     14.80   = I
  20607.60   = S
   1184.78   = W
     10.58   = O

     45.00   = T
     11.50   = I
  21378.60   = S
   1185.95   = W
     10.58   = O

     50.00   = T
      9.60   = I
  21369.60   = S
   1185.94   = W
     10.58   = O

     55.00   = T
      7.20   = I
  20715.60   = S
   1184.94   = W
     10.58   = O

     60.00   = T
```

Example Problem 3

The outfall of a highway storm water collection system is a tidal river. On the occasion of high tides the outfall is submerged and tide gates have been installed to prevent water from backing up onto the highway. A joint probability study has been performed and there is a significant risk of a storm occurring during high tide on the river. In order to drain the highway during high tides a small pumping station is proposed. The storage reservoir for this pumping station will consist of an excavated trapezoidal basin.

Determine the minimum size of the trapezoidal basin which must be provided for the following inflow hydrograph and pump parameters. The side slopes of the trapezoidal basin are 2 H:1V in both the length and width directions. The top width of the trapezoidal basin is fixed by right-of-way constraints at 50 feet. The length is not limited. The maximum depth of the reservoir is 10.0 feet.

Inflow Hydrograph

Time (min.)	Discharge (cfs)	Time (min.)	Discharge (cfs)
0	0.0	36	9.0
6	3.0	42	5.0
12	6.0	48	2.0
18	9.0	54	1.0
24	12.0	60	0.0
30	10.0		

Pump Parameters

Pump Number	On Elevation	Off Elevation
1	2.0	0.0
2	3.0	1.0
3	5.0	3.0

Pumping rate for all pumps is 1.0 cfs.

° Step 1. Stage-storage relationship for reservoir

The goal of this analysis is to determine the minimum size of trapezoidal basin which will be adequate for the given pump characteristics, inflow hydrograph, and constraints on basin configuration.

To estimate the required volume for the storage register the inflow hydrograph is examined. The total area under the inflow hydrograph represents the total volume of water which will flow into the reservoir. This volume is 20,520 cubic feet. This amount of storage would be requied if there were no pumps provided. Because the water in the reservoir is being pumped out the storage required will be less than the 20,520 cubic feet calculated above.

The maximum pumping rate will occur when all three pumps are on and is equal to 3 cfs. The volume of water represented by the area bounded by a horizontal line of 3 cfs and the inflow hydrograph as shown in Figure 4 is the minimum amount of storage which must be provided by the reservoir This volume is equal to 11,760 cubic feet.

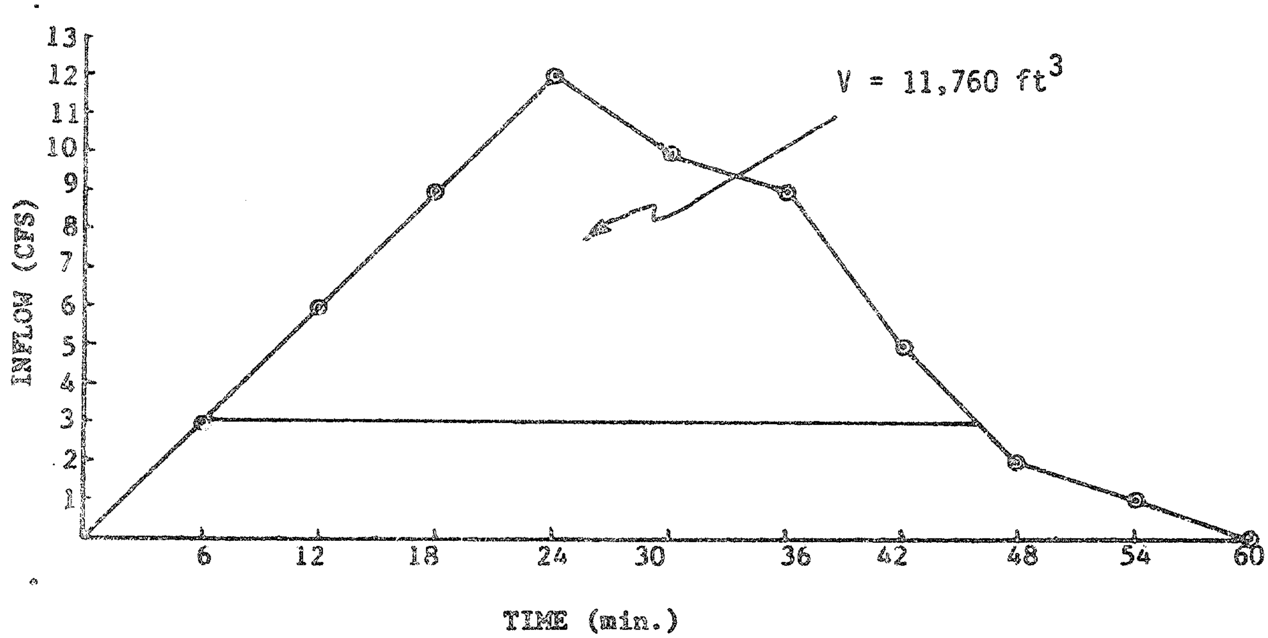


FIGURE 4. Minimum Storage Requirements

The actual volume of storage required is between 11,760 and 20,520 cubic feet.

The length of trapezoidal basin required for a given maximum volume is computed using the following equation. (Section 7, page 74).

$$V_t = \frac{\Sigma LS \times WS}{3} H^3 + \frac{(W \times \Sigma LS) + (L \times \Sigma WS)}{2} H^2 + (L \times W)H$$

where: ΣLS = the sum of the side slopes in the length direction

ΣWS = the sum of the side slopes in the width direction

L = the length of the basin floor

W = the width of the basin floor

H = the total height of the basin

The maximum height of the basin is 10 feet, the width of the basin floor is 10 feet and the slide slopes in all directions are 2:1.

Therefore H = 10 feet, W = 10 feet, LS = WS = 4

$$V_t = \frac{4 \times 4}{3} (10)^3 + \frac{(10 \times 4) + (L \times 4)}{2} (10)^2 + (L \times 10)(10)$$

$$V_t = 300L + 7333.3$$

Using the equation derived above, the length of trapezoidal basin required to provide volumes of 11,760 and 20,520 cubic feet respectively are computed.

The length of basin required will be between 15 feet and 44 feet.

As a first approximation a basin with a length of 27 feet is specified.

All basin parameters have now been specified and the stage-storage relationship for the basin may be determined using Program Label A as described in Section 4.

°Step 2. Assignment of pump parameters

The pump parameters listed above are entered using Program Label D as described in Section 4.

°Step 3. Routing of inflow hydrograph through pumping station

The inflow hydrograph is routed through the pumping station as described in Section 4.

The peak water surface elevation which occurs while routing the inflow hydrograph through the pumping station with the 27 foot long basin is 9.38 feet.

This is less than the 10.0 feet available so a smaller reservoir might work.

The maximum storage used in the 27 foot long basin is 13,440 cubic feet. This maximum amount of storage required should not change appreciably from one basin to the next.

A revised estimate of the storage required is 13,440 cubic feet. This corresponds to a basin length of about 20 feet.

A new stage-storage relationship must be determined and steps 1, 2, and 3 must be repeated for the pumping station analysis.

The maximum water surface elevation which occurs while routing the inflow hydrograph through the pumping station with the 20 feet long basin is 9.95 feet. This is very close to the 10.0 feet allowed, so the 20 foot long basin is the minimum size of trapezoidal basin that must be provided.

EXAMPLE PROBLEM NUMBER 3

```
TOP ELEVATION? EEDED
        10.
BOTTOM ELEV.?
        0.
RECT.=0, CYL.=1
        0.
BASIN LENGTH?
        27.
BASIN WIDTH?
        10.
Σ LENGTH SLOPES
        4.
Σ WIDTH SLOPES
        4.

        0.
      154.
      349.
      589.
      878.
     1220.
     1620.
     2080.
     2605.
     3199.
     3866.
     4610.
     5436.
     6346.
     7345.
     8437.
     9626.
    10916.
    12312.
    13816.
    15433.
```

```
NO. OF PUMPS?
        3.
ON EL., PUMP 3
        5.

OFF EL., PUMP 3
        3.

PUMPING RATE
        1.
ON EL., PUMP 2
        3.

OFF EL., PUMP 2
        1.

PUMPING RATE
        1.
ON EL., PUMP 1
        2.

OFF EL., PUMP 1
        0.

PUMPING RATE
        1.

INTERVAL?
        6.

ENTER INFLOW WHEN
PROMPTED BY TIME

     TIME  = T
   INFLOW  = I
  STORAGE  = S
  W.S.EL.  = W
  OUTFLOW  = O

     0.00    = T
     0.00    = I
     0.00    = S
     0.00    = W
     0.00    = O

     6.00    = T
     3.00    = I
   540.00    = S
     1.40    = W
     0.00    = O
```

```
    12.00    = T
     6.00    = I
  1860.00    = S
     3.26    = W
     2.00    = O

    18.00    = T
     9.00    = I
  3840.00    = S
     4.98    = W
     2.00    = O

    24.00    = T
    12.00    = I
  6600.00    = S
     6.63    = W
     3.00    = O

    30.00    = T
    10.00    = I
  9480.00    = S
     7.94    = W
     3.00    = O

    36.00    = T
     9.00    = I
 11820.00    = S
     8.82    = W
     3.00    = O

    42.00    = T
     5.00    = I
 13260.00    = S
     9.32    = W
     3.00    = O

    48.00    = T
     2.00    = I
 13440.00    = S
     9.38    = W
     3.00    = O

    54.00    = T
     1.00    = I
 12900.00    = S
     9.20    = W
     3.00    = O

    60.00    = T
```

```
TOP ELEVATION?
        10.
BOTTOM ELEV.?
         0.
RECT.=0, CYL.=1
         0.
BASIN LENGTH?
        20.
BASIN WIDTH?
        10.
Σ LENGTH SLOPES
         4.
Σ WIDTH SLOPES
         4.

         0.
       115.
       265.
       453.
       682.
       958.
      1284.
      1663.
      2101.
      2601.
      3166.
      3802.
      4512.
      5299.
      6169.
      7125.
      8170.
      9310.
     10548.
     11887.
     13333.
```

```
NO. OF PUMPS?
         3.
 ON EL., PUMP 3
         5.

OFF EL., PUMP 3
         3.

PUMPING RATE
         1.
 ON EL., PUMP 2
         3.

OFF EL., PUMP 2
         1.

PUMPING RATE
         1.
 ON EL., PUMP 1
         2.

OFF EL., PUMP 1
         0.

PUMPING RATE
         1.

         INTERVAL?
             6.

      ENTER INFLOW WHEN
       PROMPTED BY TIME

             TIME = T
           INFLOW = I
          STORAGE = S
           W.S.EL. = W
          OUTFLOW = O

      0.00    = T
      0.00    = I
      0.00    = S
      0.00    = W
      0.00    = O

      6.00    = T
      3.00    = I
    540.00    = S
      1.69    = W
      0.00    = O
```

```
     12.00    = T
      6.00    = I
   1740.00    = S
      3.59    = W
      2.00    = O

     18.00    = T
      9.00    = I
   3660.00    = S
      5.39    = W
      3.00    = O

     24.00    = T
     12.00    = I
   6360.00    = S
      7.10    = W
      3.00    = O

     30.00    = T
     10.00    = I
   9240.00    = S
      8.47    = W
      3.00    = O

     36.00    = T
      9.00    = I
  11580.00    = S
      9.39    = W
      3.00    = O

     42.00    = T
      5.00    = I
  13020.00    = S
      9.89    = W
      3.00    = O

     48.00    = T
      2.00    = I
  13200.00    = S
      9.95    = W
      3.00    = O

     54.00    = T
      1.00    = I
  12660.00    = S
      9.77    = W
      3.00    = O

     60.00    = T
```

Example Problem 4

A new four-lane highway is being designed. It is necessary to drain a section of this highway with a pumping station. Because of a limited capacity in the existing outlet storm drain the engineer has determined that the rate of outflow from the pumping station be limited to 10 cfs.

In order to minimize costs the infield area of an interchange will be used as the pumping station reservoir. The stage-storage relationship of this reservoir has been determined by planimetering the topographic plan sheets and is tabulaled below:

Elevation	Volume (ft^3)
121.65	0
122.65	3125
123.65	6247
124.65	13,347
125.65	20,475
126.65	52,160

Since the peak pumping rate from the pumping station is limited to 10 cfs, two 5 cfs pumps are proposed. The pump start/stop elevations are listed below:

Pump Number	On Elevation	Off Elevation
2	125.65	123.65
1	123.65	121.65

The design inflow hydrograph has been calculated and is presented below:

Time (min)	Discharge (cfs)	Time (min)	Discharge (cfs)
0	0.0	70	15.0
10	5.0	80	12.0
20	10.0	90	10.0
30	15.0	100	5.0
40	17.0	110	3.0
50	20.0	120	0.0
60	17.0		

Analyze the performance of the propsed pumping station. Also analyze the consequences of a pump failure. Determine the maximum depth of water and determine for how long there will be water stored in the reservoir. The feeder pipes do not provide significant storage.

° Step 1 Stage-storage relationship for reservoir

Because the reservoir is irregular the stage-storage relationship was determine before hand.

The intermediate values of storage required for 20 equal height increments of .25 feet are determined by linear interpolation between the predetermined values given for each 1 foot increment.

The predetermined stage-storage relationship is entered into the calculator by using Program Label A' as described in Section 4.

° Step 2. Assignment of pump parameters
The pump parameters listed above are entered into the calculator using Program Label D as Described in Section 4.

° Step 3. Routing inflow hydrograph through pumping station
The inflow hydrograph listed above is routed through the pumping station by using Program Label E.

When both pumps are operating as designed the maximum depth of water in the reservoir is 4.44 ft. Water is stored in the reservoir for 181 minutes or about 3 hours.

To analyze the consequences of a pump failure the technique presented in example problem 2 is employed again. To simulate a failure of pump 1, a pumping rate of zero is assigned to pump 1. To simulate a failure of pump 2, a pumping rate of zero is assigned to pump 2.

The consequences of a pump failure are summarized below.

Pump Failed	Max Depth	Length of Time Water Stored
1	Basin Exceeded	Indefinate
2	4.94 feet	289 Minutes (4 hours 49 min)

The consequences of pump number 1 failing are very severe. There must be some positive means of ensuring that pump number 2 takes over for pump number 1, if pumps number 1 ever fails.

To save time these printouts are terminated once the outflows have become constant (only pump number 1 on). It is a simple matter to compute the time to deplete the remaining storage with a constant outflow.

The outflow rate is 5 cubic feet per second, or 300 cubic feet per minute. To determine the time (in minutes), required to delete the remaining storage simply divide the value of the remaining storage by 300. This value is added to the time at which the outflow became constant, in order to determine the total time that water was stored in the reservoir.

Conclusion

The four example problems presented have demonstrated the use of the calculator programs in the design and analysis of pumping stations. The method of determining the stage-storage relationship for different reservoirs was demonstrated. The method of assigning and varying the pump parameters was also demonstrated. Each example problem also demonstrated how an inflow hydrograph is routed through the pumping station.

To understand exactly how the calculator programs perform the calculations the reader is directed to Section 7, which provides an in-depth description of these seven calculator program.

EXAMPLE PROBLEM NUMBER 4

```
TOP ELEVATION?
        126.65
BOTTOM ELEV.?
        121.65
VOLUME( 0)?
             0.
VOLUME( 1)?
           781.
VOLUME( 2)?
          1562.
VOLUME( 3)?
          2344.
VOLUME( 4)?
          3125.
VOLUME( 5)?
          3905.
VOLUME( 6)?
          4685.
VOLUME( 7)?
          5466.
VOLUME( 8)?
          6247.
VOLUME( 9)?
          8022.
VOLUME(10)?
          9797.
VOLUME(11)?
         11572.
VOLUME(12)?
         13347.
VOLUME(13)?
         15129.
VOLUME(14)?
         16911.
VOLUME(15)?
         18693.
VOLUME(16)?
         20475.
VOLUME(17)?
         28396.
VOLUME(18)?
         36318.
VOLUME(19)?
         44239.
VOLUME(20)?
         52160.
```

```
NO. OF PUMPS?
        2.
 ON EL., PUMP 2
     125.65

OFF EL., PUMP 2
     123.65

PUMPING RATE
        5.
 ON EL., PUMP 1
     123.65

OFF EL., PUMP 1
     121.65

PUMPING RATE
        5.

     INTERVAL?
        10.

   ENTER INFLOW WHEN
    PROMPTED BY TIME

         TIME = T
       INFLOW = I
      STORAGE = S
      W.S.EL. = W
      OUTFLOW = O

     0.00     = T
     0.00     = I
     0.00     = S
   121.65     = W
     0.00     = O

    10.00     = T
     5.00     = I
  1500.00     = S
   122.13     = W
     0.00     = O

    20.00     = T
    10.00     = I
  6000.00     = S
   123.57     = W
     0.00     = O

    30.00     = T
    15.00     = I
 10800.00     = S
   124.29     = W
     5.00     = O
```

```
    40.00     = T
    17.00     = I
 17400.00     = S
   125.22     = W
     5.00     = O

    50.00     = T
    20.00     = I
 23700.00     = S
   125.75     = W
    10.00     = O

    60.00     = T
    17.00     = I
 28800.00     = S
   125.91     = W
    10.00     = O

    70.00     = T
    15.00     = I
 32400.00     = S
   126.03     = W
    10.00     = O

    80.00     = T
    12.00     = I
 34500.00     = S
   126.09     = W
    10.00     = O

    90.00     = T
    10.00     = I
 35100.00     = S
   126.11     = W
    10.00     = O

   100.00     = T
     5.00     = I
 33600.00     = S
   126.06     = W
    10.00     = O

   110.00     = T
     3.00     = I
 30000.00     = S
   125.95     = W
    10.00     = O

   120.00     = T
     0.00     = I
 24900.00     = S
   125.79     = W
    10.00     = O

   130.00     = T
     0.00     = I
 18900.00     = S
   125.43     = W
    10.00     = O
```

140.00 = T
0.00 = I
12900.00 = S
124.59 = W
10.00 = O

150.00 = T
0.00 = I
6900.00 = S
123.74 = W
10.00 = O

160.00 = T
0.00 = I
3300.00 = S
122.71 = W
5.00 = O

170.00 = T

INTERVAL?
10.

ENTER INFLOW WHEN
PROMPTED BY TIME

TIME = T
INFLOW = I
STORAGE = S
W.S.EL. = W
OUTFLOW = O

0.00 = T
0.00 = I
0.00 = S
121.65 = W
0.00 = O

10.00 = T
5.00 = I
1500.00 = S
122.13 = W
0.00 = O

20.00 = T
10.00 = I
6000.00 = S
123.57 = W
0.00 = O

30.00 = T
15.00 = I
10800.00 = S
124.29 = W
5.00 = O

40.00 = T
17.00 = I
17400.00 = S
125.22 = W
5.00 = O

50.00 = T
20.00 = I
25500.00 = S
125.81 = W
5.00 = O

60.00 = T
17.00 = I
33600.00 = S
126.06 = W
5.00 = O

70.00 = T
15.00 = I
40200.00 = S
126.27 = W
5.00 = O

80.00 = T
12.00 = I
45300.00 = S
126.43 = W
5.00 = O

90.00 = T
10.00 = I
48900.00 = S
126.55 = W
5.00 = O

100.00 = T
5.00 = I
50400.00 = S
126.59 = W
5.00 = O

110.00 = T
3.00 = I
49800.00 = S
126.58 = W
5.00 = O

120.00 = T
0.00 = I
47700.00 = S
126.51 = W
5.00 = O

130.00 = T

INTERVAL?
10.

ENTER INFLOW WHEN
PROMPTED BY TIME

TIME = T
INFLOW = I
STORAGE = S
W.S.EL. = W
OUTFLOW = O

0.00 = T
0.00 = I
0.00 = S
121.65 = W
0.00 = O

10.00 = T
5.00 = I
1500.00 = S
122.13 = W
0.00 = O

20.00 = T
10.00 = I
6000.00 = S
123.57 = W
0.00 = O

30.00 = T
15.00 = I
13500.00 = S
124.67 = W
0.00 = O

