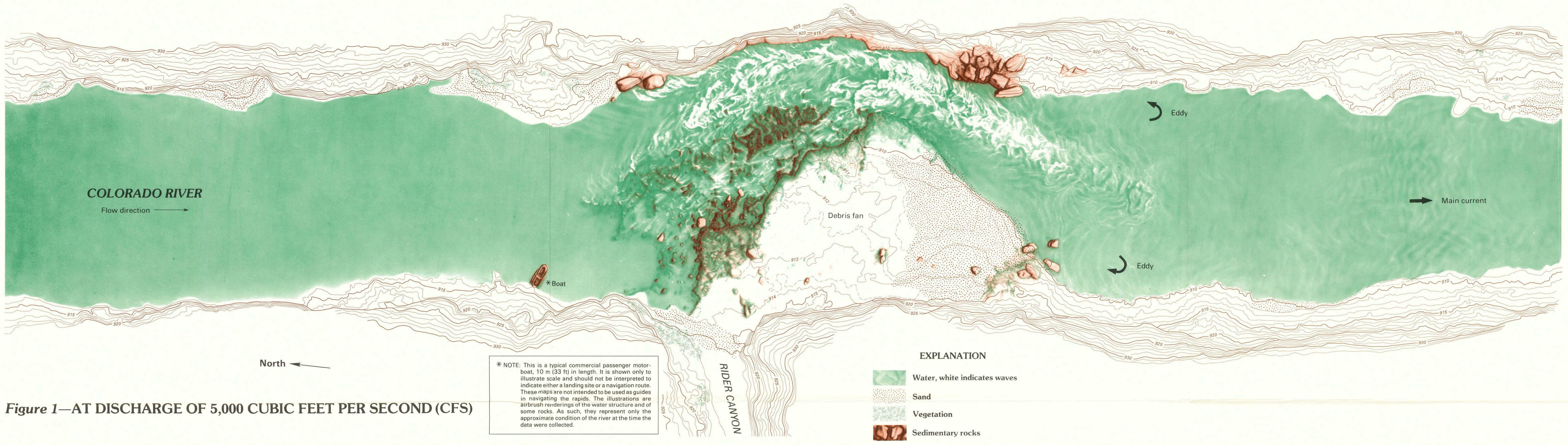

Figure 1—AT DISCHARGE OF 5,000 CUBIC FEET PER SECOND (CFS)

