PAP-626

TEST REPORT

GOVERNMENT HIGHLINE CANAL - AUTOMATION EQUIPMENT

by

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Government High Line Canal

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CONTENTS

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FEBRUARY 28, 1992

A. BACKGROUND

The Denver Office was informed of automatic controller equipment malfunctions on the West End Government Highline Canal in November 1991. The Grand Valley Water Users Association has had the Bureau, their staff, and two electrical companies evaluate the automatic controller problems but the malfunctions continue. The Water Automation Team met to discuss possible solutions to the problems.

In late November 1991, members of the Automation Team visited the site to inspect the automatic control equipment installation. Based on this visit it was decided that major improvements to the design could be added by the Denver Office. One of the sensor 24-volt power supplies was not operating correctly during the field inspection and this was causing the controller to move the gate in only one direction. The controller software evaluation and specific tests on the hardware could not be performed easily in the field so the team requested that some of the automatic control equipment be sent to the Denver Office for laboratory testing. Two PLC's (Programmable Logic Controller), two water level sensor with power supplies, and one hand held programmer were sent to the Denver Office for evaluation and testing.

The check gates are automated using the Littleman upstream control method with a downstream override function. The wasteway is automated using the upstream Littleman control method. Water levels are monitored using float/counterweight type sensors that operate a 4-20ma transducer. A Programmable Logic Controller (PLC) is used to implement the Littleman control method. The 4-20ma waterlevel signals are converted to a 0 to 100 percent scale within the PLC. The PLC is of the ladder logic type with Electrical Erasable Programmable Read Only Memory (EEPROM) memory for the control algorithm storage and battery backed Random Access Memory (RAM) for program execution.

B. SOFTWARE

The control software consists of a two-stage Littleman operation without antihunt. In addition, the software includes a downstream override function that operates the check gate when the downstream depth is outside a fixed deadband. Analysis of the existing software revealed no significant problems related to the logic contained in the Littleman control software. The major concern with the littleman control software is selection of the gate control rest (idle) times. The two-stage timers are set for 60 and 15 seconds respectively. These rest times do not allow for sufficient canal response time after a gate movement, and will cause the gates to open or close more than is required. The downstream override control function may cause undesirable control action under certain flow conditions. The deadband for operation of the downstream control is set for 30 to 90 percent of the depth measurement.

Depth measurement resolution is read only to the nearest 1 percent. The lack of finer resolution may be causing unnecessary gate operations. The deadband for the gate operation is set for 4 percent and 6 percent for the two stage operation. These deadband settings will cause greater fluctuations in the upstream water surface thereby reflecting larger flow fluctuations downstream. Because the Littleman controllers are operating in series, gate movements will be amplified as a flow change progresses downstream to each controller.

C. HARDWARE

The PLC is equipped with a two input analog module and a four output triac alternating current module. The PLC has no other alarm or status monitoring data input modules. The hand held programmer allows communications with the PLC for program development and modification, parameter monitoring, and EEPROM programming.

The analog water level sensor consists of a Bristol Babcock float driven slidewire transducer that produces a 4-20 milliampere output when used with a 24-volt dc power supply. The 4-20 ma signal is connected to the stilling well sensor using No. 14 AWG control cable.

D. LABORATORY BENCH AND CANAL MODEL TESTING

The equipment was first bench tested to determine if it was operating using the proper Littleman algorithm. A listing of the software that was in the EEPROM memory was evaluated for possible operational problems. The water level sensors and power supplies were tested. The 24-volt power supply that was sent from the wasteway structure had a voltage output of 7.5 volts rather than the 24 volts required. The power supply had a burned up resistor and shorted capacitor on the output side of the circuit. The resistor and capacitor were replaced and the power supply operated correctly with the float operated sensor to provide the desired 4-20ma output.

The canal model in Reclamation's Hydraulic Laboratory was used to test two PLC automatic controllers and one water level sensor system. The canal model has two check gates with one canal pool in between. The first check gate is located just downstream (about 10 feet) from the source of supply. The second check gate is 200 feet downstream from the first check gate. Controller performance was tested by changing inflow to the model.

TEST 1

The PLC Littleman controllers were tested with the original program installed. Gate run time was set for 1 second since the field setting of 6 seconds run time is too long for the canal model gates. The controllers were tested to determine if the control logic was operating properly and if the check gates responded to the Littleman control algorithm.

The test showed that the controllers were responding in accordance with the programmed control logic and the correct operation of the check gates was verified. The test also revealed that the programmed control logic caused the check gates to overcompensate for flow changes and the desired water level (target) could not be maintained. See Appendix A (strip chart recording No. 1).

The hardware operated as designed during the entire testing period. The water level sensor system was operated during all of the testing and no failures of the sensor occurred. The PLC equipment operated properly during the entire testing period.

TEST 2

The Littleman control program was modified with the addition of antihunt logic. Antihunt logic was added only to the second check gate for this test. The timers were the same as for test 1. The test shows that with antihunt logic the control is more stable and check gate operation does not cause water level oscillation. A definite damping can be seen in the water level trace. See Appendix A (strip chart recording No. 2).

Also, during this test, a $1^1/_2$ horsepower skill saw was controlled by the controller output to generate electrical noise and power surges to the PLC control equipment. The PLC control equipment and the 4-20ma sensor did not fail or operate erratically due to this noisy load. The saw was plugged into the same electrical outlet as the PLC and water level sensor equipment. The electrical noise generated by the skill saw is similar to that generated in the field installation by the gate motor control equipment.

TEST 3

The controllers were tested to observe the effects of the antihunt logic for flow changes with the same rest and run times as in test 1. The chart recording clearly shows the oscillations of the water level caused by the gate movements over-compensating for the flow change. With the antihunt logic initialized, the effect can been seen as reduced oscillation of the water level. Gate run time is too long and causes the gate to continually overshoot the correct position to maintain the target water level. The rest timers are too short, causing a gate movement before the water level is stabilized between successive gate movements. See Appendix A (strip chart recording No. 3).

TEST 4

The two gate rest times were changed to 5 minutes and 2 minutes for the two stage operation. The run time was set for 1 second. The test shows that the rest time is too long for the model canal. Time constants that are too long or too short cause overflows for a period of time due to the gate responding incorrectly to the flow change. See Appendix A (strip chart recording No. 4).

TEST 5

The rest timers were changed to 3 minutes and 1 minute for the two stage operation. A gate operation inhibit band of 30% and 90% was added. The purpose of the gate inhibit band is to provide a method to check the validity of the sensor data. When the PLC equipment is operating normally, the water level should not be less than the low setting (30%) or greater than the high setting (90%). If these limits are exceeded, then we assume that the gates are not responding correctly to the control algorithm and further gate operation is inhibited. This limit check allows the controller to make limited decisions about the gate status without specific data from the gate.

The test shows that the gate operation inhibit band works as programmed and the new rest timer settings provide better control of the water surface. Additional flow changes were made to test the controller operation with these settings. See Appendix A (strip chart recording Nos. 5 and 6).

TEST 6

The deadband limits were changed to 2 percent for the primary deadband and 6 percent for the secondary deadband. Although the response time to recover from a flow change decreased, this test showed that the controller has a tendency to hunt with this narrow deadband. Also, the 1-minute sample time for the antihunt logic is too fast. The gate moved when the water level was changing toward the target at a slow rate, resulting in 11 extra gate movements.

The deadband setting of 6 percent is too large, and the 2 percent setting is a little small. A primary deadband setting of 3 percent would be optimum with a second deadband of 5 percent. See Appendix A (strip chart recording No. 7).

TEST 7

The antihunt logic sample time was changed to 3 minutes using the same deadband setting as in test 6. The results of the test show that the longer sample time for the antihunt logic provides better control. When the water level is returning towards the target value, fewer gate movements occur and the target water level is obtained in a shorter time with little or no overshoot. See Appendix A (strip chart recording No. 8).

E. COMPUTER SIMULATION STUDIES

Program USM (Unsteady Model) was used to model the West End of Government Highline Canal and simulate gate controller performance. The computer model simulated the reach of canal from Mack Wash Siphon to Badger Wash Wasteway.

Structural dimensions and hydraulic properties for the computer model were based on original design specifications. Canal hydraulic operations were based on daily flow measurement data for the 1991 irrigation season. Littleman gate control logic--which is included in USM--was used to represent the West End controllers.

Canal hydraulic behavior and controller performance were studied together via multiple computer simulations. Initial computer simulations were configured to duplicate typical field operating conditions and existing controller logic. Then, to a limited extent, more severe operations (larger flow changes) and modifications to the Littleman control logic were studied.

Starting from an initial steady state flow conditions, hydraulic operations were simulated by varying inflow at the upstream end of the canal reach and varying turnout flows. USM calculated water level fluctuations, flow changes, and gate movements throughout the canal reach. This output was used to evaluate gate controller performance. Good controller performance should result in:

- minimum water level fluctuation
- minimum number of gate movements
- dampening of flow changes as they move through the canal reach
- depth and gate movement oscillations should damp out, not continue or grow with time

About a dozen computer simulations were performed to test different operating scenarios and different controller constants. Inflows from 60 to 160 ft^3/s were studied, with a maximum flow change of 60 ft^3/s in 2 hours. Turnout flows varied from 10 to 30 ft^3/s and Badger Wash Wasteway flow ranged from 0 to 90 ft^3/s. Imposed flow changes at the upstream end of the reach and at turnouts included sudden large flow changes and oscillatory flows.

Computer study results showed the Littleman gate controller logic to be quite satisfactory. Despite the fact that computer simulations included much more severe operations than are likely in the field, system response was good. Water levels were maintained near deadband limits without excessive oscillation or overshoot, and without an excessive number of gate movements. Target depth in the canal could not be maintained at Badger Wash Wasteway because the automatically controlled slide gate is too small to pass enough flow, so the water level rises until weir flow reaches equilibrium.

The littleman control algorithm can be improved with different controller parameters (constants). Tests showed that longer rest times and smaller deadband limits would reduce depth fluctuations and the number of gate movements for the imposed flow changes.

Appendix B contains example graphical output from program USM for two simulations (without parameter modification) showing gate opening versus time and water level versus time at the downstream end of each pool. Figures B-1 and B-2 show output for an inflow increase from 100 to 160 ft^3/s in the first two hours and turnout flow oscillations at all turnouts. Figures B-3 and B-4 show output for an inflow decrease from 100 to 60 ft^3/s with turnout oscillations.

F. CONCLUSIONS

The Programmable Logic Controllers did not fail or produce inadvertent operation of the gates throughout the laboratory test period. The controllers were unaffected by attempts to produce line surges and noise on the ac power lines. The problems that have occurred in the field cannot be directly attributed to controller hardware operational problems, although incorrect control operation may have been caused by large power line surges, lightning, or temporary loss of primary power.

In some cases, the mechanical limit switches have failed, causing damage to the gate uptake ropes. The controller does not monitor limit switch status, so damage to the rope uptake could occur because open and close commands continue to be issued by the controller even if the gate is at the upper or lower limit position. Additionally, hardware failure--such as the problem with the power supply from the wasteway structure--will cause incorrect control operation.

Control system software may contribute to control problems during some flow conditions. The combination of short rest time settings and no antihunt logic can cause gate control to overcompensate for some flow changes. However, the laboratory tests and computer model studies did not detect any major software problems. In addition, some of the control failures that have occurred may have been avoided if controllers included protective logic that detects problems and prevents unwarranted gate movement.

In some of the laboratory tests, the gates moved to their maximum open or closed limits. However, flow changes may have been unrealistically large and hydraulic reaction times may have been too short because of the canal model's small scale. Computer studies represented the canal's hydraulic response more accurately. Computer results did not show any major defects in the existing control logic or control parameters, but did show that short rest times are not necessary and the existing deadband is too large. Computer simulations showed that the existing control algorithm adequately controls gradual flow changes without antihunt logic. The algorithm performed more poorly at low flow than at high flow conditions, because gate movements created larger flow changes.

The major operational problem in the West End may be the excessive sedimentation in the canal. This problem was emphasized during the field inspection. Large deposits of sediment in the canal have reduced the channel's flow capacity and plugged stilling well inlet pipes. Computer simulation assumed canal hydraulic properties from original design specifications, but the channel is now much smaller. Hydraulic performance of the existing channel is certain to be much worse than the computer simulation results.

Stilling well inlet pipe plugging may be causing the automatic control problems. Incorrect water level values would cause the Littleman algorithm to function incorrectly. The PLC equipment cannot determine if the sensor reading is in error; it only determines if the sensor is out of range (e.g. <1ma or >20ma). A plugged inlet pipe will cause changes in the sensed water level to lag behind the canal water level. If an inlet pipe plugs while the stilling well level is out of the gate operation deadband, the gate will open or close to the limit.

G. RECOMMENDATIONS

Computer model simulations have verified that the Littleman method of control for the four check structures will provide the necessary canal control under anticipated flow conditions. Therefore, the control method does not need to change. Control equipment tested in the laboratory using the canal model has performed reliably and has demonstrated the capability to execute the Littleman control algorithm in an efficient and reliable manner. We do not recommend that the equipment be replaced.

Recommended changes to the control system include improved software, better selection of the control parameters, abnormal condition monitoring, and additional protective and alarm indication equipment. These improvements will require purchasing additional hardware and modifying software. The details of these recommendations are described below.

1. Software modifications

a. Downstream override control - The downstream override control logic has been removed from the software. The control action produced by this logic will have unpredictable results on the control system. Abnormal condition monitoring has to be performed by monitoring the upstream water level for the upstream Littleman control method.

b. Antihunt logic - Antihunt software was added to the two-stage Littleman algorithm. This software inhibits gate movement when the water level is returning toward the target elevation. Traditional antihunt logic inhibits gate movement until the water level exceeds the opposite control action deadband. For example, if the gate was opening and the water level began to return to the target level, the gate would not operate until the water level exceeded the close deadband. This traditional antihunt logic can cause the actual water level to stabilize outside the desired target elevation.

The antihunt logic implemented for this application samples the water level at a fixed time and compares this value to the actual value. If the actual water level is returning toward the target then gate movement is inhibited. If the sampled value is equal to the actual value, then gate movement is not inhibited. This logic prevents the water level from stabilizing outside the desired target elevation. The sample time must be selected with care. If the sample time is too short, undesired gate movement will occur when the water level is slowly moving toward the target value. The model canal test showed that changing the sample time of the antihunt logic improved the controller performance. The sample time for the Government Highline canal antihunt logic should be about 3 minutes.

c. Gate operational deadband - The Littleman algorithm does not require gate position data. Therefore, the controller issues gate movements continuously while the water level is outside the deadband. To help prevent undesirable gate movements caused by water level sensor data errors, an operational deadband for gate control has been added to the algorithm. This deadband limits are from 50% to 90% of the water level range. If the water level is less than 50% or greater than 90%, gate movement is inhibited. When the water level returns to within these deadband limits, gate movement is allowed.

d. Dual water level sensors - The stilling well inlet pipe plugging problem does not have a simple software solution. The best method to correct this problem is to add an additional sensor to monitor canal level from a different location. The problem with this idea is selecting a location along the canal that will provide reliable water level data. If a suitable location can be found, the two water level sensors could then be compared and plugging of the stilling well pipe could be detected.

Logic to operate the controller from two water level sensors has been added to the control algorithm. The logic compares two water level sensors against each other with one water level having been adjusted by a specific constant. When a water level sensor value is outside a fixed range the algorithm will automatically read the other sensor. The logic will also monitor the sensor values to be sure the values are changing when the water level is outside the deadband. If the sensor value does not change over a fixed time, the algorithm will read the other sensor. If both sensors are outside the fixed range or have not changed in value outside the deadband for a specified amount of time, gate movement will be inhibited.

The analog input hardware detects when the sensor value is outside the normal 4-20ma range. Therefore, sensor voltage failures and sensor output short circuits are detected by the input hardware. The logic uses this information to inhibit gate movement. This logic will prevent the gate from incorrect operation due to sensor or power supply failures.

2. Control parameter selection

a. Gate rest timers - The gate rest timers need to be set such that the gate will respond to normal flow changes but will not hunt when the canal is at steady state. The original settings for the rest timers were 1 minute and 15 seconds. These times were too fast for the model canal. The timers were changed to 3 minutes and 1 minute for the model canal and good results were noted. The timer settings for the West End controllers should be about 5 minutes and 1 minute. Either field calibration or more detailed computer simulations --modeling the canal with sediment-- should be used to refine rest timer settings.

b. Antihunt sample time - An antihunt logic sample time of 5 minutes was selected from computer simulation studies of the canal.

c. Deadband limits - The original deadband setting was 4% and 6% for the operation of the two rest time cycles. These setting are not tight enough for proper water level control. The deadbands have been changed to 2% and 4% The tighter deadbands will allow for more responsive control action for most flow changes.

d. Gate operation deadband limits - The gate operation deadband limits have been initially set for 90% and 30% of the upstream water level value. These settings have been verified by computer simulation tests.

3. Abnormal condition monitoring

a. Gate deadband monitoring - Gate deadband software provides a method for preventing control equipment from incorrect operation during abnormal conditions.

b. Dual sensor monitoring - A second water level sensor in the canal would prevent a plugged stilling inlet pipe from causing incorrect control actions. Sensor location will determine the overall reliability of this protection scheme.

c. Gate limit switch operation - Gate limit switches should provide information to the PLC that the gate has reached the upper or lower limit position. This addition will prevent the controller from moving the gate when it has reached a limit position, but will not protect against gate limit switch failures.

4. Protection and Alarm indication equipment

a. Limit switches - Gate limit switch operation will be monitored and a lamp on the digital input module will light when a limit switch has operated.

b. Sensor reading unreliable - If one of the water level sensors has an unreliable reading, as determined by the dual sensor logic, a lamp on the digital input board will light.

c. Gate motor torque switch - The gate motor torque switch will be monitored and a lamp will light when the gate torque switch operates.

d. Protection - The alternating current input to the PLC equipment should be protected from lightning and electrical transients. A sophisticated line protector manufactured by MCG Electronics Inc., Model 415, will be installed in each automatic control equipment cabinet. This device will protect the PLC equipment against both lightning and electrical transients that may be imposed on the ac service feeder lines to the equipment cabinet. The device has an operation time of 1 nanosecond with automatic reset and energy absorption capability of 480 joules. A green indicator lamp shows the status of the device.

MOV surge suppressor modules will be added to the PLC equipment output modules. These devices will protect the PLC equipment from undesirable operation due to transients generated by the output gate control relays. The surge suppressors mount in the PLC module slots and do not require additional wiring.

H. NEW EQUIPMENT REQUIRED

In order to improve the operation of the automatic control equipment as described above, additional equipment is required. The following equipment will be furnished and installed by the Denver Office before the automatic control equipment is placed into service.

1. Digital input module for each PLC (4-each).
2. Transient protection module for each PLC (4-each).
3. Relays for open and close limit position inputs. (8-each).
4. AC powerline transient protector for each control cabinet (4-each).
5. EEPROM memory chips (4-each).

The addition of water level sensors at each Littleman automatic control locations is required if the inlet pipe plugging problem continues. The recommended sensor is a pressure transducer manufactured by Leupold Stevens Company. The sensor would have to be installed near the gate structure in a 1.5-inch plastic pipe secured to the concrete check gate structure. The location would have to selected so that the sensor is not effected by turbulence from the gate movements. The location should not interfere with the canal maintenance procedures. The cost of the sensors is about $600.00 each. Four sensors are required.

I. RECOMMENDATIONS TO ENHANCE CANAL OPERATION

The Littleman upstream control method together with the recommended hardware and software additions should improve the West End canal operation. Additional equipment and design changes could be made to enhance the overall canal system operation. These enhancements are discussed below.

1. Installation of a radio alarm system to monitor the condition of the Littleman control equipment is strongly recommended. Response to failures and abnormal conditions would be improved without increasing manual supervision. The alarm system would notify operators at the central headquarters of abnormal site conditions so that maintenance personnel could be dispatched

immediately to diagnose and correct the problem. The alarm system would provide canal system operators with additional confidence in the present automatic control system, because failures would be known immediately. The alarm system would also augment the initial control system testing. Reaction to failures and solutions to specific problems could be handled much more efficiently with the ability to monitor site conditions on a 24-hour basis.

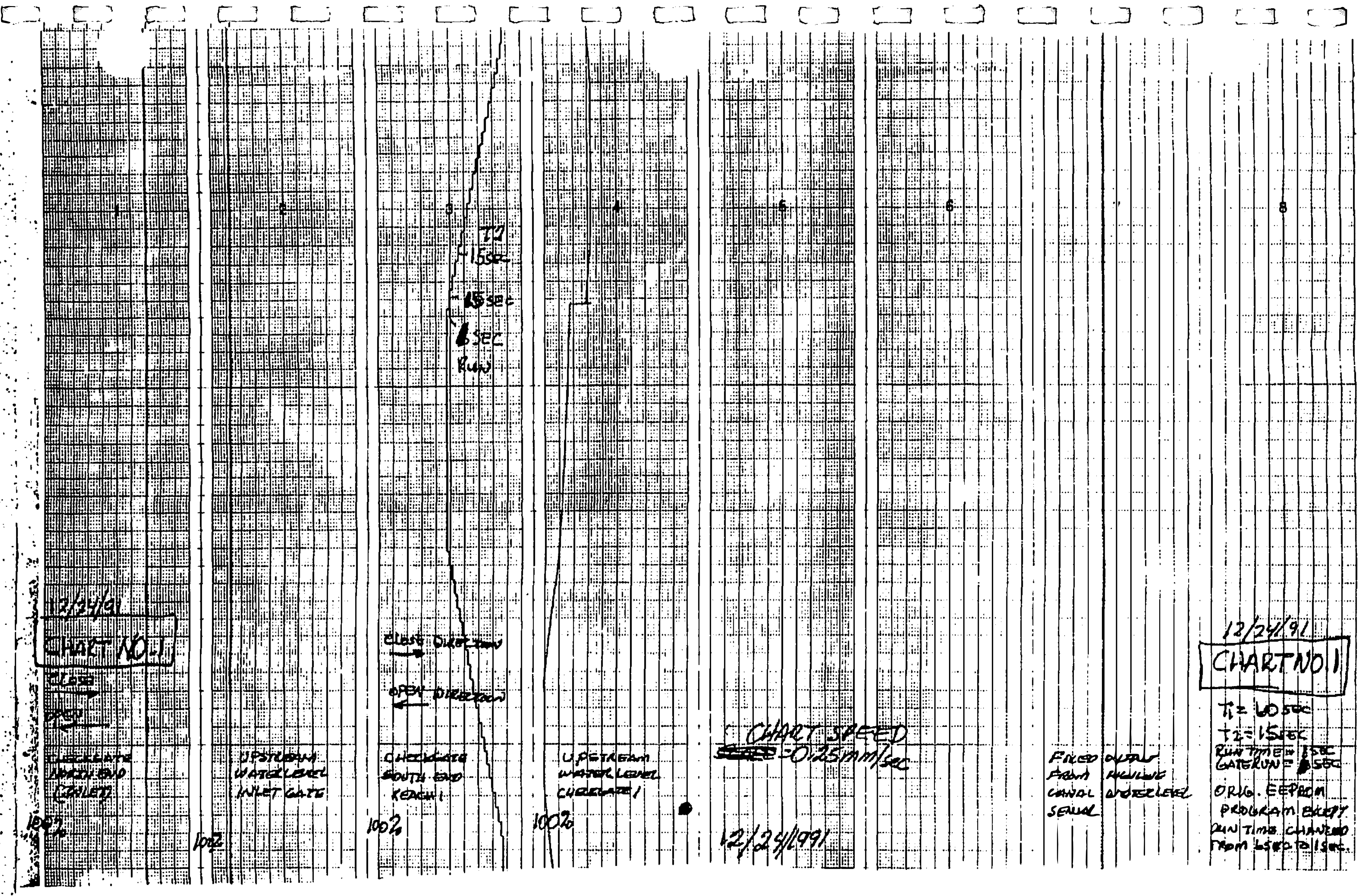
2. Presently, the Government Highline Canal uses an upstream control concept. Gates are controlled to maintain upstream water levels. As such, waste reduction must originate at the canal headworks; to reduce waste flows, less river water must be diverted into the canal. Dependable performance of the West End gate controllers may give canal operators the confidence to reduce canal inflow and match supply to demand more closely.