```
   40.00     = T
   17.00     = I
22500.00     = S
  125.71     = W
    5.00     = D

   50.00     = T
   20.00     = I
30600.00     = S
  125.97     = W
    5.00     = D

   60.00     = T
   17.00     = I
38700.00     = S
  126.23     = W
    5.00     = D

   70.00     = T
   15.00     = I
45300.00     = S
  126.43     = W
    5.00     = D

   80.00     = T
   12.00     = I
50400.00     = S
  126.59     = W
    5.00     = D

   90.00     = T
   10.00     = I

BASI N EXCEEDED
```

6.0 Program Limitations

There are several limitations which are inherent in these calculator programs. These limitations are the result of the simplifying assumptions made in order to apply the equations, and approximations necessary to implement the program algorithms.

° Discrete time increments used to route inflow hydrograph.

The most serious limitation of these calculator programs is that the routing of the inflow hydrograph must be accomplished with discrete time increments. This has been minimized by taking the time increment as 60 seconds (1 minute). It is felt that this time increment will lead to small relative errors and at the same time perform the routing calculations within a reasonable length of time. It takes about 20 seconds for the calculator to perform all the necessary calculations for a 1 minute time increment. These calcuations will be repeated a number of times (depending upon the value of Time Interval entered). For a 5 minute time interval the calculator will take 100 seconds or about 1-1/2 minutes to perform the necesary calculations.

Because the time increment used internally by the programs is 1 minute, the time interval entered by the user must be in whole minutes. Fractional minutes (e.g., 0.5 or 2.3) are not allowed.

° Discrete representation of the stage-storage relationship.

Because of the limitations on the number of data registers available, the stage-storage relationship for a given reservoir must be represented in discrete steps. The TI-59 program represents the stage-storage relationship of the reservoir in 20 discrete steps. This should provide adequate resolution for the majority of typical reservoirs used. If these algorithms are programed on another calculator, with less available memory, then this could become a more serious limitation.

° Constant pumping rates.

The pumping rates for each of the pumps is assigned by the user and is a constant. This pumping rate is actually somewhat variable, depending upon many factors including total dynamic head, horsepower, etc.

° The pump start/stop elevations are rounded off to coincide with the reservoir height increments.

Because of the way in which program algorithms encode and decode the pump start/stop elevations, it is necessary to round off the actual pump start/stop elevations so that they coincide with the reservoir height increments. This leads to some approximations in the total storage requirements. Because of the resolution provided by dividing the reservoir into 20 height increments, this is not a serious limitation with the TI-59 program. However, if less resolution is provided, as might be the case with a different calculator, then the user should be aware of this limitation.

° <u>Horizontal water surface assumed.</u>

The programs which compute the volumes for the reservoir components assume a horizontal water surface. In actuality there will be a departure from a horizontal surface due to backwater and drawdown effects. However, for a reservoir where the average flow through velocity is relatively low, these effects will be minimal.

° <u>Mild slopes are assumed for pipes and boxes.</u>

The equations used to compute the volumes is sloping pipes and boxes are based upon the assumption that the slopes are small (less than 0.10 feet per foot).

This slope is hydraulically steep, and slopes of this magnitude are infrequently used. For this reason, this limitation is not considered severe.

° <u>Horizontal pipes and boxes.</u>

Pipes and boxes with horizontal slopes must be approximated by very small but finite slopes, 1×10^{-6}, as an example.

7.0 Detailed Program Description

This section presents each of the seven independent calculator programs in detail. The underlying equations, the program algorithm, and a complete flowchart is presented for each program.

In order to present these programs so that they may be readily programmed on other claculators, the flow charts present the algorithm paralleled by the TI-59 program implementing the algorithm. In this way the TI-59 program is presented in a very detailed manner and at the same time the general method of solution and equations are presented facilitating programing on other calculators.

The seven programs are grouped into four sets of programs. Program Set One includes Program Label A, Program Label A' and Program Label E'. Program Set One may be stored on two magnetic cards. The first card will contain the program listings, a total of 293 program steps, and the second card will contain the required numbers and codes to initialize the programs and print the alpha-numeric messages. Program Set Two includes Program Label B, Program Label C and Program Label E'. Program Set Two may also be stored on two magnetic cards. The first card will contain the program listings, a total of 434 steps, and the second card will contain the required numbers and codes to initialize the programs and print the alpha-numeric messages. Program Set Three includes Program Label D and Program Label E'. Program set three may be stored on a single magnetic card. The program listings, a total of 167 program steps, are stored on bank 1 and the required numbers and codes for program initialization and printing the alpha-numeric messages are stored on bank 3. Program Set Four contains Program Label E only. Program set four may be stored on two magnetic cards. The program listing, a total of 428 program steps, is stored on the first magnetic card and the required numbers and codes for program initialization and printing of alpha-numeric messages are stored on the second magnetic card.

The complete listings for each program set including the data register contents are included at the end of this section. These should be stored on magnetic cards and then read into the calculator when the programs are needed. It will take about 2 hours to key in all of these programs by hand. This is a very worthwhile expenditure of time and will return many times the initial investment when analyzing a pumping station.

Program Set 1

Program Label A

The first program described in this set is Program Label A. As discussed in previous sections Program Label A is used to determine the stage-storage relationship for the pumping station wet well or for a trapezoidal basin. The pumping station wet well may be cylindrical or rectangular.

As mentioned in Sections 2 and 3, the calculator divides the total height of the reservoir into 20 equal increments and then determines what the corresponding volumes are for each increment of height. Before explaining the program algorithm, the two equations which are used by the program to compute volume are explained.

Underlying Equations

As mentioned above, this program will calculate volumes for cylindrical or rectangular wet wells as well as for trapezoidal basins. The equations used are explained before proceeding with the discussion of the algorithm.

The equation used to compute the volume for a trapezoidal basin is presented first, then it will be shown how the same equation may be used to compute the volume of a rectangular wet well. The equation used to determine the volume of a cyclindrical wet well is then given.

A trapezoidal basin is similar in appearance to an inverted truncated pyramid. It is formed by exacavating a rectangular hole and allowing variable side slopes. The side slopes of each side may have different values. A trapezoidal basin is shown in the figure below:

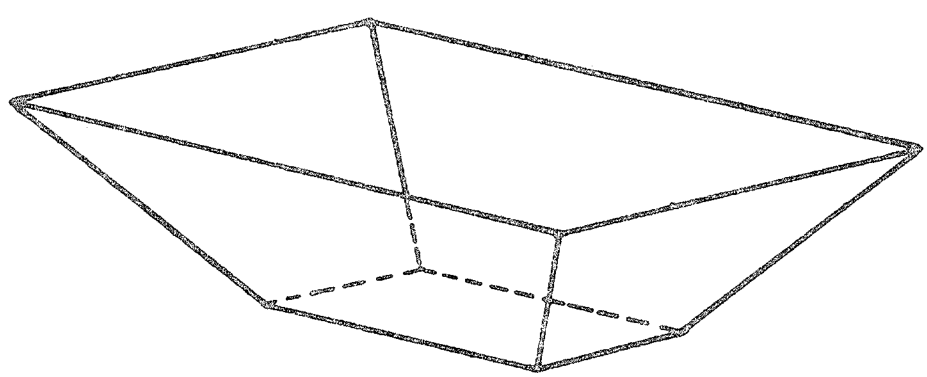


FIGURE 5. Trapezoidal Basin

Such a trapezoidal basin may be divided into component geometric elements, as shown in the figure below:

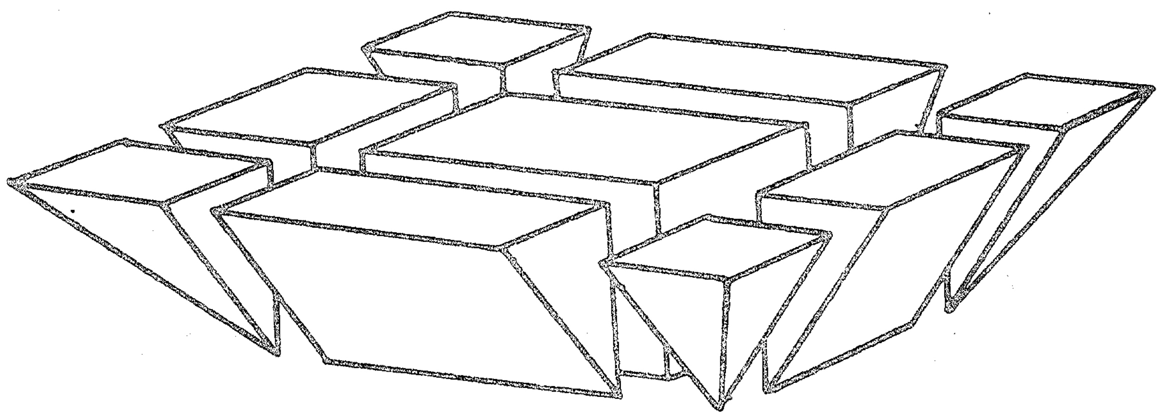


FIGURE 6. Component Elements of A Trapezoidal Basin

These component elements may then be taken separately or grouped together to determine what portion of the total volume is contributed by each.

The first component is the interior rectangular solid, the dimensions of which are: length (L), width (W) and height (H). The height of the basin may also be expressed as an integral number of height increments ($n \Delta H$), whereby the equation for the volume of the interior rectangular solid is: $(L \times W) \times (n \Delta H)$. See the figure below:

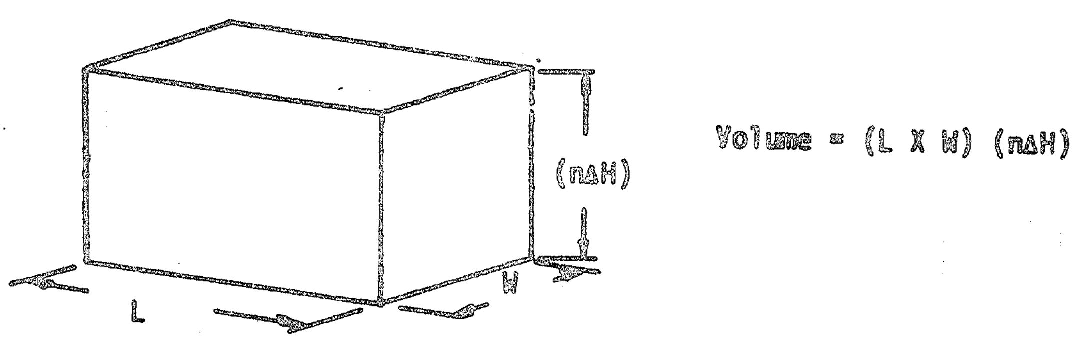


FIGURE 7. Rectangular Solid

The second component of the total volume is that contributed by the wedges abutting the rectangular solid at the width faces. These two wedges have the same width (W) and height (n Δ H) but may have different lengths depending upon the values of the side slopes in the length direction (LS). If these two wedges are brought together as shown in the figure below, the equation for the volume of the resulting solid is $1/2\ (W \times \Sigma LS) \times (n\ \Delta\ H)^2$. Where ΣLS is the sum of the two side slopes in the length direction.

$$\text{Volume} = \frac{(W \times \Sigma LS)(n\Delta H)^2}{2}$$

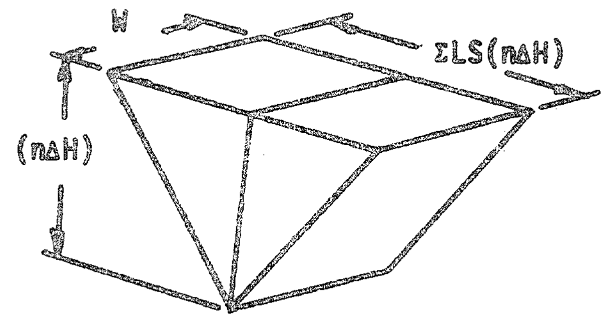
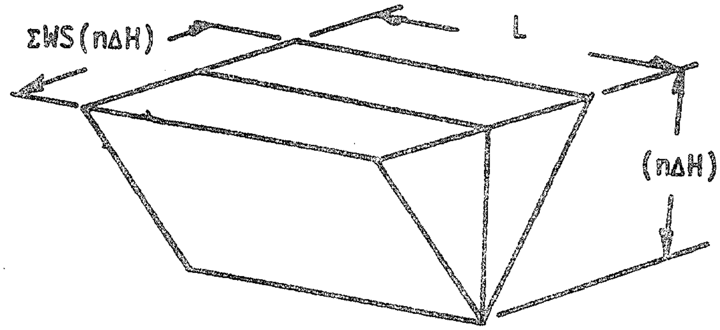


FIGURE 8. End Wedges

The third component of the total volume is that contributed by the wedges abutting the rectangular solid at the length faces. These two wedges have the same length (L) and height (n Δ H) but may have different widths depending upon the values of the side slopes in the width direction (WS). If these two wedges are brought together as shown in the figure below, the equation for the volume of the resulting solid is $1/2\ (L \times \Sigma WS) \times (n\ \Delta\ H)^2$. Where ΣWS is the sum of the two side slopes in the width direction.



$$\text{Volume} = \frac{(L \times \Sigma WS)\ (n\Delta H)^2}{2}$$

FIGURE 9. Side Wedges

The last component of the total volume is that contributed by the four pyramid shaped solids in the corners of the basin. The pyramids all have the same height ($n \Delta H$) but may have different lengths and widths depending upon the values of the side slopes in the length and width directions. These four pyramids may be brought together, as shown in the figure below, and the equation for the resulting volume is $1/3\ (\Sigma LS)(\Sigma WS)(n \Delta H)^3$.

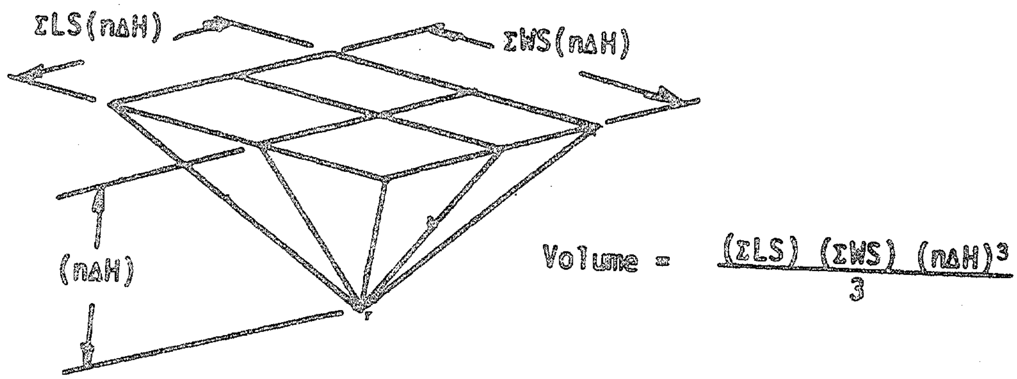


FIGURE 10. Corner Wedges

The equation for the total volume of the trapezoidal basin is the sum of the four components and is given below:

$$V_T = \frac{(\Sigma LS)(\Sigma WS)(n \Delta H)^3}{3} + \frac{(W \times \Sigma LS)(L \times \Sigma WS)(n \Delta H)^2}{2} + (L \times W)(n \Delta H)$$

This is the equation used in the calculator program to compute the volume of a trapezoidal basin.

The same equation is used to compute the volume of a rectangular wet well. A rectangular wet well will have vertical sides, therefore the value of the side slope in the length and width direction will be zero. The equation for the total volume then reduces to:

$$V_T = (L \times W)(n \Delta H)$$

which is the equation used in the calculator program to compute the volume for the rectangular wet well.

The equation used to compute the volume for a cylindrical wet well is straightforward. The equation is simply:

$$V_T = (\pi R^2)(n \Delta H)$$

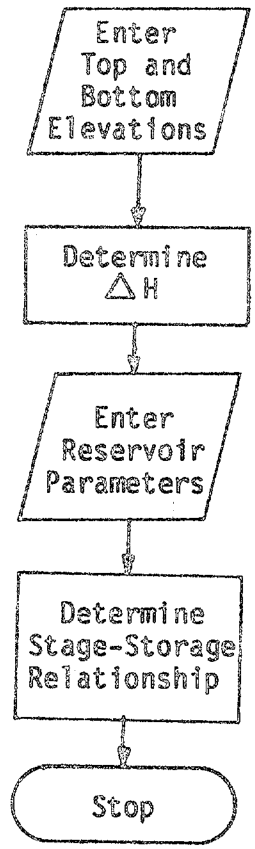
where R is the radius of the cylindrical wet well.

Program Algorithm

The algorithm of Program Label A is fairly simple and is illustrated in the simple flowchart shown below. The first step in this program is to enter the top and bottom elevations of the total storage reservoir. These two values are then used to determine the height increment which in turn will be used to define the stage-storage relationship for the reservoir. The total height of the reservoir is the top elevation minus the bottom elevation, and the height increment is the total height of the reservoir divided by some convenient number. (In the case of the TI-59 calculator program, that number is twenty (20)).

The next step is to enter the reservoir parameters. In the case of a trapezoidal basin these parameters are the length (L), the width (W), the sum of the side slopes in the length direction (ΣLS), and the sum of the side slopes in the width direction (ΣWS). For a rectangular wet well, the parameters are the same as for the trapezoidal basin, but with zero side slopes. For the cylindrical wet well, the only parameter which needs to be entered is the radius.

The next step is to determine the stage-storage relationship for the reservoir. This is accomplished by determining the volume contained within the reservoir for successively higher values of n in the expression for reservoir height ($n \Delta H$). Beginning with n equal to zero, the volume contained within the reservoir is calculated using the equations presented above. The value of n is incremented to 1, and then 2, and then 3, up to the limiting value (20 in the case of the TI-59 calculator program). For each incremental increase in the value of n, the corresponding volume contained within the reservoir is computed. In this manner the complete stage-storage relationship for the basin or wet well is defined.



TI-59 Calculator Program Label A

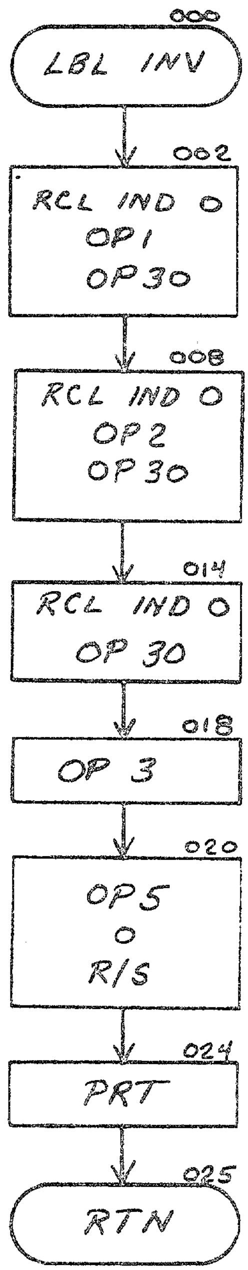
The discussion of the TI-59 calculator program developed to implement the algorithm described above presupposes a knowledge of the TI-59 calculator. If the reader is not familiar with the terminology and symbols used to describe the operations available with the TI-59 calculator, he is referred to the owner's manual for details.

The complete program listing for Program Label A is presented in the flowchart below. The interrelationship of the progrm steps is shown and the notes entered in the margins indicate the operation performed by the program steps.

Before proceding with the presentation of the flowchart for Program Label A, a discussion of subroutine "INV" is in order. Subroutine "INV" is used over and over again in Program Label A and in other programs. It is described here to avoid having to repeat this discussion in subsequent program descriptions. Subroutine "INV" is used to print alpha-numeric messages.

A flowchart of the subroutine "INV" is given below: (The numbers appearing in the upper right corner of the statement blocks are the corresponding program step numbers in the TI-59 program listing).

Subroutine "INV" transfers the contents of selected data registers into the print registers 1, 2, and 3. The numbers stored in these selected data registers are the print codes for alpha-numeric messages. These alpha-numeric messages tell the program user what information is required before processing may continue.



LABELS SUBROUTINE FOR ACCESS BY MAIN PROGRAM

INDIRECTLY RECALLS CONTENTS OF REG. # STORED IN REG. 0. STORES IN PRINT REG. 1. INCREMENTS REG. 0

INDIRECTLY RECALLS CONTENTS OF REG. # STORED IN REG. 0. STORES IN PRINT REG. 2. INCREMENTS REG. 0.

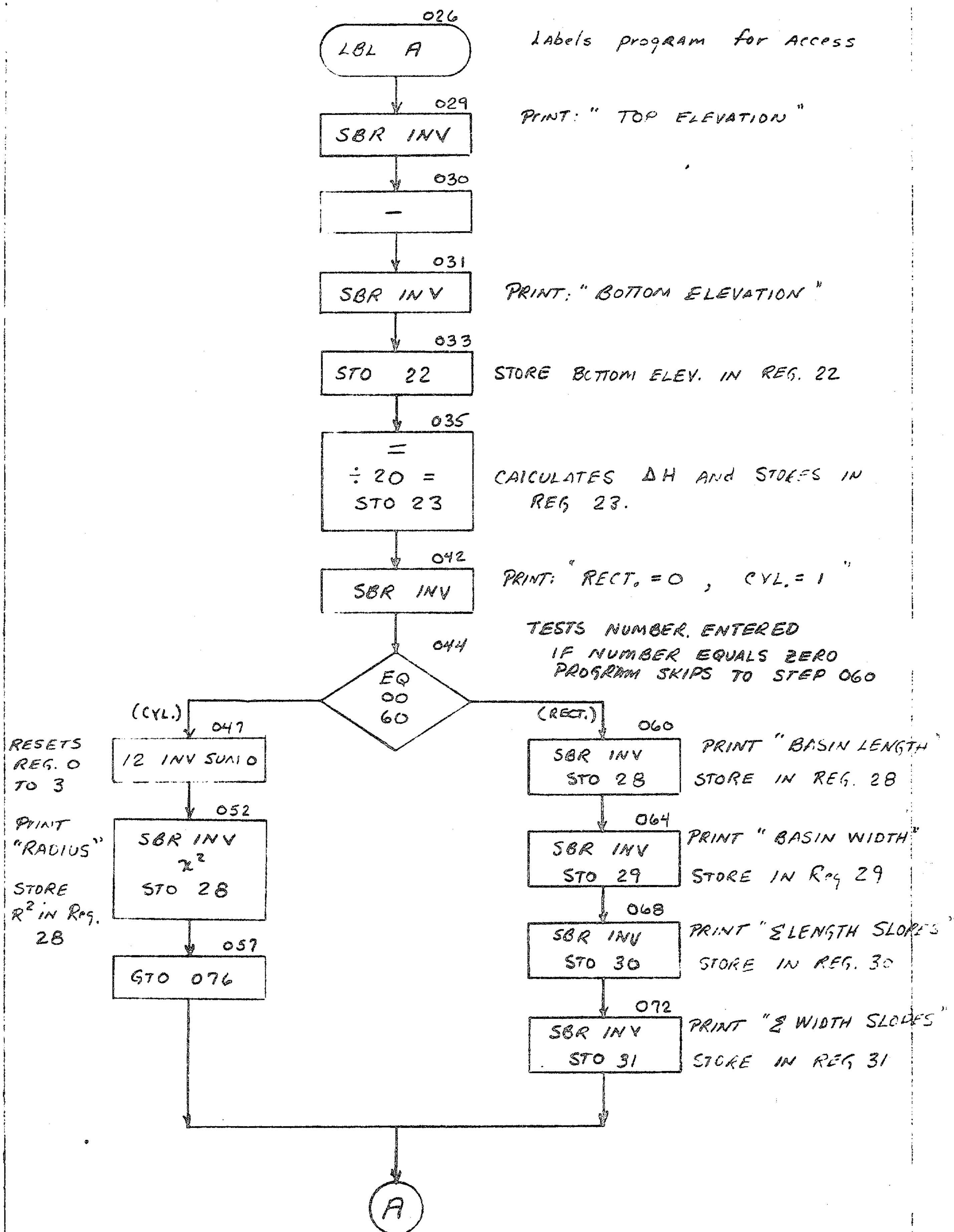
INDIRECTLY RECALLS CONTENTS OF REG. # STORED IN REG. 0. INCREMENTS REG. 0.

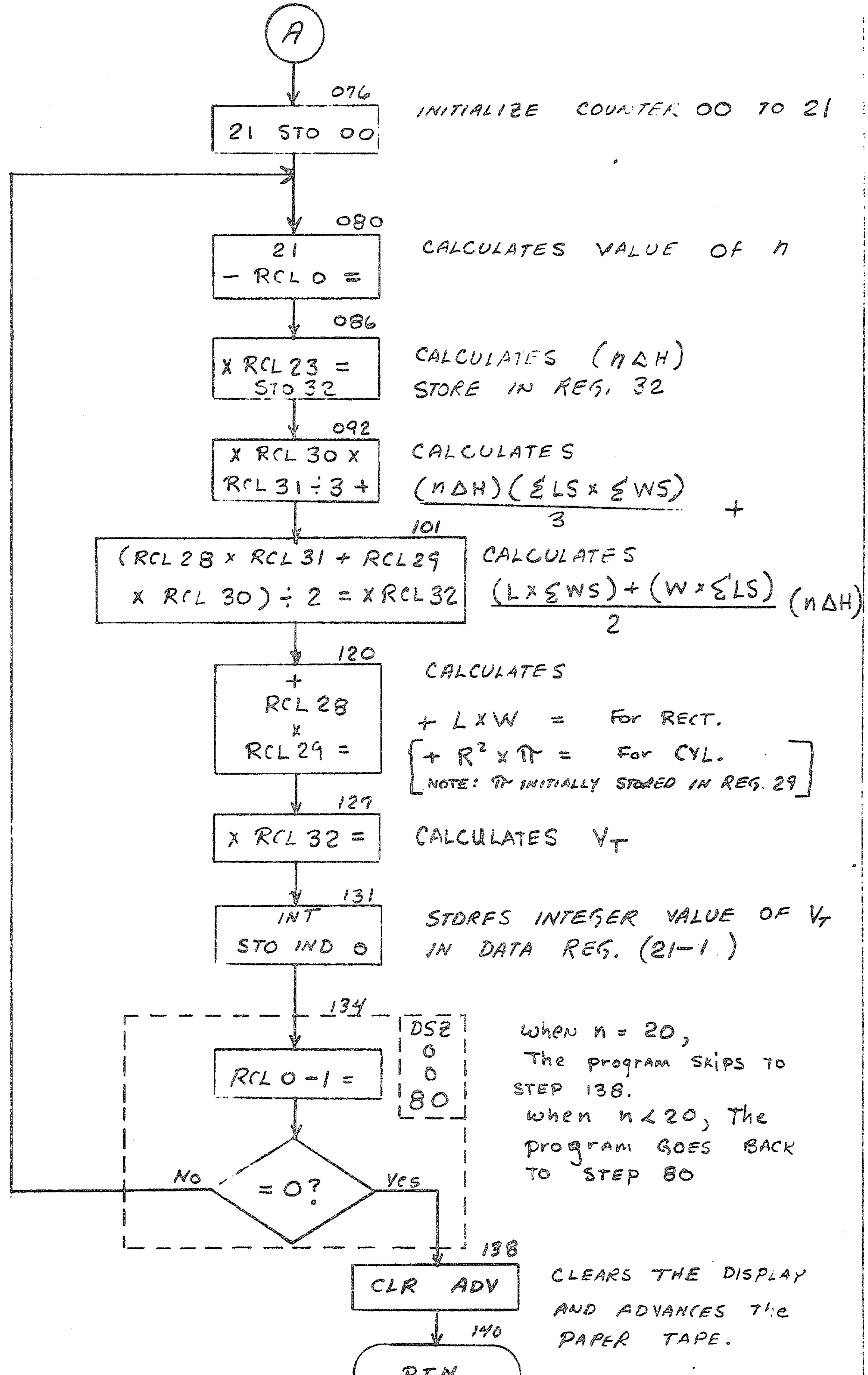
STORES # RECALLED IN STEP ABOVE IN PRINT REG. 3

PRINTS ALPHA-NUMERIC MESSAGE IN PRINT REG.S 1, 2 & 3. PLACES ZERO IN DISPLAY STOPS PROCESSING.

PRINTS # ENTERED

RETURNS TO MAIN PROGRAM


026
LBL A
Labels program for Access
029
SBR INV
PRINT: " TOP ELEVATION "
030
−
031
SBR INV
PRINT: " BOTTOM ELEVATION "
033
STO 22
STORE BOTTOM ELEV. IN REG. 22
035
=
÷ 20 =
STO 23
CALCULATES ΔH And STORES IN REG 23.
042
SBR INV
PRINT: " RECT. = 0 , CYL. = 1 "
TESTS NUMBER ENTERED
IF NUMBER EQUALS ZERO
PROGRAM SKIPS TO STEP 060
044
EQ
00
60
(CYL.)
(RECT.)
047
12 INV SUM 0
RESETS REG. 0 TO 3
052
SBR INV
x²
STO 28
PRINT "RADIUS"
STORE R² IN Reg. 28
057
GTO 076
060
SBR INV
STO 28
PRINT " BASIN LENGTH "
STORE IN REG. 28
064
SBR INV
STO 29
PRINT " BASIN WIDTH "
STORE IN Reg 29
068
SBR INV
STO 30
PRINT " Σ LENGTH SLOPES "
STORE IN REG. 30
072
SBR INV
STO 31
PRINT " Σ WIDTH SLOPES "
