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MCNARY RESERVOIR NAVIGATION AT ICE HARBOR DAM SNAKE
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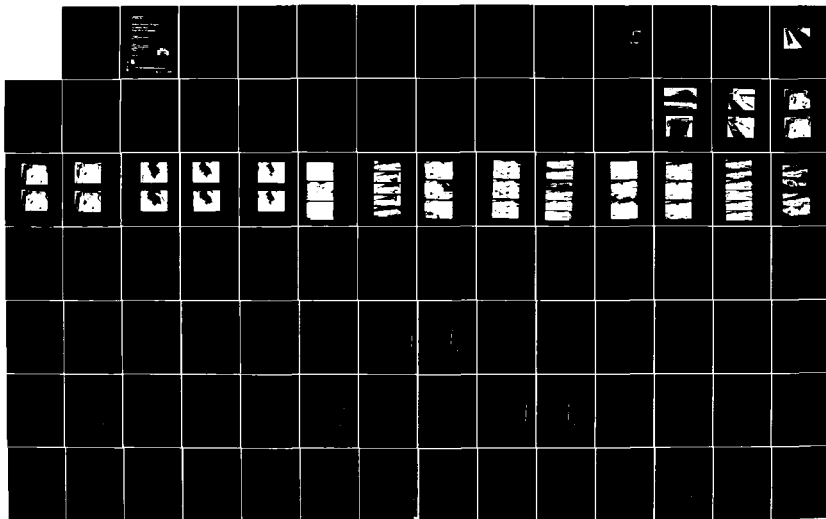
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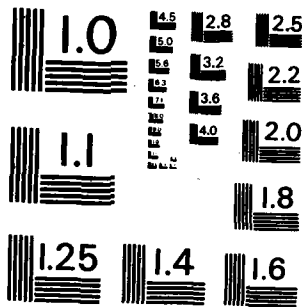
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**Military Reservoir Navigation at
Ice Harbor Dam
Snake River, Washington**

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A 1:100-scale model simulating the Ice Harbor Dam project and navigation channel and river downstream from the project was used to test various structural modifications in an attempt to remedy navigation problems which exist as a result of crossflow from the powerhouse. A radio-controlled scale model of a 2000-horsepower towboat with barges was used in evaluating the navigation improvements. Modifications tested included various length and geometric guide wall extensions as well as channel widening. Towboat operators assisted		

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in evaluation of the modifications tested. None of the tested modifications succeeded (to the satisfaction of the tow operators) in correcting the difficulties experienced while navigating downstream from the Ice Harbor lock.

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CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U.S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
feet	0.3048	metres
miles	1.609344	kilometres
feet per second	0.3048	metres per second
cubic feet per second	0.0283168	cubic metres per second
pounds (mass)	0.4535924	kilograms
kilowatt-hours	3,600,000	joules

McNARY RESERVOIR NAVIGATION AT ICE HARBOR DAM

SNAKE RIVER, WASHINGTON

Hydraulic Model Investigations

PART I: INTRODUCTION

The Prototype

1. Ice Harbor Dam is located on the Snake river 9.7 miles* upstream from the junction of the Columbia and Snake Rivers and about 12 miles east of the city of Pasco, Washington. Figure 1 is a location map of the area. The project, which began operation in 1962, is the first of four multiple-purpose dams to be constructed on the lower Snake River by the U.S. Army Corps of Engineers for power, navigation, and other uses.

2. As shown on plate 1, principle features of the 1,788-foot-long project include a powerhouse for six 90,000-kilowatt generating units (initial installation of three units), a navigation lock, a concrete gravity-type spillway with ten 50-foot-wide bays and 52.5-foot-high tainter gates, and facilities for passing migratory fish upstream over the dam. The navigation lock has net dimensions of 86 by 675 feet and maximum single lift of 103 feet between minimum tailwater elevation 337 and normal pool elevation 440.** A 600-foot-long training wall extends from the south wall of the lock to protect navigation from the turbulent flows issuing from the powerhouse and spillway. The navigation channel downstream of the lock follows the north bank of the river as shown on plate 2 and is dredged to provide a minimum of 18 feet of water with a width of 250 feet.

Navigation Problem

3. Navigation tow operators have experienced difficulty approaching and leaving the downstream end of the lock particularly with a low pool

* A table for converting British units of measurement to metric units is presented on page iii.

** All elevations are in feet above mean sea level.

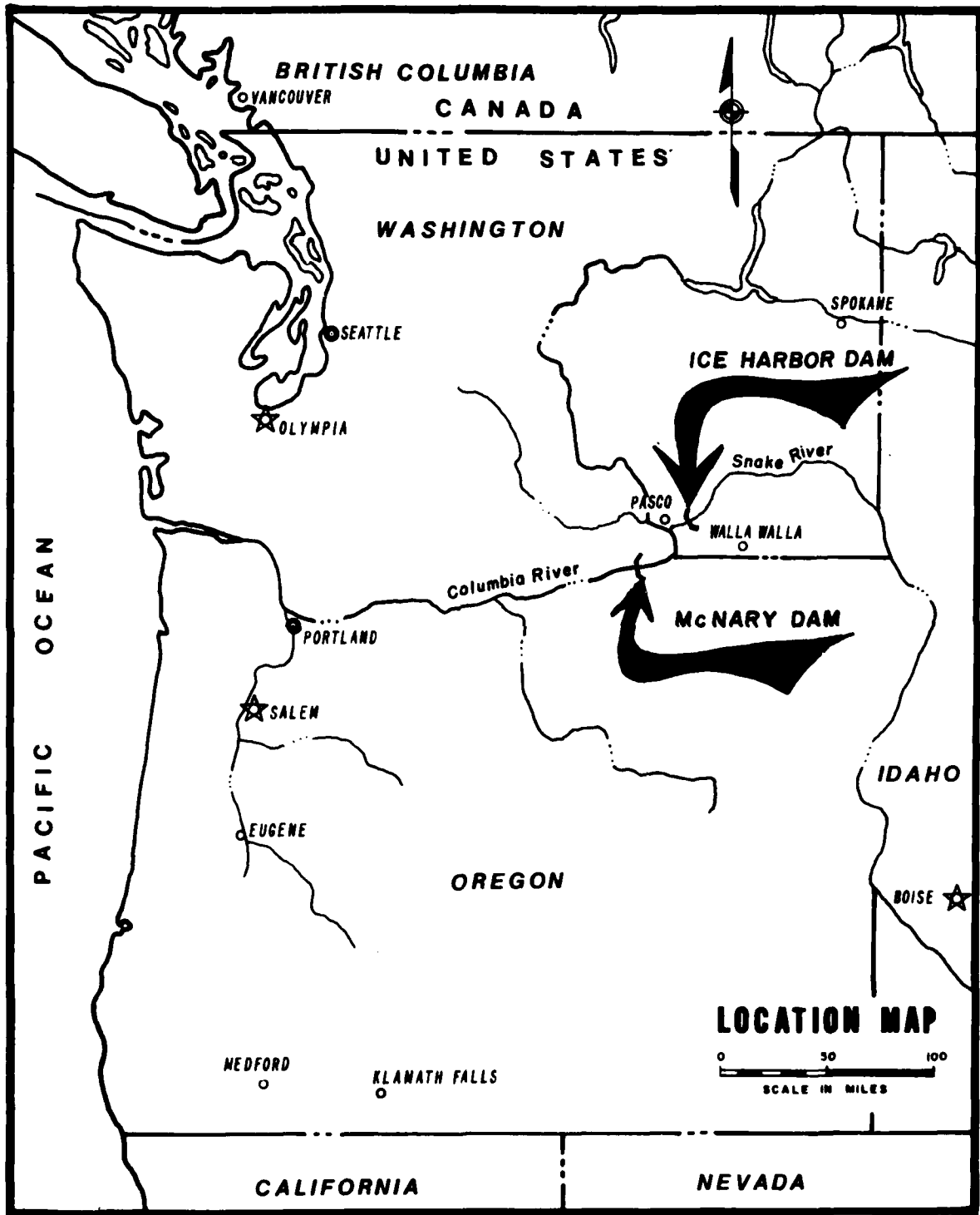


Figure 1

at the McNary Dam. Representatives of several towboat companies have stated that leaving the lock was the most difficult maneuver. Discharge from the powerhouse flows across the river and into the navigation channel at an angle with sufficient velocity to require tows to steer an angled course (crab) to stay in the channel. A safety margin of 50 feet on either side of the 250-foot-wide navigation channel is desired with present conditions because towboat operators have no way of knowing exactly where the limits of the channel are between the end of the guide wall and Buoy No. 20, 2,700 feet downstream. Upstream movement into the lock is not as difficult as downstream movement because the relative movement of water past the towboat is faster and provides more-effective steering.

Purpose of Model Studies

4. A model study was required to determine the feasibility of correcting or improving the navigation problems that result from cross currents from the powerhouse. Some form of guide wall extension or additional channel excavation was proposed as a possible solution to the problem. The effects of the changes on currents around Goose Island, about 8,000 feet downstream of the dam, were also studied because of their potential environmental impact.

PART II: THE MODEL

5. A 1:100-scale model of Ice Harbor Lock and Dam and the downstream navigation channel (figure 2, plate 3, and the photograph 1) was used to study modification to the downstream training wall. The model included the powerhouse, spillway and navigation lock, and approximately 2.3 miles of downstream river and navigation channel. Natural topography and proposed excavation were simulated by heavily grouted sea gravel molded to conform to field surveys and design plans. The dam structures were simulated using waterproofed wood, plywood, and plaster. The study area was exclusively downstream; therefore, only a limited crebay was modeled. Water was introduced into the model through a basin located 500 feet upstream of the dam. The water was pumped from large storage tanks to the model through a recirculation system and was measured by calibrated orifices in the supply lines. Discharges through the spillway and powerhouse were calibrated separately to reproduce prototype flow quantities. An overflow tailgate controlled tailwater elevations at gage 9 (plate 3) in accordance with observed and computed water surface elevations. Standard laboratory procedures were used to measure water surface elevations and velocities. Certain flow conditions were recorded photographically.

6. Model measurements were converted to prototype values with equations of similitude based on the Froude model law. The following scale multipliers were used:

Length multiplier (L_r)	=	100
Velocity multiplier ($L_r^{1/2}$)	=	10
Discharge multiplier ($L_r^{5/2}$)	=	100,000
Horsepower multiplier ($L_r^{7/2}$)	=	10,000,000

7. The river was modeled from a hydrographic survey made in March 1981, and the river roughness was verified with river water surface data observed during the spring of 1981 (table A). During verification tests, the existing navigation channel was modeled; for all other studies, the planned 1982 channel excavation was modeled.

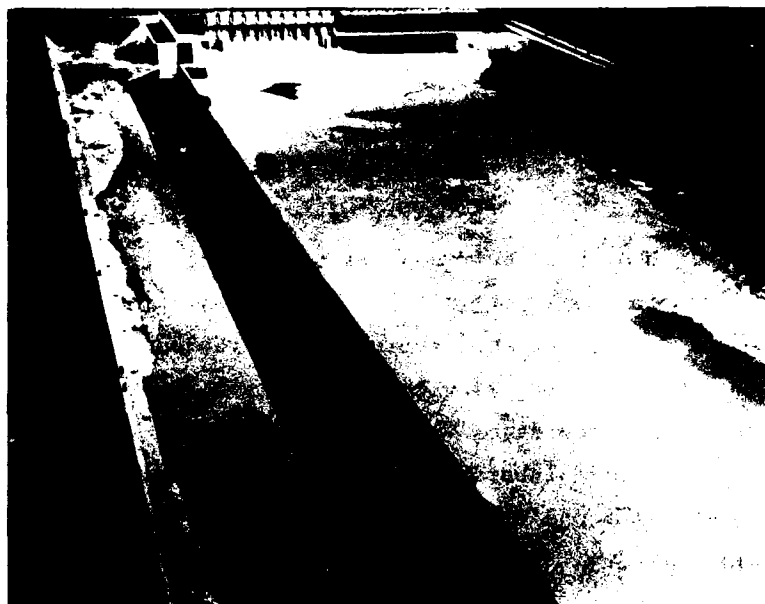


Fig. 2 1:100-scale model of Ice Harbor Lock and Dam
and navigation channel

8. A radio-controlled scale model of a 2,000-horsepower towboat was used in conjunction with the barge combinations shown in photograph 2. The barges measured 274 feet long and 42 feet wide with drafts of 13 feet loaded and 4 feet empty. The sizes used were representative of the average size tows. Information obtained from the towboat companies using the lock indicated that a maximum downstream tow would consist of two loaded barges and that a maximum upstream tow would consist of one loaded and two empty barges. Based on model demonstrations with the towboat operators, it was determined that the normal exit of a tow from the lock would be at half speed of the boat along the guide wall, approximate speed of the current at the end of the guide wall, and full speed 600 to 1,000 feet downstream where crossflow from the powerhouse is the strongest. The towboat must be at full speed at the point of crossflow in order to be moving faster than the current and have adequate steerage.

PART III: PERFORMANCE OF EXISTING NAVIGATION CHANNEL

9. The existing navigation channel configuration is comprised of the existing training wall and the planned 1982 channel excavation with the channel dredged to elevation 319 to the downstream end of the model. River discharges of 10,000, 60,000, 100,000, 150,000, 180,000, and 220,000 cfs were observed with tailwater adjusted to simulate controls by McNary Dam pool at elevations 335 and 340 with minimum power flow down the Columbia River from Priest Rapids Dam. Table B shows the effect which the 5-foot difference in McNary pool level has on water levels at Ice Harbor Dam. At higher flows when navigation is difficult, the difference in water level at Ice Harbor was less than 1 foot. There was little or no difference detectable in flow or in navigation conditions due to the difference in McNary pool level, and the results obtained for pool elevation 335 are essentially applicable to both McNary pool levels.

10. The flow pattern immediately downstream of the dam is shown by the confetti streaks in photographs 3, 4, and 5 for river discharges from 10,000 to 220,000 cfs. The flow tended to sweep diagonally across from the powerhouse towards the navigation channel to create a strong crossflow immediately downstream of the training wall. The effect was strongest at 100,000 cfs (photograph 4) with maximum powerhouse flow and zero spillway flow. At higher discharges, the additional spillway flow acted as a buffer to reduce the angle of flow approaching the navigation channel and consequently the degree of crossflow.

11. Photographs 6, 7, and 8 show the flow patterns in the vicinity of Goose Island for the range of flows tested. These pictures were taken to document existing conditions in order to evaluate effects on downstream flow conditions resulting from physical changes in the river channel or structures which were made to improve navigation. The velocities measured around Goose Island are shown in plates 4 to 9.

12. The flow patterns, velocities, and water levels measured in the model are documented in plates 4 to 9 for river discharges of 10,000 to 220,000 cfs. For 10,000 cfs (plate 4) the maximum velocities in the

navigation channel were less than 2 fps. A river discharge of 60,000 cfs passing through the powerhouse (plate 5) created maximum velocities of 8 fps in the navigation channel and 4 fps in the area of maximum crossflow. With 100,000 cfs powerhouse flow and no spill (plate 6), the maximum velocity in the navigation channel was 9 fps and 5 fps in the crossflow. At 150,000 cfs (plate 7) velocities in the channel increased to 10 fps, but the angle of crossflow was reduced due to a buffering effect of spillway flow. At 180,000 cfs (plate 8) velocities reached 11 fps, and at 220,000 cfs (plate 9) velocities reached 12 fps.

13. The movement of modeled barge tows in the existing channel is pictured in photographs 9 and 10 using a multiple-exposure technique to show the position of the tow as it progressed along the channel. There was no difficulty navigating upstream (photograph 9) since the towboat, bucking the flow, had good steering control all the way. However, a small amount of crabbing against the crossflow was necessary. At 100,000 cfs the towboat required the full 2,000 horsepower to move one full and two empty barges against the current. Moving downstream (photograph 10), the tow had to accelerate while protected by the training wall in order to achieve enough speed over and above the river current to be able to steer against the crossflow. This was not difficult at 10,000 or 60,000 cfs discharges but it required appreciably more crabbing at the latter flow. At a flow of 100,000 cfs, the tow required the full usable width of the channel to crab against the crossflow. Less crabbing was required at 150,000 cfs because of the straightening effect of the spillway flow on the powerhouse flow. At 180,000 cfs — the upper limit of flow for navigation — the towboat had to travel 1,000 to 1,500 feet before attaining full speed, so steering was not yet optimum while passing the crossflow area. During this difficult maneuver, the tow was pushed far toward the bank and maximum crabbing was required until the tow had the speed needed to hold it within the safety limits of the channel.

PART IV: PERFORMANCE OF GUIDE WALL MODIFICATIONS

Solid Guide Wall Extensions

14. Observations were made of three extensions of the downstream guide wall in line with the navigation channel and three other extensions at 30 degrees to the direction of the channel. The three in-line extensions were 500, 1,000, and 1,500 feet long. The 30-degree extensions were 70, 140, and 210 feet long. These geometries are shown in plates 10 to 15 and photographs 11 and 12 with confetti streaks indicating the flow patterns for a 100,000-cfs river discharge. The measured velocities for the three in-line extensions are shown on plates 10 to 15 for river discharges of both 100,000 (powerhouse flow only) and 150,000 cfs (powerhouse and spillway flow). The flow patterns and velocities are essentially the same for both flows. The crossflow for the 500-foot-long extension was relatively unchanged from the existing conditions, and maximum velocities in the middle of the channel were 8 to 10 fps (plates 10 and 11). The 1,000-foot-long extension isolated the navigation channel for a longer distance but beyond it the flow expanded into the channel with maximum velocities of 10 fps (plates 12 and 13). The 1,500-foot-long extension held the powerhouse flow out of the navigation channel for a greater distance but caused the river channel to become narrower and shallower just downstream from the end of the extension wall. Velocities in the navigation channel increased to 11 fps (plates 14 and 15).

15. The measured velocities for the angled end walls are given in plates 16 to 21 for flows of 100,000 and 220,000 cfs. Velocities were also measured at 150,000 cfs but the differences were too insignificant to justify including in the report. With a 70-foot extension, crossflow was about the same as with no extension. Velocities with the 100,000- and 220,000-cfs flows (plates 16 and 17) were as high as 12 fps, and flow angled across the channel for approximately 1,700 feet downstream from the end of the wall -- essentially the same condition as that without the extension. With a 140-foot extension, an additional 100 feet of the channel at the lock was protected from the crossflow which eventually cut across the channels as strong as it did without an

extension. As shown on plates 18 and 19, maximum velocities in the crossflow were 7 and 10 fps for the two flows -- the same as those without an extension. A 210-foot-long extension forced the crossflow further downstream (plates 20 and 21). The velocities of the crossflow were the same as those occurring with the existing geometry, but the crossflow was spread over a longer reach and the angle was increased. The higher river bottom and narrower channel just downstream from where the crossflow was the strongest forced the surface flow to move across the channel at an angle of approximately 30 degrees (photograph 12).

16. None of the solid guide wall extensions improved navigation. The tows are shown moving downstream in photograph 13. The towboat required full throttle by the time it cleared the end of the guide wall to make a safe exit through the reach. According to towboat captains, normal procedure with present conditions is to leave the lock at low speed, obtain half speed along the existing guide wall, and be up to full speed approximately 1,000 feet downstream from the end of the existing guide wall. Conditions with the 500-foot-long guide wall extension and the associated lower channel velocities required a moderate degree of crab to counteract the angular flow. The 1,000- and 1,500-foot-long wall extensions required much more crabbing because of the increased flow velocity that decreased the steering effectiveness. Conditions with the 1,500-foot-long wall were the most difficult for a safe exit. With the angled wall extension, navigation difficulties were roughly the same as for the existing geometry. Photograph 13 shows the degree of crabbing required to exit the lock with a riverflow of 100,000 cfs. It was desirable to keep the nose of the tow near the riverward side of the channel so that the crossflow could be counteracted. The towboat did not obtain full speed -- the conditions when steering would be most effective -- until the tow was approximately 1,000 feet downstream from the end of the guide wall; by that time, the tow was well into the crossflow and being pushed toward the shore. None of the three wall extensions improved navigation maneuverability. With a riverflow of 150,000 cfs, stronger crabbing was required and still the tow was pushed to the right side of the channel with all three wall extensions. In a

riverflow of 220,000 cfs, the high velocities and crossflow made maneuvering of the tow downstream extremely difficult with any of the three wall extensions.

Open Guide Wall Extension

17. A series of guide wall extensions with gaps were studied on the basis that the separated gaps would diffuse the crossflow that otherwise concentrated at the downstream end of the solid wall. The first geometry tested was a variation of the in-line guide wall extension that had a 300-foot-long gap between the existing wall and a 500-foot-long addition. The next was a series of wall units made of sheet pile cells located downstream from the existing guide wall. Each unit consisted of two 24-foot-diameter cells joined by 8.8-foot-radius connectors with an overall length of 53.5 feet. The purpose of the intermittent wall was to allow a small amount of the crossflow to move into the navigation channel at each gap in the wall but not enough to cause the towboat to oversteer. Groups of three to six units were tested, and the four-unit wall was selected as the most effective in breaking up the crossflow with the fewest cells. The extended wall consisted of a 200-foot space adjacent to the existing guide wall and four units with 150-foot spacing between them for a total extension length of 864 feet.

18. The flow patterns for these geometries are shown in photographs 14 and 15, and the velocities are given in plates 22 to 27. The movements of the downstream tow for these geometries are shown in photograph 16. Velocities were not a problem (plates 22 and 23) with the variation of the guide wall extension that had a 300-foot-long gap, but the strong cross-flow that came through the gap made it very difficult for the towboat to recover before passing the end of the wall into the main crossflow (photograph 16).

19. The sheet pile cells made towboat maneuvering considerably easier. Velocities were 6 fps or less with five or six units (plates 22 to 25). Only one-third power was required with minimum crabbing for safe exodus of the tow with either plan. The four-unit plan was also very easy to maneuver past with maximum velocities of 6 fps (plate 26),

and only a slight degree of crabbing was required to keep in the center of the channel (photograph 16). When the wall was shortened to three units with 150-foot spacing, velocities increased only slightly to 7 fps (plate 27) but slightly more crabbing was required to stay in the center of the channel. The three-unit wall was a workable plan with still only one-third power demand of the towboat, but the four-unit wall was considered optimum.

20. A variation of the three-unit wall was tested having a 200-foot space downstream from the existing guide wall followed by three double units (two 53.5-foot units end to end) with 150-foot spacing between them. This plan produced worse flow conditions in the channel and more crabbing as shown in photographs 15 and 16.

21. Short gravity walls were tested as alternatives to the round-nosed cells. Groups of walls with different spacing were tested at discharges of 100,000 and 150,000 cfs (plates 28 to 34). Encroachment of the crossflow into the navigation channel was worse. The square nose of the wall segments deflected flow further into the navigation channel than the circular cells. The cellular walls were superior.

22. None of the revisions to the guide wall had any effect on flow around Goose Island. Velocities and flow patterns were the same as those with existing conditions.

23. The intermittent wall of sheet pile cells provided the best hydraulic improvement of the problem of crossflow from the powerhouse into the navigation channel. However, during a demonstration for local navigation company representatives objection was raised to the intermittent wall units because they would be in the way of tows going upstream with empty barges. On windy days towboats must push the nose of their tows up to 200 feet riverward from the navigation channel to counteract the force of the wind on the high-riding empty barges. The intermittent wall would not provide sufficient shelter from the wind to alleviate this practice.

PART V: PERFORMANCE OF A WIDER NAVIGATION CHANNEL

24. An alternative to extending the guide wall was to widen the channel. One of the major problems for towboat captains is the inability to determine the lateral position of their tows in the navigation channel. To provide an extra 50-foot safety margin on each side, the channel was widened 100 feet on the river side for 2,700 feet downstream from the guide wall, and downstream navigation was tested with flows of 100,000 and 150,000 cfs. The degree of crabbing was just as severe as in the original channel but the margin of safety was greater (photograph 17). Velocities with riverflows of 10,000, 60,000, 100,000, 150,000, 180,000, and 220,000 cfs are shown on plates 35 to 39. The maximum velocities of 8 and 9 fps were the same as those existing before the channel was widened. Only minimal local change occurred along the new left towline.

25. The general consensus of the navigators present was that widening the channel would not be totally effective. One towboat operator indicated that even if the channel were wider he would not have enough power to get out into the new area (against the crossflow) in order to take advantage of it. Others indicated that they could get out into the area but the extra dredging would not be worth the investment. They all agreed that channel widening would not worsen conditions.

26. Several other schemes of offset walls, angled intermittent walls, and combinations of walls and excavation were suggested and tried during the joint work session and at a later demonstration of the model. Those present agreed that none of the schemes adequately improved navigation conditions. No other suggestions for improved navigation were made and testing was terminated.

PART VI: SUMMARY

27. None of the modifications formally tested, including guide wall extensions and channel widening, succeeded (to the satisfaction of the tow operators) in correcting the difficulties experienced while navigating barge tows downstream from the Ice Harbor Lock due to conditions caused by crossflows from the powerhouse. All other modifications explored superficially during workshop sessions with tow operators were also unsuccessful or impractical.

28. The solid 500-, 1,000-, and 1,500-foot-long extensions to the existing 600-foot-long guide wall all caused concentrated crossflows at the end of the guidewall, and the longer extensions restricted the powerhouse flows so that the velocities were higher downstream. Navigation was more difficult because the tows had to achieve a speed in excess of these velocities in order to have rudder control.

29. The short-angled extensions of 70-, 140-, and 210-foot-long had essentially no effect on the crossflow and consequently provided no improvement to downstream navigation.

30. Open extensions that allowed the powerhouse flow to enter the navigation channel through gaps were successful in reducing the concentration of crossflows and allowed the barge tows to move downstream without employing excessive crabbing to stay in the channel. The most effective configuration had four units consisting of pairs of 24-foot-diameter sheet pile cells spaced 150 feet apart with a 200-foot space adjacent to the existing guide wall -- for a total length of 864 feet. However, open extensions were not satisfactory to the tow operators because upstream tows have to travel as much as 200 feet south of the navigation channel to avoid being blown by high winds onto the north bank and the cellular units would be in the way.

31. Widening the navigation channel from 250 feet to 350 feet by dredging a 100-foot-path on the south side did not change the crossflow or reduce the amount of crabbing required to navigate downstream but did provide more safety clearance. However, the consensus of the operators was that this would not help a great deal and some would have difficulty moving their tow southward against the crossflow to take advantage of the increased width.

TABLE A
ELEVATION-DISCHARGE RATING TABLE
SNAKE RIVER NAVIGATION CHANNEL BELOW ICE HARBOR DAM
1981 OBSERVED DATA

Discharge in cfs		McNary Forebay Elevations in Feet					
		335	337	340	335	337	340
		Water Surface Elevations in Feet					
Snake R.	Columbia R.	Gage 9 at Pumping Plant			Gage 3 at Navigation Lock		
0	36,000	335.0	337.0	340.0	335.0	337.0	340.0
10,000	46,000	335.3	337.2	340.1	335.9	337.5	340.2
50,000	86,000	338.6	339.4	341.3	341.8	342.2	343.1
100,000	136,000	342.3	342.7	343.7	346.6	346.7	347.1
150,000	186,000	345.3	345.6	346.2	350.1	350.2	350.4
200,000	236,000	347.9	348.1	348.6	353.0	353.1	353.3
250,000	286,000	350.2	350.4	350.8	355.6	355.6	355.8
300,000	336,000	352.4	352.5	352.7	357.9	358.0	358.1
350,000	386,000	354.3	354.4	354.5	360.0	360.1	360.2

Note: Gage locations shown on plate 3.

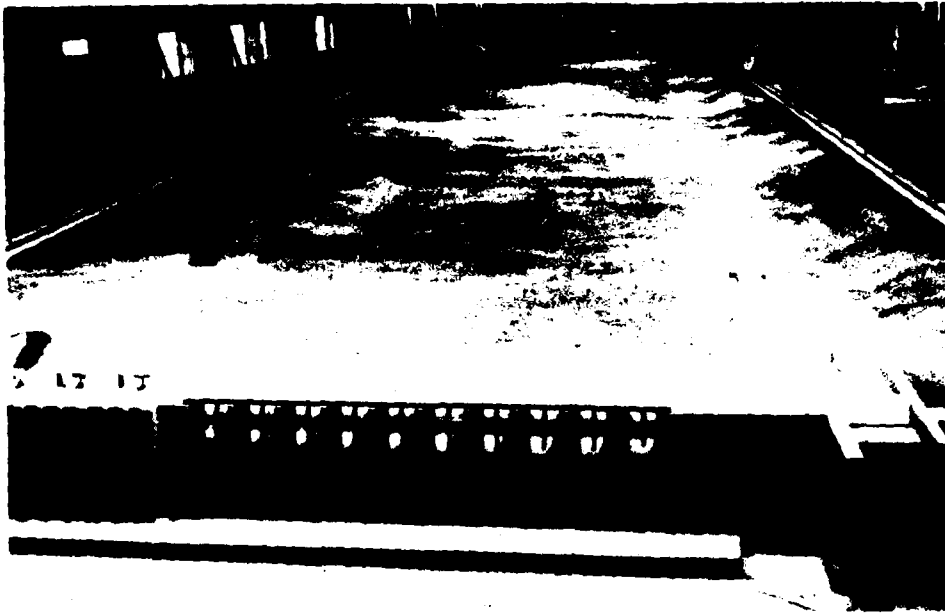
TABLE A

TABLE B

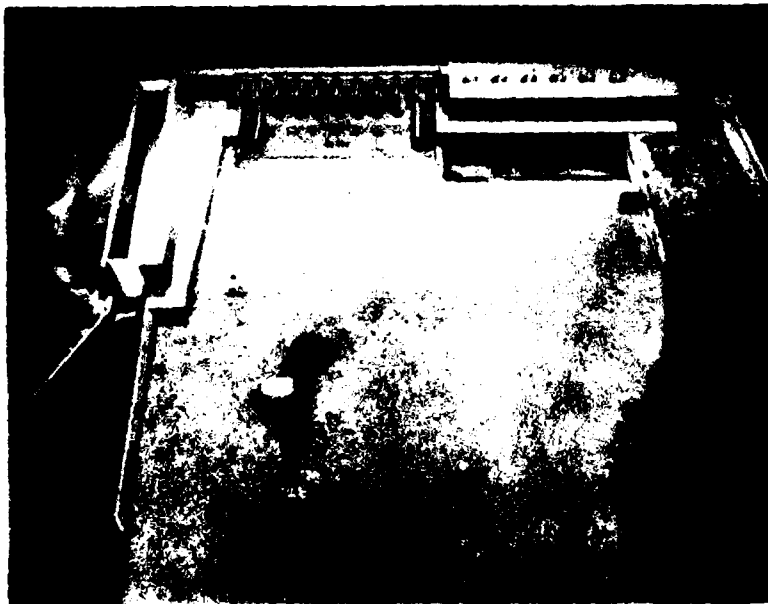
WATER LEVELS RECORDED ON THE MODEL

River Discharge in cfs	Water Levels in Feet at Gage 9 at Downstream End of Model		Water Levels in Feet at Gage 3 at Navigation Lock	
	McNary Pool Levels in Feet			
	335	340	335	340
10,000	335.6	340.1	336.0	340.3
60,000	339.4	341.7	342.7	344.0
100,000	342.3	343.7	346.2	346.9
150,000	345.3	346.2	349.5	350.0
180,000	346.9	347.7	351.2	351.5
220,000	348.9	349.5	353.5	353.5

TABLE B

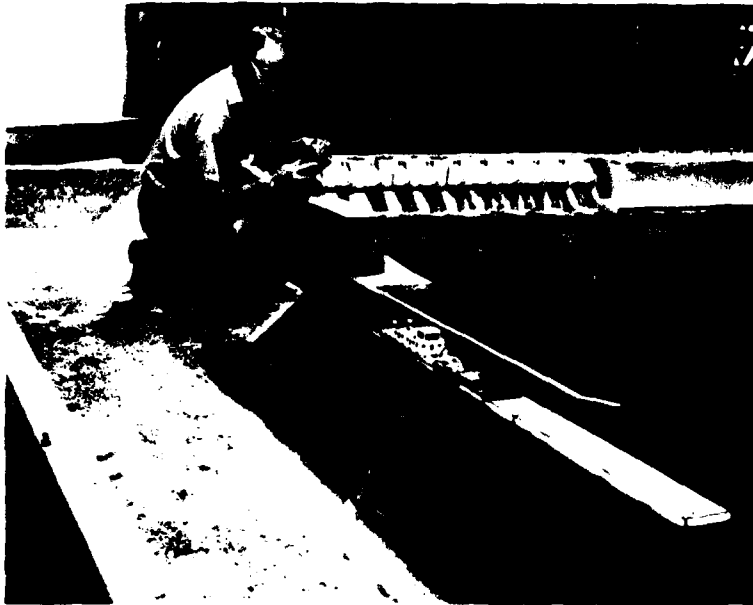


Model before verification changes, viewed
from upstream.

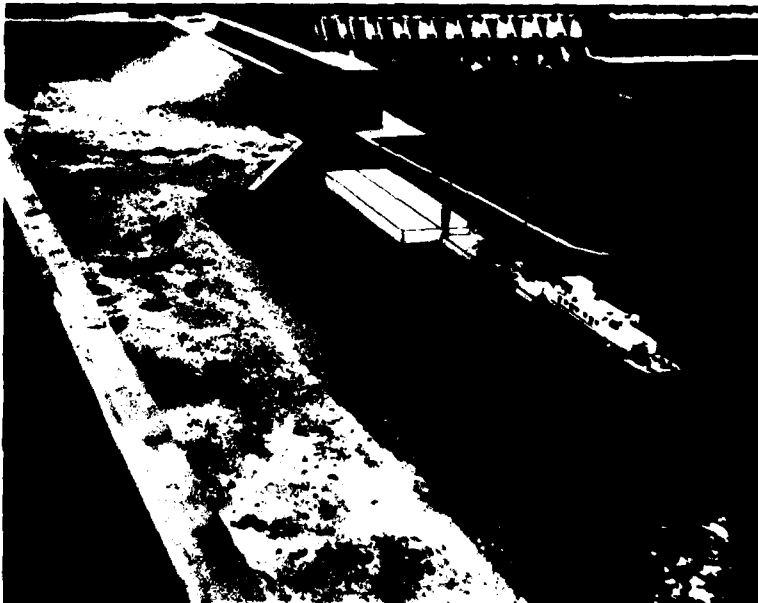


Model after verification changes, viewed
from above and looking upstream.

Photograph 1. Model of Ice Harbor Lock and Dam and
navigation channel.

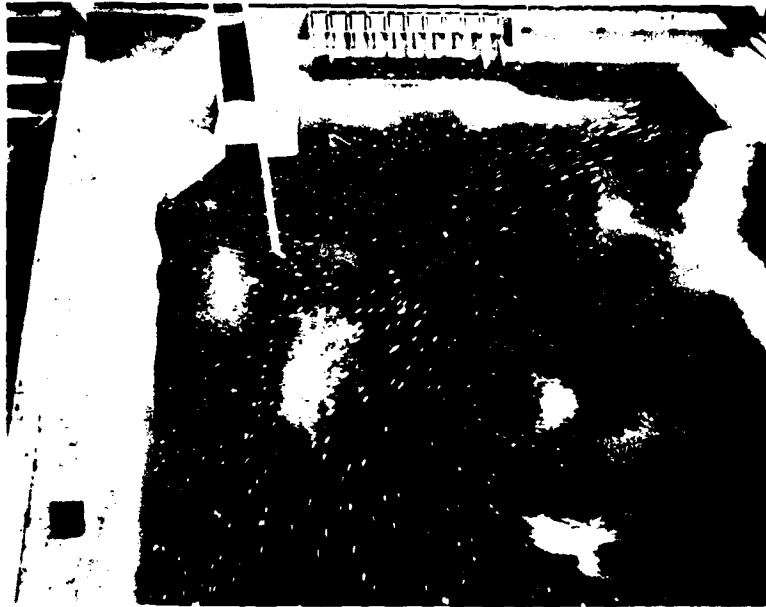


Towboat with two loaded barges for downstream navigation.



Towboat with one loaded barge and two unloaded barges for upstream navigation.

Photograph 2. Radio controlled model towboat with barges.



River discharge of 10,000 cfs from Unit 1.

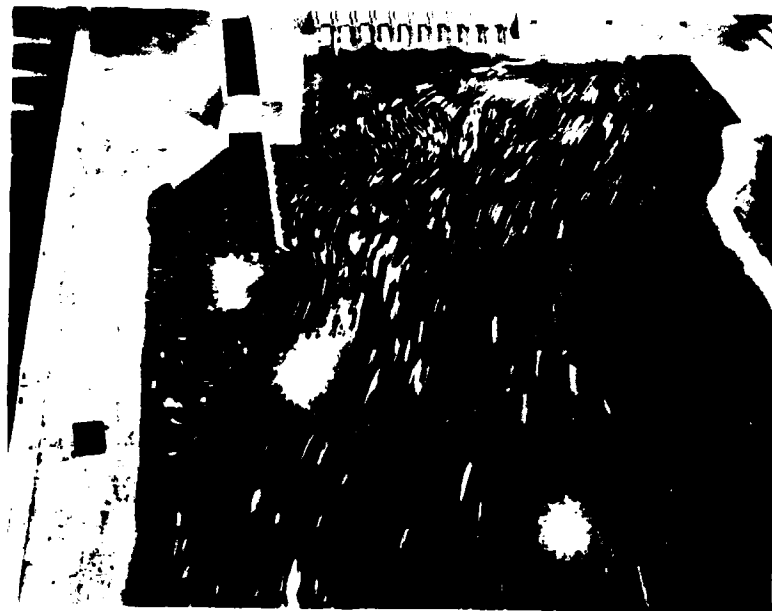


River discharge of 60,000 cfs from Units 1 to 4.

Photograph 3. Water surface flow conditions with existing channel and McNary pool at elev 335.
River discharges of 10,000 & 60,000 cfs

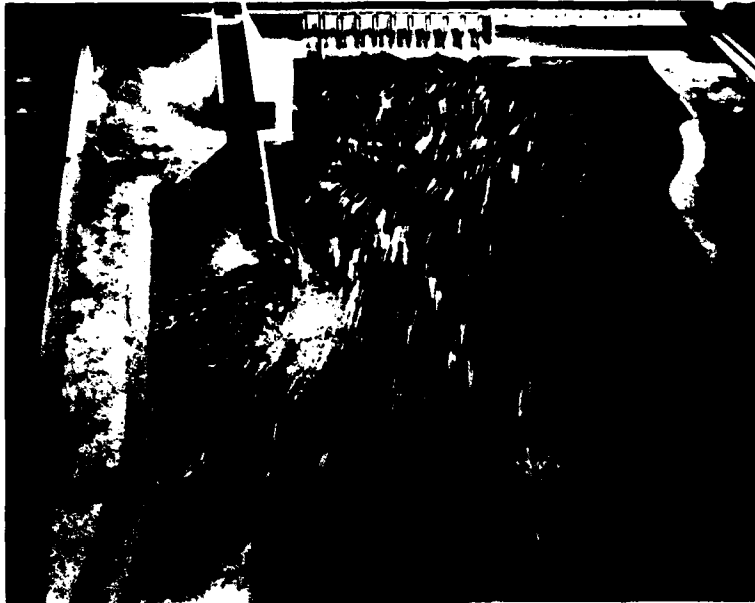


River discharge of 100,000 cfs from Units 1 to 6.



River discharge of 150,000 cfs; 100,000 cfs from powerhouse and 50,000 cfs from spillway.

Photograph 4. Water surface flow conditions with existing channel and McNary pool at elev 335.
River discharges of 100,000 and 150,000 cfs

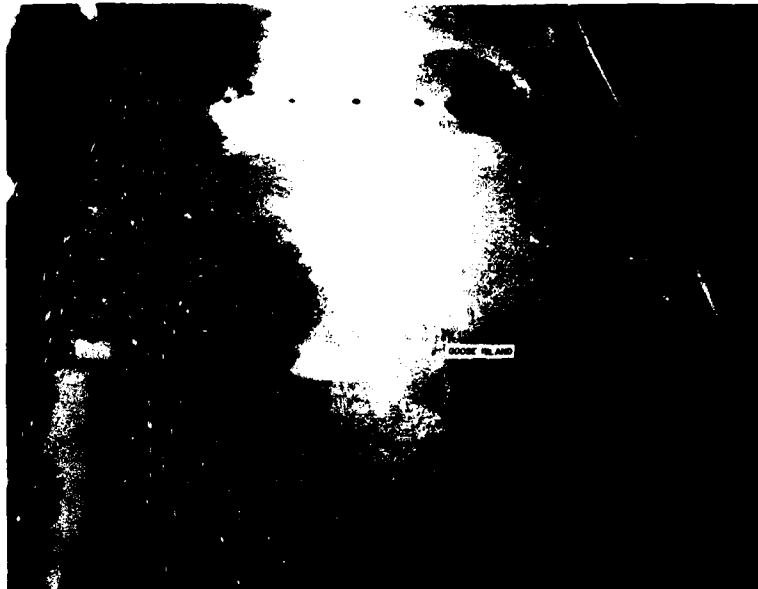


River discharge of 180,000 cfs; 100,000 cfs from powerhouse and 80,000 cfs from spillway.



River discharge of 220,000 cfs; 100,000 cfs from powerhouse and 120,000 from spillway.

Photograph 5. Water surface flow conditions with existing channel and McNary pool at elev 335.
River discharges of 180,000 and 220,000 cfs



10,000 cfs, water surface elev 336



60,000 cfs, water surface elev 341

Photograph 6. Surface flow pattern around Goose Island,
McNary pool elev 335, river discharges
10,000 and 60,000 cfs



100,000 cfs, water surface at elev 344



150,000 cfs, water surface at elev 347

Photograph 7. Surface flow pattern around Goose Island, McNary pool at elev 335, river discharge of 100,000 & 150,000 cfs

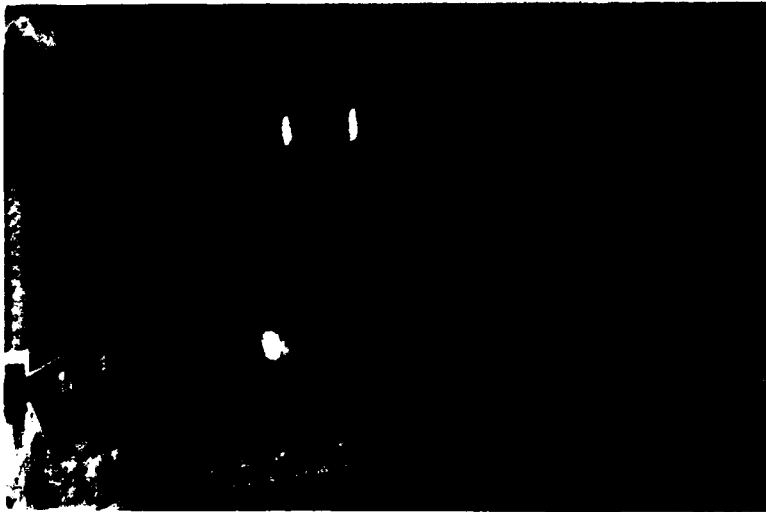


180,000 cfs, water surface at elev 349



220,000 cfs, water surface at elev 351

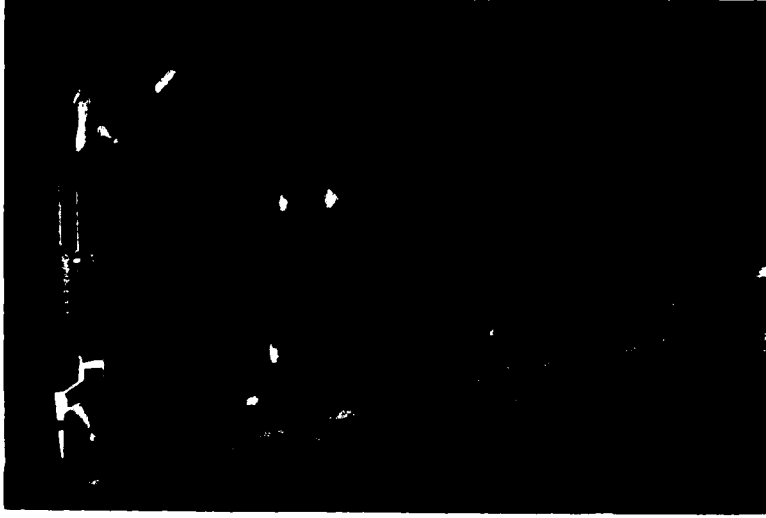
Photograph 8. Surface flow pattern around Goose Island, McNary pool at elev 335, river discharges of 180,000 & 220,000 cfs



River discharge of 10,000 cfs

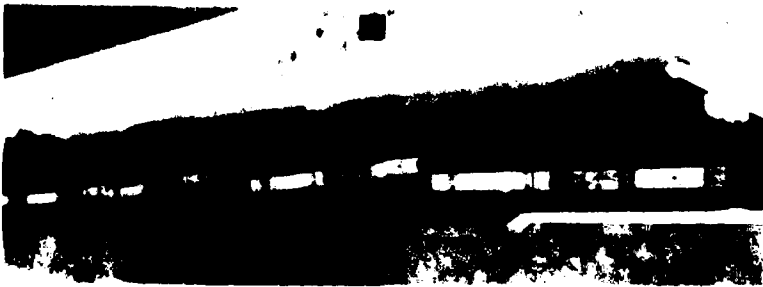


River discharge of 60,000 cfs

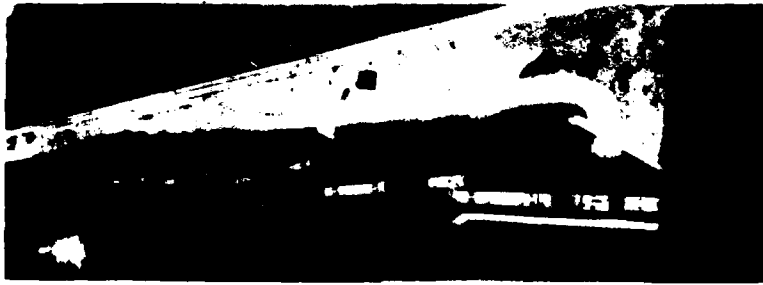


River discharge of 100,000 cfs

Photograph 9. Multiple exposures of tow navigating upstream in existing channel, and McNary pool at elev 335



10,000 cfs



60,000 cfs



100,000 cfs

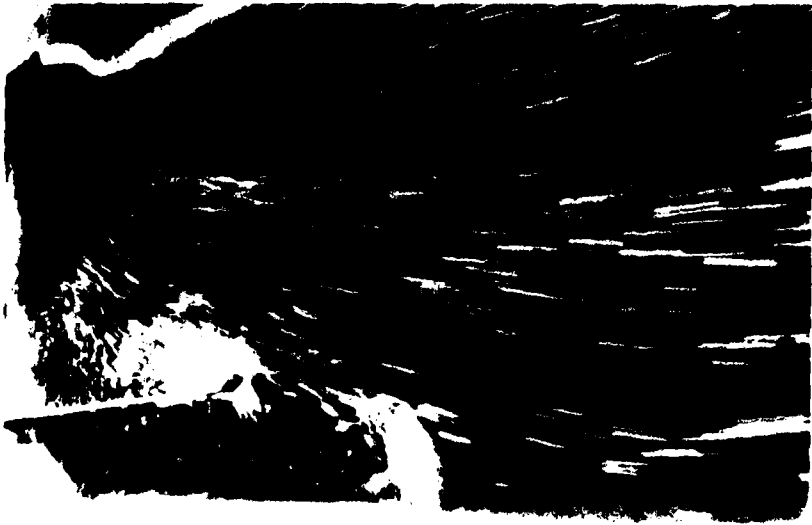


150,000 cfs

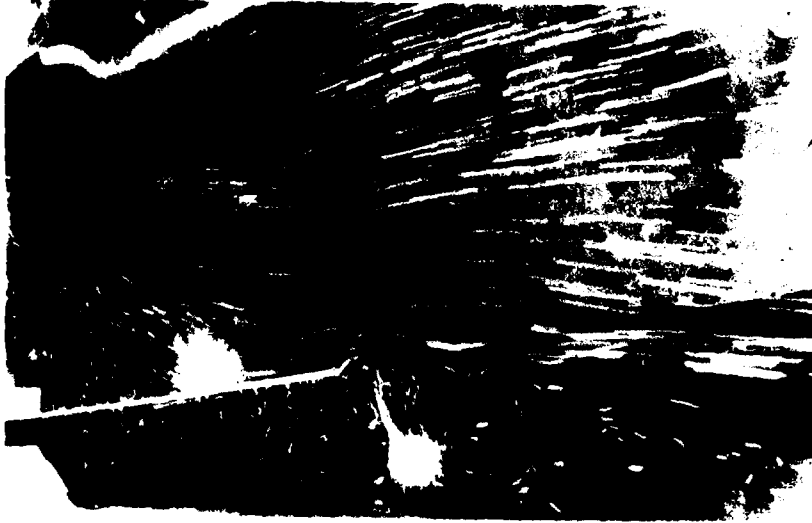


180,000 cfs

Photograph 10. Multiple exposures of tow navigating downstream in existing channel, McNary pool at elev 335



500-ft wall extension

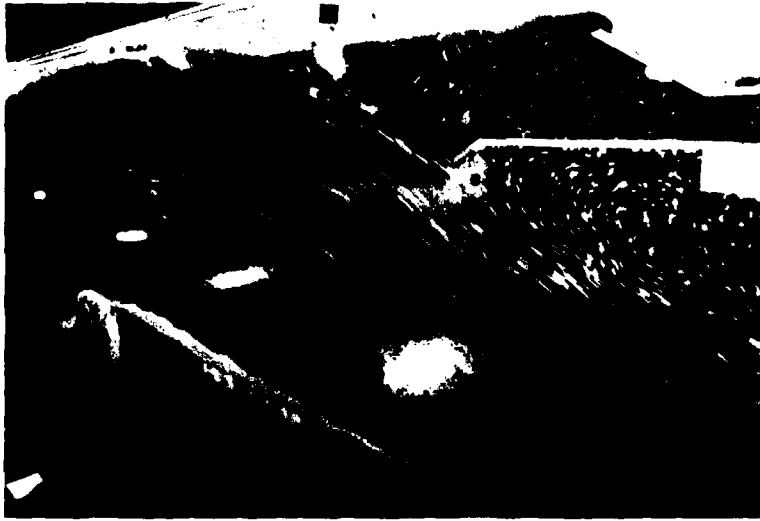


1000-ft wall extension



1500-ft wall extension

Photograph 11. Water surface flow conditions with solid guidewall extensions, river discharge at 100,000 cfs and McNary pool at elev 335



70-ft wall extension
at 30 degrees

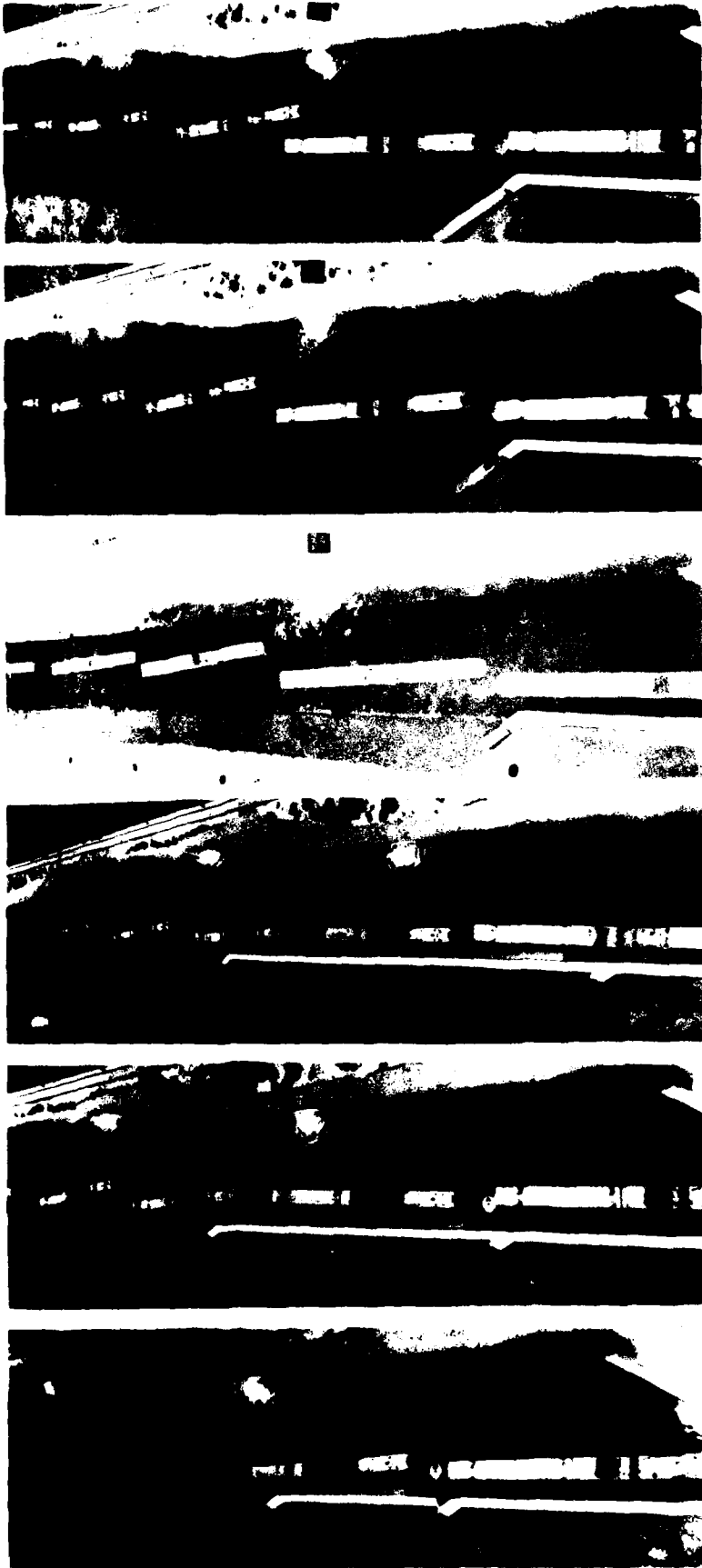


140-ft wall extension
at 30 degrees



210-ft wall extension
at 30 degrees

Photograph 12. Water surface flow conditions with angled guidewall extensions, river discharge at 100,000 cfs and McNary pool at elev 335

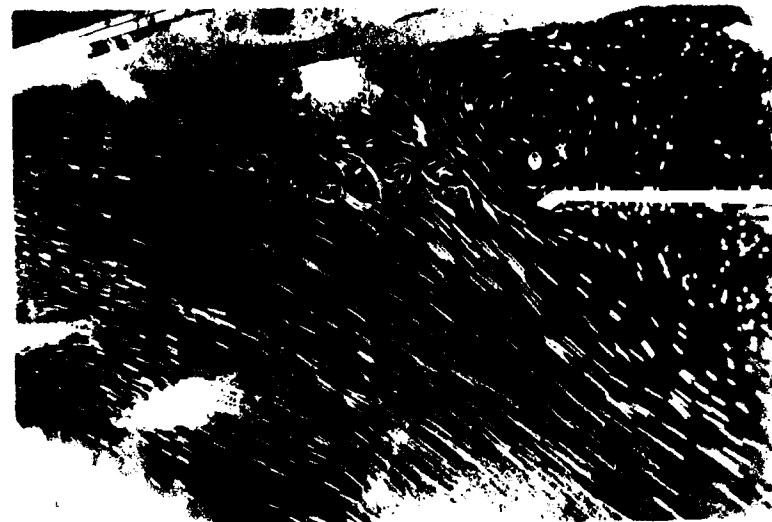


500-ft ext. 1000-ft ext. 1500-ft ext. 70-ft 30° ext. 140-ft 30° ext. 210-ft 30° ext.

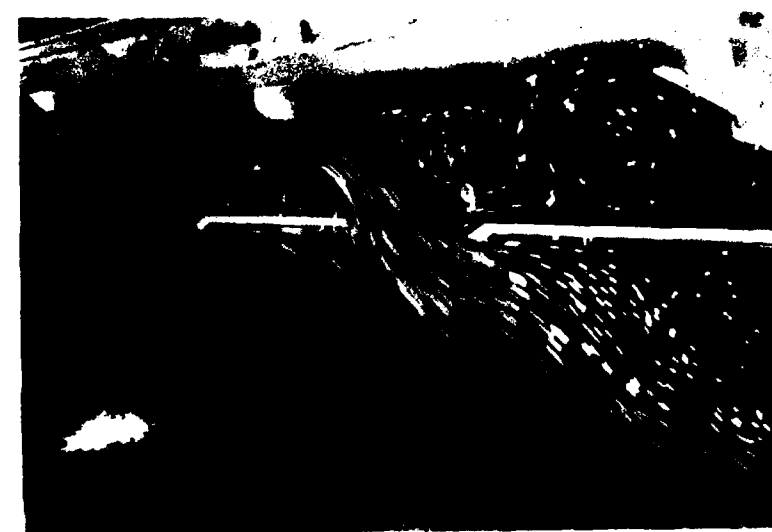
Photograph 13. Multiple exposures of tow navigating downstream with solid guide wall extensions, river discharge 100,000 cfs and McNary pool at elev 335



five-unit extension at
100-ft spacing



six-unit extension at
70-ft spacing



500-ft extension with
300-ft gap

Photograph 14. Water surface flow conditions with open guidewall extensions, river discharge of 100,000 cfs and McNary pool at elev 335



three double-unit extension
at 150-ft spacing



three-unit extension at
150-ft spacing



four-unit extension at
150-ft spacing

Photograph 15. Water surface flow conditions with open guidewall extensions, river discharge 100,000 cfs and McNary pool elev 335



three-unit
double ext.
150-ft spacing



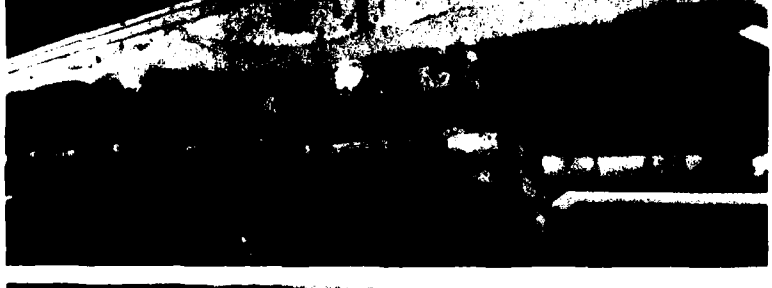
three-unit ext.
150-ft spacing



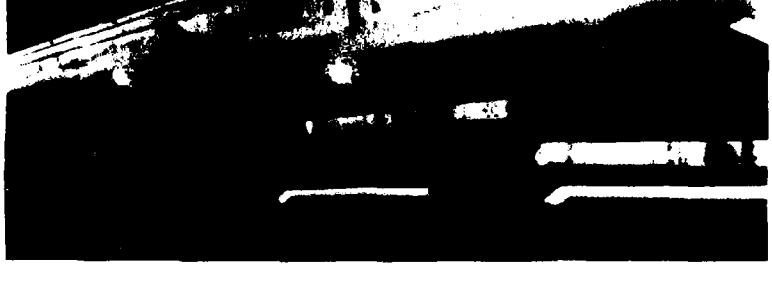
four-unit ext.
150-ft spacing



five-unit ext.
100-ft spacing



six-unit ext.
70-ft spacing

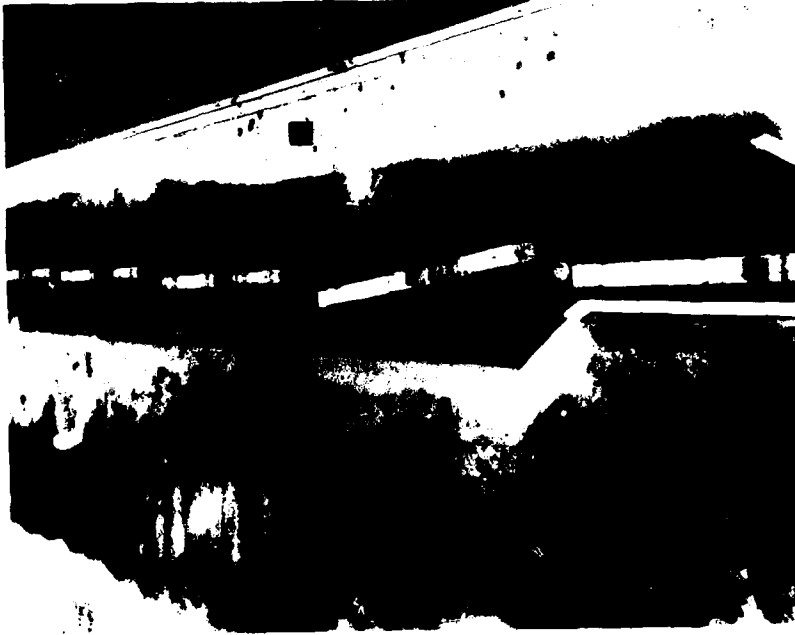


500-ft ext.
300-ft gap

Photograph 16. Multiple exposures of tow navigating downstream with open guide wall extensions, river discharge of 100,000 cfs and McNary pool at elev 335

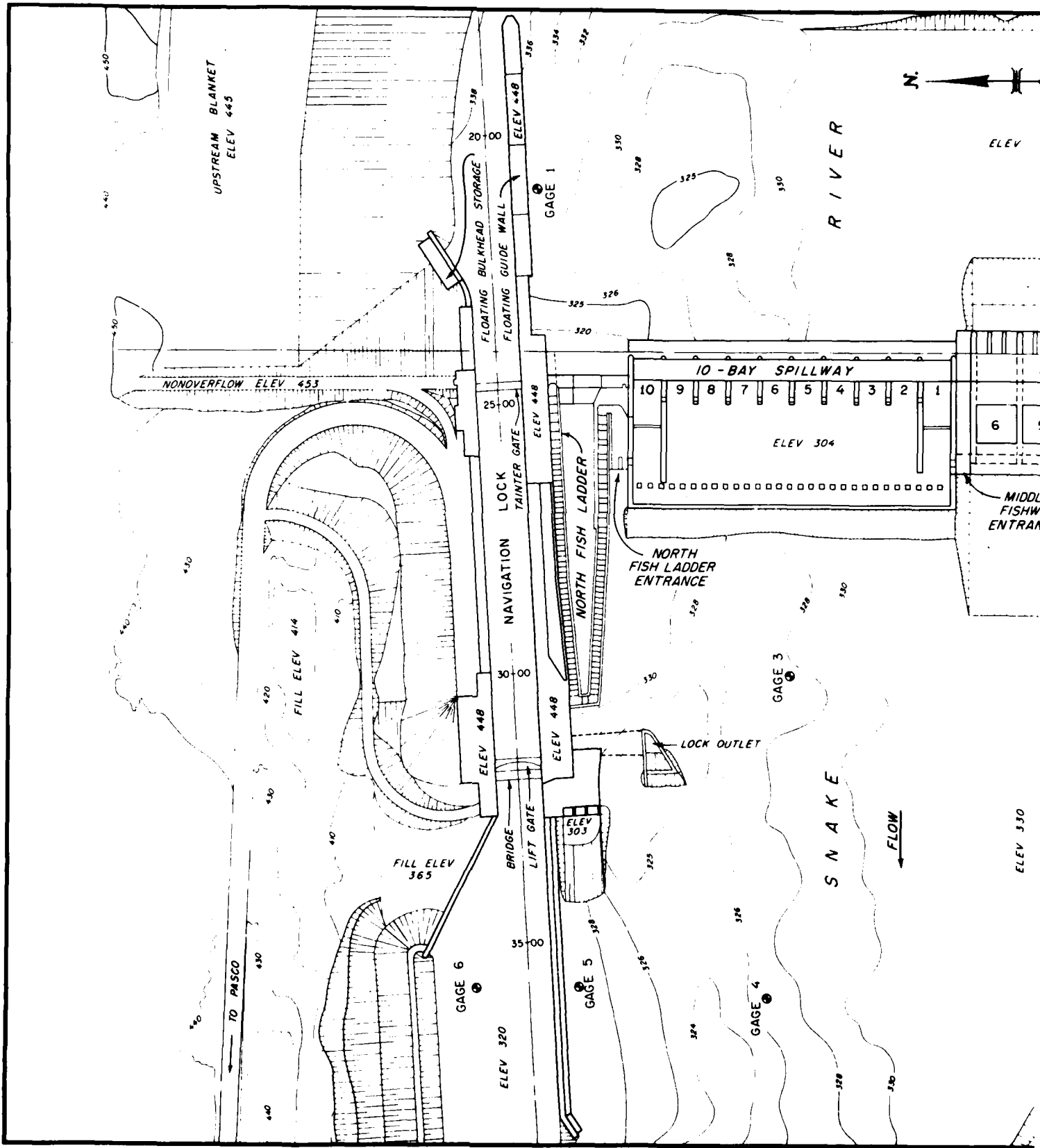


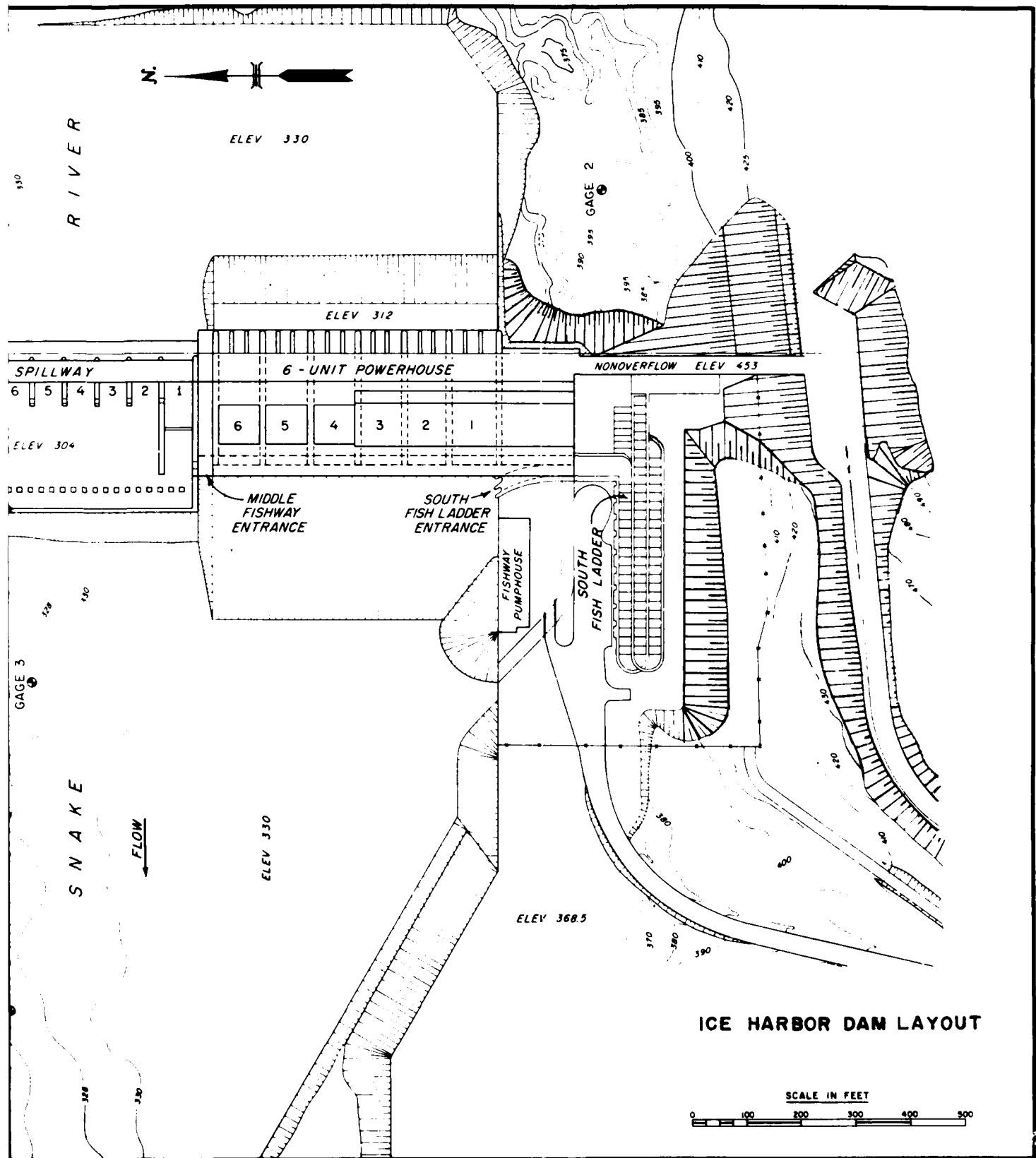
River discharge of 150,000 cfs



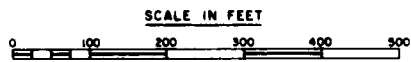
River discharge of 100,000 cfs

Photograph 17. Multiple exposures of tow navigating downstream with no wall extension but channel widened to 350 ft. McNary pool at elev 335