If waste reduction is a primary goal, the downstream control method should be considered. Downstream control reacts to changes in demand. Intermediate regulatory storage would be required to convert the West End to downstream control.

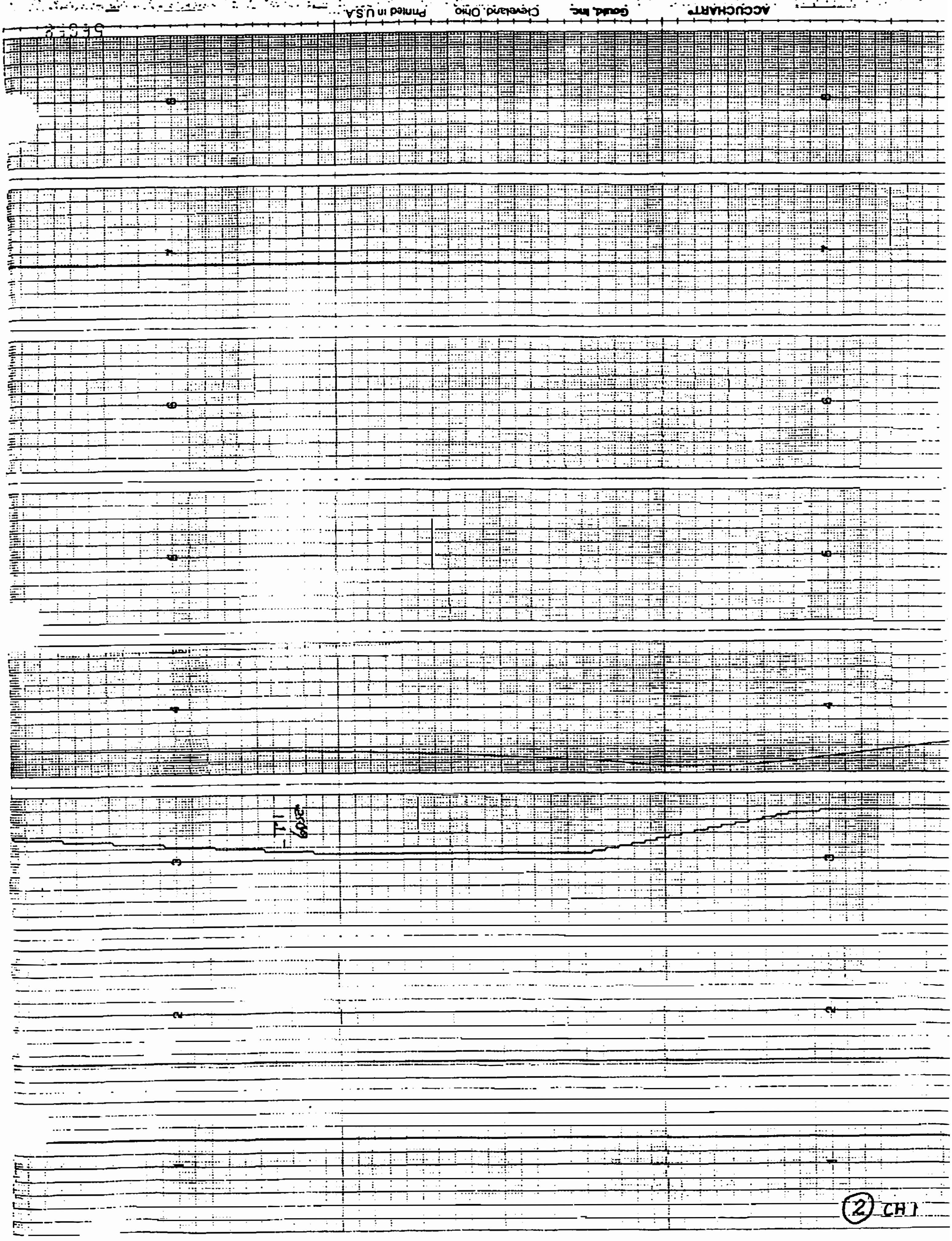
3. Supervisory control of check structures would provide waste reduction, automatic downstream control, and centralize the operation of the canal. Operating and alarm information could be collected at each check structure and monitored at a central location. This control method would enhance canal operation by improving response to abnormal conditions and provide the ability to change the control algorithm parameters at all check structures in a short time from one central location. Remote manual control could be used to override the automatic control operation at each check structure.

APPENDIX A

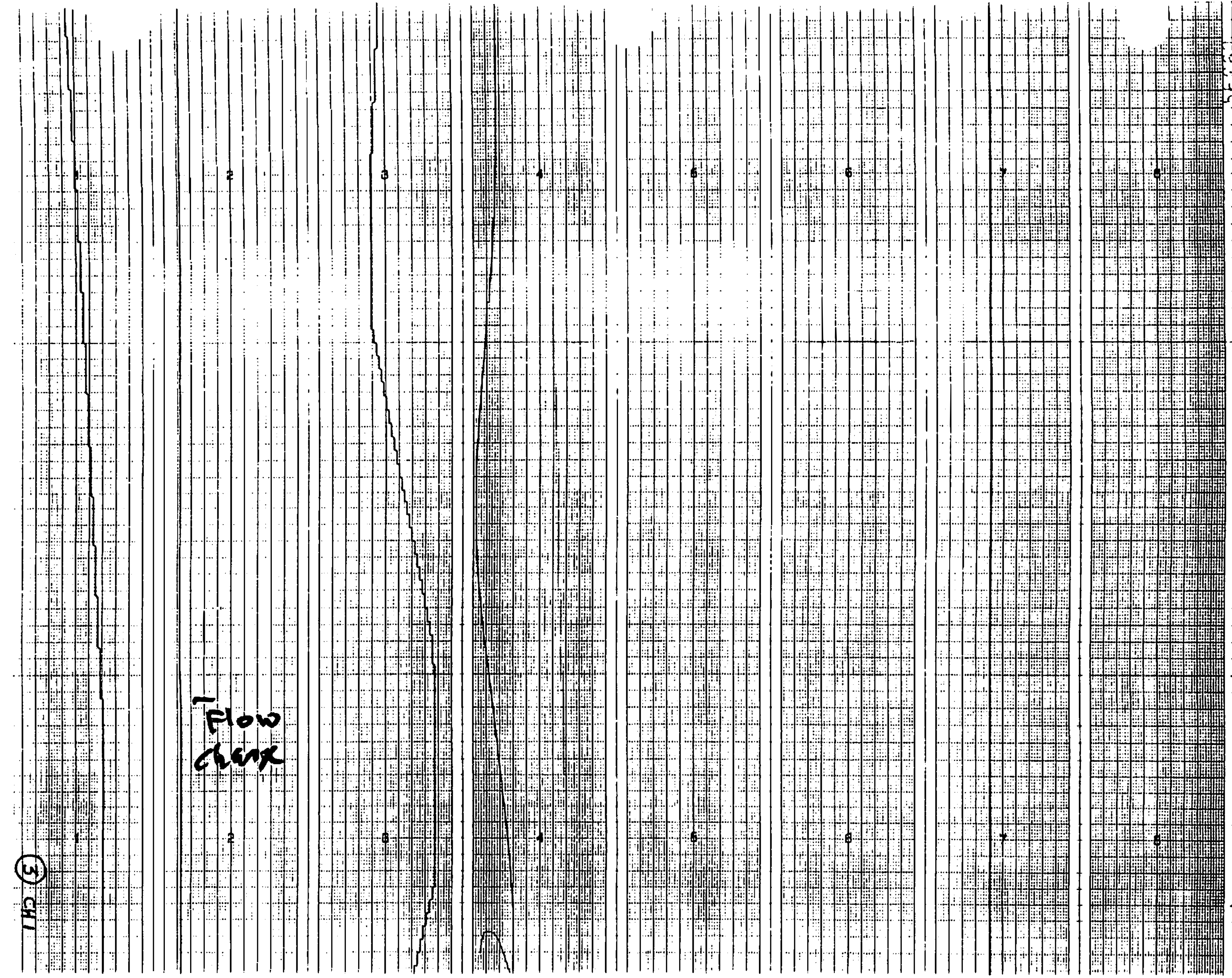
CHART 1

1
2
3
4
5
6
7
8
T2
15SEC
15SEC
6SEC
RUN
12/24/91
CHART NO.1
CLOSE
OPEN
CHECKGATE
NORTH END
(INLET)
100%
UPSTREAM
WATERLEVEL
INLET GATE
100%
CLOSE DIRECTION
OPEN DIRECTION
CHECKGATE
SOUTH END
REACH 1
100%
UPSTREAM
WATER LEVEL
CHECKGATE 1
100%
CHART SPEED
~~SCALE~~ =0.25MM/SEC
12/24/1991
FIXED VALUE
FROM
CANAL
SERIAL
ACTUAL
WATERLEVEL
12/24/91
CHART NO.1
T1 = 60SEC
T2 = 15SEC
RUN TIME = 1SEC
GATERUN = 6SEC
ORIG. EEPROM
PROGRAM EXCEPT
RUN TIME CHANGED
FROM 6SEC TO 1SEC.

① CH1.