STORE IN REG 31
A


A
076
21 STO 00
INITIALIZE COUNTER 00 TO 21
080
21 - RCL 0 =
CALCULATES VALUE OF n
086
x RCL 23 = STO 32
CALCULATES (n ΔH)
STORE IN REG. 32
092
x RCL 30 x RCL 31 ÷ 3 +
CALCULATES
(n ΔH)(Σ LS x Σ WS) / 3 +
101
(RCL 28 x RCL 31 + RCL 29 x RCL 30) ÷ 2 = x RCL 32
CALCULATES
(L x Σ WS) + (W x Σ LS) / 2 (n ΔH)
120
+ RCL 28 x RCL 29 =
CALCULATES
+ L x W = For RECT.
+ R² x π = For CYL.
NOTE: π INITIALLY STORED IN REG. 29
127
x RCL 32 =
CALCULATES V_T
131
INT STO IND 0
STORES INTEGER VALUE OF V_T IN DATA REG. (21-1)
134
RCL 0 - 1 =
DSZ 0 0 80
= 0?
No
Yes
when n = 20, The program skips to STEP 138.
when n < 20, The program GOES BACK TO STEP 80
138
CLR ADV
CLEARS THE DISPLAY AND ADVANCES The PAPER TAPE.
140
RTN
STOPS The program

Program Label A'

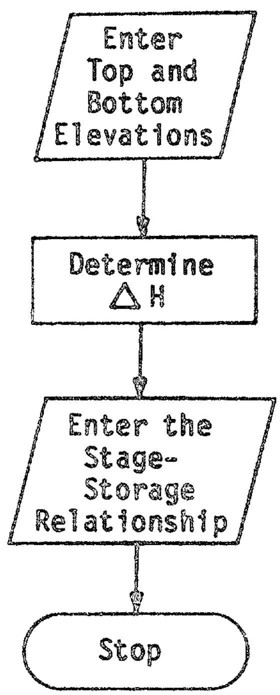
The second program contained in program set one is Program Label A'. As discussed in previous sections Program Label A' is used to enter a predetermined stage-storage relationship into the calculator.

Underlying Equations

Program Label A' involves the simple transfer of information from a predetermined stage-storage curve to the appropriate data registers of the calculator. There are no equations to be solved.

Program Algorithm

The algorithm of Program Label A' is very simple, as the flowchart presented below illustrates.



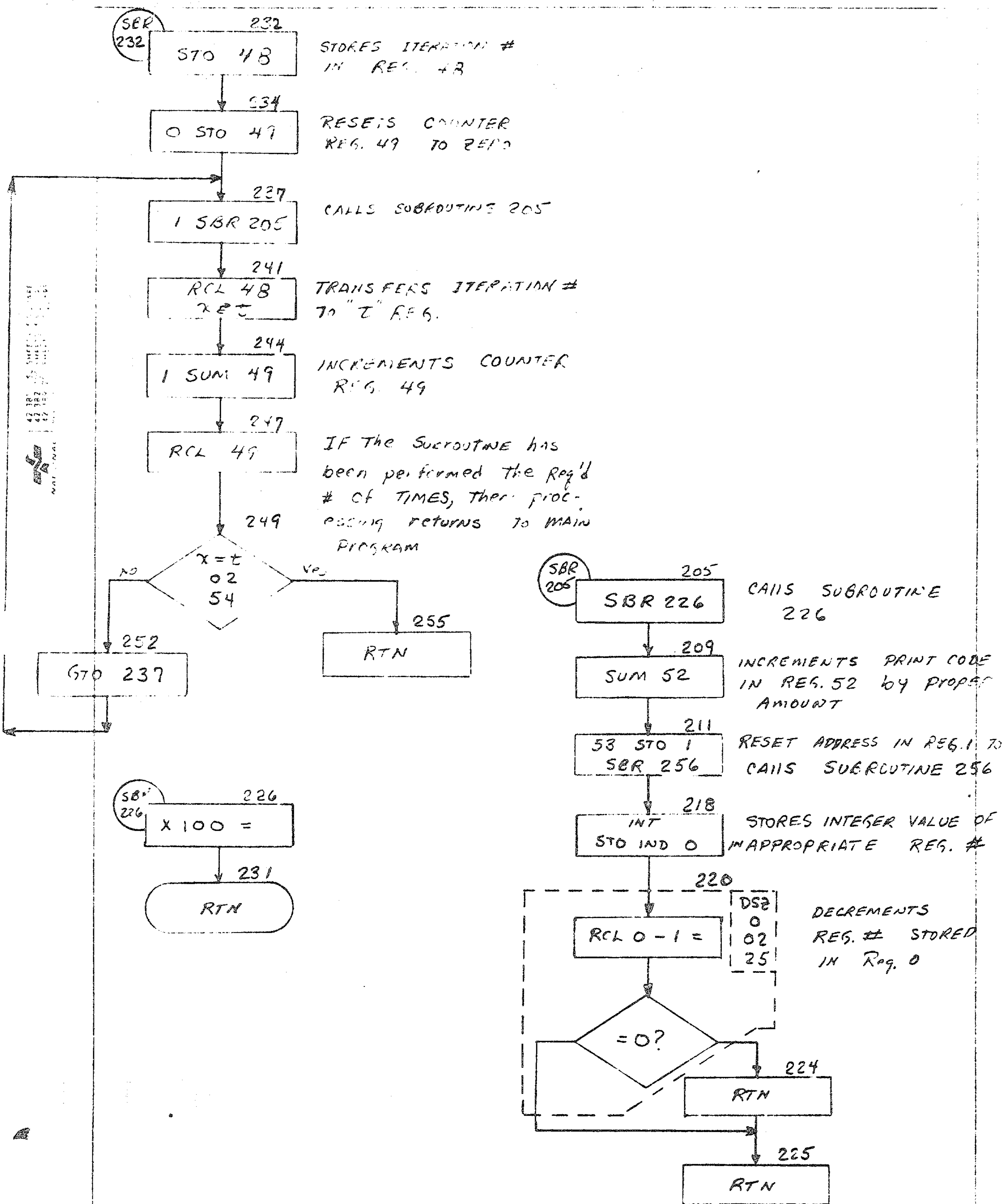
The first step is to enter the top and bottom elevation of the reservoir. These two values are then used to determine the height increment which defines the stage-storage relationship for the reservoir. The total height of the reservoir is the top elevation minus the bottom elevation, and the height increment is the total height of the reservoir divided by some convenient number. (In the case of the TI-59 calculator program, that number is twenty.) The next step is to enter the twenty values of storage which described the stage-storage relationship for the reservoir. Once this has been done the program is complete.

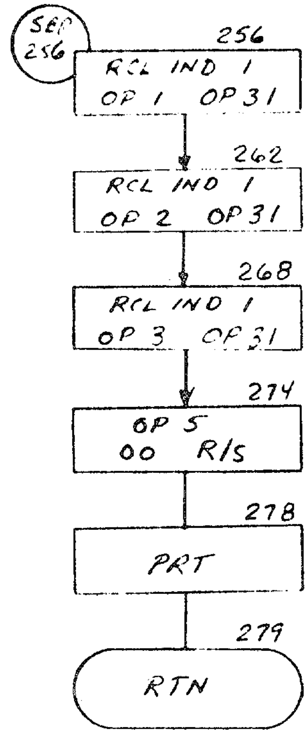
TI-59 Program Label A'

The TI-59 calculator program developed to implement the simple algorithm presented above is described in the following paragraph.

Almost all of this program is devoted to the printing of the alpha-numeric messages which prompt the user to enter the required data. There are several nested subroutines used to manipulate the print codes for these alpha-numeric messages and to transfer them to the appropriate print registers. These subroutines are presented in the complete flowchart for Program Label A' below:

141	LBL A'	
143	OP 00 59 STO 0	CLEARS ALL PRINT REGISTERS INITIALIZES REG. 0 TO 59
149	SBR INV	PRINT " TOP ELEVATION "
151	−	
152	SBR INV STO 22	PRINT " BOTTOM ELEVATION " STORE IN REG. 22
156	= ÷ 20 = STO 23	CALCULATES ΔH STORE IN REG. 23
163	21 STO 00	INITIALIZE COUNTER 00 TO 21
167	7 SBR 232	PERFORMS SUBROUTINE 232, 7 TIMES WHICH PRINTS " VOLUME 0 thru 6" These ARE STORED IN REG S 21 Thru 15
171	3 SBR 205	PRINTS " VOLUME 7", WHICH IS THEN STORED IN REG. 14
175	2 SBR 232	PERFORMS SUBROUTINE 232 TWICE WHICH PRINTS " VOLUME 8 AND 9 ". THESE ARE STORED IN REG S 13 AND 12.
179	189 SBR 205	PRINTS " VOLUME 10 " which is then STORED IN REG. 11
185	6 SBR 232	PERFORMS SUBROUTINE 232, 6 TIMES WHICH PRINTS " VOLUME 11 thru 16. These ARE STORED IN REG.S 10 Thru 5.
189	3 SBR 205	PRINTS " VOLUME 17 " which is Then STORED IN REG. 4
193	2 SBR 232	PERFORMS SUBROUTINE 232 TWICE PRINTING " VOLUME 18 And 19 " which ARE STORED IN REG. S 3 And 2.
197	89 SBR 205	PRINTS " VOLUME 20 " which IS then STORED IN REG. 1
202	CLR ADV RTN	CLEARS The display, ADVANCES The PAPER [illegible] THEN STOPS PROCESSING.


SBR 232
232
STO 48
STORES ITERATION # IN REG. 48
234
0 STO 49
RESETS COUNTER REG. 49 TO ZERO
237
1 SBR 205
CALLS SUBROUTINE 205
241
RCL 48 x⇄t
TRANSFERS ITERATION # TO "t" REG.
244
1 SUM 49
INCREMENTS COUNTER REG. 49
247
RCL 49
IF The Subroutine has been performed the Req'd # of TIMES, then processing returns to MAIN Program
249
x = t 02 54
NO
YES
252
GTO 237
255
RTN
SBR 226
226
X 100 =
231
RTN
SBR 205
205
SBR 226
CALLS SUBROUTINE 226
209
SUM 52
INCREMENTS PRINT CODE IN REG. 52 by Proper AMOUNT
211
53 STO 1 SBR 256
RESET ADDRESS IN REG. 1 TO
CALLS SUBROUTINE 256
218
INT STO IND 0
STORES INTEGER VALUE OF IN APPROPRIATE REG. #
220
DSZ 0 02 25
RCL 0 - 1 =
DECREMENTS REG. # STORED IN Reg. 0
= 0?
224
RTN
225
RTN


SEP 256
256
RCL IND 1
OP 1 OP 31
262
RCL IND 1
OP 2 OP 31
268
RCL IND 1
OP 3 OP 31
274
OP 5
00 R/S
278
PRT
279
RTN

TI-59 Calculator Program Label E'

The simple Program Label E' is flowcharted below. This program prints the contents of data registers 21 through 1 in succession. The stage-storage relationship for any reservoir is contained in data registers 21 through 1. The volume associated with the bottom elevation of the reservoir is stored in data register 21 and the volume associated with the top elevation of the reservoir is stored in data register 1.

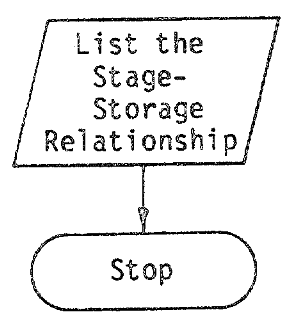
Program Label E' has been included in program sets 1, 2, and 3, so that the user may print the current stage-storage relationship at any time. The program step numbers for Program Label E' will change from one program set to the next but the program itself is identical. Program Label E' will only be discussed here and subsequent discussions of Program Label E' will refer back to this flowchart.

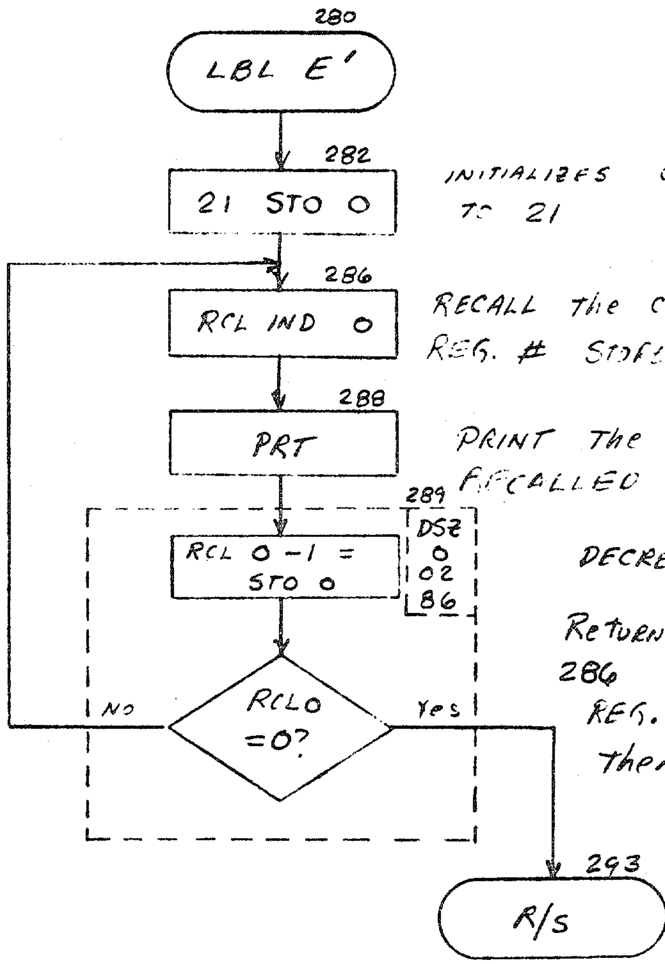
Program E'

The third, and last program, contained in program set one is Program Label E' As discussed in previous sections, Program Label E' is used to list the stage-storage relationship for the pumping station reservoir, once it has been calculated. This is a very simple program, so simple that the algorithm is simply the statement: print the stage-storage relationship. There are no equations used in this program.

Program Algorithm

As stated above, the algorithm for this program is very simple as shown in the one block flowchart below:





INITIALIZES COUNTER REG 0 TO 21

RECALL the CONTENTS OF the REG. # STORED IN Reg. 0

PRINT The VALUE OF STORAGE RECALLED ABOVE

DECREMENTS COUNTER Reg 0

Returns Processing to Step 286 UNLESS CONTENTS Of REG. 0. EQUAL ZERO. then processing stops

Program Set 2

Program Label B

The first program contained in program set two is Program Label B. As discussed in previous sections, Program Label B is used to determine the additional storage provided by circular pipes which feed into the pumping station wet well.

Program Label B is complex because the computation of the volume provided by a sloping circular pipe of a given length is a complicated problem, as will be demonstrated by the discussion of Program Label B below.

Equations

There are three equations used in this program to compute the volume added to the reservoir by a fixed length of circular pipe, of a certain diameter and slope. The first equation is used when the pipe is full throughout its length. This is simply the end area of the pipe times its length or:

$$V = \frac{\pi D^2}{4} L$$

where: V is the volume computed in cubic feet.

D is the inside diameter of the pipe in feet.

L is the length of the pipe in feet.

The second equation, presented below, is used when the volume of water in the pipe may be represented by a truncated right circular cylinder. This is illustrated in the figure below:

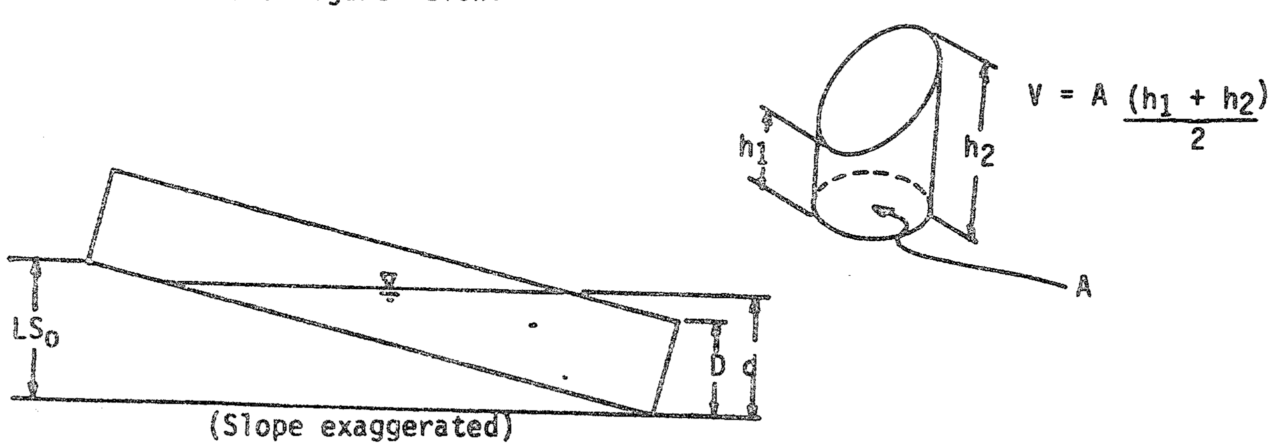


FIGURE 11. Truncated Right Circular Cylinder

where:

h_2 is equal to d/S_o, h_1 is equal to $(d - D)/S_o$
and $d = (n \Delta H)$

The total volume of water is given by the equation:

$$V = \frac{\pi D^2}{4S_o} \left((n \Delta H) - D/2\right)$$

where: D is the inside pipe diameter in feet.

$(n \Delta H)$ is the depth of the water in integral height increments as defined above for trapezoidal basins.

S_o is the slope of the pipe in feet per foot.

The third equation is somewhat more complicated and is used to compute the volume of water in an ungula or wedge of a right circular cylinder. This is used frequently in Program Label B. To derive this equation, one must resort to integral calculus. The derivation is lengthy and will not be given here. However, this equation is given in a number of handbooks [1] for those who wish to verify its applicability.

The equation for the volume contained within an ungula of a right circular cylinder is:

$$V = \frac{h}{3\,b} \left[a(3R^2 - a^2) + 3R^2\,(b - R)\phi\right]$$

where $$\phi = \pi - \text{Cos}^{-1}\left[\frac{2b}{D} - 1\right]$$

and $a = \frac{D}{2} \text{Sin}\ \phi$

[1] Handbook of Engineering Fundamentals, Eshbach, John Wiley Publishers.

as shown in the figure

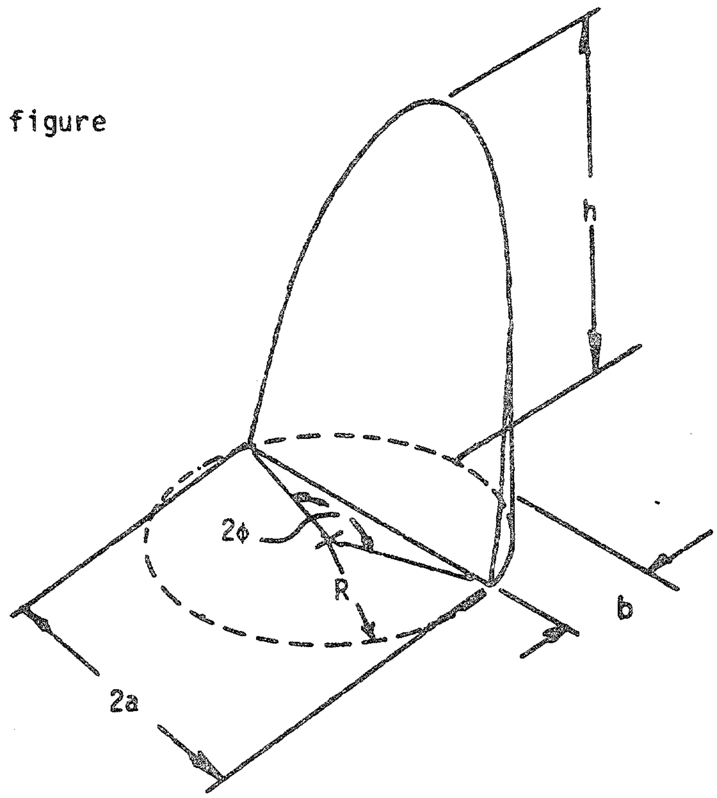


FIGURE 12. Ungula of A Cylinder

for the case of a horizontal water surface intersecting the inside surface of a sloping circular pipe, as illustrated below:

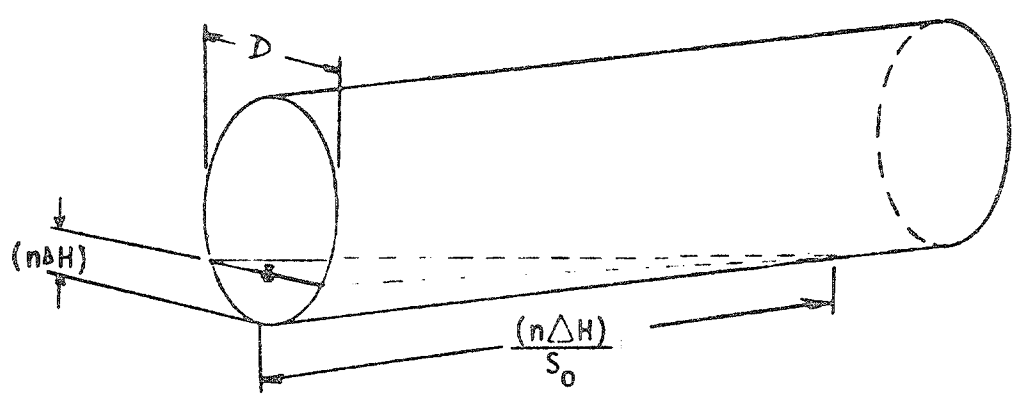


FIGURE 13. Horizontal Water Surface Intersecting Inside Surface of a Sloping Circular Pipe

The above equation may be rewritten as:

$$V = \frac{1}{3S_o}\left[a\left(3\left(\frac{D}{2}\right)^2 - a^2\right) + 3\left(\frac{D}{2}\right)^2\left((n\Delta H) - \left(\frac{D}{2}\right)\right)\phi\right]$$

where: $(n \Delta H)$ is defined above and

$$b = (n \Delta H),\ h = \frac{n \Delta H}{S_o},\ a = \frac{D}{2}\ \text{Sin}\ \phi,\ \phi = \pi - \text{Cos}^{-1}\left[\frac{2(n \Delta H)}{D} - 1\right]$$

This form of the equation is used in Program Label B to determine the volume of water within an ungula of a right circular cylinder.

With the three equations presented it is possible to compute the additional volume provided by a pipe feeding into the pumping station wet well.

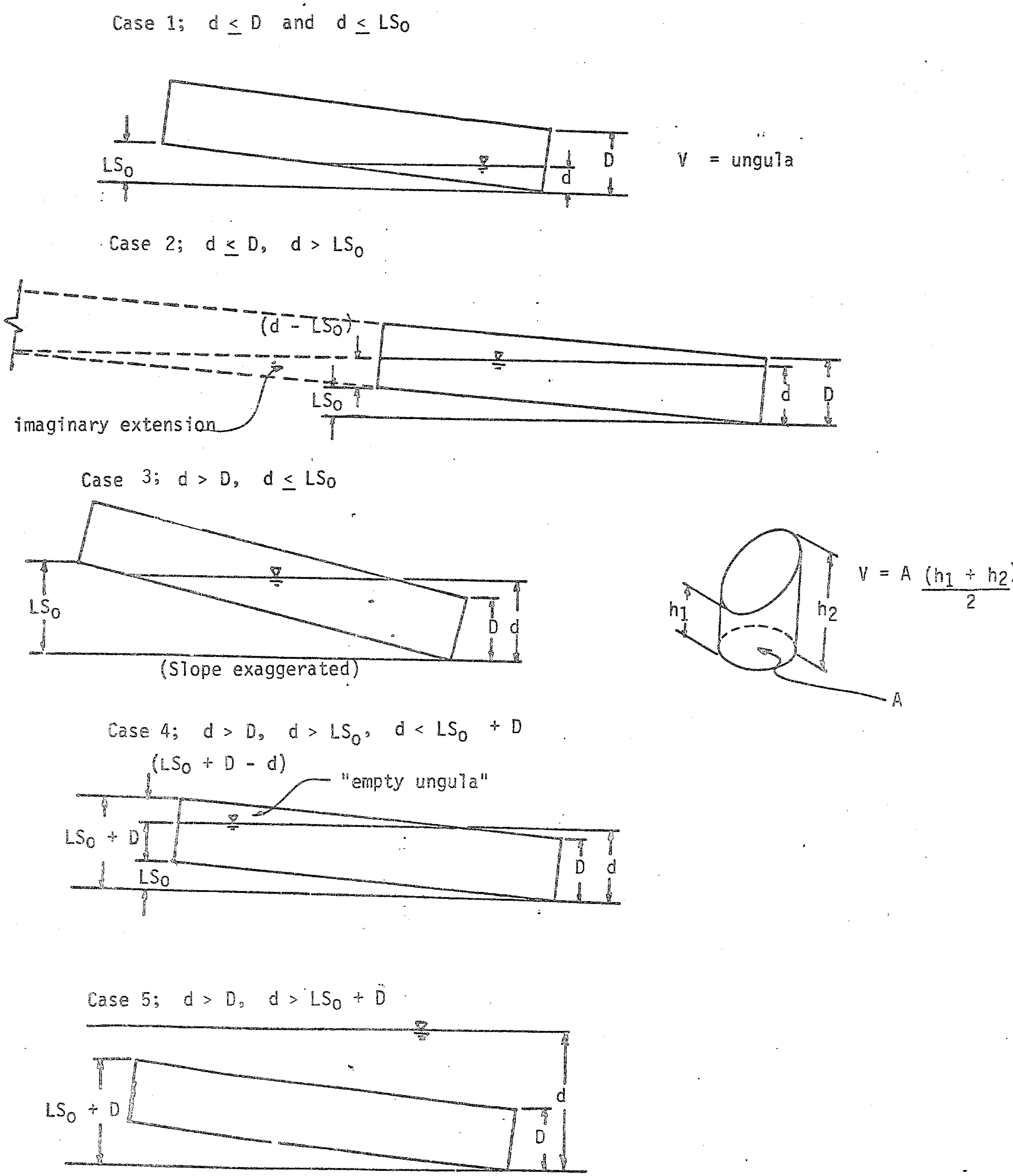
Before proceding with a description of the program algorithm for Program Label B, it is necessary to discuss how the three equations presented above are used to compute the volume of water contained in a sloping circular pipe. As illustrated in the figure on the next page there are five cases which describe the problem completely.

- Case number 1 occurs when the depth of the water is less than the pipe diameter and also less than the elevation of the far invert of the pipe. This volume is computed by a straightforward application of the "ungula" equation.

- Case number 2 occurs when the depth of water is less than the pipe diameter but greater than the elvation of the far invert of the pipe. This volume is computed by a double application of the ungula formula. First, the pipe is "imaginarily" extended until the situation is the same as in case 1, i.e., the depth of water is less than the far invert elevation of the pipe. This volume is computed by the "ungula" equation. Second, the volume of water contained within the "imaginary extention" is computed, again using the "ungula" equation. This second volume is subtracted from the first, to compute the actual volume within the pipe.

- Case number 3 occurs when the depth of water is greater than the pipe diameter and less than the far invert elevation of the pipe. (This case occurs for steep or very long pipes). This volume is computed by a straightforward application of the equation for a truncated right circular cylinder described above.

Figure 14. Volume in Sloping Circular Pipes



- Case number 4 occurs when the depth of water is greater than the pipe diameter, greater than the far invert of the pipe but less than the far crown of the pipe (i.e., the pipe is not full). In this case the volume of water contained within the pipe is computed by a combination of two equations. First, the volume of a full pipe is computed using the equation presented above for the full pipe. Second, the volume of the "empty ungula" is computed, using the ungula equation. The volume of the "empty ungula" is then subtracted from the full pipe to compute the volume of water contained in the pipe.

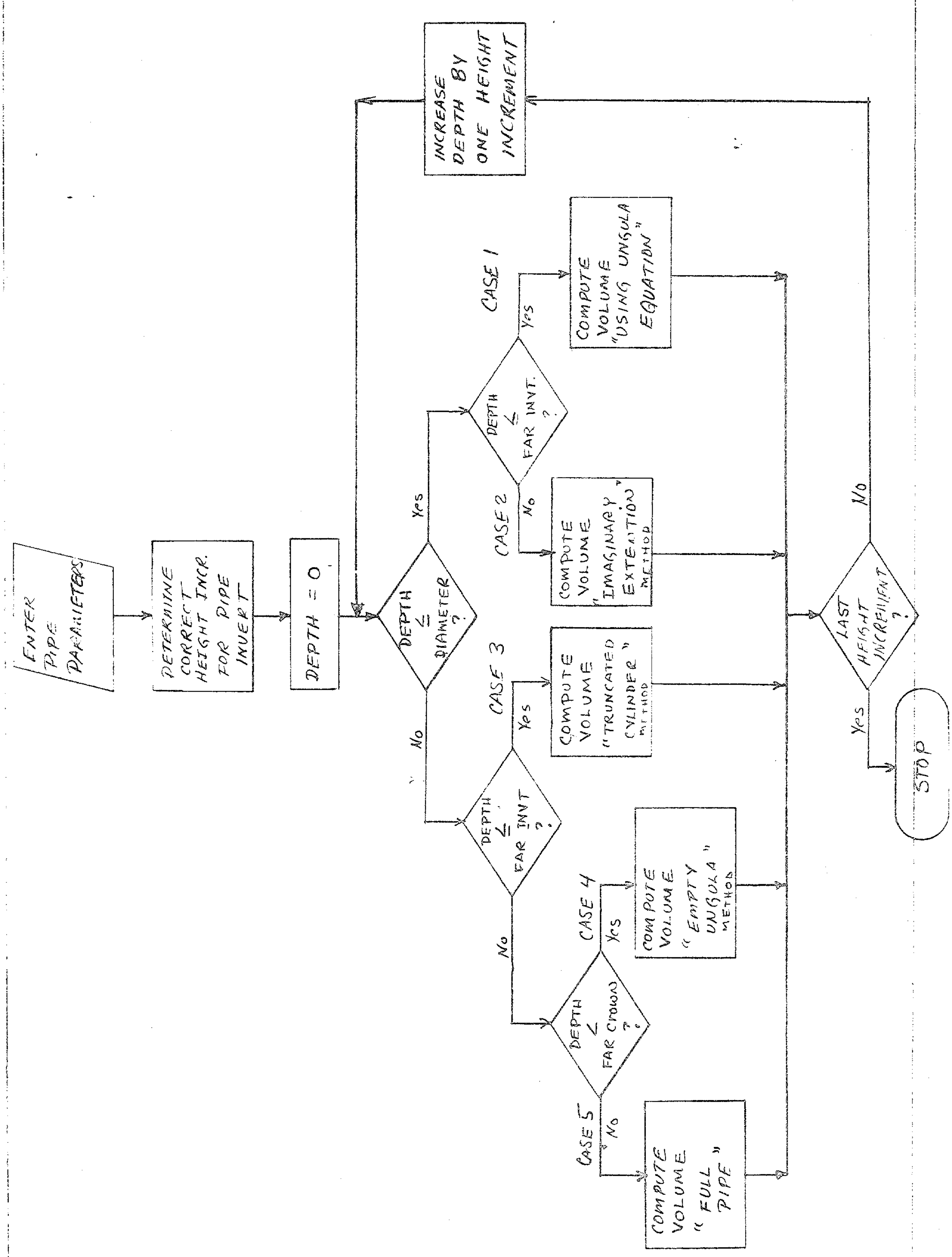
- Case number 5 occurs when the pipe is full. This occurs when the depth of water is greater than the pipe diameter, and also greater than the far crown of the pipe. The volume of water contained in a full pipe is computed by a straightforward application of the equation presented above for a full pipe.

As illustrated in the flowchart for the program algorithm, much of the program is dedicated to determining what case we are dealing with.

Program Algorithm

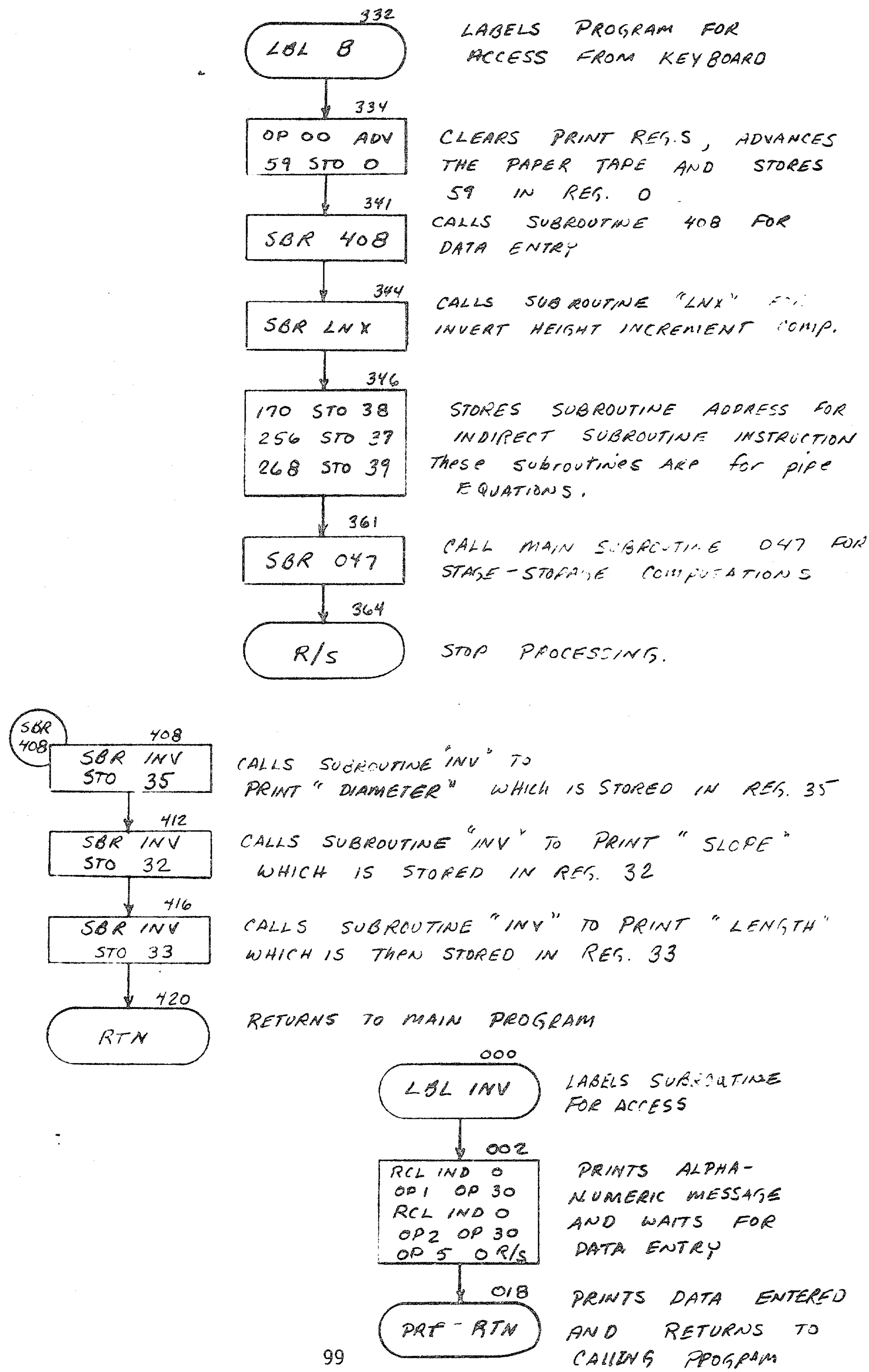
The first step in this program is to enter the necessary pipe parameters of diameters (D), slope (S_o), length (L), and downstream invert elevation. The next step is to determine which height increment the downstream invert elevation corresponds to. This allows the program to add the volume contributed by the pipe to the correct data registers. The next step is to determine the additional volume provided by the pipe for each reservoir height increment above the pipe invert and add this to the cumulative stage-storage relationship being developed. This step requires a number of iterations, in order to account for all of the reservoir height increments above the invert of the pipe. For each iteration, it is necessary to determine which case we are dealing with and consequently which equations to apply.

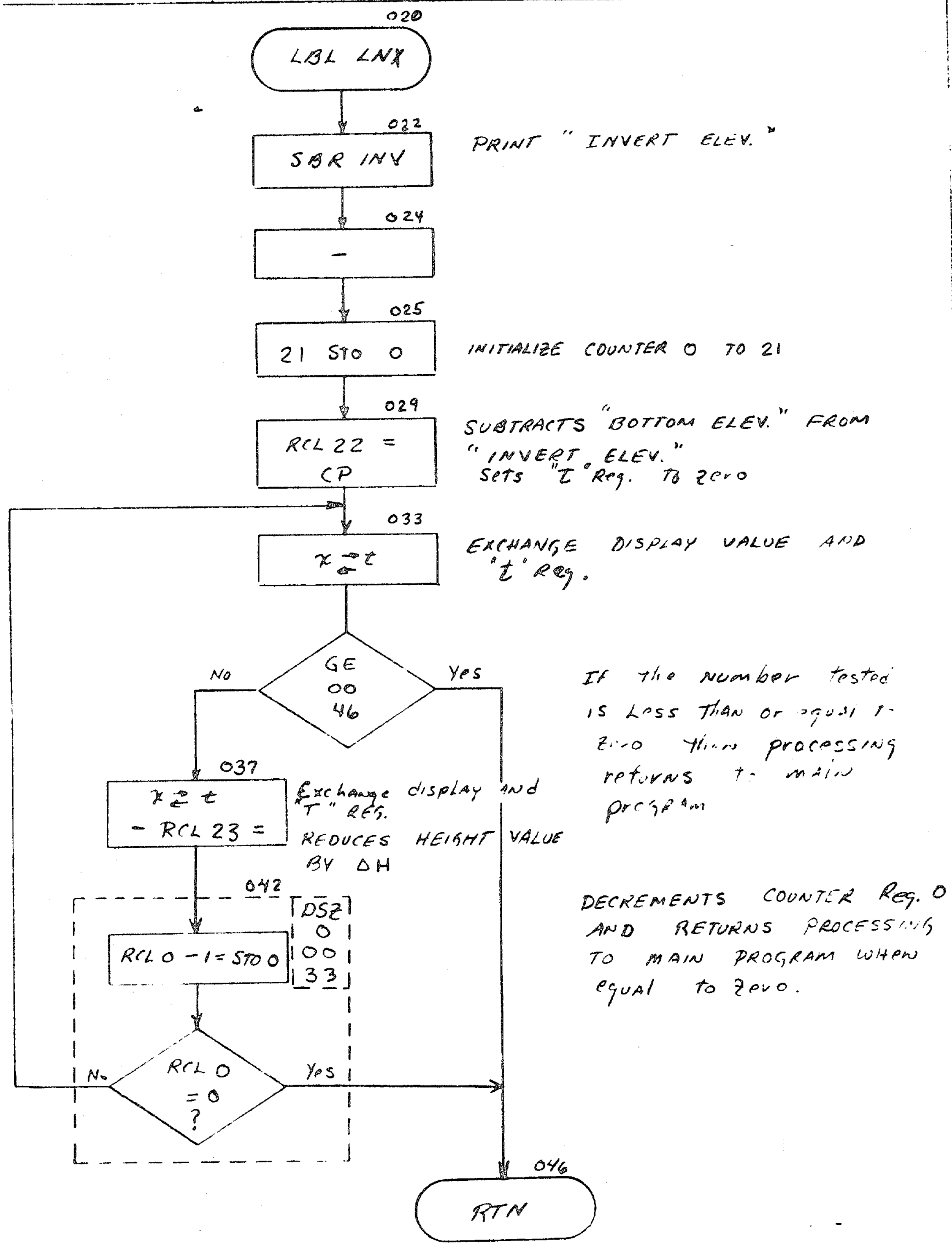
This complex algorithm is presented in the flowchart on the next page.

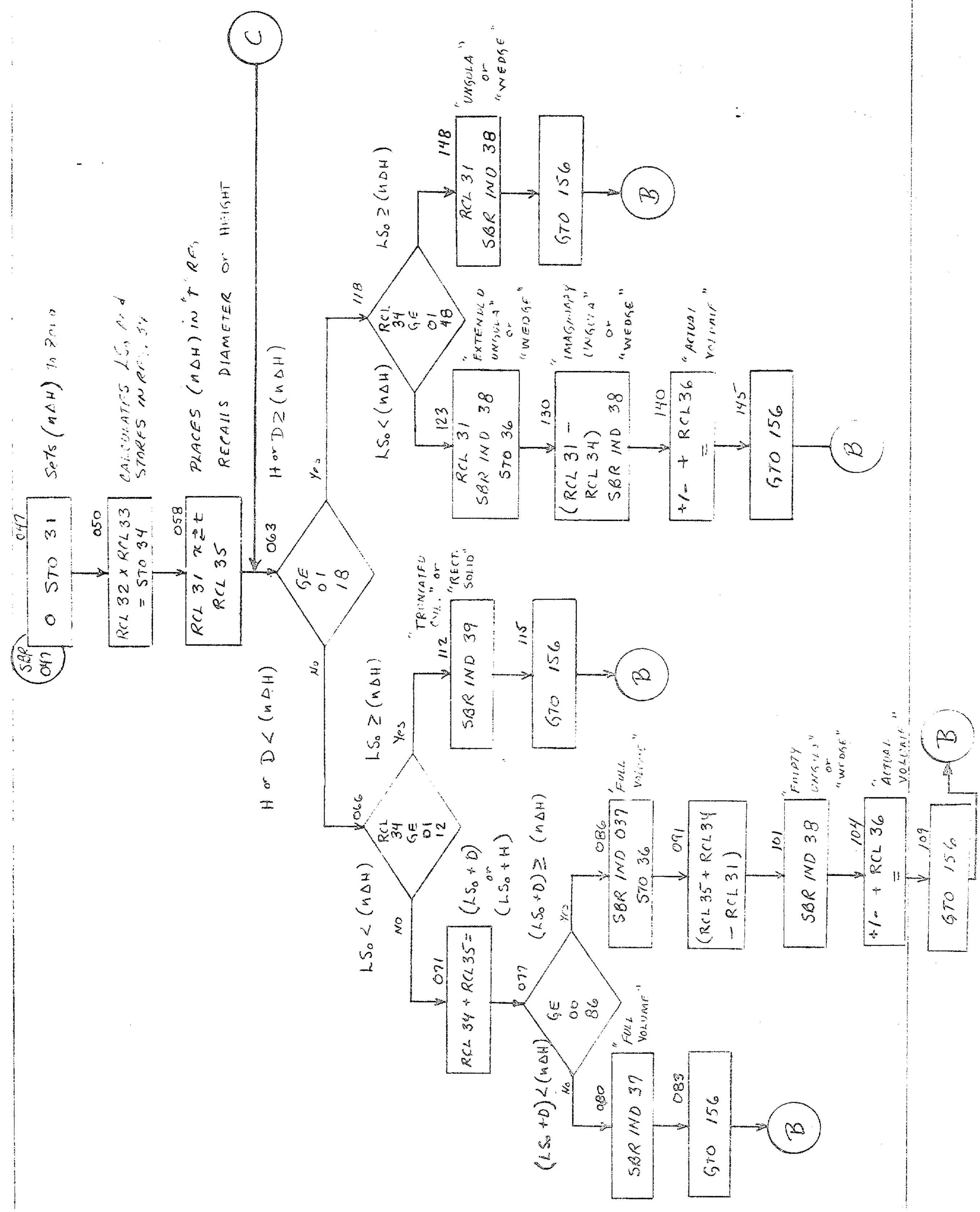

ENTER PIPE PARAMETERS
DETERMINE CORRECT HEIGHT INCR. FOR PIPE INVERT
DEPTH = 0
DEPTH ≤ DIAMETER ?
Yes
No
DEPTH ≤ FAR INVT. ?
CASE 1
Yes
COMPUTE VOLUME "USING UNGULA EQUATION"
CASE 2
No
COMPUTE VOLUME "IMAGINARY EXTENSION" METHOD
DEPTH ≤ FAR INVT ?
CASE 3
Yes
COMPUTE VOLUME "TRUNCATED CYLINDER" METHOD
No
CASE 4
Yes
COMPUTE VOLUME "EMPTY UNGULA" METHOD
DEPTH ≤ FAR CROWN ?
CASE 5
No
COMPUTE VOLUME "FULL PIPE"
LAST HEIGHT INCREMENT ?
Yes
STOP
No
INCREASE DEPTH BY ONE HEIGHT INCREMENT

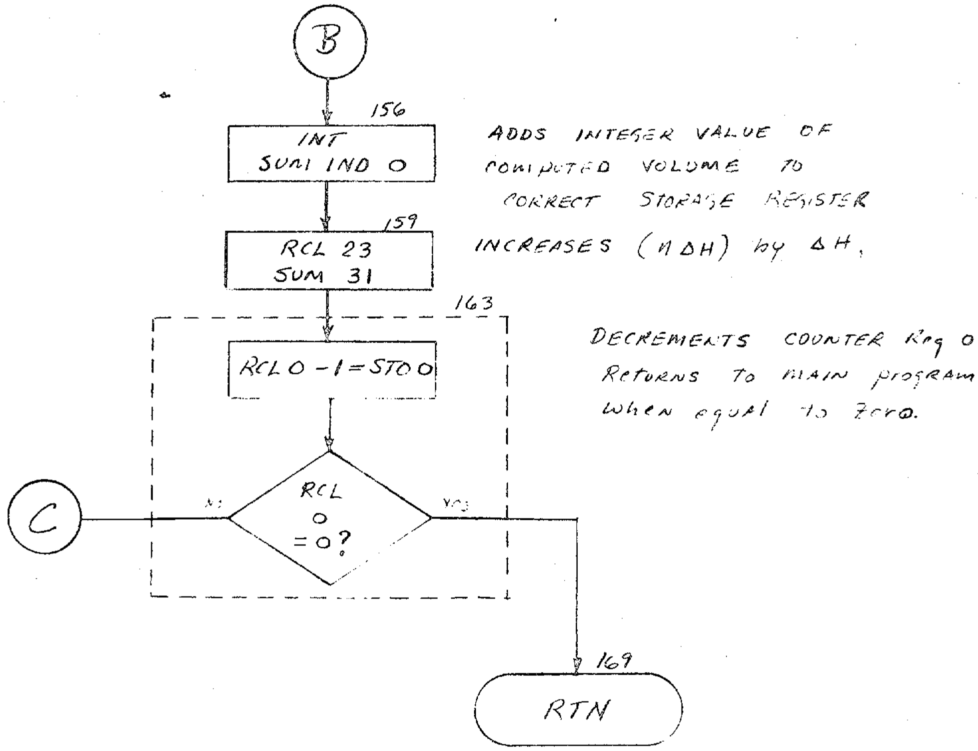
TI-59 Program Label B

The program developed to implement the algorithm presented above is described in the flowchart on the following pages.


332
LBL 8
LABELS PROGRAM FOR ACCESS FROM KEYBOARD
334
OP 00 ADV
59 STO 0
CLEARS PRINT REG.S, ADVANCES THE PAPER TAPE AND STORES 59 IN REG. 0
341
SBR 408
CALLS SUBROUTINE 408 FOR DATA ENTRY
344
SBR LNX
CALLS SUBROUTINE "LNX" FOR INVERT HEIGHT INCREMENT COMP.
346
170 STO 38
256 STO 37
268 STO 39
STORES SUBROUTINE ADDRESS FOR INDIRECT SUBROUTINE INSTRUCTION
These subroutines are for pipe EQUATIONS.
361
SBR 047
CALL MAIN SUBROUTINE 047 FOR STAGE-STORAGE COMPUTATIONS
364
R/S
STOP PROCESSING.
SBR 408
408
SBR INV
STO 35
CALLS SUBROUTINE "INV" TO PRINT "DIAMETER" WHICH IS STORED IN REG. 35
412
SBR INV
STO 32
CALLS SUBROUTINE "INV" TO PRINT "SLOPE" WHICH IS STORED IN REG. 32
416
SBR INV
STO 33
CALLS SUBROUTINE "INV" TO PRINT "LENGTH" WHICH IS THEN STORED IN REG. 33
420
RTN
RETURNS TO MAIN PROGRAM
000
LBL INV
LABELS SUBROUTINE FOR ACCESS
002
RCL IND 0
OP 1 OP 30
RCL IND 0
OP 2 OP 30
OP 5 0 R/S
PRINTS ALPHA-NUMERIC MESSAGE AND WAITS FOR DATA ENTRY
018
PRT - RTN
PRINTS DATA ENTERED AND RETURNS TO CALLING PROGRAM


020
LBL LNX
022
SBR INV
PRINT "INVERT ELEV."
024
025
21 STO 0
INITIALIZE COUNTER 0 TO 21
029
RCL 22 =
CP
SUBTRACTS "BOTTOM ELEV." FROM "INVERT ELEV."
Sets "t" Reg. To zero
033
x ⇄ t
EXCHANGE DISPLAY VALUE AND "t" Reg.
GE
00
46
No
Yes
If the number tested is less than or equal to zero then processing returns to main program
037
x ⇄ t
- RCL 23 =
Exchange display and "T" REG.
REDUCES HEIGHT VALUE BY ΔH
042
DSZ
0
00
33
RCL 0 - 1 = STO 0
DECREMENTS COUNTER Reg. 0 AND RETURNS PROCESSING TO MAIN PROGRAM WHEN equal to zero.
RCL 0
= 0
?
No
Yes
046
RTN


SBR 047
047
0 STO 31
Sets (nΔH) in R31
050
RCL 32 x RCL33 = STO 34
058
RCL 31 x⇄t RCL 35
PLACES (nΔH) in "t" REG.
RECALLS DIAMETER or HEIGHT
C
063
GE 01 18
H or D ≥ (nΔH)
Yes
H or D < (nΔH)
No
066
RCL 34 GE 01 12
LS₀ ≥ (nΔH)
Yes
112
SBR IND 39
"TRUNCATED CYL." or "RECT. SOLID"
115
GTO 156
B
LS₀ < (nΔH)
NO
071
RCL 34 + RCL35 =
(LS₀ + D) or (LS₀ + H)
077
GE 00 86
(LS₀ + D) ≥ (nΔH)
Yes
086
SBR IND 037 STO 36
"FULL VOLUME"
091
(RCL 35 + RCL 34 − RCL 31)
101
SBR IND 38
"EMPTY UNGULA" or "WEDGE"
104
+/- + RCL 36 =
"ACTUAL VOLUME"
109
GTO 156
B
(LS₀ + D) < (nΔH)
No
080
SBR IND 37
"FULL VOLUME"
083
GTO 156
B
118
RCL 34 GE 01 48
LS₀ ≥ (nΔH)
148
RCL 31 SBR IND 38
"UNGULA" or "WEDGE"
