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The Influence of Hydraulics on Boat Trajectories and Boating Accidents on the Colorado River, Grand Canyon, Arizona

by

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Abstract

A summary of data collected by National Park Service volunteers on recreational boating trajectories and accidents is presented. The boat trajectories are compared with flow streamlines. The comparison suggests that in rapids motorboats are powerful enough to deviate from the streamlines on which they enter the rapid, but that non-motorboats are restricted in their maneuverability to deviations of a few to perhaps 15 feet.

Introduction

During the summer of 1986, recreational boating in nine rapids of the Colorado River in the Grand Canyon (House Rock, Twenty-four and One Half Mile, Hance, Horn Creek, Granite, Crystal, Deubendorff, Upset, and Lava Falls Rapids) was observed by National Park Service (N.P.S.) volunteers. (For a discussion of the hydraulics, geomorphology, and location of these rapids, see Kieffer, 1987.) The observers were asked by the N.P.S. to document boating accidents as part of a recreational use study in cooperation with the Bureau of Reclamation (for more information on the background of the observers see Brown and Hahn-O'Neill, 1987). The United States Geological Survey (U.S.G.S.) is studying the hydraulics of rapids in the Grand Canyon, including all but one (Upset) of the rapids observed. Having the observers located at these rapids provided an opportunity for additional data collection and integration of recreational and hydraulic observations.

Susan Kieffer and Margie Marley of the U.S.G.S. provided the observers with forms containing maps (for an example, see figure 1) to be used for plotting the trajectories of boats through the rapids. There were three desired products; (1) a record of boat trajectories to compare with previously obtained float data on streamlines and flow velocities (Kieffer, 1987), (2) a data base for relating the boat trajectories to the hydraulic features in these rapids, and (3) a record of accident locations.

This report summarizes the observations and presents a preliminary hydraulic explanation for the observed boat trajectories and accidents. The original forms and one duplicate set intended for the N.P.S. are on file with the Bureau of Reclamation (Dave Wegner, Grand Canyon Study Manager), and the U.S.G.S. (Sue Kieffer) retains one duplicate set.

Method

Prior to entering the canyon, the observers met with Kieffer and Marley for instructional training. A video tape (Kieffer, 1986) showing and describing the rapids was viewed by the observers and a question and answer session followed for about an hour. The observers were given observation forms (like figure 1) on which they recorded data. The detailed topography on the forms was a preliminary version of hydraulic maps (Kieffer, in press);

Figure 1. Sample observer form

INSTRUCTIONS:

1. Pick a starting lane.
2. Put key points on the trajectory.
3. Connect the dots!
4. Mark accident locations with "X".
5. Record color code on this form.

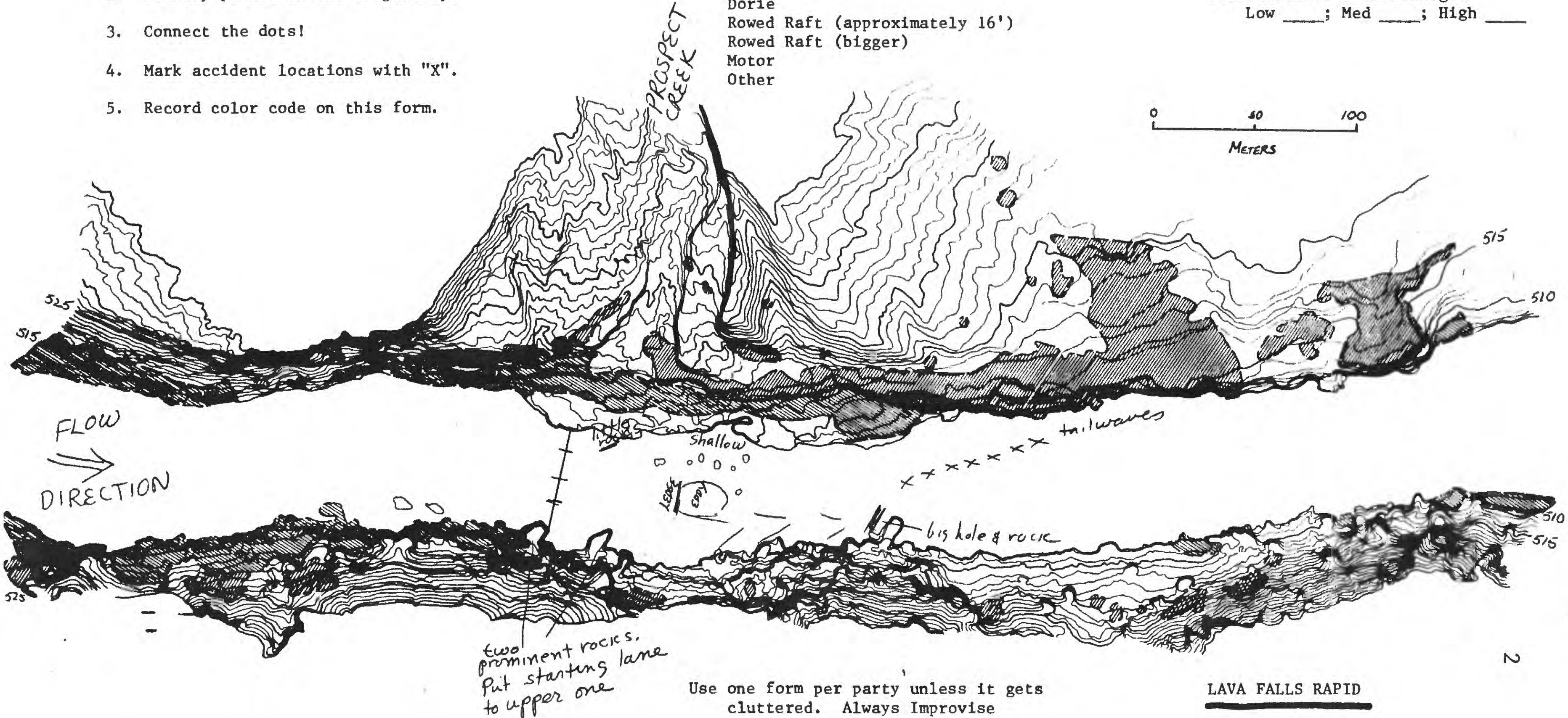
Boat Type: Show your code.
(Do not use kayaks or small inflatables.)

CODE	BOAT TYPE
	Dorie
	Rowed Raft (approximately 16')
	Rowed Raft (bigger)
	Motor
	Other

Observer's Name: ____________

Date: __________ Time of Day: ______

Your Estimate of Discharge:
Low ____; Med ____; High ____



Use one form per party unless it gets cluttered. Always Improvise when necessary!

LAVA FALLS RAPID

Contour Invterval = 1 m
Dashed Contour Interval = ½ m
Sand ▨ Tree ▨

Remember; The shoreline shown is for 5,000 cfs, i.e., low water. Shoreline changes with discharge.

hydraulic features had to be sketched in because accurate rendering of these features was not available at the time. Detailed explanation was provided to the observers on how to locate hydraulic features on the maps (figure 1) and on how best to estimate and record boat trajectories.

A major problem in observing and plotting boat trajectories is the speed with which events happen. During the training, the observers were instructed to locate key points in the rapid (e.g., a rock or a large wave) and to construct trajectories for an observed boat by marking the position of the boat as it passed the key points. After the boat was through the rapid, the observers were then to connect the marks to recreate the boat trajectory.

The recreational boats observed were either: (1) motorized, (2) rowed, or (3) paddled. Data on kayaks and inflatable canoes were not collected because of the difficulty of documenting their trajectories as there are typically more than one in the rapid simultaneously. The observer form provides specific information for boat type: the categories are dories (14-18 ft), rowed rafts (14-18 ft), bigger rowed rafts (18-22 ft), motorboats (approximately 33 ft), and "other" (all "other" recorded were small inflatable rafts (14-18 ft) powered by a crew with paddles--a paddle boat).

