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STUDY OF AN AUTOMATIC UPSTREAM CONTROL SYSTEM FOR CANALS

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16. ABSTRACT

A study was made to develop an automatic upstream control system utilizing the P+PR (proportional plus proportional reset) mode of control for the bypass drain check gates of the Yuma Desalting Plant. Mathematical model simulation studies show the P+PR controller can automatically transfer all degrees of flow change from upstream to downstream and return the water surface (upstream of canal check structures) back to desired target surfaces within a reasonable period of time. Included in the study were the development of a digital filter for microprocessor units and logic for reducing "saw-tooth" gate control responses during steady-state flow conditions. The SOT/VRT (set-operate-time/variable-rest-time) mode of control was analyzed as an unsuccessful alternative to the P+PR controller. Operating criteria for normal and emergency flow conditions is also presented to assist the operators in the future operation of the bypass drain.

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STUDY OF AN AUTOMATIC UPSTREAM CONTROL SYSTEM FOR CANALS

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CONTENTS

APPENDIX

CONTENTS - Continued

TABLES

FIGURES

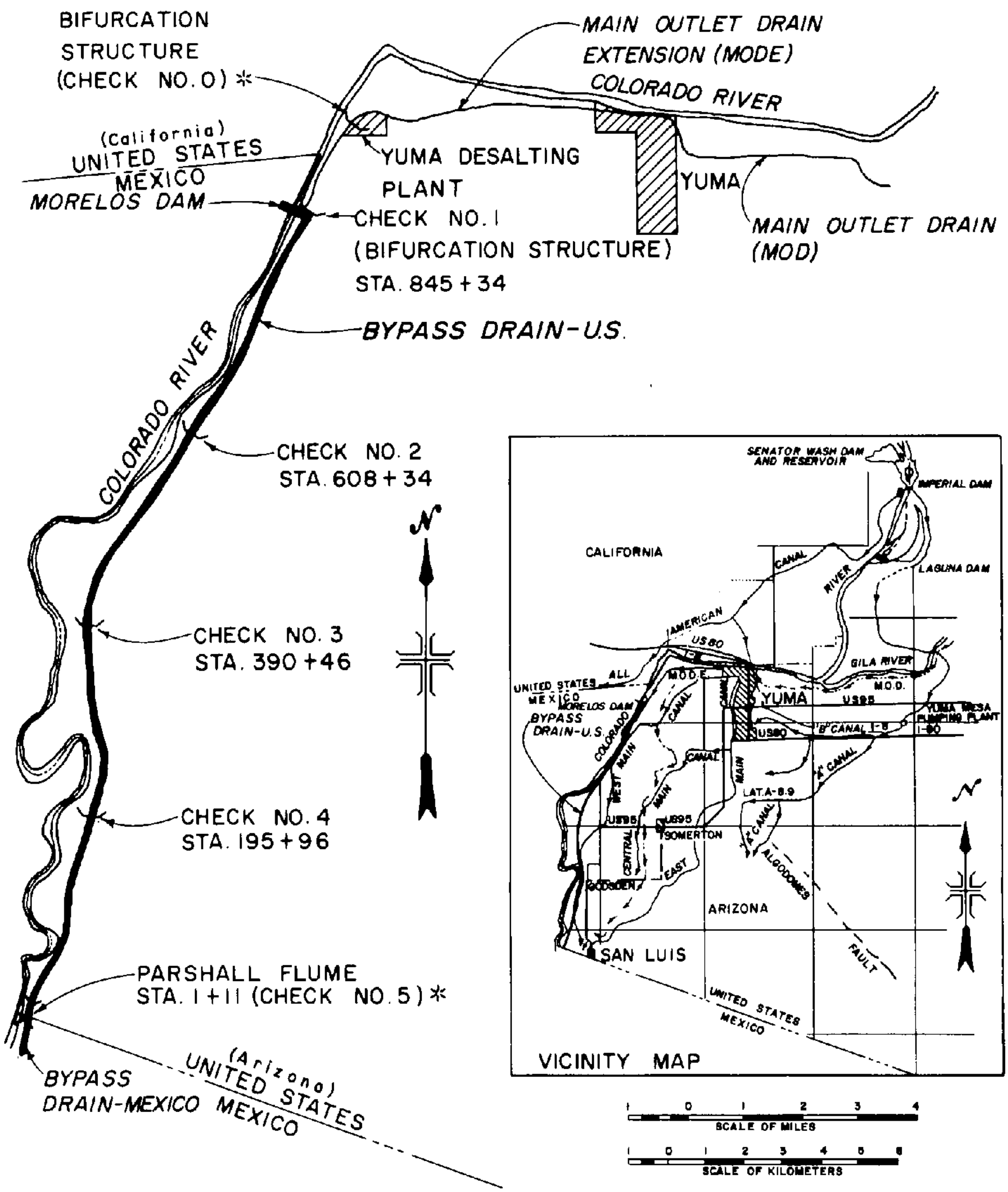
PURPOSE

This report describes an automatic upstream control system that will achieve desired water surface elevation response for the bypass drain. Sufficient detail is included for writing specifications for procurement. Also reported are investigations made to provide criteria to assist in the future operation of the bypass drain.

The analysis of the P+PR method applied to the automatic upstream control concept shows that a stable, self-regulating control system which maintains a reasonably constant water surface elevation, can easily be achieved in all canal reaches. The P+PR method developed in this report has application to other canal systems wherever the upstream control concept is required; that is, the transfer of flow changes from upsteam to downstream.

INTRODUCTION

The bypass drain is being designed to convey reject flow (brine) from the Yuma Desalting Plant and excess Wellton-Mohawk drainage water to the United States-Mexico International Boundary (fig. 1) as part of the Colorado River Basin Salinity Control Project, Title I Division. A description and physical properties of the bypass drain are summarized in appendix IV. Upstream control is the most logical



* Note: Check No. 0 and check No. 5 are used in this report as labels for the M.O.D.E. Bifurcation structure and the Bypass Drain Parshall Flume.

Figure 1. - Bypass drain location map.

concept to transfer the reject flow and excess drainage water downstream. The results of the study to develop the control algorithm for automatic upstream control are presented in this report.

An analysis was made of the proportional plus proportional reset, labeled the P+PR, mode of control as the basic method of an automatic upstream control system. Included in the P+PR study was the development of a digital filter and a technique to reduce "sawtooth" gate response characteristics during steady-state flow conditions. The filter element is required to eliminate unnecessary gate responses to wind-wave action and local disturbances. The reduction of "sawtooth" gate responses reduces the wear and tear on the gate hoist mechanism.

The set-operate/variable-rest mode of control known as the "Colvin Controller" presently under development, was studied as an alternative method for automatic upstream control. A number of mathematical model computer runs were made to establish operating criteria which should be useful to canal operators when the bypass drain becomes operational.

CONCLUSIONS

1. The P+PR (proportional plus proportional reset) mode of control provides desirable water surface elevation response characteristics and the speed of response is satisfactory. The P+PR is recommended

as the best method to achieve a satisfactory automatic upstream control system for the bypass drain.

2. The P+PR mode of control, with properly selected control parameters, will control with stability any degree of flow change. This includes for example an emergency shutdown of the Yuma Desalting Plant when operating at maximum capacity.

3. An electronic filter is required to modify the output of the water surface sensor to eliminate unnecessary gate control responses that would be caused by wind-wave action and local disturbances.

4. A technique of reducing the "sawtooth" gate responses that are characteristic during steady-state flow conditions has been developed. The technique defined as "GDB modification" should be implemented to reduce wear and tear on the gate hoist mechanism.

5. The set-operate/variable-rest mode of control known as the "Colvin Controller" will not adequately maintain water surface elevations near the desired target level during steady-state flow conditions.

6. Flow increases during normal operation should be limited to $2.8(m^3/s)/h$ $(100(ft^3/s)/h)$ to limit water surface surges to 0.11 m (0.35 ft). Flow reductions will be limited to the water drawdown criteria.

7. The adjustment of the desired water surface target or set point by remote control from the Yuma Desalting Plant is not required.

The analysis of an automatic upstream control system for the bypass drain presented in this report is the first major effort made in this regard, and the study was very beneficial. The P+PR provides satisfactory automatic upstream control and the selection of control parameters is relatively easy. The study developed a digital filter and a logic to reduce the sawtooth gate response characteristics, labeled GDB modification, during steady-state flow conditions. The digital filter and the logic for GDB modification can be used with all modes of automatic control that adjust check gates where logic circuits are available in mini or micro computers.

Additional mathematical model studies were made to develop operational criteria. The operational criteria discussed will assist operators in the future and provides guidelines for both normal and emergency conditions.

BACKGROUND

Development of automatic upsteam control systems has previously been accomplished largely through field trial and error experimentation. The set-operate-time/set-rest-time method known as "Little Man" is an example of a simple control system designed to maintain constant water surface elevations upstream of check structures and was developed, empirically, by field operating personnel and through field experimentation over several years [1].[1] The original design was modified to increase capability and to overcome some of the problems that cause instability [2]. The set-operate-time/variable-rest-time method known as the "Colvin Controller" has been developed in recent years by field experimentation with minimal mathematical model simulation studies. The HyFLO, and later, the EL-FLO plus RESET method of automatic downsteam control of canal check gates, used mathematical model studies exclusively to develop the control system "on-the-bench" [3, 4]. Field tests were then made to verify the theoretical analysis and the mathematical model simulation [4]. The basic mode of EL-FLO plus RESET method control, otherwise called "proportional plus proportional reset," has been applied to the automatic upstream control of canal check gates. The study of an upstream control system for the bypass drain presented in this report is the first extensive effort to develop a suitable and stable automatic upstream control system for canal check gates. Through past experience, enough confidence has been gained in the accuracy of mathematical model simulation, that "on-the-bench" studies can advance directly to the prototype installation.

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[1]Numbers in brackets refer to literature cited in the bibliography.

P+PR (PROPORTIONAL PLUS PROPORTIONAL RESET)

The P+PR mode of control has been applied to the automatic upstream control concept. The upstream control concept requires that an increase in the upstream water surface elevation (modified by a filter) produce an increase in the controlled gate opening immediately downstream to increase the flow into the downstream canal reach. Likewise, a decrease in the water surface elevation upstream decreases the flow downstream. Changes in canal flow arriving at a check gate from upstream are, therefore, automatically transferred downstream.

General Theory

The elements of the P+PR automatic upstream control system are shown in the block diagram, figure 2. The first element is the sensor that measures the water surface in the stilling well located immediately upstream of the controlled gate. The output signal, YWELL, of the stilling well water level sensor is modified by the filter element to eliminate unnecessary gate movements that would be caused by wind-wave action or local disturbances of short durations. The requirements for the filter element are described in subsequent paragraphs. The output signal YF of the filter element is the input to the proportional,

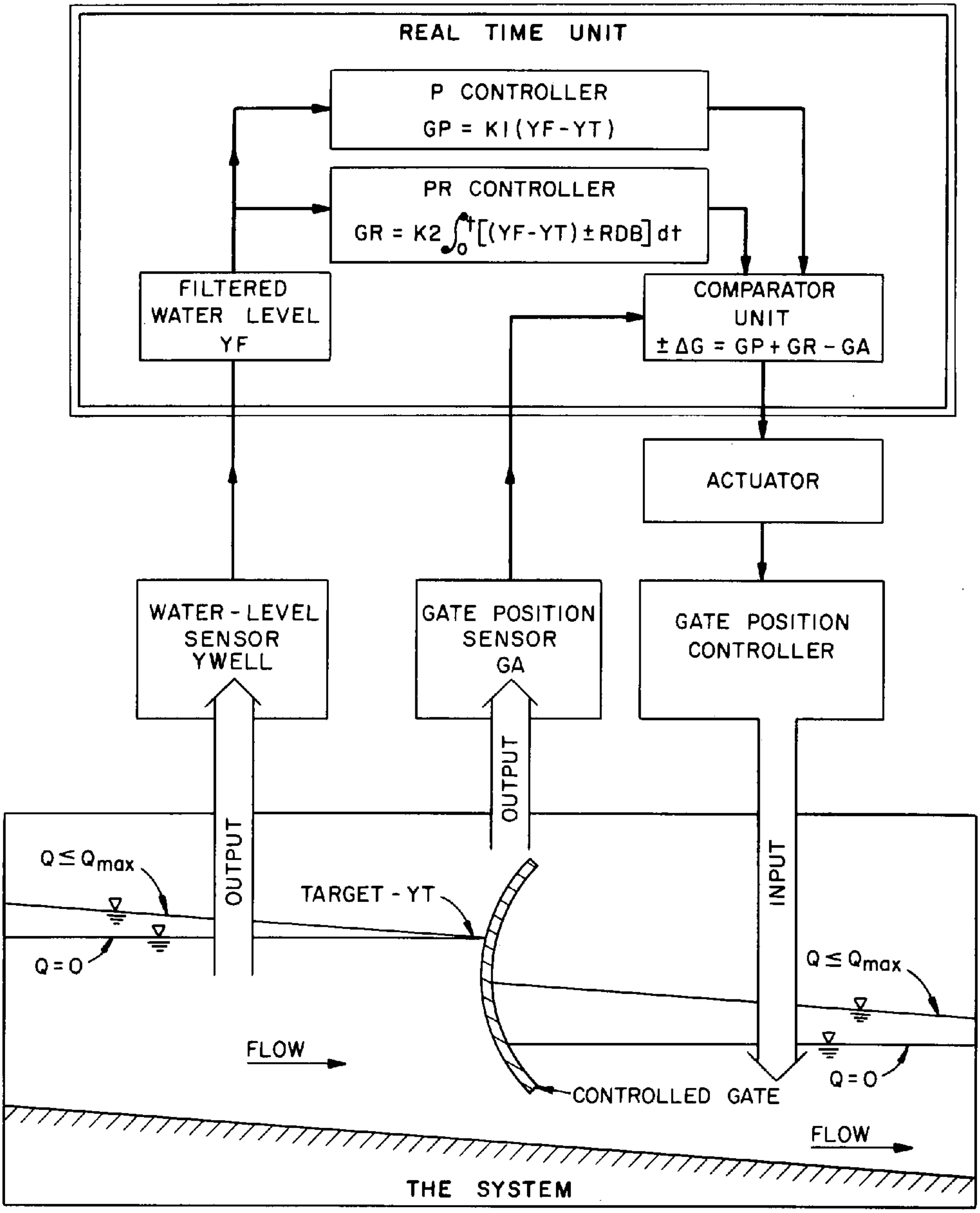


Figure 2. - Proportional plus Proportional Reset (P+PR) automatic upstream control system block diagram.

P-controller, and to the proportional reset, PR-controller. The P-controller solves the equation:

$$GP = K1 * (YF-YT) \quad (1)$$

where:

GP is the desired P-controller gate opening (meters)

K1 is the proportional gain constant

YT is the selected target water level (meters)

YF is the canal water level modified by the filter element (meters)

The PR-controller solves the equation:

$$GR = K2 * \int_0^t [(YF-YT) \pm RDB]dt \quad (2)$$

where:

GR is the desired PR-controller gate opening (meters)

K2 is the proportional reset gain constant, per second

t is real time, seconds

dt is the discrete time interval, seconds

±RDB is the required deadband for the PR-controller

The amount of "offset," (YF-YT), when multiplied by the P-controller gain, K1, results in a positioning of the controlled gate (immediately downstream) to control the flow into the downstream canal reach. The residual water level "offset" characteristics of the P-controller are gradually eliminated by the PR-controller as time progresses. The PR-controller integrates or sums the area of the "offset" with respect to time. The accumulated area is multiplied by the PR-controller gain, K2, to obtain an additional positioning of the controlled gate.

The P-controller provides the primary control response immediately after a flow change from upstream arrives at the water level sensor. As a new steady-state flow condition develops at the target depth, YT, the PR-controller provides the primary control response. Typical response is shown (fig. 3) of the P+PR automatic upstream control to a sudden increase of canal flow upstream. The PR-controller does not sum the area within the PR-controller deadband, RDB, and it is turned "on" when the absolute value of the "offset" (YF-YT) is greater than or equal to RDB (fig. 3b).

The output signals, GP and GR, (fig. 2) of the P- and PR-controllers are input signals to the comparator unit. The comparator unit sums

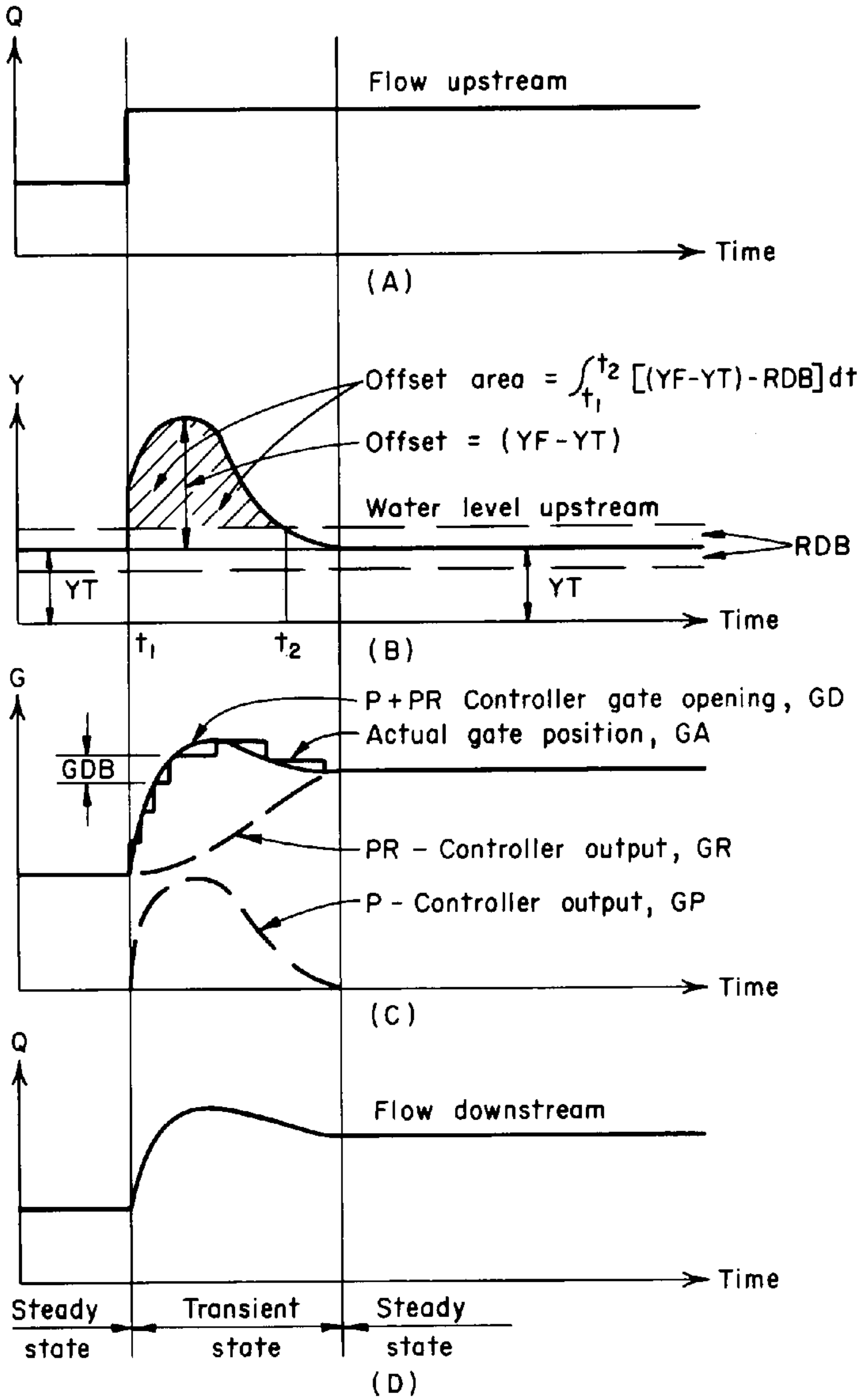


Figure 3. - Typical response of the P+PR automatic upstream control to a sudden increase of upstream canal flow.

algebraically the input signals, GP and GR to obtain the total gate opening, GD, as follows:

$$GD = GP+GR \qquad (3)$$

The total desired gate opening is then compared to the actual gate position, GA, to obtain the error signal, $\pm\Delta G$, as follows:

$$\pm\Delta G = GD-GA \qquad (4)$$

The value of actual gate position, GA, is measured by a sensor usually driven by the gate hoist shaft. If the error signal, $\pm\Delta G$, is greater than the referenced gate movement deadband, GDB (fig. 3c) the comparator unit (fig. 2) will energize the raise or lower relay of the actuator element. The actuator then energizes the gate motor to raise or lower the gate depending on the polarity of the error signal, $\pm\Delta G$. The gate will raise or lower until the error signal, $\pm\Delta G$, is zero, at which time gate motion stops. The gate movement referenced input deadband, GDB, is necessary because of the very fast rate of gate movement characteristic relative to the computed desired gate opening, GD.

Filter Element

The investigation approach used the assumption that the water surface sensor (fig. 2) would be located a very short distance upstream of the controlled gate. Therefore the dead time of the system, the time required for a transient wave to travel between the water level sensor and the gate, would be very short. A system with a very short dead time would not need a time lag compensator to provide control stability. However, the stilling well design does not provide sufficient or satisfactory dampening. Waves of high magnitudes and of relatively high frequency caused by the wind or from local disturbances, such as from gate movements, would not be significantly dampened by the stilling well. As a result, frequent gate control responses will occur which are not associated with changes of flow upstream. The unnecessary gate responses caused by wind or local disturbances can be eliminated for this purpose only by including the filter element having a small time constant, TC.

The filter element is a necessary time lag compensator for automatic downstream control systems such as the EL-FLO plus RESET controller [4]. For the EL-FLO plus RESET control system, the filter-time constant, TC, ranges from 100 to 4000 seconds to provide control stability. Effects of waves of high frequency are filtered out with a time constant of 100 seconds or more and, therefore, are not a problem with automatic downstream control systems.

An electronic filter as used in the EL-FLO plus RESET controller could be used as a filter element in the P+PR automatic upstream control system. Using a time constant, TC, of 100 seconds, high frequency waves would be damped out. The design of the electronic filter is adequately described in reference [4].

A hydraulic filter could also be used. The hydraulic filter involves a small well with a very small diameter capillary tube inlet placed inside the canalside stilling well. The water surface elevation, YF, in the small well would be measured for the input signals to the P+PR controller. Reference [5] adequately describes the hydraulic filter design. However, long-term operation of a hydraulic filter has not proven to be reliable [4].

This report offers a digital filter that could be used in microprocessors or where logic circuits are available. The digital filter is actually a mathematical simulation of the hydraulic filter [5] using the finite element method to solve for the new filter water surface elevation, YF.

The digital filter logic statements are as follows:

1. Initialize the following variables at time zero or at startup:

   DOLD = YWELL

   YOLD = YWELL

DT = 0.5

TC = 100.0

CIDT = 0.5 * DT/TC

2. Real time computation at discrete time intervals, DT, are as follows:

YF = [CIDT * (YOLD+YWELL)-DOLD * (CIDT-1.0)]/(CIDT+1.0)

YOLD = YWELL

DOLD = YF

where:

DT is the discrete time interval (seconds)

TC is the filter time constant (seconds)

YWELL is the water surface sensor output (meters)

YF is the simulated filter output (meters)

YOLD is the old YWELL value

DOLD is the old YF value

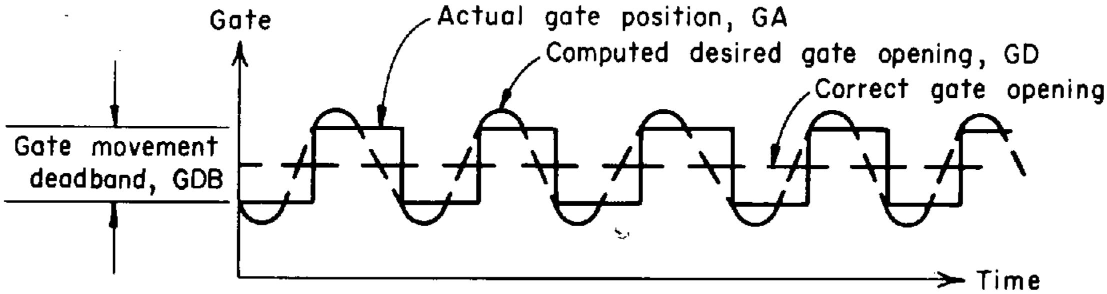
CIDT is a constant representing the simulated hydraulic filter

The selection of the discrete time interval, DT, is very important. It must be 0.5 second or less in order to define a high-frequency sinusoidal wave with a period of 1 second or less. Therefore, the water surface sensor output, YWELL, and the logic statements in item 2, page 15, are computed at intervals of DT equal to 0.5 second. The time interval, DT, could also be the same dt in equation (2). However, the equation (2) discrete time interval, dt, could be much larger (such as 60 seconds) without affecting the accuracy of the PR-controller output, GR.

