U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Comparison of Sand Distribution Between April 1994 and June 1996 along Six Reaches of the Colorado River in Grand Canyon, Arizona

by

Roberto J. Anima[1], Michael S. Marlow[1], David M. Rubin[1],

David J. Hogg[1]

Open-File Report 98-141

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editoral standards (or with the North American Stratigraphic Code). Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

[1]U.S. Geological Survey, Mail Stop 999, 345 Middlefield Road, Menlo Park California, 94025

1998

List or Figures:

Table:

Comparison of Sand Distribution Between April 1994 and June 1996 along in Six Reaches of the Colorado River, in Grand Canyon, Arizona

Roberto J. Anima, Michael S. Marlow, David M. Rubin and David J. Hogg
U.S. Geological Survey Coastal and Marine Geology Team
345 Middlefield Road M/S 999 , Menlo Park, CA. 94025

Abstract

Two geophysical surveys in April, 1994 and June, 1996 collected data along 15 reaches of the Colorado River in Grand Canyon. This report discusses six of those reaches between the Little Colorado River and Tanner Rapid. The surveys imaged the distribution of sand and mixtures of sand with pebbles, cobbles and boulders stored within the reaches. The surveys established a baseline of sand distribution before an experimental flood in March, 1996 and mapped changes in the areal distribution of sand within each reach after the 1996 flood. This study does not attempt to estimate the volume change in sediment stored within the reaches. Survey control relied on a network of monuments established by the Glen Canyon Environmental Study (GCES) and the United States Geological Survey Water Resources Division (WRD). The 1994 survey utilized a high-resolution seismic-reflection profiler, a side-scan sonar system, a bathymetric profiler, and underwater video system. The 1996 survey did not use the high-resolution seismic profiler because the system was generally unsuccessful in detecting subsurface structure due to multiples created in shallow water. Both surveys used underwater video to collect images of the river bed to validate our interpretations of the side-scan record. This report describes data collection, interpretation, and discusses trends found along the reaches studied in detail.

Introduction

This report is part of a study by the U.S. Geological Survey (USGS) and the Glen Canyon Environmental Study (GCES, now the Grand Canyon Monitoring and Research Center, GCMRC), to analyze sediment transport within the Grand Canyon system in response to controlled water releases at Glen Canyon Dam (Fig. 1). Graf et al. (1995) give an excellent summary of the establishment of GCES, and the Congressional mandates regulating Glen Canyon Dam. This report presents data collected by the USGS (Coastal and Marine Geology Team) for GCES during two cruises. The first cruise was conducted between April 24 and May 13, 1994, and the second in June of 1996, following the experimental flow of March 1996. Data shown in this report include side-scan sonar and video images for both cruises, and examples of the high-resolution seismic-reflection records collected during the 1994 cruise. Data were collected along 32 traverses that cross 6 reaches located along 11 kilometers below the Little Colorado River (LCR) to Tanner Rapid (Fig. 2). This study provides a baseline of sediment distribution and its temporal variability for six reaches below the LCR) Additional data were collected along 10 additional reaches both above and below the LCR (Table 1). All analog and digital data are stored in U.S. Geological Survey Coastal and Marine Geology Team archives.

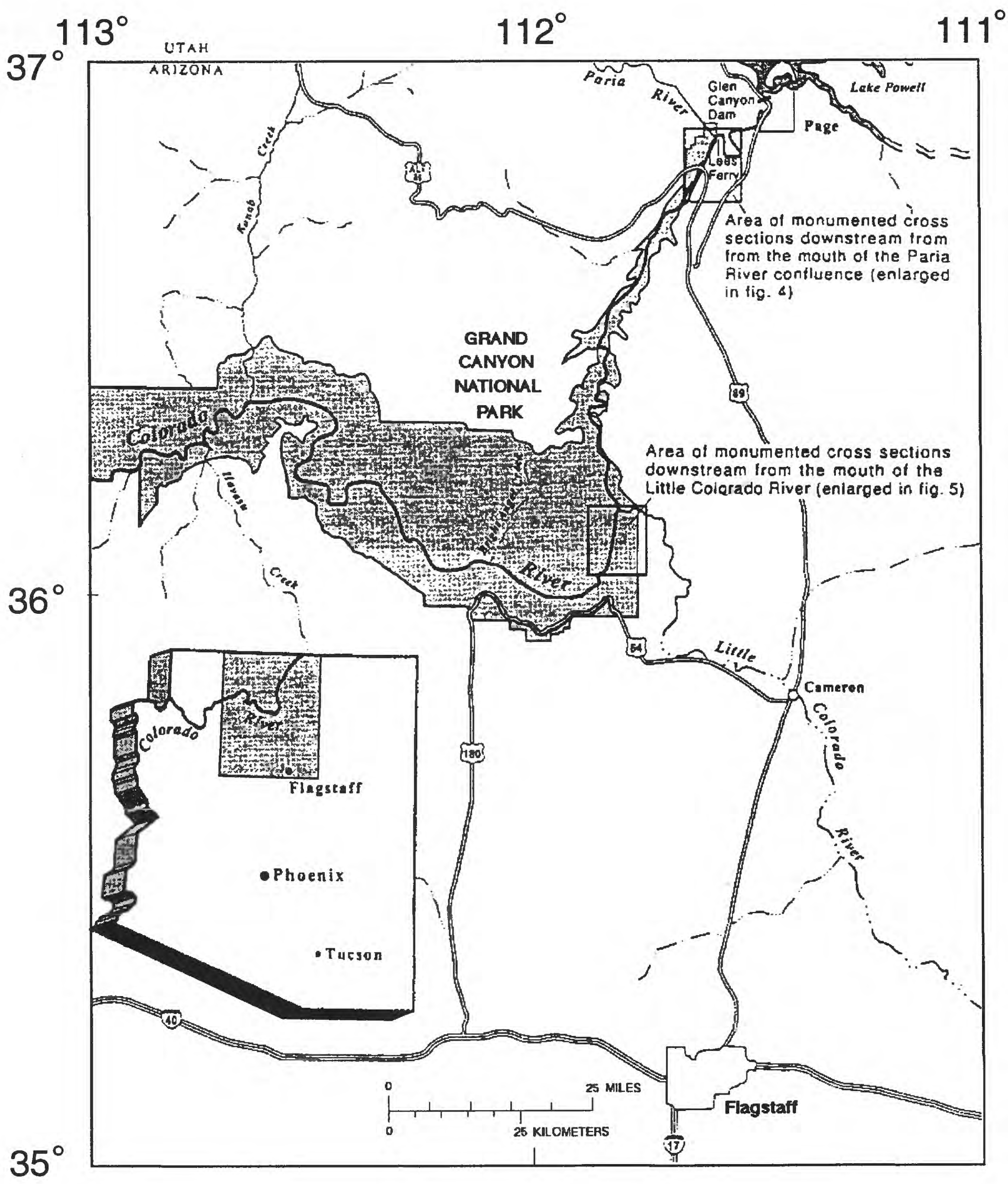


Figure 1 Location map of the study area below the Little Colorado River. Modified from Graf et al. (1995).

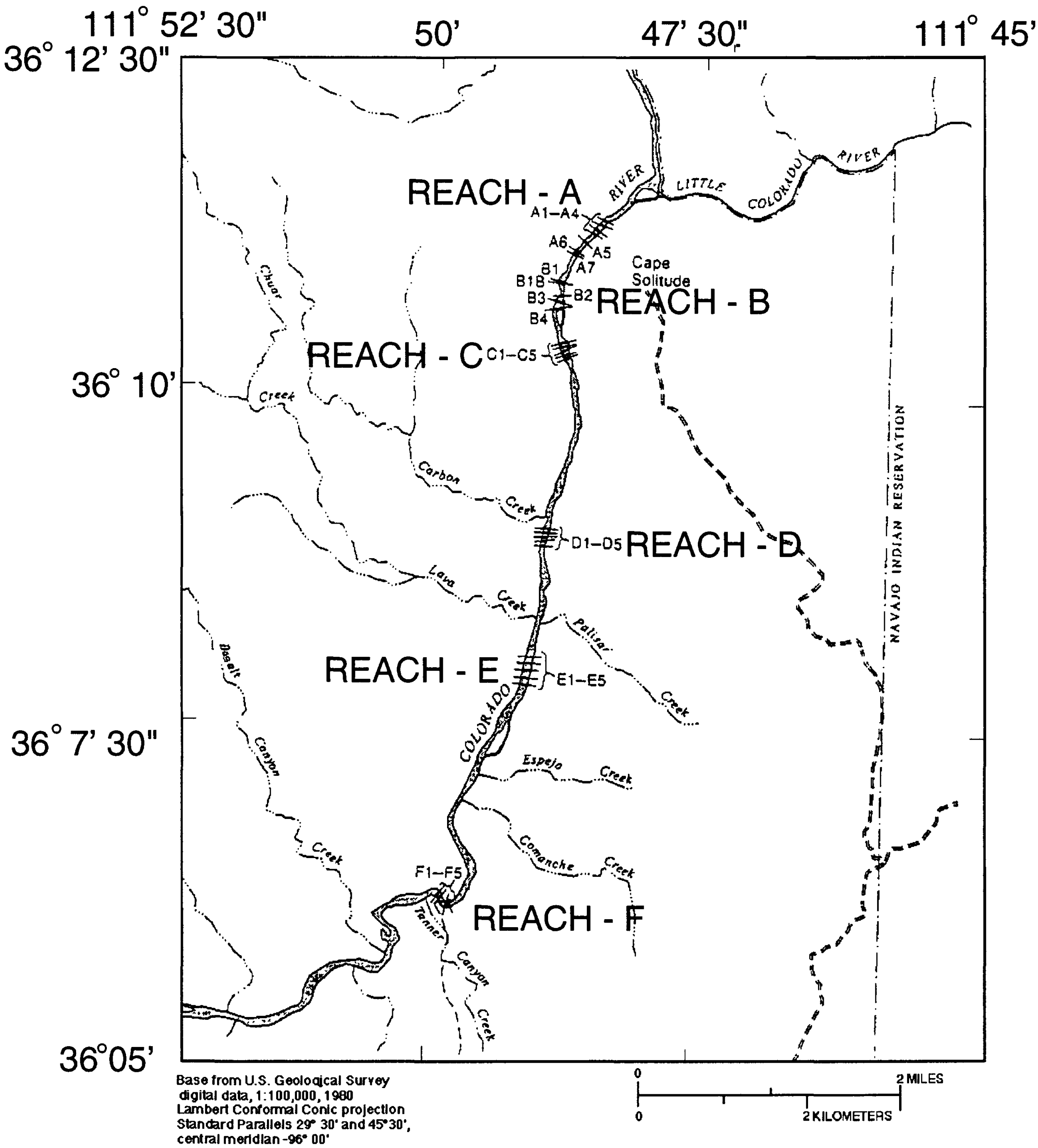


Figure 2 Location of the six monumented cross sections on the Colorado River downstream from the mouth of the Little Colorado River. Modified from Graf et al. (1995).

Table 1 Reaches along the Colorado River Corridor surveyed using geophysical techniques. The letters in the reach column in parentheses represent the numbering convention used by Water Resources Division (Graf et al., 1995). Reaches without WRD letters were added by the authors.

Reach	River Mile (*)	Cruise Dates
1- President Harding (h)	42-43	5/94, 6/96
2- Eminence Break	44	6/96
3- Saddle Canyon	47.5	6/96
4- Nankoweep(w)	51.5	5/94,6/96
5- Above the LCR(lg)	61	5/94, 6/96
6- Below the LCR(l)		
Reach-A(la)	62	5/94, 6/96
7- Reach-B(lb)	62.6	5/94, 6/96
8- Reach-C(lc)	63.2	5/94, 6/96
9- Reach-D(ld)	64.8	5/94, 6/96
10- Reach-E(le)	65.8	5/94, 6/96
11- Reach-F(lf)	68.5	5/94, 6/96
12- Cremation (g)	87.5	5/94, 6/96
13- Above Crystal(c)	98	5/94, 6/96
14 National Canyon(n)	166	5/94, 6/96
15 Above Lava(v)	179	5/94, 6/96

* River miles are measure from Lee's Ferry (Mile 0) down river.

Methods

Navigation

The survey used established monuments (Graf et al., 1994; Fig. 2) as navigation control of the geophysical traverses. Where possible, survey control consisted of extending a measured line, marked at 10 foot (3.048 meters) intervals, across the river between established monuments. Flags, aligned with monuments, were used to control traverses where a line was not strung across the river. The survey tracklines traverse the river and run longitudinally parallel to shore. Longitudinal lines cross the monumented traverses, and the flags served as range markers whose crossings were noted on the video, paper, and digitized records.

Longitudinal side-scan lines were run down the center of the river and along both banks to provide overlapping sonar images. Established monuments and the water's edge for the Colorado River below the LCR are well located on GIS maps published by Graf et al., (1995). We used these maps as a base for our interpretative maps, which in turn were derived from the geophysical and video data. Traverse profiles were located on her base map, using the water's edge as imaged on side-scan records for control.

Instrumentation

Seismic Reflection

The seismic profiler used for the survey consisted of a Geopulse receiver model 5210, power supply model 5420, using a model 5813A a single-plate boomer sound source generating 105 joules over a frequency 1 to 4 Khz,, recorded at an 1/8 second fire rate and record rate, on a EPC 1600 high-resolution seismic recorder. A single element hydrophone streamer and a 3 element streamer were used simultaneously to record the returning echos. The seismic-reflection survey instrumention was deployed from a 23 foot (7.5 meter) inflatable raft.