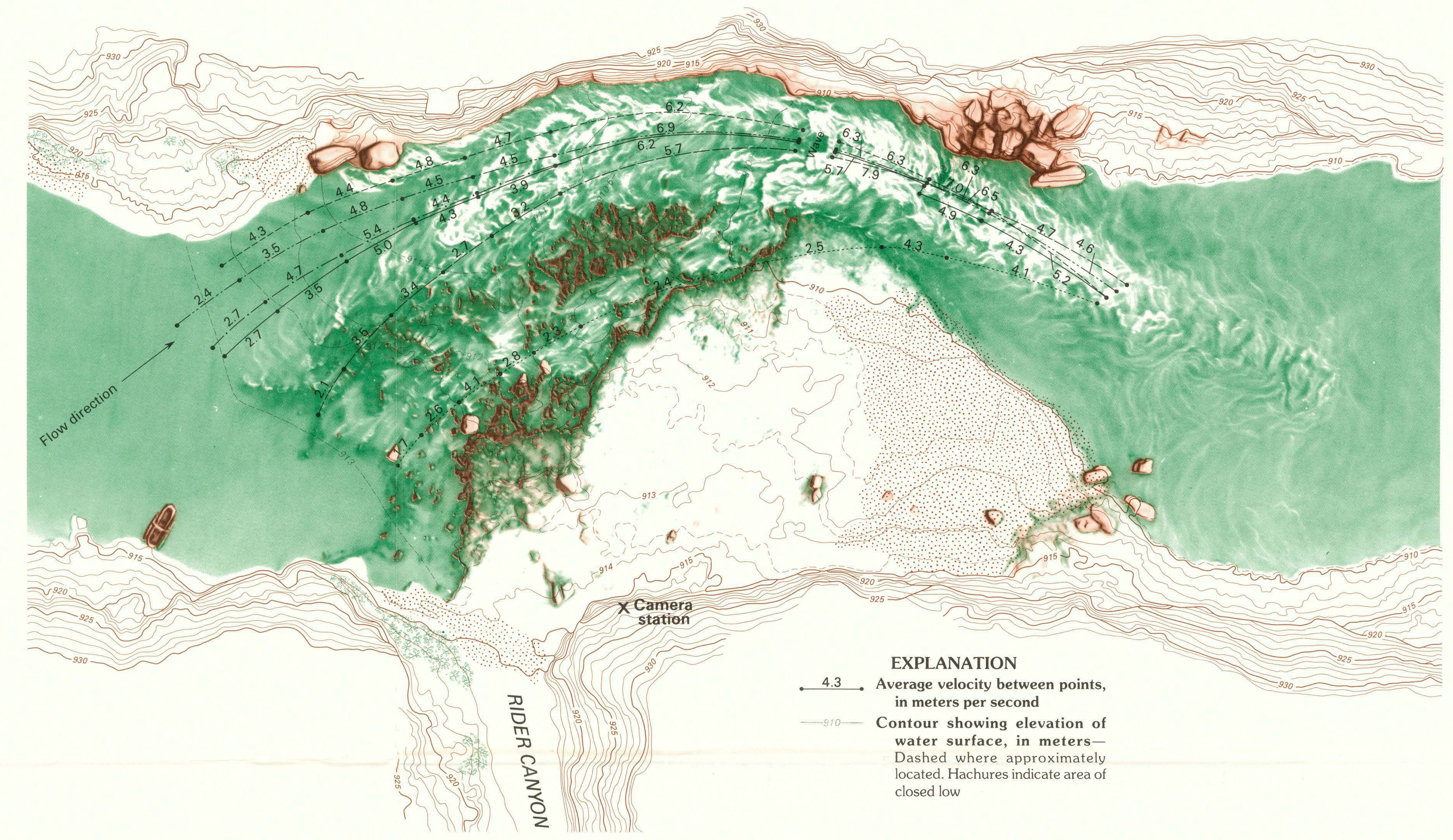

Figure 5—FLOAT VELOCITIES

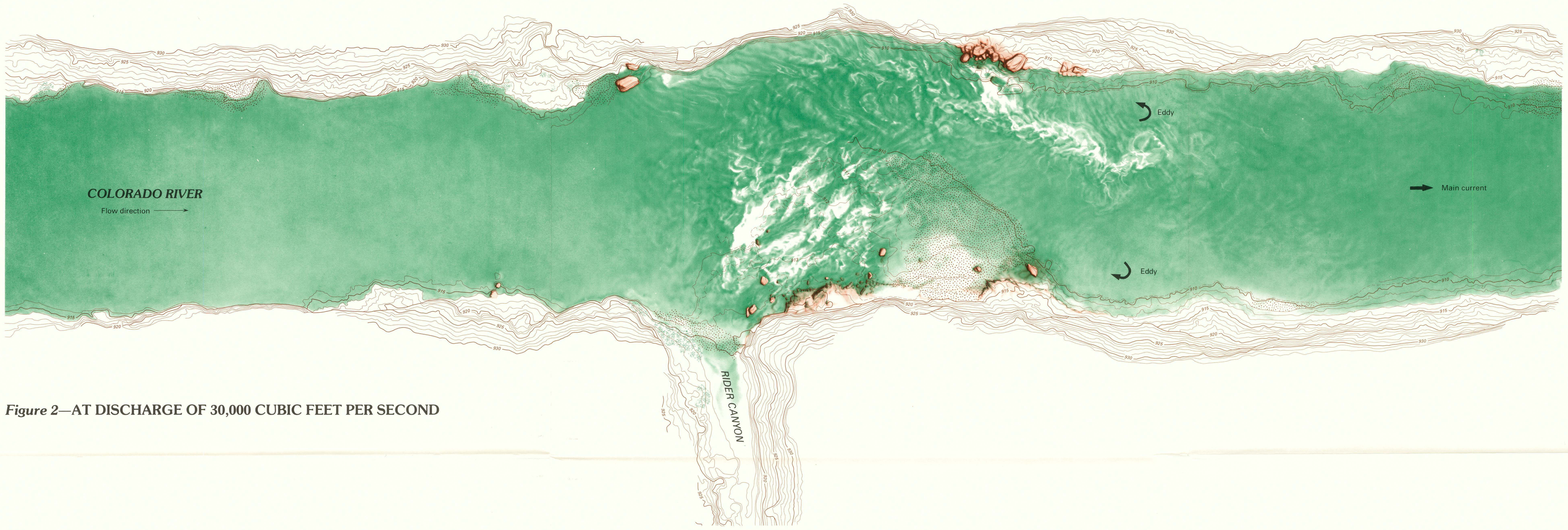

Figure 2—AT DISCHARGE OF 30,000 CUBIC FEET PER SECOND

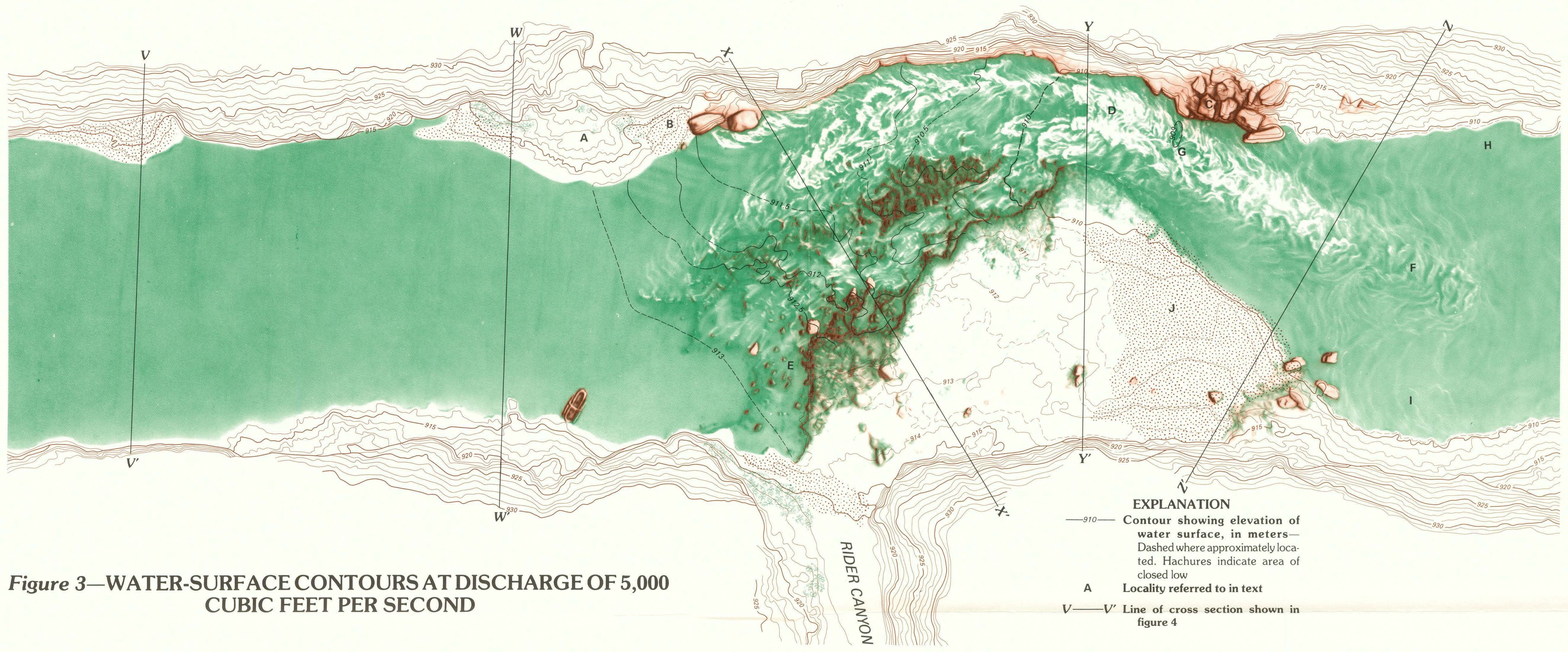

Figure 3—WATER-SURFACE CONTOURS AT DISCHARGE OF 5,000 CUBIC FEET PER SECOND

DISCUSSION

House Rock Rapids is caused by a debris fan from Rider Canyon (figs. 1 and 2). The drop of the water surface through the rapids is approximately 4 m at 5,000 cubic feet per second (cfs) (from approximately 913.5-m to 909.5-m elevation, fig. 3). As discharge changes, the average slope of the water surface in the rapid changes: at 5,000 cfs, the average slope is about 1 ft/100 ft, whereas at 30,000 cfs, the average slope is only about 0.75 ft/100 ft. Centrifugal force pushes the water higher on the east wall than on the west debris fan (this effect is especially prominent from the shoreline shown in fig. 2).

The Rider Canyon debris fan has forced the Colorado River over to the east wall of the canyon. Much of the Rider Canyon debris fan is exposed when the discharge is below 5,000 cfs (fig. 1); however, water ponds behind the fan (in the vicinity of the boat shown in fig. 1) even at low discharges. Because the debris fan has a shallow gradient everywhere, high discharges cause water from this pond to spill across the fan into a backwater in Rider Canyon, as shown at 30,000 cfs in figure 2.