GTO 156
B
LS₀ < (nΔH)
123
RCL 31 SBR IND 38 STO 36
"EXTENDED UNGULA" or "WEDGE"
130
(RCL 31 − RCL 34) SBR IND 38
"IMAGINARY UNGULA" or "WEDGE"
140
+/- + RCL 36 =
"ACTUAL VOLUME"
145
GTO 156
B


B
156
INT
SUM IND 0
ADDS INTEGER VALUE OF COMPUTED VOLUME TO CORRECT STORAGE REGISTER
159
RCL 23
SUM 31
INCREASES (n ΔH) by ΔH.
163
RCL 0 - 1 = STO 0
DECREMENTS COUNTER Reg 0 Returns to main program when equal to zero.
RCL 0 = 0?
C
169
RTN

This Subroutine calculates the volume of an [illegible]

SBR 170

170: RAD / STO 40 — Sets calculator to radian mode. Stores $(n\Delta H)$ in Reg. 45

173: π − (2 × RCL 40 ÷ RCL 35 − 1) INV COS = — Calculates $\phi = \pi - \cos^{-1}\left(\frac{2(n\Delta H)}{D} - 1\right)$

189: STO 41 / SIN / × (RCL 35 ÷ 2) = STO 42 — Calculates $a = \left(\frac{D}{2}\right)\sin\phi$

202: NOP
1 ÷ 3 ÷ RCL 32 × (RCL 42 × (3 × (RCL 35 ÷ 2) x^2 − RCL 42 x^2)
+ 3 × (RCL 35 ÷ 2) x^2 × (RCL 40 − RCL 35 ÷ 2) × RCL 41) =

Calculates

$$V = \frac{1}{3S_o}\left[a\left(3\left(\frac{D^2}{2}\right) - a^2\right) + 3\left(\frac{D}{2}\right)^2\left(n\Delta H - \left(\frac{D}{2}\right)\right)\phi\right]$$

254: DEG — Resets calculator [illegible] Degree mode

255: RTN — Returns processing to calling subroutine.

SBR 256

256: π × RCL 35 x^2 ÷ 4 × RCL 33 = — Calculates volume of full pipe $\frac{\pi D^2}{4} L$

267: RTN

SBR 268

268: π × RCL 35 x^2 ÷ 4 ÷ RCL 32 × — Calculates volume of truncated cylinder $\frac{\pi D^2}{4 S_o}\left((n\Delta H) - \frac{D}{2}\right)$

279: (RCL 31 − RCL 35 ÷ 2) =

289: RTN

Program Label C

The second program contained in program set two is Program Label C. As discussed in previous sections, Program Label C is used to determine the additional storage provided by box conduits which feed into the pumping station wet well.

Program Label C is very similar to Program Label B. The program algorithm is virtually identical, the only difference being that the volumes computed are for boxes and wedges rather than cylinders and ungulas. The main program is slightly different because there is an additional parameter, the box width, which must be accounted for and there are different print codes which must be loaded into the print registers.

Underlying Equations

There are three equations used in this program to compute the volume added to the reservoir by a fixed length of box conduit, of certain dimensions and slope.

The first equation is used when the box is full throughout its length. This is simply the end area of the box multiplied by its length or:

$$V = B \times H \times L$$

where: B is the width of the box conduit in feet.

H is the height of the box conduit in feet.

L is the length of the box conduit in feet.

The second equation is used when the volume of the water in the box may be represented by a truncated rectangular solid as shown in the figure below:

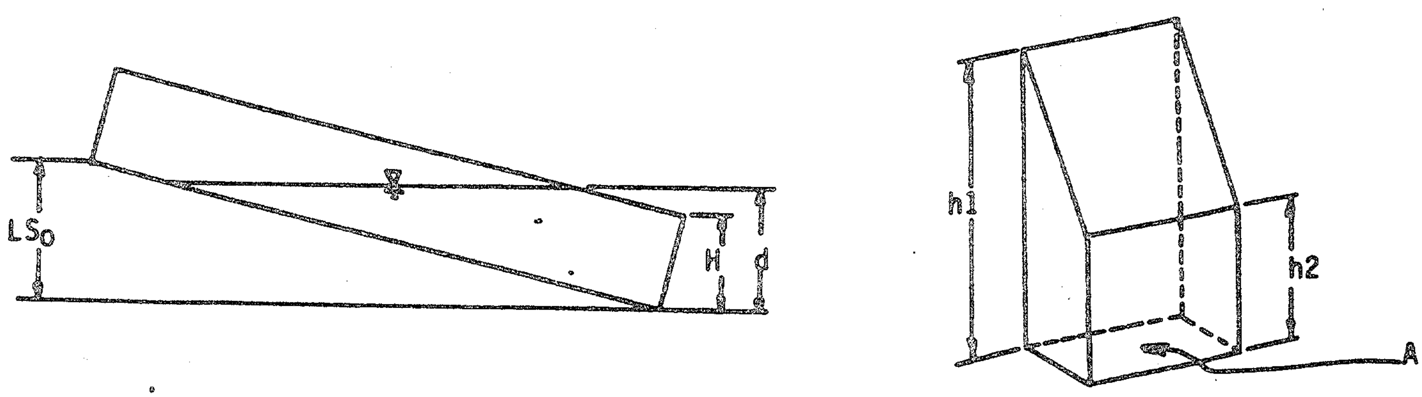


FIGURE 15. Truncated Rectangular Solid

where h_1 is equal to $\frac{d}{S_o}$

h_2 is equal to $\frac{(d - H)}{S_o}$

The volume of the water in the box is given by the equation

$$V = \frac{B}{S_o} \quad H\,(n\,\Delta H) - \frac{H^2}{2}$$

where S_o is the slope of the box conduit in feet per foot.

$(n\,\Delta H)$ is the depth of the water expressed as an integral number of height increments.

The third equation is used when the volume being computed may be represented as a wedge. Once such instance is illustrated in the figure below:

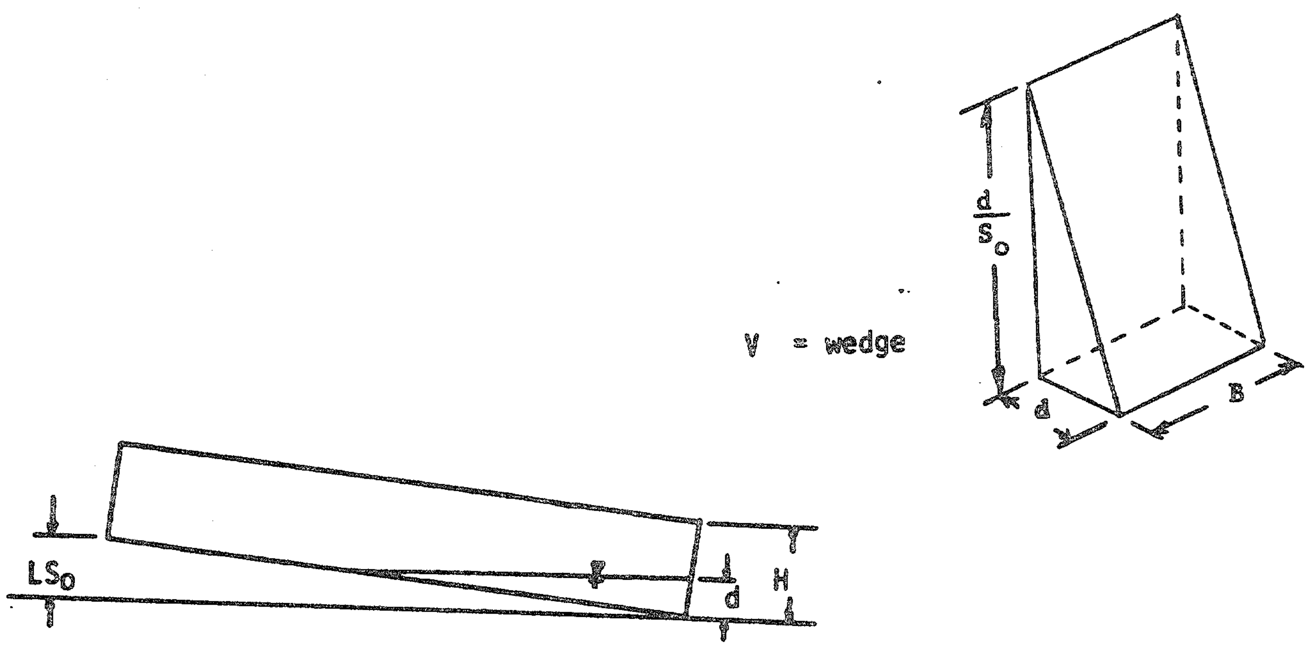


FIGURE 16. Wedge

where the variables are as defined previously. The equation for the volume of such a wedge is:

$$V = \frac{(n \, \Delta H)^2 \, B}{2 \, S_o}$$

With these three equations it is possible to compute the additional volume provided by a box conduit feeding into the pumping station wet well.

Before proceding with a description of the program algorithm for Program Label C, it is necessary to discuss how the three equations presented above are used to compute the volume of water contained in a sloping box conduit. As illustrated in the figure on the next page, there are five cases which describe the problem completely.

- Case number 1 occurs when the depth of water is less than the height of the box and also less than the elevation of the far invert of the box. This volume is computed by a straightforward application of the wedge equation, the third equation presented above.

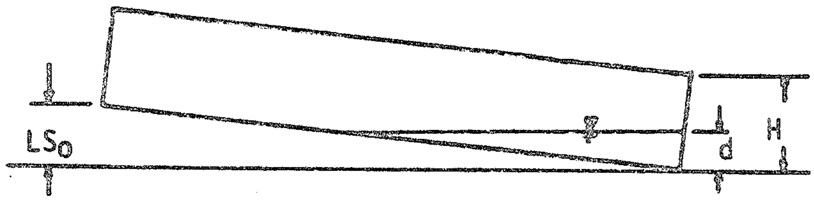
- Case number 2 occurs when the depth of water is less than the height of the box but greater than the elevation of the far invert. This volume is computed by a double application of the wedge equation. First the box is imaginarily extended until the situation is the same as in case one above, i.e., the depth of water is less than the far invert elevation of the box. This volume is then computed by the wedge equation. Second, the volume of water in the "imaginary" extention is computed, again using the wedge equation. This second volume is subtracted from the first, to find the actual volume within the box.

- Case number 3 occurs when the depth of water is greater than the box height and less than the far invert elevation of the box (this case occurs for steep or very long boxes). This volume is computed by a straightforward application of the equation for a truncated rectangular solid, equation two, presented above.

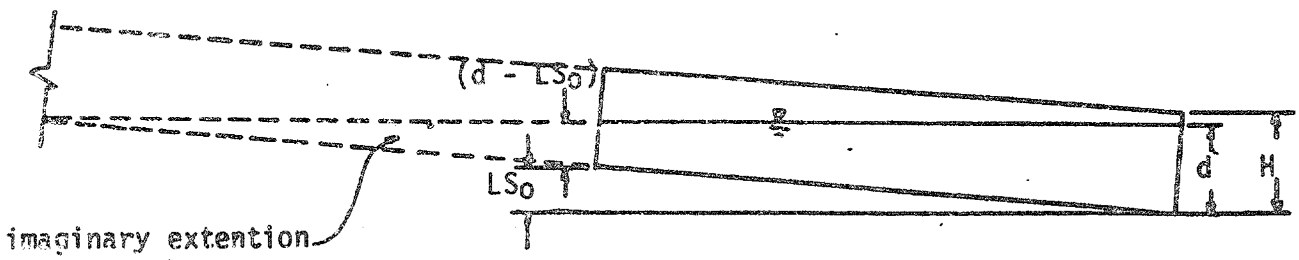
- Case number 4 occurs when the depth of water is greater than the box height, greater than the far invert of the box, but less than the far crown of the box (i.e. the box is not full). In this case the volume of water contained within the box is computed by a combination of two equations. First, the volume of the full box is computed using the first equation presented above. Second, the volume of the "empty wedge" is computed, using the wedge equation. The volume of the "empty wedge" is subtracted from the full box to compute the volume of water actually contained in the box.

FIGURE 17. **Volume in a Sloping Box Conduit**

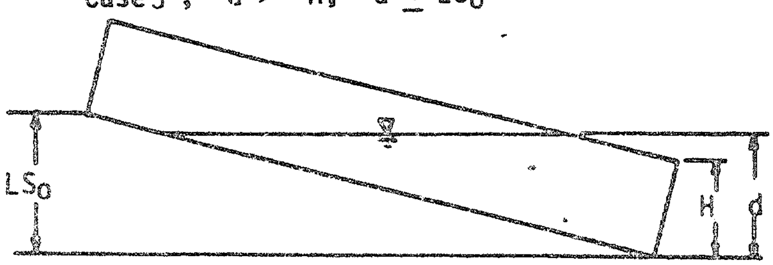
Case 1; $d \leq H$, $d \leq LS_o$

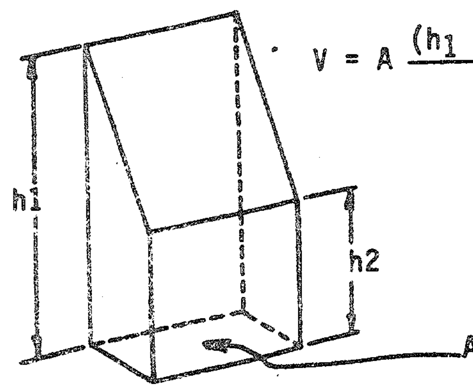


Case 2 ; $d \leq H$, $d > LS_o$



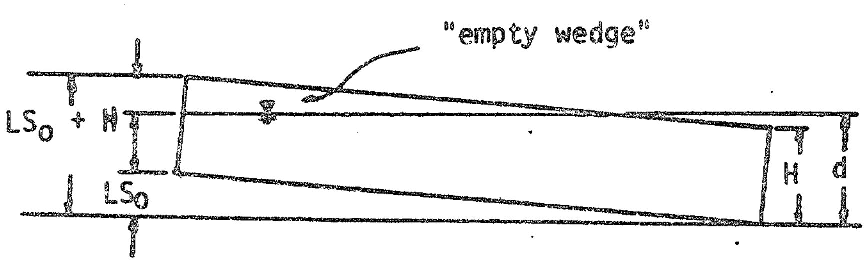
Case 3 ; $d > H$, $d \leq LS_o$



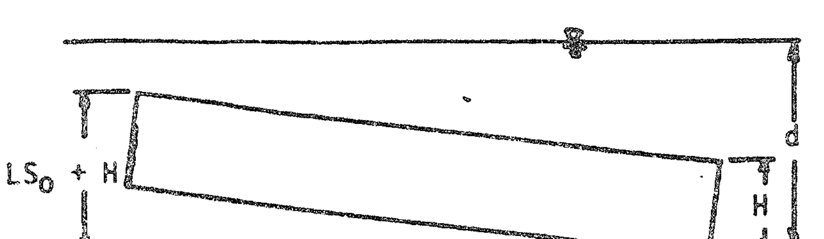


$$V = A\,\frac{(h_1 + h_2)}{2}$$

Case 4 ; $d > H$, $d > LS_o$, $d < LS_o + H$



Case 5; $d > H$, $d > LS_o + H$



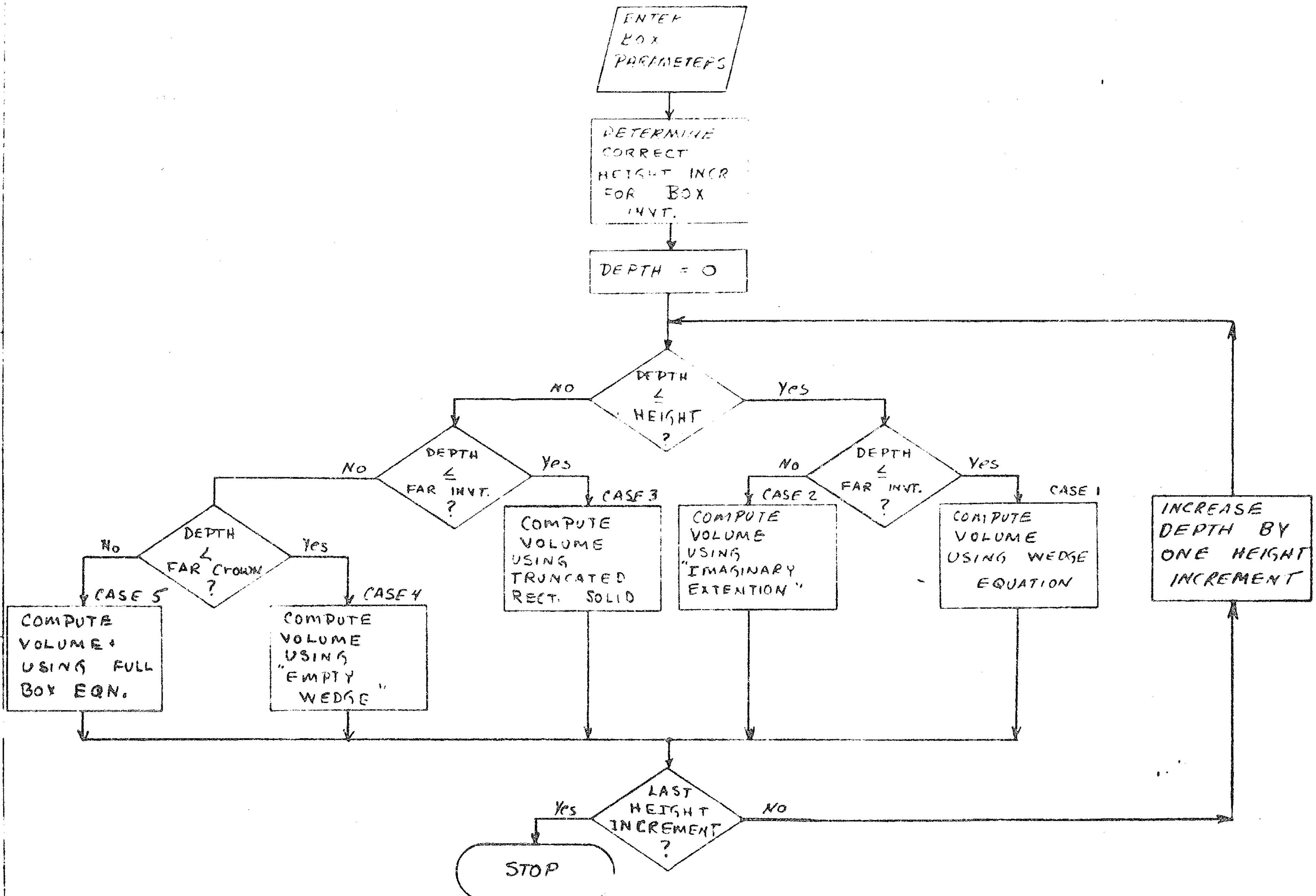
- Case number 5 occurs when the box is full. This occurs when the depth of water is greater than the box height, and also greater than the far crown of the box. This volume is computed by a straightforward application of the first equation presented above for full box conduits.

As illustrated in the flowchart for the algorithm, presented below, much of the program is dedicated to determining what case we are dealing with.

Program Algorithm

The first step in the program is to enter the necessary box conduit parameters, namely box height (H), slope (S_o), box length (L), box width (B), and the downstream invert elevation. Once these five box parameters have been entered, the next step is to determine which height increment the downstream invert elevation corresponds to. This will allow the additional volume provided by the box conduit to be added to the correct portion of the stage-storage relationship. The next step is to determine the additional volume provided by the box for each reservoir height increment above the box invert and to add this to the cumulative stage-storage relationship being developed. This step requires a number of iterations, in order to account for all the reservoir height increments above the downstream invert of the box. For each iteration it is necessary to determine which case applies and consequently which equations to apply.

This complex algorithm is presented in the flowchart on the next page.


ENTER BOX PARAMETERS
DETERMINE CORRECT HEIGHT INCR FOR BOX INVT.
DEPTH = 0
DEPTH ≤ HEIGHT ?
NO
Yes
DEPTH ≤ FAR INVT. ?
No
Yes
CASE 3
COMPUTE VOLUME USING TRUNCATED RECT. SOLID
DEPTH ≤ FAR INVT. ?
No
Yes
CASE 2
COMPUTE VOLUME USING "IMAGINARY EXTENTION"
CASE 1
COMPUTE VOLUME USING WEDGE EQUATION
DEPTH ≤ FAR CROWN ?
No
Yes
CASE 5
COMPUTE VOLUME USING FULL BOX EQN.
CASE 4
COMPUTE VOLUME USING "EMPTY WEDGE"
INCREASE DEPTH BY ONE HEIGHT INCREMENT
LAST HEIGHT INCREMENT ?
Yes
NO
STOP

TI-59 Program Label C

The complete program developed to implement the algorithm presented above is presented in the flowchart on the following pges.

Several of the subroutines used are the same as those used in Program Label B and are repeated here for continuity.

365 — LBL C — LABELS PROGRAM FOR ACCESS FROM KEYBOARD

367 — OP 00 / INV FIX / ADV / 51 STO 0 — CLEARS PRINT REGISTERS, REMOVES FIXED POINT MODE, ADVANCES PAPER TAPE, INITIALIZES Reg. 0 TO 51

376 — SBR 408 — CALLS SUBROUTINE 408 FOR PROMTING MESSAGES AND DATA ENTRY

379 — SBR INV / STO 30 — CALLS SUBROUTINE "INV" TO PRINT "BOX WIDTH" AND STORES IN REG. 30

383 — 53 STO 0 — RESETS REG. 0 TO 53

387 — SBR LNX — CALLS SUBROUTINE "LNX" FOR INVERT HEIGHT COMPUTATIONS

389 — 290 STO 38 / 301 STO 37 / 311 STO 39 — STORES SUBROUTINE ADDRESSES FOR INDIRECT SUBROUTINE INSTRUCTIONS. These Subroutines ARE FOR BOX CONDUIT EQUATIONS

404 — SBR 047 — CALLS MAIN SUBROUTINE 047 FOR STAGE-STORAGE COMPUTATIONS

407 — R/S — STOPS PROCESSING

(SBR 408) 408 — SBR INV / STO 35 — CALLS SUBROUTINE "INV" TO PRINT "BOX HEIGHT" AND STORES IN REG. 35

SBR INV / STO 32 — CALLS SUBROUTINE "INV" TO PRINT "SLOPE" AND STORES IN REG. 32

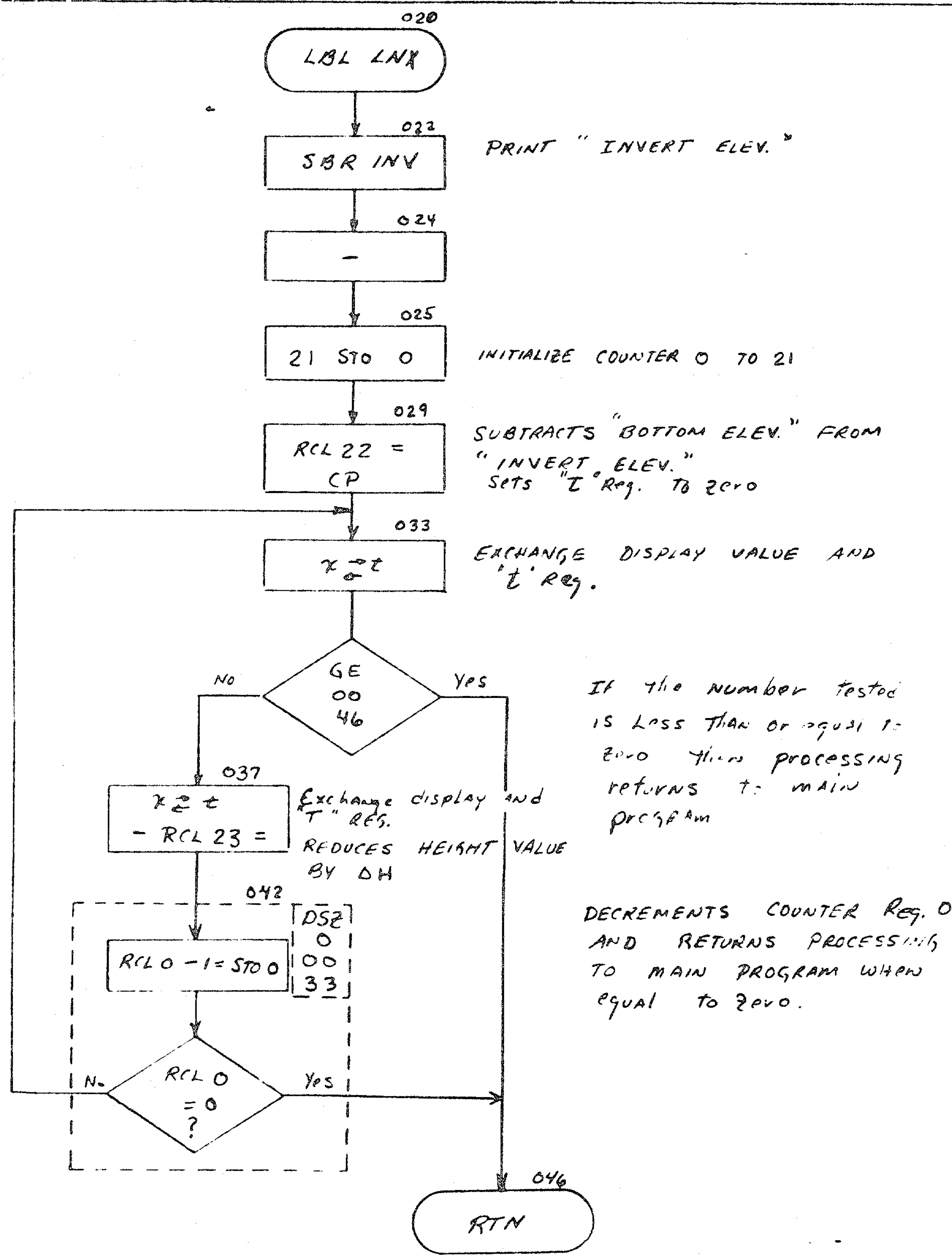
SBR INV / STO 33 — CALLS SUBROUTINE "INV" TO PRINT "BOX LENGTH" AND STORES IN REG. 33

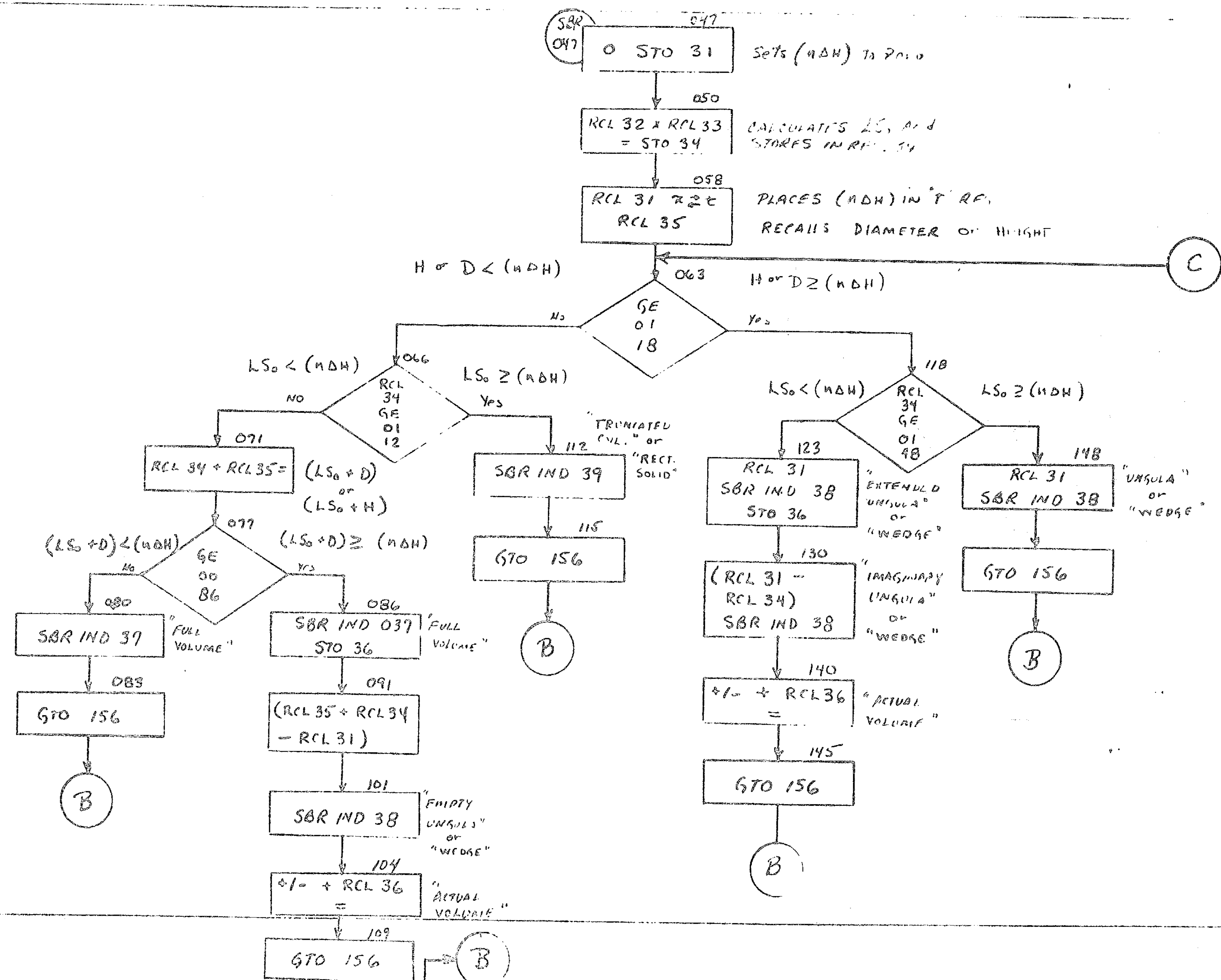
RTN — RETURNS PROCESSING TO MAIN PROGRAM

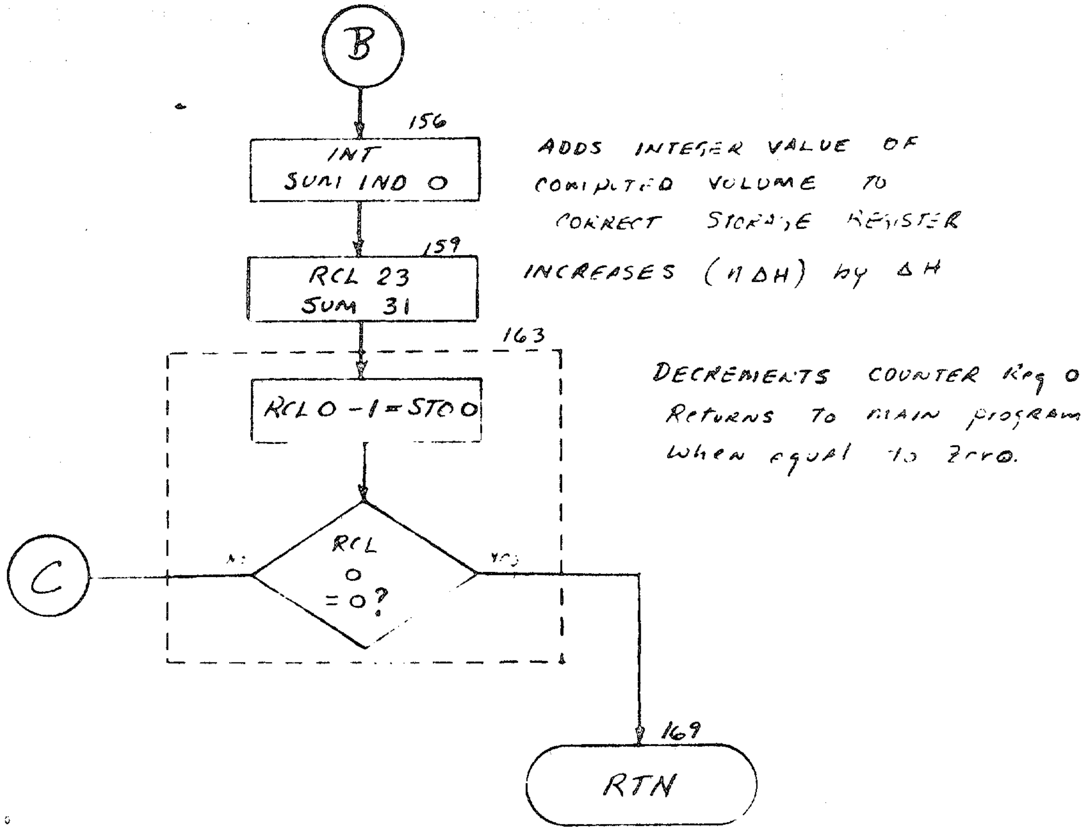
000 — LBL INV — LABELS SUBROUTINE FOR ACCESS

002 — RCL IND 0 / OP 1 OP 30 / RCL IND 0 / OP 2 OP 30 / OP 5 0 R/S — PRINTS ALPHA-NUMERIC MESSAGE AND WAITS FOR DATA ENTRY

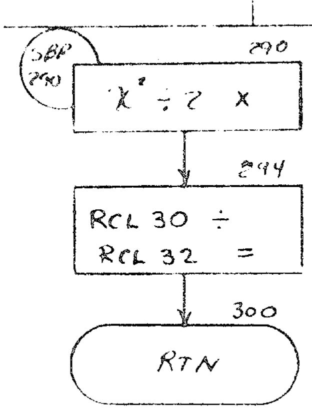
018 — PRT RTN — PRINTS DATA ENTERED AND RETURNS TO CALLING PROGRAM


020
LBL LNX
022
SBR INV
PRINT "INVERT ELEV."
024
-
025
21 STO 0
INITIALIZE COUNTER 0 TO 21
029
RCL 22 =
CP
SUBTRACTS "BOTTOM ELEV." FROM "INVERT ELEV."
SETS "T" Reg. TO zero
033
x ⇄ t
EXCHANGE DISPLAY VALUE AND 't' Reg.
GE
00
46
No
Yes
If the number tested is Less than or equal to zero then processing returns to main program
037
x ⇄ t
- RCL 23 =
Exchange display and "T" REG.
REDUCES HEIGHT VALUE BY ΔH
042
DSZ
0
00
33
RCL 0 - 1 = STO 0
RCL 0
= 0
?
No
Yes
DECREMENTS COUNTER Reg. 0 AND RETURNS PROCESSING TO MAIN PROGRAM WHEN equal to zero.
046
RTN


SBR 047
047
0 STO 31
Sets (nΔH) to Zero
050
RCL 32 x RCL 33 = STO 34
CALCULATES LS, and STORES IN RE. 34
058
RCL 31 x≷t RCL 35
PLACES (nΔH) IN 't' RE.
RECALLS DIAMETER or HEIGHT
C
H or D < (nΔH)
H or D ≥ (nΔH)
063
GE 01 18
No
Yes
066
RCL 34 GE 01 12
LS₀ < (nΔH)
LS₀ ≥ (nΔH)
NO
Yes
071
RCL 34 + RCL 35 =
(LS₀ + D) or (LS₀ + H)
077
GE 00 86
(LS₀ + D) < (nΔH)
(LS₀ + D) ≥ (nΔH)
No
Yes
080
SBR IND 37
"FULL VOLUME"
083
GTO 156
B
086
SBR IND 037 STO 36
"FULL VOLUME"
091
(RCL 35 + RCL 34 − RCL 31)
101
SBR IND 38
"EMPTY UNGULA" or "WEDGE"
104
+/- + RCL 36 =
"ACTUAL VOLUME"
109
GTO 156
B
112
SBR IND 39
"TRUNCATED CYL." or "RECT. SOLID"
115
GTO 156
B
118
RCL 34 GE 01 48
LS₀ < (nΔH)
LS₀ ≥ (nΔH)
123
RCL 31 SBR IND 38 STO 36
"EXTENDED UNGULA" or "WEDGE"
130
(RCL 31 − RCL 34) SBR IND 38
"IMAGINARY UNGULA" or "WEDGE"
140
+/- + RCL 36 =
"ACTUAL VOLUME"
145
GTO 156
B
148
RCL 31 SBR IND 38
"UNGULA" or "WEDGE"
GTO 156
B

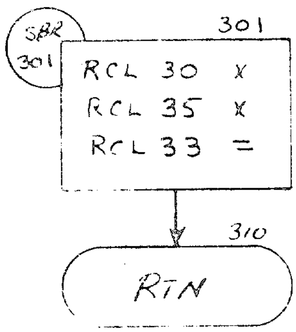


B
156
INT
SUM IND 0
ADDS INTEGER VALUE OF COMPUTED VOLUME TO CORRECT STORAGE REGISTER
159
RCL 23
SUM 31
INCREASES (n ΔH) by ΔH
163
RCL 0 - 1 = STO 0
DECREMENTS COUNTER Reg 0
Returns To MAIN program when equal to zero.
RCL
0
= 0?
C
169
RTN



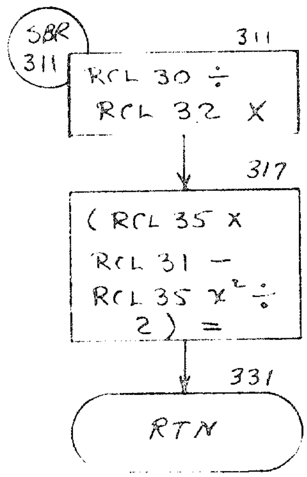
CALCULATES WEDGE VOLUME:

$$\frac{(n\Delta H)^2}{2}\frac{B}{S_0}$$



CALCULATES FULL BOX VOLUME:

$$B \times H \times L$$



CALCULATES TRUNCATED RECTANGULAR [illegible] VOLUME:

$$\frac{B}{S_0}\left[H(n\Delta H) - \frac{H^2}{2}\right]$$

Program Set 3

Program set three contains two programs. These are Program Label D and Program Label E'. Program Label D is used to enter the various pump parameters and Program Label E' is used to list the stage-storage relationship stored in the calculator's memory. Program Label D combines the pump on/off information with the stage-storage relationship, developed previously. Program Label E' allows the user to check the pump on/off information. Program Label E' has been described in the discussion of program set one.

Program Label D

As described in prevous sections, Program Label D is used to enter the pump parameters: on elevation, off elevation, and pumping rate. Program Label D can handle a maximum of six pumps.

Equations

This program is straightforward and there are no equations used within the program which require explanation.

Program Algorithm

This program takes the pump parameters entered and stores this information in the calculators memory in such a way that it can be used by the next program, Program Label E which routes a hydrograph through the pumping station. For each pump, Program Label D must store three pieces of information: the on elevation of the pump, the off elevation of the pump, and the pumping rate for the pump. Because of the limitations on the number of data registers available in the calculator, this information must be stored in a condensed form. The method selected for condensing this information is to combine the pump on/off information in the same data registers as those used to store the stage-storage relationship. The "on" information is stored in the tenths digit of the number stored in the data register, and the "off" information is stored in the hundreths digit of the number stored in the data register.

The value of the number stored in these digits indicates how many pumps the on/off information applies to. This is illustrated on the next page.

The contents of data registers 21 through 1 are listed below, after Program Label D has been used to enter the pump parameters for two pumps.

Data Register#	Value Stored	#Pump On	#Pump Off
21	0.00	-	Both
20	594.01	-	2
19	1794.01	-	2
18	3576.01	-	2
17	5518.01	-	2
16	7460.12	1	-
15	9402.12	1	-
14	11,344.12	1	-
13	13,286.12	1	-
12	15,235.12	1	-
11	16,959.12	1	-
10	18,108.22	2	-
9	18,689.22	2	-
8	19,076.22	2	-
7	19,463.22	2	-
6	19,851.22	2	-
5	20.238.22	2	-
4	20,625.22	2	-
3	21,012.22	2	-
2	21,397.22	2	-
1	21,765.22	2	-

The following information has been encoded into the numbers stored in the data registers.

Pump number 1 turns on when the storage in the pumping station reservoir is greater than or equal to 7460 cubic feet.

Pump number 2 turns on when the storage in the pumping station reservoir is greater than or equal to 18,108 cubic feet.

Pump number 2 turns off when the storage in the pumping station reservoir falls below 5,518 cubic feet.

Pump number 1 turns off when the storage in the pumping station reservoir falls below 594 cubic feet.

The way in which the program decides which value of storage corresponds to the "on" or "off" elevation entered by the user is described below.

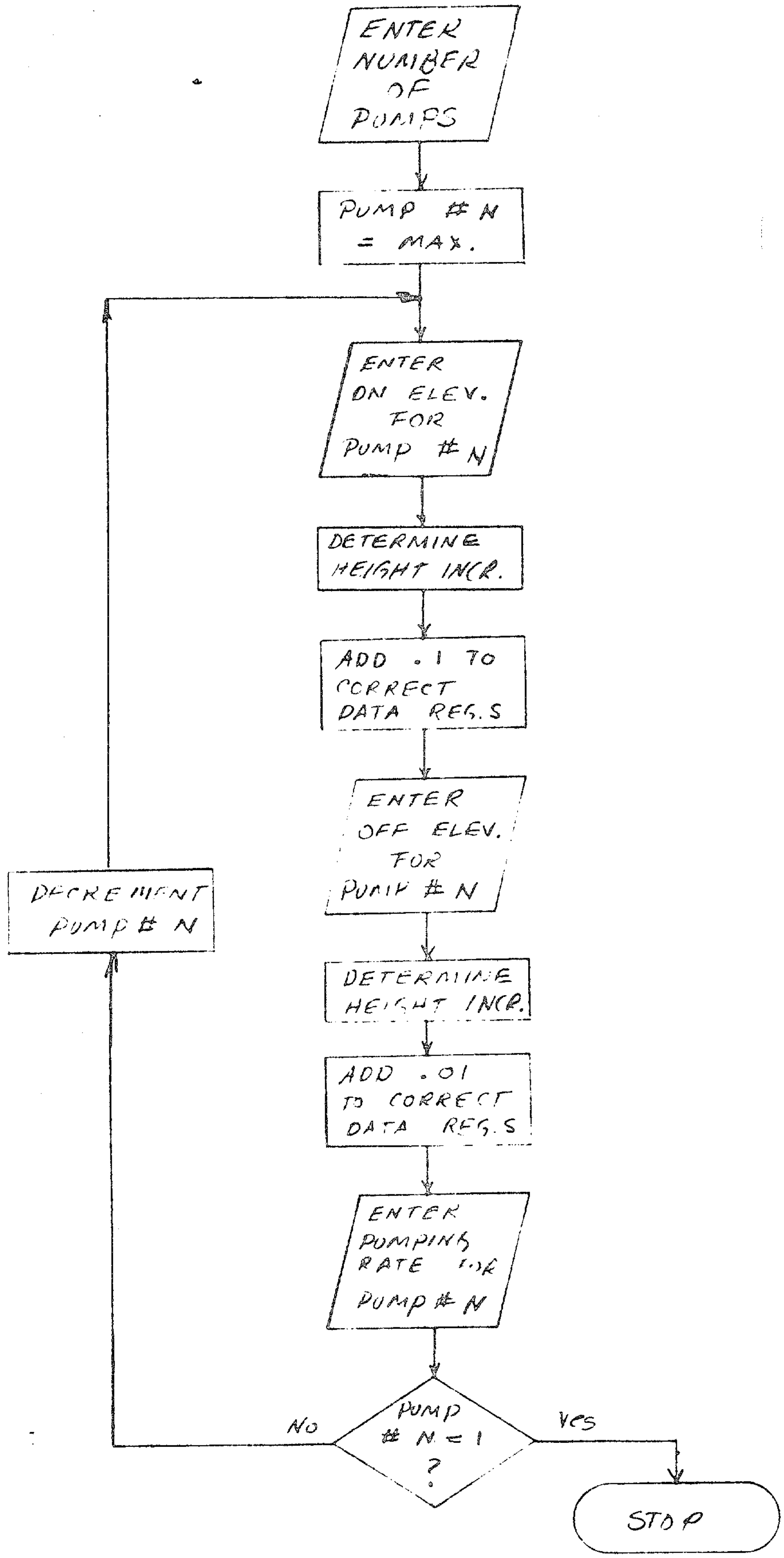
For each elevation entered, the program subtracts the bottom elevation of the reservoir and divides the result by the value of the reservoir height increment. This value is then rounded to the nearest whole number. The result is the height increment which correspond to the elevation entered. The program then decides which data register corresponds to that height increment. A value of .1 or .01 is added to that data register and all data registers below it. A .1 or .01 will be added depending upon whether the elevation entered was to specify the "on" or "off" respectively. This process is repeated until all the pumps have been accounted for, up to a maximum of six pumps.

The pumping rates for each pump are stored in dedicated data registers as listed below:

Pump #	Data Register #
1	24
2	25
3	26
4	27
5	28
6	29

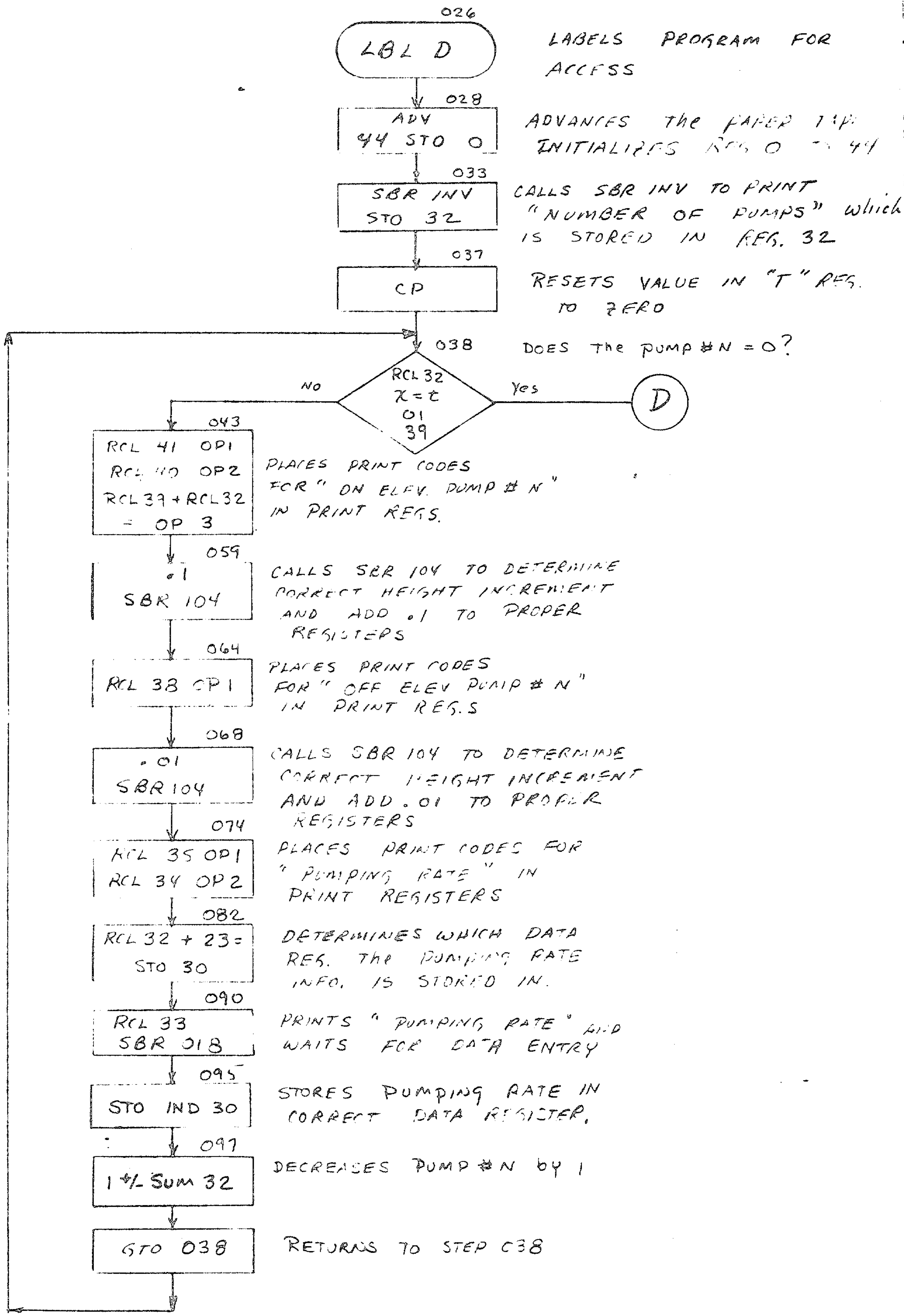
Once the parameters for all the pumps have been entered the program is finished.

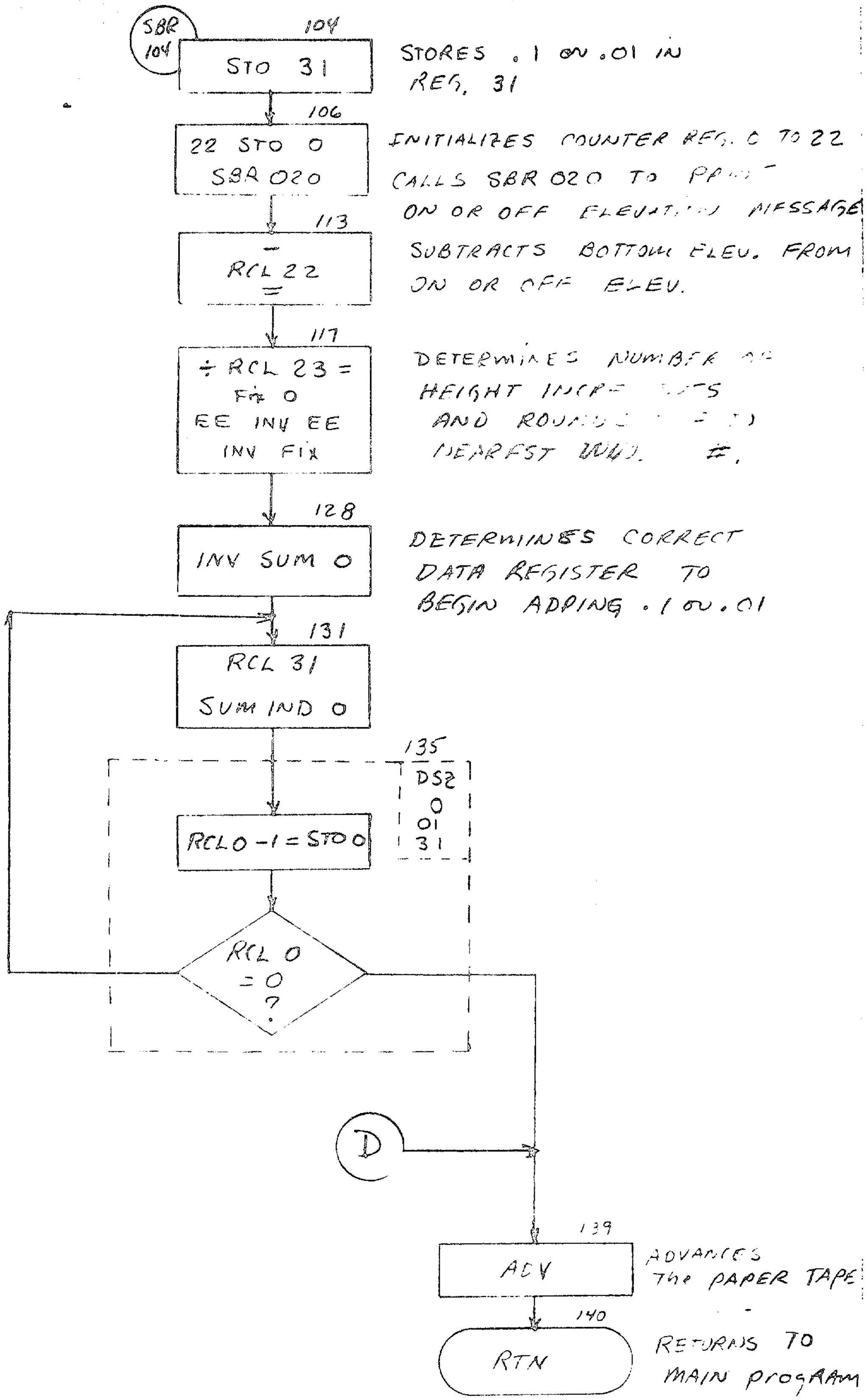
