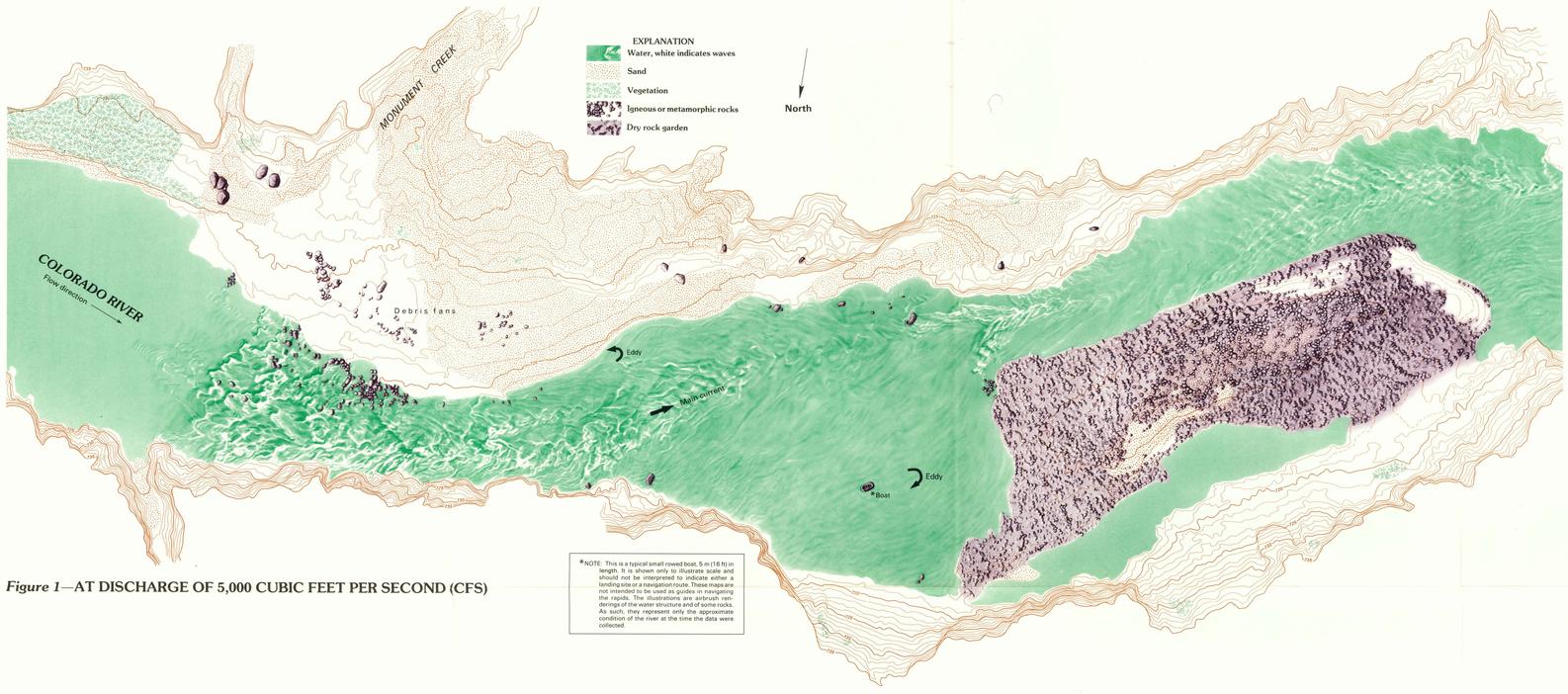


*NOTE: This is a typical small rowed boat, 5 m (16 ft) in length. It is shown only to illustrate scale and should not be interpreted to indicate either a landing site or a navigation route. These maps are not intended to be used as guides in navigating the rapids. The illustrations are airbrush renderings of the water structure and of some rocks. As such, they represent only the approximate condition of the river at the time the data were collected.