Rockfalls from the cliffs of the Wescogame Formation of the Supai Group are common on both sides of the river. On the east side, rocks have fallen directly into the river channel (**A, C, G,** and probably **D,** fig. 3). An eddy behind a rockfall (**A,** fig. 3) on the east side at the head of the rapid traps sand so that a small beach (**B,** fig. 3) can form upstream of the rapid if the sand supply is sufficient. At the foot of the rapid on the east side, boulders as much as 5 m in diameter have fallen into the river channel (**C,** fig. 3). These rocks, as well as a rock in the center of the channel (**D,** fig. 3), visible only when discharges are less than 5,000 cfs, cause large waves when discharges are less than about 30,000 cfs. At greater discharges, the water is sufficiently deep that these rocks do not cause large waves.

Discharge in all cross sections (fig. 4) is 5,000 cfs. Depths in the cross sections *V–V′* and *W–W′* (fig. 4) were measured during fathometer traverses; depths in the other cross sections (fig. 3) were calculated from the mass-continuity equation as described in Kieffer (1987).

Streamlines (paths of floats) and velocities of floats launched upstream of the rapid (fig. 5) were determined from Super-8 motion pictures taken from the camera station indicated. The floats and experimental technique were described by Kieffer (1987). Each velocity (fig. 5) refers to the section of streamline between dots adjacent to the velocity numeral; the different dash and dot patterns are used to distinguish float trajectories.

The flow pattern in the main channel is determined by the constrictions and divergences of the channel; these changes in channel shape occur both laterally (map view, fig. 1) and vertically (cross sections, fig. 4). For a general discussion and hydraulic analysis of the flow patterns in rapids, see Kieffer (1985, 1987).

The entire area above House Rock Rapids shown on this map is a backwater caused by the constriction of the Rider Canyon debris fan; because this region is a backwater, flow velocities are very low (approximately 0.4 m/s at 5,000 cfs). Flow accelerates from the backwater into the constriction. The constricting influence of the Rider Canyon debris fan extends upstream of its surface outcrops because the debris fan causes the formation of a relatively quiescent pond on its upstream side (in the vicinity of the boat illustrated in fig. 1). In addition, the rockfall at **A** (fig. 3) constricts the channel on the east side. Thus, between *V–V′* and *W–W′*, the main-channel flow narrows noticeably as the water is squeezed between the eddy upstream of the debris fan and the rockfall. The water surface drops about 0.5 m between *V–V′* and *W–W′*; the channel bottom drops about 3 m from 909-m to about 906-m elevation—the lowest elevation of the channel bottom in this vicinity. In this same reach, the flow velocities increase gradually from about 0.4 m/s to about 0.5 or 0.6 m/s.