All of the non-motorboats have been grouped into one category for this report. The trajectories of the different sizes and types of non-motorboats were similar. For the sake of simplicity, the paddled or rowed boats (non-motor) will be referred to as "POR boats." The boat trajectories of the motorboats and POR boats were distinctly different, and no accidents involved motorboats. Therefore, POR and motorboats are the two groups discussed.

The observer forms (figure 1) have a topographic base with which to locate landmarks relative to the river and the position of boats through rapids. The shoreline on all of the maps represents the river stage at a discharge of 5,000 cubic feet per second (cfs). The contour intervals are closely spaced (1 m) and provide detailed topographic information. Photocopy reduction was required to make each map fit within 8-1/2 x 14 inches, so that although all of the original maps were the same scale (1:1000), the scales varied after reduction for the observer form. The scale is indicated on the forms. (Since no topographic map existed for Upset Rapids, an improvised form had to be developed.)

At the head of each rapid, the width of the river was divided into four zones ("starting lanes") so that the entry position of the boat could be easily estimated by the observers. In contrast, only three zones are used in this summary--left, center, and right--to conform with the data collected for the N.P.S. and for simplicity of terminology. It should be emphasized that the "starting lanes" only indicate the positions of boats starting at the top of the rapid, and are not necessarily indicative of position in the main part of, or at the bottom of, the rapid.

Many known hydraulic features were sketched on the river to help estimate the location of boat trajectories. These features include tongues, waves, eddies, ledges, rocks, pourovers, etc. (see Kieffer, 1987, for definitions). Sand and trees are shaded to assist with locations at the rapid.

Some observer forms have the river flowing from left to right (i.e., House Rock) and others have the river flowing from right to left (i.e., Hance). The orientation of map and text on the form was chosen so that observers on river-left or river-right (direction as seen looking downstream) could read and write on the form showing the rapid as seen from their observation location.

The date and time of day were requested on the form so that discharge could be correlated to the observer form. The observers were also responsible for estimating the discharge. The estimate was recorded as: low (7,000 to 10,000 cfs), medium (10,000 to 20,000 cfs), or high (20,000 to 30,000 cfs). However, the discharges during the data collection time period are also known from the recorded discharge at Lee's Ferry and Bright Angel gage stations. A code for the type of boat was devised and was useful in determining the runs that boats of different size and speed made during specific water levels.

The observers were transported by boat down the river and dropped off in pairs at the assigned rapids. (Upon arrival at Horn Creek, however, the projected releases from Glen Canyon Dam caused concern that the water level would rise above the small camp at which the observers were to live. Therefore, quite unexpectedly, one pair of observers was assigned to Granite Rapids with observer forms of Horn Creek for a data base. This pair of observers was innovative and modified the Horn Creek form to apply to Granite Rapids. Horn Creek was later observed by a Park Service employee.) The observers stayed at each rapid for approximately 15 days (from the end of July through the middle of August, 1986). Horn Creek was observed for only six days.

Results[1]

Figures 2-9 summarize the data for each rapid, and specific narrative comments follow here, with the rapids discussed in the order they occur downstream. The observed limits of the runs are drawn in the river area of figures 2-9. Diagrammatic boat routes for the three entry positions are drawn within the limits. The boat routes are generalized and compiled from the data set; they are not meant to imply recommended routes. In this discussion, the rapids are described in terms used by river-runners with no intention of the use of rigorous hydraulic terms.

The total number of motor- and POR boats, and the percentage of boats taking left, right, or center runs are shown in tables on the figures 2-9. The number of motorboats observed varied from a minimum of 38 at Horn Creek Rapids to a maximum of 101 at Hance Rapids; the number of POR boats observed varied from a minimum of 55 at Horn Creek Rapids to a maximum of 132 at Hance Rapids.

Accidents were recorded at six of the nine rapids and none of them involved motorboats. Types of accidents recorded include: losing control of

1. The following discussion is based on the documentation provided on the forms by the observers, and on the author's interpretation of the observer's documentation. Additional information collected simultaneously by these observers was provided to Grand Canyon National Park and may be helpful in further analysis of the data.

an oar, losing an oar or paddle, losing a person overboard, hitting a rock, and flipping a boat. The location and type of accidents are keyed in figures 2,4,6,7,9, and 10.

House Rock Rapids (figure 2) has a large debris fan on river right and a sheer wall on the left. The geometry of the river constriction as it curves around the fan causes the river to flow towards the left wall. This curvature of the flow towards the wall is greater at low discharges (<10,000 cfs) when the debris fan is not covered with water and the channel is narrow than at high discharges, when the debris fan becomes submerged so that the water surface widens and the space available for boats on the right side of the river increases.

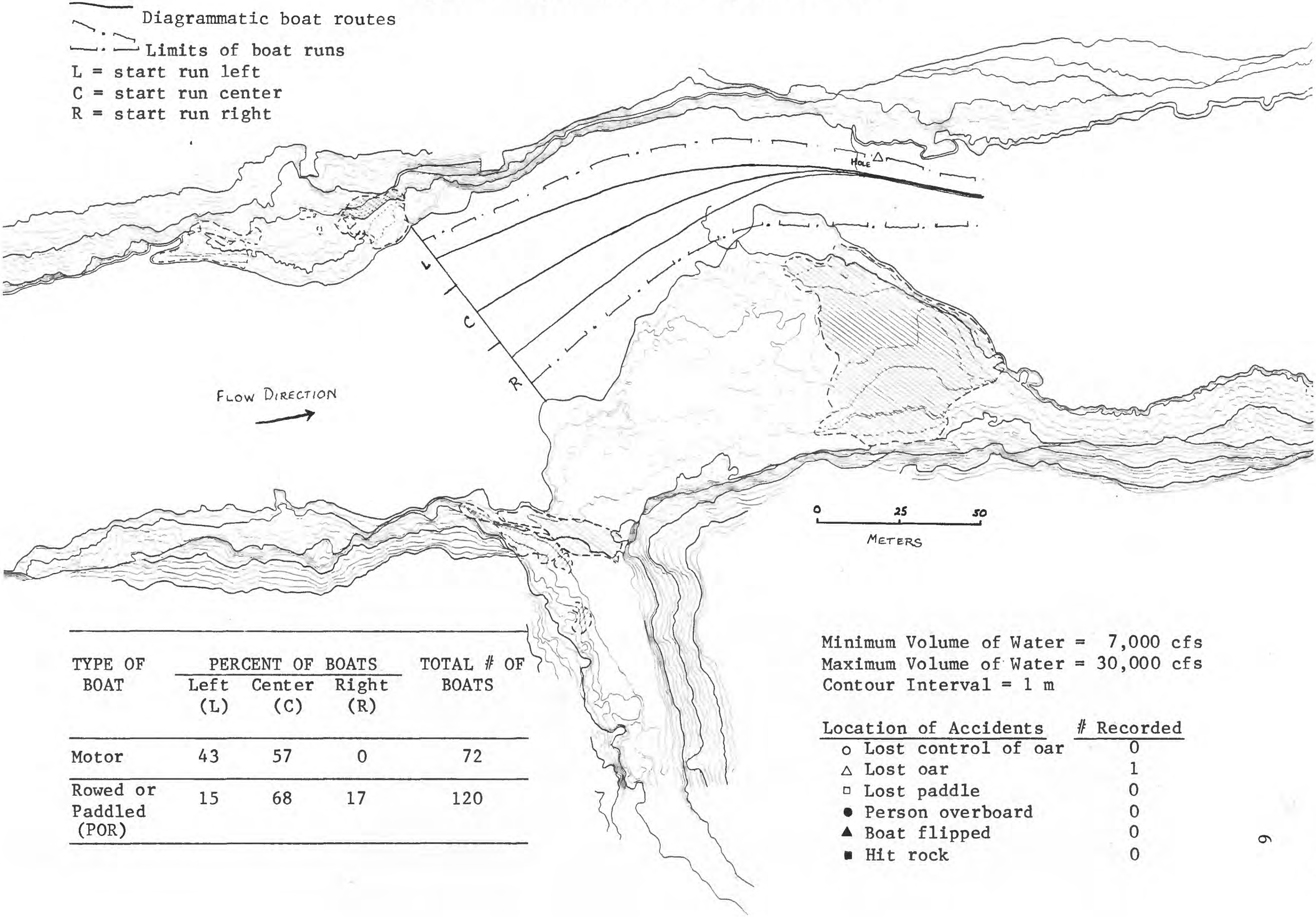
The major hydraulic hazard in the rapid is a hole at the bottom of the rapid (located by the triangle on figure 2 that indicates the loss of an oar in one accident). The observers wrote that the hole at the bottom of the rapid appeared to be largest when the flow was approximately 10,000 cfs. Upstream of this large hole there is another hole which had a "crest" pushing away from the wall. In the only accident observed, one POR boat went through the lower hole and lost an oar. Although boats started at the top of the rapid along a broad band from far right to far left (along the line labeled L, C, R on figure 2), boat trajectories converged in the left-center of the channel just above and to the right of the bottom hole (this is particularly true at low discharges where the trajectories are strongly bunched toward the left side of the river). None of the motorboats started on the right side of the channel, and only 15% of the rowed boats started on the left side of the channel.