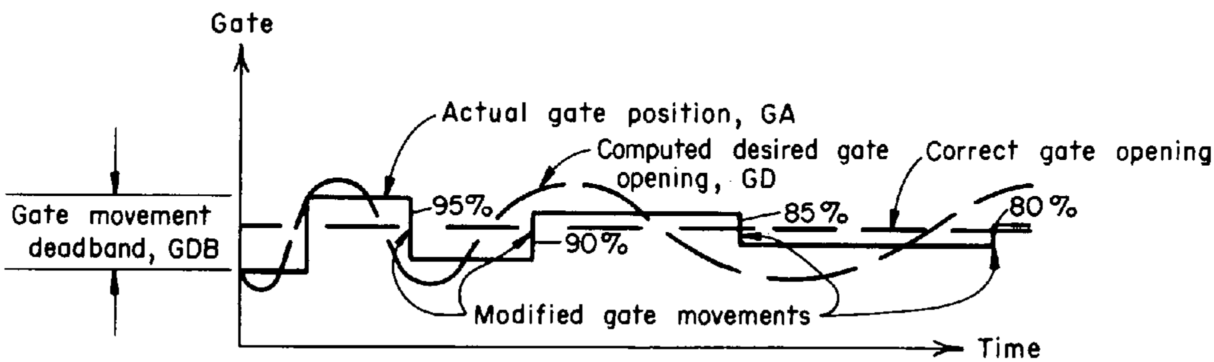
Gate Movement Deadband Modification

A gate movement deadband, GDB, is necessary because of the very fast rate of gate movement characteristics relative to the computed desired gate opening, GD equation (3). For example, the bypass drain gate hoist moves the gate at a rate of 0.43 m/min (1.42 ft/min) as compared to a typical computed gate opening, GD, rate of 0.006 m/min (0.02 ft/min). Therefore, the gate movement has to be stepped into position. The stepping or "jogging" happens whenever the selected difference or deadband, GDB, occurs between the computed gate opening, GD, and the actual gate opening, GA, as described earlier.

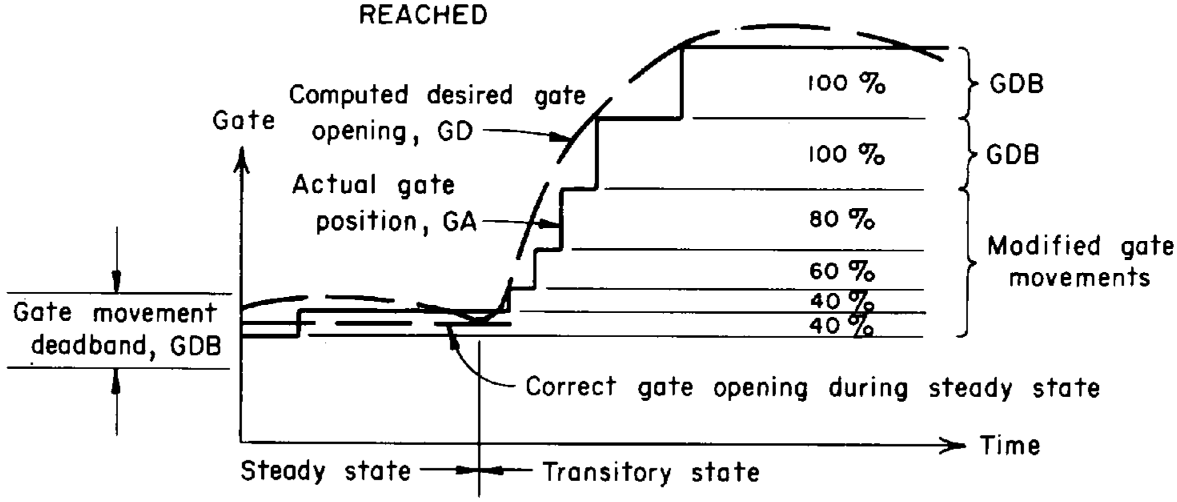
The jogging of the gate into position during the transient state (fig. 3) does not present a problem. However, during the steady state, gate jogging can be frequent, causing many gate movements and the wear and tear on mechanical equipment of the gate hoist increases. Figure 4(A) illustrates a typical gate "sawtooth" operation during a steady-state flow condition. The number of



(A) – TYPICAL GATE SAW-TOOTH OPERATION DURING STEADY STATE FLOW CONDITIONS.



(B) – GDB MODIFICATION OF A GATE SAW-TOOTH OPERATION DURING STEADY STATE FLOW CONDITIONS. GATE MOVEMENTS ARE REDUCED BY 5% INTERVALS UNTIL 40% OF GDB IS REACHED



(C) – GDB MODIFICATION OF A GATE SAW-TOOTH OPERATION FROM STEADY TO TRANSITORY STATE FLOW CONDITIONS. (STARTING WITH MINIMUM MODIFIED GATE MOVEMENTS OF 40% OF GDB)

Figure 4. - Gate saw-tooth operation (A) modified, (B) and uncorrected (C) by the GDB modification procedure.

sawtooths can be as many as six to eight per hour. If logic can be programed by using a microprocessor unit or by using logic circuits added to the analog-type controllers, a relatively simple procedure can reduce the number of sawtooth gate operations in a given time period by a factor of 40.

The procedure developed in this report is labeled the "GDB modification." The gate movement deadband, GDB, is not actually changed. The gate, however, is not allowed to travel the full distance of the deadband, GDB. If the gate movement direction is opposite to the last gate movement, the gate travel distance is reduced by 5 percent. The 5 percent reduction continues as long as each gate movement is in the opposite direction of the previous gate movement until a minimum value of 40 percent of the deadband, GDB, is reached.

The sawtooth operation is modified (fig. 4(B)) but not completely eliminated by the GDB modification. The GDB modification procedure, however, allows the gate to obtain a position closer to the correct gate opening (fig. 4(A)). Notice (fig. 4(B)) the value of the gate movement deadband, GDB, remains constant and that for each reversed gate movement the gate is allowed to move 95 percent of GDB, then 90 percent, 85 percent, 80 percent, etc. The minimum value should not be less than 40 percent because of the very short run times (about

2 seconds) involved in operating the gate hoist motors. Shorter run times may damage the motor windings.

It is important that the GDB modification selected as 5 percent not be too large. Larger corrections can cause the gate to undershoot and the next gate movement will be in the same direction.

The GDB modification procedure just described must be "uncorrected" when a change of flow occurs or the canal is now in the transitory state. If the next gate movement is in the same direction as the previous direction, the percent of GDB modification remains the same and the gate moves the same distance as the previous distance. If, however, the gate has moved in the same direction for three consecutive jogs, the gate travel distance is increased by 20 percent. The 20 percent increase continues as long as the gate continues moving in the same direction and until 100 percent of the GDB modification is reached. The "uncorrected" procedure results in a slower initial response to changes of flow and may cause a slightly larger offset (fig. 3b) before the water surface elevation returns to the target value. The slower response at the beginning of the transitory state, however, was not considered to have significantly affected the desired response of the control system. The "uncorrected" GDB modification (fig. 4(C)) starts with a minimum of 40 percent gate travel modification during a steady state.

The following logic statements will accomplish the GDB modification procedure:

1. Initiate the following variables at time zero (startup):

```
     GD = GA
    GDB = 0.03
   GDBM = 1.0
     DB = 0.003
    JG1 = 2
    JG2 = 1
    JG3 = 1
 NLOWER = 0
 NRAISE = 0
```

2. Real time gate movement modification at discrete time intervals, dt, is as follows:

```
  IF(GD.LT.0.0) GD = 0.0
  GDIFF = GD-GA
  IF(ABS(GDIFF).LT.(GDB)) GO TO 1
  IF(GDIFF) 2,1,3
2 JG2 = 1
  GO TO 4
3 JG2 = 2
```

```
 4 IF(JG1.NE.JG2) GDBM = GDBM-0.05
   IF(JG3.NE.JG2) GDBM = GDBM-0.05
   IF(GDBM.LT.0.4) GDBM = 0.4
   IF(JG1.EQ.JG2.AND.JG3.EQ.JG1.) GDBM = GDBM+0.2
   IF(GDBM.GT.1.0) GDBM = 1.0
   GMOD = GA + GDIFF * GDBM
   JG3 = JG1
   JG1 = JG2
   IF(GMOD.LT.0.0) GMOD = 0.0
```

3. Example of real time gate movement by the comparator-actuator units with modified desired gate opening, GMOD:

```
 8 IF(GMOD-GA) 5,6,7
 5 NLOWER = 1
   NRAISE = 0
   TO to 6
 7 NRAISE = 1
   NLOWER = 0
 6 IF(ABS(GMOD-GA).GT.DB) GO TO 8
   NLOWER = 0
   NRAISE = 0
 1 CONTINUE
```

where:

GA is the actual measured gate opening (meters)

GD is the computed desired gate opening, equation (3) (meters)

GDB is the gate deadband at "turn on" (meters)

GDBM is the modified gate movement value

GMOD is the modified desired gate opening (meters)

DB is the gate deadband at "shutoff" (meters)

JG1 is the current gate travel direction

JG2 is the previous gate travel direction

JG3 is the second previous gate travel direction

NLOWER is the gate actuator lower relay sense switch, 1 = "ON" and 0 = "OFF"

NRAISE is the gate actuator raise relay sense switch, 1 = "ON" and 0 = "OFF"

ABS is the absolute value

GDIFF is the difference between the computed gate opening, GD, and the actual gate opening, GA, equation (4)

The above example of real time gate movement by the comparator-actuator units, item 3, is shown to complete the GDB modification procedure. The example does not include the logic necessary for fail-safe operation.

P+PR Controller Response Characteristics

P+PR mode provides the best method of upstream control for the bypass drain gates, used for this study. The P+PR controller will automatically regulate all possible flow changes that can occur on the bypass drain. However, there are practical restraints that should be employed during normal operating conditions. The restraints for normal operation are discussed in greater detail in the section on operating criteria.

Numerous mathematical model computer runs simulating the bypass drain were made to test the performance and stability of the P+PR upstream control system. One of the computer runs, run No. 42 shown in appendix I, is included in this report to demonstrate the P+PR response characteristics for transferring a sudden abnormal change of flow downstream. The abnormal change is actually a simulation of an emergency shutdown of the Yuma Desalting Plant assuming operation at maximum (ultimate) capacity. In run No. 42, the flow downstream from the bifurcation structure (intake to the desalting plant on the Wellton-Mohawk Drain Extension, labeled as check No. 0) increases 5 m^3/s (177 ft^3/s). It was assumed in run No. 42 that the bifurcation check No. 0 was opened at the gate hoist speed by remote manual control. A delay of 15 minutes in opening the gate was purposely chosen because a longer delay (more than 20 minutes) would cause the water surface upstream to top the canal lining. Therefore, the bifurcation check No. 0 should begin to open within the first 15 minutes after a desalting plant emergency shutdown.

The time history plot of run No. 42 appendix I, shows that the maximum water level rise of about 0.27 m (0.9 ft) will occur above check No. 1 of the bypass drain. A lesser water surface rise would have occurred if the bifurcation check No. 0 had started to open immediately after the desalting plant shutdown and at a slower rate, or smaller increments. A P+PR upstream controller at bifurcation check No. 0 would have also reduced the peak water level rise upstream from the bypass drain check No. 1. The water surface peak rise, upstream of the bypass drain checks No. 2, 3, and 4, averaged about 0.14 m (0.46 ft). The maximum rate of water surface rise at the Parshall flume (labeled as check No. 5) at the United States-Mexico International Boundary is about 0.2 m/h (0.7 ft/h).

Run No. 42 demonstrates the P+PR controller performance characteristics for transferring a sudden abnormal change of flow downstream. The water surface peak rise was within desirable limits. The water surface return to the target depths for the new steady-state flow was within a reasonable time period for control stability. Computer simulation runs were also made to analyze the response characteristics for small, large, increased, and decreased flow changes at low and high initial steady-state flow conditions. The output of the simulation runs to obtain response characteristics, are not included in this report because a large volume of time history plots were generated. However in all cases, the P+PR upstream controller performed with stability, achieved satisfactory response characteristics, and automatically regulated all degrees of flow change satisfactorily, including an emergency shutdown of the Yuma Desalting Plant.

P+PR Control Parameters

The control parameters were selected to achieve desirable water level response characteristics, and include the P-controller gain, K1, the PR-controller gain, K2, the filter time constant, TC, the target depth, YT, and the deadbands for gate movement, GDB, and the PR-controller, RDB. The control parameters are dependent on the geometry of the check gate structure and the canal section immediately upstream and downstream. Because the geometry including the bottom slope and the distance between check gates is nearly the same, the control parameters are identical for all of the bypass drain check gate structures. The dead time of the system (the travel time of a transient wave between the upstream water surface elevation sensor and the controlled gate) is very short. A filter is, therefore, not required as a timelag compensator to maintain control stability. However, a filter with a time constant of 100 seconds is required to eliminate gate control responses that would be caused by high-frequency wind waves or local disturbances as discussed previously. The description and physical properties of the bypass drain are summarized in appendix IV.

The selected control parameters are summarized (table 1) for the recommended bypass drain P+PR upstream control system including maximum discrete time intervals. It should be noted that all measured and computed values of the control system must be correctly scaled and calibrated if each element (fig. 2) is to perform in accordance with equations (1) through (4).

SOT/VRT (SET-OPERATE-TIME/VARIABLE-REST-TIME)

The SOT/VRT mode of control known as the "Colvin controller" was analyzed as an alternative to the P+PR controller. The SOT/VRT method does not have reset capabilities; that is, the residual "offset" of the water surface is not eliminated. The mathematical model studies simulating the bypass drain with the SOT/VRT mode of automatic upstream control showed that the water surface elevations would not return to the YT (desired target level). Run No. 44 appendix II, illustrates the performance of the SOT/VRT controller using the same emergency shutdown of the Yuma Desalting Plant as was simulated in run No. 42 appendix I. The water surface reached a depth of nearly 2.1 m (7.0 ft) upstream of check No. 1, which is the top of the bypass drain lining. The water surface remained at this

Table 1. - *Bypass drain P+PR control parameters*

Bypass drain check No.	Station, m (ft)	Target YT m	Target YT (ft)
1	258+65.96 (845+34.0)	1.77	(5.81)
2	185+42.20 (608+34.0)	1.85	(6.06)
3	119+01.22 (390+46.0)	1.65	(5.41)
4	59+72.86 (195+96.0)	1.65	(5.41)
5	0+33.83 (1+11)	Free flow 6-m (20-ft) Parshall flume, $Q = 76.25 H_a^{1.6}$	

Parameters common to all bypass drain checks except number 5:
- P-gain (K1) = 1.0
- PR-gain per second K2 = 0.00058
- Filter (TC) = 100 seconds
- Discrete time intervals: P+PR DT (max) = 60 seconds; Filter DT (max) = 0.5 seconds
- Deadbands: Gate GDB = 0.03 m (0.1 ft); Reset GDB = 0.015 m (0.05 ft)

depth for the new steady-state flow condition and did not return to the YT, nor did it upstream of checks No. 2, 3, and 4. If reset was added to the SOT/VRT mode of control, the resulting control algorithm would approach that of the P+PR controller having similar response characteristics, but no such attempt was made.

The SOT/VRT mode of control without reset capabilities will not provide adequate maintenance of water surface elevations at YT (fig. 2) during steady-state flow conditions; therefore SOT/VRT is not recommended for automatic upstream control of the bypass drain check gates.

OPERATIONAL CRITERIA

Several mathematical model computer runs are made to establish operational criteria for normal operating conditions. As discussed previously the P+PR controller, with the selected control parameters (table 1), will provide automatic upstream control for flow changes that can occur on the bypass drain. However, during normal flow conditions certain restraints should be employed at the bifurcation check No. 0 on the change of flows to be transferred downstream to minimize the water surface changes upstream and downstream of each bypass drain check structure.

Flow increases should be held to about 2.8(m^3/s)/h (100(ft^3/s)/h) (run No. 29, appendix III, illustrates a ramp function of this flow increase at the bifurcation check No. 0). The water surface upstream from the bypass drain checks reached a peak rise of 0.05 m (0.15 ft), well within acceptable limits. Flows could increase to the above limit in steps or instantaneously; however, the maximum water level peak rise would increase to about 0.1 m (0.35 ft) which is not too unreasonable. The decrease of flow, however, is limited to drawdown criteria imposed on the bypass drain. Assuming a 0.3-m/d (1.0-ft/d) drawdown criteria, the decrease in flow would range from 3.1(m^3/s)/d (110(ft^3/s)/d) at high initial flows to 1.2 m^3/s/d (43(ft^3/s)/d) at low flow conditions. The decreased flow limitation versus the initial steady-state flow condition is shown (fig. 5) based on a maximum 0.3-m/d (1.0-ft/d) drawdown. This limitation is based on this maximum decreased water level immediately downstream from the check structures where the largest change of water surface elevation occurs, since the water surface at the downstream end of the canal reach is held nearly constant.

Check No. 5, shown in run No. 29 appendix III, is the Parshall flume located at the United States-Mexico International Boundary. The changes of flow arrive at the Parshall flume about 5 hours after the change of flow is made at the Yuma Desalting Plant bifurcation check No. 0. Run No. 42 appendix I, shows that the average change in flow

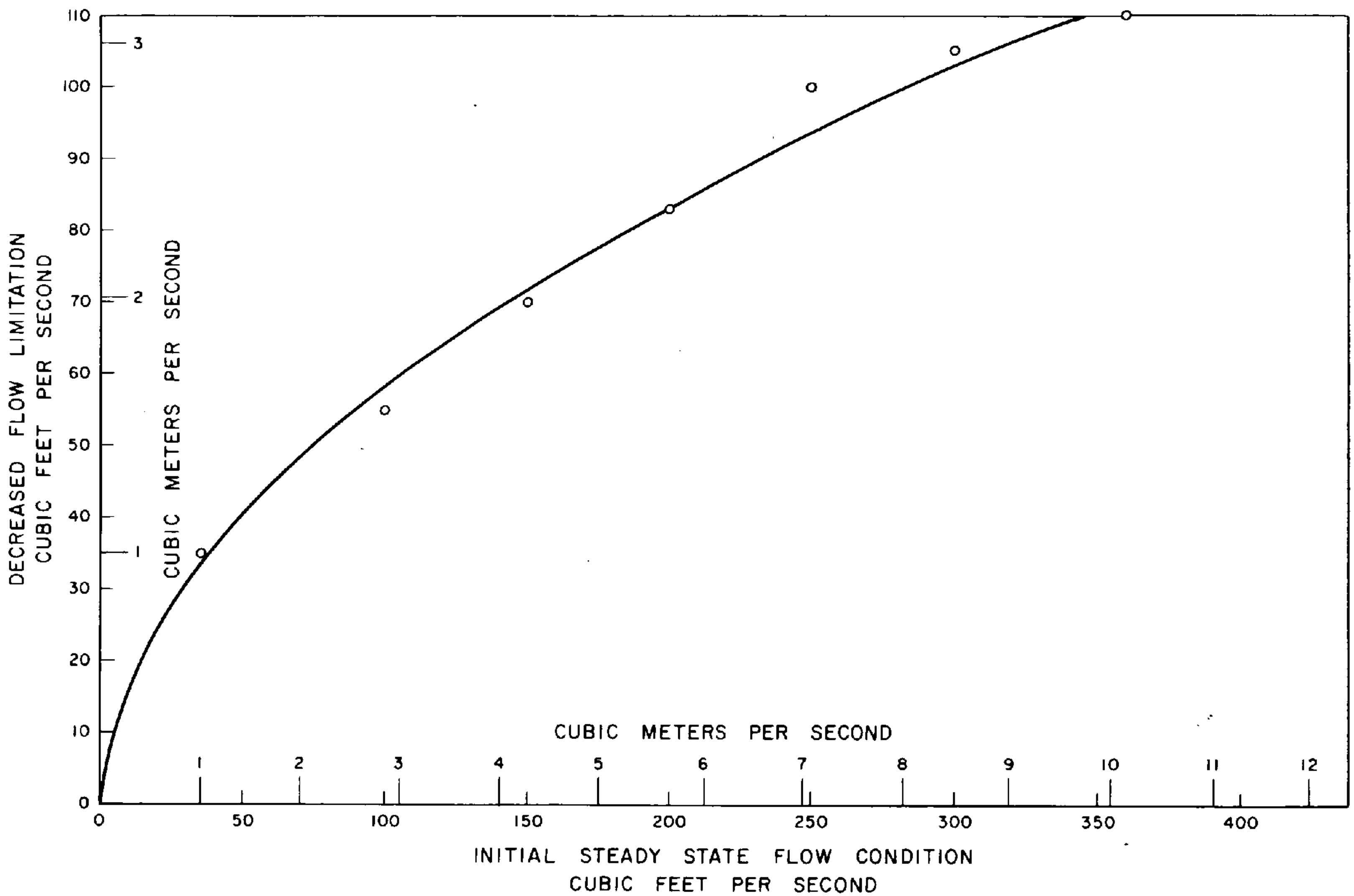


Figure 5. - Bypass drain flow reduction limitation based on 0.3-m/day (1.0-ft/day) water surface elevation drawdown criteria.

occurs at the flume, about 5.5 hours and a new steady state is reached in about 7.5 hours, after a sudden change of flow occurs at the bifurcation check No. 0. Run No. 29, appendix III, shows that the discharge has reached a new steady state 7 hours after the stop of the ramp change in flow has occurred at the bifurcation check No. 0. The arrival times of flow changes at the United States-Mexico International Boundary were shown because the operators of the bypass drain located in Mexico will have to be given this information if the bypass drain is to be operated manually. If the same automatic upstream P+PR control system is installed on the bypass drain check structures in Mexico, then notification of exact arrival times of flow changes will not be necessary.

Throughout the analysis of the P+PR automatic upstream control system and the development of operating criteria the YT's (fig. 2) were held constant at the depth of maximum design flow in the bypass drain. Because the P+PR control system returns the water surface back to the selected YT's after a flow change has occurred, there does not appear to be a reason to change the YT for control purposes. Changing the YT for the purpose of either storing flow or releasing additional flows from storage within the bypass drain prism would also appear to have minimal benefits because the time periods involved would be too short to allow for significant outages of the bypass drain for maintenance purposes downstream in Mexico. Therefore, adjusting the desired YT by remote control from the Yuma Desalting Plant would have minor benefits and is not required for automatic upstream control.