Between *W–W′* and *X–X′*, the water surface drops 1.5 m (at 5,000 cfs) and the channel bottom rises about 3 m back to the elevation of 909 m. At 5,000 cfs, the average water depth at *X–X′* is about 2 m. The water surface drops another 1 m between *X–X′* and *Y–Y′*, but the elevation of the bottom appears to be relatively constant at about 909 m; the flow reaches its minimum average depth of only about 1 m in the constriction. The drop of water-surface elevation in the diverging section of the channel is small (approximately 0.5 m between *Y–Y′* and *Z–Z′*), but the bottom elevation drops, reaching 907 m at *Z–Z′*.

These data indicate a local point of minimum elevation (906 m) in the channel-bottom topography above House Rock Rapids (cross section *W–W′*). This "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 Rider Canyon debris fan mantle the channel. If this interpretation is correct, the sand deposits may have been about 3 m thick (between the elevations of 906 and 909 m) at the time the fathometer and velocity measurements were made (November 17, 1986, during fluctuating flows from Glen Canyon Dam; compare *V–V′* and *W–W′* in fig. 4). Debris transported downstream from the debris fan may mantle the bedrock channel as far as several hundred meters below the rapid. Where the bedrock channel is covered by sedimentary deposits (particularly, fine material upstream of a rapid), the geometry can be expected to change with discharge and with sediment load of the river.

The Froude number ($Fr = \bar{u}/(gD)^{1/2}$, where $\bar{u}$ is the average flow velocity, D is the average depth of the flow, and g is the acceleration of gravity) is a dimensionless measure of the relative importances of inertial vs. 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. Standing waves are stable features in the flow if the Froude number exceeds 1.

The Froude number of the flow at a discharge of 5,000 cfs can be calculated for each cross section from the measured and inferred depths and velocities: Fr=0.06 at *V–V′*; Fr=0.07 at *W–W′*; Fr=1.1 at *X–X′*; Fr=1.8 at *Y–Y′*; and Fr=1.1 at *Z–Z′*. Estimated uncertainties for these values are of the order of 30 percent. Nevertheless, these Froude numbers indicate that the flow changes from subcritical conditions (Fr<1) upstream of the constriction to supercritical conditions (Fr>1) in the convergence and constriction and back to critical conditions (Fr=1) in the diverging section. The flow decelerates back to subcritical conditions below the rapid.

The standing waves of House Rock Rapids are features in supercritical flow. In the converging part of the channel, water accelerates down a smooth tongue into a trough and breaking wave (**D,** fig. 3). The turbulence in the breaking wave is sufficient to entrain air into the water so that clear (nonbubbly) water of the tongue becomes a bubbly foam in this wave. Downstream of this aerating wave, a large hole and wave stand where water pours over the large rocks on the east shore (**G,** fig. 3; fig. 6). As shown by the streamlines (fig. 5) and the cross sections (fig. 4), most water in the channel passes through these two large waves at low discharges.

The runout from the rapid (**F,** fig. 3) consists of six to seven gently breaking waves and several minor swells that appear to be in flow that is at Fr=1. There are eddies (**H** and **I,** fig. 3, and indicated schematically in figs. 1 and 2) both east and west of the main current below the rapid. The west eddy is the larger and can produce a large sandy beach at high flows if sediment is available (**J,** fig. 3). Note the reverse flow in the eddy (shown schematically in figs. 1 and 2) and in cross section *Z–Z′* (fig. 4). The shearing between the eddies and main jet produces pronounced vortices and small whirlpools in the region of the tailwaves.