The seismic-reflection profiler was included in our first survey to investigate the amount of sediment cover over bedrock and/or talus. The idea was to image the cross-sectional area of sediment in the subsurface, then calculate the total volume stored along each reach. Because of the relatively shallow water depths encountered, the seismic-profiling system was not successful for this purpose because shallow-water multiples overprinted the record.

The seismic system records an air-water interface multiple reflection that occurs simultaneously with the subbottom reflections, at twice the water depth ("Multiples", Fig. 3). Because the depths of the reaches studied were on average 3 to 5 meters, the air-water multiple overprints the seismic-reflection record at these depths, making sediment thickness estimates difficult for most areas (Fig. 3).

Side-scan Sonar

The side-scan sonar system consisted of a Klein wet-paper recorder model 531T and a 500 Khz tow fish. Side-scan sonar measures the sonic reflectance of the bed material along the vessel's path and then converts that reflectance signal to an analog pulse that is both converted to a digital signal to be stored, and sent to a recorder where it burns the signal onto a wet paper record. Areas with high reflectance will image in black to gray, such as a boulder or rock outcrop. Fine sand will image a light tan color to almost white because of poor reflectance. Coarse sand, pebbles, and cobbles will image progressively darker than sand and show a more mottled appearance.

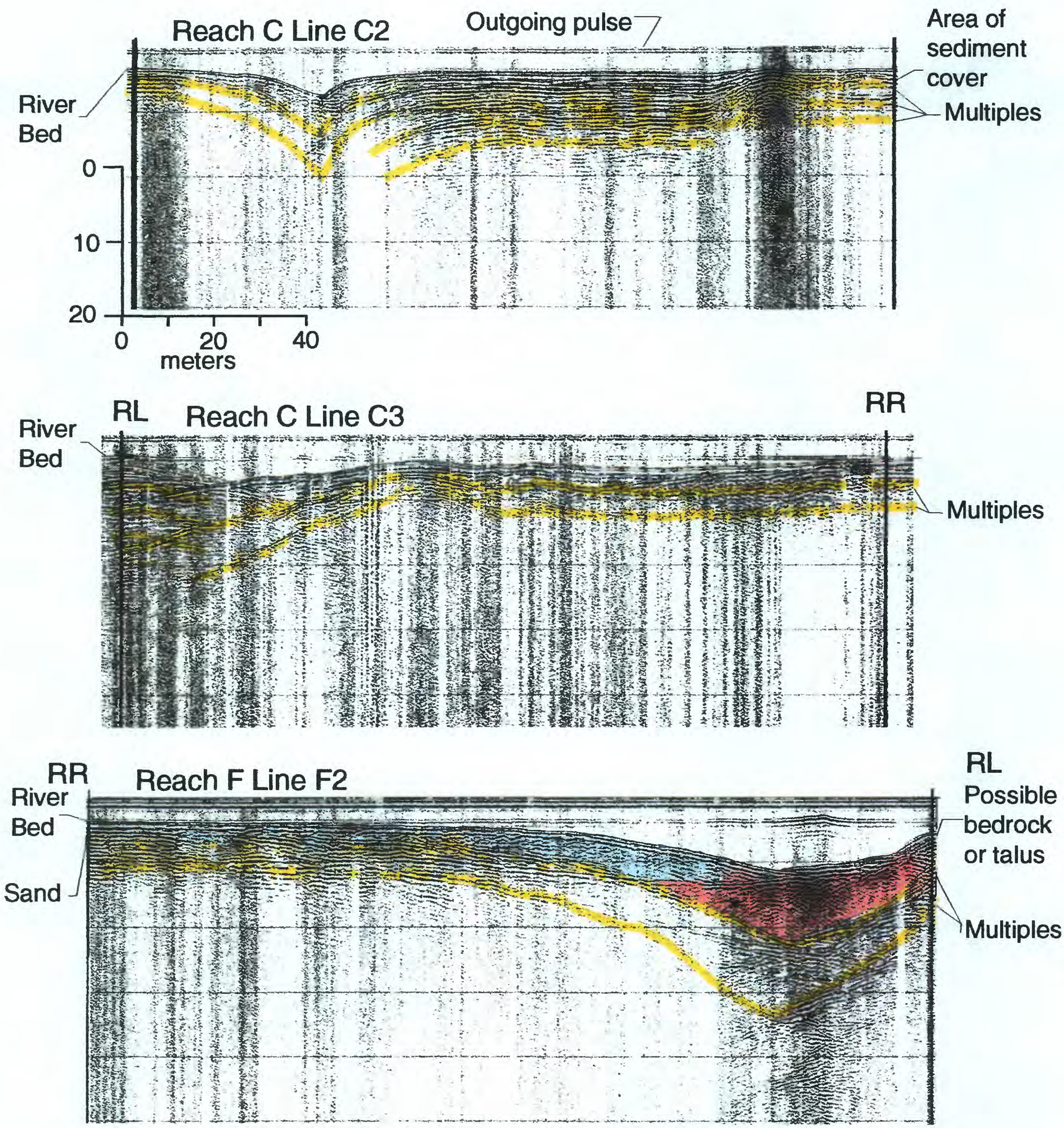


Figure 3. Seismic-reflection profiles along reaches C2, C3, and F2. The profiles show the multiples caused by the water bottom reflection. The multiples repeat water bottom reflections down through the profile, obscuring the usable data. Although an interpretation has been suggested along line F2, seismic record interpretations of sand, bedrock, and talus contacts cannot be made with confidence due to the multiples.

This system can image the whole river bed with two to three shore-parallel lines. The image covers a 50-meter swath on either side of the tow fish. The side-scan sonar surveys imaged the distribution of river-bed material along each reach with an average overlap of 25 to 50 meters between lines.

Underwater Video

The underwater video camera sled (constructed by the USGSS) consists of a .9 X .3 X .3 meter aluminum frame rigged with a four point lifting harness. Attached to the frame are lead weights for vertical stability and stabilizer fins to control the sled in the horizontal plane. The single-chip color-video camera is aided by a wide beam 250 watt quartz-halogen light. The camera sled was towed from the front of the vessel at one- to-two meters above the bottom, depending on water clarity. Height above the bottom is controlled by a manually operated wire winch. A video monitor on the vessel and either VHS or High-Eight recorder was used for real-time data acquisition and viewing. The video recording system allowed a time and date stamp for future reference as well as an audio input describing riverbed features and position along the river traverses. Video images were still framed and downloaded onto a computer to produce the images displayed in Figure 4.

Data Analysis

We determined riverbed composition by imaging the river bottom using the side-scan sonar and observing where the various reflectivity patterns suggested textural changes in sediment size. We then used the underwater video run along the crossing lines to determine if the visual bottom characteristics matched the composition suggested by the side-scan sonar imagery. The compositions for the reaches below the LCR (mile 62) to Tanner Rapid (mile 68.5) were compiled on 1:50,000 scale topographic maps of Graf, et al., (1995) (Figs 5 - 11). These maps show the water depths and the contours along the shorelines at a river discharge of 5,000 cubic feet per second (cfs). The river discharge during this survey was between 8,000 to 15,000 cfs resulting in an overall change in shoreline position of between 3 to 8 meters. Swift currents resulted in a boat-tracking error of 3-4 meters between the longitudinal and the transverse lines.

The shorelines on both sides of the river are defined in the side-scan sonar imagery by areas where the image abruptly turns white (i.e., no reflectance). The white area is usually adjacent to areas with very dark reflectance that indicate bedrock or boulders (Fig. 4). Points marking the shoreline and the raft's tracklines, and subsequently the interpreted imagery of the river bed were plotted on the GIS base maps of Graf et al. (1995).

The interpretative maps show only those areas with sand or mixtures of sand with other components. Areas with gray shading are areas of only bedrock, boulders, cobbles or pebbles without detectable amounts of sand. Video images resolved individual features as small as medium sand (.35 mm) to as large as medium sized boulders (1042 mm) (Fig 4). Line to line correlation on the side-scan sonar records of features such as ripple marks and sand waves to video images support the side-scan imagery interpretations (Fig. 4).

The changes in textural distribution within each reach can be attributed to the time lapse between the two surveys, variables in stream dynamics such as the occurrence of flash floods from side canyons, seasonal variations of side-canyon input of sediment, the high-volume experimental water flow, and the daily differences in the discharge rate. Also noted but not mapped were sand waves oriented normal to the flow at the base of reattachment bars. The sand waves are part of reattachment bar systems reported by Rubin et al. (1991) and Schmidt and Rubin (1995) as being part of the recirculation eddy pattern noted in their work.

Grand Canyon
Reach 1A

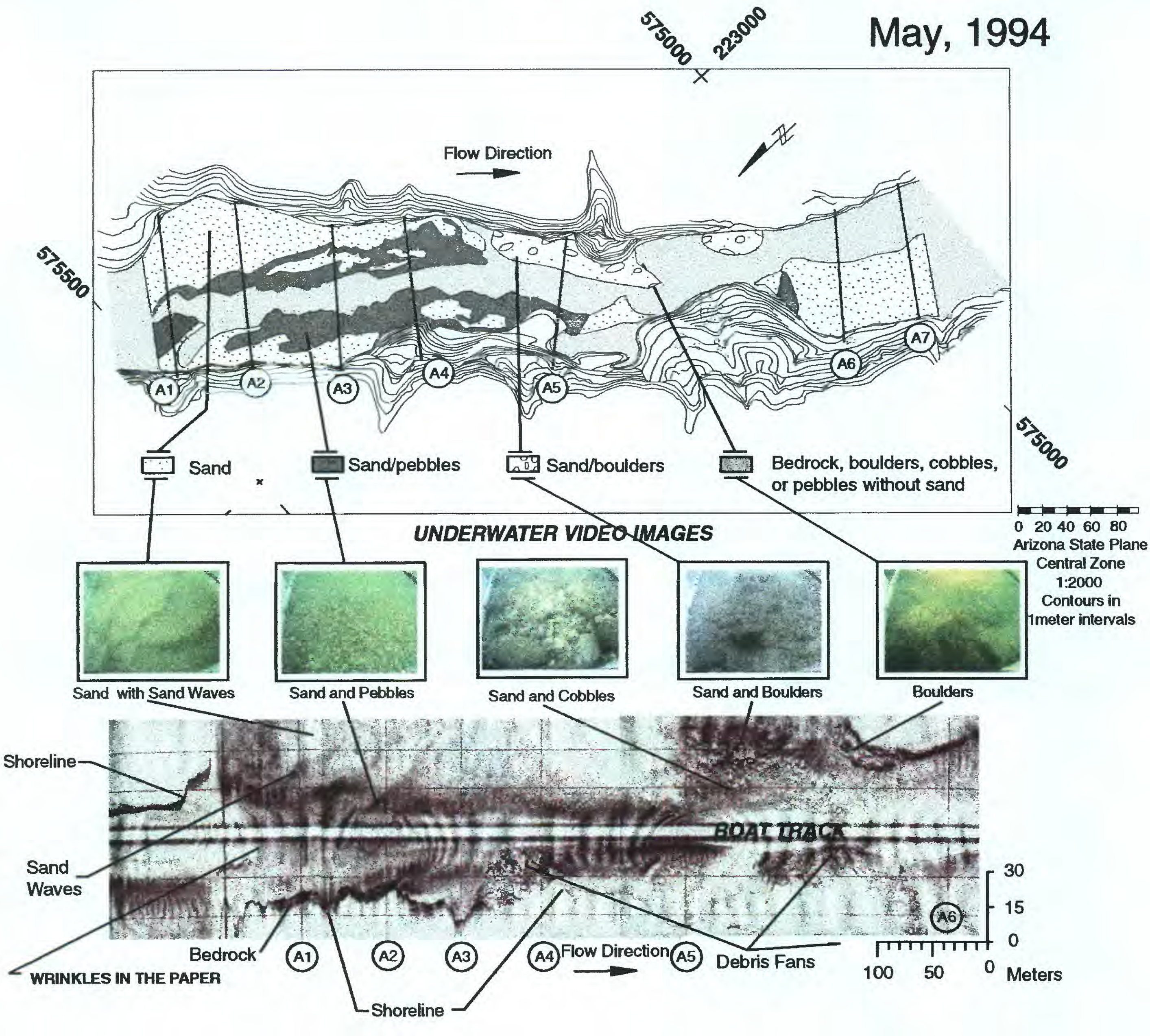


Figure 4. Map, photo, and side-scan sonar images showing the relationships of the side-scan sonar images and underwater video stills. The map used for this figure was modified from Graf et al., (1993). Contours shown on this and other maps are onland at 1 meter intervals from the waters edge.

Changes in bedforms (sand ripples, sand waves) were not mapped unless a change in sediment texture was seen in conjunction with the bedforms.

Description of Reaches

The six reaches surveyed between the LCR and Tanner Rapid (Fig. 2) are numbered using a slight modification of the letter and number designation convention of Water Resources Division of the U.S. Geological Survey (WRD) and GCES (Konieczki et al., 1997)(this study; A1, B3, F2, etc., study by Konieczki et al., 1997; la1, lb3, lf2, etc.). The use of river miles is referenced to miles below Lees Ferry. The use of river right or left is with reference to the down-river direction. The reaches, which are pools between rapids or riffles, average 348 meters in length and 115 meters in length. Onshore, reaches vary from sand beaches to extensive boulder fields to exposed bedrock.