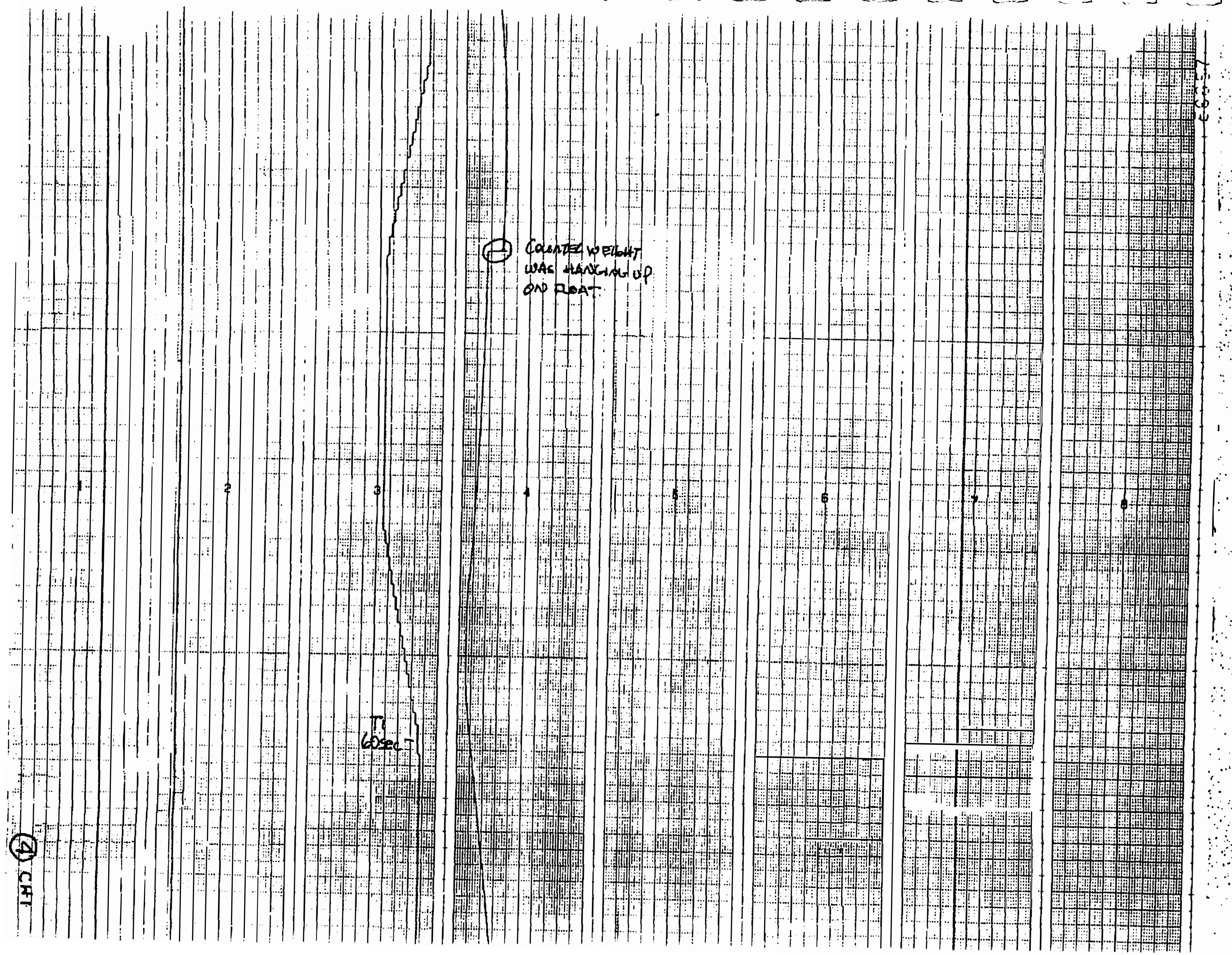


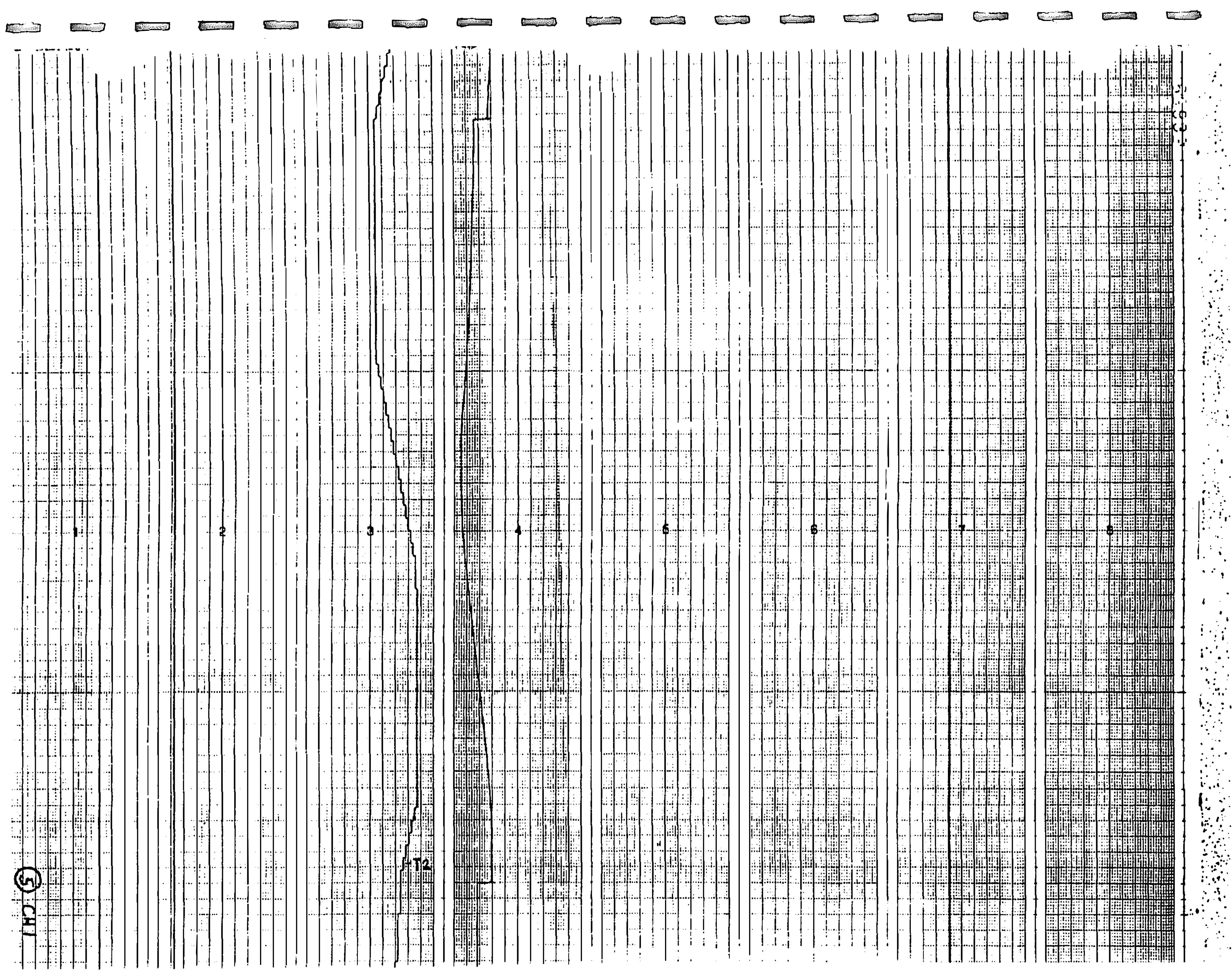
② CH 1



Flow check

③ CH1

1
2
3
4
5
6
7
8
① COUNTER WEIGHT WAS HANGING UP ON FLOAT
T1 60SEC T
④ CH1

⑤ CH1
T2
1
2
3
4
5
6
7
8

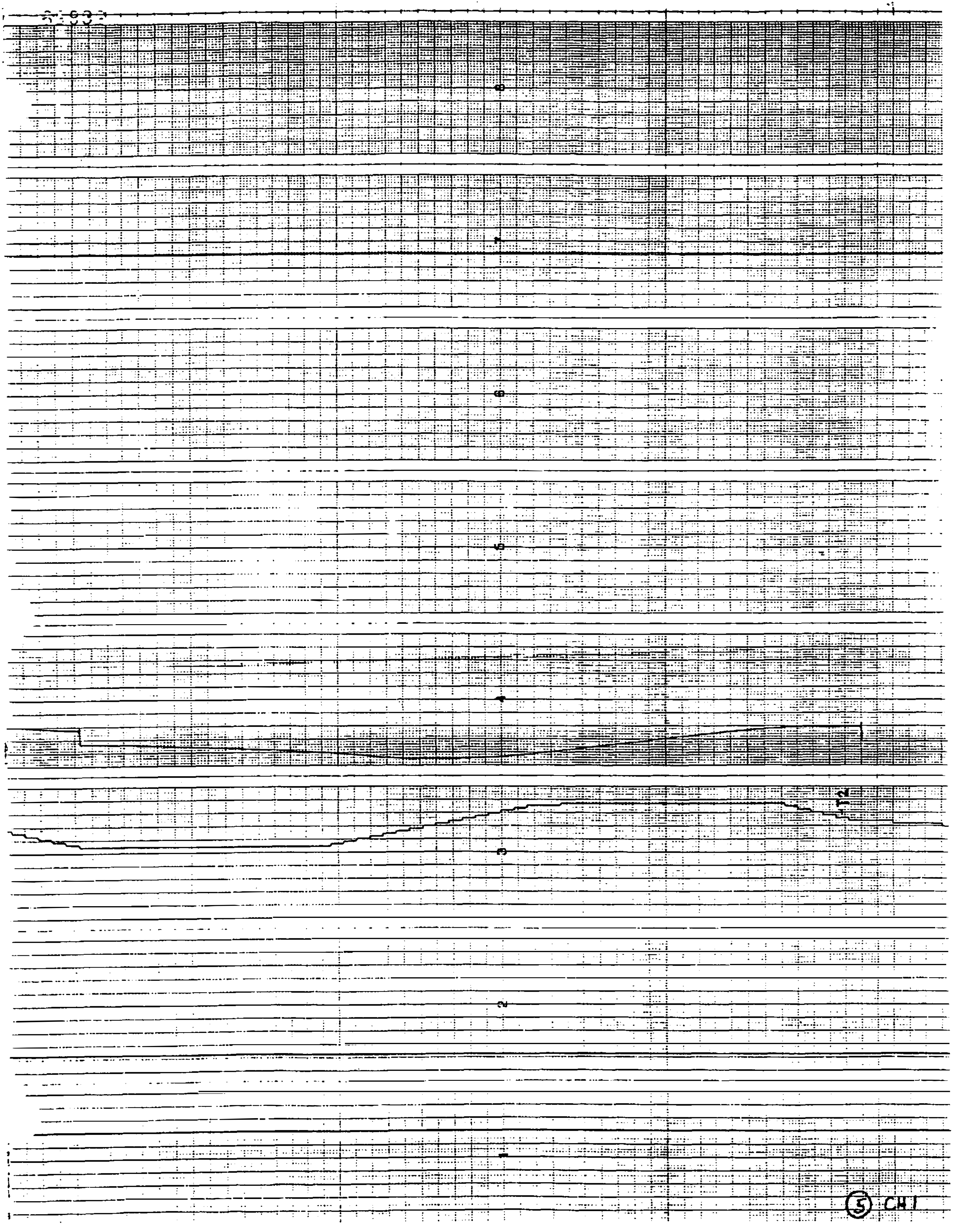
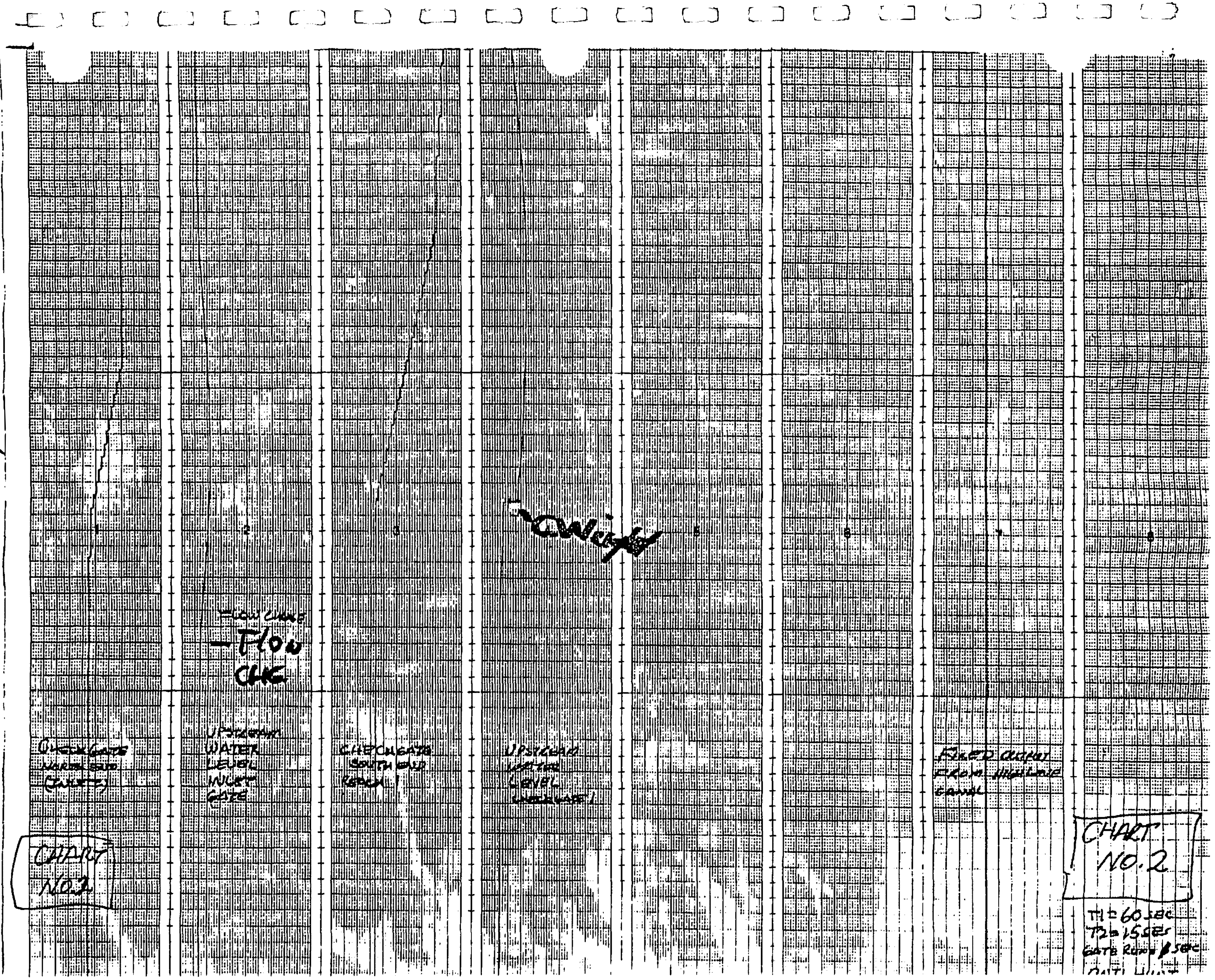
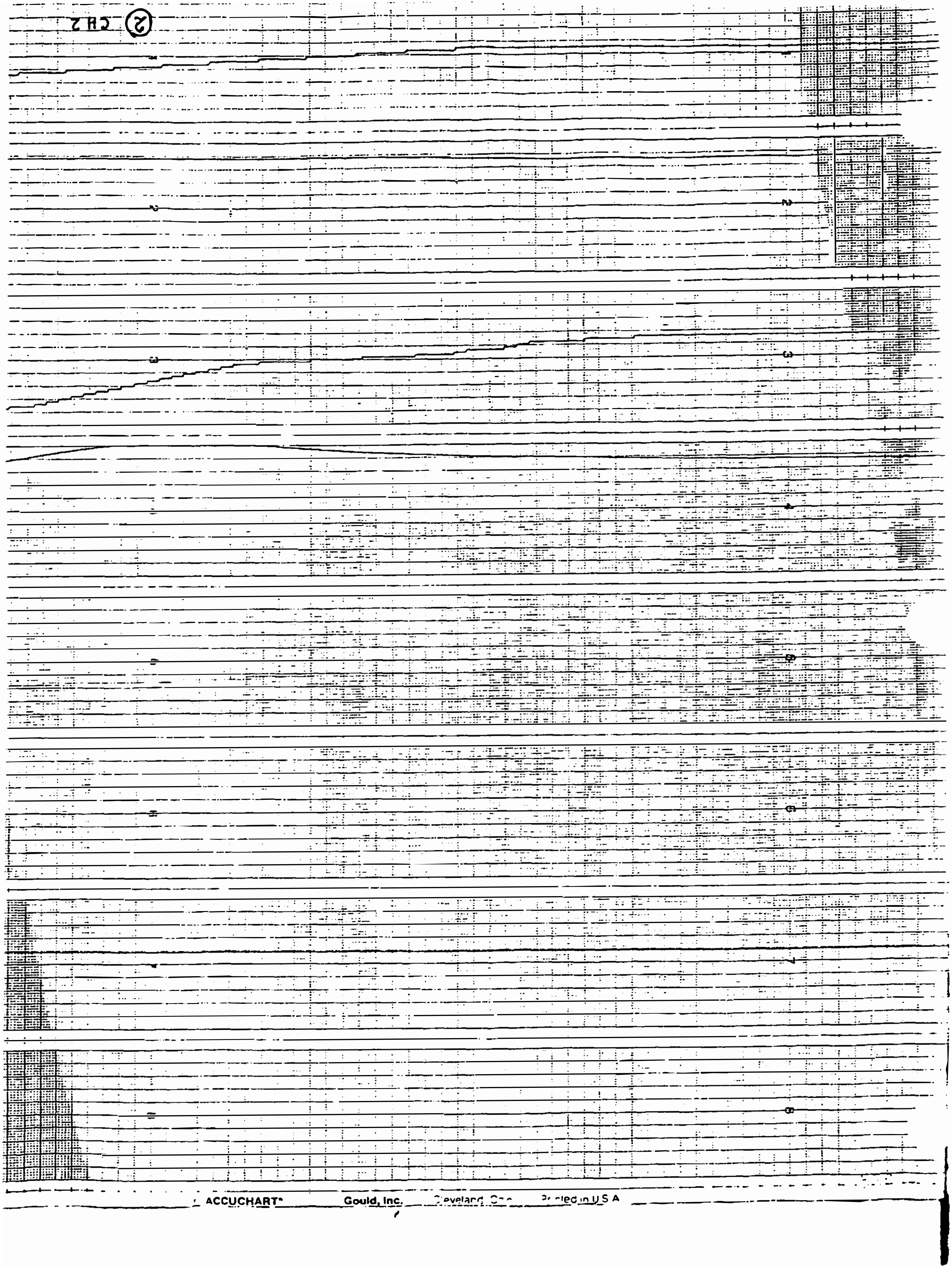
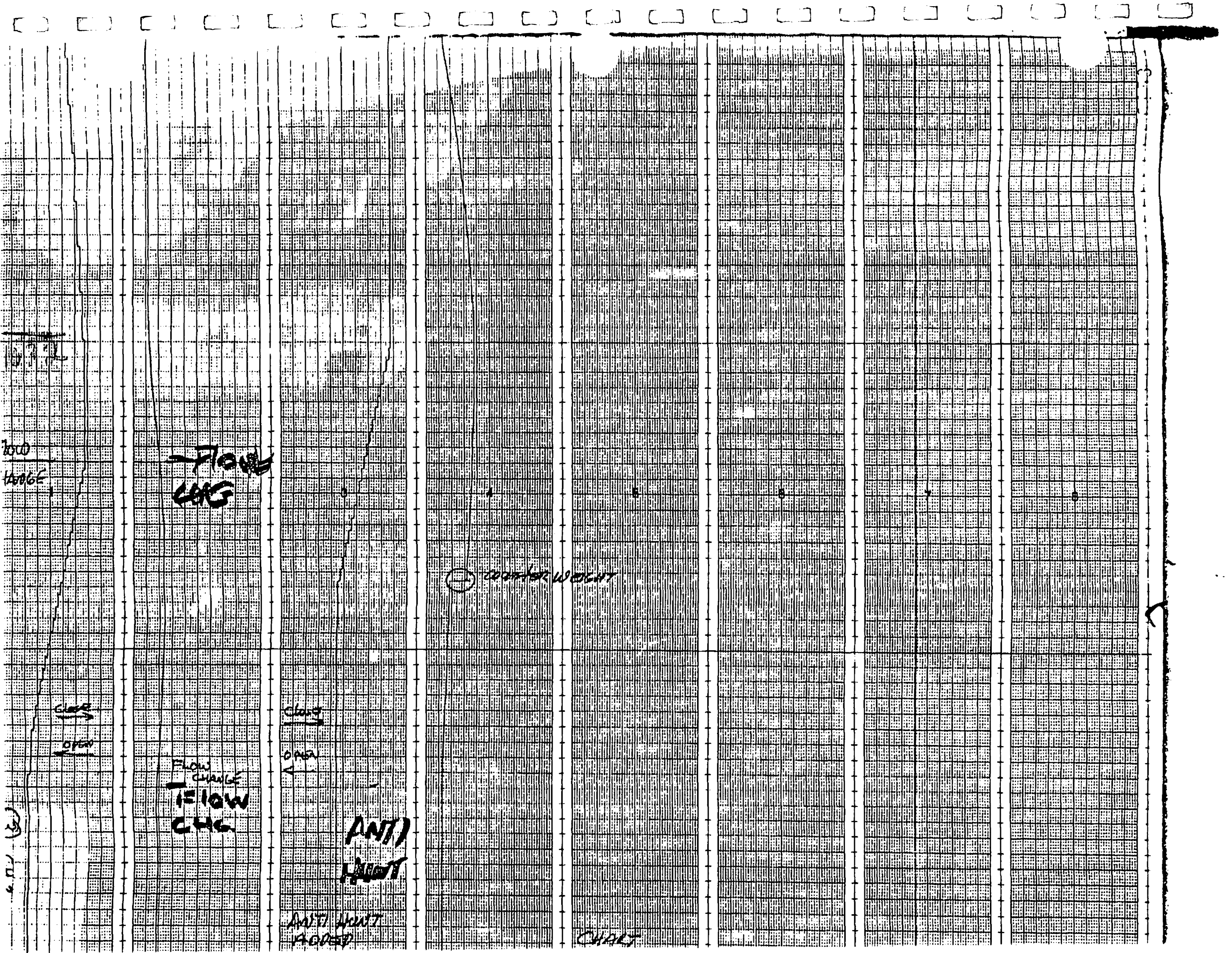

8
7
6
5
4
T2
3
2
1
⑤ CH1

CHART 2


1
2
3
4
5
6
7
8
CHECK GATE
NORTH END
UPSTREAM
WATER
LEVEL
INLET
GATE
FLOW CHANGE
– Flow
CHG
CHECK GATE
SOUTH END
REACH 1
UPSTREAM
WATER
LEVEL
CHECKGATE 1
FIXED OUTPUT
FROM HIGHLINE
CANAL
CHART
NO. 2
CHART
NO. 2
T1 = 60 sec
T2 = 15 sec
GATE RATE [illegible] sec

① CH2


② CH 2
ACCUCHART®
Gould, Inc.
Cleveland, Ohio
Printed in U.S.A


19?2
2000
RANGE
1
FLOW CHG
3
4
5
6
7
8
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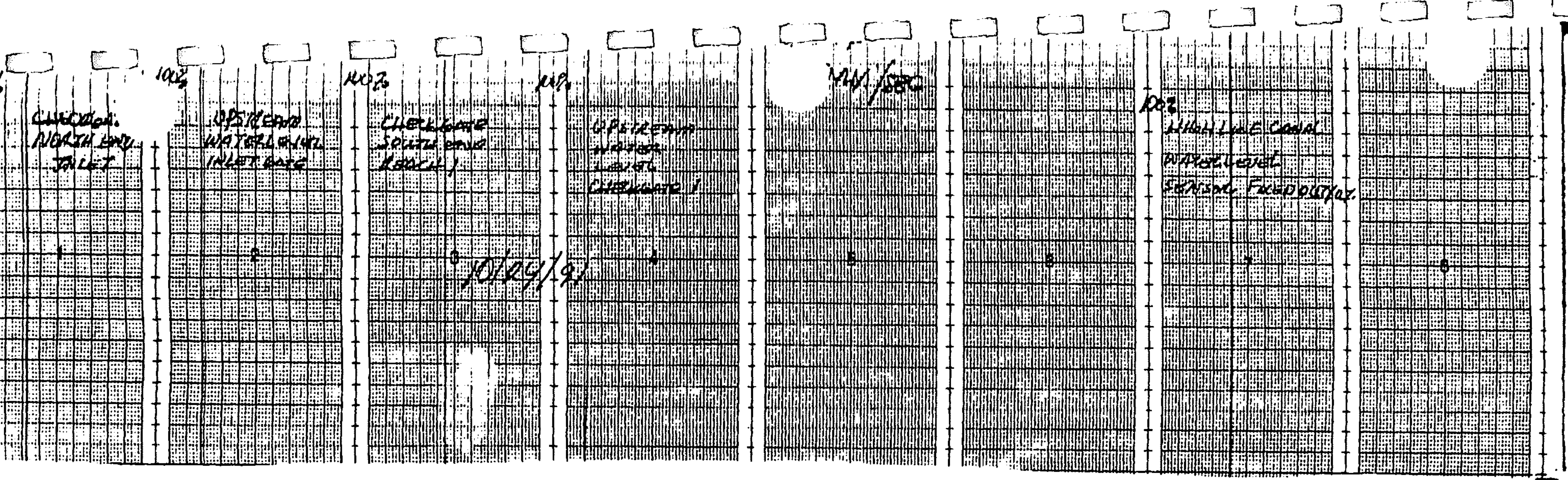
FLOW CHANGE
FLOW CHG
ANTI HUNT
ANTI HUNT ADDED
CHART

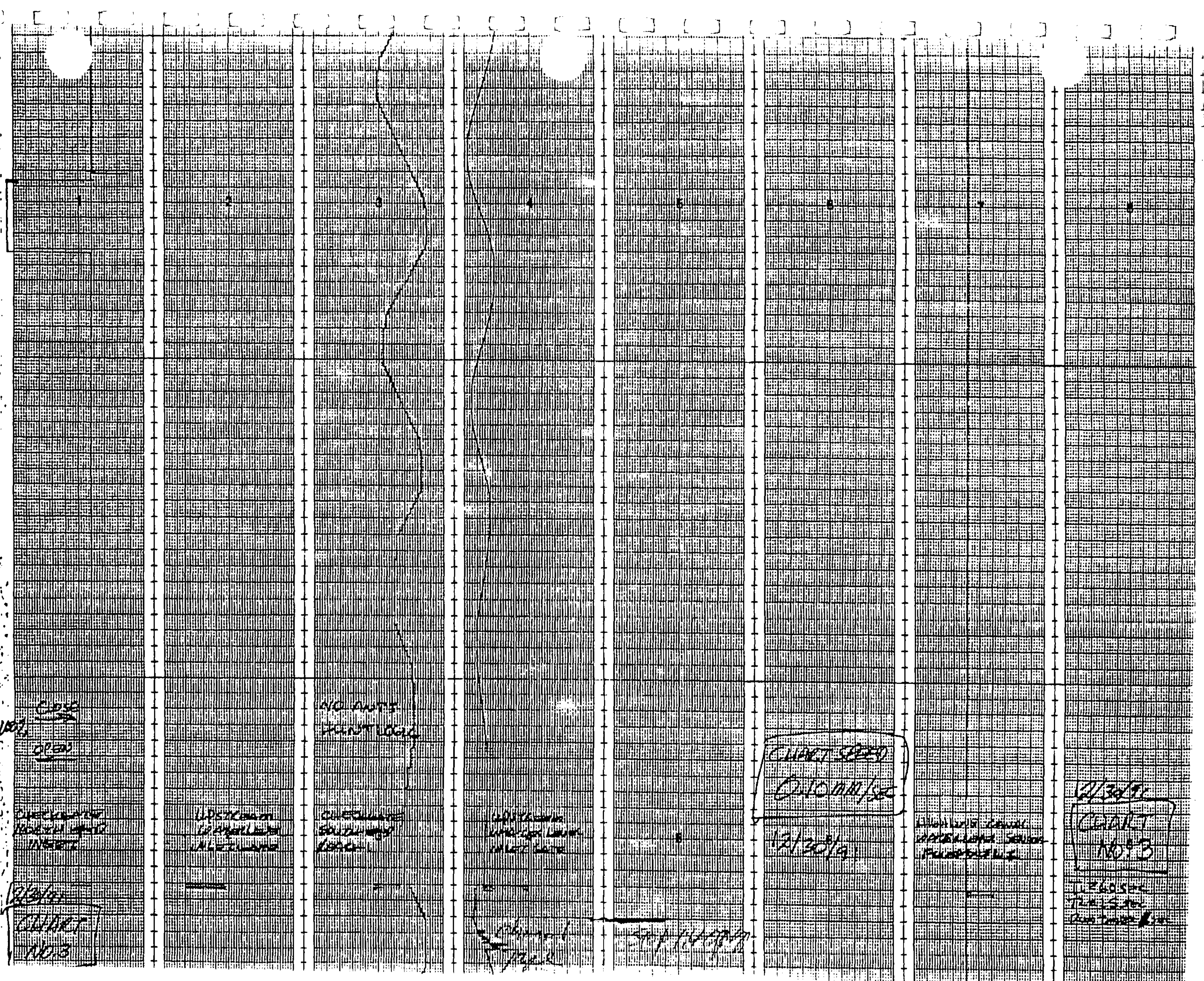

100%
CHECKGATE:
NORTH END
INLET
100%
UPSTREAM
WATERLEVEL
INLET GATE
100%
CHECKGATE
SOUTH END
REACH 1
100%
UPSTREAM
WATER
LEVEL
CHECKGATE 1
MM/SEC
100%
HIGH LINE CANAL
WATER LEVEL
SENSOR FEEDBACK
1
2
3
4
5
6
7
8

10/24/91

④ CH 2

CHART 3

① CH2


1
2
3
4
5
6
7
8
CLOSE
100%
OPEN
NO ANTI HUNT LOGIC
CHART SPEED 0.10 MM/SEC
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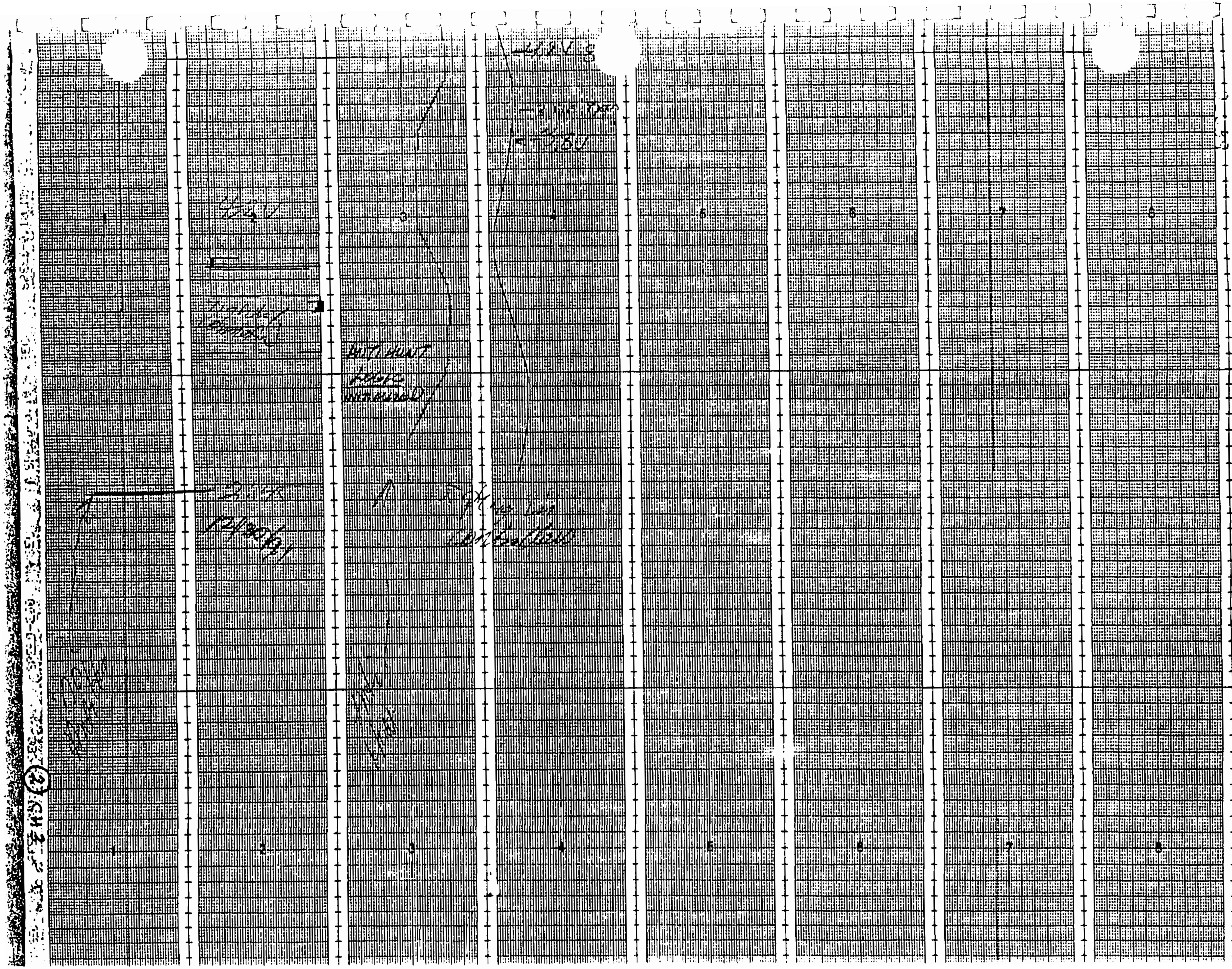
12/30/91
CHART NO. 3