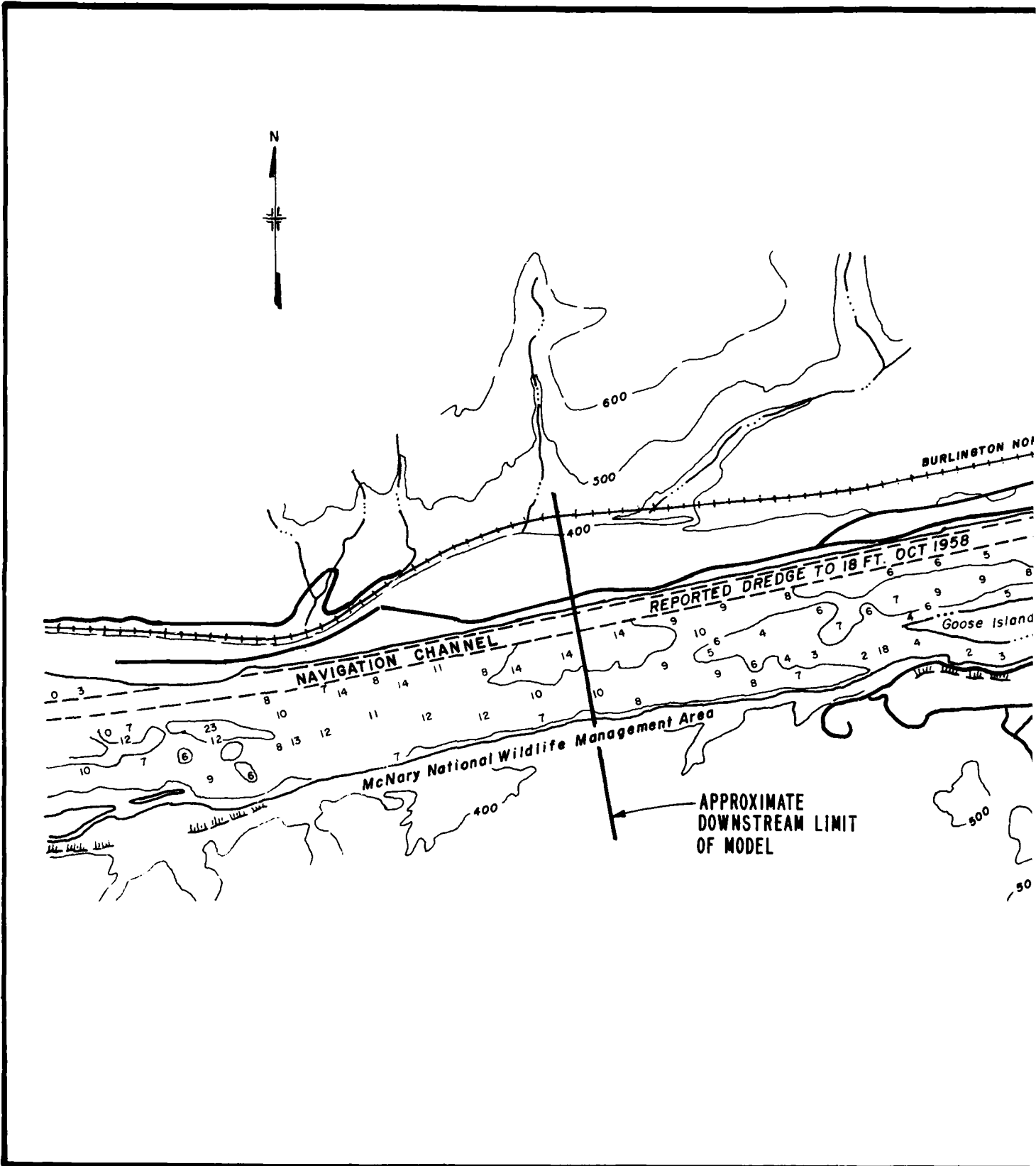


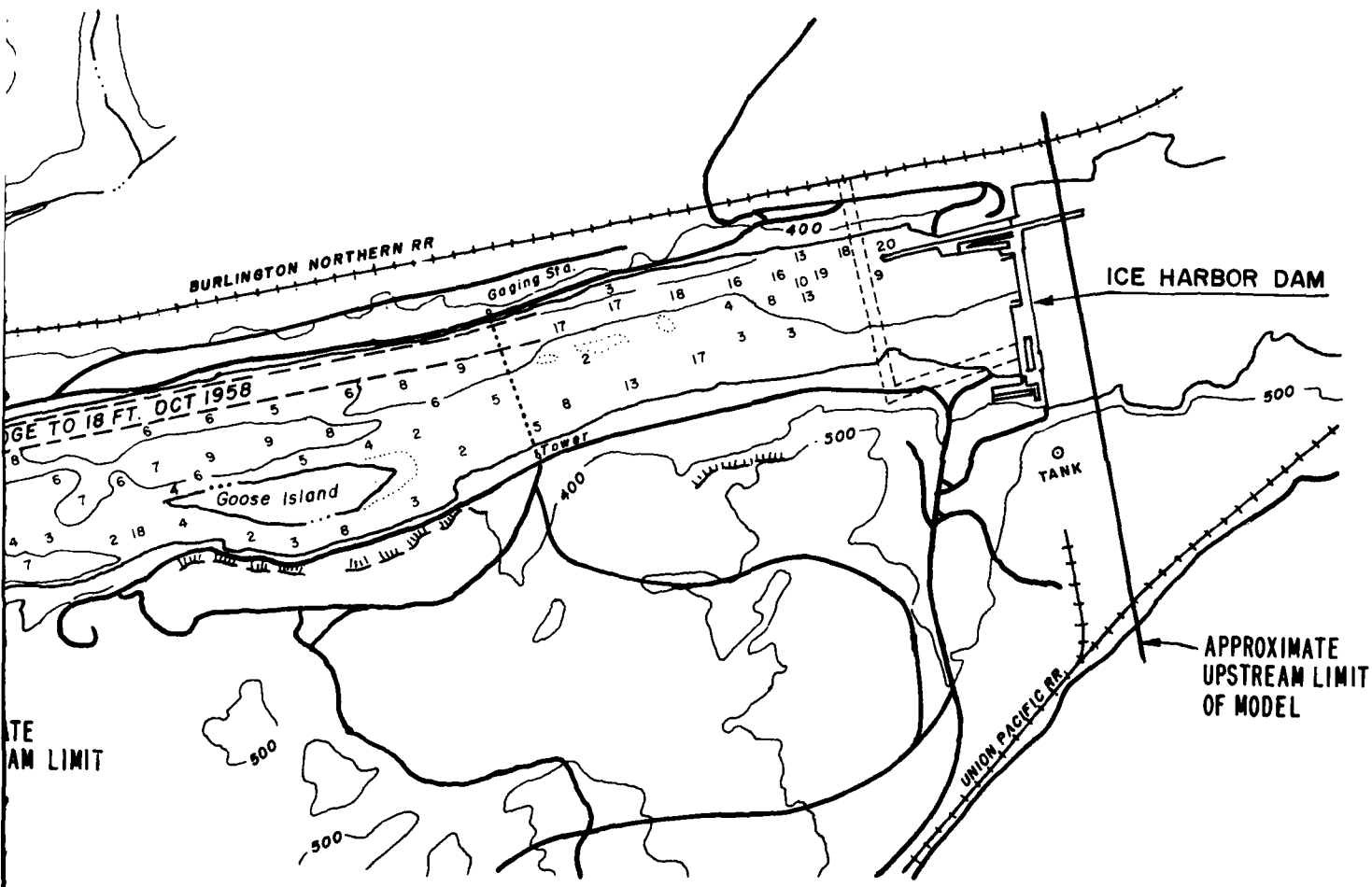


ICE HARBOR DAM LAYOUT



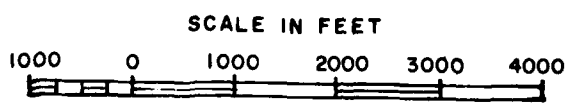
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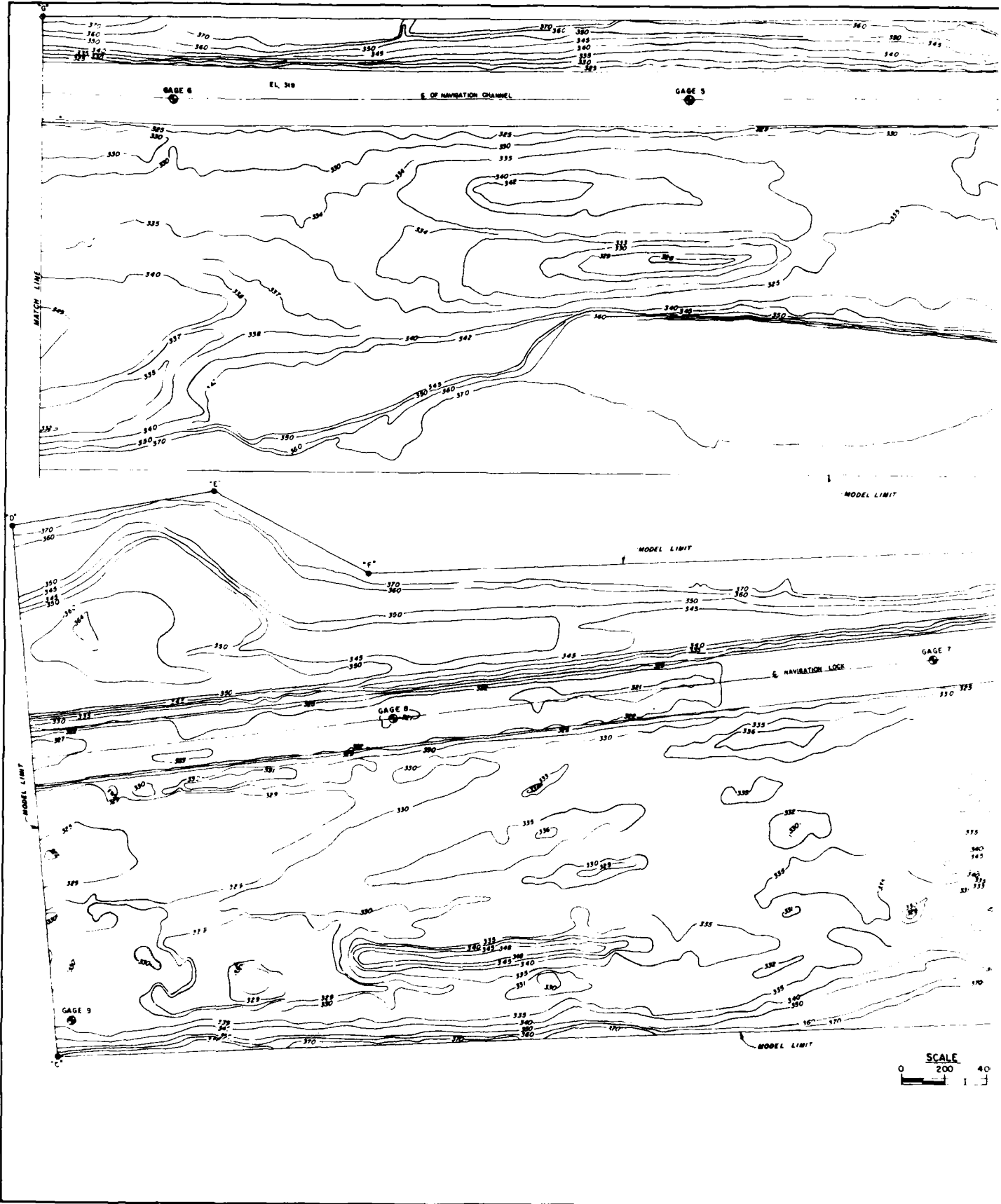


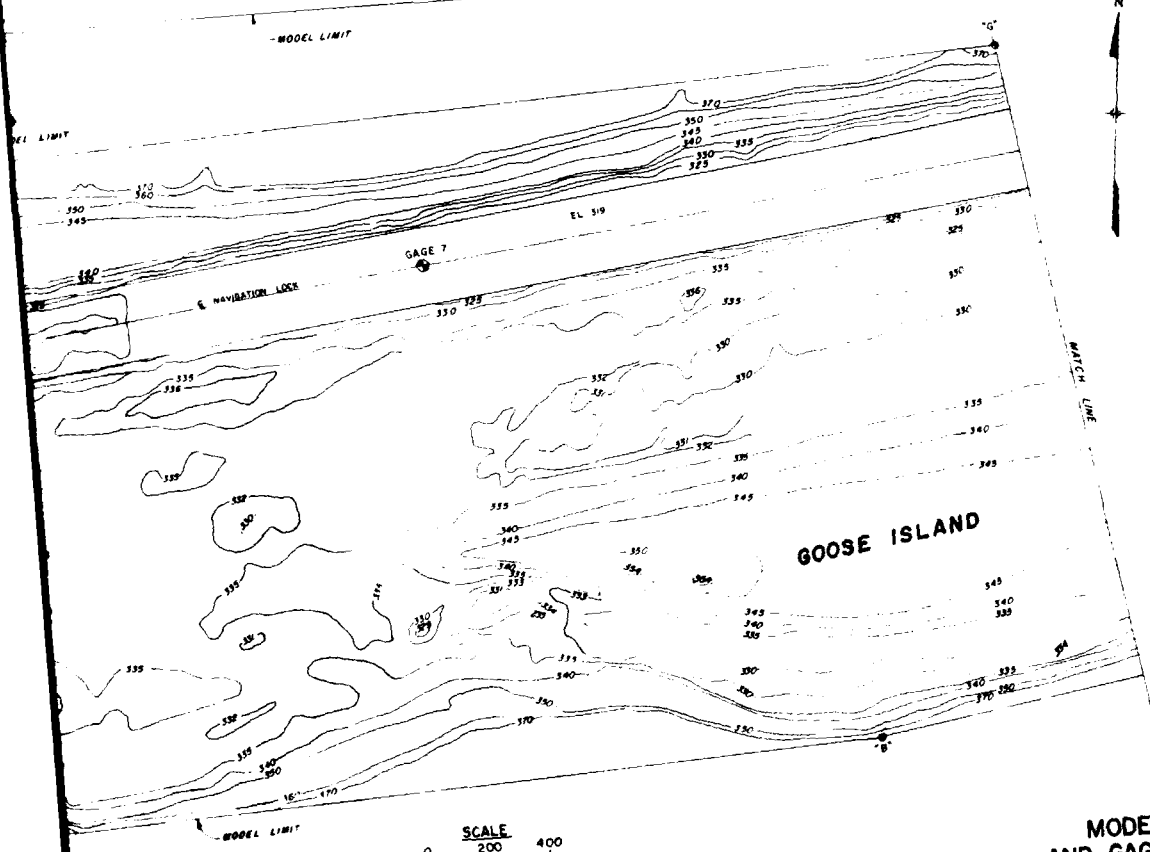
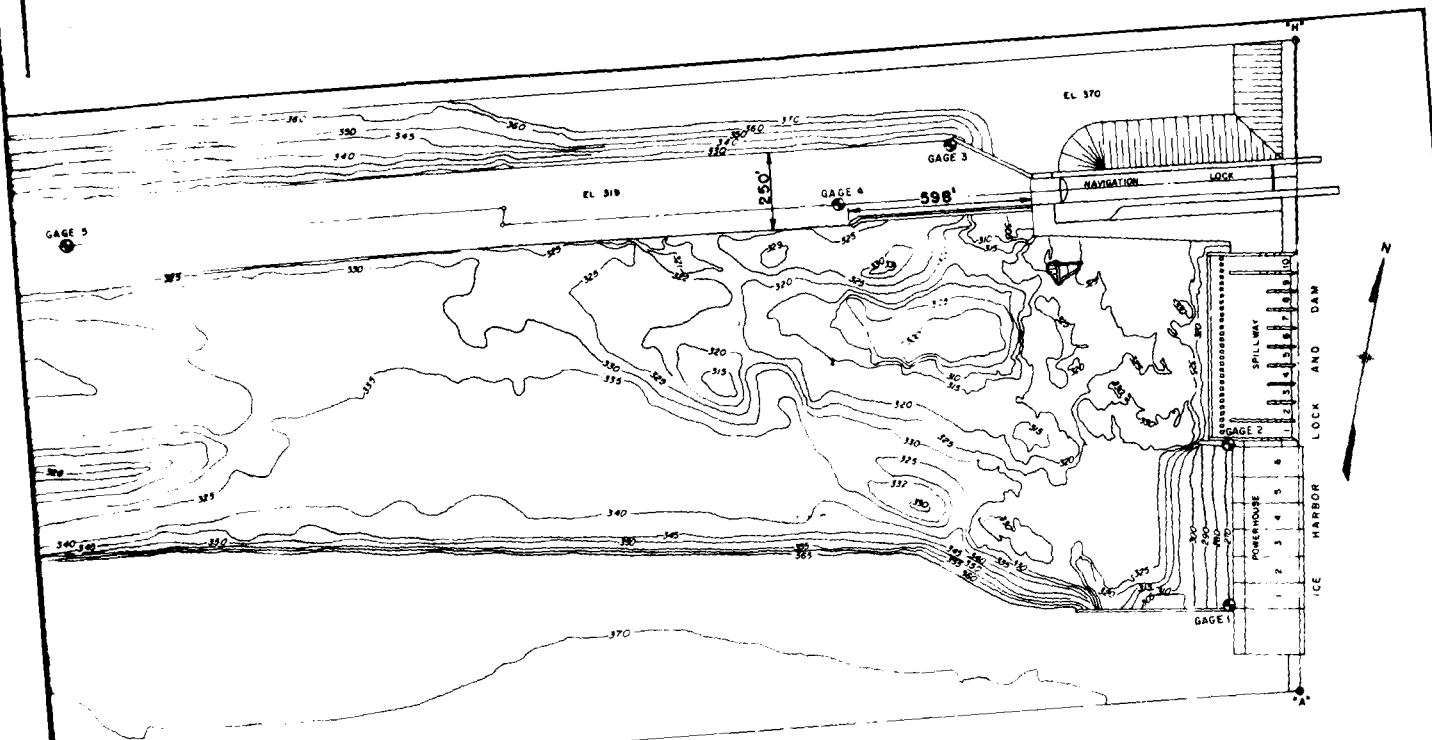
ATE
AM LIMIT

NAVIGATION CHANNEL

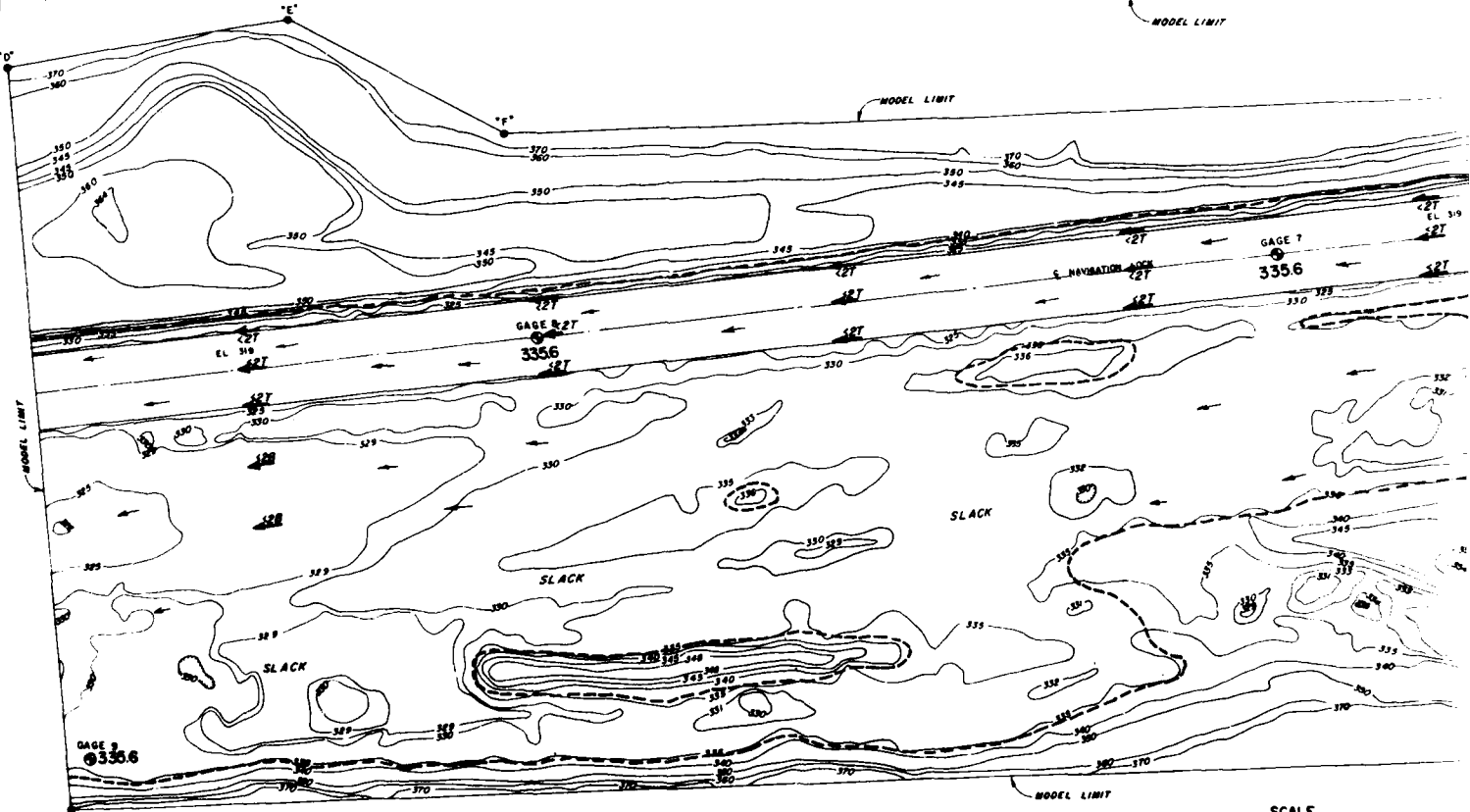
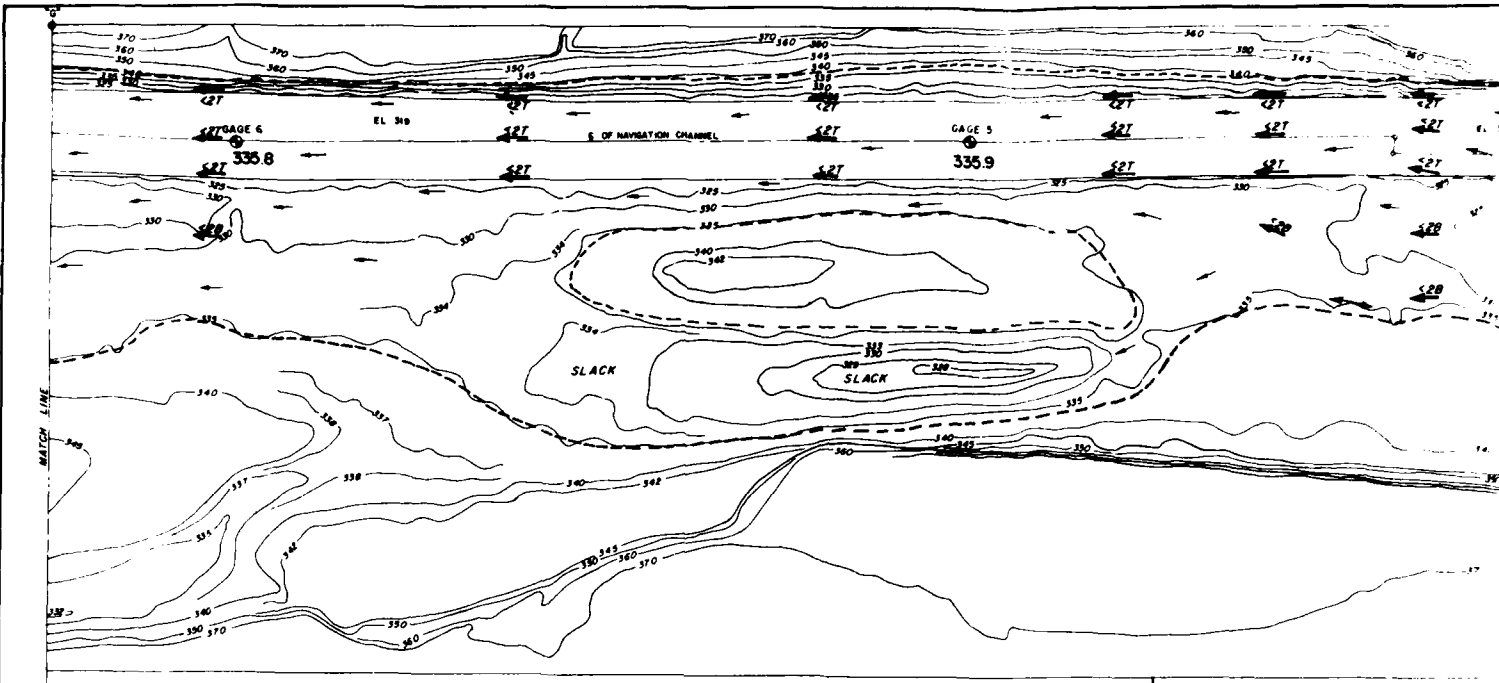


2





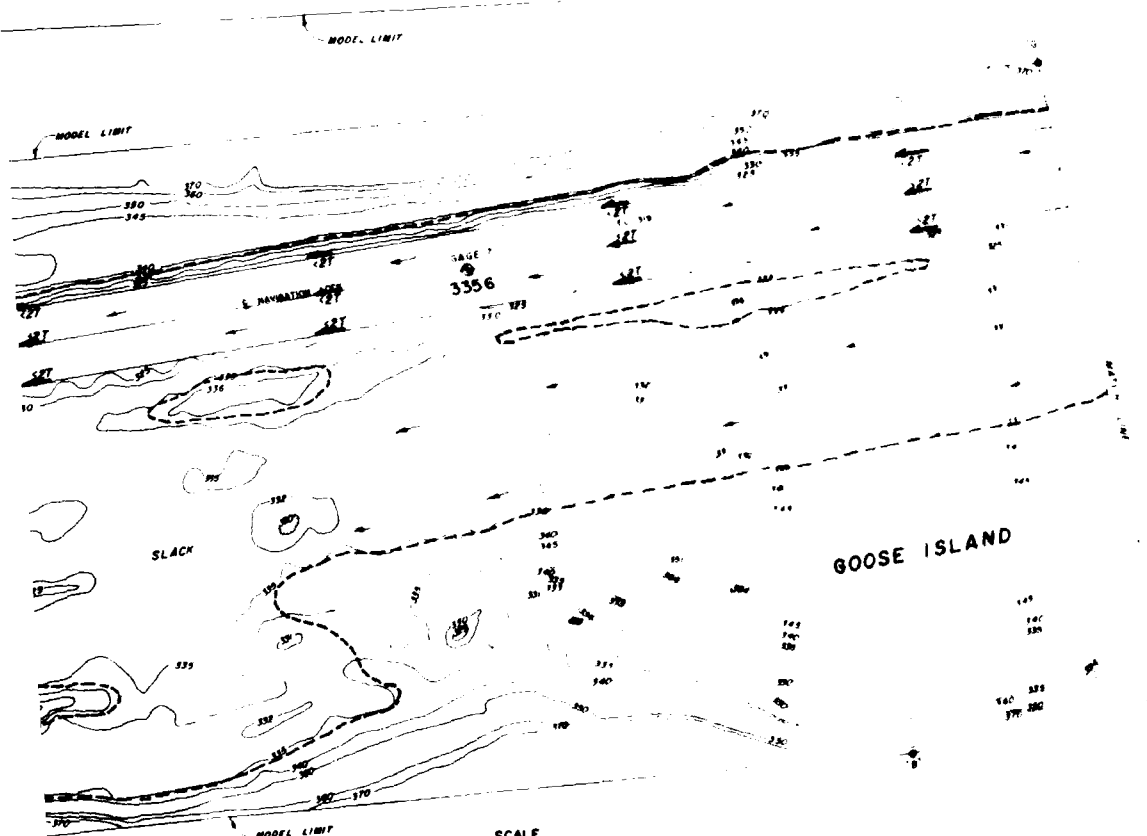
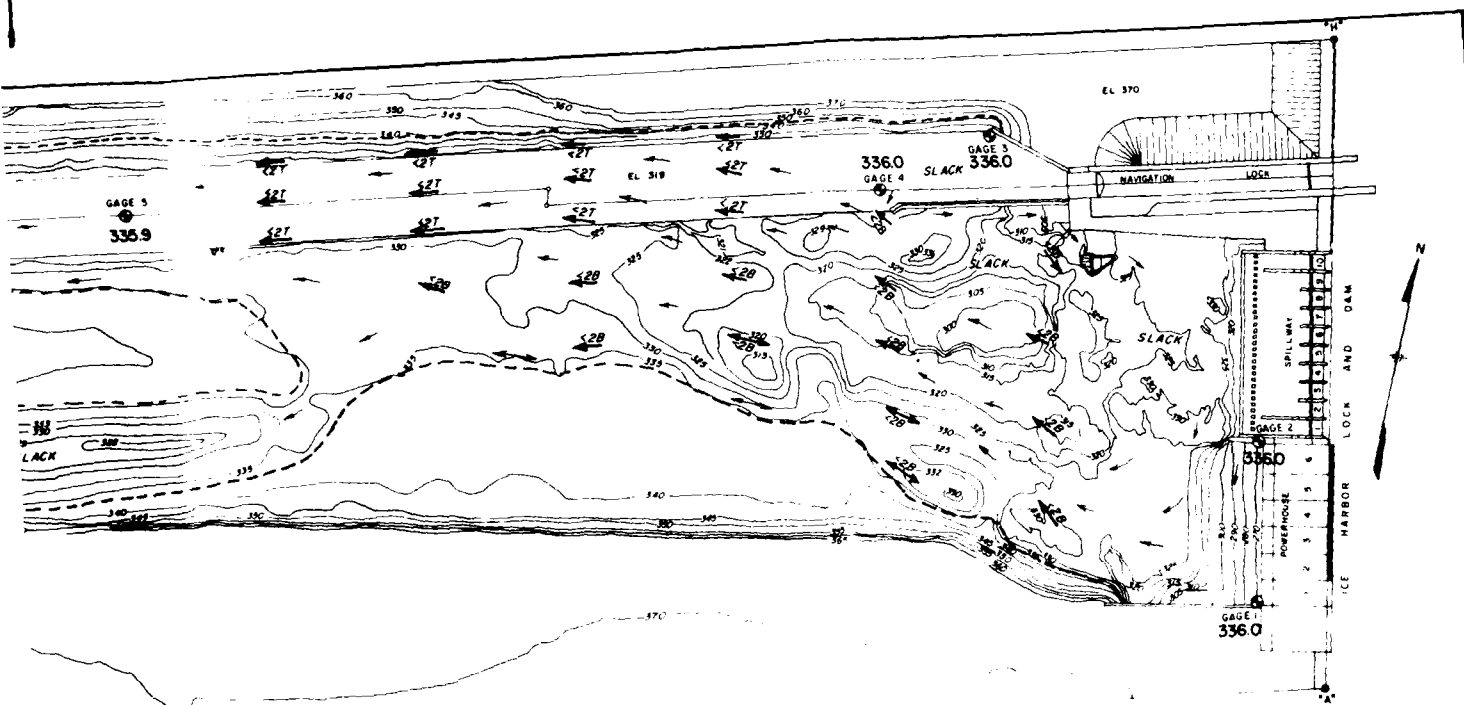
MODEL LAYOUT
AND GAGE LOCATIONS



LEGEND
 — VELOCITIES MEASURED IN FPS
 T 7-FT DEPTH
 B 5 FT OFF BOTTOM
 — FLOW DIRECTION

FLOW DISTRIBUTION
 SPILLWAY BAYS 1 TO 10
 POWERHOUSE UNIT 1
 CLOSED
 10 000 CFS

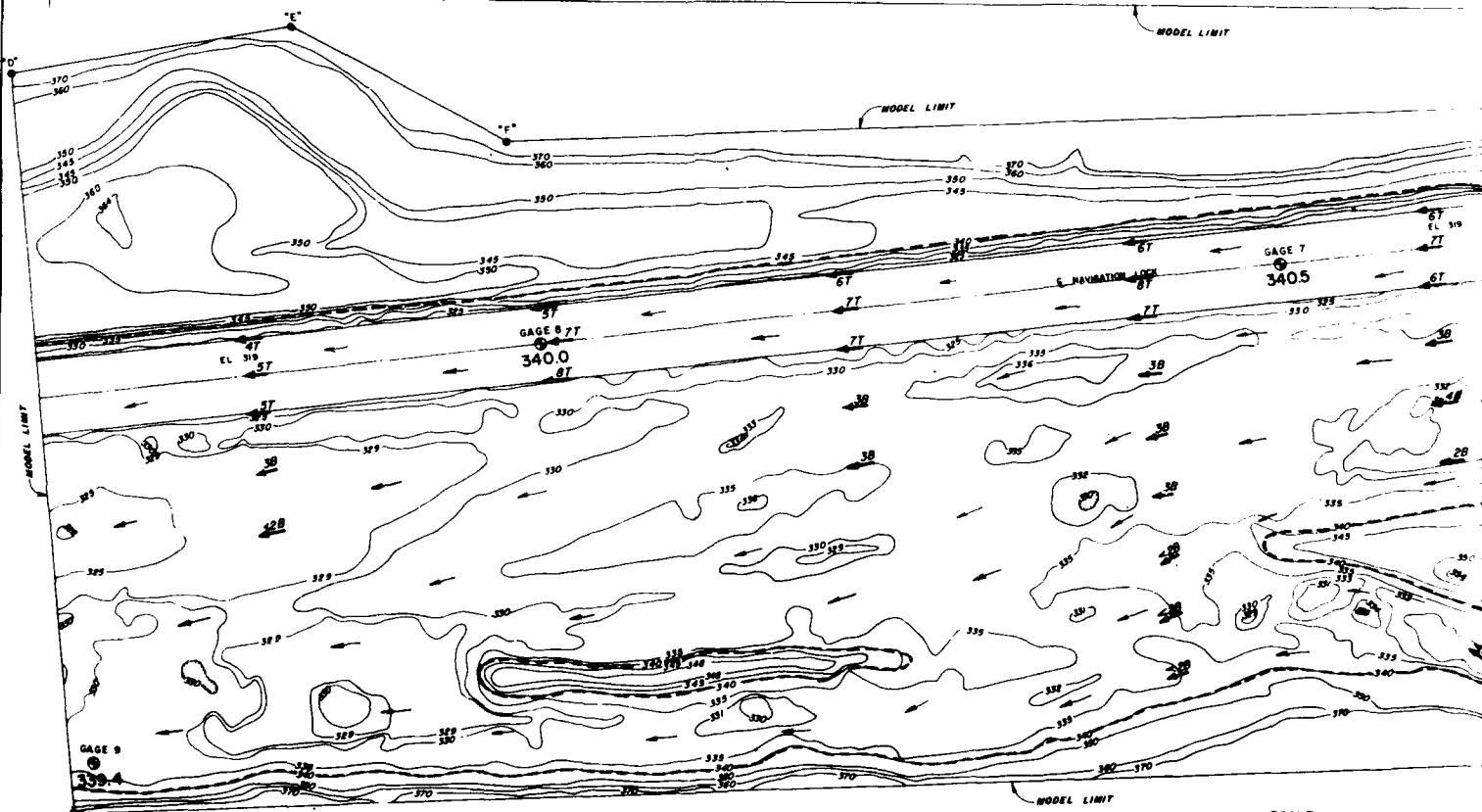
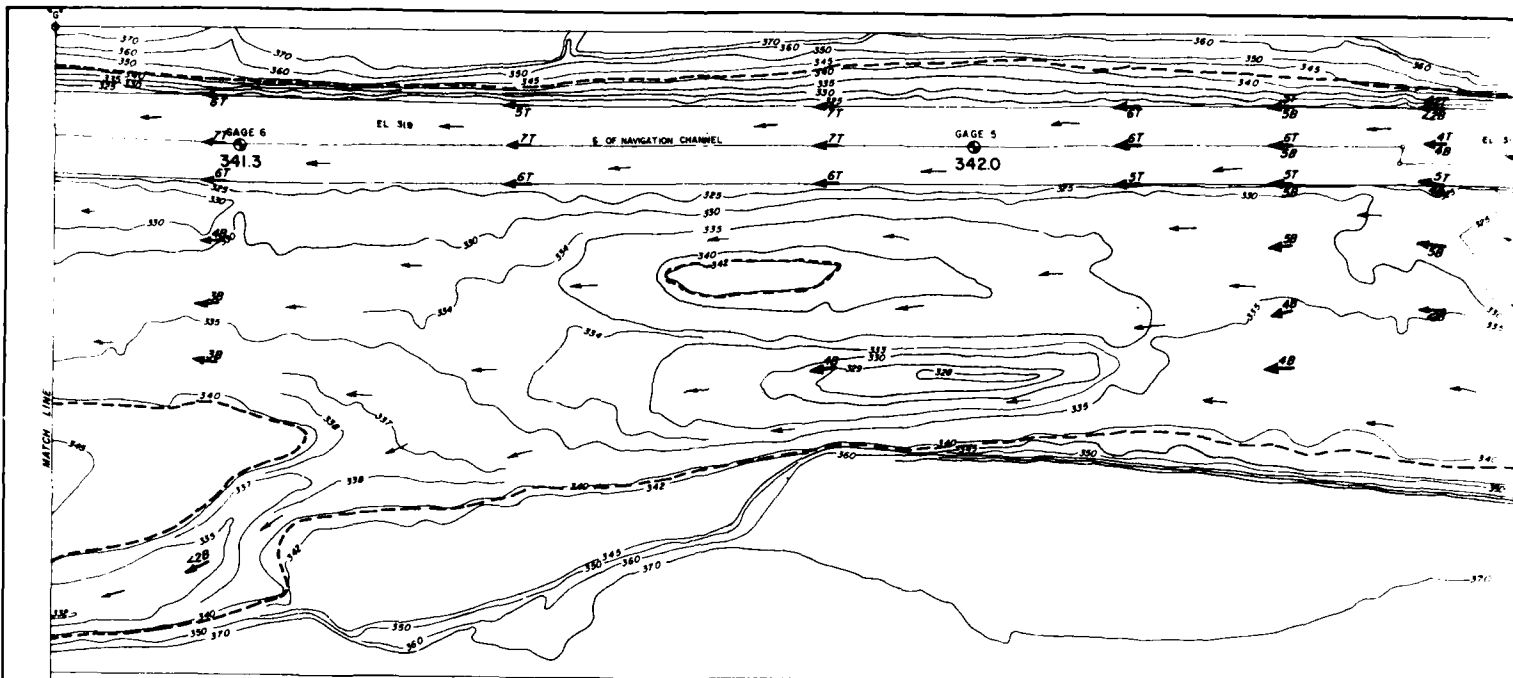
SCALE
 0 200 400



NOTATION
 CLOSED
 10 000 CFS

SCALE
 0 200 400

**FLOW CONDITIONS
 EXISTING CHANNEL**
 RIVER DISCHARGE 10 000 CFS
 McNARY POOL EL 335

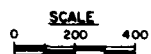


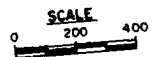
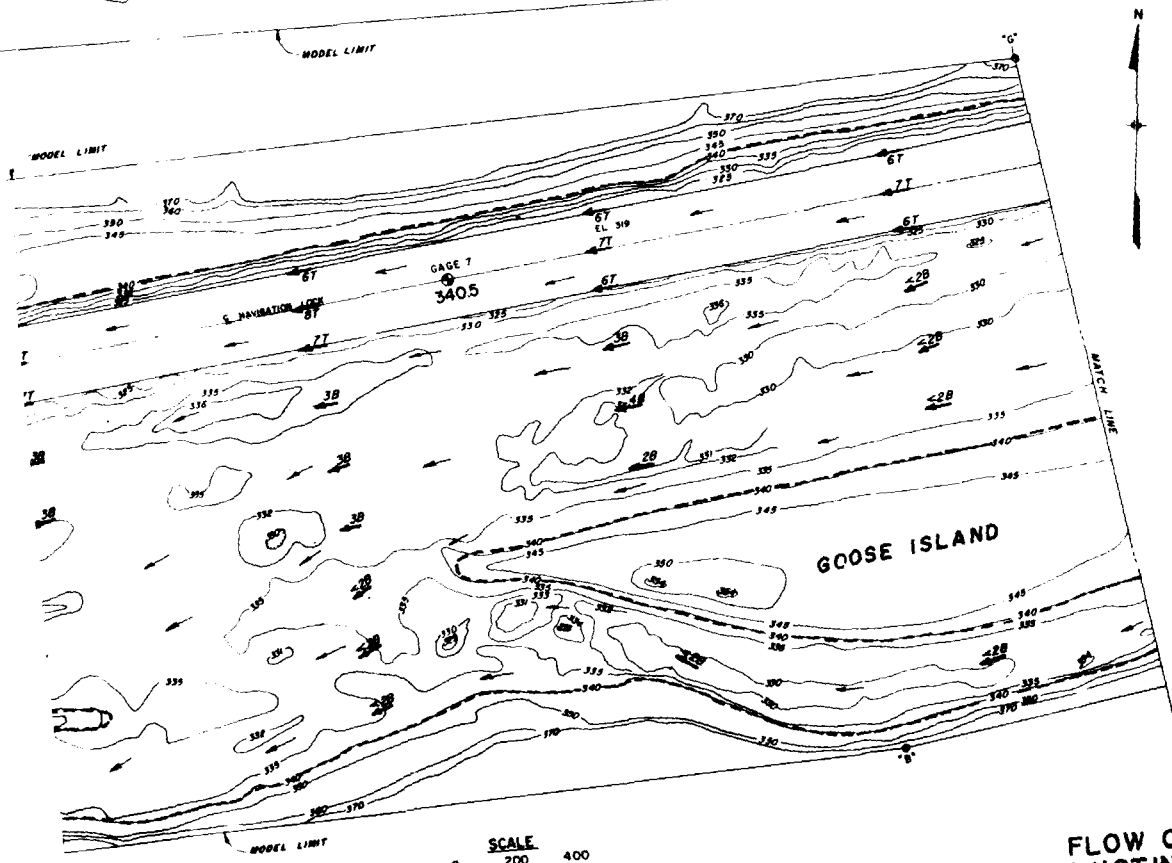
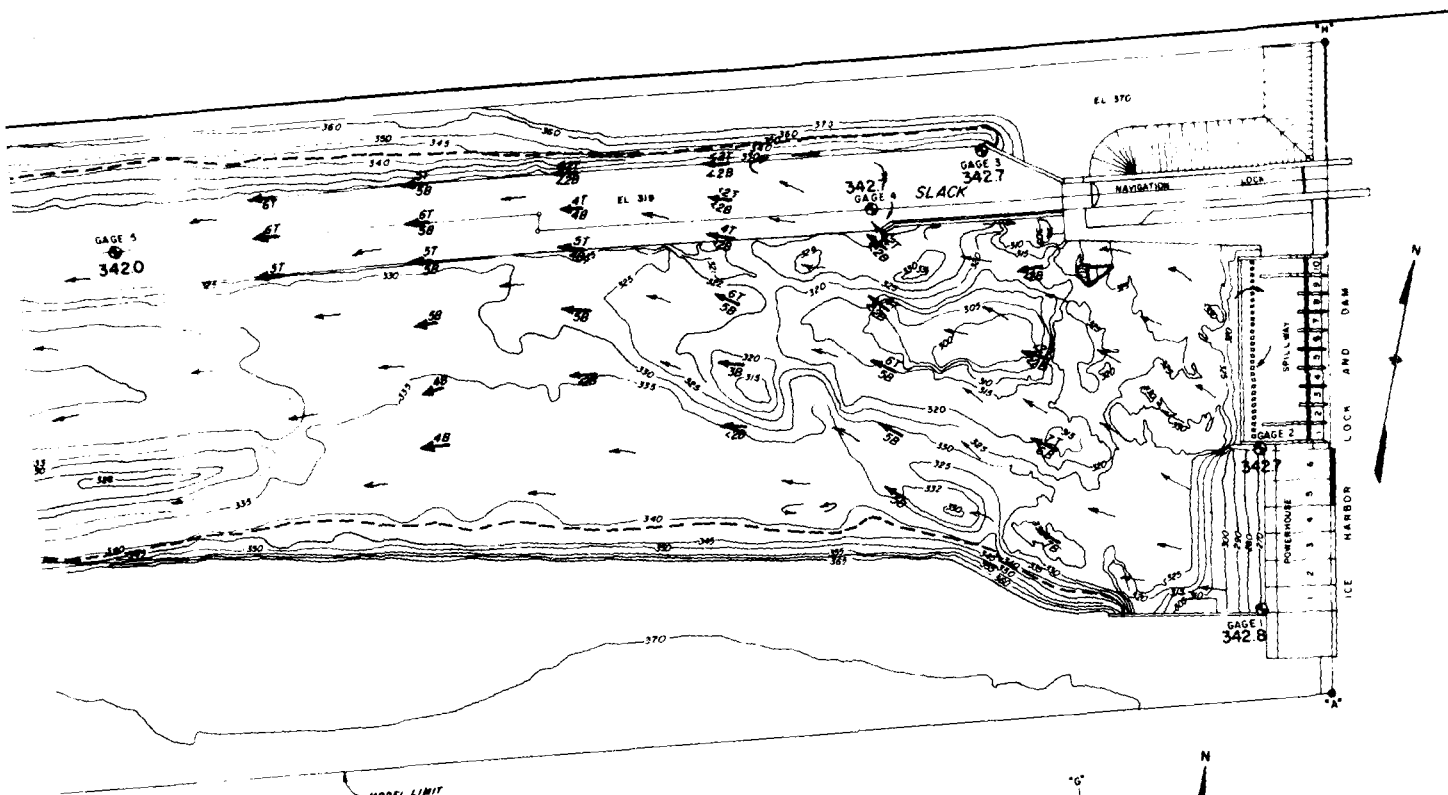
LEGEND

- VELOCITIES MEASURED IN FPS
- T 7-FT DEPTH
- B 5 FT OFF BOTTOM
- FLOW DIRECTION

FLOW DISTRIBUTION

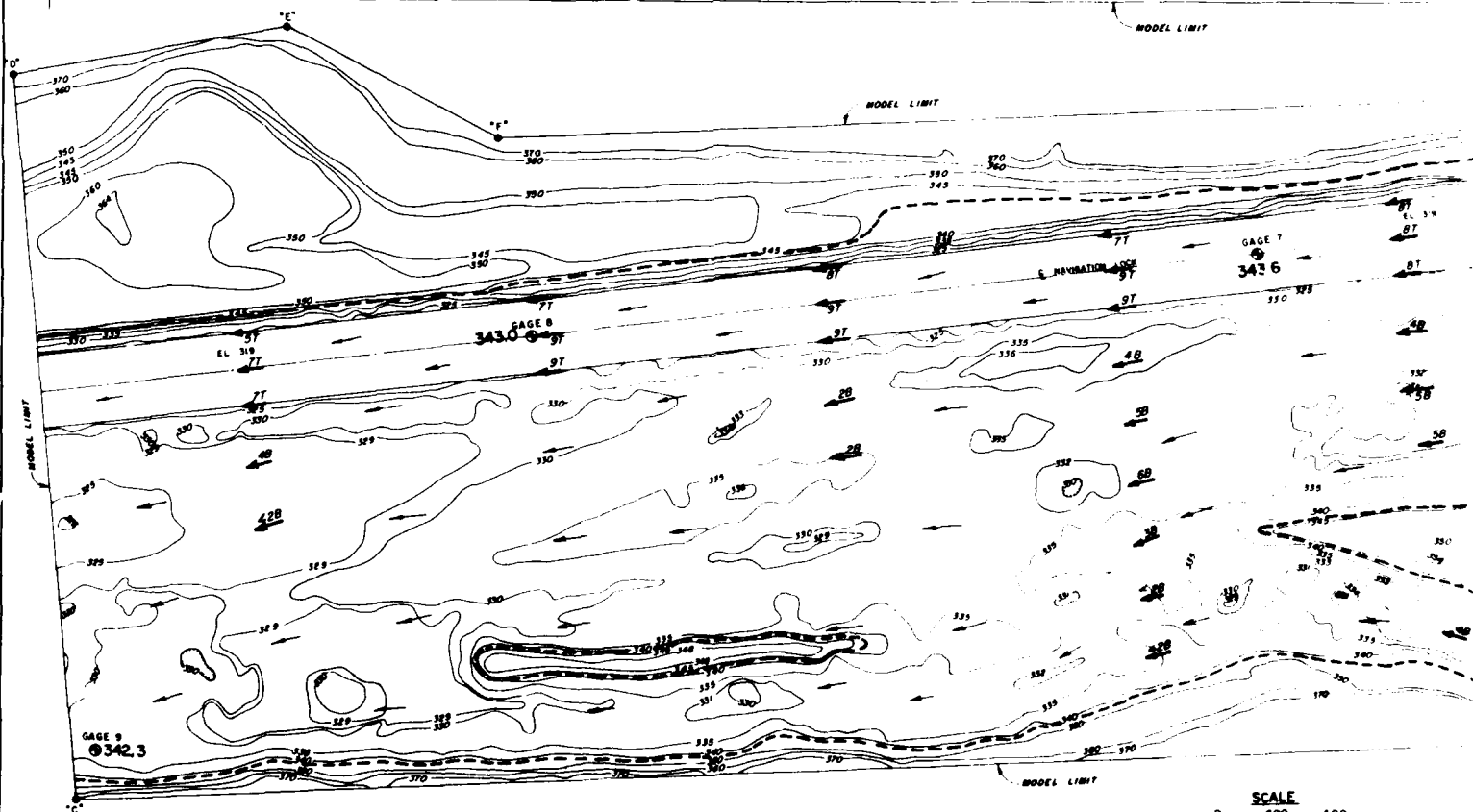
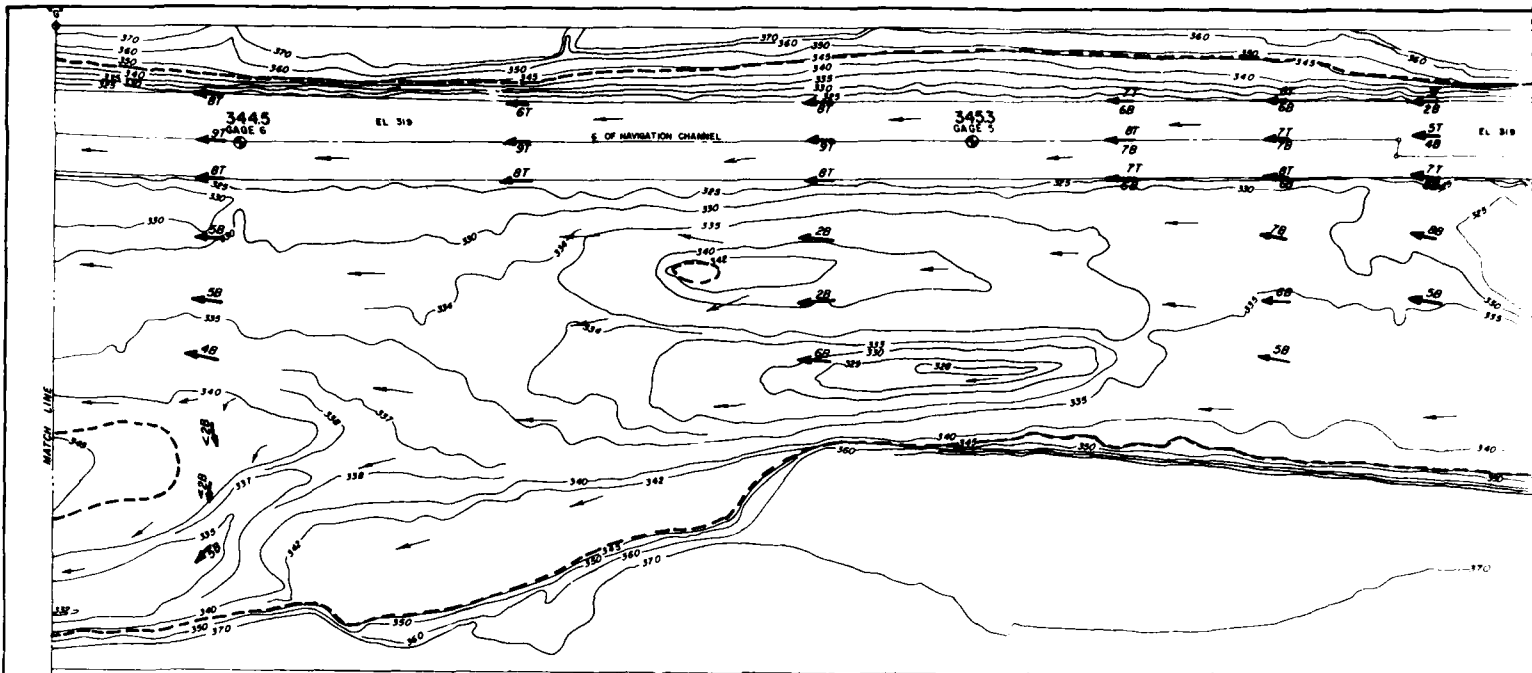
- SPILLWAY BAYS 1 TO 10 CLOSED
- POWERHOUSE UNITS 1 TO 3 42 000 CFS
- POWERHOUSE UNIT 4 18 000 CFS





NOTATION
 CLOSED
 42 000 CFS
 18 000 CFS

**FLOW CONDITIONS
 EXISTING CHANNEL**
 RIVER DISCHARGE 60 000 CFS
 McNARY POOL EL 335

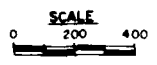


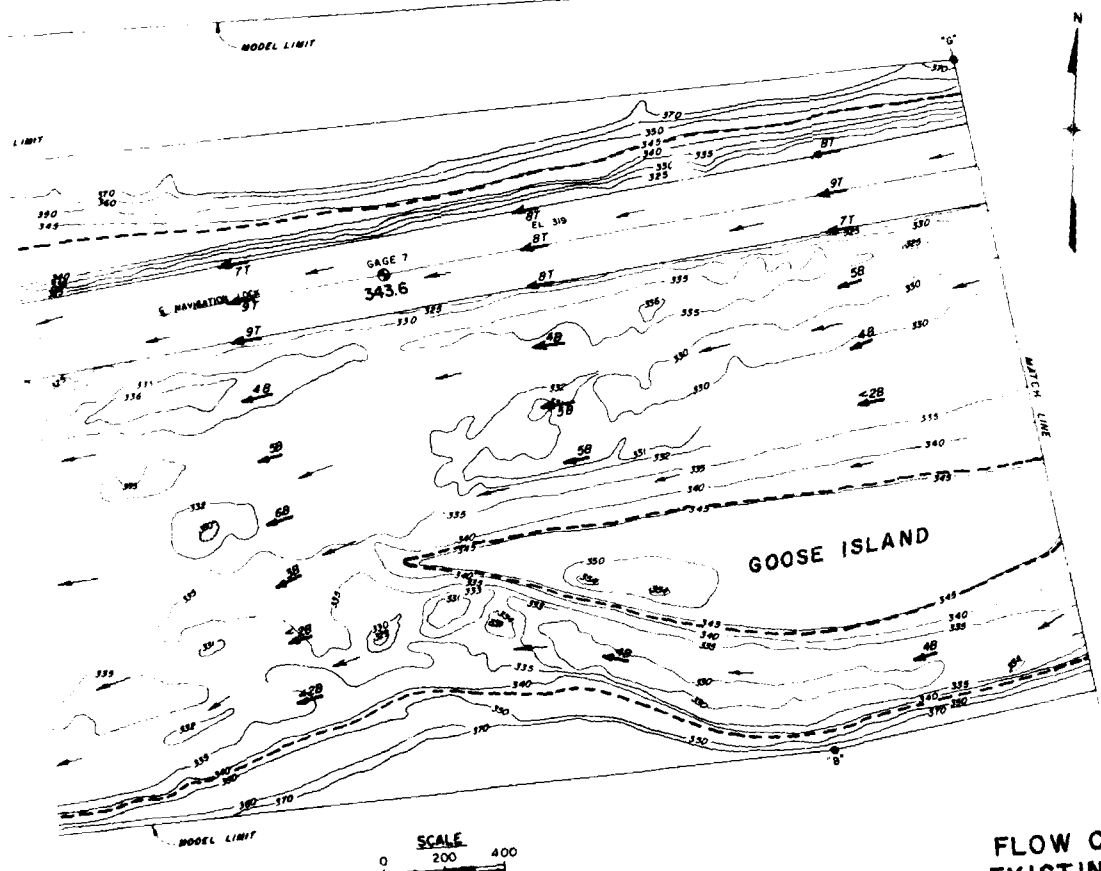
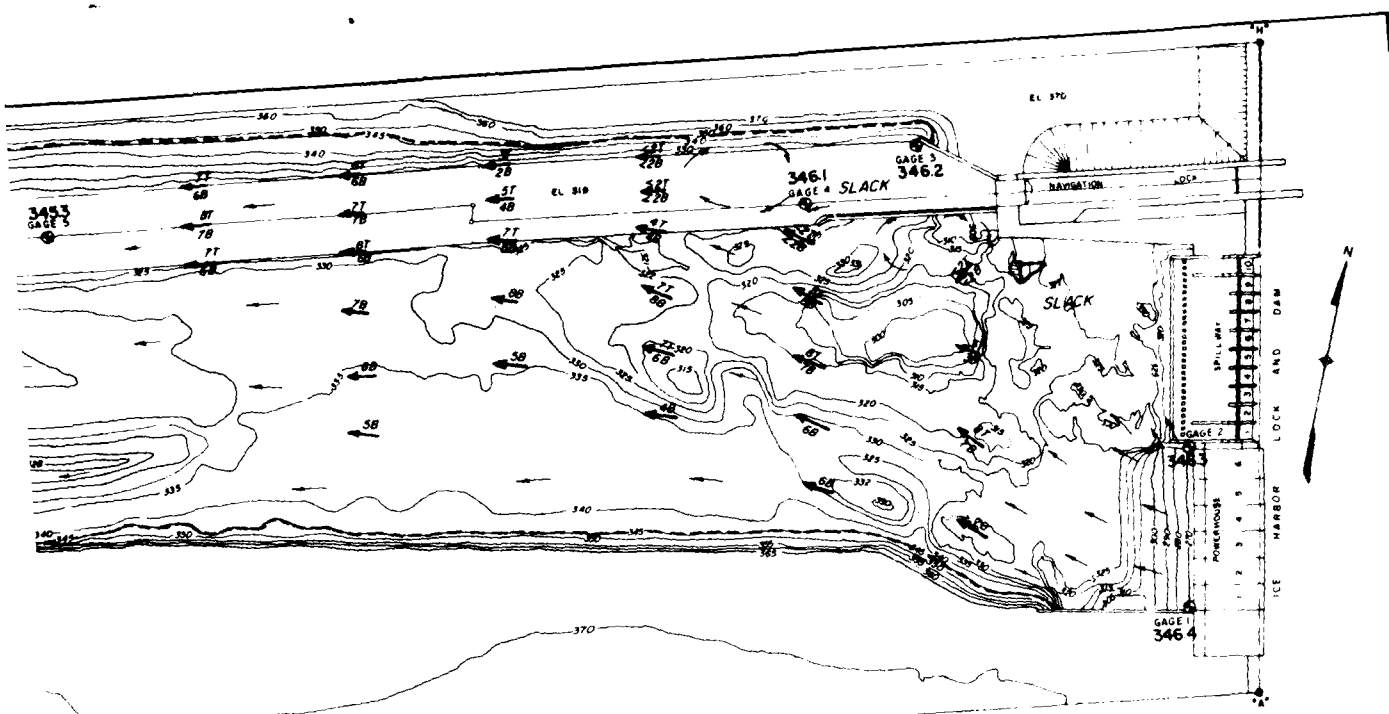
LEGEND

E VELOCITIES MEASURED IN FPS
 T 7-FT DEPTH
 B 5 FT OFF BOTTOM
 — FLOW DIRECTION

FLOW DISTRIBUTION

SPILLWAY BAYS 1 TO 10	CLOSED
POWERHOUSE UNITS 1 TO 3	43 300 CFS
POWERHOUSE UNITS 4 TO 6	56 700 CFS



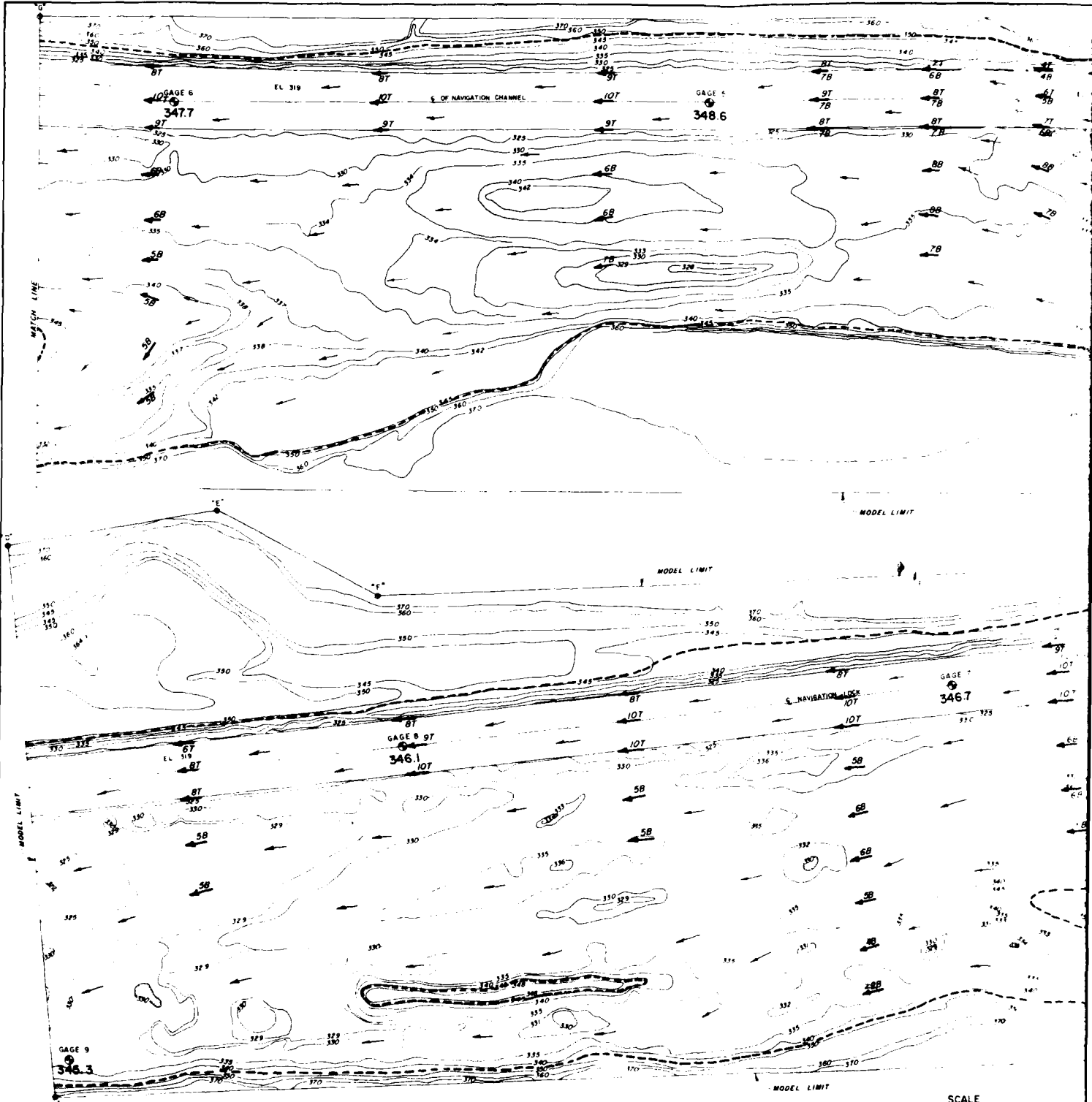


SCALE
0 200 400

CLOSED
300 CFS
700 CFS

FLOW CONDITIONS
EXISTING CHANNEL
RIVER DISCHARGE 100 000 CFS
MCNARY POOL EL 335

PLATE 6

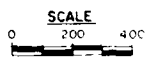


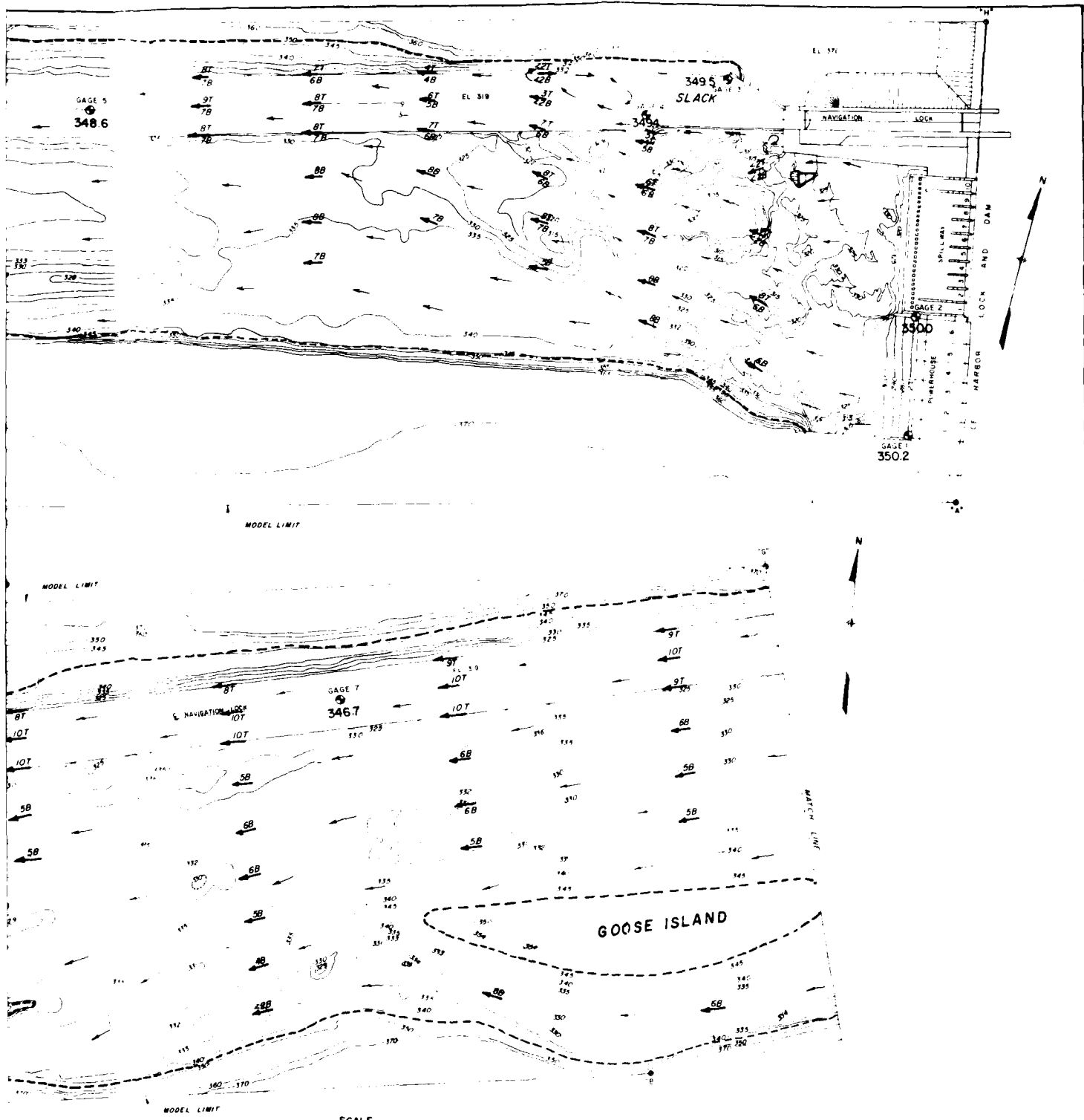
LEGEND

- \leftarrow VELOCITIES MEASURED IN FPS
- T 7-FT DEPTH
- B 5 FT OFF BOTTOM
- \rightarrow FLOW DIRECTION

FLOW DISTRIBUTION

- SPILLWAY BAYS 1 TO 10 50 000 CFS
- POWERHOUSE UNITS 1 TO 3 43 300 CFS
- POWERHOUSE UNITS 4 TO 6 56 700 CFS





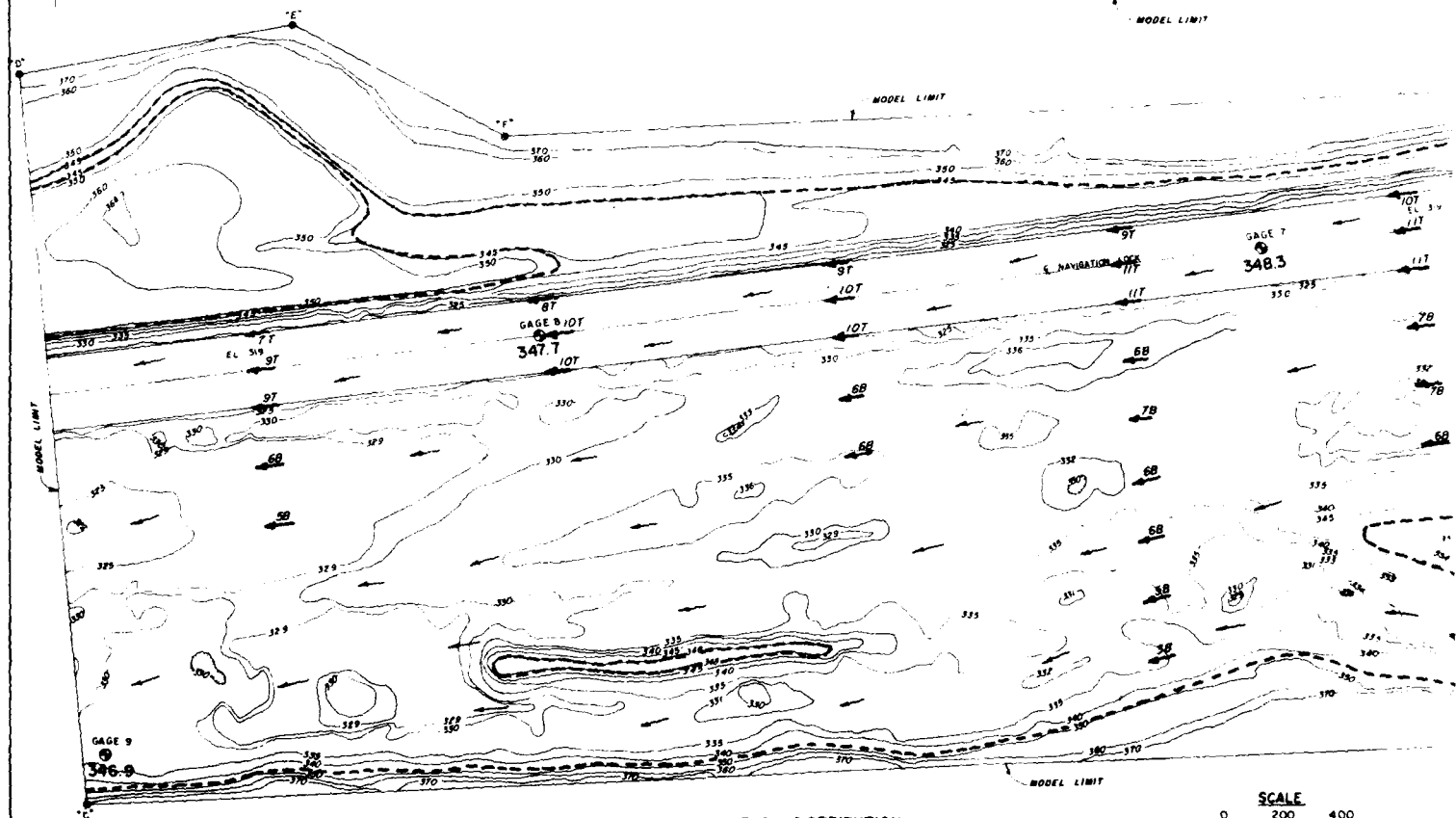
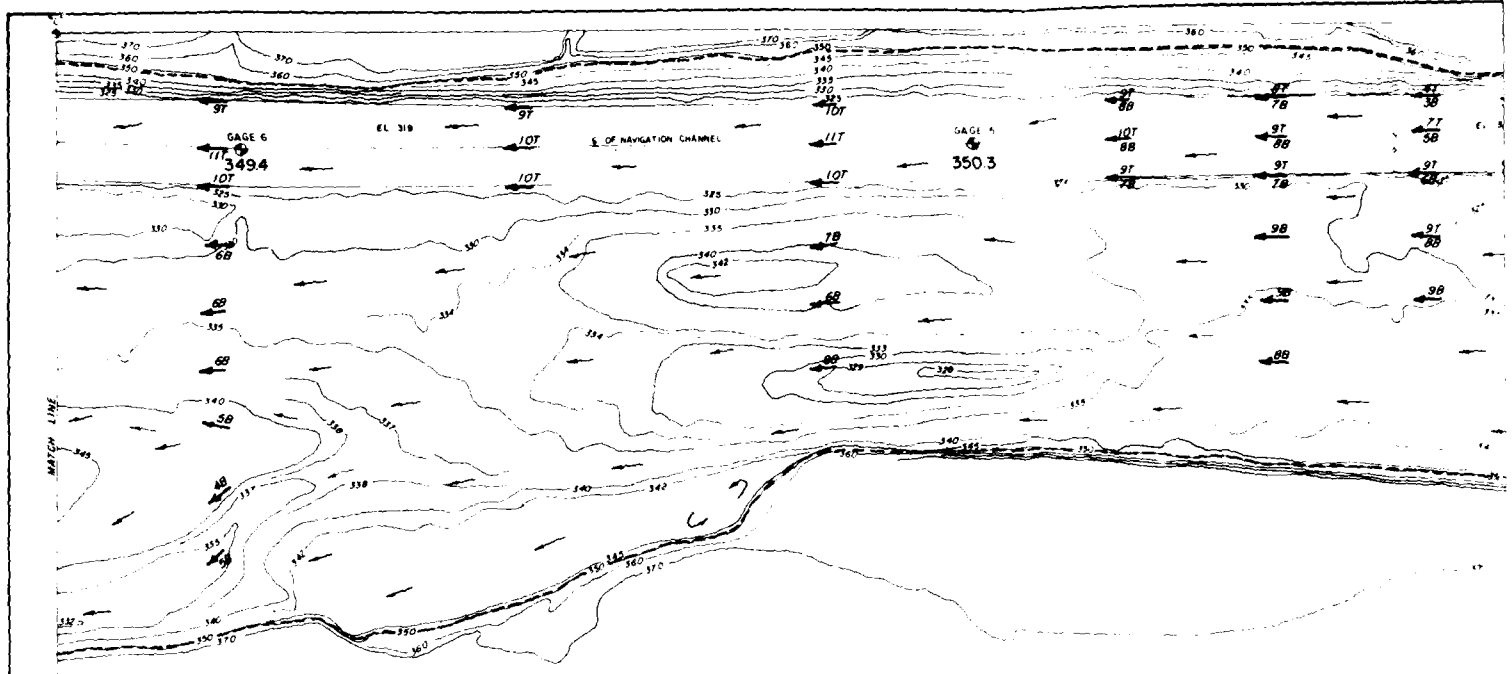
DISTRIBUTION

50 000 CFS
43 300 CFS
58 700 CFS



**FLOW CONDITIONS
EXISTING CHANNEL**

RIVER DISCHARGE 150 000 CFS
McNARY POOL EL 335

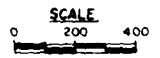


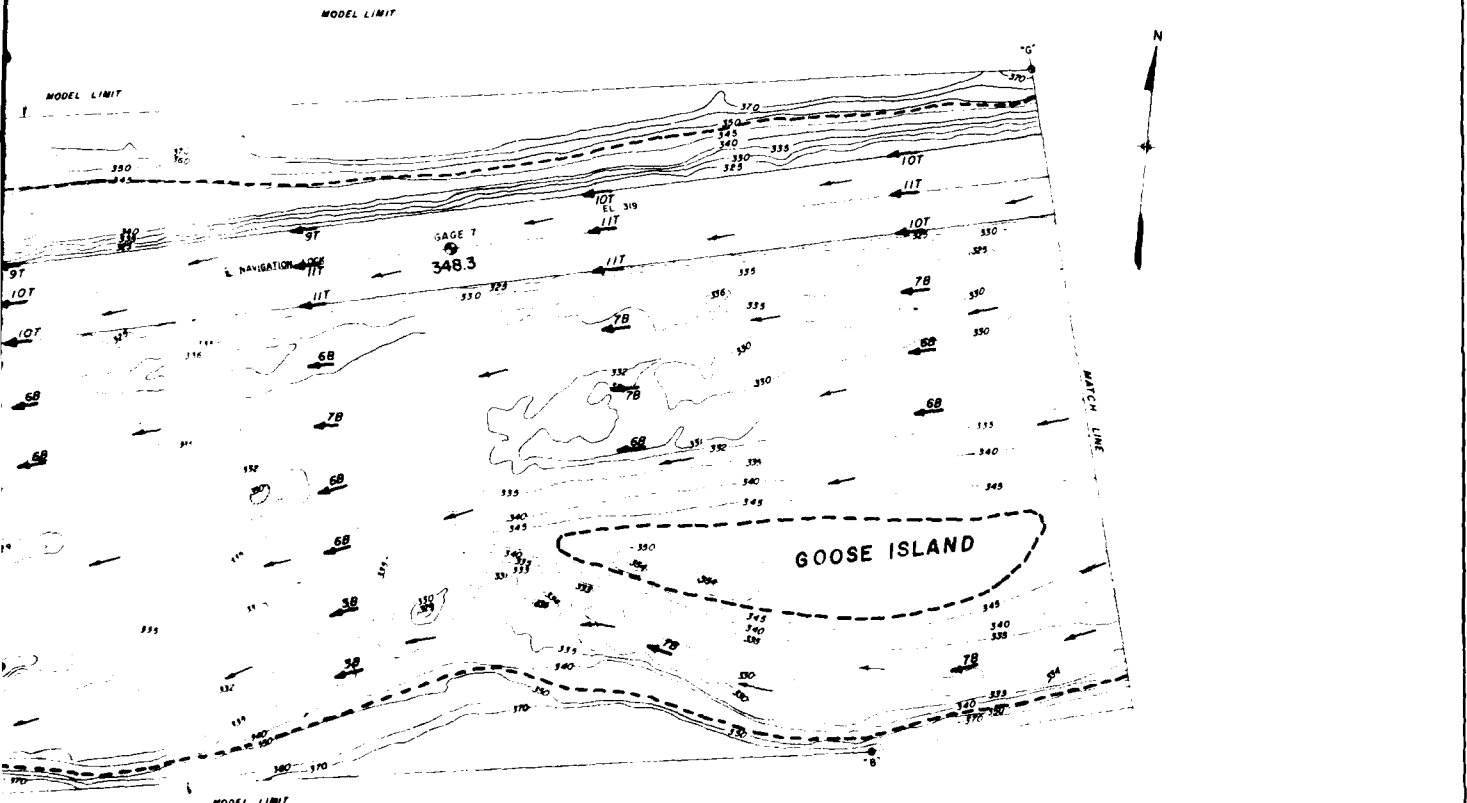
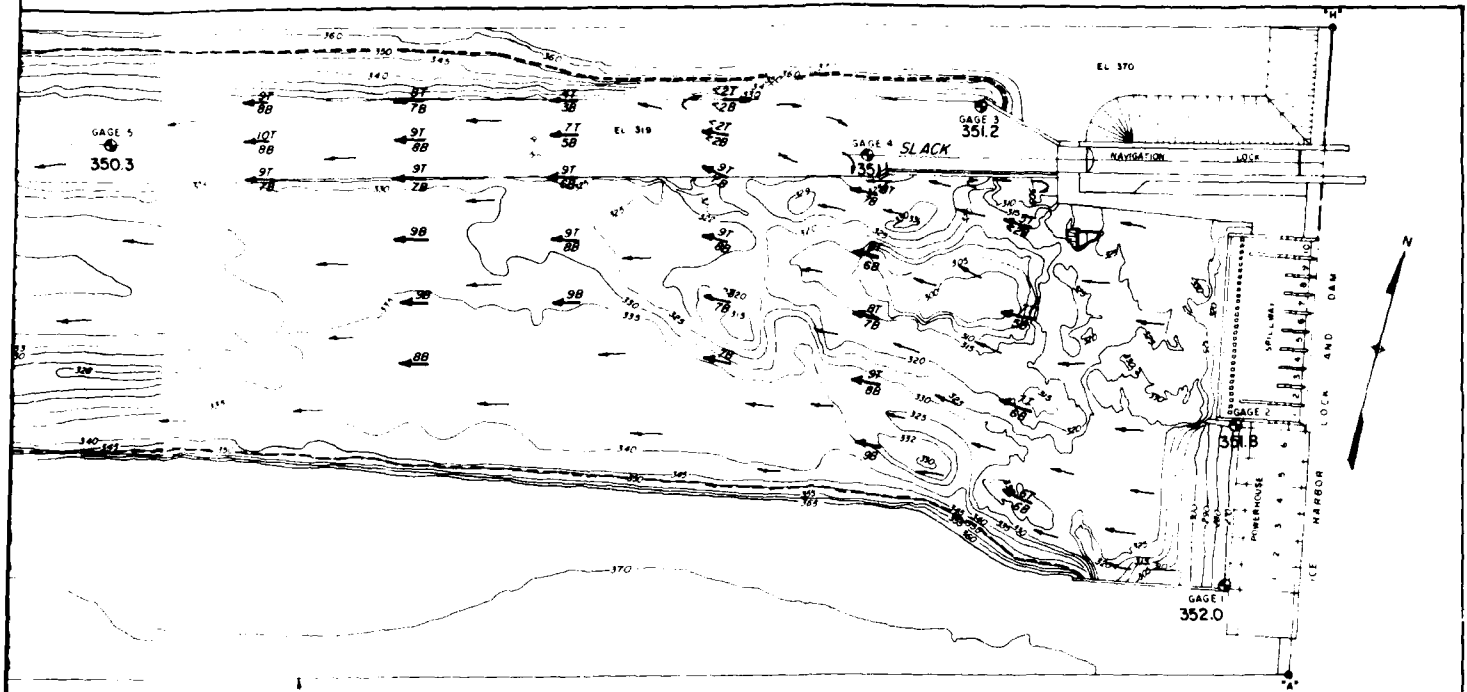
LEGEND

