COLORADO RIVER SEDIMENT STORAGE IN GRAND CANYON DURING CALENDAR YEAR 1997

FINAL REPORT

By

Matt Kaplinski, Joseph E. Hazel, Jr., Mark F. Manone, Roderic A. Parnell, and Alan Dale

Department of Geology
Northern Arizona University
Box 4099
Flagstaff, AZ 86011

ABSTRACT

This study examined thirty-three study sites to quantify sediment storage changes during calendar year 1997. Surveys were conducted in February, April, and September to assess changes due to high steady dam releases that occurred from February to March and again in June to July. Study sites were distributed throughout the river corridor at fan-eddy complexes located at the mouths of tributaries. Repeated topographic mapping was used to document geomorphic change to bar, eddy, and channel morphology at each site.

Sediment storage increased from February to April. Sand bars, eddies and channel pools all gained volume during this period, particularly downstream of the Little Colorado River (LCR). Bar volumes show sediment was deposited at lower bar elevations, while the higher elevations (above the 556 m^3/s stage elevation) eroded. Eddy and channel sand storage increased system-wide, but volume increases downstream of the LCR were larger than gains above (Figure 6). Eddy channel thickness increased 0.07 m above the LCR and 0.4 m below. Channel bed thickness increased an average of 0.4 m system-wide.

Unlike the high flows between February and April that resulted in bar building, the high flow period between April and June was mostly erosional. However, the decrease in storage was of lesser magnitude. Both the high and low elevations of sand bars were eroded. Eddy and channel volumes decreased slightly.

Compared to the changes induced by the 1996 Beach/Habitat-Building Test Flow (BHBF) controlled flood, changes measured during this monitoring period are relatively small. Sediment storage within the eddy and channel increased during this monitoring period, particularly between the February to April comparisons. In April, sediment volume within eddies was greater than that measured before the 1996 experimental flow. Because there was little sediment input from the major tributaries during this time, we hypothesize that high elevation erosion of channel margin and sandbar deposits during the higher flows of 765 m^3/s (27,000 ft^3/s) and 680 m^3/s (24,000 ft^3/s) transferred sediment into main channel and eddy localities. Despite these steady high flows being initially depositional, continued high flows through the summer re-established the trend of high-elevation sand bar sediment storage depletion.

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INTRODUCTION

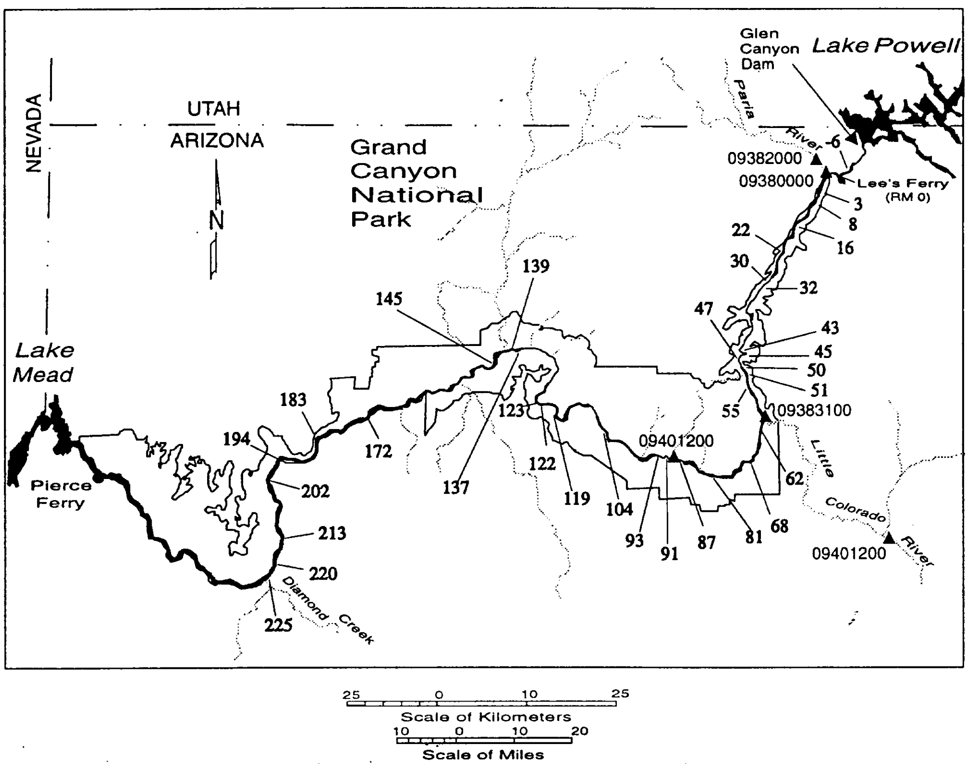
Nearly four decades of flow regulation from Glen Canyon Dam (GCD) have altered the downstream environment along the Colorado River in Glen Canyon National Recreational Area and Grand Canyon National Park (GCNP) [U.S. Dept. of Interior, *1995*]. The Grand Canyon Protection Act of 1992 (GCPA) requires the Secretary of the Interior (Secretary) to operate GCD:

> *...in such a manner as to protect, mitigate adverse impacts to, and improve the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established, including, but not limited to natural and cultural resources...*

In October 1996 , the Secretary signed a Record of Decision (ROD) adopting the Preferred Alternative of the Glen Canyon Dam Environmental Impact Statement (GCD-EIS) as the operating criteria for GCD operations. The Grand Canyon Monitoring and Research Center (GCMRC) was also established at this time to facilitate a long-term monitoring and research program that would assure compliance with the GCPA and the GCD-EIS. The monitoring and research programs are designed to evaluate the impacts of dam operations on the downstream resources in Glen and Grand Canyons.

Fine-grained, clay to sand-sized sediment is a fundamental element of the downstream riparian ecosystem [U.S. Dept. of Interior, 1995]. GCD has terminated the transport of approximately 85% of the sediment that was typically supplied to the Colorado River system in Grand Canyon [*Andrews*, 1991]. GCD has also reduced the magnitude and frequency of floods characteristic of the pre-dam era. Consequently, the supply and transport of sediment has been severely reduced. Sandbars have degraded in the post-dam era [Kearsley et al., 1994; Schmidt and Graf, 1990; Webb, 1996] and sand bar maintenance is a high priority of GCMRC and GCNP. This project was established to monitor fine-grained sediment storage changes within the river corridor and evaluate the impacts of dam operations on this important physical resource.

This report assesses the effects of GCD flow regimes during FY1997, including high steady flows, by comparing topographic and bathymetric surveys conducted February, April, and September at 33 long term study sites (Figure 2). Comparison of these surveys provides quantitative analysis of topographic change at the study sites. Analysis includes an assessment of long-term trends in sediment storage since the beginning of Interim Flow operations in 1991 and the 1996 BHBF.



EXPLANATION

▲ 09383100 USGS STREAMFLOW-GAGING STATION-Number is station identifier

145 STUDY SITE-Number is in Stevens (1983) River Miles

Figure 1. Location map showing Colorado River, major tributaries, Grand Canyon National Park, study locations, and USGS streamflow-gaging stations.

BACKGROUND

Sediment Transport and Storage

Large tributaries, such as the Little Colorado and Paria Rivers, are the primary sources of sediment to the post-dam Colorado River below Glen Canyon Dam. These perennial streams drain relatively low elevation, semi-arid parts of the Colorado River basin [*Hereford*, 1984; *Graf et al.*, 1991] and combine to provide a highly variable average of 1.2×10^7 Mg/yr of sand-sized sediment to the mainstem Colorado River, particularly during winter or mid-late summer storms [*Andrews*, 1991]. Sediment contribution from these tributaries has decreased in the 20th century as a result of a change in the magnitude and frequency of large floods [*Andrews*, 1991; *Graf et al.*, 1991].

Sand supplied by tributaries in Grand Canyon is temporarily stored on the channel bed in pools of tranquil (subcritical) flow [*Howard and Dolan*, 1981]. However, an estimate of the total amount of sand in storage has not been accurately developed, either empirically or with theoretical, quantitative models. *Schmidt and Rubin* [1995] suggest that rather being stored on the channel bed, as much as 75% of the fine-grained sediment in Grand Canyon resides within zones of recirculating flow, or eddies along the channel margins. Channel bed material maps constructed from side-scan sonar surveys indicate that the bed of the Colorado River in Grand Canyon was about 60% bedrock or boulders in 1983 [Wilson, 1986]. The channel bed appears to be relatively immobile and little material greater than sand-size is entrained under flow conditions in the post-dam era except in the rapids where flow is supercritical [*Kieffer*, 1985]. Low sediment-concentration dam releases quickly transport sand supplied by tributaries downstream [*Graf et al.*, 1995]; a process that becomes particularly effective as discharges surpass 425 m^3/s [*Wiele et al.*, 1996]. If the quantity of sand stored in the system and supplied by tributaries is sufficient, sand bars can be maintained in Grand Canyon by periodic high flow releases [*Hazel et al.*, 1997; *Kearsley and Quartoroli*, 1997].

GCD Flow Releases: 1991 to 1997

To retain tributary-derived sediment and protect downstream resources until completion of the EIS and the Record of Decision (ROD), interim flow operations were implemented in August 1991 (Figure 2). This change in dam operations restricted the maximum peak discharge to 566 m^3/s, limited minimum releases to 142 m^3/s at night and 226 m^3/s during the day, and limited the up and downramp rates to 71 $m^3/s/hr$ and 42 $m^3/s/hr$ respectively. Like previous flow regimes, higher-volume flows were released during mid-summer and mid-winter, and lower volume flows were released in May and September (Figure 2). The 1996 ROD adopted the Modified Low Fluctuating Flow (MLFF) alternative of the EIS as the operating criteria under which GCD would operate. Under the MLFF criteria, maximum peak discharge was limited to 708 m^3/s, and upramp rate are limited to 113 $m^3/s/hr$. The MLFF also included Beach/Habitat-Building flows. Any releases greater than 708 m^3/s are required to be steady on a daily basis and would be made in response to high inflow and reservoir storage conditions.

Regardless of dam operations, tributary flows can raise mainstem flows above the 708 m^3/s dam release limit or powerplant capacity. Three tributary floods from the Little Colorado River in 1993 (LCR) raised flows downstream to levels not reached since the high releases of 1983-1986. These moderate floods on the mainstem occurred on January 12-16, January 19-23, and February, 23-26, 1993, and raised flows at the Grand Canyon gage (RM88, crngc #09402500) to approximately 966 m^3/s, 793 m^3/s, and 824 m^3/s, respectively. By raising mainstem flows to slightly above powerplant capacity and delivering a significant amount of sediment, the 1993 winter floods provided an unexpected test-case of a bar-building flow event [*Hazel et al.*, 1993; *Kaplinski et al.*, 1995] and an opportunity to test sediment transport models [*Wiele et al.*, 1996].

High surface runoff from the upper Colorado River basin resulted in abnormally high flow releases beginning in June, 1995 (Figure 2). Daily mean flows from GCD between June and October 1995 averaged 523 m^3/s. In comparison, daily mean flow ranged from 350 m^3/s to 412 m^3/s for the same period from 1991 to 1994.

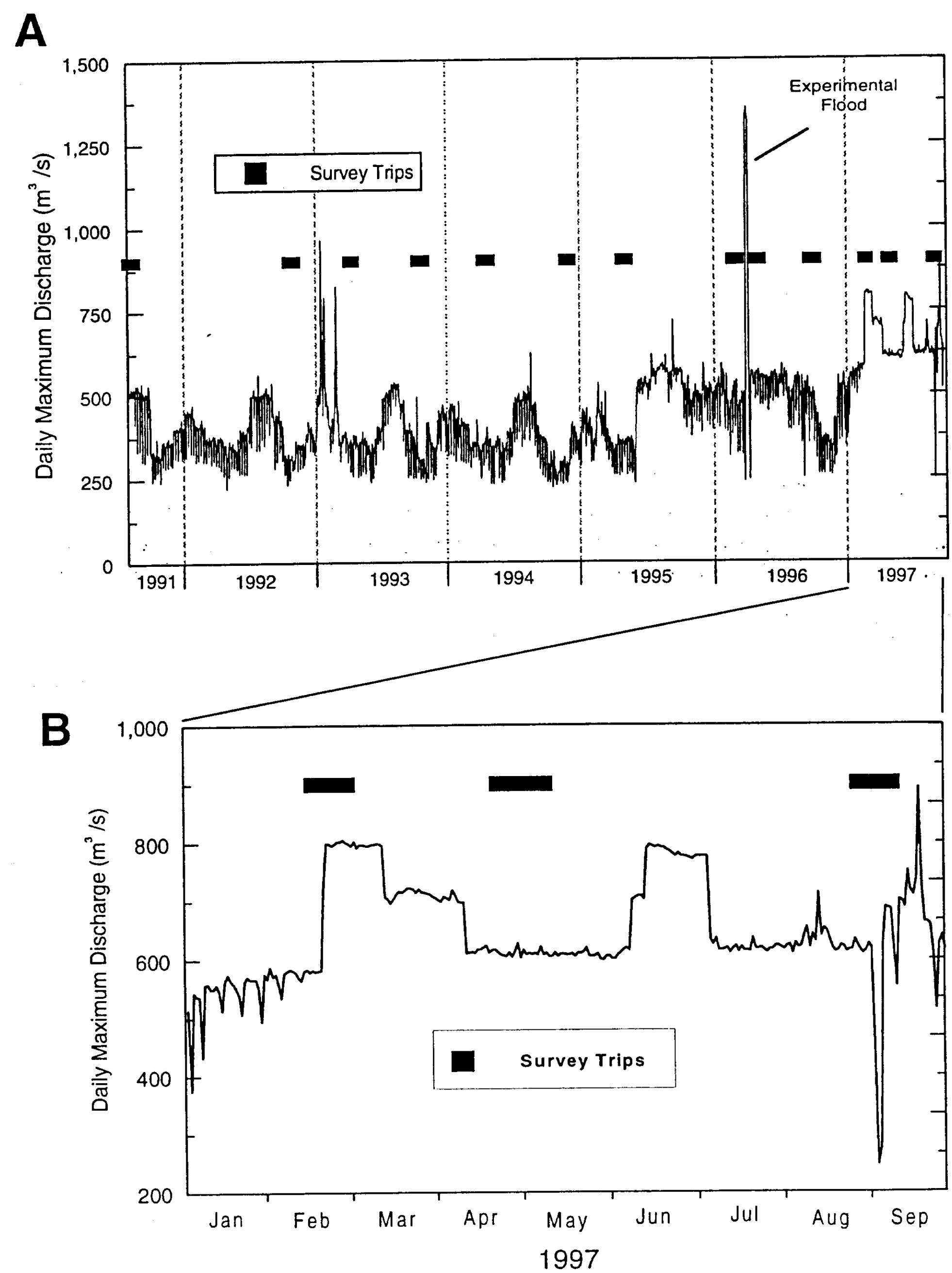


Figure 2. Daily maximum discharge from USGS streamflow-gaging stations, Colorado River near Grand Canyon (09402500). A) 1991 to 1997. B) 1997. Survey trip dates are highlighted by short horizontal bars.

The Beach/Habitat Building Flow (BHBF) was released from GCD in Spring 1996. This experimental flow consisted of a high steady release of 1274 m^3/s for seven days. This flow was designed to benefit downstream resources by depositing sediment at higher sand bar elevations and returning the natural spring flood cycle to the ecosystem [Collier et al., 1997].

Almost one year after the BHBF, high reservoir inflow resulted in a flow regime change from MLFF operations. On February 18, 1997 flows were raised from high-volume MLFF to a constant high flow level of approximately 765 m^3/s for 20 days. Flows were then lowered to 680 m^3/s on March 11 for 29 days, then lowered again on April 10 and held steady at 600 m^3/s. Another high steady flow event occurred in June when flows were raised to a steady 765 m^3/s for twenty days. Releases were then lowered to a steady 600 m^3/s until the Labor day weekend, 1997. At this time a 3 day, 227 m^3/s steady flow was released for aerial photography of the river corridor.

Historical Patterns of Sand Bar Change

Over two decades of monitoring studies have examined geomorphic changes of sand bars in Grand Canyon [*Howard*, 1975; *Beus et al., 1985*; *Schmidt and Graf*, 1990; *Beus and Avery*, 1992; *Kaplinski et al.*, 1995; *Dexter et al.*, 1995; *Schmidt and Leschin*, 1995]. Sand bar inventories using aerial photography indicate that the area and number of sand bars decreased rapidly after closure of Glen Canyon Dam [*Schmidt and Graf*, 1990; *Kearsley et al.*, 1994]. However, *Howard and Dolan* [1981] suggested that the erosional trend had stabilized by the late 1970's. The 1983 flood created or enlarged many sand bars, aggrading many sites that had eroded after dam closure [*Beus et al.*, 1985; *Schmidt and Graf*, 1990]. These changes were short-lived and stratigraphic and sedimentologic studies indicate that the high releases between 1984 and 1986 deposited little sediment on sand bars [*Rubin et al.*, 1990; 1994]. The entire sequence of flows, from 1983 to 1986, resulted in net erosion from eddies [*Schmidt and Graf*, 1990] and some sand bars used as campsites were completely eroded [*Beus et al.*, 1985; *Kearsley et al.*, 1994]. Repeated topographic monitoring of sand bars from 1991 to 1995 indicated that bars continued to erode despite interim flow operations [*Kaplinski et al.*,1995]. In addition, the volume of sand stored at high elevation bar locations decreased at a system-wide rate of -1%/yr [*Parnell et al.*, 1996]. However, *Kaplinski et al.* [1995], concluded that interim operating criteria had successfully minimized seepage erosion and that tractive forces were the dominant erosional mechanism during this period.

A suite of studies were conducted in 1996 to examine changes caused by the BHBF. *Hazel et al.* [1997] concluded that the BHBF caused a net increase in the area and volume of high-elevation sand throughout the Grand Canyon. *Hazel et al.* [1997] also reported that much of the sediment deposited at higher elevations was scoured from the channel bed. A synthesis of the physical studies conducted for the 1996 BHBF concluded that the objective of mobilizing sediment stored on the channel bed and redepositing it at higher elevations along the channel margins was accomplished [*Schmidt et al.*, 1998].

Following the 1996 BHBF newly aggraded bars quickly eroded and erosion rates decreased with time [*Hazel et al.*, 1997; *Kearsley and Quartoroli*, 1997]. Sand eroding from bars was being deposited at lower elevations in eddies, but little was accumulating on the channel bed [*Hazel et al.*, 1997]. Sediment eroding from bars following the flood was either redistributed to lower elevations in eddies or was in mainstem transport and being trapped by downstream eddies. *Hazel et al.* [1997] concluded that when sediment concentrations in the main-stem are low, such as after a large sediment transporting event, deposition rates in eddies are higher than deposition rates in the main channel.

STUDY SITES

Thirty-three sites, distributed throughout Grand Canyon, were selected for repeated surveys of bar and channel topography (Table 1). The criteria for site selection were (1) distribution throughout 13 bedrock-defined, geomorphic reaches identified by *Schmidt and Graf* [1990], (2) bar type, (3) availability of historical topographic data, and (4) variation in recreation use intensity and vegetation cover.

Each study site is located at what *Schmidt and Rubin* [1995] termed the fan-eddy complex (Figure 3). This fundamental geomorphic assemblage is composed of a channel-constricting debris fan, a pool upstream of the debris fan, a downstream gravel bar, and one or more eddies [zones of flow separation] in the downstream channel expansion. Expansion ratios at the study sites, the ratio of width in the channel expansion to the width of the upstream constriction [*Schmidt and Graf*, 1990], ranges from 1.17 to 3.0, with a mean of 1.89 (Table 1).

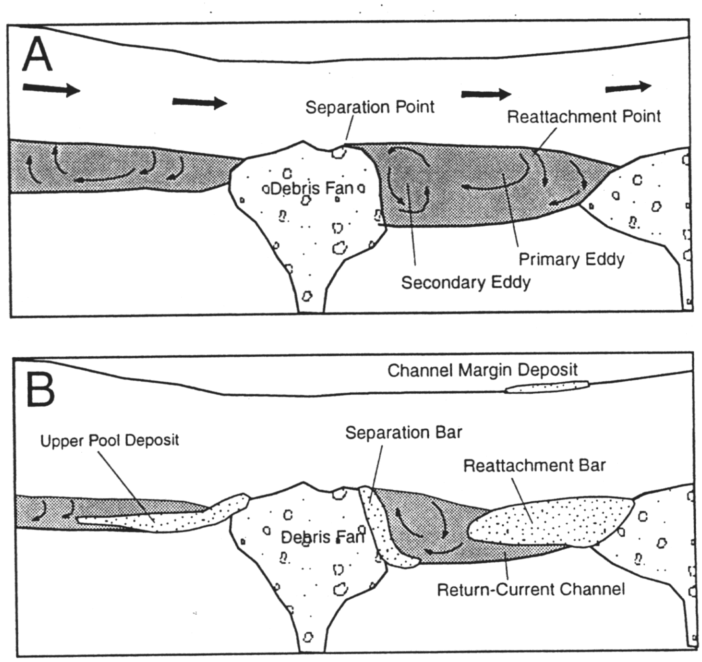


Figure 3. Schematic diagram showing flow patterns and configuration of bed deposits in a typical fan-eddy complex. A) Flow patterns during higher volume flows. B) Configuration of bed deposits during lower volume flows. Modified from Schmidt and Graf [1990].

The geomorphology of the Colorado River in Grand Canyon is detailed in *Howard and Dolan* [1981], *Webb et al.* [1989], *Schmidt and Graf* [1990], and *Schmidt and Rubin* [1995]; only a brief description follows. Deposition of fine-grained (<2mm) sediment is typically localized near eddy stagnation points where flow separates from (separation point) and reattaches to the bank (reattachment point). *Schmidt* [1990] classified bars from each of these depositional areas as separation and reattachment bars. Separation bars typically mantle the downstream portion of the debris fan. This type of bar is typically steeper and of higher elevation than reattachment bars. Reattachment bars are typically deposited along the downstream regions of the eddy by sediment swept across the eddy toward the shore, perpendicular to the main river current [*Rubin et al.*, 1990]. This type of bar is characterized by a broad platform that extends upstream into the eddy. Return current channels form along the shoreward side of the reattachment bar platform where the eddy current is redirected along the shoreline. Return current channels provide an important backwater habitat for aquatic species [*Valdez and Ryel*, 1995], and at lower flows are the primary area of fluvial marsh development along the Colorado River [*Stevens et al.*, 1995]. Sand bars that lack the morphology typical of separation or reattachment bars but are eddy-associated were termed "undifferentiated eddy bars" by *Leschin and Schmidt* [1995]. Each fan-eddy complex examined in this study contains one or more deposits from each of these depositional areas (Table 1).

The morphology and sedimentology of eddy sand bars is closely associated with changing flow patterns in the eddy [*Rubin et al.*, 1990; *Schmidt*, 1990]. During periods of lower discharge, recirculation zones generally consist of a smaller, primary eddy and large areas where both reattachment and separation bars are exposed [*Schmidt and Graf*, 1990]. As discharge increases, recirculation zones expand as more bar area is inundated, and secondary eddies or low velocity zones develop upstream of the return current channel. This results in downstream migration of the reattachment point and upstream migration of the separation point onto the debris fan [*Schmidt*, 1990]. Deposition rates also increase as sand is entrained from storage areas on the channel bed [*Schmidt et al.*, 1993]. The reattachment bar may fill much of the recirculation zone beneath the primary eddy.

Table 1. Sand Bar Monitoring Sites

Site Ref. #	River Mile (RM)[1]	Site Name	Deposit Type[2]	Expansion Ratio[3]	Stage Change (m)[4]	Reach/ Relative Width[5]
-6	-6.5	Hidden Sloughs	U	1.17	3.64	0/W
3	2.6	Cathedral Wash	R	1.97	4.05	1/W
8	7.9	Lower Jackass	S	1.67	3.69	1/W
16	16.4	Hot Na Na	S	2.11	3.68	2/N
22	21.8		R	1.25	6.89	2/N
30	30.0	Fence Fault	R	1.57	5.86	3/N
32	31.6	South Canyon	U	2.24	3.52	3/N
43	43.1	Anasazi Bridge	R	3.00	4.82	4/W
45	44.6	Eminence Break	S,R	2.28	4.79	4/W
47	47.1	Lower Saddle	R	2.57	4.27	4/W
50	50.0	Dino	S,R	1.43	4.64	4/W
51	51.2		R	2.22	4.15	4/W
55	55.5	Kwagunt Marsh	R	1.88	2.95	4/W
62	62.4	Crash Canyon	R	2.47	4.41	5/W
68	68.2	Tanner	U	1.76	2.82	5/W
81	81.1	Grapevine	U	1.56	4.35	6/N
87	87.5	Cremation	U	1.36	4.88	6/N
91	91.1	Above Trinity	S	1.29	5.01	6/N
93	93.3	Upper Granite	U	1.87	3.46	6/N
104	103.9		R	1.27	4.57	6/N
119	119.1		R	1.79	5.45	7/N
122	122.2		R	2.84	4.96	7/N
123	122.7	Upper Forster	R	1.85	5.10	7/N
137	136.7		R	1.53	4.90	8/N
139	139.0		U	1.59	5.41	8/N
145	145.1	Above Olo	R	1.70	5.90	9/N
172	172.2		R	1.56	4.16	10/W
183	182.8		R	1.63	5.00	10/W
194	194.1		R	2.36	4.22	10/W
202	201.9		S	2.38	4.61	10/W
213	212.9	Pumpkin Springs	U	2.64	6.89	10/W
220	219.9	Middle Gorilla	U	1.75	3.47	11/N
225	225.3		R	2.00	3.04	11/N

[1]Distance downstream from Lees Ferry in river miles (RM). From *Stevens* [1983].
[2]Deposit type: R - reattachment bar, S - separation bar, U - undifferentiated eddy bar.
[3]Average channel width in expansion divided by average channel width in constriction at ~594 m^3s^{-1}
[4]Difference in water surface elevations between the 142 m^3s^{-1} and the 1270 m^3s^{-1} stage.
[5]Geomorphic reach (0-11) and channel width (W-wide, N-narrow) from *Schmidt and Graf* [1990].

METHODS

Topographic mapping was accomplished using total stations equipped with digital data collectors. Site size and topographic complexity determined the point density needed to form the topographic models (Figure 4a). Smaller sites (~2000 m^2) typically require 200-400 points and larger sites (~10,000 m^2) require 750-2000 points. Points were also collected offshore to depths of approximately 1 m to provide overlapping coverage with the bathymetry survey. Survey protocol was developed during the GCES Phase II test flows [*Beus et al.*, 1992] and documented according to standard survey practices for ground surveying. Benchmark and backsight relationships were verified at all sites during March, 1991. Terrestrial survey coverage typically extends from the 142 m^3/s (5,000 ft^3/s) stage elevation to above the 1,274 m^3/s (45,000 ft^3/s) stage elevation. A hydrographic survey system expanded ground-based coverage to include the entire river channel and recirculation zone of each fan-eddy complex (Figure 4a). The hydrographic system consists of a shore-based total station, a boat-mounted transducer, a digital/analog receiving unit, and a computer that controls the data collection process. The shore station data is radio-telemetered to the boat computer where depth-position data is calculated and automatically stored. The location of the boat is determined by targeting a reflective prism mounted directly above the transducer. Digital depth records are checked by comparison with the analog sonar recording. Channel and eddy surveys were made by crossing the river at 10 m intervals combined with upstream and downstream longitudinal lines to form a grid.

The ground-based and bathymetric survey points are combined and used to form a Triangulated Irregular Network (TIN) surface model of channel, eddy, and sand bar topography Figure 4b). Breaklines were coded during ground-based data collection along identifiable features (ie. cutbanks, water surface lines, slope breaks, etc.). Results from the GCES Phase II test flows showed that comparisons of volumes measured at a single bar multiple times over several days using the aforementioned total station survey procedures were within three percent of each other (Beus et al., 1992). Therefore, for this analysis, sand bar changes greater than three percent are considered significant. Verification of x,y position and depth data found that HSP coordinate data have a horizontal error of <1 m and z elevation data < 0.5 m. Eddy and channel volumes were rounded off accordingly.

Plan area and volume were determined from each surface model within three distinct boundaries (bar, eddy, and channel) that enclose three distinct geomorphic regions within the complex (Figure 4b). The bar boundary encompasses a subset of the survey area that spans the elevation range of dam operations (142-850 m^3/s). Within the bar boundary, volume and area are calculated between 142 m^3/s, 283 m^3/s, 425 m^3/s, 566 m^3/s and above the 566 m^3/s stage elevation contours. The elevation range at each site was determined from empirically derived stage-discharge relations [*Kaplinski et al.*, 1995]. Volume and area of the eddy and channel were calculated below the 142 m^3/s stage elevation within boundaries that estimate the shape of the features at a discharge of 566 m^3/s. The eddy boundary was only created at 23 of 33 sites because several sites (e.g. RM 81L Grapevine) do not have a distinct eddy that is a discernable feature separate from the bar itself at flows of 566 m^3/s. In order to compare sites of varying dimensions, volume and area are expressed as the percent change from one survey to the next, and as a percentage of the pre-flood surveys conducted in February, 1996.

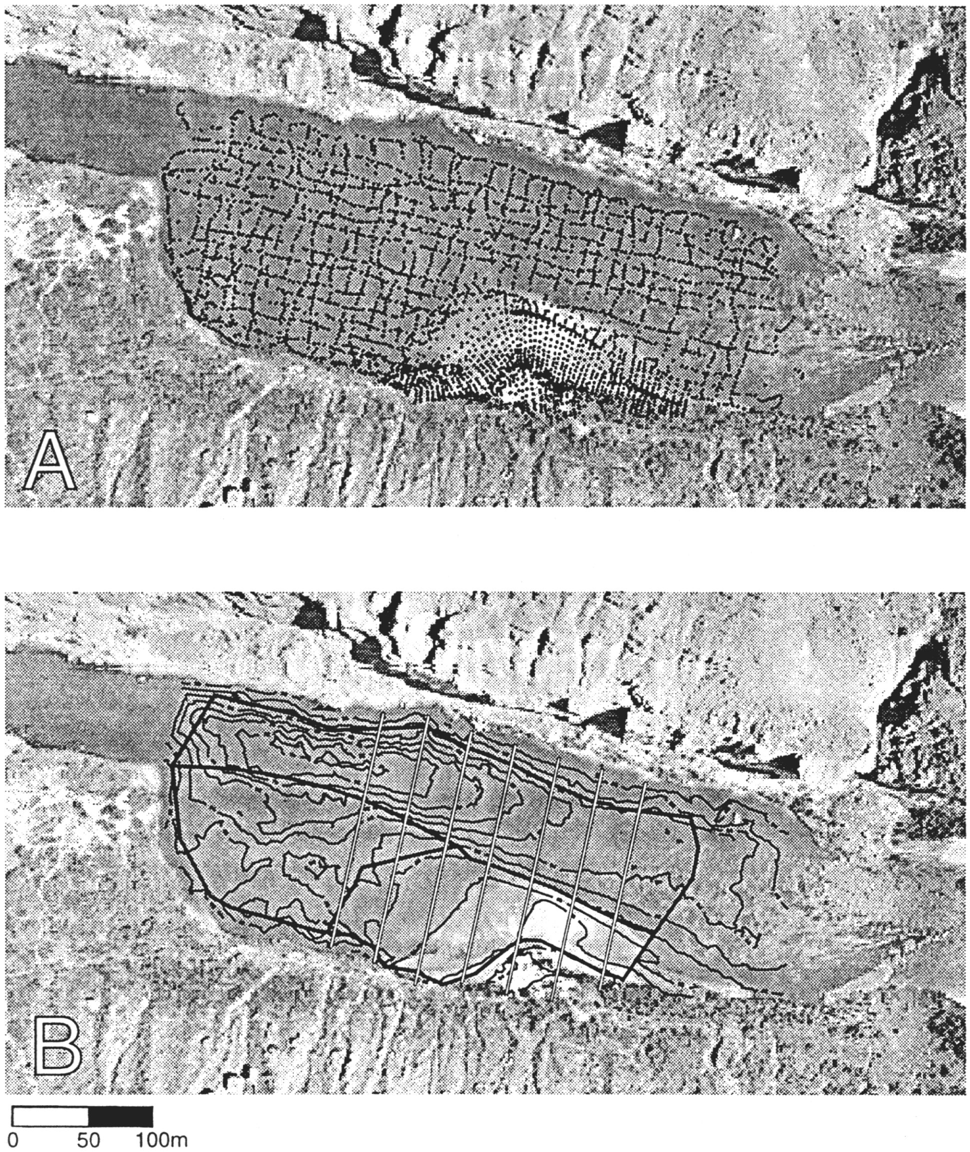


Figure 4. Aerial photograph of the RM47 study site, at low discharge (~227 m^3s^{-1}), April 6, 1996. Flow in main channel is from left to right. (a) Topographic data (1,225 ground points and 3,170 bathymetric points) collected on April 19, 1997. (b) Topographic map, boundaries (dark solid lines) for area and volume computations and profile locations. (DF)=Debris Fan, (R)=reattachment bar. The dashed line is the approximate location of the eddy fence at 566 m^3s^{-1} and is the boundary separating eddy and channel (CH) computations. The contour interval in b is 1 m.