Figure 1—AT DISCHARGE OF 5,000 CUBIC FEET PER SECOND (CFS)

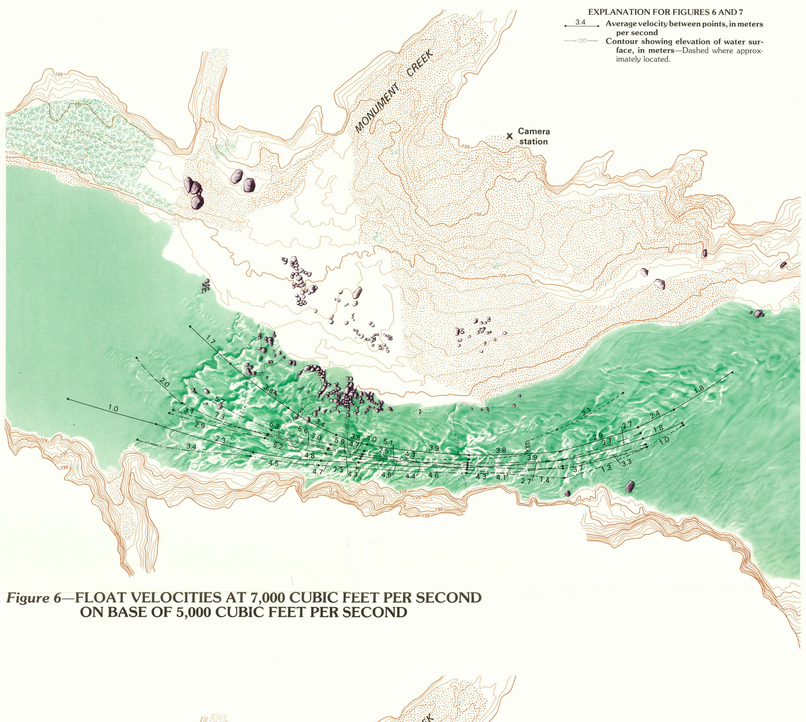


Figure 6—FLOAT VELOCITIES AT 7,000 CUBIC FEET PER SECOND ON BASE OF 5,000 CUBIC FEET PER SECOND

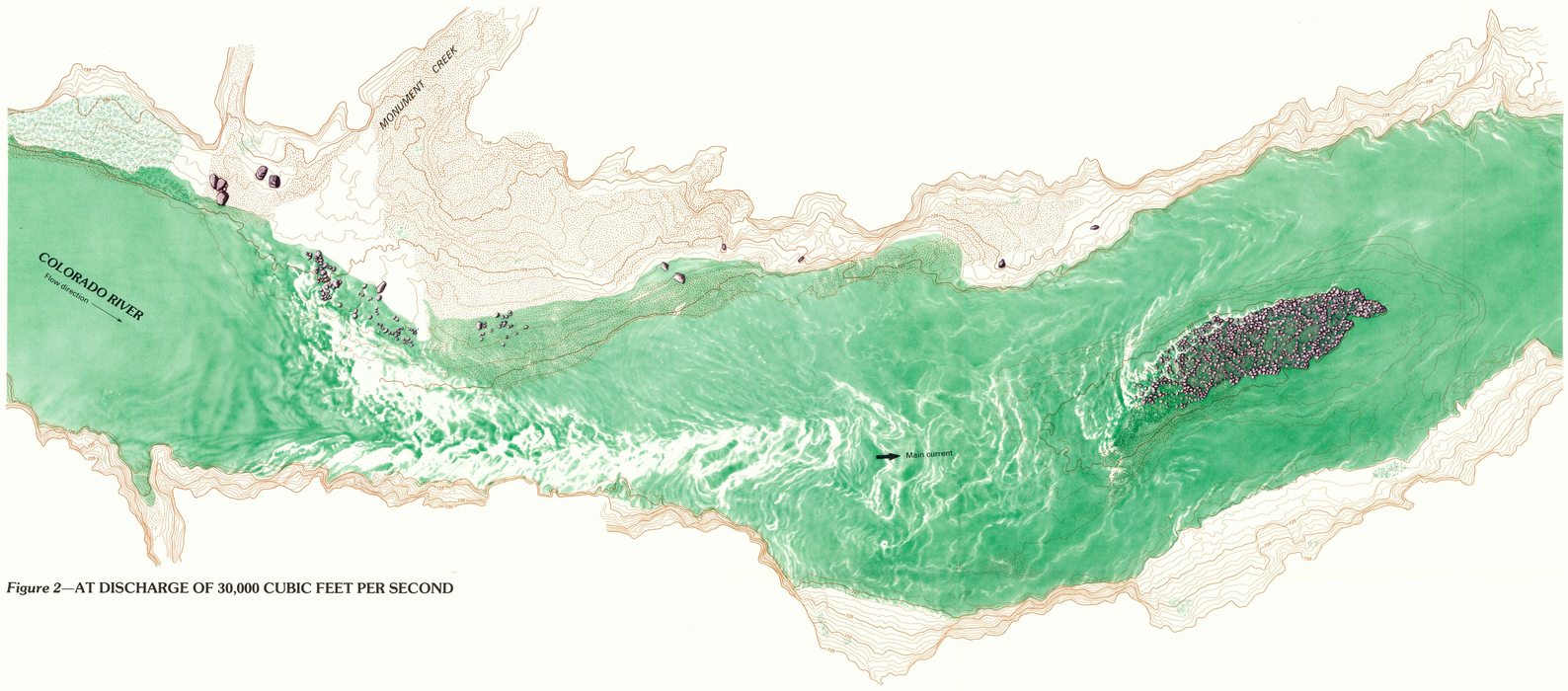