- C VELOCITIES MEASURED IN FPS
- T 7-FT DEPTH
- B 5 FT OFF BOTTOM
- FLOW DIRECTION

FLOW DISTRIBUTION

SPILLWAY BAYS 1 TO 10	79 500 CFS
POWERHOUSE UNITS 1 TO 3	44 400 CFS
POWERHOUSE UNITS 4 TO 6	56 100 CFS



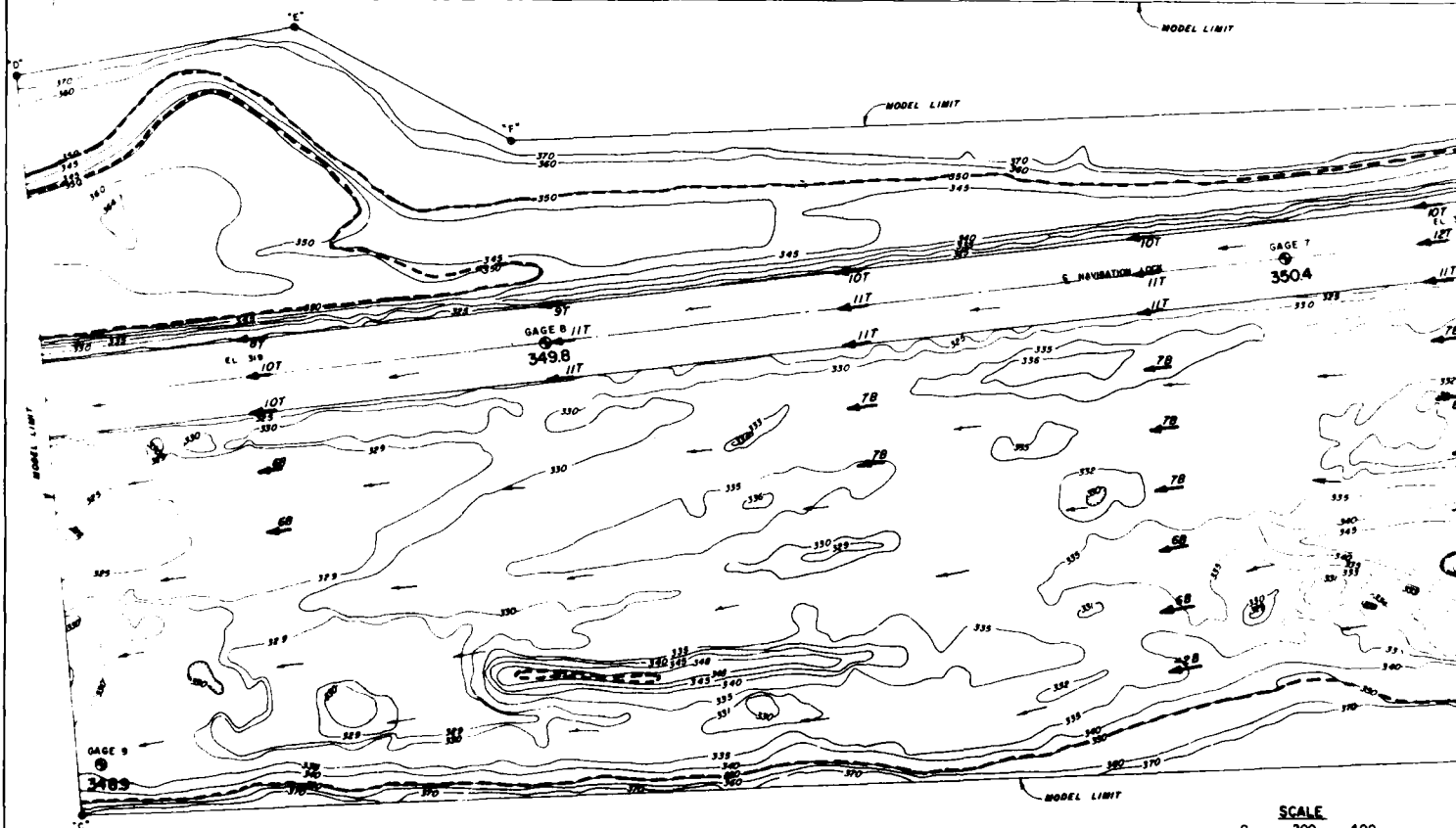
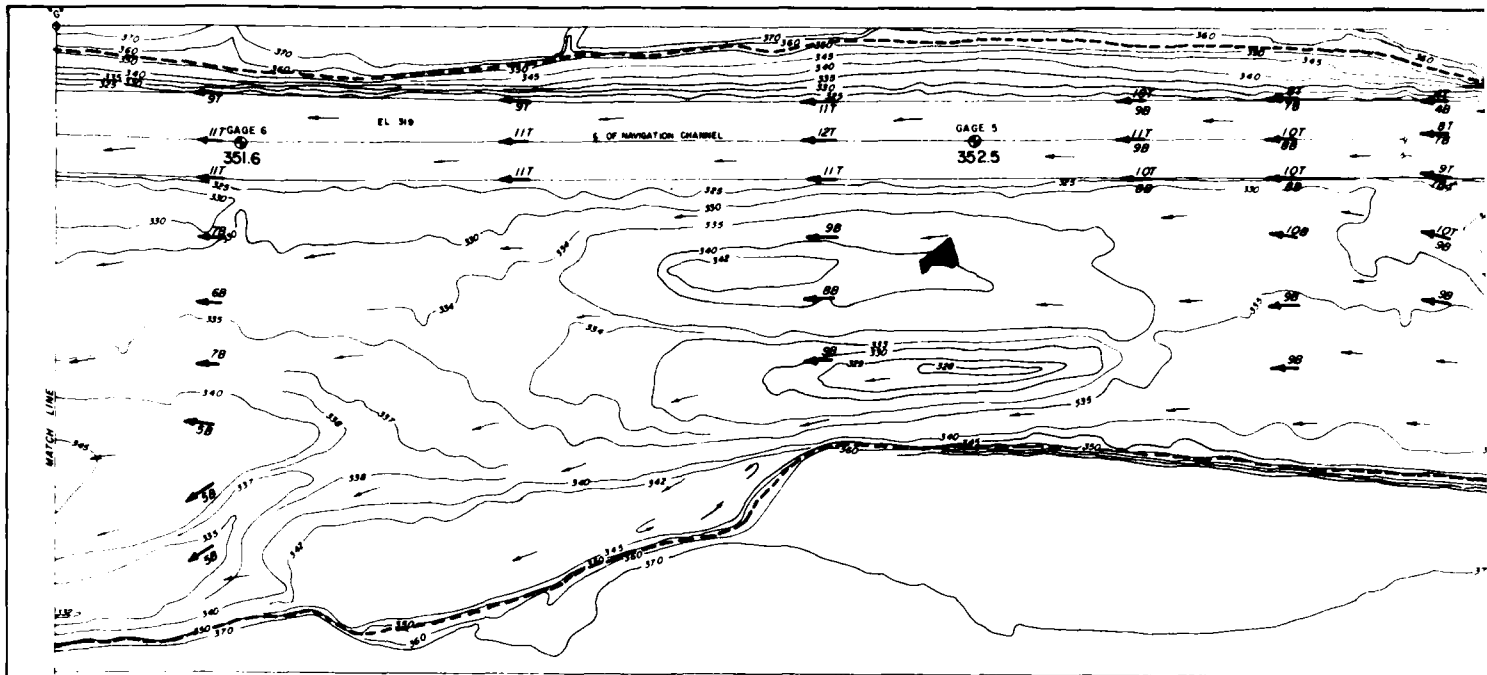


DISTRIBUTION

D 3	79 500 CFS
D 5	44 400 CFS
D 6	56 100 CFS



**FLOW CONDITIONS
EXISTING CHANNEL**
RIVER DISCHARGE 180 000 CFS
McNARY POOL EL 335

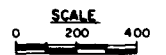


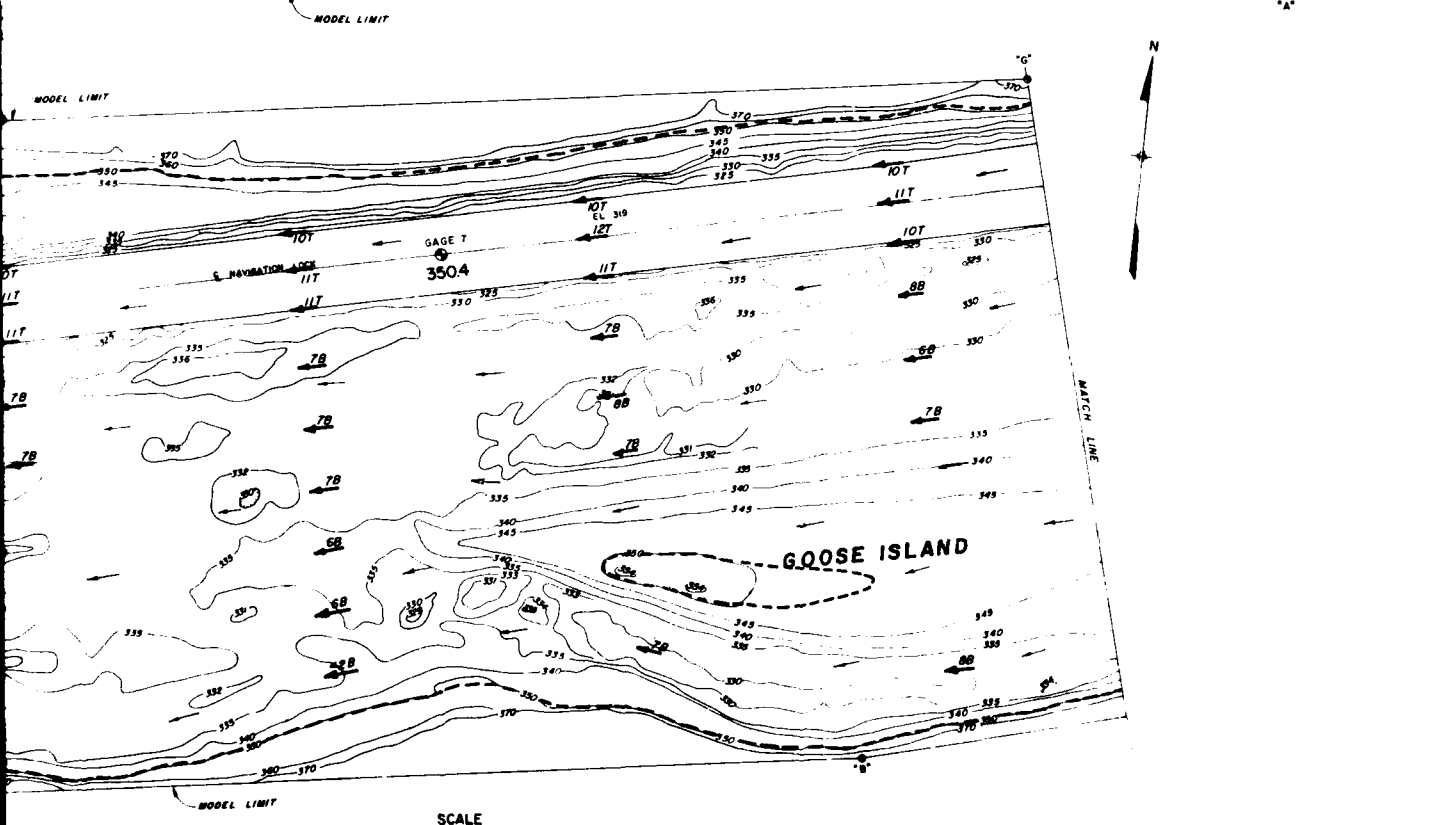
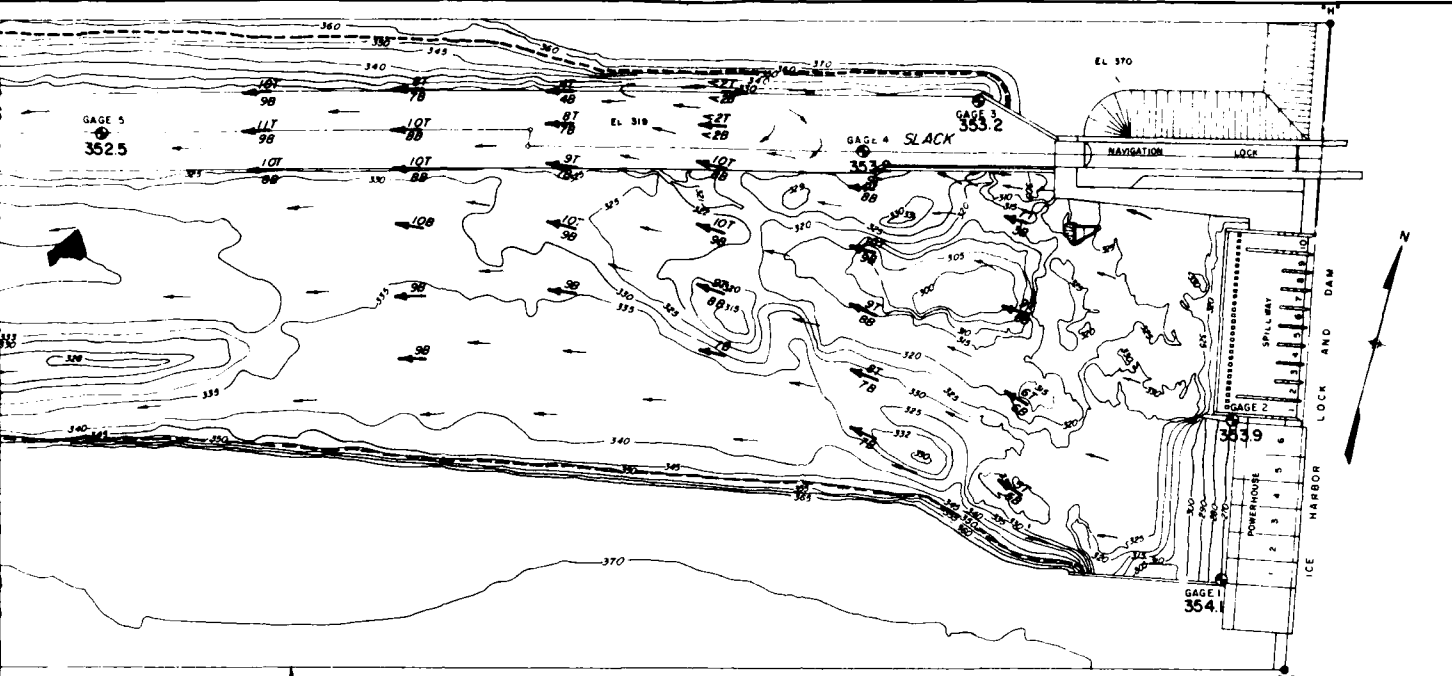
LEGEND

- ← S VELOCITIES MEASURED IN FPS
- T 7-FT DEPTH
- B 5 FT OFF BOTTOM
- ← FLOW DIRECTION

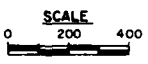
FLOW DISTRIBUTION

- SPILLWAY BAYS 1 TO 10 119 200 CFS
- POWERHOUSE UNITS 1 TO 3 45 300 CFS
- POWERHOUSE UNITS 4 TO 6 55 500 CFS

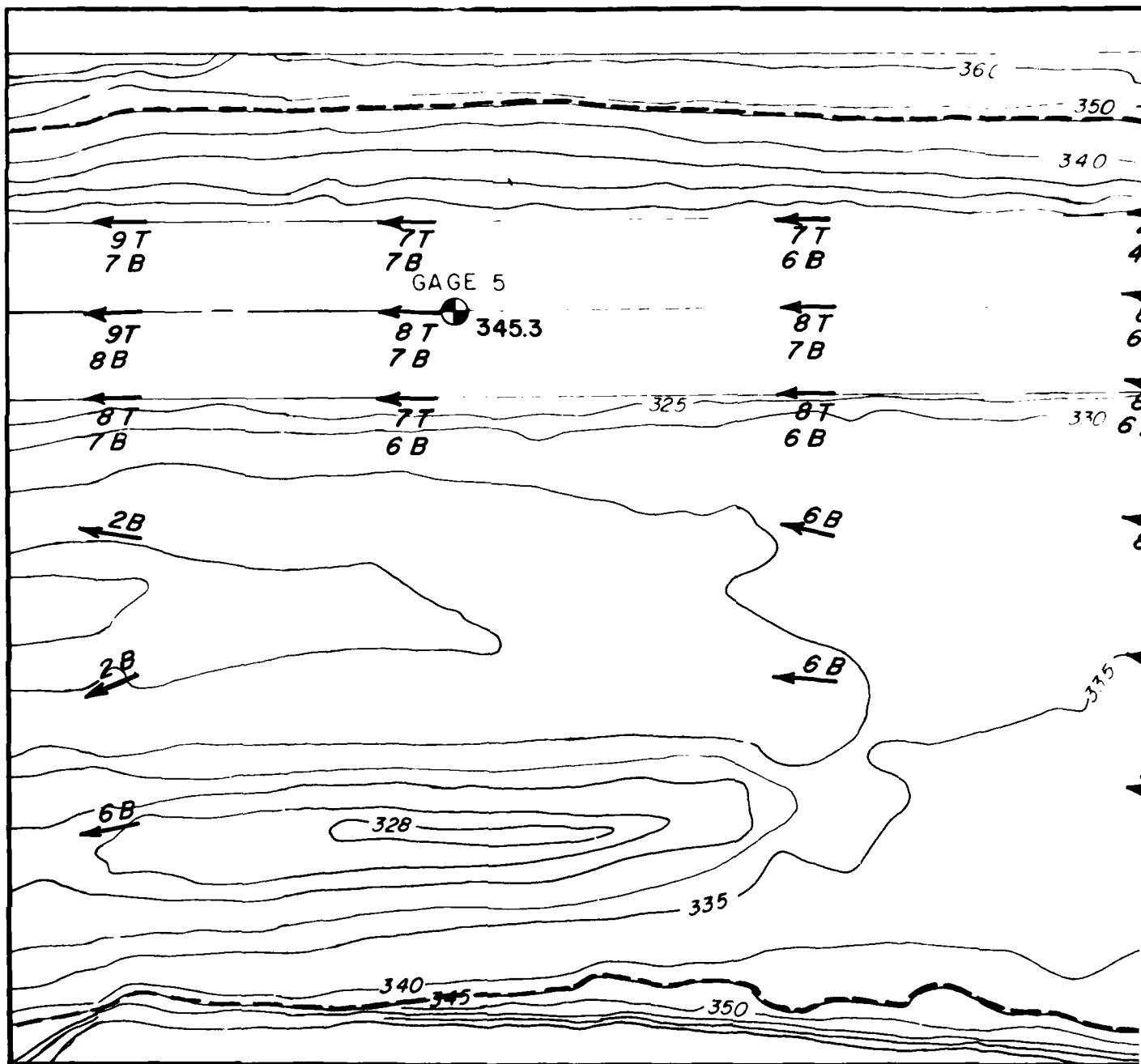




119 200 CFS
 49 300 CFS
 55 500 CFS

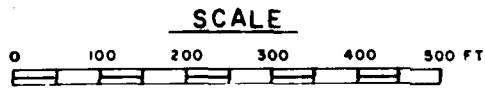
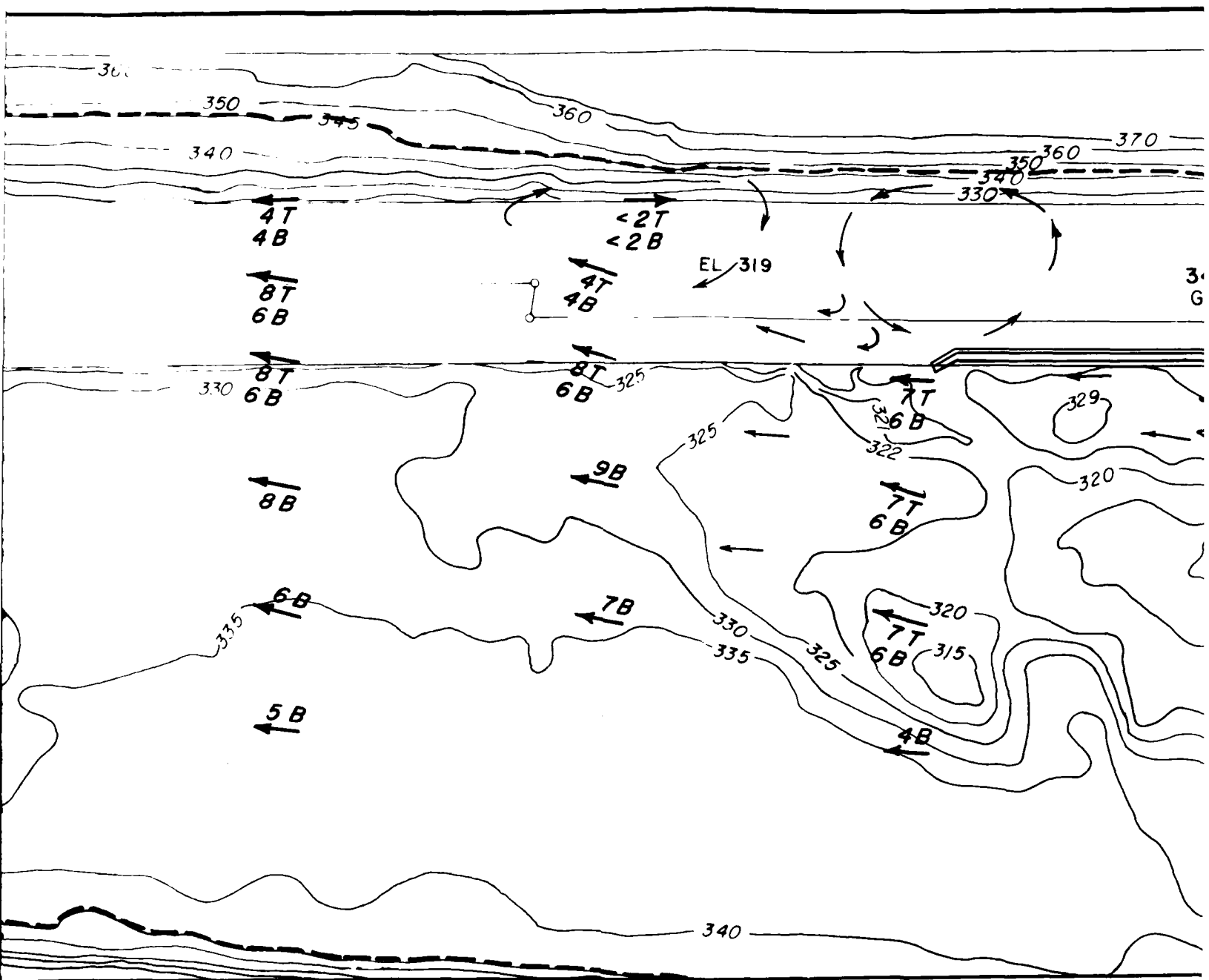


**FLOW CONDITIONS
 EXISTING CHANNEL**
 RIVER DISCHARGE 220 000 CFS
 McNARY POOL EL 335



LEGEND

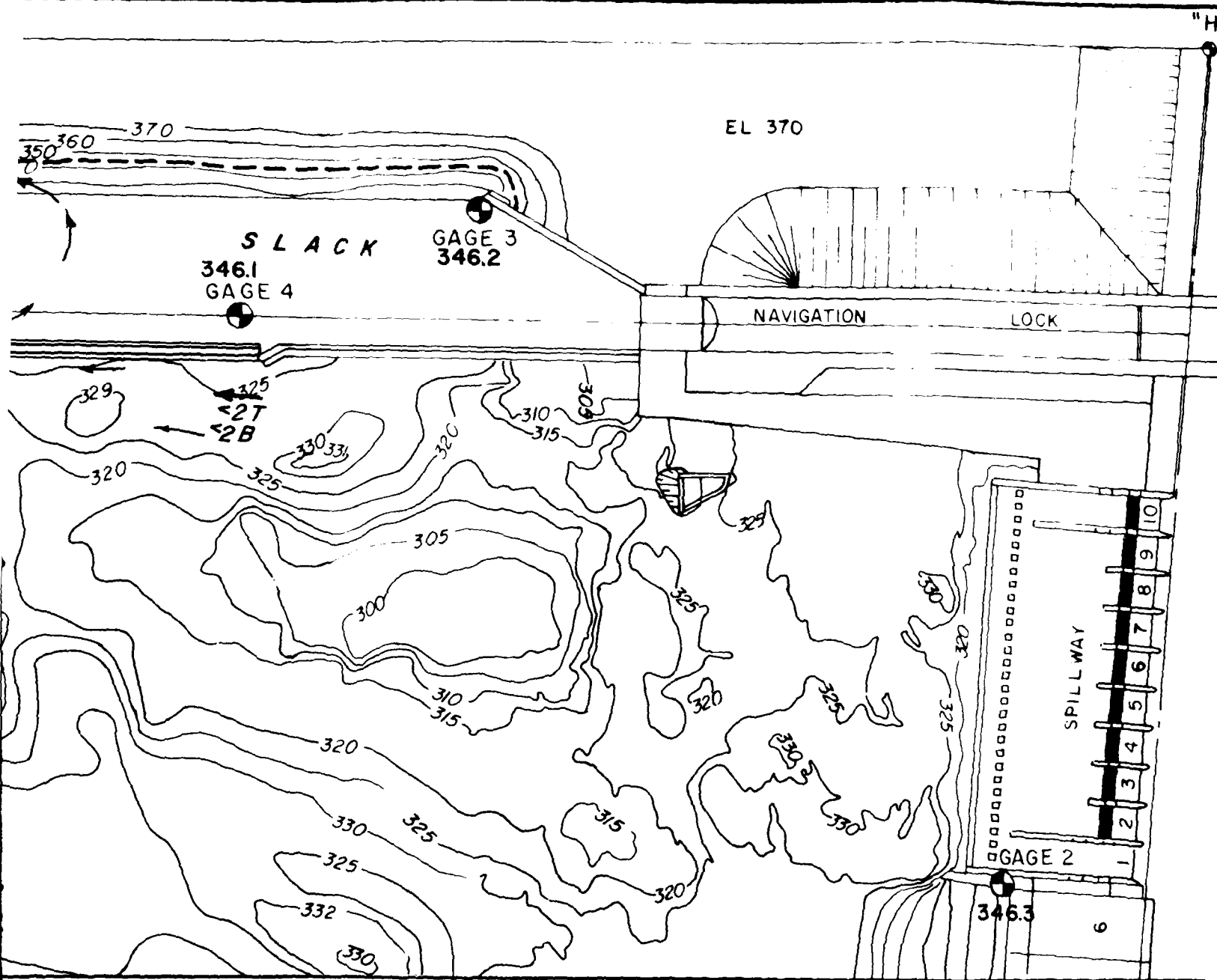
- 4** VELOCITIES IN FPS
- T** 5-FT DEPTH
- B** 5 FT ABOVE BOTTOM



FLOW DISTRI

- SPILLWAY BAYS 1 TO 10
- POWERHOUSE UNITS 1 TO 3
- POWERHOUSE UNITS 4 TO 6

2



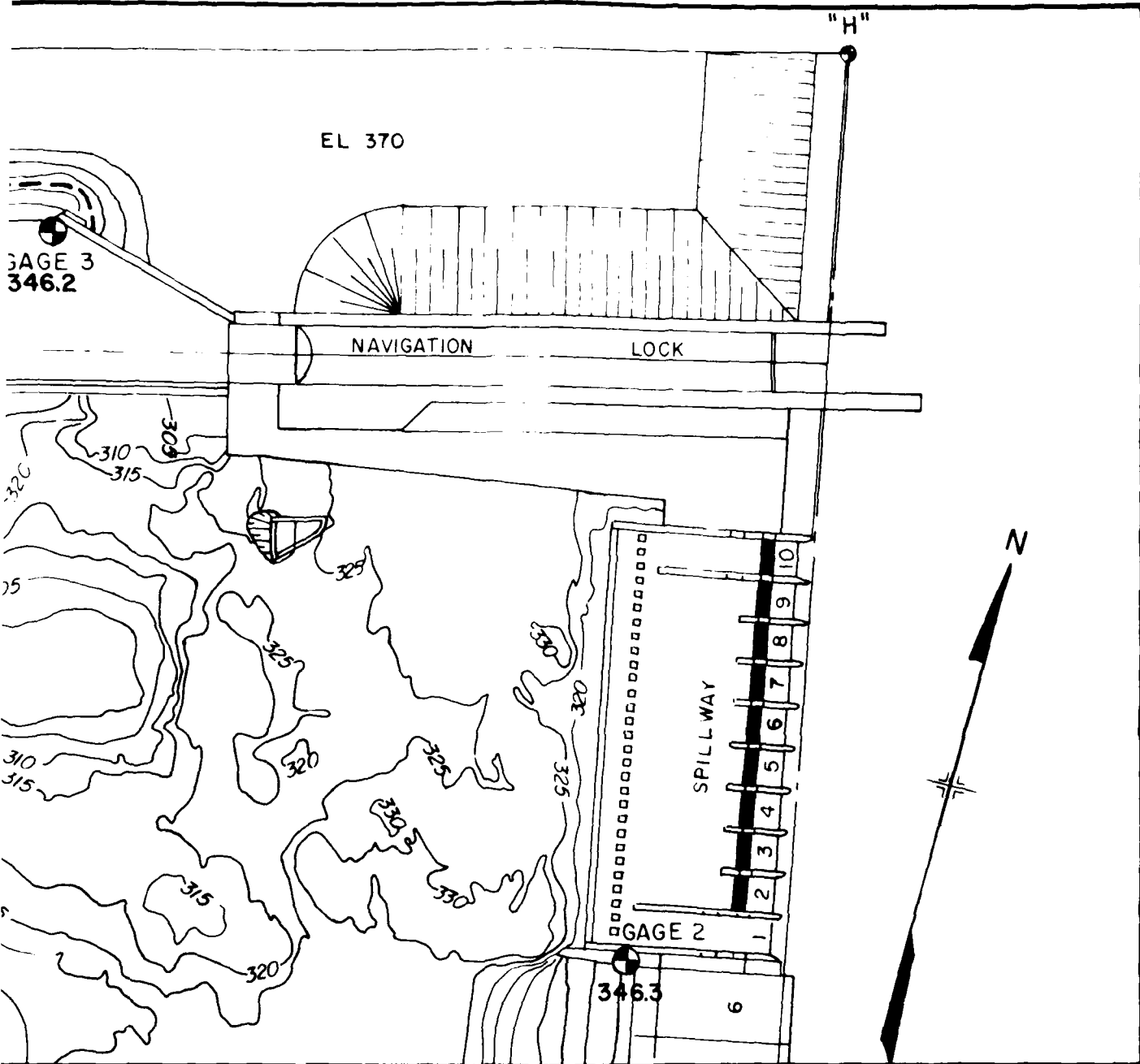
FLOW DISTRIBUTION

500-FT W

BAYS 1 TO 10	CLOSED
DUSE UNITS 1 TO 3	43 300 CFS
DUSE UNITS 4 TO 6	56 700 CFS

FLOW ()
 RIVER DISCHA
 McNARY ()

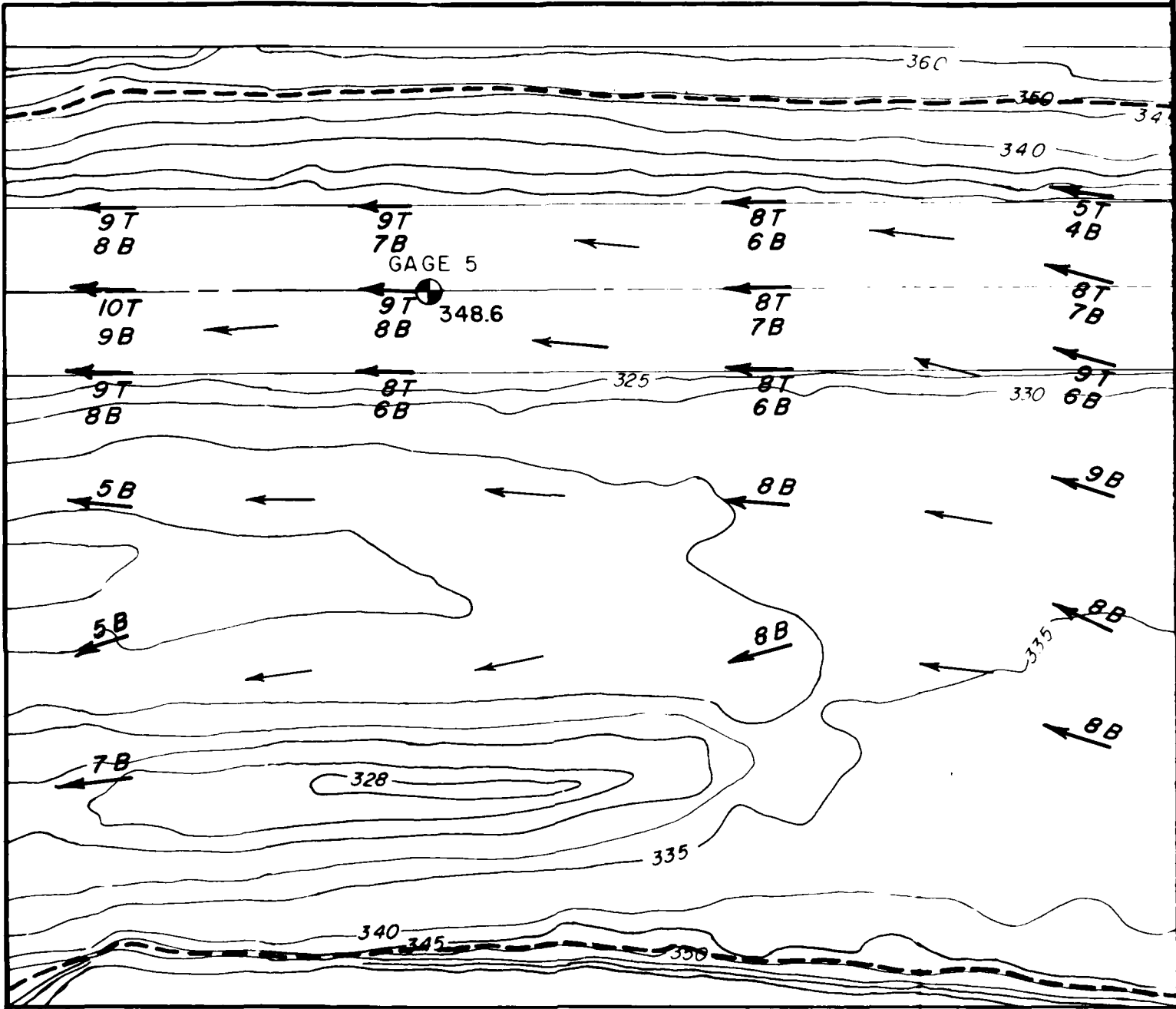
3



500-FT WALL EXTENSION

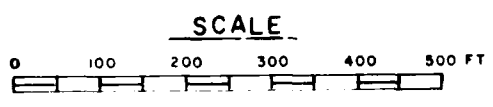
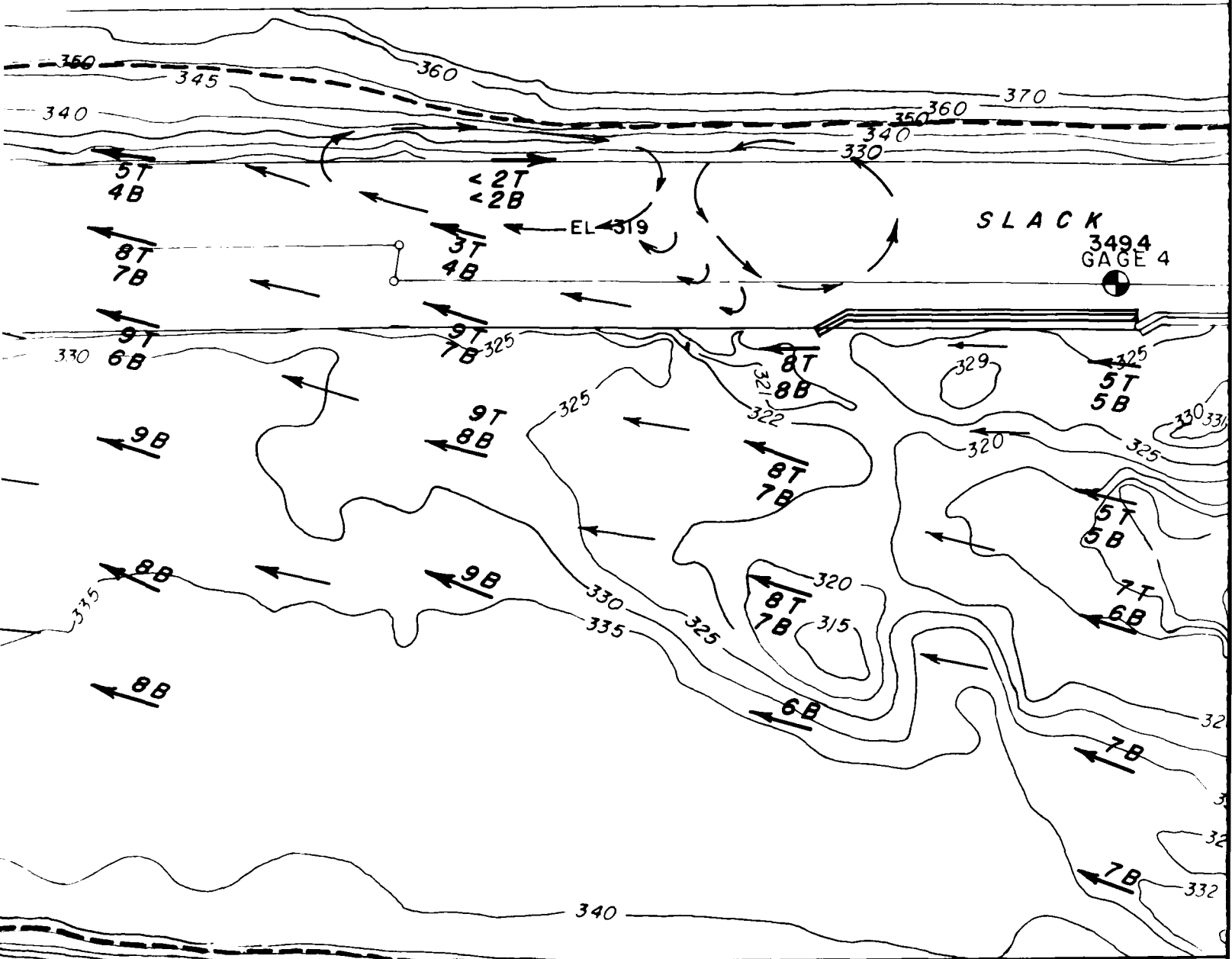
FLOW CONDITIONS
 RIVER DISCHARGE 100 000 CFS
 McNARY POOL EL 335

4



LEGEND

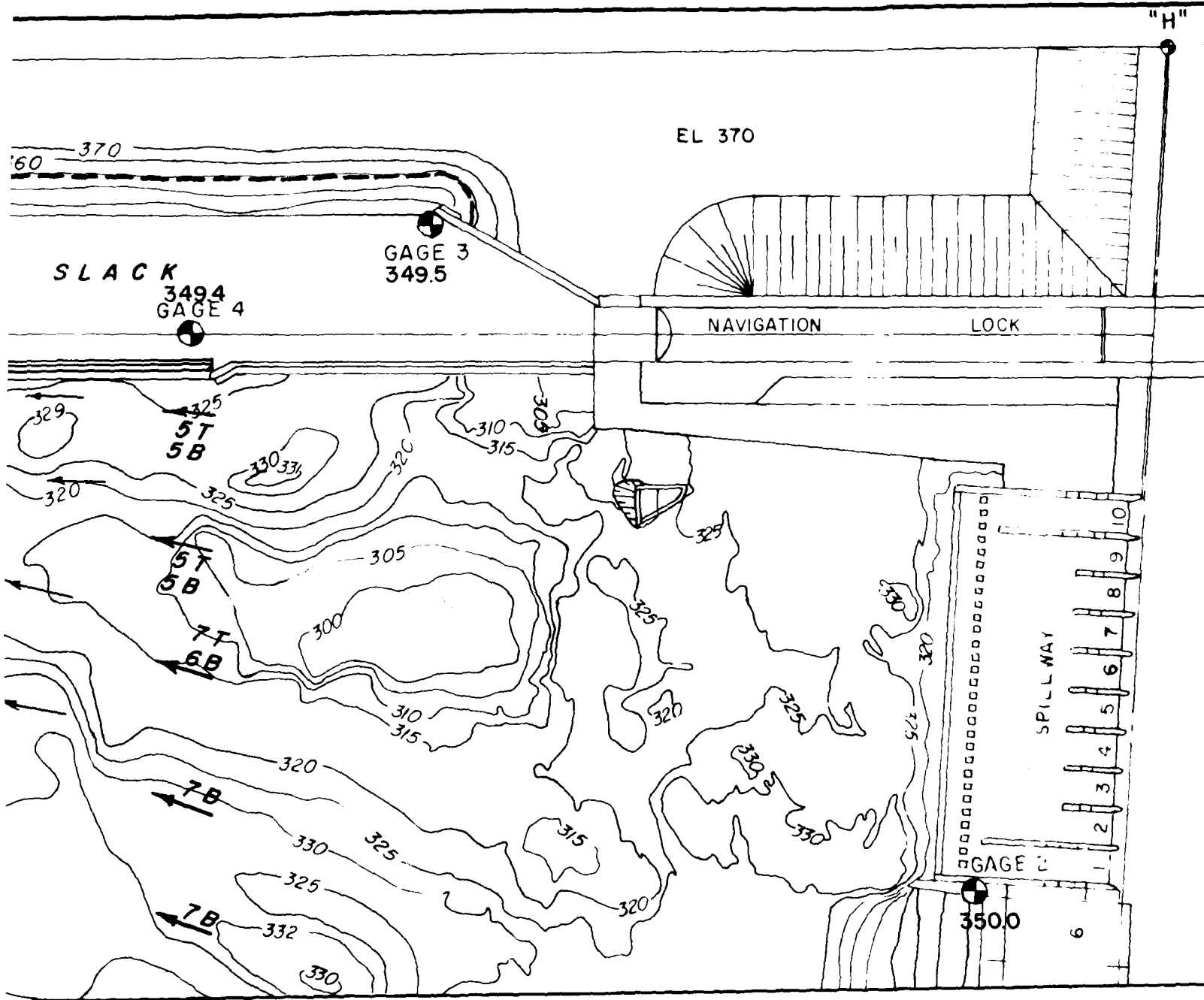
- 4** VELOCITIES IN FPS
- T** 5-FT DEPTH
- B** 5 FT ABOVE BOTTOM



FLOW DISTRIBUTION

SPILLWAY BAYS 1 TO 10	50 000
POWERHOUSE UNITS 1 TO 3	43 300
POWERHOUSE UNITS 4 TO 6	56 700

2



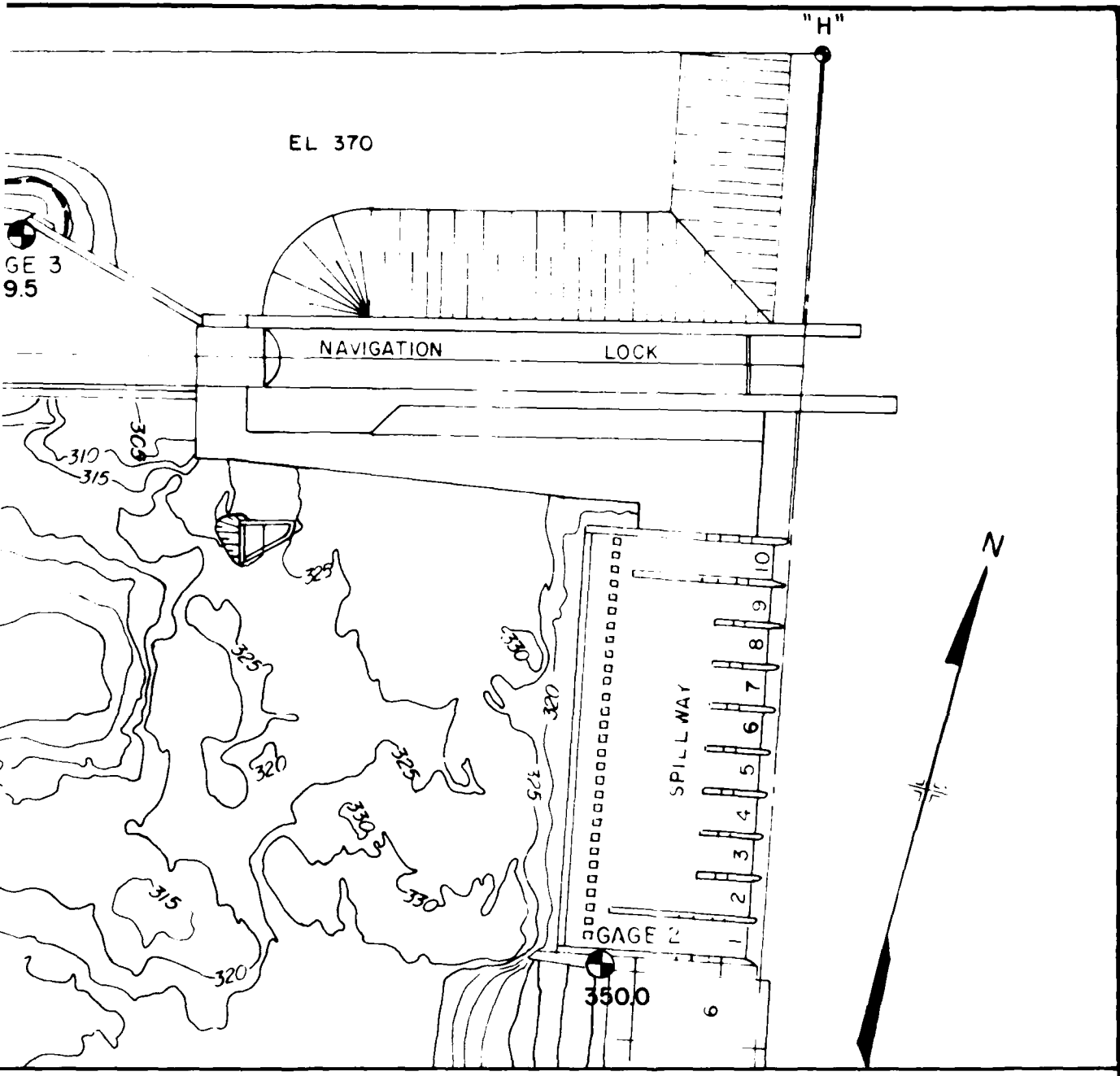
FLOW DISTRIBUTION

YS 1 TO 10	50 000	CFS
UNITS 1 TO 3	43 300	CFS
UNITS 4 TO 6	56 700	CFS

500-FT WAL

FLOW CO

RIVER DISCHARGE
MCNARY PO



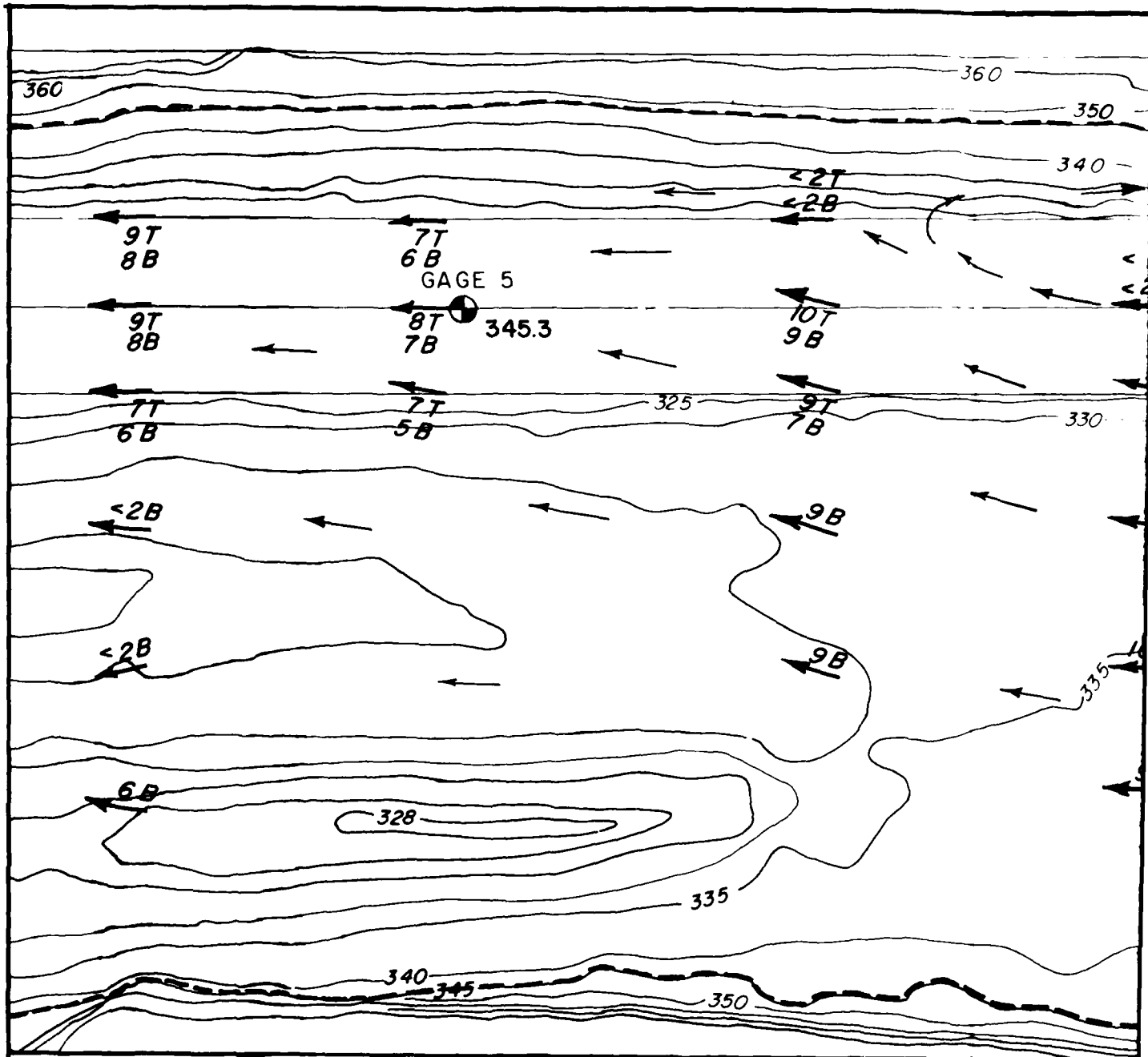
500-FT WALL EXTENSION

FLOW CONDITIONS

RIVER DISCHARGE 150000 CFS
 McNARY POOL EL 335

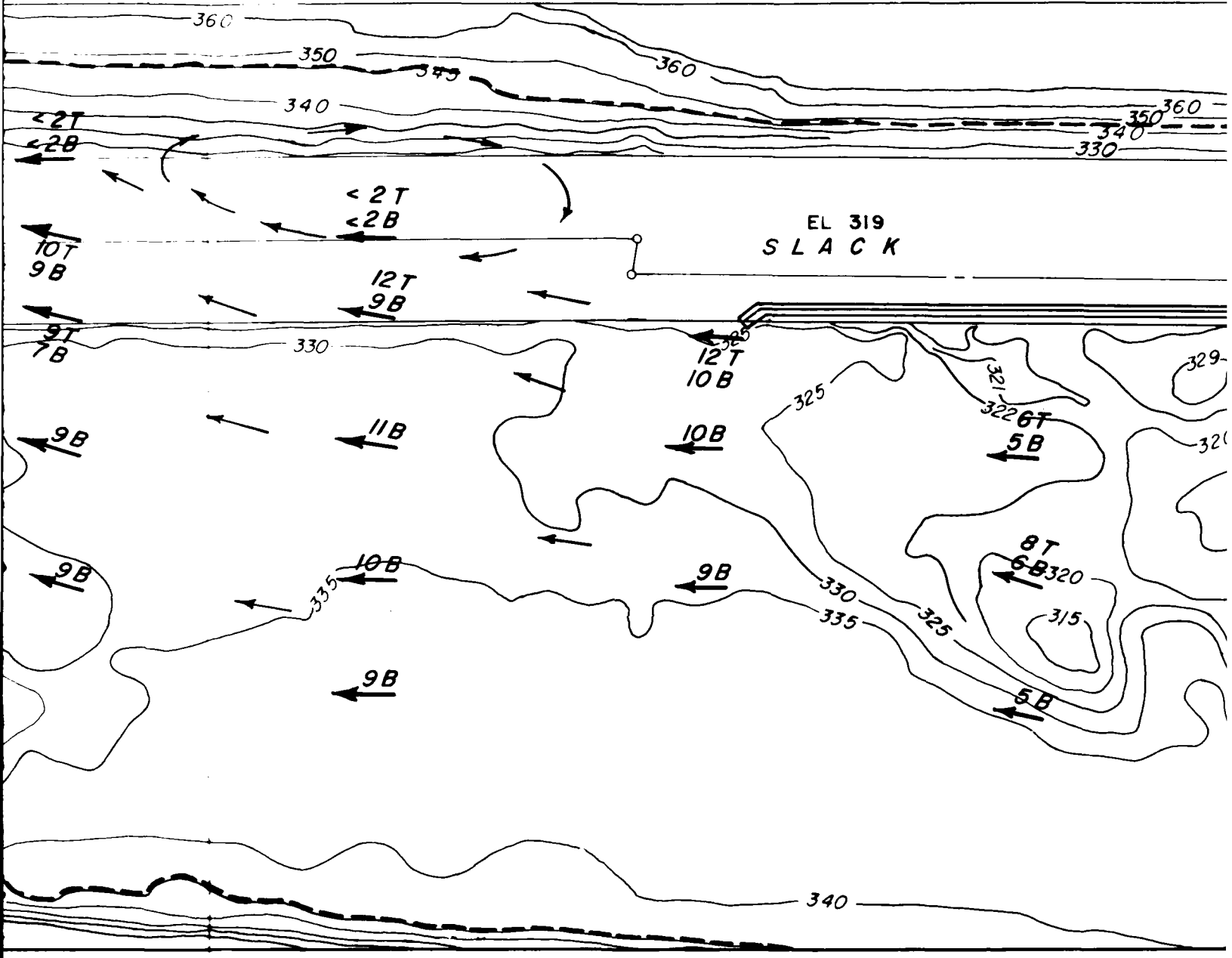
PLATE II

4



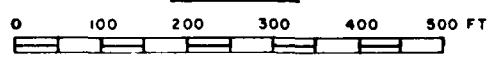
LEGEND

- 4** VELOCITIES IN FPS
- T** 5-FT DEPTH
- B** 5 FT ABOVE BOTTOM



EL 319
SLACK

SCALE

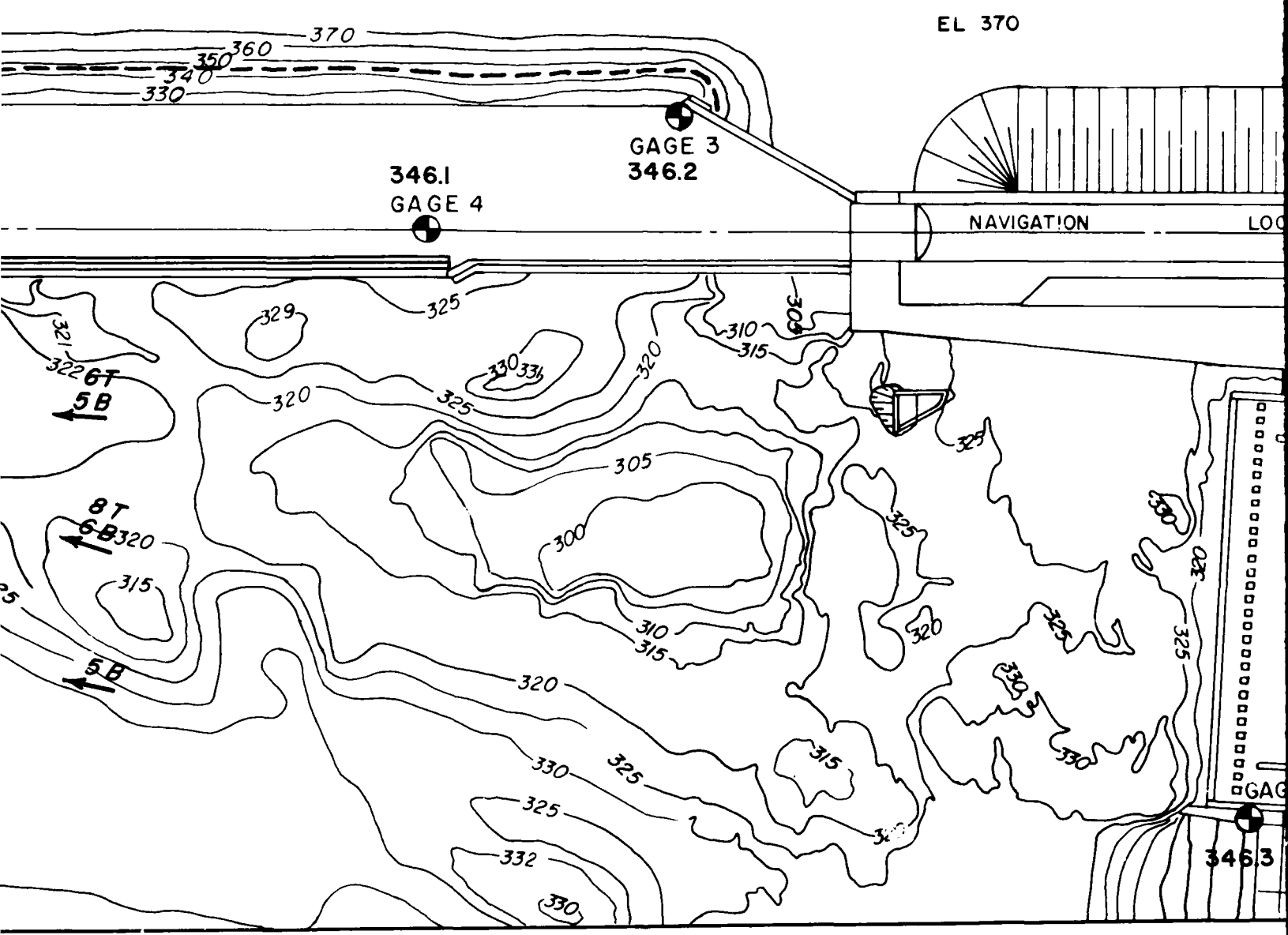


FLOW

SPILLWAY BAYS I TO
POWERHOUSE UNITS
POWERHOUSE UNITS

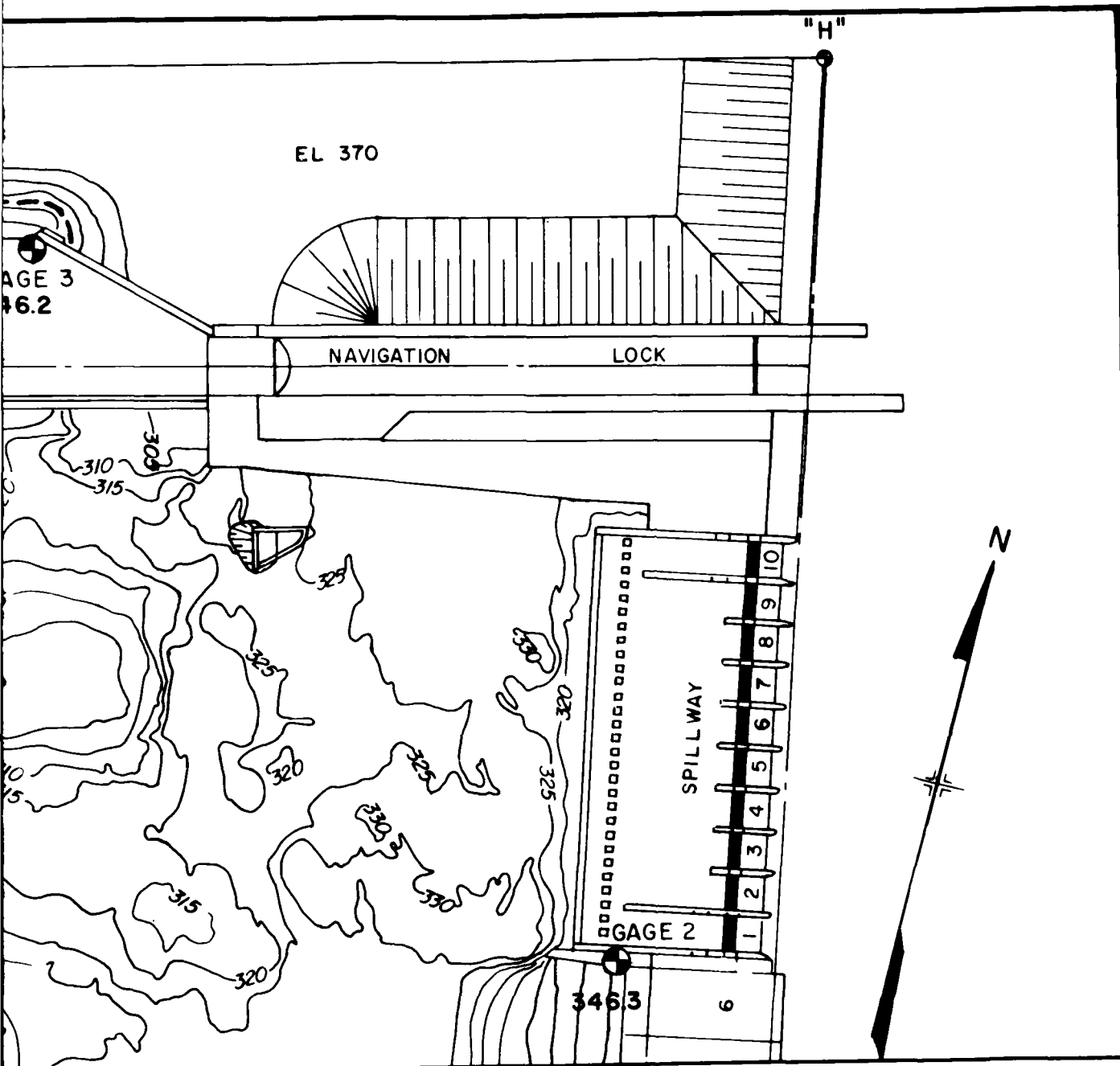
IN FPS
M
E BOTTOM

2



FLOW DISTRIBUTION

SPILLWAY BAYS 1 TO 10	CLOSED
POWERHOUSE UNITS 1 TO 3	43 300 CFS
POWERHOUSE UNITS 4 TO 6	56 700 CFS



1000-FT WALL EXTENSION

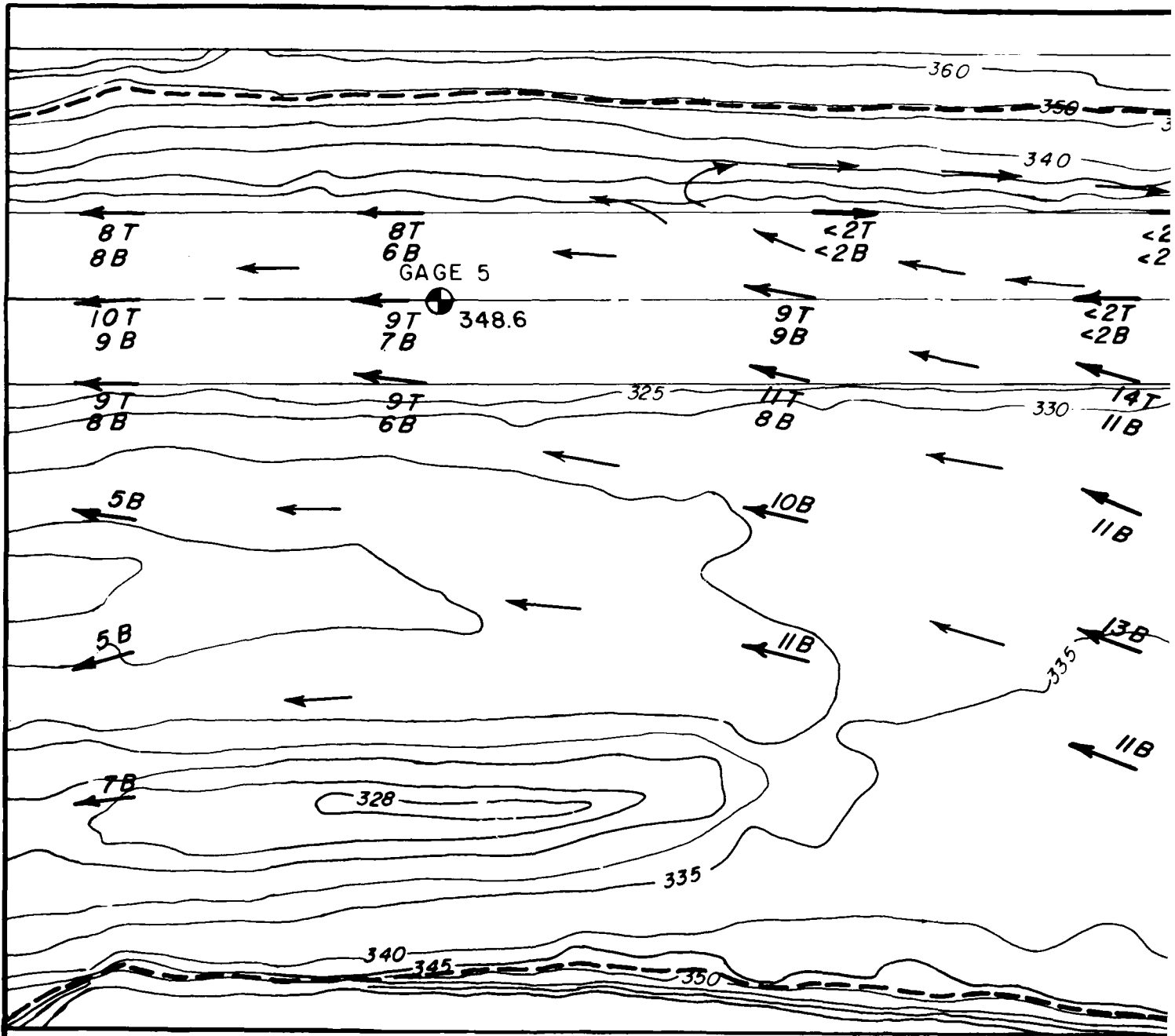
FLOW CONDITIONS

RIVER DISCHARGE 100 000 CFS

McnARY POOL EL 335

PLATE 12

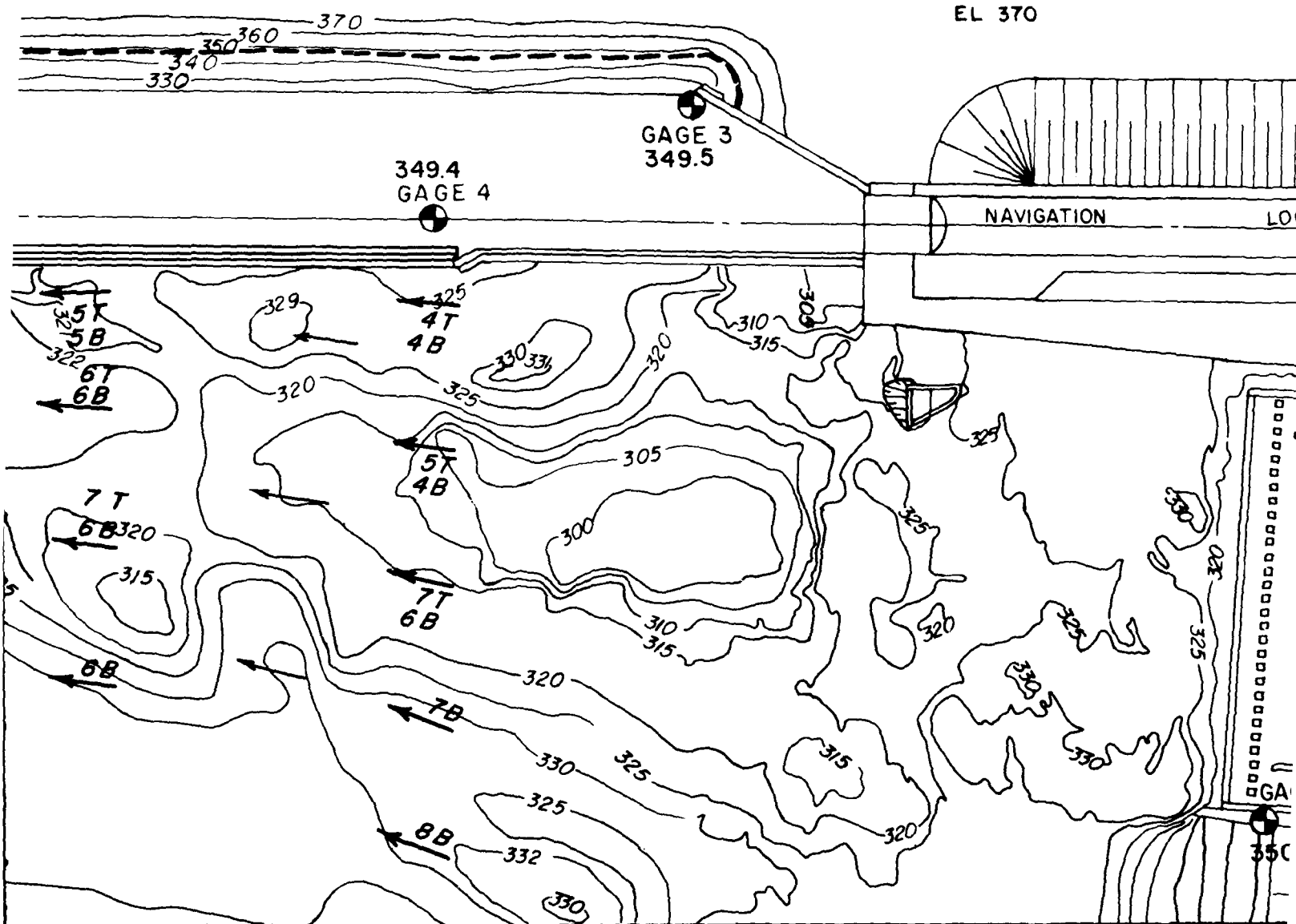
4



LEGEND

- 4 VELOCITIES IN FPS
- T 5-FT DEPTH
- B 5 FT ABOVE BOTTOM

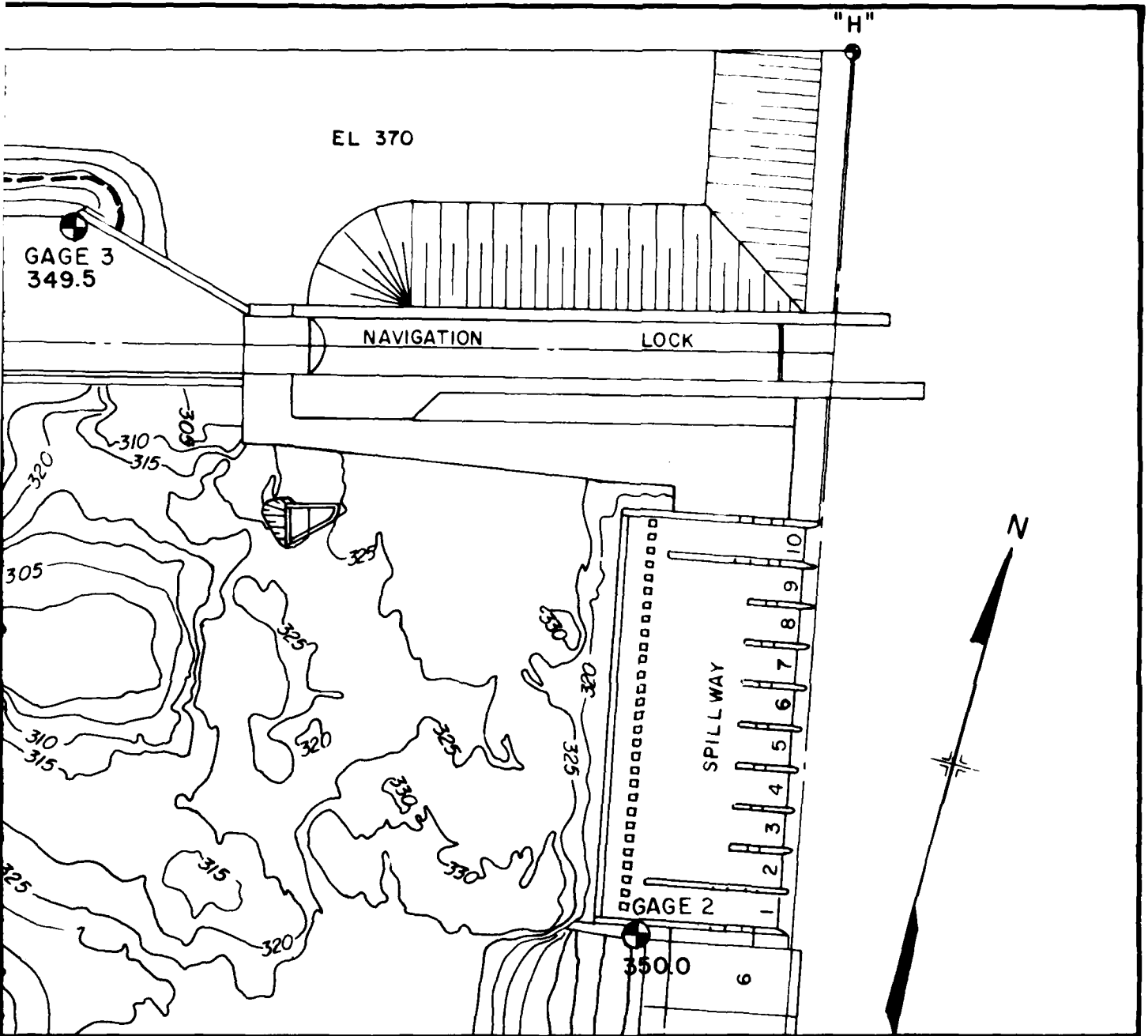




FLOW DISTRIBUTION

SPILLWAY BAYS 1 TO 10	50 000	CFS
POWERHOUSE UNITS 1 TO 3	43 300	CFS
POWERHOUSE UNITS 4 TO 6	56 700	CFS

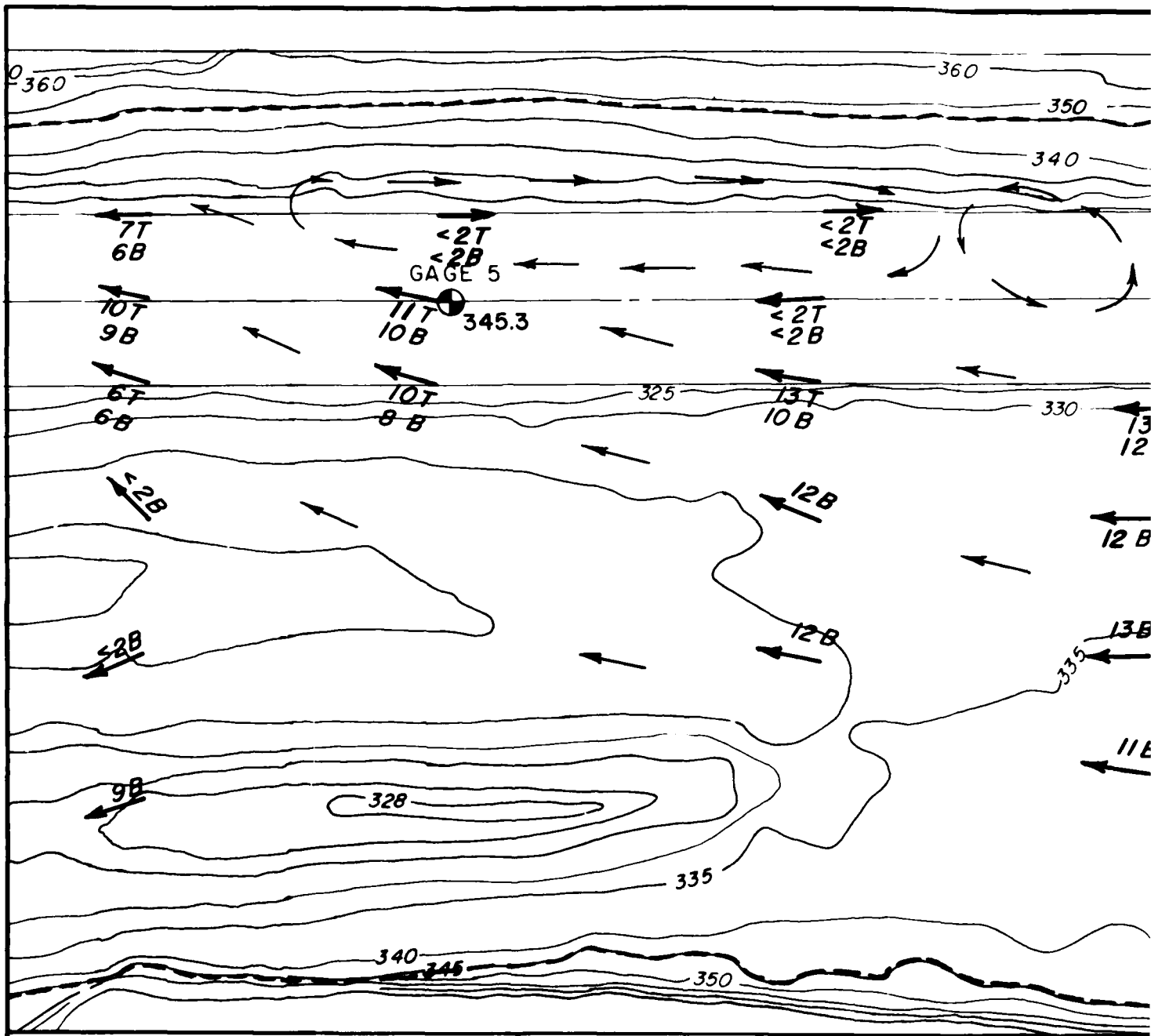
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1000-FT WALL EXTENSION