②CH 2
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HUT HUNT
LOGIC
INHIBITED
12/20/91
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2
3
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6
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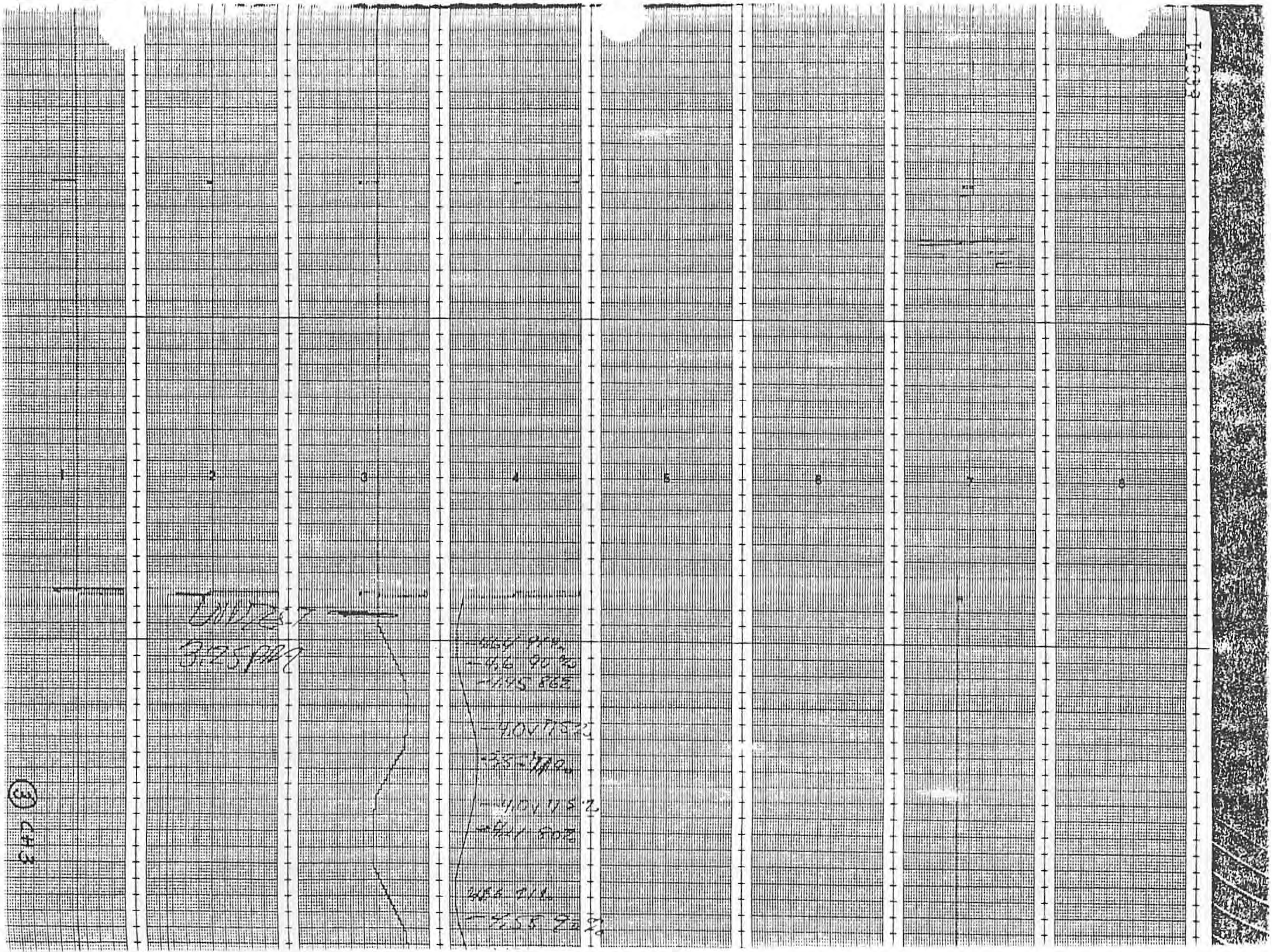
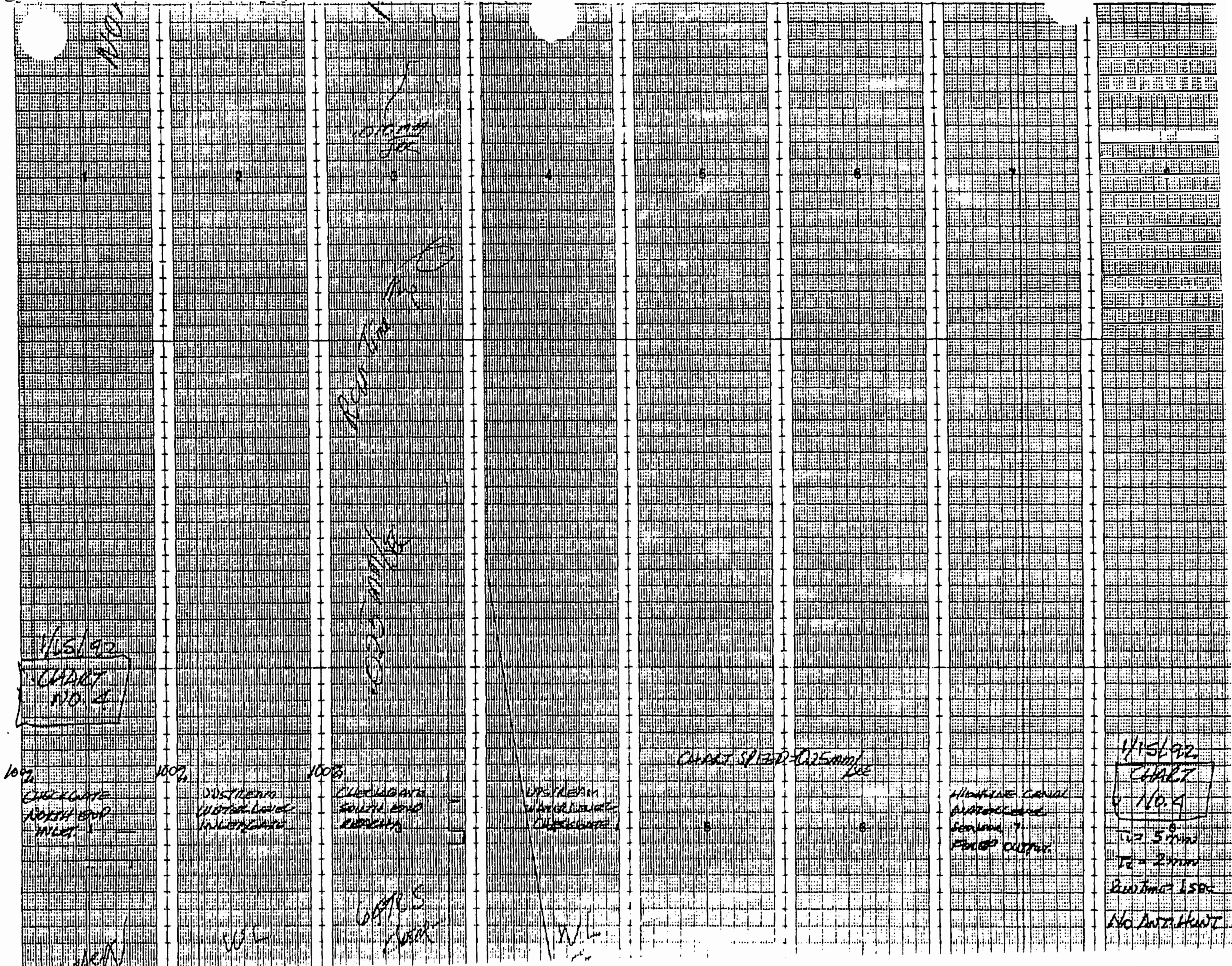
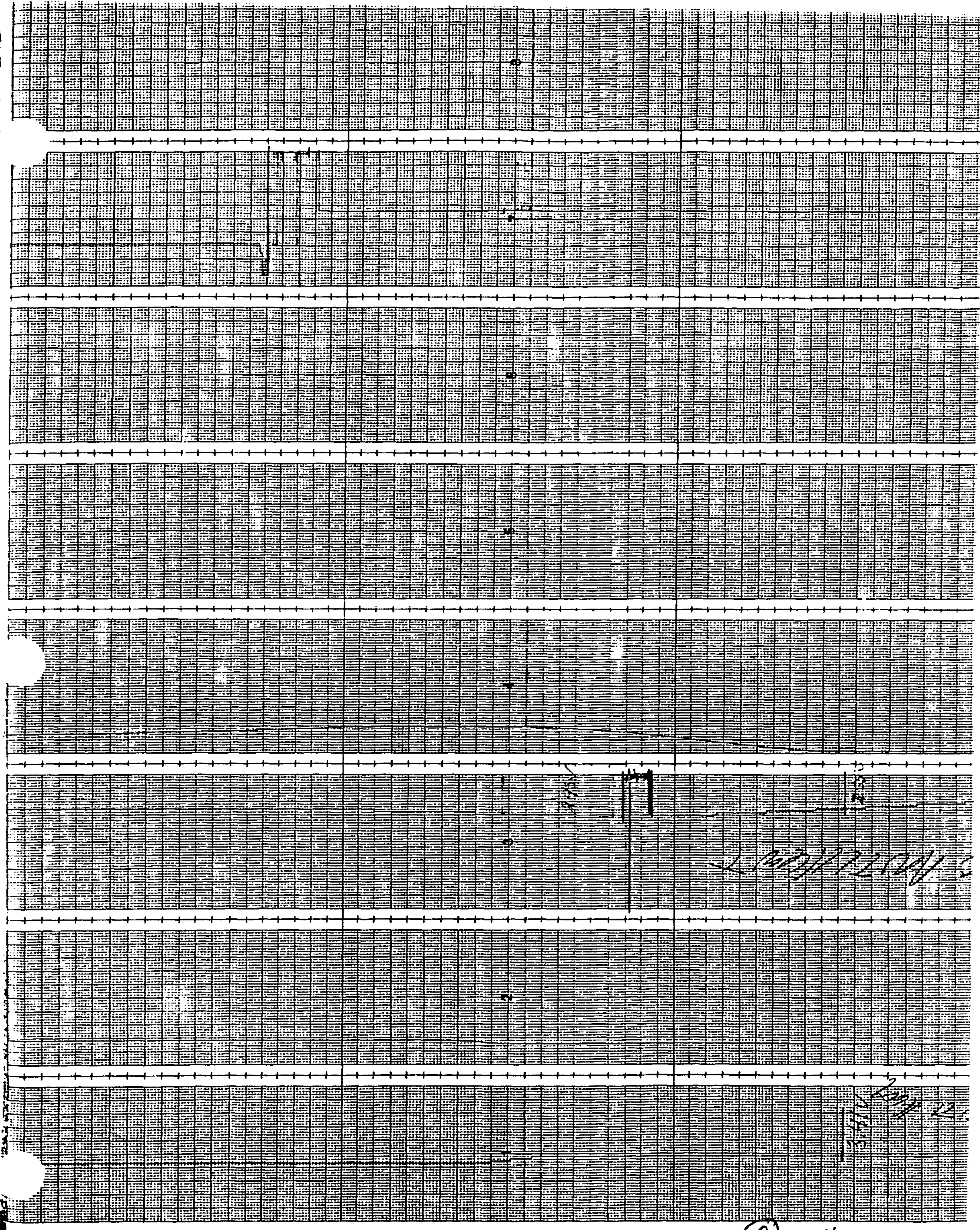

③ CH3
1
2
3
4
5
6
7
8
3:25PM
4.6 90%
40V 75.2
455 92%

CHART 4

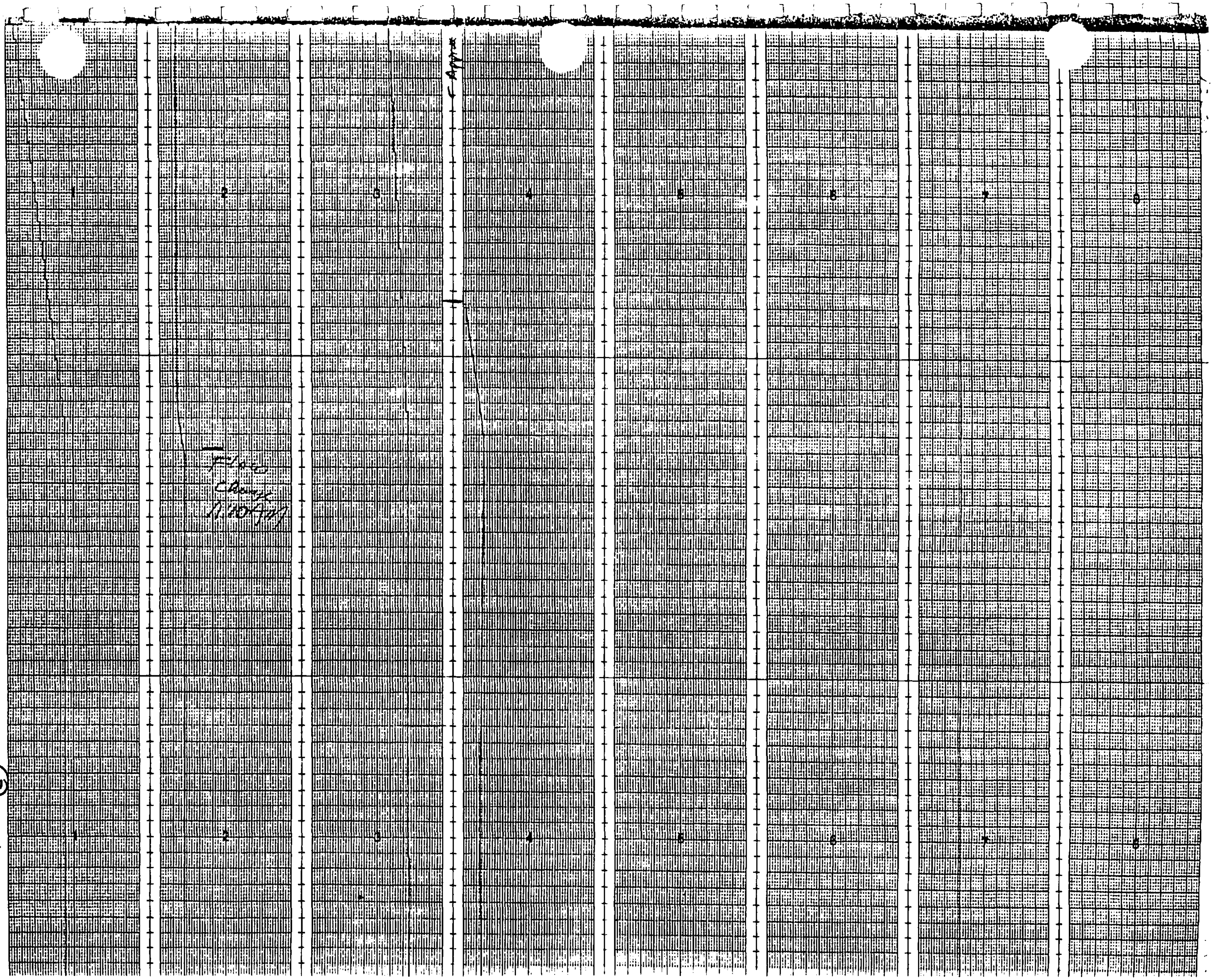
① C44

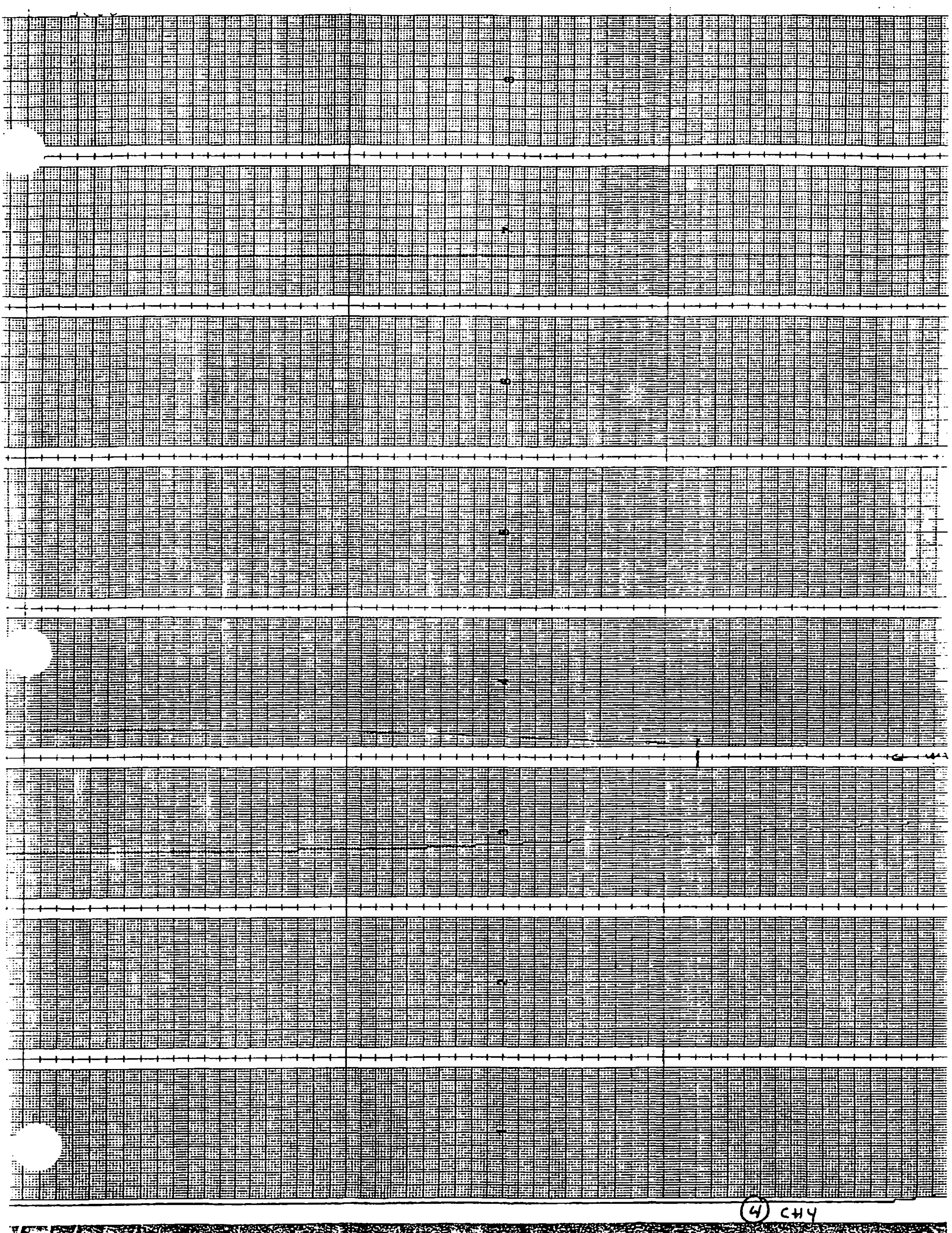

1
2
3
4
5
6
7
8
10 mm/sec
1/15/92
CHART NO. 4
100%
CHECKGATE NORTH END INLET 1
100%
DOWNSTREAM WATER LEVEL INLETGATE
100%
CHECKGATE SOUTH END [illegible]
UPSTREAM WATER LEVEL CHECKGATE
CHART SPEED=0.25mm/sec
HIGHLINE CANAL [illegible] Section 7 PUMP OUTLET
1/15/92
CHART No. 4
T1 = 5 min
T2 = 2 min
Run time = 15 sec
No Adjustment
W.L.
GATES [illegible]
W.L.