Figure 2—AT DISCHARGE OF 30,000 CUBIC FEET PER SECOND

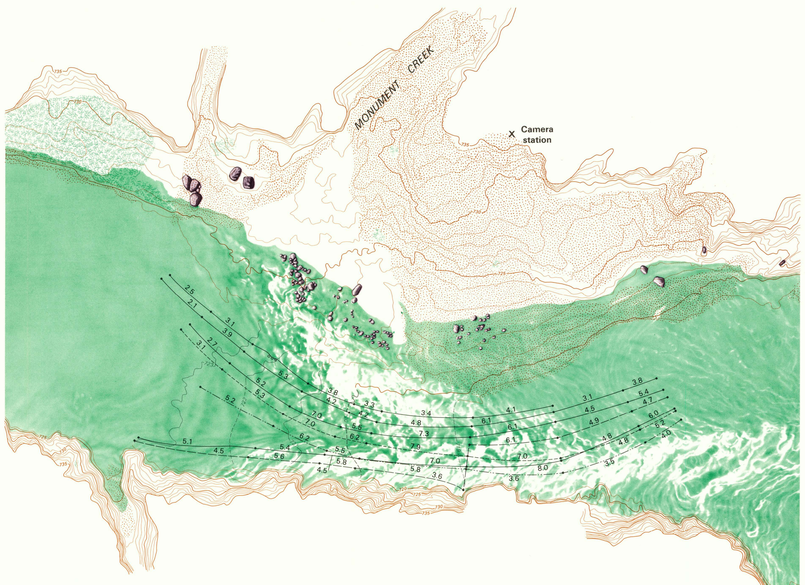


Figure 7—FLOAT VELOCITIES AT 20,000 CUBIC FEET PER SECOND ON BASE OF 30,000 CUBIC FEET PER SECOND

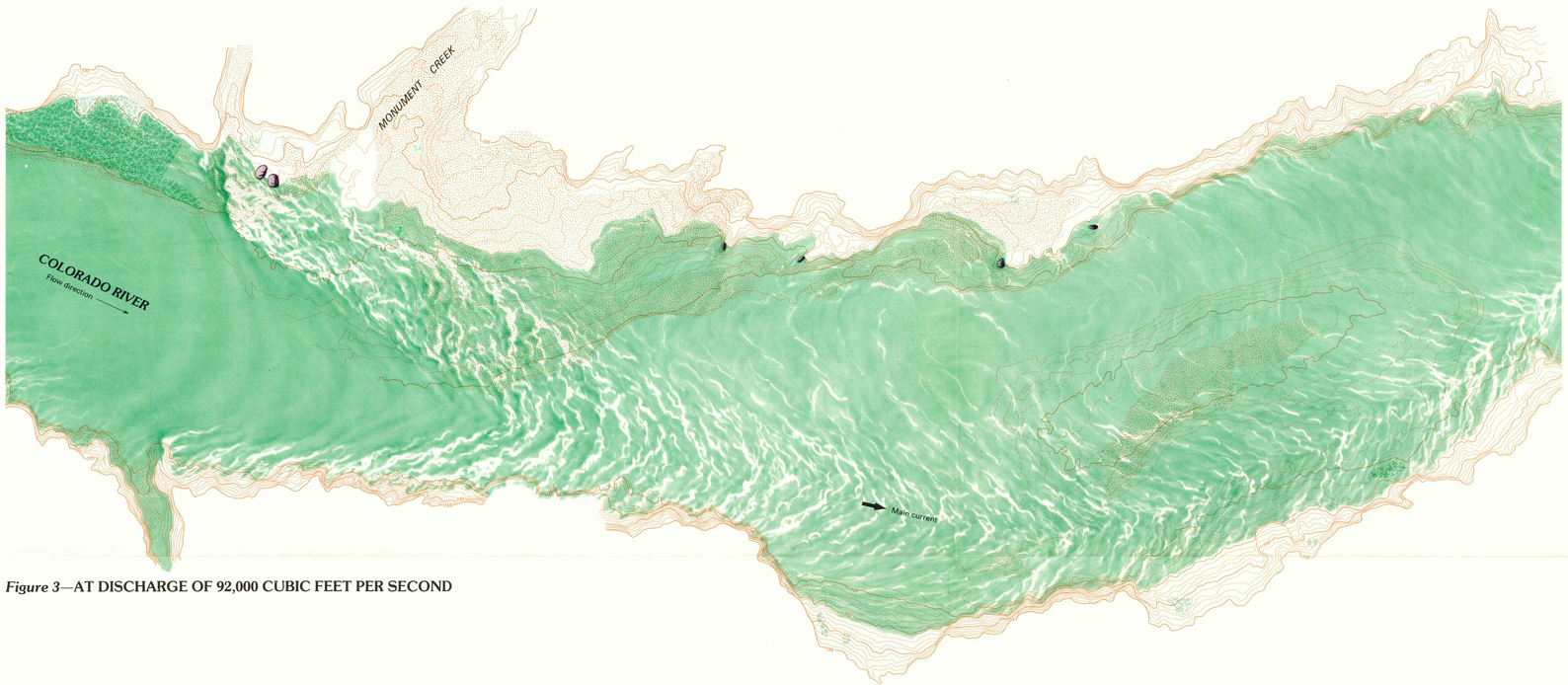