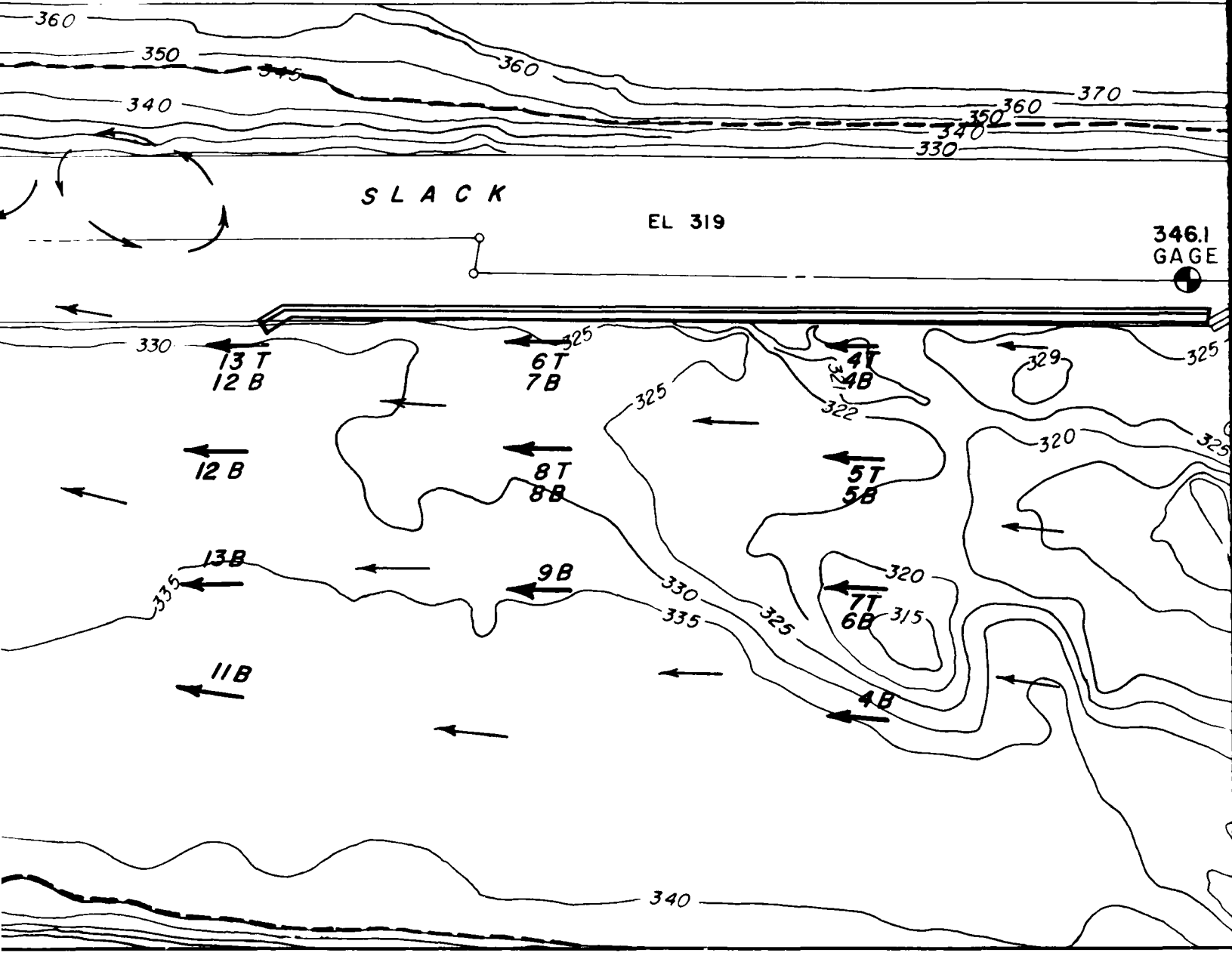
FLOW CONDITIONS
 RIVER DISCHARGE 150 000 CFS
 McNARY POOL EL 335

4

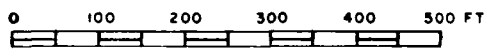


LEGEND

- ← 4 VELOCITIES IN FPS
- T 5-FT DEPTH
- B 5 FT ABOVE BOTTOM



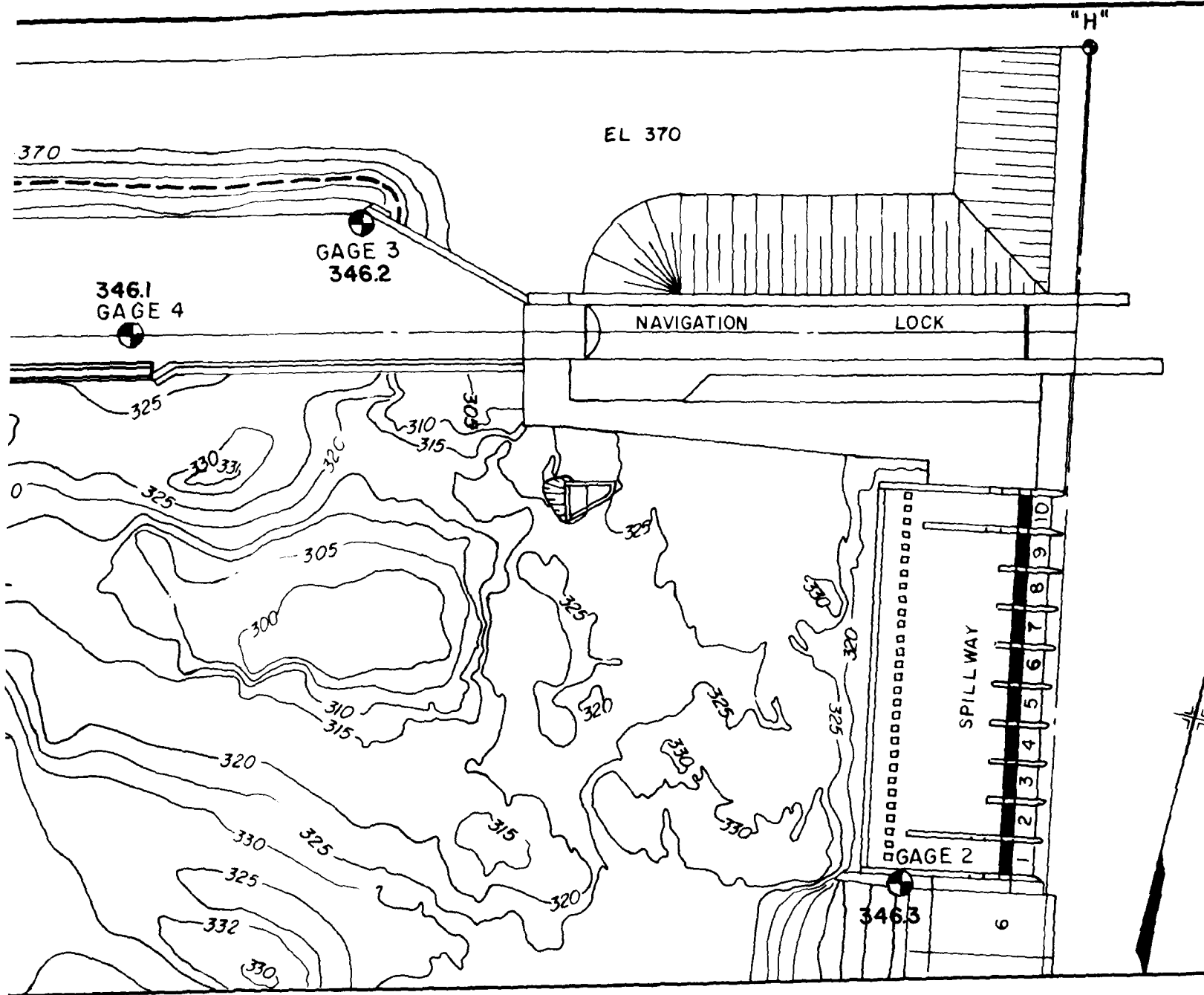
SCALE



FLOW DISTRIBUTION

- SPILLWAY BAYS 1 TO 10
- POWERHOUSE UNITS 1 TO 3
- POWERHOUSE UNITS 4 TO 6

J



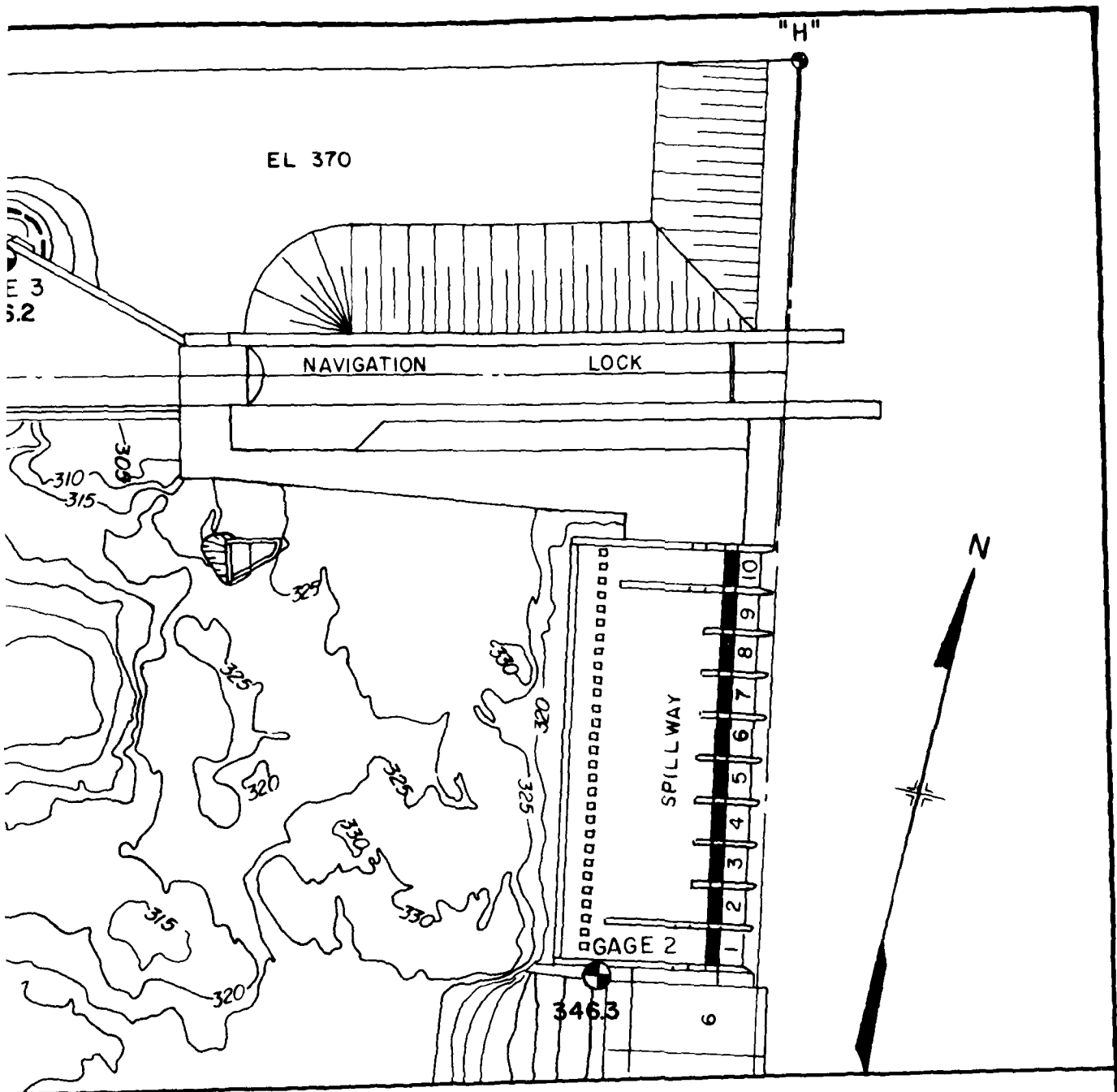
1500-FT WALL EXT

W DISTRIBUTION

TO 10	CLOSED
S 1 TO 3	43 300 CFS
S 4 TO 6	56 700 CFS

FLOW CONDITIO
 RIVER DISCHARGE 1000
 McNARY POOL EL.

3

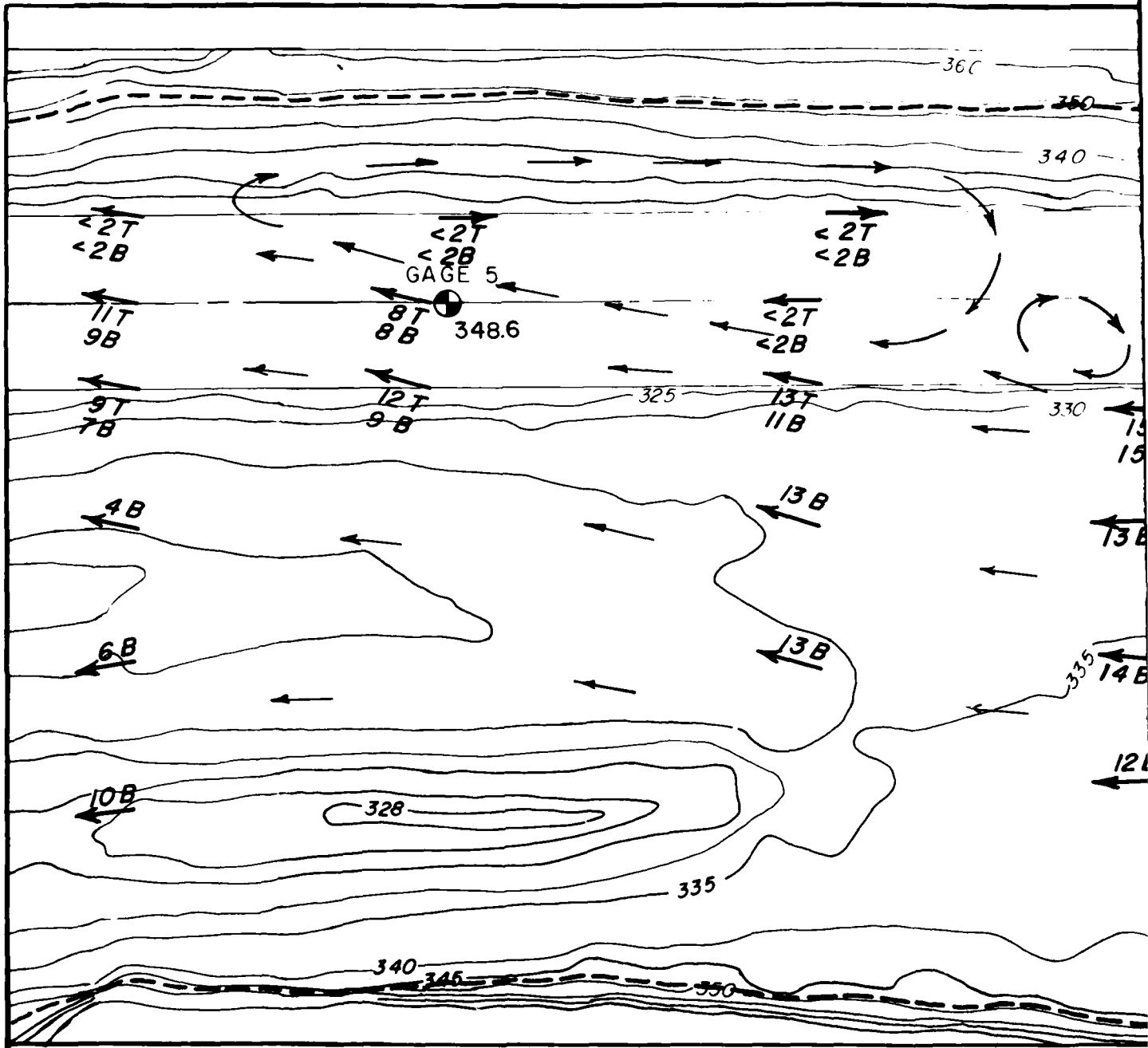


1500-FT WALL EXTENSION


FLOW CONDITIONS

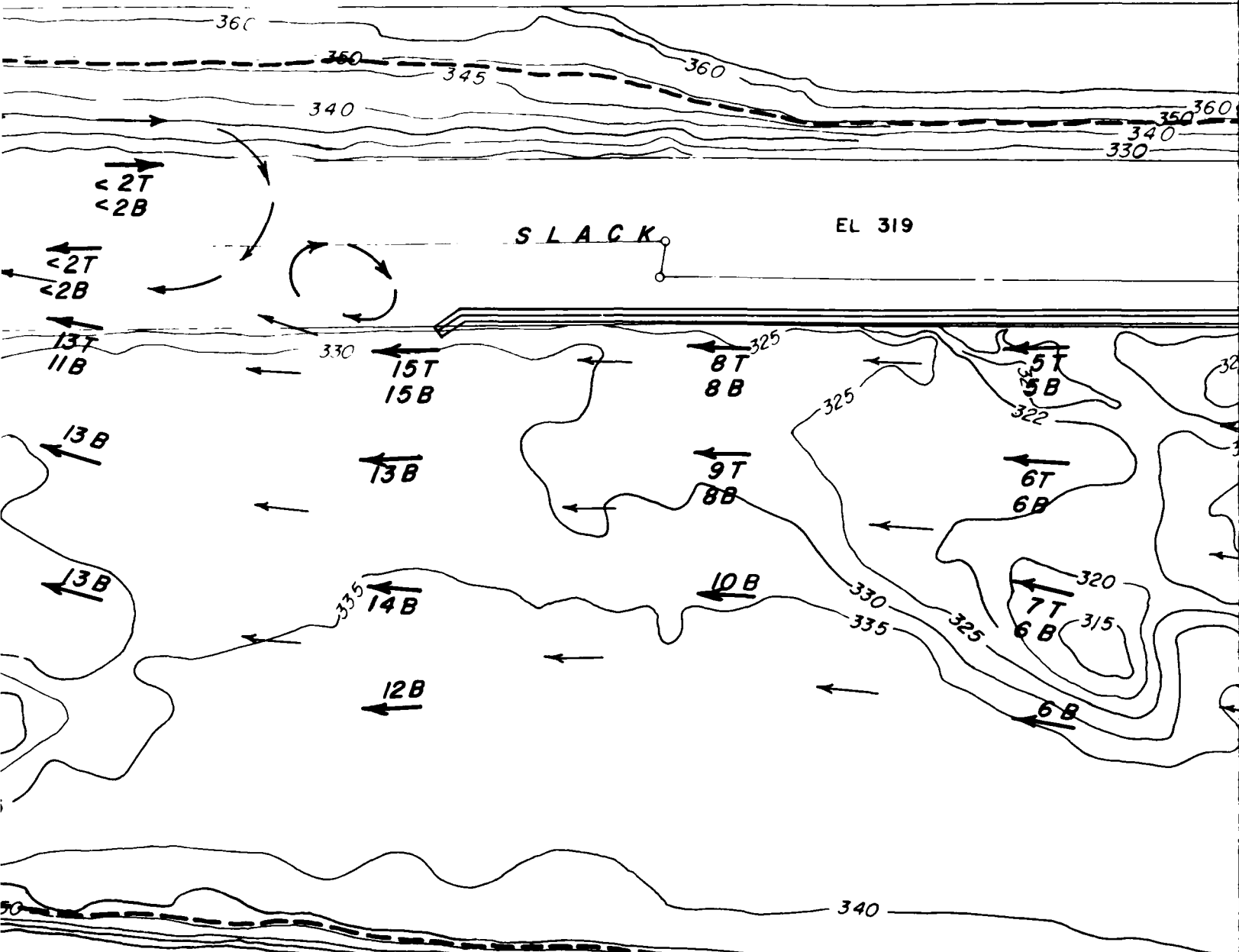
RIVER DISCHARGE 100 000 CFS
 McNARY POOL EL 335

PLATE 14

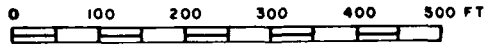


LEGEND

-  VELOCITIES IN FPS
- T 5-FT DEPTH
- B 5 FT ABOVE BOTTOM



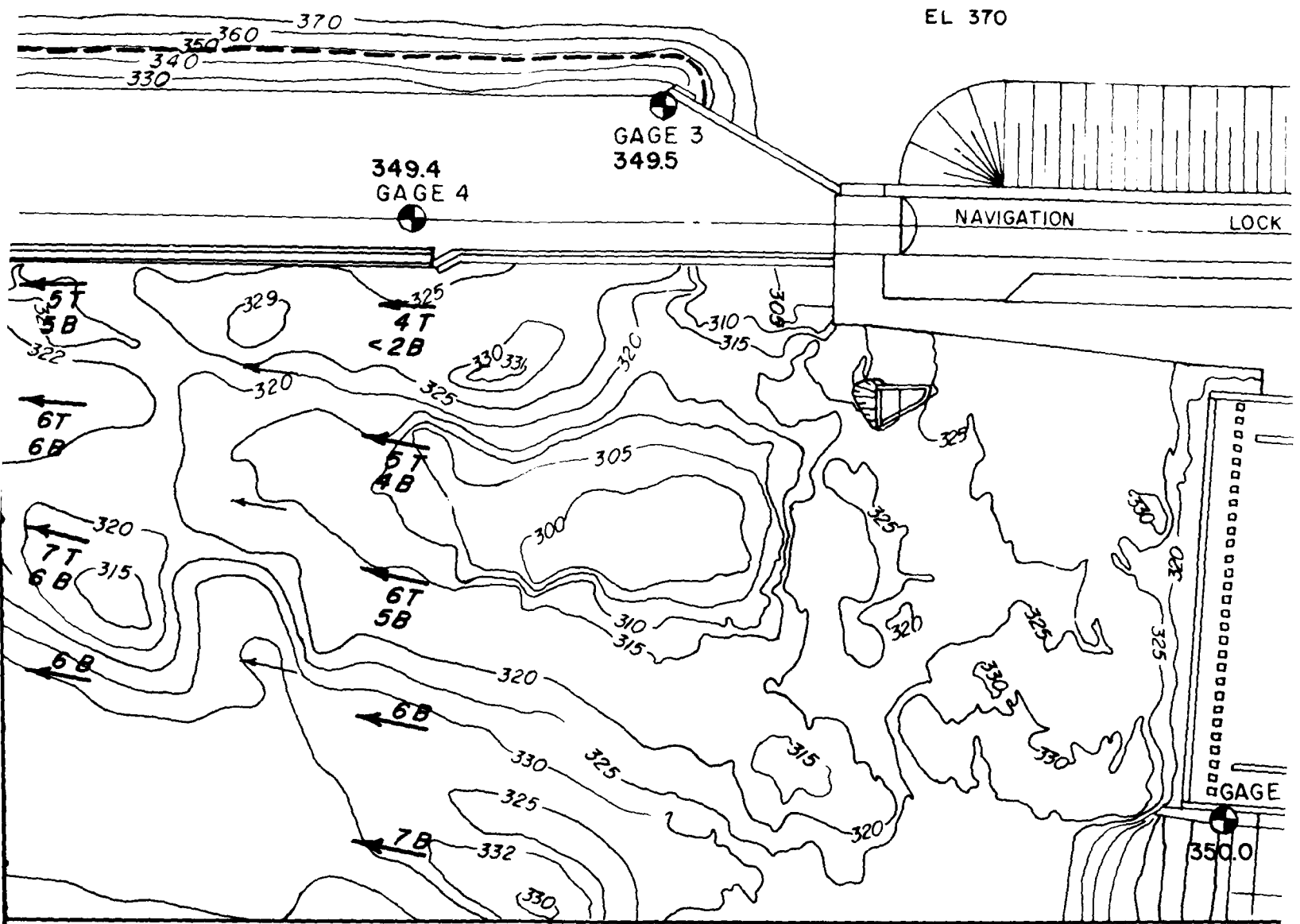
SCALE



ND
ES IN FPS
EPH
OVE BOTTOM

FLO
SPILLWAY BAYS I
POWERHOUSE UNIT
POWERHOUSE UNIT

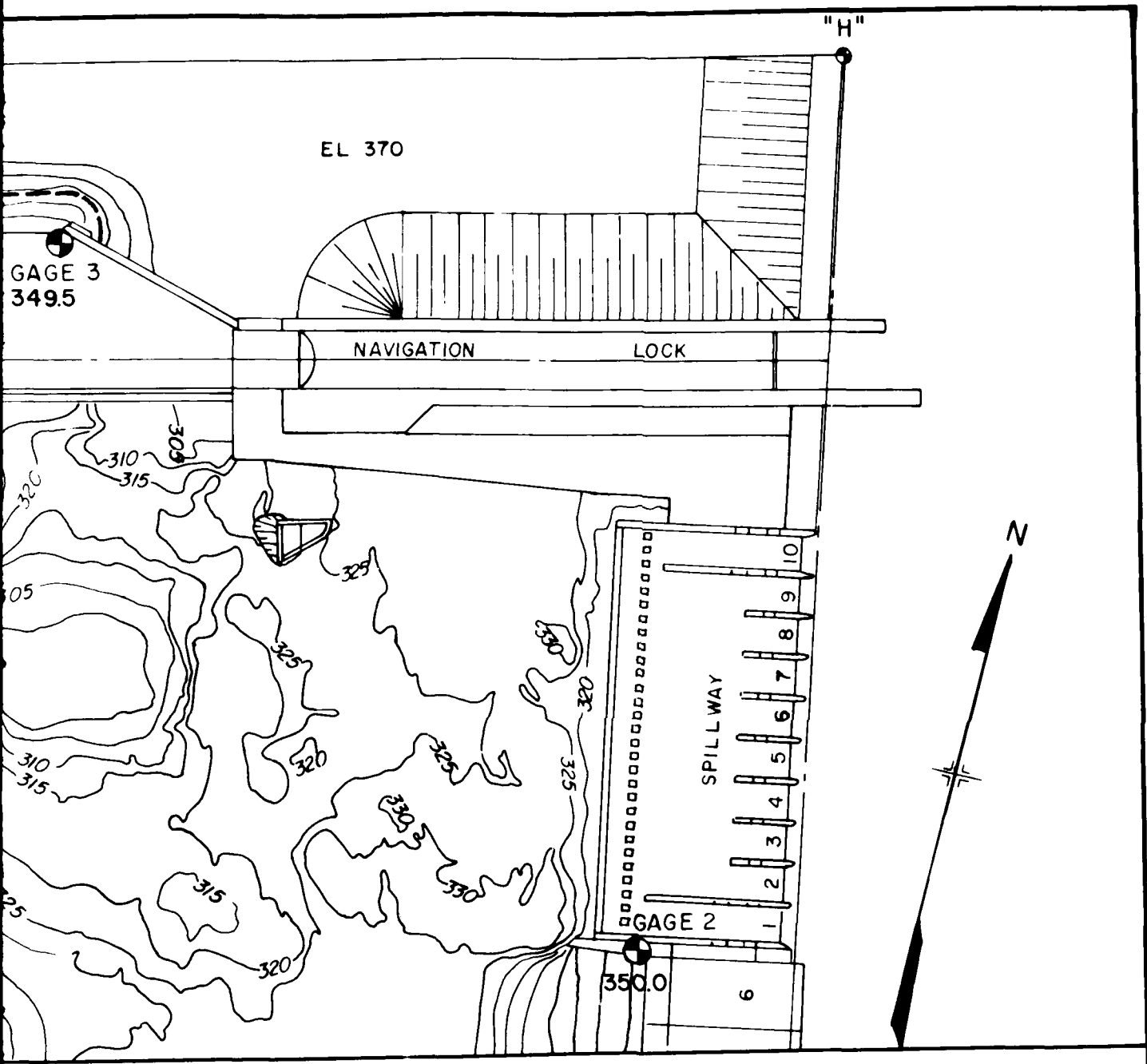
Handwritten mark resembling a stylized '2' or 'X'.



FLOW DISTRIBUTION

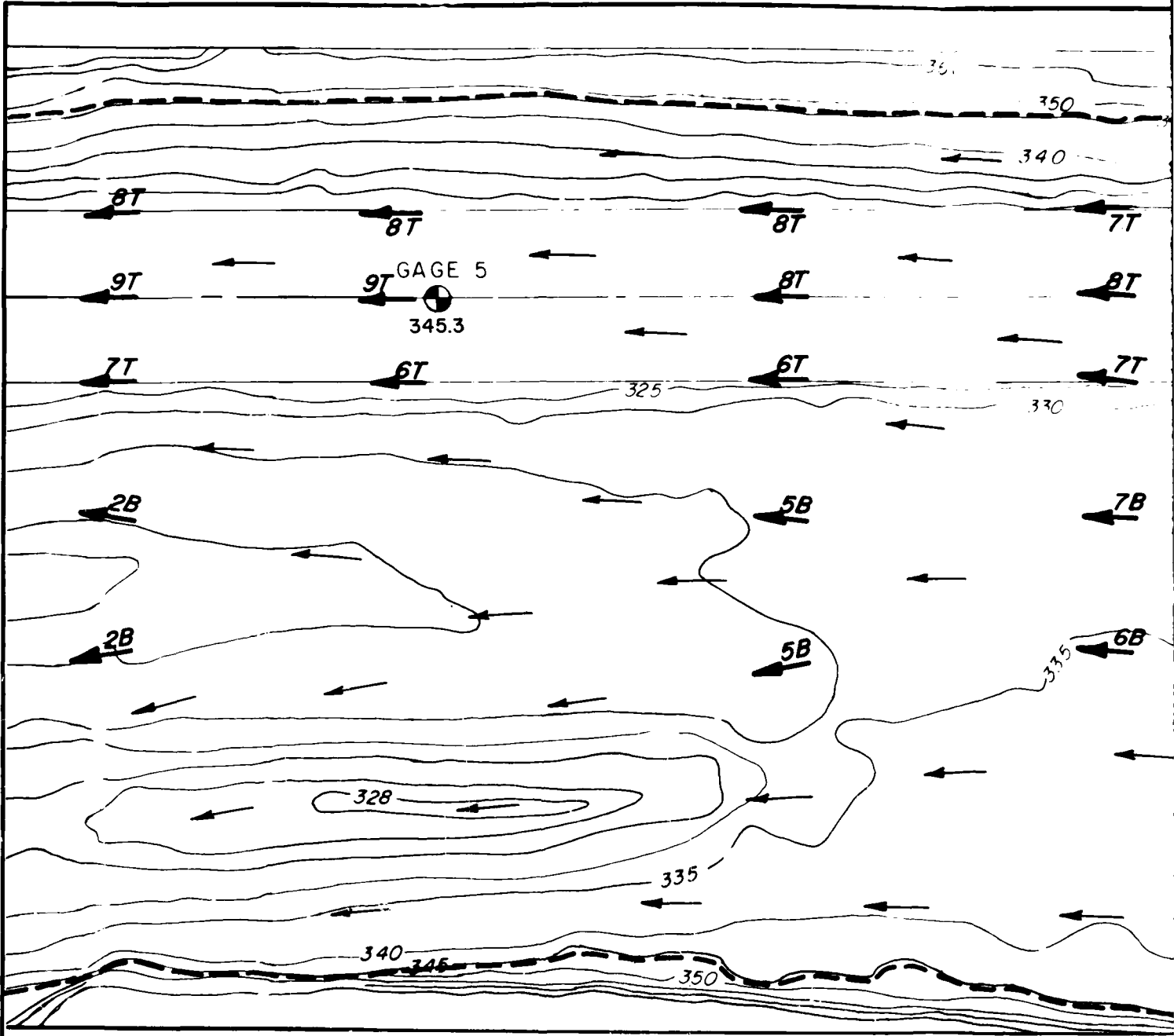
SPILLWAY BAYS 1 TO 10	50 000 CFS
POWERHOUSE UNITS 1 TO 3	43 000 CFS
POWERHOUSE UNITS 4 TO 6	66 700 CFS

3



1500-FT WALL EXTENSION

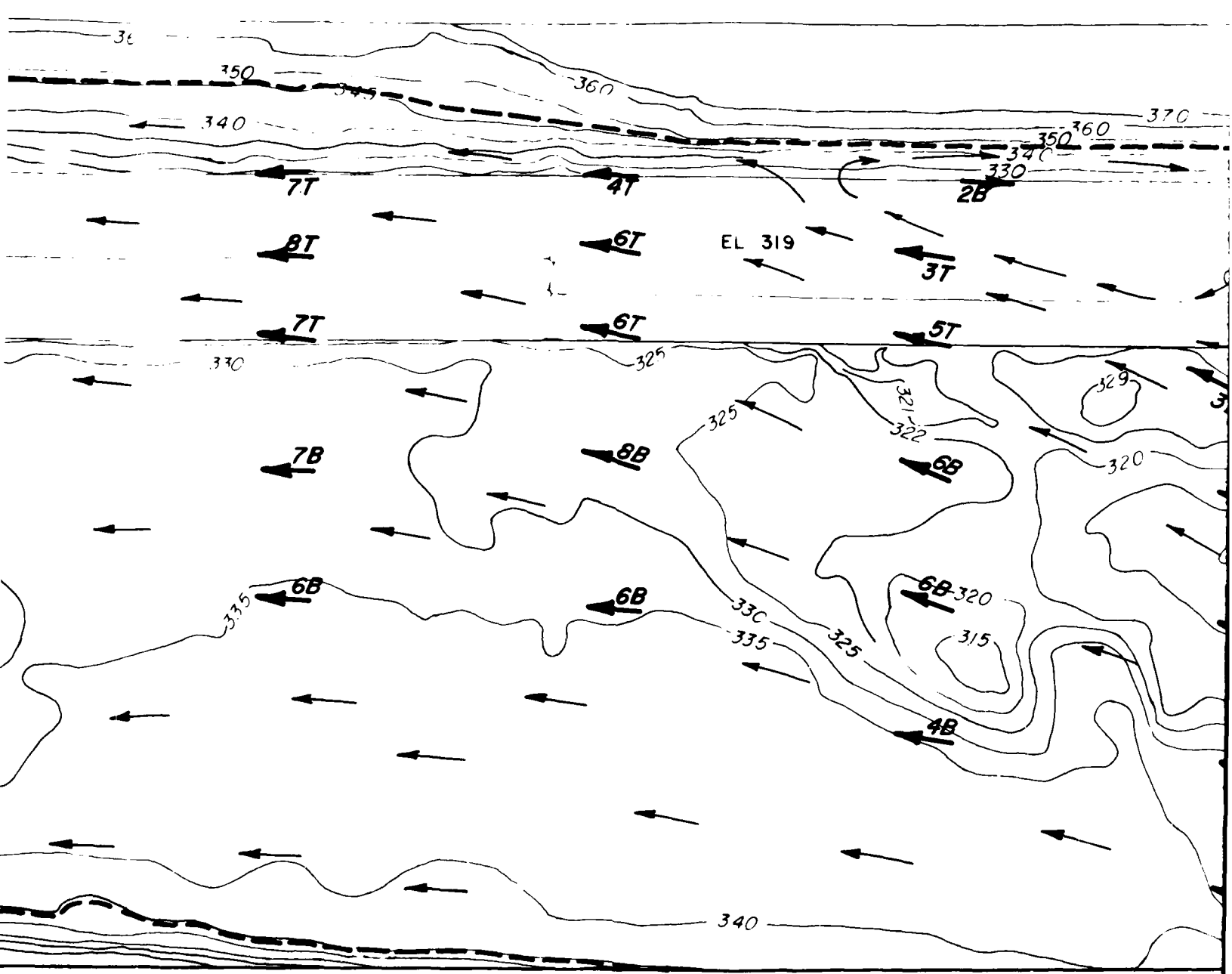
FLOW CONDITIONS
 RIVER DISCHARGE 150 000 CFS
 McNARY POOL EL 335



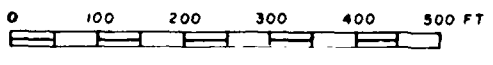
LEGEND

- 4 VELOCITIES IN FPS
- T 5-FT DEPTH
- B 5 FT ABOVE BOTTOM





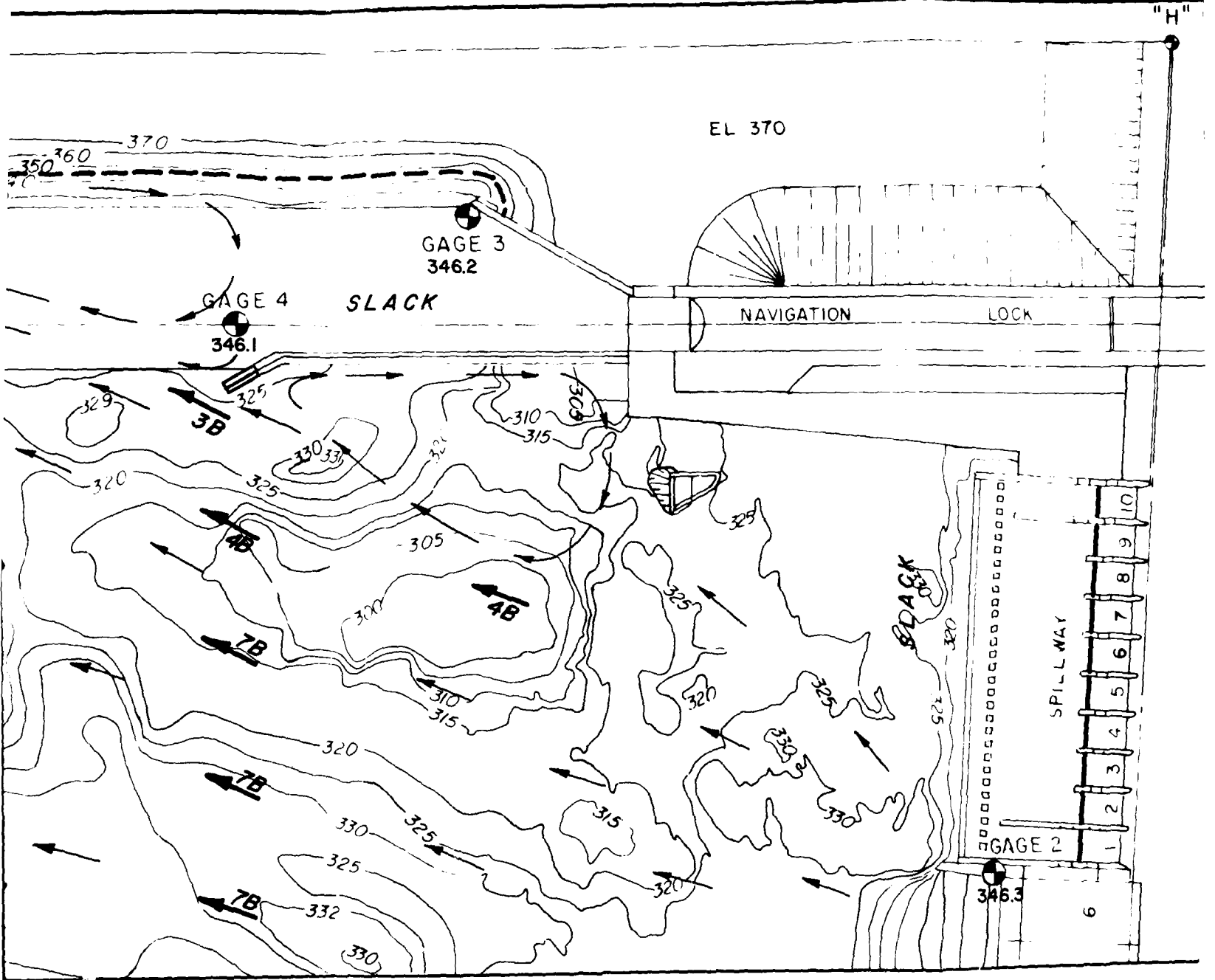
SCALE



FLOW DISTR

- SPILLWAY BAYS 1 TO 10
- POWERHOUSE UNITS 1 TO 3
- POWERHOUSE UNITS 4 TO 6

2

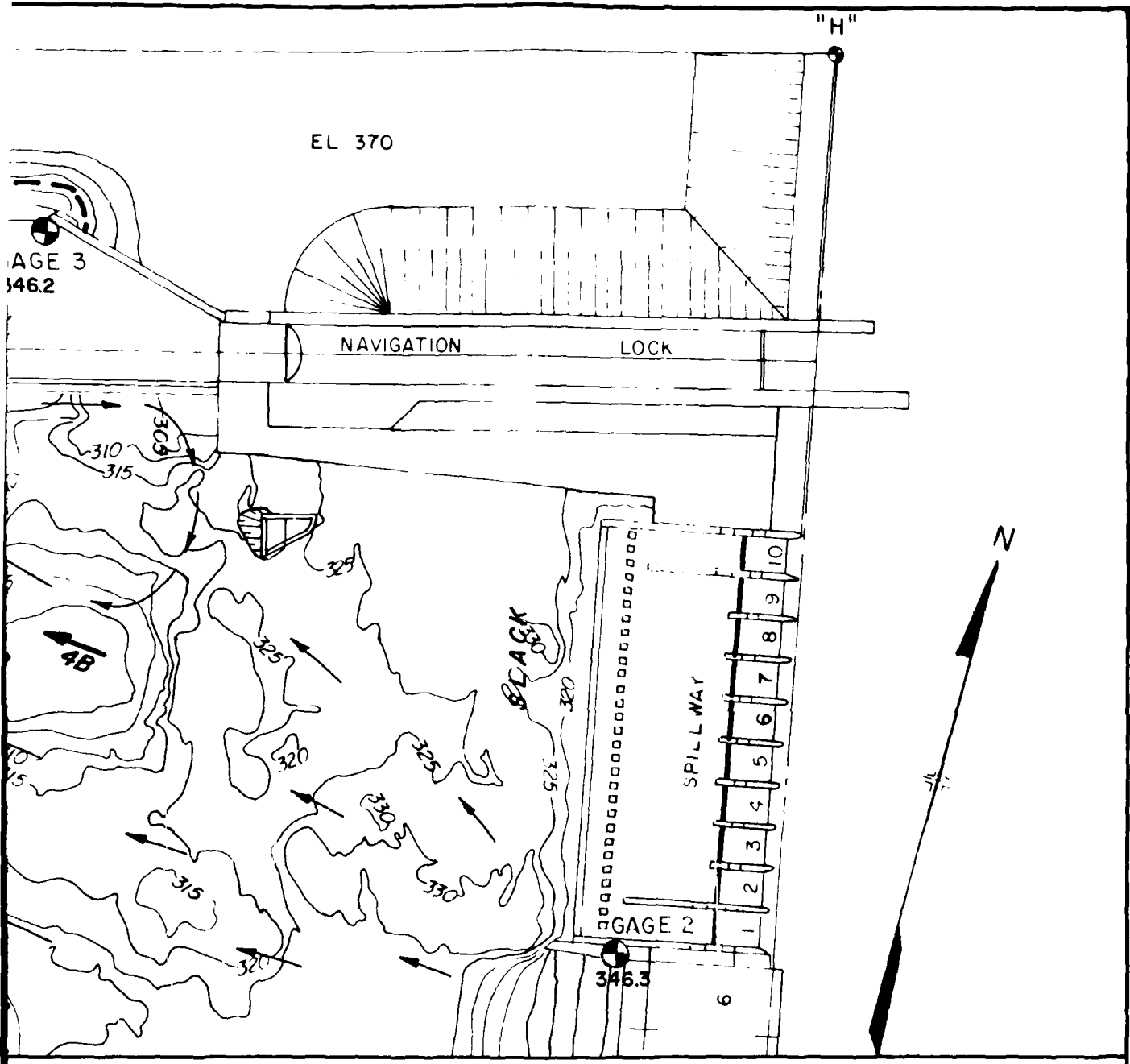


FLOW DISTRIBUTION

Y BAYS 1 TO 10	CLOSED
HOUSE UNITS 1 TO 3	43 300 CFS
HOUSE UNITS 4 TO 6	56 700 CFS

70-FT EXTENSI

FLOW C
RIVER DISCHA
MCNARY P



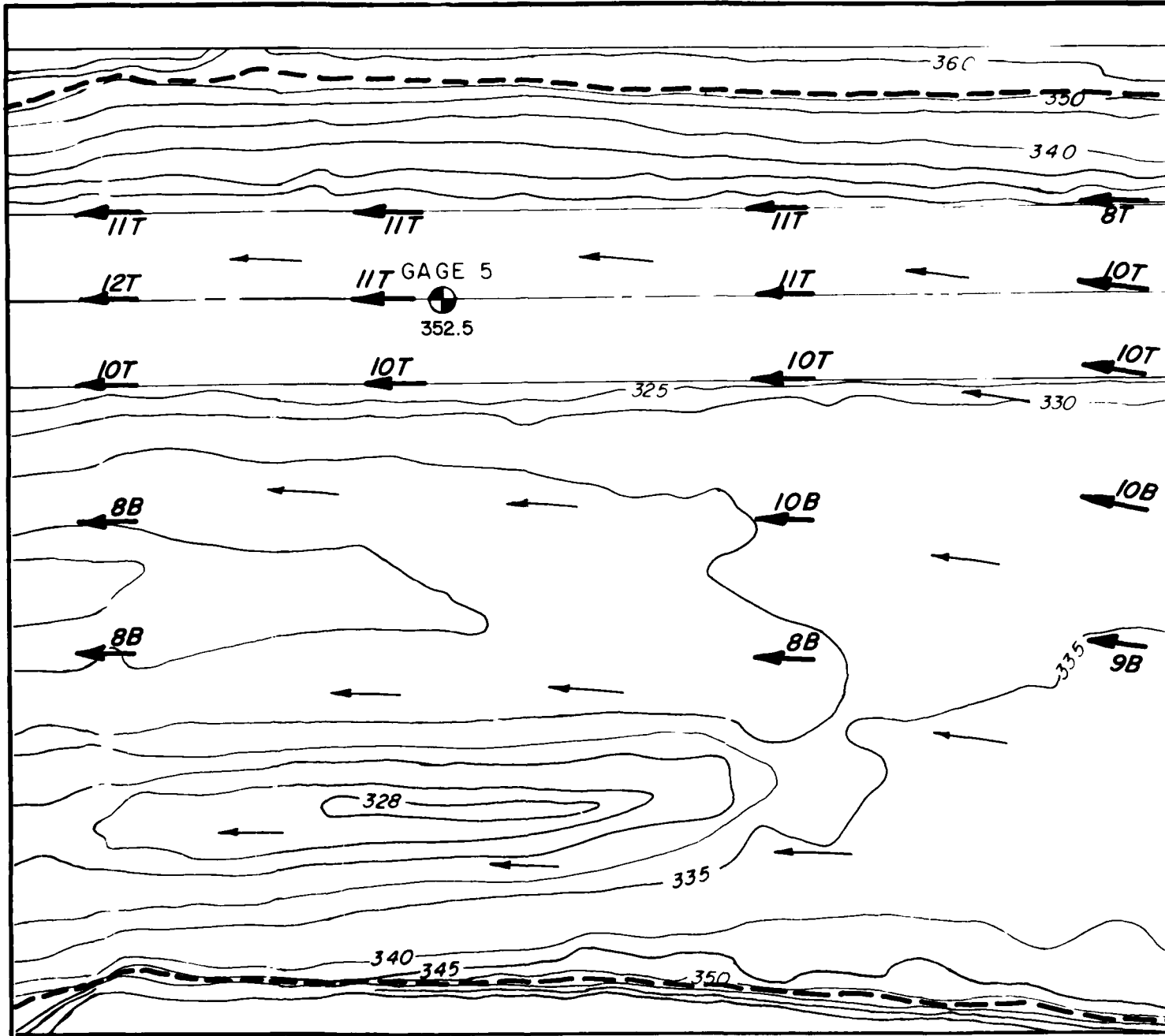
70-FT EXTENSION TO GUIDE WALL

FLOW CONDITIONS

RIVER DISCHARGE 100 000 CFS
 MCNARY POOL EL 335

4

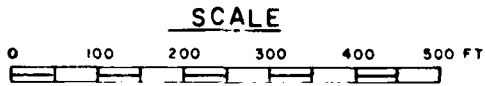
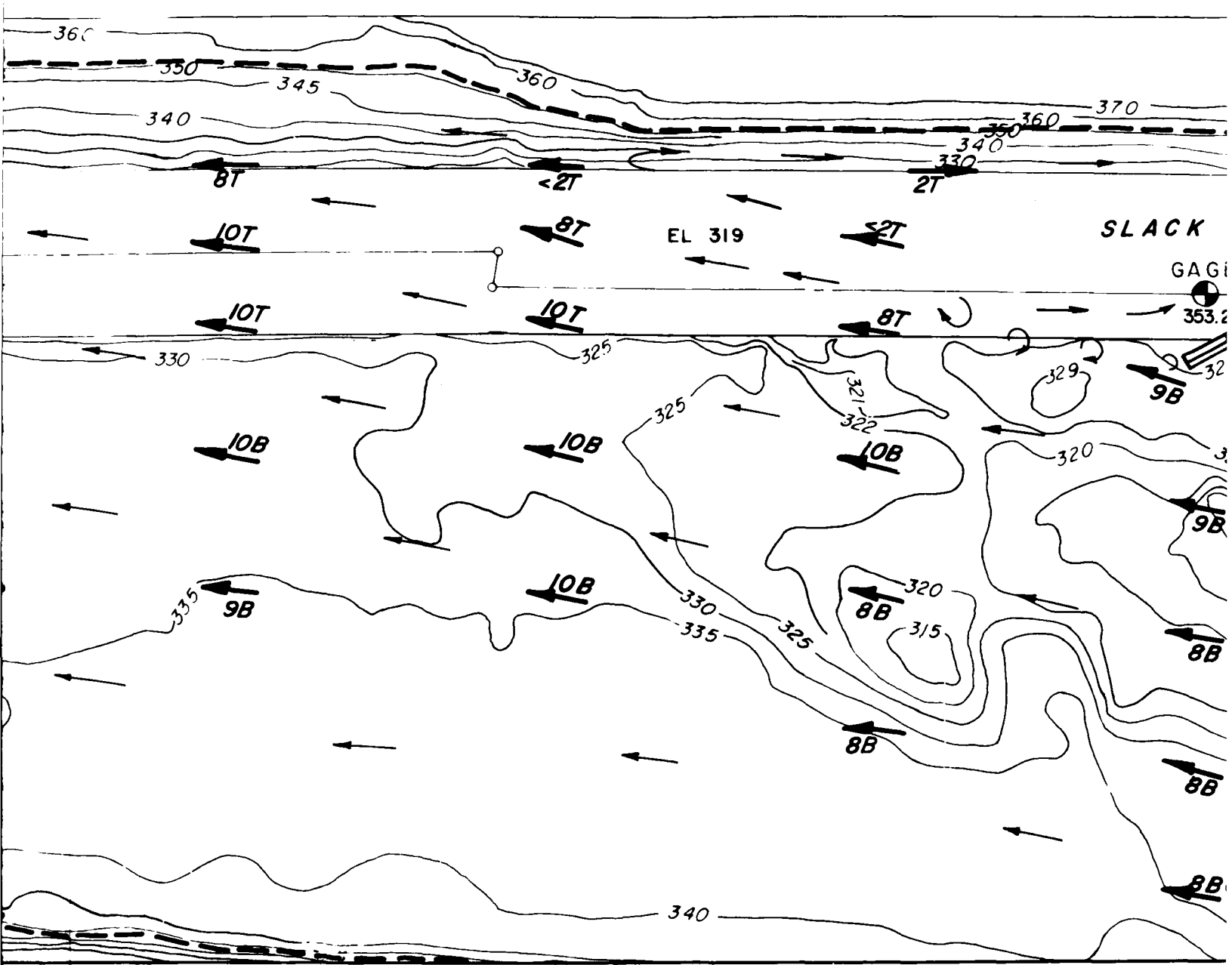
PLATE 16



LEGEND

- 4 VELOCITIES IN FPS
- T 5-FT DEPTH
- B 5 FT ABOVE BOTTOM

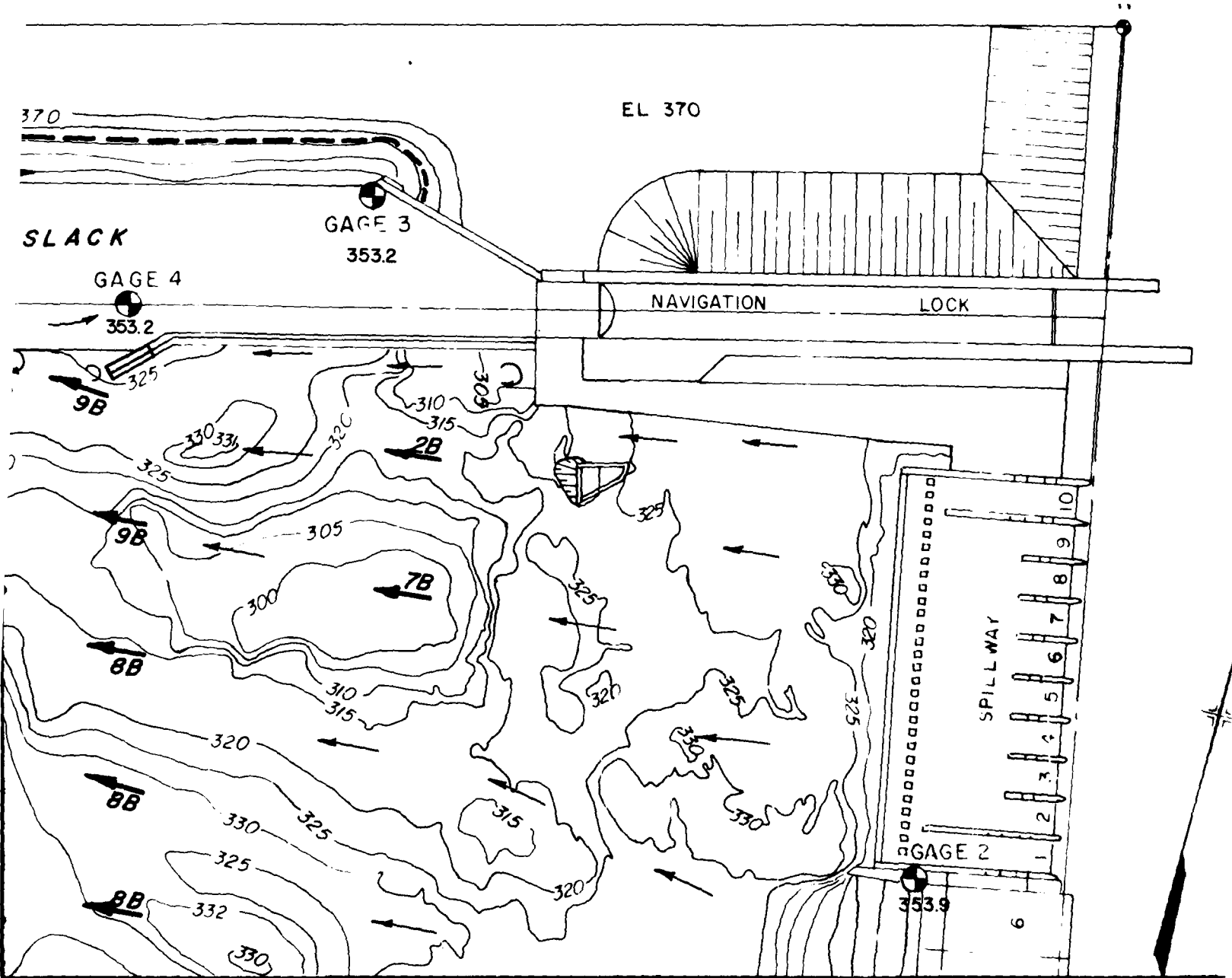
° E



FLOW DISTRIBUTION

- SPILLWAY BAYS 1 TO 10
- POWERHOUSE UNITS 1 TO 3
- POWERHOUSE UNITS 4 TO 6

2



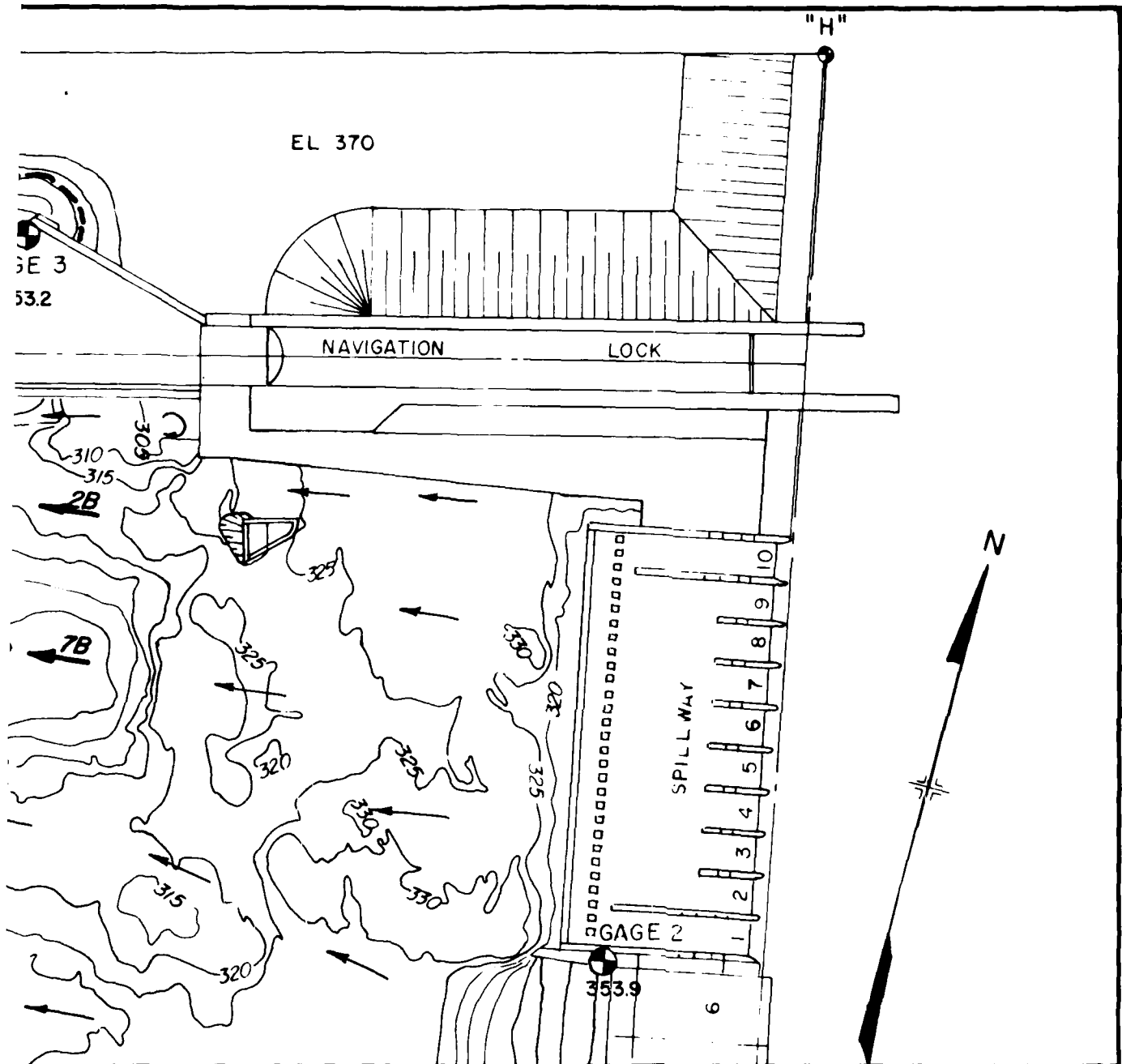
DISTRIBUTION

10	119 200	CFS
1 TO 3	45 300	CFS
4 TO 6	55 500	CFS

70-FT EXTENSION TO GUI

FLOW COM
RIVER DISCHARGE
MCNARY POND

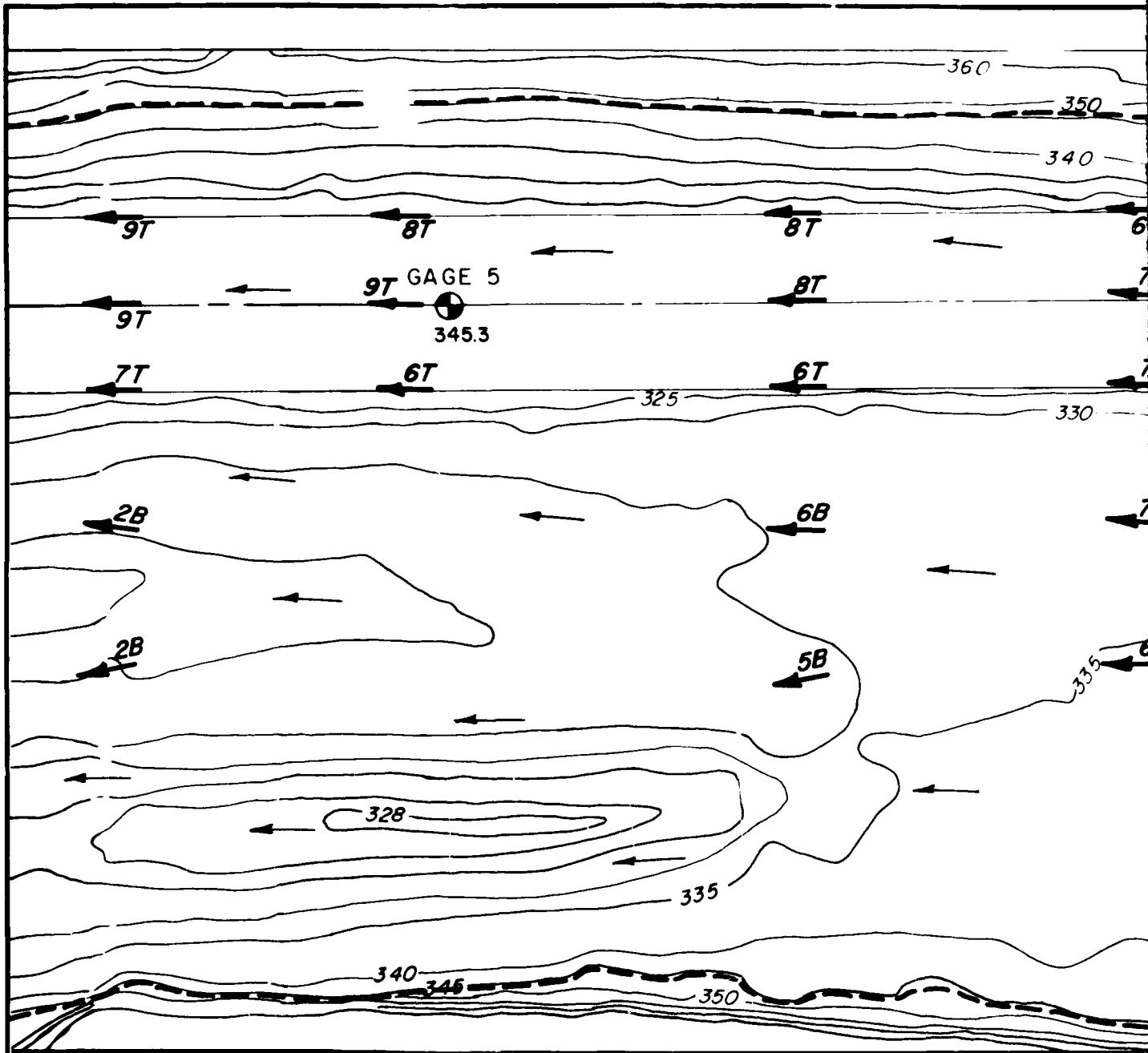
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70-FT EXTENSION TO GUIDE WALL