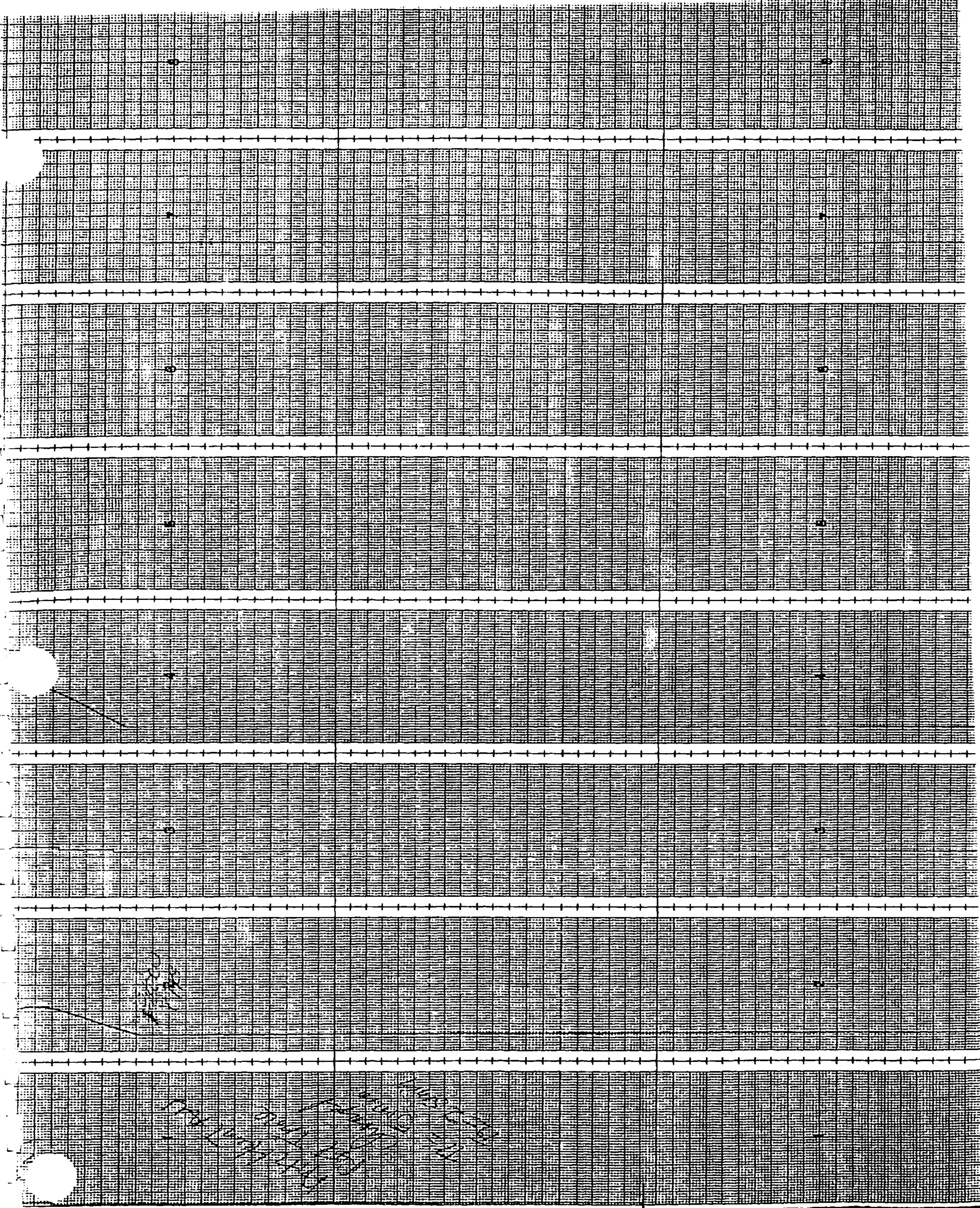
② CH4

③ CH4





④ CH4



(5) CH4

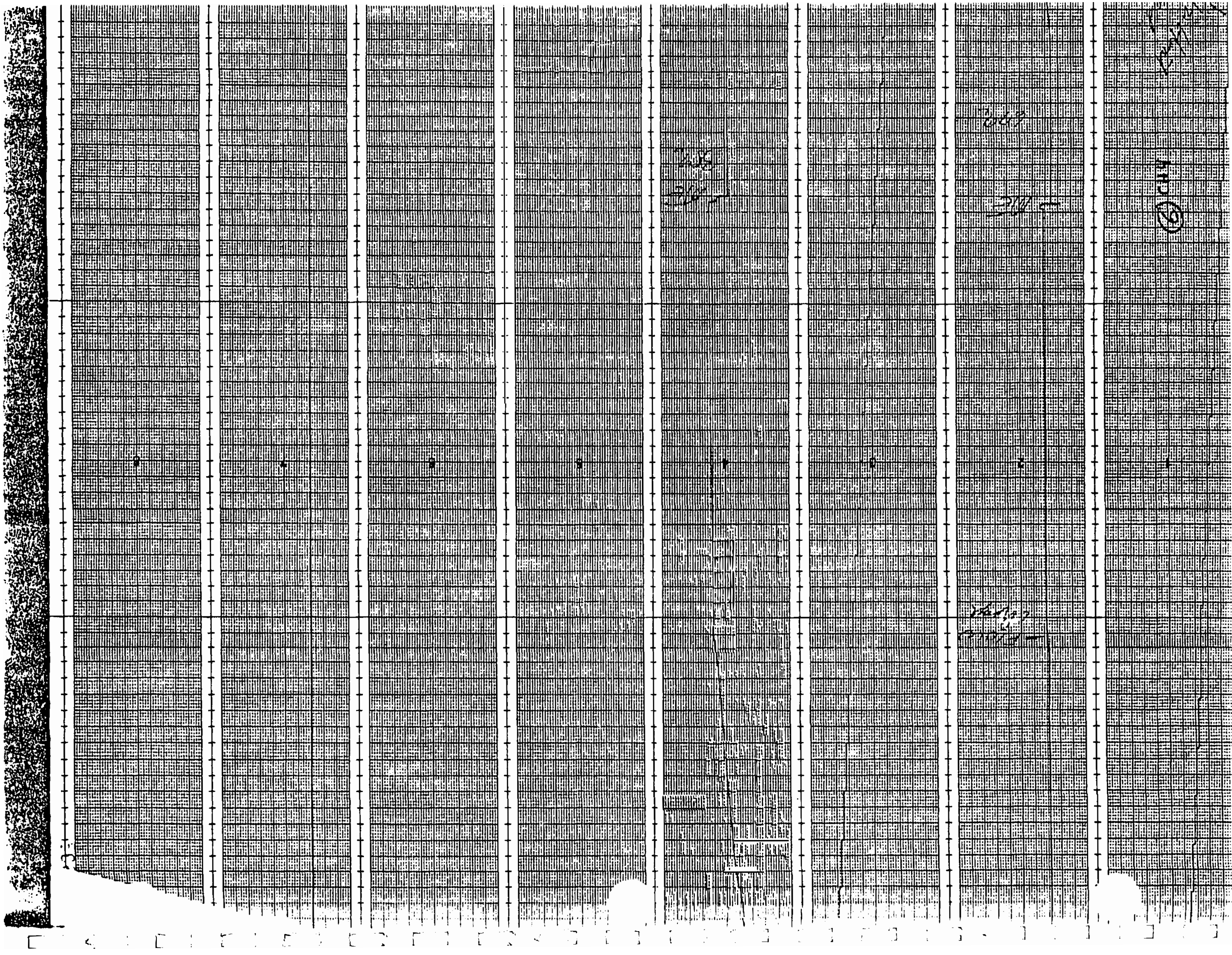
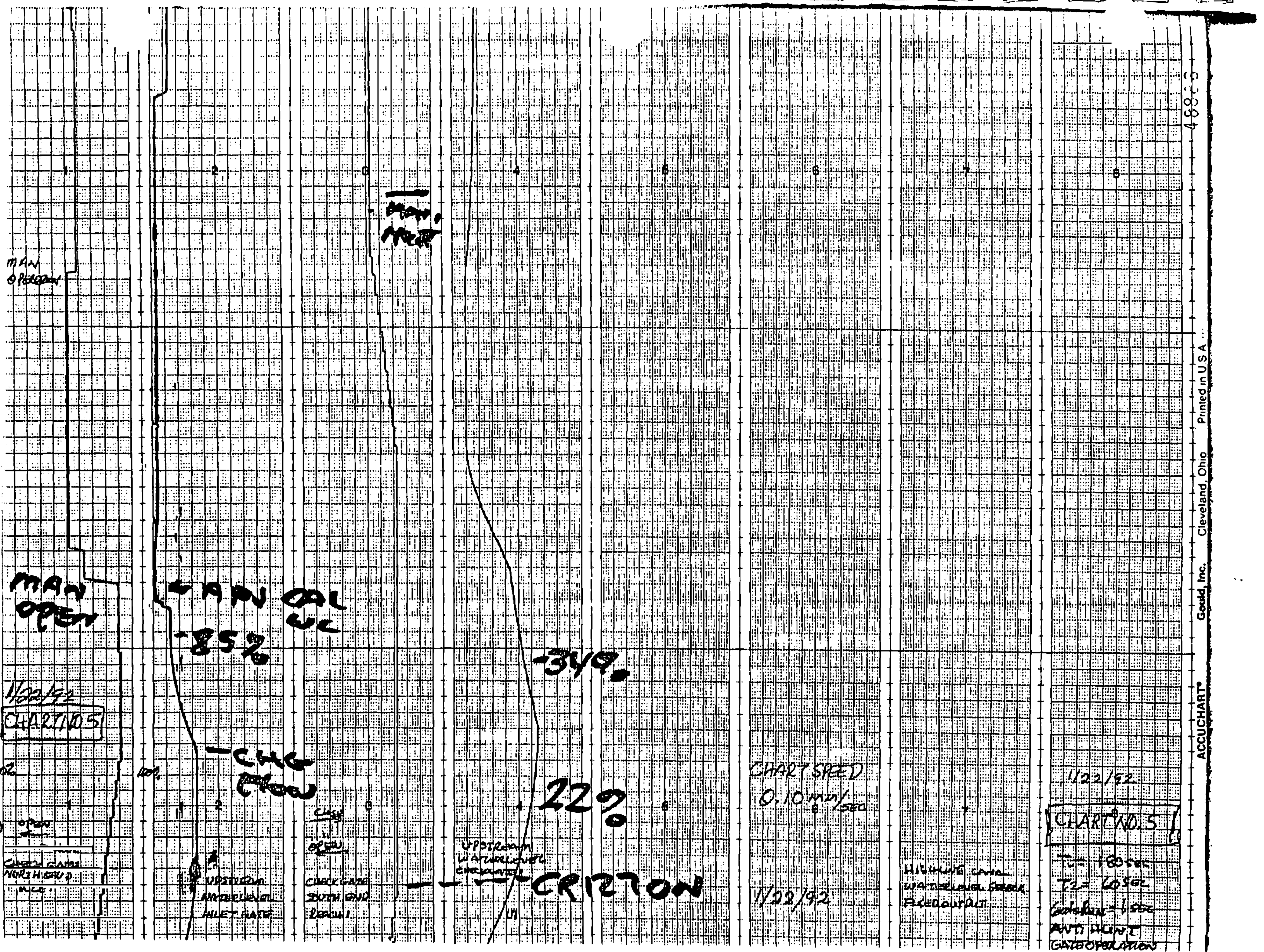
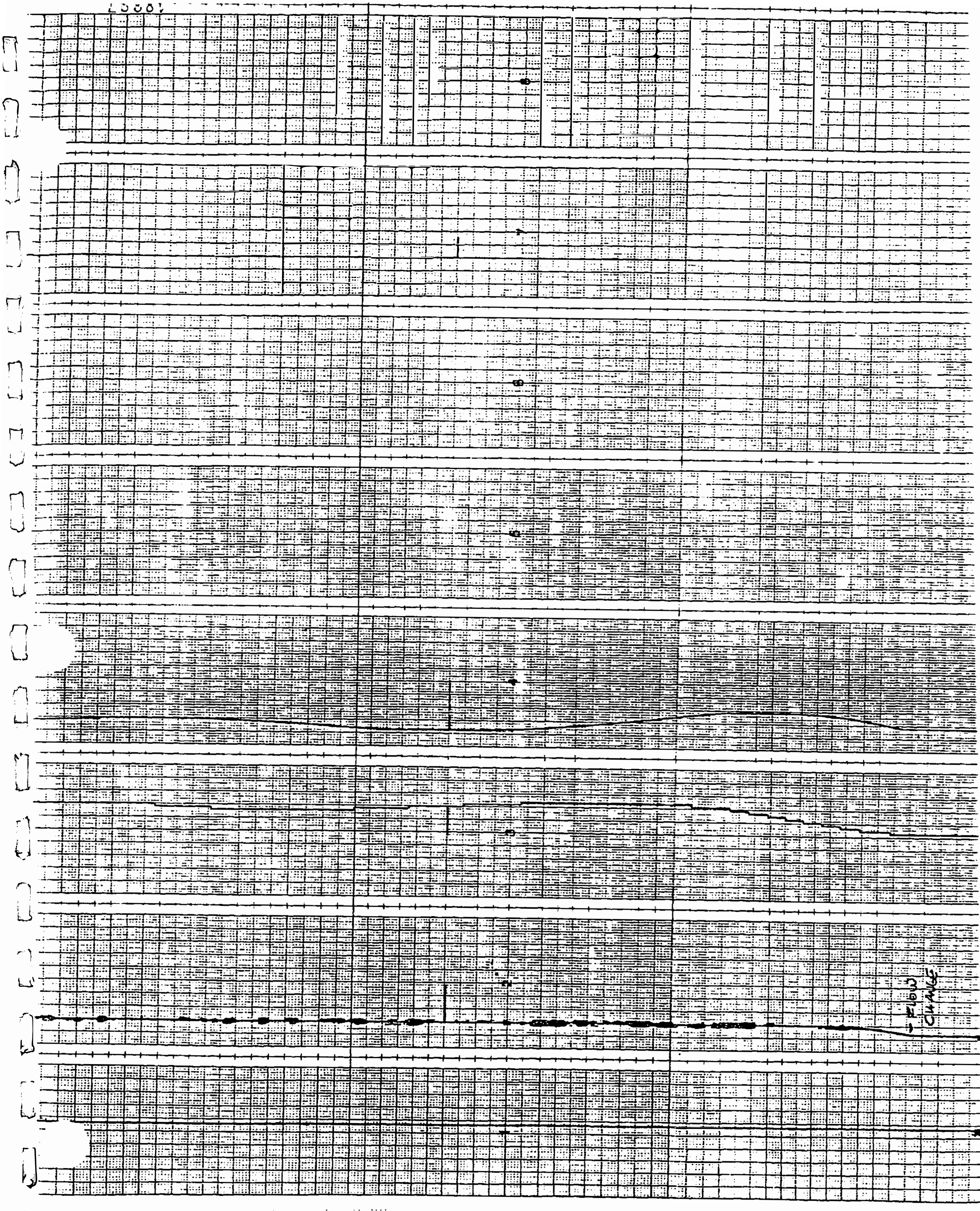

CH ⑥

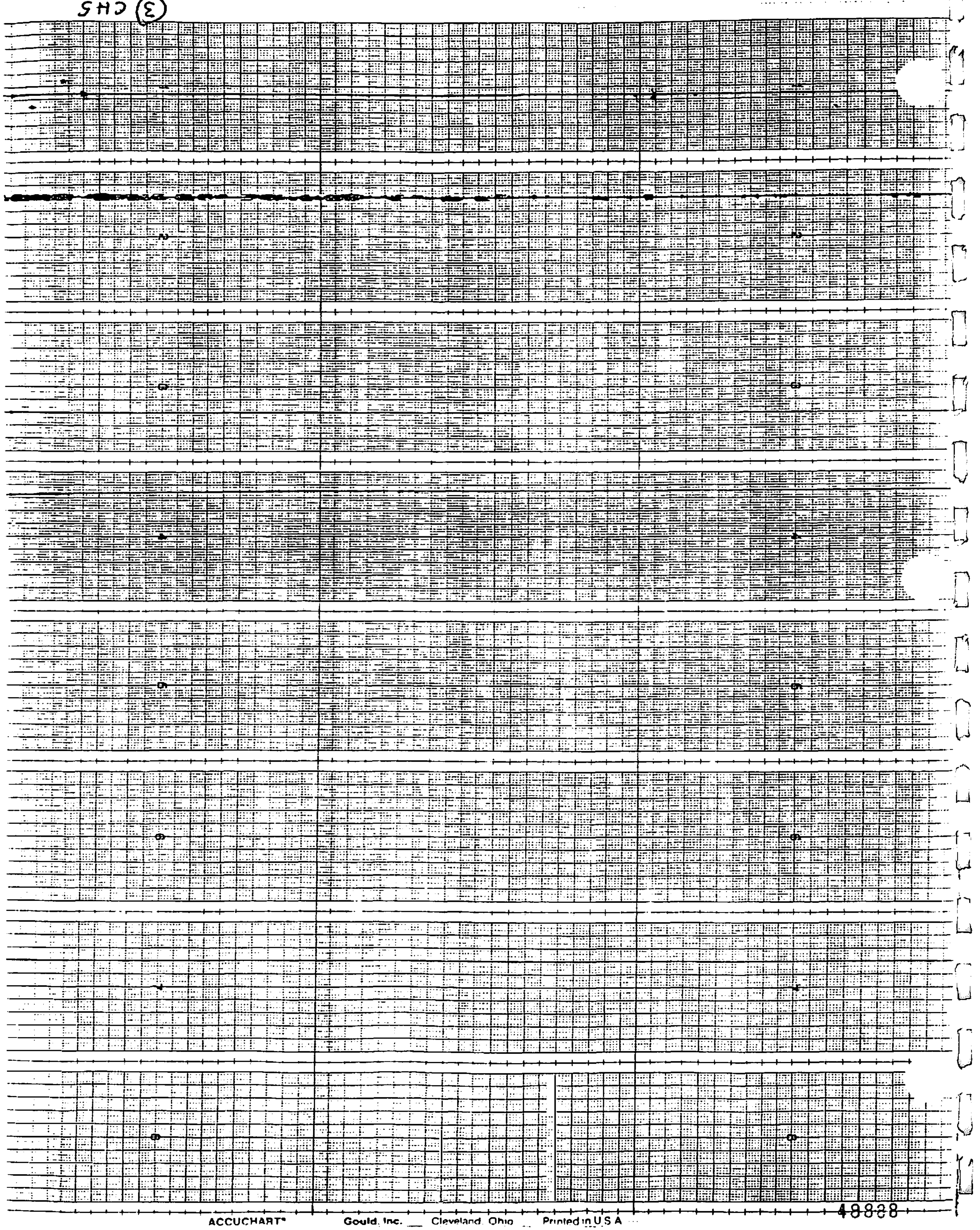
CHART 5


MAN OPERATION
MAN OPEN
← MAN CAL WL
-85%
-CHG FLOW
-34%
22%
MAN. MEAS
1/22/92
CHART NO 5
OPEN
CHECK GATE NORTH END WL
UPSTREAM ANGLE LEVEL INLET GATE
CLOSE
OPEN
CHECK GATE SOUTH END REACH 1
UPSTREAM WATER LEVEL CHECK GATE
CRIZTON
UL
CHART SPEED 0.10 min/sec
1/22/92
HIGHLINE CANAL WATER LEVEL SENSOR FEEDOUT
1/22/92
CHART NO. 5
T1 = 180 sec
T2 = 60 sec
Gate Rate = 1 sec
ANTI HUNT
GATE OPERATION
1
2
3
4
5
6
7
8
ACCUCHART®
Gould, Inc.
Cleveland, Ohio
Printed in U.S.A.
4681-5