This sequence of operations is illustrated in the flowchart of the program algorithm presented on the next page.

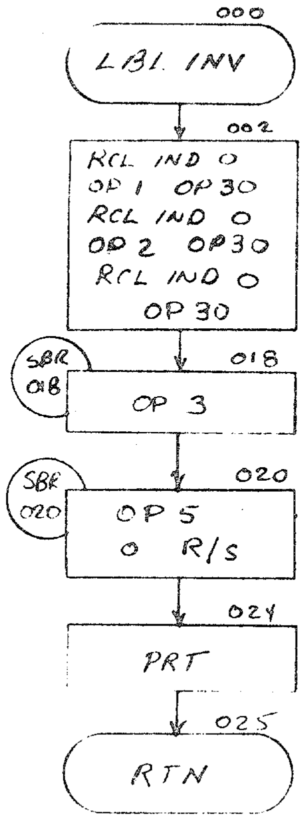

ENTER NUMBER OF PUMPS
PUMP # N = MAX.
ENTER ON ELEV. FOR PUMP # N
DETERMINE HEIGHT INCR.
ADD .1 TO CORRECT DATA REG.S
ENTER OFF ELEV. FOR PUMP # N
DETERMINE HEIGHT INCR.
ADD .01 TO CORRECT DATA REG.S
ENTER PUMPING RATE FOR PUMP # N
PUMP # N = 1 ?
No
Yes
DECREMENT PUMP # N
STOP

TI-59 Program Label D

The program developed for the TI-59 calculator to implement the algorithm is presented on the following pages.


026
LBL D
LABELS PROGRAM FOR ACCESS
028
ADV
44 STO 0
ADVANCES THE PAPER TAPE
INITIALIZES REG. 0 TO 44
033
SBR INV
STO 32
CALLS SBR INV TO PRINT "NUMBER OF PUMPS" which IS STORED IN REG. 32
037
CP
RESETS VALUE IN "T" REG. TO ZERO
038
DOES THE PUMP # N = 0?
RCL 32
x = t
01
39
No
Yes
D
043
RCL 41 OP1
RCL 40 OP2
RCL 39 + RCL 32
= OP 3
PLACES PRINT CODES FOR " ON ELEV. PUMP # N " IN PRINT REGS.
059
.1
SBR 104
CALLS SBR 104 TO DETERMINE CORRECT HEIGHT INCREMENT AND ADD .1 TO PROPER REGISTERS
064
RCL 38 OP1
PLACES PRINT CODES FOR " OFF ELEV PUMP # N " IN PRINT REGS.
068
.01
SBR 104
CALLS SBR 104 TO DETERMINE CORRECT HEIGHT INCREMENT AND ADD .01 TO PROPER REGISTERS
074
RCL 35 OP1
RCL 34 OP2
PLACES PRINT CODES FOR " PUMPING RATE " IN PRINT REGISTERS
082
RCL 32 + 23 =
STO 30
DETERMINES WHICH DATA REG. THE PUMPING RATE INFO. IS STORED IN.
090
RCL 33
SBR 018
PRINTS " PUMPING RATE " AND WAITS FOR DATA ENTRY
095
STO IND 30
STORES PUMPING RATE IN CORRECT DATA REGISTER.
097
1 +/- SUM 32
DECREASES PUMP # N BY 1
GTO 038
RETURNS TO STEP 038


SBR 104
104
STO 31
STORES .1 or .01 IN REG. 31
106
22 STO 0
SBR 020
INITIALIZES COUNTER REG. 0 TO 22
CALLS SBR 020 TO
ON OR OFF
113
−
RCL 22
=
SUBTRACTS BOTTOM ELEV. FROM ON OR OFF ELEV.
117
÷ RCL 23 =
Fix 0
EE INV EE
INV FIX
DETERMINES NUMBER
HEIGHT
AND
NEAREST
128
INV SUM 0
DETERMINES CORRECT DATA REGISTER TO BEGIN ADDING .1 or .01
131
RCL 31
SUM IND 0
135
DSZ
0
01
31
RCL 0 − 1 = STO 0
RCL 0
= 0
?
D
139
ADV
ADVANCES The PAPER TAPE
140
RTN
RETURNS TO MAIN program



TRANSFERS PRINT CODES FROM DATA REGISTERS TO PRINT REGISTERS.

TRANSFERS VALUE IN X REGISTER TO PRINT REG. 3

PRINTS CONTENTS OF PRINT REGISTERS, PLACES ZERO IN DISPLAY AND HALTS

PRINTS VALUE OF X REG.

RETURNS TO CALLING PROGRAM

Program Label E

The only program contained in program set four is Program Label E. As discussed in previous section Program Label E is used to route an inflow hydrograph through the pumping station and to calculate the values of storage (S), water surface elevation (W), and outflow (O) as the hydrograph is routed through the pumping station.

Equations

The equation used to route the inflow hydrograph is derived from the basic storage equation. This equation states that the change in storage within the pumping station reservoir is equal to the average inflow minus the average outflow times the time increment, as in the equation:

$$\Delta S = (\bar{I} - \bar{O})\, \Delta T$$

The average inflow, $\bar{I}$, is calculated by averaging the current value of inflow, $I_{(\Sigma T)}$, and the previous value of inflow, $I_{(\Sigma T - T.I.)}$ or

$$\bar{I} = \frac{I_{(\Sigma T)} + I_{(\Sigma T - T.I.)}}{2}$$

The average outflow, $\bar{O}$, is normally calculated by the equation

$$\bar{O} = \frac{O_1 + O_2}{2}$$

where O_1 is the initial value of the outflow and O_2 is the final value of outflow, for the time increment, ΔT. The value of O_2 will depend upon whether any pumps turns on or off during the time increment. This is illustrated in the figure on the next page.

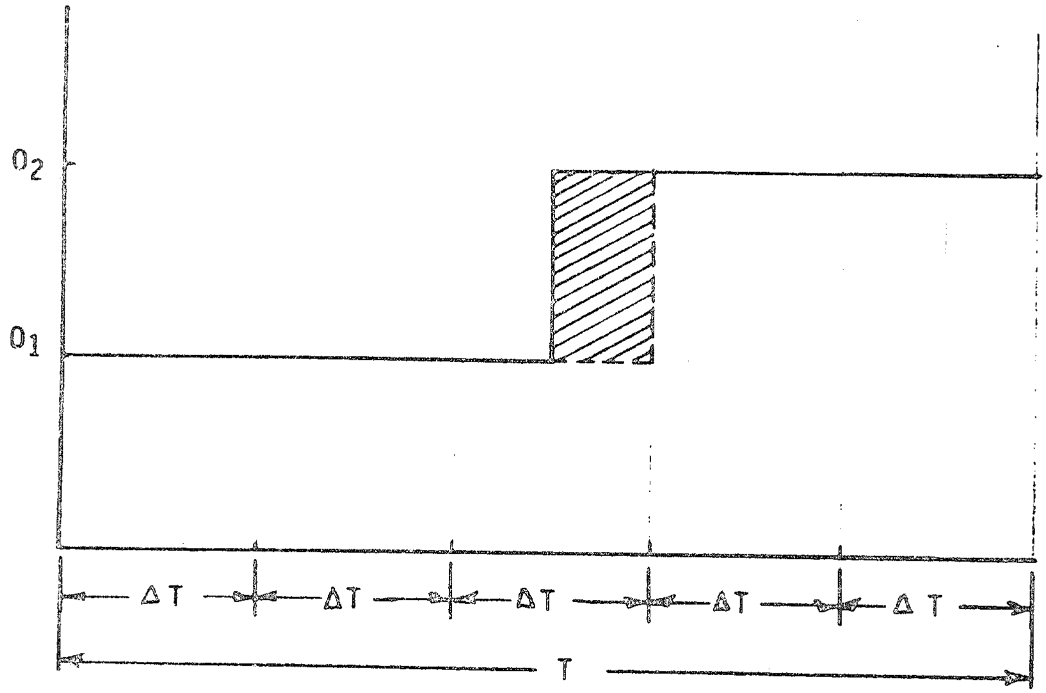


FIGURE 18. Error Introduced by Approximation of Average Outflow

If the average outflow, $\overline{O}$, for a given time increment T is assumed to be the initial value of outflow, O_1, then the error introduced by such an assumption is equal to the shaded area in the figure above. If ΔT is selected small enough the relative error, relative to the total outflow during time T, introduced by this assumption is small. This assumption can lead to a maximum error of, $(O_2 - O_1)\ \Delta T$. Where $(O_2 - O_1)$ is the difference between two sequential pumping rates and T is the time increment.

This assumption is used in the calculator program Label E. The value of time increment has been predetermined to be 1 minute (60 seconds). The equation for calculating the change in storage for a 1 minute time increment is then:

$$\Delta S = (\overline{I} - O_1)\ 60$$

where ΔS is the change in storage in cubic feet.

$\overline{I}$ is the average inflow in cfs.

O_1 is the initial outflow in cfs.

This is the equation used in the calculator Program Label E to determine the change in storage for a 1 minute time increment.

Program Algorithm

This program routes an inflow hydrograph through the pumping station. All of the pumping station parameters have been computed by previous application of Programs Label A through D. The algorithm used to perform this routing is detailed below. It will be helpful to follow the description by tracing the operations described on the flowchart. This will aid in understanding the complex interrelationship of operations.

The inflow hydrograph is defined by successive inflow values corresponding to successive values of equal time intervals. The first step in this algorithm is to enter the value of the time interval (T.I.) used to define the inflow hydrograph. This is used in the program to keep track of the number of iterations required for storage calculations and to prompt the user that the next inflow value is needed.

The next step in the algorithm is to initialize the program variables of ΣT, $\Sigma\Delta S$, O_1, and $I_{(\Sigma T\ -\ T.I.)}$. These variables are defined below:

ΣT is the current value of elapsed time. This is determined by adding one time interval (T.I.) for each sequential inflow hydrograph value.

$\Sigma\Delta S$ is the current value of storage used in the pumping station reservoir.

O_1 is the initial outflow value for a given time increment.

$I_{(\Sigma T\ -\ T.I.)}$ is the inflow value for the previous time interval, used in the calculation of the average inflow.

Once these program variables have been intialized the value of T is printed.

The initial inflow value corresponding to time equal to zero is then entered.

In order to keep track of the iterations a counting variable ($\Sigma\Delta T$) is defined and initialized with a value of one.

For the first time interval, the average inflow, $\bar{I}$, is computed.

Using the average inflow and the initial outflow the change in storage for the first 1 minute increment is computed.

This is summed to determine the cumulative value of storage in the reservoir.

The value of the counting variable, $\Sigma\Delta T$, is tested to see if it is equal to the value of the time interval entered in the first step. If it is then the current value of the cumulative storage is printed.

The next step tests the cumulative storage against the maximum storage available in the reservoir. If the cumulative storage computed is greater than the maximum storage available, then the message, "BASIN EXCEEDED" is printed and the program stops. If the cumulative storage is less than the maximum the program proceeds to the next step.

The next step is to compute the water surface elevation corresponding to the cumulative storage computed above.

The counting variable, $\Sigma\Delta T$, is tested again and if it is equal to the value of the time interval then the value of water surface elevation computed above is printed.

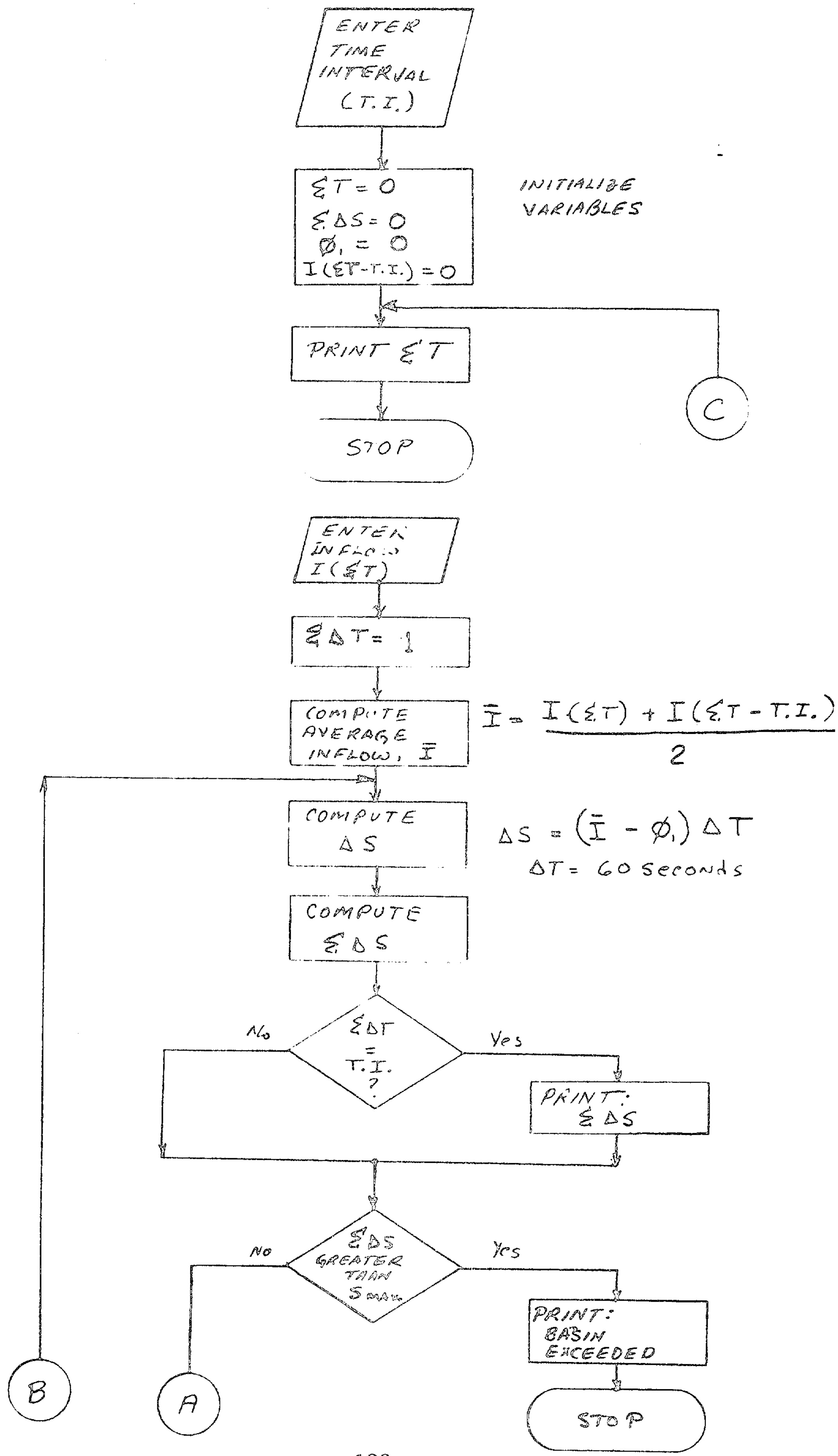
The next step is to determine which pumps are on. The cumulative storage computed above is checked against the stage-storage pump relationship in the calculator memory to determine which pumps are on.

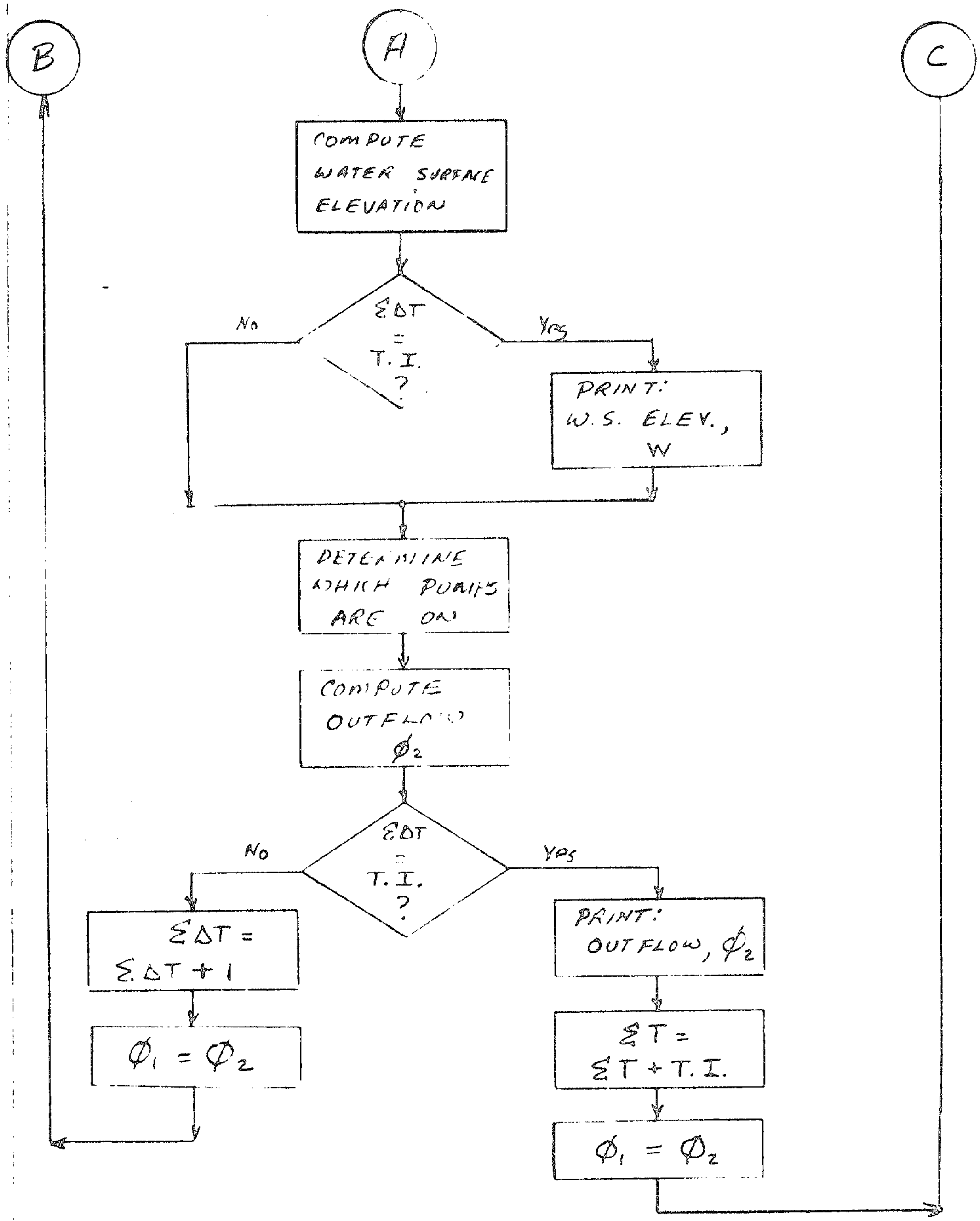
The outflow value is then determined by adding the pumping rates for all pumps which are on.

The counting variable $\Sigma\Delta T$ is again tested. If it is equal to the value of the time interval, the outflow computed in the step above is printed. The current value of elapsed time is then increased by one time interval and the initial outflow value is replace by the value for outflow computed above. The program then returns to the step where the current value of time elapsed is printed (point C on the algorithm flowchart). The new value of the elapsed time is printed and the program stops, waiting for the next value of inflow to be entered.

If the counting variable is not equal to the time interval then the program increases the value of the counting variable by one. The initial outflow value is replace by the value of outflow computed above and the program returns to recompute the change in storage (point B on the algorithm flowchart). The storage and associated parameters of water surface elevation and outflow are recomputed for another 1 minute time increment. These steps are reiterated until the counting variable $\Sigma\Delta T$ is equal to the time interval T.I., as described in the paragraph above.

The computations described above are shown on the algorithm flowchart presented on the following pages.


ENTER TIME INTERVAL (T.I.)
ΣT = 0
ΣΔS = 0
Ø₁ = 0
I(ΣT-T.I.) = 0
INITIALIZE VARIABLES
PRINT ΣT
STOP
C
ENTER INFLOW I(ΣT)
ΣΔT = 1
COMPUTE AVERAGE INFLOW, Ī
Ī = (I(ΣT) + I(ΣT - T.I.)) / 2
COMPUTE ΔS
ΔS = (Ī - Ø₁) ΔT
ΔT = 60 seconds
COMPUTE ΣΔS
ΣΔT = T.I.?
No
Yes
PRINT: ΣΔS
ΣΔS GREATER THAN Smax
No
Yes
PRINT: BASIN EXCEEDED
STOP
B
A


B
A
C
COMPUTE WATER SURFACE ELEVATION
ΣΔT = T.I. ?
No
Yes
PRINT: W.S. ELEV., W
DETERMINE WHICH PUMPS ARE ON
COMPUTE OUTFLOW Ø2
ΣΔT = T.I. ?
No
Yes
ΣΔT = ΣΔT + 1
Ø1 = Ø2
PRINT: OUTFLOW, Ø2
ΣT = ΣT + T.I.
Ø1 = Ø2

TI-59 Program Label E

The TI-59 program developed to implement the algorithm described above is detailed in the following paragraphs.

The first step in the the algorithm is implemented by program steps 0 through 048.

Steps 049 through 172 print messages which identify the labels used in the program output and also print the message "0.00 = T", which prompts the user to enter the inflow hydrograph value associated with time equal to zero.

Steps 173 through 183 calculate the average inflow I.

The way in which this program tests the counting variable $\Sigma\Delta T$ is to set flag number 7 initially and then to reset flag number 7 when the counting variable $\Sigma\Delta T$ is equal to the time interval. The counting variable is tested by checking the status of flag number 7. If it is set, then the counting variable, $\Sigma\Delta T$, is not equal to the time interval and processing continues via the left path indicated on the flowchart of the program. If flag number 7 is reset then the counting variable, $\Sigma\Delta T$, is equal to the time interval and processing proceeds via the path on the right of the flowchart.

Program steps 184 through 200 test the value of the counting variable, $\Sigma\Delta T$, which is stored in register 31 and sets or resets flag number 7, as appropriate.

Program steps 201 through 220 compute the incremental change in storage for a 1 minute time increment and also compute the value of cumulative storage in the reservoir.

Program steps 221 through 232 ensure that negative values of storage are not allowed. These might be computed when the outflow is greater than the inflow.

Program steps 233 through 238 test the status of flag number 7 and print the value of the cumulative storage computed above if flag 7 is reset.

Program steps 239 through 306 perform the combined functions of determining the water surface elevation corresponding to the cumulative storage computed above, and also testing to see if the cumulative storage is greater than the maximum available in the reservoir. If the cumulative storage is greater than the maximum available then the message, "BASIN EXCEEDED" is printed and processing stops. The water surface elevation is computed by interpolating between the reservoir height increments which bracket the storage value computed above.

Program steps 307 through 312 test the status of flag number 7 and print the value of the water surface elevation computed above if the flag is reset.

Program steps 313 through 373 determine which pumps are on. Program steps 313 through 342 set flags numbers 1 through 6, depending upon the value of the tenths digit of the number stored in the data register corresponding to the cumulative storage value. Program steps 343 through 373 reset flags numbers 1 through 6, depending upon the value of the hundreths digit of the number stored in the data register corresponding to the cumulative storage value.

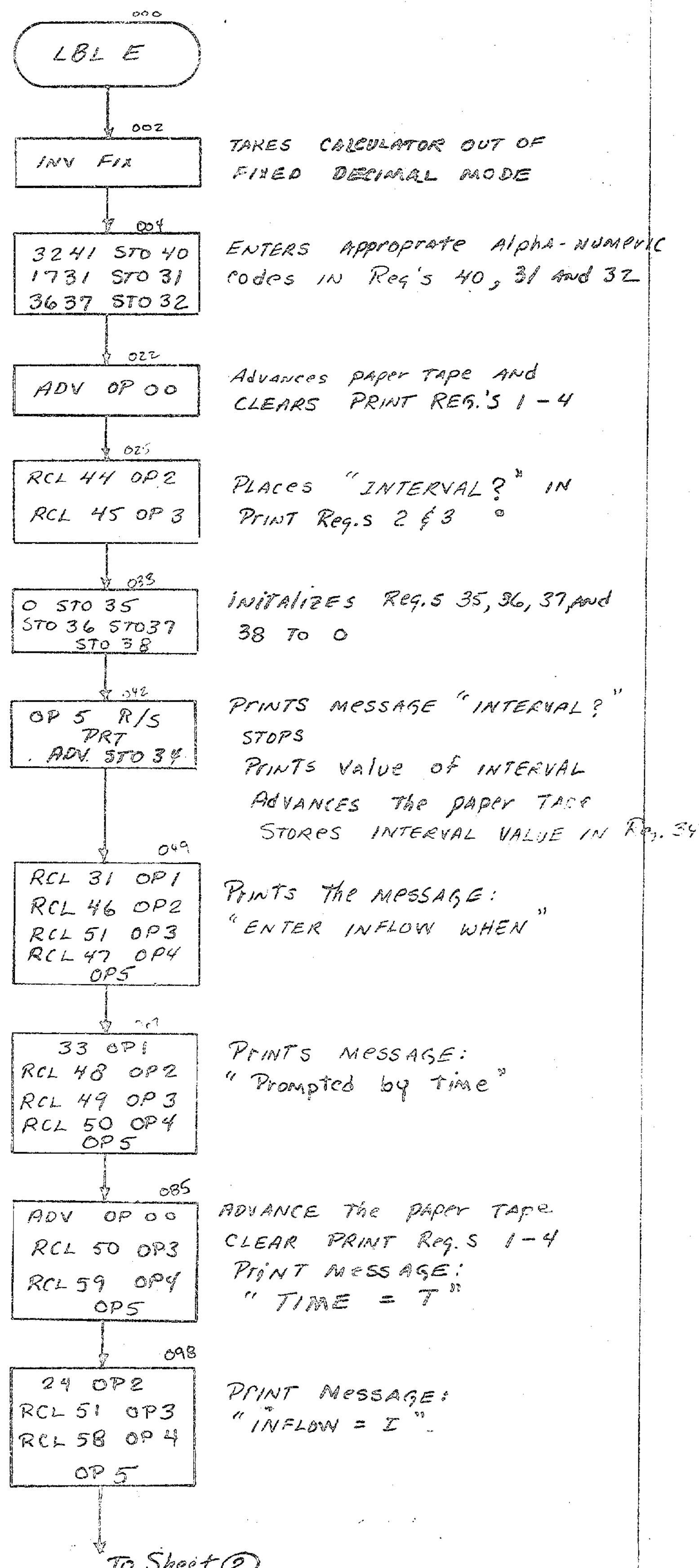
Program steps 374 through 406 determine the outflow rate adding up the pumping rates for any pumps which are on.

Steps 407 through 410 tests the status of flag number 7. If flag number 7 is set then the counter variable, $\Sigma\Delta T$, is incremented by one and processing returns to step 189.

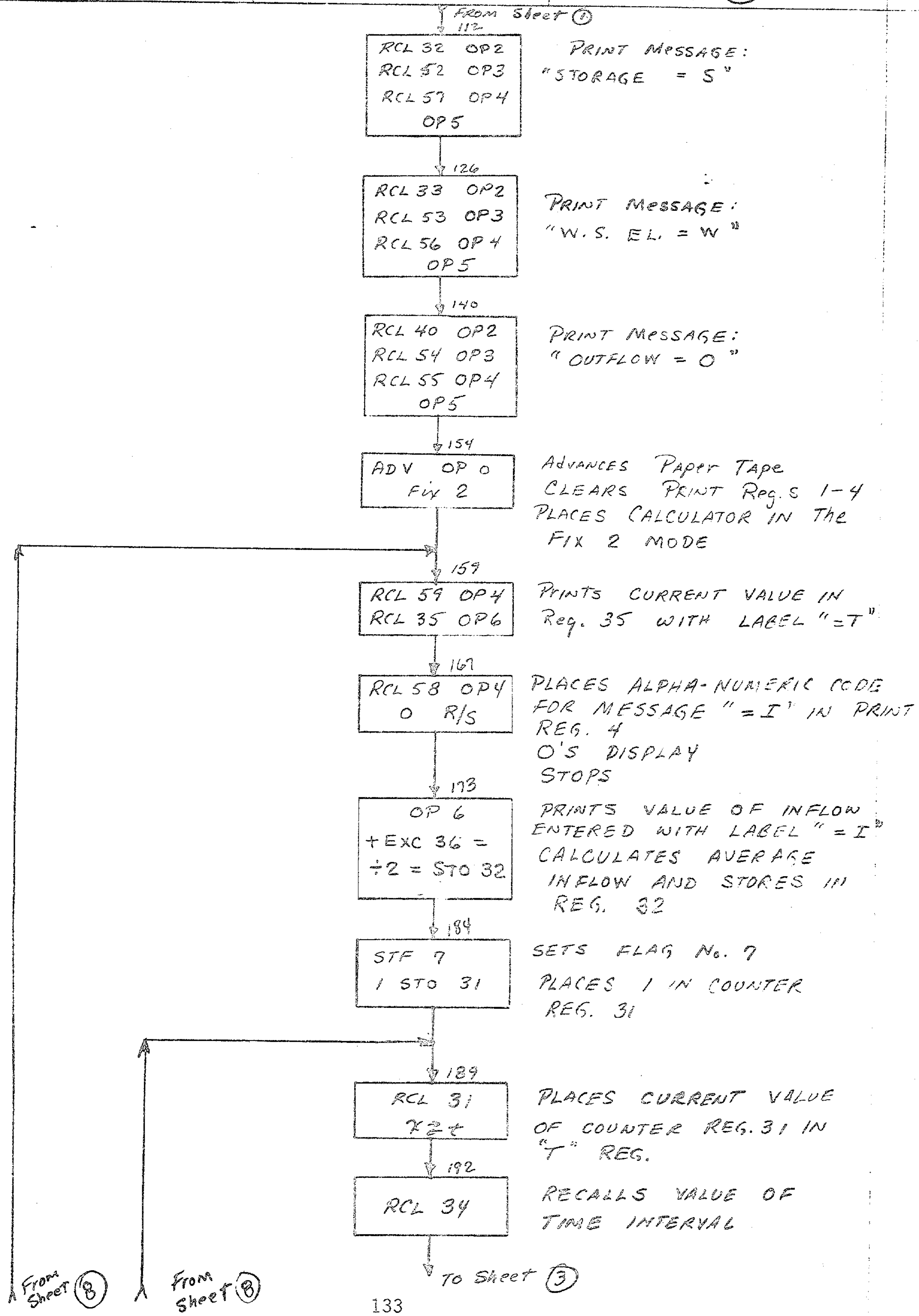
If flag number 7 is reset then the outflow value computed above is printed, the elapsed time, ΣT, is increased by T.I. and processing returns to step 159.

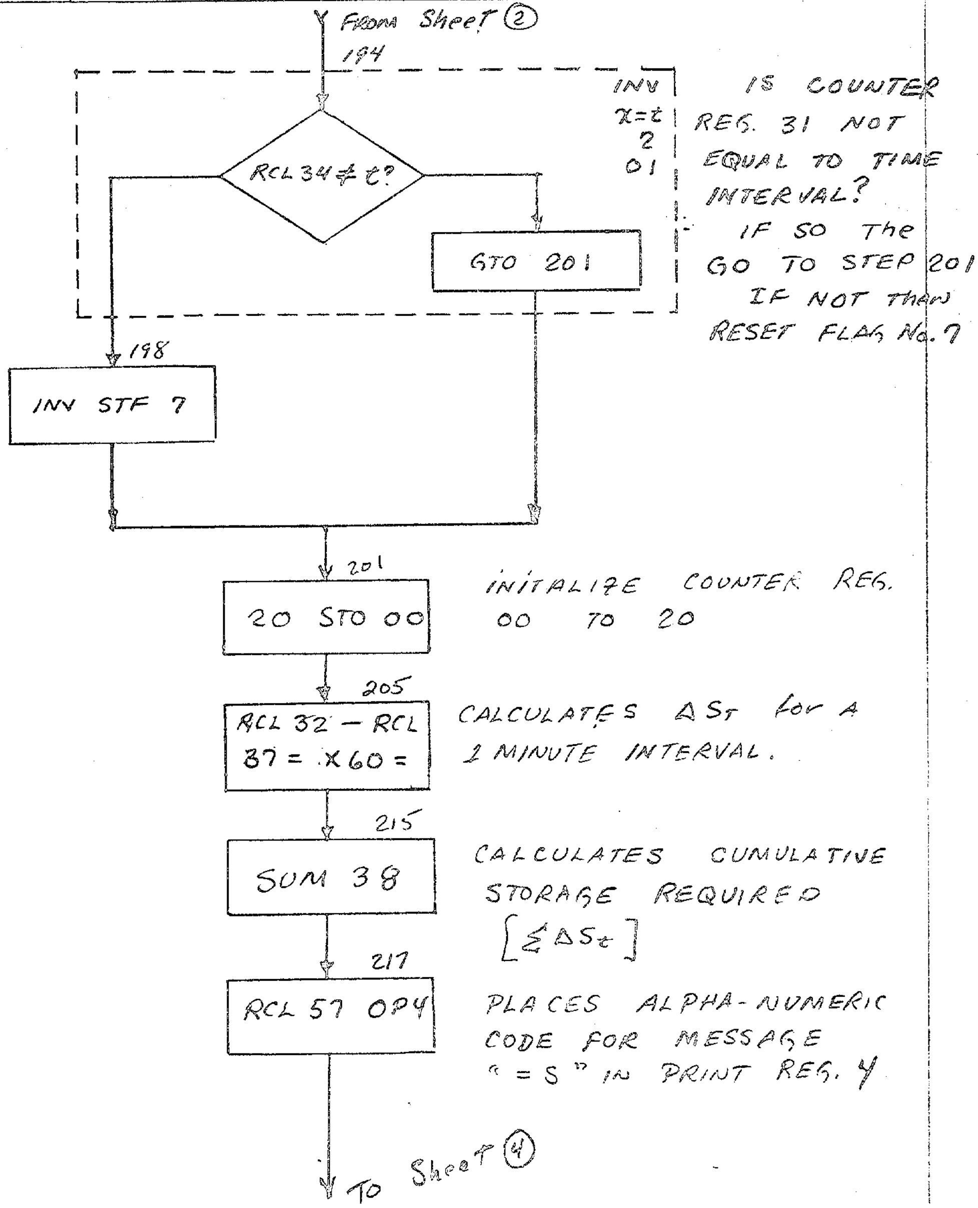
The flowchart presented on the next page details the TI-59 Program Label E described above.

PROGRAM # 3 | [STORAGE - ROUTING PROGRAM] | SHEET (1)
PUMPING STATION

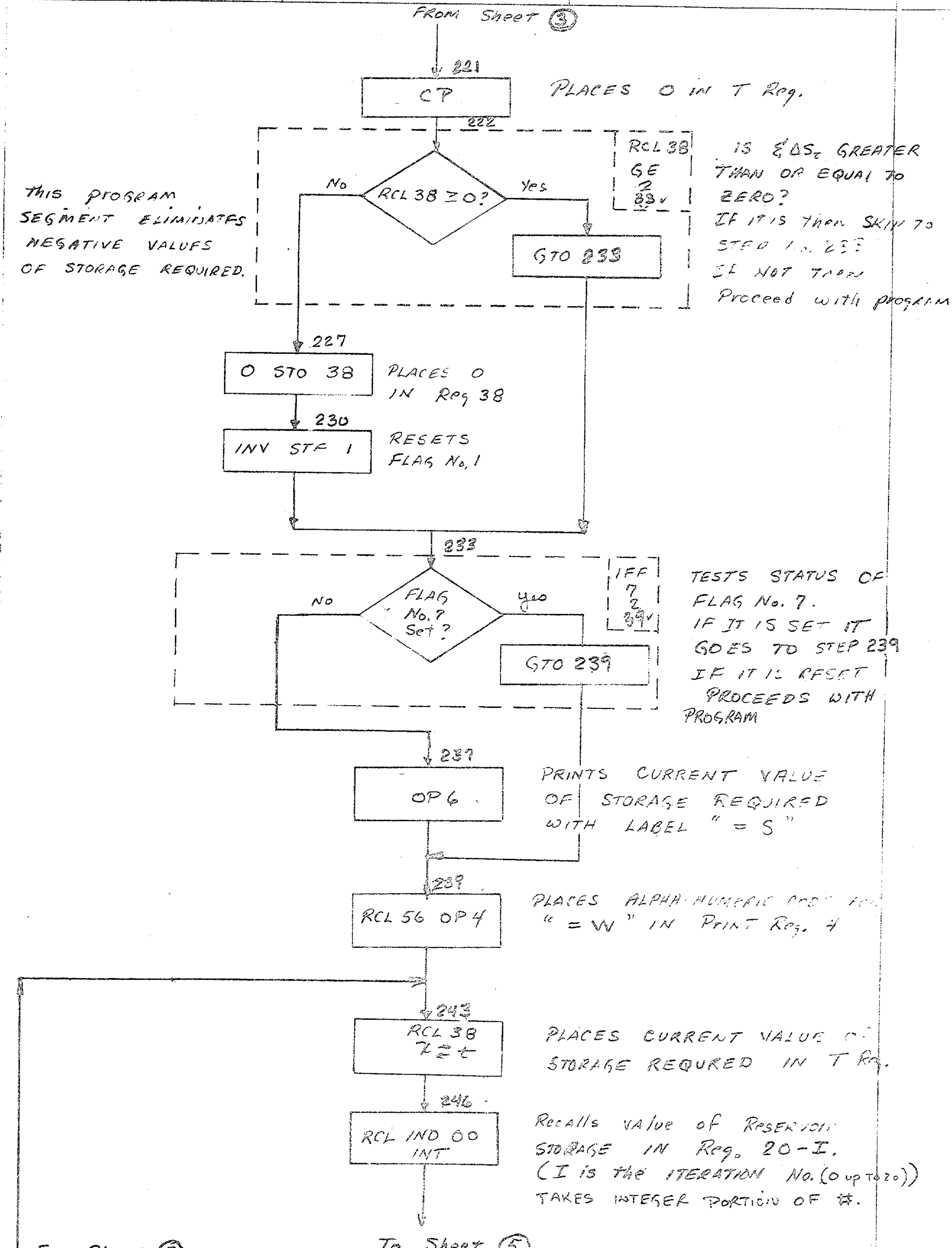


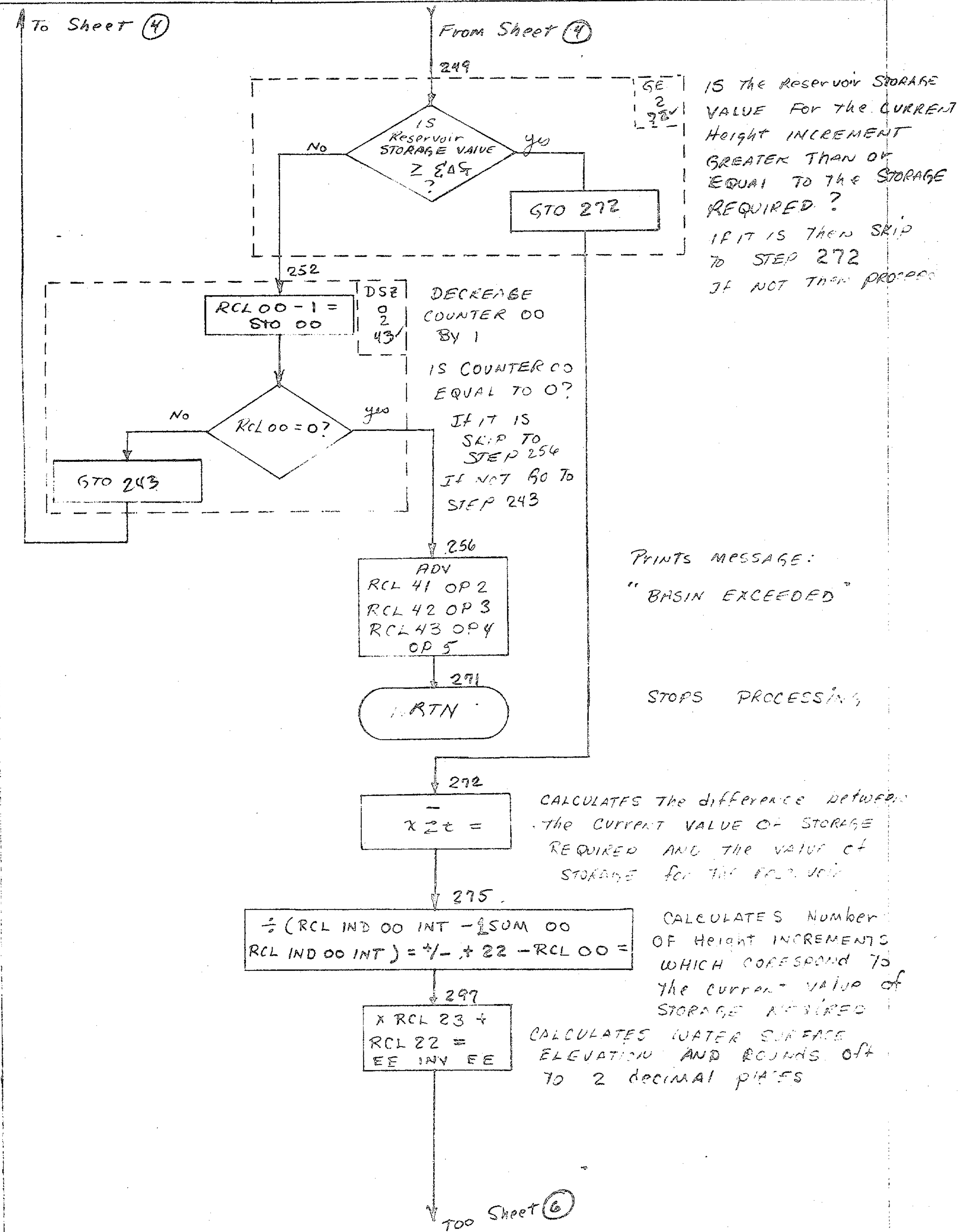
PROGRAM # 3 PUMPING STATION	[STORAGE - ROUTING PROGRAM]	Sheet (2)

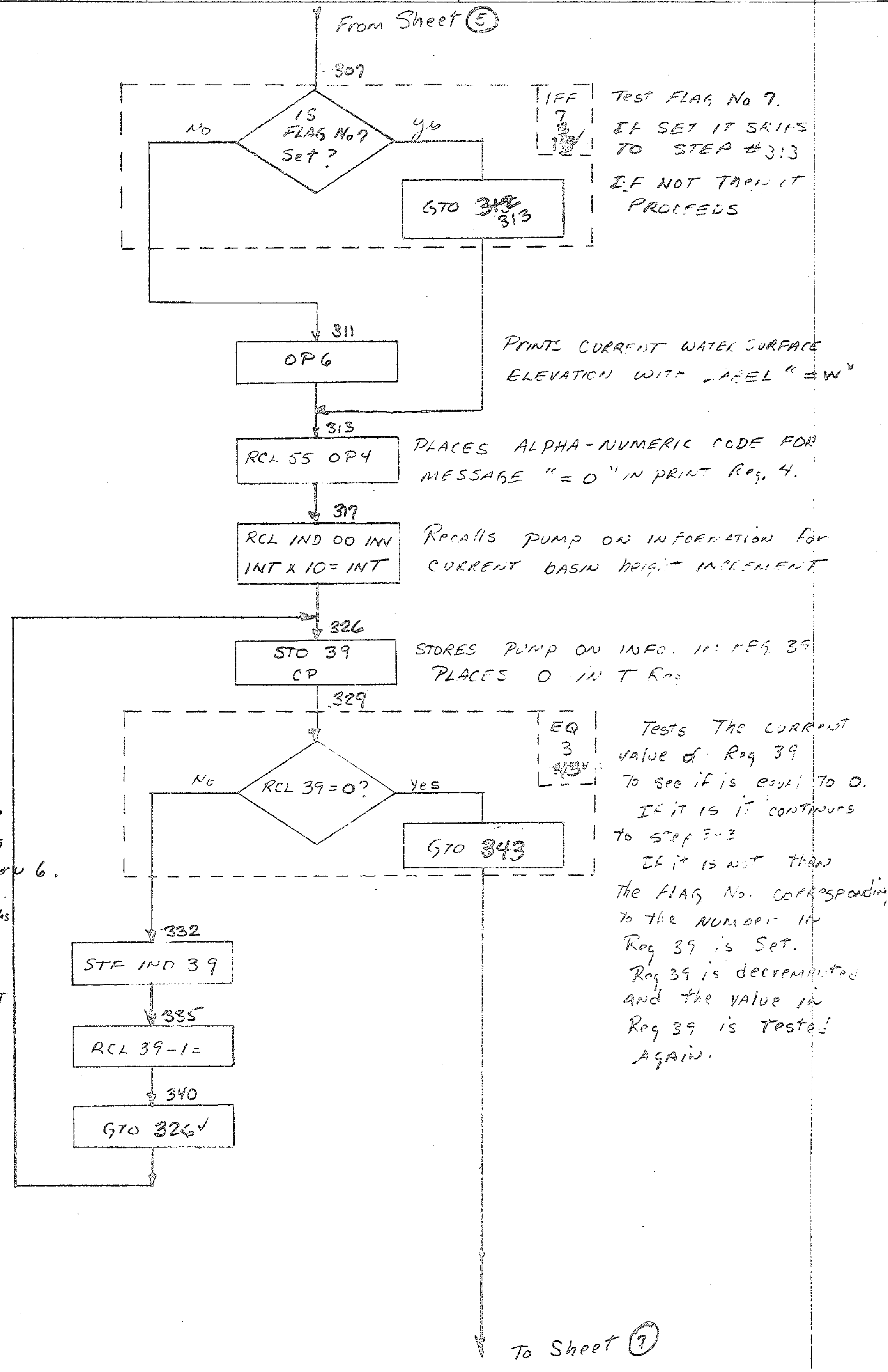



FROM Sheet (2)
194
INV
x=t
2
01
RCL 34 ≠ t?
GTO 201
IS COUNTER REG. 31 NOT EQUAL TO TIME INTERVAL?
IF SO THE GO TO STEP 201
IF NOT THEN RESET FLAG No. 7
198
INV STF 7
201
20 STO 00
INITALIZE COUNTER REG. 00 TO 20
205
RCL 32 − RCL 37 = X 60 =
CALCULATES ΔS_T FOR A 1 MINUTE INTERVAL.
215
SUM 38
CALCULATES CUMULATIVE STORAGE REQUIRED [Σ ΔS_t]
217
RCL 57 OP4
PLACES ALPHA-NUMERIC CODE FOR MESSAGE "= S" IN PRINT REG. 4
TO Sheet (4)

PROGRAM #3 PUMPING STATION | [STORAGE - ROUTING PROGRAM] | Sheet (4)

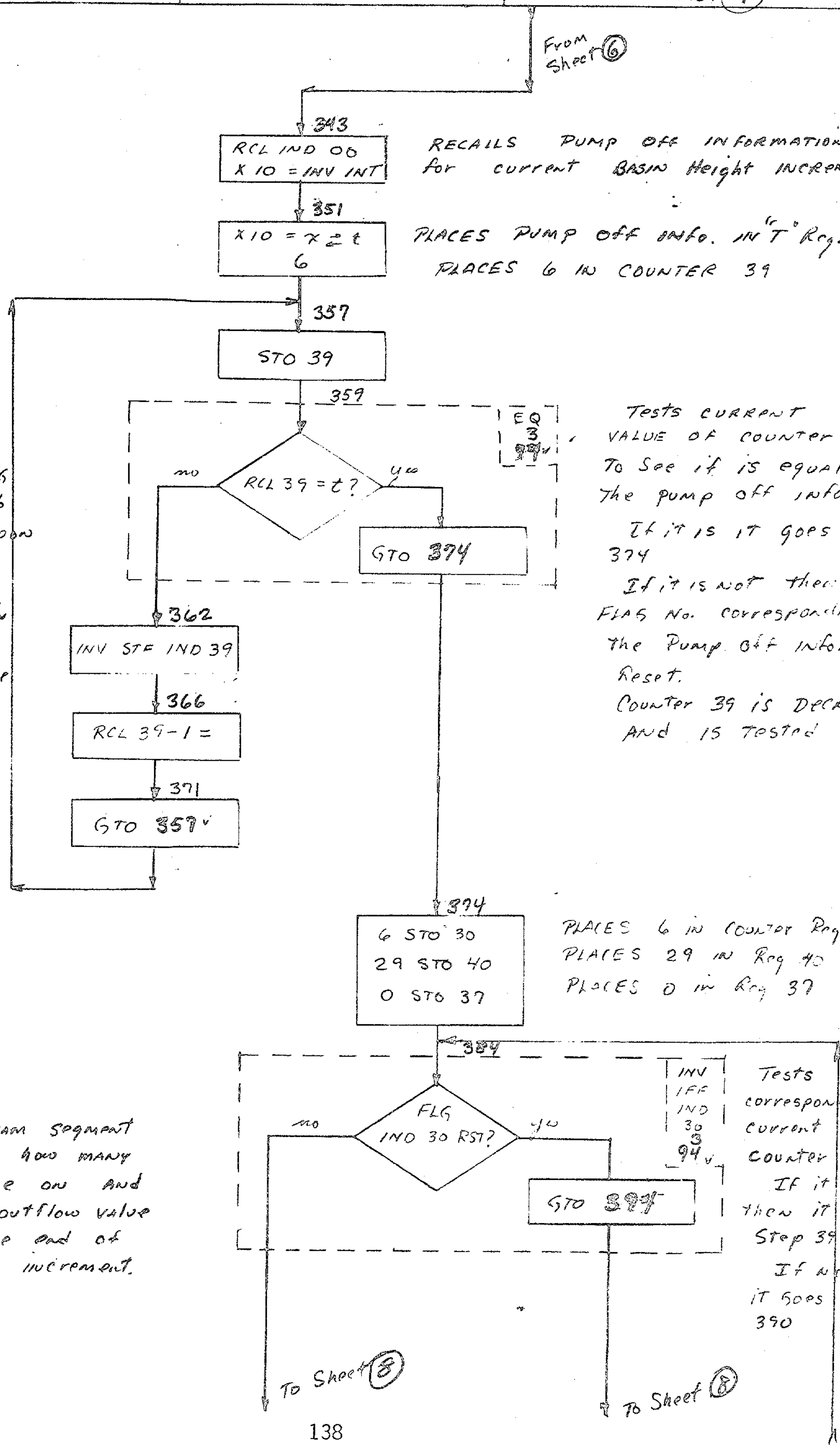



To Sheet (4)
From Sheet (4)
249
GE 2 72
IS Reservoir STORAGE VALUE ≥ ΣΔS?
No
yes
GTO 272
IS THE RESERVOIR STORAGE VALUE FOR THE CURRENT HEIGHT INCREMENT GREATER THAN OR EQUAL TO THE STORAGE REQUIRED?
IF IT IS THEN SKIP TO STEP 272
IF NOT THEN PROCEED
252
DSZ 0 2 43
RCL 00 - 1 = STO 00
DECREASE COUNTER 00 BY 1
RCL 00 = 0?
No
yes
GTO 243
IS COUNTER 00 EQUAL TO 0?
IF IT IS SKIP TO STEP 256
IF NOT GO TO STEP 243
256
ADV
RCL 41 OP 2
RCL 42 OP 3
RCL 43 OP 4
OP 5
PRINTS MESSAGE: "BASIN EXCEEDED"
271
RTN
STOPS PROCESSING
272
x ⇄ t =
CALCULATES THE DIFFERENCE BETWEEN THE CURRENT VALUE OF STORAGE REQUIRED AND THE VALUE OF STORAGE FOR THE RESERVOIR
275
÷ (RCL IND 00 INT − ΣSUM 00
RCL IND 00 INT) = +/− + 22 − RCL 00 =
CALCULATES NUMBER OF HEIGHT INCREMENTS WHICH CORRESPOND TO THE CURRENT VALUE OF STORAGE REQUIRED
297
x RCL 23 +
RCL 22 =
EE INV EE
CALCULATES WATER SURFACE ELEVATION AND ROUNDS OFF TO 2 DECIMAL PLACES
TOO Sheet (6)



This program Segment Sets FLAGS No.'s 1 thru 6 corresponding to Pumps 1 thru 6. Depending upon the 10ths digit of the Number for the current BASIN Height INCREMENT

PROGRAM #3
Pumping Station | [STORAGE - ROUTING Program] | Sheet No. (7)



RECALLS PUMP OFF INFORMATION for current BASIN Height INCREMENT.

PLACES PUMP OFF INFO. IN "T" Reg.
PLACES 6 IN COUNTER 39

This program Segment Resets FLAG No.S 1 thru 6 depending upon the pump off info. contained in the 100's digit of the Number for the current height increment.

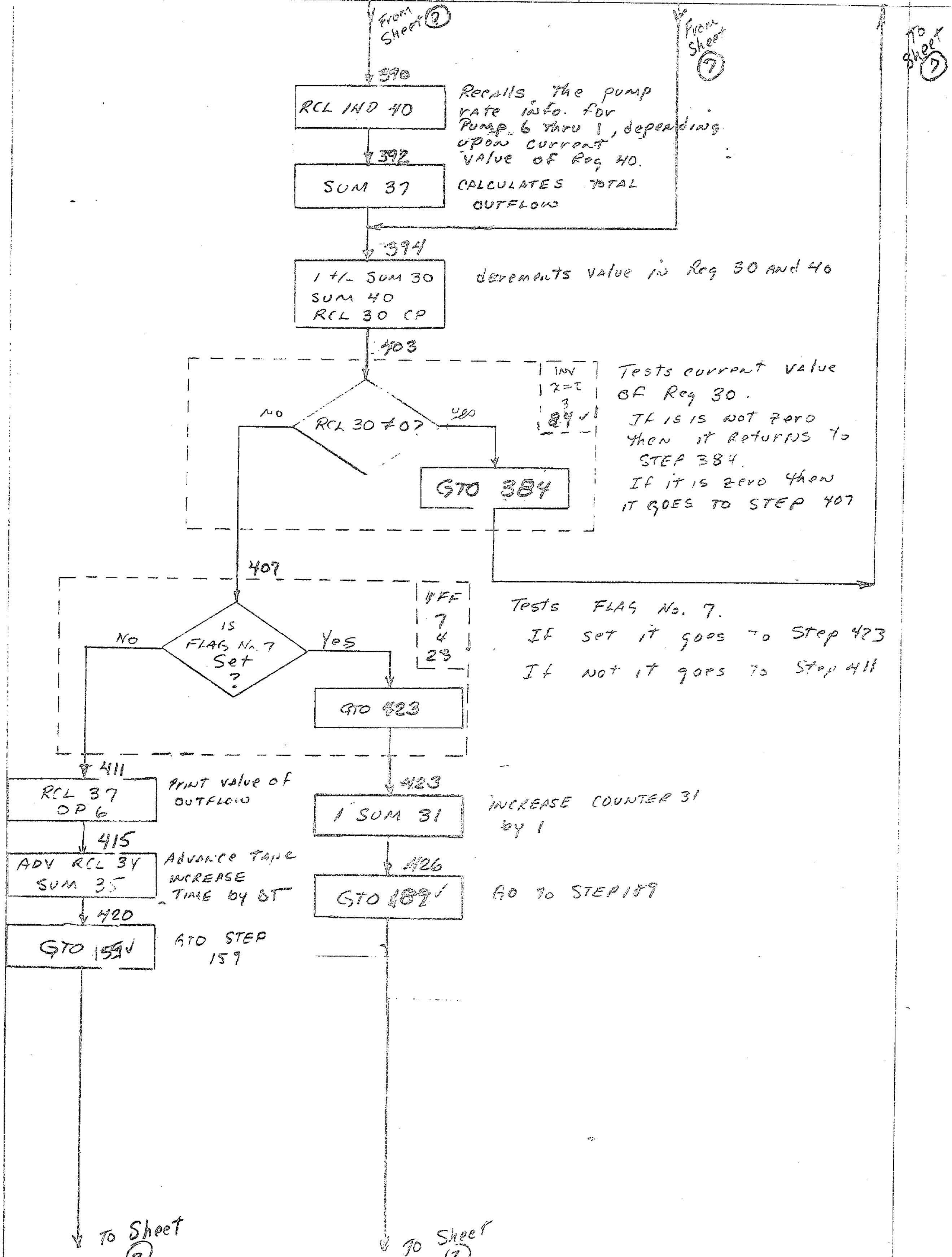
Tests current VALUE OF COUNTER Rg 39 To See if is equal to The pump off info.
If it is it goes to Step 374
If it is not then the FLAG No. corresponding to The Pump off info. is Reset.
Counter 39 is Decremented And is Tested Again.

PLACES 6 in Counter Reg 30
PLACES 29 in Reg 40
PLACES 0 in Reg 37

This program segment determins how many Pumps Are on And what the outflow value is At the end of the Time increment.

Tests Flag No. corresponding to current value in Counter Reg 30.
If it is Reset then it goes to Step 394
If not then it goes to Step 390

PROGRAM #3 PUMPING STATION	[STORAGE - ROUTING PROGRAM]	Sheet (8)



APPENDIX A

Program Listings

PROGRAM SET 1