At discharges higher than about 30,000 cfs, the only significant wave in House Rock Rapids is a right-lateral wave at the top of the rapid where the water begins to converge into the channel narrowed by the debris fan (approximately at **E,** fig. 3; compare with fig. 2). At 30,000 cfs (fig. 2) the stage of the river is about 3 m higher above the rapid and 5 m higher below the rapid than it is at 5,000 cfs. Velocities of the river have not been measured at 30,000 cfs; however, they are probably not dramatically different from the values obtained at 5,000 cfs. If so, the increase in depth in the main channel with increasing discharge is sufficient to cause the Froude number to drop from the values above unity (1.8 in the constriction at *Y–Y′*) to below unity. Thus, the absence of waves on the east side of the river at House Rock Rapids during high discharges reflects the change of the flow regime in the main channel to subcritical flow conditions. The only area of supercritical flow at high discharges is along the west part of the channel where the flow is shallow over the upstream side of the debris fan.

The hydraulic features of House Rock Rapids reflect a dynamic equilibrium between the flow in the Colorado River channel, rockfalls from the channel walls, and flooding events from Rider Canyon. 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. The channel configuration changes with time, both gradually and catastrophically.

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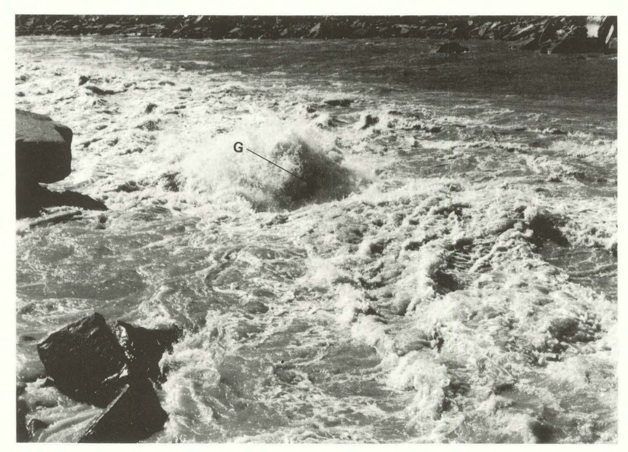


Figure 6—THE LOWER "HOLE" VIEWED FROM THE EAST SHORE

EXPLANATION FOR FIGURE 4

- Channel boundary—Dashed where estimated
- Inferred contact
- Shear zone in the flow
- Fr — Froude number
- $\bar{u}$ — Average flow velocity, in meters per second
- Debris fan
- Rockfall
- Water
- Sand