RESULTS AND DISCUSSION

February to April, 1997

Sand bar volume increased between February and April 1997 (Figure 5). Volume computations between specific bar elevations show that sediment was deposited at lower bar elevations, while the higher elevations (above the 556 m^3/s stage elevation) eroded (Figure 6). However, volume gains at lower elevations were greater than high elevation losses, and sand bars gained a net 10% average increase in volume (Table 2). Volume above the 556 m^3/s stage elevation decreased by about 5%, whereas the three stage level zones below (142 to 566 m^3/s) increased by approximately 10% each (Figure 6). The magnitude of change at sand bars located downstream from the LCR was twice that of bars in Marble Canyon (Figure 7). Sand bars below the LCR gained a greater percentage of volume than sites above (Figure 7). Sand bars in wide reaches gained more than sites in narrow reaches (Figure 8).

These results show that the magnitude of change at sand bars increased with increasing distance downstream. Our survey of bars downstream of the LCR coincided exactly with the onset of the high steady 765 m^3/s release on February 18, 1997. We conclude that the high flow period between February and April 1997 was predominately depositional, but only to the level of inundation reached by flows during this period. Above this elevation, high elevation sand continued to erode.

The higher elevations of sand bars are important areas for recreational camping. Our measurements of sand bar change above the 556 m^3/s stage level can be used as a proxy measurement of campsite size because this level is typically above the water during the recreational seasons. This stage elevation is also utilized by *Kearsley and Quatoroli* [1997] in their assessment of campsite area. Despite the 5% loss of bar volume above the 556 m^3/s stage elevation, bar area increased 7% (Figure 9). The elevation reached by the high sustained flows was sufficient to result in cutbank retreat and volume loss but deposition at the elevations reached by flows of 556 to 765 m^3/s increased bar area (Figure 10). These results show that reworking of the higher elevation areas of the bar increased camping area by producing bars that were wider, not higher.

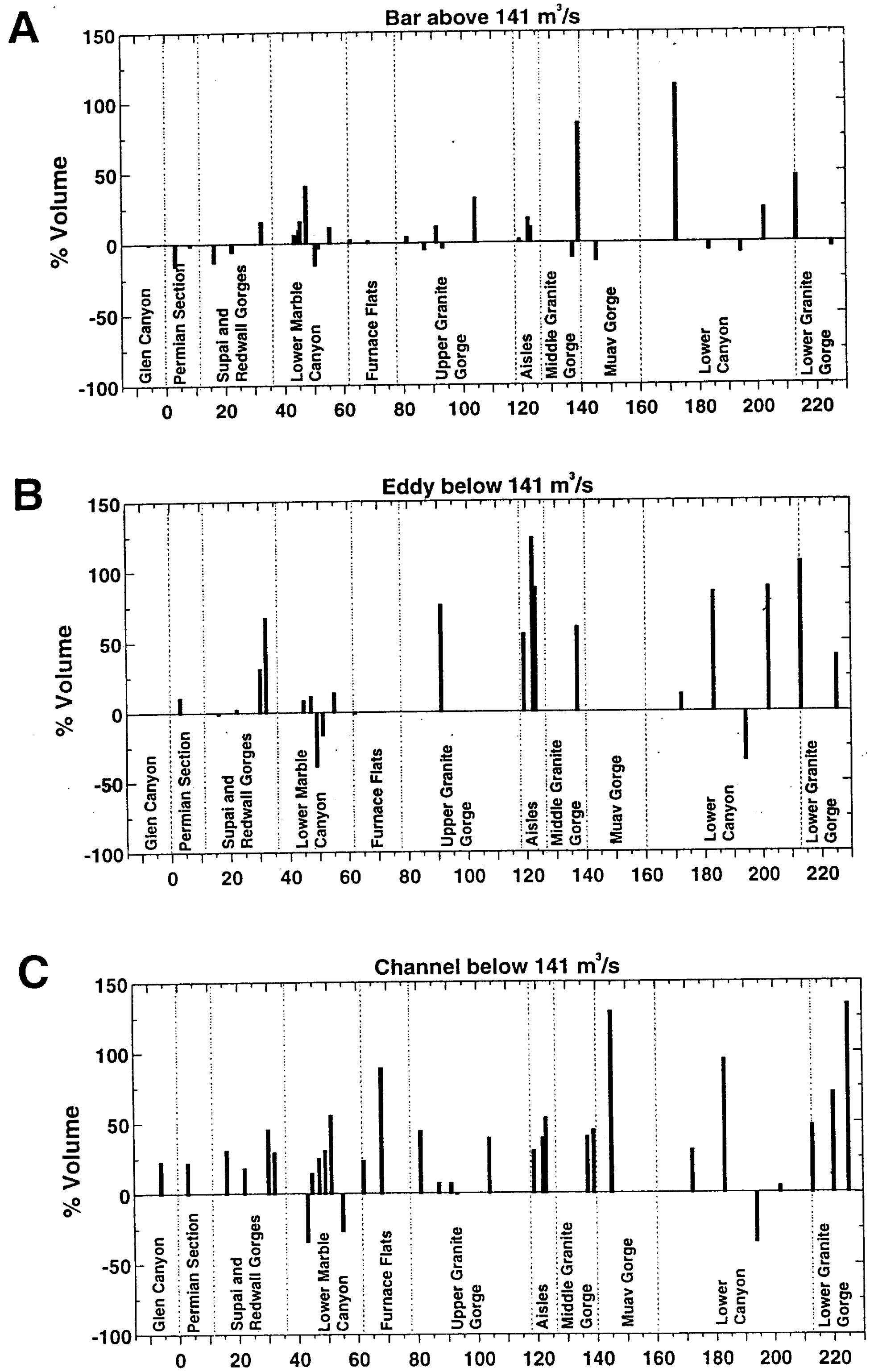


Figure 5. Percent volume change in the A) sand bar, B) eddy, and C) channel for each study site versus distance downstream of Lee's Ferry, AZ. Comparison is between volumes measured in February 1997 to April 1997.

Table 2. % Area and Volume changes from February to April, 1997

	Sandbar								
	Total Bar		Above 566 m^3s^{-1}		142-283 m^3s^{-1}	283-425 m^3s^{-1}	425-566 m^3s^{-1}	Eddy	Channel
Site	Area	Volume	Area	Volume	Volume	Volume	Volume	Volume	Volume
-6	0.00	-0.45	7.57	-9.80	0.64	-0.60	0.67		22.83
3	-10.42	-15.45	-19.62	-17.24	-13.28	-16.42	-17.49	10.34	21.94
8	9.41	-1.55	-7.28	-17.78	5.97	2.05	-2.38		
16	-23.87	-12.81	9.51	7.56	-18.40	-7.85	-8.71	-1.08	30.77
22	1.43	-5.79	-5.96	-14.75	-1.80	-5.09	2.93	2.08	18.25
30	1.97	-0.15	5.03	-17.19	2.34	5.15	12.47	30.77	45.45
32	29.98	15.17	-7.50	-16.61	22.39	19.05	-0.54	67.27	29.25
43	4.59	5.48	3.45	0.15	6.31	8.92	7.58		-34.17
44.6	6.13	8.96	19.34	0.86	7.58	11.12	19.83	8.33	14.53
45	15.66	15.44	-2.38	0.75	18.13	26.14	13.37		
47	36.09	40.86	10.53	-6.09	55.44	53.87	32.13	11.17	25.05
50 up	13.04	0.13	22.57	-3.16	-0.24	-4.24	10.91	-38.89	30.53
50 lo	-1.72	-15.34	-34.25	-39.77	-6.74	-8.01	6.64		
51	14.54	-3.60	-8.02	-10.49	4.09	-7.99	-5.85	-16.67	55.37
55	17.66	10.91	1.38	-0.84	20.53	20.64	7.13	13.40	-26.73
62	-16.09	2.11	32.85	18.75	-11.78	2.00	20.57	-1.08	23.28
68	4.83	1.34	15.64	-3.94	2.65	7.37	12.29		88.66
81	0.00	3.99	23.06	2.44	-0.11	2.66	15.69		44.07
87	-6.54	-4.92	-0.94	-0.48	-6.83	-7.56	-4.47		7.19
91	27.31	11.06	3.53	1.43	25.00	15.19	7.04	75.68	7.02
93	-12.55	-3.82	14.13	7.05	-13.35	-8.79	9.32		-0.60
104	28.34	31.41	45.15	13.92	34.52	40.54	46.67		38.89
119	4.58	2.02	-0.28	-4.80	5.69	4.47	1.57	55.00	30.00
122	24.00	16.95	8.43	-6.33	25.39	20.83	15.35	123.08	39.00
123	32.55	10.74	-3.85	-2.61	26.09	11.06	0.60	87.80	53.21
137	3.11	-10.79	-65.89	-39.77	3.65	5.72	-26.23	60.00	40.00
139	49.14	84.49	56.80	14.49	67.72	115.76	121.18		44.55
145	-5.49	-13.11	-24.41	-17.91	-7.31	-11.79	-15.97		128.57
172	89.14	111.66	42.75	5.24	122.18	170.58	138.90	11.79	30.43
183	2.66	-5.75	-40.88	0.53	1.59	-7.22	-25.35	84.62	94.55
194	3.68	-7.67	26.68	-1.54	-13.30	-10.29	-5.34	-35.29	-34.90
202	25.57	23.72	30.41	6.52	22.44	29.65	34.11	87.82	4.71
213	19.18	46.38	76.31	-5.04	30.37	68.74	99.00	105.88	47.62
220	0.57	-0.21	-0.81	-0.21	0.28	-0.15	-0.95		70.59
225	3.82	-3.87	0.09	-0.42	-10.06	-2.09	-0.15	39.13	133.82
mean	11.21	9.64	6.66	-4.49	11.65	15.53	14.93	35.51	35.12
s.e.	3.48	4.44	4.50	2.12	4.54	6.26	6.05	8.45	6.71

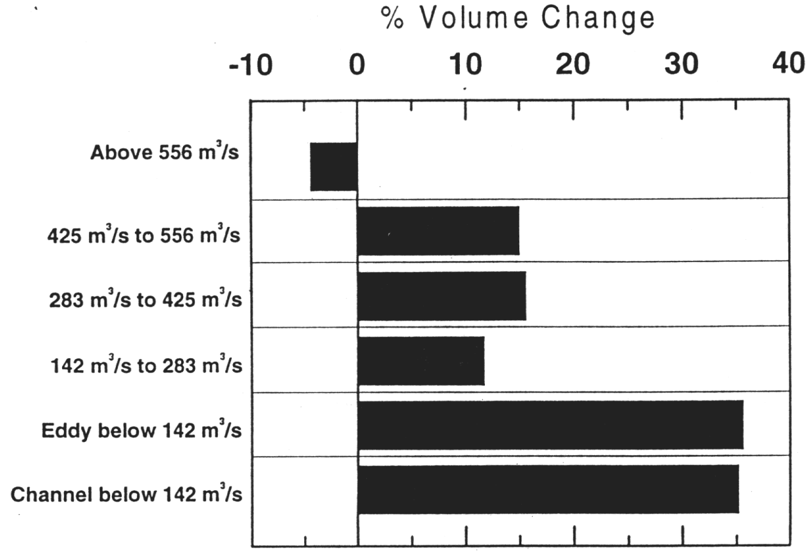


Figure 6. System-wide, average percent volume change from February to April, 1997 for the four different stage-elevation levels of the sand bar, and changes within the eddy and channel.

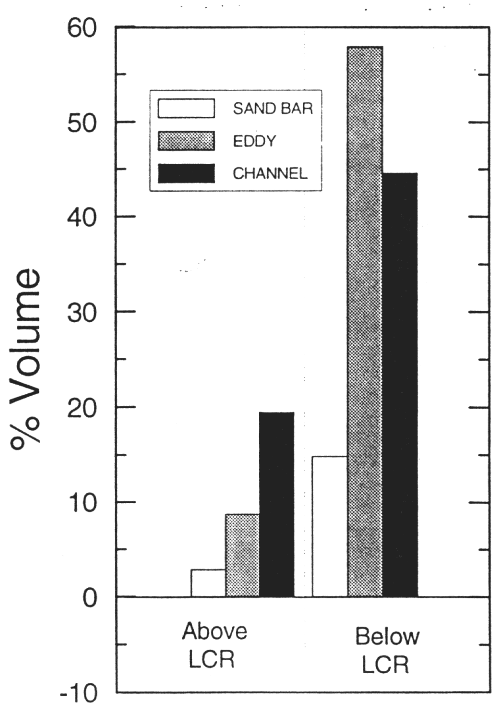


Figure 7. Average percent volume change above and below the Little Colorado River from February 1997 to April 1997 within the bar, eddy and channel boundaries.

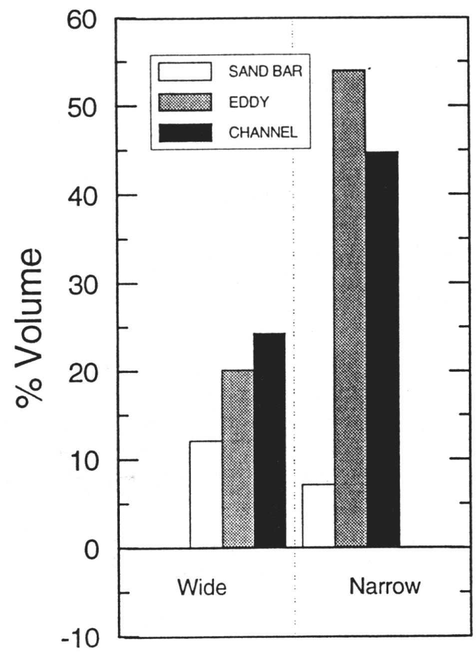


Figure 8. Average percent volume change in wide and narrow reaches from February 1997 to April 1997 within the bar, eddy and channel boundaries.

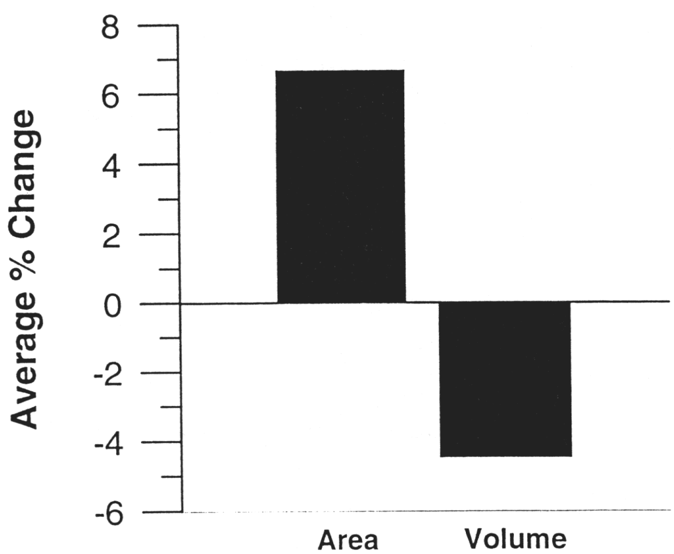


Figure 9. Average percent change in the volume and area of sediment stored above the 556 m^3/s stage elevation.

119 R

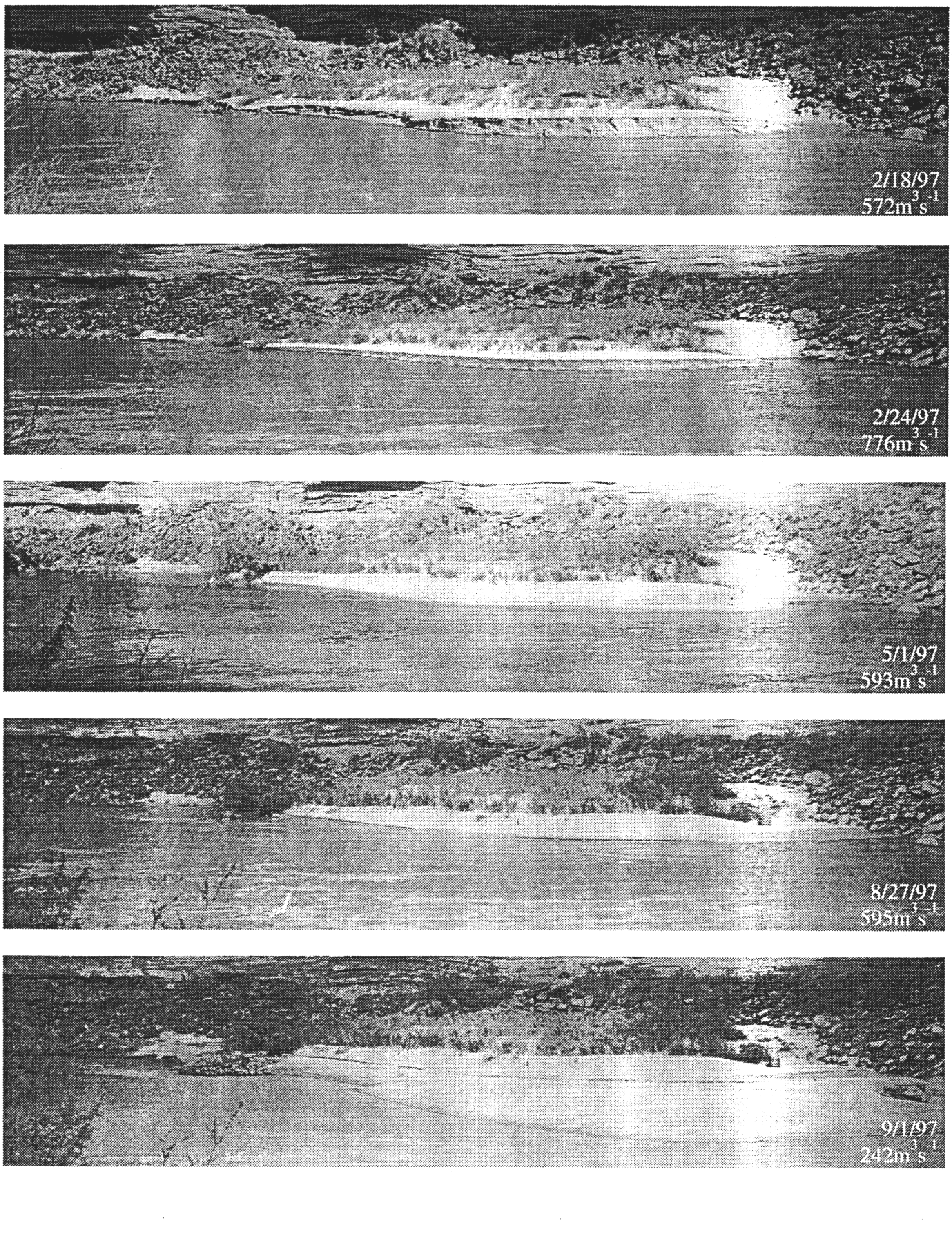


Figure 10. Selected daily photographs from the reattachment bar in the RM119 fan-eddy complex. Flow in main channel is from right to left.

Eddy and channel sand storage increased system-wide (Figure 5). Eddy volumes increased an average of 35% and channel volumes increased by 36% (Figure 6). Volume increases downstream of the LCR were larger than gains above (Figure 7). In contrast to the bar data, sites in narrow reaches gained more than those in wide reaches. However, like the sand bar data, the magnitude of change was greater in the lower half of Grand Canyon.

In addition to volumetric calculations, we calculated the average change in eddy and channel bed thickness at each site. Thickness was calculated by dividing the volume change in the eddy or channel by the area of the measurement. For eddies, we summed the changes from both the bar and eddy boundaries. Plots of thickness change within eddies with distance downstream show the greater magnitude of change downstream of the LCR (Figure 11a). Histograms of site response in Marble Canyon are unimodal and the average increase in eddy thickness was a only 0.07 m (Figure 11a). However, site response downstream from the LCR was bimodal and the average increase was a much more substantial 0.4 m. The bimodal distribution reflects increases in bed thickness at several sites greater than 1 m.

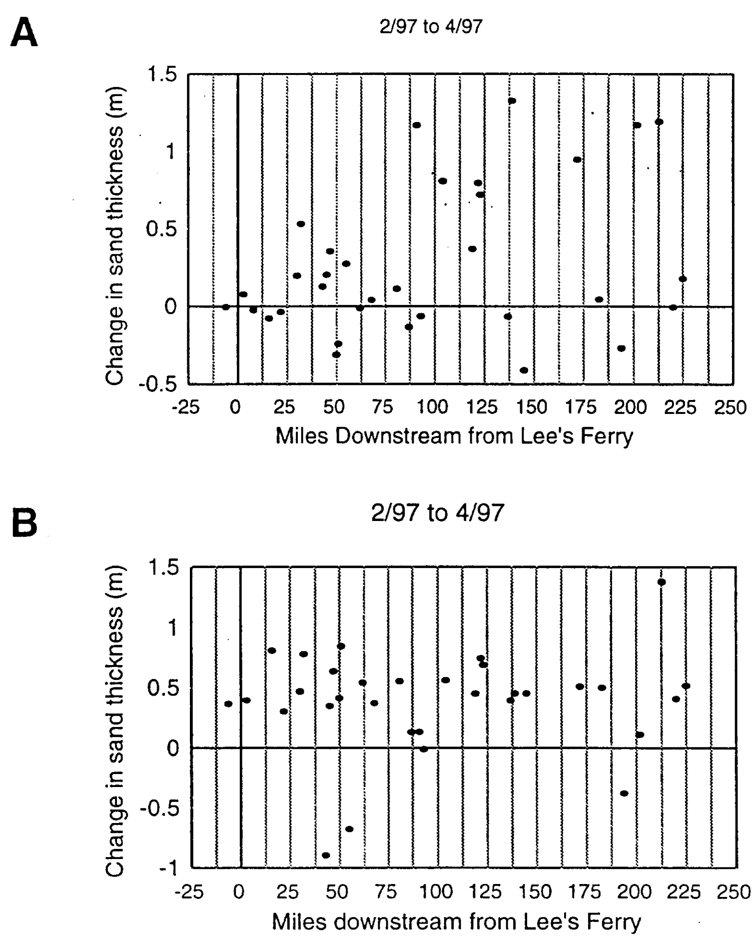


Figure 11. Distribution of the change from 2/97 to 4/97 in sediment thickness for the A) eddy, and B) channel areas.

Channel bed thickness increased an average of 0.4 m (Figure 11b). Although the magnitude of change was greater downstream of the LCR there was a greater degree of variability. In comparison to these bed changes, we measured an average response in eddy and channel thickness to the 1996 BHBF of 0.64 m and -0.45 m, respectively.

Sediment storage increased throughout the system during this monitoring period, with the exception of storage at high elevation sand bars, and a large increase in the magnitude of change was noted downstream of the LCR. However, the interpretation of these results is hindered by the change in flow halfway through the monitoring trip. The greater magnitude of change evident downstream from the LCR can either be attributed to the change in flow regime that occurred coincidentally as our survey trip had reached the confluence, or the increase could be the result of tributary sediment input and increasing downstream accumulation. However, in 1996 and winter/spring 1997 there was essentially no sediment input from these tributaries. The lack of significant change in eddy thickness, despite large volume increases at low elevation, indicates that much of the aggradation is the result of redistribution of sand from high to low elevations in eddies.

Profiles from reattachment bars downstream of the LCR show that the steady high flows resulted in cutbank retreat of high elevation sand but in front of the eroded portion of the bar, new bar platforms were aggraded to approximately the water surface elevation reached by the 765 m^3/s stage levels (Appendix A: 145 Mile, 183 Mile). Because the February trip was used as the baseline against which changes for the February to April period were determined, sediment storage changes in response to the change in flow regime should be reflected in the volume comparison. While this is true for sand bars located downstream of the LCR, channel bed thickness increased in both Marble and Grand Canyons. Previous monitoring studies indicated that as of February 1997 the channel bed was in a scoured condition and eddies were the primary storage location for sediment [*Hazel et al.*, 1997]. Monitoring of monumented cross sections by the U.S. Geological Survey indicate a similar pattern [*Koniecki et al.*, 1997; *Graf et al.*, 1997]. We conclude that increases in channel storage are the result of redistribution of high elevation sand from sand bars and channel margin deposits because there had been essentially no tributary input between the 1996 BHBF and February 1996.

April to September 1997

The April to September comparison indicates a loss in bar volume above the 141 m3/s stage elevation (Figure 12a). Individual site response was more variable in Marble Canyon than downstream of the LCR. Although changes measured during this period were generally of smaller magnitude than changes measured from February to April, they do show that a greater elevation range of sand bars were being eroded system-wide (Figure 13). The average percent change of all sites from within the four stage elevation levels shows that the magnitude of erosion increased with increasing bar elevation through the bar (Figure 13). The magnitude of bar erosion was greater downstream from the LCR (Figure 14). Sites in wide reaches decreased slightly more than sites in narrow reaches (Figure 15). In contrast to the February to April comparison, sediment was eroded from low elevation bar locations. In addition, both the area and volume of sand bars above the 556 m^3/s stage elevation also decreased (Figure 16).

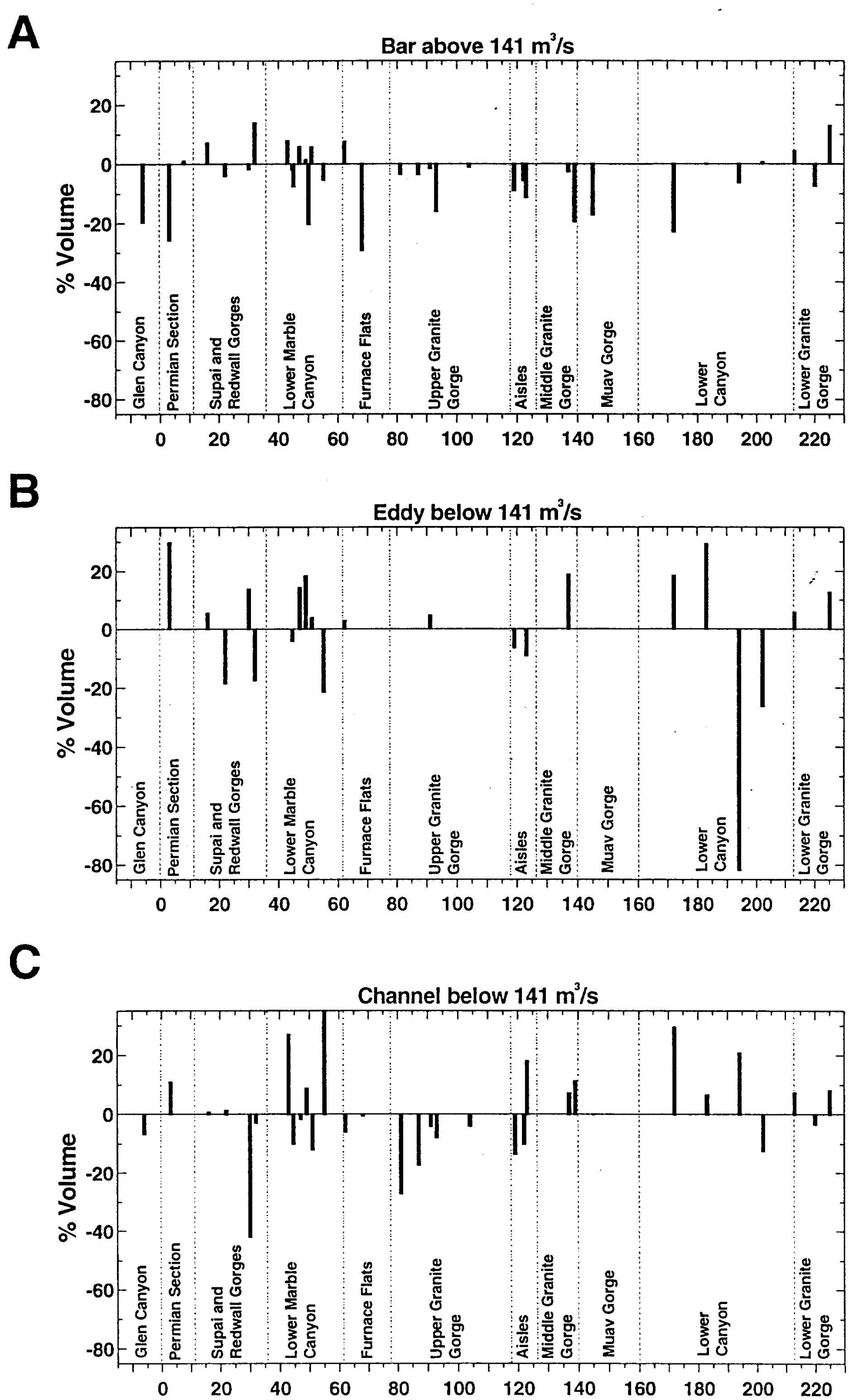


Figure 12. Percent volume change in the A) sand bar, B) eddy, and 3) channel for each study site versus distance downstream of Lee's Ferry, AZ. Comparison is between volumes measured in April 1997 to September 1997.

Table 3. % Area and Volume changes from April to September, 1997

	Sandbar								
	Total Bar		Above 566 m^3s^{-1}		142-283 m^3s^{-1}	283-425 m^3s^{-1}	425-566 m^3s^{-1}	Eddy	Channel
Site	Area	Volume	Area	Volume	Volume	Volume	Volume	Volume	Volume
-6	1.27	-14.15	4.77	-6.96	-3.42	-36.72	-5.35		-6.69
3	25.27	-25.82	-38.03	-43.45	-6.26	-36.61	-42.39	29.69	10.88
8	-4.45	0.97	-3.32	-7.57	-0.90	7.86	2.20		
16	13.51	6.98	-10.80	2.34	10.69	9.24	-5.18	5.43	0.69
22	-7.62	-4.06	4.75	-12.24	-4.64	1.95	2.33	-18.37	1.23
30	1.45	-1.69	-20.71	-21.30	2.04	6.29	-0.56	13.73	-41.96
32	2.82	13.80	-10.38	-10.17	15.91	24.36	-6.20	-17.39	-2.92
43	11.40	7.69	0.63	-4.69	17.11	7.18	7.83		26.98
44.6	-5.03	-1.84	-5.90	-4.88	-4.26	-1.60	6.04	-4.03	-9.98
45	-4.77	-7.52	-1.96	1.39	-7.74	-15.23	-5.50		
47	6.08	5.73	-13.37	-15.91	7.38	18.02	-6.83	14.22	-1.62
50 up	9.60	1.43	-4.46	-8.52	8.89	0.89	-2.97	18.18	8.77
50 lo	-8.19	-20.38	-7.31	-4.72	-14.22	-33.20	-33.45		
51	-2.98	5.66	-1.21	-9.25	6.05	13.99	8.75	3.81	-12.10
55	-3.92	-5.39	-2.05	-1.40	-6.48	-9.69	-4.53	-21.36	34.97
62	21.38	7.39	3.64	-1.40	16.19	5.23	3.32	2.73	-6.01
68	-0.66	-29.32	-2.70	1.64	-1.82	-3.08	0.47		-0.55
81	-0.29	-3.56	-2.84	-6.57	-0.85	-2.71	-2.12		-27.06
87	-4.67	-3.67	-5.08	-2.17	-3.96	-4.24	-4.68		-17.32
91	4.18	-1.41	2.27	-7.85	0.25	2.57	4.69	4.62	-4.10
93	-16.63	-15.99	-16.03	-8.66	-17.62	-19.40	-18.43		-7.83
104	-1.28	-1.09	0.00	0.45	-1.51	-2.75	-0.65		-4.00
119	-8.67	-9.07	-13.90	-13.75	-8.00	-7.20	-7.42	-6.45	-13.68
122	-6.22	-5.65	13.89	6.27	-8.32	-10.53	-0.09	0.00	-10.07
123	-14.54	-11.27	-17.13	-19.54	-12.40	-7.07	-5.52	-9.09	17.96
137	3.62	-2.63	-23.32	-27.46	3.08	-0.88	2.31	18.75	7.14
139	4.60	-19.57	-25.08	-8.23	-2.28	-34.58	-43.79		11.32
145	-19.50	-17.30	-15.10	-29.39	-15.60	-12.02	-10.69		0.00
172	-6.72	-22.96	-43.96	-21.47	-12.99	-25.38	-41.13	18.31	29.39
183	3.54	-0.13	1.96	-1.21	1.52	-2.44	3.38	29.17	6.54
194	-25.57	-6.42	-28.03	-4.48	-7.80	-7.43	-6.57	-81.82	20.80
202	1.60	0.64	-9.22	-8.96	3.44	1.09	2.10	-26.28	-12.50
213	-1.35	4.29	43.82	31.36	-1.56	-1.68	12.39	5.71	7.26
220	-0.81	-7.48	-23.19	-9.04	-0.97	-3.68	-18.58		-3.45
225	22.82	12.91	0.18	0.00	34.33	11.37	0.59	12.50	8.18
mean	-0.31	-4.88	-7.69	-7.94	-0.48	-4.80	-6.18	-0.36	0.32
s.e.	1.82	1.78	2.57	2.05	1.76	2.48	2.35	3.95	2.64

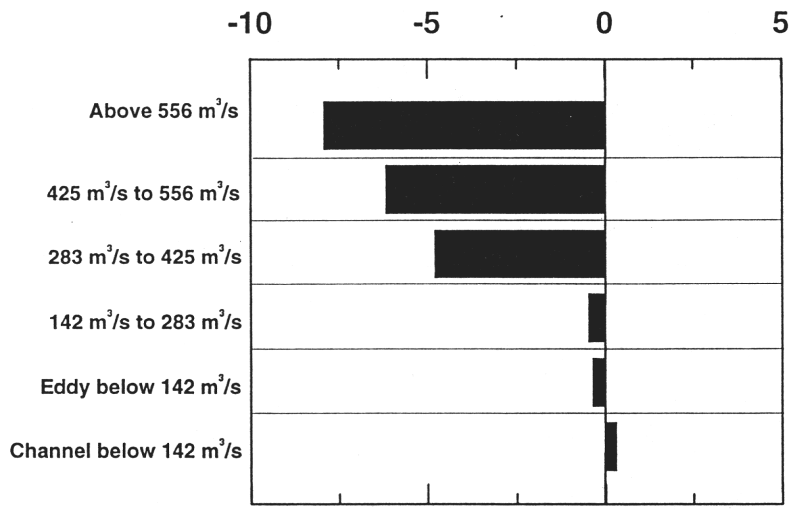


Figure 13. System-wide, average percent volume change from April to September, 1997 for the four different stage-elevation levels of the sand bar, and changes within the eddy and channel.