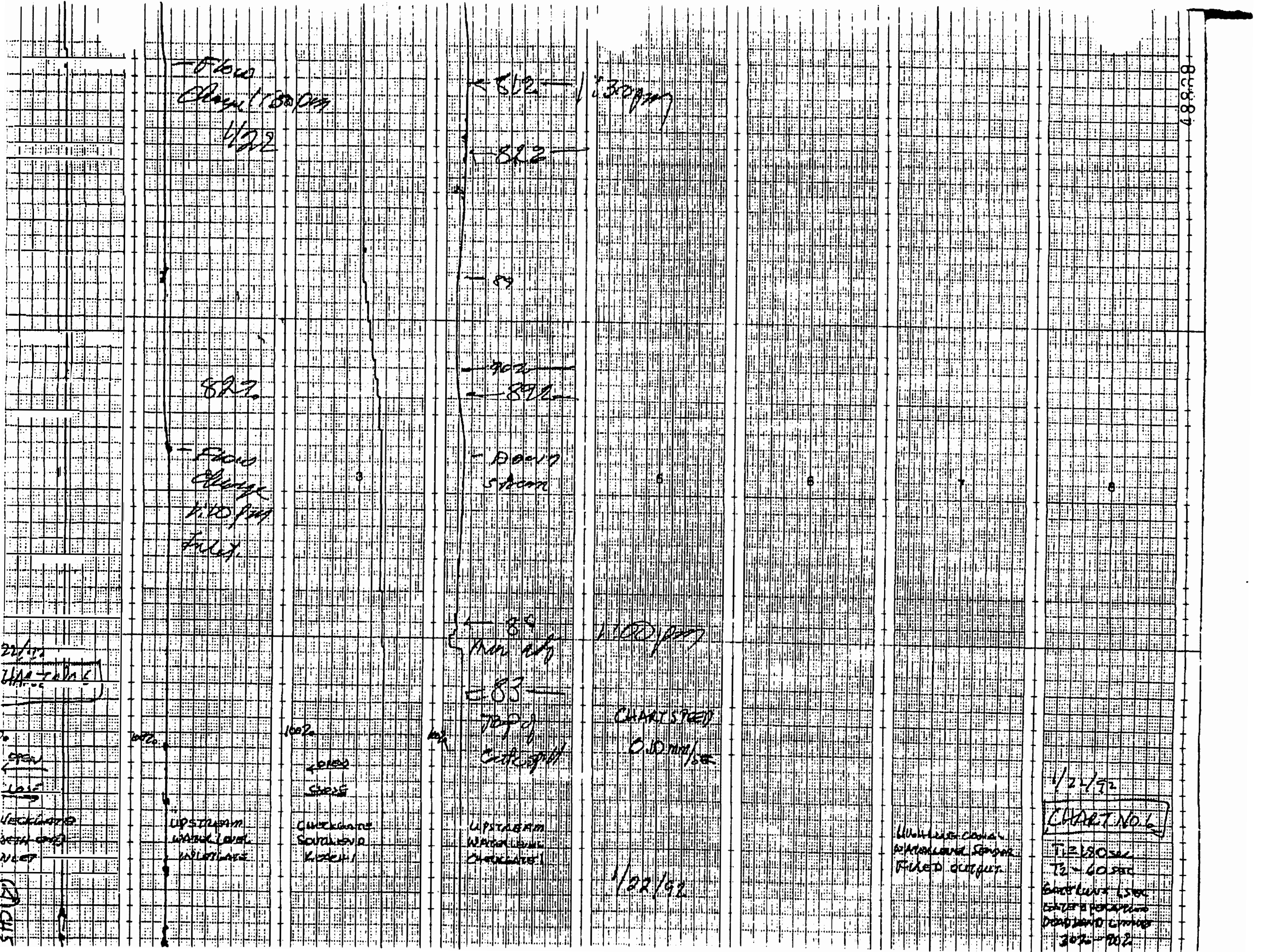


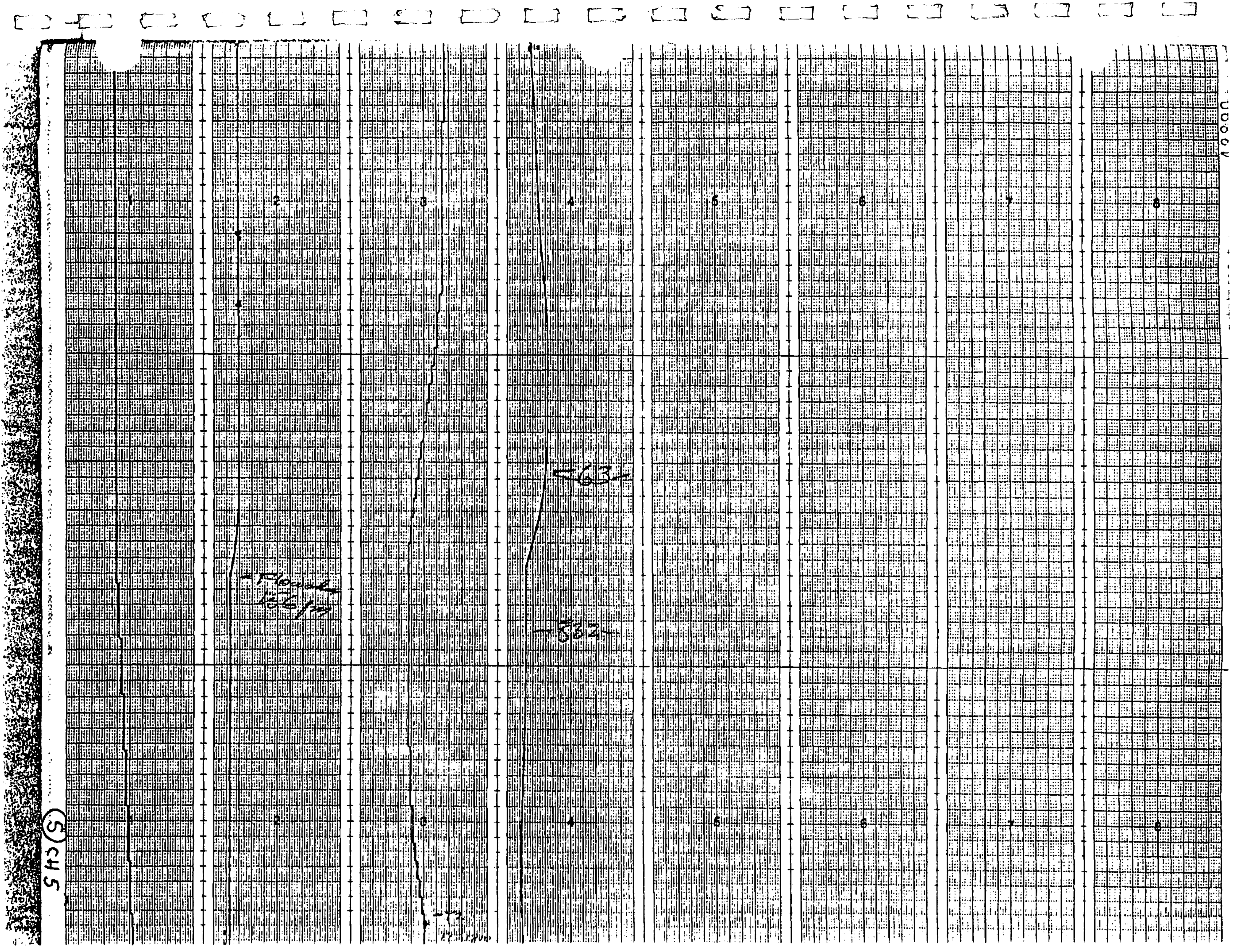
② CHS

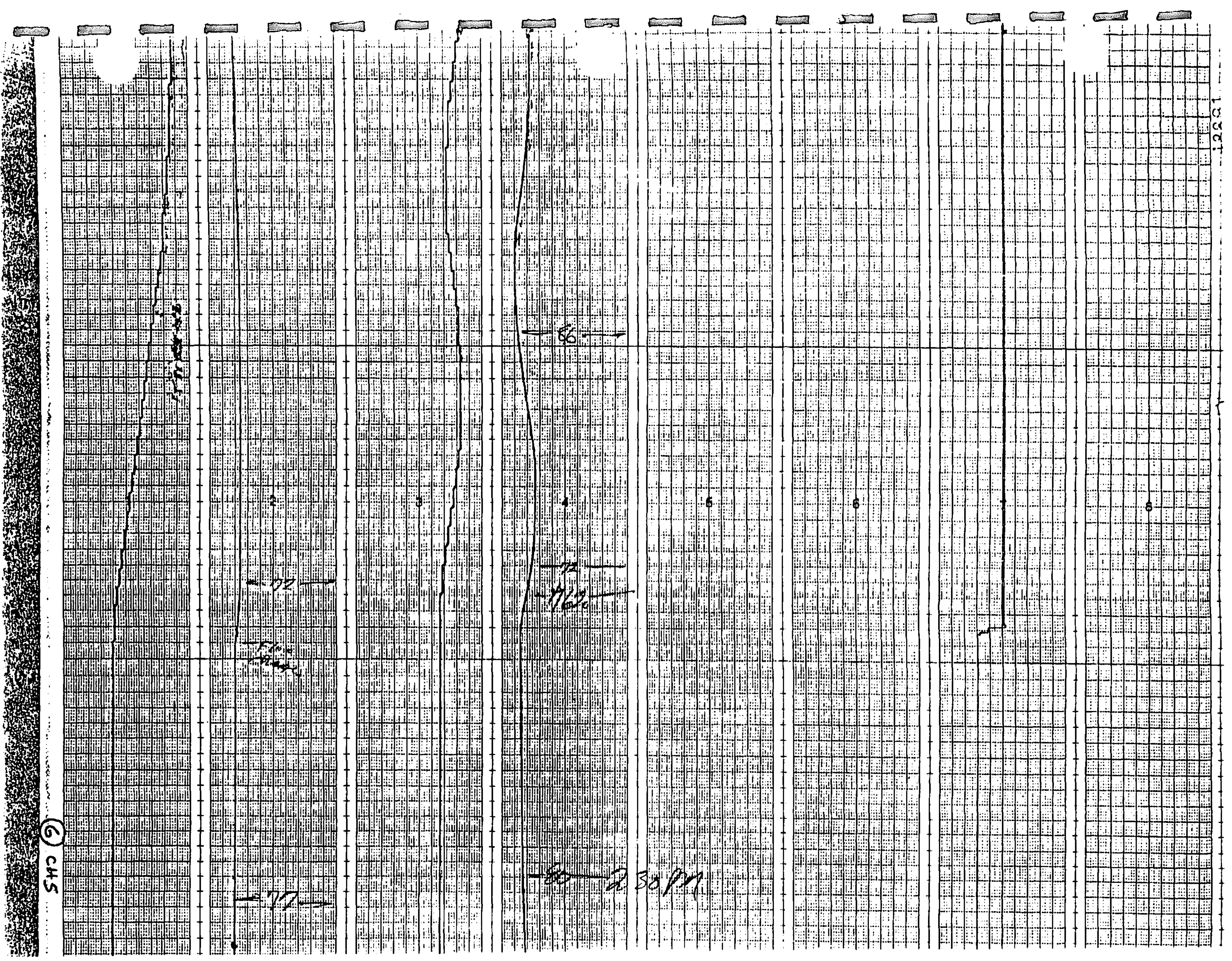
③ CH5

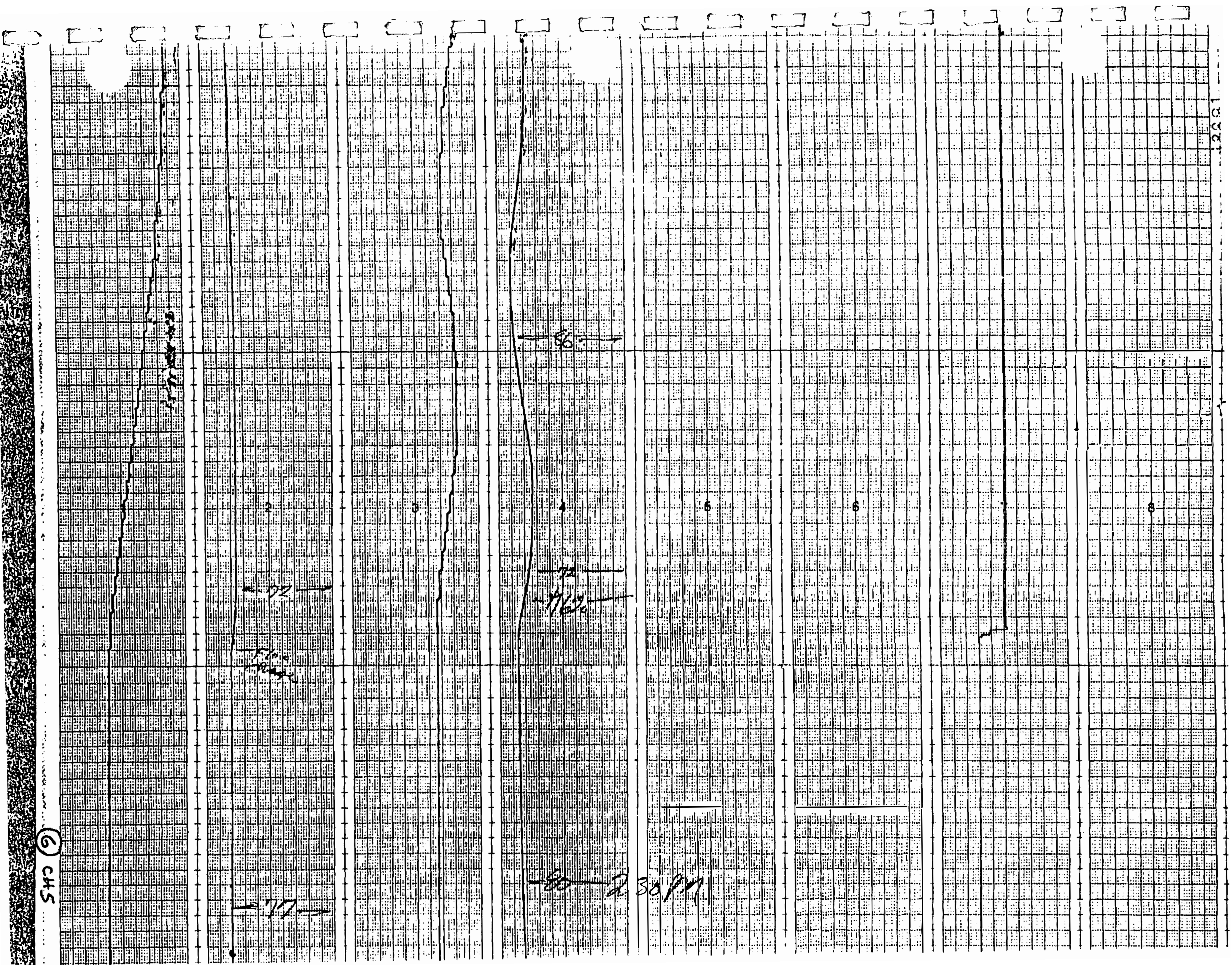


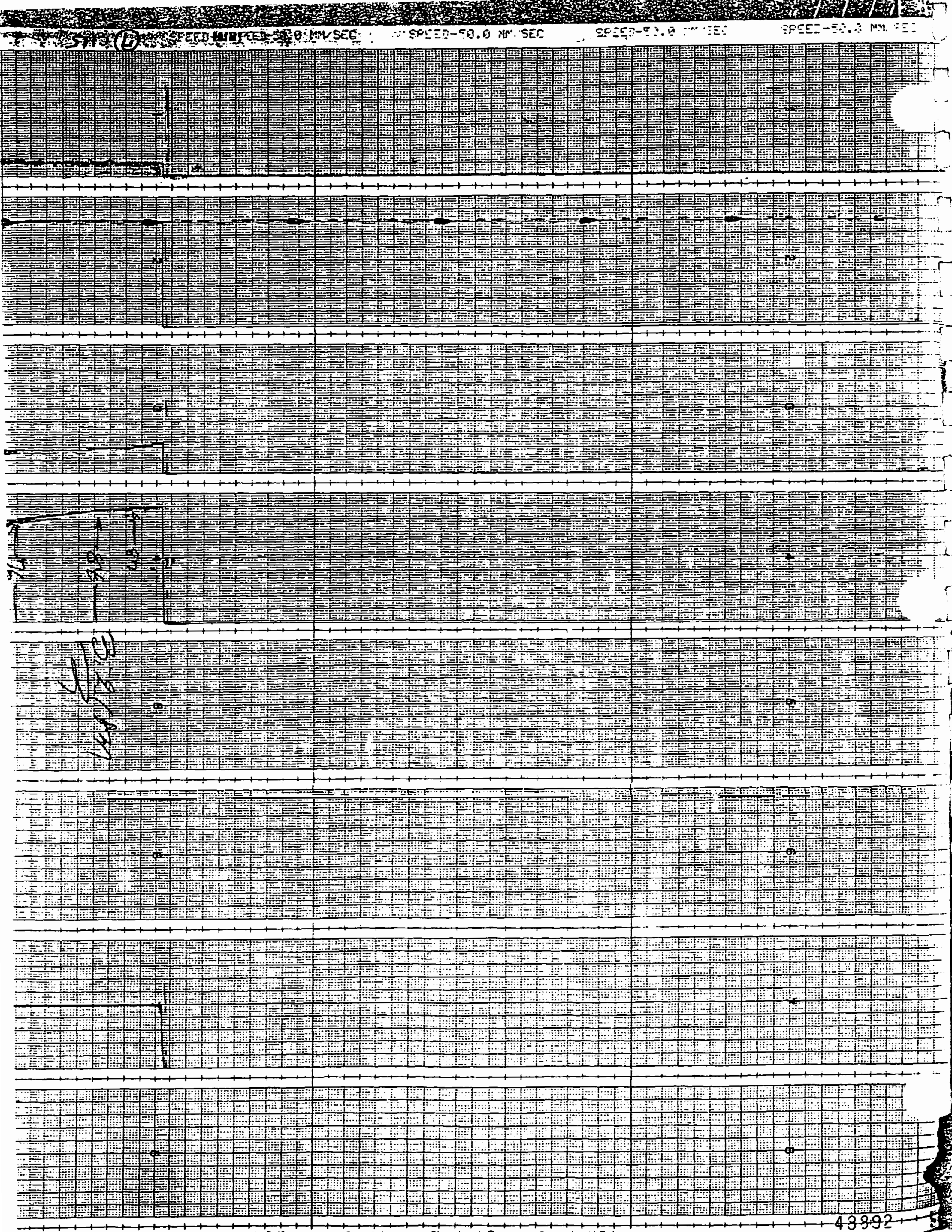
ACCUCHART® Gould, Inc. Cleveland, Ohio Printed in U.S.A


Flow Change 1:30 pm
1/22
822
Flow Change 1:00 pm Inlet
812 — 1:30 pm
822
84
902
892
Drain Storm
84
Man adj
83
Top of Cutthroat
1:00 pm
CHART SPEED 0.10 mm/sec
1/22/92
100%
100%
100%
open
close
open
close
UPSTREAM WATER LEVEL INLET GATE
CHECKGATE SOLENOID Kicker 1
UPSTREAM WATER LEVEL CHECKGATE 1
WOLMAN CANAL WATERLEVEL SENSOR FILTERED OUTPUT
1/22/92
CHART NO. 6
T1 = 180 sec
T2 ~ 60 sec
Gate Limit 1.5 sec
Gate 2 Deadband
Deadband Limits
30% - 90%
3
5
6
7
8
48838
22/92
NLET


1
2
0
4
5
6
7
8
<63-
-Flowck
126/m
-832-
5 CH 5


⑥ CHS
86
72
76½
72
77
80
2:30 PM
2
3
4
6
8
12221


⑥ CHS
86
72
76¾
72
77
80
2:30 PM
2
3
4
5
6
7
8
12201



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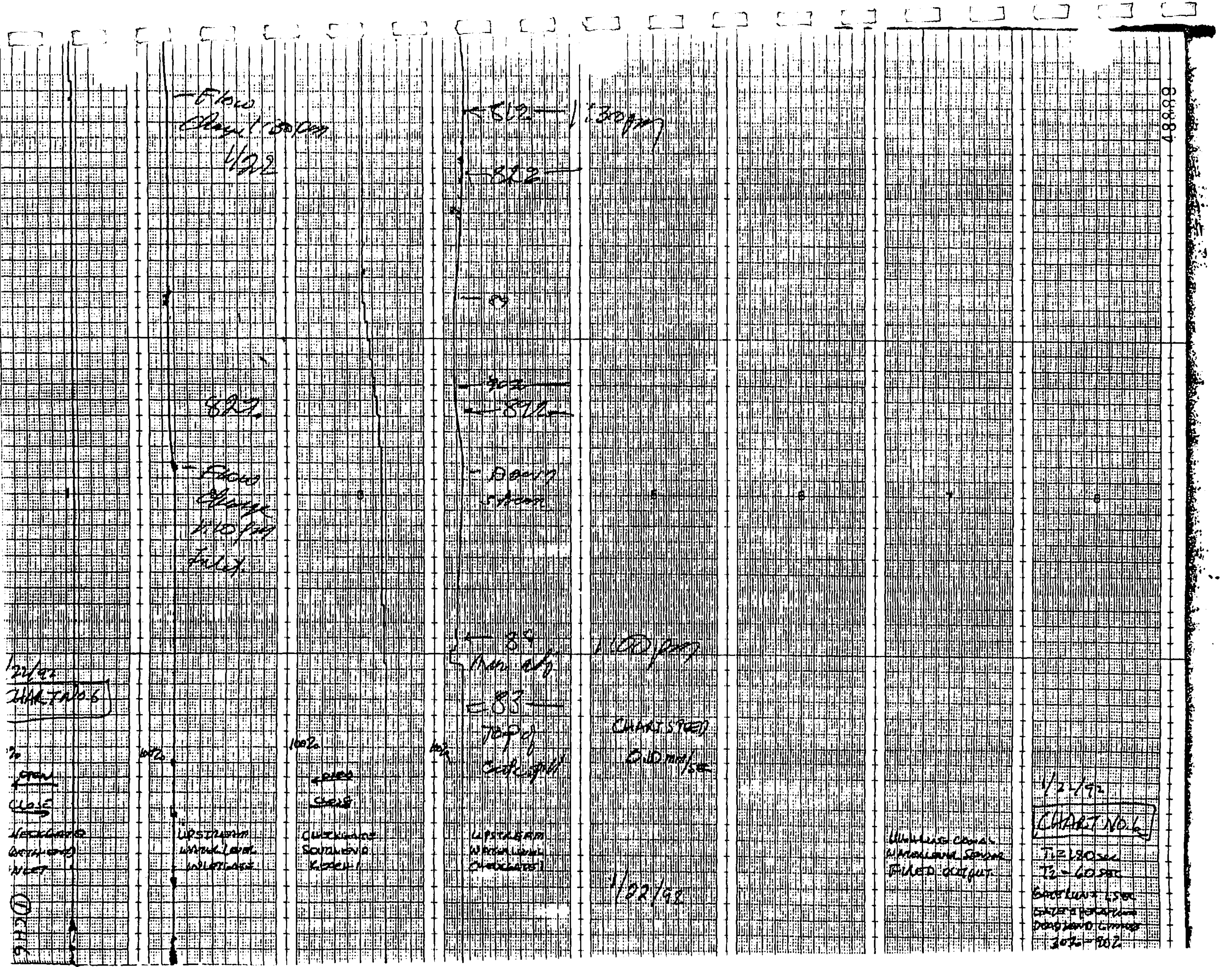
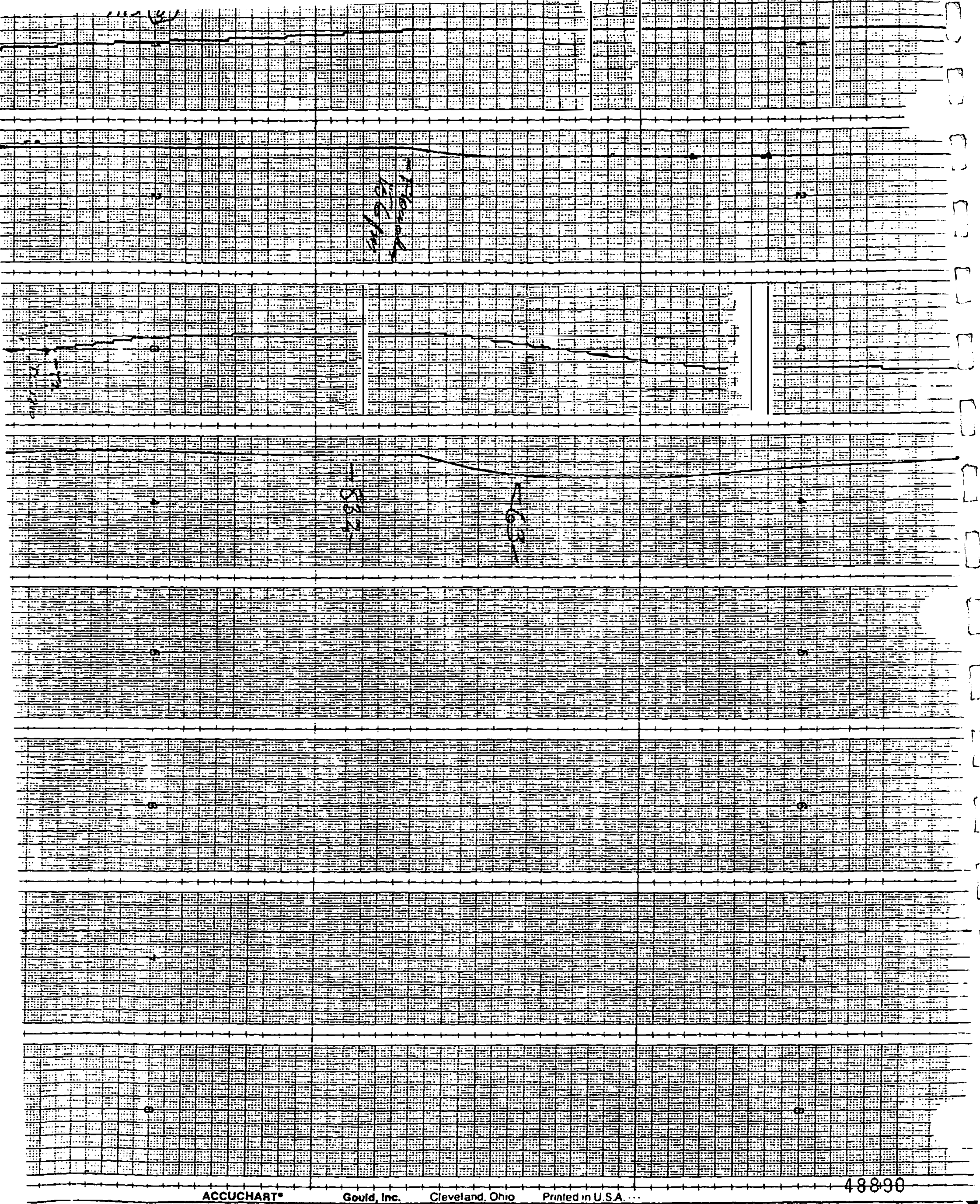
43892

CHART 6

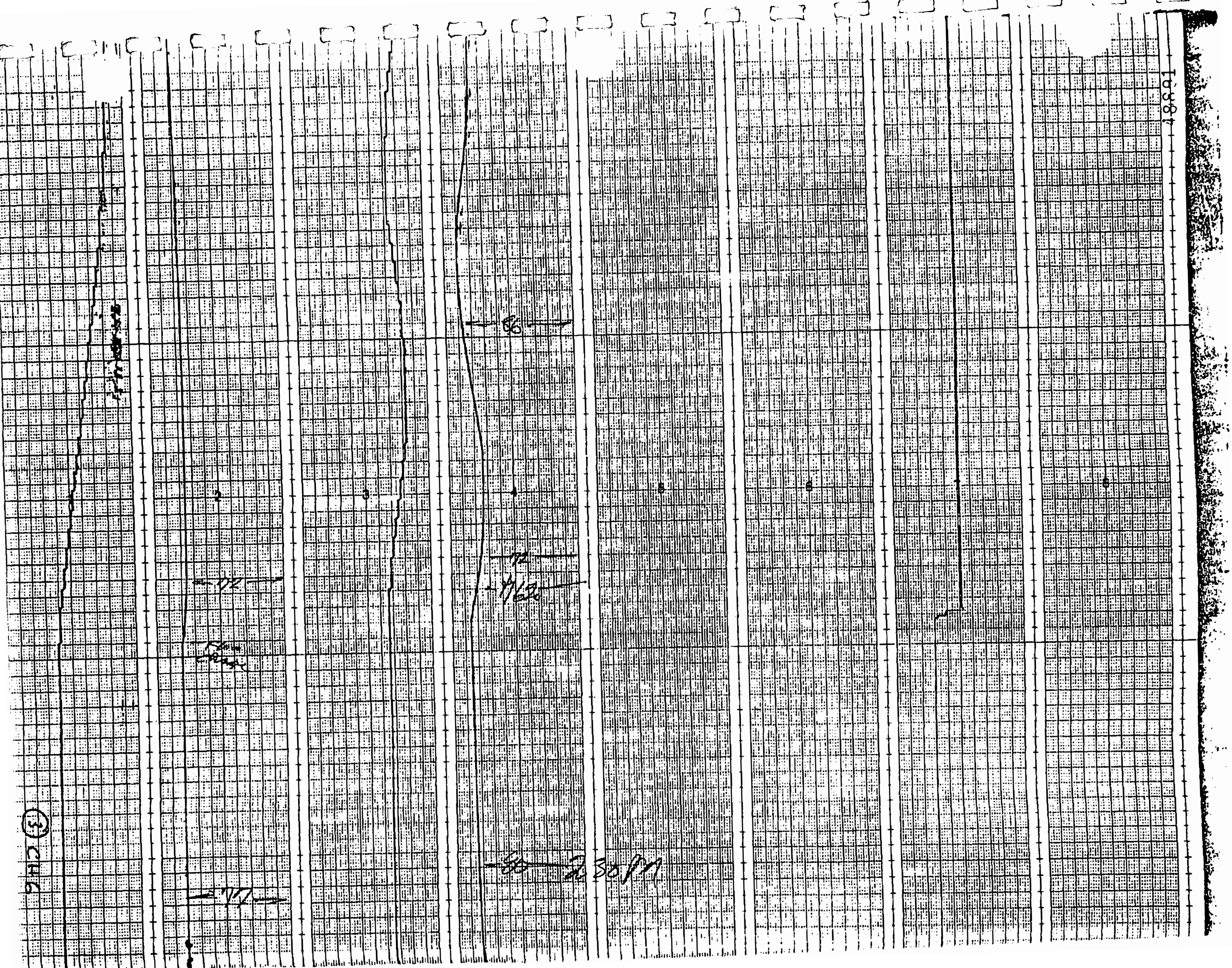


Flow
Change 1:30 pm
1/22
822
Flow
Change
1:10 pm
Inlet
812
1:30 pm
822
84
80%
82%
Drain
Syphon
84
1:00 pm
Man adj
83
Top of
Crest gate
CHART SPEED
0.10 mm/sec
1/22/92
%
100%
100%
40%
OPEN
CLOSE
[illegible]
[illegible]
INLET
UPSTREAM
WATER LEVEL
INLET GATE
[illegible]
SOUTHEND
[illegible]
UPSTREAM
WATER LEVEL
[illegible]
[illegible]
[illegible]
FILTERED OUTPUT
1/22/92
CHART NO. 6
CHART NO. 6
T1 = 180 sec
T2 = 60 sec
GATE LIMIT 5 SEC
GATE OPERATION
DEADBAND LIMITS
30% - 90%
1
3
5
6
7
8
①
CH6
48999



ACCUCHART® Gould, Inc. Cleveland, Ohio Printed in U.S.A.