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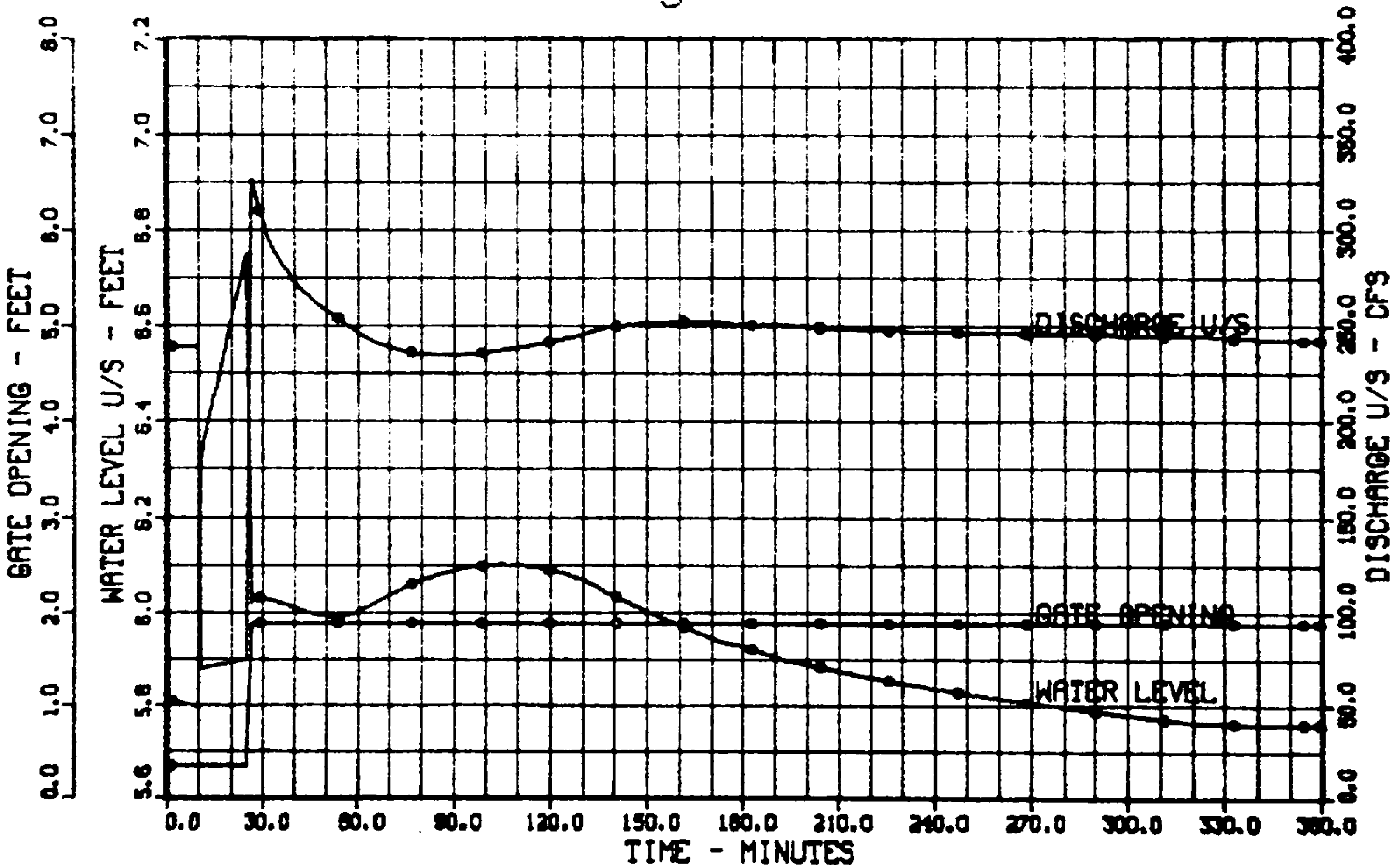
APPENDIX I

Bypass Drain Time History Plot, Run No. 42

Mathematical model simulation of the bypass drain with the P+PR automatic upstream control, illustrates the controller performance using the abnormal flow change of an emergency shutdown of the Yuma Desalting Plant, when operating at maximum (ultimate) capacity.

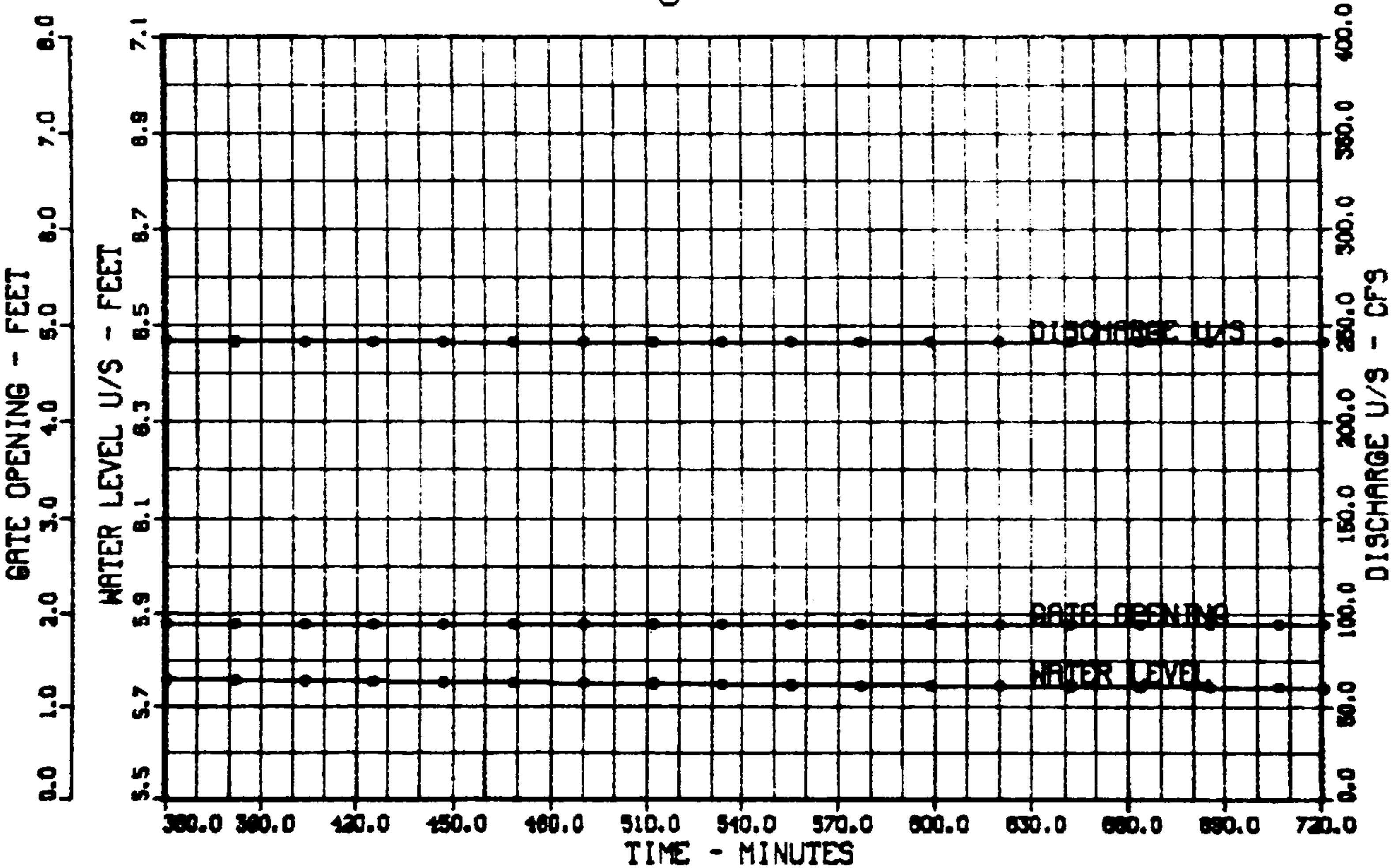
BYPASS DRAIN - CHECK NO. 0

Time History Plot Run No. 42

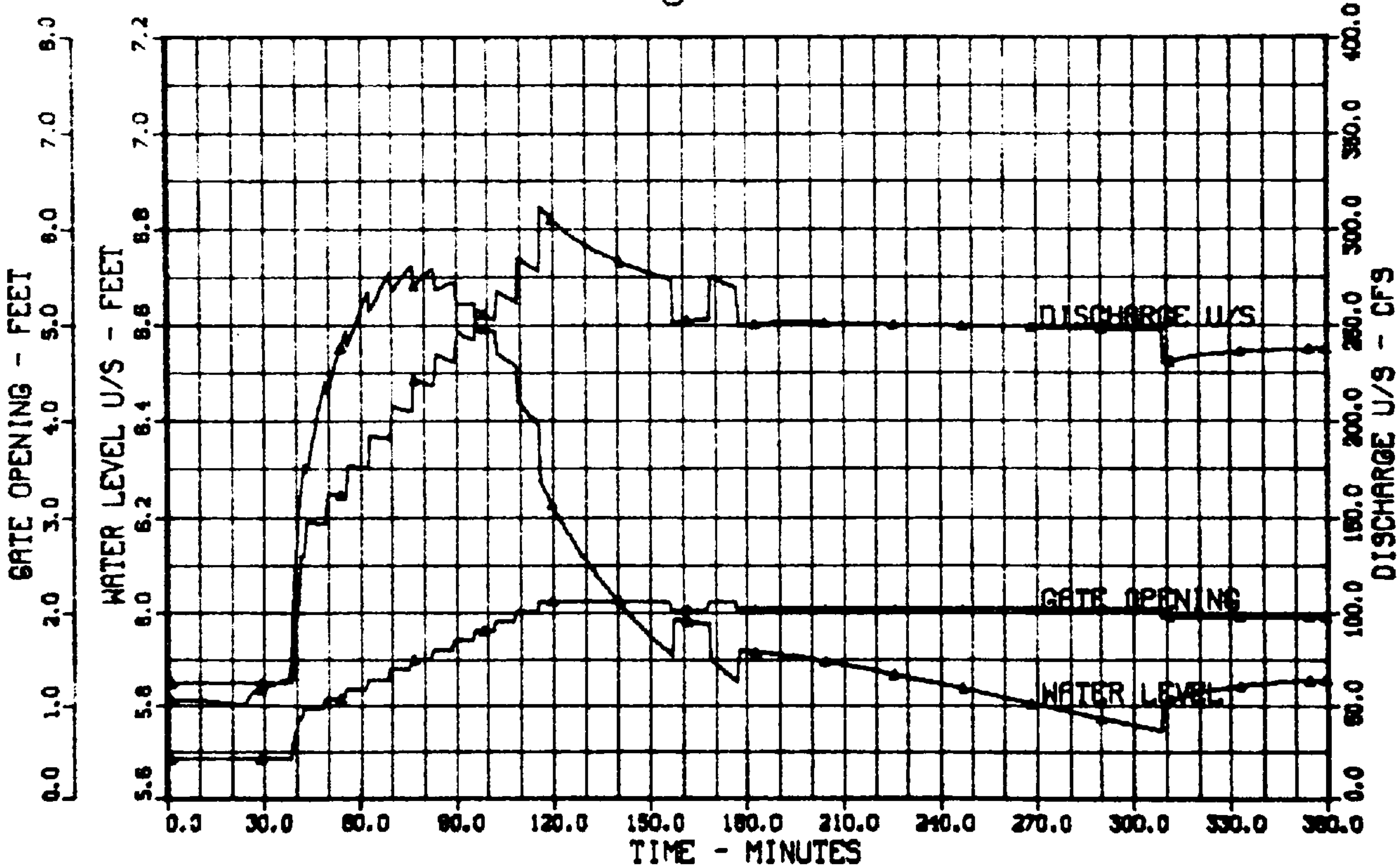


BYPASS DRAIN - CHECK NO. 0

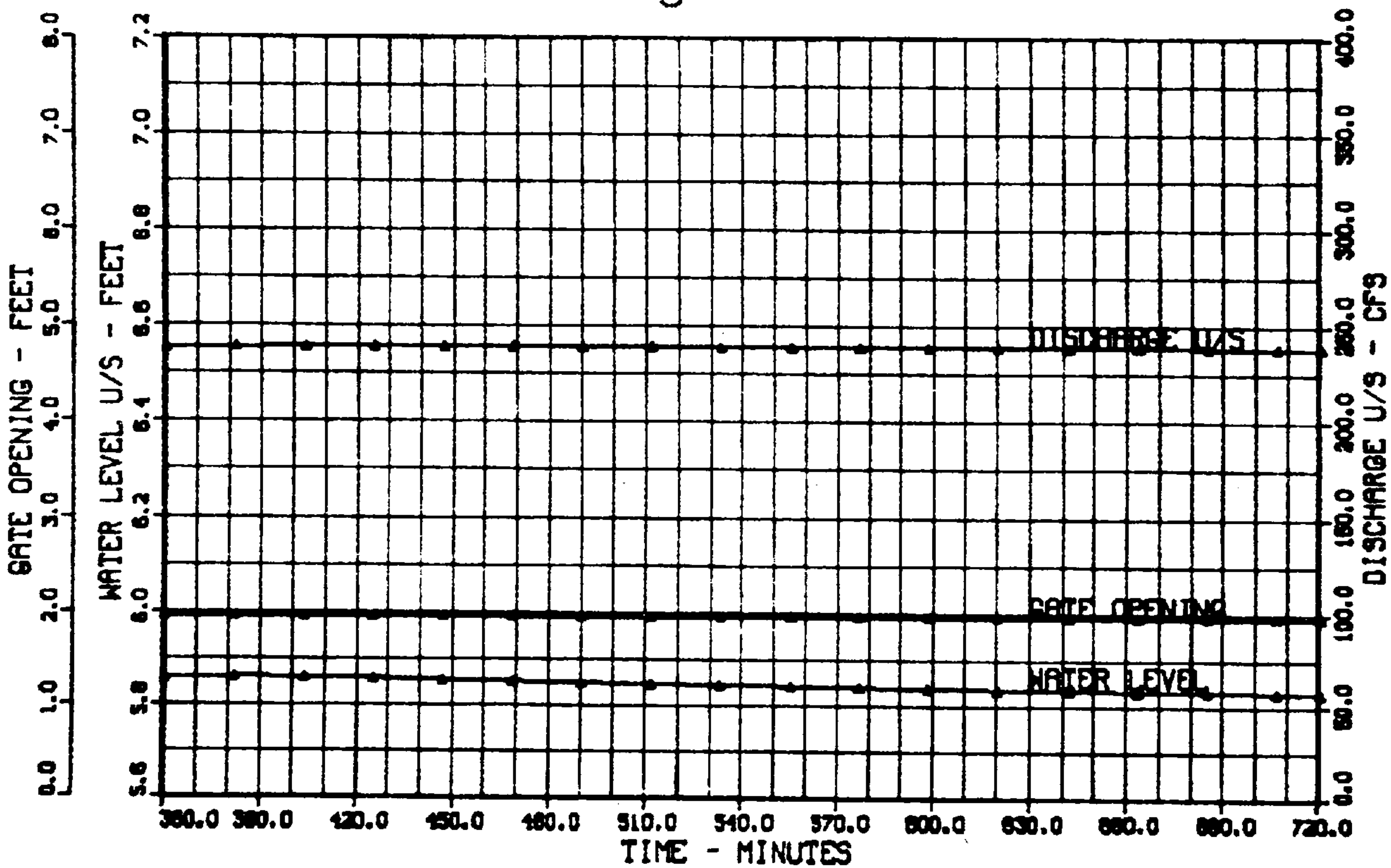
Time History Plot Run No. 42



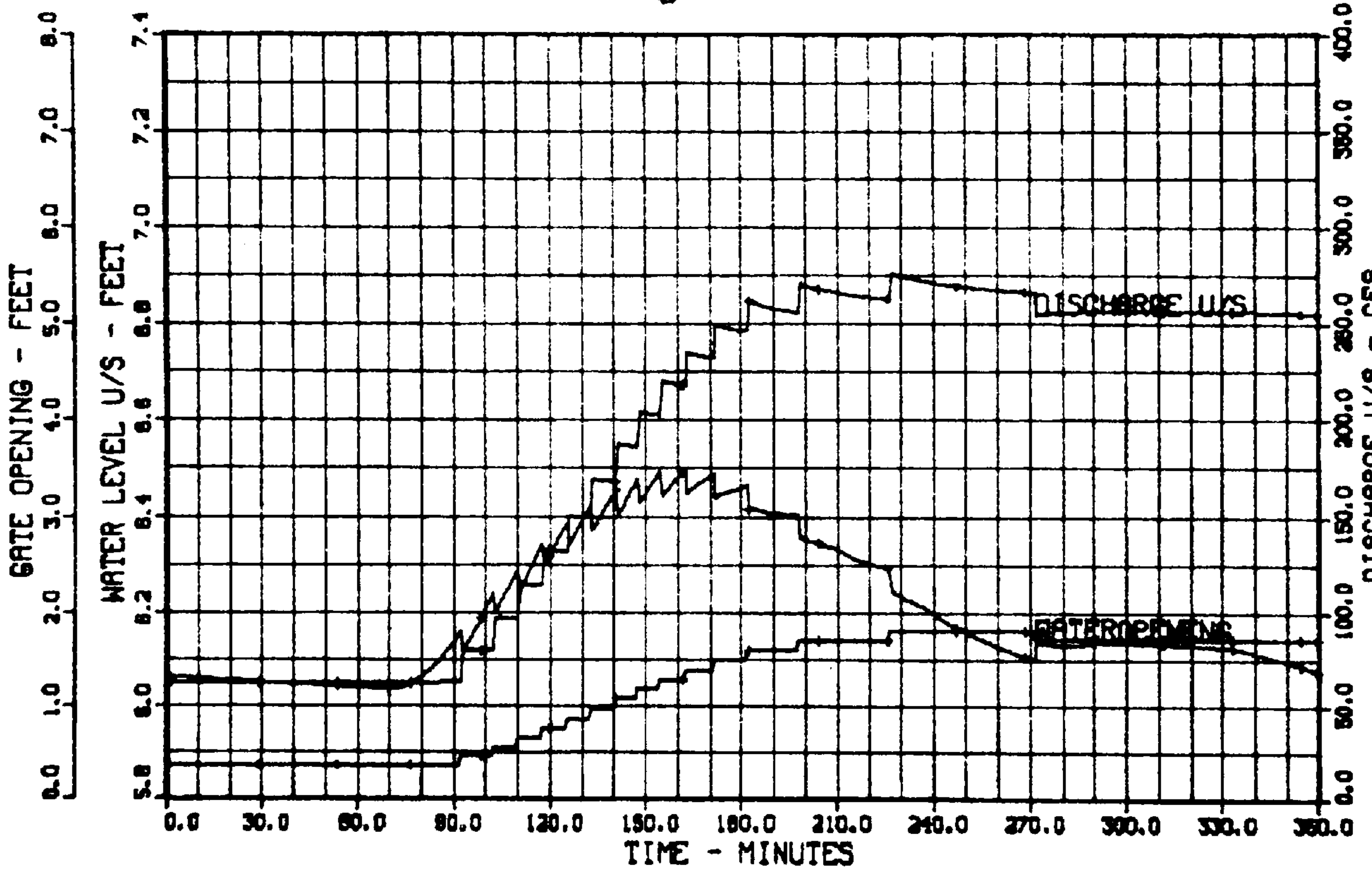
BYPASS DRAIN - CHECK NO. 1
Time History Plot Run No. 42



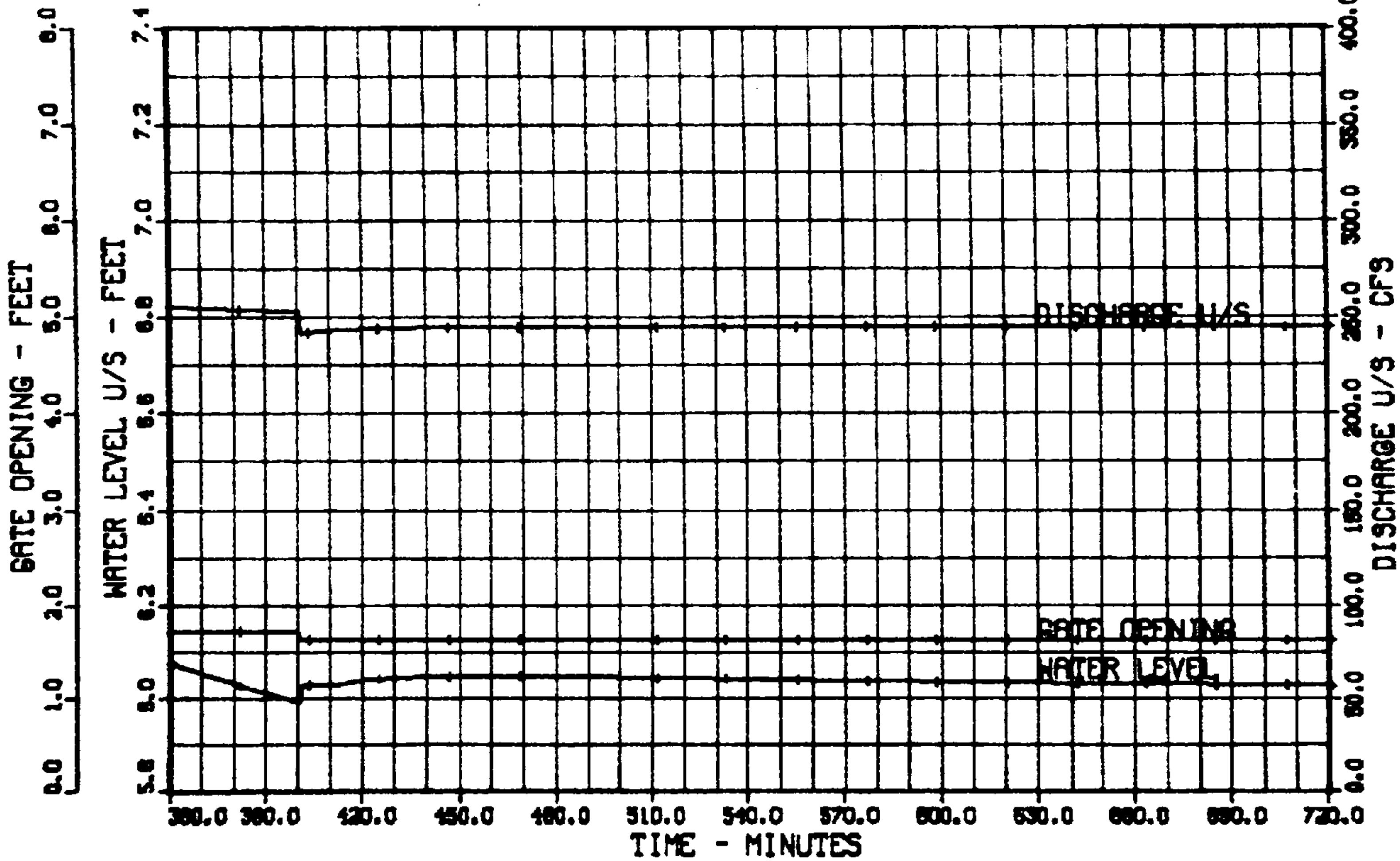
BYPASS DRAIN - CHECK NO. 1
Time History Plot Run No. 42