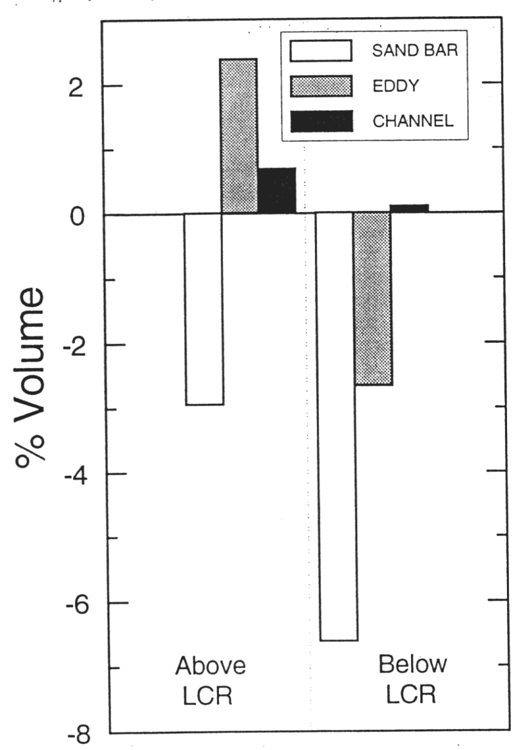


Figure 14. Average percent volume change above and below the Little Colorado River from April 1997 to September 1997 within the bar, eddy and channel.

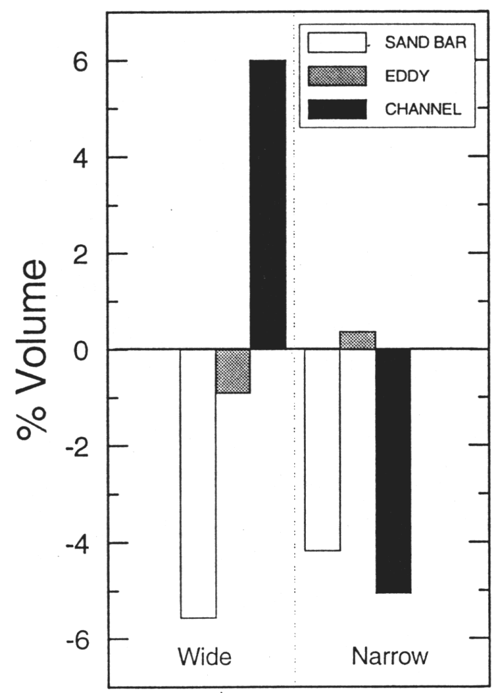


Figure 15. Average percent volume change in wide and narrow reaches from April 1997 to September 1997 within the bar, eddy and channel boundaries.

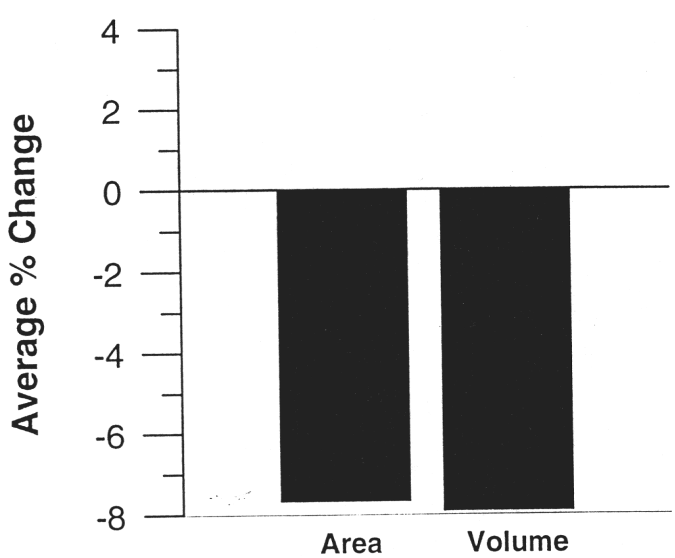


Figure 16. Average percent change in the volume and area of sediment stored above the 556 m^3/s stage elevation.

Between April and September, eddy and channel volume changes indicate a high degree of system variability (Figure 12 b and c). However, eddy volume and channel volume in Marble Canyon increased whereas eddy volume decreased downstream from the LCR with negligible change to channel storage (Figure 14). There was little difference in the pattern of change based on geomorphic reach for eddy storage with a slight decrease in wide reaches and a similiar magnitude of decrease in narrow reaches. However, there was a large increase in channel volume in wide versus narrow reaches (Figure 15). Eddy and channel bed thickness changes reflect the system variability but overall the change was negligible (Figure 17). The distribution of thickness change was unimodal for both eddy and channel storage with no relation to distance downstream from GCD or tributary location. Sediment accumulated on the bed in wide reaches was eroded from narrow reaches and is possibly related to the greater streampower of high sustained flows in narrow reaches where the stage changes are greater (Table 1).

Unlike the high flows between April and September that resulted in bar building, the high flow period between April and June was mostly erosional. The greater magnitude of bar erosion downstream from the LCR is attributed to antecedent condition because our measurements in this half of the canyon reflect the onset of the high steady flow period and newly rebuilt bars.

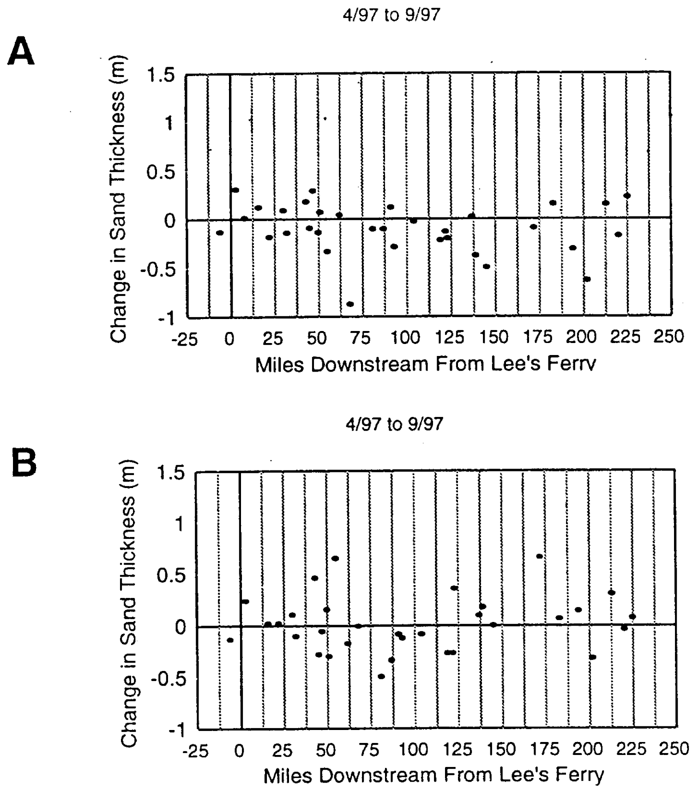


Figure 17. Distribution of the change in sediment thickness from 4/97 to 9/97 for the A) eddy, and B) channel areas.

Historical Trends in Sediment Storage: 1991 to 1997

In order to compare the magnitude of geomorphic change produced by the high steady flows in 1997, we compared the volume measurements presented above to changes documented since 1991. Time series data from bar, eddy, and channel are illustrated in Figures 18 and 19 for 1991-1997. Volumes are determined as percentage of the pre-1996 BHBF surveys in February 1996. Changes within the sand bar boundary through time demonstrate the importance of both the 1993 LCR floods and the 1996 BHBF in sand bar maintenance, particularly in the amount of sediment stored above the 556 m^3/s stage elevation (Figure 18). Compared to the changes induced by the 1996 BHBF, changes measured during this monitoring period are relatively small. However, high elevation bar volume continued to decrease (Figure 19). Low elevation deposition measured from February to April 1997 temporarily reversed the trend of decreasing sand bar volume (Figure 18). As of September 1997, sand bars still contain more volume than before the 1996 BHBF.

Sediment storage within the eddy and channel increased during this monitoring period, particularly between the February to April comparisons (Figure 18). In April, sediment volume within eddies was greater than that measured before the 1996 experimental flow. Because there was little sediment input from the major tributaries during this time, we hypothesize that high elevation erosion of channel margin and sandbar deposits during the higher flows of 765 m^3/s (27,000 ft^3/s) and 680 m^3/s (24,000 ft^3/s) transferred sediment into main channel and eddy localities. Despite these steady high flows being initially depositional, continued high flows through the summer re-established the trend of sediment storage depletion that has previously been documented by *Kaplinski et al.*[1995]; *Parnell et al.*[1996]; and *Hazel et al.*[1997]; (Figure 18).

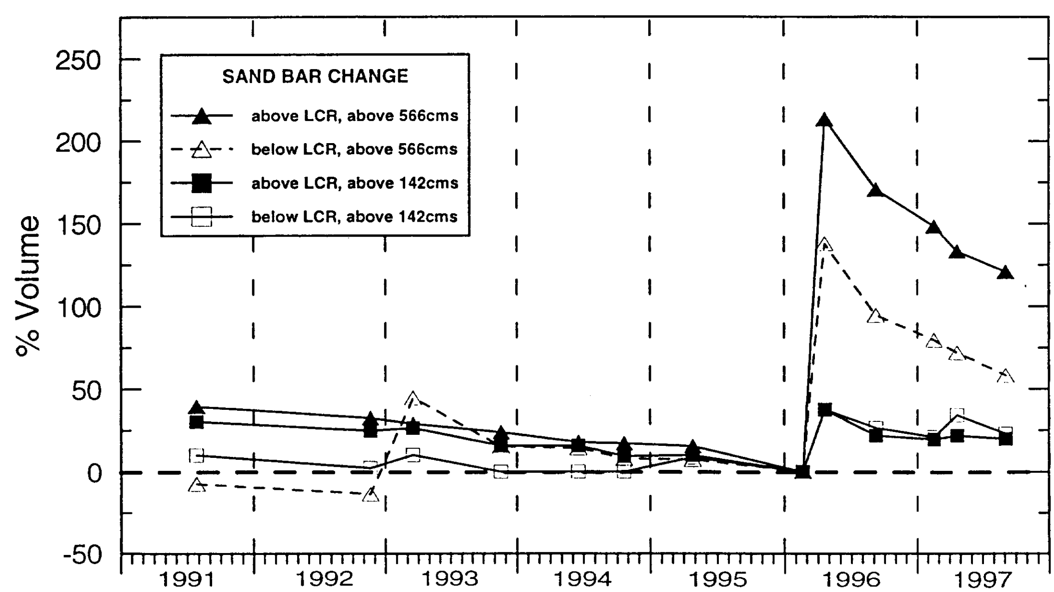


Figure 18. Average sand bar volume for the total bar (above 142 m^3/s stage elevation) and above the 556 m^3/s stage elevation, relative to the 2/96 surveys, for all sites plotted against time.

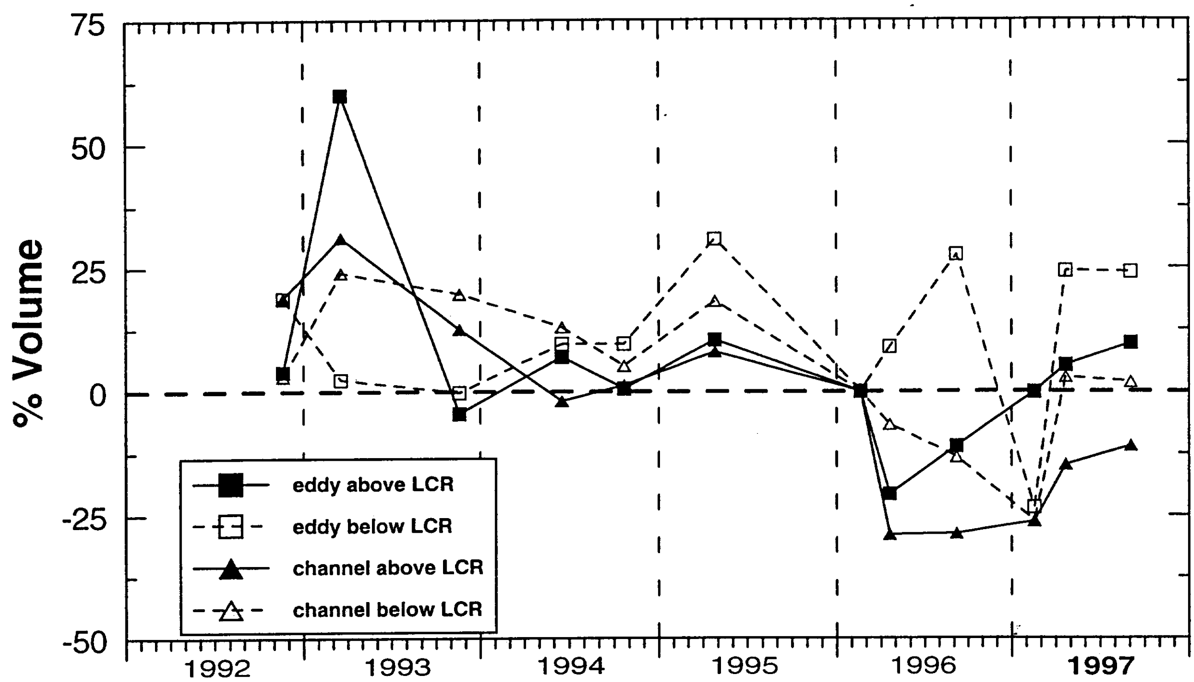


Figure 19. Sediment storage changes plotted against time. Volume within the eddy, and channel boundaries for sites above and below the LCR, relative to the 2/96 surveys.

Conclusions

This report presents the results from three monitoring survey river trips conducted during Fiscal Year 1997. Between February and April sand bars, eddies and channel pools all gained volume, particularly downstream of the LCR. Bar volumes show sediment was deposited at lower bar elevations, while the higher elevations (above the 556 m^3/s stage elevation) eroded. While the magnitude of deposition in February and March was considerably less than that documented during the 1996 BHBF, the average thickness of sediment within the recirculation zone increased an average of 0.08 m in Marble Canyon, and 0.4 m in Grand Canyon. Channel bed thickness increased an average of 0.4 m system-wide. Apparently, high steady flows of 765 m^3/s (27,000 ft^3/s) and 680 m^3/s (24,000 ft^3/s) during February and April were depositional.

Comparison of surveys conducted in April and September show that that high steady flows between April and September were erosional and little bar-building was measured. Both the high and low elevations of sand bars were eroded. Eddy and channel volumes decreased slightly. However, the decrease in storage was of lesser magnitude than the deposition measured between February and April.

During 1997, the total volume of sediment in recirculation zones increased and was still greater than levels measured before the 1996 experimental flow. Because there was little tributary sediment input during this time, we hypothesize that sediment eroded from the high elevations of sandbar and channel margin deposits was transferred into the main channel and eddies. Although the steady high flows in February and March were depositional, continued high flows through the summer re-established the trend of high-elevation sand bar sediment storage depletion. Likewise, we suspect that the accumulation on the main channel bed was the result of sediment eroded from bars.

We conclude that the high flows in FY 1997 were not of sufficient magnitude to result in net long-term, deposition at high-elevation sand bars. Our results show that the only flows that result in long-term sand bar deposition are flows greater than powerplant capacity. We recommend that future high flows be greater than powerplant capacity but the duration be limited. However, high flows releases when main-channel sediment storage conditions are low have the potential to erode sand bars. Unavoidable high flows, if required to be of long duration should be limited to less than powerplant capacity. Management actions that result in future high flow events need to be supported by an effective monitorng program combined with an accurate sediment budget so that decisions can be based on the most current assessment of resource conditions.

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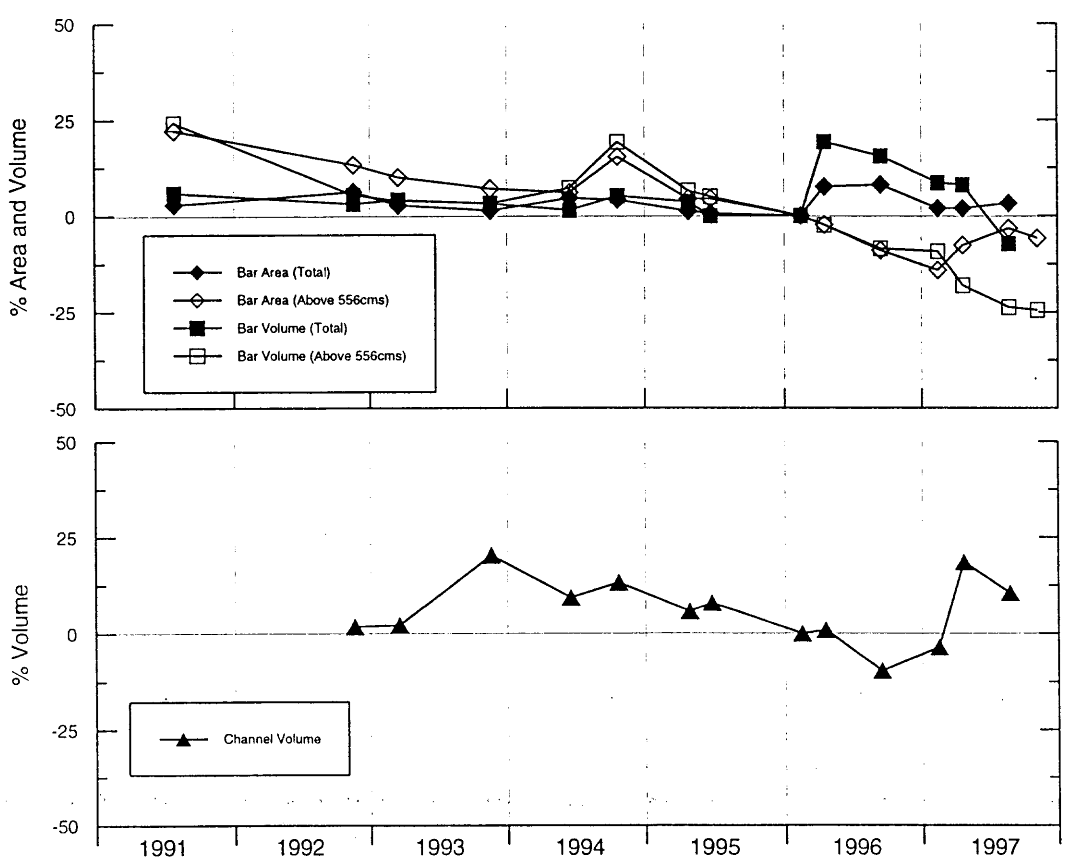
Appendix A: Individual Study Site Data

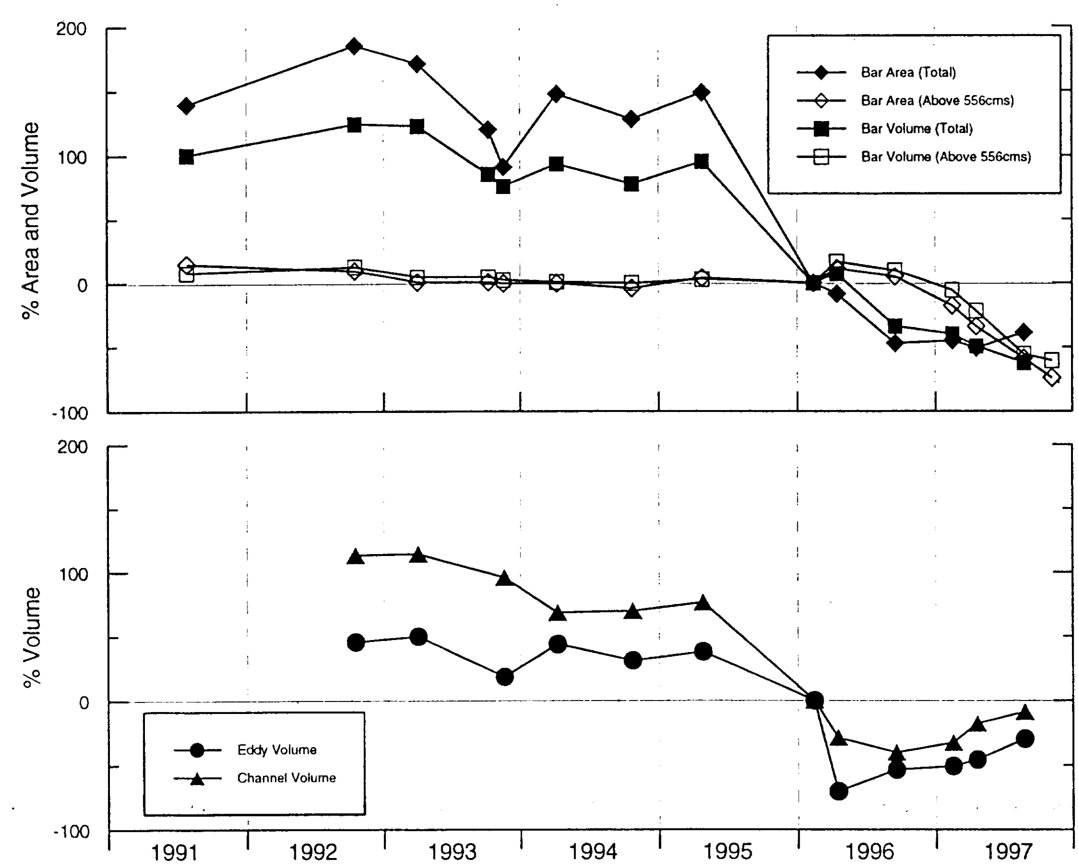
-6R

SURVEY DATE	JULIAN DAYS	SAND BAR TOTAL AREA (m2)	SAND BAR > 20 K AREA (m2)	SAND BAR TOTAL VOL (m3)	SAND BAR > 20 K VOL (m3)	EDDY VOL (m3)	CHANNEL VOL (m3)	SAND BAR TOTAL AREA (%)	SAND BAR > 20 K AREA (%)	SAND BAR TOTAL VOL (%)	SAND BAR > 20 K VOL (%)	EDDY VOL (%)	CHANNEL VOL (%)
910726	572	3584	527	3666	349			2.84	22.27	5.83	24.20		
921118	1053	3700	488	3571	296		23100	6.17	13.23	3.09	5.34		1.76
930317	1172	3578	474	3607	292		23200	2.67	9.98	4.13	3.91		2.20
931117	1417	3529	461	3573	290		27300	1.26	6.96	3.15	3.20		20.26
940616	1628	3643	457	3512	301		24800	4.53	6.03	1.39	7.12		9.25
941020	1754	3628	497	3641	335		25700	4.10	15.31	5.11	19.22		13.22
950425	1941	3525	450	3589	299		24000	1.15	4.41	3.61	6.41		5.73
950622	1999	3506	450	3464	295		24500	0.60	4.41	0.00	4.98		7.93
960213	2235	3485	431	3464	281		22700	0.00	0.00	0.00	0.00		0.00
960415	2297	3745	421	4130	274		22900	7.46	-2.32	19.23	-2.49		0.88
960912	2447	3761	392	3999	257		20500	7.92	-9.05	15.44	-8.54		-9.69
970213	2601	3550	370	3756	255		21900	1.87	-14.15	8.43	-9.25		-3.52
970421	2668	3550	398	3739	230		26900	1.87	-7.66	7.94	-18.15		18.50
970623	2792	3595	417	3210	214		25100	3.16	-3.25	-7.33	-23.84		10.57



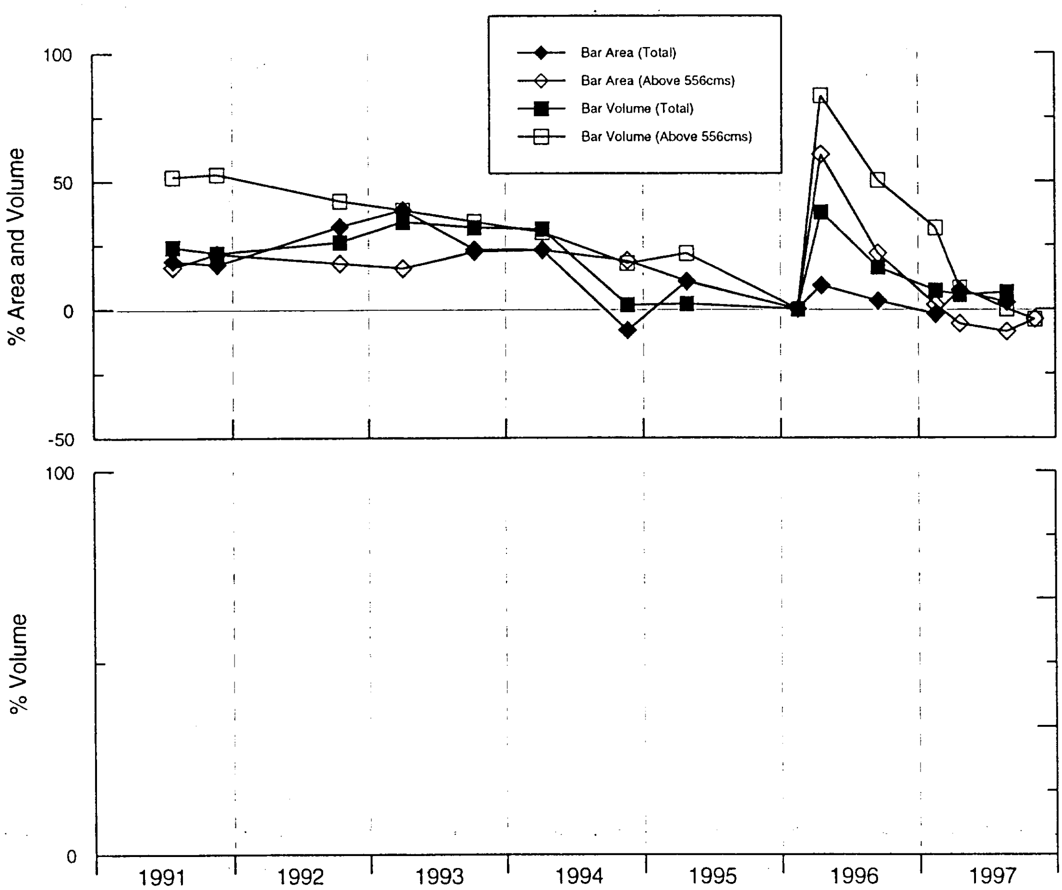
3L

SURVEY DATE	JULIAN DAYS	SAND BAR TOTAL AREA (m2)	SAND BAR > 20 K AREA (m2)	SAND BAR TOTAL VOL (m3)	SAND BAR > 20 K VOL (m3)	EDDY VOL (m3)	CHANNEL VOL (m3)	SAND BAR TOTAL AREA (%)	SAND BAR > 20 K AREA (%)	SAND BAR TOTAL VOL (%)	SAND BAR > 20 K VOL (%)	EDDY VOL (%)	CHANNEL VOL (%)
910726	572	3162	370	3986	232			139.36	14.91	100.00	7.91		
911123	692	2629	334	3064	226								
921015	1019	3766	353	4465	242	17200	62100	185.09	9.63	124.03	12.56	45.76	113.40
930401	1187	3580	325	4435	225	17700	62400	171.01	0.93	122.53	4.65	50.00	114.43
931007	1376	2906	325	3689	225			119.98	0.93	85.10	4.65		
931117	1417	2518	321	3498	220	14000	57000	90.61	-0.31	75.51	2.33	18.64	95.88
940407	1558	3267	321	3849	217	17000	49000	147.31	-0.31	93.13	0.93	44.07	68.38
941021	1755	3010	309	3536	215	15500	49400	127.86	-4.04	77.42	0.00	31.36	69.76
950424	1940	3280	335	3885	221	16300	51300	148.30	4.04	94.93	2.79	38.14	76.29
950623	1999	3227	325	3910	215	15500	45800						
960212	2234	1321	322	1993	215	11800	29100	0.00	0.00	0.00	0.00	0.00	0.00
960414	2296	1205	358	2133	250	3500	20700	-8.78	11.18	7.02	16.28	-70.34	-28.87
960913	2448	696	338	1317	236	5500	17400	-47.31	4.97	-33.92	9.77	-53.39	-40.21
970214	2602	720	265	1191	203	5800	19600	-45.50	-17.70	-40.24	-5.58	-50.85	-32.65
970420	2667	645	213	1007	168	6400	23900	-51.17	-33.85	-49.47	-21.86	-45.76	-17.87
970824	2793	808	132	747	95	8300	26500	-38.83	-59.01	-62.52	-55.81	-29.66	-8.93