Twenty-four and One Half Mile Rapids (figure 3) has a prominent rock at the top left of the rapid that precludes entry on the left at discharges less than 11,000 cfs. Only 6% of the POR boats and no motorboats took this route. Three boats ran the left side when the discharge was 11,000 cfs and went over the barely submerged rock. The remaining four boats that entered left ran the rapid at 16,000 cfs and went left of the rock. The center and right entrances merge as there is no obstacle to separate them. 92% of the motorboats and 82% of the POR boats went down the center. No accidents were reported at any location in the rapid.

Hance Rapids (figure 4) is wide, long and rocky. It has three entry routes which may be run at different water levels. During the study the right run was used by all motorboats, but only by 4% of the POR boats. The left run was used by 92% of all POR boats. In the left run all boats except one went left of a large rock at the top (this rock is shown by a contour on the map of figure 4 and is outlined by a V-shaped area). The trajectory of the boat that went right of the rock is not included on figure 4. The remaining 4% of POR boats took the center run. All but one of the five boats that took the center run were from the same party and for all five runs the flow was 28,000 cfs. The center run is very rocky. At lower discharges rocks in the center are obstacles to be avoided, and at higher discharges they form severe pourovers, also to be avoided.

Hance had eight accidents, the third largest number observed (same number as Lava Falls). Three of the accidents are located downstream of two large rocks at the top of the left run (see figure 4 for site and nature of

Figure 2. Map of House Rock Rapids with Data



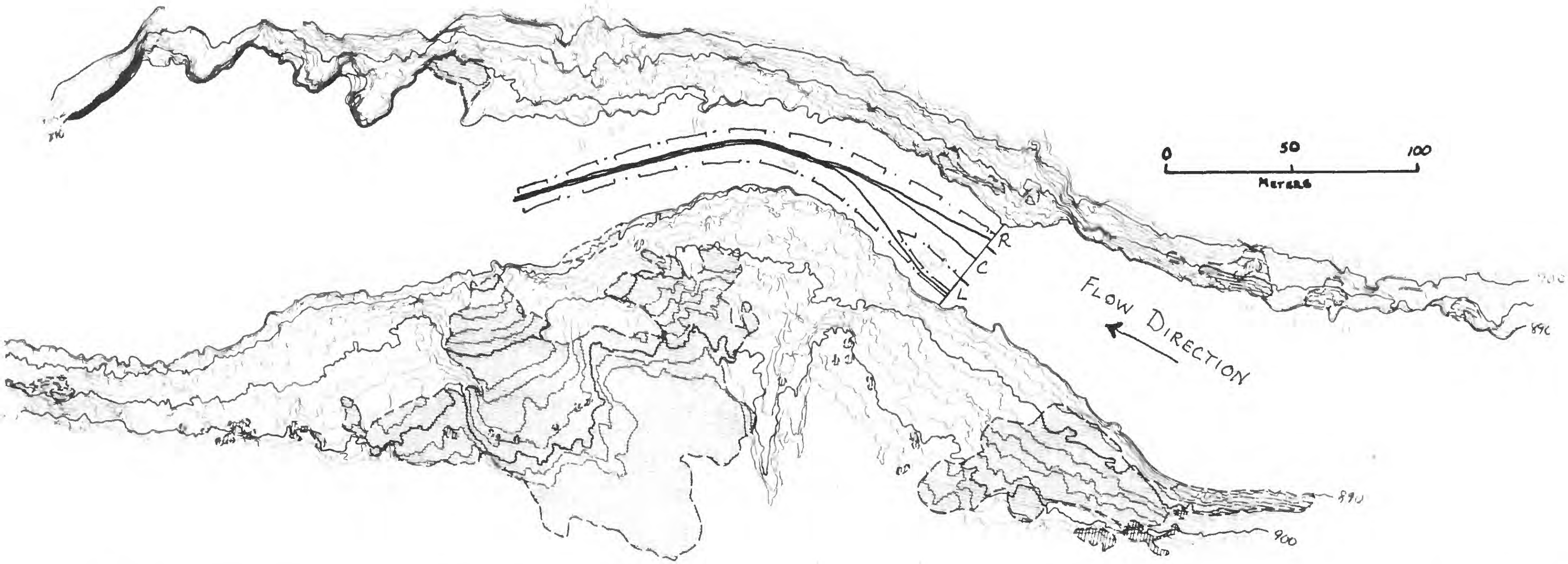
TYPE OF BOAT	PERCENT OF BOATS Left (L)	Center (C)	Right (R)	TOTAL # OF BOATS
Motor	43	57	0	72
Rowed or Paddled (POR)	15	68	17	120

Minimum Volume of Water = 7,000 cfs
Maximum Volume of Water = 30,000 cfs
Contour Interval = 1 m

Location of Accidents	# Recorded
○ Lost control of oar	0
△ Lost oar	1
□ Lost paddle	0
● Person overboard	0
▲ Boat flipped	0
■ Hit rock	0

Figure 3. Map of Twenty-four and One Half Mile Rapids with Data

—— Diagrammatic boat routes
⌐·⌐ Limits of boat runs
L = start run left
C = start run center
R = start run right