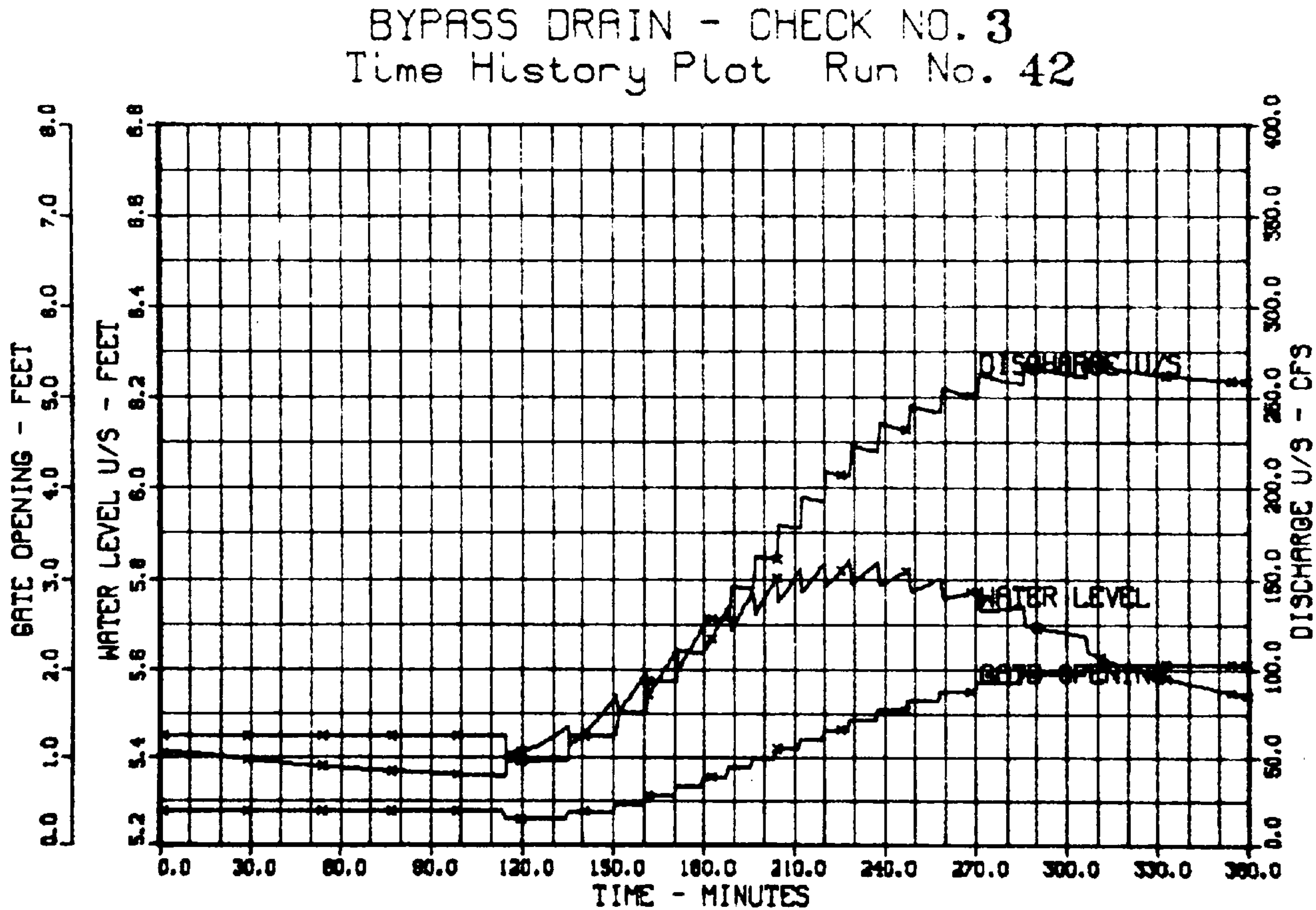


BYPASS DRAIN - CHECK NO. 2
Time History Plot Run No. 42

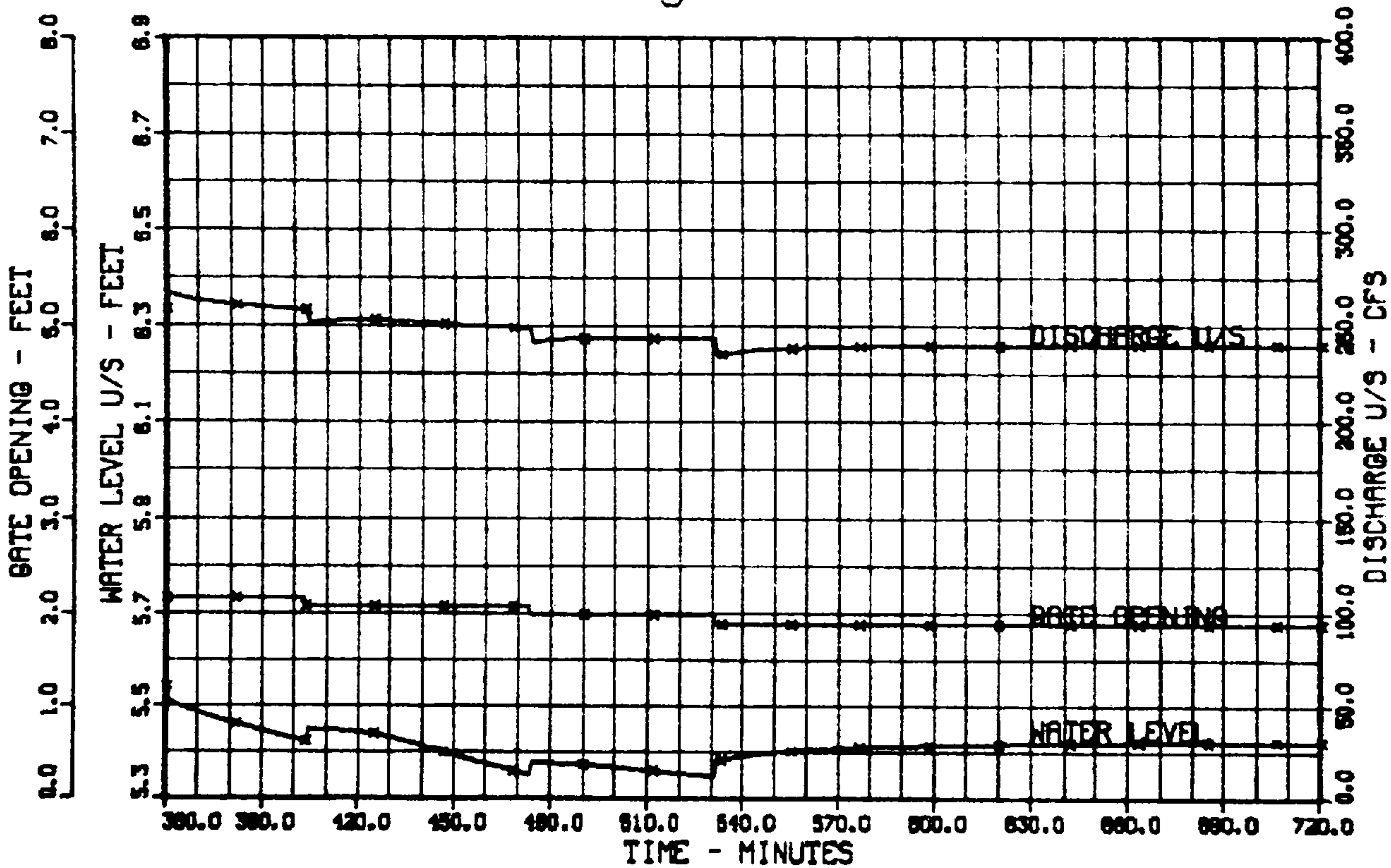


BYPASS DRAIN - CHECK NO. 2
Time History Plot Run No. 42

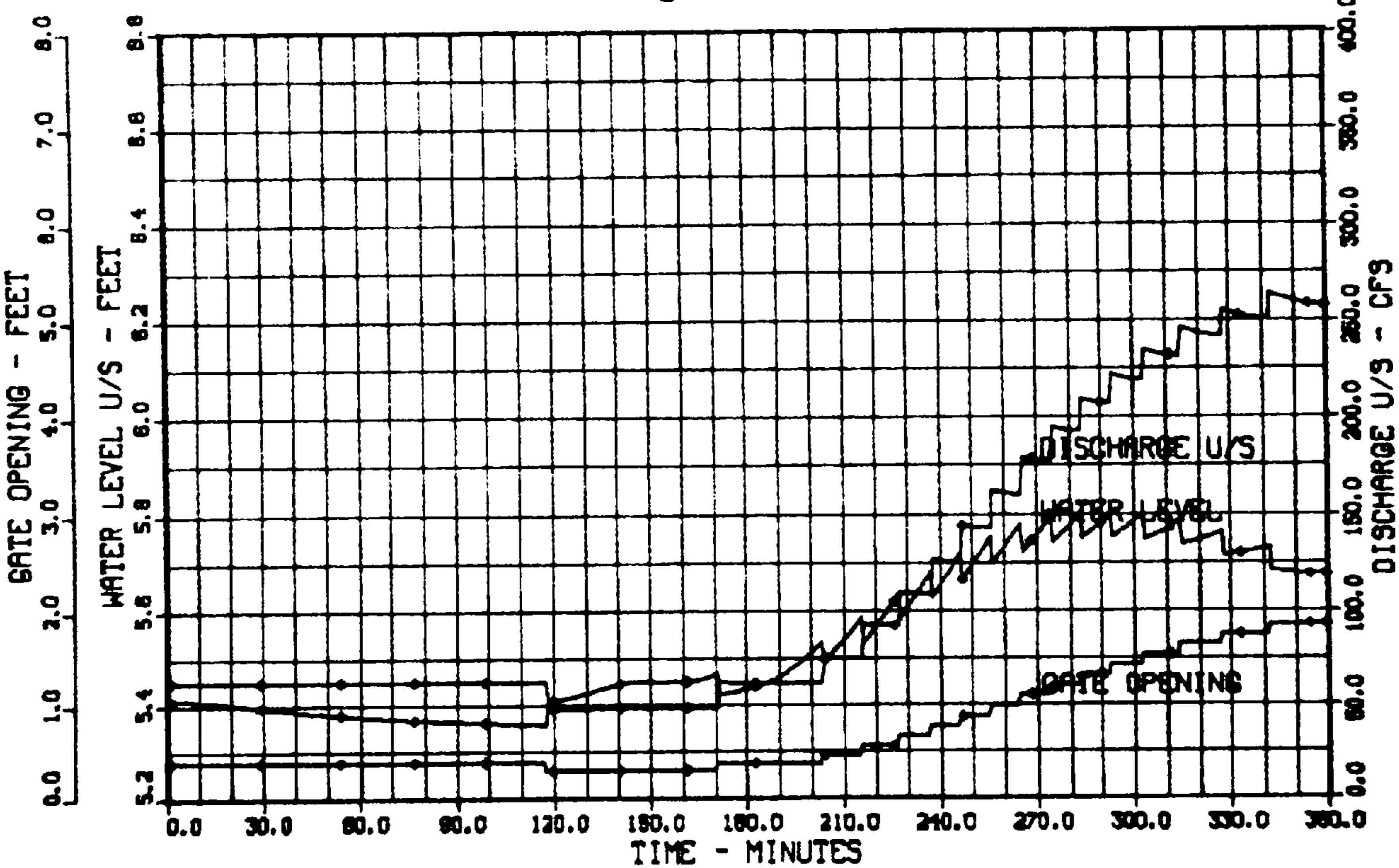



BYPASS DRAIN - CHECK NO. 3
Time History Plot Run No. 42
GATE OPENING - FEET
WATER LEVEL U/S - FEET
DISCHARGE U/S - CFS
TIME - MINUTES
DISCHARGE U/S
WATER LEVEL
GATE OPENING
0.0
30.0
60.0
90.0
120.0
150.0
180.0
210.0
240.0
270.0
300.0
330.0
360.0

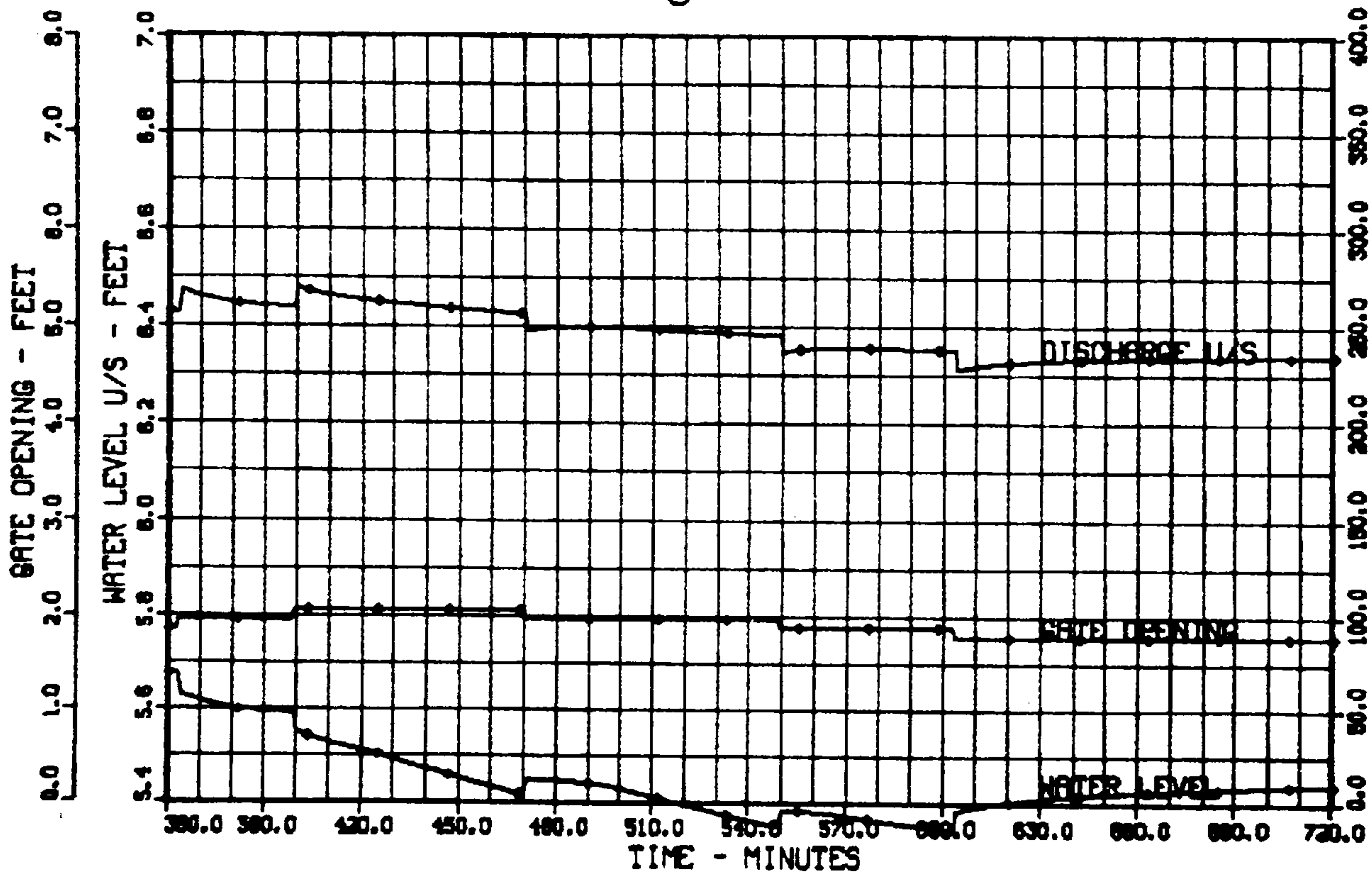
BYPASS DRAIN - CHECK NO. 3
Time History Plot Run No. 42

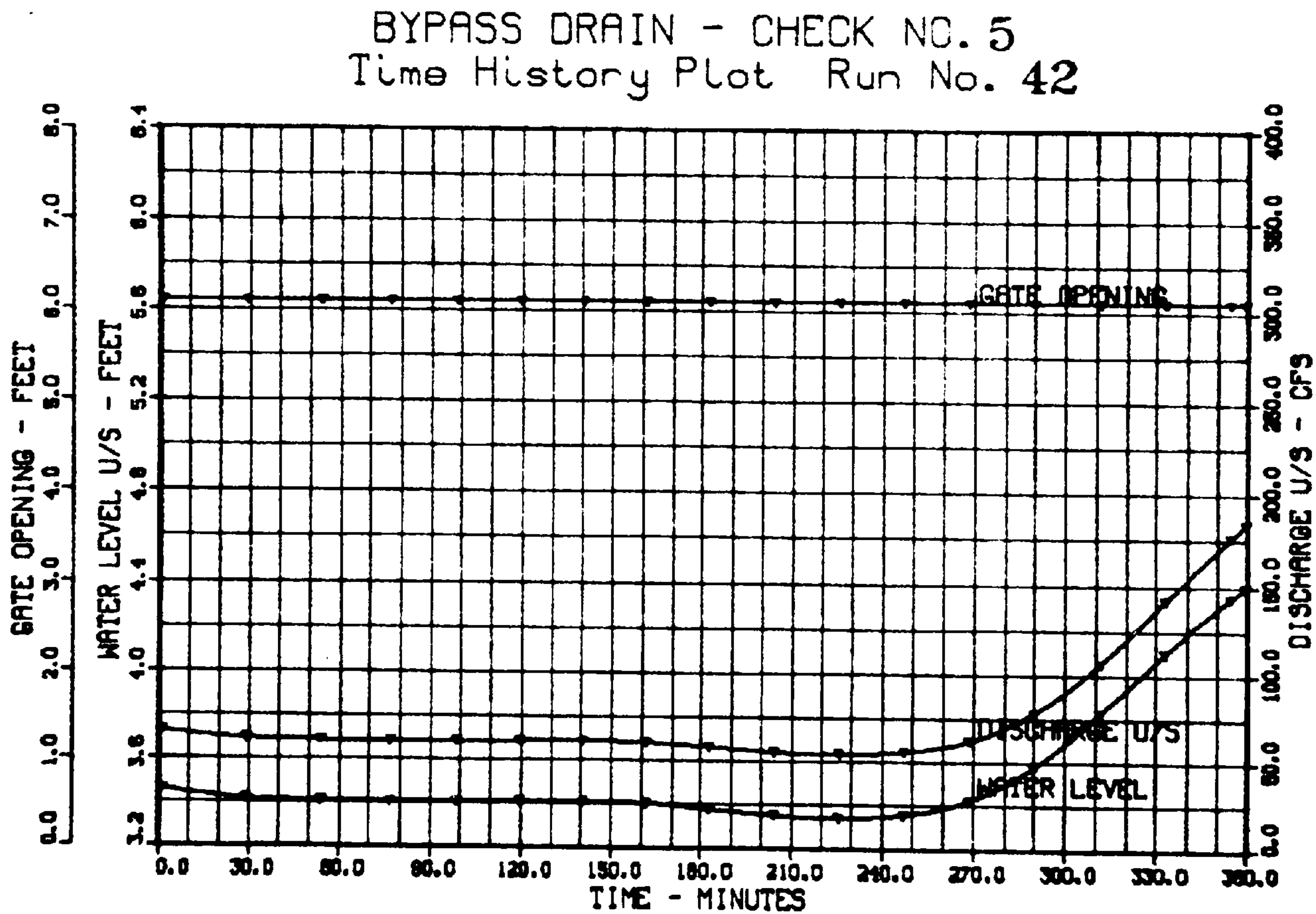


BYPASS DRAIN - CHECK NO. 4
Time History Plot Run No. 42

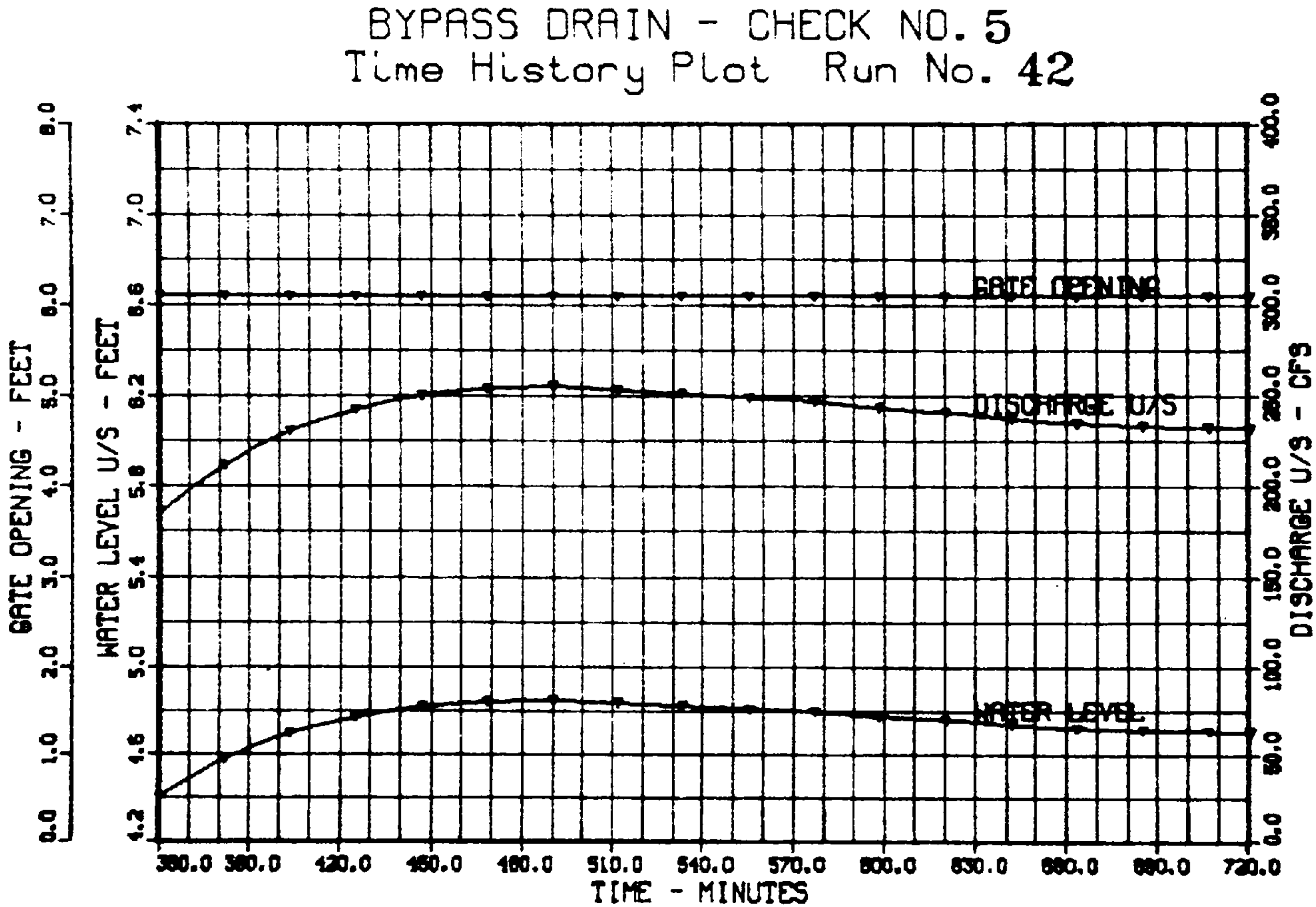


BYPASS DRAIN - CHECK NO. 4
Time History Plot Run No. 42




BYPASS DRAIN - CHECK NO. 5
Time History Plot Run No. 42
GATE OPENING - FEET
WATER LEVEL U/S - FEET
DISCHARGE U/S - CFS
TIME - MINUTES
GATE OPENING
DISCHARGE U/S
WATER LEVEL
0.0
30.0
60.0
90.0
120.0
150.0
180.0
210.0
240.0
270.0
300.0
330.0
360.0