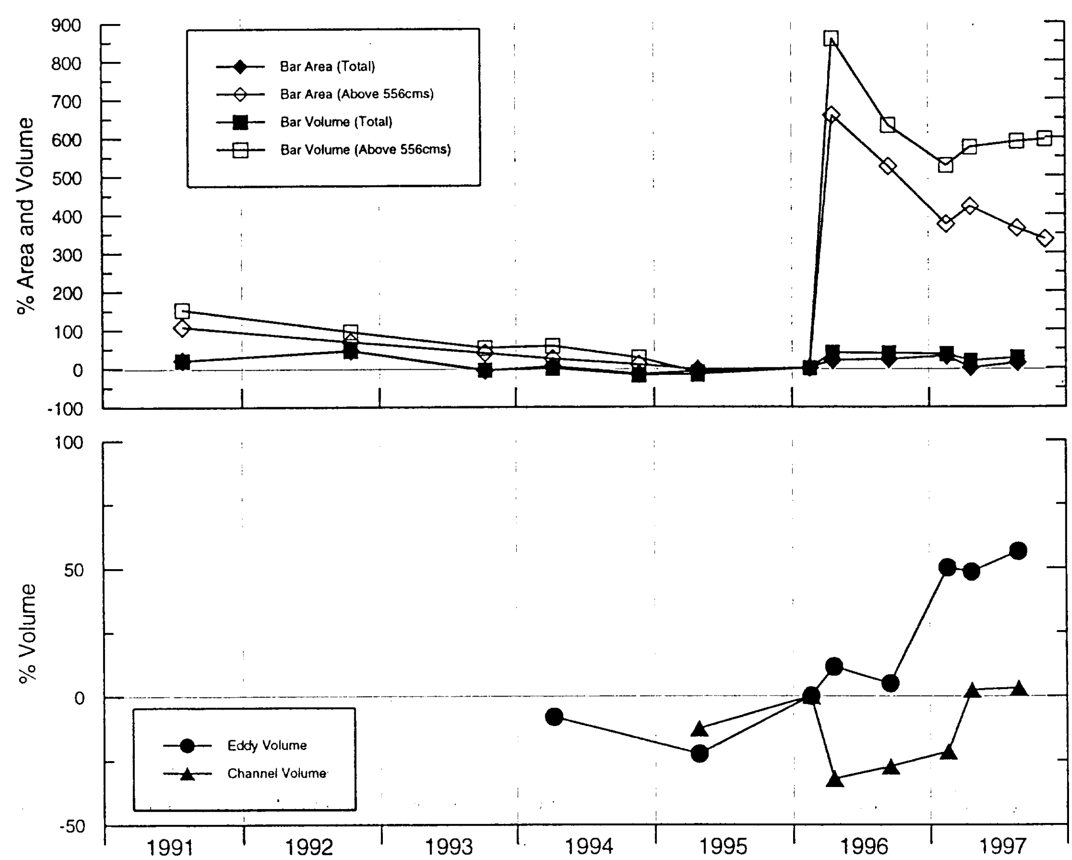
8L

SURVEY DATE	JULIAN DAYS	SAND BAR TOTAL AREA (m2)	SAND BAR > 20 K AREA (m2)	SAND BAR TOTAL VOL (m3)	SAND BAR > 20 K VOL (m3)	EDDY VOL (m3)	CHANNEL VOL (m3)	SAND BAR TOTAL AREA (%)	SAND BAR > 20 K AREA (%)	SAND BAR TOTAL VOL (%)	SAND BAR > 20 K VOL (%)	EDDY VOL (%)	CHANNEL VOL (%)
910727	573	1891	818	2544	519			18.63	16.36	24.22	51.75		
911122	691	1870	855	2494	522			17.31	21.62	21.78	52.63		
921015	1019	2105	828	2582	486			32.06	17.78	26.07	42.11		
930401	1187	2208	814	2743	474			38.52	15.79	33.94	38.60		
931008	1377	1964	860	2697	458			23.21	22.33	31.69	33.92		
940408	1559	1961	864	2683	444			23.02	22.90	31.01	29.82		
941120	1785	1461	835	2080	403			-8.34	18.78	1.56	17.84		
950425	1941	1762	779	2087	416			10.54	10.81	1.90	21.64		
960215	2237	1594	703	2048	342			0.00	0.00	0.00	0.00		
960417	2299	1738	1128	2820	627			9.03	60.46	37.70	83.33		
960914	2449	1643	856	2379	514			3.07	21.76	16.16	50.29		
970214	2602	1562	714	2193	450			-2.01	1.56	7.08	31.58		
970421	2668	1709	662	2159	370			7.21	-5.83	5.42	8.19		
970825	2794	1633	640	2180	342			2.45	-8.96	6.45	0.00		



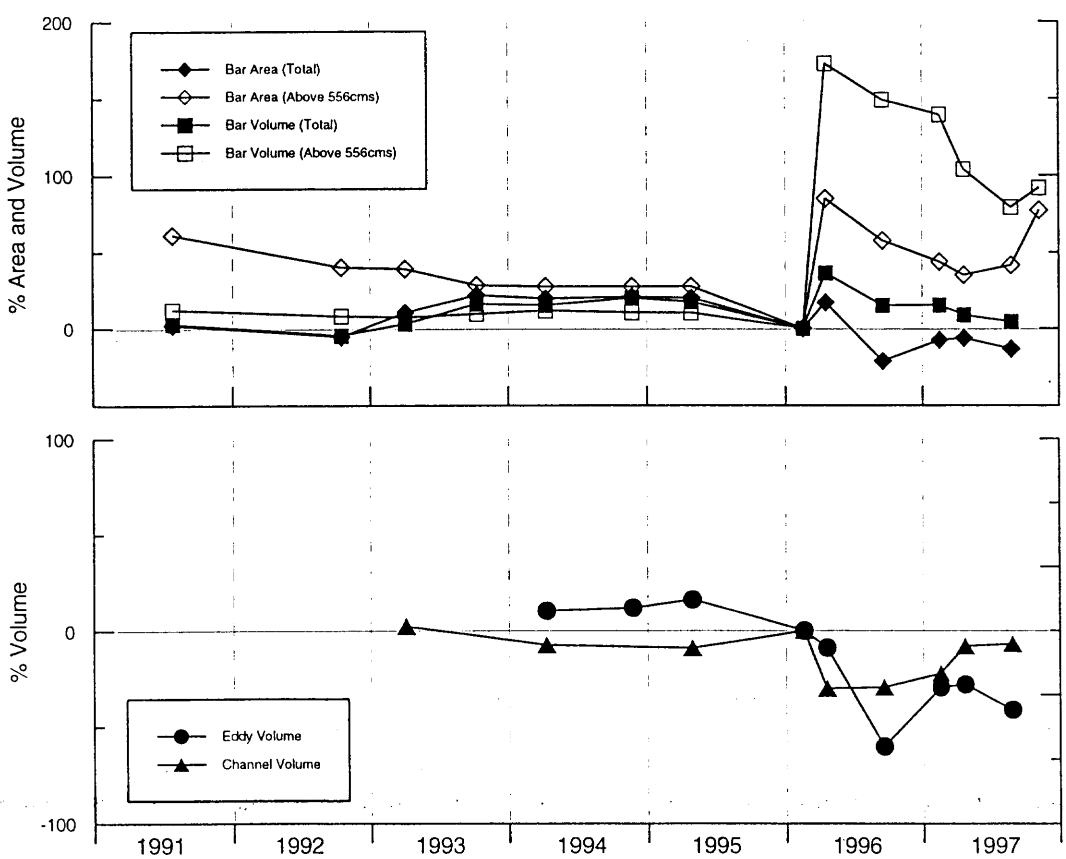
16L

SURVEY DATE	JULIAN DAYS	SAND BAR TOTAL AREA (m2)	SAND BAR > 20 K AREA (m2)	SAND BAR TOTAL VOL (m3)	SAND BAR > 20 K VOL (m3)	EDDY VOL (m3)	CHANNEL VOL (m3)	SAND BAR TOTAL AREA (%)	SAND BAR > 20 K AREA (%)	SAND BAR TOTAL VOL (%)	SAND BAR > 20 K VOL (%)	EDDY VOL (%)	CHANNEL VOL (%)
910727	573	1525	170	2104	48			20.08	107.32	20.09	152.63		
921016	1020	1837	138	2554	37			44.65	68.29	45.78	94.74		
931008	1377	1186	114	1665	29			-6.61	39.02	-4.97	52.63		
940408	1559	1329	102	1731	30	5700		4.65	24.39	-1.20	57.89	-8.06	
941120	1786	1063	89	1424	24			-16.30	8.54	-18.72	26.32		
940425	1941	1161	79	1460	17	4800	24600	-8.58	-3.66	-16.67	-10.53	-22.58	-12.77
960216	2238	1270	82	1752	19	6200	28200	0.00	0.00	0.00	0.00	0.00	0.00
960417	2299	1519	621	2440	182	6900	19100	19.61	657.32	39.27	857.89	11.29	-32.27
960914	2449	1558	512	2420	139	6500	20500	22.68	524.39	38.13	631.58	4.84	-27.30
970215	2603	1663	389	2381	119	9300	22100	30.94	374.39	35.90	526.32	50.00	-21.63
970421	2668	1266	426	2076	128	9200	28900	-0.31	419.51	18.49	573.68	48.39	2.48
970825	2794	1437	380	2221	131	9700	29100	13.15	363.41	26.77	589.47	56.45	3.19



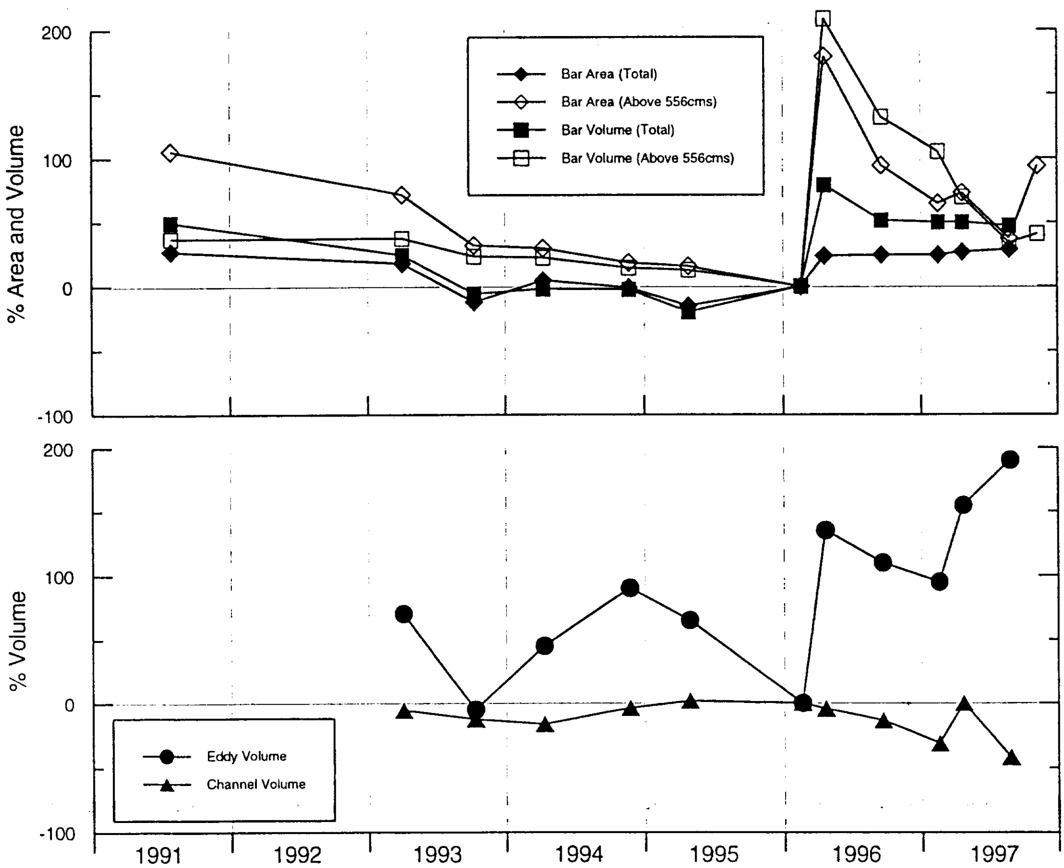
22R

SURVEY DATE	JULIAN DAYS	SAND BAR TOTAL AREA (m2)	SAND BAR > 20 K AREA (m2)	SAND BAR TOTAL VOL (m3)	SAND BAR > 20 K VOL (m3)	EDDY VOL (m3)	CHANNEL VOL (m3)	SAND BAR TOTAL AREA (%)	SAND BAR > 20 K AREA (%)	SAND BAR TOTAL VOL (%)	SAND BAR > 20 K VOL (%)	EDDY VOL (%)	CHANNEL VOL (%)
910727	573	2085	753	4856	758			2.01	61.24	2.77	11.96		
911025	663	1824	714	4443	726								
921016	1020	1930	655	4506	731			-5.58	40.26	-4.63	7.98		
930402	1188	2254	650	4872	727	6100	18000	10.27	39.19	3.11	7.39		2.27
931008	1377	2491	600	5477	741			21.87	28.48	15.92	9.45		
940409	1560	2444	595	5444	755	7500	16300	19.57	27.41	15.22	11.52	10.29	-7.39
941121	1786	2466	595	5665	747	7600		20.65	27.41	19.89	10.34	11.76	
950426	1942	2449	595	5540	746	7900	16000	19.81	27.41	17.25	10.19	16.18	-9.09
960216	2238	2044	467	4725	677	6800	17600	0.00	0.00	0.00	0.00	0.00	0.00
960417	2299	2387	863	6437	1845	6200	12300	16.78	84.80	36.23	172.53	-8.82	-30.11
960915	2450	1608	736	5425	1685	2700	12400	-21.33	57.60	14.81	148.89	-60.29	-29.55
970215	2603	1888	671	5444	1620	4800	13700	-7.63	43.68	15.22	139.29	-29.41	-22.16
970422	2669	1915	631	5129	1381	4900	16200	-6.31	35.12	8.55	103.99	-27.94	-7.95
970826	2795	1769	661	4921	1212	4000	16400	-13.45	41.54	4.15	79.03	-41.18	-6.82



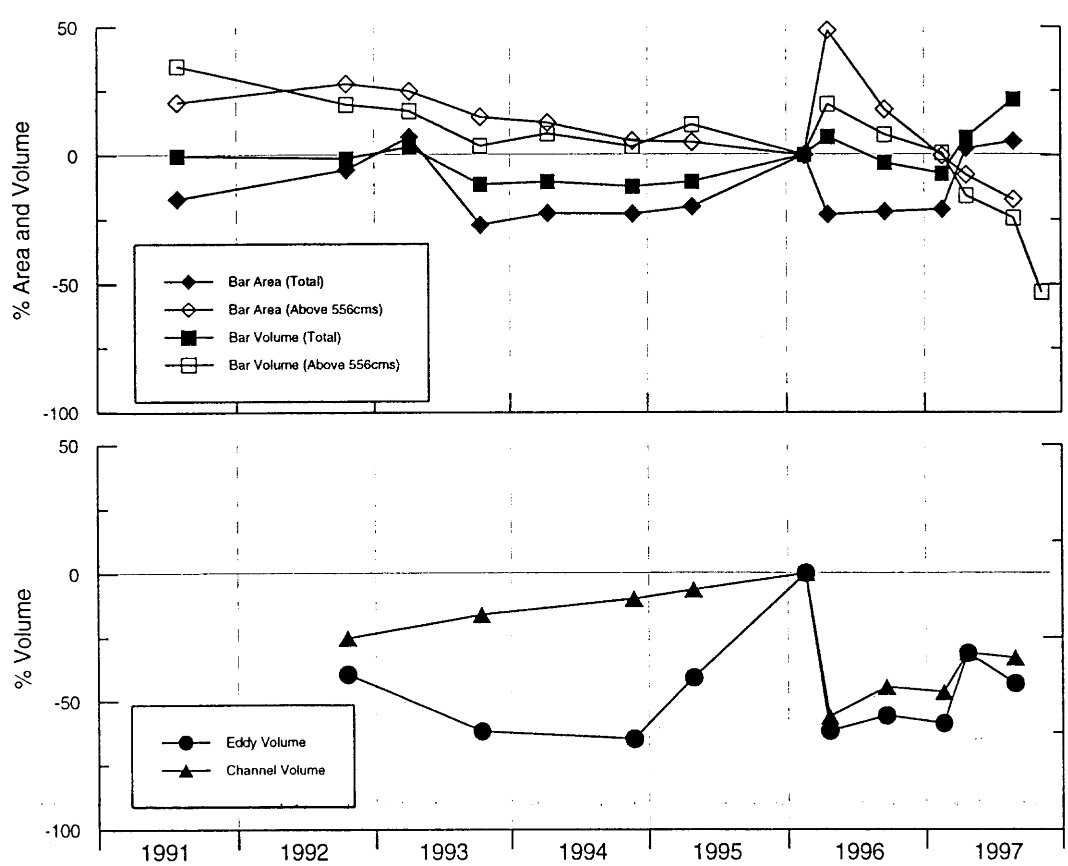
30R

SURVEY DATE	JULIAN DAYS	SAND BAR TOTAL AREA (m2)	SAND BAR > 20 K AREA (m2)	SAND BAR TOTAL VOL (m3)	SAND BAR > 20 K VOL (m3)	EDDY VOL (m3)	CHANNEL VOL (m3)	SAND BAR TOTAL AREA (%)	SAND BAR > 20 K AREA (%)	SAND BAR TOTAL VOL (%)	SAND BAR > 20 K VOL (%)	EDDY VOL (%)	CHANNEL VOL (%)
910728	574	4150	1464	9861	1506			26.95	105.62	49.64	37.03		
930402	1188	3853	1222	8191	1507	3400	10600	17.86	71.63	24.29	37.12	70.00	-5.36
931009	1378	2873	938	6200	1355	1900	9800	-12.11	31.74	-5.92	23.29	-5.00	-12.50
940409	1560	3415	922	6459	1343	2900	9400	4.47	29.49	-1.99	22.20	45.00	-16.07
941121	1786	3239	842	6432	1256	3800	10800	-0.92	18.26	-2.40	14.29	90.00	-3.57
950426	1942	2771	824	5268	1238	3300	11400	-15.23	15.73	-20.06	12.65	65.00	1.79
960216	2238	3269	712	6590	1099	2000	11200	0.00	0.00	0.00	0.00	0.00	0.00
960417	2299	4039	1987	11777	3388	4700	10700	23.55	179.07	78.71	208.28	135.00	-4.46
960915	2450	4065	1383	9956	2545	4200	9700	24.35	94.24	51.08	131.57	110.00	-13.39
970215	2603	4058	1172	9871	2251	3900	7700	24.14	64.61	49.79	104.82	95.00	-31.25
970421	2669	4138	1231	9856	1864	5100	11200	26.58	72.89	49.56	69.61	155.00	0.00
970826	2795	4198	976	9689	1467	5800	6500	28.42	37.08	47.03	33.48	190.00	-41.96



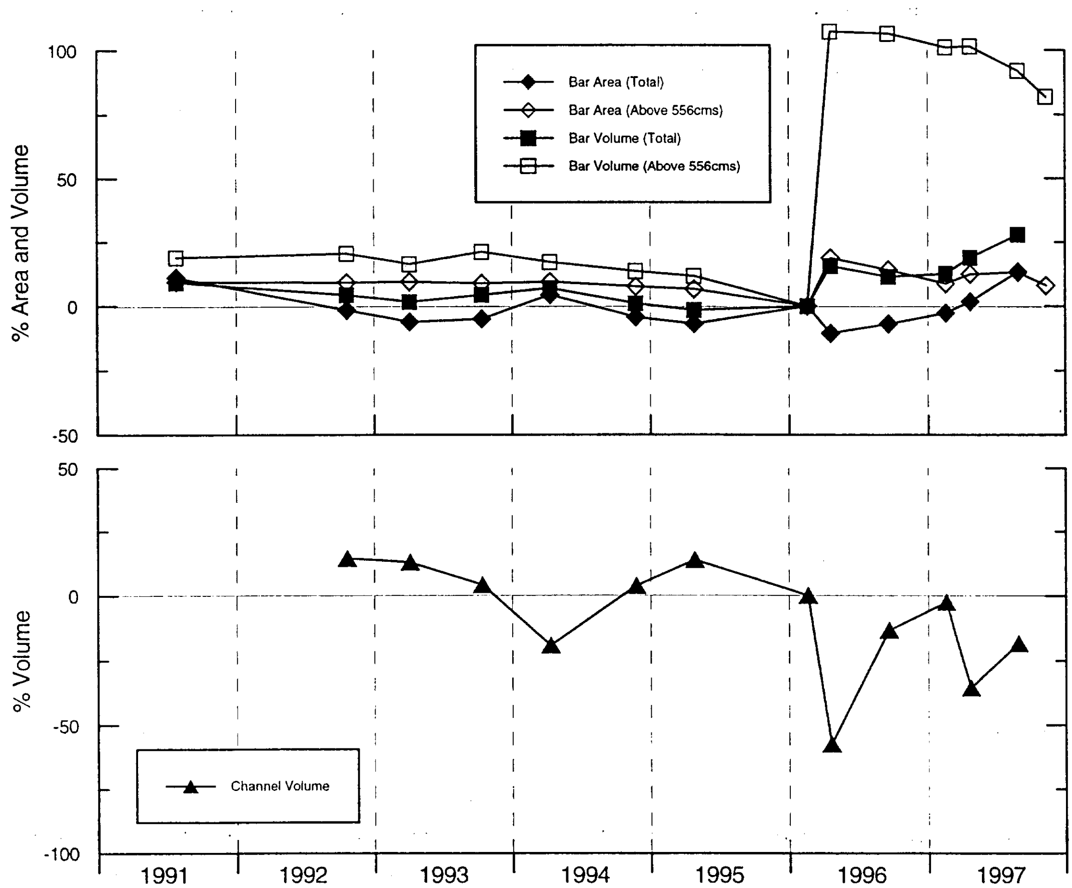
32R

SURVEY DATE	JULIAN DAYS	SAND BAR TOTAL AREA (m2)	SAND BAR > 20 K AREA (m2)	SAND BAR TOTAL VOL (m3)	SAND BAR > 20 K VOL (m3)	EDDY VOL (m3)	CHANNEL VOL (m3)	SAND BAR TOTAL AREA (%)	SAND BAR > 20 K AREA (%)	SAND BAR TOTAL VOL (%)	SAND BAR > 20 K VOL (%)	EDDY VOL (%)	CHANNEL VOL (%)
910728	574	2899	692	3263	378			-17.12	20.56	-0.43	34.52		
910925	633												
911026	664	2810	674	3104	335								
921017	1021	3296	734	3234	336	8100	14900	-5.77	27.87	-1.31	19.57	-39.55	-25.13
930403	1189	3743	717	3378	329			7.00	24.91	3.08	17.08		
931009	1379	2544	660	2900	291	5100	16700	-27.27	14.98	-11.50	3.56	-61.94	-16.08
940410	1561	2704	647	2932	304			-22.70	12.72	-10.53	8.19		
941121	1786	2694	606	2873	290	4700	17900	-22.98	5.57	-12.33	3.20	-64.93	-10.05
950426	1942	2788	603	2931	314	7900	18600	-20.30	5.05	-10.56	11.74	-41.04	-6.53
960216	2238	3498	574	3277	281	13400	19900	0.00	0.00	0.00	0.00	0.00	0.00
960418	2300	2685	853	3507	336	5100	8700	-23.24	48.61	7.02	19.57	-61.94	-56.28
960915	2450	2723	676	3175	303	5900	11000	-22.16	17.77	-3.11	7.83	-55.97	-44.72
970215	2603	2755	573	3033	283	5500	10600	-21.24	-0.17	-7.45	0.71	-58.96	-46.73
970422	2669	3581	530	3493	236	9200	13700	2.37	-7.67	6.59	-16.01	-31.34	-31.16
970826	2795	3682	475	3975	212	7600	13300	5.26	-17.25	21.30	-24.56	-43.28	-33.17



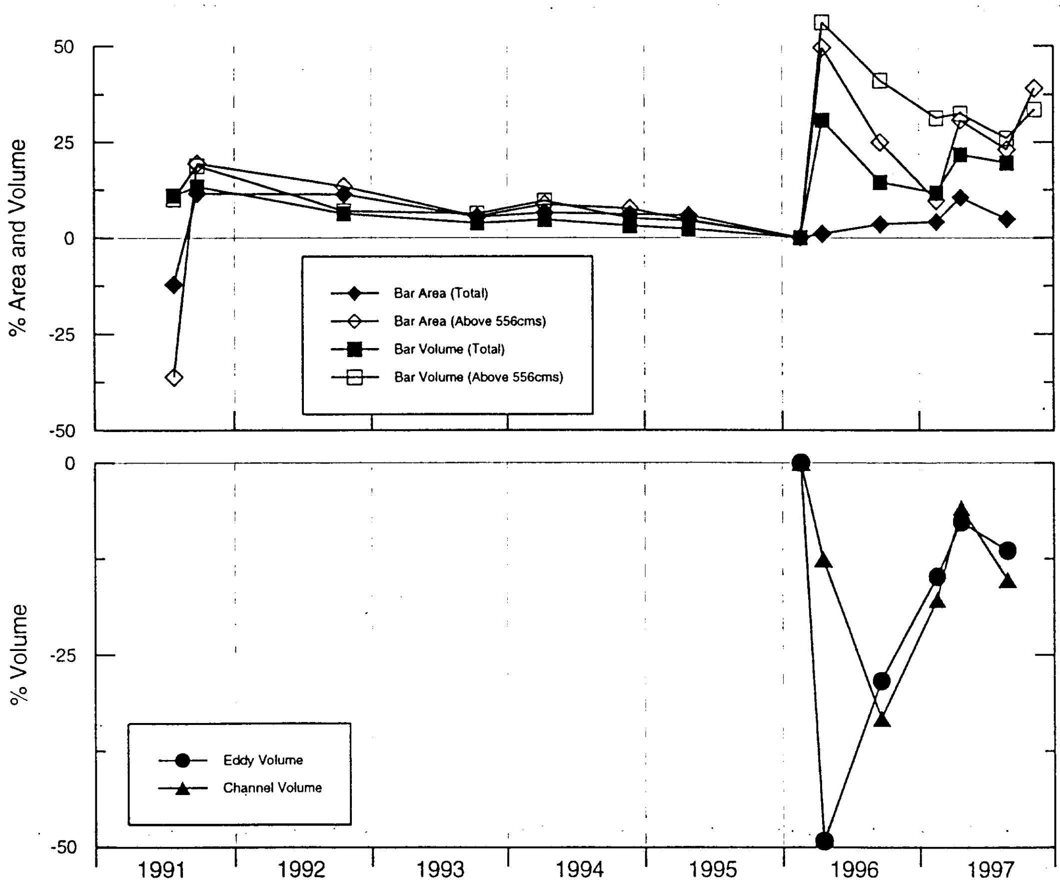
43L

SURVEY DATE	JULIAN DAYS	SAND BAR TOTAL AREA (m2)	SAND BAR > 20 K AREA (m2)	SAND BAR TOTAL VOL (m3)	SAND BAR > 20 K VOL (m3)	EDDY VOL (m3)	CHANNEL VOL (m3)	SAND BAR TOTAL AREA (%)	SAND BAR > 20 K AREA (%)	SAND BAR TOTAL VOL (%)	SAND BAR > 20 K VOL (%)	EDDY VOL (%)	CHANNEL VOL (%)
910726	572	2542	1081	4974	807			11.25	9.41	9.27	19.03		
910926	634	2307	1084	4910	824								
911026	664	2345	1088	4889	819								
921019	1023	2247	1080	4752	817		60800	-1.66	9.31	4.39	20.50		14.50
930403	1189	2142	1081	4623	789		60000	-6.26	9.41	1.56	16.37		12.99
931010	1380	2167	1076	4752	821		55300	-5.16	8.91	4.39	21.09		4.14
940410	1561	2386	1081	4869	794		42900	4.42	9.41	6.96	17.11		-19.21
941122	1787	2186	1063	4600	770		55100	-4.33	7.59	1.05	13.57		3.77
950426	1942	2124	1053	4479	757		60500	-7.05	6.58	-1.60	11.65		13.94
960217	2239	2285	988	4552	678		53100	0.00	0.00	0.00	0.00		0.00
960418	2300	2043	1173	5260	1404		22600	-10.59	18.72	15.55	107.08		-57.44
960916	2451	2126	1127	5077	1399		46000	-6.96	14.07	11.53	106.34		-13.37
970216	2604	2222	1074	5126	1363		51800	-2.76	8.70	12.61	101.03		-2.45
970423	2670	2324	1111	5407	1365		34100	1.71	12.45	18.78	101.33		-35.78
970827	2796	2589	1118	5823	1301		43300	13.30	13.16	27.92	91.89		-18.46



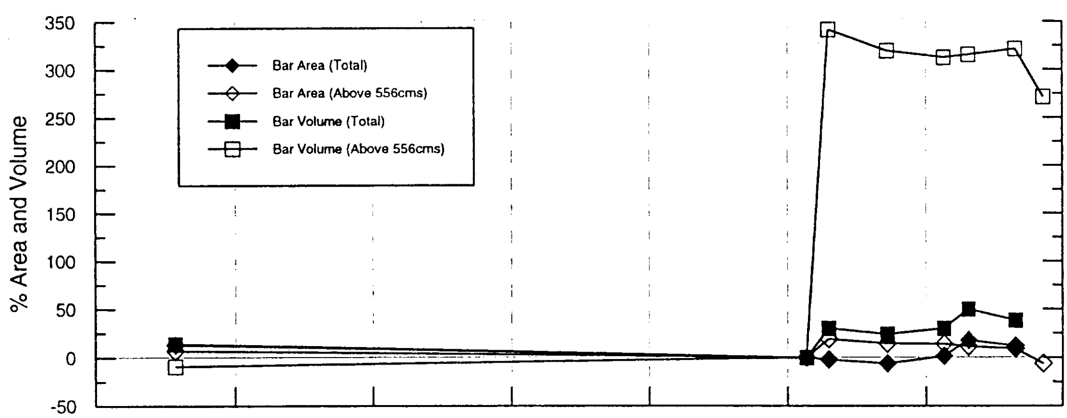
45L - Upper

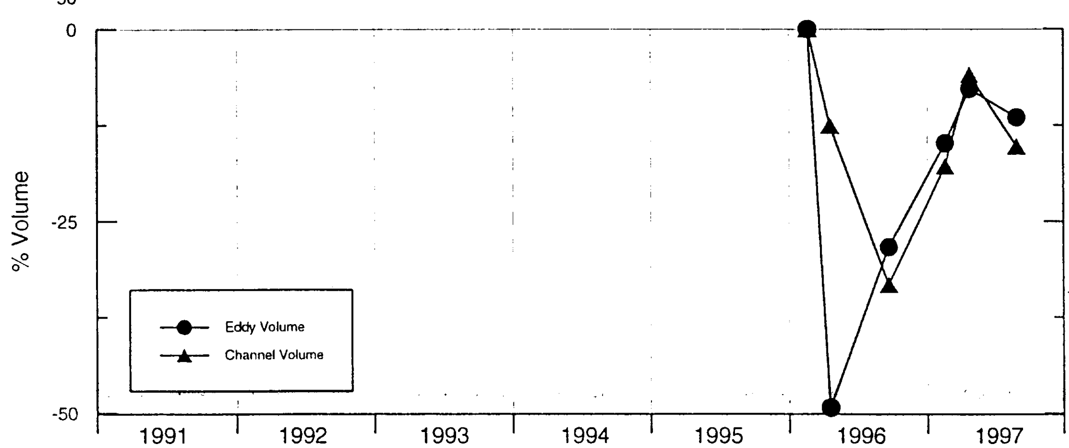
SURVEY DATE	JULIAN DAYS	SAND BAR TOTAL AREA (m2)	SAND BAR > 20 K AREA (m2)	SAND BAR TOTAL VOL (m3)	SAND BAR > 20 K VOL (m3)	EDDY VOL (m3)	CHANNEL VOL (m3)	SAND BAR TOTAL AREA (%)	SAND BAR > 20 K AREA (%)	SAND BAR TOTAL VOL (%)	SAND BAR > 20 K VOL (%)	EDDY VOL (%)	CHANNEL VOL (%)
910726	572	2892	777	7089	1364			-12.20	-36.21	10.96	10.09		
910926	634	3670	1453	7237	1471			11.41	19.29	13.27	18.72		
921019	1023	3663	1380	6787	1324			11.20	13.30	6.23	6.86		
931010	1379	3467	1284	6625	1316			5.25	5.42	3.69	6.21		
940411	1562	3507	1323	6683	1357			6.47	8.62	4.60	9.52		
941122	1787	3493	1310	6581	1302			6.04	7.55	3.01	5.08		
940427	1943	3484	1274	6531	1292			5.77	4.60	2.22	4.28		
960217	2239	3294	1218	6389	1239	29600	62800	0.00	0.00	0.00	0.00	0.00	0.00
960415	2297	3324	1820	8352	1934	15000	54900	0.91	49.43	30.72	56.09	-49.32	-12.58
960916	2451	3409	1521	7313	1747	21200	41900	3.49	24.88	14.46	41.00	-28.38	-33.28
970216	2604	3426	1334	7133	1627	25200	51600	4.01	9.52	11.65	31.32	-14.86	-17.83
970423	2670	3636	1592	7772	1641	27300	59100	10.38	30.71	21.65	32.45	-7.77	-5.89
970827	2796	3453	1498	7629	1561	26200	53200	4.83	22.99	19.41	25.99	-11.49	-15.29