```
000  76  LBL
001  22  INV
002  73  RC*
003  00   00
004  69  OP
005  01   01
006  69  OP
007  30   30
008  73  RC*
009  00   00
010  69  OP
011  02   02
012  69  OP
013  30   30
014  73  RC*
015  00   00
016  69  OP
017  30   30
018  69  OP
019  03   03
020  69  OP
021  05   05
022  00   0
023  91  R/S
024  99  PRT
025  92  RTN
026  76  LBL
027  11   A
028  71  SBR
029  22  INV
030  75   -
031  71  SBR
032  22  INV
033  42  STO
034  22   22
035  95   =
036  55   ÷
037  02   2
038  00   0
039  95   =
040  42  STO
041  23   23
042  71  SBR
043  22  INV
044  67   EQ
045  00   00
046  60   60
047  01   1
048  02   2
049  22  INV
050  44  SUM
051  00   00
052  71  SBR
053  22  INV
054  33  X²
055  42  STO
056  28   28
057  61  GTO
058  00   00
059  76   76
060  71  SBR
061  22  INV
062  42  STO
063  28   28
064  71  SBR
065  22  INV
066  42  STO
067  29   29
068  71  SBR
069  22  INV
070  42  STO
071  30   30
072  71  SBR
073  22  INV
074  42  STO
075  31   31
076  02   2
077  01   1
078  42  STO
079  00   00
080  02   2
081  01   1
082  75   -
083  43  RCL
084  00   00
085  95   =
086  65   ×
087  43  RCL
088  23   23
089  95   =
090  42  STO
091  32   32
092  65   ×
093  43  RCL
094  30   30
095  65   ×
096  43  RCL
097  31   31
098  55   ÷
099  03   3
100  85   +
101  53   (
102  43  RCL
103  28   28
104  65   ×
105  43  RCL
106  31   31
107  85   +
108  43  RCL
109  29   29
110  65   ×
111  43  RCL
112  30   30
113  54   )
114  55   ÷
115  02   2
116  95   =
117  65   ×
118  43  RCL
119  32   32
120  85   +
121  43  RCL
122  28   28
123  65   ×
124  43  RCL
125  29   29
126  95   =
127  65   ×
128  43  RCL
129  32   32
130  95   =
131  59  INT
132  72  ST*
133  00   00
134  97  DSZ
135  00   00
136  00   00
137  80   80
138  25  CLR
139  98  ADV
140  92  RTN
141  76  LBL
142  16  A'
143  69  OP
144  00   00
145  05   5
146  09   9
147  42  STO
148  00   00
149  71  SBR
150  22  INV
151  75   -
152  71  SBR
153  22  INV
154  42  STO
155  22   22
156  95   =
157  55   ÷
158  02   2
159  00   0
160  95   =
161  42  STO
162  23   23
163  02   2
164  01   1
165  42  STO
166  00   00
167  07   7
168  71  SBR
169  02   02
170  32   32
171  03   3
172  71  SBR
173  02   02
174  05   05
175  02   2
```

176	71	SBR
177	02	02
178	32	32
179	01	1
180	08	8
181	09	9
182	71	SBR
183	02	02
184	05	05
185	06	6
186	71	SBR
187	02	02
188	32	32
189	03	3
190	71	SBR
191	02	02
192	05	05
193	02	2
194	71	SBR
195	02	02
196	32	32
197	08	8
198	09	9
199	71	SBR
200	02	02
201	05	05
202	25	CLR
203	98	ADV
204	91	R/S
205	71	SBR
206	02	02
207	26	26
208	44	SUM
209	52	52
210	05	5
211	03	3
212	42	STO
213	01	01
214	71	SBR
215	02	02
216	56	56
217	59	INT
218	72	ST*
219	00	00
220	97	DSZ
221	00	00
222	02	02
223	25	25
224	92	RTN
225	92	RTN
226	65	×
227	01	1
228	00	0
229	00	0
230	95	=
231	92	RTN
232	42	STO
233	48	48
234	00	0
235	42	STO
236	49	49

237	01	1
238	71	SBR
239	02	02
240	05	05
241	43	RCL
242	48	48
243	32	X:T
244	01	1
245	44	SUM
246	49	49
247	43	RCL
248	49	49
249	67	EQ
250	02	02
251	55	55
252	61	GTO
253	02	02
254	37	37
255	92	RTN
256	73	RC*
257	01	01
258	69	OP
259	01	01
260	69	OP
261	31	31
262	73	RC*
263	01	01
264	69	OP
265	02	02
266	69	OP
267	31	31
268	73	RC*
269	01	01
270	69	OP
271	03	03
272	69	OP
273	31	31
274	69	OP
275	05	05
276	00	0
277	91	R/S
278	99	PRT
279	92	RTN
280	76	LBL
281	10	E'
282	02	2
283	01	1
284	42	STO
285	00	00
286	73	RC*
287	00	00
288	99	PRT
289	97	DSZ
290	00	00
291	02	02
292	86	86
293	91	R/S

24.	00
0.	01
3671000000.	02
3513162441.	03
3233173600.	04
3723003627.	05
7700432416.	06
2732331736.	07
2237230036.	08
7700271731.	09
2371000000.	10
8043241637.	11
1413362431.	12
3723710000.	13
8027173122.	14
1413362431.	15
4527406402.	16
6401570015.	17
3517153740.	18
4240710000.	19
3000172717.	20
1432373732.	21
2432317100.	22
2717421337.	23
3732330017.	24
0.	25
0.	26
0.	27
0.	28
3.141592654	29
0.	30
0.	31
0.	32
0.	33
0.	34
0.	35
0.	36
0.	37
0.	38
0.	39
0.	40
0.	41
0.	42
0.	43
0.	44
0.	45
0.	46
0.	47
0.	48
0.	49
0.	50
7100000000.	51
1755000056.	52
4232274130.	53
4240710000.	54
3000172717.	55
1432373732.	56
2432317100.	57
2717421337.	58
3732330017.	59

PROGRAM SET 2