47



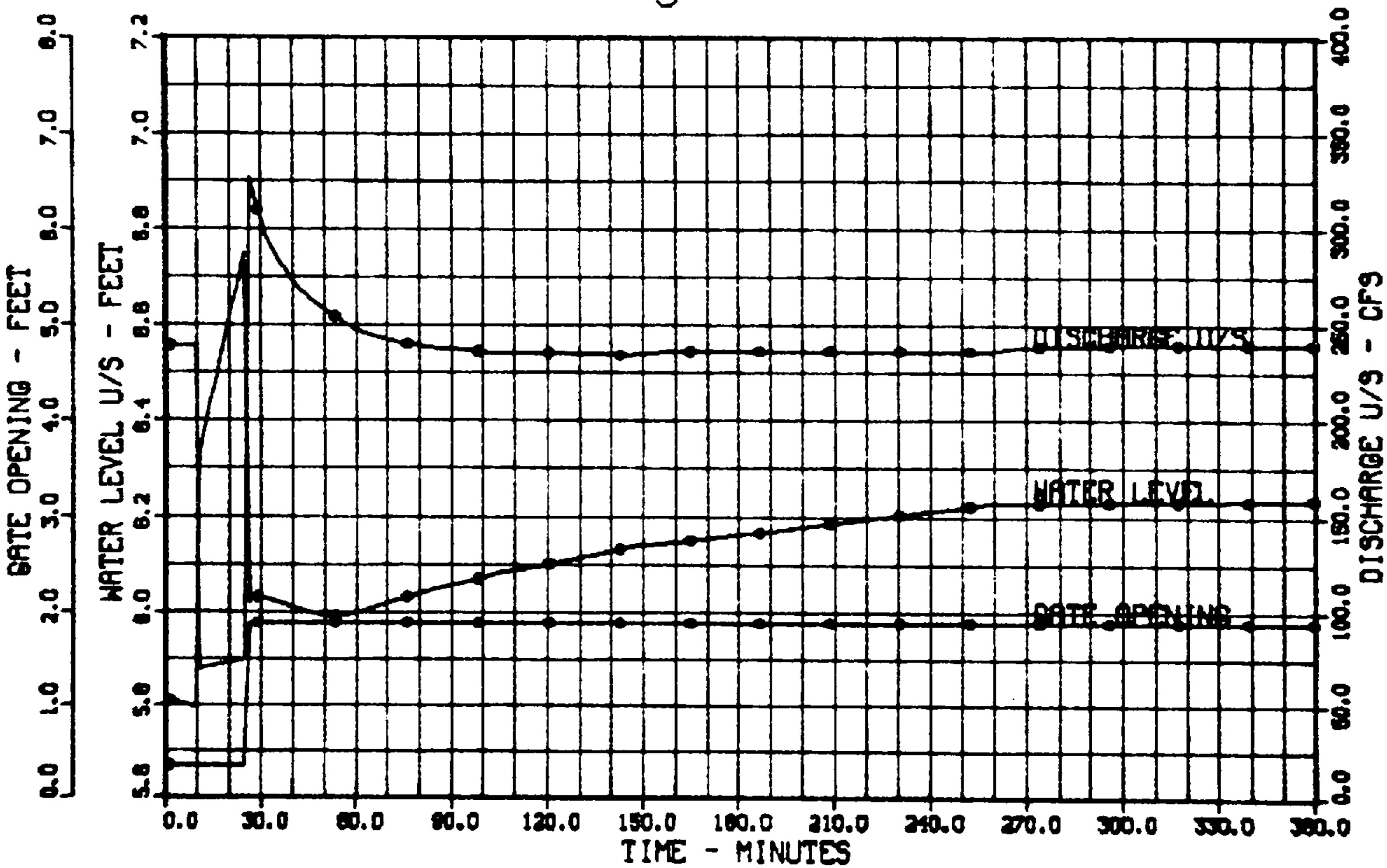
BYPASS DRAIN - CHECK NO. 5
Time History Plot Run No. 42
GATE OPENING - FEET
WATER LEVEL U/S - FEET
DISCHARGE U/S - CFS
TIME - MINUTES
GATE OPENING
DISCHARGE U/S
WATER LEVEL

APPENDIX II

Bypass Drain Time History Plot, Run No. 44

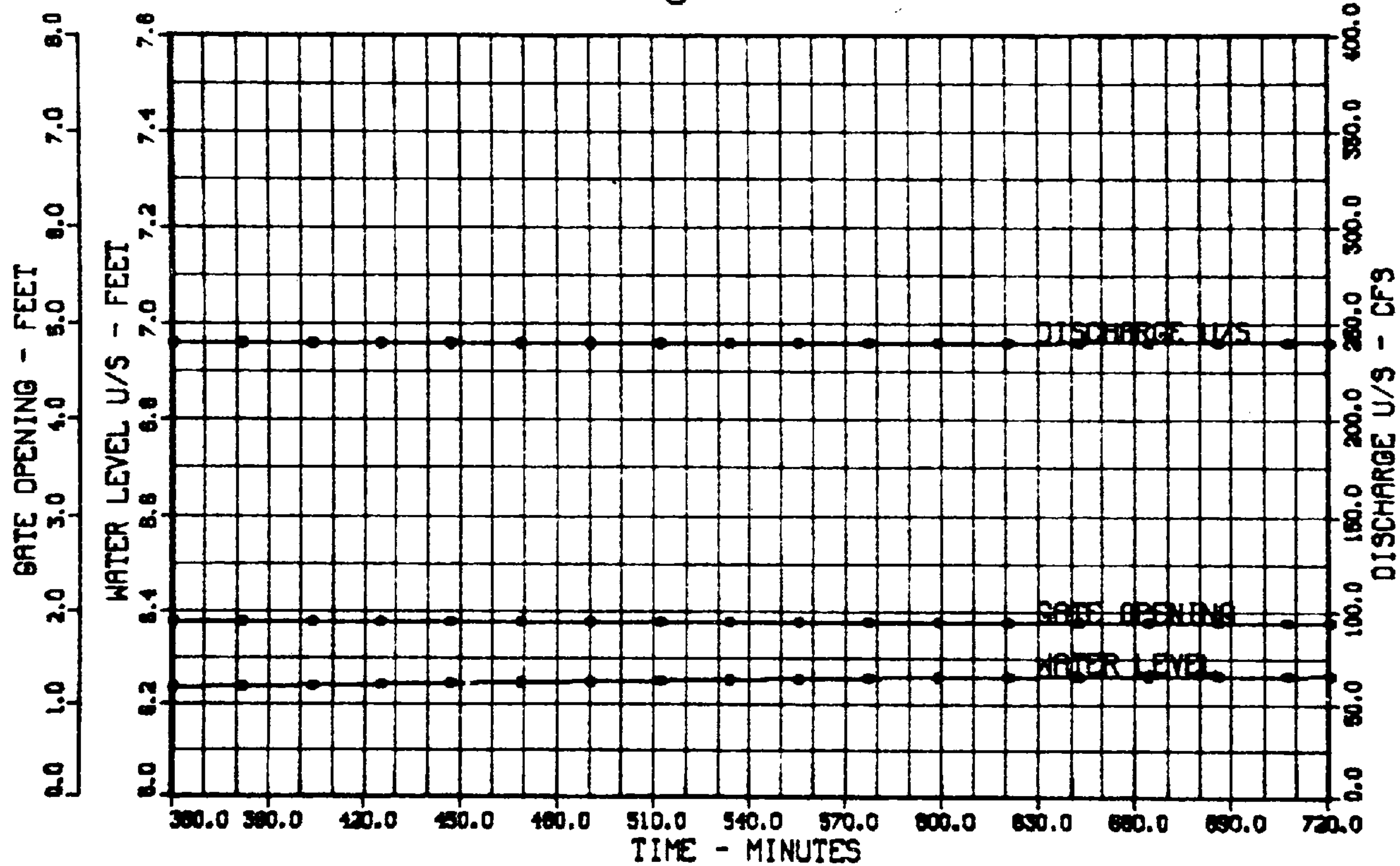
Mathematical model simulation of the bypass drain with the SOT/VRT automatic upstream control, known as the "Colvin Controller," illustrates the controller performance using the abnormal flow change of an emergency shutdown of the Yuma Desalting Plant (same as run No. 42, appendix I) when operating at maximum (ultimate) capacity.

BYPASS DRAIN - CHECK NO. 0
Time History Plot Run No. 44

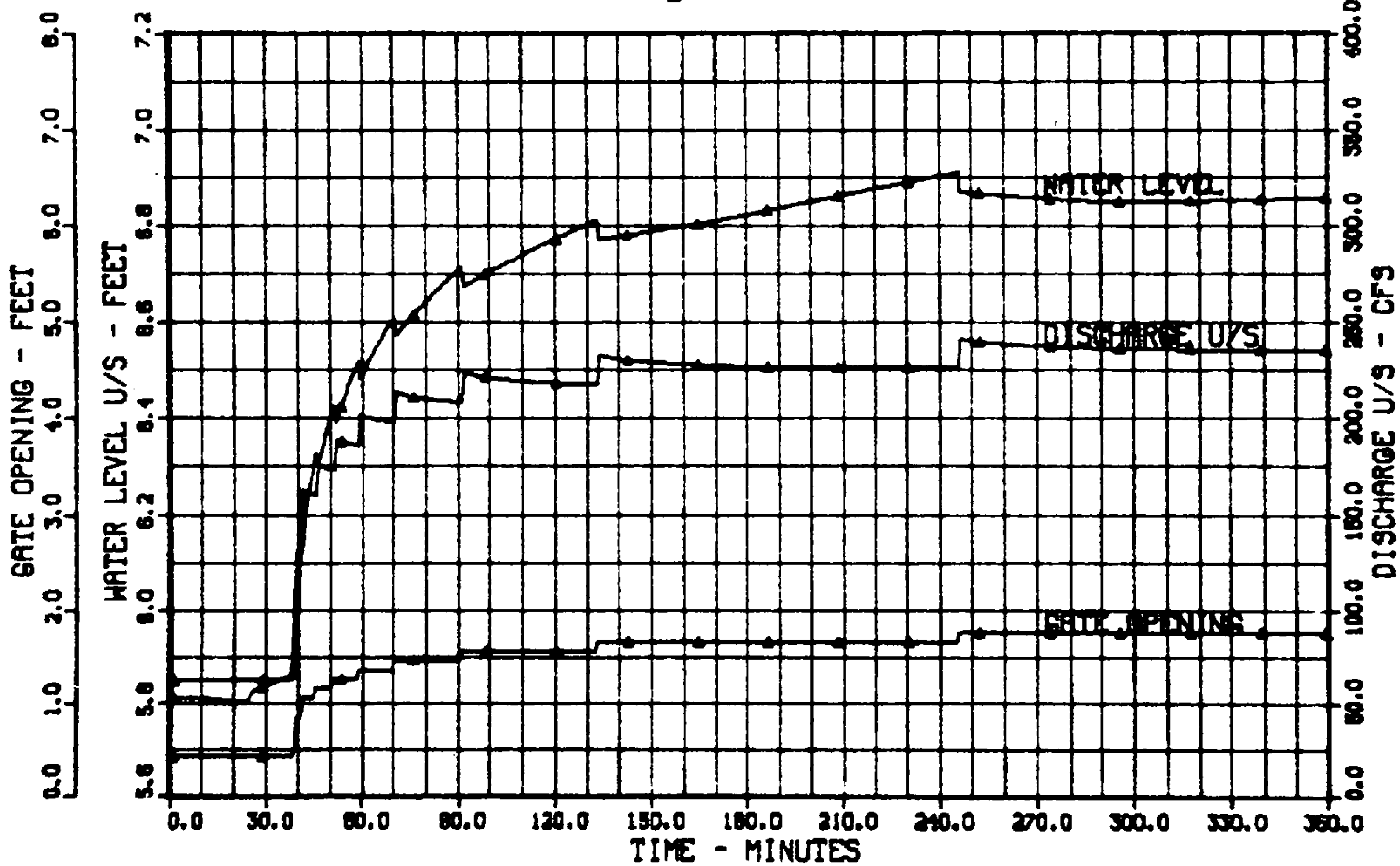


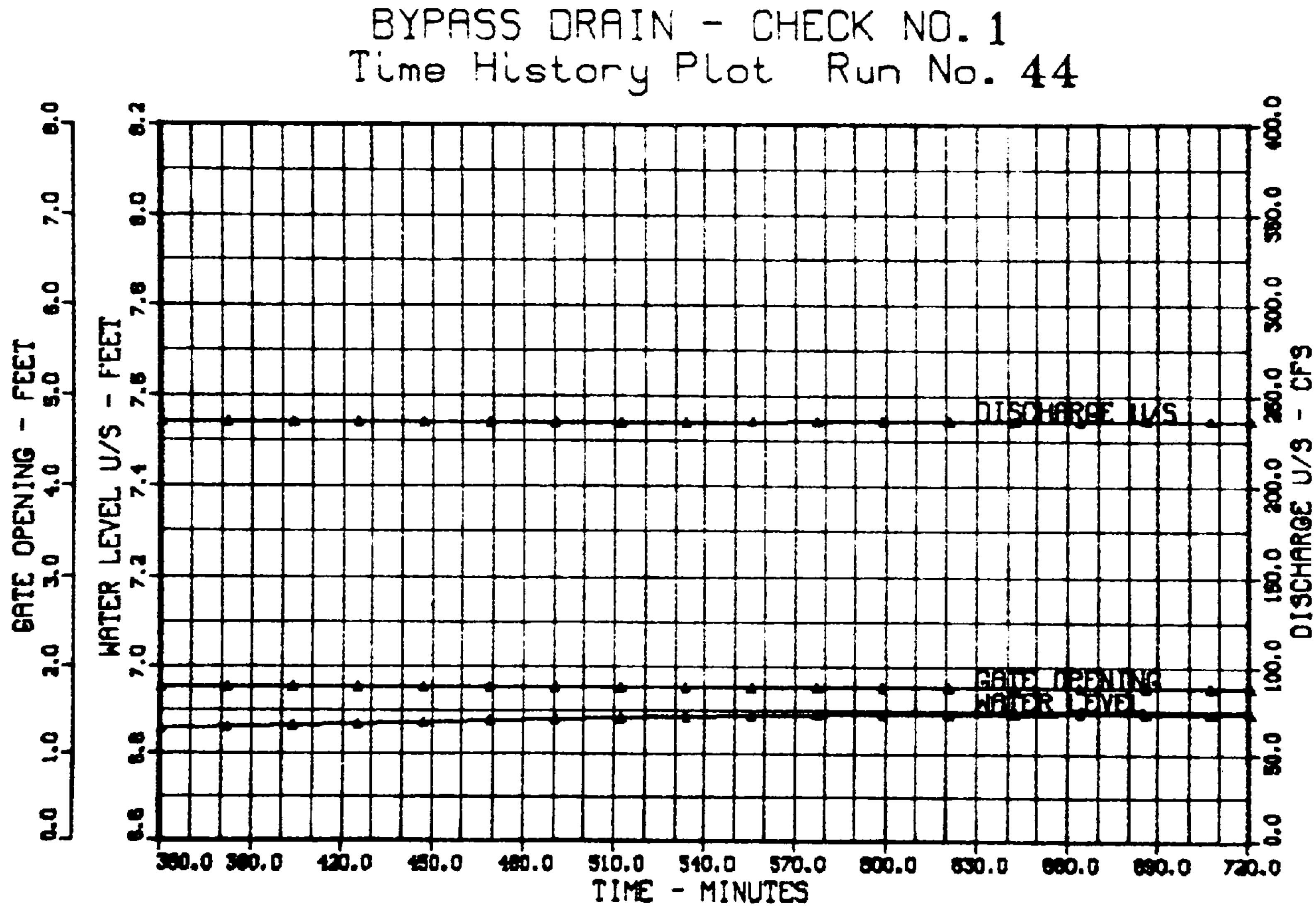
BYPASS DRAIN - CHECK NO. 0

Time History Plot Run No. 44



BYPASS DRAIN - CHECK NO. 1
Time History Plot Run No. 44

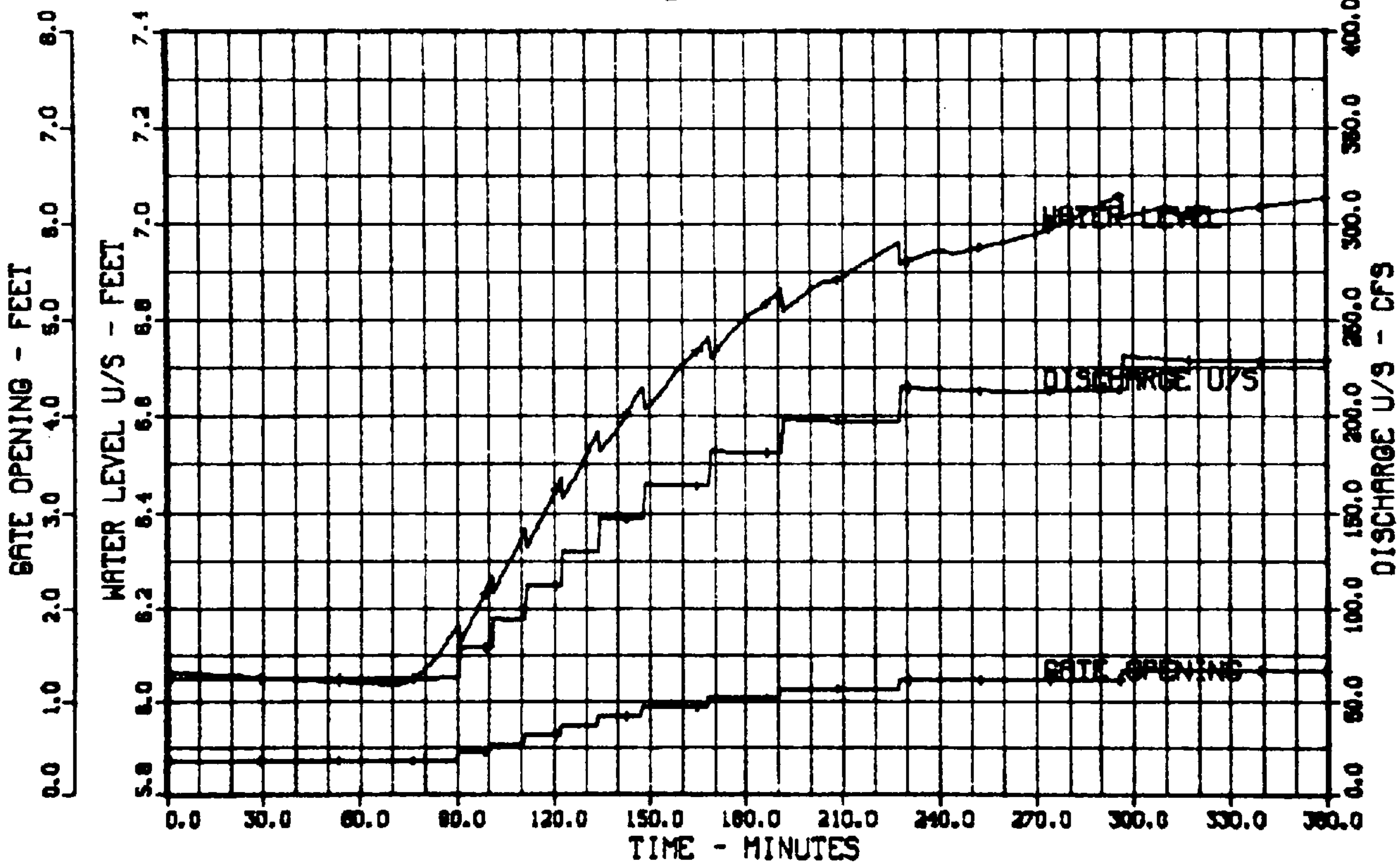




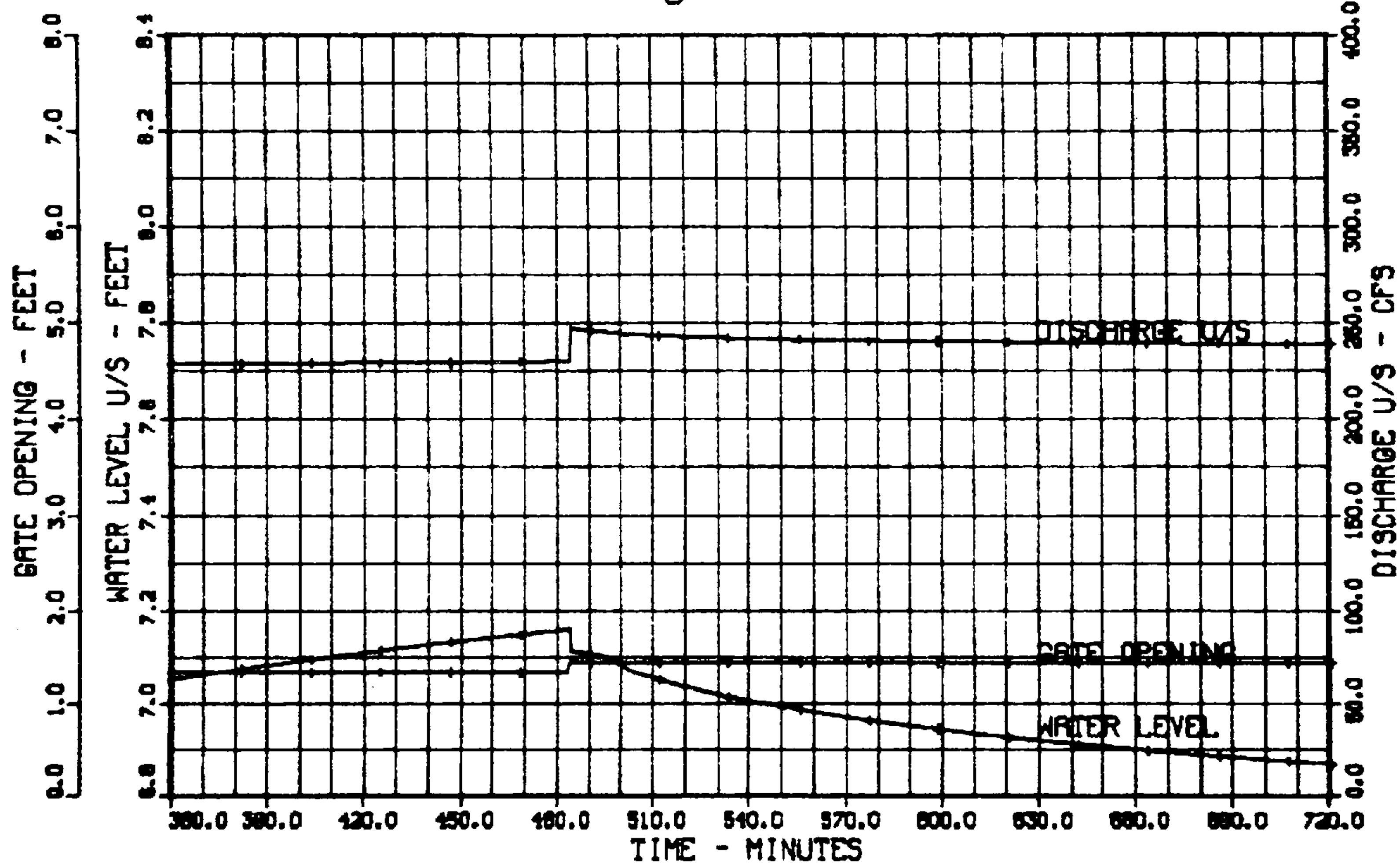
BYPASS DRAIN - CHECK NO. 1
Time History Plot Run No. 44
GATE OPENING - FEET
WATER LEVEL U/S - FEET
DISCHARGE U/S - CFS
DISCHARGE U/S
GATE OPENING
WATER LEVEL
TIME - MINUTES