45L - Lower

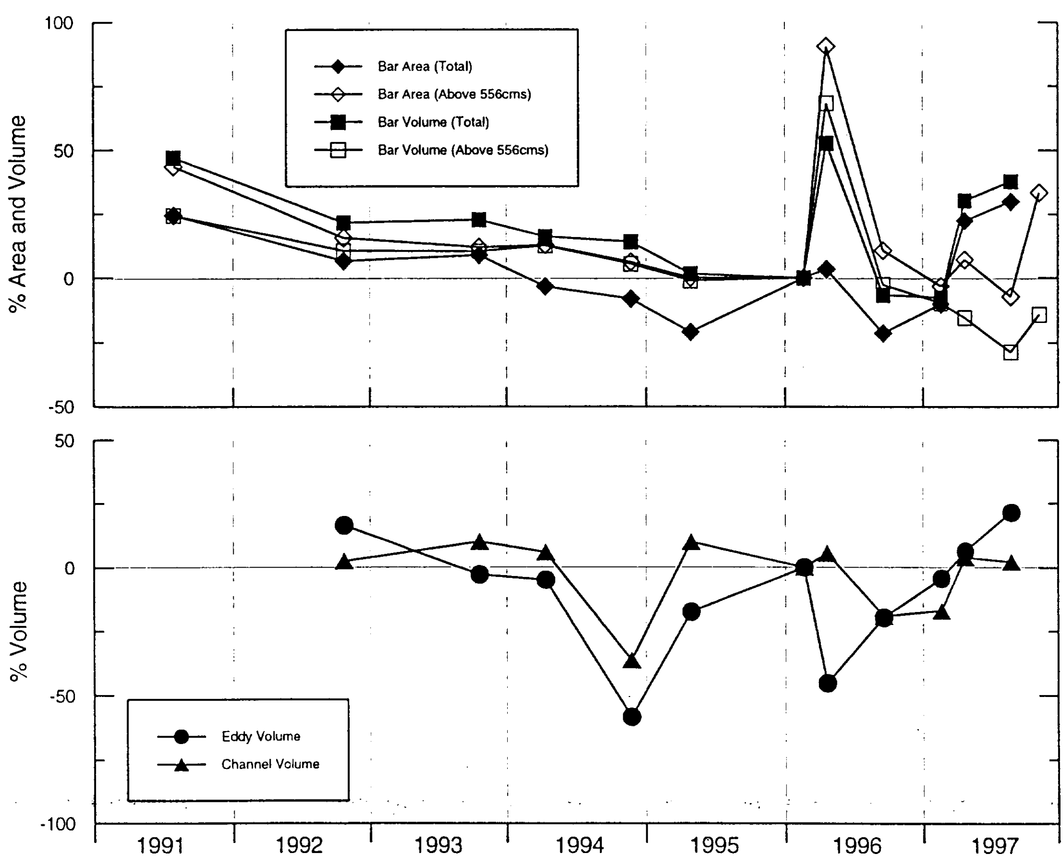
SURVEY DATE	JULIAN DAYS	SAND BAR TOTAL AREA (m2)	SAND BAR > 20 K AREA (m2)	SAND BAR TOTAL VOL (m3)	SAND BAR > 20 K VOL (m3)	EDDY VOL (m3)	CHANNEL VOL (m3)	SAND BAR TOTAL AREA (%)	SAND BAR > 20 K AREA (%)	SAND BAR TOTAL VOL (%)	SAND BAR > 20 K VOL (%)	EDDY VOL (%)	CHANNEL VOL (%)
910726	572	6570	1815	9175	503			12.91	6.64	13.96	-9.04		
960217	2239	5819	1702	8051	553			0.00	0.00	0.00	0.00		
960415	2297	5696	2022	10457	2439			-2.11	18.80	29.88	341.05		
960916	2451	5454	1947	9958	2319			-6.27	14.39	23.69	319.35		
970216	2604	5912	1936	10437	2280			1.60	13.75	29.64	312.30		
970423	2670	6838	1890	12048	2297			17.51	11.05	49.65	315.37		
970827	2796	6512	1853	11142	2329			11.91	8.87	38.39	321.16		





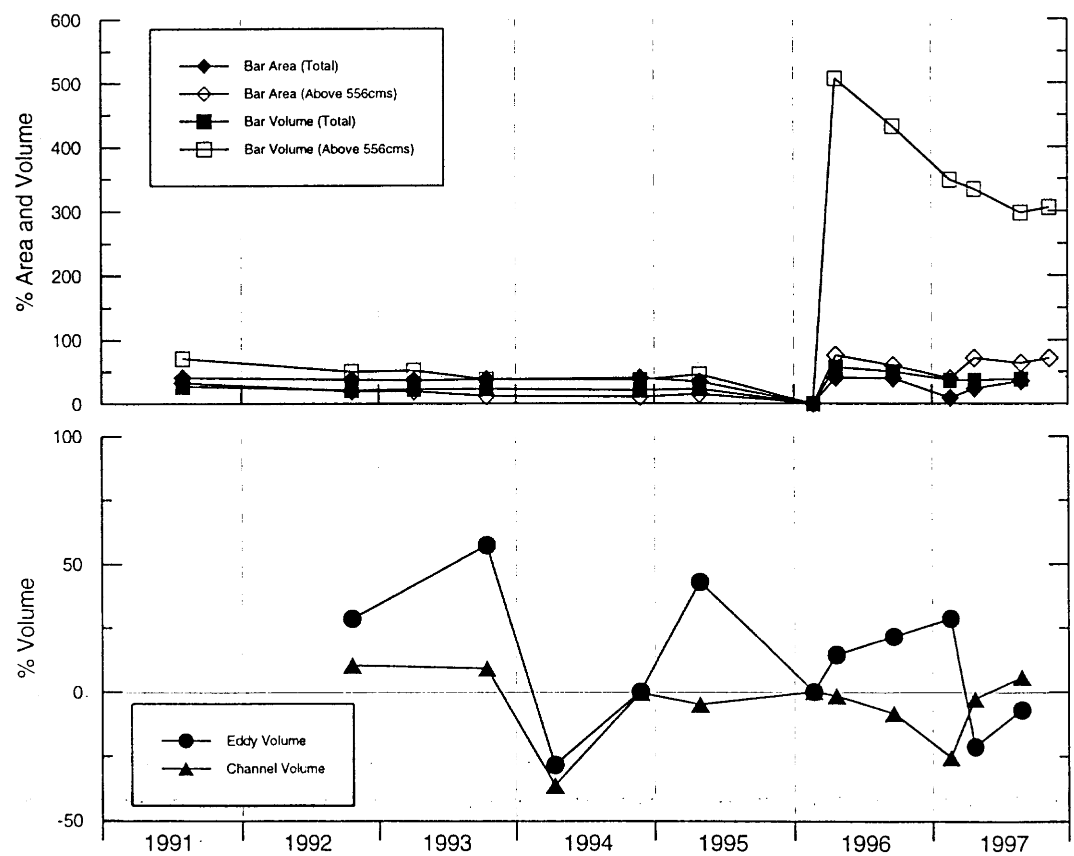
47R

		SAND BAR				EDDY	CHANNEL	SAND BAR				EDDY	CHANNEL
SURVEY DATE	JULIAN DAYS	TOTAL AREA (m2)	> 20 K AREA (m2)	TOTAL VOL (m3)	> 20 K VOL (m3)	VOL (m3)	VOL (m3)	TOTAL AREA (%)	> 20 K AREA (%)	TOTAL VOL (%)	> 20 K VOL (%)	VOL (%)	VOL (%)
910727	573	9125	2336	13256	2041			24.35	43.49	46.91	24.38		
921022	1026	7812	1882	10967	1813	44700	67100	6.46	15.60	21.54	10.48	16.41	2.60
931011	1388	7976	1822	11066	1810	37300	72000	8.69	11.92	22.64	10.30	-2.86	10.09
940411	1562	7085	1836	10460	1846	36500	69300	-3.45	12.78	15.93	12.49	-4.95	5.96
941123	1787	6741	1728	10282	1728	16000	41700	-8.14	6.14	13.95	5.30	-58.33	-36.24
950428	1944	5797	1629	9158	1621	31700	71900	-21.00	0.06	1.50	-1.22	-17.45	9.94
960218	2240	7338	1628	9023	1641	38400	65400	0.00	0.00	0.00	0.00	0.00	0.00
960419	2301	7587	3102	13764	2761	21100	69000	3.39	90.54	52.54	68.25	-45.05	5.50
960916	2450	5763	1802	8424	1598	30900	52900	-21.46	10.69	-6.64	-2.62	-19.53	-19.11
970217	2605	6591	1577	8333	1479	36700	54300	-10.18	-3.13	-7.65	-9.87	-4.43	-16.97
970424	2671	8970	1743	11738	1389	40800	67900	22.24	7.06	30.09	-15.36	6.25	3.82
970827	2796	9515	1510	12411	1168	46600	66800	29.67	-7.25	37.55	-28.82	21.35	2.14



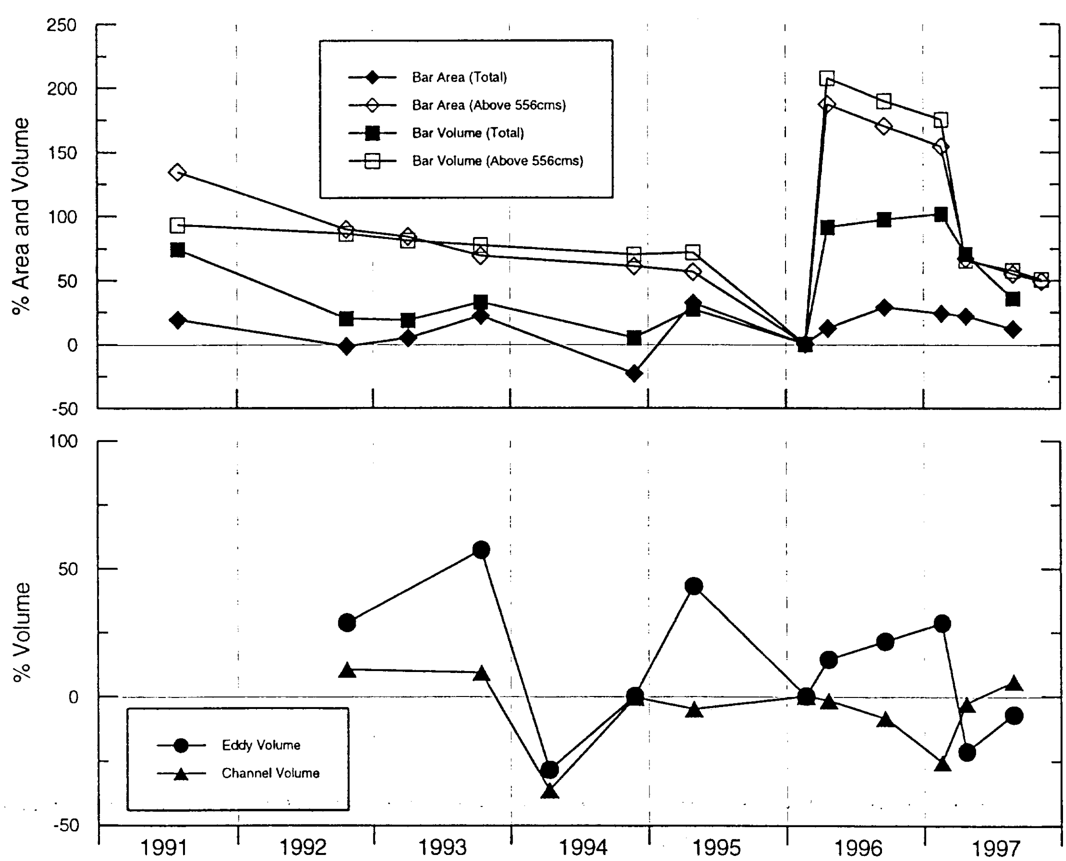
50L - Upper

SURVEY DATE	JULIAN DAYS	SAND BAR TOTAL AREA (m2)	SAND BAR > 20 K AREA (m2)	SAND BAR TOTAL VOL (m3)	SAND BAR > 20 K VOL (m3)	EDDY VOL (m3)	CHANNEL VOL (m3)	SAND BAR TOTAL AREA (%)	SAND BAR > 20 K AREA (%)	SAND BAR TOTAL VOL (%)	SAND BAR > 20 K VOL (%)	EDDY VOL (%)	CHANNEL VOL (%)
910730	576	1353	400	2073	157			40.64	32.45	26.87	70.65		
921020	1024	1321	360	1973	138	1800	19400	37.32	19.21	20.75	50.00	28.57	10.23
930404	1189	1314	360	2008	140			36.59	19.21	22.89	52.17		
931011	1381	1331	339	2011	127	2200	19200	38.36	12.25	23.07	38.04	57.14	9.09
940411	1562					1000	11200					-28.57	-36.36
941123	1788	1346	334	1981	126	1400	17500	39.92	10.60	21.24	36.96	0.00	-0.57
950428	1944	1291	348	2007	134	2000	16700	34.20	15.23	22.83	45.65	42.86	-5.11
960219	2241	962	302	1634	92	1400	17600	0.00	0.00	0.00	0.00	0.00	0.00
960419	2301	1353	530	2567	558	1600	17300	40.64	75.50	57.10	506.52	14.29	-1.70
960917	2451	1345	482	2456	489	1700	16100	39.81	59.60	50.31	431.52	21.43	-8.52
970217	2605	1051	421	2230	412	1800	13100	9.25	39.40	36.47	347.83	28.57	-25.57
970424	2671	1188	516	2233	399	1100	17100	23.49	70.86	36.66	333.70	-21.43	-2.84
970827	2796	1302	493	2265	365	1300	18600	35.34	63.25	38.62	296.74	-7.14	5.68



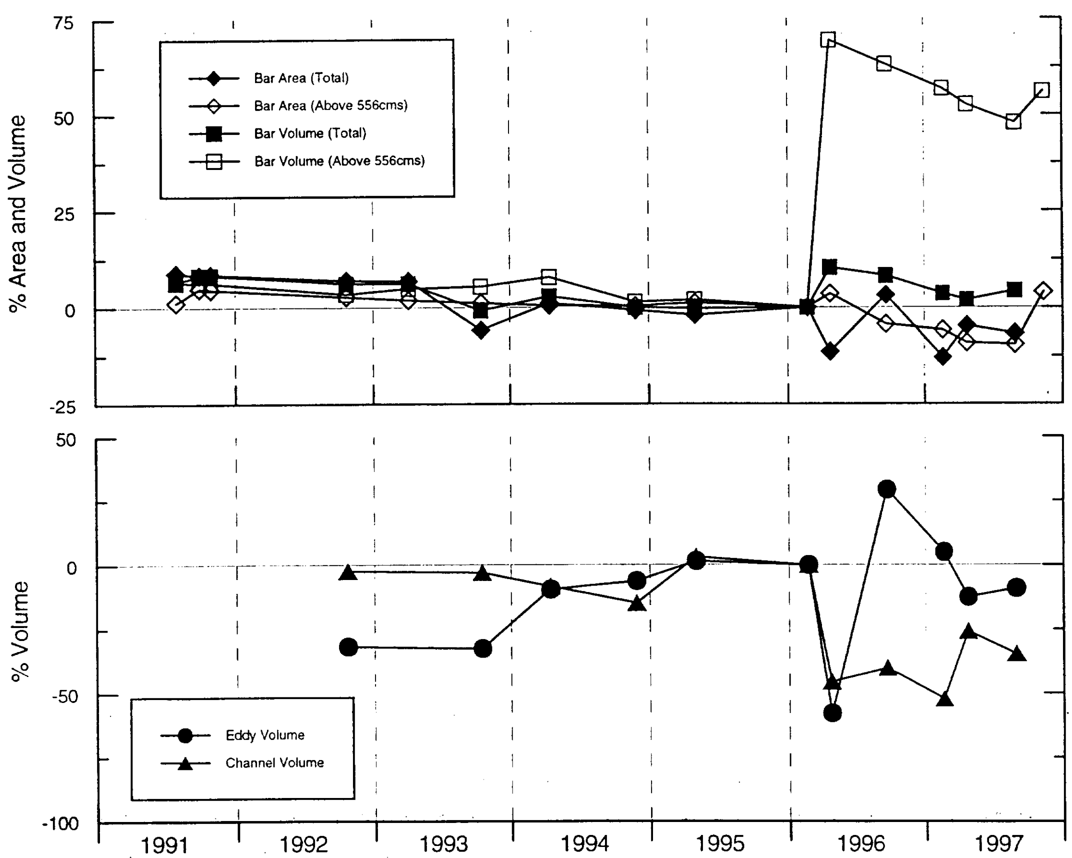
50L - Lower

SURVEY DATE	JULIAN DAYS	SAND BAR TOTAL AREA (m2)	SAND BAR > 20 K AREA (m2)	SAND BAR TOTAL VOL (m3)	SAND BAR > 20 K VOL (m3)	EDDY VOL (m3)	CHANNEL VOL (m3)	SAND BAR TOTAL AREA (%)	SAND BAR > 20 K AREA (%)	SAND BAR TOTAL VOL (%)	SAND BAR > 20 K VOL (%)	EDDY VOL (%)	CHANNEL VOL (%)
910730	576	2175	940	4925	1237			19.11	134.41	74.34	93.28		
921020	1024	1797	760	3387	1192			-1.59	89.53	19.89	86.25		
930404	1189	1914	738	3353	1159			4.82	84.04	18.69	81.09		
931011	1381	2229	678	3749	1135			22.07	69.08	32.71	77.34		
940411	1562												
941123	1788	1407	646	2959	1088			-22.95	61.10	4.74	70.00		
950428	1944	2412	628	3589	1099			32.09	56.61	27.04	71.72		
960219	2241	1826	401	2825	640			0.00	0.00	0.00	0.00		
960419	2301	2047	1151	5402	1969			12.10	187.03	91.22	207.66		
960917	2451	2350	1083	5574	1853			28.70	170.07	97.31	189.53		
970217	2605	2262	1019	5691	1760			23.88	154.11	101.45	175.00		
970424	2671	2223	670	4818	1060			21.74	67.08	70.55	65.63		
970827	2796	2041	621	3836	1010			11.77	54.86	35.79	57.81		



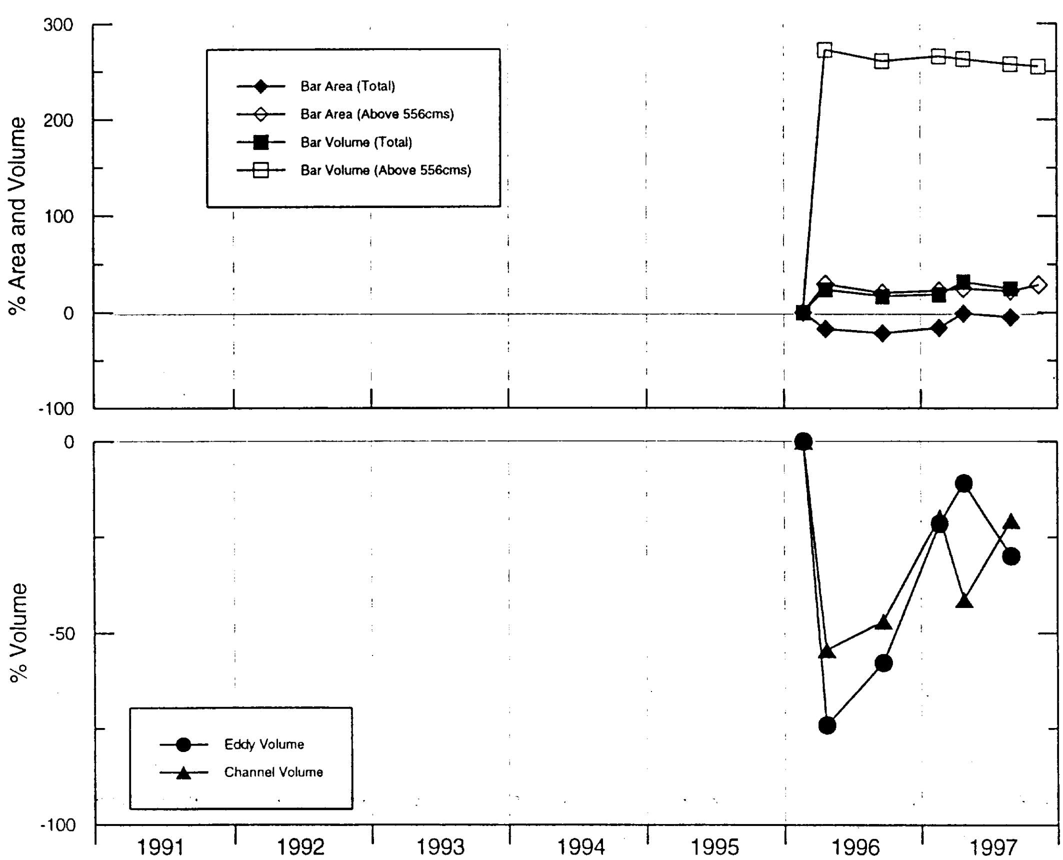
51L

SURVEY DATE	JULIAN DAYS	SAND BAR TOTAL AREA (m2)	SAND BAR > 20 K AREA (m2)	SAND BAR TOTAL VOL (m3)	SAND BAR > 20 K VOL (m3)	EDDY VOL (m3)	CHANNEL VOL (m3)	SAND BAR TOTAL AREA (%)	SAND BAR > 20 K AREA (%)	SAND BAR TOTAL VOL (%)	SAND BAR > 20 K VOL (%)	EDDY VOL (%)	CHANNEL VOL (%)
910728	574	12851	6916	27079	5970			8.91	1.24	6.66	6.46		
910927	635	12796	7164	27500	5965			8.44	4.87	8.32	6.37		
911027	665	12811	7151	27515	5963			8.57	4.68	8.38	6.33		
921021	1025	12634	7021	26971	5805	16400	98900	7.07	2.78	6.24	3.51	-31.67	-2.37
930404	1190	12620	6963	26986	5886			6.95	1.93	6.30	4.96		
931012	1382	11113	6910	25174	5914	16200	98300	-5.82	1.16	-0.84	5.46	-32.50	-2.96
940412	1563	11927	6864	26111	6051	21700	92800	1.08	0.48	2.85	7.90	-9.58	-8.39
941124	1789	11710	6860	25376	5684	22500	86200	-0.76	0.42	-0.04	1.36	-6.25	-14.91
950429	1945	11569	6911	25299	5719	24343	104400	-1.96	1.17	-0.35	1.98	1.43	3.06
960219	2241	11800	6831	25387	5608	24000	101300	0.00	0.00	0.00	0.00	0.00	0.00
960420	2302	10451	7075	28014	9496	10100	55100	-11.43	3.57	10.35	69.33	-57.92	-45.61
960917	2451	12174	6534	27470	9144	31000	60700	3.17	-4.35	8.20	63.05	29.17	-40.08
970217	2605	10272	6428	26294	8793	25200	48400	-12.95	-5.90	3.57	56.79	5.00	-52.22
970424	2671	11234	6205	25871	8556	21000	75200	-4.80	-9.16	1.91	52.57	-12.50	-25.77
970828	2797	11008	6174	26479	8290	21800	66100	-6.71	-9.62	4.30	47.82	-9.17	-34.75



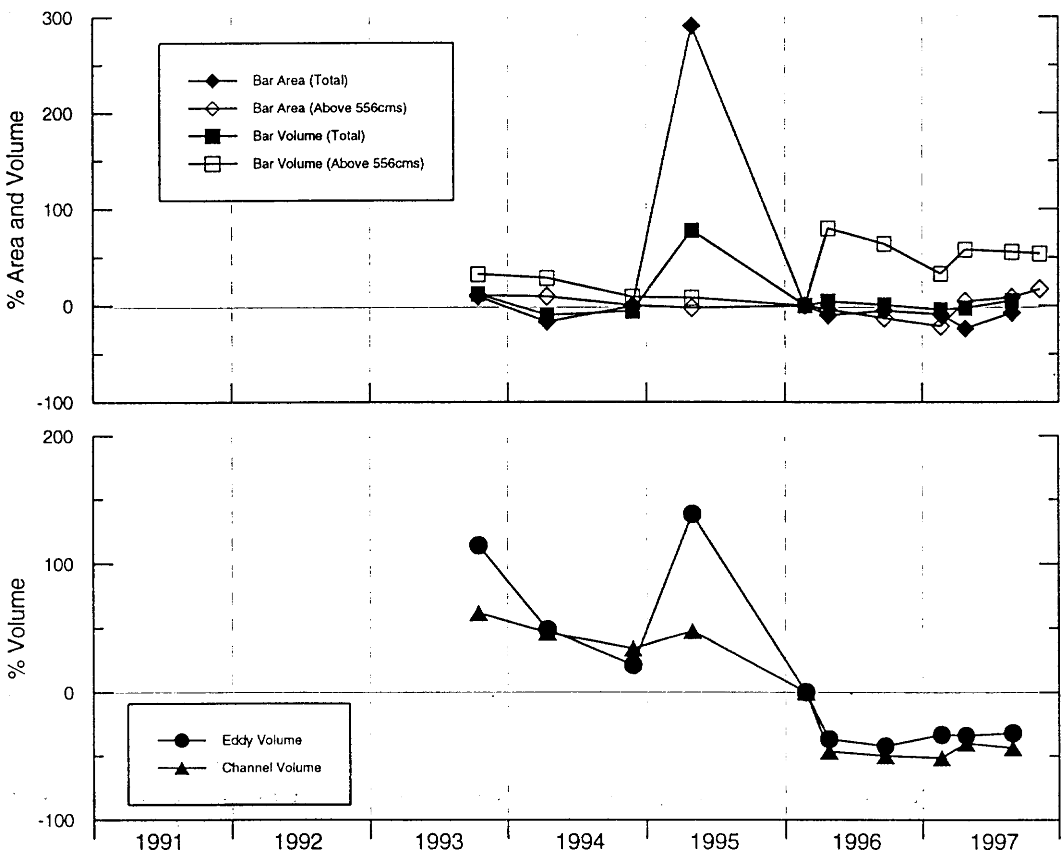
55R

SURVEY DATE	JULIAN DAYS	SAND BAR TOTAL AREA (m2)	SAND BAR > 20 K AREA (m2)	SAND BAR TOTAL VOL (m3)	SAND BAR > 20 K VOL (m3)	EDDY VOL (m3)	CHANNEL VOL (m3)	SAND BAR TOTAL AREA (%)	SAND BAR > 20 K AREA (%)	SAND BAR TOTAL VOL (%)	SAND BAR > 20 K VOL (%)	EDDY VOL (%)	CHANNEL VOL (%)
960220	2242	12886	6314	16356	1836	24700	100600	0.00	0.00	0.00	0.00	0.00	0.00
960420	2302	10644	8166	20182	6833	6400	45800	-17.40	29.33	23.39	272.17	-74.09	-54.47
960918	2453	10078	7592	19010	6618	10400	53500	-21.79	20.24	16.23	260.46	-57.89	-46.82
970218	2606	10826	7751	19382	6706	19400	80800	-15.99	22.76	18.50	265.25	-21.46	-19.68
970425	2672	12738	7858	21497	6650	22000	59200	-1.15	24.45	31.43	262.20	-10.93	-41.15
970829	2798	12239	7697	20339	6557	17300	79900	-5.02	21.90	24.35	257.14	-29.96	-20.58



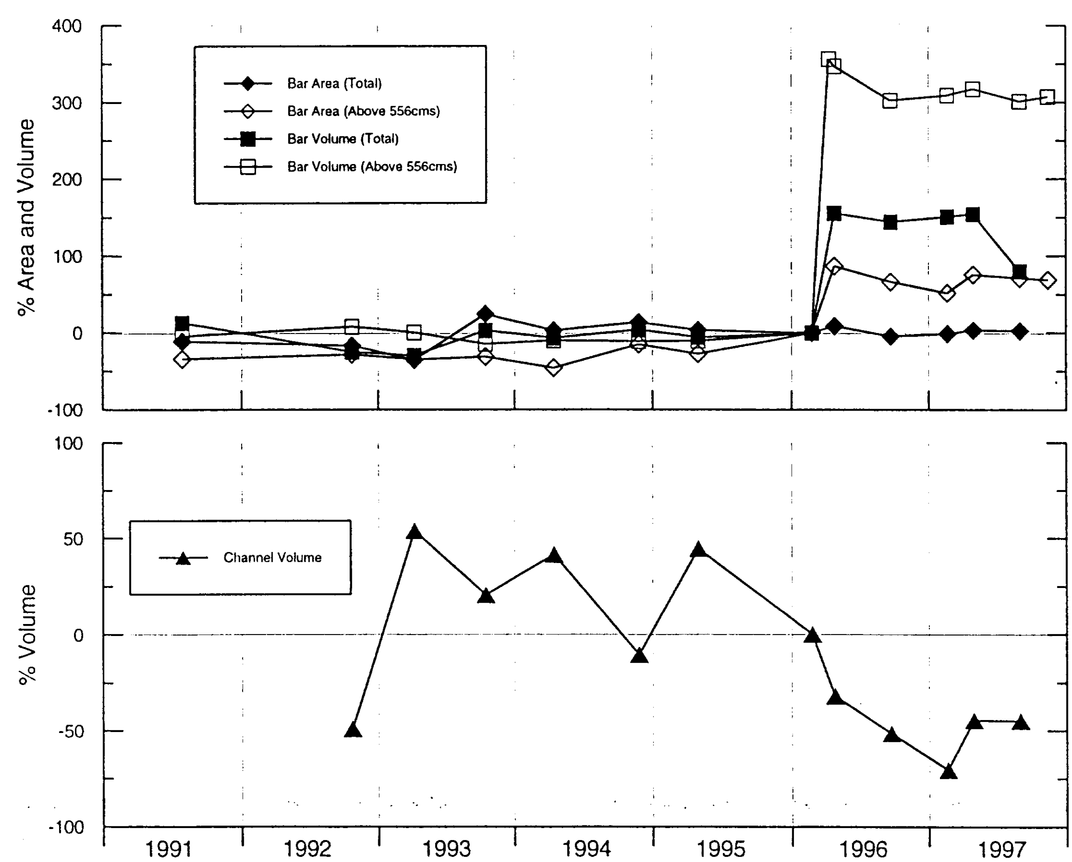
62R

SURVEY DATE	JULIAN DAYS	SAND BAR TOTAL AREA (m2)	SAND BAR > 20 K AREA (m2)	SAND BAR TOTAL VOL (m3)	SAND BAR > 20 K VOL (m3)	EDDY VOL (m3)	CHANNEL VOL (m3)	SAND BAR TOTAL AREA (%)	SAND BAR > 20 K AREA (%)	SAND BAR TOTAL VOL (%)	SAND BAR > 20 K VOL (%)	EDDY VOL (%)	CHANNEL VOL (%)
910729	575												
	667												
921022	1026												
930405	1191	8310	5057	15997	4271	87200	80400						
931013	1382	1040	291	1446	239	59300	62900	9.36	10.65	11.92	32.04	114.08	61.70
940413	1564	791	288	1163	232	41200	56900	-16.82	9.51	-9.98	28.18	48.74	46.27
941124	1790	942	264	1219	197	33500	52100	-0.95	0.38	-5.65	8.84	20.94	33.93
950430	1946	3710	257	2293	195	66100	57400	290.12	-2.28	77.48	7.73	138.63	47.56
950801	2039	904	258	1205	188	32500	42200						
960221	2243	951	263	1292	181	27700	38900	0.00	0.00	0.00	0.00	0.00	0.00
960422	2304	855	253	1346	325	17500	20800	-10.09	-3.80	4.18	79.56	-36.82	-46.53
960919	2454	898	229	1299	296	16000	19400	-5.57	-12.93	0.54	63.54	-42.24	-50.13
970218	2606	864	207	1233	240	18500	18900	-9.15	-21.29	-4.57	32.60	-33.21	-51.41
970426	2673	725	275	1259	285	18300	23300	-23.76	4.56	-2.55	57.46	-33.94	-40.10
970829	2798	880	285	1352	281	18800	21900	-7.47	8.37	4.64	55.25	-32.13	-43.70