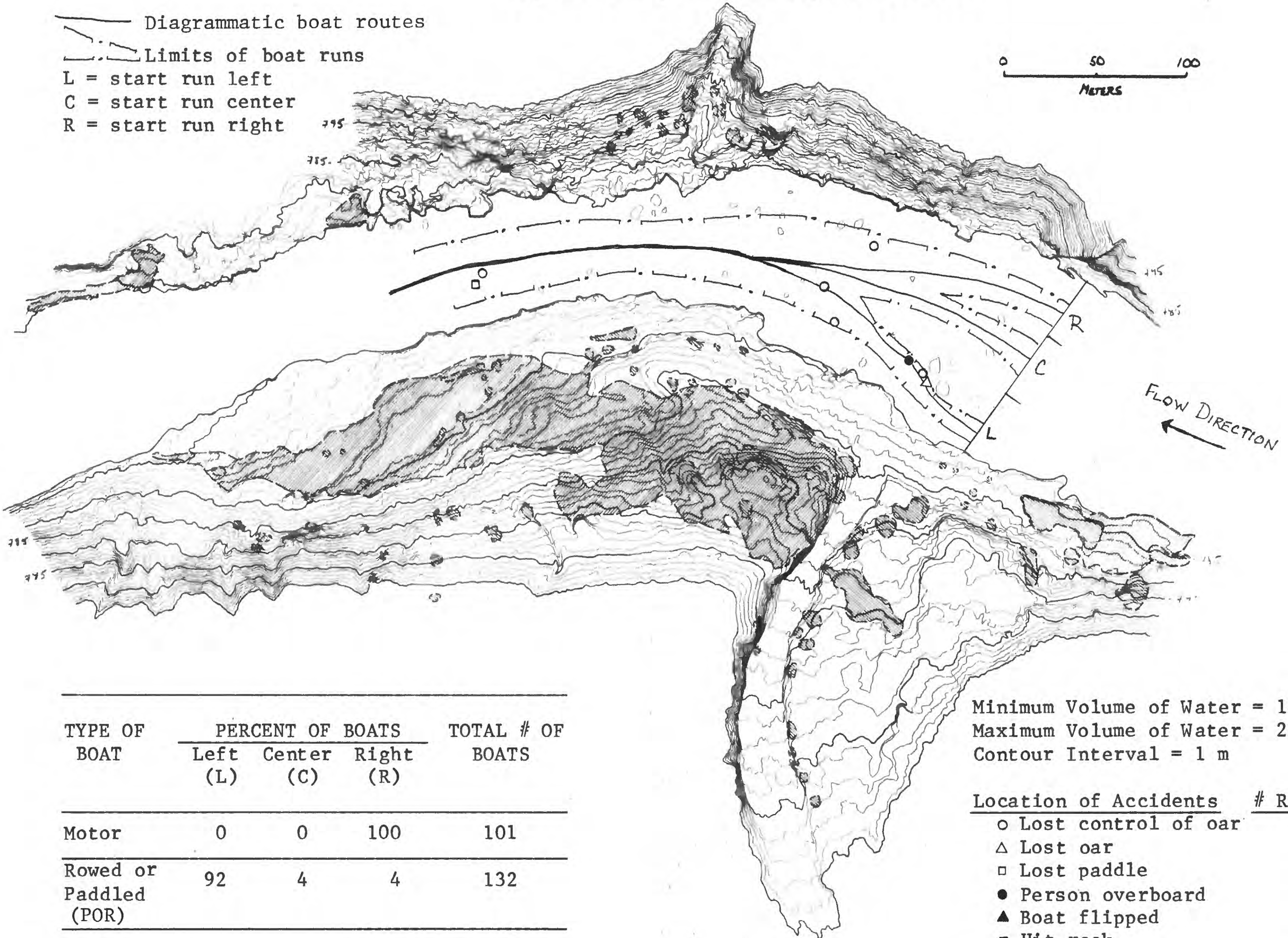


TYPE OF BOAT	PERCENT OF BOATS Left (L)	Center (C)	Right (R)	TOTAL # OF BOATS
Motor	0	92	8	92
Rowed or Paddled (POR)	6	82	12	103

Minimum Volume of Water = 8,000 cfs
Maximum Volume of Water = 28,000 cfs
Contour Interval = 1 m

Location of Accidents	# Recorded
○ Lost control of oar	0
△ Lost oar	0
▫ Lost paddle	0
● Person overboard	0
▲ Boat flipped	0
■ Hit rock	0

Figure 4. Map of Hance Rapids with Data



TYPE OF BOAT	PERCENT OF BOATS Left (L)	Center (C)	Right (R)	TOTAL # OF BOATS
Motor	0	0	100	101
Rowed or Paddled (POR)	92	4	4	132

Minimum Volume of Water = 18,000 cfs
Maximum Volume of Water = 28,000 cfs
Contour Interval = 1 m

Location of Accidents	# Recorded
○ Lost control of oar	5
△ Lost oar	1
□ Lost paddle	1
● Person overboard	1
▲ Boat flipped	0
■ Hit rock	0

accidents). The hydraulic feature associated with these three accidents is a small but potentially turbulent eddy. If a boat crosses the eddy fence, accidents may occur due to the sudden change of flow direction between the main stream and the eddy. The remainder of the accidents appear to be associated with large waves near the middle of the rapid, and with waves between two large eddy systems that occur both on the right and left in the lower part of the rapid.

Horn Creek Rapids (figure 5) was observed for only six days for reasons mentioned above. At Horn Creek Rapids, the canyon is straight and narrow. Two large submerged rocks form the "horns" at the top of the rapid. No boats went over the rock on the left, but some went over the rock to the right. During the observation period, the discharge never dropped below 17,000 cfs. No accidents were observed. However, accidents at Horn Creek are more frequent at water levels less than 10,000 cfs (Brown and Hahn-O'Neill, 1987). The beginning of the boat trajectories are similar to those at Twenty-four and One Half Mile Rapids; the left route is separate from the center and right runs which are continuous across the top. 84% POR boats and 87% motorboats took the center run.

Granite Rapids (figure 6) has a sheer wall on the right (looking downstream) and a large debris fan on the left. The topography at Granite is similar to that at House Rock, but larger in scale. The current is constricted by the debris fan and the sheer wall. Boats starting left are moved swiftly towards the right. The boat trajectories in Granite meet in the convergent part of the rapid; the trajectories in House Rock meet in the divergent part of the rapid. As at House Rock, no motorboats took the run adjacent to the debris fan due to the shallow water (right at House Rock, and left at Granite).

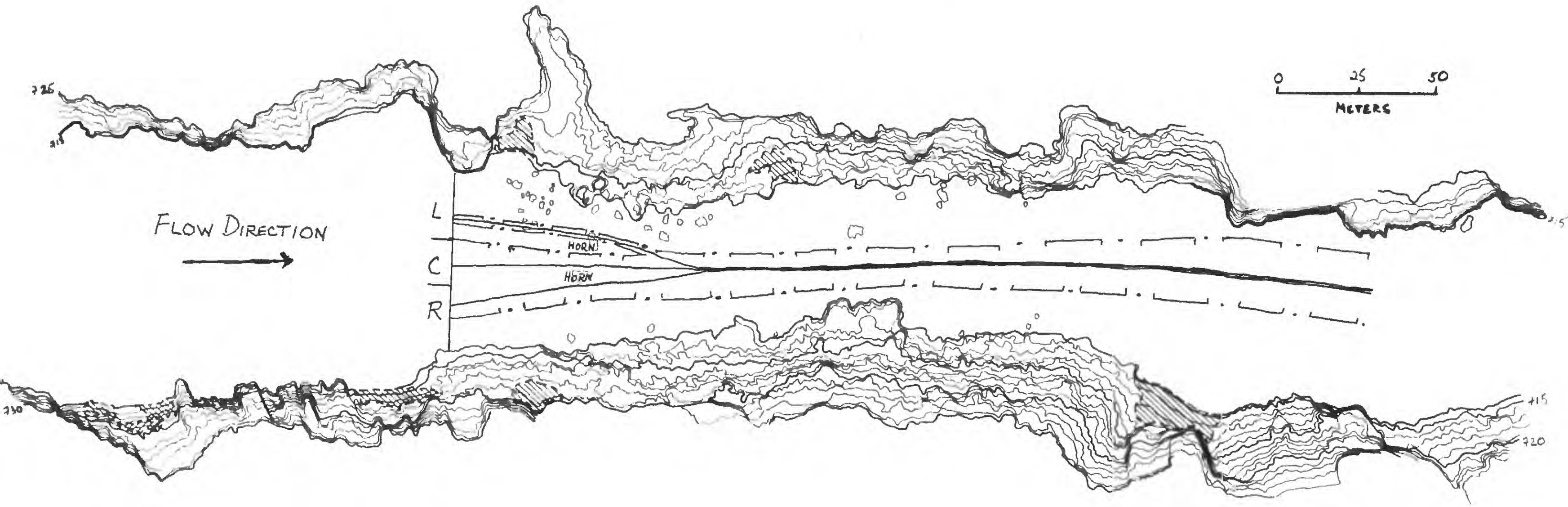
Granite has very large waves in the main current against the wall, and the accidents occurred in these waves. Nine accidents were reported; in eight of these control of an oar was lost. This rapid had the second largest number of accidents reported, but only one of them was serious. In the serious accident a small (13.5 ft) boat flipped. Granite has a large and strong eddy on the bottom right. Three boats were noted as being "stuck" in it (there was no mention of how many times they recirculated). No other rapid observed had any notes about boats being stuck in eddies.