Figure 3—AT DISCHARGE OF 92,000 CUBIC FEET PER SECOND

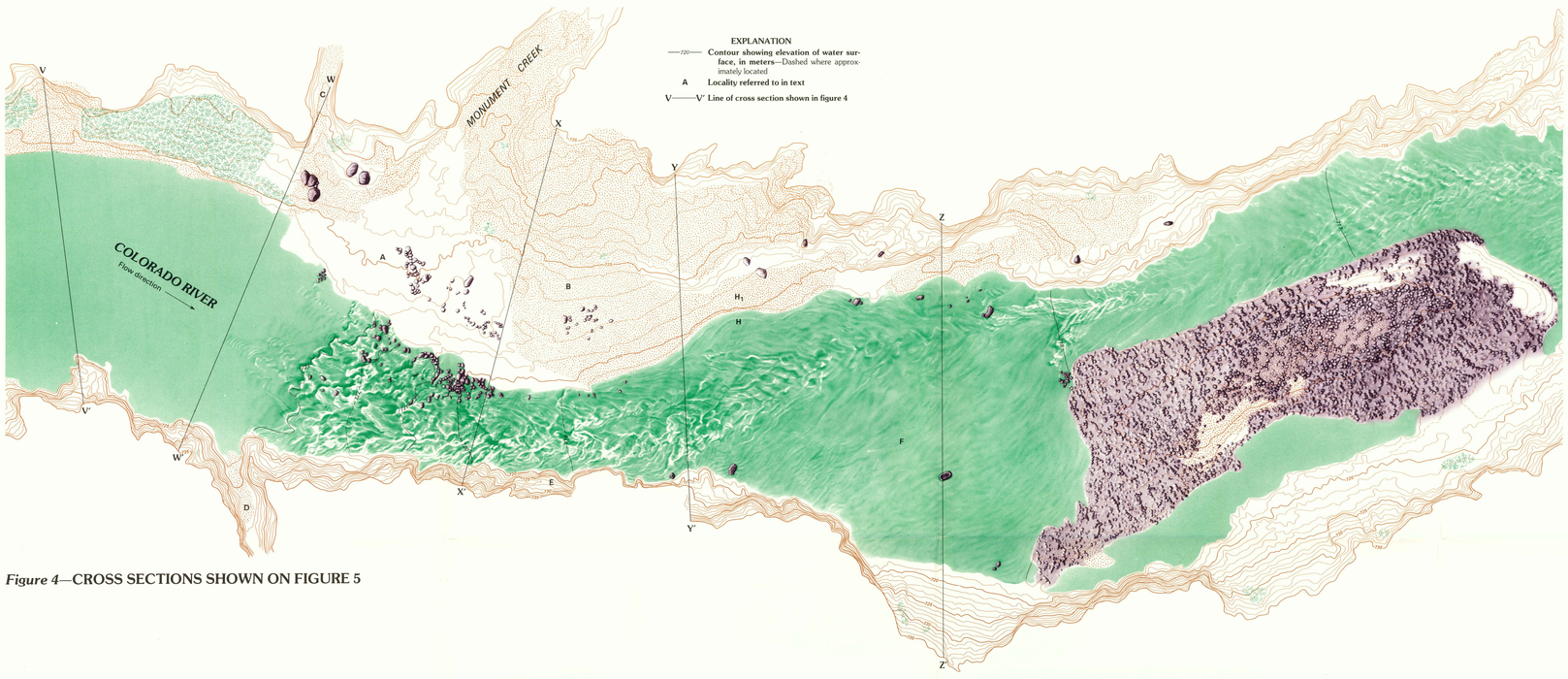


Figure 4—CROSS SECTIONS SHOWN ON FIGURE 5

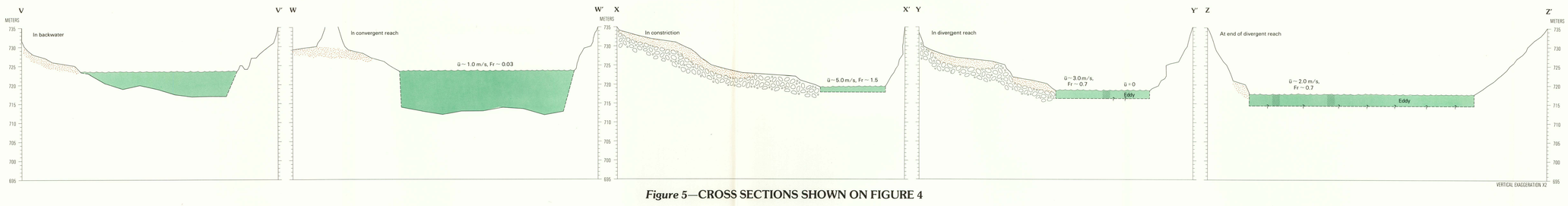
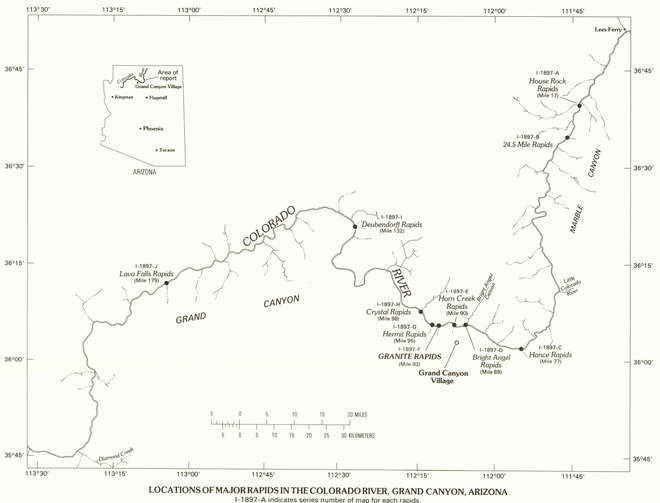
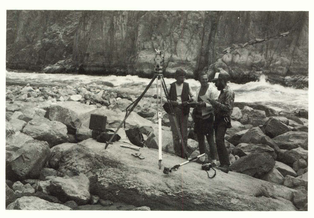


Figure 5—CROSS SECTIONS SHOWN ON FIGURE 4



LOCATIONS OF MAJOR RAPIDS IN THE COLORADO RIVER, GRAND CANYON, ARIZONA
I-1897-A indicates series number of map for each rapids.