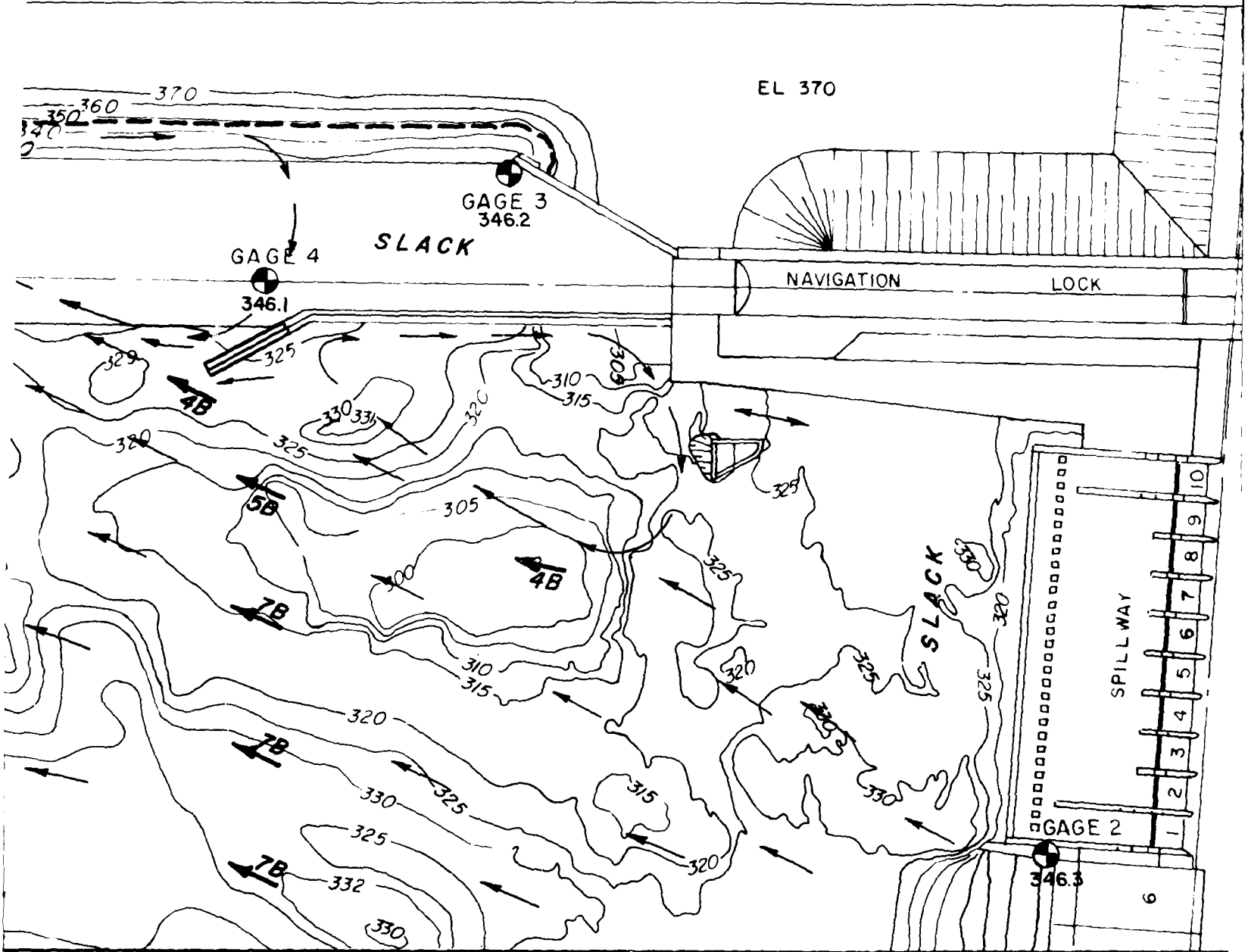
FLOW CONDITIONS

RIVER DISCHARGE 220 000 CFS
M McNARY POOL EL 335



LEGEND

- 4** VELOCITIES IN FPS
- T** 5-FT DEPTH
- B** 5 FT ABOVE BOTTOM

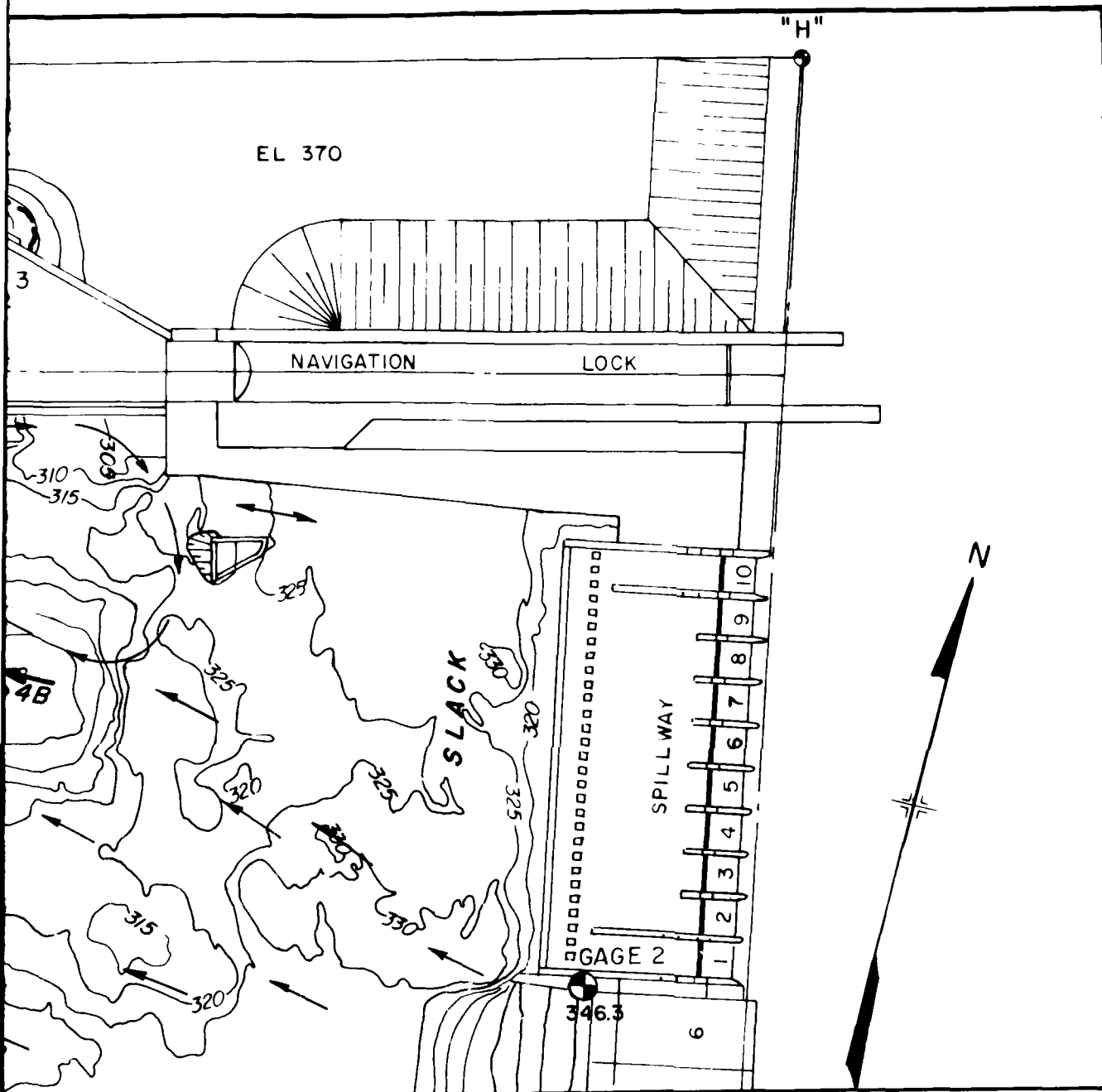


FLOW DISTRIBUTION

140-FT EXTEN

WAY BAYS 1 TO 10	CLOSED
HOUSE UNITS 1 TO 3	43 300 CFS
HOUSE UNITS 4 TO 6	56 700 CFS

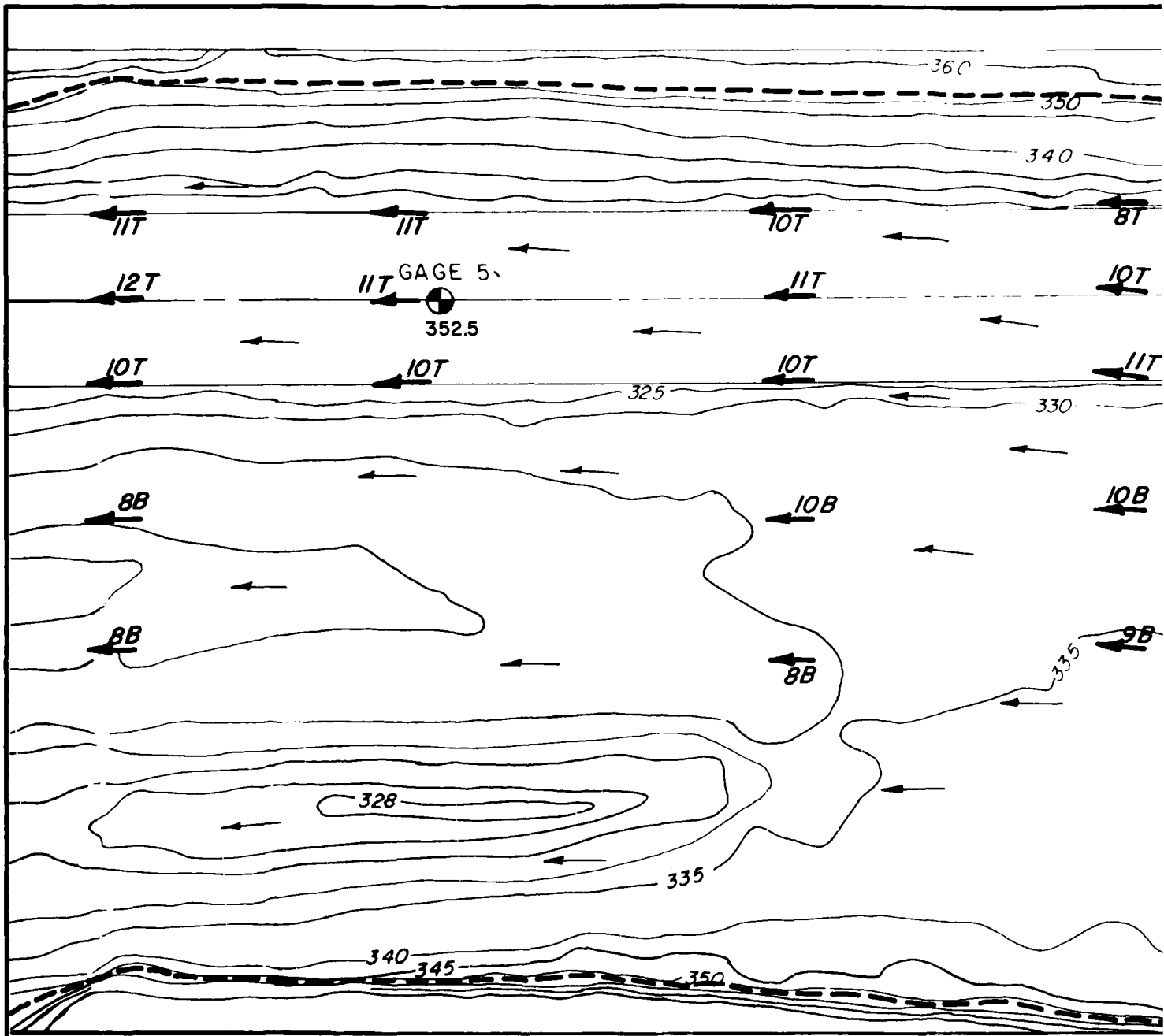
FLOW
RIVER DIS
MCNARY



140-FT EXTENSION TO GUIDE WALL

FLOW CONDITIONS

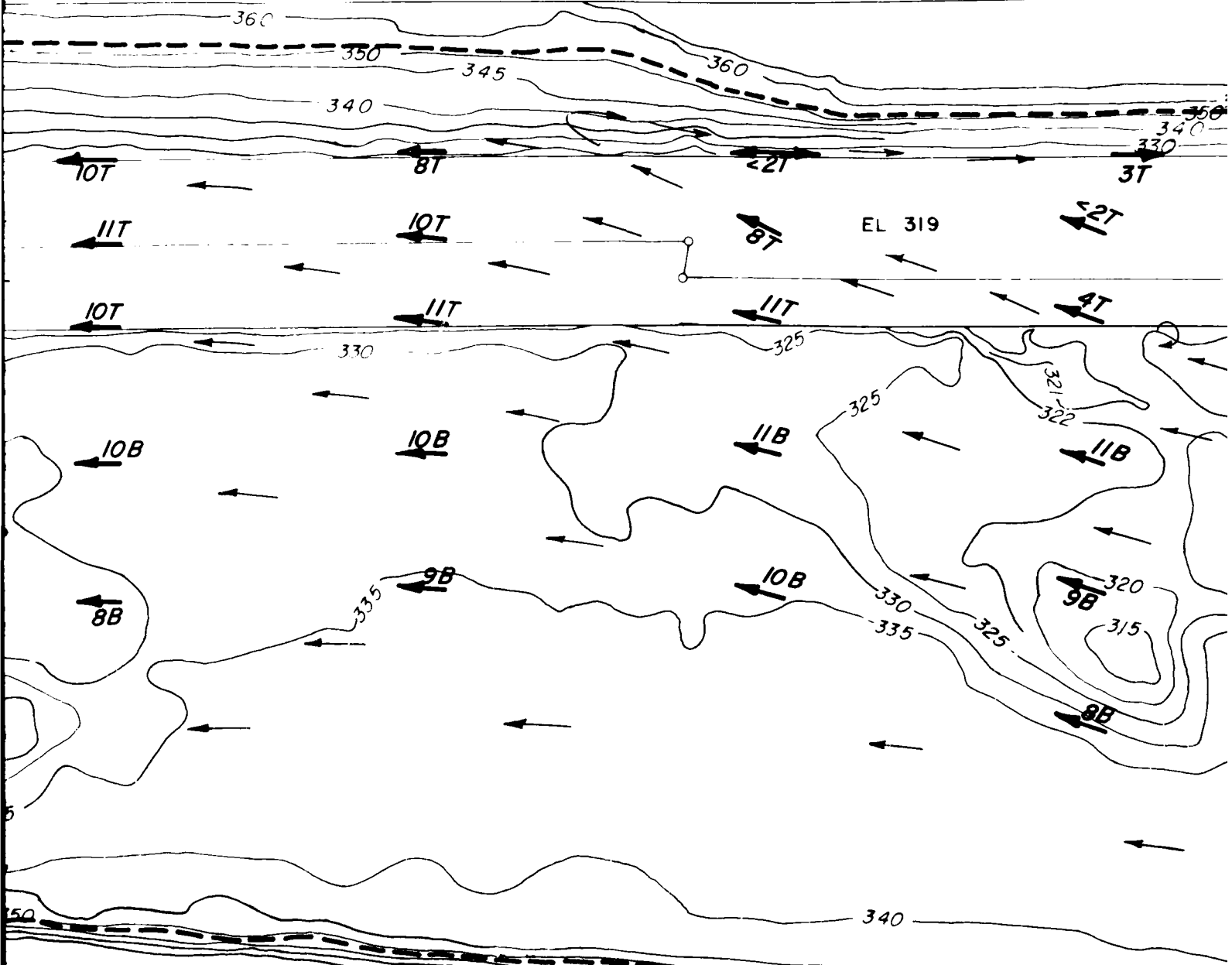
RIVER DISCHARGE 100 000 CFS
 McNARY POOL EL 335



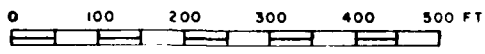
LEGEND

- ← 4 VELOCITIES IN FPS
- T 5-FT DEPTH
- B 5 FT ABOVE BOTTOM

0
E



SCALE



END
IES IN FPS
EPH
BOVE BOTTOM

SPILLWAY BAY
POWERHOUSE
POWERHOUSE

2

AD-A134 686

MCNARY RESERVOIR NAVIGATION AT ICE HARBOR DAM SNAKE
RIVER WASHINGTON HYDR. (U) ARMY ENGINEER DIV NORTH
PACIFIC BONNEVILLE OR DIV HYDRAULIC L. . . AUG 83

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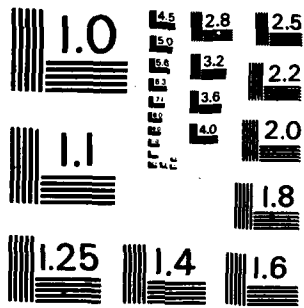
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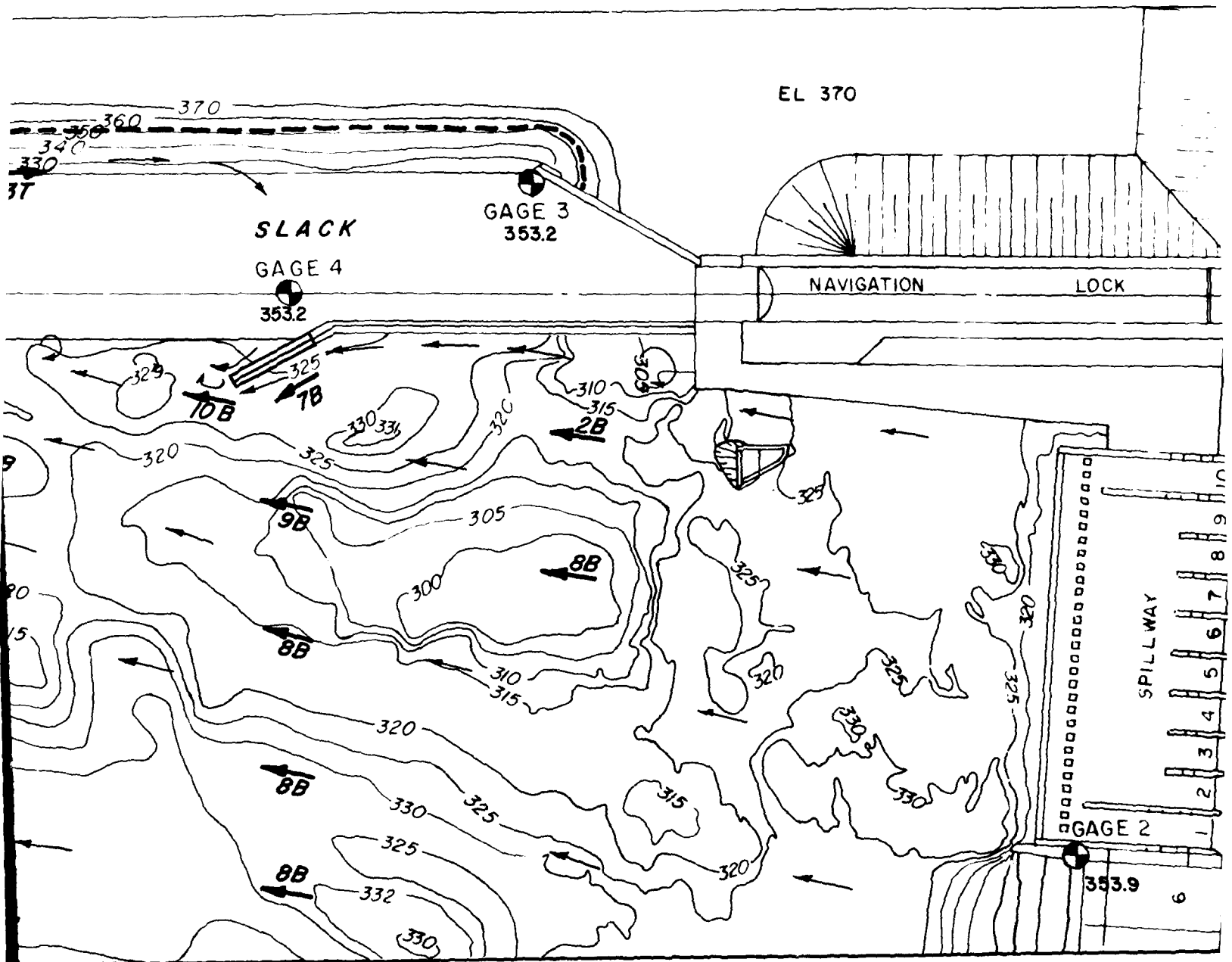
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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



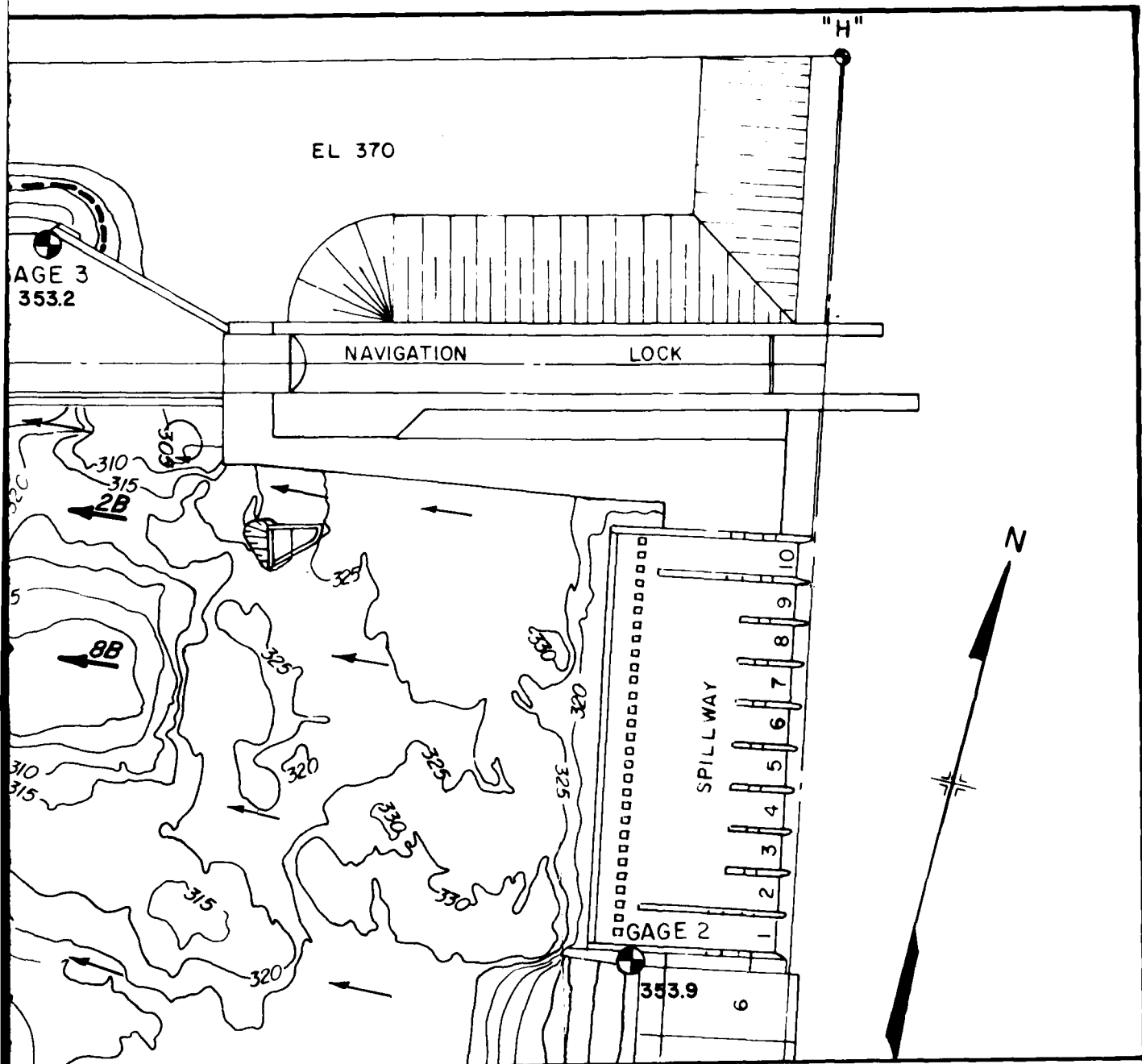
FLOW DISTRIBUTION

140-FT EX

SLUICeway BAYS 1 TO 10	119 200 CFS
POWERHOUSE UNITS 1 TO 3	45 300 CFS
POWERHOUSE UNITS 4 TO 6	55 500 CFS

FL
RIVER
MCN

3



EL 370

GAGE 3
353.2

NAVIGATION LOCK

SPILLWAY

GAGE 2

353.9

140-FT EXTENSION TO GUIDE WALL

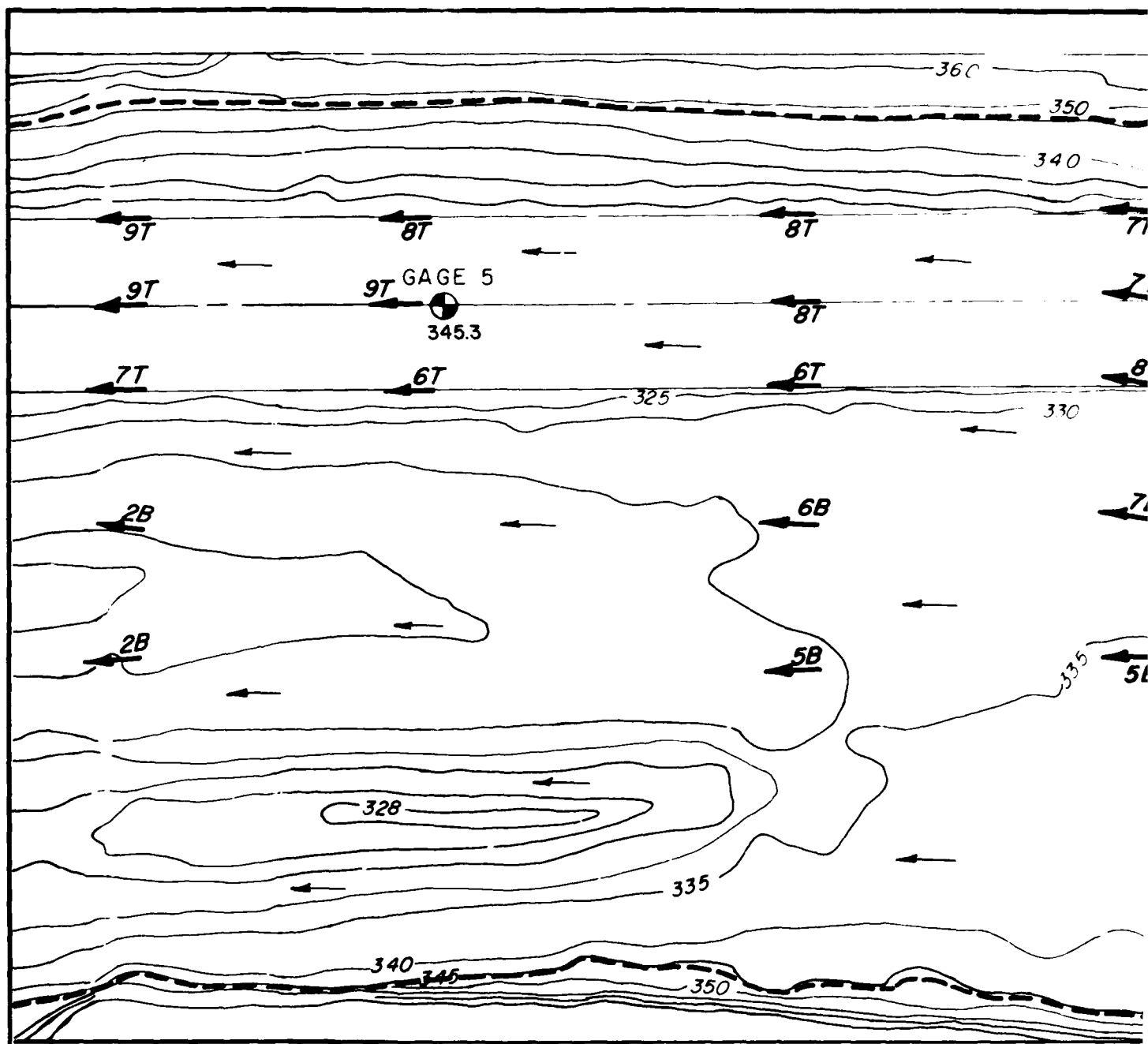
FLOW CONDITIONS

RIVER DISCHARGE 220 000 CFS

MCNARY POOL EL 335

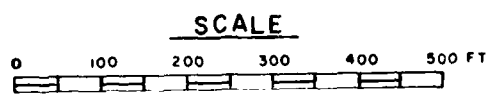
PLATE 19

4



LEGEND

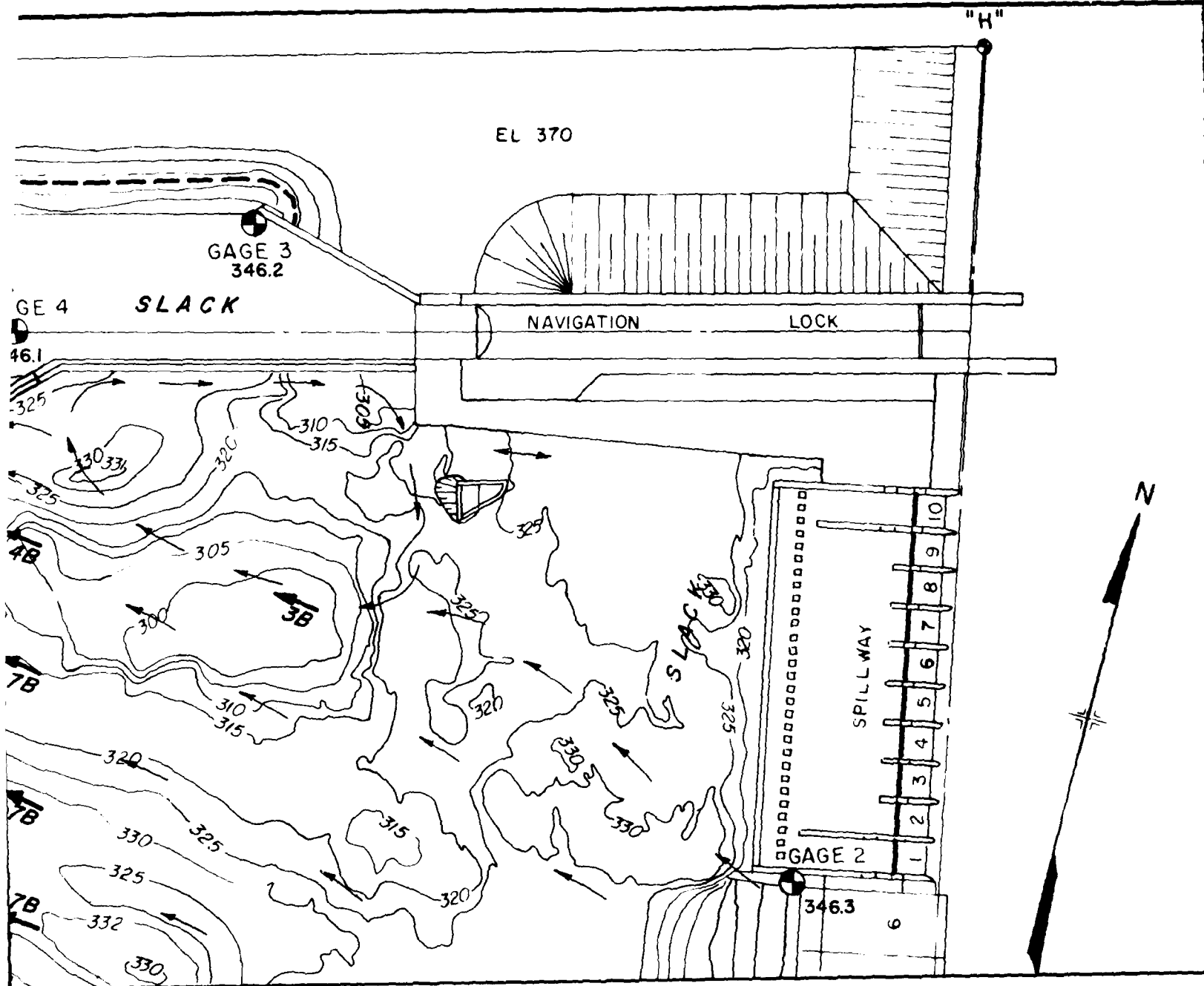
- 4 VELOCITIES IN FPS
- T 5-FT DEPTH
- B 5 FT ABOVE BOTTOM



FLOW DISTRIBUTION

- SPILLWAY BAYS 1 TO 10
- POWERHOUSE UNITS 1 TO 3
- POWERHOUSE UNITS 4 TO 6

2



UTION

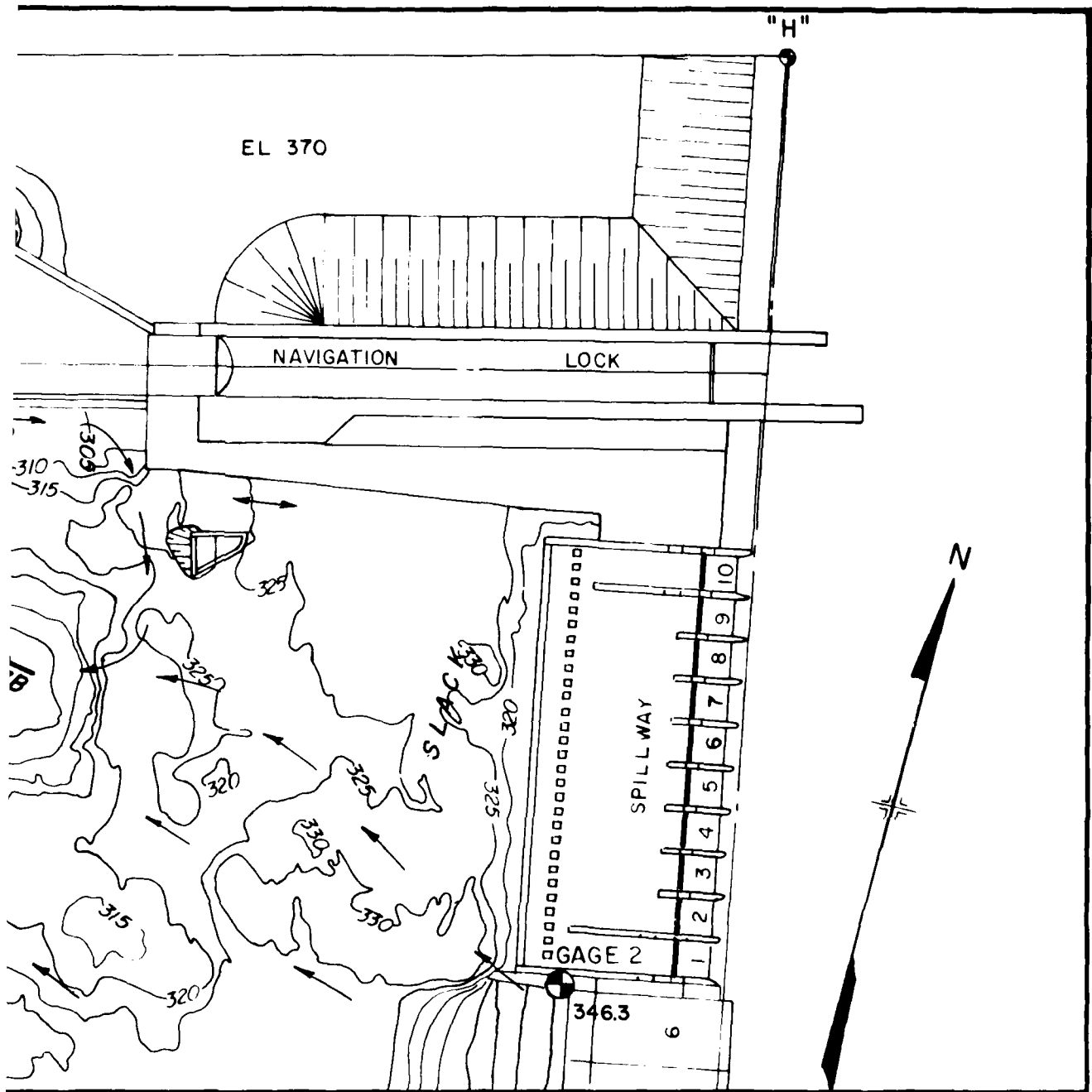
CLOSED
 43 300 CFS
 56 700 CFS

210-FT EXTENSION TO GUIDE WALL

FLOW CONDITIONS
 RIVER DISCHARGE 100 000 CFS
 MCNARY POOL EL 335

3

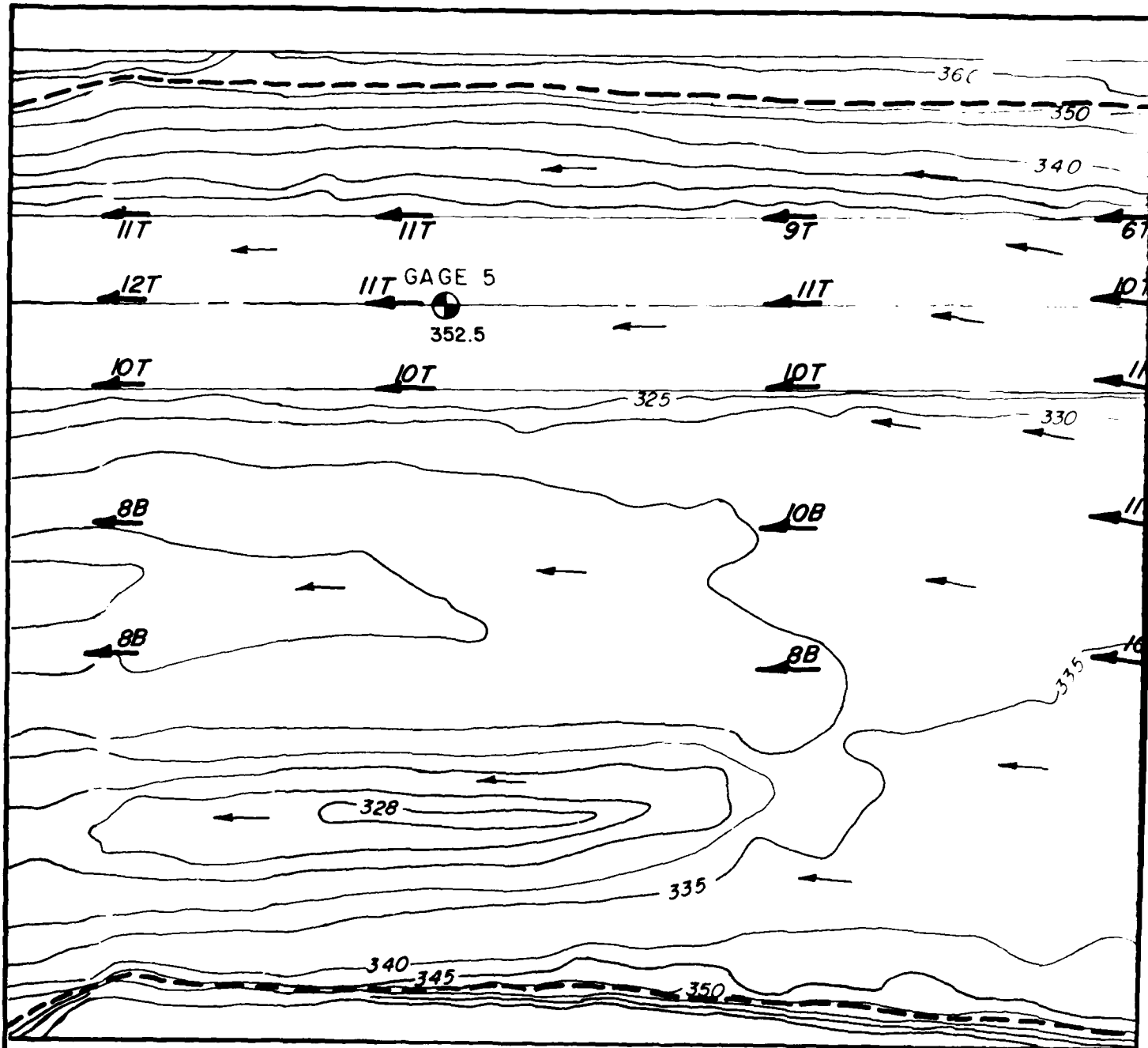
PLAT



210-FT EXTENSION TO GUIDE WALL

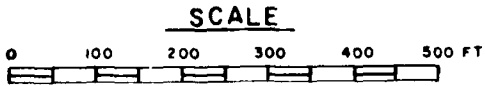
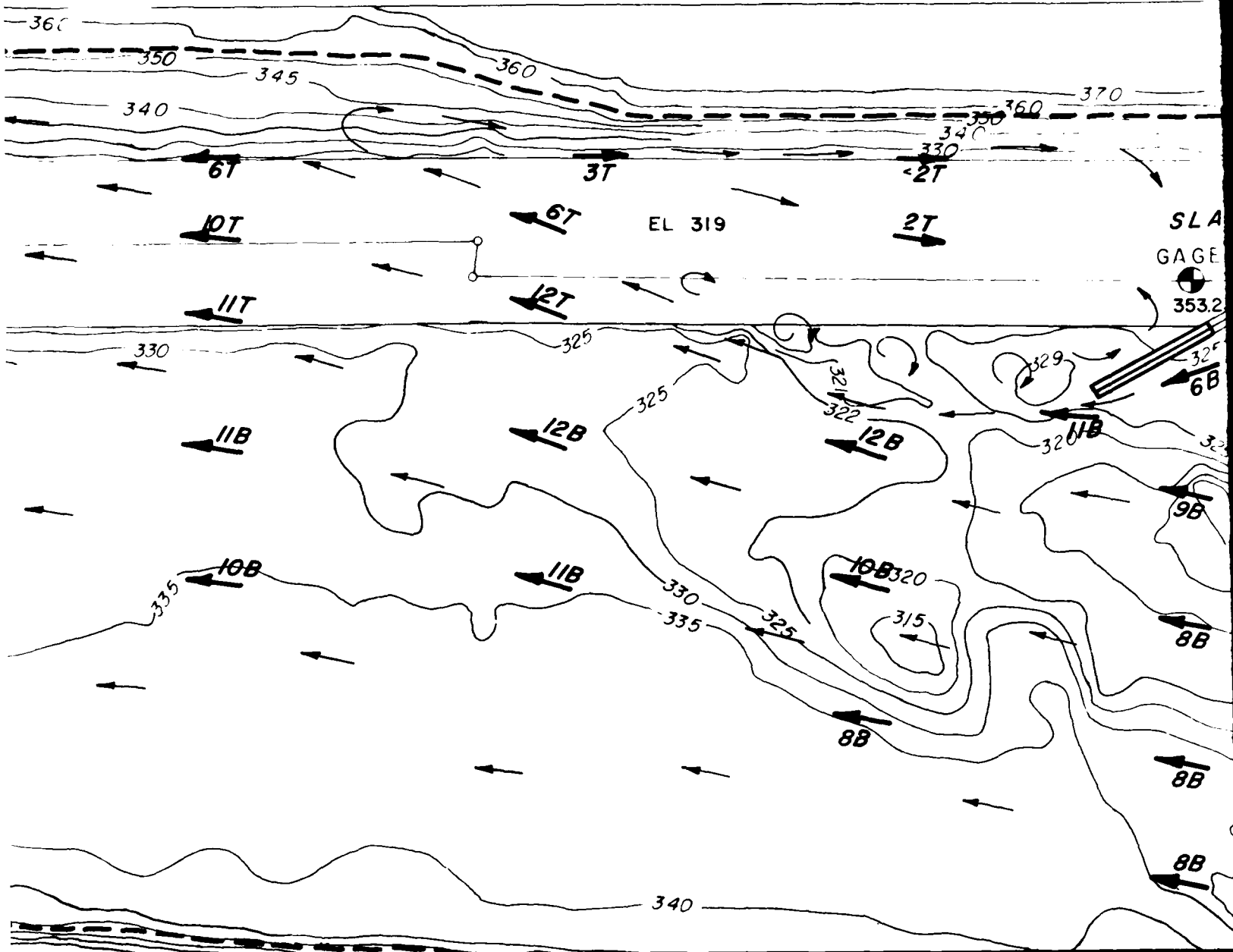
FLOW CONDITIONS
 RIVER DISCHARGE 100 000 CFS
 McNARY POOL EL 335

4



LEGEND

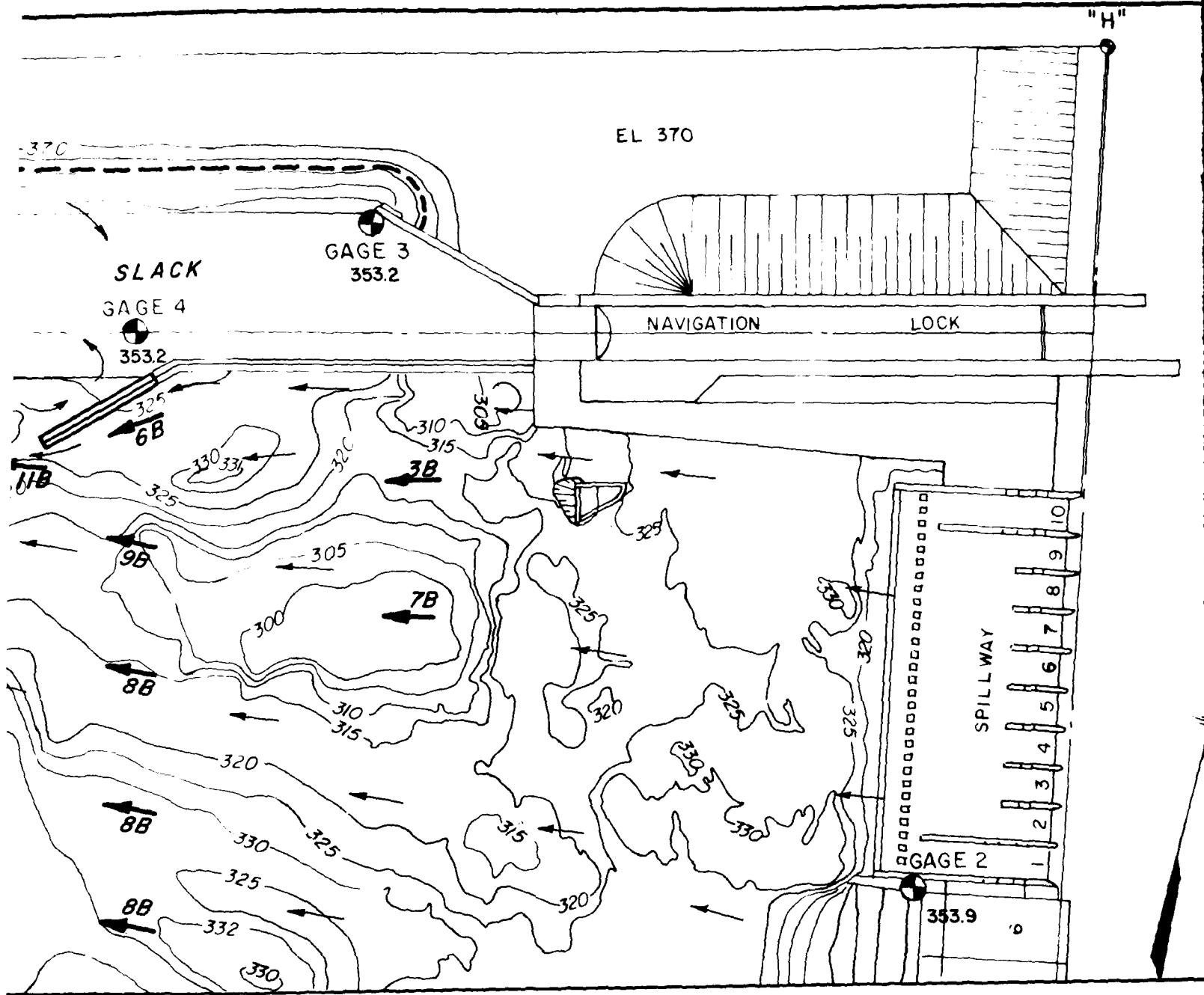
- ← 4 VELOCITIES IN FPS
- T 5-FT DEPTH
- B 5 FT ABOVE BOTTOM



FLOW DISTRIBUTION

- SPILLWAY BAYS 1 TO 10
- POWERHOUSE UNITS 1 TO 3
- POWERHOUSE UNITS 4 TO 6

2

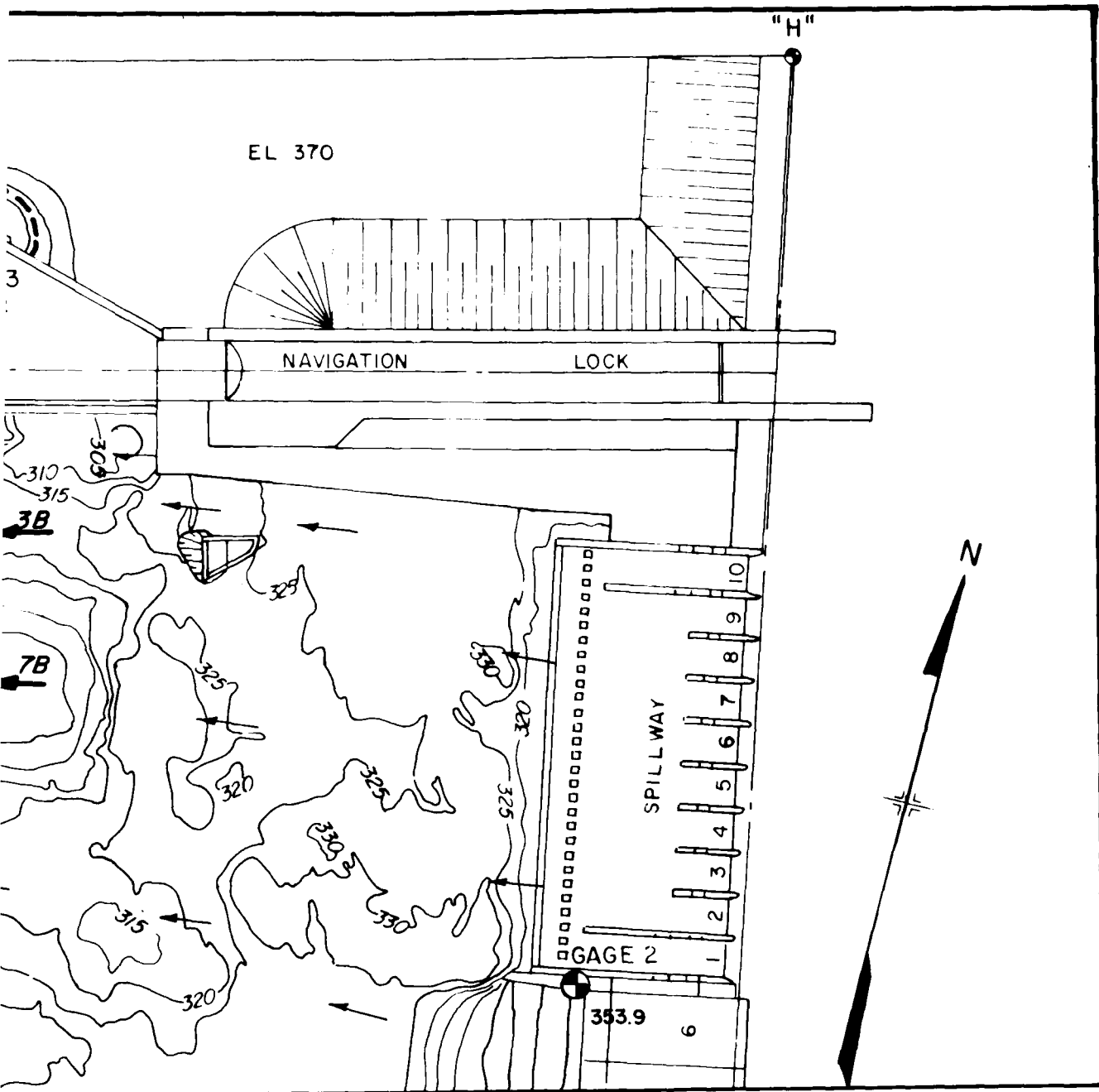


W DISTRIBUTION

TO 10	119 200 CFS
S 1 TO 3	45 300 CFS
S 4 TO 6	55 500 CFS

210-FT EXTENSION TO C

FLOW CONDITI
 RIVER DISCHARGE
 MCNARY

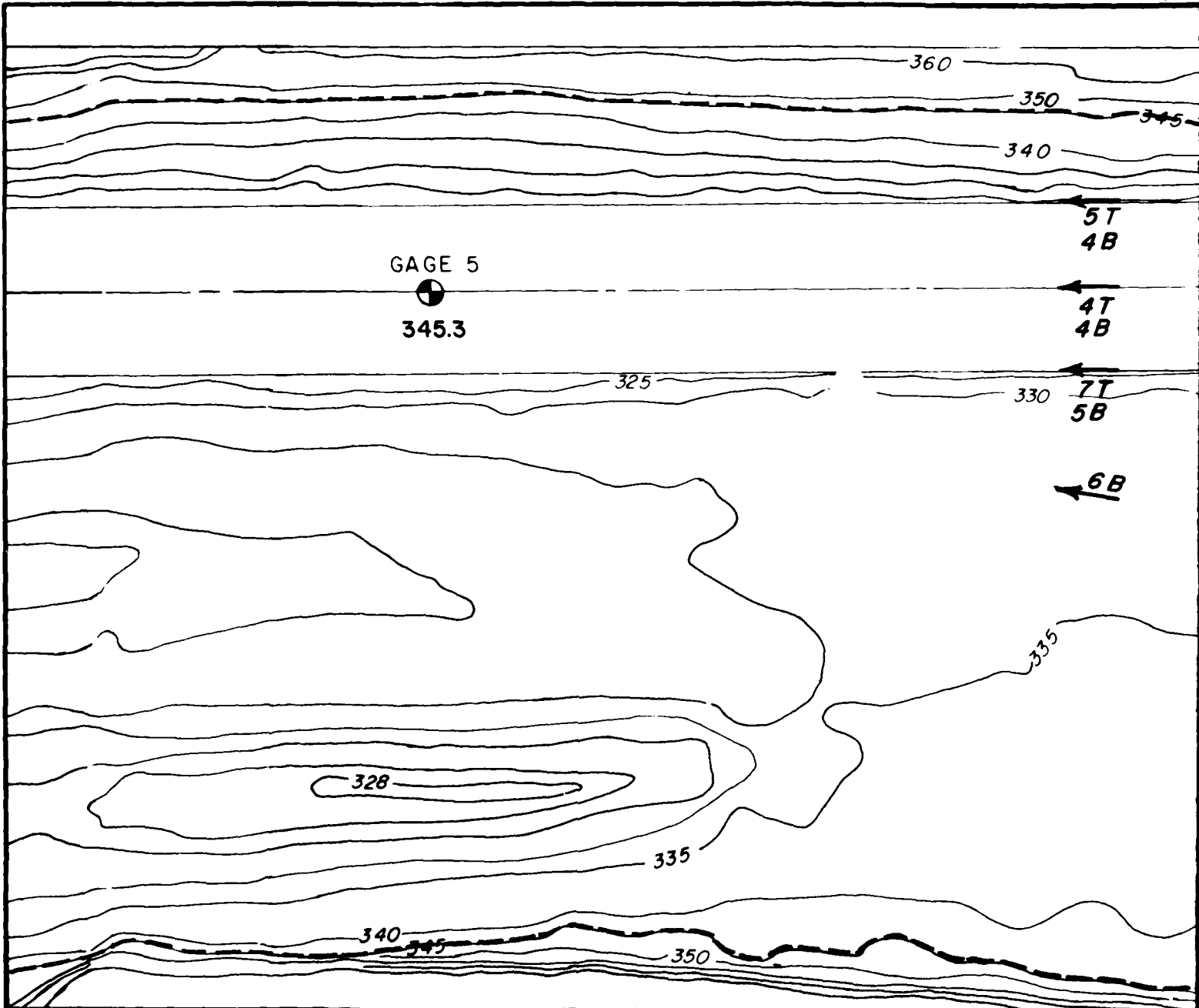


210-FT EXTENSION TO GUIDE WALL

FLOW CONDITIONS

RIVER DISCHARGE 220 000 CFS
McnARY POOL EL 335

PLATE 21



GAGE 5



345.3

5T
4B

4T
4B

7T
5B

6B

325

330

335

320

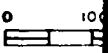
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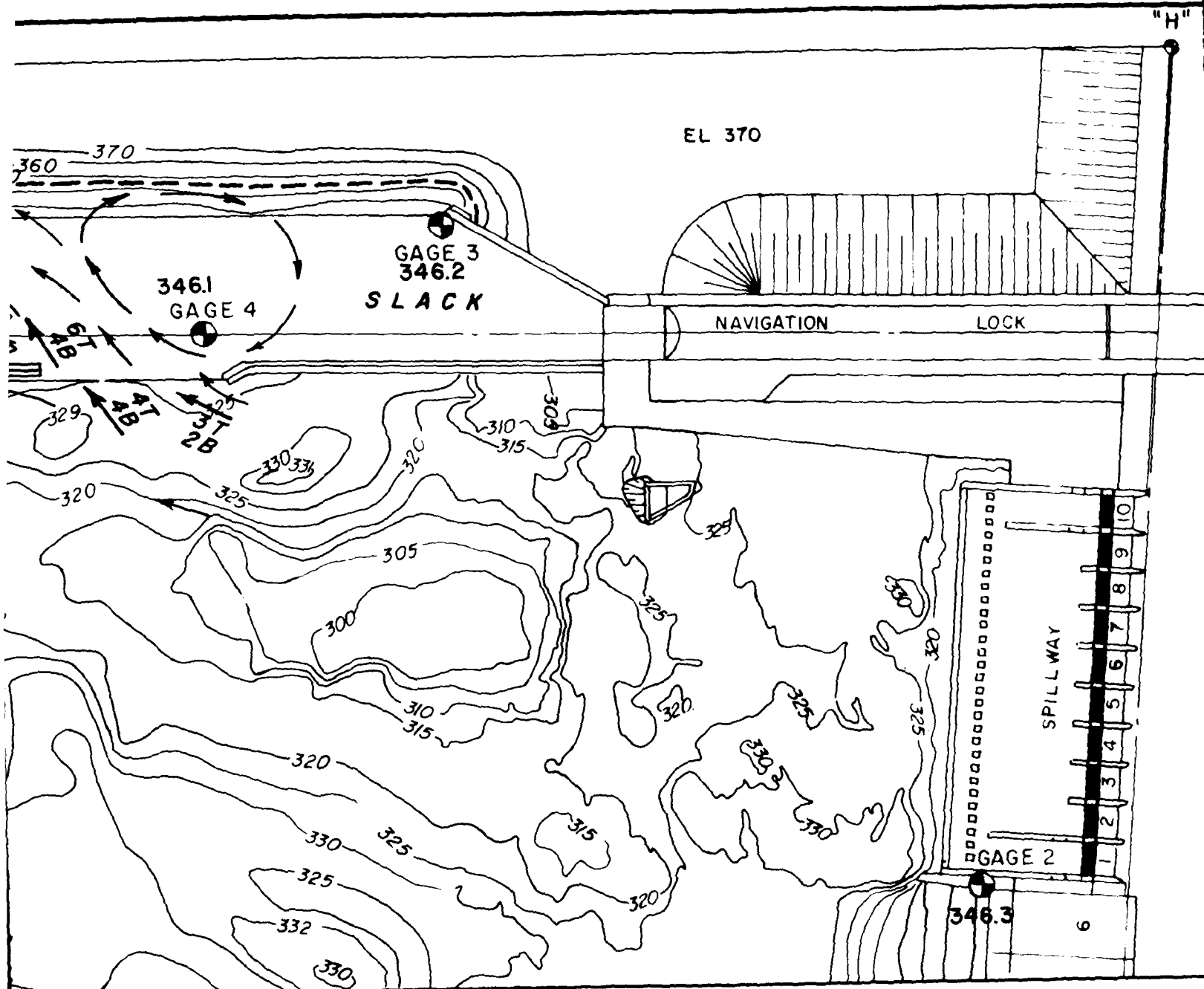
340

350

LEGEND

- ← VELOCITIES IN FPS
- T 5-FT DEPTH
- B 5 FT ABOVE BOTTOM





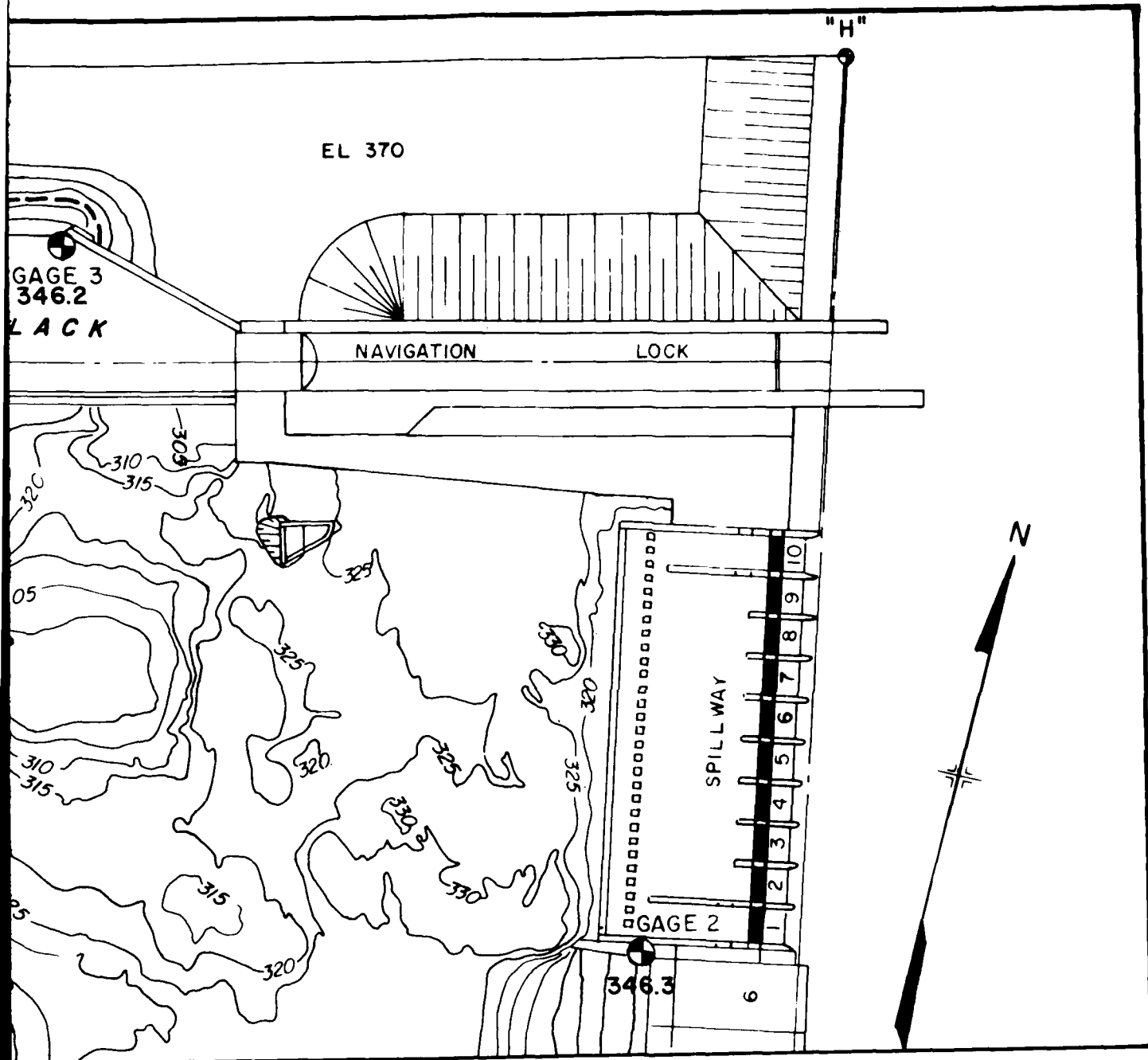
FLOW DISTRIBUTION

WAYS	1 TO 10	CLOSED
E	UNITS 1 TO 3	43 300 CFS
E	UNITS 4 TO 6	56 700 CFS

500-FT WALL WI

FLOW CC

RIVER DISCHAR
M McNARY PO

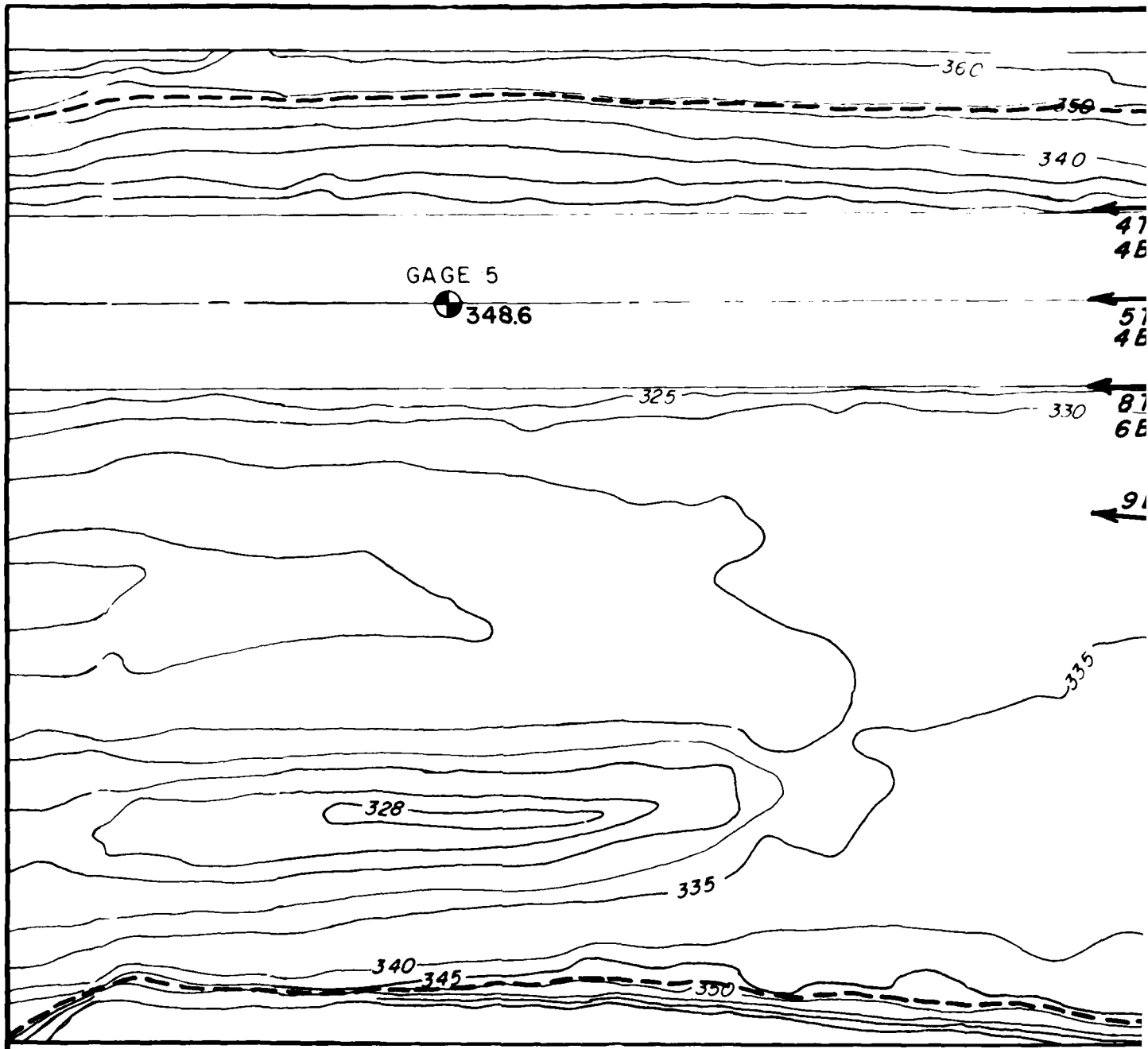


500-FT WALL WITH 300-FT SPACE

FLOW CONDITIONS

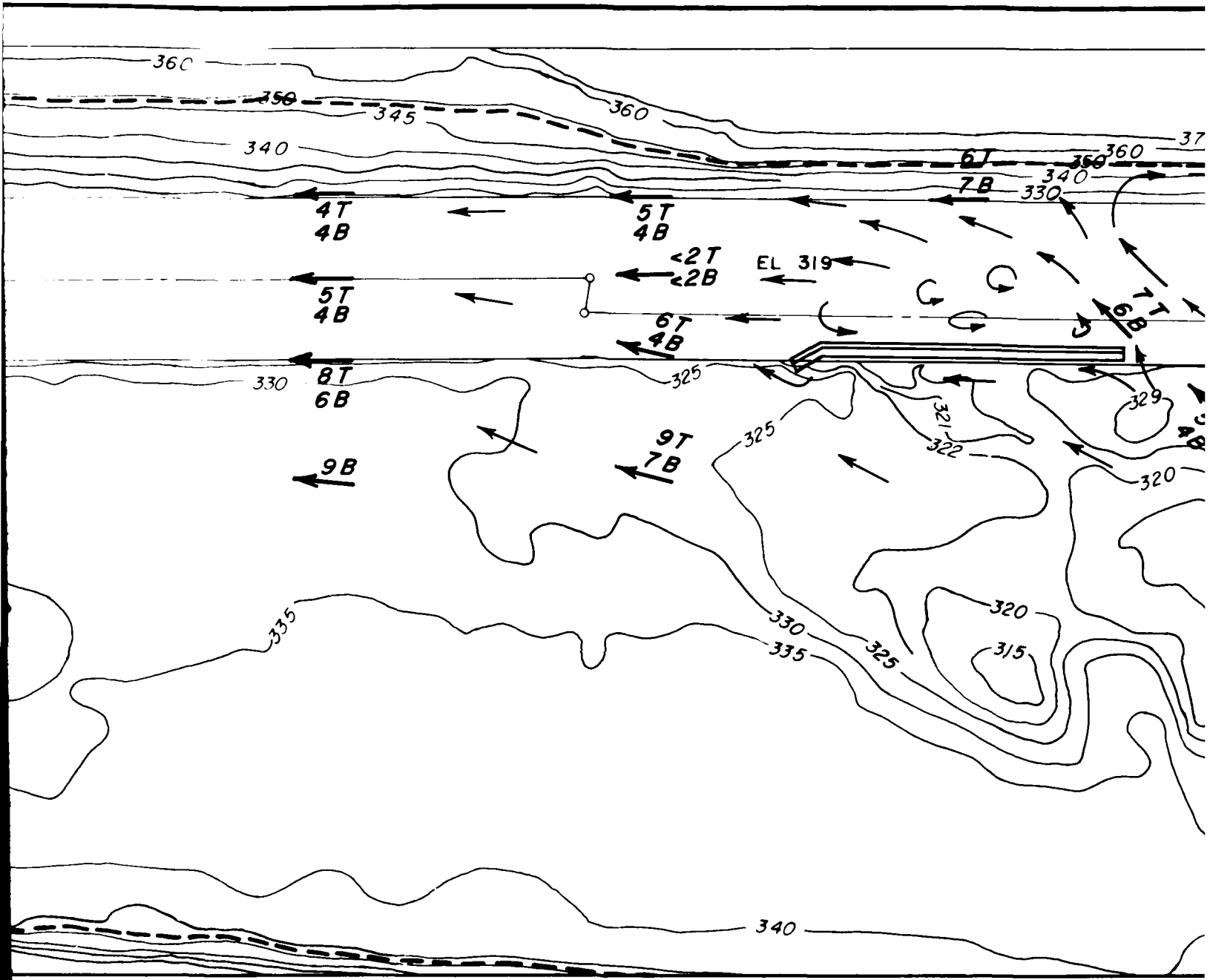
RIVER DISCHARGE 100 000 CFS
 McNARY POOL EL 335