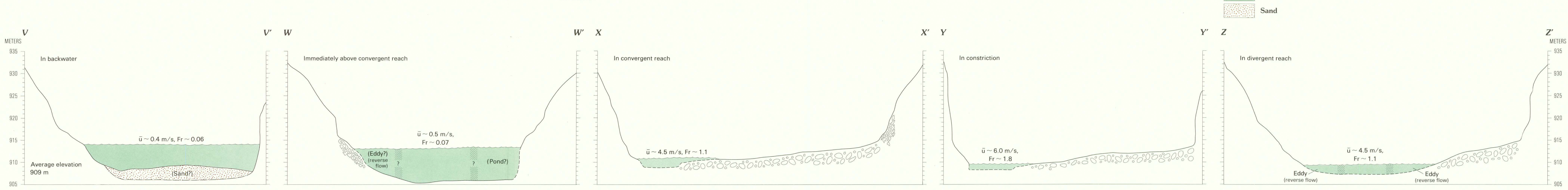
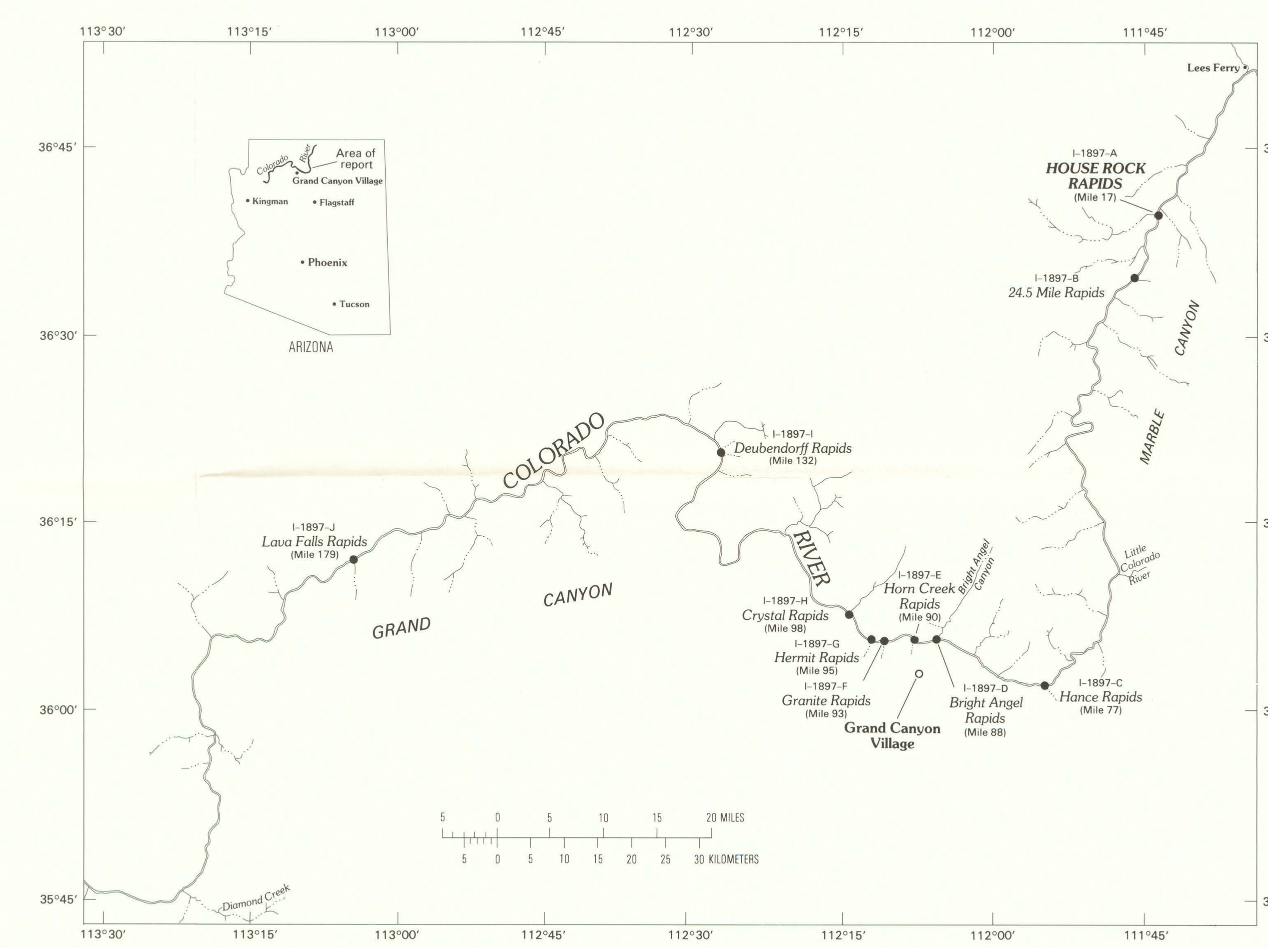


Figure 4—CROSS SECTIONS SHOWN ON FIGURE 3



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

INTERIOR—GEOLOGICAL SURVEY, RESTON, VA—1988

SCALE 1:1 000
100 0 100 200 300 FEET
10 0 10 20 30 40 50 60 70 80 90 METERS
CONTOUR INTERVAL 1 METER
LONG DASHED LINES REPRESENT 0.5 METER CONTOURS

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 GCES

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–40–04190

HYDRAULIC MAP OF HOUSE ROCK RAPIDS, GRAND CANYON, ARIZONA

By
Susan Werner Kieffer
1988

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