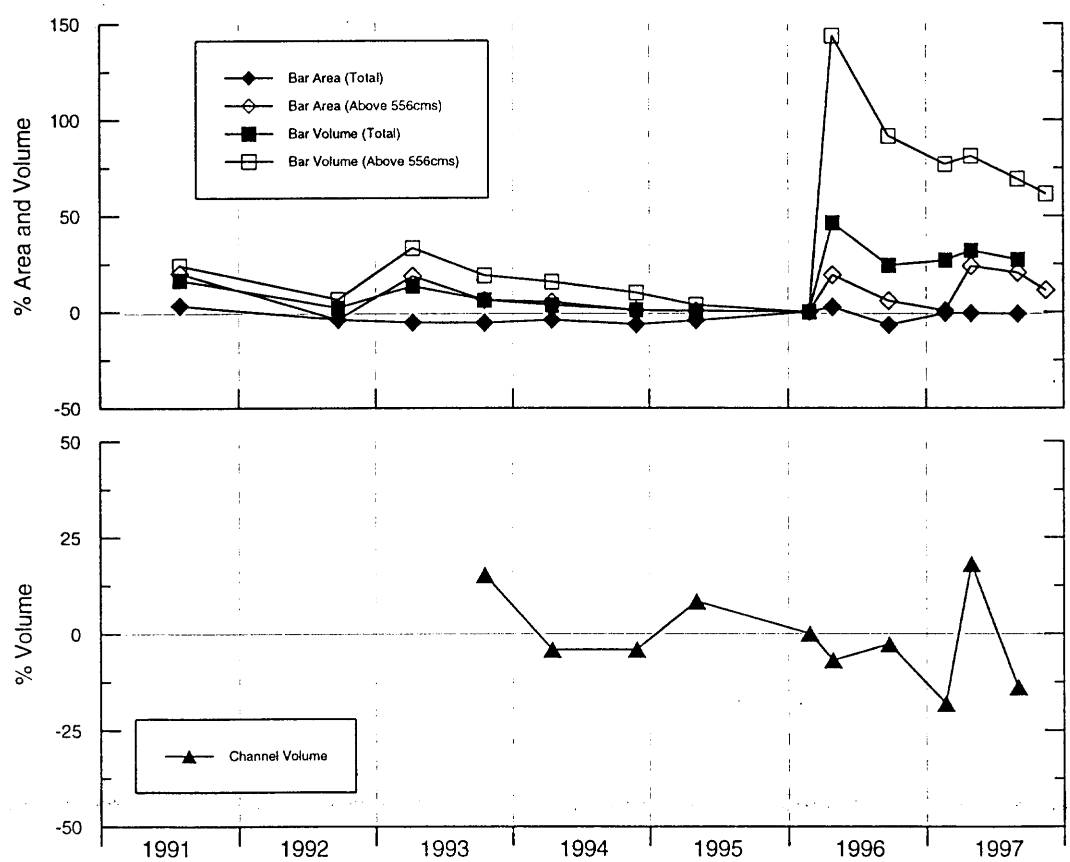
68R

SURVEY DATE	JULIAN DAYS	SAND BAR TOTAL AREA (m2)	SAND BAR > 20 K AREA (m2)	SAND BAR TOTAL VOL (m3)	SAND BAR > 20 K VOL (m3)	EDDY VOL (m3)	CHANNEL VOL (m3)	SAND BAR TOTAL AREA (%)	SAND BAR > 20 K AREA (%)	SAND BAR TOTAL VOL (%)	SAND BAR > 20 K VOL (%)	EDDY VOL (%)	CHANNEL VOL (%)
910729	575	4261	1066	6580	464			-11.67	-34.32	12.77	-4.53		
910929	637			0									
911029	667	4136	1057	4487	463								
921022	1026	4008	1159	4376	523		11585	-16.92	-28.59	-25.00	7.61		-49.14
930406	1192	3101	1052	4087	488		35032	-35.72	-35.18	-29.96	0.41		53.79
931013	1382	5978	1114	6004	414		27455	23.92	-31.36	2.90	-14.81		20.53
940414	1565	4950	878	5433	435		32219	2.61	-45.90	-6.89	-10.49		41.44
941124	1790	5487	1378	6080	432		20372	13.74	-15.10	4.20	-11.11		-10.57
950430	1946	4972	1173	5489	434		32923	3.07	-27.73	-5.93	-10.70		44.53
960222	2244	4824	1623	5835	486		22779	0.00	0.00	0.00	0.00		0.00
960408	2290	5225	3379	16059	2217		12600				356.17		
960422	2304	5222	3028	14899	2172		15498	8.25	86.57	155.34	346.91		-31.96
960919	2454	4590	2691	14239	1956		11041	-4.85	65.80	144.03	302.47		-51.53
970218	2606	4742	2462	14625	1988		6700	-1.70	51.69	150.64	309.05		-70.59
970428	2675	4971	2847	14821	2028		12640	3.05	75.42	154.00	317.28		-44.51
970830	2799	4938	2770	10476	1948		12570	2.36	70.67	79.54	300.82		-44.82



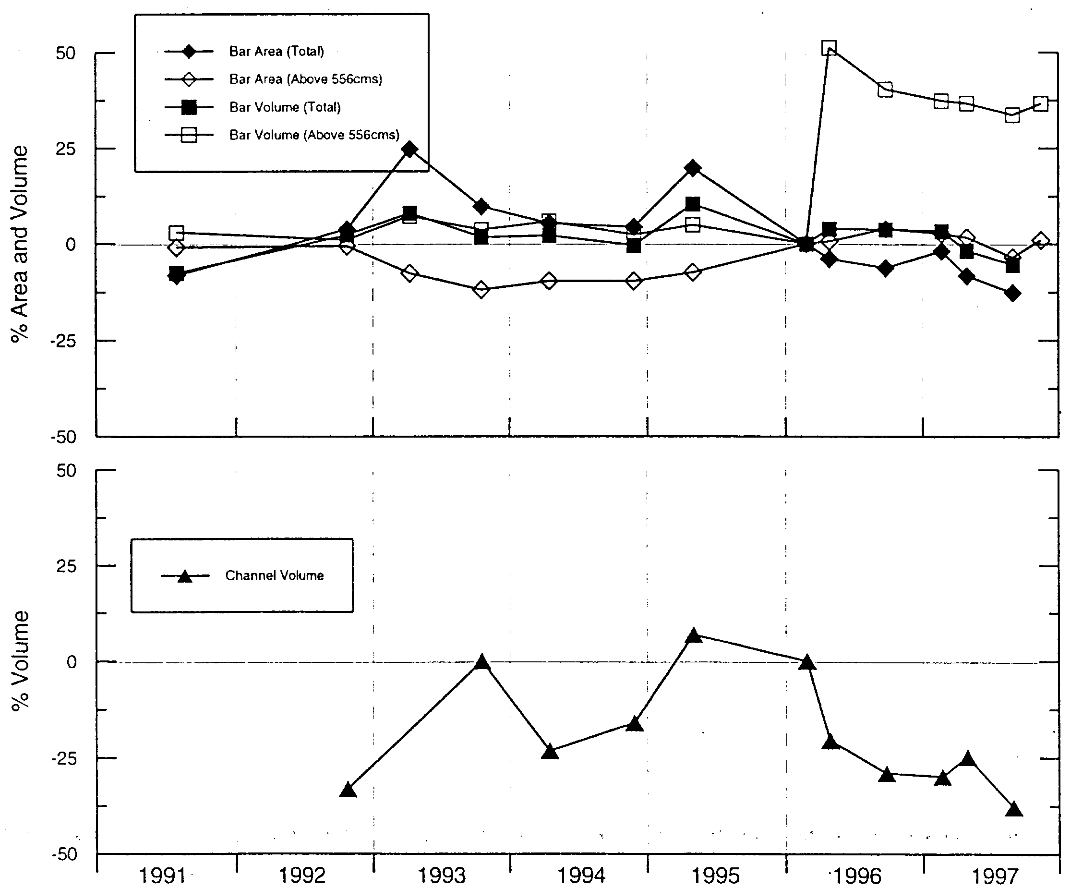
81L

SURVEY DATE	JULIAN DAYS	SAND BAR TOTAL AREA (m2)	SAND BAR > 20 K AREA (m2)	SAND BAR TOTAL VOL (m3)	SAND BAR > 20 K VOL (m3)	EDDY VOL (m3)	CHANNEL VOL (m3)	SAND BAR TOTAL AREA (%)	SAND BAR > 20 K AREA (%)	SAND BAR TOTAL VOL (%)	SAND BAR > 20 K VOL (%)	EDDY VOL (%)	CHANNEL VOL (%)
910729	575	1418	1091	3498	981			3.13	19.89	16.33	24.18		
911001	639	1221	944	3126	943								
911031	669	1178	942	3103	951								
920923	996	1319	873	3068	841			-4.07	-4.07	2.03	6.46		
921023	1027	57.7	57.7	298.3									
930407	1194	1298	1080	3408	1053			-5.60	18.68	13.34	33.29		
931015	1384	1296	965	3193	940		8300	-5.75	6.04	6.19	18.99		15.28
940415	1566	1317	956	3111	914		6900	-4.22	5.05	3.46	15.70		-4.17
941126	1791	1283	917	3037	868		6900	-6.69	0.77	1.00	9.87		-4.17
950501	1947	1311	913	3021	817		7800	-4.65	0.33	0.47	3.42		8.33
960224	2246	1375	910	3007	790		7200	0.00	0.00	0.00	0.00		0.00
960425	2307	1409	1084	4398	1924		6700	2.47	19.12	46.26	143.54		-6.94
960921	2456	1280	961	3732	1512		7000	-6.91	5.60	24.11	91.39		-2.78
970219	2607	1365	915	3812	1396		5900	-0.73	0.55	26.77	76.71		-18.06
970429	2676	1365	1126	3964	1430		8500	-0.73	23.74	31.83	81.01		18.06
970831	2800	1361	1094	3823	1336		6200	-1.02	20.22	27.14	69.11		-13.89



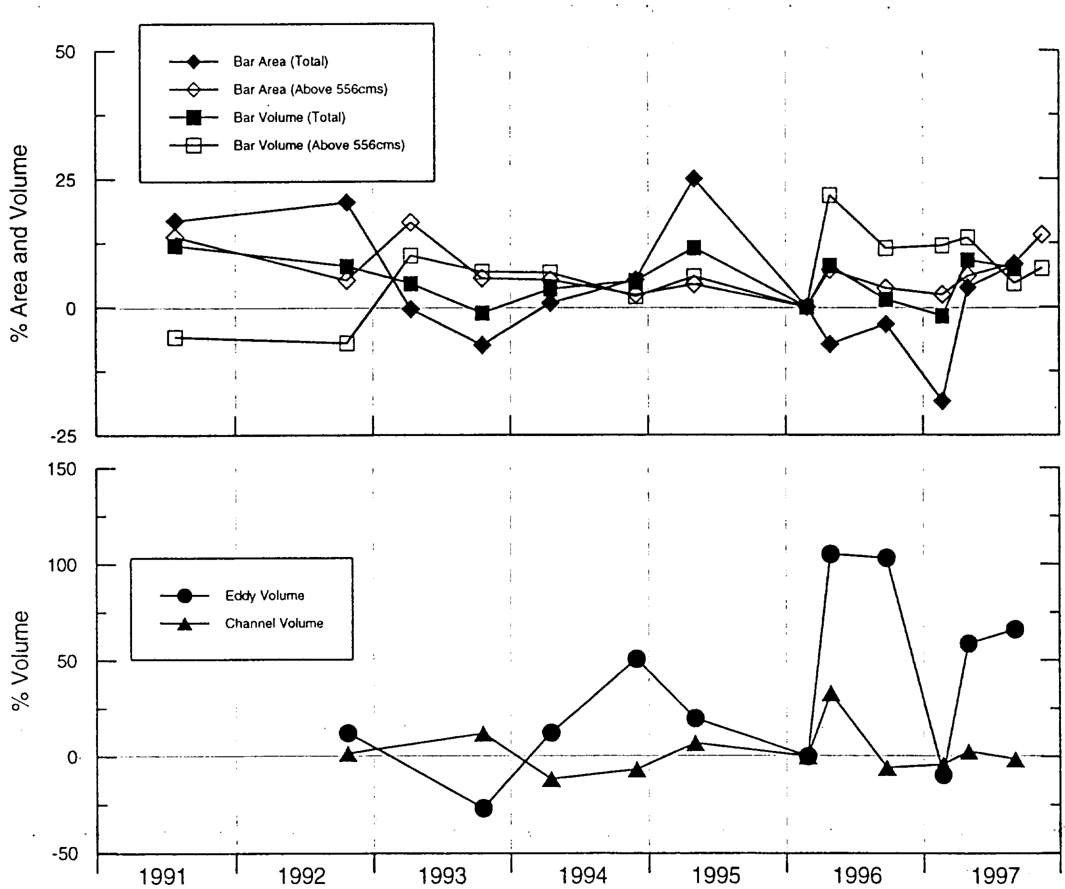
87L

SURVEY DATE	JULIAN DAYS	SAND BAR TOTAL AREA (m2)	SAND BAR > 20 K AREA (m2)	SAND BAR TOTAL VOL (m3)	SAND BAR > 20 K VOL (m3)	EDDY VOL (m3)	CHANNEL VOL (m3)	SAND BAR TOTAL AREA (%)	SAND BAR > 20 K AREA (%)	SAND BAR TOTAL VOL (%)	SAND BAR > 20 K VOL (%)	EDDY VOL (%)	CHANNEL VOL (%)
910729	575	558	307	1437	312			-8.22	-0.97	-7.59	2.97		
911001	639	582	313	1444	298								
921023	1027	631	308	1590	306		15900	3.78	-0.65	2.25	0.99		-33.19
930407	1193	758	286	1680	325			24.67	-7.74	8.04	7.26		
931015	1384	667	273	1581	314		23800	9.70	-11.94	1.67	3.63		0.00
940415	1566	641	280	1588	321		18300	5.43	-9.68	2.12	5.94		-23.11
941117	1791	635	280	1548	310		20000	4.44	-9.68	-0.45	2.31		-15.97
950501	1947	728	287	1717	318		25400	19.74	-7.42	10.42	4.95		6.72
960224	2246	608	310	1555	303		23800	0.00	0.00	0.00	0.00		0.00
960425	2307	584	312	1615	458		18900	-3.95	0.65	3.86	51.16		-20.59
960921	2456	570	322	1613	425		16900	-6.25	3.87	3.73	40.26		-28.99
970219	2607	596	318	1606	416		16700	-1.97	2.58	3.28	37.29		-29.83
970429	2676	557	315	1527	414		17900	-8.39	1.61	-1.80	36.63		-24.79
970831	2800	531	299	1471	405		14800	-12.66	-3.55	-5.40	33.66		-37.82



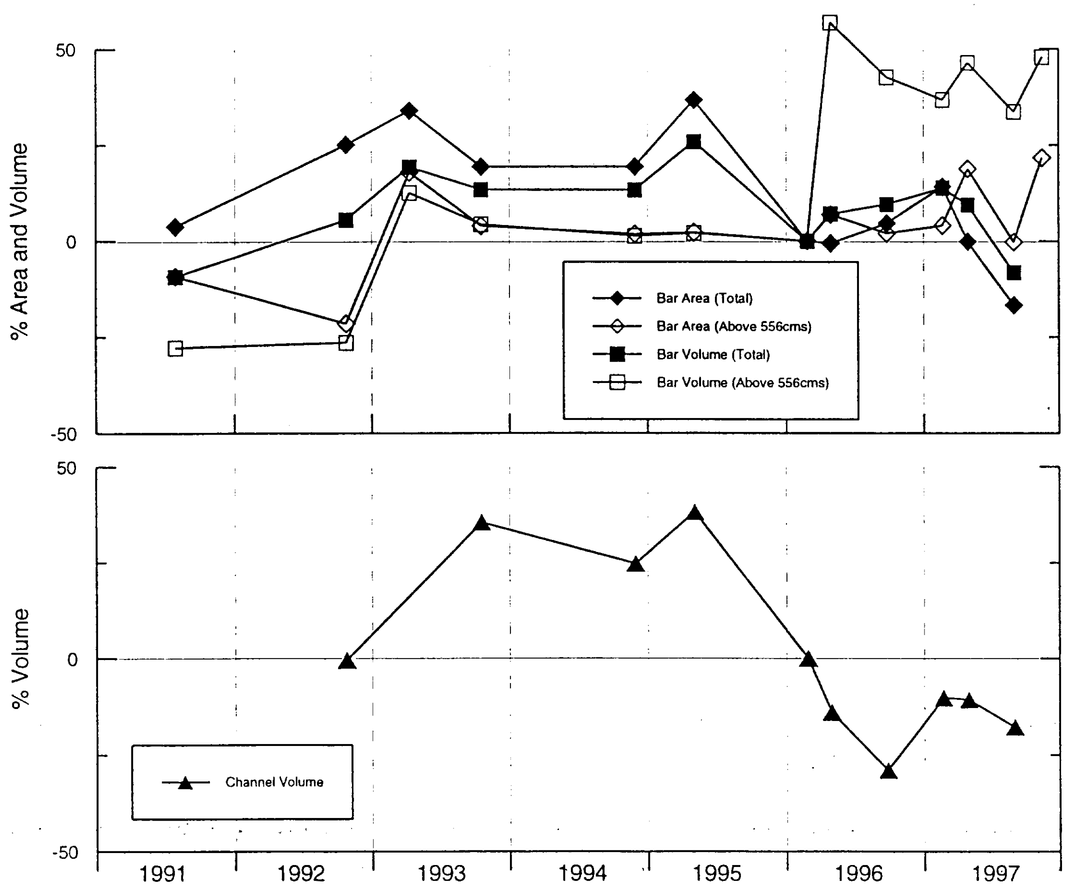
91R

SURVEY DATE	JULIAN DAYS	SAND BAR TOTAL AREA (m2)	SAND BAR > 20 K AREA (m2)	SAND BAR TOTAL VOL (m3)	SAND BAR > 20 K VOL (m3)	EDDY VOL (m3)	CHANNEL VOL (m3)	SAND BAR TOTAL AREA (%)	SAND BAR > 20 K AREA (%)	SAND BAR TOTAL VOL (%)	SAND BAR > 20 K VOL (%)	EDDY VOL (%)	CHANNEL VOL (%)
910727	573	619	283	1453	412			16.79	13.65	11.94	-5.94		
911002	640	468	269	1257	433								
910001	670	466	268	1276	462								
921024	1028	638	262	1401	407	4600	12100	20.38	5.22	7.94	-7.08	12.20	1.68
930408	1195	528	290	1358	482			-0.38	16.47	4.62	10.05		
931016	1385	490	263	1282	468	3000	13300	-7.55	5.62	-1.23	6.85	-26.83	11.76
940416	1567	534	262	1343	467	4600	10500	0.75	5.22	3.47	6.62	12.20	-11.76
941127	1792	558	255	1364	447	6170	11100	5.28	2.41	5.08	2.05	50.49	-6.72
950502	1948	662	260	1447	464	4900	12700	24.91	4.42	11.48	5.94	19.51	6.72
960225	2247	530	249	1298	438	4100	11900	0.00	0.00	0.00	0.00	0.00	0.00
960426	2308	491	267	1402	533	8400	15800	-7.36	7.23	8.01	21.69	104.88	32.77
960922	2457	512	258	1317	488	8322	11200	-3.40	3.61	1.46	11.42	102.98	-5.88
970220	2608	432	255	1275	490	3700	11400	-18.49	2.41	-1.77	11.87	-9.76	-4.20
970430	2677	550	264	1416	497	6500	12200	3.77	6.02	9.09	13.47	58.54	2.52
970901	2801	573	270	1396	458	6800	11700	8.11	8.43	7.55	4.57	65.85	-1.68



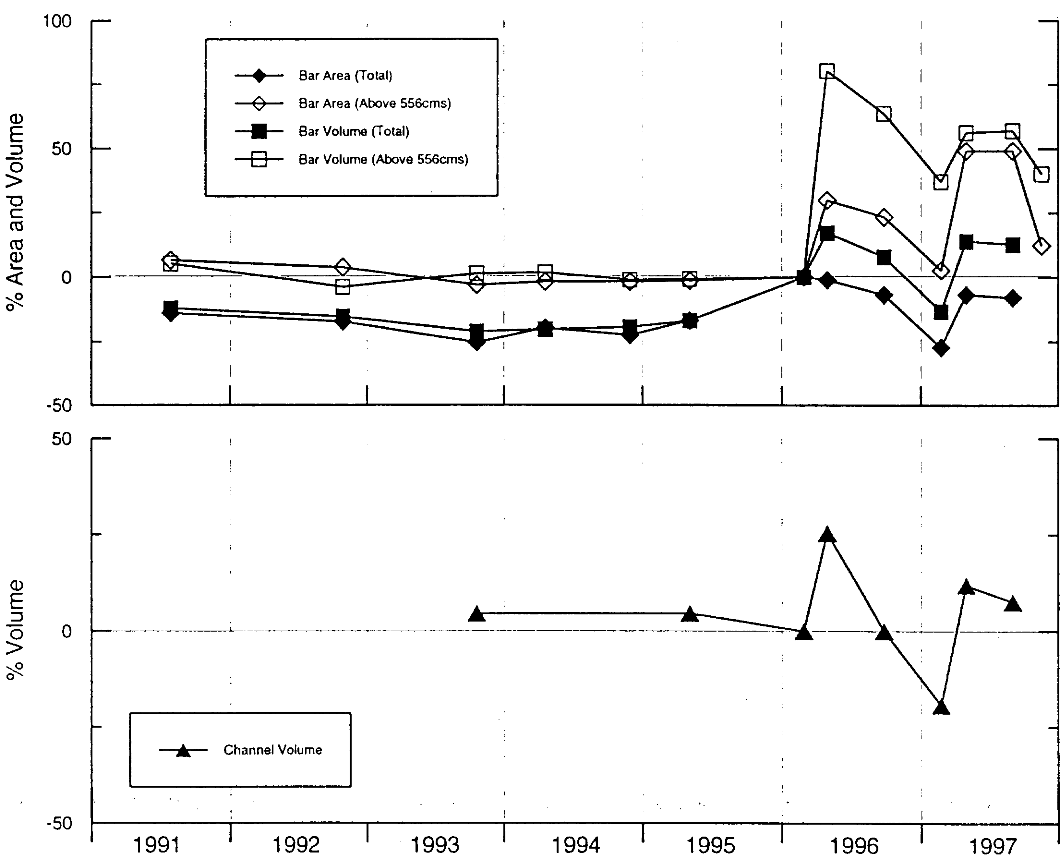
93L

SURVEY DATE	JULIAN DAYS	SAND BAR TOTAL AREA (m2)	SAND BAR > 20 K AREA (m2)	SAND BAR TOTAL VOL (m3)	SAND BAR > 20 K VOL (m3)	EDDY VOL (m3)	CHANNEL VOL (m3)	SAND BAR TOTAL AREA (%)	SAND BAR > 20 K AREA (%)	SAND BAR TOTAL VOL (%)	SAND BAR > 20 K VOL (%)	EDDY VOL (%)	CHANNEL VOL (%)
910727	573	1781	797	2570	382			3.67	-9.23	-9.25	-27.79		
911002	640	1387	723	2115	370								
		0											
921024	1028	2148	689	2986	389		18500	25.03	-21.53	5.44	-26.47		-0.54
930408	1195	2302	1034	3377	595			33.99	17.77	19.24	12.48		
931016	1385	2049	912	3209	552		25200	19.27	3.87	13.31	4.35		35.48
940416	1567	2304	903	3420	546		23500						
941127	1792	2050	894	3206	536		23200	19.32	1.82	13.21	1.32		24.73
940502	1948	2347	897	3562	540		25700	36.61	2.16	25.78	2.08		38.17
960225	2247	1718	878	2832	529		18600	0.00	0.00	0.00	0.00		0.00
960425	2308	1707	938	3030	830		16000	-0.64	6.83	6.99	56.90		-13.98
960922	2457	1797	895	3101	754		13200	4.60	1.94	9.50	42.53		-29.03
970220	2608	1960	913	3219	723		16700	14.09	3.99	13.67	36.67		-10.22
960430	2677	1714	1042	3096	774		16600	-0.23	18.68	9.32	46.31		-10.75
970901	2801	1429	875	2601	707		15300	-16.82	-0.34	-8.16	33.65		-17.74



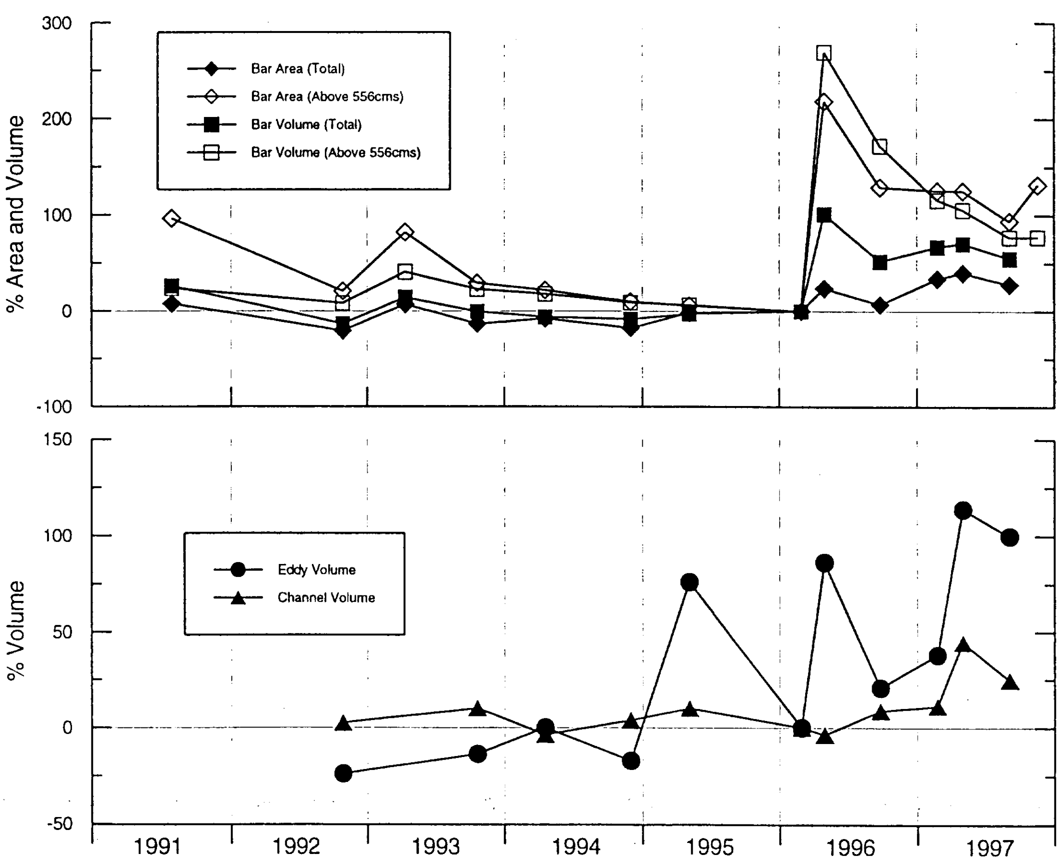
104R

SURVEY DATE	JULIAN DAYS	SAND BAR TOTAL AREA (m2)	SAND BAR > 20 K AREA (m2)	SAND BAR TOTAL VOL (m3)	SAND BAR > 20 K VOL (m3)	EDDY VOL (m3)	CHANNEL VOL (m3)	SAND BAR TOTAL AREA (%)	SAND BAR > 20 K AREA (%)	SAND BAR TOTAL VOL (%)	SAND BAR > 20 K VOL (%)	EDDY VOL (%)	CHANNEL VOL (%)
910727	573	577	278	1268	298			-14.01	6.51	-12.19	5.30		
921025	1029	554	271	1222	272			-17.44	3.83	-15.37	-3.89		
931017	1386	500	253	1137	287		7000	-25.48	-3.07	-21.26	1.41		4.48
940417	1568	538	256	1150	288			-19.82	-1.92	-20.36	1.77		
941127	1792	519	256	1162	280			-22.65	-1.92	-19.53	-1.06		
950503	1949	557	257	1198	281		7000	-16.99	-1.53	-17.04	-0.71		4.48
960226	2248	671	261	1444	283		6700	0.00	0.00	0.00	0.00		0.00
960426	2308	664	339	1691	510		8400	-1.04	29.89	17.11	80.21		25.37
960922	2457	625	322	1559	463		6700	-6.86	23.37	7.96	63.60		0.00
970221	2609	487	268	1251	388		5400	-27.42	2.68	-13.37	37.10		-19.40
960430	2677	625	389	1644	442		7500	-6.86	49.04	13.85	56.18		11.94
970901	2801	617	389	1626	444		7200	-8.05	49.04	12.60	56.89		7.46



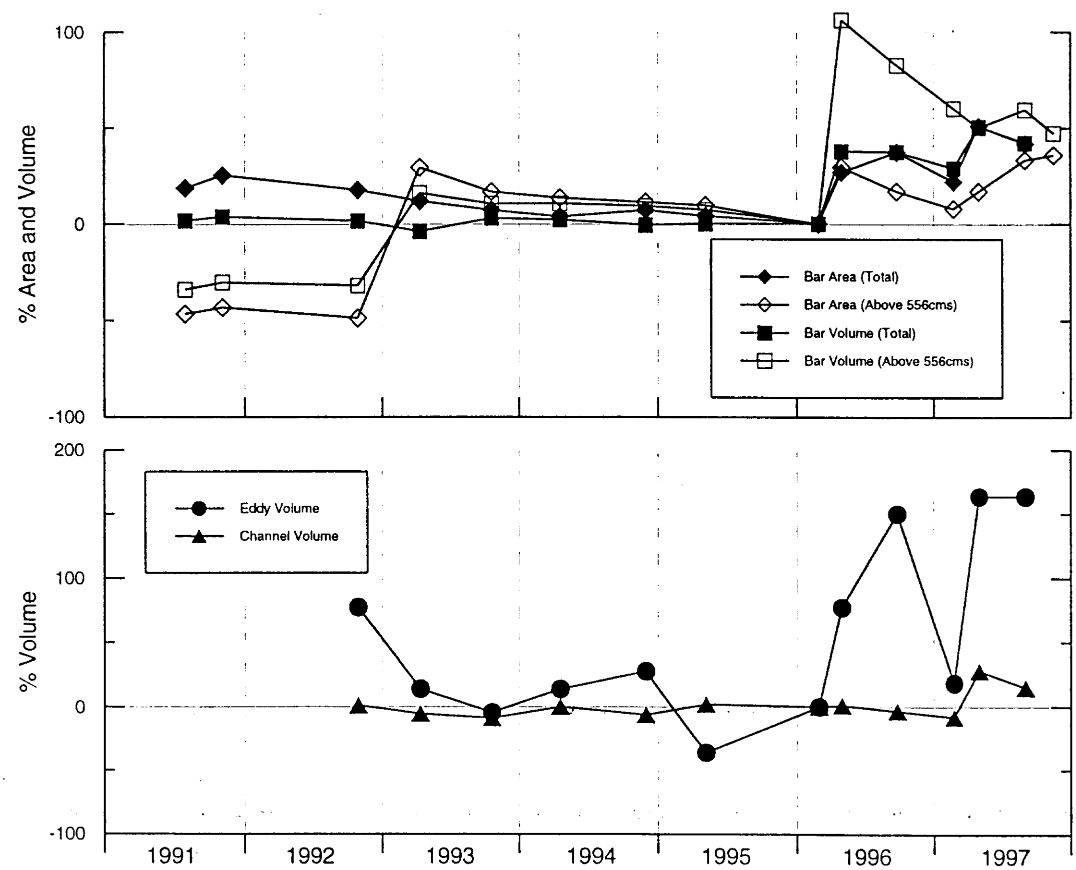
119R

SURVEY DATE	JULIAN DAYS	SAND BAR TOTAL AREA (m2)	SAND BAR > 20 K AREA (m2)	SAND BAR TOTAL VOL (m3)	SAND BAR > 20 K VOL (m3)	EDDY VOL (m3)	CHANNEL VOL (m3)	SAND BAR TOTAL AREA (%)	SAND BAR > 20 K AREA (%)	SAND BAR TOTAL VOL (%)	SAND BAR > 20 K VOL (%)	EDDY VOL (%)	CHANNEL VOL (%)
910728	574	3658	1540	8614	1679			7.78	96.43	26.53	24.09		
911004	642	3153	1348	7217	1563								
921026	1030	2678	949	5893	1467	2200	8300	-21.10	21.05	-13.44	8.43	-24.14	2.47
930410	1196	3637	1428	7786	1906			7.16	82.14	14.37	40.87		
931018	1387	2935	1015	6769	1664	2500	8900	-13.52	29.46	-0.57	22.99	-13.79	9.88
940417	1568	3123	957	6376	1597	2900	7800	-7.98	22.07	-6.35	18.03	0.00	-3.70
941128	1793	2784	861	6213	1474	2400	8400	-17.97	9.82	-8.74	8.94	-17.24	3.70
950503	1949	3332	829	6615	1440	5100	8900	-1.83	5.74	-2.83	6.43	75.86	9.88
960226	2248	3394	784	6808	1353	2900	8100	0.00	0.00	0.00	0.00	0.00	0.00
960427	2309	4208	2493	13693	4999	5400	7800	23.98	217.98	101.13	269.48	86.21	-3.70
960922	2457	3627	1796	10353	3680	3500	8800	6.87	129.08	52.07	171.99	20.69	8.64
970221	2609	4545	1768	11365	2918	4000	9000	33.91	125.51	66.94	115.67	37.93	11.11
970501	2678	4753	1763	11594	2778	6200	11700	40.04	124.87	70.30	105.32	113.79	44.44
970902	2802	4341	1518	10542	2396	5800	10100	27.90	93.62	54.85	77.09	100.00	24.69