PLATE 22

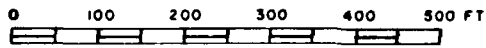


GAGE 5
 ● 348.6

LEGEND
 ← 4 VELOCITIES IN FPS
 T 5-FT DEPTH
 B 5 FT ABOVE BOTTOM



SCALE

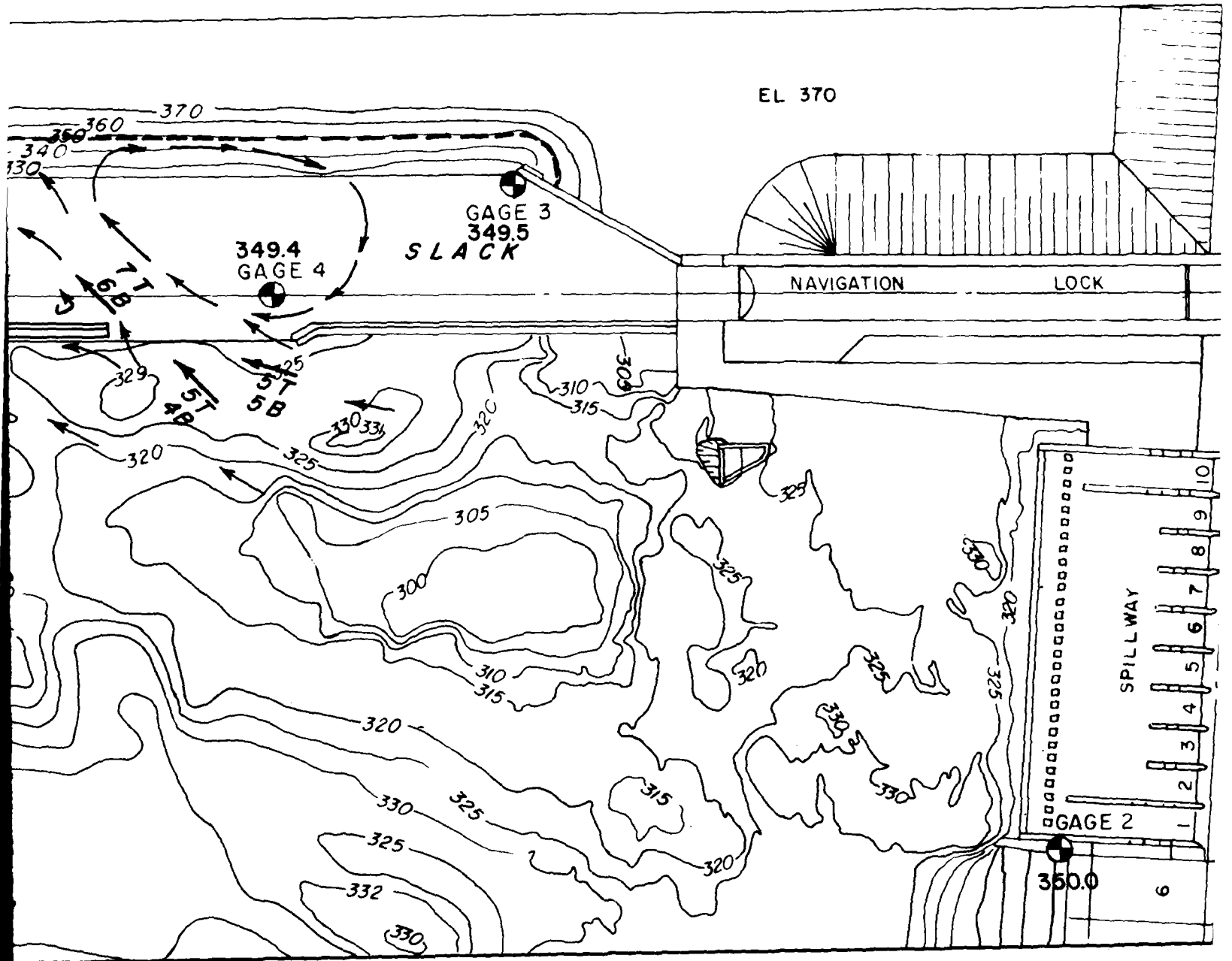


FLOW DI

SPILLWAY BAYS 1 TO 10
 POWERHOUSE UNITS 1 TO
 POWERHOUSE UNITS 4 TO

FPS
 TOM

2



EL 370

GAGE 3
349.5
SLACK

349.4
GAGE 4

NAVIGATION

LOCK

SPILLWAY

GAGE 2

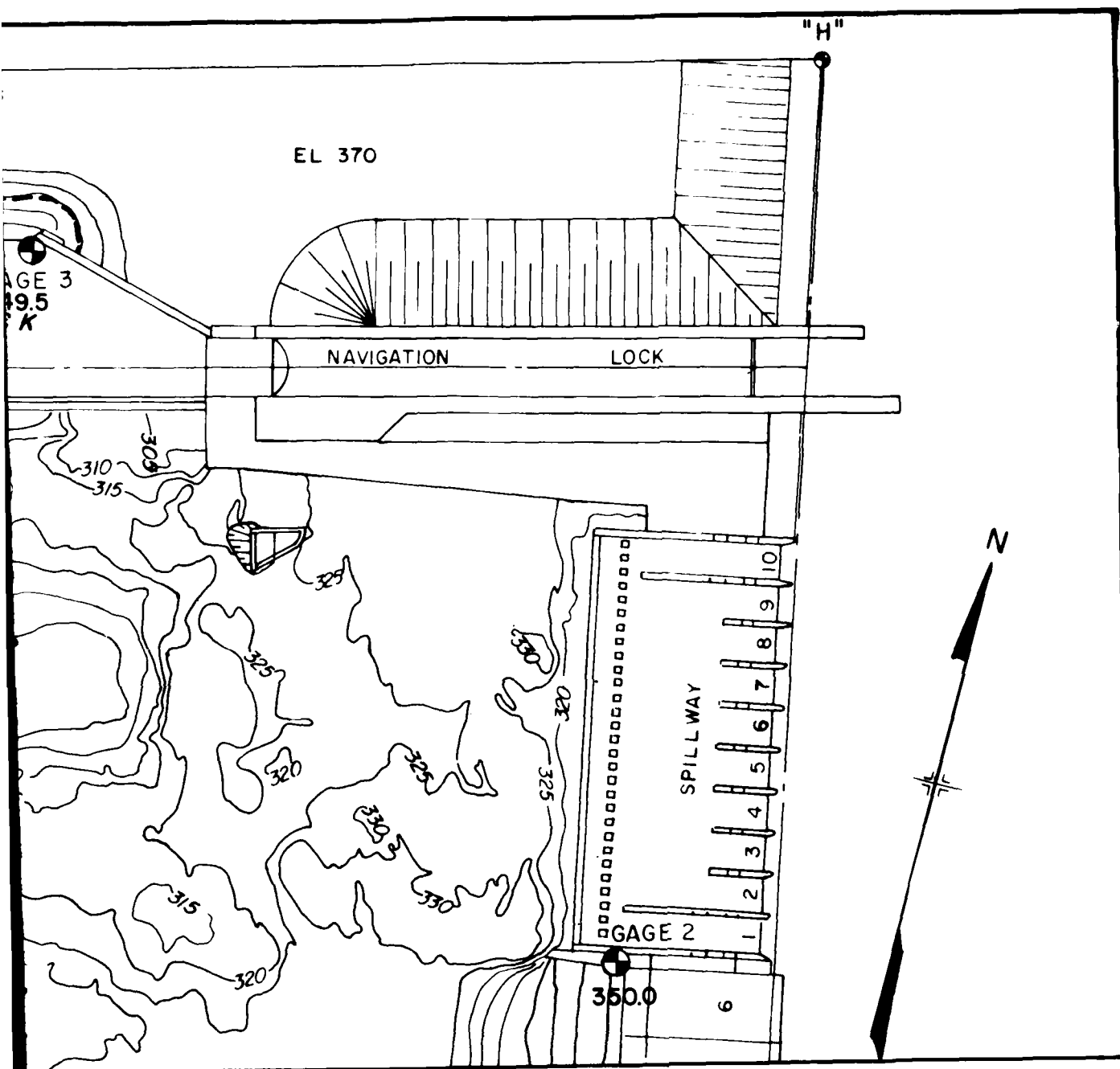
350.0

FLOW DISTRIBUTION

500-FT WAI

WAY BAYS 1 TO 10	60 000 CFS
ERHOUSE UNITS 1 TO 3	43 300 CFS
ERHOUSE UNITS 4 TO 6	56 700 CFS

FLI
RIVER I
MCN



500-FT WALL WITH 300-FT SPACE

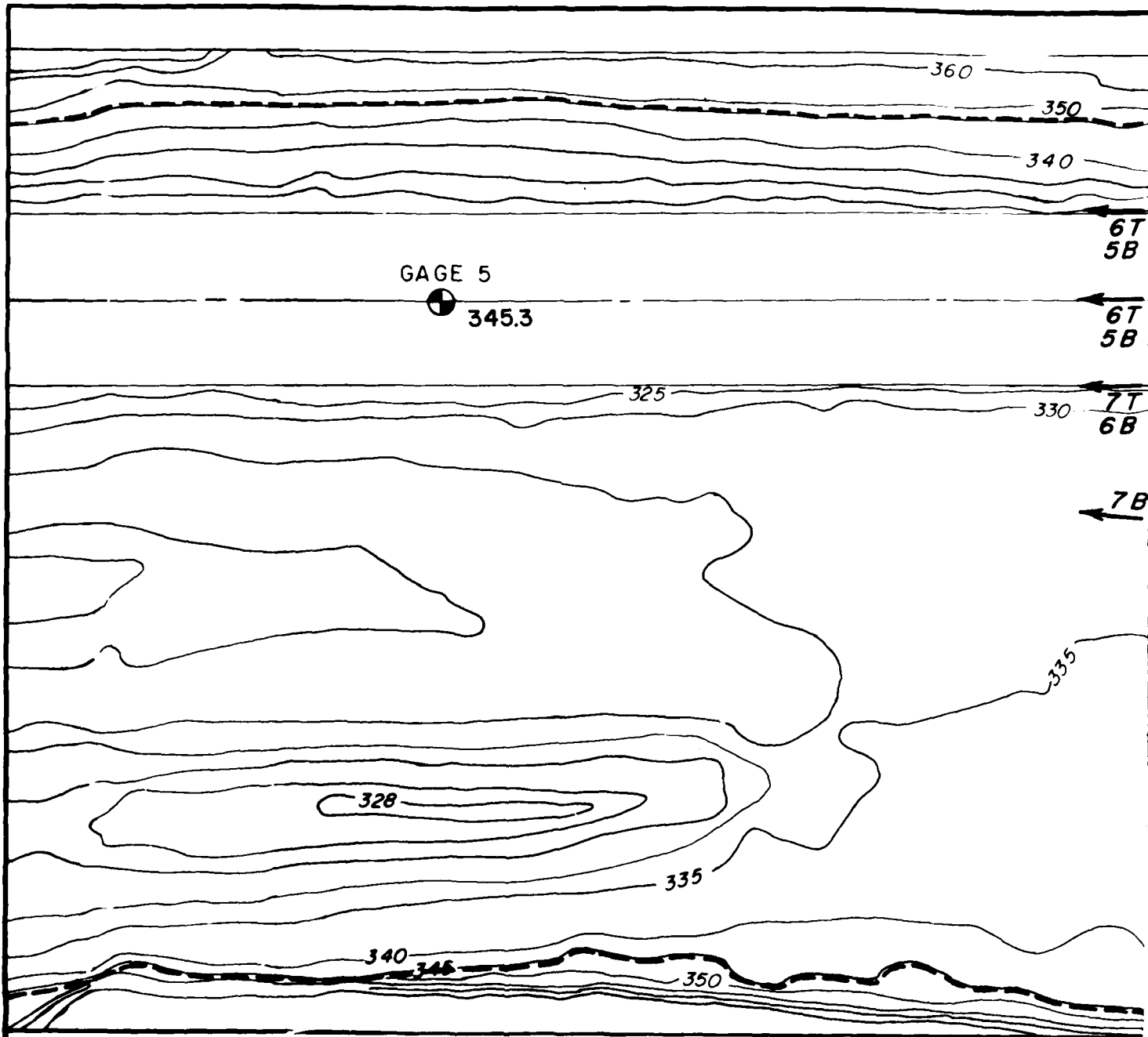
FLOW CONDITIONS

RIVER DISCHARGE 150 000 CFS

McnARY POOL EL 335

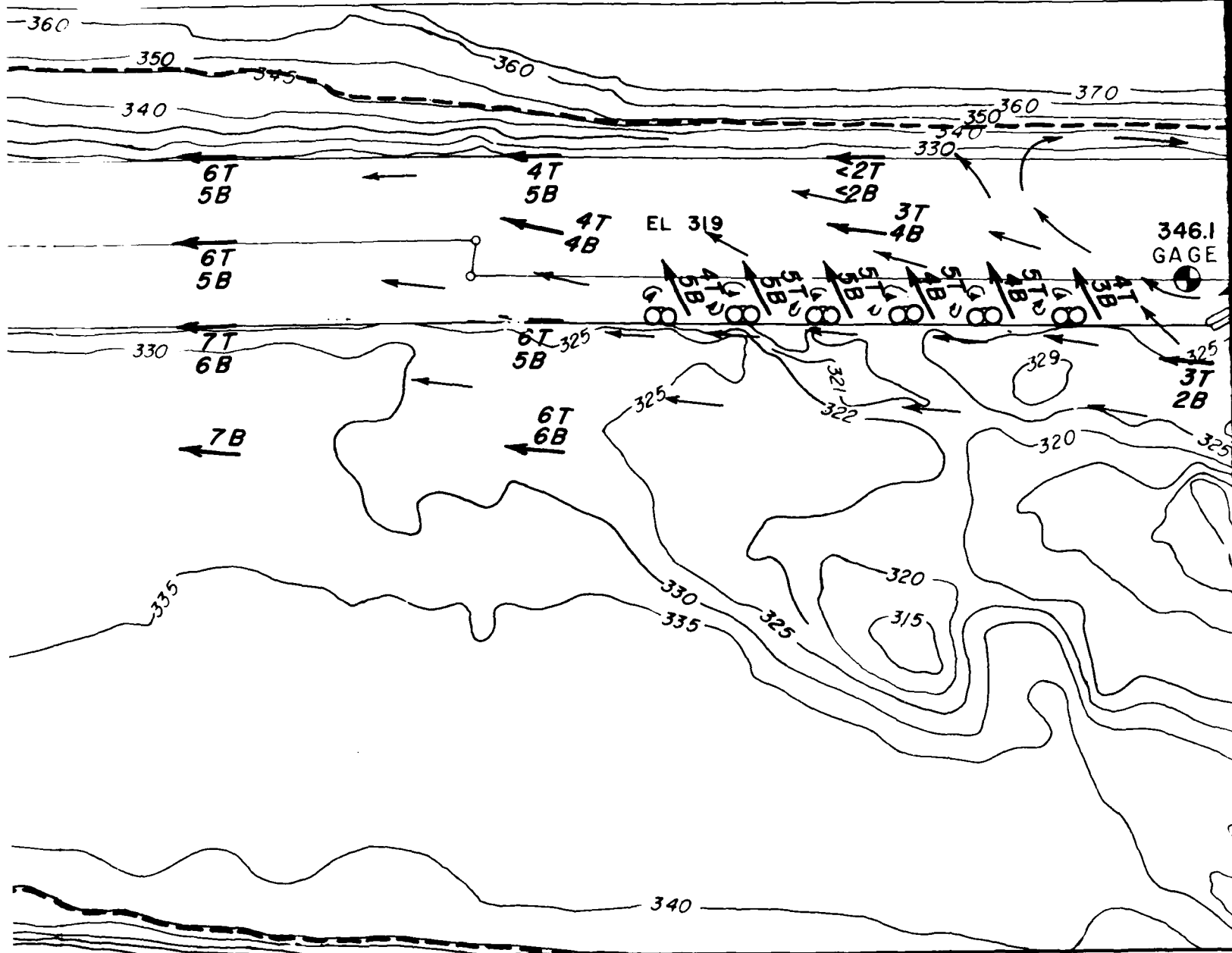
PLATE 23

4

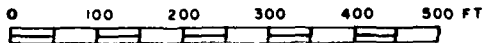


LEGEND

- ← VELOCITIES IN FPS
- T 5-FT DEPTH
- B 5 FT ABOVE BOTTOM



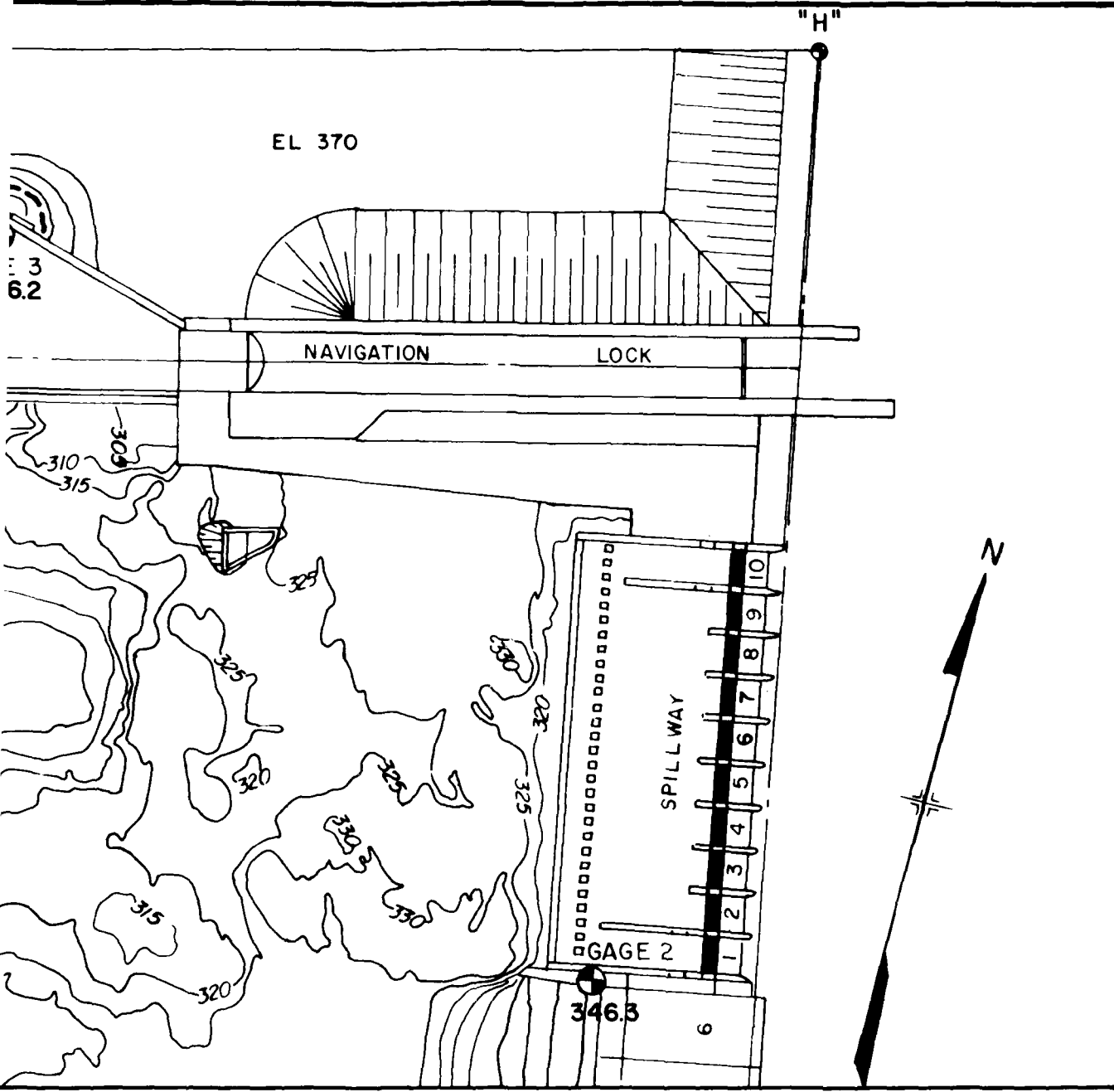
SCALE



FLOW DISTRIBUTION

- SPILLWAY BAYS 1 TO 10
- POWERHOUSE UNITS 1 TO 3
- POWERHOUSE UNITS 4 TO 6

2



SIX UNITS WITH 70-FT SPACING

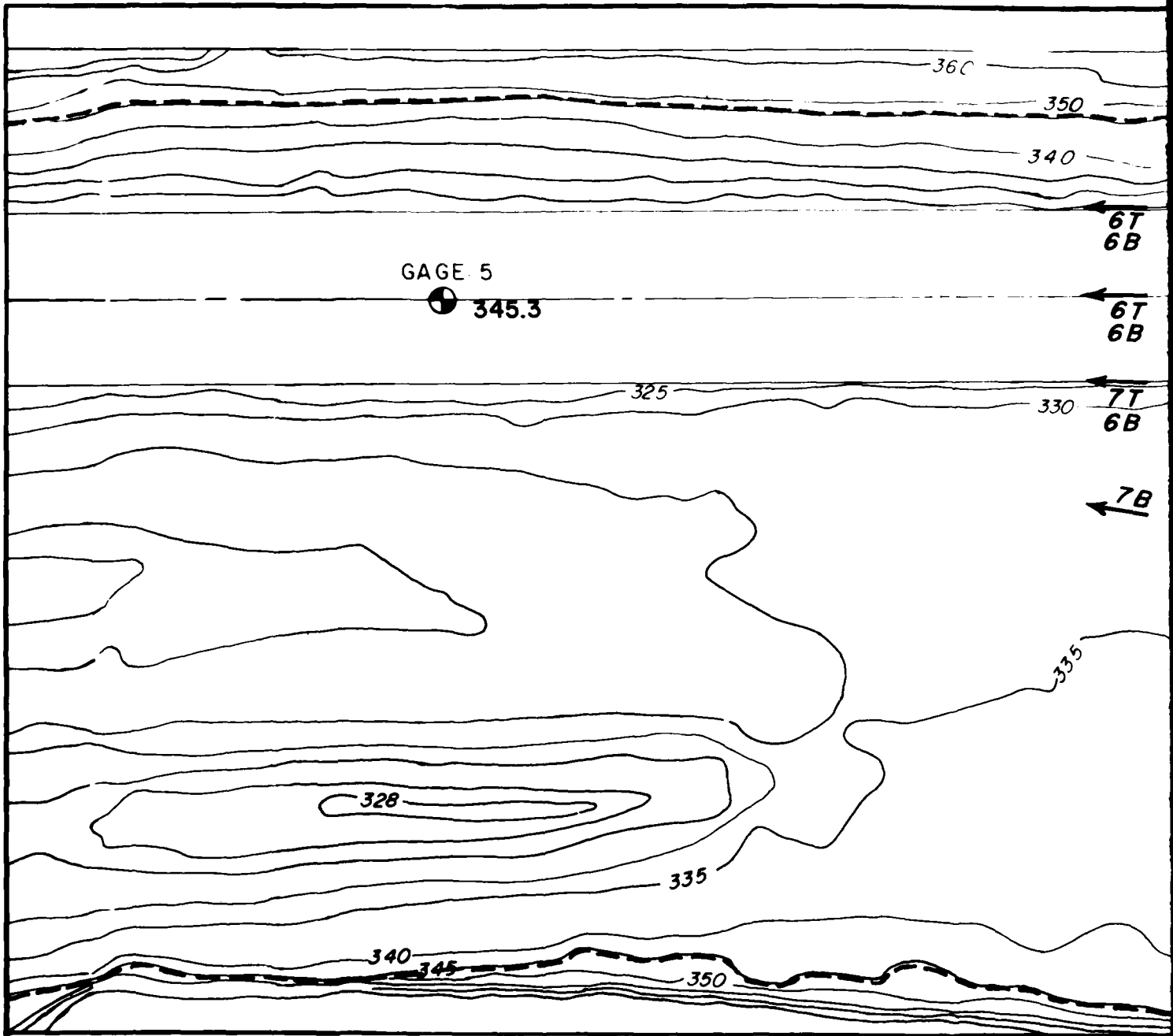
FLOW CONDITIONS

RIVER DISCHARGE 100 000 CFS
 McNARY POOL EL 335

PLATE 24

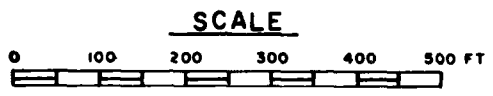
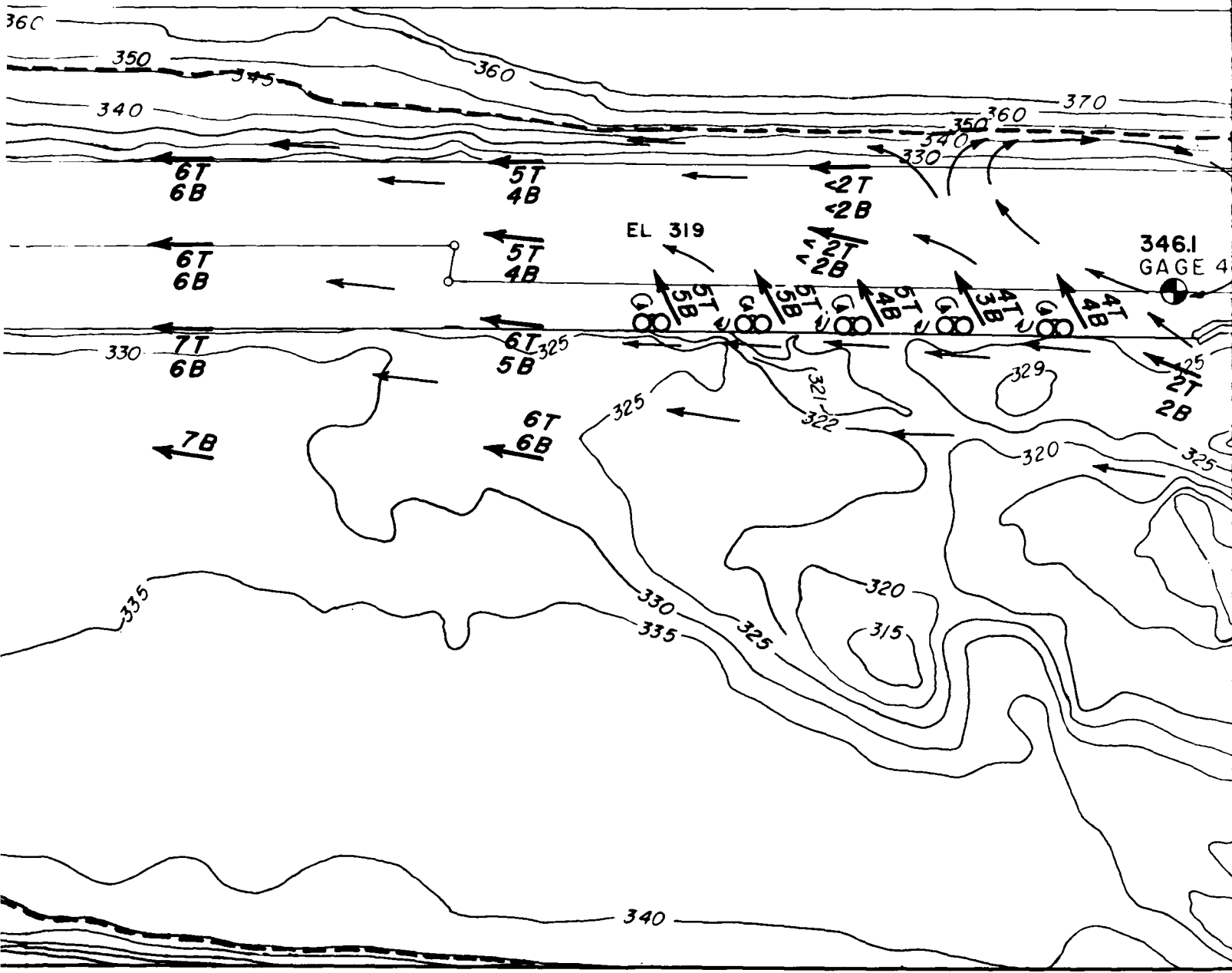
3

4



LEGEND

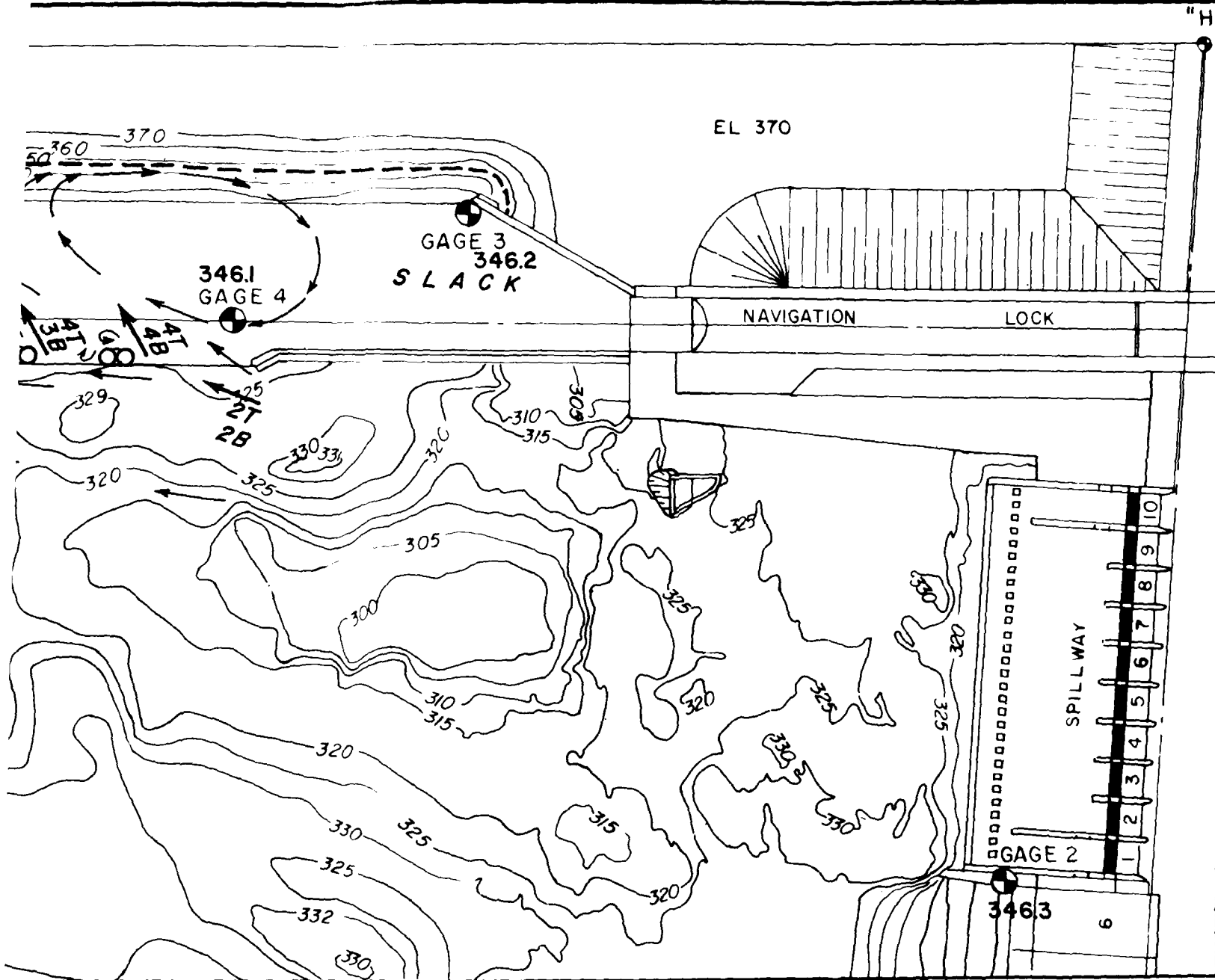
- ← VELOCITIES IN FPS
- T 5-FT DEPTH
- B 5 FT ABOVE BOTTOM



FLOW DISTRIBUTION

- SPILLWAY BAYS 1 TO 10
- POWERHOUSE UNITS 1 TO 3
- POWERHOUSE UNITS 4 TO 6

2

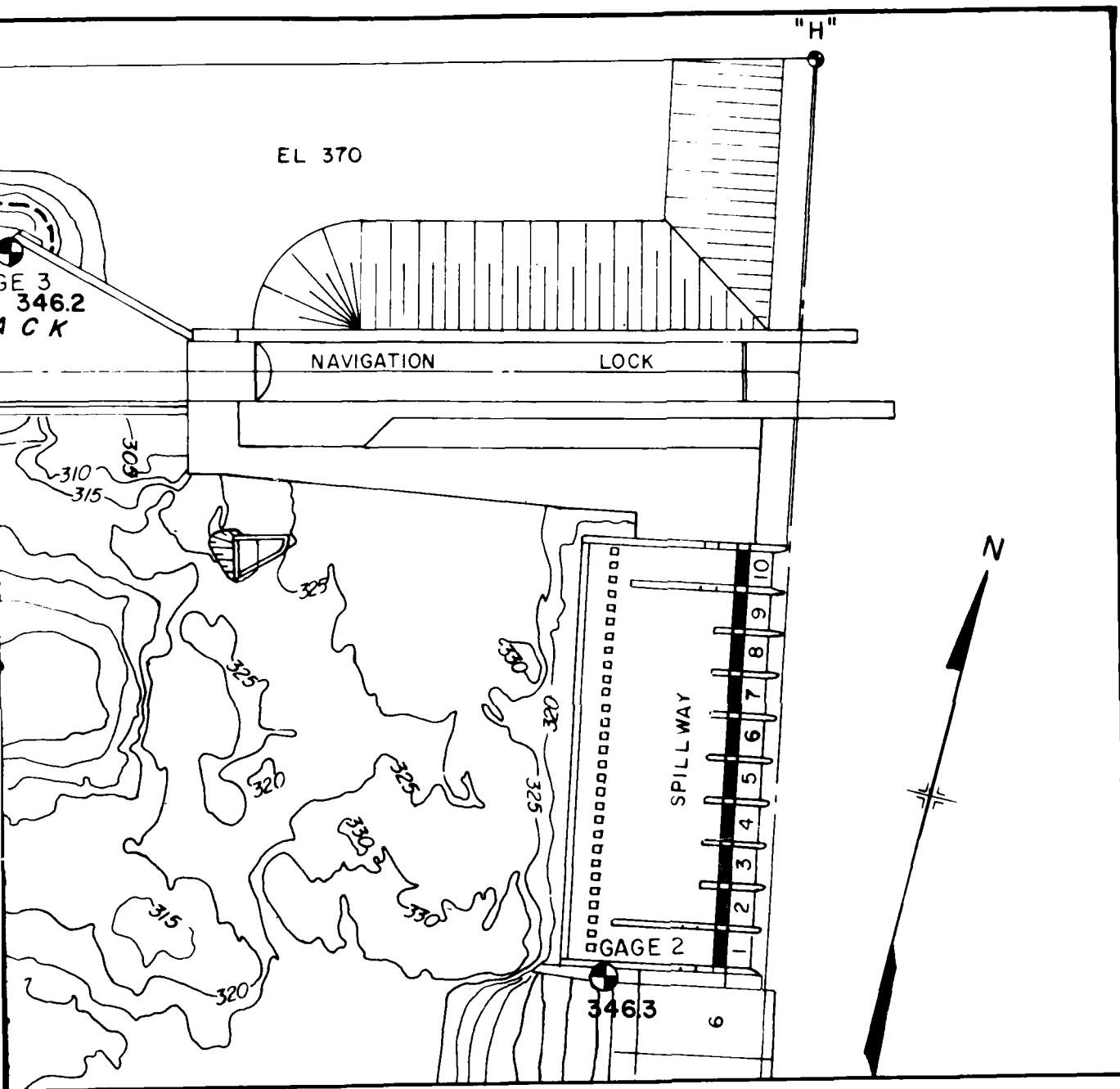


FLOW DISTRIBUTION

BAYS 1 TO 10	CLOSED
USE UNITS 1 TO 3	43 300 CFS
USE UNITS 4 TO 6	56 700 CFS

FIVE UNITS WITH

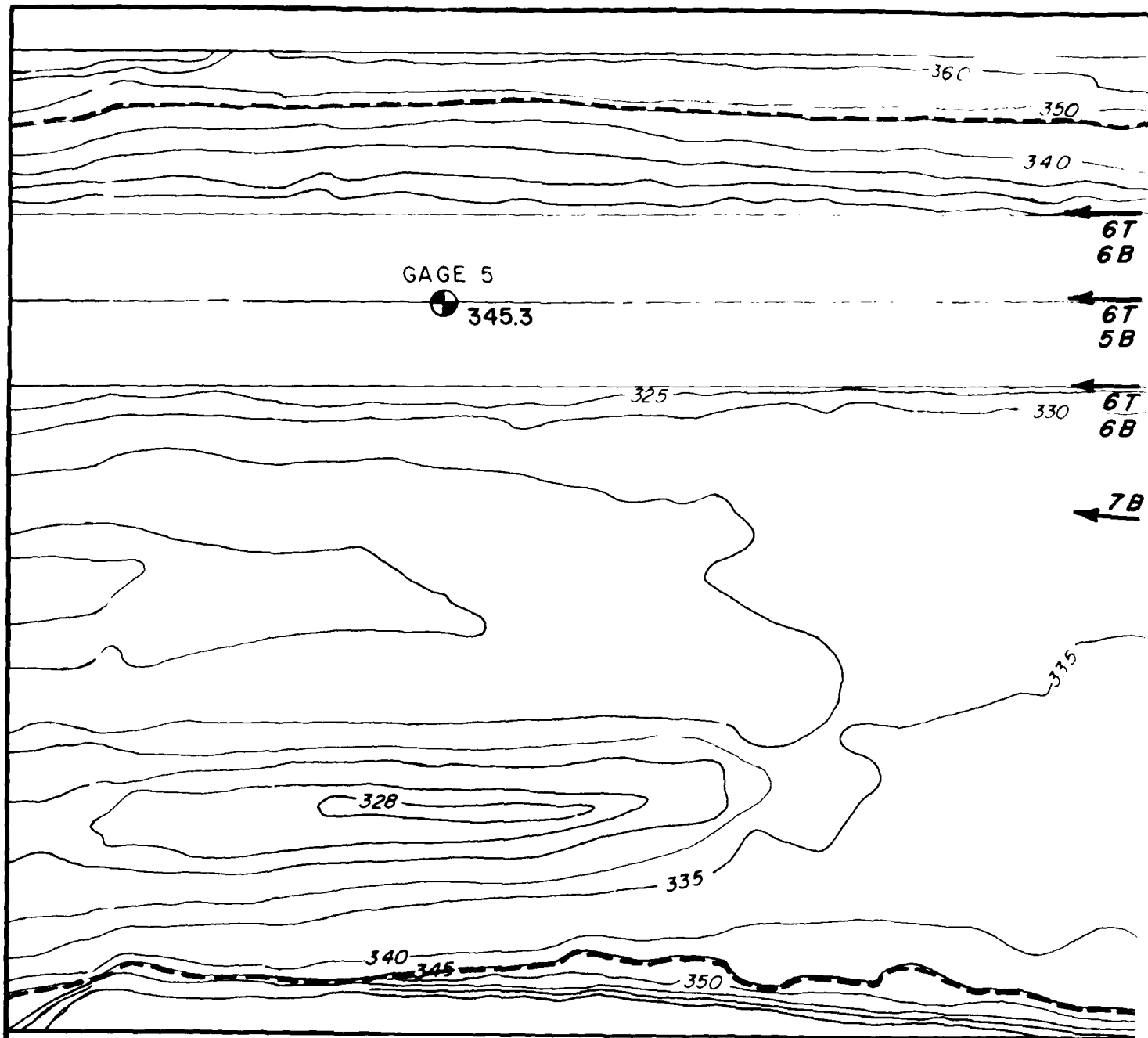
FLOW C
RIVER DISCHA
MCNARY F



FIVE UNITS WITH 100-FT SPACING

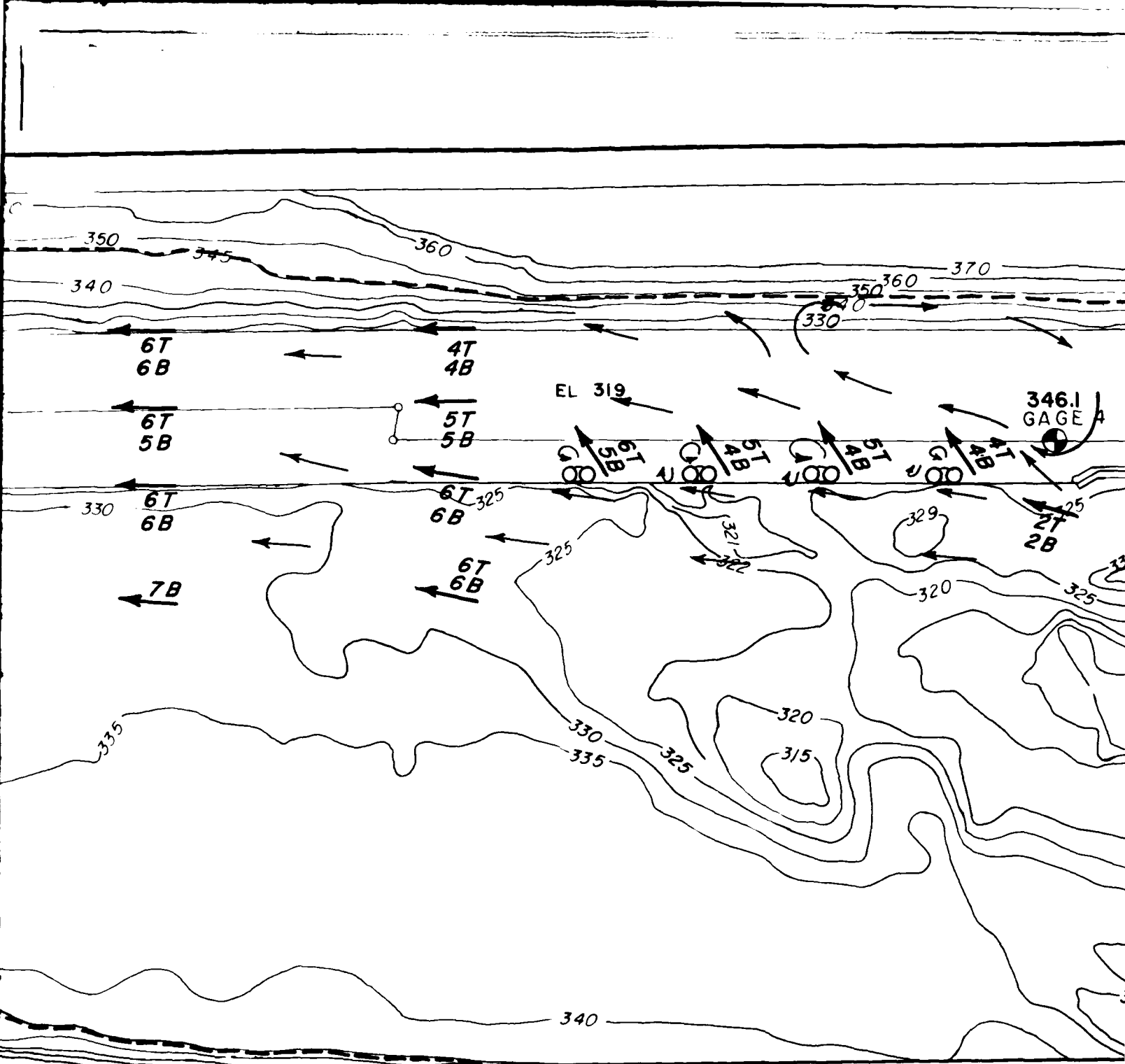
FLOW CONDITIONS
 RIVER DISCHARGE 100 000 CFS
 McNARY POOL EL 335