48890


③ CH6
77
72
86
72
7/26
90
2:30PM
2
3
4
5
6
7
8
48891

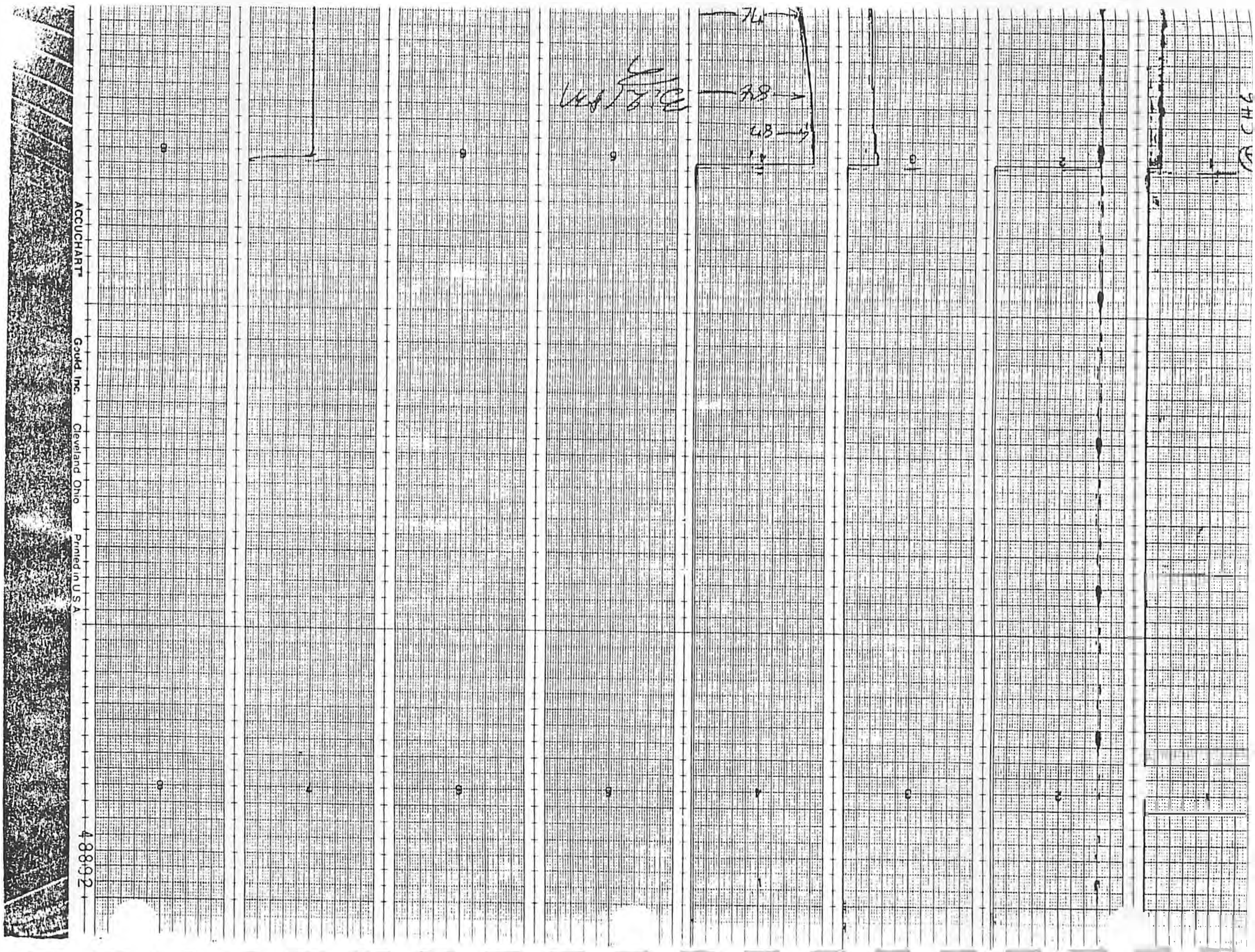
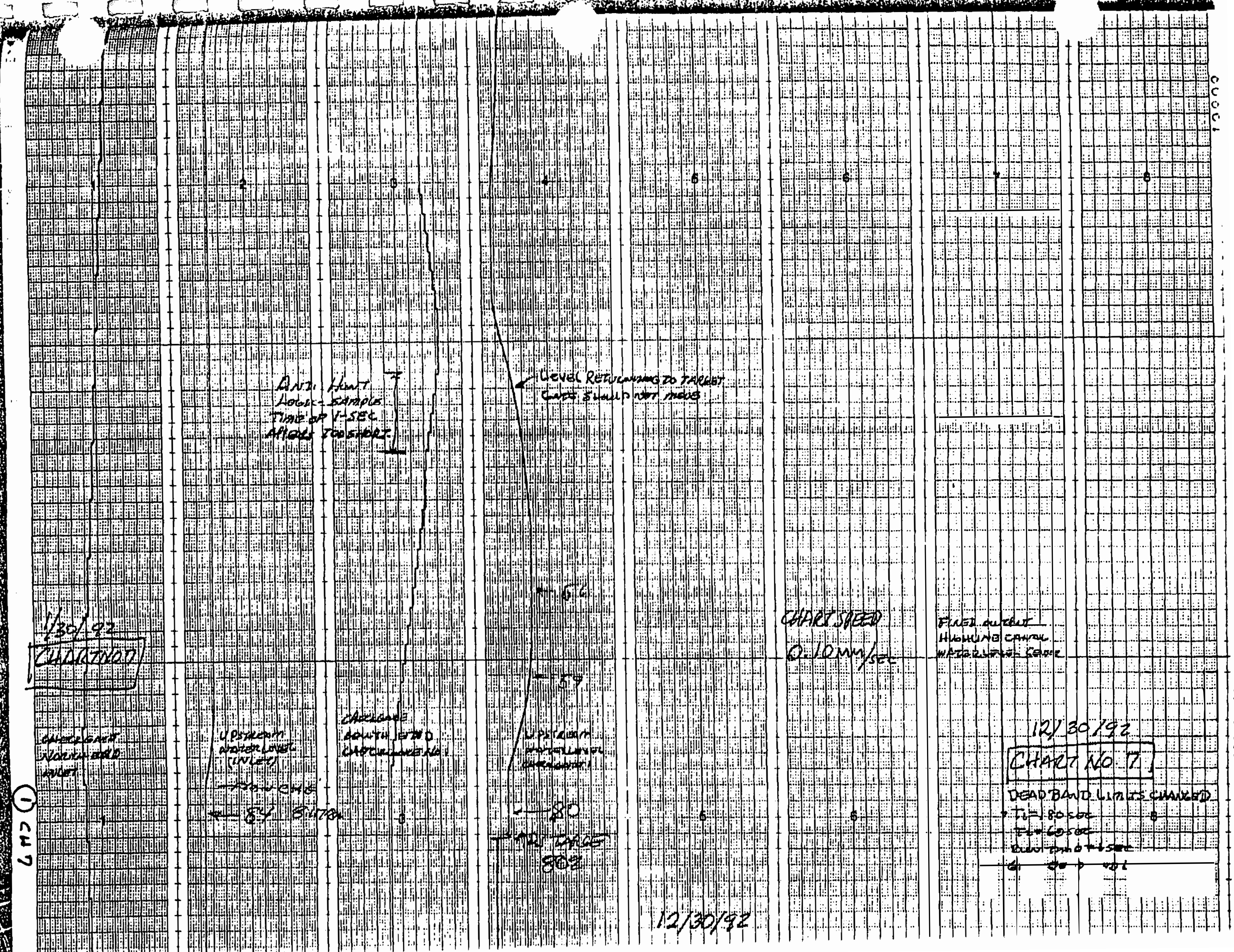

ACCUCHART™ Gould, Inc. Cleveland Ohio Printed in U.S.A.
4 8892
74
78
48
CH2

CHART 7



ANTI HUNT LOGIC - SAMPLE TIME OF 1-SEC APPEARS TOO SHORT

LEVEL RETURNING TO TARGET GATE SHOULD NOT MOVE

← 66

← 59

CHART SPEED 0.10MM/SEC

FIXED OUTPUT HIGHLINE CANAL WATER LEVEL GAGE

1/30/92
CHART NO 17

CHECKGATE NORTH END INLET

UPSTREAM WATER LEVEL (INLET)

← FROM CMS

← 84 8:17PM

CHECKGATE SOUTH END CAPTURE [illegible]

UPSTREAM WATER LEVEL CHECKGATE 1

← 80

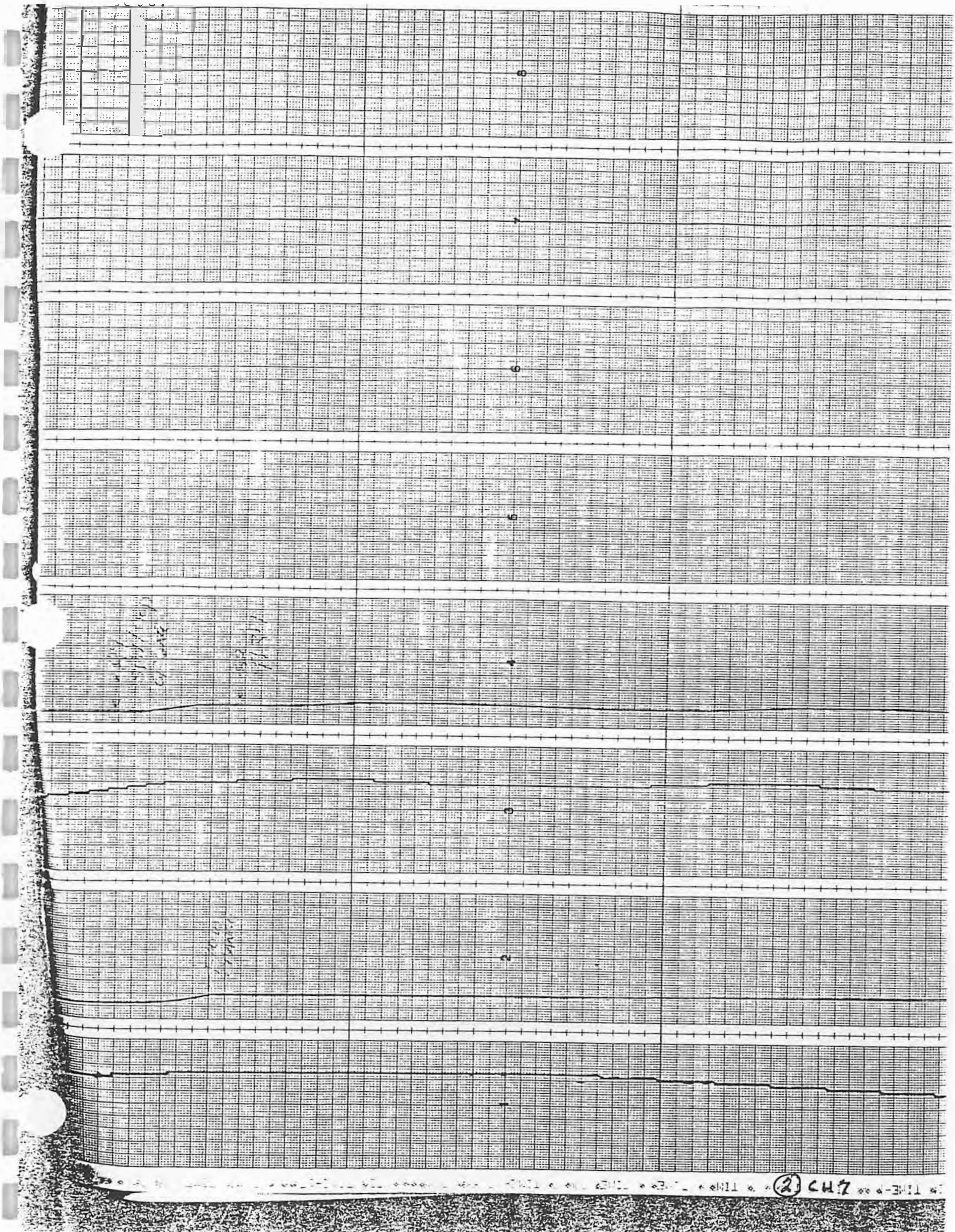
TARGET 802

12/30/92
CHART NO 17

DEAD BAND LIMITS CHANGED
Ti = 180 sec
Td = 60 sec
[illegible]

12/30/92

① CH7

② CH7
TIME
8
7
6
5
4
3
2
1

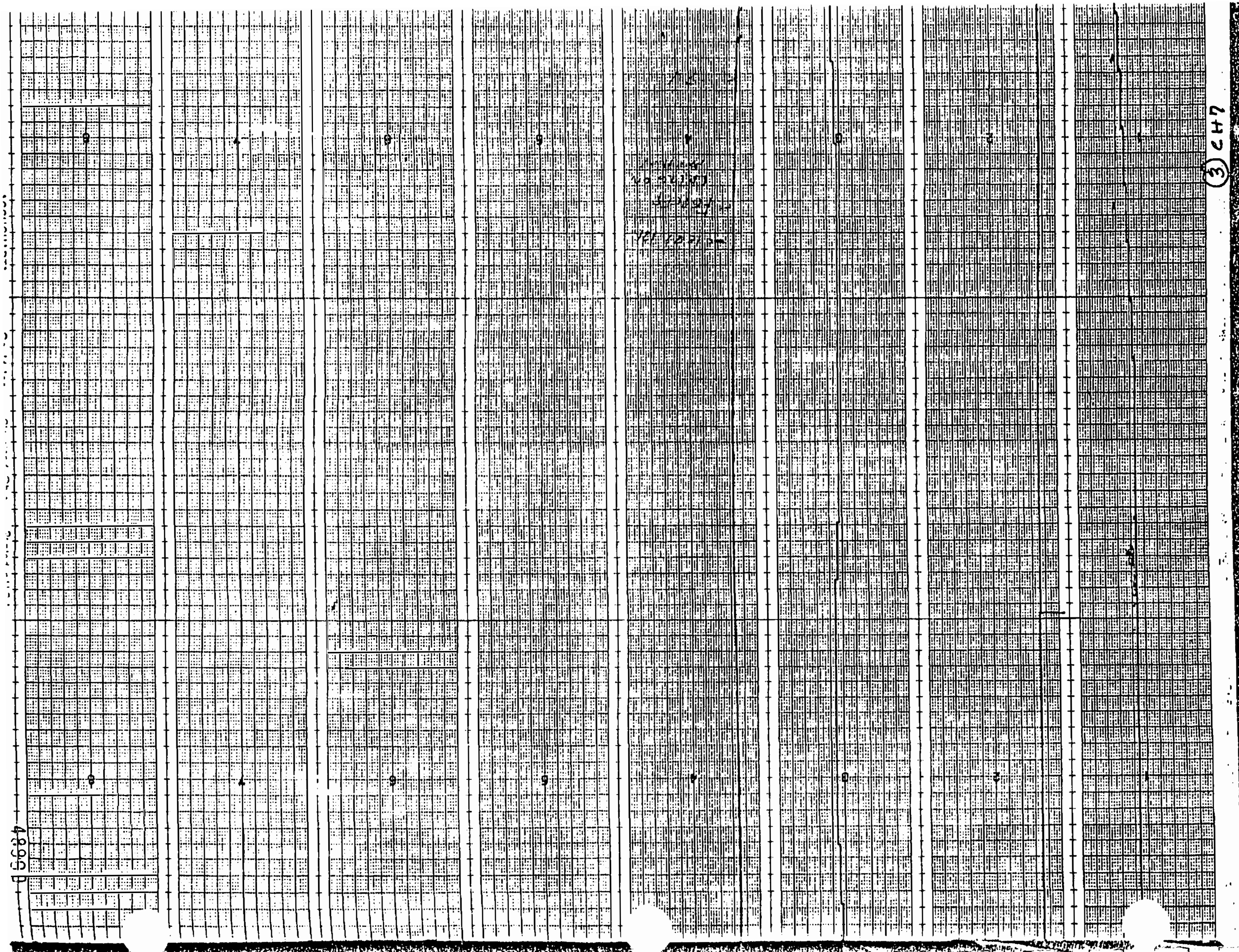
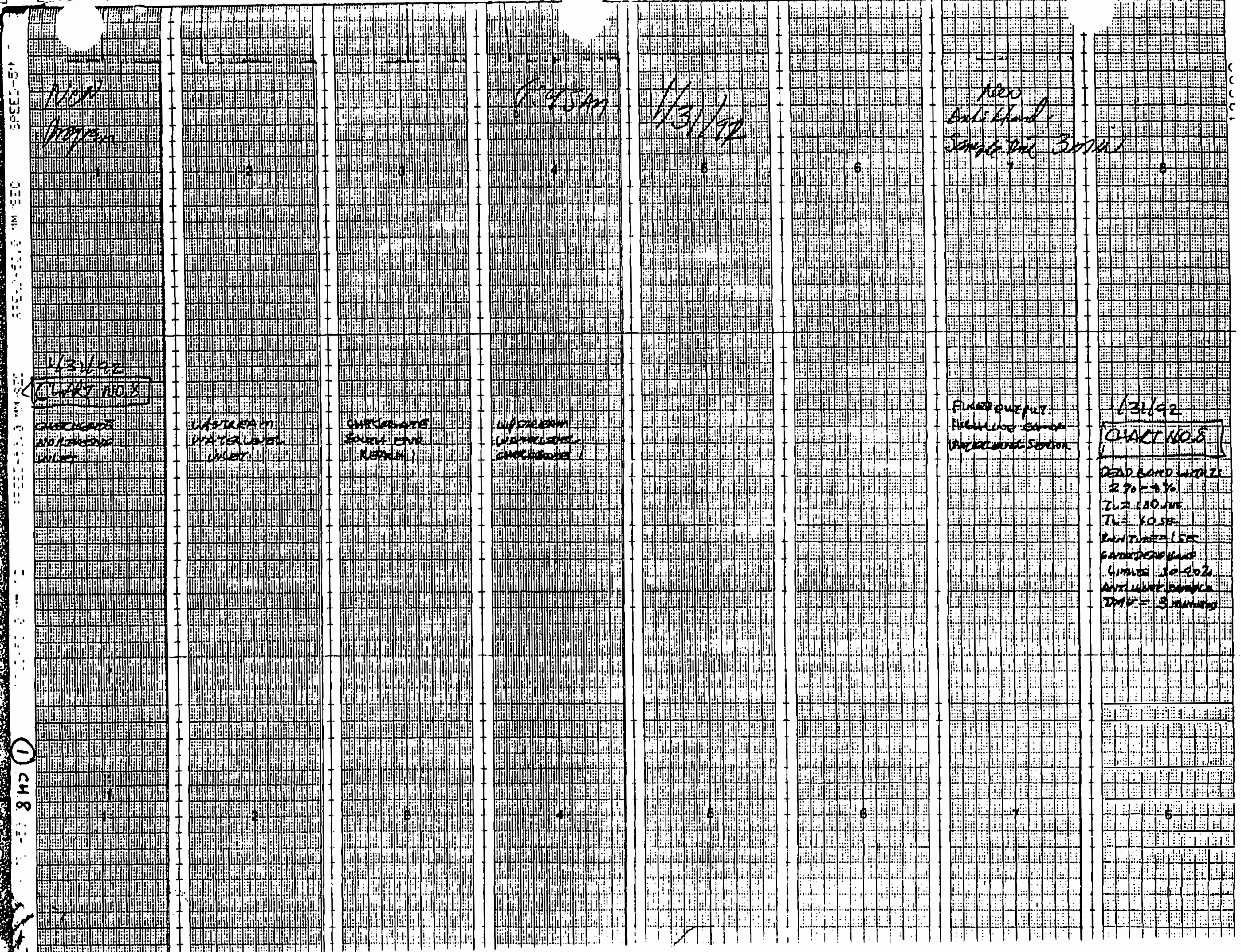
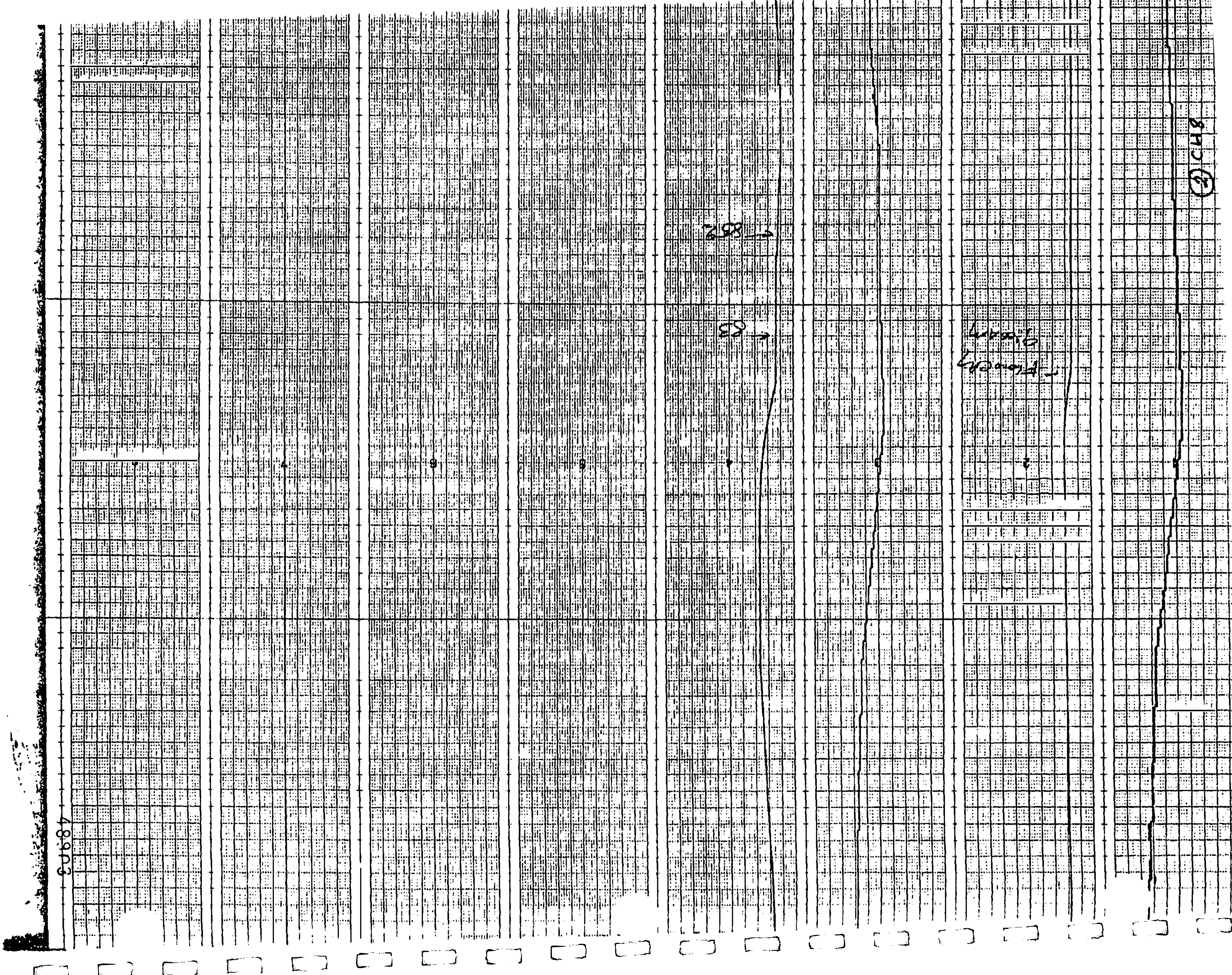
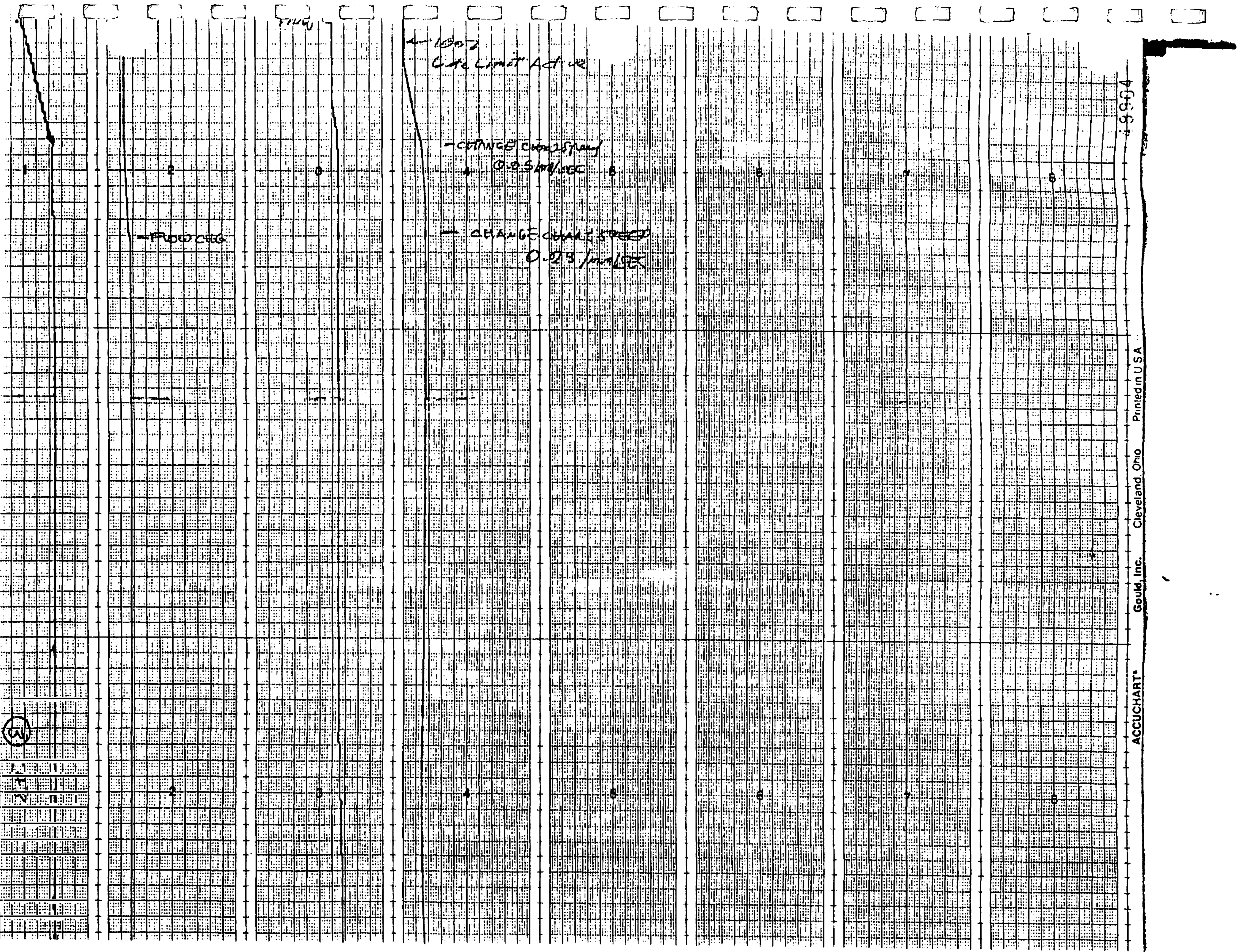