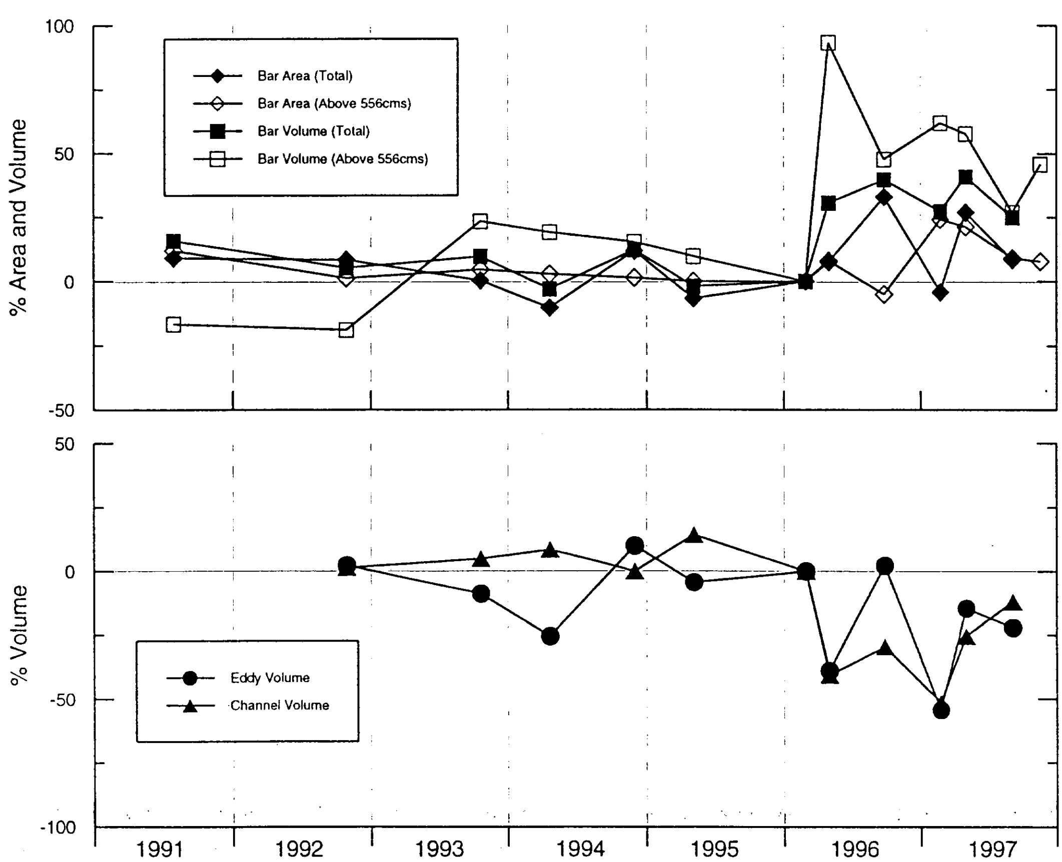
122R

SURVEY DATE	JULIAN DAYS	SAND BAR TOTAL AREA (m2)	SAND BAR > 20 K AREA (m2)	SAND BAR TOTAL VOL (m3)	SAND BAR > 20 K VOL (m3)	EDDY VOL (m3)	CHANNEL VOL (m3)	SAND BAR TOTAL AREA (%)	SAND BAR > 20 K AREA (%)	SAND BAR TOTAL VOL (%)	SAND BAR > 20 K VOL (%)	EDDY VOL (%)	CHANNEL VOL (%)
910728	574	5108	1077	11122	1082			18.41	-46.58	1.63	-33.98		
		5402	1095	11353	1100			25.22	-45.68	3.74	-32.89		
911103	672	5402	1144	11353	1144			25.22	-43.25	3.74	-30.20		
921027	1031	5066	1035	11110	1114	3900	11000	17.43	-48.66	1.52	-32.03	77.27	0.92
930409	1196	4822	2605	10500	1898	2500	10300	11.78	29.22	-4.06	15.80	13.64	-5.50
931018	1387	4619	2351	11254	1809	2100	9900	7.07	16.62	2.83	10.37	-4.55	-9.17
940417	1568	4472	2288	11164	1811	2500	10900	3.66	13.49	2.01	10.49	13.64	0.00
941128	1793	4619	2245	10868	1790	2800	10200	7.07	11.36	-0.69	9.21	27.27	-6.42
950504	1950	4484	2211	10944	1757	1400	11100	3.94	9.67	0.00	7.20	-36.36	1.83
960227	2249	4314	2016	10944	1639	2200	10900	0.00	0.00	0.00	0.00	0.00	0.00
960428	2310	5463	2610	15062	3376	3900	11000	26.63	29.46	37.63	105.98	77.27	0.92
960923	2458	5915	2355	15036	2989	5500	10500	37.11	16.82	37.39	82.37	150.00	-3.67
970222	2610	5249	2172	14085	2624	2600	10000	21.67	7.74	28.70	60.10	18.18	-8.26
970501	2678	6509	2355	16473	2458	5800	13900	50.88	16.82	50.52	49.97	163.64	27.52
970902	2802	6104	2682	15542	2612	5800	12500	41.49	33.04	42.01	59.37	163.64	14.68



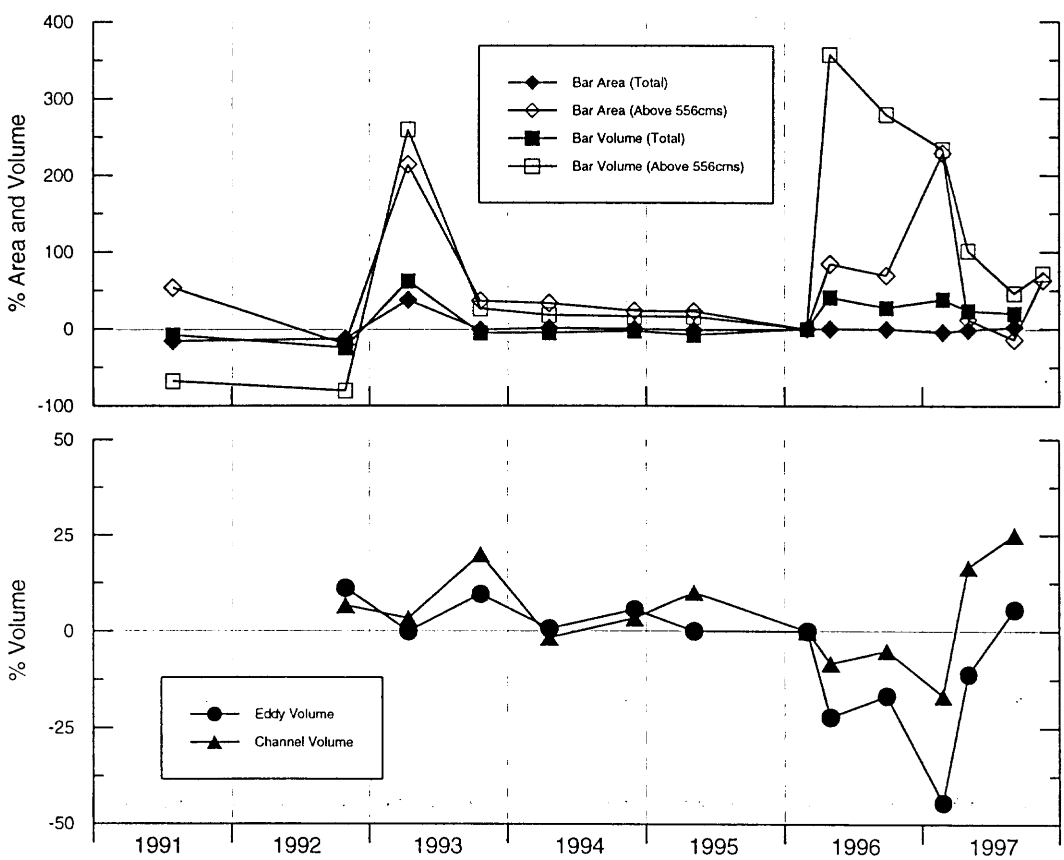
123L

SURVEY DATE	JULIAN DAYS	SAND BAR TOTAL AREA (m2)	SAND BAR > 20 K AREA (m2)	SAND BAR TOTAL VOL (m3)	SAND BAR > 20 K VOL (m3)	EDDY VOL (m3)	CHANNEL VOL (m3)	SAND BAR TOTAL AREA (%)	SAND BAR > 20 K AREA (%)	SAND BAR TOTAL VOL (%)	SAND BAR > 20 K VOL (%)	EDDY VOL (%)	CHANNEL VOL (%)
910728	574	1898	695	3178	414			9.02	23.89	15.69	-16.70		
921027	1031	1886	575	2889	403	9200	22700	8.33	2.50	5.17	-18.91	2.22	1.34
931018	1387	1743	611	3009	613	8200	23500	0.11	8.91	9.54	23.34	-8.89	4.91
940419	1570	1562	592	2662	592	6700	24300	-10.28	5.53	-3.09	19.11	-25.56	8.48
941128	1793	1946	576	3080	573	9900	22400	11.77	2.67	12.12	15.29	10.00	0.00
950504	1950	1625	561	2695	545	8600	25600	-6.66	0.00	-1.89	9.66	-4.44	14.29
960227	2249	1741	561	2747	497	9000	22400	0.00	0.00	0.00	0.00	0.00	0.00
960428	2310	1870	651	3585	961	5500	13300	7.41	16.04	30.51	93.36	-38.89	-40.63
960923	2458	2314	505	3838	734	9200	15800	32.91	-9.98	39.72	47.69	2.22	-29.46
970222	2610	1665	832	3493	804	4100	10900	-4.37	48.31	27.16	61.77	-54.44	-51.34
970501	2679	2207	800	3868	783	7700	16700	26.77	42.60	40.81	57.55	-14.44	-25.45
970903	2803	1886	663	3432	630	7000	19700	8.33	18.18	24.94	26.76	-22.22	-12.05



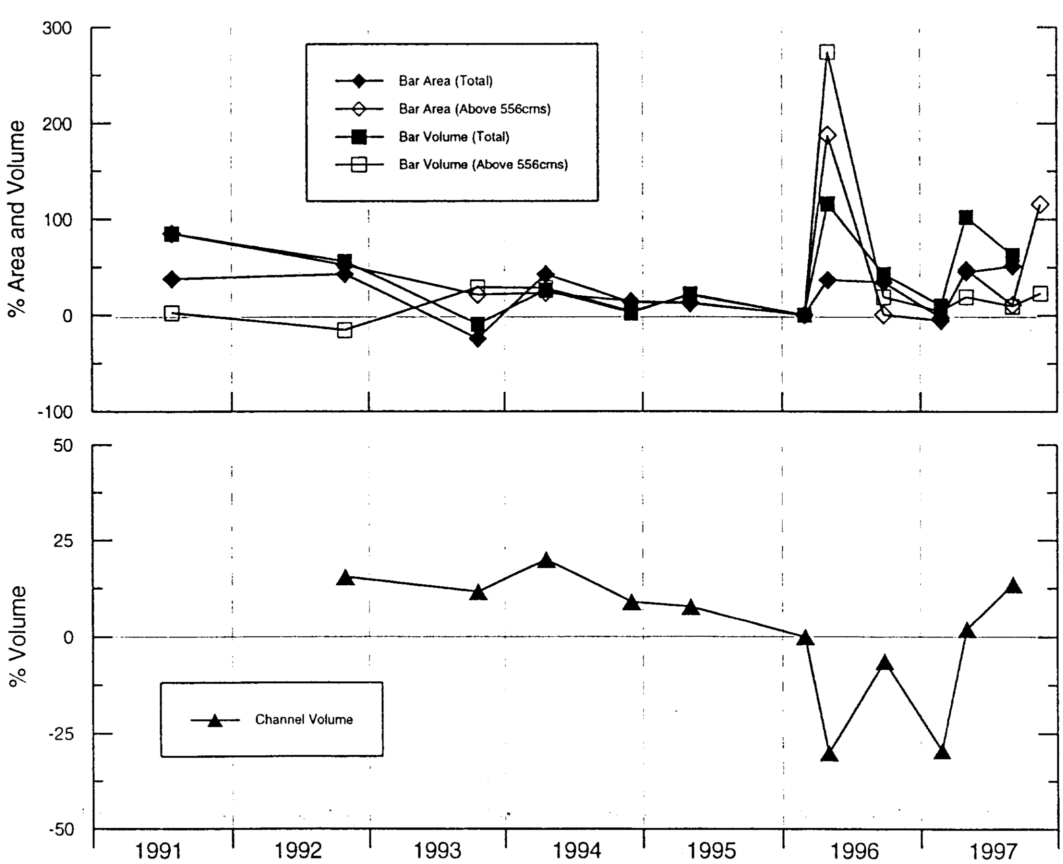
137L

SURVEY DATE	JULIAN DAYS	SAND BAR TOTAL AREA (m2)	SAND BAR > 20 K AREA (m2)	SAND BAR TOTAL VOL (m3)	SAND BAR > 20 K VOL (m3)	EDDY VOL (m3)	CHANNEL VOL (m3)	SAND BAR TOTAL AREA (%)	SAND BAR > 20 K AREA (%)	SAND BAR TOTAL VOL (%)	SAND BAR > 20 K VOL (%)	EDDY VOL (%)	CHANNEL VOL (%)
910729	575	2976	940	5579	165			-16.15	53.59	-8.50	-68.27		
911005	642	3078	647	4726	102								
911104	673	3041	701	4789	150								
921028	1032	3071	486	4573	100	2000	6400	-13.47	-20.59	-25.00	-80.77	11.11	6.67
930411	1197	4864	1923	9866	1868	1800	6200	37.05	214.22	61.82	259.23	0.00	3.33
931019	1388	3494	834	5734	655	1972	7200	-1.55	36.27	-5.95	25.96	9.56	20.00
940418	1569	3579	817	5787	612	1811	5900	0.85	33.50	-5.08	17.69	0.61	-1.67
941129	1794	3543	754	5887	603	1900	6200	-0.17	23.20	-3.44	15.96	5.56	3.33
950505	1951	3478	751	5598	600	1800	6600	-2.00	22.71	-8.18	15.38	0.00	10.00
960228	2250	3549	612	6097	520	1800	6000	0.00	0.00	0.00	0.00	0.00	0.00
960428	2310	3542	1130	8588	2375	1400	5500	-0.20	84.64	40.86	356.73	-22.22	-8.33
960924	2459	3525	1036	7759	1970	1500	5700	-0.68	69.28	27.26	278.85	-16.67	-5.00
970223	2611	3375	2011	8404	1735	1000	5000	-4.90	228.59	37.84	233.65	-44.44	-16.67
970502	2680	3480	686	7497	1045	1600	7000	-1.94	12.09	22.96	100.96	-11.11	16.67
970903	2803	3606	526	7300	758	1900	7500	1.61	-14.05	19.73	45.77	5.56	25.00



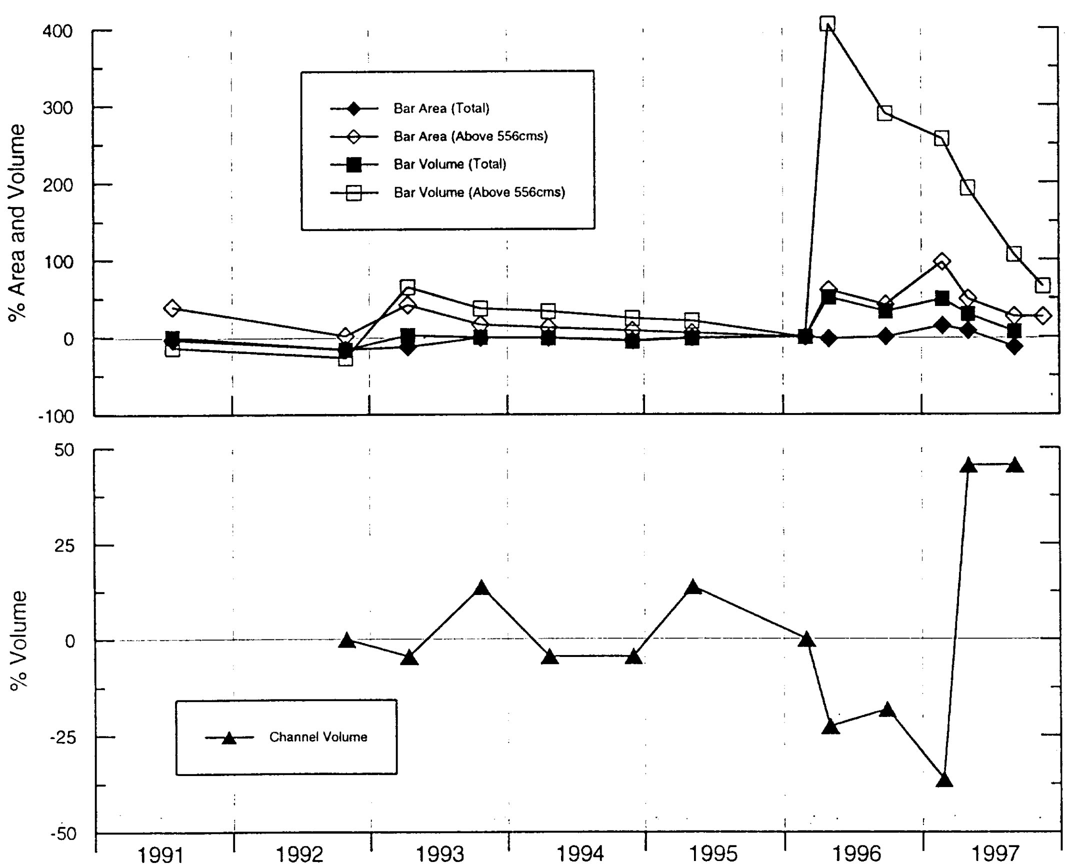
139R

SURVEY DATE	JULIAN DAYS	SAND BAR TOTAL AREA (m2)	SAND BAR > 20 K AREA (m2)	SAND BAR TOTAL VOL (m3)	SAND BAR > 20 K VOL (m3)	EDDY VOL (m3)	CHANNEL VOL (m3)	SAND BAR TOTAL AREA (%)	SAND BAR > 20 K AREA (%)	SAND BAR TOTAL VOL (%)	SAND BAR > 20 K VOL (%)	EDDY VOL (%)	CHANNEL VOL (%)
910729	575	1820	406	3397	136			37.57	85.39	84.92	2.26		
921028	1032	1887	333	2864	112		18000	42.63	52.05	55.91	-15.79		15.38
931019	1388	997	265	1657	171		17400	-24.64	21.00	-9.80	28.57		11.54
940418	1570	1883	270	2305	170		18700	42.33	23.29	25.48	27.82		19.87
941130	1795	1495	250	1877	138		17000	13.00	14.16	2.18	3.76		8.97
950505	1951	1478	247	2237	160		16800	11.72	12.79	21.77	20.30		7.69
960228	2250	1323	219	1837	133		15600	0.00	0.00	0.00	0.00		0.00
960429	2311	1802	630	3960	497		10900	36.21	187.67	115.57	273.68		-30.13
960924	2459	1773	220	2618	158		14600	34.01	0.46	42.51	18.80		-6.41
970224	2612	1282	206	2011	138		11000	-3.10	-5.94	9.47	3.76		-29.49
970502	2680	1912	323	3710	158		15900	44.52	47.49	101.96	18.80		1.92
970903	2803	2000	242	2984	145		17700	51.17	10.50	62.44	9.02		13.46



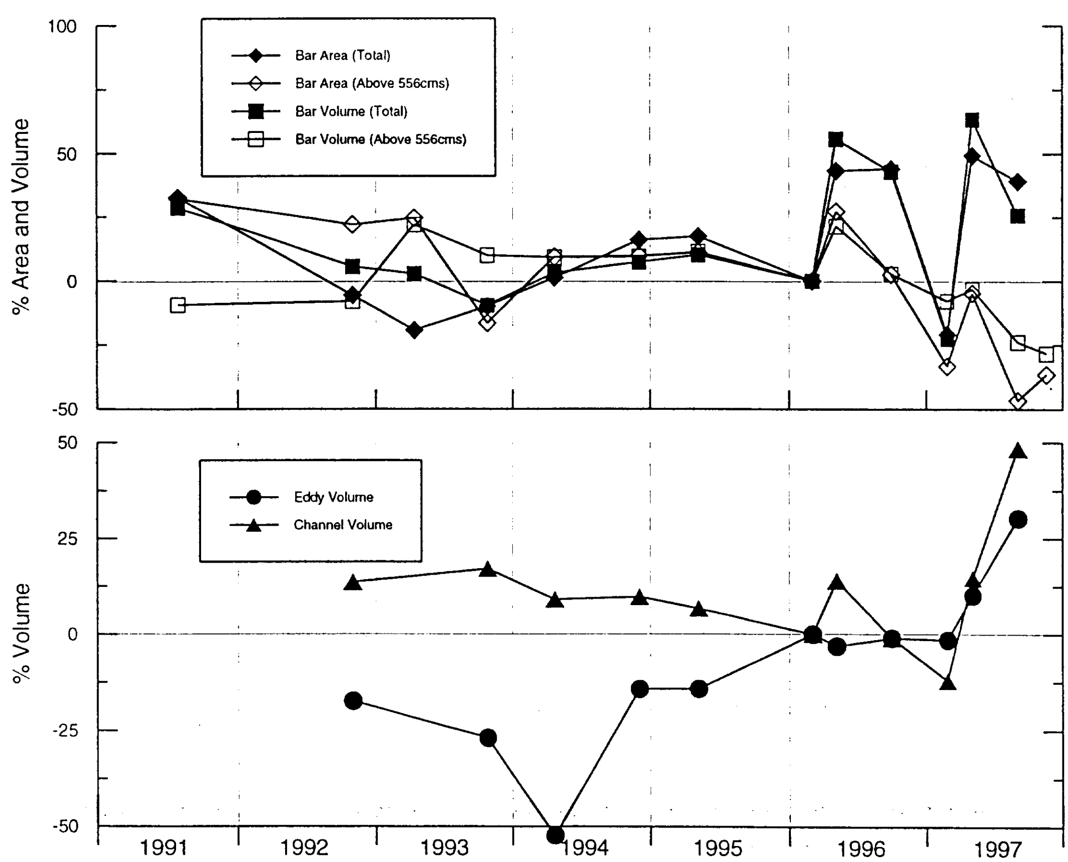
145L

SURVEY DATE	JULIAN DAYS	SAND BAR TOTAL AREA (m2)	SAND BAR > 20 K AREA (m2)	SAND BAR TOTAL VOL (m3)	SAND BAR > 20 K VOL (m3)	EDDY VOL (m3)	CHANNEL VOL (m3)	SAND BAR TOTAL AREA (%)	SAND BAR > 20 K AREA (%)	SAND BAR TOTAL VOL (%)	SAND BAR > 20 K VOL (%)	EDDY VOL (%)	CHANNEL VOL (%)
910727	573	644	358	1620	160			-3.88	38.76	0.25	-13.51		
911006	644	623	316	1478	137								
911105	674	596	317	1451	157								
921029	1033	560	261	1347	135		2200	-16.42	1.16	-16.65	-27.03		0.00
930411	1197	583	364	1650	304		2100	-12.99	41.09	2.10	64.32		-4.55
931020	1389	662	299	1608	253		2500	-1.19	15.89	-0.50	36.76		13.64
940419	1570	662	289	1594	246		2100	-1.19	12.02	-1.36	32.97		-4.55
941130	1795	638	279	1526	229		2100	-4.78	8.14	-5.57	23.78		-4.55
950506	1952	662	271	1584	223		2500	-1.19	5.04	-1.98	20.54		13.64
960228	2250	670	258	1616	185		2200	0.00	0.00	0.00	0.00		0.00
960429	2311	653	413	2437	935		1700	-2.54	60.08	50.80	405.41		-22.73
960925	2460	671	365	2140	719		1800	0.15	41.47	32.43	288.65		-18.18
970224	2612	765	508	2402	659		1400	14.18	96.90	48.64	256.22		-36.36
970503	2681	723	384	2087	541		3200	7.91	48.84	29.15	192.43		45.45
970904	2804	582	326	1726	382		3200	-13.13	26.36	6.81	106.49		45.45



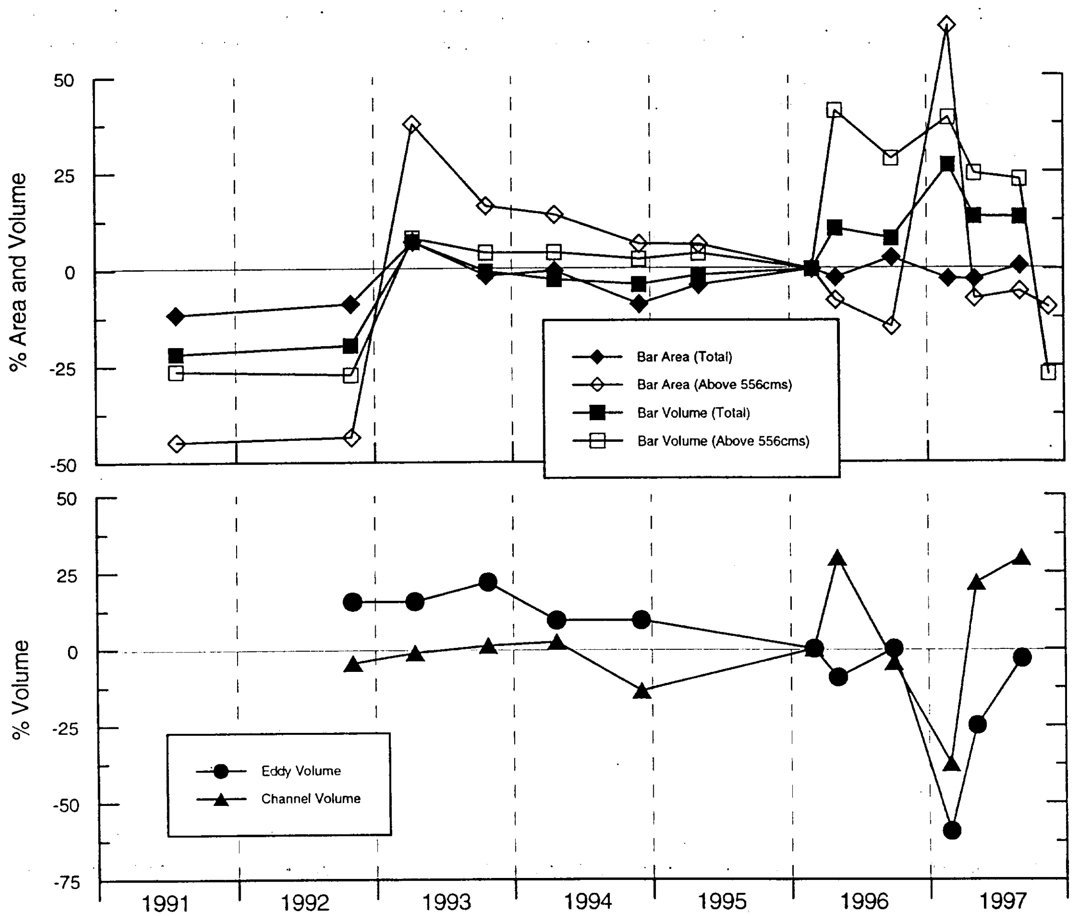
172L

SURVEY DATE	JULIAN DAYS	SAND BAR TOTAL AREA (m2)	SAND BAR > 20 K AREA (m2)	SAND BAR TOTAL VOL (m3)	SAND BAR > 20 K VOL (m3)	EDDY VOL (m3)	CHANNEL VOL (m3)	SAND BAR TOTAL AREA (%)	SAND BAR > 20 K AREA (%)	SAND BAR TOTAL VOL (%)	SAND BAR > 20 K VOL (%)	EDDY VOL (%)	CHANNEL VOL (%)
910728	574	3829	1518	6306	789			32.72	32.35	28.64	-9.41		
911007	645	2376	1411	4647	808								
911106	675	2410	1424	4680	813								
921030	1034	2722	1400	5176	801	5200	32700	-5.65	22.06	5.59	-8.04	-17.46	13.54
930412	1198	2324 0	1430	5043	1063			-19.45	24.67	2.88	22.04		
941023	1392	2596	958	4432	958	4600	33700	-10.02	-16.48	-9.59	9.99	-26.98	17.01
940421	1572	2919	1255	5064	951	3000	31400	1.18	9.42	3.30	9.18	-52.38	9.03
941201	1796	3348	1260	5262	953	5400	31600	16.05	9.85	7.34	9.41	-14.29	9.72
950507	1953	3384	1276	5399	970	5400	30700	17.30	11.25	10.14	11.37	-14.29	6.60
960229	2251	2885	1147	4902	871	6300	28800	0.00	0.00	0.00	0.00	0.00	0.00
960501	2314	4133	1461	7627	1057	6100	32800	43.26	27.38	55.59	21.35	-3.17	13.89
960926	2461	4154	1177	7006	895	6237	28500	43.99	2.62	42.92	2.76	-1.00	-1.04
970225	2613	2274	765	3782	801	6200	25300	-21.18	-33.30	-22.85	-8.04	-1.59	-12.15
970504	2682	4301	1092	8005	843	6931	33000	49.08	-4.80	63.30	-3.21	10.02	14.58
970904	2804	4012	612	6167	662	8200	42700	39.06	-46.64	25.81	-24.00	30.16	48.26



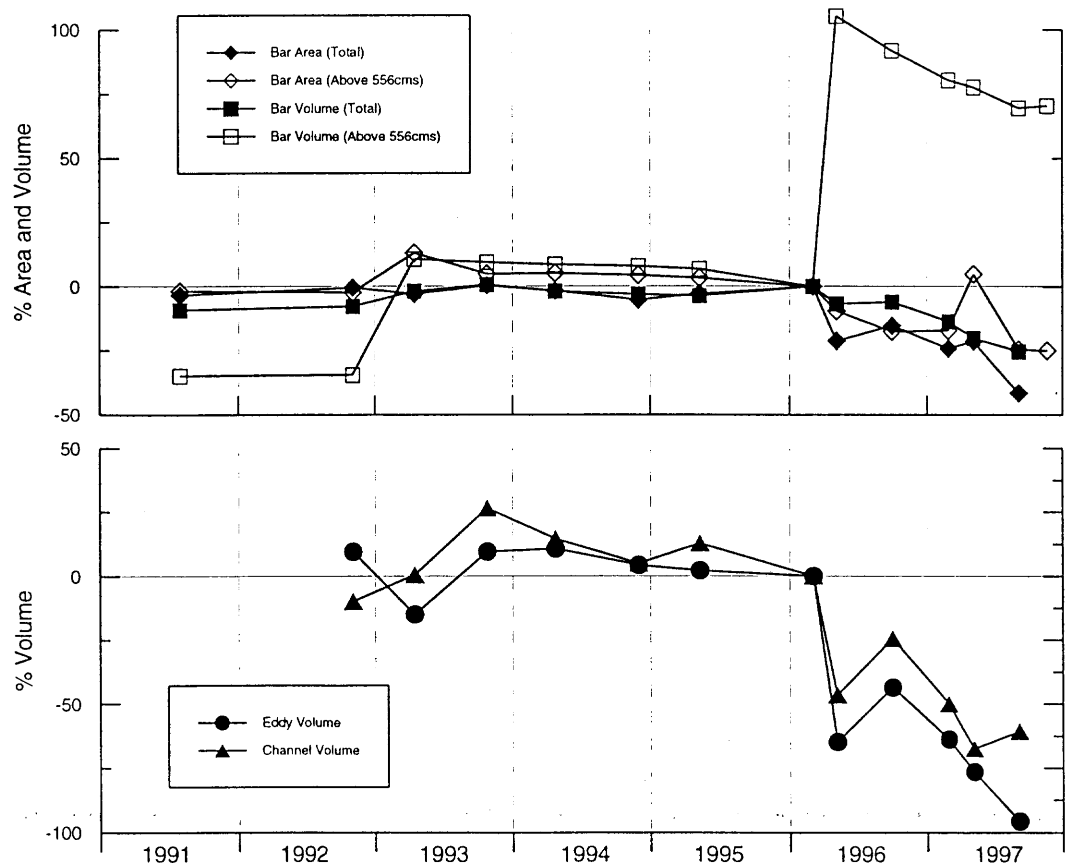
183R

SURVEY DATE	JULIAN DAYS	SAND BAR TOTAL AREA (m2)	SAND BAR > 20 K AREA (m2)	SAND BAR TOTAL VOL (m3)	SAND BAR > 20 K VOL (m3)	EDDY VOL (m3)	CHANNEL VOL (m3)	SAND BAR TOTAL AREA (%)	SAND BAR > 20 K AREA (%)	SAND BAR TOTAL VOL (%)	SAND BAR > 20 K VOL (%)	EDDY VOL (%)	CHANNEL VOL (%)
910728	574	2595	641	5327	1470			-11.58	-44.69	-21.79	-26.32		
911008	646	2762	638	5413	1460								
921031	1035	2675	655	5477	1451	3700	8400	-8.86	-43.49	-19.59	-27.27	15.63	-4.55
930412	1198	3146	1594	7298	2156	3700	8700	7.19	37.53	7.15	8.07	15.63	-1.14
931023	1392	2885	1348	6776	2080	3900	8900	-1.70	16.31	-0.51	4.26	21.88	1.14
940422	1572	2922	1321	6630	2081	3500	9000	-0.44	13.98	-2.66	4.31	9.38	2.27
941201	1796	2668	1234	6538	2046	3500	7600	-9.10	6.47	-4.01	2.56	9.38	-13.64
950508	1954	2812	1233	6704	2075			-4.19	6.38	-1.57	4.01		
960229	2251	2935	1159	6811	1995	3200	8800	0.00	0.00	0.00	0.00	0.00	0.00
960501	2313	2868	1065	7518	2807	2900	11400	-2.28	-8.11	10.38	40.70	-9.38	29.55
960926	2461	3020	986	7345	2559	3200	8400	2.90	-14.93	7.84	28.27	0.00	-4.55
970225	2613	2858	1886	8624	2771	1300	5500	-2.62	62.73	26.62	38.90	-59.38	-37.50
970505	2683	2856	1070	7723	2483	2400	10700	-2.69	-7.68	13.39	24.46	-25.00	21.59
970905	2805	2957	1091	7713	2453	3100	11400	0.75	-5.87	13.24	22.96	-3.13	29.55