Crystal Rapids (figure 7) had the largest number of and most serious accidents. Reported accidents on the observer forms include seven flips, four people overboard, five lost oars, two broken oars, three lost control of oar, and four hit rocks. The majority of these accidents are located in and near the "new wave" formed in 1983 (see location on figure 7).

78% of all POR boats entered Crystal on the right during the observation period. These boats started right and stayed right. The center run was used by 26 (21%) POR boats; two boats stayed in the center and 24 cut to the right. One (1%) POR boat started left and stayed far left. Only 32% of the motorboats started on the right side of the rapid. The remainder of the motorboats started left (13%) or mid-channel (55%) and cut (under power) to the right at the top of the rapid.

Figure 5. Map of Horn Creek Rapids with Data

Diagrammatic boat routes
Limits of boat runs
L = start run left
C = start run center
R = start run right



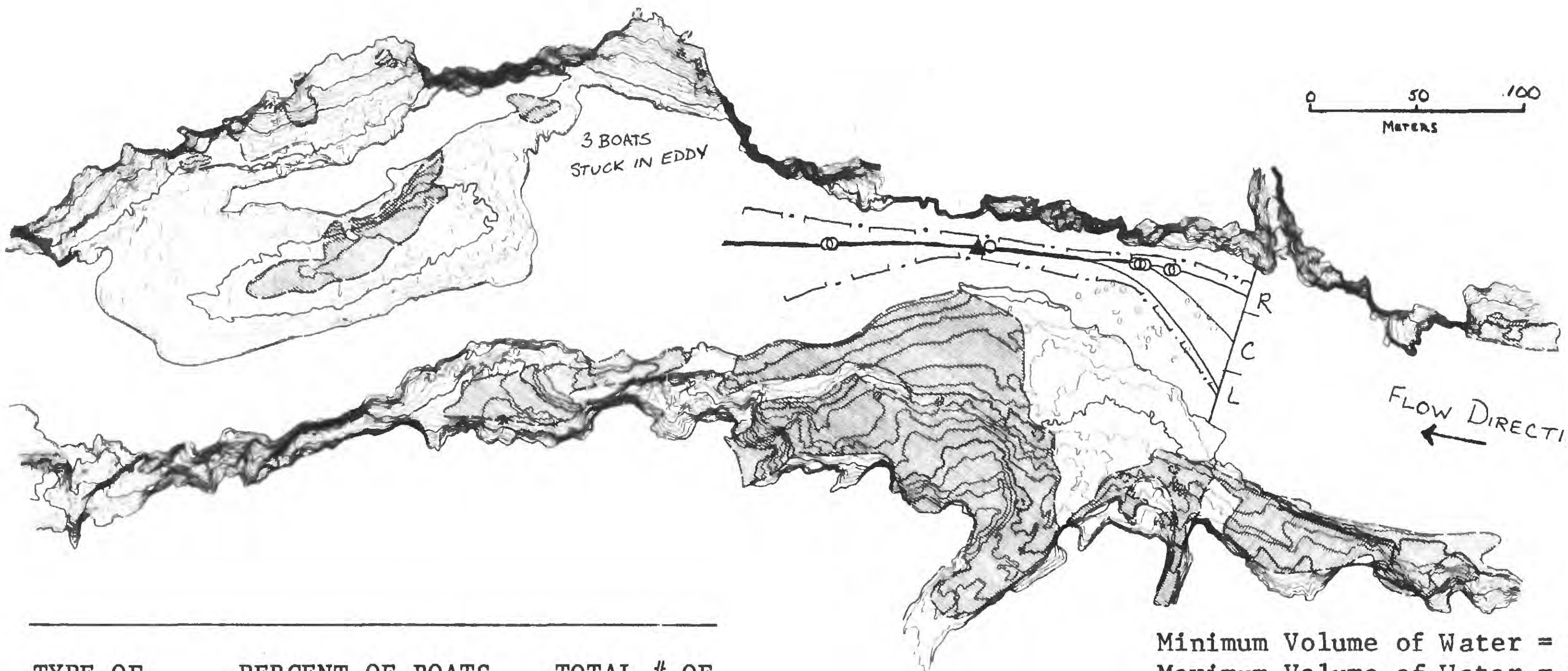
TYPE OF BOAT	PERCENT OF BOATS Left (L)	Center (C)	Right (R)	TOTAL # OF BOATS
Motor	0	84	16	38
Rowed or Paddled (POR)	4	87	9	55

Minimum Volume of Water = 17,000 cfs
Maximum Volume of Water = 26,000 cfs
Contour Interval = 1 m

Location of Accidents	# Recorded
o Lost control of oar	0
△ Lost oar	0
□ Lost paddle	0
● Person overboard	0
▲ Boat flipped	0
■ Hit rock	0

Figure 6. Map of Granite Rapids with Data

Diagrammatic boat routes
Limits of boat runs
L = start run left
C = start run center
R = start run right



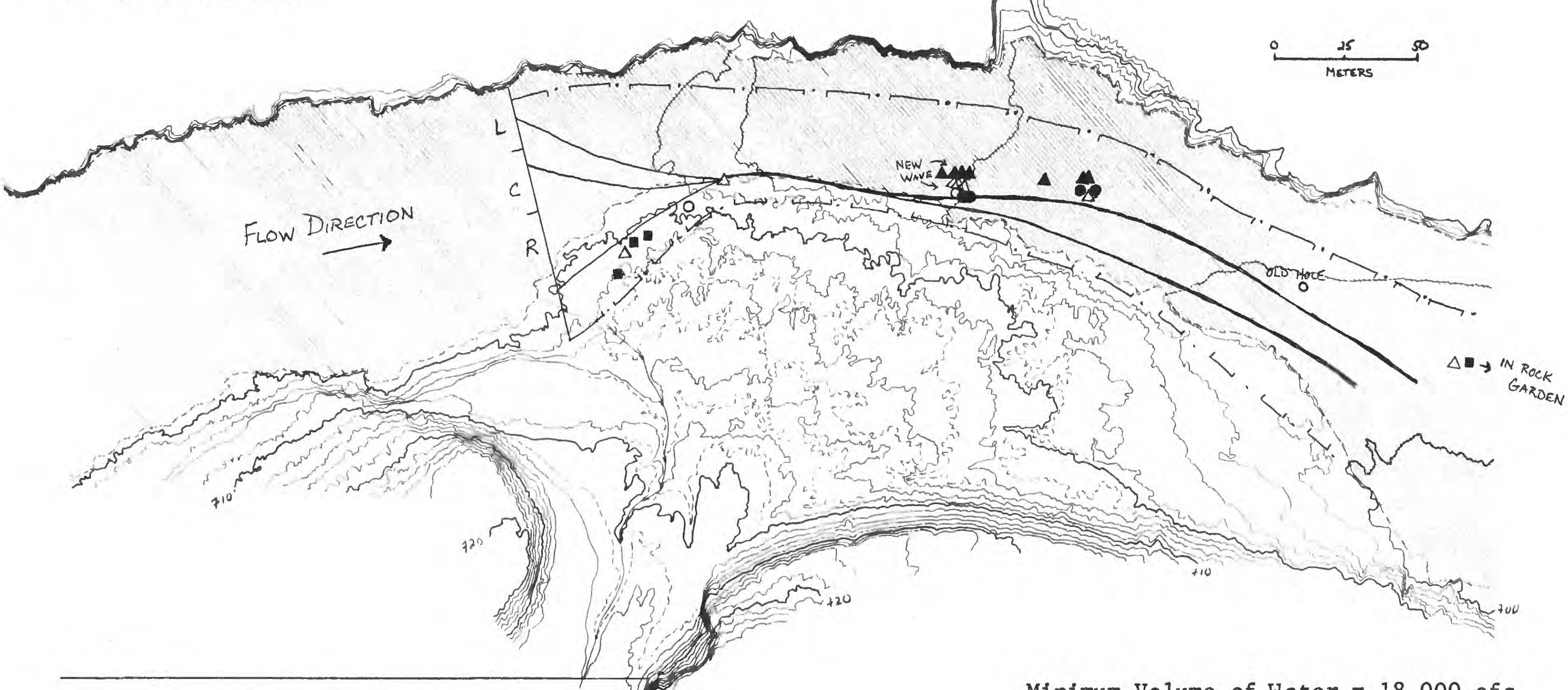
TYPE OF BOAT	PERCENT OF BOATS Left (L)	Center (C)	Right (R)	TOTAL # OF BOATS
Motor	0	13	87	85
Rowed or Paddled (POR)	5	66	29	105