4

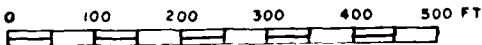


LEGEND

- 4 VELOCITIES IN FPS
- T 5-FT DEPTH
- B 5 FT ABOVE BOTTOM



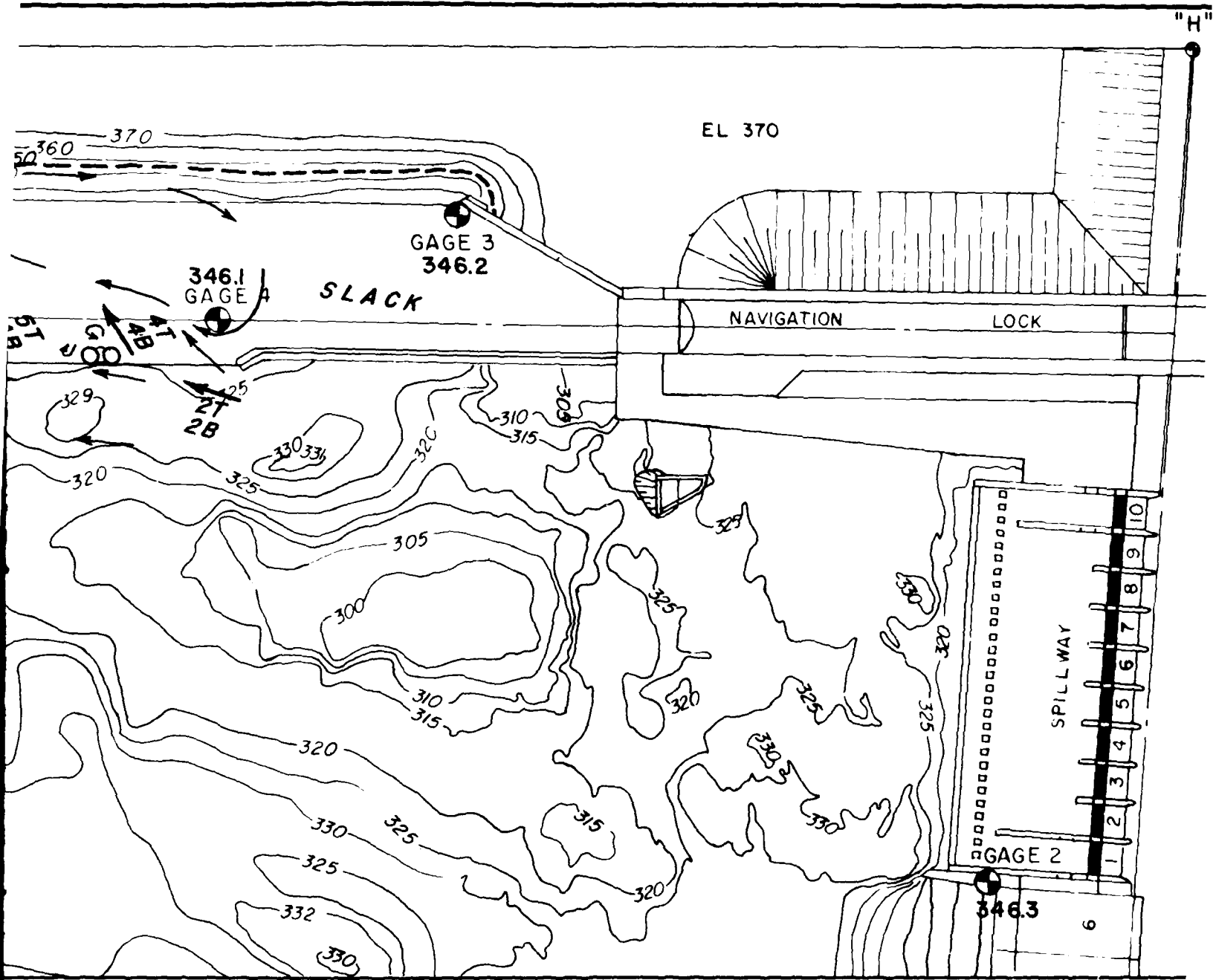
SCALE



FLOW DISTRIBUTION

- SPILLWAY BAYS 1 TO 10
- POWERHOUSE UNITS 1 TO 3
- POWERHOUSE UNITS 4 TO 6

2

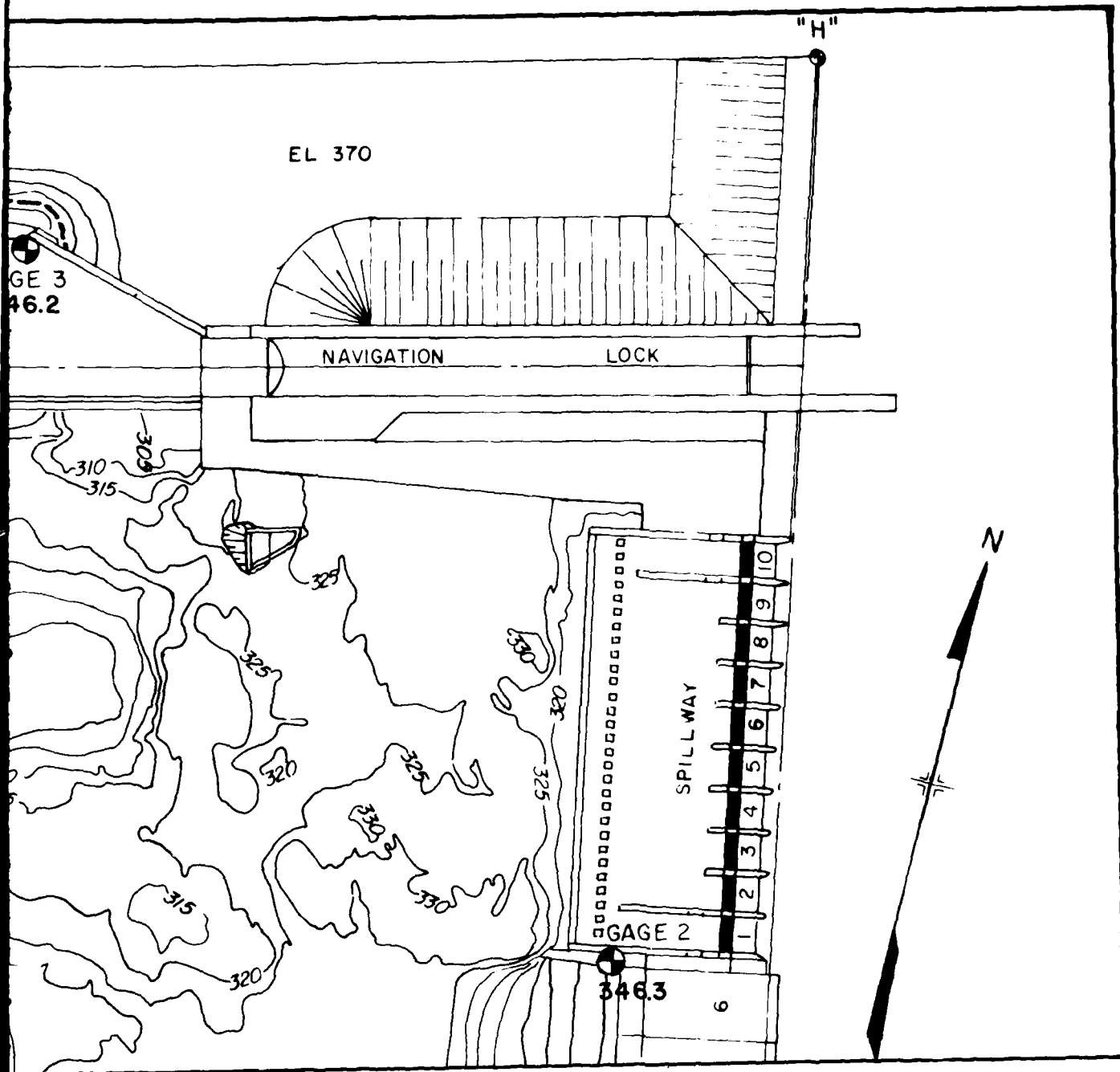


FLOW DISTRIBUTION

BAYS 1 TO 10	CLOSED
USE UNITS 1 TO 3	43 300 CFS
USE UNITS 4 TO 6	56 700 CFS

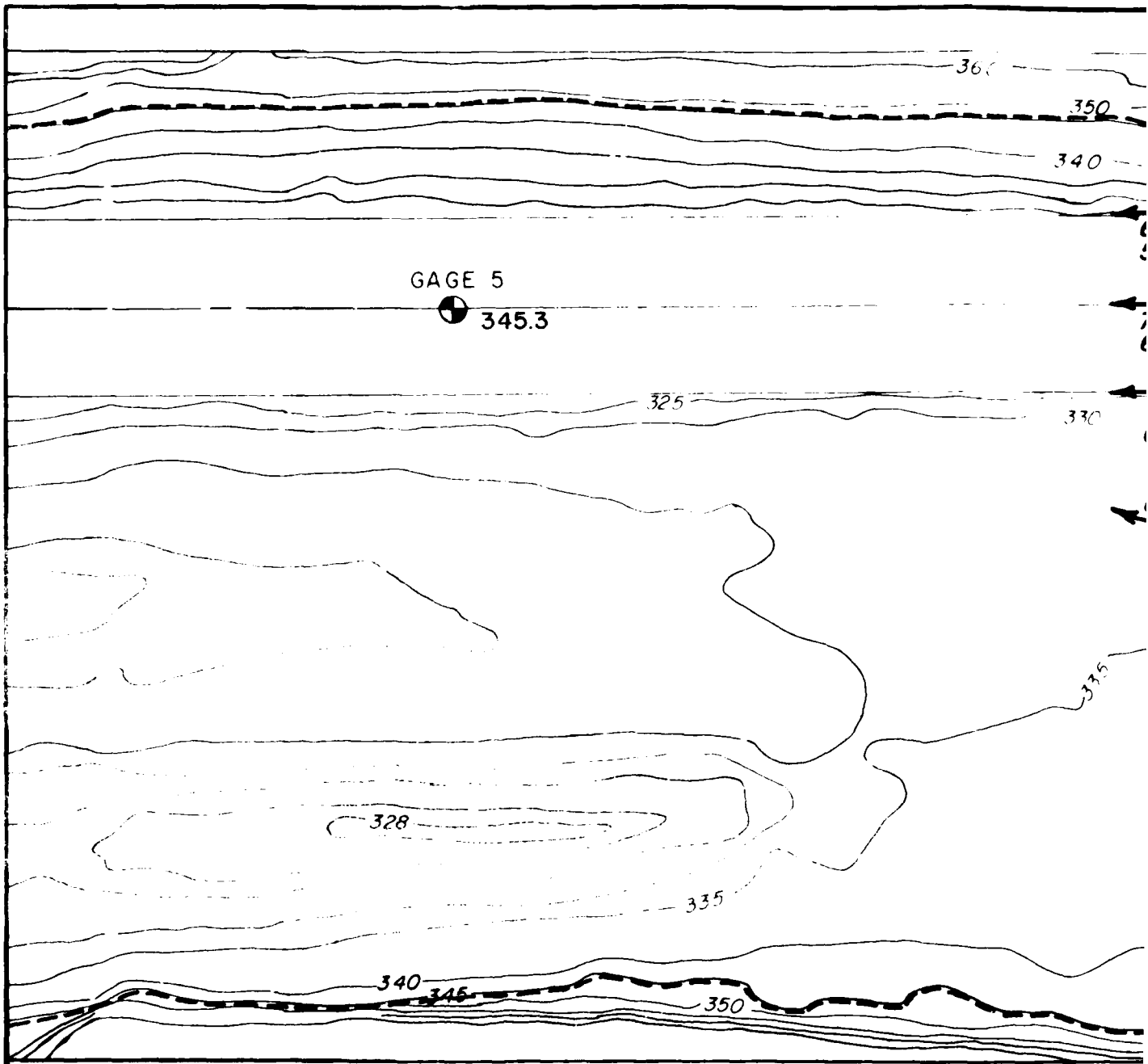
FOUR UNITS WIT

FLOW
RIVER DISCH
MCNARY



FOUR UNITS WITH 150-FT SPACING

FLOW CONDITIONS
 RIVER DISCHARGE 100 000 CFS
 McNARY POOL EL 335



GAGE 5

345.3

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340

345

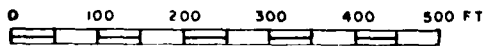
350

LEGEND

- 4 VELOCITIES IN FPS
- T 5-FT DEPTH
- B 5 FT ABOVE BOTTOM



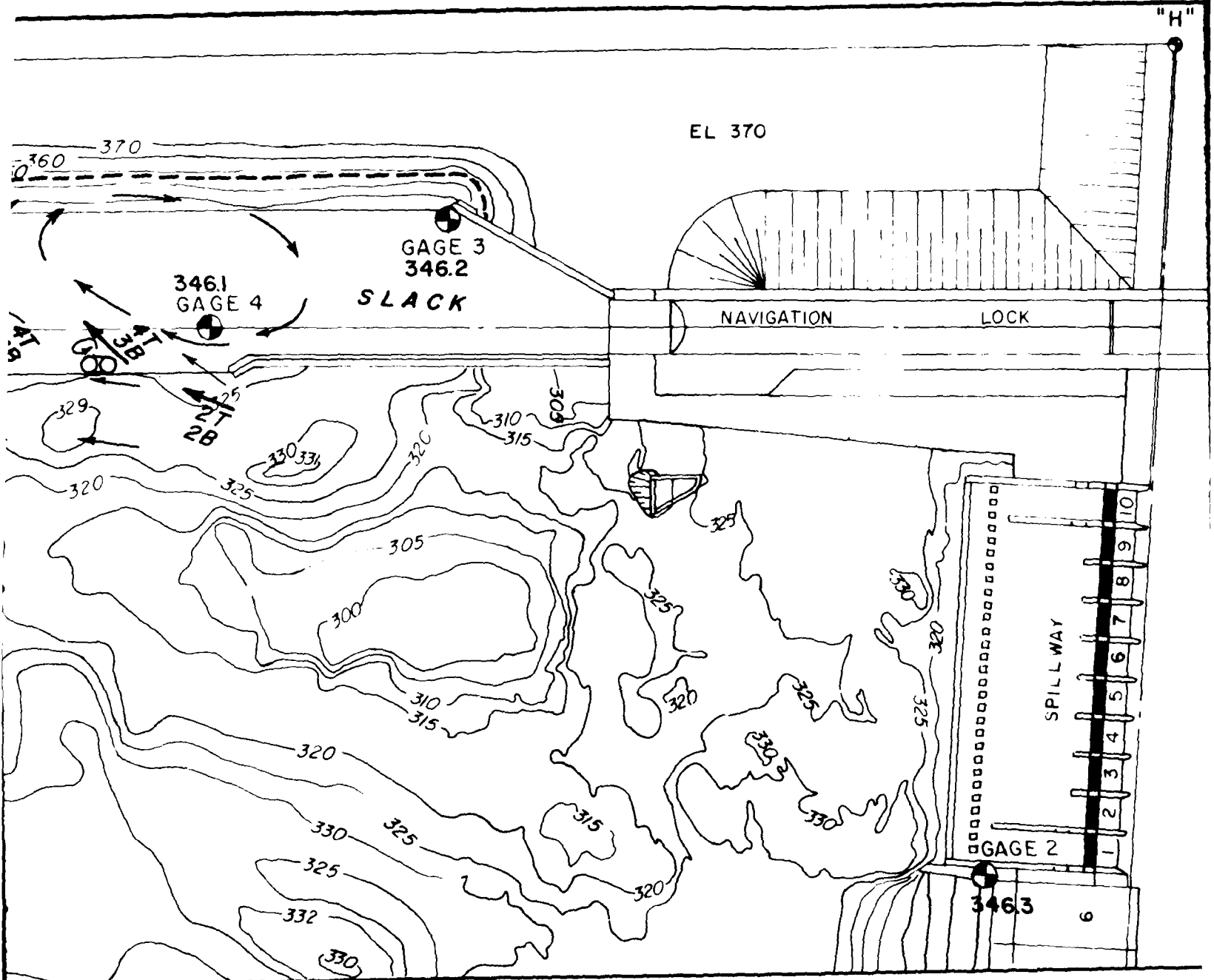
SCALE



FLOW DISTRIE

SPILLWAY BAYS 1 TO 10
 POWERHOUSE UNITS 1 TO 3
 POWERHOUSE UNITS 4 TO 6

2

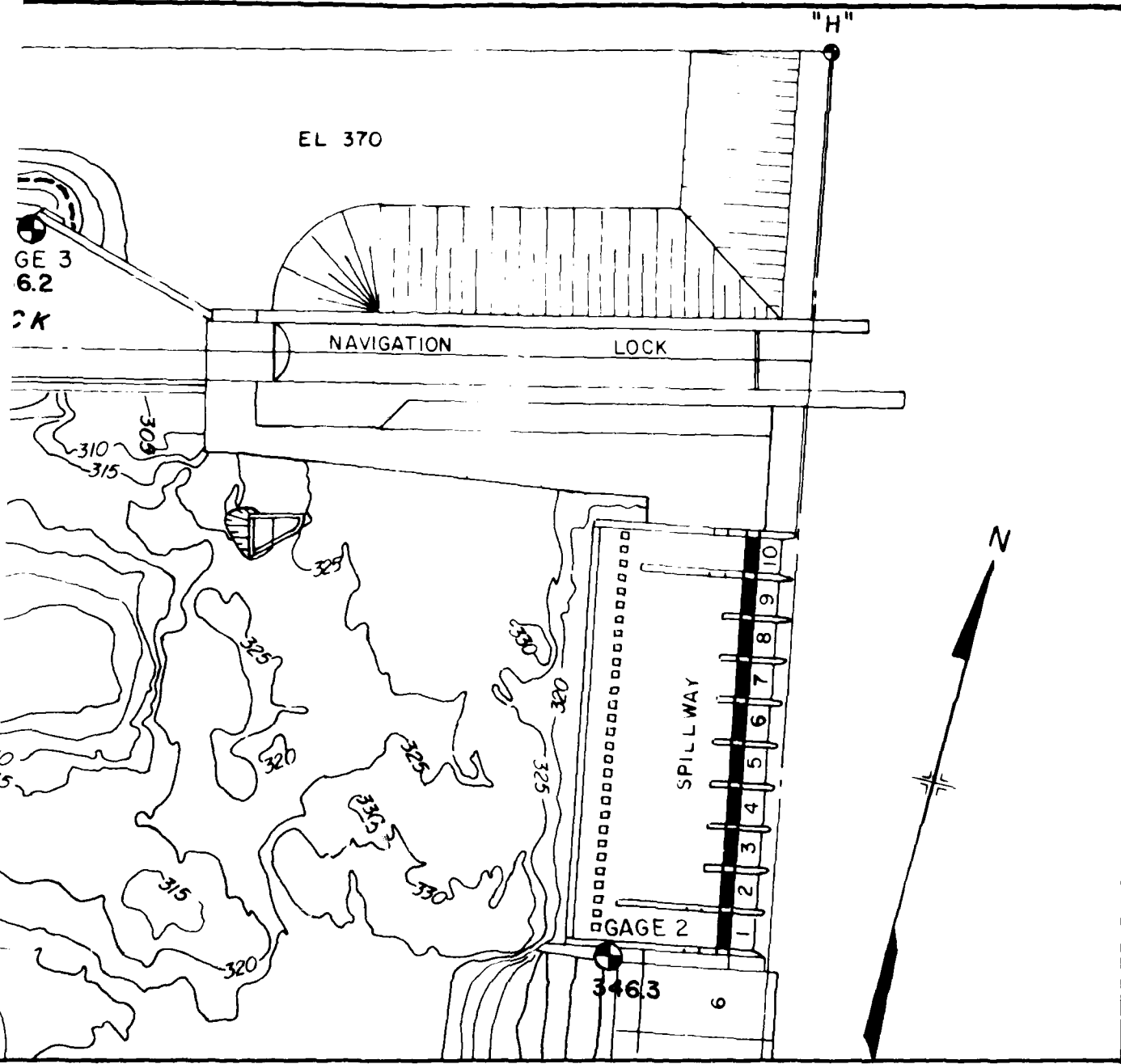


FLOW DISTRIBUTION

BAYS 1 TO 10	CLOSED
USE UNITS 1 TO 3	43 300 CFS
USE UNITS 4 TO 6	56 700 CFS

THREE UNITS WITH

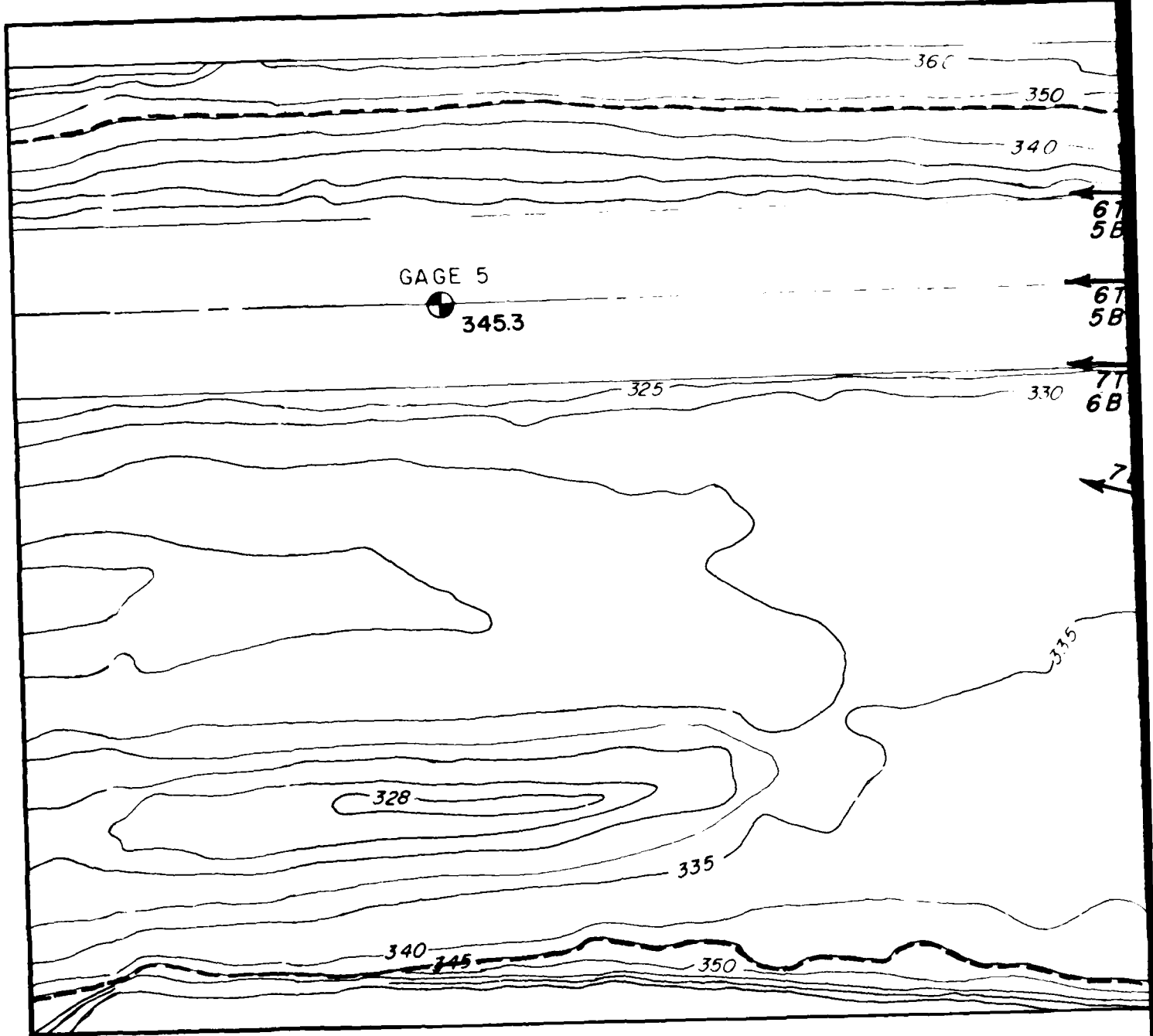
FLOW C
RIVER DISCHAI
MCNARY P



THREE UNITS WITH 150-FT SPACING

FLOW CONDITIONS
 RIVER DISCHARGE 100 000 CFS
 McNARY POOL EL 335

4

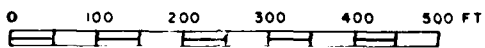


LEGEND

- 4 VELOCITIES IN FPS
- T 5-FT DEPTH
- B 5 FT ABOVE BOTTOM



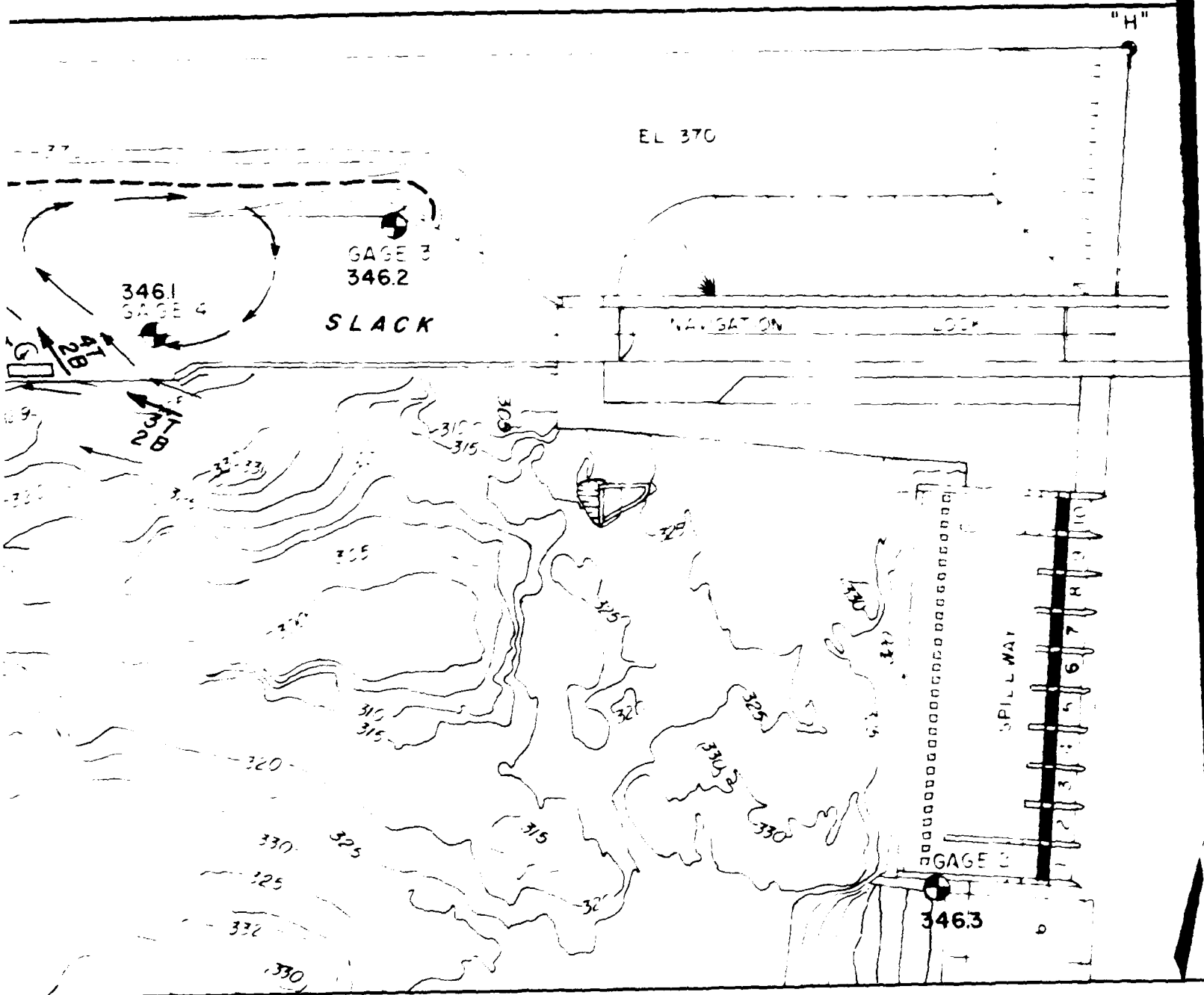
SCALE



FLOW DISTRIB

- SPILLWAY BAYS
- POWERHOUSE UNITS
- POWERHOUSE UNITS

2

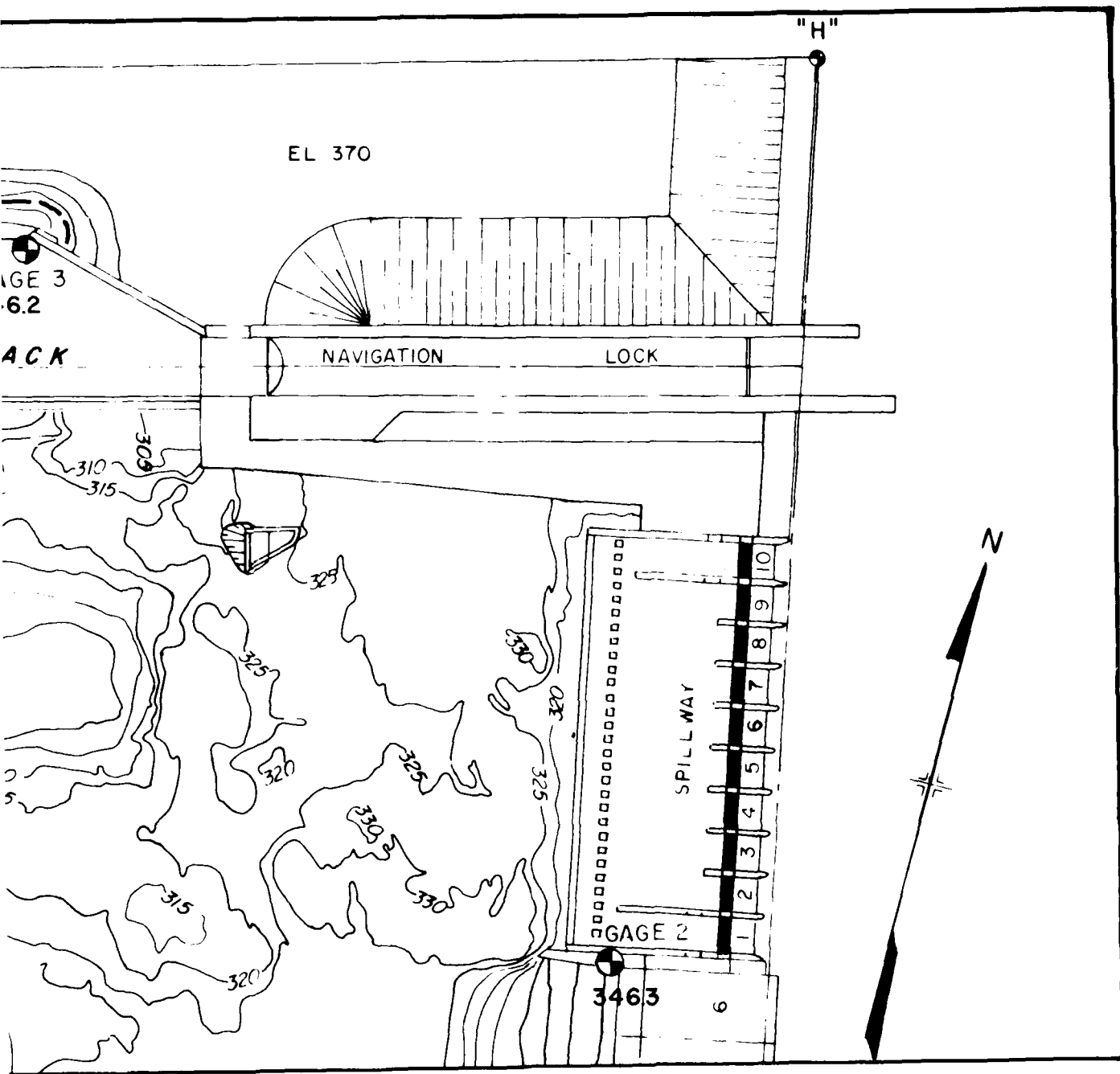


FLOW DISTRIBUTION

	CLOSED
TS	43 300 CFS
ITS	56 700 CFS

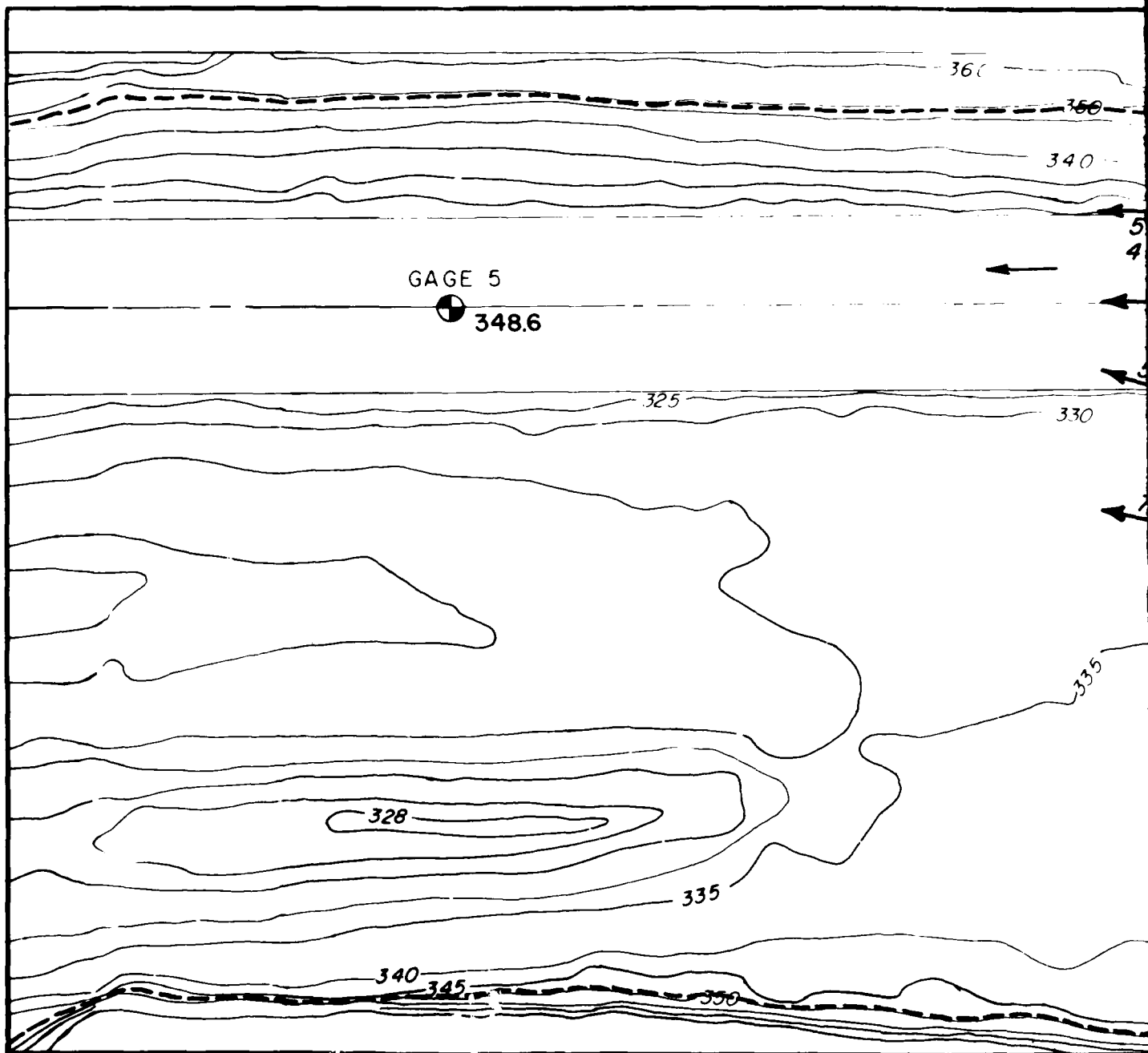
SIX 70-FT WALLS WITH

FLOW COND
RIVER DISCHARGE
MCNARY POOL



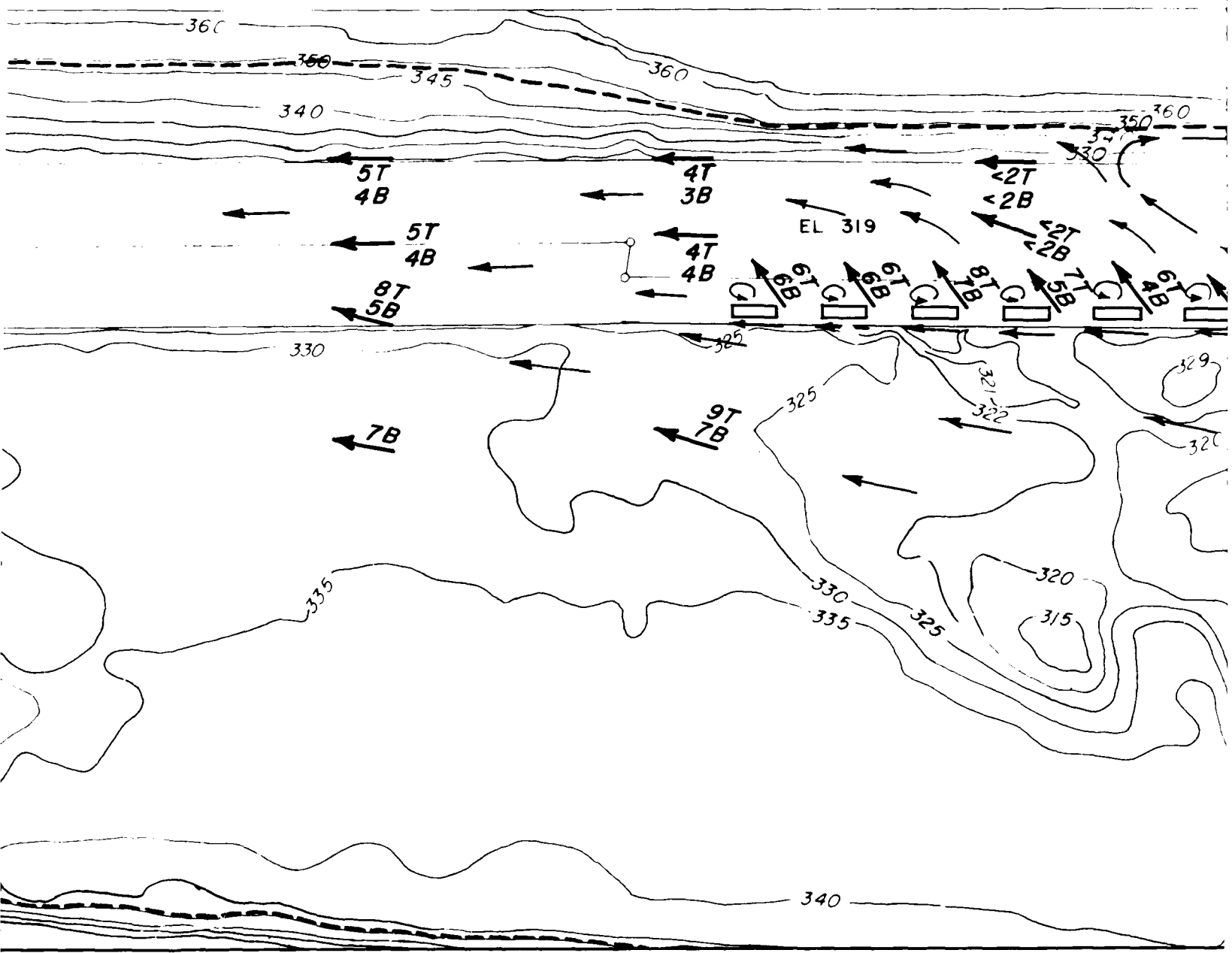
SIX 70-FT WALLS WITH 70-FT SPACING

FLOW CONDITIONS
 RIVER DISCHARGE 100 000 CFS
 McNARY POOL EL 335

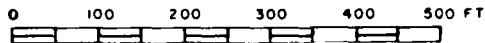


LEGEND

- 4 VELOCITIES IN FPS
- T 5-FT DEPTH
- B 5 FT ABOVE BOTTOM



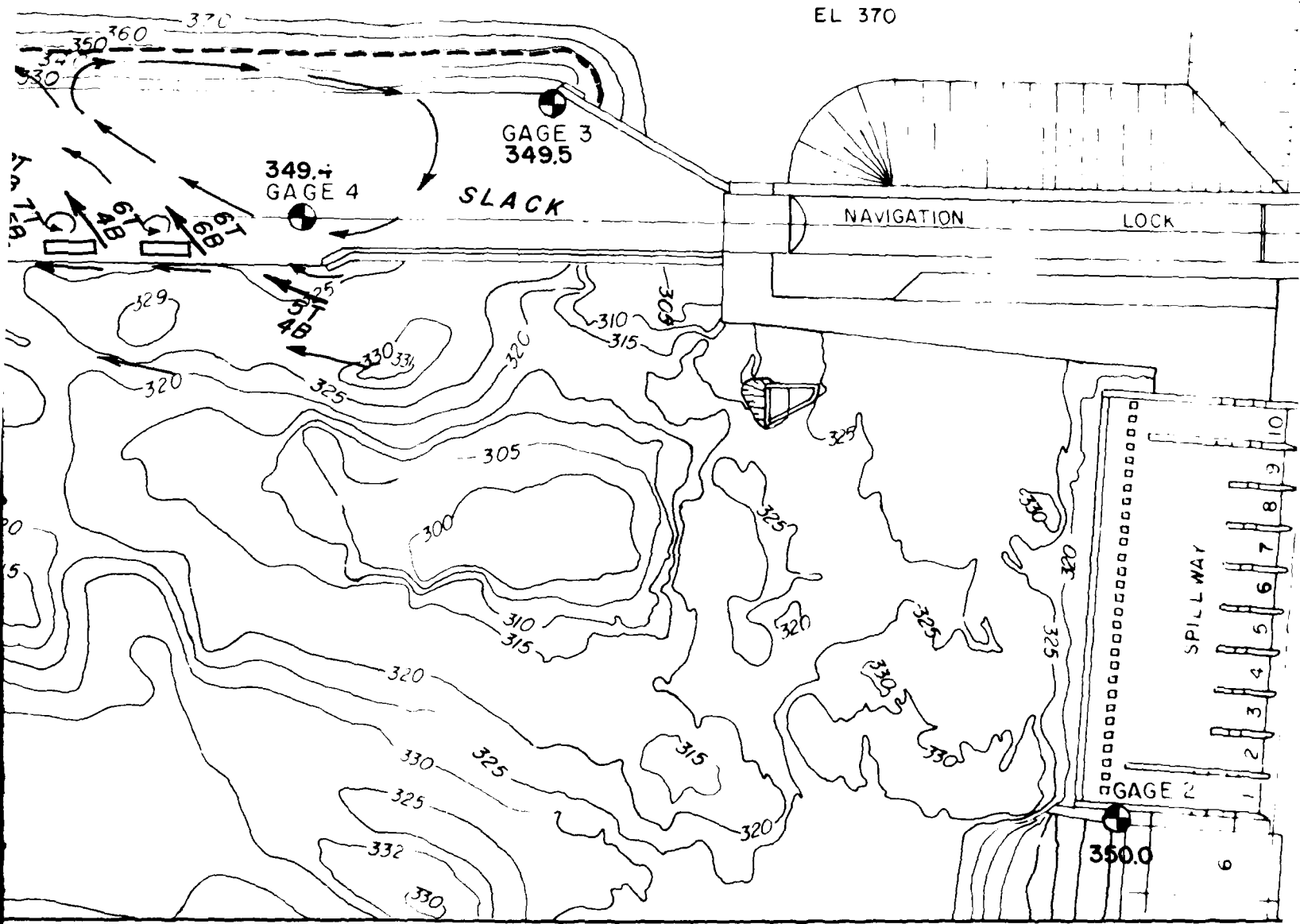
SCALE



IN FPS
H
E BOTTOM

FLOW

SPILLWAY BAYS I TO
POWERHOUSE UNITS
POWERHOUSE UNITS

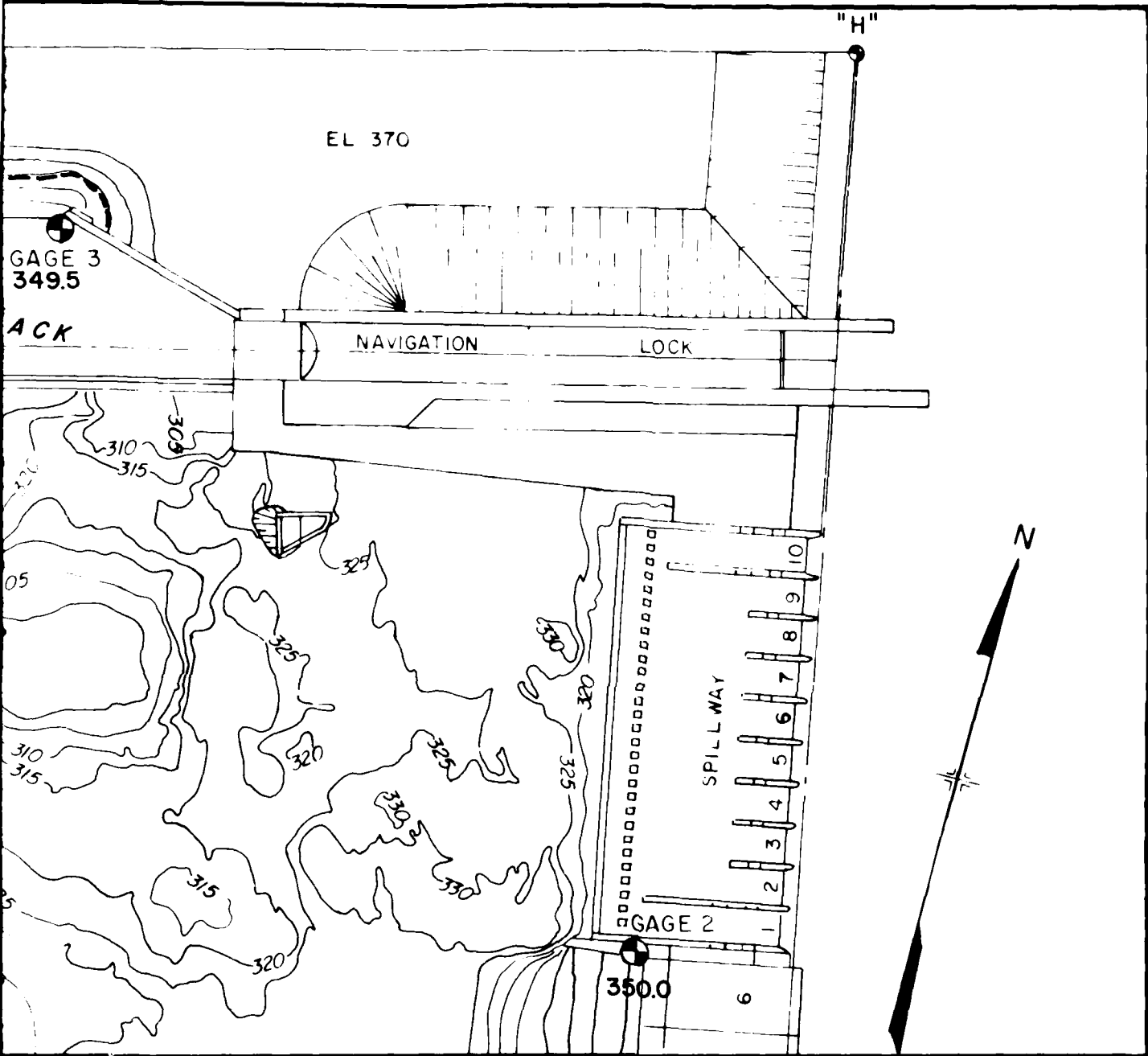


FLOW DISTRIBUTION

WALLWAY BAYS 1 TO 10	50 000 CFS
OVERHOUSE UNITS 1 TO 3	43 300 CFS
OVERHOUSE UNITS 4 TO 6	56 700 CFS

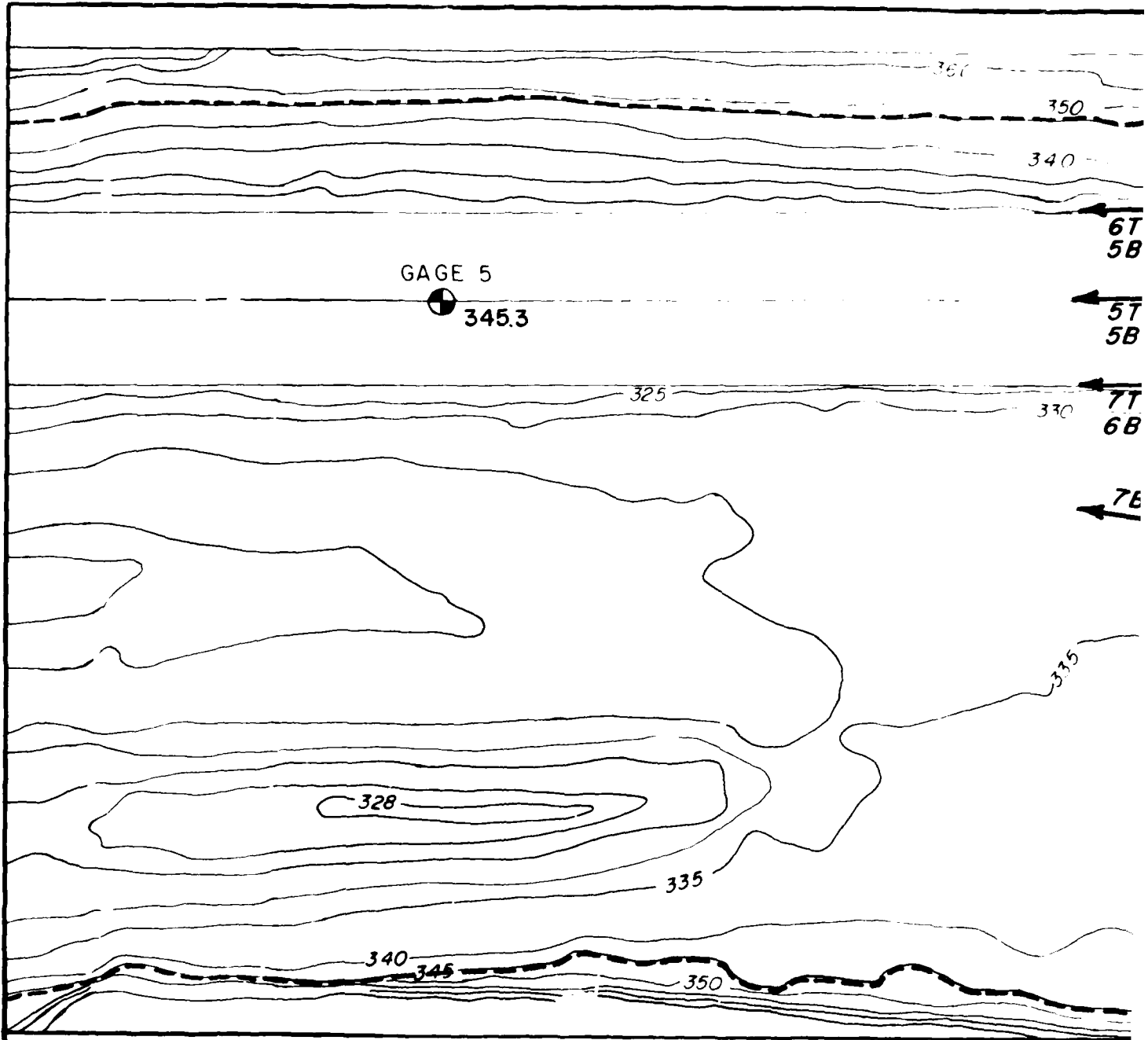
SIX 70-FT WALL

FLC
RIVER D
MCNA



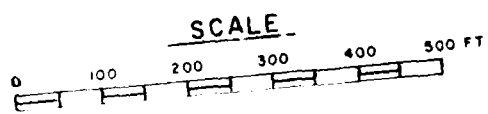
SIX 70-FT WALLS WITH 70-FT SPACING

FLOW CONDITIONS
 RIVER DISCHARGE 150 000 CFS
 McNARY POOL EL 335



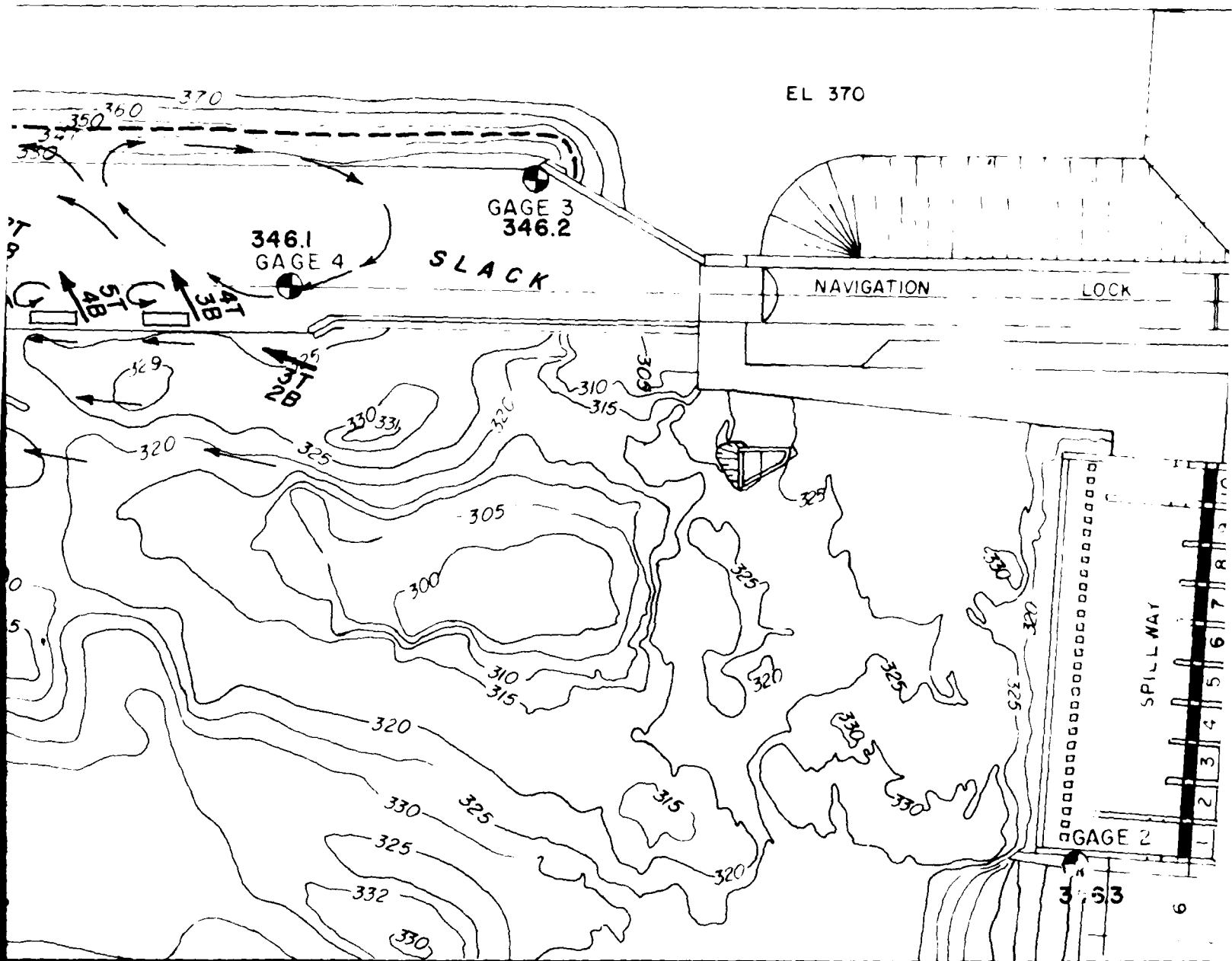
LEGEND

- ← 4 VELOCITIES IN FPS
- T 5-FT DEPTH
- B 5 FT ABOVE BOTTOM



FLOW DISTRIBUTION
 SPILLWAY BAYS 1 TO 10
 POWERHOUSE UNITS 1 TO 3
 POWERHOUSE UNITS 4 TO 6

2



EL 370

SLACK

NAVIGATION

LOCK

SPILLWAY

GAGE 2

315.3

FLOW DISTRIBUTION

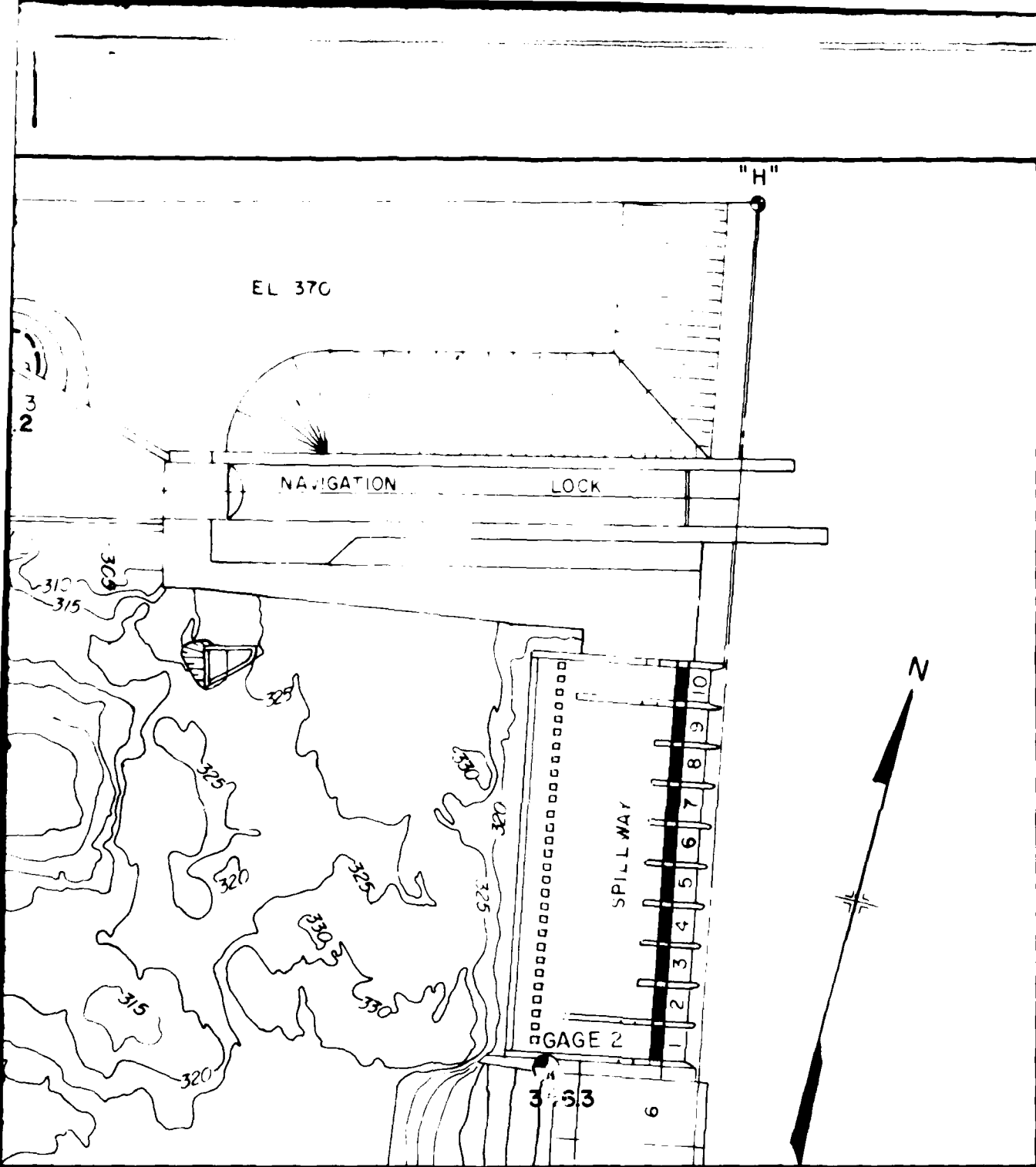
FIVE 70-FT WA

LOWWAY BAYS 1 TO 10	CLOSED
WERHOUSE UNITS 1 TO 3	43 300 CFS
WERHOUSE UNITS 4 TO 6	56 700 CFS

FI

RIVER
MC

3



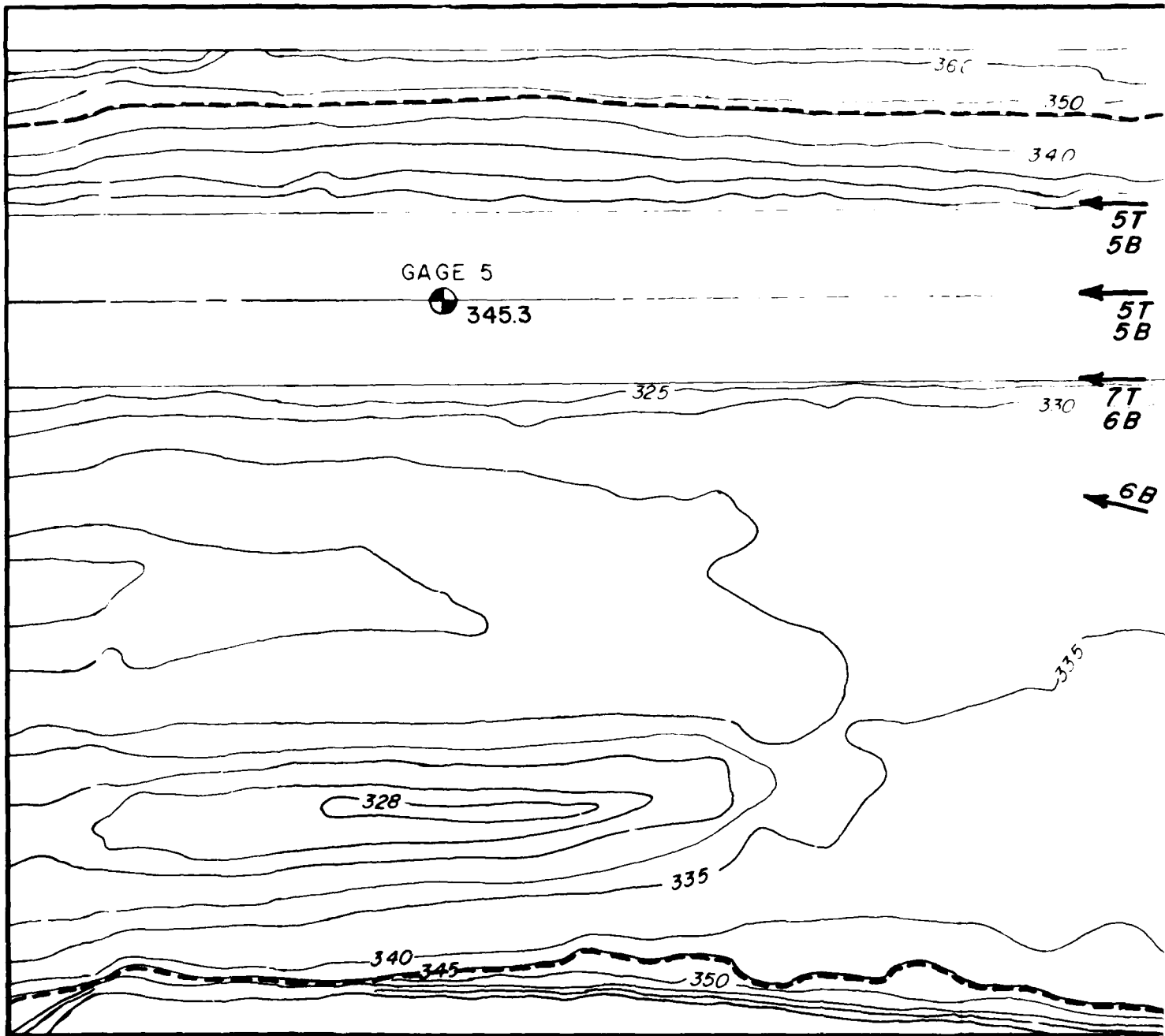
FIVE 70-FT WALLS WITH 100-FT SPACING

FLOW CONDITIONS

RIVER DISCHARGE 100000 CFS
 McNARY POOL EL 335

3

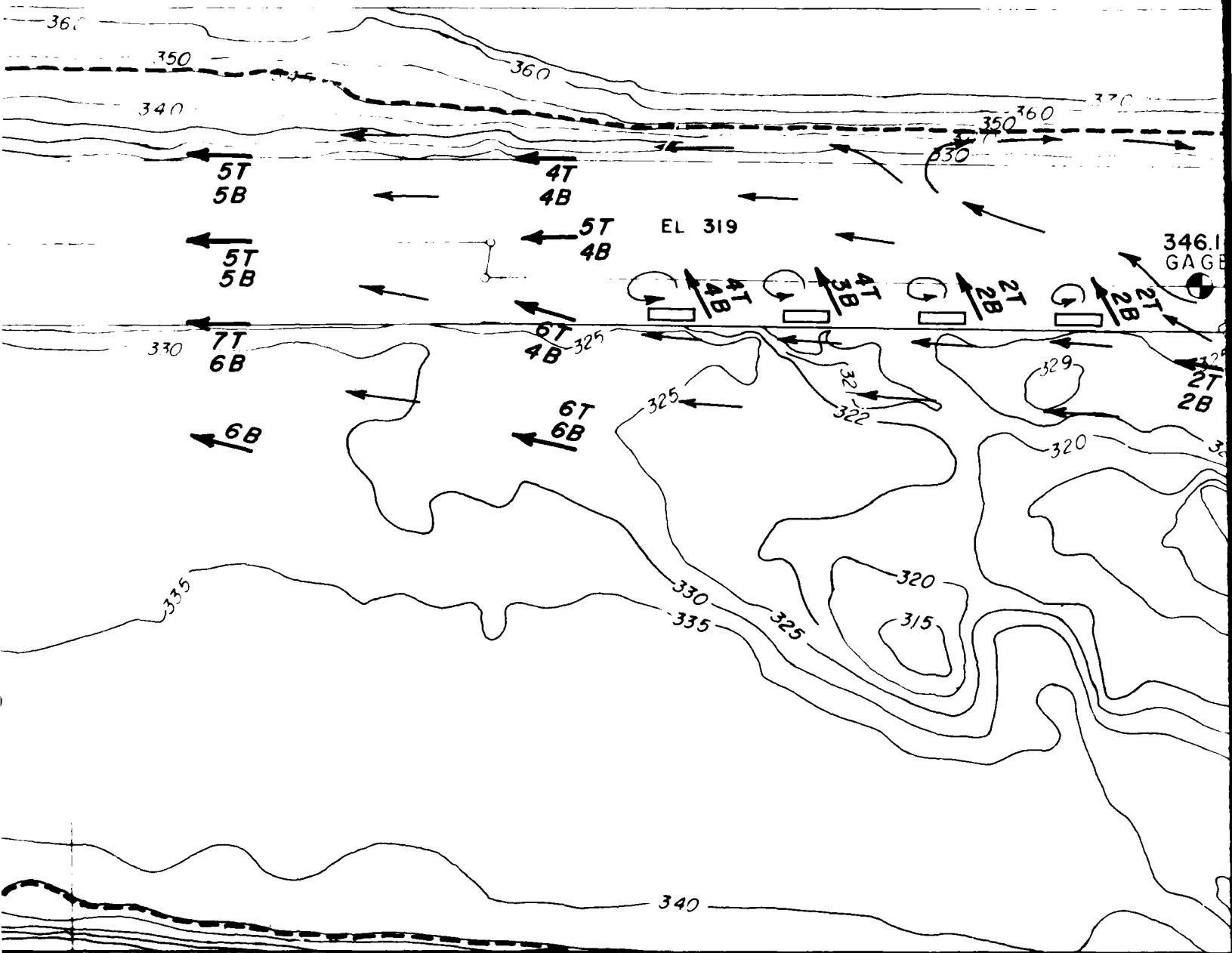
4



LEGEND

- ← 4 VELOCITIES IN FPS
- T 5-FT DEPTH
- B 5 FT ABOVE BOTTOM

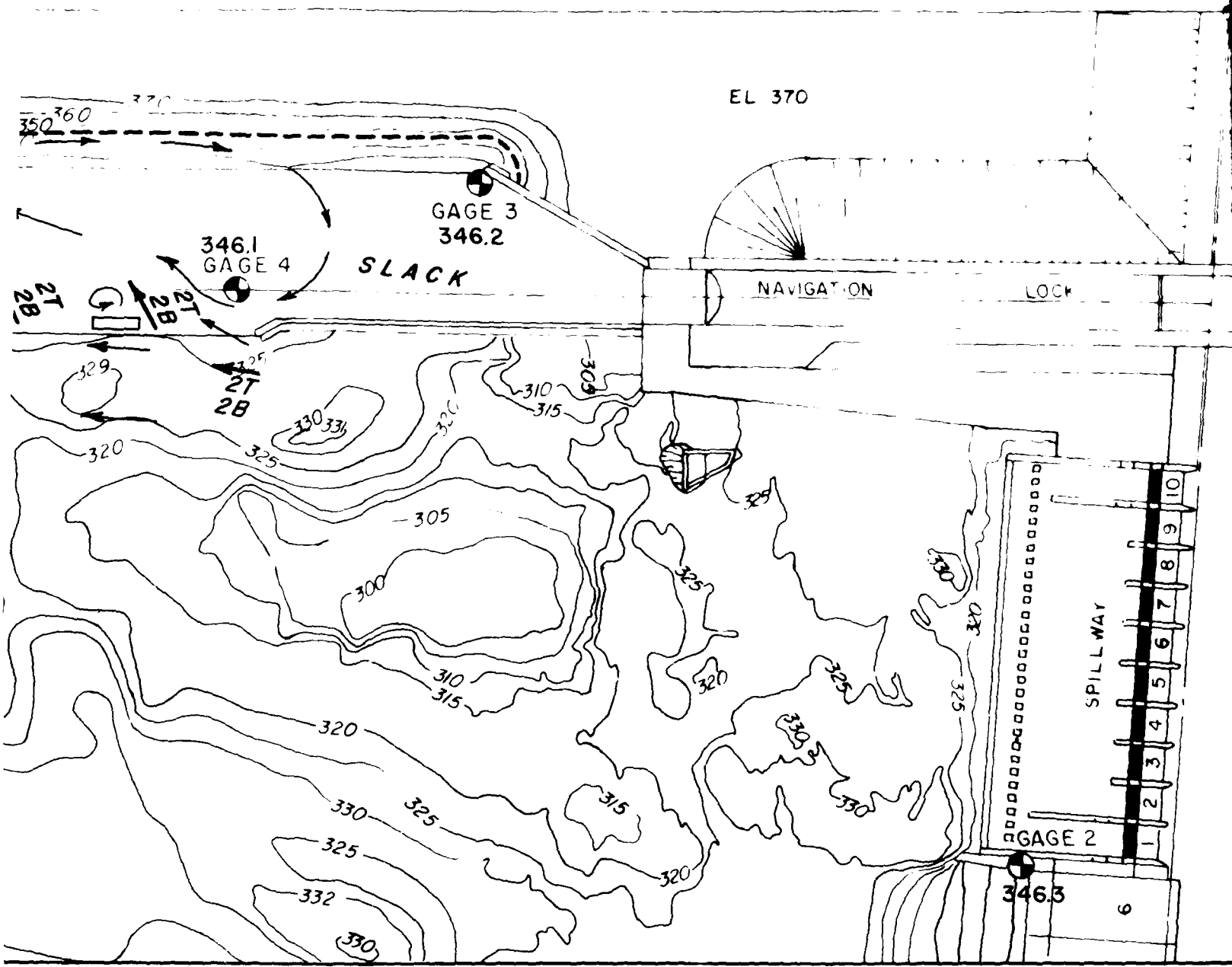
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E



FLOW DISTRIBUTION

SPILLWAY BAYS 1 TO 10
 POWERHOUSE UNITS 1 TO 3
 POWERHOUSE UNITS 4 TO 6

2



FLOW DISTRIBUTION

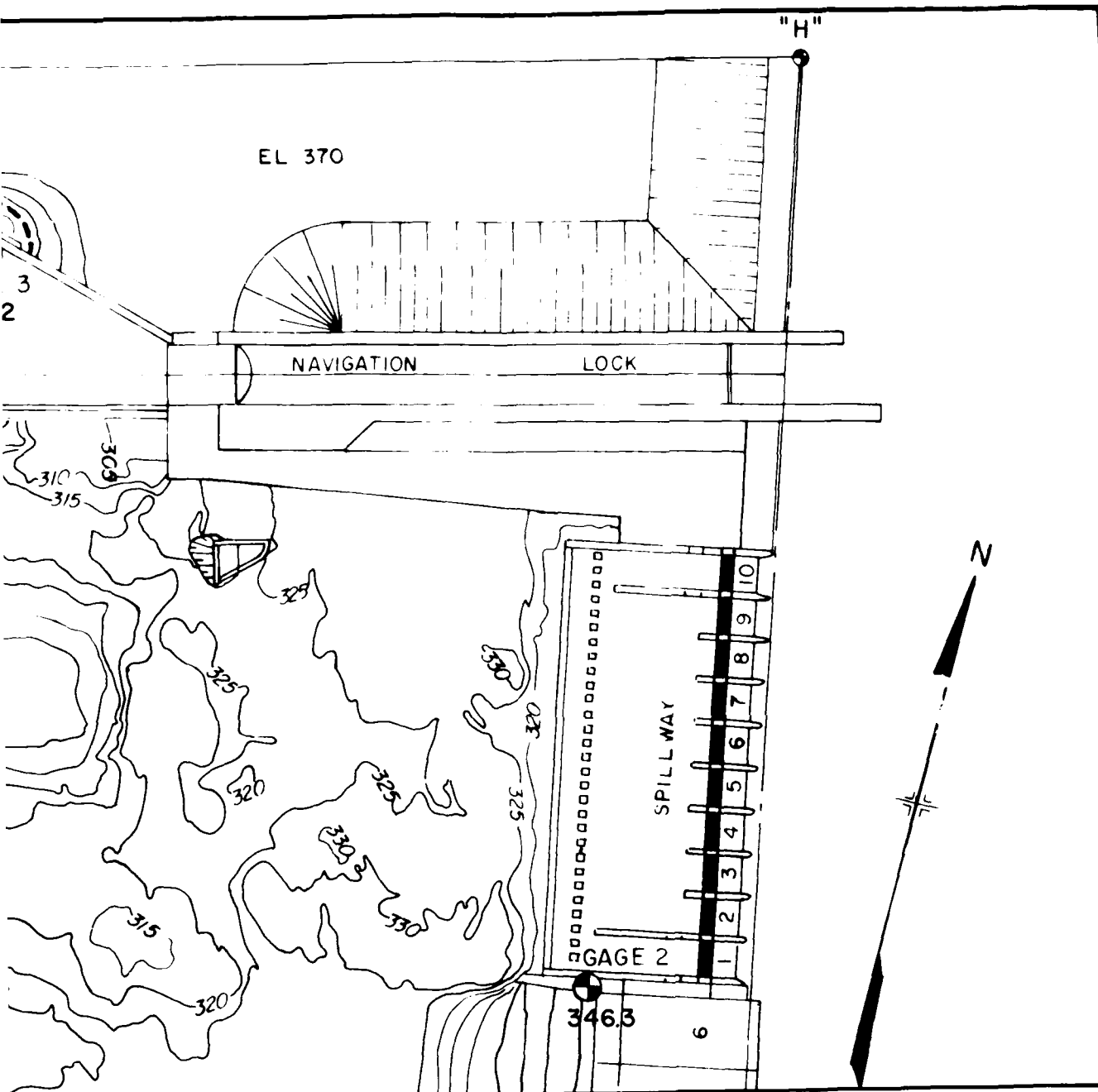
FOUR 70-FT WALLS W

BAYS 1 TO 10	CLOSED
USE UNITS 1 TO 3	43 300 CFS
USE UNITS 4 TO 6	56 700 CFS

FLOW (

RIVER DISCH
MCNARY]

3



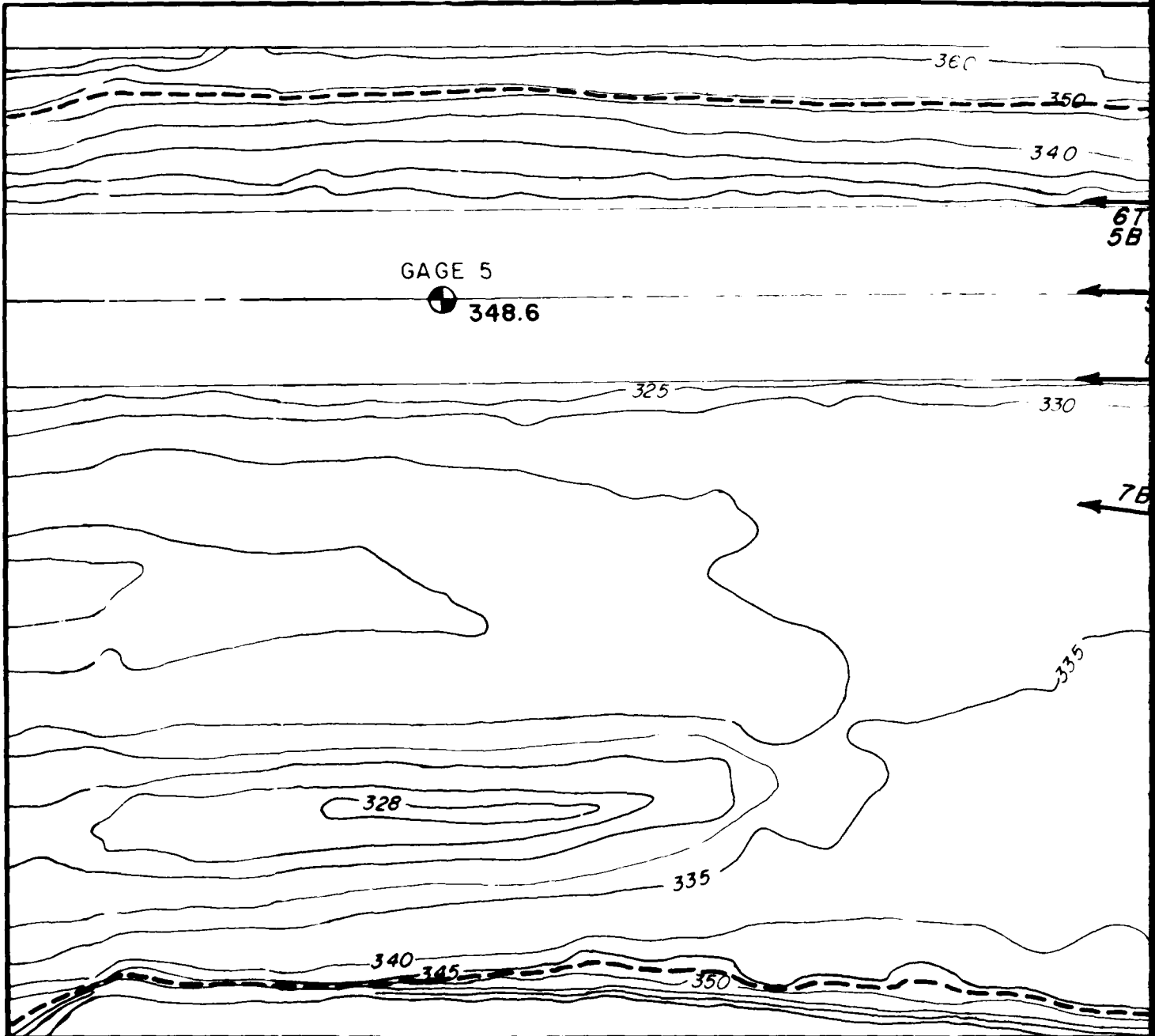
FOUR 70-FT WALLS WITH 140-FT SPACING

FLOW CONDITIONS

RIVER DISCHARGE 100 000 CFS
McnARY POOL EL 335

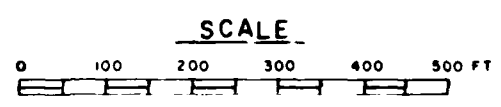
PLATE 31

4



LEGEND

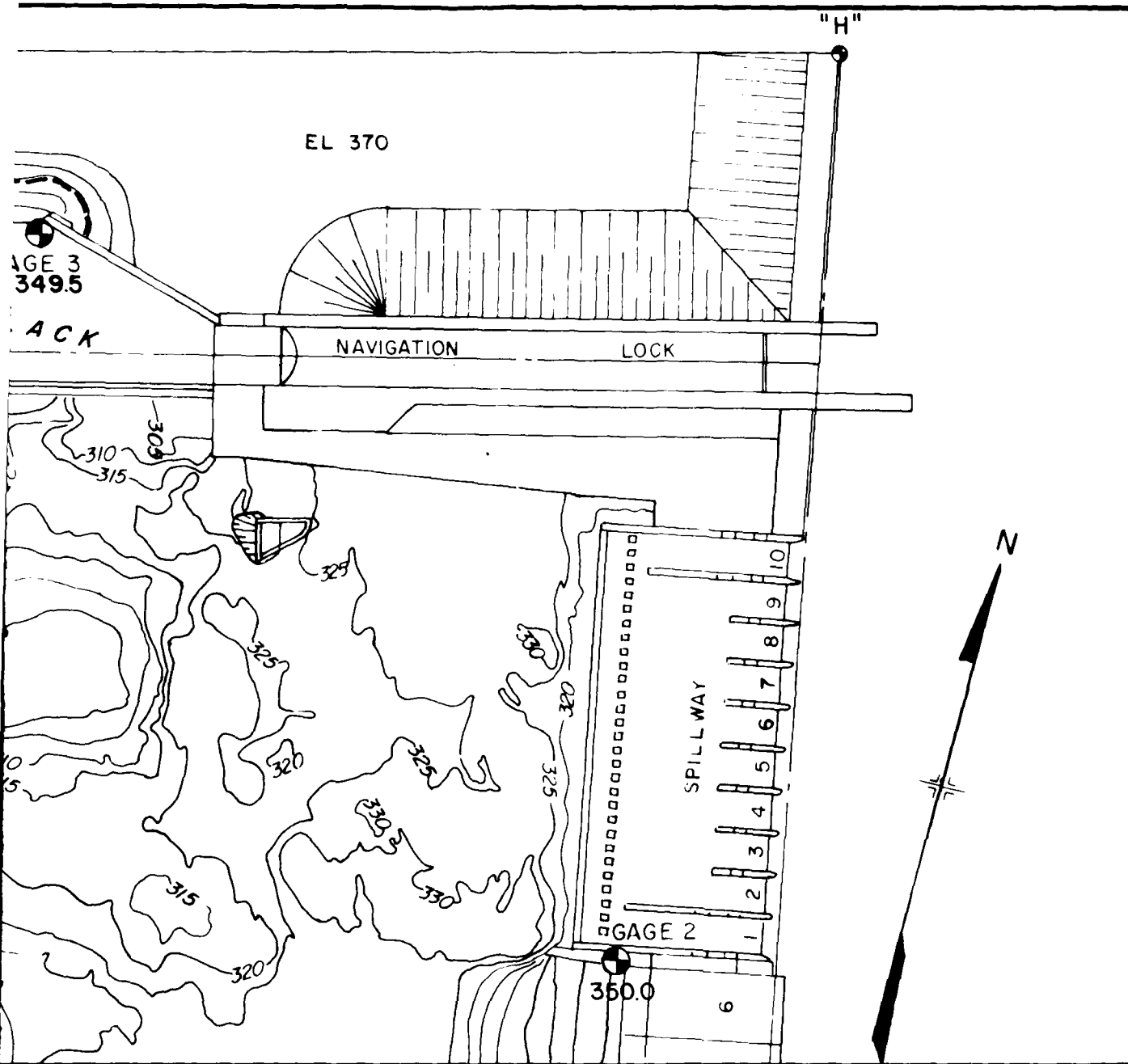
- 4 VELOCITIES IN FPS
- T 5-FT DEPTH
- B 5 FT ABOVE BOTTOM



FLOW DISTRIBUTION

- SPILLWAY BAYS 1 TO 10
- POWERHOUSE UNITS 1 TO 3
- POWERHOUSE UNITS 4 TO 6

2



AGE 3
349.5

BACK

EL 370

NAVIGATION

LOCK

"H"

N

GAGE 2

350.0

SPILLWAY

FOUR 70-FT WALLS WITH 140-FT SPACING

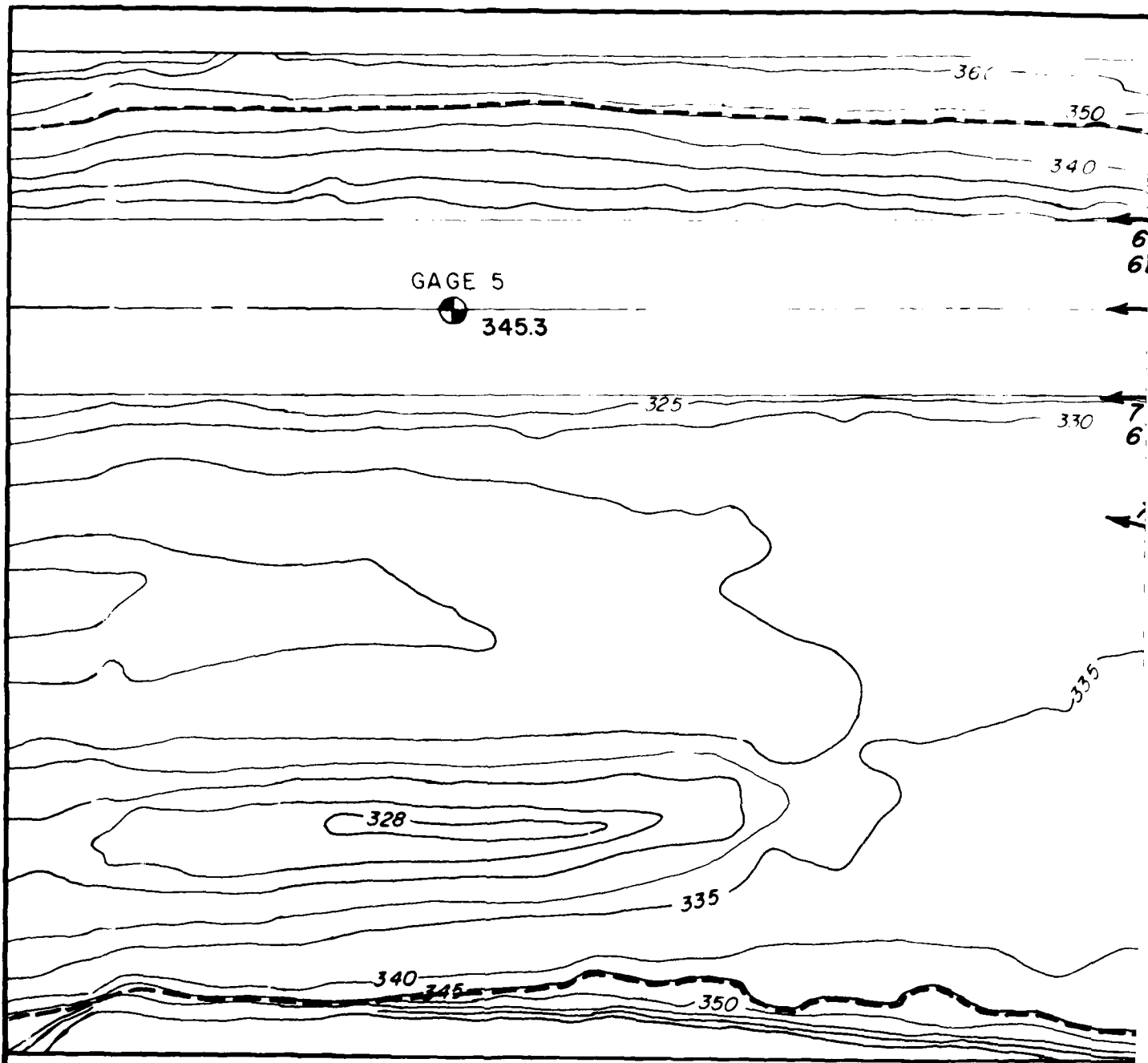
FLOW CONDITIONS

RIVER DISCHARGE 150 000 CFS

MENARY POOL EL 335

PLATE 32

4

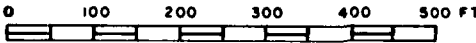


LEGEND

- 4** VELOCITIES IN FPS
- T** 5-FT DEPTH
- B** 5 FT ABOVE BOTTOM



SCALE

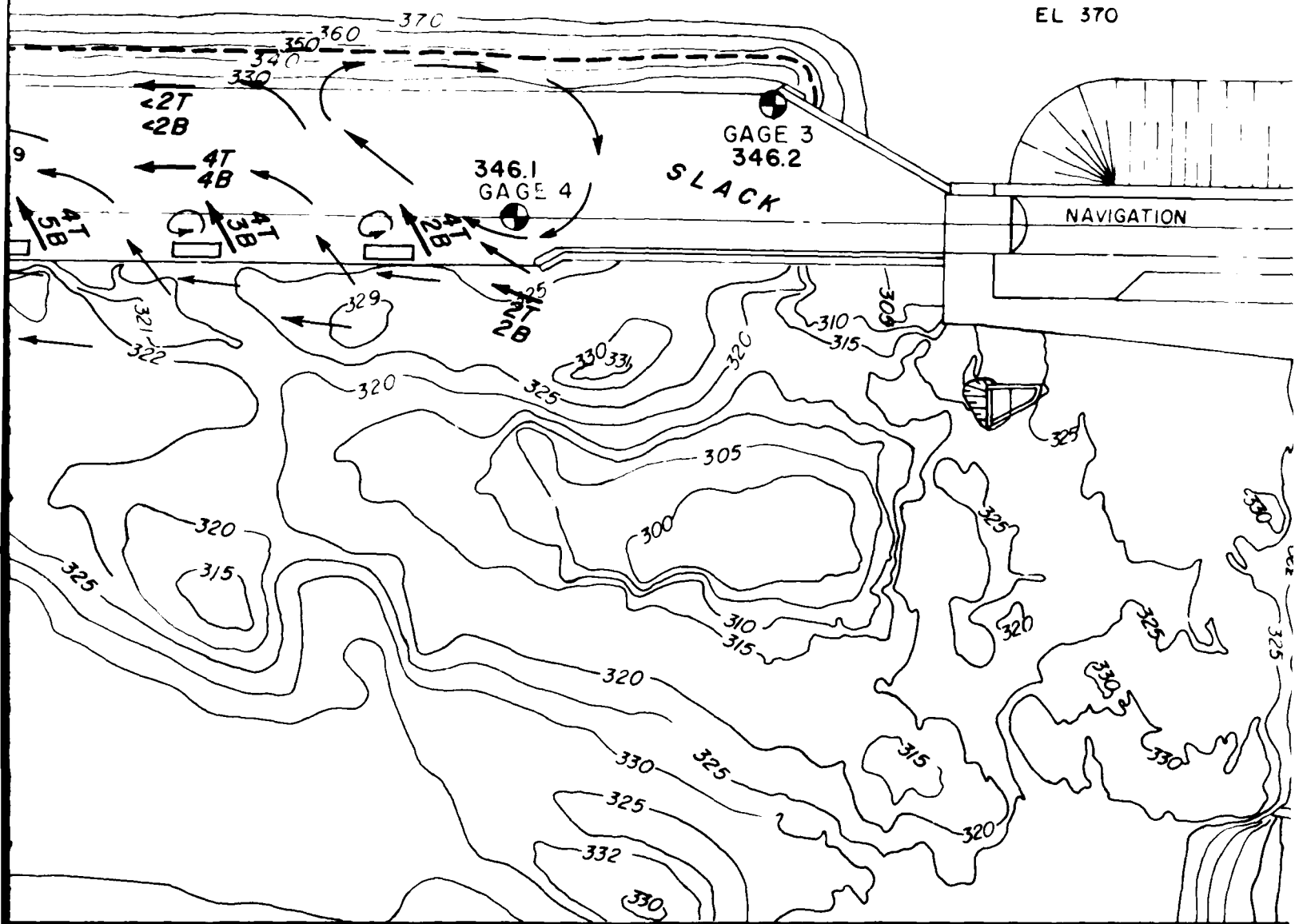


FLOW D

SPILLWAY BAYS 1 TO 10
 POWERHOUSE UNITS 1 TO
 POWERHOUSE UNITS 4 TO

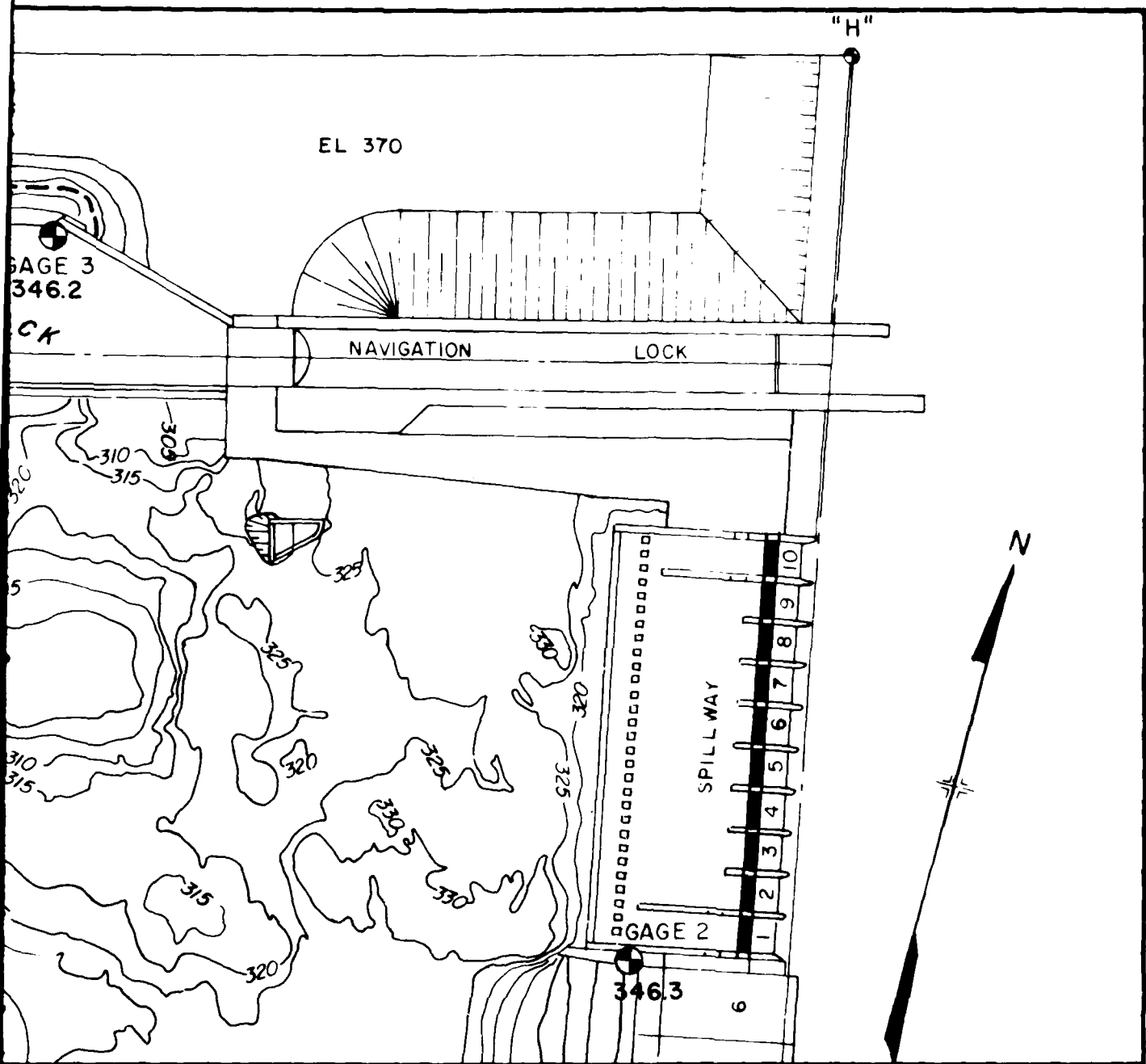
FPS
 TTOM

2



FLOW DISTRIBUTION

SPILLWAY BAYS 1 TO 10	CLOSED
POWERHOUSE UNITS 1 TO 3	43 300 CFS
POWERHOUSE UNITS 4 TO 6	56 700 CFS



EL 370

GAGE 3
346.2

CK

NAVIGATION LOCK

"H"

SPILLWAY

GAGE 2

346.3

N

THREE 70-FT WALLS WITH 210-FT SPACING

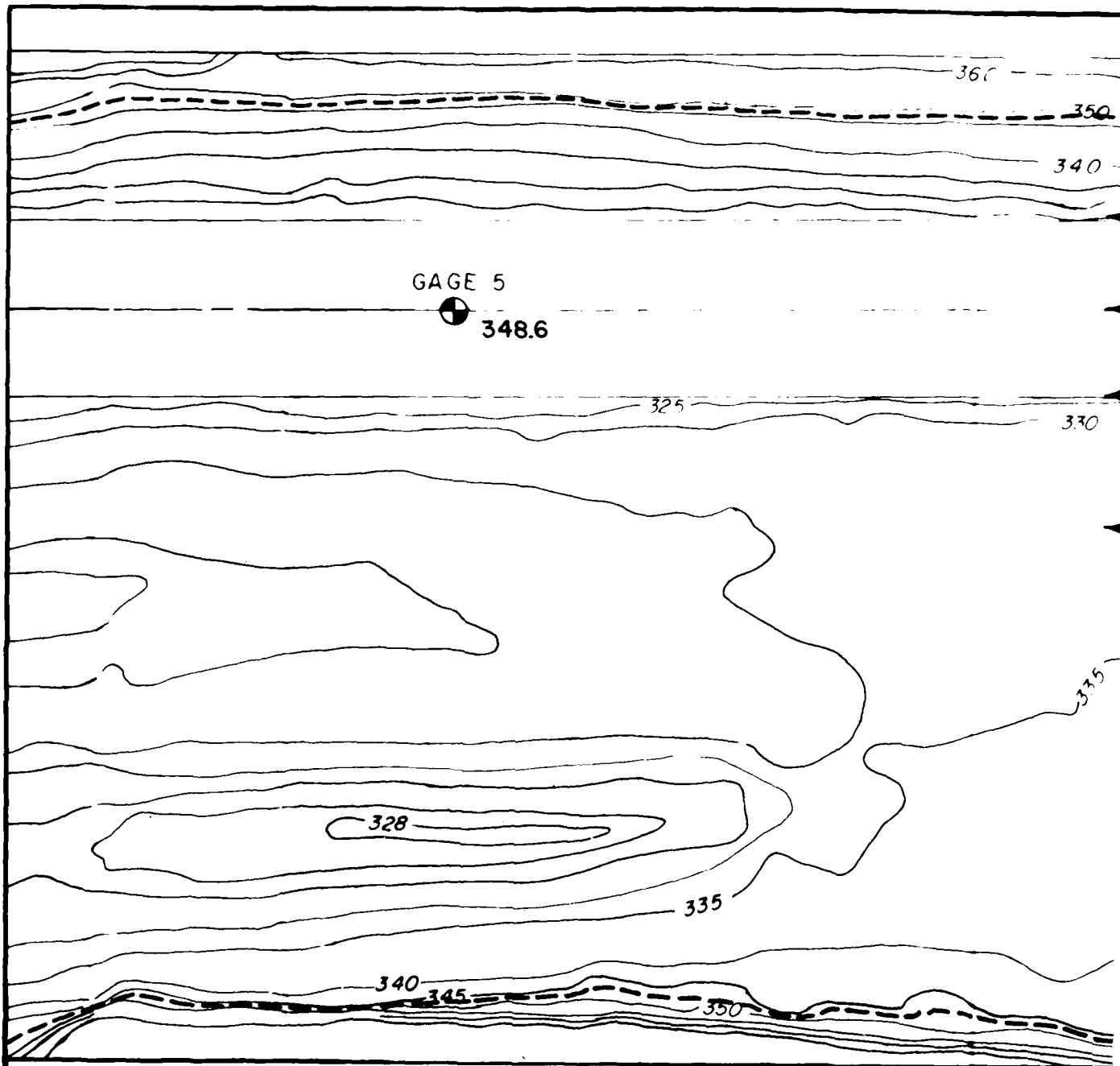
FLOW CONDITIONS

RIVER DISCHARGE 100 000 CFS

MCNARY POOL EL 335

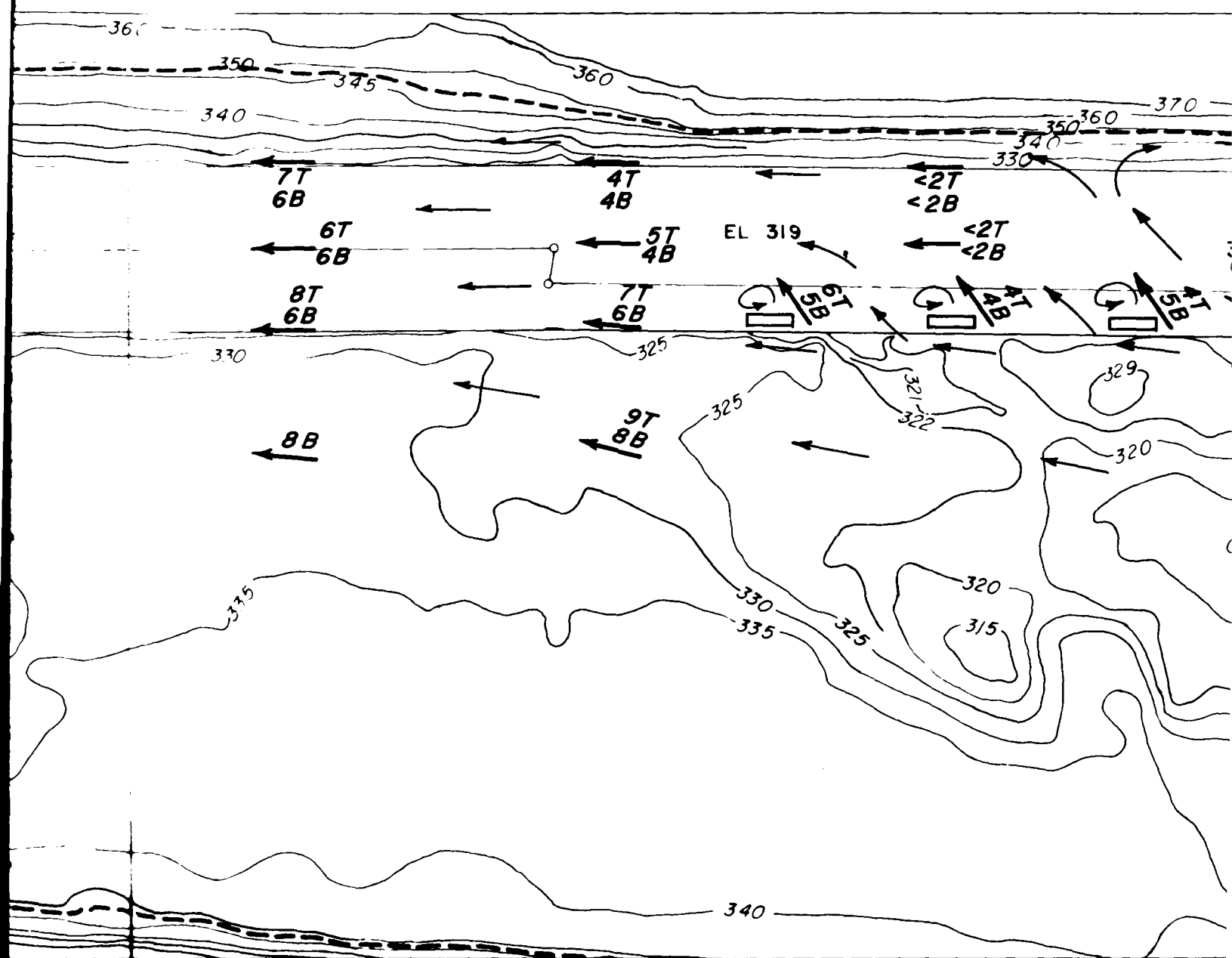
PLATE 33

4

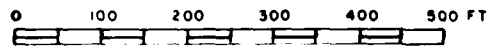


LEGEND

- 4 VELOCITIES IN FPS
- T 5-FT DEPTH
- B 5 FT ABOVE BOTTOM



SCALE



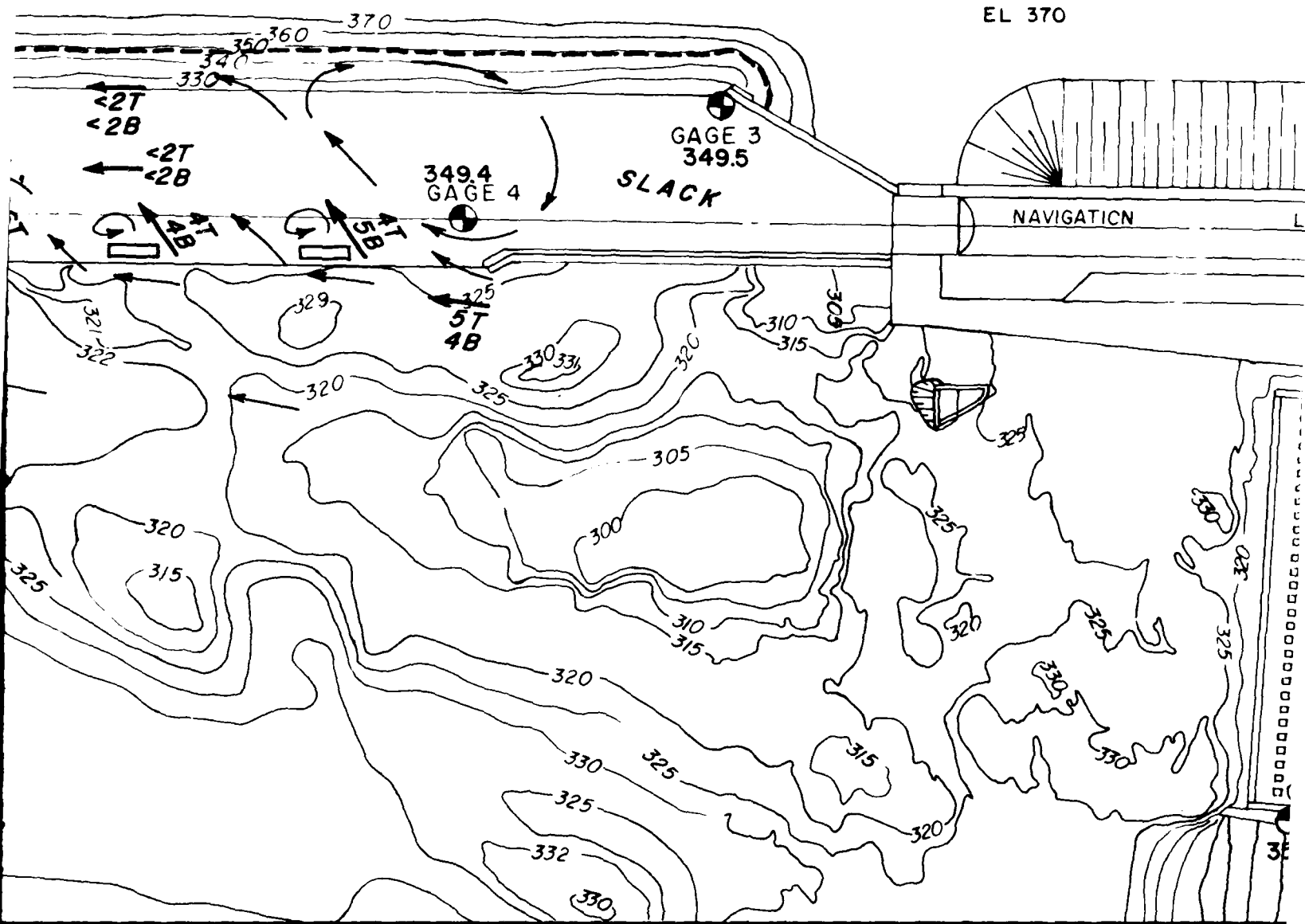
FLOW DISTR

SPILLWAY BAYS 1 TO 10

POWERHOUSE UNITS 1 TO 10

POWERHOUSE UNITS 4 TO 10

2



EL 370

NAVIGATION

GAGE 3
349.5
SLACK

349.4
GAGE 4

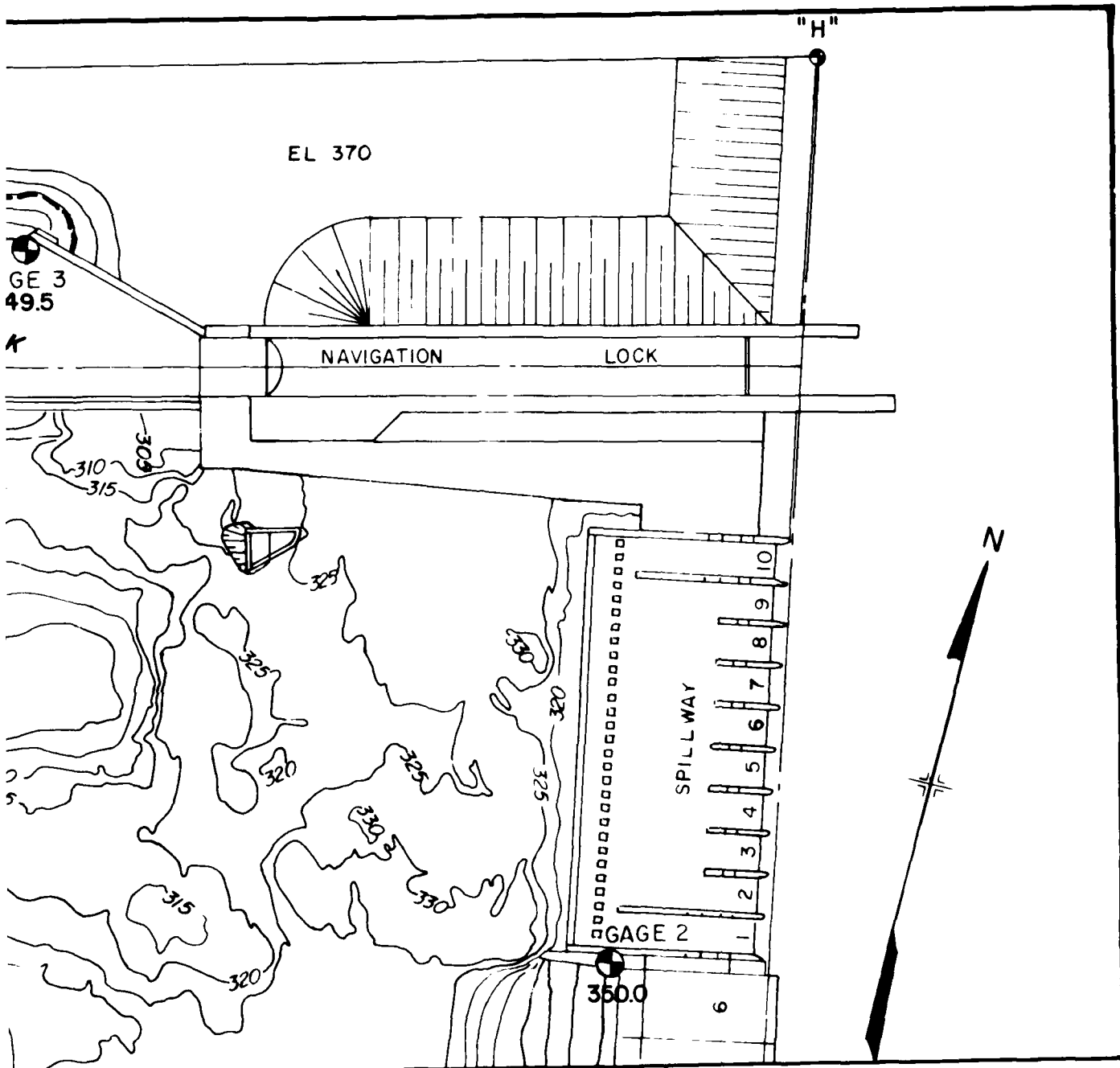
<2T
<2B

325
5T
4B

FLOW DISTRIBUTION

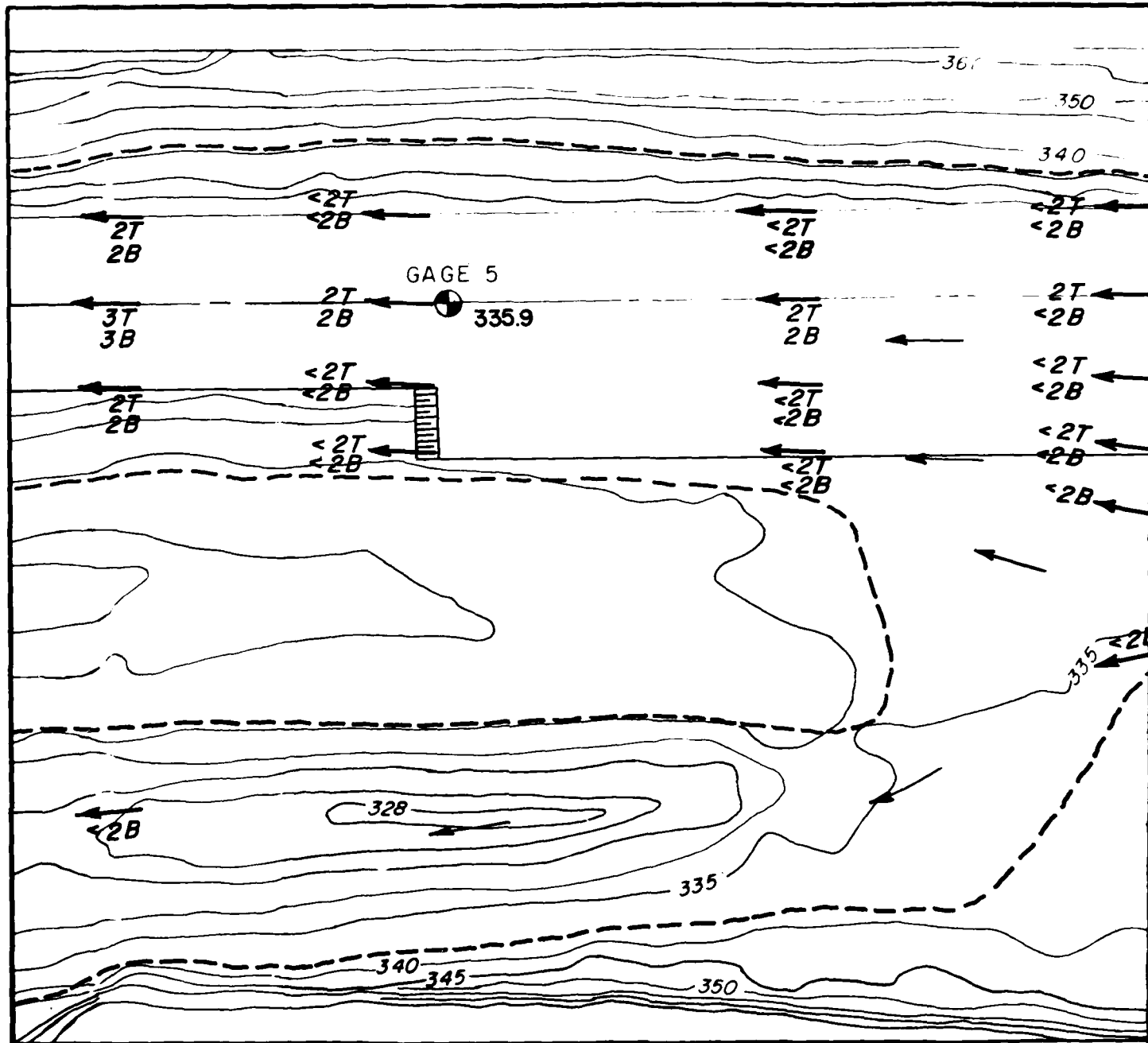
SPILLWAY BAYS 1 TO 10	50 000 CFS
POWERHOUSE UNITS 1 TO 3	43 300 CFS
POWERHOUSE UNITS 4 TO 6	56 700 CFS