```
000  76  LBL
001  22  INV
002  73  RC*
003  00  00
004  69  OP
005  01  01
006  69  OP
007  30  30
008  73  RC*
009  00  00
010  69  OP
011  02  02
012  69  OP
013  30  30
014  69  OP
015  05  05
016  00  0
017  91  R/S
018  99  PRT
019  92  RTN
020  76  LBL
021  23  LNX
022  71  SBR
023  22  INV
024  75  -
025  02  2
026  01  1
027  42  STO
028  00  00
029  43  RCL
030  22  22
031  95  =
032  29  CP
033  32  X:T
034  77  GE
035  00  00
036  46  46
037  32  X:T
038  75  -
039  43  RCL
040  23  23
041  95  =
042  97  DSZ
043  00  00
044  00  00
045  33  33
046  92  RTN
047  00  0
048  42  STO
049  31  31
050  43  RCL
051  32  32
052  65  ×
053  43  RCL
054  33  33
055  95  =
056  42  STO
057  34  34
058  43  RCL
059  31  31
060  32  X:T
061  43  RCL
062  35  35
063  77  GE
064  01  01
065  18  18
066  43  RCL
067  34  34
068  77  GE
069  01  01
070  12  12
071  43  RCL
072  34  34
073  85  +
074  43  RCL
075  35  35
076  95  =
077  77  GE
078  00  00
079  86  86
080  71  SBR
081  40  IND
082  37  37
083  61  GTO
084  01  01
085  56  56
086  71  SBR
087  40  IND
088  37  37
089  42  STO
090  36  36
091  53  (
092  43  RCL
093  35  35
094  85  +
095  43  RCL
096  34  34
097  75  -
098  43  RCL
099  31  31
100  54  )
101  71  SBR
102  40  IND
103  38  38
104  94  +/-
105  85  +
106  43  RCL
107  36  36
108  95  =
109  61  GTO
110  01  01
111  56  56
112  71  SBR
113  40  IND
114  39  39
115  61  GTO
116  01  01
117  56  56
118  43  RCL
119  34  34
120  77  GE
121  01  01
122  48  48
123  43  RCL
124  31  31
125  71  SBR
126  40  IND
127  38  38
128  42  STO
129  36  36
130  53  (
131  43  RCL
132  31  31
133  75  -
134  43  RCL
135  34  34
136  54  )
137  71  SBR
138  40  IND
139  38  38
140  94  +/-
141  85  +
142  43  RCL
143  36  36
144  95  =
145  61  GTO
146  01  01
147  56  56
148  43  RCL
149  31  31
150  71  SBR
151  40  IND
152  38  38
153  61  GTO
154  01  01
155  56  56
156  59  INT
157  74  SM*
158  00  00
159  43  RCL
160  23  23
161  44  SUM
162  31  31
163  97  DSZ
164  00  00
165  00  00
166  58  58
167  98  ADV
168  25  CLR
169  92  RTN
170  70  RAD
171  42  STO
172  40  40
173  89  π
174  75  -
175  53  (
176  02  2
```

177	65	×
178	43	RCL
179	40	40
180	55	÷
181	43	RCL
182	35	35
183	75	-
184	01	1
185	54	)
186	22	INV
187	39	COS
188	95	=
189	42	STO
190	41	41
191	38	SIN
192	65	×
193	53	(
194	43	RCL
195	35	35
196	55	÷
197	02	2
198	54	)
199	95	=
200	42	STO
201	42	42
202	68	NOP
203	01	1
204	55	÷
205	03	3
206	55	÷
207	43	RCL
208	32	32
209	65	×
210	53	(
211	43	RCL
212	42	42
213	65	×
214	53	(
215	03	3
216	65	×
217	53	(
218	43	RCL
219	35	35
220	55	÷
221	02	2
222	54	)
223	33	X²
224	75	-
225	43	RCL
226	42	42
227	33	X²
228	54	)
229	85	+
230	03	3
231	65	×
232	53	(
233	43	RCL
234	35	35
235	55	÷
236	02	2
237	54	)
238	33	X²
239	65	×
240	53	(
241	43	RCL
242	40	40
243	75	-
244	43	RCL
245	35	35
246	55	÷
247	02	2
248	54	)
249	65	×
250	43	RCL
251	41	41
252	54	)
253	95	=
254	60	DEG
255	92	RTN
256	89	π
257	65	×
258	43	RCL
259	35	35
260	33	X²
261	55	÷
262	04	4
263	65	×
264	43	RCL
265	33	33
266	95	=
267	92	RTN
268	89	π
269	65	×
270	43	RCL
271	35	35
272	33	X²
273	55	÷
274	04	4
275	55	÷
276	43	RCL
277	32	32
278	65	×
279	53	(
280	43	RCL
281	31	31
282	75	-
283	43	RCL
284	35	35
285	55	÷
286	02	2
287	54	)
288	95	=
289	92	RTN
290	33	X²
291	55	÷
292	02	2
293	65	×
294	43	RCL
295	30	30
296	55	÷
297	43	RCL
298	32	32
299	95	=
300	92	RTN
301	43	RCL
302	30	30
303	65	×
304	43	RCL
305	35	35
306	65	×
307	43	RCL
308	33	33
309	95	=
310	92	RTN
311	43	RCL
312	30	30
313	55	÷
314	43	RCL
315	32	32
316	65	×
317	53	(
318	43	RCL
319	35	35
320	65	×
321	43	RCL
322	31	31
323	75	-
324	43	RCL
325	35	35
326	33	X²
327	55	÷
328	02	2
329	54	)
330	95	=
331	92	RTN
332	76	LBL
333	12	B
334	69	OP
335	00	00
336	98	ADV
337	05	5
338	09	9
339	42	STO
340	00	00
341	71	SBR
342	04	04
343	08	08
344	71	SBR
345	23	LNX
346	01	1
347	07	7
348	00	0
349	42	STO
350	38	38
351	02	2
352	05	5
353	06	6
354	42	STO
355	37	37
356	02	2
357	06	6
358	08	8
359	42	STO
360	39	39