Reach A

Reach A is located directly below the LCR, at mile 62, and is traversed by seven cross lines (Fig. 5). Reach A is approximately 650 meters in length, and crossing lines average 106 m in length. The right bank of reach A consists of ledges of Tapeats Sandstone (Hutoon, et al., 1976) exposed onshore at the ends of lines 1, 2, and 3. Midway between lines 3 and 4, the shore is composed of large boulders from a debris fan that extends down river to line 6. From line 6 to the end of the reach, the river bank is sand. The left bank of reach A is composed of talus and sand with exposures of Tapeats Sandstone.

Reach A shows variability in the bottom texture during both surveys (Fig. 5a, 5b). Figure 6 highlights the changes noted between surveys. The predominant feature is the large amount of sand that was imaged along the middle and left sides of the river. A small gravel and cobble patch was noted during the 1996 survey located along river right above the debris fan. These two features were the only evidence of change from the 1994 survey.

Reach B

Reach B (Fig. 7), which starts at the lower end of mile 62, is approximately 350 meters in length and is traversed by 5 crossing lines averaging 143 meters in length. The reach contains two debris fans that extend into the channel (Fig. 7). The first debris fan is located on river right between crossing lines B1b and B2. The second debris fan extends into the channel from river left, is smaller, and lies directly downstream from the first debris fan. Except along the margins of the debris fans, reach B is dominated by sand along its length. Along the edges of the two debris fans, boulders and sand, and sand with pebbles are found. Tapeats Sandstone is well exposed from the start of the reach at B1 to just upstream of the river-left debris fan.

The 1996 survey show three new pebble and gravel patches and one new sand patch. The pebble and gravel were found upstream and downstream of the river right debris fan and downstream along mid-channel between line B3 to the end of the reach (Fig. 8). The new sand patch was found just upstream and extending to slightly downstream of the apex of the river right debris fan.

Reach C

Reach C, mile 63 to mile 63.25, is located in a pool downstream from a large mid-channel bar and debris-fan complex that extends from river left (Not seen in Fig. 9). Reach C is between two debris fans, the upstream fan extends from river left, the downstream fan from river right (barely visible in Figure 9). Reach C is

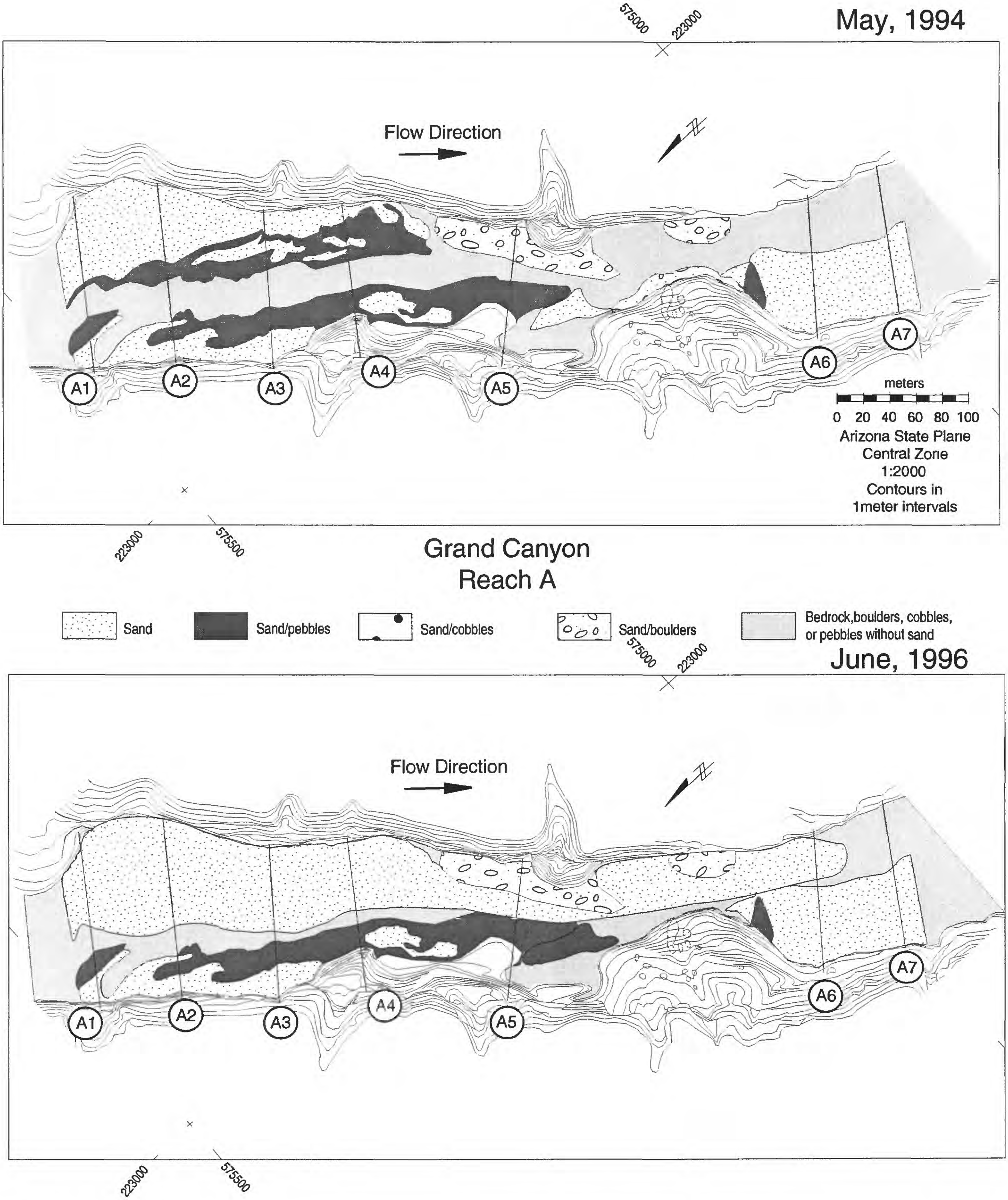


Figure 5. Maps of Reach A, showing that a large area along river left was covered with sand in 1996, but had exposures of pebbles and cobbles in 1994.

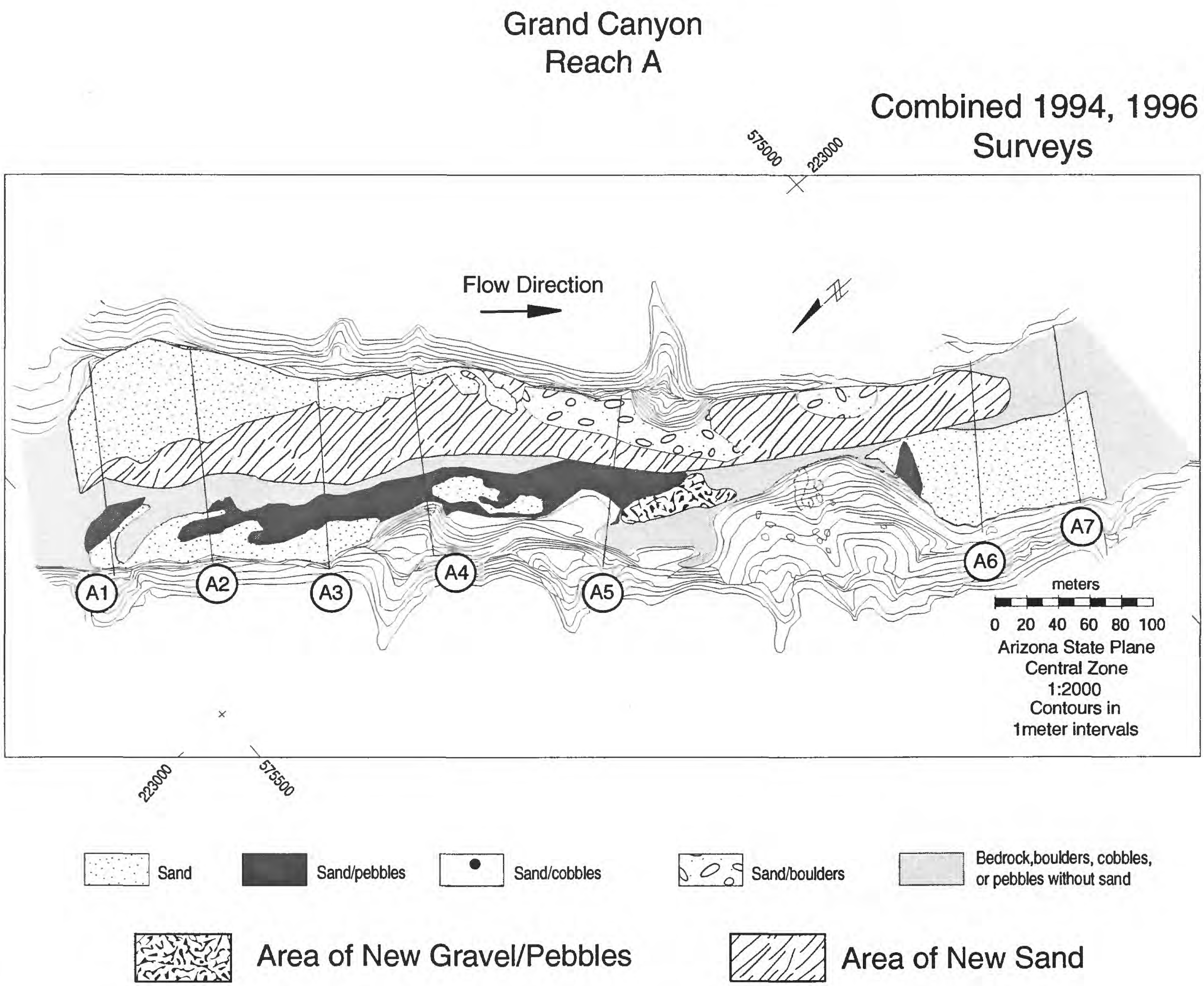


Figure 6. Map of Reach A, showing the cumulative changes observed between the 1994 and 1996 surveys.

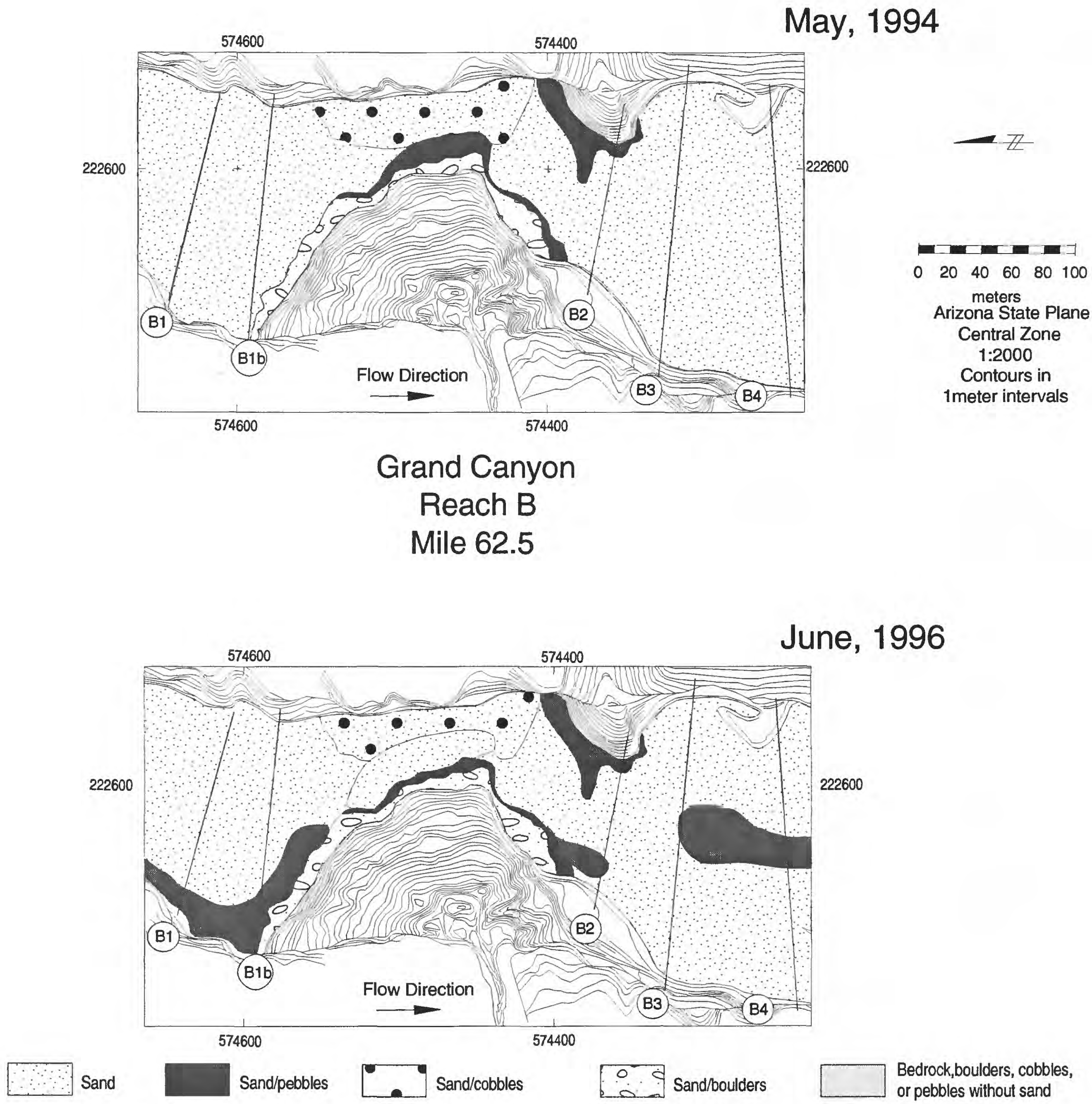


Figure 7. Maps of Reach B showing that the areas of erosion were upstream and downstream of the debris fans. Deposition occurred near the apex and downstream the river right debris fan.