THI



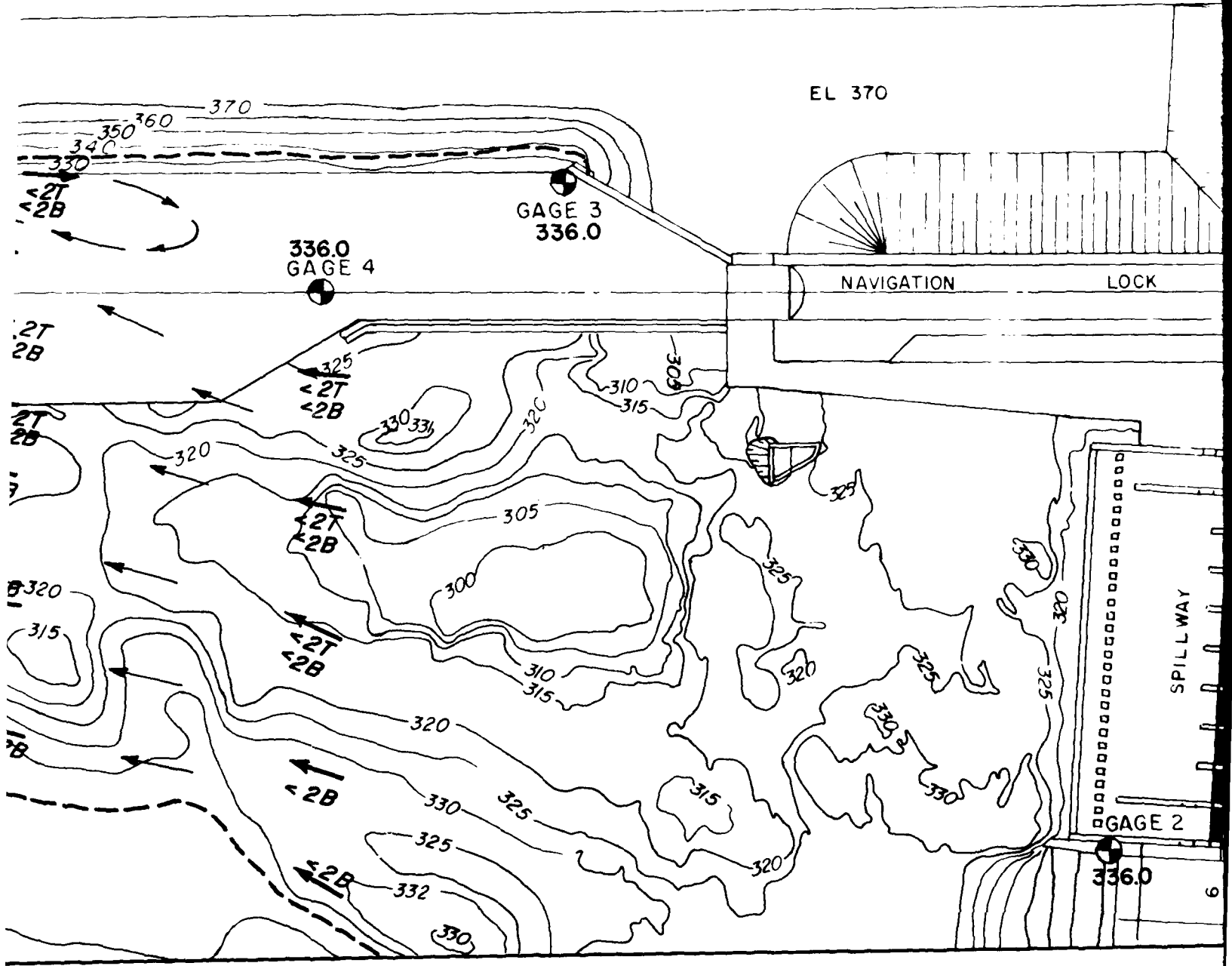
THREE 70-FT WALLS WITH 210-FT SPACING

FLOW CONDITIONS
 RIVER DISCHARGE 150 000 CFS
 McNARY POOL EL 335



LEGEND

- 4 VELOCITIES IN FPS
- T 5-FT DEPTH
- B 5 FT ABOVE BOTTOM

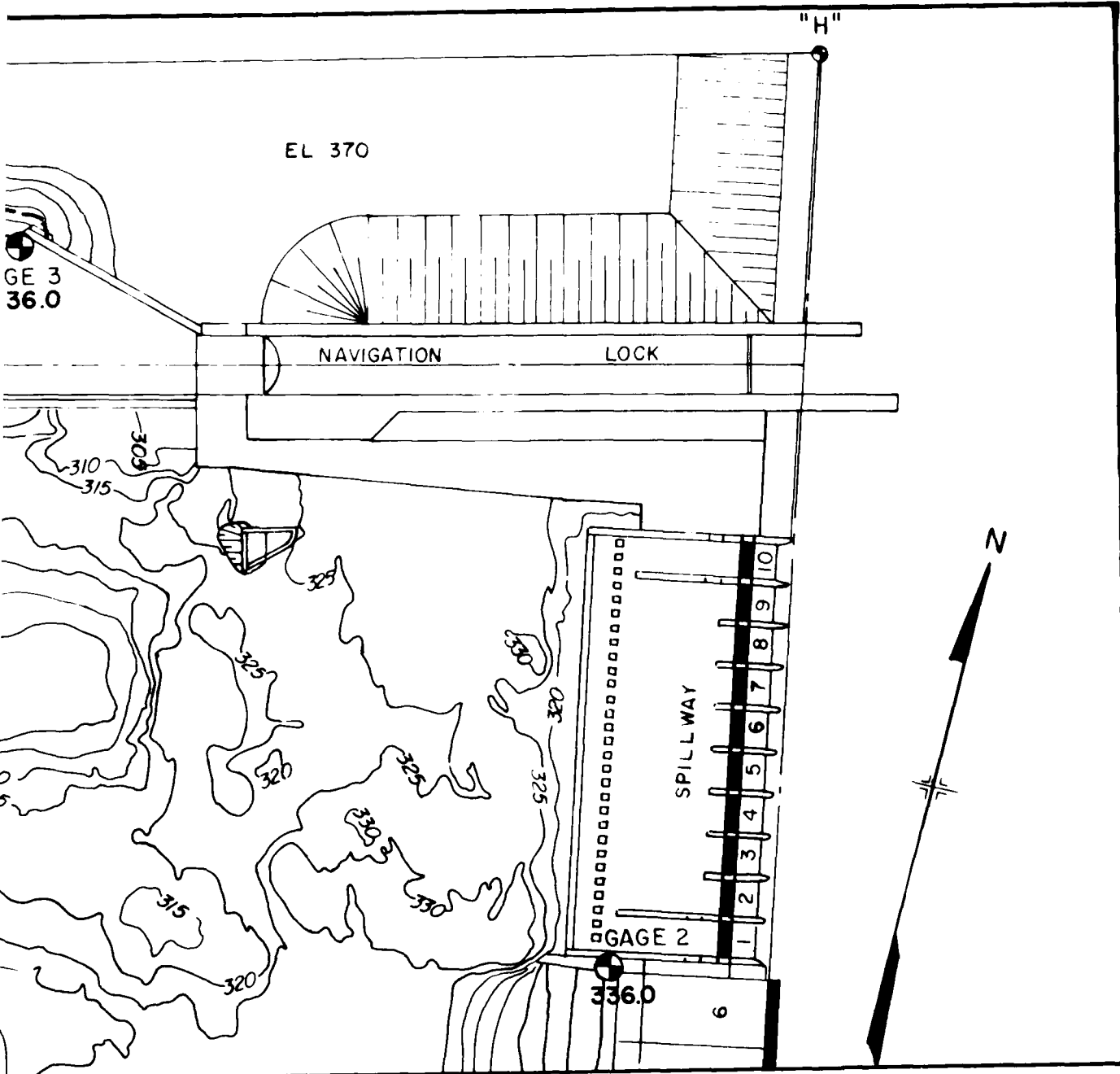


FLOW DISTRIBUTION

- | | |
|-------------------------|------------|
| SPILLWAY BAYS 1 TO 10 | CLOSED |
| POWERHOUSE UNIT 1 | 10 000 CFS |
| POWERHOUSE UNITS 4 TO 6 | CLOSED |

RIVE
A

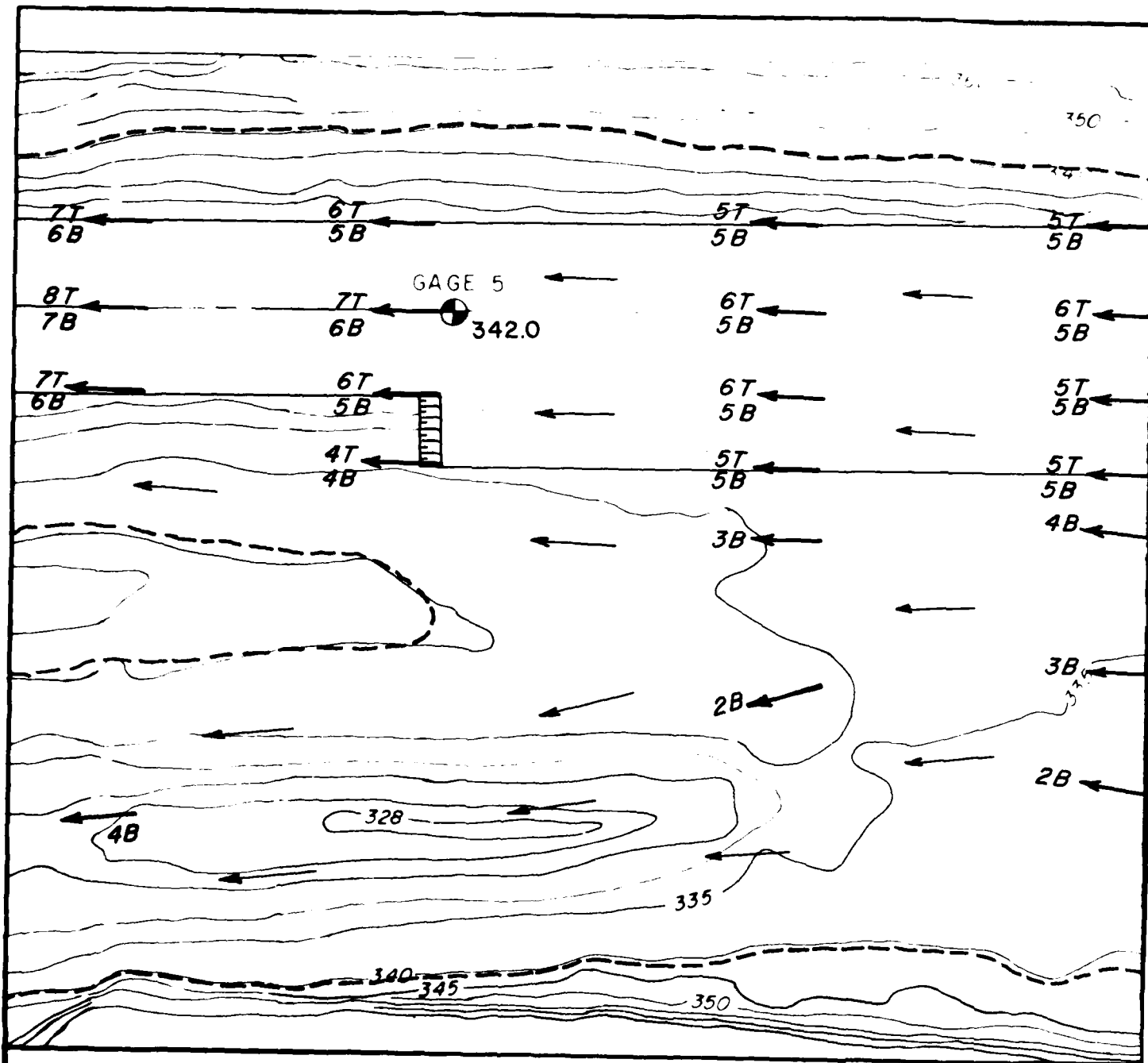
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100-FT EXPANSION OF CHANNEL

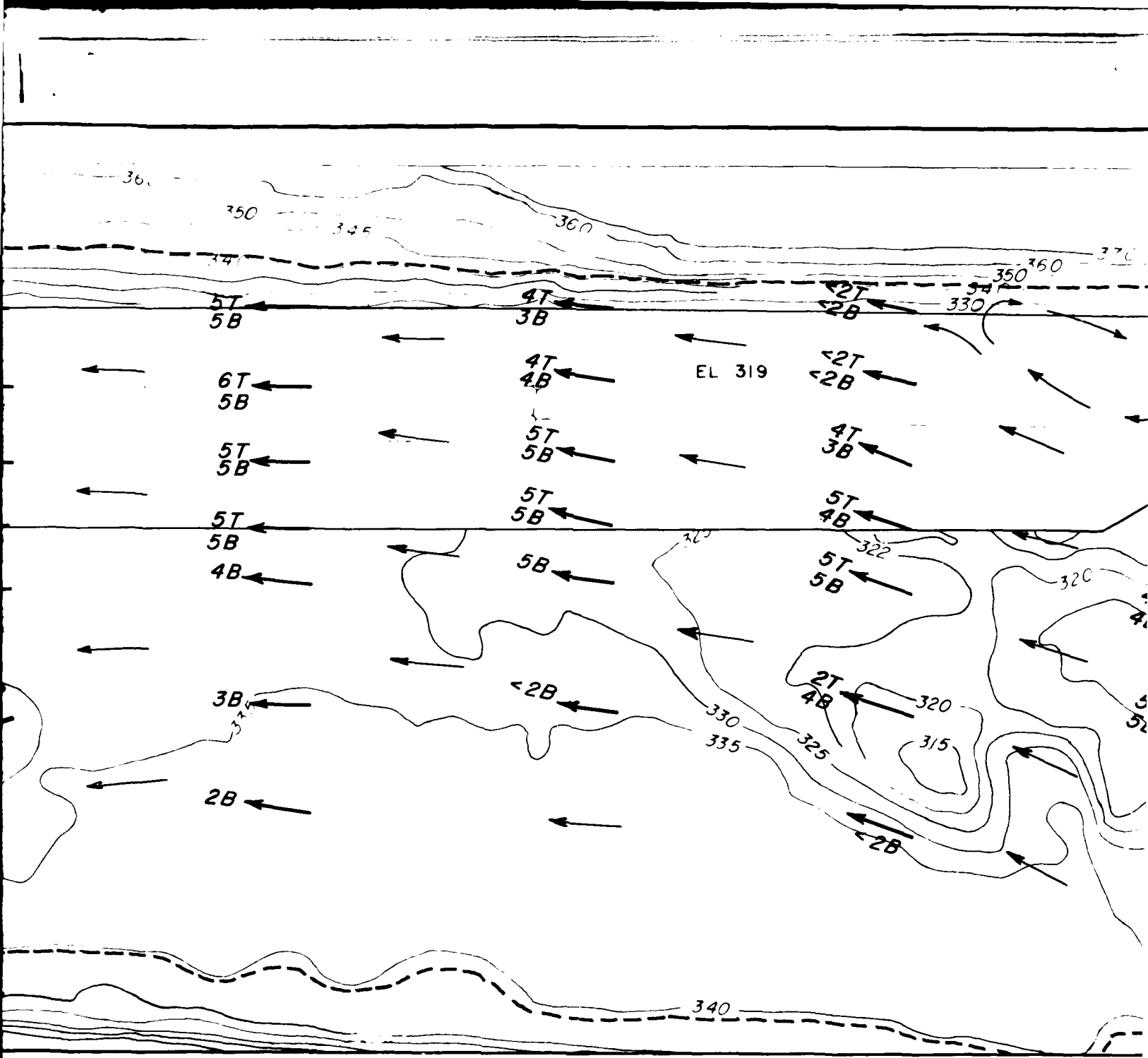
FLOW CONDITIONS
 RIVER DISCHARGE 10 000 CFS
 McNARY POOL EL 335

4

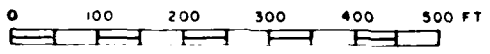


LEGEND

- 4 VELOCITIES IN FPS
- T 5-FT DEPTH
- B 5 FT ABOVE BOTTOM



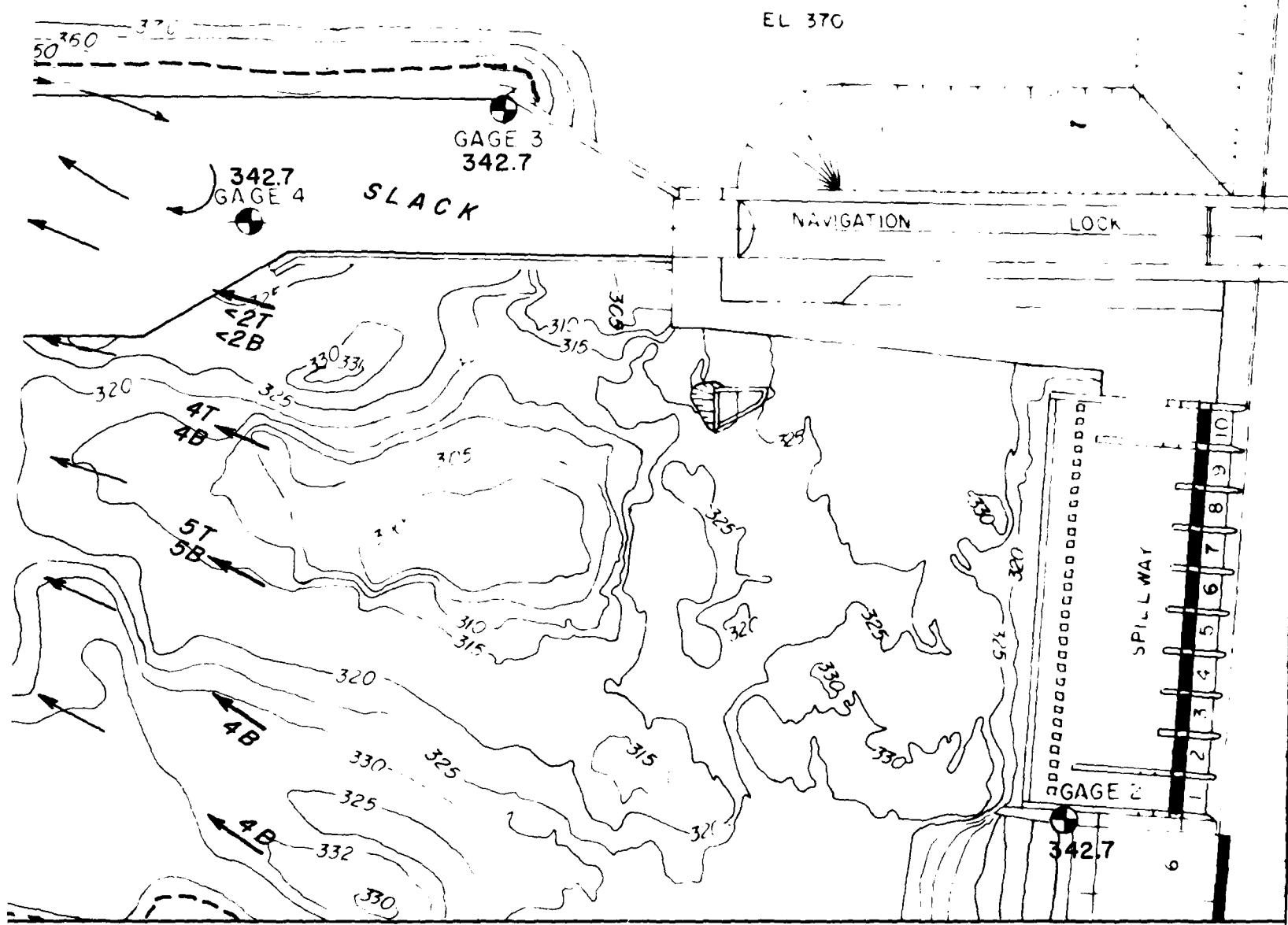
SCALE



FLOW DIST

- SPILLWAY BAYS 1 TO 10
- POWERHOUSE UNITS 1 TO 3
- POWERHOUSE UNIT 4

2



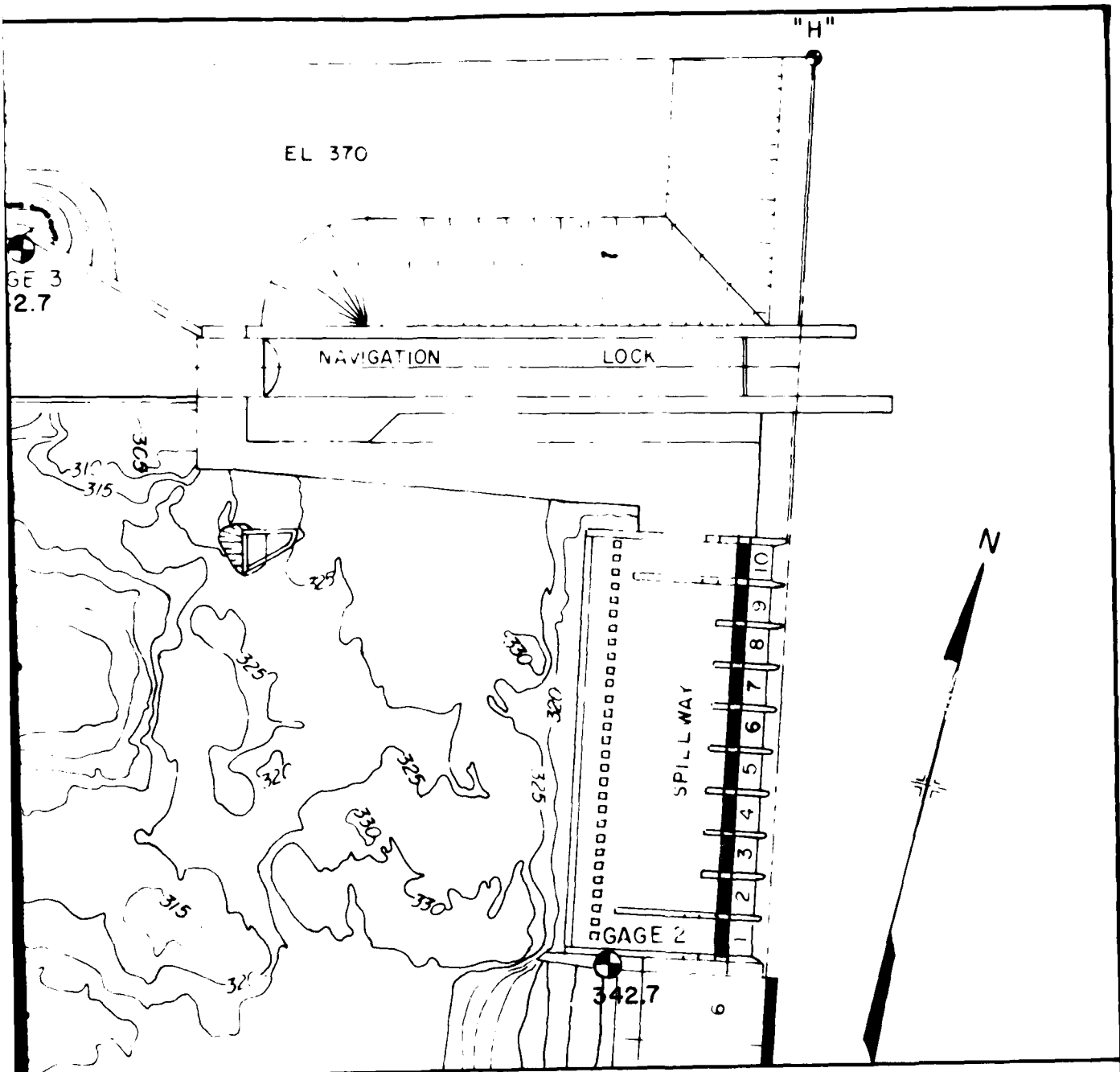
FLOW DISTRIBUTION

100-FT EXPANSION

BAYS 1 TO 10	CLOSED
DUSE UNITS 1 TO 3	42 000 CFS
DUSE UNIT 4	18 000 CFS

FLOW C
RIVER DISCHA
MCNARY F

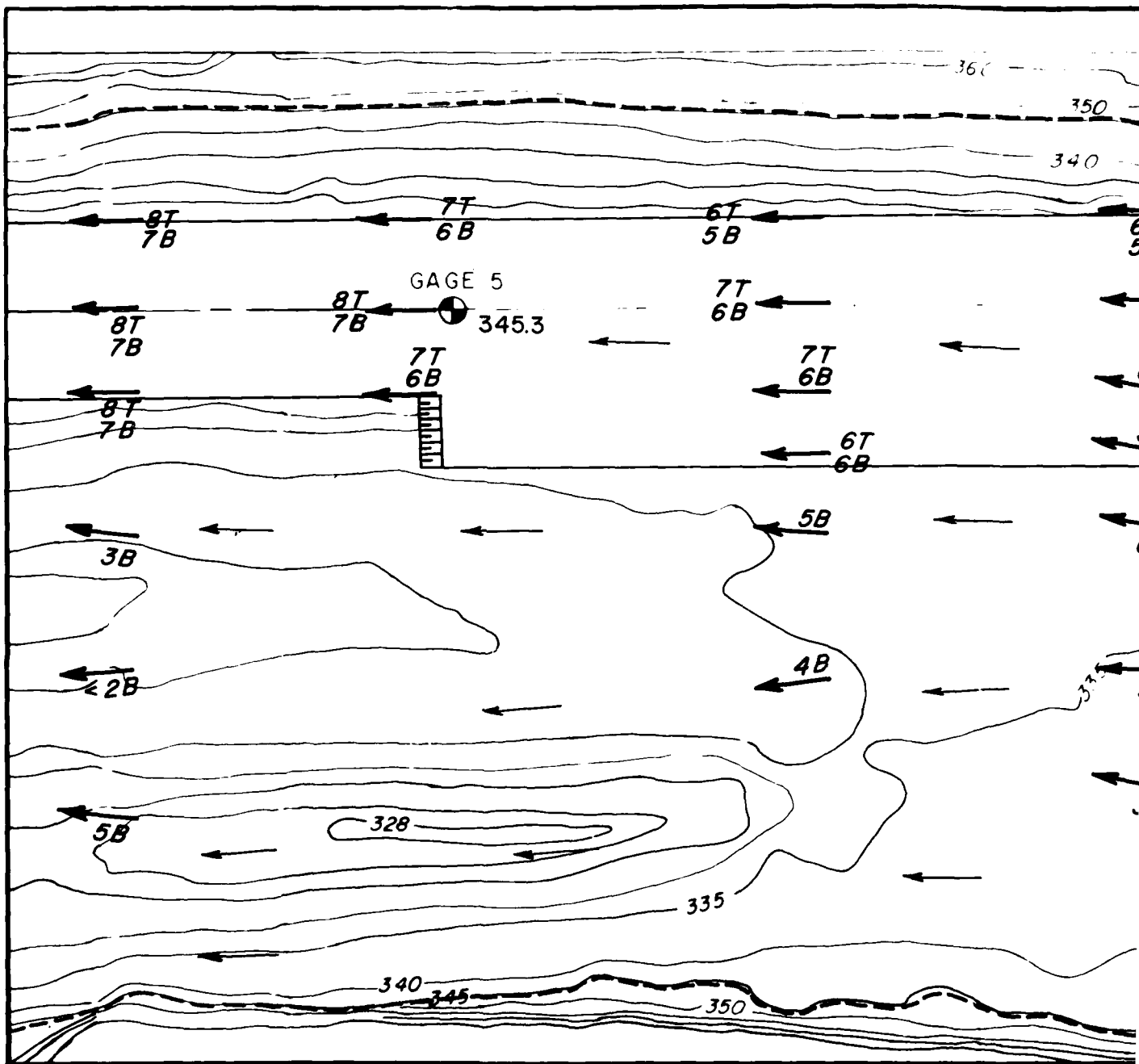
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100-FT EXPANSION OF CHANNEL

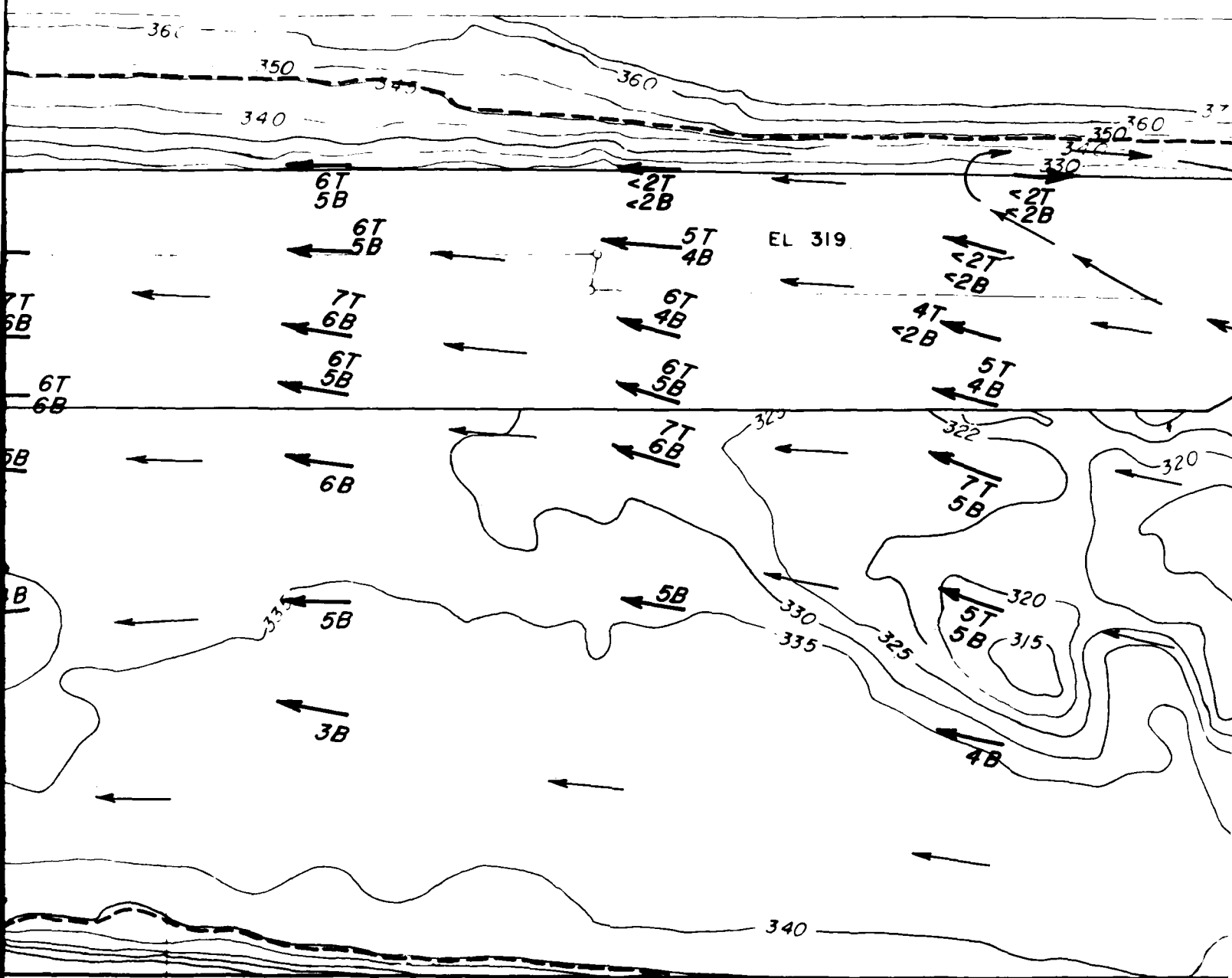
FLOW CONDITIONS
 RIVER DISCHARGE 60 000 CFS
 McNARY POOL EL 335

4

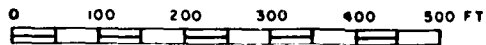


LEGEND

- 4 VELOCITIES IN FPS
- T 5-FT DEPTH
- B 5 FT ABOVE BOTTOM



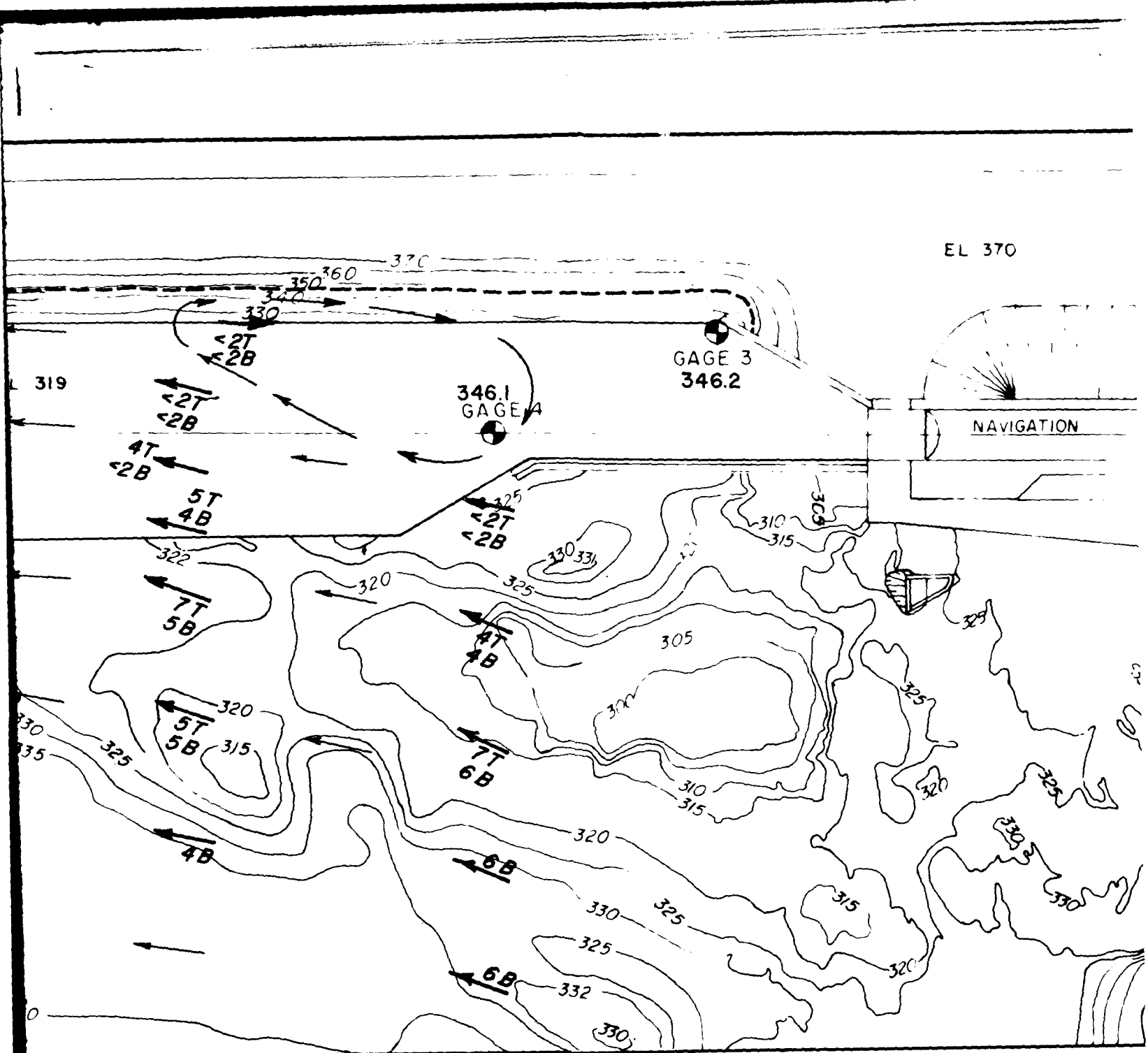
SCALE



FLOW DI

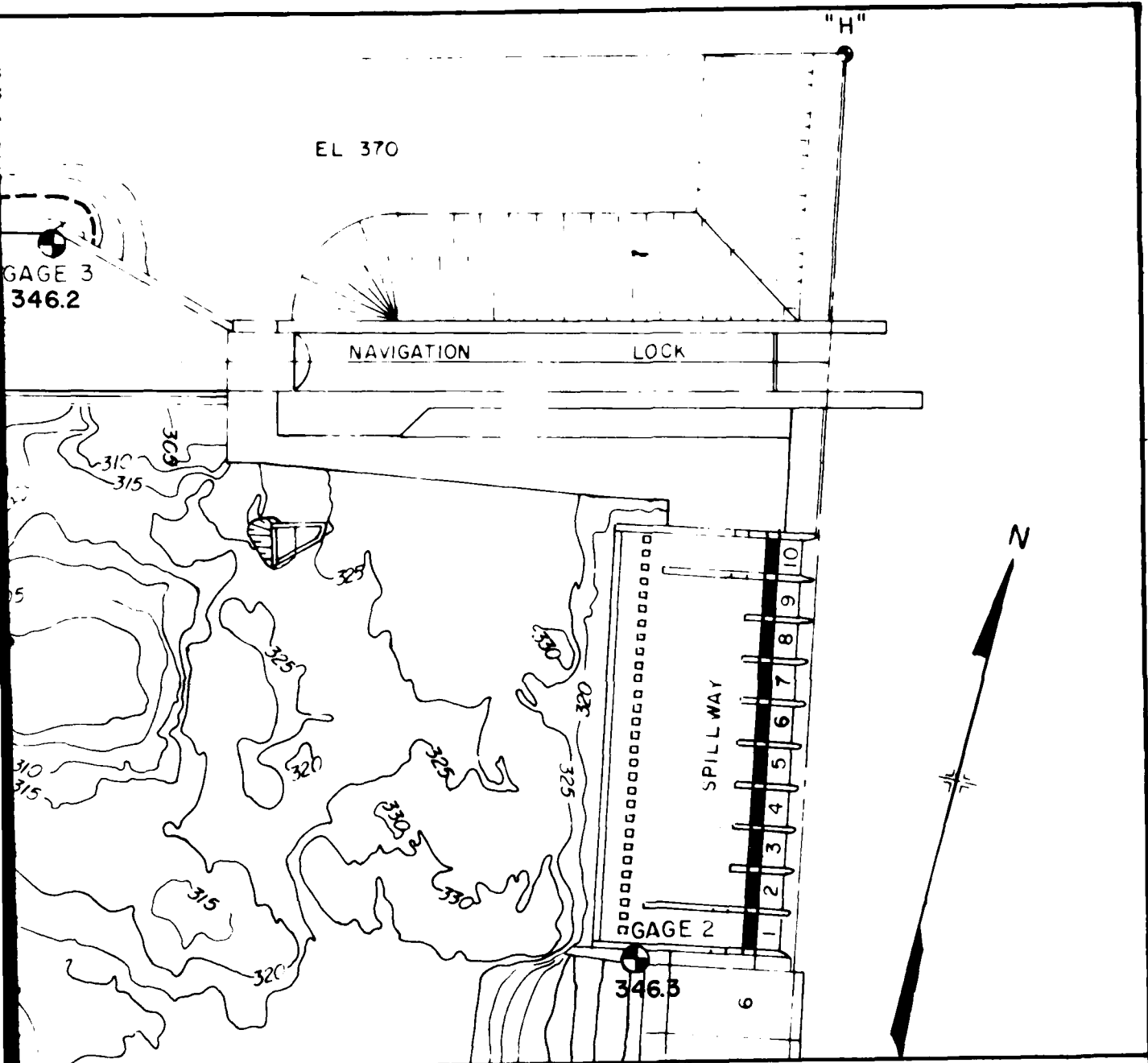
SPILLWAY BAYS 1 TO 10
 POWERHOUSE UNITS 1 TO
 POWERHOUSE UNITS 4 TO

2



FLOW DISTRIBUTION

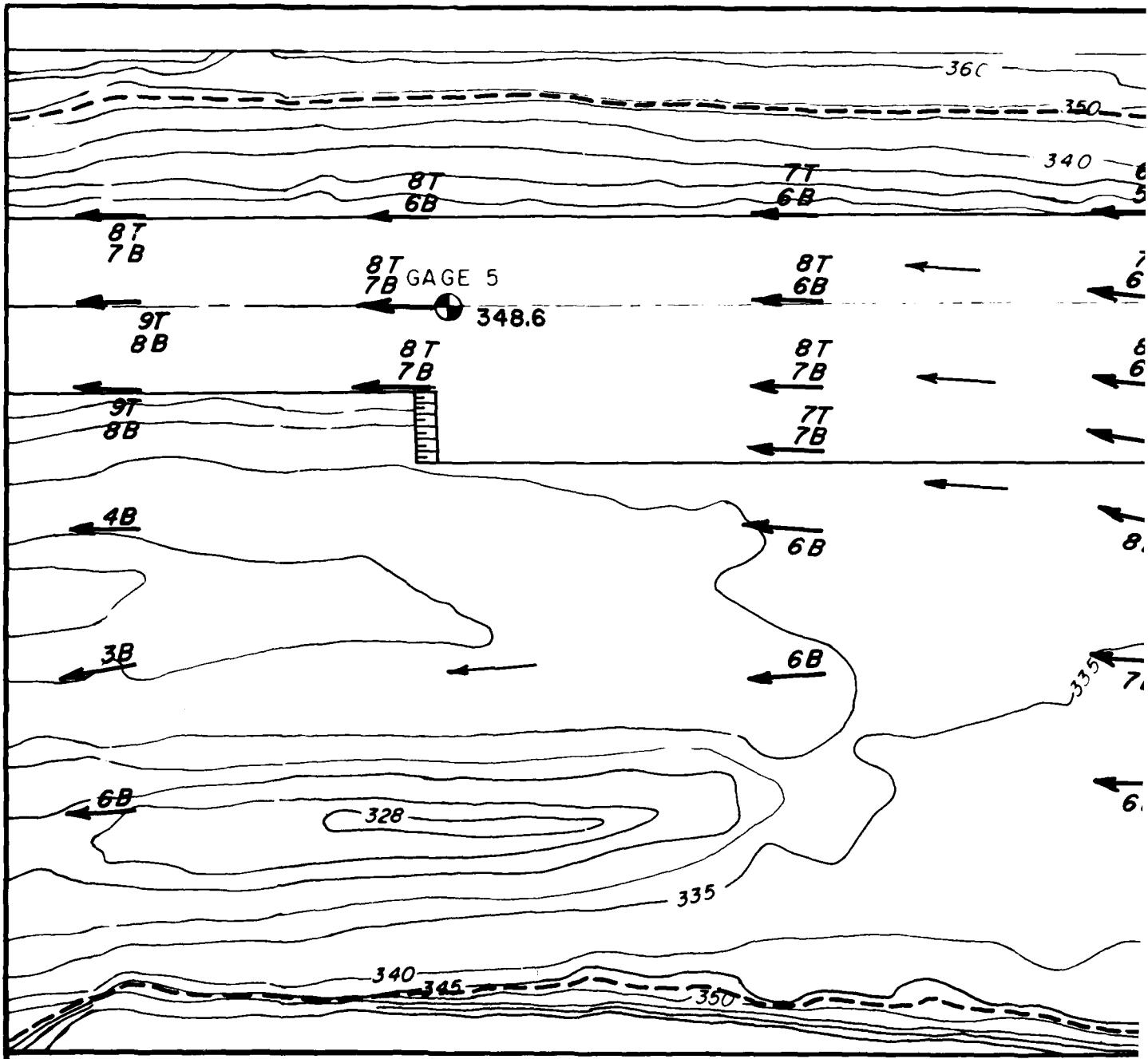
SPILLWAY BAYS 1 TO 10	CLOSED
POWERHOUSE UNITS 1 TO 3	43 300 CFS
POWERHOUSE UNITS 4 TO 6	56 700 CFS



100-FT EXPANSION OF CHANNEL

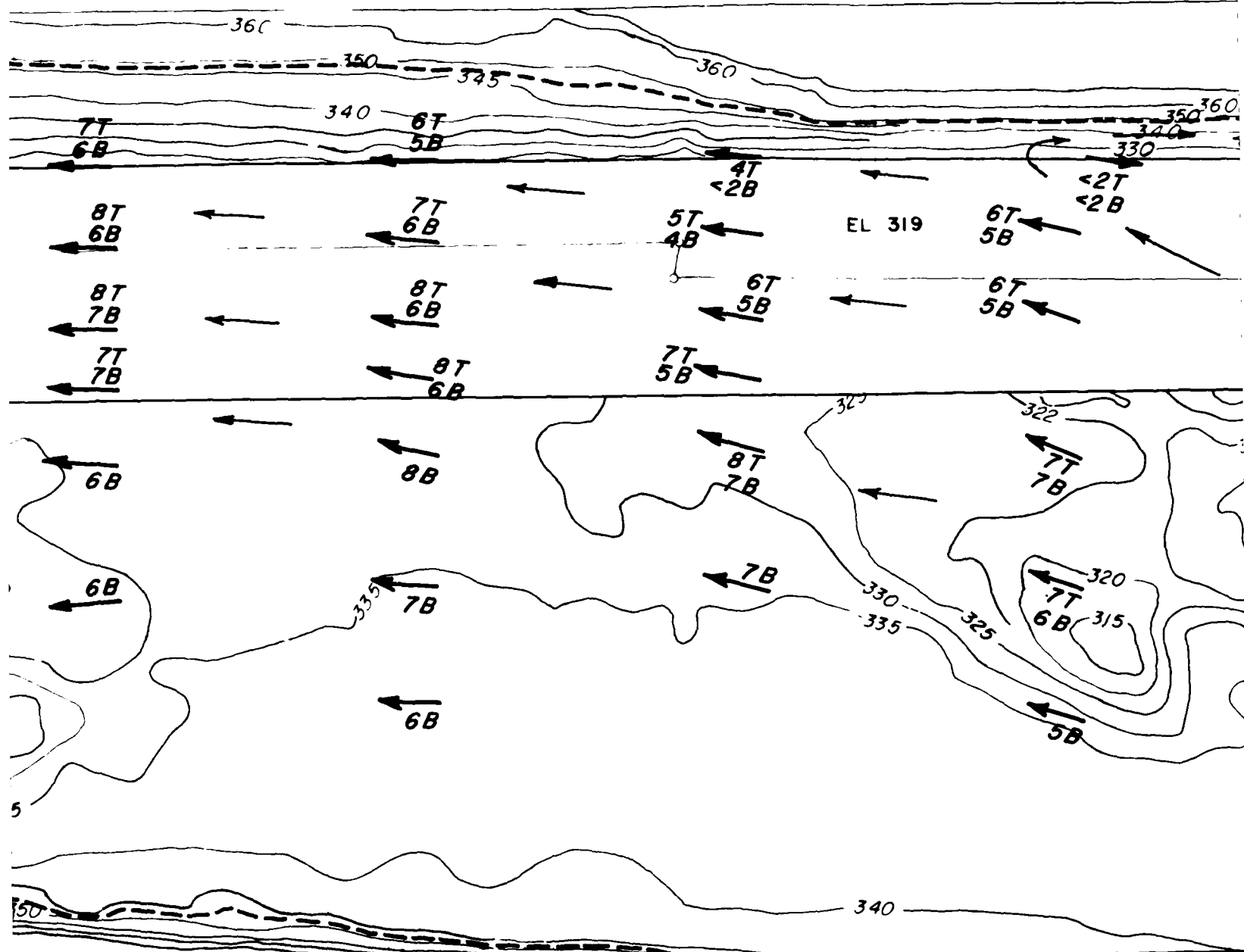
FLOW CONDITIONS
 RIVER DISCHARGE 100 000 CFS
 McNARY POOL EL 335

4

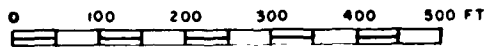


LEGEND

- ← VELOCITIES IN FPS
- T 5-FT DEPTH
- B 5 FT ABOVE BOTTOM



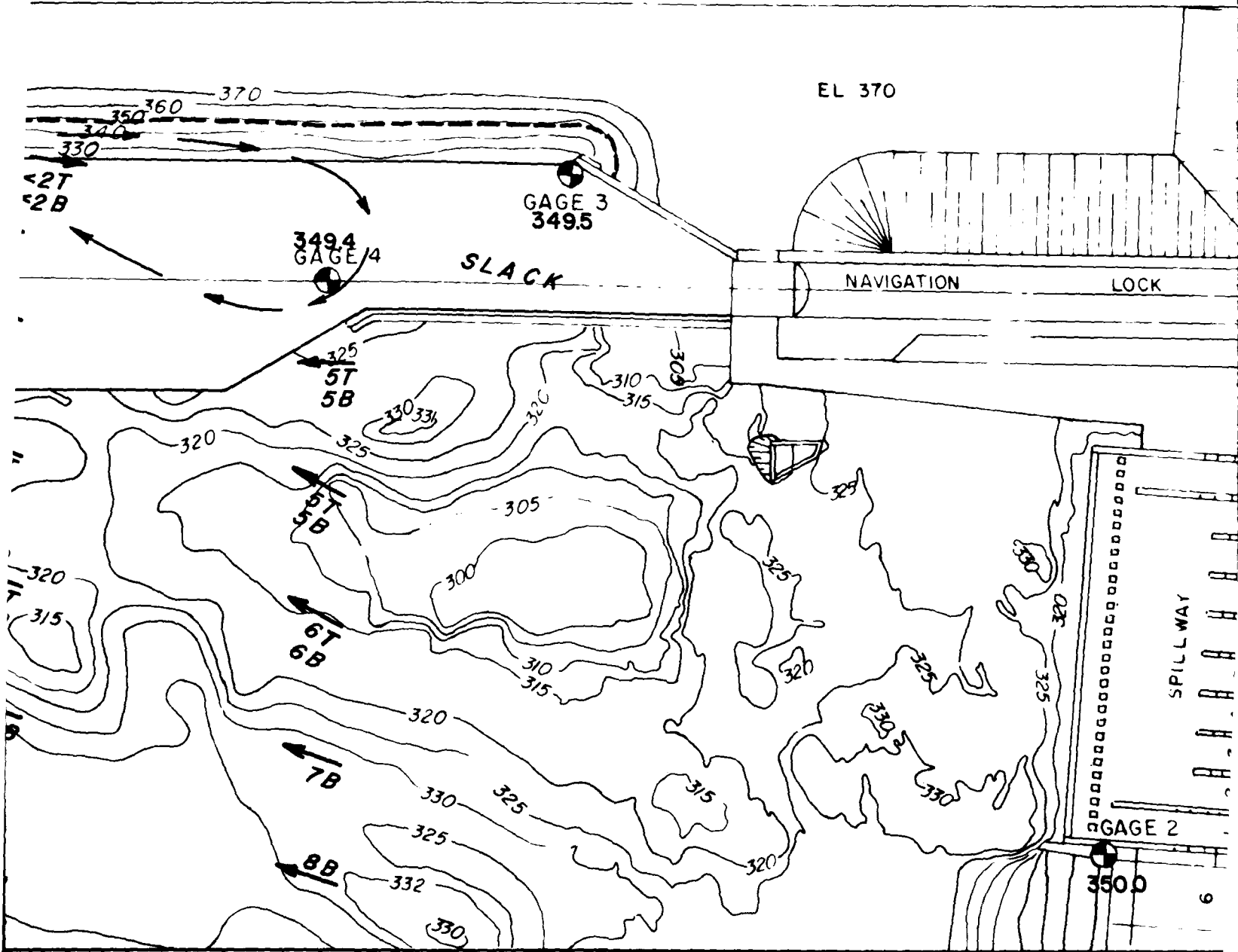
SCALE



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SPILLWAY BAYS
 POWERHOUSE UNI
 POWERHOUSE UNI

END
 VES IN FPS
 EPTH
 BOVE BOTTOM

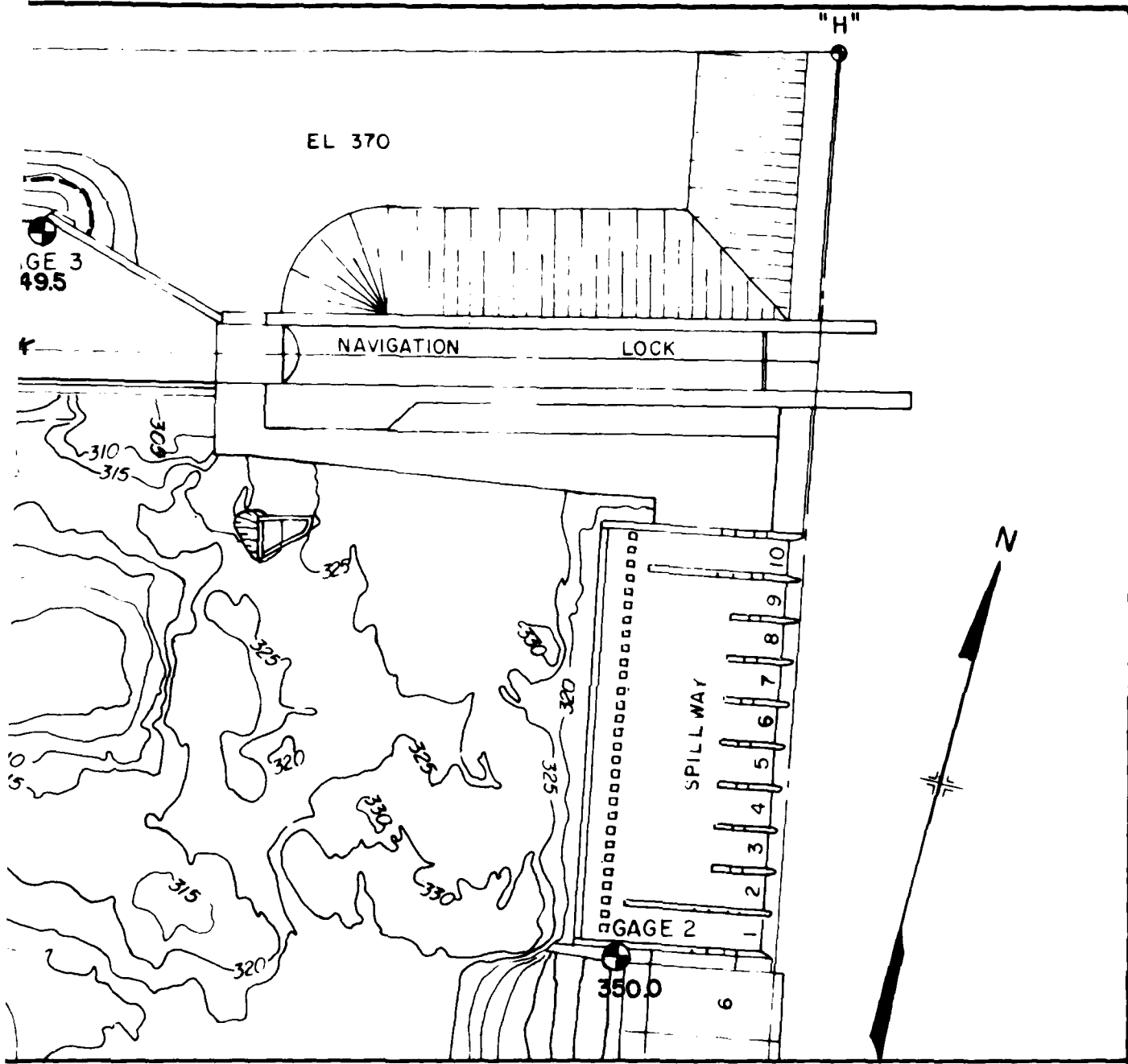


FLOW DISTRIBUTION

100-FT

SPILLWAY BAYS 1 TO 10	50 000 CFS
POWERHOUSE UNITS 1 TO 3	43 300 CFS
POWERHOUSE UNITS 4 TO 6	56 700 CFS

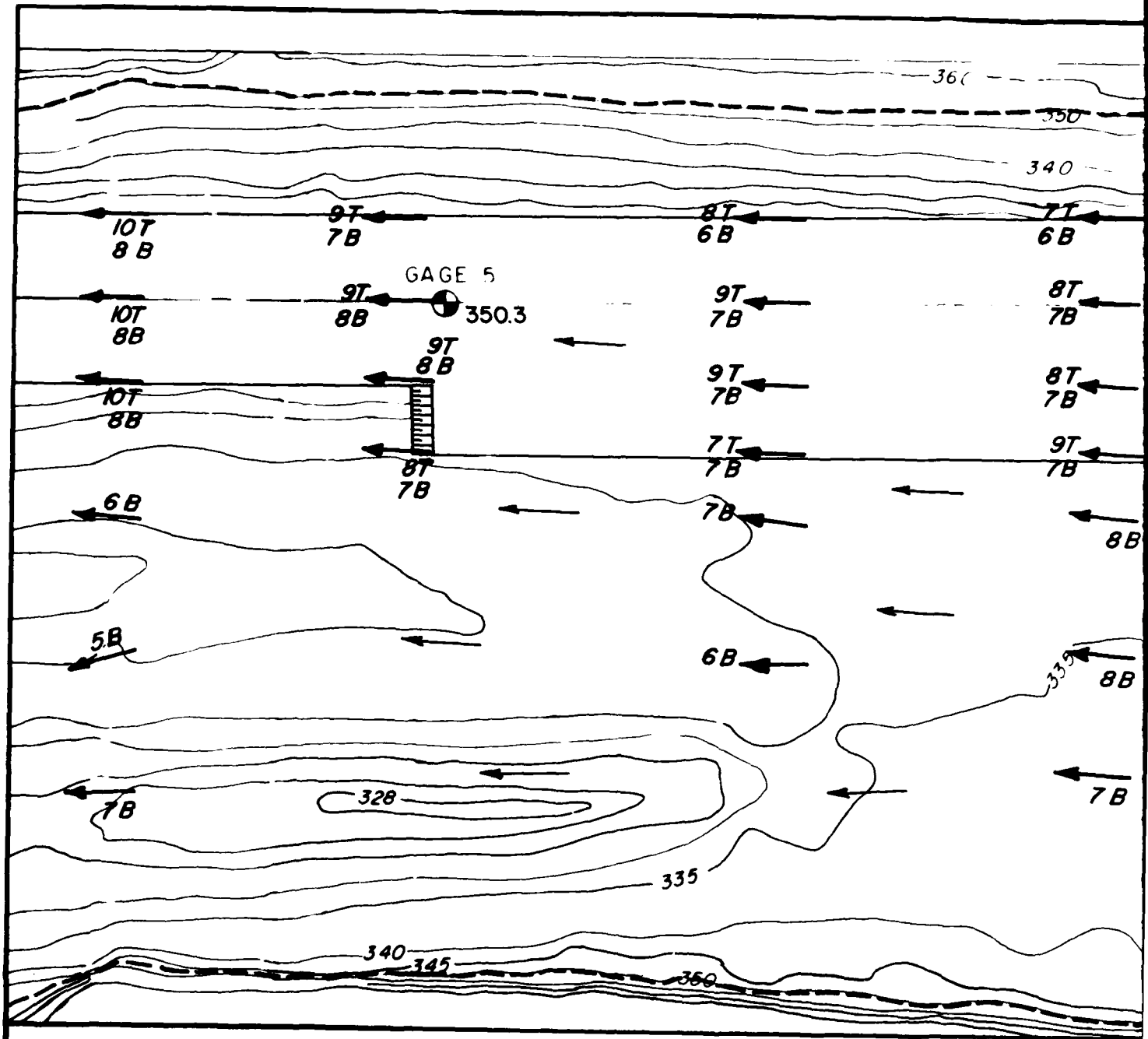
RIVER
N




100-FT EXPANSION OF CHANNEL

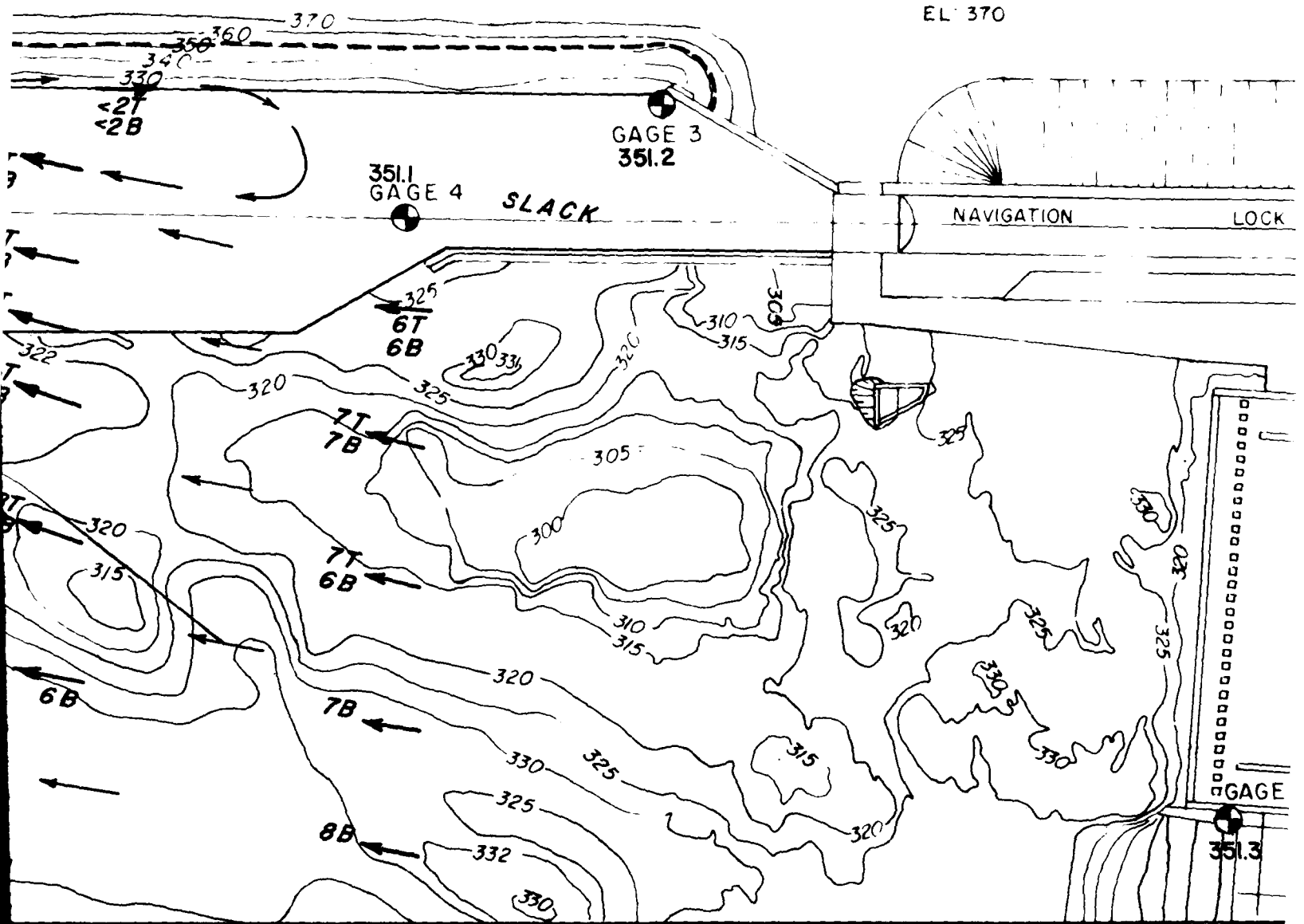
FLOW CONDITIONS
 RIVER DISCHARGE 150 000 CFS
 MCNARY POOL EL 335

4



LEGEND

-  VELOCITIES IN FPS
- T 5-FT DEPTH
- B 5 FT ABOVE BOTTOM



EL 370

GAGE 3
351.2

351.1
GAGE 4

SLACK

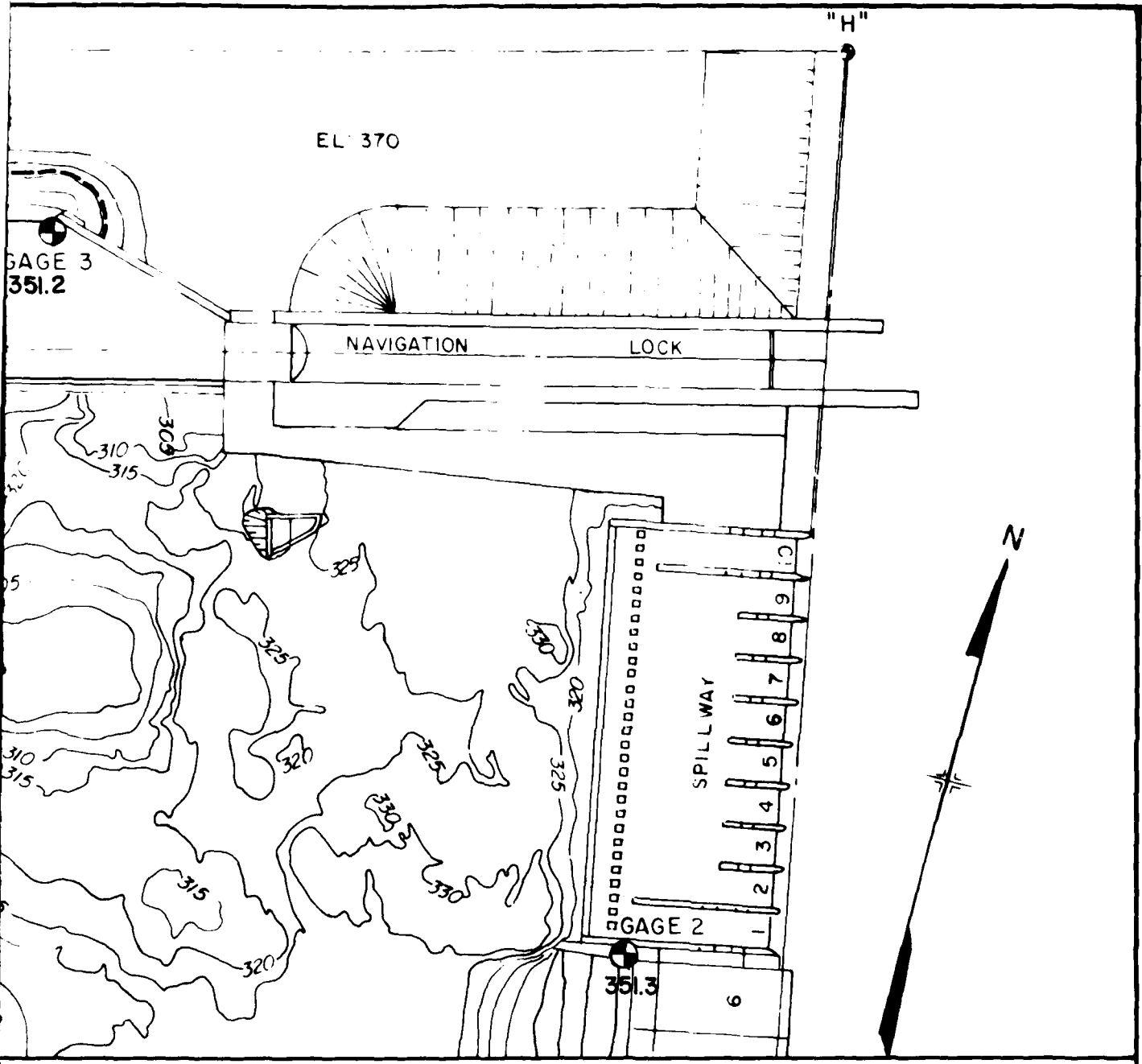
NAVIGATION

LOCK

GAGE
351.3

FLOW DISTRIBUTION

SPILLWAY BAYS 1 TO 10	79 500 CFS
POWERHOUSE UNITS 1 TO 3	44 400 CFS
POWERHOUSE UNITS 4 TO 6	56 100 CFS



100-FT EXPANSION OF CHANNEL

FLOW CONDITIONS
 RIVER DISCHARGE 180 000 CFS
 McNARY POGL EL 335

4

**LATE
LMED**