Minimum Volume of Water = 19,000 cfs
Maximum Volume of Water = 29,000 cfs
Contour Interval = 1 m

Location of Accidents	# Recorded
○ Lost control of oar	8
△ Lost oar	0
□ Lost paddle	0
● Person overboard	0
▲ Boat flipped	1
■ Hit rock	0

Figure 7. Map of Crystal Rapids with Data

Diagrammatic boat routes
Limits of boat runs
L = start run left
C = start run center
R = start run right



TYPE OF BOAT	PERCENT OF BOATS Left (L)	Center (C)	Right (R)	TOTAL # OF BOATS
Motor	13	55	32	102
Rowed or Paddled (POR)	1	21	78	122

Minimum Volume of Water = 18,000 cfs
Maximum Volume of Water = 29,000 cfs
Contour Interval = 1 m

Location of Accidents	# Recorded
○ Lost control of oar	3
△ Lost or broke oar	7
□ Lost paddle	0
● Person overboard	4
▲ Boat flipped	7
■ Hit Rock	4

This left-to-right maneuver is a good example of the maneuverability available to a motorboat but not to a POR boat. A POR boat can not run the right side of Crystal by starting left because they lack the power to cut quickly across the current. Motorboats can do so because the boat under power builds momentum as it cuts across the tongue. This momentum keeps the boat on the right side of the rapid once it reaches the right side. 60% of the motorboats starting center or left made it to the right of the new wave. The POR boats that started in the center and cut to the right were not as successful as the motorboats; only 7 of the twenty-six POR boats (30%) attempting this maneuver went right of the new wave (the remainder went through it).

Deubendorff Rapids (figure 8) is a very rocky rapid at low water. There are many rocks exposed in the center of the rapid at its head. 26% of all POR boats were described as taking the center run (the discharge exceeded 13,000 cfs during the entire observation period). 96% of all motorboats took the left run, but only 53% of POR boats went left. The water levels observed (13,000 to 29,000 cfs) allowed variety in the runs taken by POR boats, whereas motorboats stayed to the left. (The observers commented that the fluctuations in water levels made it difficult to correlate boat runs using the topographic base with a shoreline of 5,000 cfs shown on the form.) No accidents were recorded.

A sketch of **Upset Rapids** (figure 9) was drawn from an aerial photo with a water level of 5,000 cfs[2]. A large rock located at the top right of the rapid separates the center run from the right run. The right run becomes non-existent at a medium flow (the lowest water observed). The majority of boats took the center run. The only accident recorded at Upset was a person overboard. This incident appears to have been the result of going through a large hole at the bottom of the rapid.

Lava Falls Rapids (figure 10) has a large hole in the center top called the "ledge hole." Only 10% of the motorboats and 11% of the POR boats ran the center (just to the right or left of the ledge hole or through it). 64% of the POR boats took the left run and 78% of the motorboats took the right run. The left run, which crosses the debris fan from Prospect Creek is rocky at low and medium water levels. Approximately 45% of the POR boats went left at flows between 15,000 and 20,000 cfs and 97% went left above 20,000 cfs. No motorboats went left when the water level was below 29,000 cfs; 42% went left above 29,000 cfs.

The observers recorded the locations for accidents (figure 10); these sites are related to strong hydraulic features. However, the nature of the accidents was not documented.

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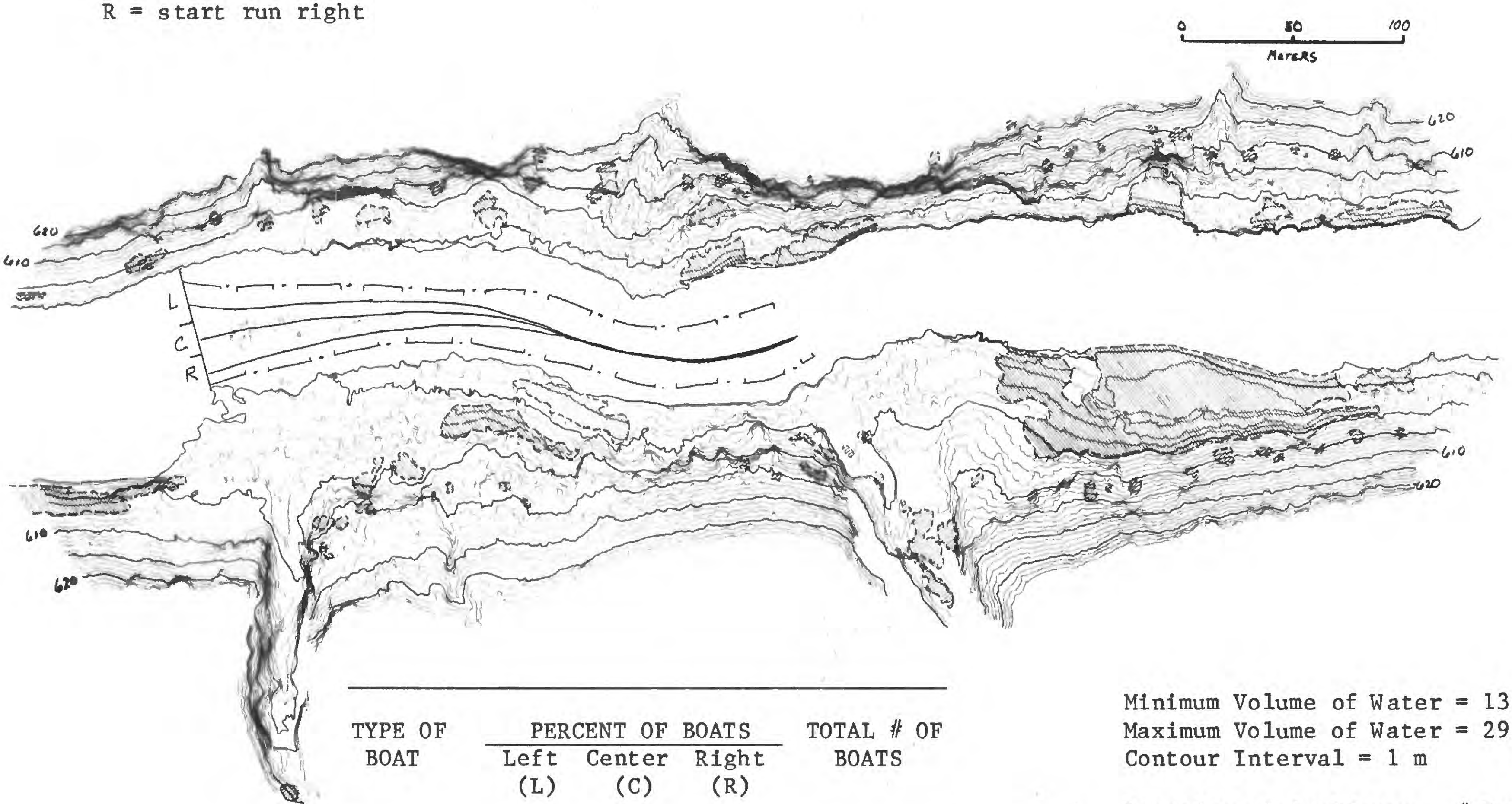
2. The observers must have thought the form showed a higher water level than 5,000 cfs because they sketched a narrower channel on the form to represent low water (their estimate of the low water shoreline is shown as a dashed line in Figure 9). The flows they saw never dropped below 5,000 cfs. The low water shore they drew in is probably for a flow of about 12,000 cfs as this is the lowest flow they witnessed. The original shore on the form is interpreted as the highest observed shore (30,000 cfs). The volunteers drew boat paths relative to the new shore that they made and did not draw boat runs above the original shore.