③ CH7
4899

CHART 8



DEAD BAND WIDTH Z1
2% - 8%
ZL = 180 sec
TL = 40 sec
RUN TIME = 15 SEC
LIMITS 80-102
TIME = 5 minutes


② CH8
82
83
Flow Chg
9:58 am
489N3


← 1807
Gate Limit Active
– CHANGE CHART SPEED
0.05 mm/SEC
– CHANGE CHART SPEED
0.025 mm/SEC
– FLOW CHG
FLOW
③
1
2
3
4
5
6
7
8
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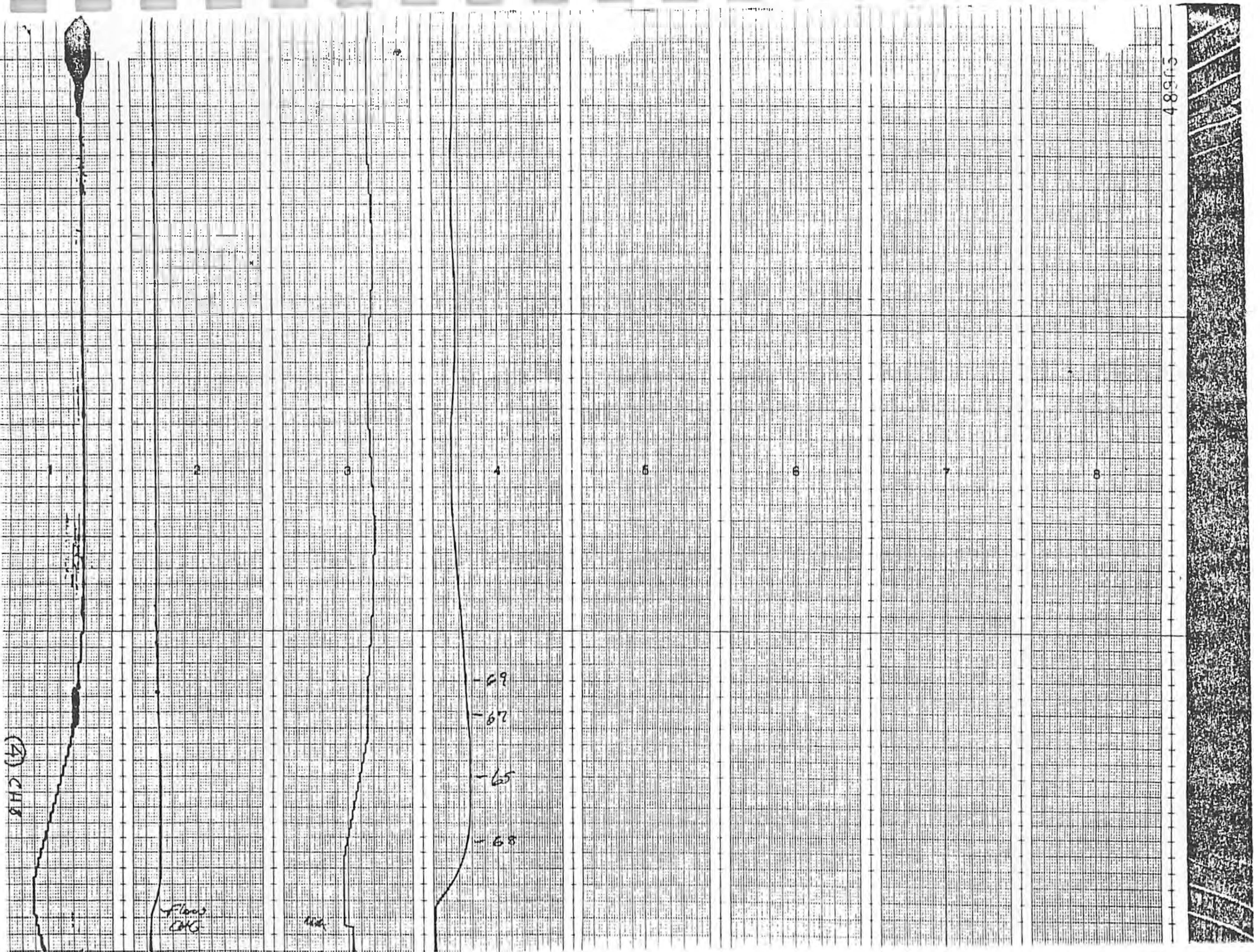
9994


48963
1
2
3
4
5
6
7
8
69
67
65
68
Flow CHG
(4) CH8

APPENDIX B

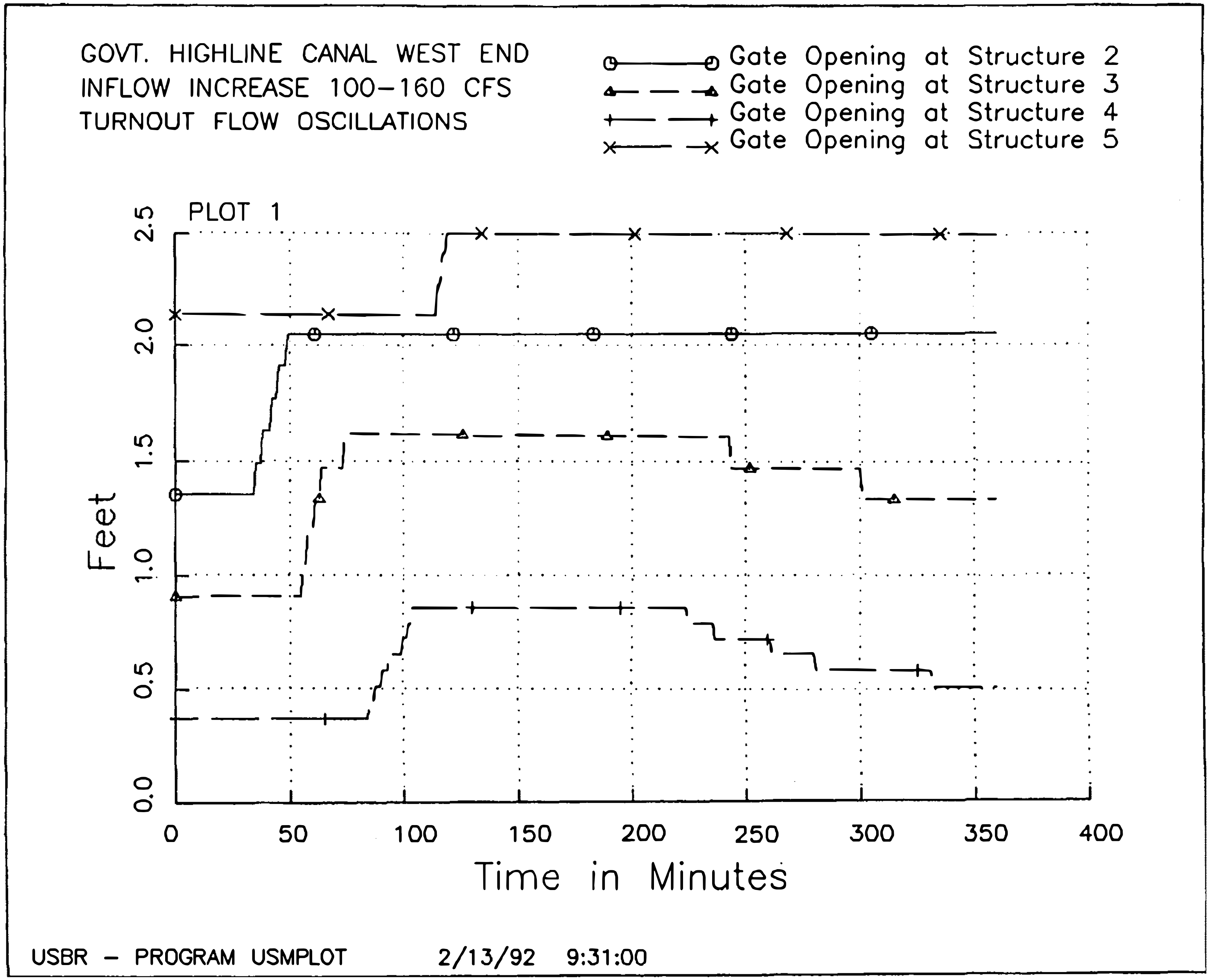

GOVT. HIGHLINE CANAL WEST END
INFLOW INCREASE 100-160 CFS
TURNOUT FLOW OSCILLATIONS
Gate Opening at Structure 2
Gate Opening at Structure 3
Gate Opening at Structure 4
Gate Opening at Structure 5
PLOT 1
Feet
0.0
0.5
1.0
1.5
2.0
2.5
0
50
100
150
200
250
300
350
400
Time in Minutes
USBR - PROGRAM USMPLOT 2/13/92 9:31:00

FIGURE B1

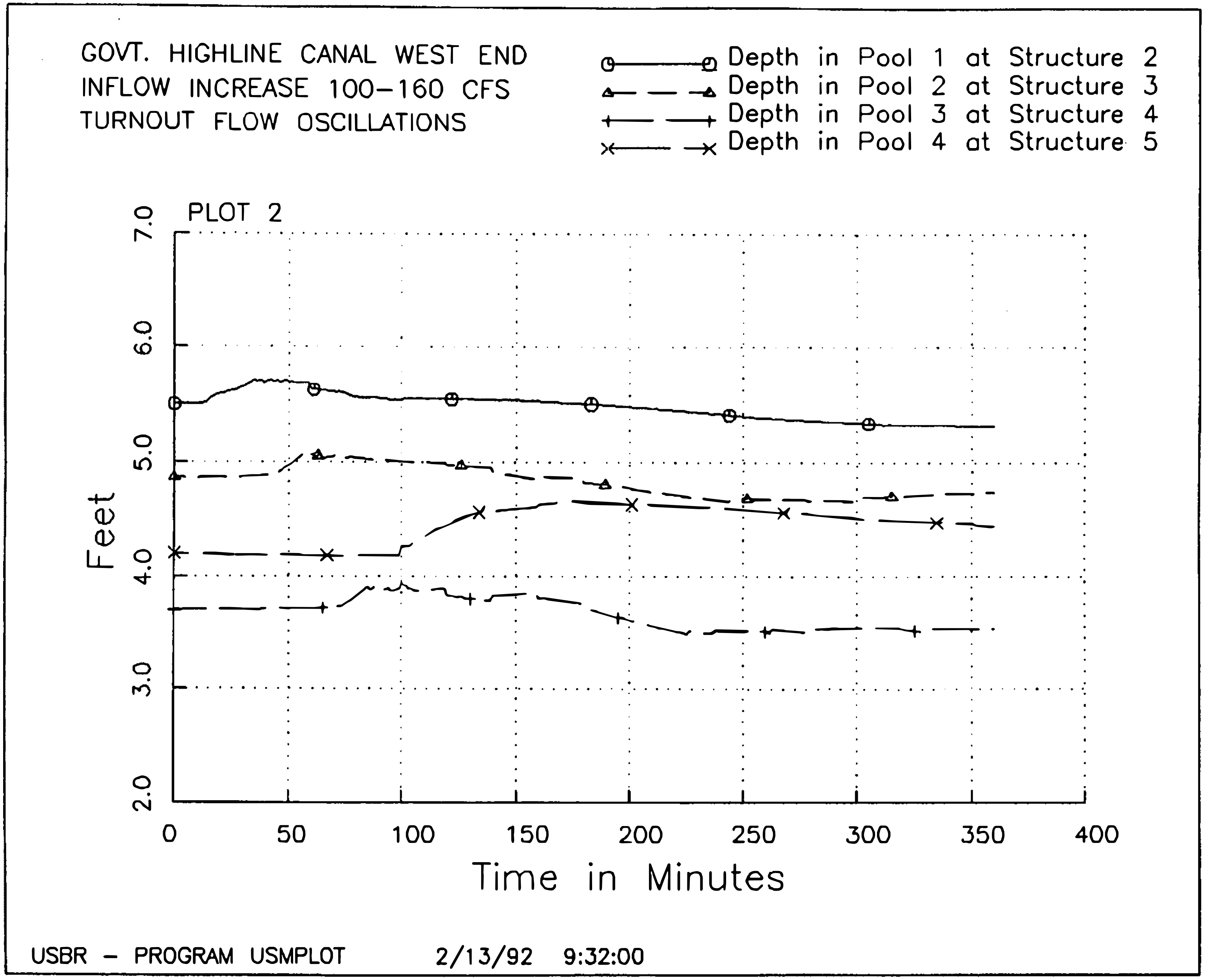

GOVT. HIGHLINE CANAL WEST END
INFLOW INCREASE 100-160 CFS
TURNOUT FLOW OSCILLATIONS
Depth in Pool 1 at Structure 2
Depth in Pool 2 at Structure 3
Depth in Pool 3 at Structure 4
Depth in Pool 4 at Structure 5
PLOT 2
Feet
2.0
3.0
4.0
5.0
6.0
7.0
0
50
100
150
200
250
300
350
400
Time in Minutes
USBR - PROGRAM USMPLOT 2/13/92 9:32:00

FIGURE B2

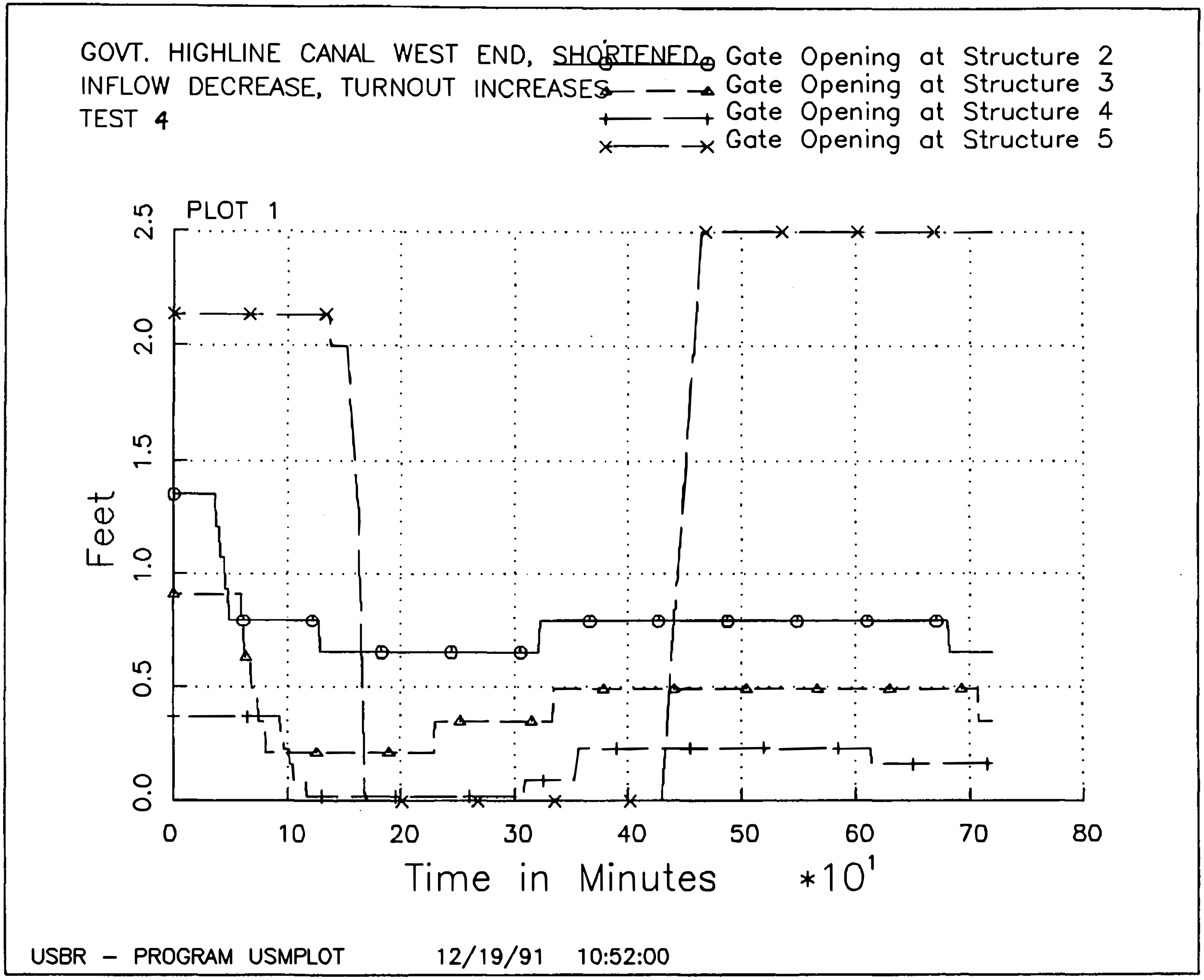

GOVT. HIGHLINE CANAL WEST END, SHORTENED
INFLOW DECREASE, TURNOUT INCREASES
TEST 4
Gate Opening at Structure 2
Gate Opening at Structure 3
Gate Opening at Structure 4
Gate Opening at Structure 5
PLOT 1
Feet
0.0
0.5
1.0
1.5
2.0
2.5
0
10
20
30
40
50
60
70
80
Time in Minutes *10^1
USBR - PROGRAM USMPLOT 12/19/91 10:52:00

FIGURE B3

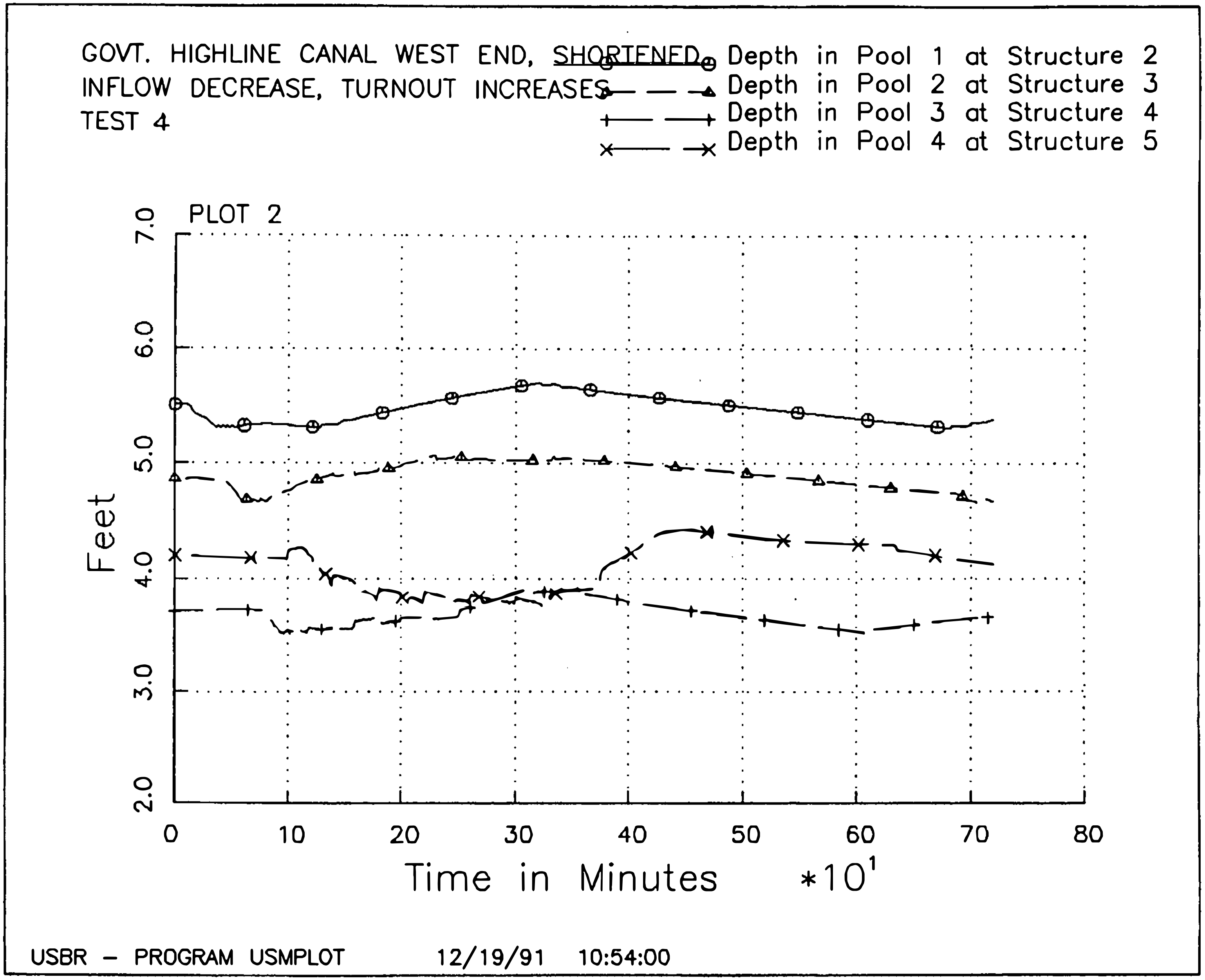

GOVT. HIGHLINE CANAL WEST END, SHORTENED
INFLOW DECREASE, TURNOUT INCREASES
TEST 4
Depth in Pool 1 at Structure 2
Depth in Pool 2 at Structure 3
Depth in Pool 3 at Structure 4
Depth in Pool 4 at Structure 5
PLOT 2
Feet
7.0
6.0
5.0
4.0
3.0
2.0
0
10
20
30
40
50
60
70
80
Time in Minutes *10¹
USBR - PROGRAM USMPLOT 12/19/91 10:54:00

FIGURE B4