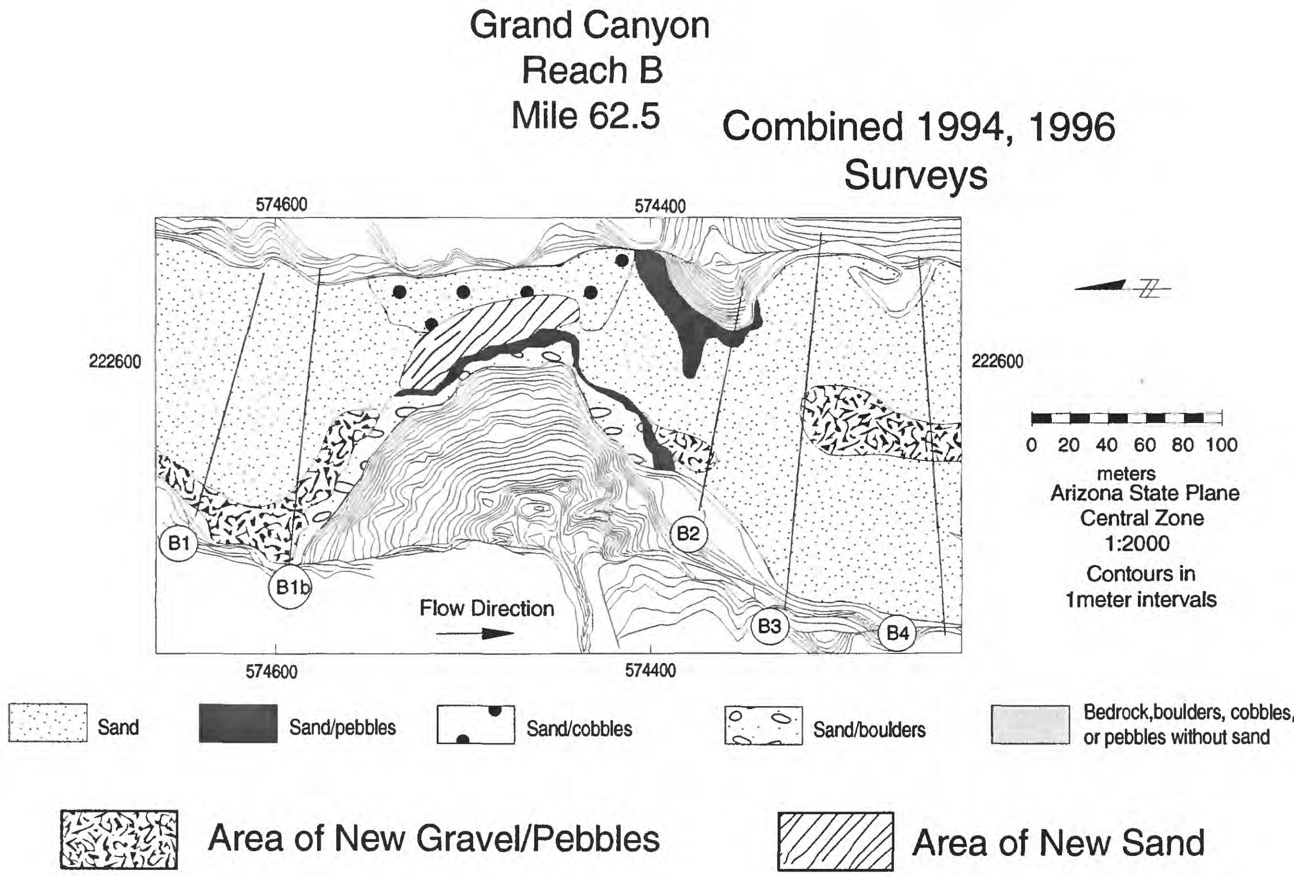


Figure 8. Reach B, map view of the cumulative changes in areas of erosion and deposition between the 1994 and 1996 surveys.

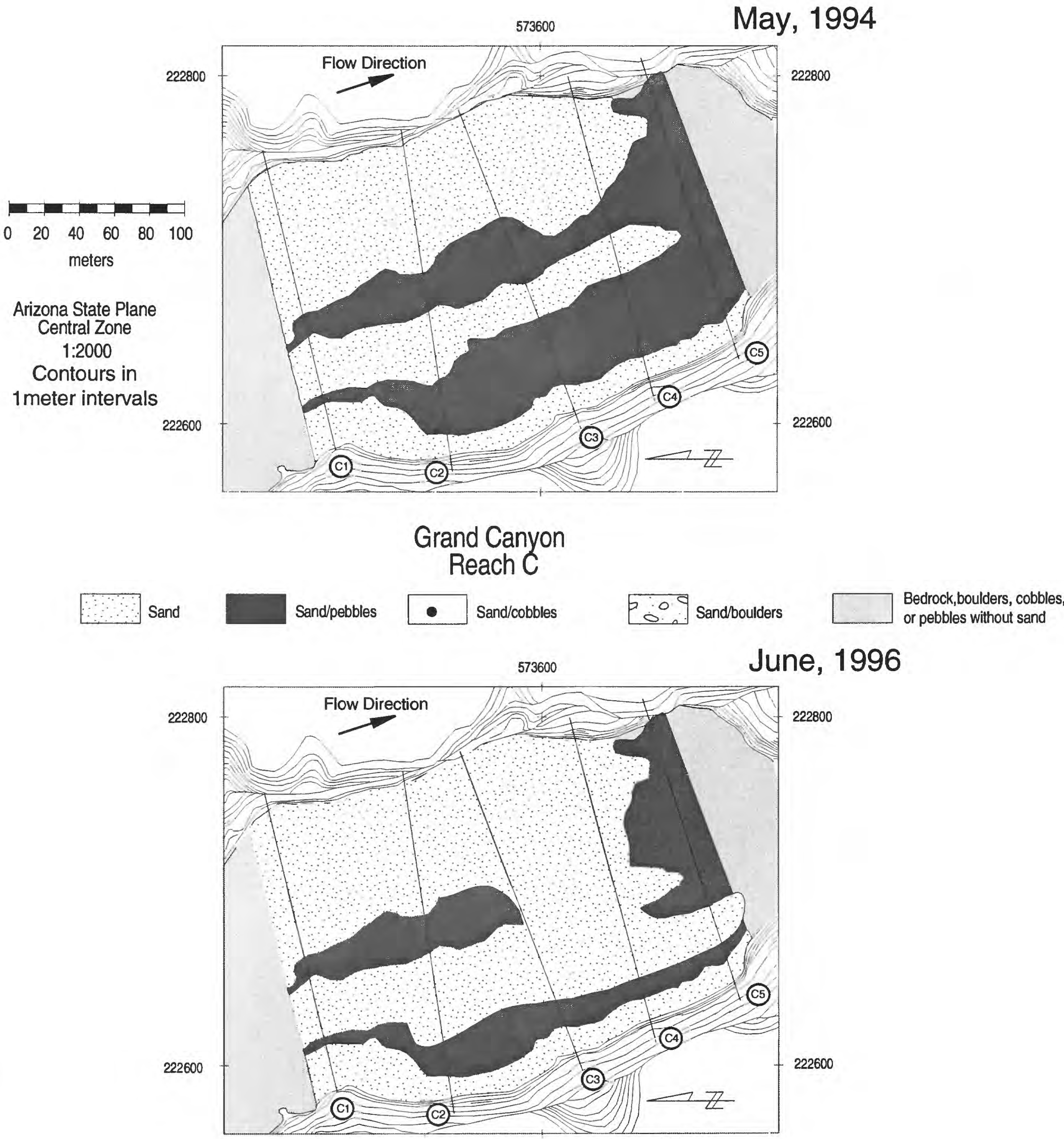


Figure 9. Reach C, had the most sand redistribution of any of the six reaches reported here. The center of the channel and both sides of the channel showed sand deposition over previously exposed cobbles and pebbles.

approximately 260 meters in length and is traversed by 5 crossing lines that average 174 meters in length. Reach C is the widest of all the reaches in this report. Onshore, Reach C consists of boulders and talus along river right as well as bedrock exposures of Tapeats Sandstone. The river's edge along river left consists predominately of boulders.

Reach C was the only reach that did not show any new pebble and gravel patches. Instead new sand was found in areas imaged as pebbles and gravel during the 1994 survey. The new sand patches are both along river right and mid river. The river right sand patch extends from line C2 to the end of the reach along river right. The sand patch along mid channel lies between lines C3 and C4 (Fig. 10).

Reach D

Reach D at mile 64.6 to mile 64.9 is located on the upper part of a large pool downstream from a debris fan that formed at the mouth of Carbon Creek (Fig 11) (Stevens, 1983, Belknap, 1996). Reach D is approximately 240 meters in length traversed by 5 crossing lines averaging 78 meters in length. Along river right, sand-bar deposits extend from line D-1 downstream to below line D-3 (Fig. 11). Dox Formation is exposed along river right from just above line D-4 to the end of the reach. River left is composed of talus slope deposits and Dox Formation.

Changes along Reach D consisted of one sand patch along the mid channel area between D2 and upstream of D4. In addition two gravel pebble patches were noted at mid channel below D4 and downstream and along river right of D5 (Fig. 12).

Reach E

Reach E, below Lava Rapids, between mile 65.6 and 65.9, is approximately 300 meters in length traversed by 5 crossing lines averaging 107 meters in length (Fig. 13). The reach begins downstream from the constriction in the river caused by the debris fan formed at the mouth of Lava Canyon (Fig. 13). Along river right, the shore line is dominated by exposures of Dox Formation as well as terrace gravel deposits, which increases in boulder and cobble content at line E5. River left, between E3 and E4, a well-formed reattachment bar eddy return channel formed in the channel. The river left channel margin is floored predominantly by boulders and large cobbles deposited as a debris fan from the mouth of Palisades Creek.

The changes mapped from 1996 survey shows Reach E to have relatively large gravel pebble patches along both river right and river left. The gravel pebble patches were located at E1 and between E3 and E5. Two new sand patches were found very close to one another along river left between lines E2 and E3 (Fig. 14). The areas of sediment changes are within the area of the reattachment bar eddy return channel complex.

Reach F

Reach F is the last reach of the six reaches below the LCR. Reach F is located between mile 68 to above Tanner Rapid (Fig. 15). The reach is approximately 290 meters in length and traversed by 5 crossing lines,averaging 85 meters in length. This is the only reach that is located along a river bend and exhibits features of a cut bank (river left) and accretionary bank deposit (river right) (Reineck and Singh, 1975, Allen, 1970, 1964). The shoreline along river right consists of vegetation along the entire reach and a very large reattachment bar along the downstream end of the reach (accretionary bank deposit). This area was not surveyed due to shallow depths. River left consists of exposures of Dox Formation from the start of the reach to line F2. From line F2 to the end of the