Figure 8. Map of Deubendorff Rapids with Data

Diagrammatic boat routes
Limits of boat runs
L = start run left
C = start run center
R = start run right



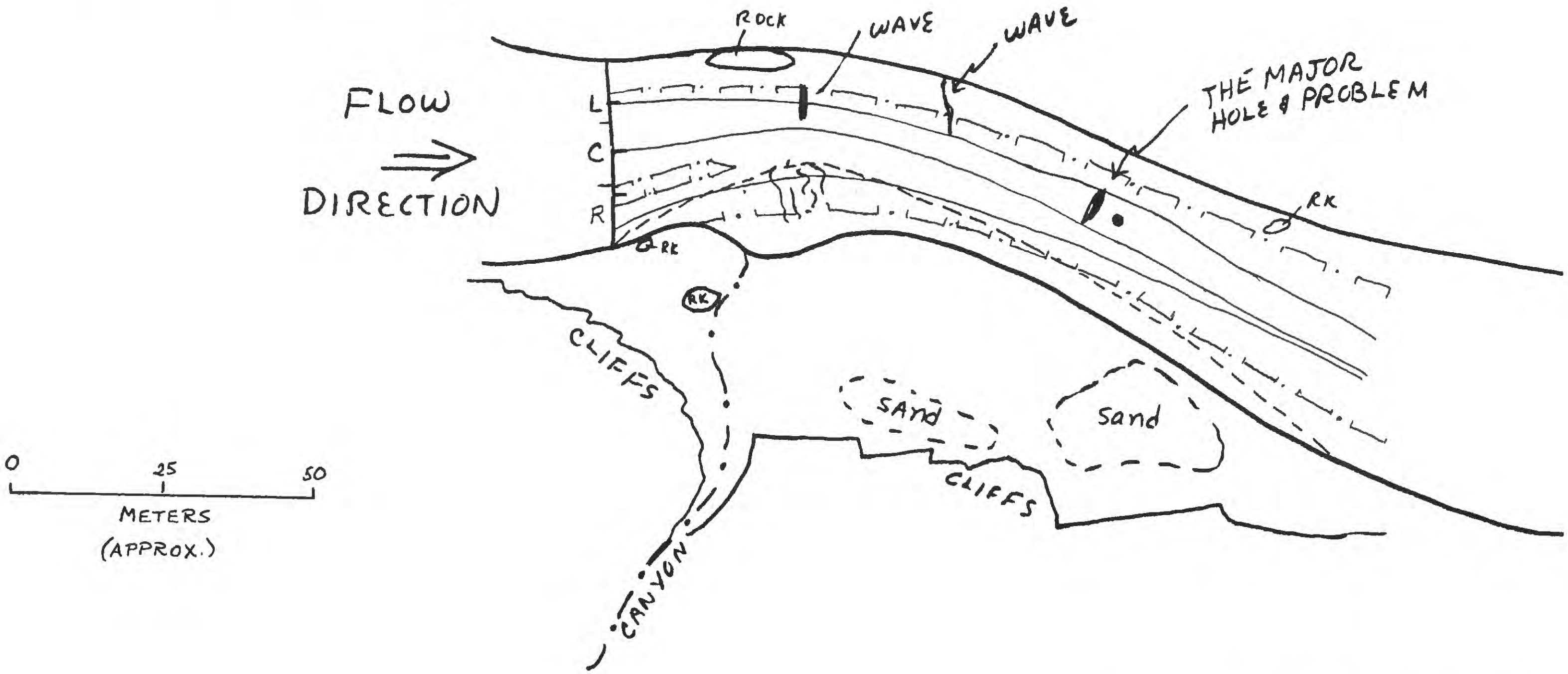
TYPE OF BOAT	PERCENT OF BOATS			TOTAL # OF BOATS
	Left (L)	Center (C)	Right (R)	
Motor	96	1	3	74
Rowed or Paddled (POR)	53	26	21	111

Minimum Volume of Water = 13,000 cfs
Maximum Volume of Water = 29,000 cfs
Contour Interval = 1 m

Location of Accidents	# Recorded
○ Lost control of oar	0
△ Lost oar	0
□ Lost paddle	0
● Person overboard	0
▲ Boat flipped	0
■ Hit rock	0

Figure 9. Map of Upset Rapids with Data

Diagrammatic boat routes
Limits of boat runs
L = start run left
C = start run center
R = start run right
--- low water shoreline



TYPE OF BOAT	PERCENT OF BOATS			TOTAL # OF BOATS
	Left (L)	Center (C)	Right (R)	
Motor	25	68	7	83
Rowed or Paddled (POR)	27	59	14	110

Minimum Volume of Water = 12,000 cfs
Maximum Volume of Water = 30,000 cfs
Contour Interval = 1 m

Location of Accidents	# Recorded
○ Lost control of oar	0
△ Lost oar	0
□ Lost paddle	0
● Person overboard	1
▲ Boat flipped	0
■ Hit rock	0

Figure 10. Map of Lava Falls Rapids with Data

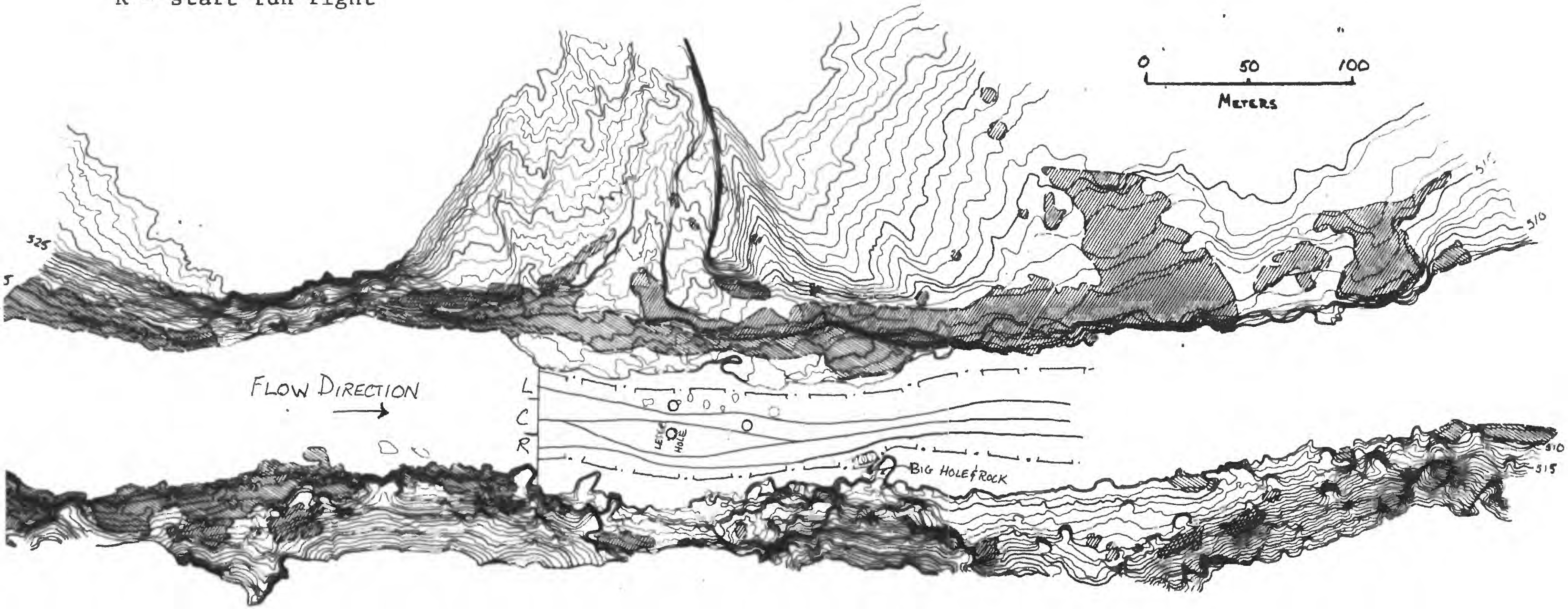
Diagrammatic boat routes

Limits of boat runs

L = start run left

C = start run center

R = start run right



TYPE OF BOAT	PERCENT OF BOATS Left (L)	Center (C)	Right (R)	TOTAL # OF BOATS
Motor	12	10	78	78
Rowed or Paddled (POR)	64	11	25	116