BYPASS DRAIN - CHECK NO. 2

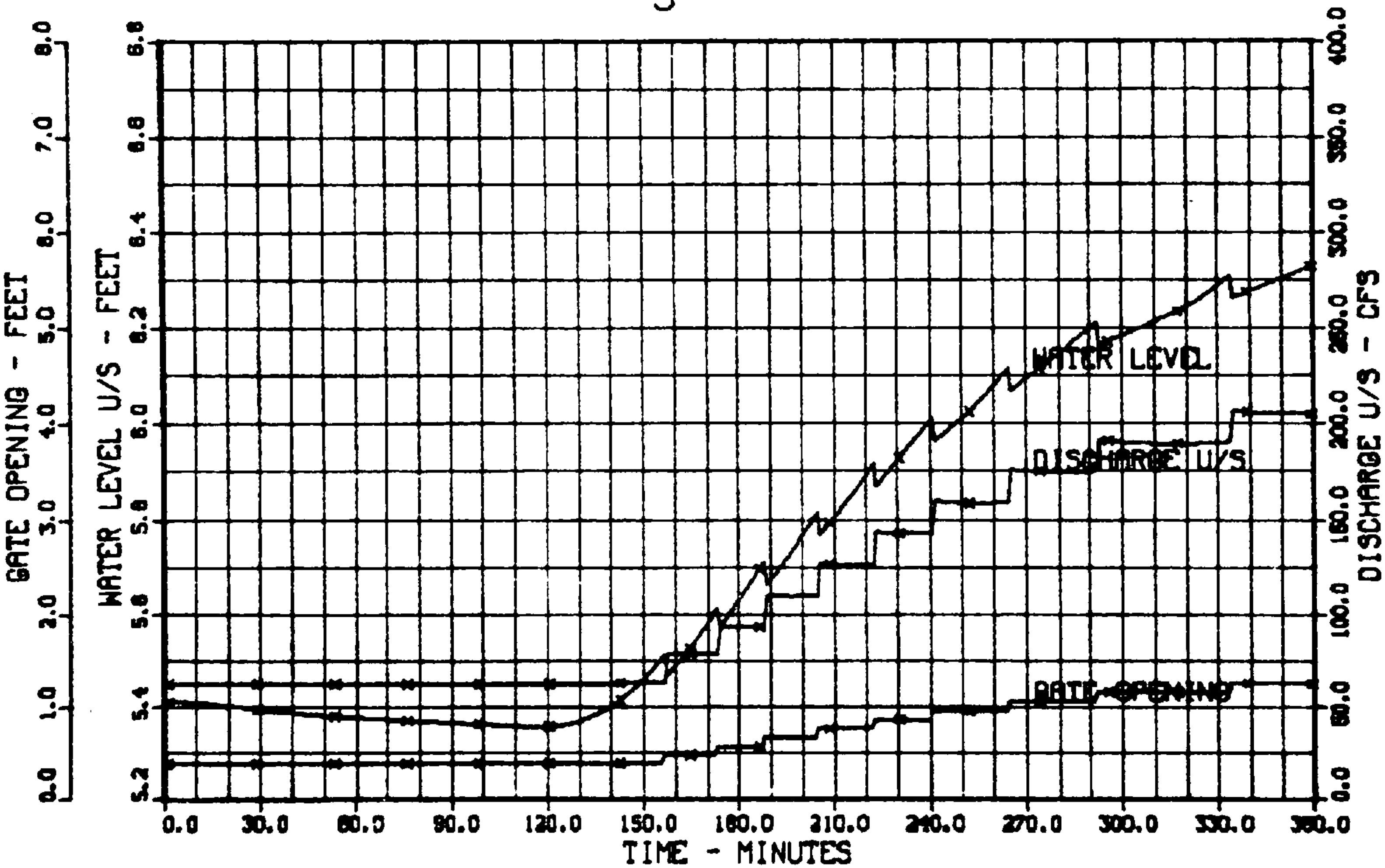
Time History Plot Run No. 44



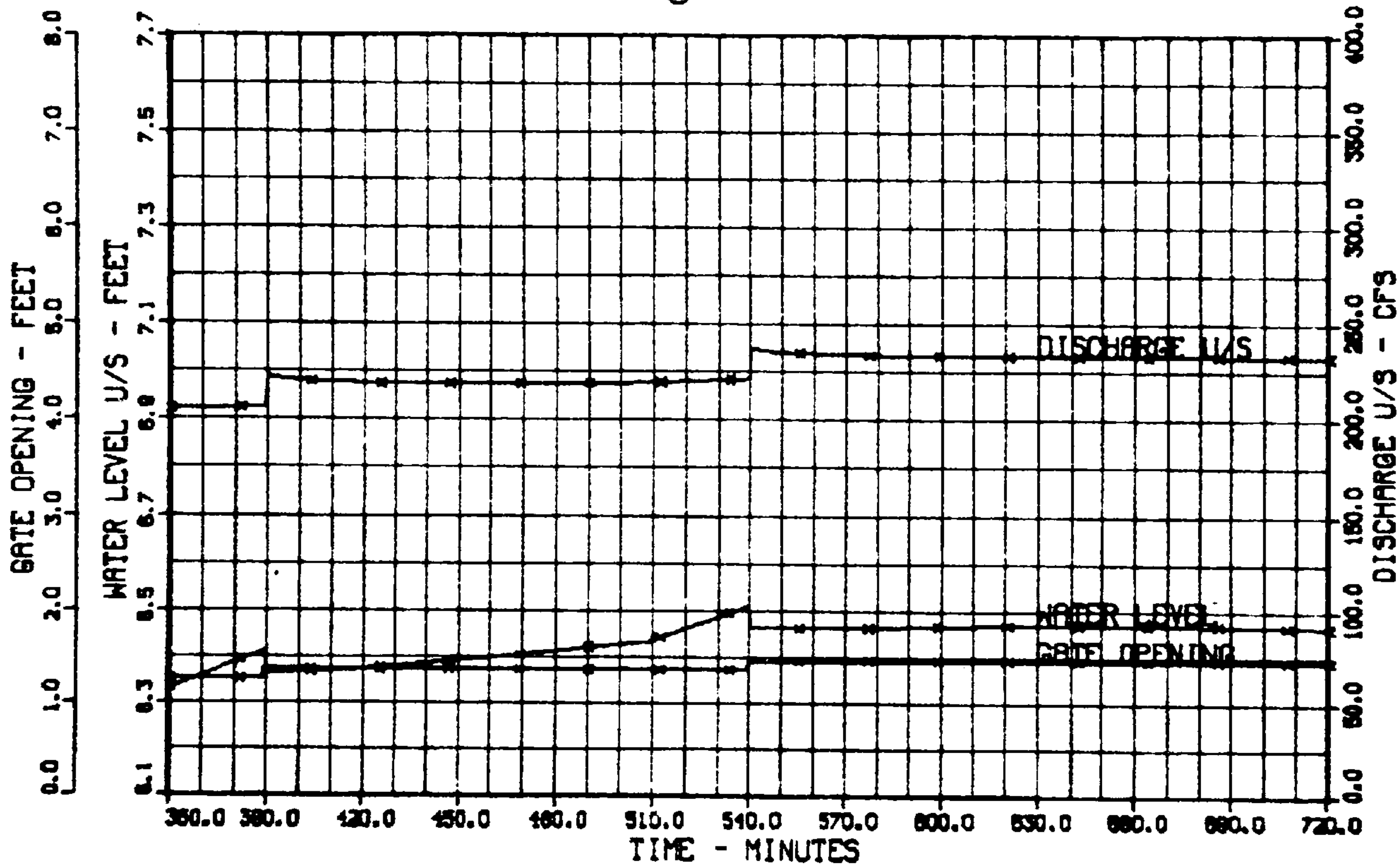
BYPASS DRAIN - CHECK NO. 2
Time History Plot Run No. 44



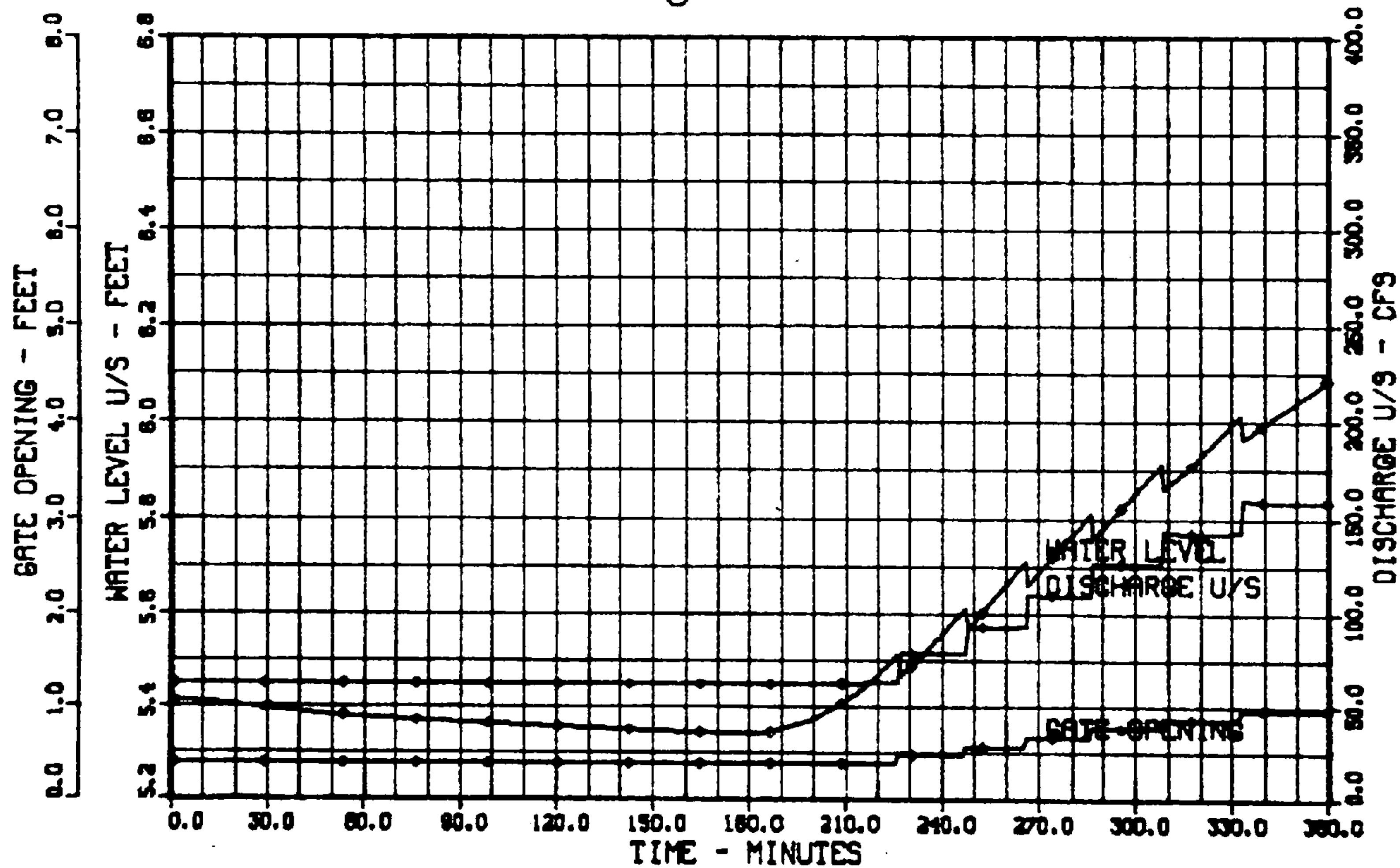
BYPASS DRAIN - CHECK NO. 3
Time History Plot Run No. 44