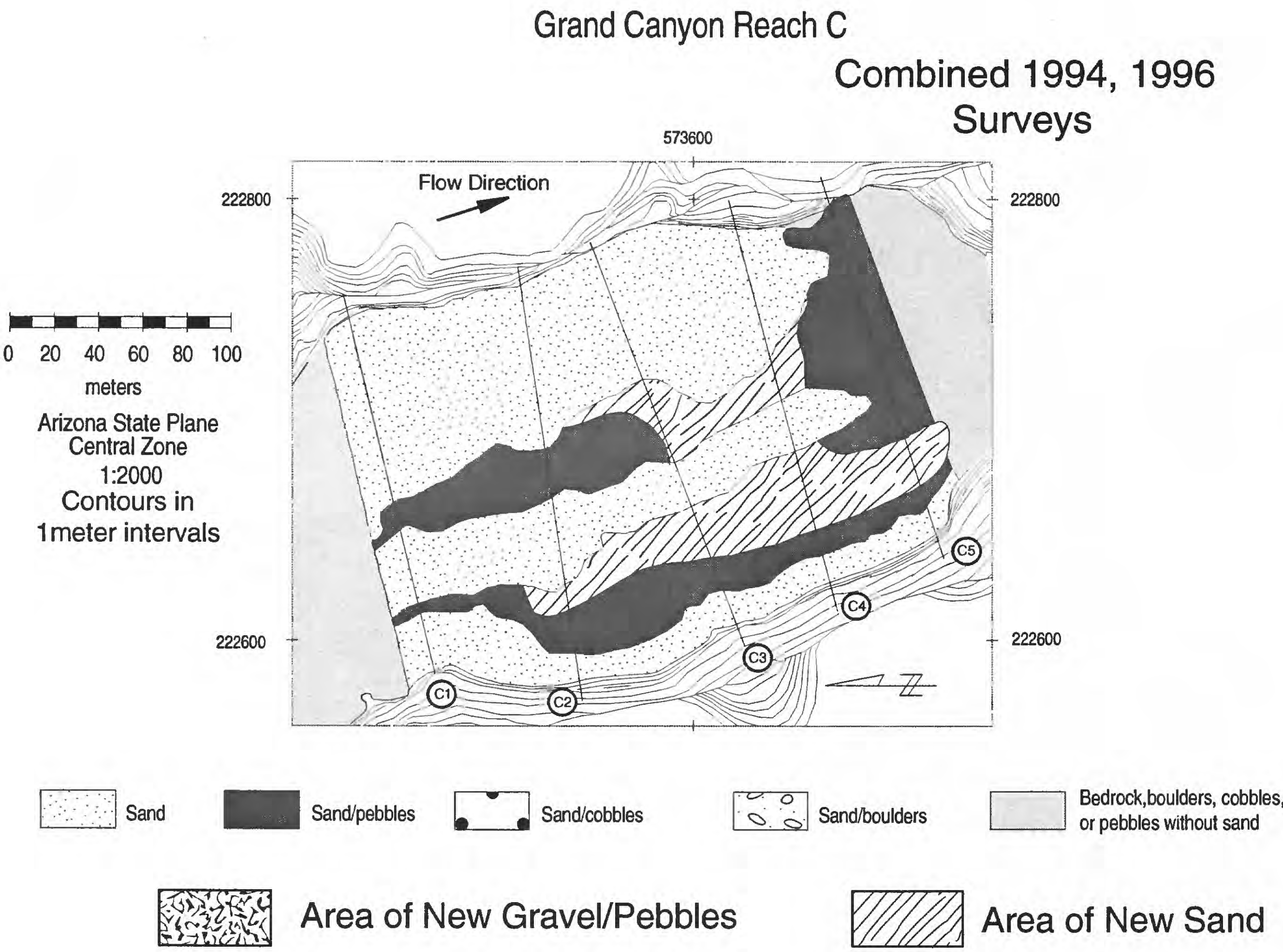


Figure 10. Reach C, map of the combined changes of areas of deposition between the 1994 to 1996 surveys.

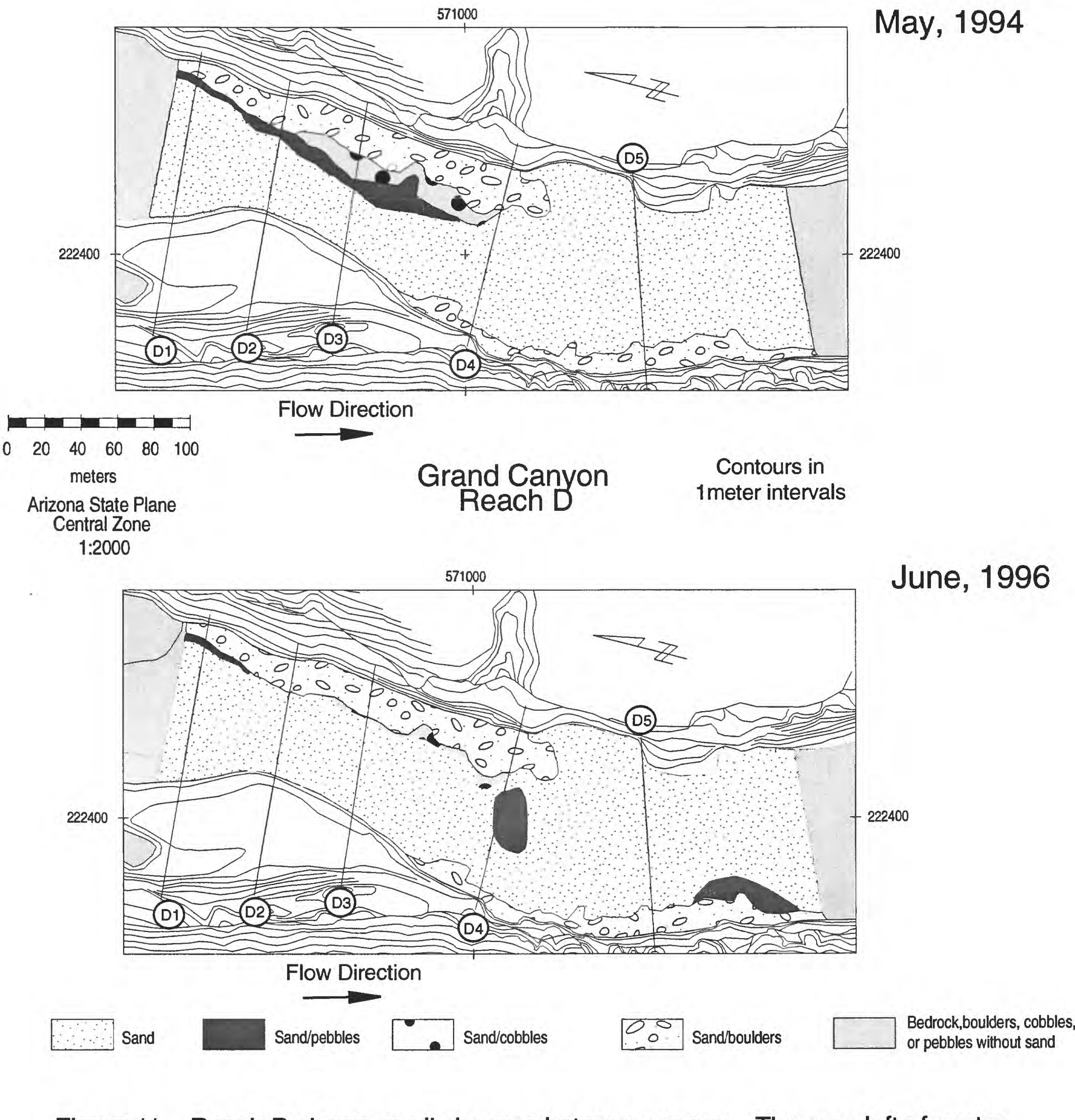


Figure 11. Reach D shows small changes between surveys. The area left of center, between D2 and D4, showed a covering of pebbles and cobbles. Previously unexposed pebbles were seen in two areas downstream of D4 and D5.

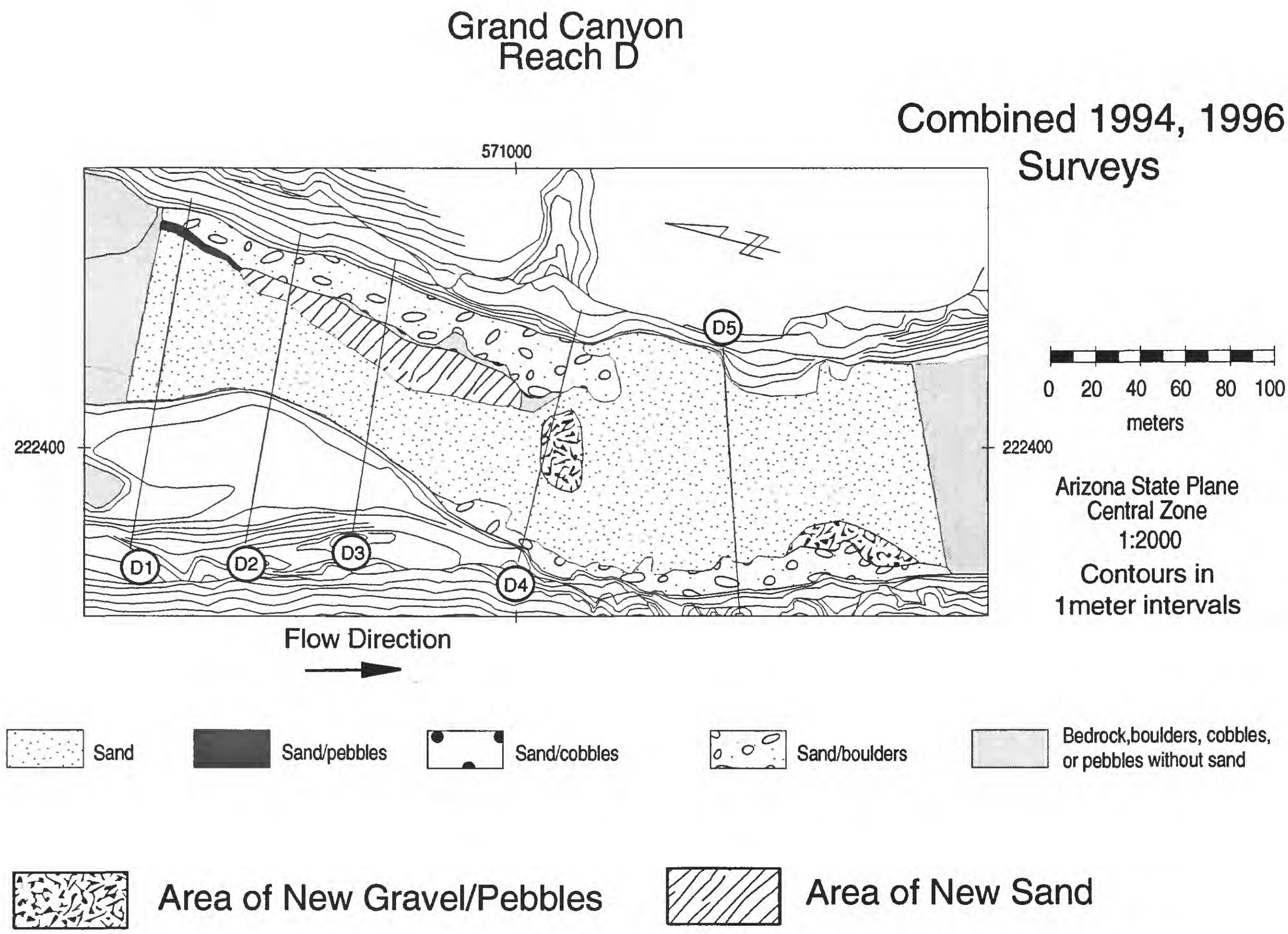


Figure 12. Reach D map shows small cumulative changes between the 1994 and 1996 surveys.

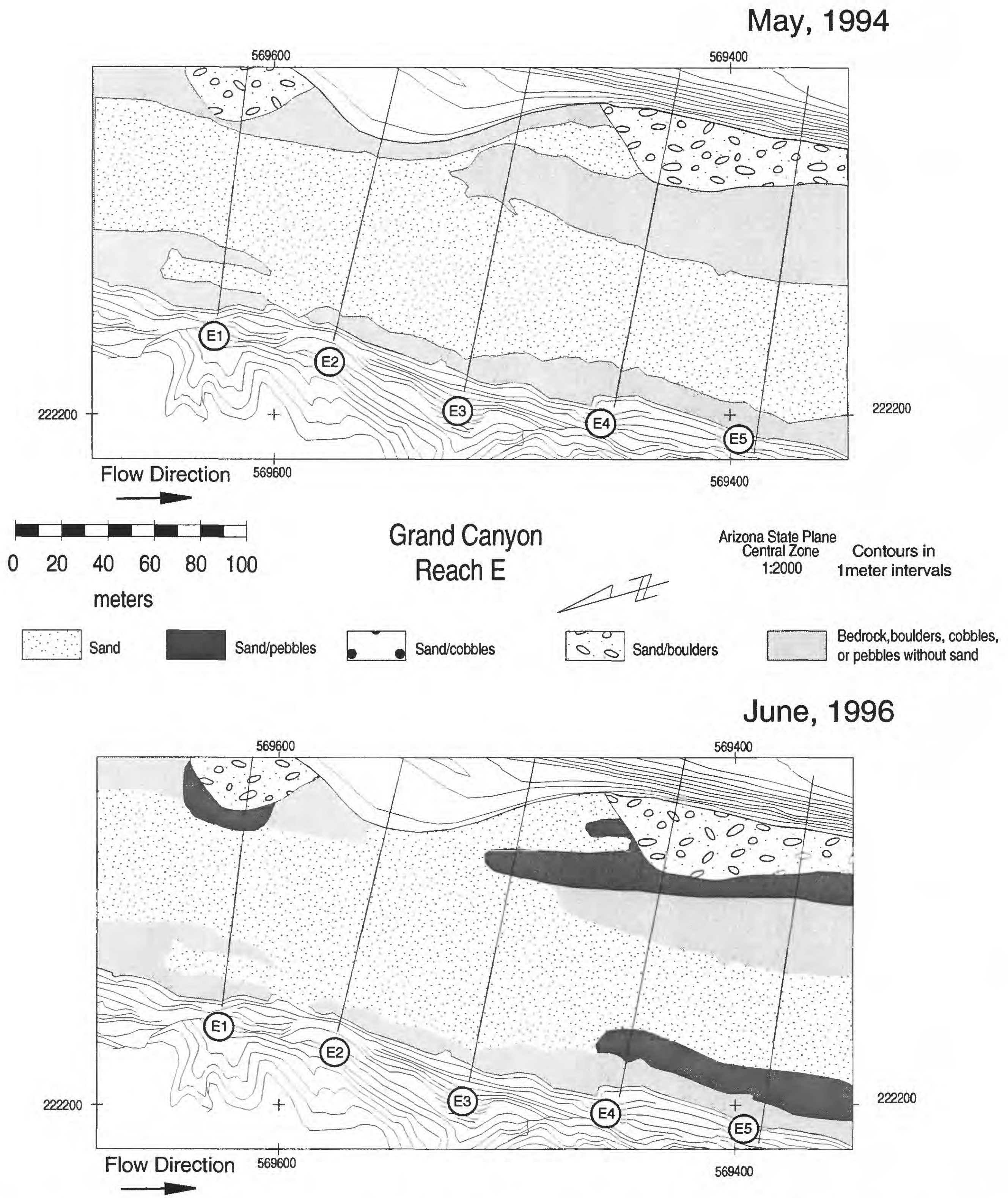


Figure 13. Maps of Reach E showing that the reach previously (1994) had exposed bedrock and pebbles and cobbles. New exposures of sand/pebbles (black) are found along three areas of the reach.