Minimum Volume of Water = 12,000 cfs
Maximum Volume of Water = 32,000 cfs
Contour Interval = 1 m

Location of Accidents	# Recorded
o Nature of accidents is unkown (see text)	8

Conclusion: Preliminary analysis on the relation between flow streamlines and boat trajectories

The relation between boat trajectories and the flow streamlines depends on the configuration of the rapid and the power of the boat. Some of the rapids are more difficult and require avoiding undesirable hydraulic features or rocks located on certain streamlines.

At the discharge levels observed (less than 30,000 cfs) motorboats were highly maneuverable (i.e., had enough power to be able to power nearly the full river width across flow streamlines within a fraction of the length of the rapid, e.g., see the diagrammatic boat routes on Crystal Rapids, figure 7). However, at low discharge conditions motorboats lose this maneuverability because of an increase in the number of exposed rocks and shallow water.

On the other hand, POR boats are much more strictly committed to a course determined by the streamline upon which they enter the rapid. This can be seen by comparing the trajectories of POR boats in House Rock Rapids (figure 2), with the trajectories of floats (i.e., streamlines) in House Rock (figure 11, from Kieffer, 1987). In this case the rowed boats and floats were both swept into the most constricted part of the river. The rowed boats had enough maneuverability to stay to the right of the large hole in the constriction, typically deviating from the streamlines by less than five meters.

Streamline data were obtained by analysis of float trajectories in House Rock, Hance, Horn Creek, Crystal, and Lava Falls Rapids using real time movies taken from the shore. Preliminary comparison of the streamline data (Kieffer, in press) and boat trajectories indicates that in these five rapids the POR boats made small corrections from the streamline trajectories to avoid the major hydraulic features, but that large deviations from flow streamlines were not made. Accidents occur when the streamlines sweep boats into major hydraulic features within regions of supercritical[3] flow of the rapids (see Kieffer, 1987 for detailed hydraulic description). It is hypothesized that at high discharges, when velocities become greater and large waves are major hydraulic features, the smaller POR boats are more strictly confined to streamlines and have less time and/or relative power to deviate from a streamline. Under such conditions accidents may increase. Only when discharge increases, stage raises, and waves become "washed out" (i.e., flow becomes essentially subcritical[3]) would one then expect the number of accidents to diminish.

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3. Flow in channels can be in either of two energy states: <u>subcritical</u>, in which potential energy dominates over kinetic energy and in which standing waves cannot occur; and <u>supercritical</u>, in which kinetic energy dominates and standing waves can occur. The flow in backwaters above rapids is subcritical; the flow through the narrowest part of a rapid is typically supercritical.

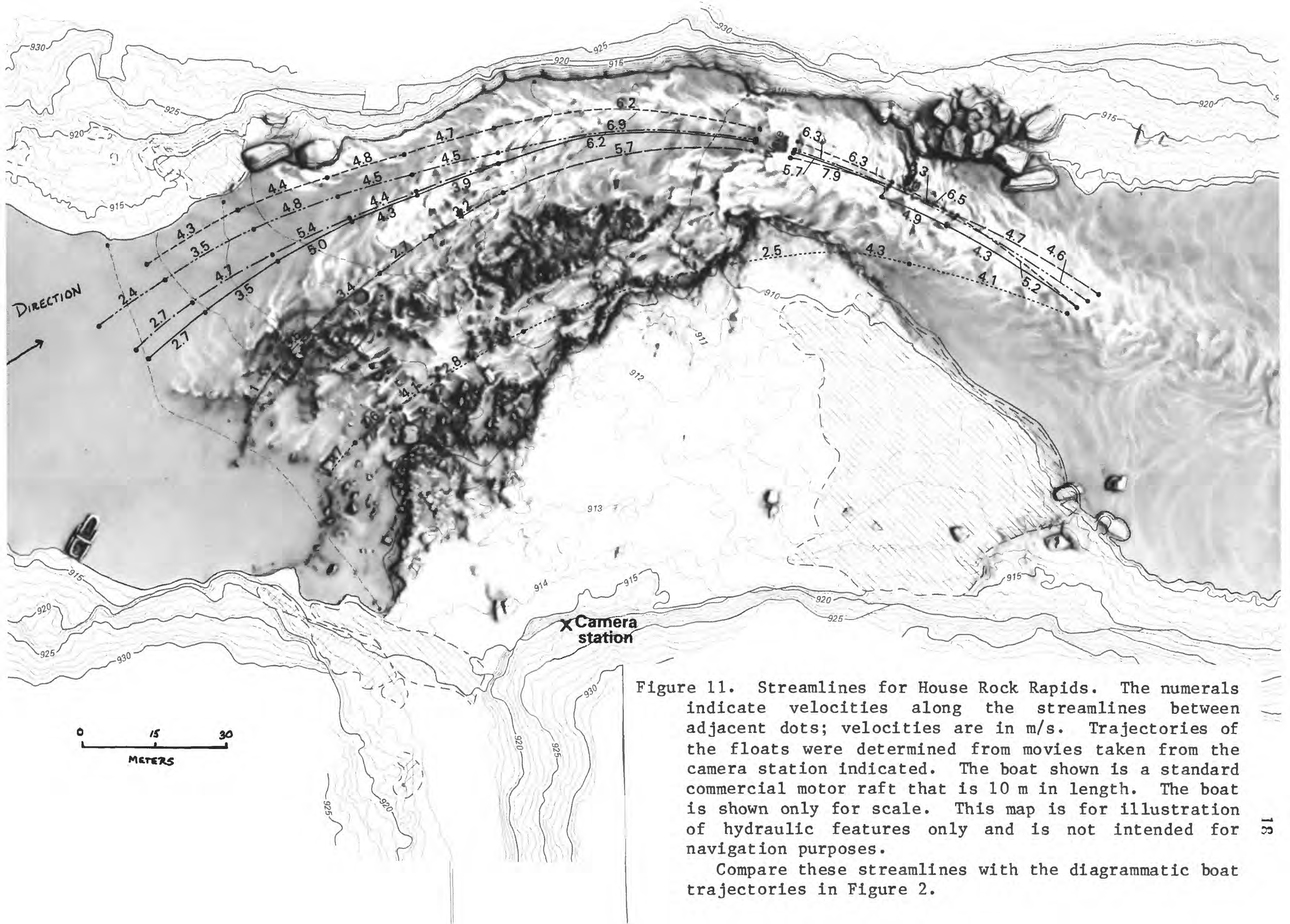

Figure 11. Streamlines for House Rock Rapids. The numerals indicate velocities along the streamlines between adjacent dots; velocities are in m/s. Trajectories of the floats were determined from movies taken from the camera station indicated. The boat shown is a standard commercial motor raft that is 10 m in length. The boat is shown only for scale. This map is for illustration of hydraulic features only and is not intended for navigation purposes.

Compare these streamlines with the diagrammatic boat trajectories in Figure 2.

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