BYPASS DRAIN - CHECK NO. 3
Time History Plot Run No. 44

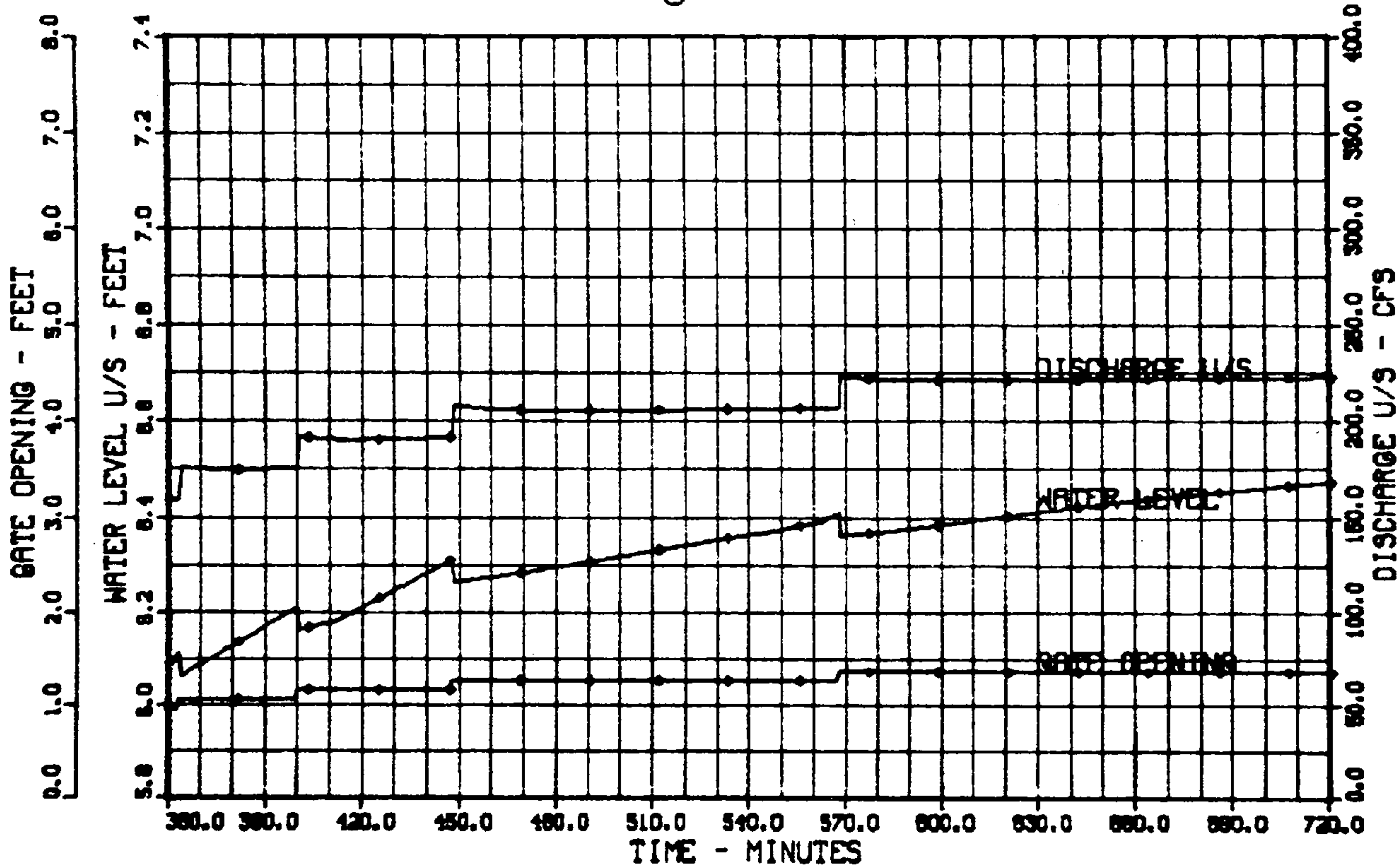


BYPASS DRAIN - CHECK NO. 4
Time History Plot Run No. 44

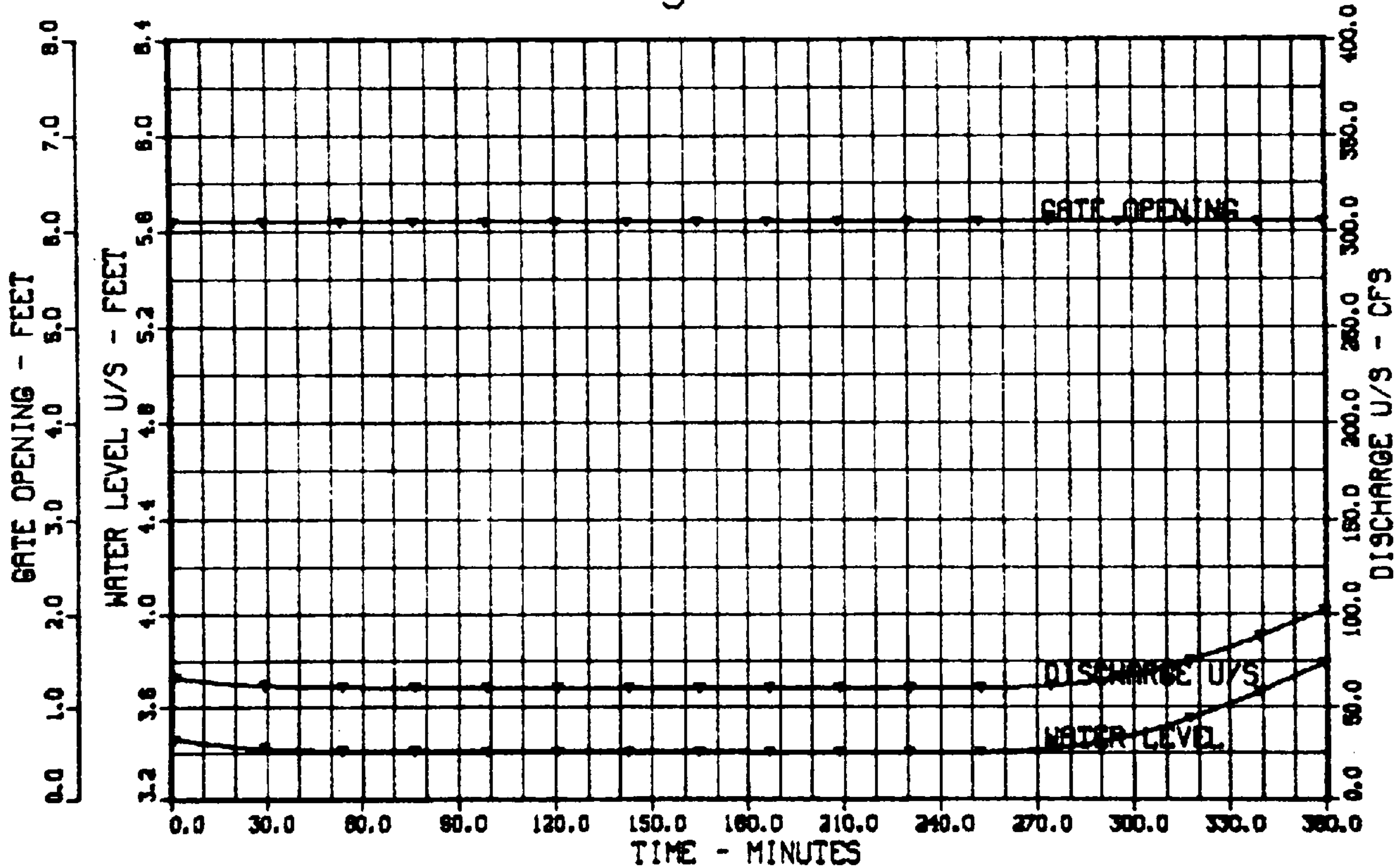


BYPASS DRAIN - CHECK NO. 4

Time History Plot Run No. 44

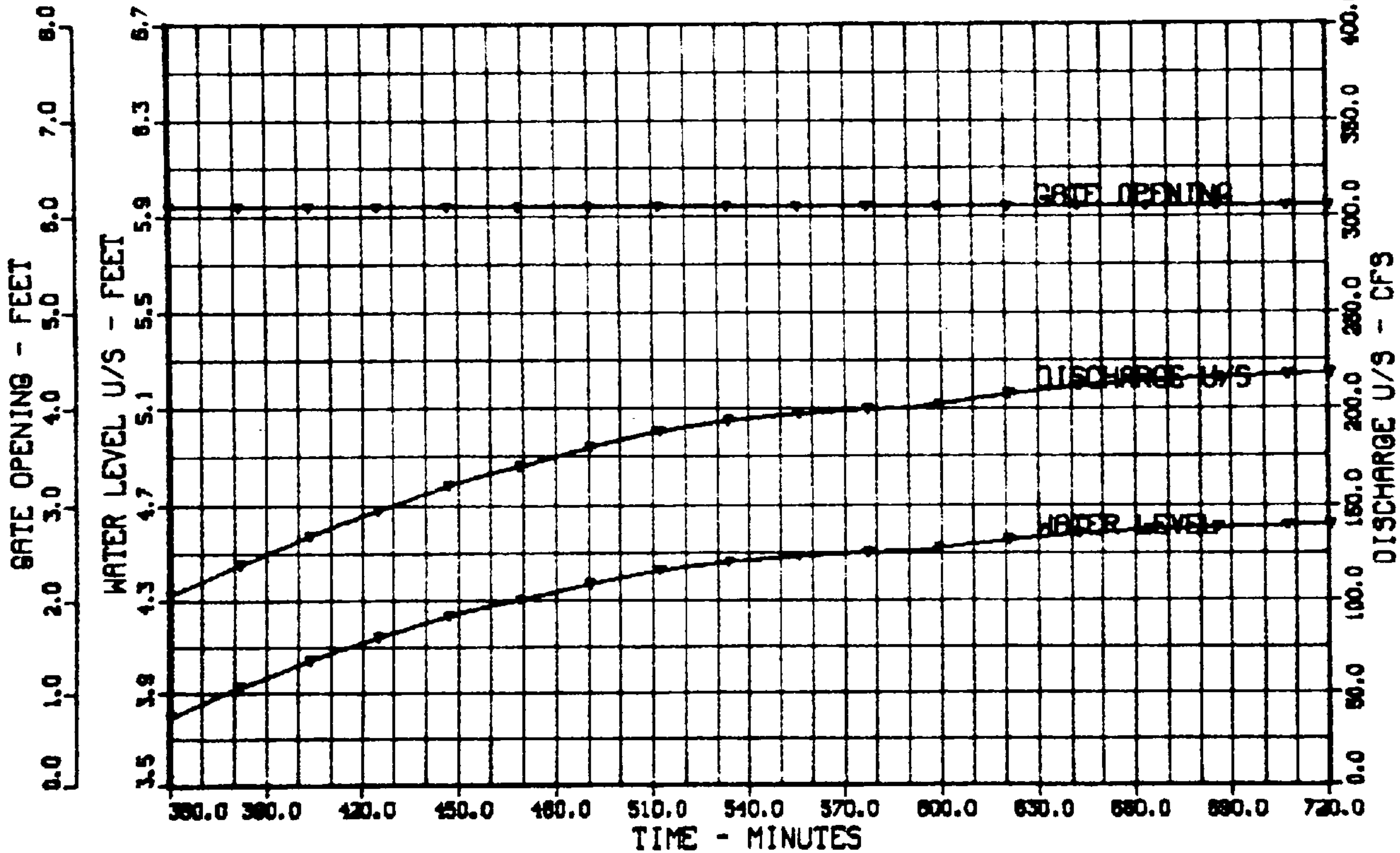


BYPASS DRAIN - CHECK NO. 5
Time History Plot Run No. 44



BYPASS DRAIN - CHECK NO. 5

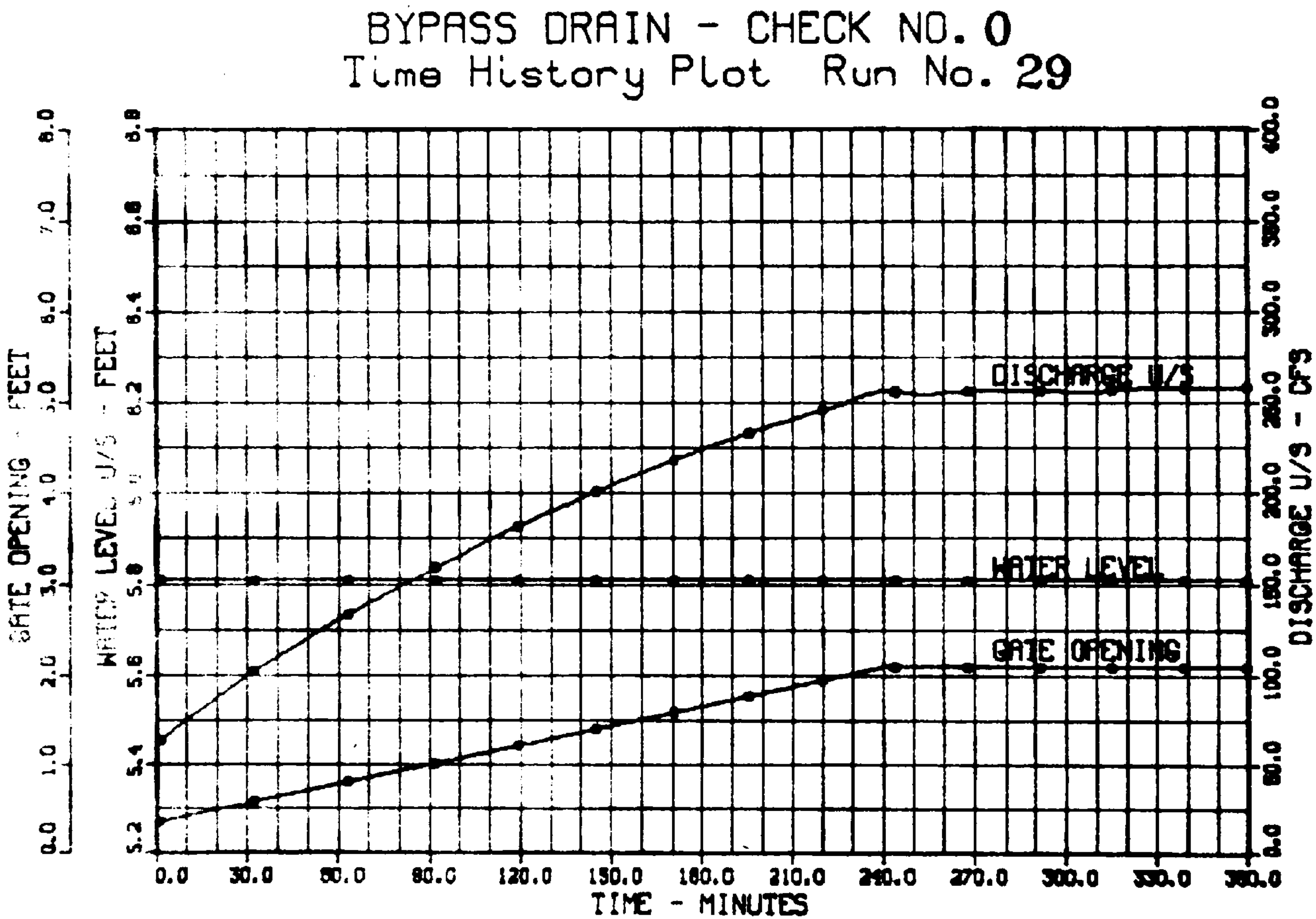
Time History Plot Run No. 44



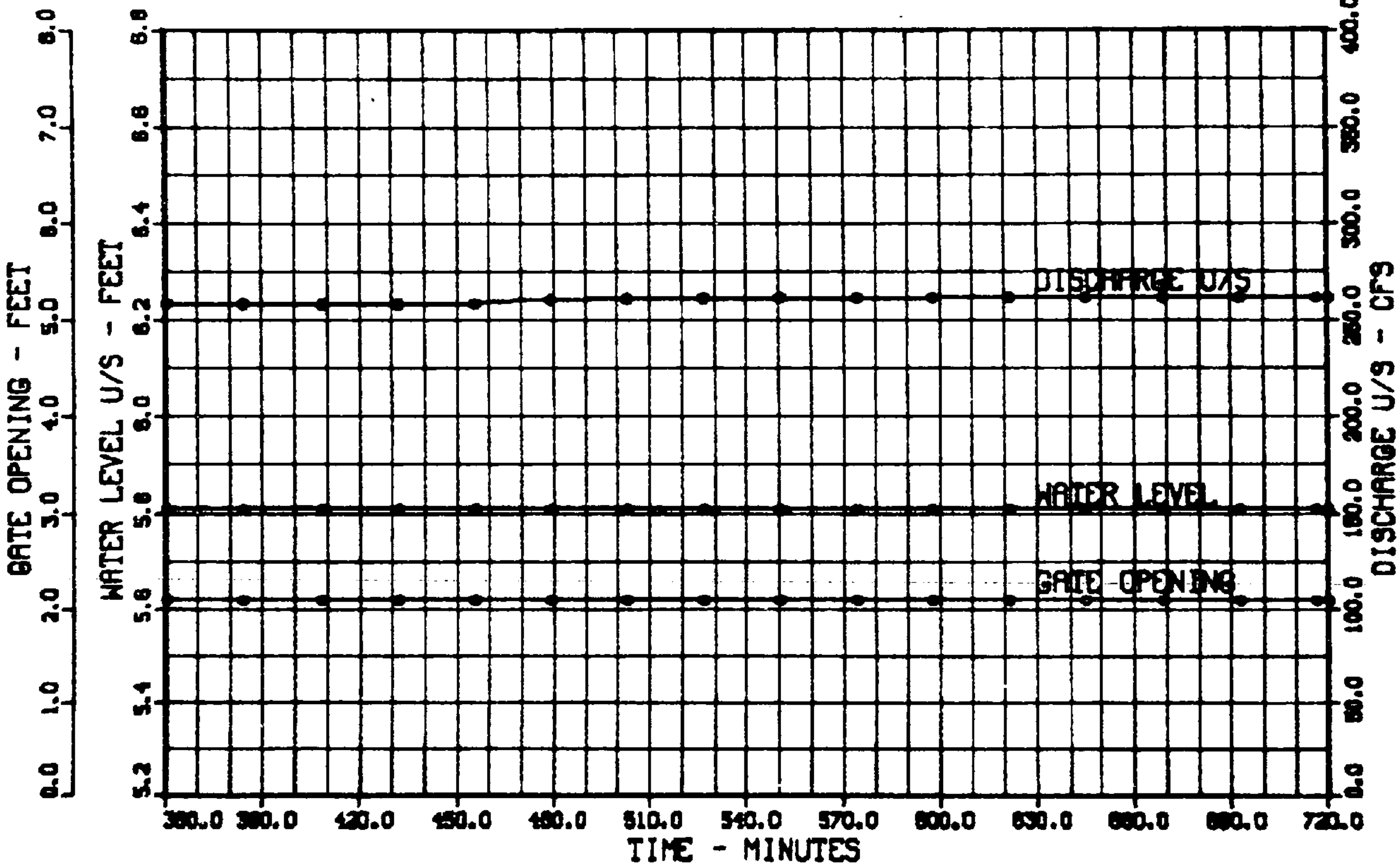
APPENDIX III

Bypass Drain Time History Plot, Run No. 29

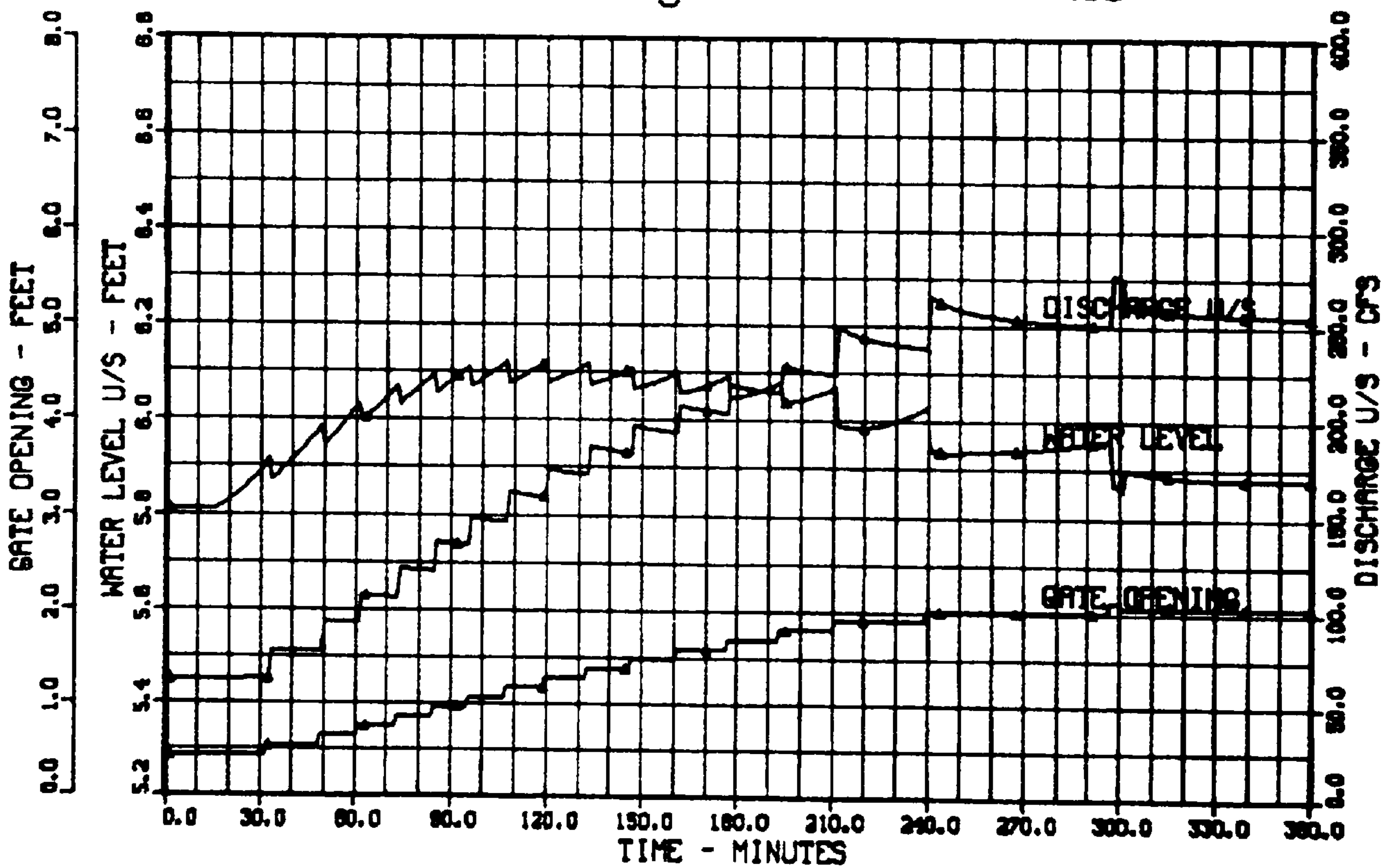
Mathematical model simulation of the bypass drain with P+PR automatic upstream control, illustrates the controller performance using a ramp function flow change of 2.8(m^3/s)/h (100(ft^3/s)/h) at the bifurcation check No. 0 (intake to the desalting plant).

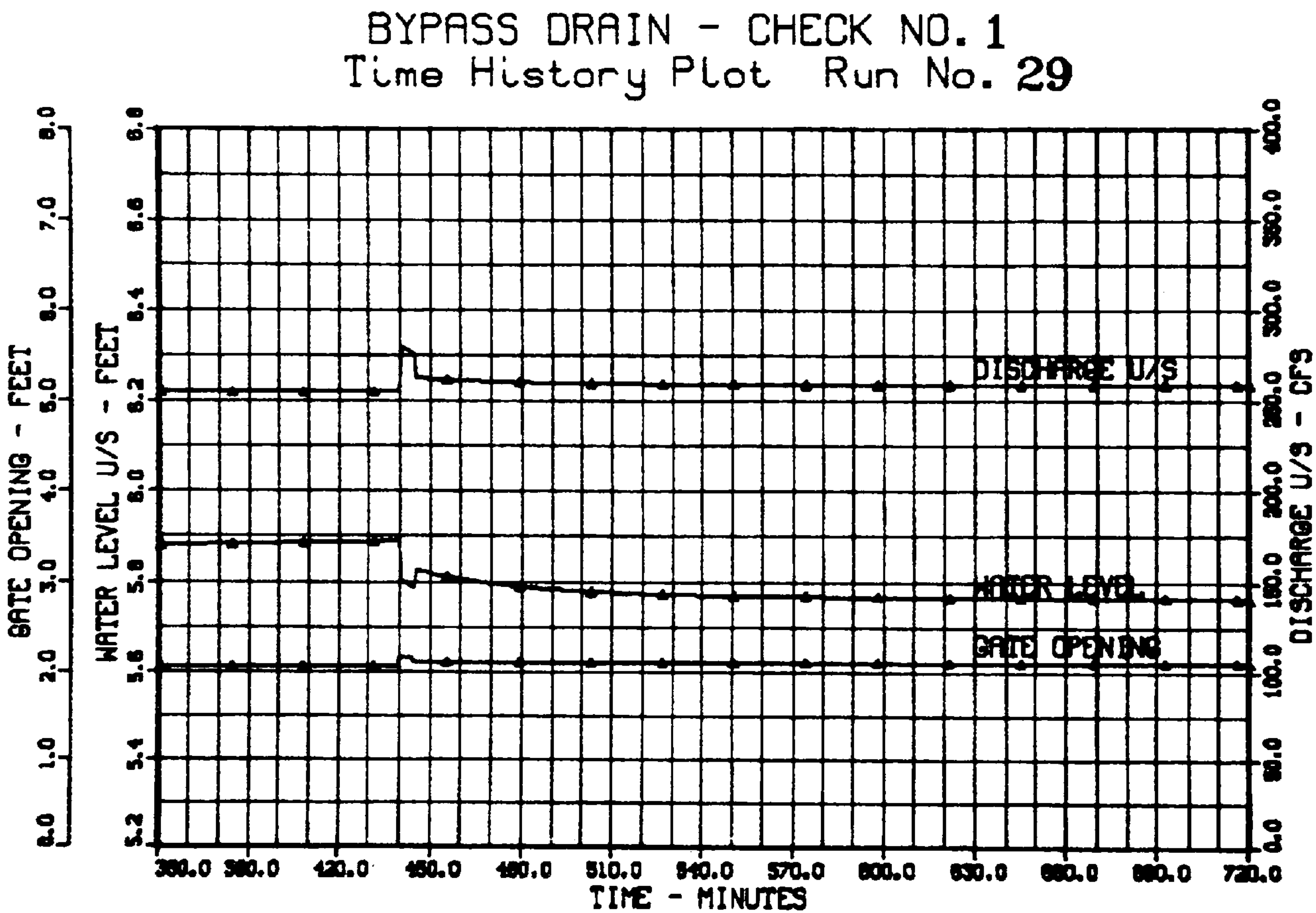

BYPASS DRAIN - CHECK NO. 0
Time History Plot Run No. 29
DISCHARGE U/S
WATER LEVEL
GATE OPENING
GATE OPENING - FEET
WATER LEVEL U/S - FEET
DISCHARGE U/S - CFS
TIME - MINUTES
0.0
30.0
60.0
90.0
120.0
150.0
180.0
210.0
240.0
270.0
300.0
330.0
360.0

BYPASS DRAIN - CHECK NO. 0
Time History Plot Run No. 29



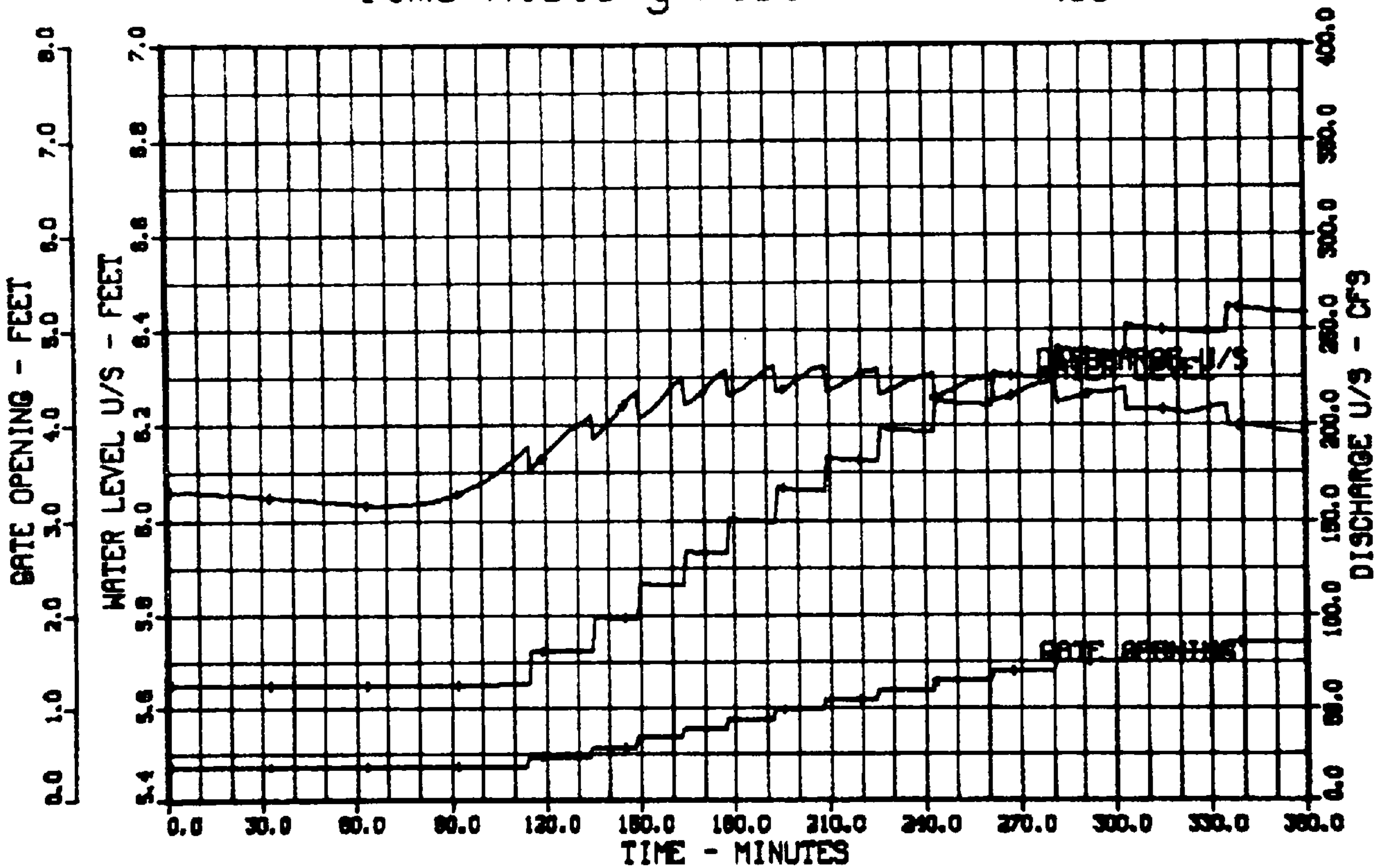
BYPASS DRAIN - CHECK NO. 1
Time History Plot Run No. 29



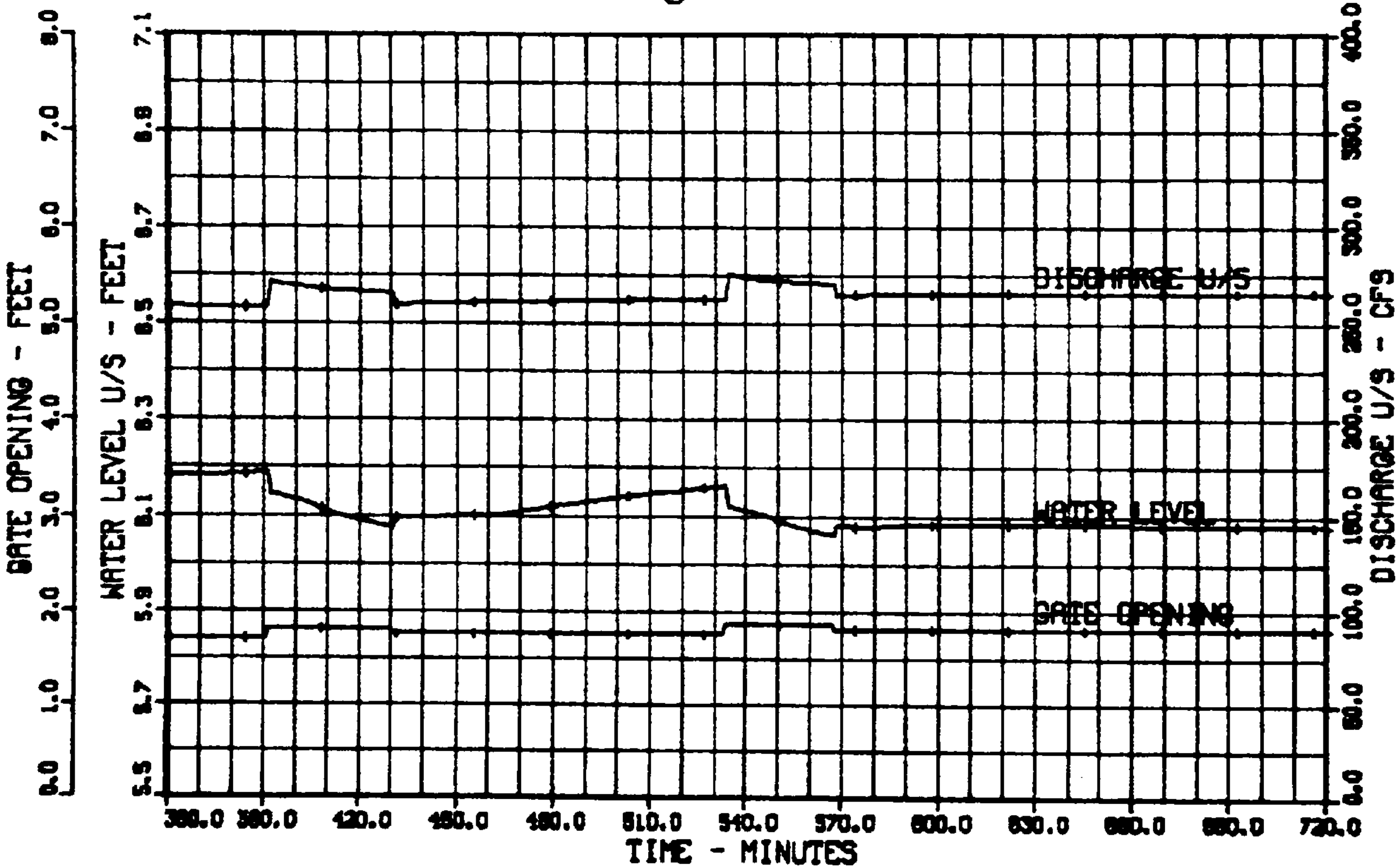


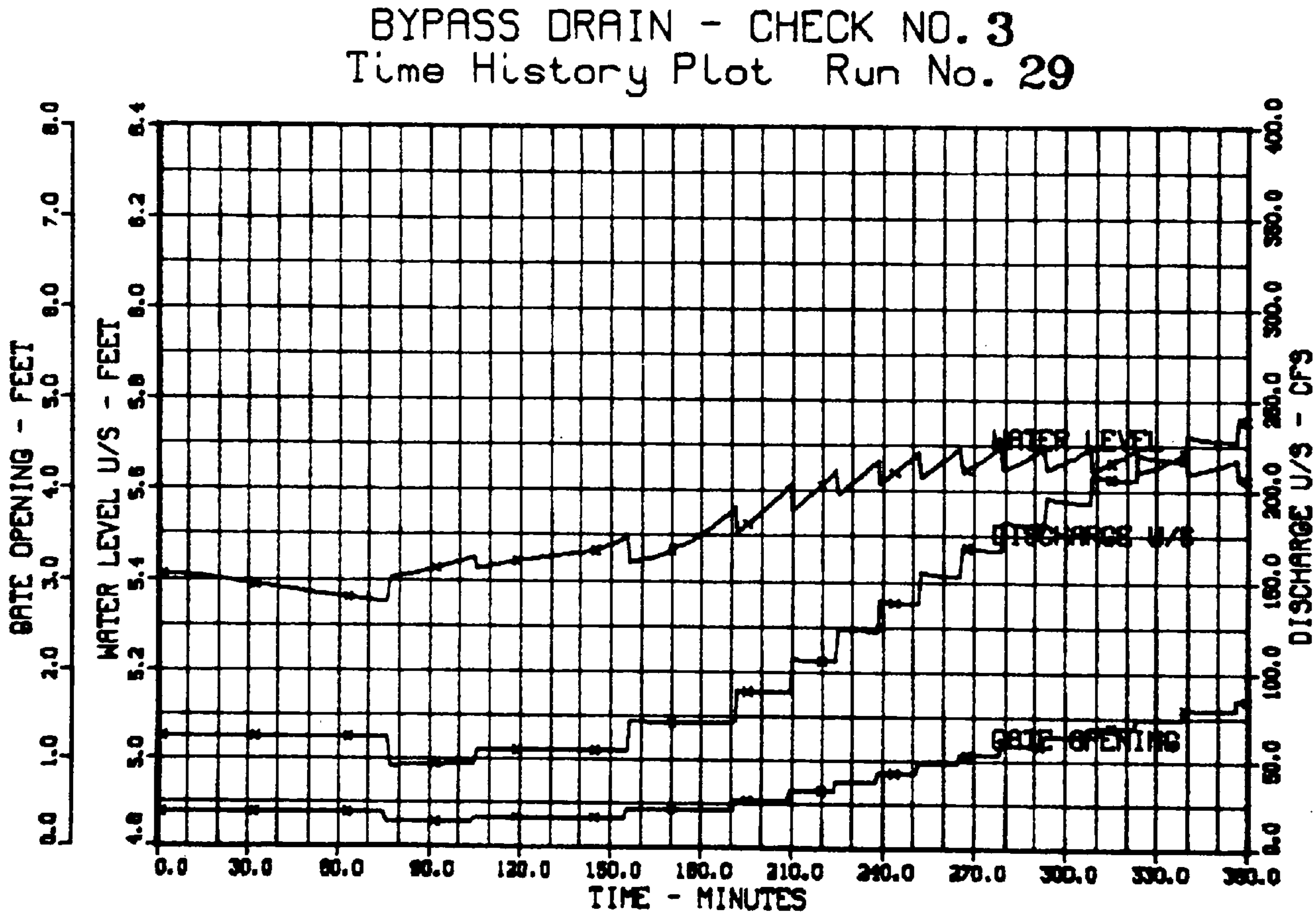
BYPASS DRAIN - CHECK NO. 1
Time History Plot Run No. 29
GATE OPENING - FEET
WATER LEVEL U/S - FEET
DISCHARGE U/S - CFS
DISCHARGE U/S
WATER LEVEL
GATE OPENING
TIME - MINUTES