Surveying station at Granite Rapids, showing electronic theodolite and reflecting mirror on pole (on rock). All maps in this series were generated by photogrammetry from control points calibrated by this equipment.
Many photographs published in this map series, as well as most documentary photographs for the field work, were taken by Jennifer Whipple.

DISCUSSION

Granite Rapids (called Granite Falls Rapids on older topographic maps) (figs. 1–3) is caused by a debris fan emerging from Monument Creek that has forced the Colorado River against the north wall of the river channel. In recent times, this debris fan has intermittently been renewed by flows from Monument Creek; for example, most of the surficial material now emanating from the mouth of Monument Creek was emplaced in July 1984 (**A**, fig. 4); older and coarser debris fan material is visible to the west of this debris fan (**B**, fig. 4). Much of the debris fan, including prominent groups of large rocks on the south side of the channel, is exposed when the discharge of the Colorado River is below 5,000 cubic feet per second (cfs) (fig. 1). Bedrock at river level consists of mica schists and quartzo-feldspathic schists of the Vishnu Schist and intrusive pegmatite-granite dikes; however, many of the boulders on the debris fan have washed down Monument Creek from higher Paleozoic outcrops. The lower part of the north bank of the channel is nearly vertical Proterozoic bedrock.

The area around Granite Rapids provides an excellent example of the influence that faulting and bedrock strength have in controlling the location of tributary canyons. At least two faults can be seen near the head of the rapid (**C** and **D**, fig. 4) (Dolan and others, 1978). The bedrock directly across the river from Monument Creek is faulted (**D**), yet there is no carved reentrant in the rock between **D** and **E** where the water velocities in the rapid are high and are focused against the north wall (at House Rock Rapids, for example, the bedrock across from Rider Canyon is strongly eroded back toward the south by the focusing of water toward the wall by the debris fan, Map I-1897-A). This observation may suggest that Granite Rapids is one of the younger rapids on the river (G.H. Billingsley, oral commun., 1989). On the other hand, the north wall of the channel downstream of the rapid (north of **F**) contains a very large reentrant, and I speculate that this is because the bedrock there is somewhat weaker than upstream at the head of the rapid (this is a very difficult area to reach for a field check). This reentrant in the bedrock probably has stabilized the large eddy (**F**, fig. 4) and contributed to the stability of the rock garden, **G**.

At 5,000 and 30,000 cfs, the waves in Granite Rapids are typical of standing waves associated with converging-diverging channels—that is, a prominent tongue is bounded by oblique waves that evolve into a train of criss-crossing standing waves spaced at roughly 15 m (50 ft) intervals. Because the main current is sharply focused toward the north wall of the channel and because this wall is nearly vertical bedrock, strong oblique waves emanate from this wall (fig. 2). At about 30,000 cfs discharge, a short tongue to the south of the main tongue ends by plunging toward a strong hole and wave, and the flow from this region rejoins the main current approximately at the position of the second strong oblique wave on the south. From some vantage points overlooking the rapid, the strong oblique waves take on the appearance of undulating braids. At 92,000 cfs the tongue of the rapid and waves remain on the north side of the channel, but the waves emanating from the top of the debris fan on the south side of the river are amplified in height (compare figs. 2 and 3). For a general discussion of the flow patterns in rapids, see Kieffer (1985, fig. 1 and 1987).

At a discharge of 5,000 cfs, the water surface through the rapid drops 7 m from nearly 723.5- to 716.5-m elevation (fig. 4 and water surface elevations shown in fig. 5). Of this drop, 4 m occurs in the first 100 m of the rapid (compare with Lava Falls Rapids, Map I-1897-J, where the water surface drops 4 m in the first 55 m at the head of the rapid). The surface slope of the water through the rapid decreases as the discharge increases, as can be seen by a comparison of the water-surface elevations above and below the rapid in figures 1–3.

The most spectacular features of Granite Rapids are the oblique waves at, and just downstream from, the narrowest point in the rapid (**E**, fig. 4; figs. 2 and 3) and the large eddy and rock garden at the bottom of the rapid (**F** and **G**, fig. 4). This eddy is so strong that there are rarely sand deposits on the north side of the river in this area, but rather, the spectacular imbricated cobble bar, **G**. A smaller eddy exists on the south side of the river (**H**) from which a sandy beach can be deposited at high discharges if sufficient sediment is available (**H_1**).