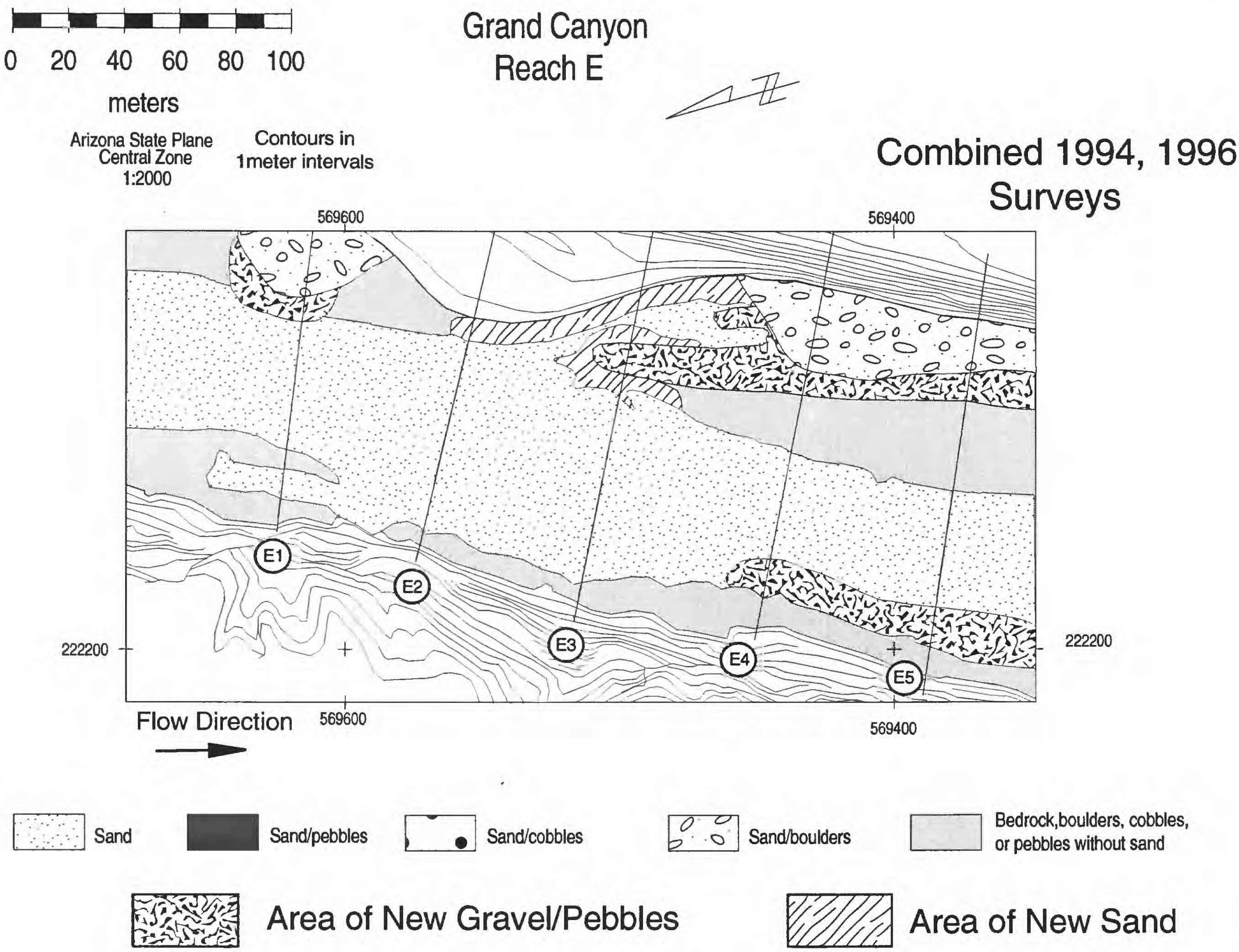


Figure 14. Map of Reach E showing the cumulative changes between the 1994 and 1996 surveys.

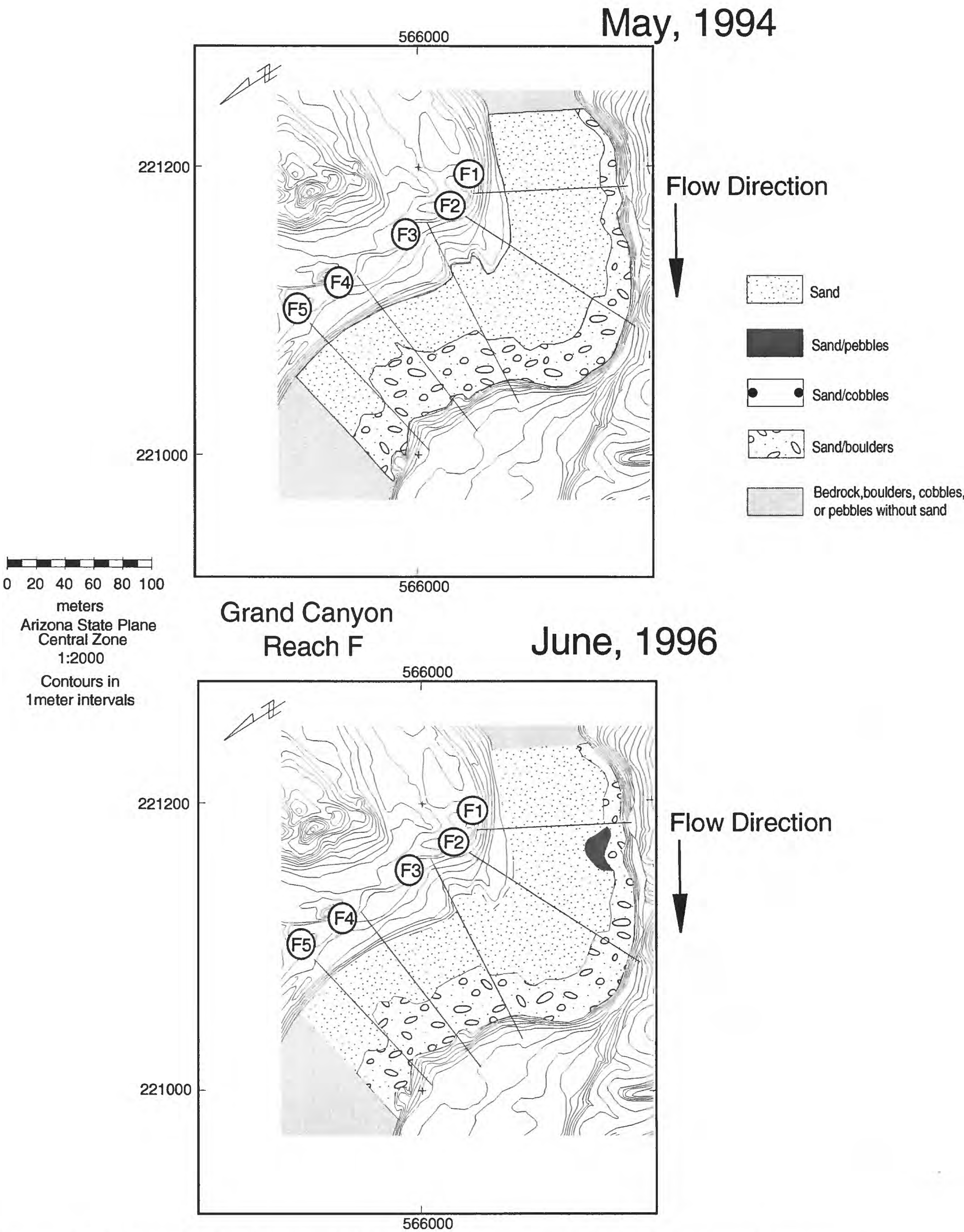


Figure 15. Maps of Reach F, that is located above Tanner Rapid. Two small areas (above F2 and at F4) have new (1996) sand that covers boulders. Some cobbles and gravels were removed downstream from F1.

reach along river left consists of boulders and large cobbles that are part of the Tanner Canyon debris fan.

Reach F showed very minor areas of new sand, gravel and pebbles. Two patches of new sand were noted along the margins of the boulders upstream of F2 and at F4. The gravel pebble patch was found downstream from F1 (Fig. 16). This reach did show changes along the river right shore line between F3 and F5. These changes appeared to be in the amount of material removed from the shore. This was not surveyed during the study.

Discussion

Our interpretation of two river-imaging data sets is based on comparison of underwater video to side-scan sonar imagery, we note where bedrock, boulders, cobbles, and pebbles were or were not exposed during the two surveys. The variations in the reflectivity intensity and image patterns of the river bottom on the side-scan data were matched with variations in sediment texture in the video data. The interpretative maps distinguish areas with sand from those with mixtures of sand. Although volumetric changes can not be made using side-scanning sonar, the areal distribution of sediment can be mapped. Changes in sediment distribution between the two surveys varied widely. Constrictions in the river, which commonly effect sediment distribution did not seem to be the controlling factor between the reaches studied.

The distribution of sand in the 1994 and 1996 surveys was measured along each of the crossing lines for each reach below the Little Colorado River. The results are plotted as a percentage of the river bottom covered by sand along each crossing line (figs. 17, 18, and 19). Figures 20 and 21 show the same data plotted for the reaches combined. Included in each plot is the ratio of change in the percent of sand from 1996 to 1994 along each line, as well as the downstream ratio of change along each reach. The ratio of change was determined by dividing the difference in the percentage of sand between 1996 to 1994, along each line, by the averaged percentage of sand in 1994 and 1996 (%sand in 96 - %sand in 94)/(%sand in 96 + %sand in 94)/2). The ratio of change was included to present a single number that provides information about sand coverage along the reaches, and, to show how much it changed relative to how much sand there was between surveys

The plots show the longitudinal variation in sand coverage, and show the change in sand coverage from 1994 to 1996. With the exception of reach B, and reach D, there was a general increase in sand coverage between 1994 to 1996. Reaches A and C, showed the greatest increases in sand coverage from 1994 to 1996. Reach B showed the greatest decrease in sand coverage at the upstream and downstream ends of the reach. Reaches D and E show increases in sand coverage on the upstream ends of the reaches and decreases at their downstream ends Reach F shows a decrease in sand coverage along the upstream end of the reach with an increase at the downstream end.

Between 1994 and 1996, sand coverage on the bed generally increased, with the greatest increase in reaches A and C (figs. 17, 18, and 19). The remainder of the reaches showed variable changes, and in the case of reaches D and F suggest more of a change in sand cover from upstream to downstream. Reach B showed the greatest change in sand coverage of all the reaches, with a decrease in sand coverage along the upstream and downstream sections of the reach.

The graphs show a variability in overall sediment redistribution, with the ratio of change between 1996 to 1994 suggesting that the largest increase in sand coverage occurred along the first three reaches.

The volumes of sediment measured by Konieczki, et al. (1997) show a trend of erosion for reaches A, B, and C, while for the lower reaches D, E, and F, their data show appreciably less erosion, with some deposition along reach F. This study found the greatest increase in sand distribution along the first three reaches of the study area. The three lower reaches also showed a change in sand distribution but those changes were not as great in magnitude as along the upper reaches. The greater coverage of sand in 1996 may have resulted from post-flood reworking of the flood deposits, or may have resulted from tributary input.

Conclusion

Sand distribution in the channel of the Colorado River was imaged and mapped in April, 1994 and June, 1996. The 1994 survey was before the experimental flow and the 1996 survey was done almost three months after the experimental flood. We anticipated that the reaches would be depleted of sand, with greater areas of exposed pebbles, boulders, and bedrock. This, however, was not the case. Instead, the sand was more widely distributed in the channel after, than before, the flood (figs. 17-21). The study showed that the distribution of sand-size sediment that floors the reaches reported here changed between the two surveys. The study did not show an overall depletion of sand coverage. The results of the side-scan sonar and underwater video survey show that changes of sand coverage along the 6 reaches below the Little Colorado River were variable.

Acknowledgments

The authors want to thank the individuals who helped with the field and office work that made this report possible. We thank Julie Graf, and her crew for their assistance with the initial surveys and allowing us to tag along on one of their bathymetric surveying trips. Special thanks to Christie O'Day who accompanied us on the second survey to help us in finding the marks. The authors wish to thank the two boatman who put the boat where we needed to be, John Toner and Lars Neimi, without them the data gathering and quality would have been sorely lacking. We want to thank Kay Kinshita, and Fujiko Issaya for their assistance in the field. And thanks to Rex Sanders and Jingping Xu for their review of the manuscript.