```
361  71 SBR
362  00  00
363  47  47
364  91 R/S
365  76 LBL
366  13  C
367  69 DP
368  00  00
369  22 INV
370  58 FIX
371  98 ADV
372  05  5
373  01  1
374  42 STD
375  00  00
376  71 SBR
377  04  04
378  08  08
379  71 SBR
380  22 INV
381  42 STD
382  30  30
383  05  5
384  03  3
385  42 STD
386  00  00
387  71 SBR
388  23 LNX
389  02  2
390  09  9
391  00  0
392  42 STD
393  38  38
394  03  3
395  00  0
396  01  1
397  42 STD
398  37  37
399  03  3
400  01  1
401  01  1
402  42 STD
403  39  39
404  71 SBR
405  00  00
406  47  47
407  91 R/S
408  71 SBR
409  22 INV
410  42 STD
411  35  35
412  71 SBR
413  22 INV
414  42 STD
415  32  32
416  71 SBR
417  22 INV
418  42 STD
419  33  33
```

```
420  92 RTN
421  76 LBL
422  10 E'
423  02  2
424  01  1
425  42 STD
426  00  00
427  73 RC*
428  00  00
429  99 PRT
430  97 DSZ
431  00  00
432  04  04
433  27  27
434  91 R/S
435  00  0
436  00  0
437  00  0
```

```
            0.   30
            0.   31
            0.   32
            0.   33
            0.   34
            0.   35
            0.   36
            0.   37
            0.   38
            0.   39
            0.   40
            0.   41
            0.   42
            0.   43
 2416372300.   44
 1432440043.   45
 1731223723.   46
 1432440027.   47
 3627323317.   48
            0.   49
 1724222337.   50
 1432440023.   51
 1727174240.   52
 2431423740.   53
 1731223723.   54
          27.   55
 3627323317.   56
            0.   57
 3717350000.   58
 1624133017.   59
```

PROGRAM SET 3

```
000  76 LBL
001  22 INV
002  73 RC*
003  00  00
004  69 OP
005  01  01
006  69 OP
007  30  30
008  73 RC*
009  00  00
010  69 OP
011  02  02
012  69 OP
013  30  30
014  73 RC*
015  00  00
016  69 OP
017  30  30
018  69 OP
019  03  03
020  69 OP
021  05  05
022  00  0
023  91 R/S
024  99 PRT
025  92 RTN
026  76 LBL
027  14  D
028  98 ADV
029  04  4
030  04  4
031  42 STO
032  00  00
033  71 SBR
034  22 INV
035  42 STO
036  32  32
037  29 CP
038  43 RCL
039  32  32
040  67  EQ
041  01  01
042  39  39
043  43 RCL
044  41  41
045  69 OP
046  01  01
047  43 RCL
048  40  40
049  69 OP
050  02  02
051  43 RCL
052  39  39
053  85  +
054  43 RCL
055  32  32
056  95  =
057  69 OP
058  03  03
059  93  .
060  01  1
061  71 SBR
062  01  01
063  04  04
064  43 RCL
065  38  38
066  69 OP
067  01  01
068  93  .
069  00  0
070  01  1
071  71 SBR
072  01  01
073  04  04
074  43 RCL
075  35  35
076  69 OP
077  01  01
078  43 RCL
079  34  34
080  69 OP
081  02  02
082  43 RCL
083  32  32
084  85  +
085  02  2
086  03  3
087  95  =
088  42 STO
089  30  30
090  43 RCL
091  33  33
092  71 SBR
093  00  00
094  18  18
095  72 ST*
096  30  30
097  01  1
098  94 +/-
099  44 SUM
100  32  32
101  61 GTO
102  00  00
103  38  38
104  42 STO
105  31  31
106  02  2
107  01  1
108  42 STO
109  00  00
110  71 SBR
111  00  00
112  20  20
113  75  -
114  43 RCL
115  22  22
116  95  =
117  55  ÷
118  43 RCL
119  23  23
120  95  =
121  58 FIX
122  00  00
123  52 EE
124  22 INV
125  52 EE
126  22 INV
127  58 FIX
128  22 INV
129  44 SUM
130  00  00
131  43 RCL
132  31  31
133  74 SM*
134  00  00
135  97 DSZ
136  00  00
137  01  01
138  31  31
139  98 ADV
140  92 RTN
141  76 LBL
142  10 E'
143  02  2
144  01  1
145  42 STO
146  00  00
147  73 RC*
148  00  00
149  99 PRT
150  97 DSZ
151  00  00
152  01  01
153  47  47
154  91 R/S
155  00  0
156  00  0
157  00  0
158  00  0
```

0.	30
0.	31
0.	32
3717000000.	33
3122003513.	34
3341303324.	35
0.	36
0.	37
3221210017.	38
4130330001.	39
2740570033.	40
8032310017.	41
3336710000.	42
2100334130.	43
3132400032.	44
0.	45
0.	46
0.	47
0.	48
0.	49
0.	50
0.	51
0.	52
0.	53
0.	54
0.	55
0.	56
0.	57
0.	58
0.	59

PROGRAM SET 4

```
000  76 LBL
001  15  E
002  22 INV
003  58 FIX
004  03  3
005  02  2
006  04  4
007  01  1
008  42 STO
009  40  40
010  01  1
011  07  7
012  03  3
013  01  1
014  42 STO
015  31  31
016  03  3
017  06  6
018  03  3
019  07  7
020  42 STO
021  32  32
022  98 ADV
023  69 OP
024  00  00
025  43 RCL
026  44  44
027  69 OP
028  02  02
029  43 RCL
030  45  45
031  69 OP
032  03  03
033  00  0
034  42 STO
035  35  35
036  42 STO
037  36  36
038  42 STO
039  37  37
040  42 STO
041  38  38
042  69 OP
043  05  05
044  91 R/S
045  99 PRT
046  98 ADV
047  42 STO
048  34  34
049  43 RCL
050  31  31
051  69 OP
052  01  01
053  43 RCL
054  46  46
055  69 OP
056  02  02
057  43 RCL
058  51  51
059  69 OP
060  03  03
061  43 RCL
062  47  47
063  69 OP
064  04  04
065  69 OP
066  05  05
067  03  3
068  03  3
069  69 OP
070  01  01
071  43 RCL
072  48  48
073  69 OP
074  02  02
075  43 RCL
076  49  49
077  69 OP
078  03  03
079  43 RCL
080  50  50
081  69 OP
082  04  04
083  69 OP
084  05  05
085  98 ADV
086  69 OP
087  00  00
088  43 RCL
089  50  50
090  69 OP
091  03  03
092  43 RCL
093  59  59
094  69 OP
095  04  04
096  69 OP
097  05  05
098  02  2
099  04  4
100  69 OP
101  02  02
102  43 RCL
103  51  51
104  69 OP
105  03  03
106  43 RCL
107  58  58
108  69 OP
109  04  04
110  69 OP
111  05  05
112  43 RCL
113  32  32
114  69 OP
115  02  02
116  43 RCL
117  52  52
118  69 OP
119  03  03
120  43 RCL
121  57  57
122  69 OP
123  04  04
124  69 OP
125  05  05
126  43 RCL
127  33  33
128  69 OP
129  02  02
130  43 RCL
131  53  53
132  69 OP
133  03  03
134  43 RCL
135  56  56
136  69 OP
137  04  04
138  69 OP
139  05  05
140  43 RCL
141  40  40
142  69 OP
143  02  02
144  43 RCL
145  54  54
146  69 OP
147  03  03
148  43 RCL
149  55  55
150  69 OP
151  04  04
152  69 OP
153  05  05
154  98 ADV
155  69 OP
156  00  00
157  58 FIX
158  02  02
159  43 RCL
160  59  59
161  69 OP
162  04  04
163  43 RCL
164  35  35
165  69 OP
166  06  06
167  43 RCL
168  58  58
169  69 OP
170  04  04
171  00  0
172  91 R/S
173  69 OP
174  06  06
175  85  +
```

```
176  48  EXC
177  36   36
178  95   =
179  55   ÷
180  02   2
181  95   =
182  42  STD
183  32   32
184  86  STF
185  07   07
186  01   1
187  42  STD
188  31   31
189  43  RCL
190  31   31
191  32  X:T
192  43  RCL
193  34   34
194  22  INV
195  67   EQ
196  02   02
197  01   01
198  22  INV
199  86  STF
200  07   07
201  02   2
202  00   0
203  42  STD
204  00   00
205  43  RCL
206  32   32
207  75   -
208  43  RCL
209  37   37
210  95   =
211  65   ×
212  06   6
213  00   0
214  95   =
215  44  SUM
216  38   38
217  43  RCL
218  57   57
219  69  DP
220  04   04
221  29  CP
222  43  RCL
223  38   38
224  77   GE
225  02   02
226  33   33
227  00   0
228  42  STD
229  ·38   38
230  22  INV
231  86  STF
232  01   01
233  87  IFF
234  07   07
235  02   02
236  39   39
237  69  DP
238  06   06
239  43  RCL
240  56   56
241  69  DP
242  04   04
243  43  RCL
244  38   38
245  32  X:T
246  73  RC*
247  00   00
248  59  INT
249  77   GE
250  02   02
251  72   72
252  97  DSZ
253  00   00
254  02   02
255  43   43
256  98  ADV
257  43  RCL
258  41   41
259  69  DP
260  02   02
261  43  RCL
262  42   42
263  69  DP
264  03   03
265  43  RCL
266  43   43
267  69  DP
268  04   04
269  69  DP
270  05   05
271  92  RTN
272  75   -
273  32  X:T
274  95   =
275  55   ÷
276  53   (
277  73  RC*
278  00   00
279  59  INT
280  75   -
281  01   1
282  44  SUM
283  00   00
284  73  RC*
285  00   00
286  59  INT
287  54   )
288  95   =
289  94  +/-
290  85   +
291  02   2
292  02   2
293  75   -
294  43  RCL
295  00   00
296  95   =
297  65   ×
298  43  RCL
299  23   23
300  85   +
301  43  RCL
302  22   22
303  95   =
304  52  EE
305  22  INV
306  52  EE
307  87  IFF
308  07   07
309  03   03
310  13   13
311  69  DP
312  06   06
313  43  RCL
314  55   55
315  69  DP
316  04   04
317  73  RC*
318  00   00
319  27  INV
320  59  INT
321  65   ×
322  01   1
323  00   0
324  95   =
325  59  INT
326  42  STD
327  39   39
328  29  CP
329  67   EQ
330  03   03
331  43   43
332  86  STF
333  40  IND
334  39   39
335  43  RCL
336  39   39
337  75   -
338  01   1
339  95   =
340  61  GTD
341  03   03
342  26   26
343  73  RC*
344  00   00
345  65   ×
346  01   1
347  00   0
348  95   =
349  22  INV
350  59  INT
351  65   ×
352  01   1
353  00   0
354  95   =
355  32  X:T
356  06   6
357  42  STD
358  39   39
359  67   EQ
```

360	03	03
361	74	74
362	22	INV
363	86	STF
364	40	IND
365	39	39
366	43	RCL
367	39	39
368	75	-
369	01	1
370	95	=
371	61	GTO
372	03	03
373	57	57
374	06	6
375	42	STO
376	30	30
377	02	2
378	09	9
379	42	STO
380	40	40
381	00	0
382	42	STO
383	37	37
384	22	INV
385	87	IFF
386	40	IND
387	30	30
388	03	03
389	94	94
390	73	RC*
391	40	40
392	44	SUM
393	37	37
394	01	1
395	94	+/-
396	44	SUM
397	30	30
398	44	SUM
399	40	40
400	43	RCL
401	30	30
402	29	CP
403	22	INV
404	67	EQ
405	03	03
406	84	84
407	87	IFF
408	07	07
409	04	04
410	23	23
411	43	RCL
412	37	37
413	69	OP
414	06	06
415	98	ADV
416	43	RCL
417	34	34
418	44	SUM
419	35	35
420	61	GTO
421	01	01
422	59	59
423	01	1
424	44	SUM
425	31	31
426	61	GTO
427	01	01
428	89	89

0.	30
0.	31
0.	32
4340.	33
0.	34
0.	35
0.	36
0.	37
0.	38
0.	39
0.	40
8014133624.	41
3100174415.	42
1717161716.	43
24313717.	44
3542132771.	45
3717350024.	46
8043231731.	47
3532303337.	48
1716001445.	49
37243017.	50
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3235132217.	52
3640172740.	53
3721273243.	54
8064003200.	55
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8064003600.	57
8064002400.	58
8064003700.	59

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