Streamlines (paths of floats) and velocities of floats were determined from Super-8 motion pictures taken from the camera station shown (figs. 6 and 7). The floats and experimental technique are described in Kieffer (1987). The floats were launched upstream of the rapid, approximately at the place where the streamlines begin on the map. Each velocity numeral in figures 6 and 7 (in units of meters/second, m/s) refers to the section of streamline between large dots. The different dash-dot patterns distinguish the different streamlines. The trajectories (fig. 6) of floats launched when the discharge was about 7,000 cfs are shown on the hydraulic map of conditions at 5,000 cfs. The trajectories (fig. 7) of floats launched when the discharge was over 20,000 cfs are shown on the hydraulic map of conditions at 30,000 cfs. For both figures, the hydraulic maps closely resemble the water-surface structure at the time the floats were launched. The velocities at the higher discharge are, in many places, nearly double the velocities in the same places at the lower discharge. The floats show a much broader range of trajectories at the higher discharge because the main current is broader. A very similar behavior was observed with float sets launched at two different discharges at Crystal Rapids (Map I-1897-H).

At low discharges, regardless of launch point, the floats follow trajectories that converge strongly toward the north shore. Measured velocities in Granite Rapids are rather low compared with similar large rapids (compare with Hermit Rapids, just 3 km downstream, Map I-1897-G). These relatively low velocities are typical of rapids in which there are many waves: turbulence on the water surface caused by the waves significantly slows down the floats. In addition to the specific effect of the waves, all floats are slowed by shear between the water surface and the atmosphere, especially if any up-canyon wind is present. In all rapids, therefore, I believe that the float velocities represent lower limits for water-surface velocities or vertically averaged water velocities; this is especially true for rapids with many large breaking waves such as Granite Rapids.

In order to demonstrate the complexity of the flow in the rapids, perspectives of vertical, as well as horizontal, relations are shown in the cross sections (fig. 5). A number of fathometer traverses were run about 50 m upstream of the left side of the maps shown here, and the results are so reproducible that two fathometer tracings of the channel bottom are shown in cross sections *V–V′* and *W–W′*. No velocities were measured as far upstream as section *V–V′*, but an average velocity of about 1 m/s was determined for cross section *W–W′*. By assuming that the channel is rectangular in shape (see fig. 5) the Froude number was determined to be 0.03. The Froude number [$Fr=\bar{u}/(gD)^{1/2}$; $\bar{u}$=average velocity in the cross section; g is the acceleration of gravity, D=average depth] is a dimensionless measure of the relative importances of inertial versus potential energy, and it was calculated for each cross section from the measured and inferred depths and velocities. Froude numbers less than 1 indicate subcritical flow dominated by potential energy, and Froude numbers greater than 1 indicate supercritical flow dominated by kinetic energy. The value of Fr=0.03 in section *W–W′* is typical of subcritical flow in hydraulic backwaters above rapids (compare with House Rock, for example, Map I-1897-A).

Whereas in cross sections *V–V′* and *W–W′*, both depth and velocity were measured, in the other cross sections (*X–X′*, *Y–Y′*, *Z–Z′*), velocities were measured and depths obtained from the mass-continuity equation. In these cross sections, the channel was assumed to be rectangular for calculations. The average depth of the channel can therefore be obtained from the relation Q=$\bar{u}$wD (Q=discharge; w=average width). The depths so calculated are averages for the whole cross section, and irregularities in bottom topography and the presence of large rocks can cause significant deviations from the calculated values. The fact that measured velocities are believed to be lower limits for the depth-averaged velocities means that the calculated depths are probably maximum average depths. Note the dramatic shallowing of the river in the constricted part of the rapid (sections *X–X′*, *Y–Y′*, and *Z–Z′*) and the near constancy of the river bottom at the elevation of 717 m, except for the much deeper region in cross section *W–W′*. This same shape of bed above and through a rapid was seen at House Rock Rapids (Map I-1897-A, fig. 3), and the same explanation is suggested for the geometry of the bed at Granite—namely, I propose that at the time these measurements were made (October 7, 1985 [1]), there was a region of local minimum elevation at the head of the rapid. This topographic low in the channel bottom (a "hole") may represent a local base of bedrock (or very coarse, relatively immobile debris) above which (upstream) fine-grained sedimentary deposits (silt and sand) mantle the channel, and below which (downstream) coarse boulders from the Monument Creek debris fan mantle the channel. If this interpretation is correct, the sand deposits may have been about 5 m thick (between the elevations of about 712 and 717 m) at the time the fathometer and velocity measurements were made.