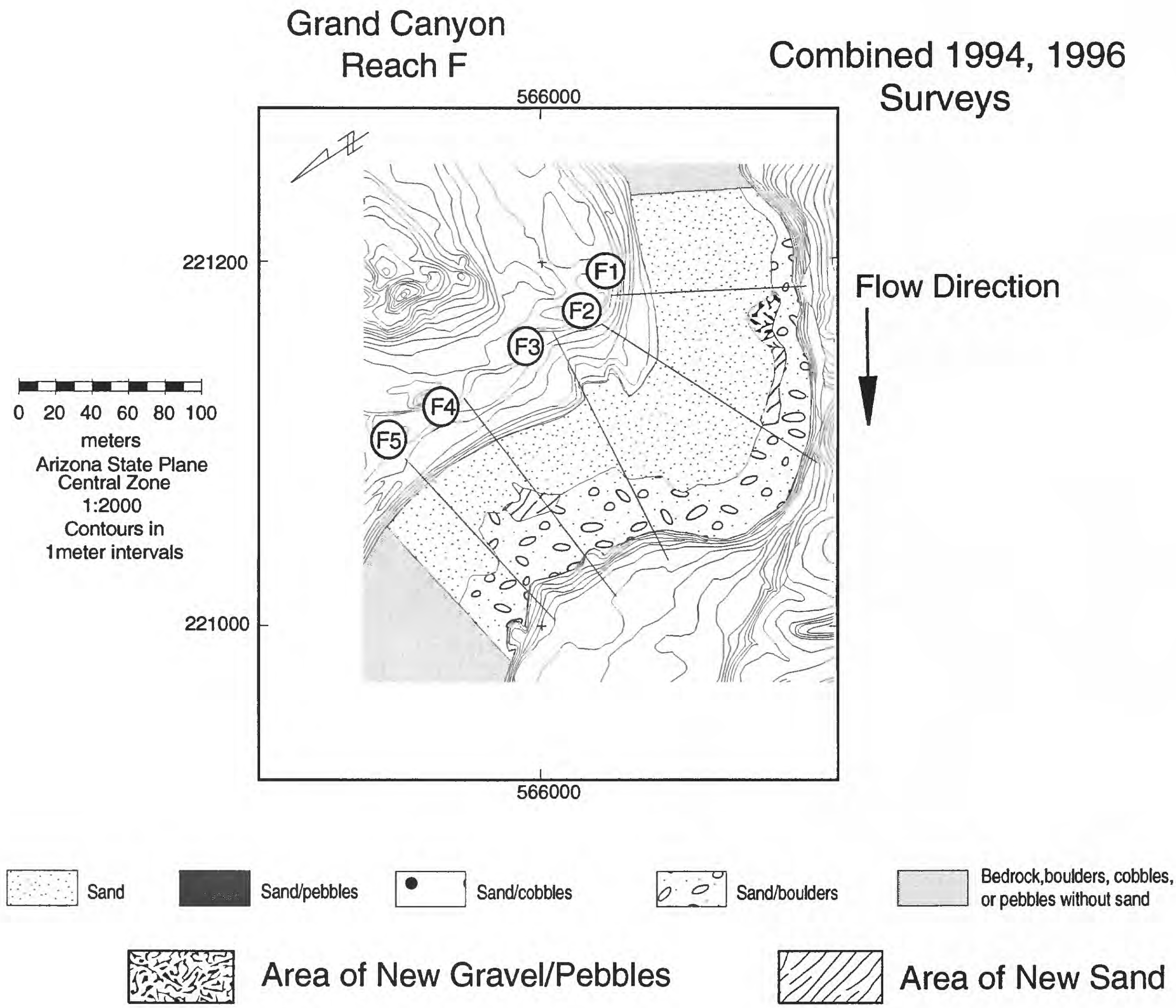
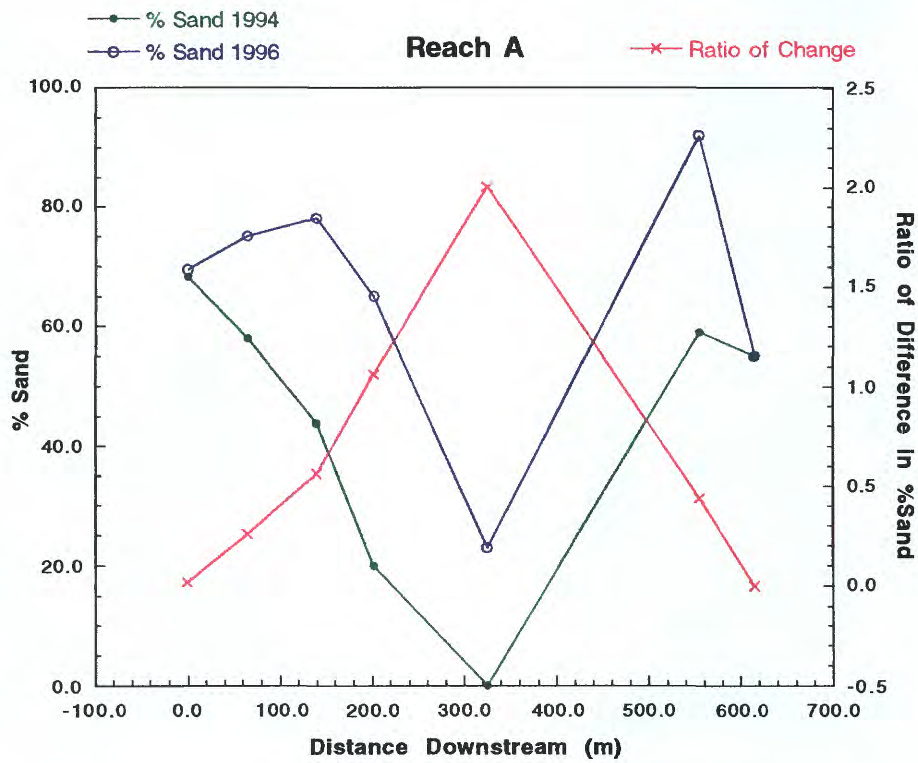


Figure 16. Map of Reach F showing the cumulative changes along the reach between the 1994 and 1996 surveys.

Figure 17 Plots of percentages of sand-size sediment at the river bottom for each crossing line along reaches A and B between 1994 to 1996. Also plotted is the ratio of change from 1996 to 1994 (see text for explanation).


% Sand 1994
% Sand 1996
Reach A
Ratio of Change
100.0
80.0
60.0
40.0
20.0
0.0
% Sand
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
Ratio of Difference in %Sand
-100.0
0.0
100.0
200.0
300.0
400.0
500.0
600.0
700.0
Distance Downstream (m)

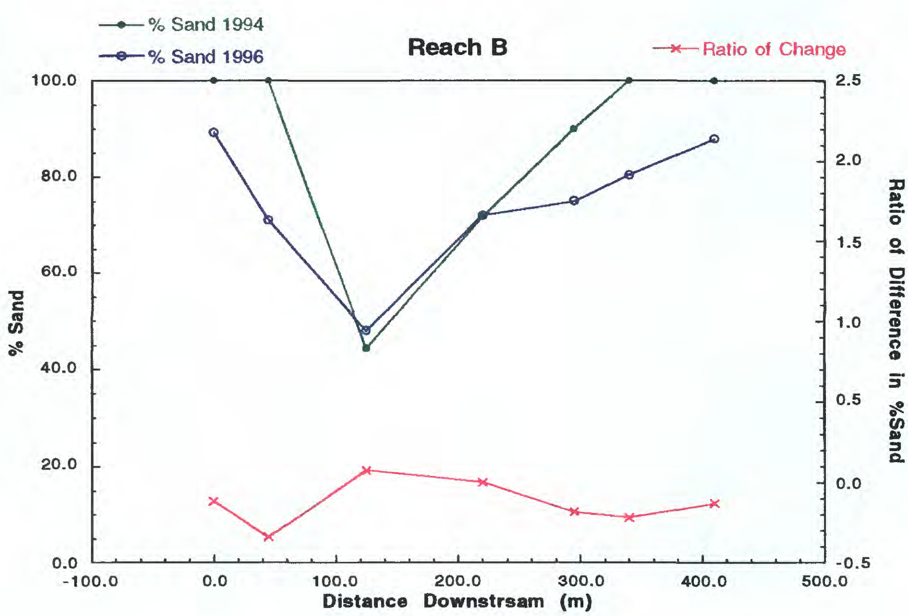
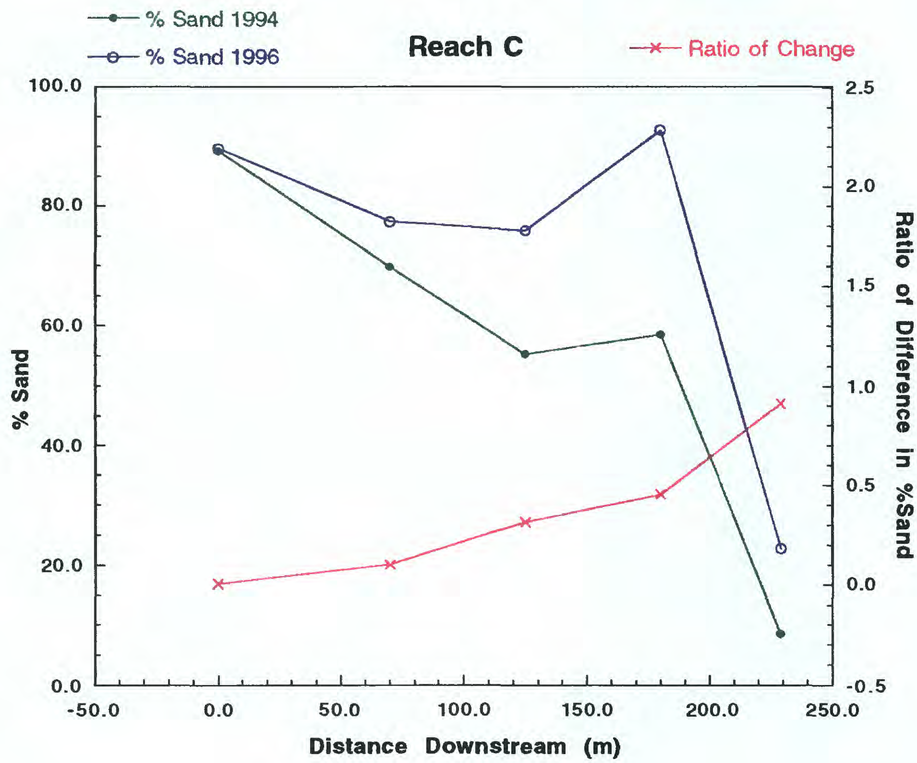

% Sand 1994
% Sand 1996
Reach B
Ratio of Change
100.0
80.0
60.0
40.0
20.0
0.0
% Sand
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
Ratio of Difference in %Sand
-100.0
0.0
100.0
200.0
300.0
400.0
500.0
Distance Downstrsam (m)

Figure 18 Plots of percentages of sand-size sediment at the river bottom for each crossing line along reach C and D between 1994 to 1996. Also plotted is the ratio of change from 1996 to 1994 (see text for explanation).


% Sand 1994
% Sand 1996
Reach C
Ratio of Change
% Sand
Ratio of Difference in %Sand
Distance Downstream (m)
100.0
80.0
60.0
40.0
20.0
0.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-50.0
0.0
50.0
100.0
150.0
200.0
250.0