BYPASS DRAIN - CHECK NO. 2
Time History Plot Run No. 29



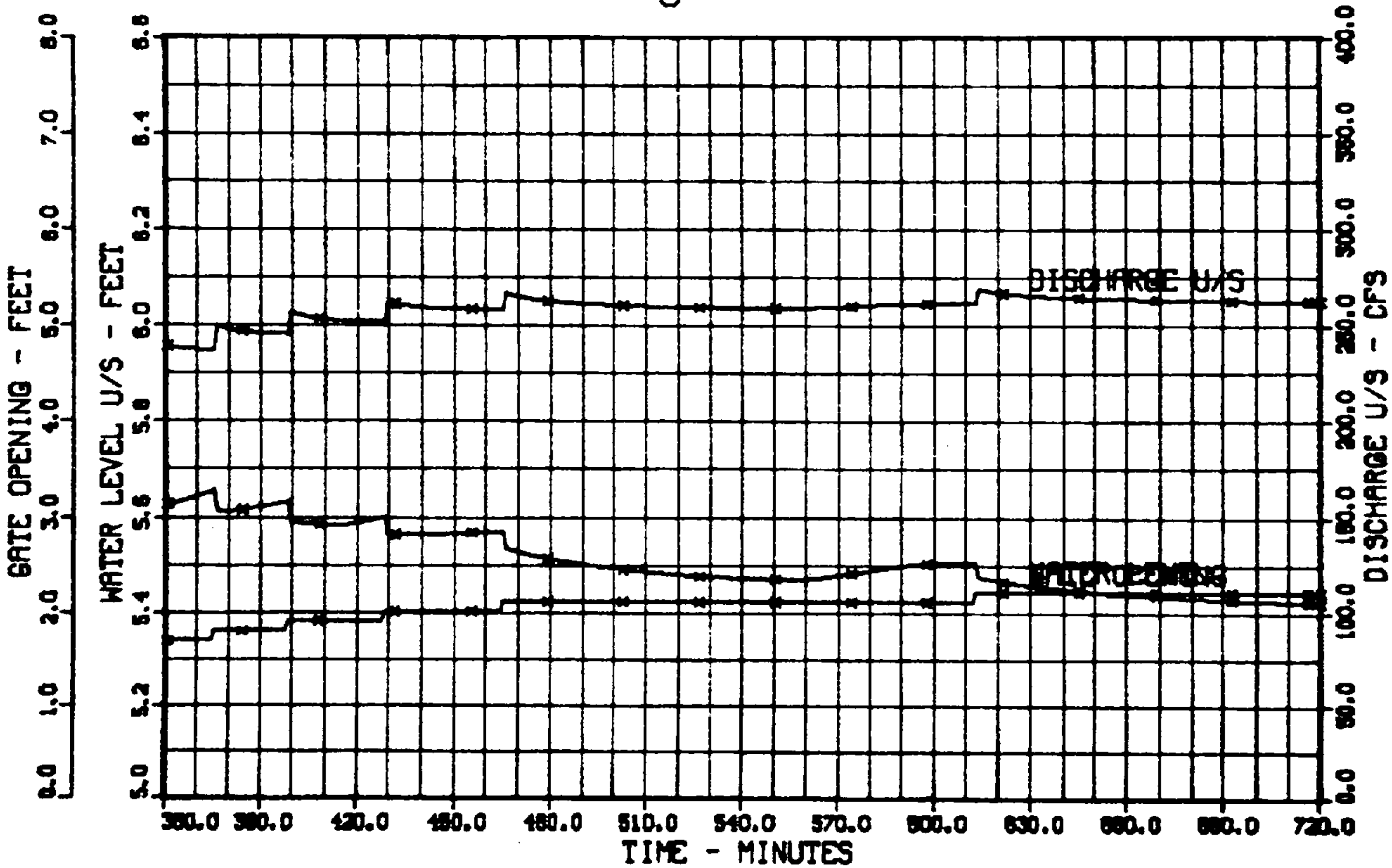
BYPASS DRAIN - CHECK NO. 2
Time History Plot Run No. 29



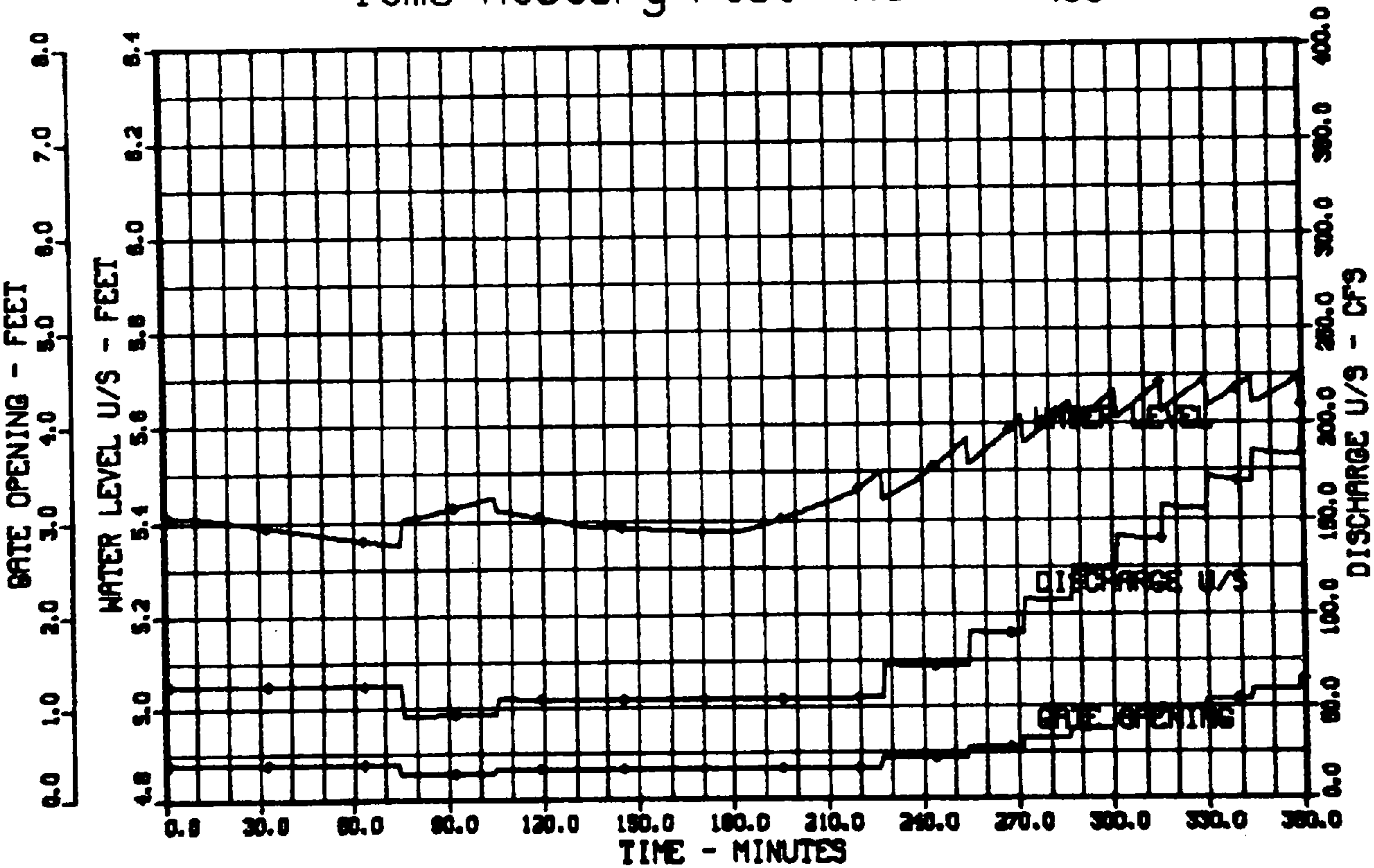

BYPASS DRAIN - CHECK NO. 3
Time History Plot Run No. 29
GATE OPENING - FEET
WATER LEVEL U/S - FEET
DISCHARGE U/S - CFS
TIME - MINUTES
WATER LEVEL
DISCHARGE U/S
GATE OPENING

BYPASS DRAIN - CHECK NO. 3

Time History Plot Run No. 29

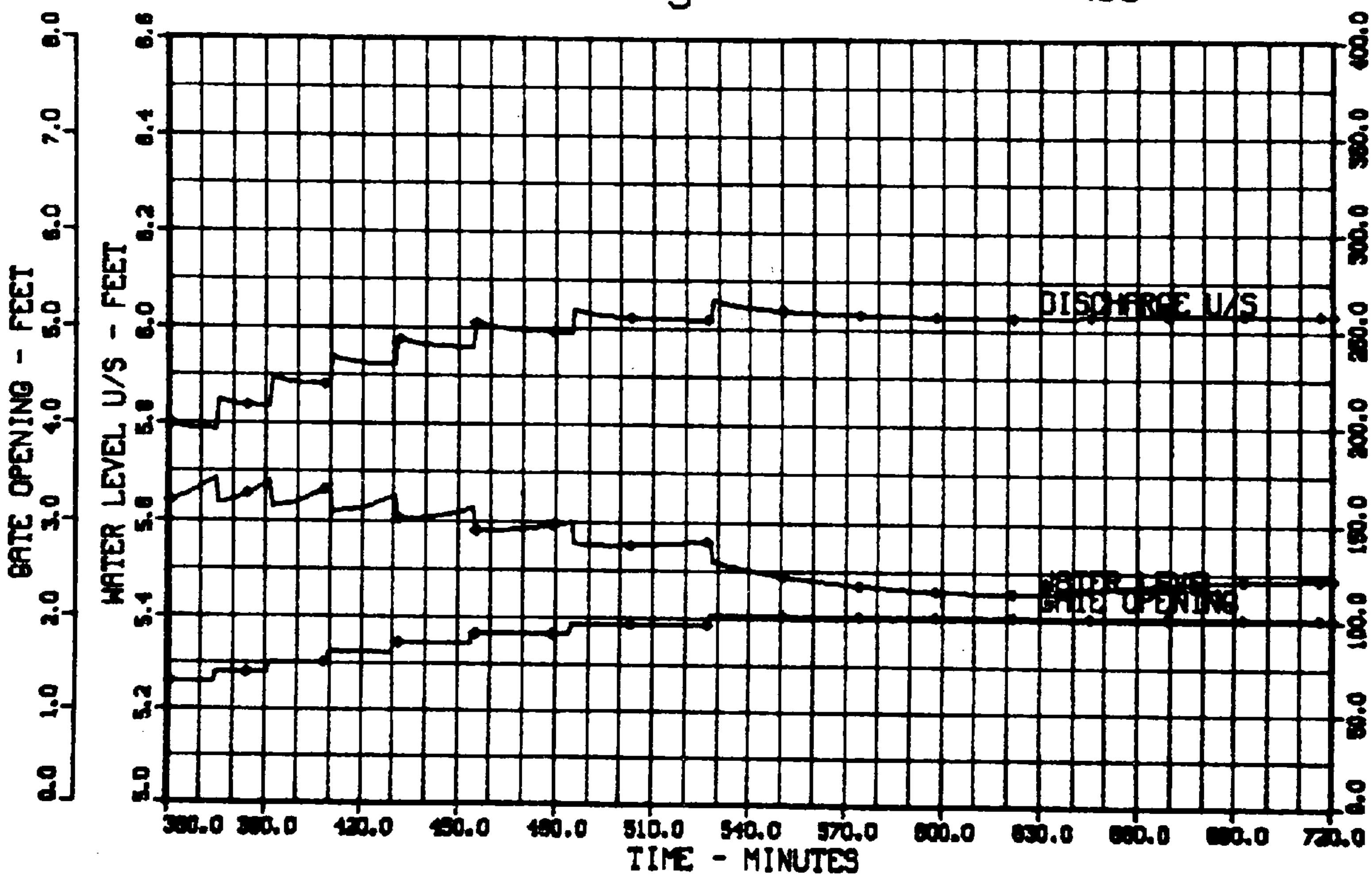


BYPASS DRAIN - CHECK NO. 4
Time History Plot Run No. 29

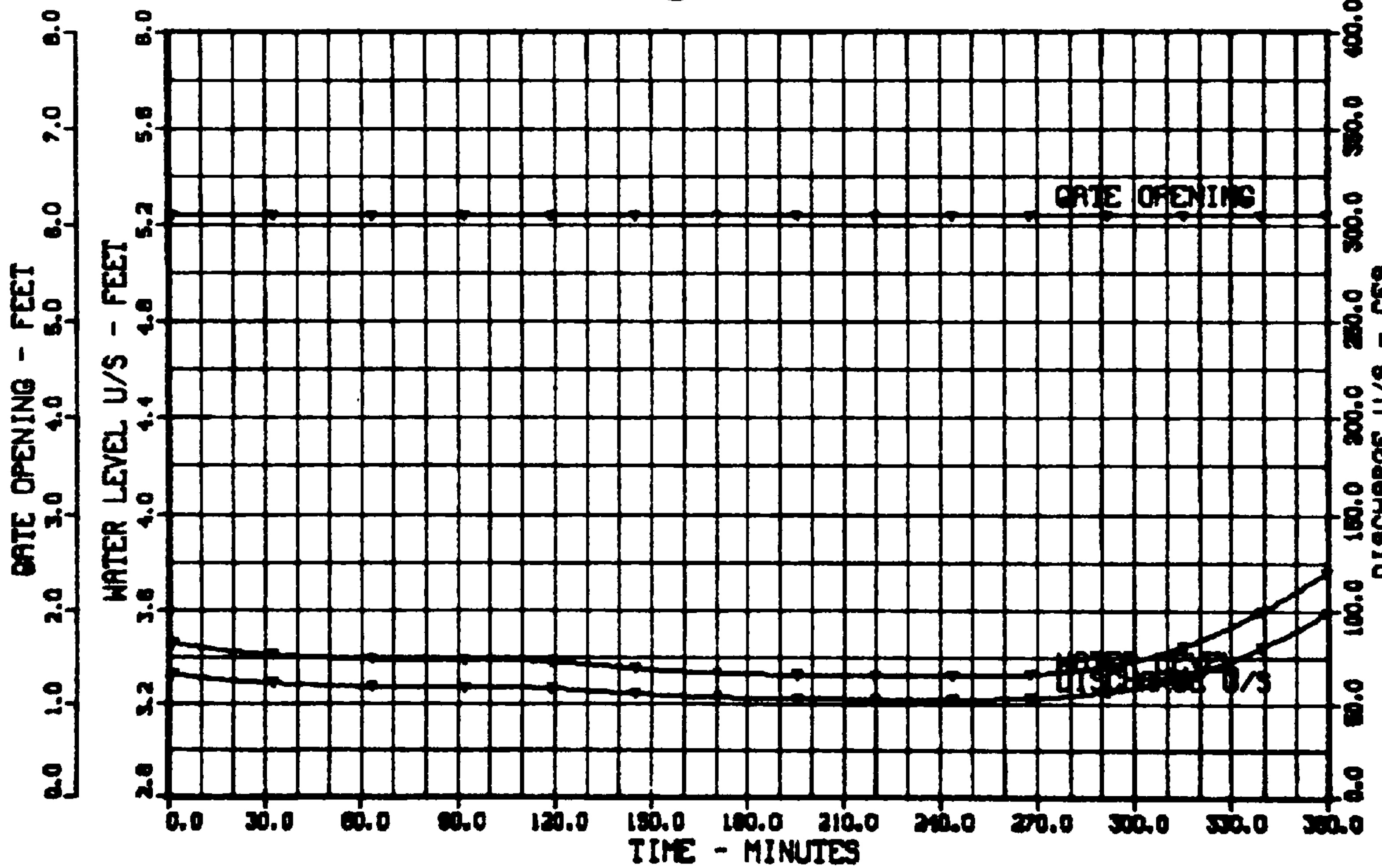


BYPASS DRAIN - CHECK NO. 4

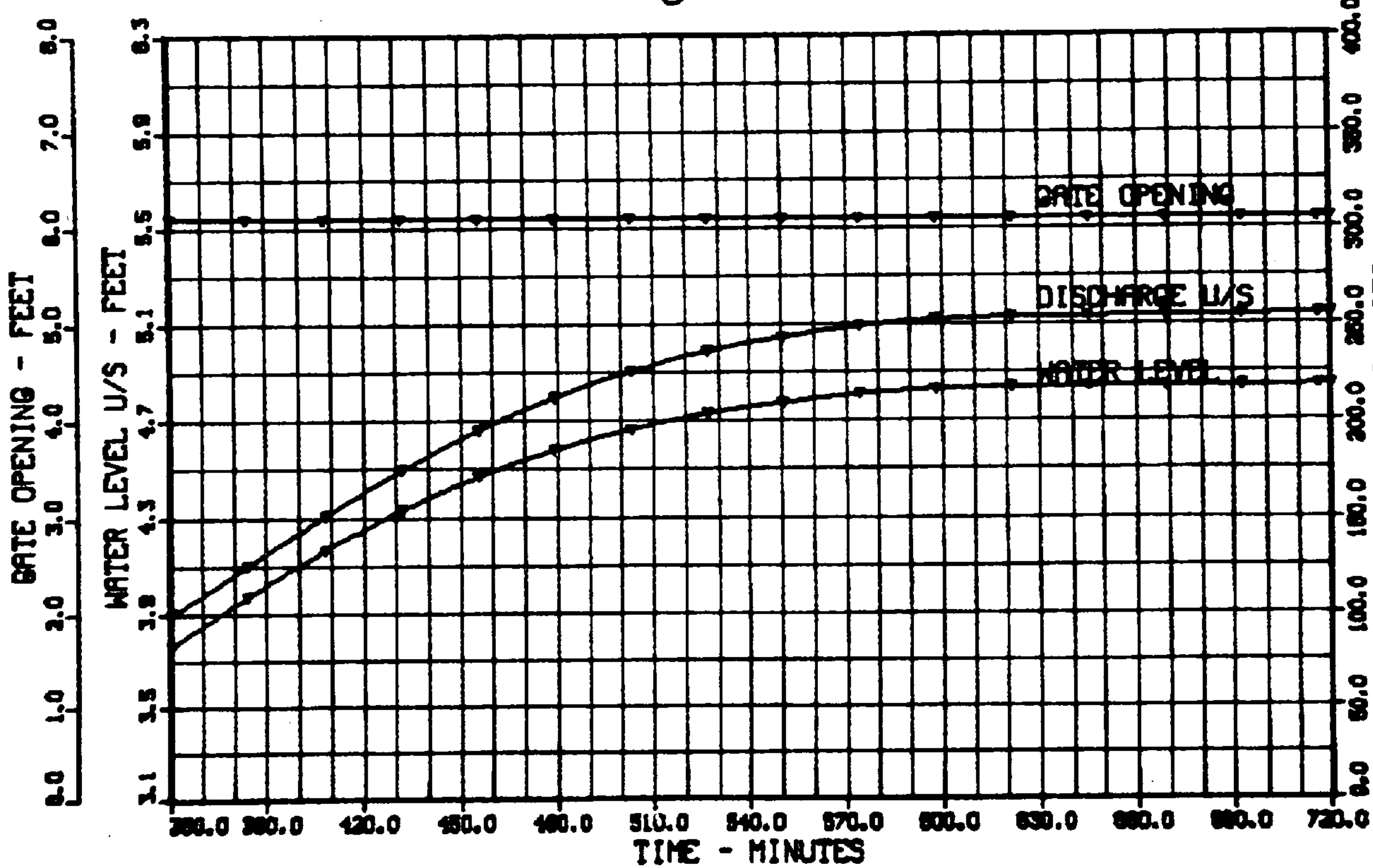
Time History Plot Run No. 29



BYPASS DRAIN - CHECK NO. 5
Time History Plot Run No. 29



BYPASS DRAIN - CHECK NO. 5
Time History Plot Run No. 29



APPENDIX IV

Summary of the Bypass Drain Description and Physical Properties

The bypass drain will be a continuation of the existing Wellton-Mohawk Main Outlet Drain Extension. Brine waste from the Yuma Desalting Plant will be conveyed through the drain extension to a bifurcation structure located at the Morelos Dam, where the bypass drain begins, a distance of 3.2 km (2.0 mi). The brine waste and excess drain extension flows will be diverted through the bifurcation structure and conveyed to the United States-Mexico International Boundary by the bypass drain a distance of 25.8 km (16.0 mi). The beginning of the bypass drain, check No. 1, at the Morelos Dam is located about 8 km (5 mi) west of Yuma, Arizona, and ends at the United States-Mexico International Boundary near San Luis, Arizona. South of the International Boundary the bypass drain continues to the Santa Clara Slough, Gulf of California.

The U.S. segment of the bypass drain has four 3.7-m (12-ft) wide radial check gate structures, and four reaches (table 2), each 6.6-km (4.1-mi) average length. A free-flow, 6-m (20-ft), Parshall flume is located at the end of the U.S. bypass drain. The maximum capacity of the bypass drain is 10.0 m^3/s (353 ft^3/s).

Table 2. - *Bypass drain physical properties*

Reach number[1]	Reach length,		Accumulated length,		YT design depth,	
	km	(ft)	km	(ft)	m	(ft)
1	7.2	(23 650)	7.2	(23 650)	1.85	(6.06)
2	6.7	(21 838)	13.9	(45 488)	1.65	(5.41)
3	5.9	(19 450)	19.8	(64 938)	1.65	(5.41)
4	5.9	(19 485)	25.7	(84 423)	1.65	(5.41)

[1] All reaches: Capacity 10 m^3/s (353 ft^3/s)
Bottom width 3.66 m (12.0 ft)
Side slopes 1.5:1

GPO 845-959

ABSTRACT

A study was made to develop an automatic upstream control system utilizing the P+PR (proportional plus proportional reset) mode of control for the bypass drain check gates of the Yuma Desalting Plant. Mathematical model simulation studies show the P+PR controller can automatically transfer all degrees of flow change from upstream to downstream and return the water surface (upstream of canal check structures) back to desired target surfaces within a reasonable period of time. Included in the study were the development of a digital filter for microprocessor units and logic for reducing "sawtooth" gate control responses during steady-state flow conditions. The SOT/VRT (set-operate-time/variable-rest-time) mode of control was analyzed as an unsuccessful alternative to the P+PR controller. Operating criteria for normal and emergency flow conditions is also presented to assist the operators in the future operation of the by-pass drain.

ABSTRACT

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GR-78-4
Buyalski, C. P.
STUDY OF AN AUTOMATIC UPSTREAM CONTROL SYSTEM FOR CANALS

Bur Reclam Rep GR-78-4, Div Gen Res, Aug 1977.
Bureau of Reclamation, Denver, 79 p, 5 fig, 2 tab, 4 app, 5 ref.

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