The flow pattern at Granite Rapids is determined by the constriction and divergence of the channel that occurs both laterally (map view, fig. 1) and vertically (cross sections, fig. 5). The channel bottom remains remarkably constant at an elevation of about 717 m, except for the hole in the vicinity of *W–W′*. The calculated and measured velocities show that the water accelerates from about 1 m/s upstream of the rapid into the constricted area where it reaches velocities of about 5 m/s at about 5,000 cfs and 6 to 7 m/s at about 20,000 cfs. The water depth decreases from about 10 m in the hole at *W–W′* (when the discharge is 7,000 cfs) to about 1 m in the constriction; the water depth is highly variable because of the many rocks that litter the channel. Velocities decrease to about 2 m/s in the runout of the rapid, but probably slightly increase as the flow is funneled into a southern channel around the rock garden (**G**, fig. 4); velocities could not be measured this far downstream because of the large distances involved.

The calculated Froude numbers for a discharge of 7,000 cfs range from 0.03 in the backwater to a maximum of 1.5 in cross section *X–X′*. This value of Froude number that exceeds unity is consistent with the fact that there are large standing waves in this region of the rapid; the exact value of the Froude number is probably uncertain by 50 percent because of difficulties in measuring velocities and local variations in river depth. The Froude number decreases back below unity in the runout *Y–Y′* and *Z–Z′*. Although no velocity measurements were made as far downstream as the channel that passes to the south of the rock garden, the standing-wave structure on the flow in this channel suggests that the Froude number rises back to unity in this region (see Kieffer, 1985 for further discussion of the relation of wave structure to Froude number).

The most significant hydraulic features in Granite Rapids at normal discharges characteristic of Glen Canyon Dam (5,000–30,000 cfs) are the deflection of the flow toward the nearly vertical bedrock wall on the north side of the river, the strong oblique waves that emanate from this wall, and the very large eddy below the rapid on the north side of the river. Although the reconstruction of the hydraulic features at 92,000 cfs (fig. 3) is quite schematic and has not been verified by field observations, the wave structure is consistent with that seen at 30,000 cfs. The presence of standing waves at this high discharge suggests that Granite Rapids maintains supercritical flow at this high discharge—that is, unlike many rapids along the river (for example, House Rock Rapids), Granite Rapids is not "drowned" to subcritical ("tranquil") conditions at higher discharges.

The hydraulic features of Granite Rapids reflect a dynamic equilibrium between the flow in the Colorado River channel, flooding or debris flows from Monument Creek, and, probably to a lesser extent, rock falls on the north bank of the river channel. The configuration of the channel bottom depends not only on the bedrock topography and the contribution from the catastrophic rockfalls and tributary floods, but also on the transient sediment load of the river—particularly on reworking of sand and gravel at the bottom of the rapid. The channel configuration changes with time, both gradually and and catastrophically.

[1] Map I-1897-A erroneously states that the measurements at House Rock Rapids were made on November 17, 1986; the correct year is 1985.

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SCALE 1:1 000
CONTOUR INTERVAL 1 METER
LONG-DASHED LINES REPRESENT 0.5-METER CONTOURS

INTERIOR—GEOLOGICAL SURVEY, RESTON, VA—1988

Hydraulic data collected in October–November 1985 by Susan Werner Kieffer, assisted by Margie Marley.

Contour lines compiled on analytical stereoplotters at the U.S. Geological Survey, Flagstaff, Arizona, from aerial photographs flown in 1984 by the Bureau of Reclamation, Series 6233.

Airbrush portrayal of hydraulic features by Patricia Hagerty Gray, U.S. Geological Survey.

Prepared on behalf of the Bureau of Reclamation under Interagency Acquisition No. 6–AA–40–04130.

HYDRAULIC MAP OF GRANITE RAPIDS, GRAND CANYON, ARIZONA

By
Susan Werner Kieffer
1988

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