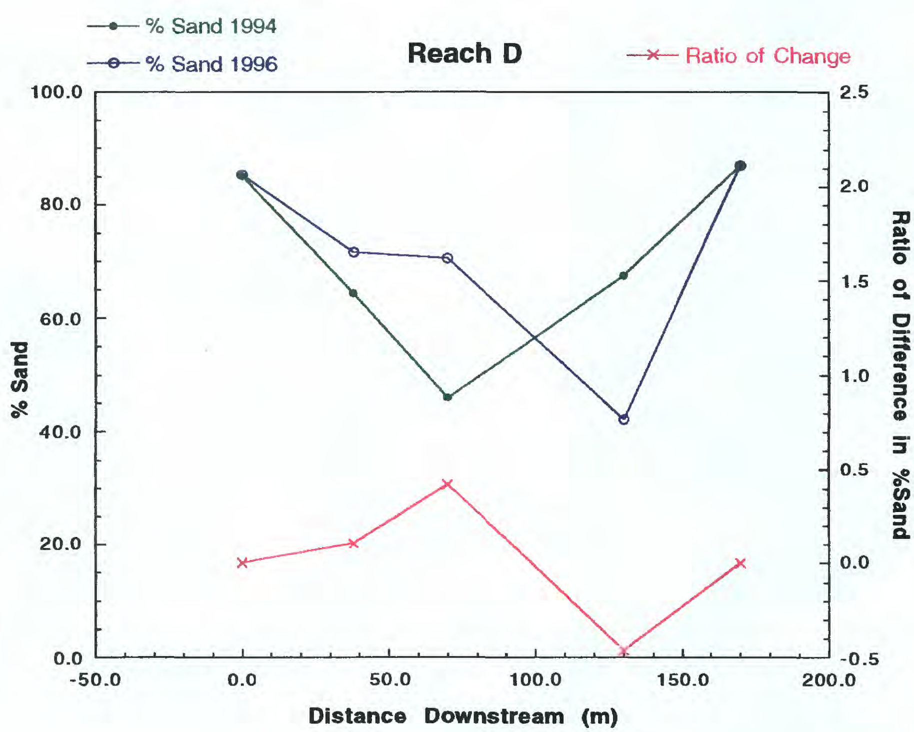
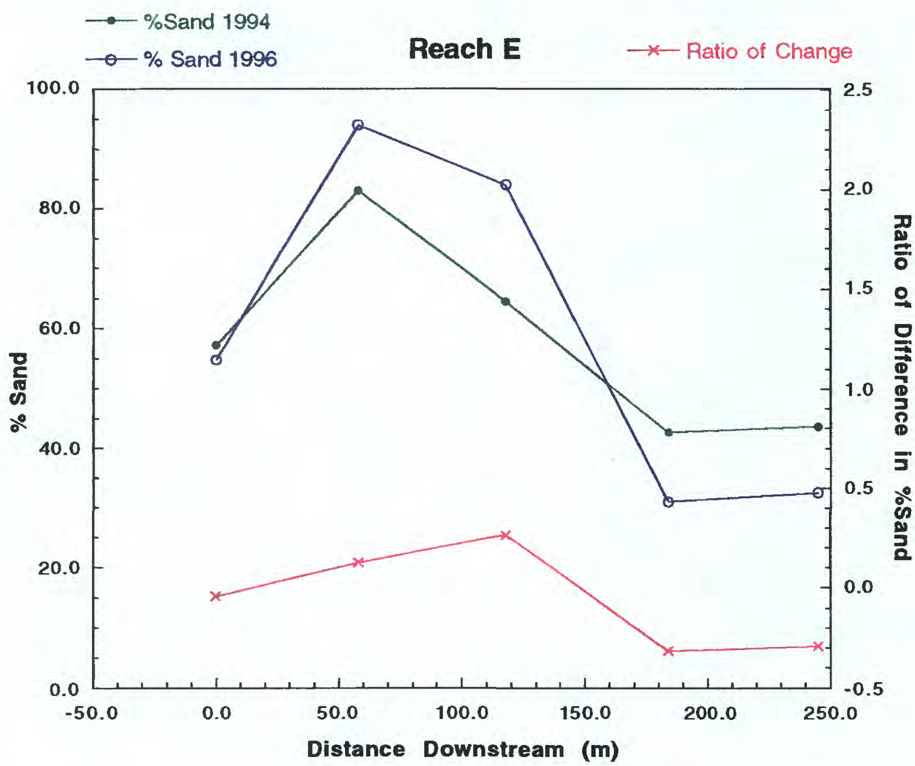

% Sand 1994
% Sand 1996
Reach D
Ratio of Change
% Sand
Ratio of Difference in %Sand
Distance Downstream (m)
100.0
80.0
60.0
40.0
20.0
0.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-50.0
0.0
50.0
100.0
150.0
200.0

Figure 19 Plots of percentages of sand-size sediment at the river bottom for each crossing line along reach E and F between 1994 to 1996. Also plotted is the ratio of change from 1996 to 1994 (see text for explanation).


%Sand 1994
% Sand 1996
Reach E
Ratio of Change
100.0
80.0
60.0
40.0
20.0
0.0
% Sand
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
Ratio of Difference in %Sand
-50.0
0.0
50.0
100.0
150.0
200.0
250.0
Distance Downstream (m)

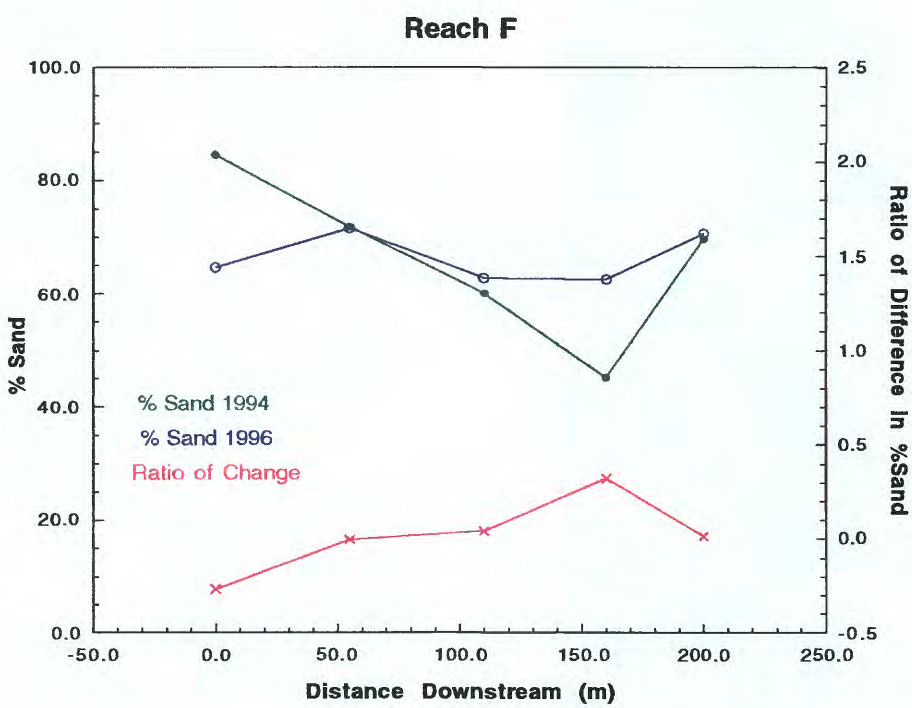
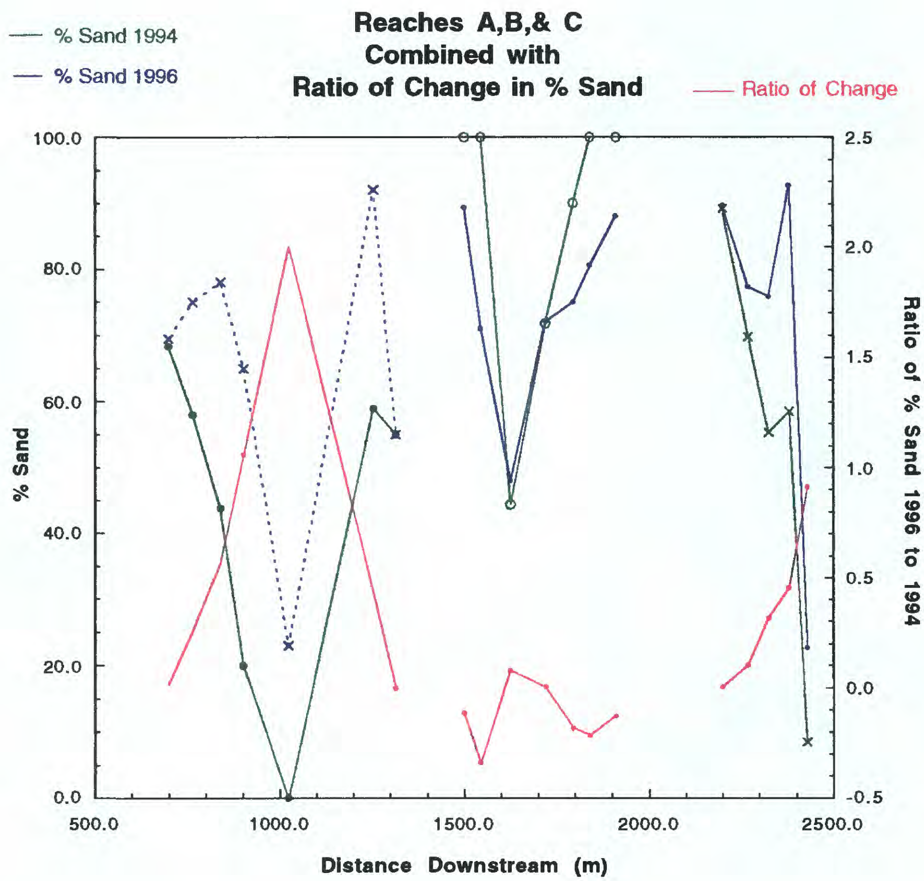
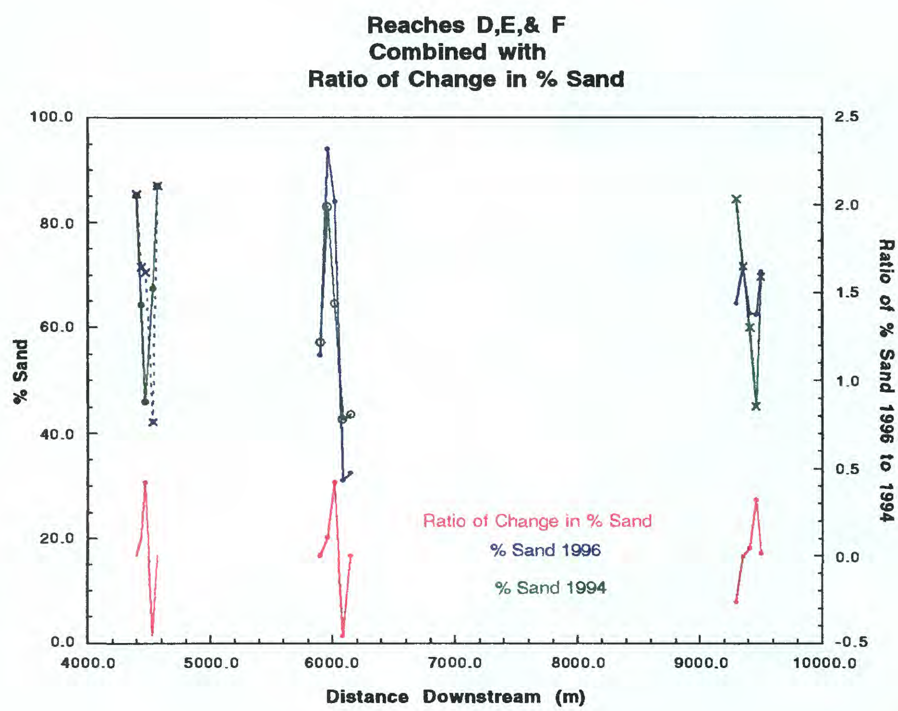

Reach F
100.0
80.0
60.0
40.0
20.0
0.0
% Sand
% Sand 1994
% Sand 1996
Ratio of Change
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
Ratio of Difference in %Sand
-50.0
0.0
50.0
100.0
150.0
200.0
250.0
Distance Downstream (m)

Figure 20 Plots of reaches A, B, and C combined, and D, E, and F combined



% Sand 1994
% Sand 1996
Reaches A,B,& C
Combined with
Ratio of Change in % Sand
Ratio of Change
% Sand
Ratio of % Sand 1996 to 1994
Distance Downstream (m)



Reaches D,E,& F
Combined with
Ratio of Change in % Sand
% Sand
Ratio of % Sand 1996 to 1994
Ratio of Change in % Sand
% Sand 1996
% Sand 1994
Distance Downstream (m)

References

Allen, J.R.L., 1964, Studies in fluviatile sedimentation: Six cyclothem from the lower Old Red Sandstone, Anglo-Welsh Basin. Sedimentology, 3, 163-198.

Allen, J.R.L., 1970, A quantitative model of grain size and sedimentary structures in lateral deposits. Journal of Geology, 7, 129-146.

Belknap, B, Evans, L.B., 1996, Grand Canyon River Guide, Seventh edition, Westwater Books, 96 pages.

Graf, J.B., Marlow, J.E., Fisk, G.G., Jansen S.M.D., 1994, Sand storage changes in the Colorado River downstream from the Paria and Little Colorado Rivers, June 1992 to February 1994, U.S. Geological Survey Open-File Report 95-446, 61 pages.

Graf, J.B., Jansen, S.M.D., Fisk, G G., and Marlow, J.E., 1995, Topography and bathymetry of the Colorado River, Grand Canyon National Park, Little Colorado River to Tanner Rapids; U.S. Geological Survey Open-File Report 95-726.

Hutoon, P.W., Billingsley, G.H. Jr., Breed, W.J., Sears, J.W., Ford, T.D, Clark, M.D., Babcock, R.S., Brown, E.H., 1976, Geologic Map of Grand Canyon National Park, Arizona: Grand Canyon Natural History Association Map, scale 1:62,500.

Konieczki, A.D., Graf, J.B., Carpenter M.C., 1997, Streamflow and sediment data collected to determine the effects of a controlled flood in March and April 1996 on the Colorado River between Lees Ferry and Diamond Creek, Arizona. U.S. Geological Survey Open-File Report 97-224, 55 pages, 11 Tables, 18 Figures.

Reineck , H.E., Singh, I.B., 1975 Depositional Sedimentary Environments, with Reference to Terrigenous Clastics, Springer-Verlag, New York, Heidelberg, Berlin, 439 pgs, 579 figures.

Rubin, D.M., Schmidt, J.C., Moore, J.N., 1991, Origin, structure, and evolution of a reattachment bar, Colorado River, Grand Canyon, Arizona: Journal of Sedimentry Petrology, Vol. 60, No. 6, P. 982-991.

Schmidt, J.C., and Rubin, D.M., 1995, Regulated streamflow, fine-grained deposits, and effective discharge in canyons with abundant debris fans, *in* Natural and Anthropogenic Influences in Fluvial Geomorphology: Washington, D.C., American Geophysical Union, Geophysical Monograph 89, p. 177-195.

Stevens, L., 1983, The Colorado River in Grand Canyon, a Comprehensive Guide to its Natural and Human History, 3d edit., Red Lake Books, P.O. Box 1315, Flagstaff, Arizona, 86002, 115 pgs.