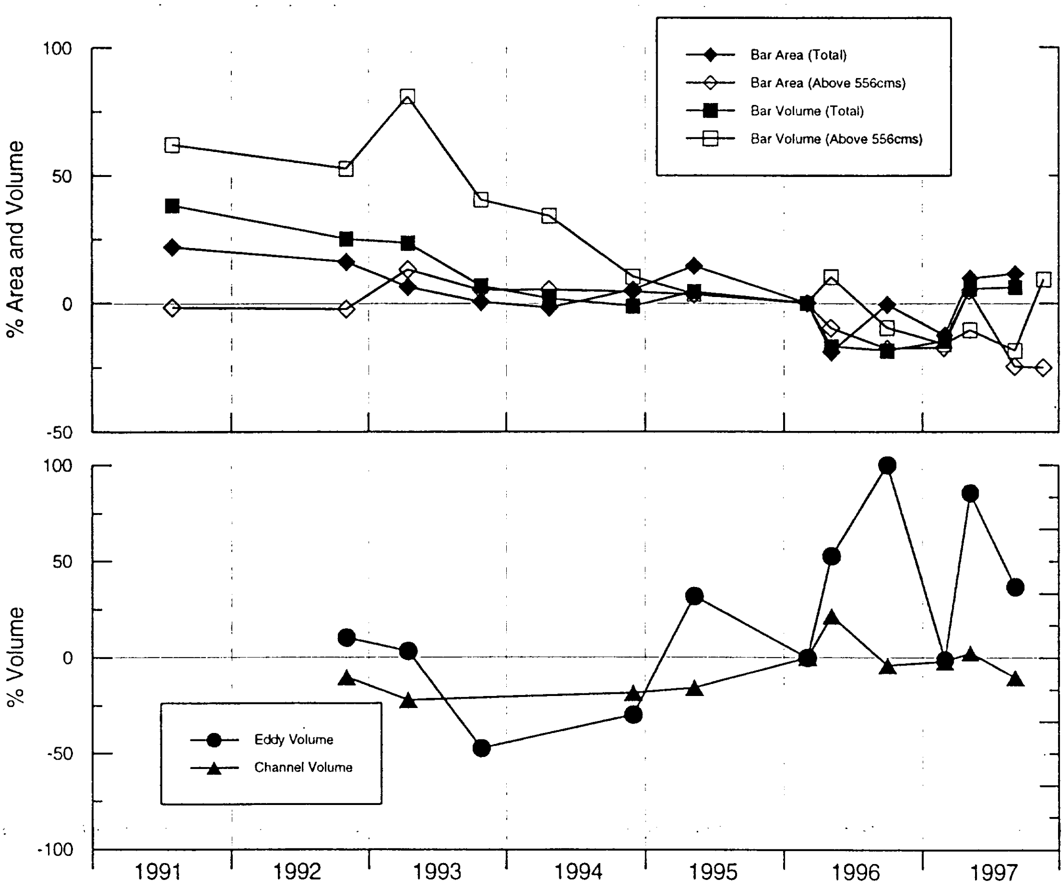
194L

SURVEY DATE	JULIAN DAYS	SAND BAR TOTAL AREA (m2)	SAND BAR > 20 K AREA (m2)	SAND BAR TOTAL VOL (m3)	SAND BAR > 20 K VOL (m3)	EDDY VOL (m3)	CHANNEL VOL (m3)	SAND BAR TOTAL AREA (%)	SAND BAR > 20 K AREA (%)	SAND BAR TOTAL VOL (%)	SAND BAR > 20 K VOL (%)	EDDY VOL (%)	CHANNEL VOL (%)
910729	575	5171	2637	9832	1031			-3.62	-1.71	-9.38	-34.95		
		5162	2570	9673	1022								
		5055	2667	9896	1182								
921101	1036	5337	2621	9984	1038	10300	34600	-0.52	-2.31	-7.98	-34.51	9.57	-9.90
930413	1199	5202	3034	10643	1752	8000	38600	-3.04	13.08	-1.91	10.54	-14.89	0.52
931023	1392	5381	2817	10917	1732	10300	48600	0.30	4.99	0.62	9.27	9.57	26.56
940422	1573	5269	2821	10649	1718	10400	44000	-1.79	5.14	-1.85	8.39	10.64	14.58
941202	1793	5072	2801	10509	1709	9800	40300	-5.46	4.40	-3.14	7.82	4.26	4.95
950509	1955	5209	2771	10433	1691	9600	43300	-2.91	3.28	-3.84	6.69	2.13	12.76
960301	2252	5365	2683	10850	1585	9400	38400	0.00	0.00	0.00	0.00	0.00	0.00
960502	2314	4214	2423	10101	3252	3300	20500	-21.45	-9.69	-6.90	105.17	-64.89	-46.61
960927	2462	4532	2210	10178	3038	5300	29000	-15.53	-17.63	-6.19	91.67	-43.62	-24.48
970226	2614	4051	2219	9344	2855	3400	19200	-24.49	-17.29	-13.88	80.13	-63.83	-50.00
970505	2683	4200	2811	8627	2811	2200	12500	-21.71	4.77	-20.49	77.35	-76.60	-67.45
970905	2805	3126	2023	8073	2685	400	15100	-41.73	-24.60	-25.59	69.40	-95.74	-60.68



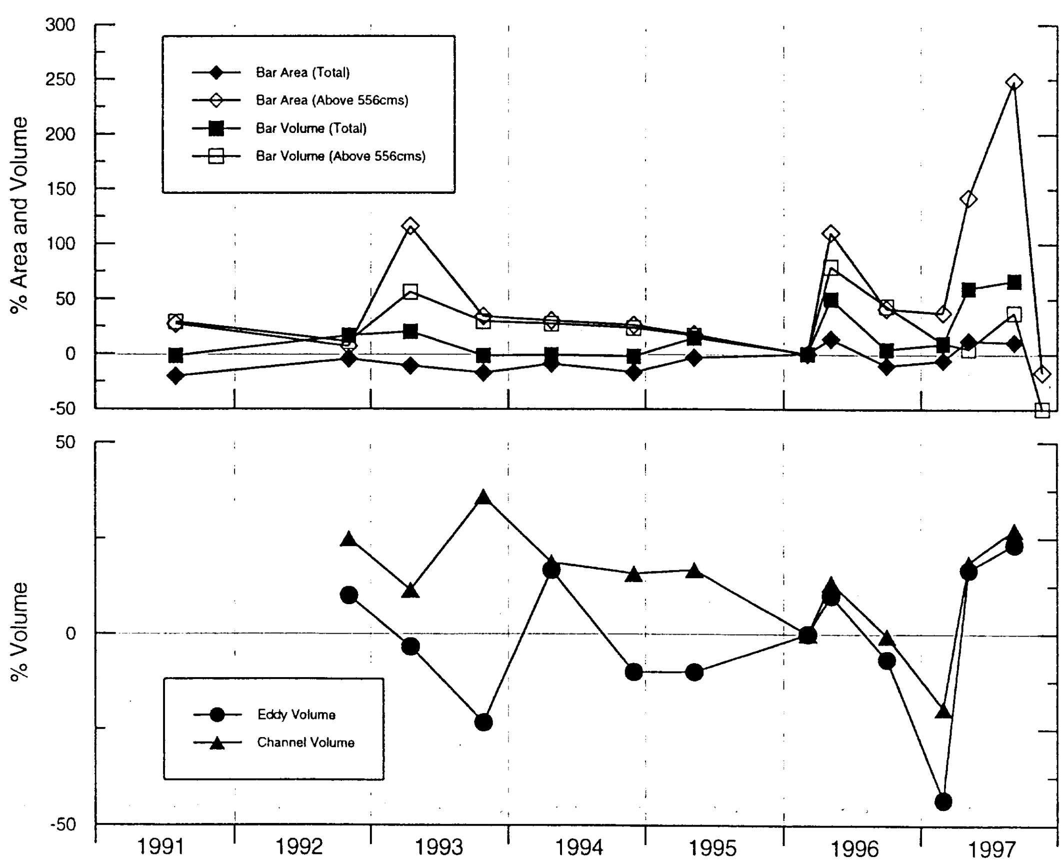
202R

		SAND BAR				EDDY	CHANNEL	SAND BAR				EDDY	CHANNEL
SURVEY DATE	JULIAN DAYS	TOTAL AREA (m2)	> 20 K AREA (m2)	TOTAL VOL (m3)	> 20 K VOL (m3)	VOL (m3)	VOL (m3)	TOTAL AREA (%)	> 20 K AREA (%)	TOTAL VOL (%)	> 20 K VOL (%)	VOL (%)	VOL (%)
910729	575	2926	1512	5909	1213			21.87	56.52	38.13	61.95		
921101	1036	2785	1265	5350	1142	17400	17500	15.99	30.95	25.06	52.47	10.13	-10.26
930413	1199	2550	1576	5274	1354	16300	15200	6.21	63.15	23.28	80.77	3.16	-22.05
931024	1393	2409	1120	4563	1050	8300		0.33	15.94	6.66	40.19	-47.47	
940423	1574	2355	1075	4354	1002			-1.92	11.28	1.78	33.78		
941202	1794	2523	945	4225	826	11100	15900	5.08	-2.17	-1.24	10.28	-29.75	-18.46
950509	1955	2746	898	4464	775	20793	16400	14.37	-7.04	4.35	3.47	31.60	-15.90
960301	2252	2401	966	4278	749	15800	19500	0.00	0.00	0.00	0.00	0.00	0.00
960503	2315	1944	767	3557	825	24100	23700	-19.03	-20.60	-16.85	10.15	52.53	21.54
960927	2462	2384	705	3487	677	31600	18700	-0.71	-27.02	-18.49	-9.61	100.00	-4.10
970228	2616	2096	740	3647	629	15600	19100	-12.70	-23.40	-14.75	-16.02	-1.27	-2.05
970507	2685	2632	965	4512	670	29300	20000	9.62	-0.10	5.47	-10.55	85.44	2.56
970906	2806	2674	876	4541	610	21600	17500	11.37	-9.32	6.15	-18.56	36.71	-10.26



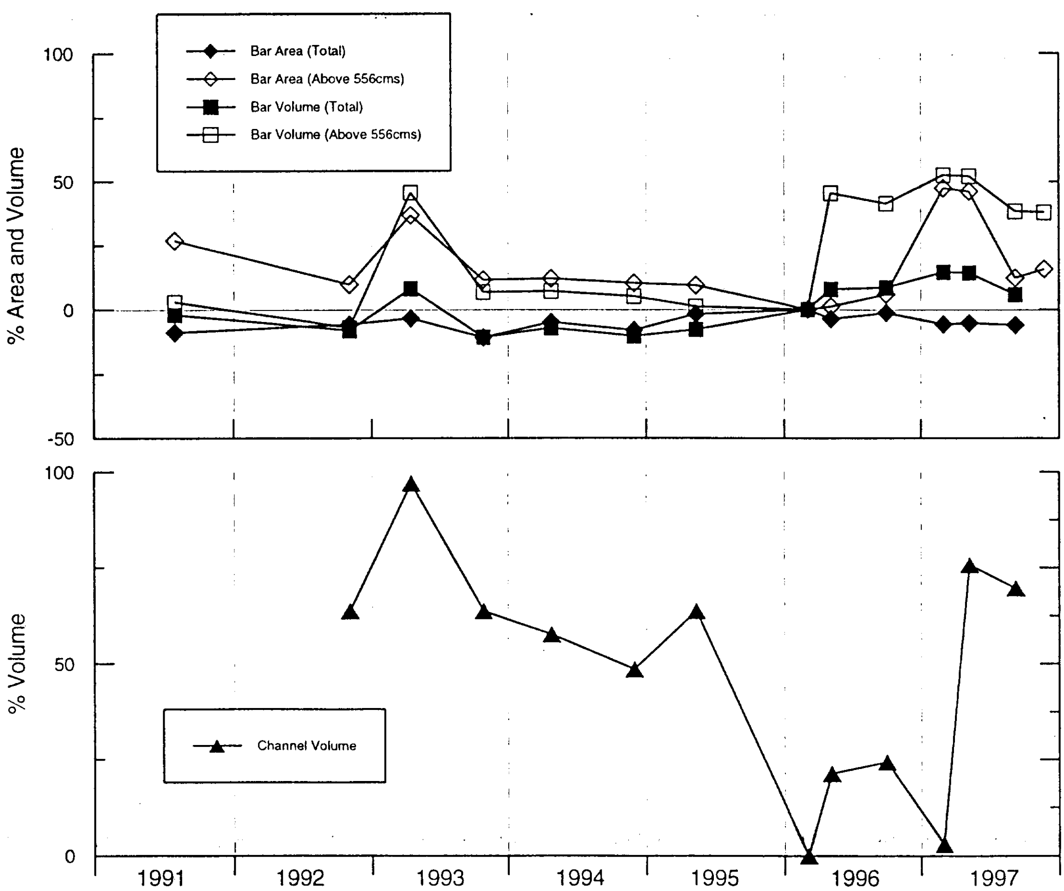
213L

		SAND BAR				EDDY	CHANNEL	SAND BAR				EDDY	CHANNEL
SURVEY DATE	JULIAN DAYS	TOTAL AREA (m2)	> 20 K AREA (m2)	TOTAL VOL (m3)	> 20 K VOL (m3)	VOL (m3)	VOL (m3)	TOTAL AREA (%)	> 20 K AREA (%)	TOTAL VOL (%)	> 20 K VOL (%)	VOL (%)	VOL (%)
910729	575	1684	584	4596	817			-20.53	27.51	-1.65	29.27		
921102	1037	2022	489	5454	702	3300	26100	-4.58	6.77	16.71	11.08	10.00	24.88
930414	1200	1885	989	5614	986	2900	23300	-11.04	115.94	20.14	56.01	-3.33	11.48
931025	1394	1749	615	4595	818	2300	28400	-17.46	34.28	-1.67	29.43	-23.33	35.89
940423	1575	1924	597	4641	805	3500	24800	-9.20	30.35	-0.68	27.37	16.67	18.66
941204	1794	1757	580	4568	781	2700	24200	-17.08	26.64	-2.25	23.58	-10.00	15.79
950509	1955	2047	540	5355	737	2700	24400	-3.40	17.90	14.59	16.61	-10.00	16.75
960303	2254	2119	458	4673	632	3000	20900	0.00	0.00	0.00	0.00	0.00	0.00
960503	2315	2410	963	7006	1132	3300	23700	13.73	110.26	49.93	79.11	10.00	13.40
960928	2463	1893	647	4871	906	2800	20800	-10.67	41.27	4.24	43.35	-6.67	-0.48
970228	2616	1992	629	5093	695	1700	16800	-5.99	37.34	8.99	9.97	-43.33	-19.62
970507	2685	2374	1109	7455	660	3500	24800	12.03	142.14	59.53	4.43	16.67	18.66
970907	2807	2342	1595	7775	867	3700	26600	10.52	248.25	66.38	37.18	23.33	27.27



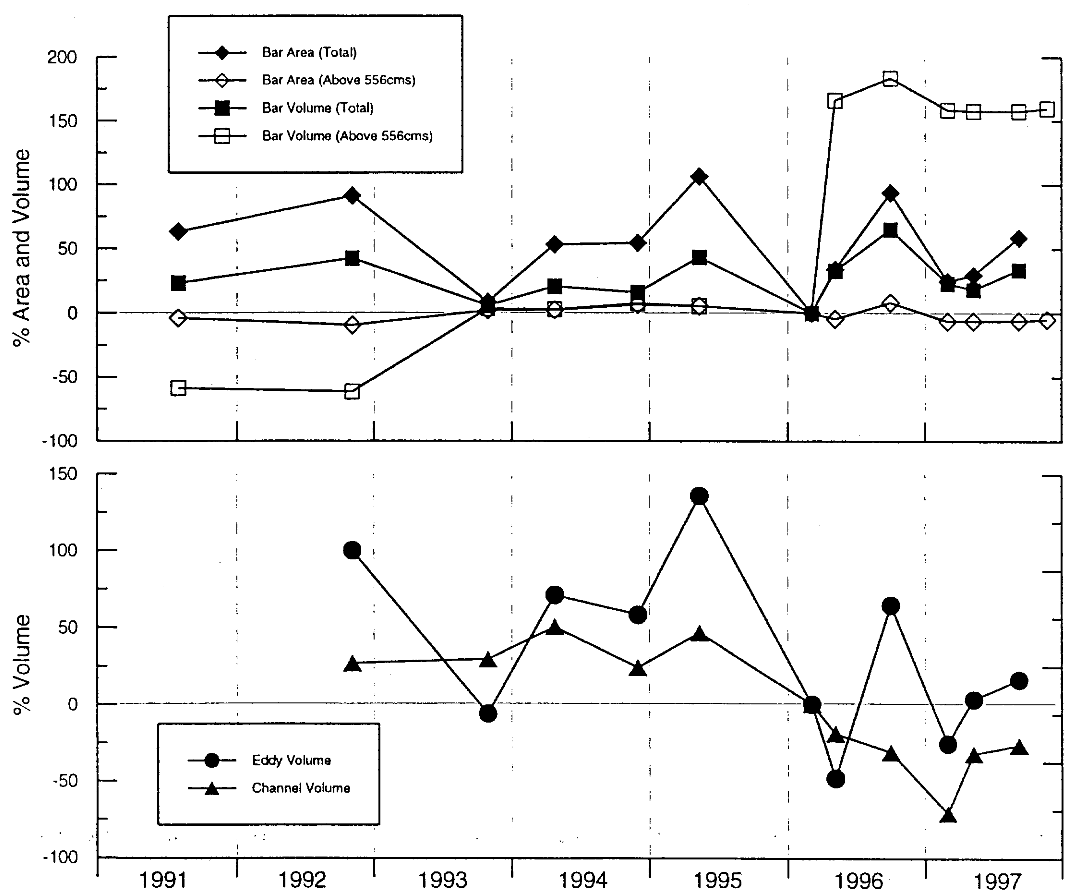
220R

SURVEY DATE	JULIAN DAYS	SAND BAR TOTAL AREA (m2)	SAND BAR > 20 K AREA (m2)	SAND BAR TOTAL VOL (m3)	SAND BAR > 20 K VOL (m3)	EDDY VOL (m3)	CHANNEL VOL (m3)	SAND BAR TOTAL AREA (%)	SAND BAR > 20 K AREA (%)	SAND BAR TOTAL VOL (%)	SAND BAR > 20 K VOL (%)	EDDY VOL (%)	CHANNEL VOL (%)
910730	576	1193	854	2471	651			-9.07	26.89	-2.22	2.84		
911109	678	1256	779	2368	590								
921102	1037	1234	739	2319	588		5400	-5.95	9.81	-8.23	-7.11		63.64
930414	1200	1266	921	2729	921		6500	-3.51	36.85	7.99	45.50		96.97
931025	1394	1167	750	2251	675		5400	-11.05	11.44	-10.92	6.64		63.64
940424	1575	1245	754	2342	678		5200	-5.11	12.04	-7.32	7.11		57.58
941204	1794	1205	742	2264	665		4900	-8.16	10.25	-10.41	5.06		48.48
950510	1956	1287	736	2327	640		5400	-1.91	9.36	-7.91	1.11		63.64
960303	2254	1312	673	2527	633		3300	0.00	0.00	0.00	0.00		0.00
960504	2316	1263	681	2724	920		4000	-3.73	1.19	7.80	45.34		21.21
960928	2463	1293	713	2740	894		4100	-1.45	5.94	8.43	41.23		24.24
970228	2616	1234	991	2892	964		3400	-5.95	47.25	14.44	52.29		3.03
970508	2685	1241	983	2886	962		5800	-5.41	46.06	14.21	51.97		75.76
970907	2807	1231	755	2670	875		5600	-6.17	12.18	5.66	38.23		69.70



225R

SURVEY DATE	JULIAN DAYS	SAND BAR TOTAL AREA (m2)	SAND BAR > 20 K AREA (m2)	SAND BAR TOTAL VOL (m3)	SAND BAR > 20 K VOL (m3)	EDDY VOL (m3)	CHANNEL VOL (m3)	SAND BAR TOTAL AREA (%)	SAND BAR > 20 K AREA (%)	SAND BAR TOTAL VOL (%)	SAND BAR > 20 K VOL (%)	EDDY VOL (%)	CHANNEL VOL (%)
910729	576	2746	1127	4416	226			63.16	-4.09	22.80	-58.98		
921028	1037	3217	1062	5114	212	6200	29800	91.15	-9.62	42.21	-61.52	100.00	26.81
931019	1395	1821	1198	3790	570	2900	30400	8.20	1.96	5.39	3.45	-6.45	29.36
940418	1575	2580	1202	4326	565	5300	35300	53.30	2.30	20.30	2.54	70.97	50.21
941204	1794	2596	1251	4161	591	4900	29100	54.25	6.47	15.71	7.26	58.06	23.83
950510	1956	3469	1237	5150	579	7300	34400	106.12	5.28	43.21	5.08	135.48	46.38
960303	2254	1683	1175	3596	551	3100	23500	0.00	0.00	0.00	0.00	0.00	0.00
960504	2316	2248	1121	4768	1465	1600	19000	33.57	-4.60	32.59	165.88	-48.39	-19.15
960928	2463	3260	1272	5940	1561	5100	16100	93.70	8.26	65.18	183.30	64.52	-31.49
970228	2616	2094	1100	4416	1424	2300	6800	24.42	-6.38	22.80	158.44	-25.81	-71.06
970508	2686	2174	1101	4245	1418	3200	15900	29.17	-6.30	18.05	157.35	3.23	-32.34
970907	2807	2670	1103	4793	1418	3600	17200	58.65	-6.13	33.29	157.35	16.13	-26.81



Appendix B: Evaluation of Water Year 1997 Flow Alternatives

Evaluation of Water Year 1997 Flow Alternatives from Glen Canyon Dam on the Colorado River Sand Budget, Lees Ferry to Little Colorado River

Joe Hazel and Matt Kaplinski
Department of Geology, Northern Arizona University

Introduction

The effects of unanticipated high water releases from Glen Canyon Dam (GCD) on downstream sediment conditions and other resources are presently the subject of concern to managers. In this report we use volumetric calculations of sand mass determined from repeated topographic surveys and a sand mass-balance model to quantify sediment conditions from Lees Ferry to the Little Colorado River (Marble Canyon) that existed prior to Water Year 1997. The sand mass-balance model is used to evaluate the effects of alternative water releases patterns on sediment storage conditions in Marble Canyon. This reach is the focus of this analysis because it is the most susceptible to reductions in sand storage if unexpected controlled flooding occurs.

Background

Sediment mass balance is important because the decrease in size and number of Grand Canyon sand bars is assumed to result from a long-term loss of sand stored on the bed of the Colorado River. Sediment accumulation on the channel bed can vary widely because of sediment mass-balance in the reach, sediment-transport capacity, and dam operations (Schmidt, 1992; Randle et al., 1993; Smillie et al., 1993). Tributary sand inputs into the Marble Canyon reach are highly variable on an annual basis (Fig. 1). Previous mass-balance calculations have shown that sediment accumulates during years when dam releases are less than powerplant capacity (33,200 ft^3/s), but is removed and transported downstream to Lake Mead when releases exceed powerplant capacity (Howard and Dolan, 1981; Schmidt, 1992; Randle et al., 1993; Smillie et al., 1993).

Low releases between 1963 and 1982, as Lake Powell filled after dam closure, allowed accumulation of tributary-derived sediments (Fig. III-15; U.S. Bureau of Reclamation, 1995). However, flows exceeded powerplant capacity by 2 - 3 fold for 1 - 3 months/yr during the high inflow years of 1983 to 1986 and removed this accumulated sediment (Schmidt, 1992; Randle et al., 1993). Sediment scoured from the bed during the 1983 high flow was deposited on sand bars at high elevations (Beus et al., 1985; Schmidt and Graf, 1990). Unlike the 1983 spill which had a high peak discharge, the high releases that occurred annually between 1984-1986 consisted of long duration, steady releases. Stratigraphic and sedimentologic studies show that this sequence of flows deposited little sediment on sand bars (Rubin et al., 1994). The entire sequence of flows, 1983-1986, resulted in net erosion from eddy systems (Schmidt and Graf, 1990) and some sand bars used as campsites were completely eroded (Beus et al., 1985; Kearsley et al., 1994).

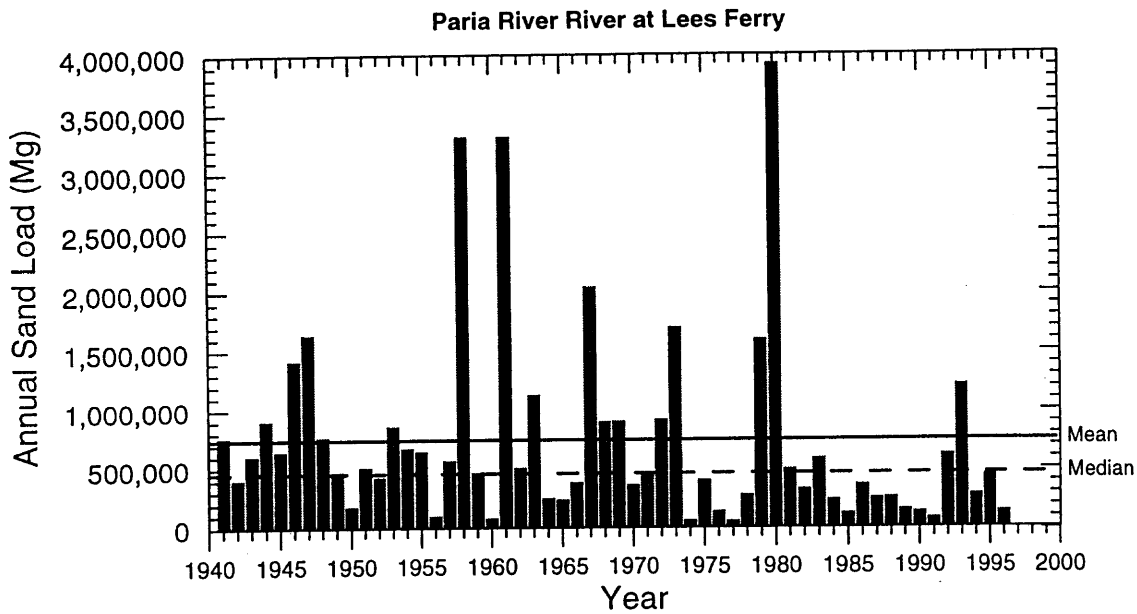


Fig. 1. Annual sand input from the Paria River (1941-1996).

In August of 1991, a GCD operating strategy was implemented that consisted of restricted maximum flow and reduced fluctuation. The purpose of these operating criteria, termed interim flows, was to maintain a positive mass sediment balance and minimize sand bar erosion until a Record of Decision on the GCD-Environmental Impact Statement (GCD-EIS). However, our data from sand bar monitoring of 34 sites between GCD and Diamond Creek, from 1991-1996, indicate that bars continued to decrease in size and volume after this change in flow regime (Fig. 2) (Kaplinski et al.,1995; Hazel et al., 1996). Although none of the bars completely eroded during this time interval, the volume of stored sand at high elevation bar locations (above the 15,000 ft^3/s stage elevation) decreased at a system-wide rate of 5 to 7% per year (Fig. 2).

A beach/habitat-building flow, in excess of powerplant capacity, was included in the Preferred Alternative recommended in the GCD-EIS (Bureau of Reclamation, 1995). An experimental controlled flow release with a high steady discharge of 45,000 ft^3/s was released from GCD for seven days between March 26 and April 3, 1996. The test flow restored sediment to high elevation bar locations in the Marble Canyon reach. The volume of sand in storage increased an average of 228% compared to the pre-test flow condition (Fig. 2) (Kaplinski et al., 1996). Erosion rates were initially high after the test flow but declined with time and at the end of Water Year 1996, 6 months after the test flow, approximately 129% of high elevation sand deposited by the test flow remained (Parnell et al., in prep). An increasing runoff forecast for the Upper Basin of the Colorado River and rising inflow to Lake Powell resulted in a prediction of reservoir filling in 1997. The need for contingency flood planning was recognized by the Department of Interior and this document addresses the impacts of alternative flow regimes on sand storage and transport downstream from GCD in 1997.

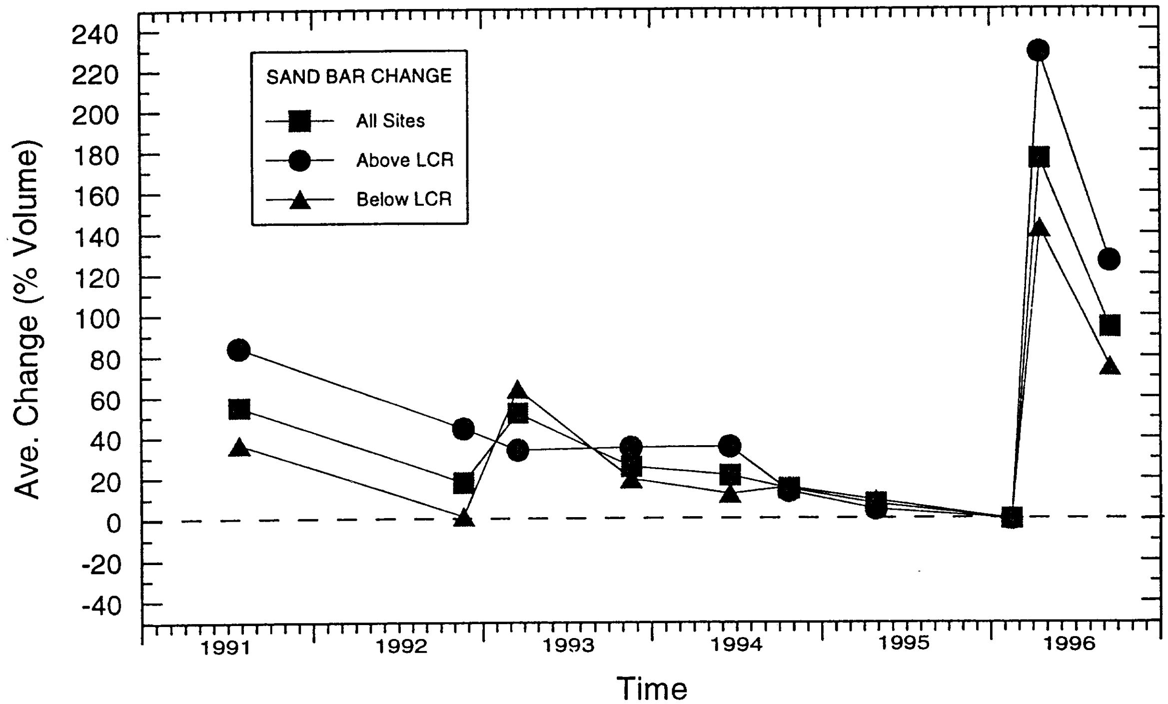


Fig. 2. Averaged percent change in the volume of stored sand (above the 15,000 ft^3/s stage elevation) for each survey run relative to values measured prior to the 1996 beach/habitat-building flow.

Methods

We use volumetric calculations of sand mass determined from repeated topographic surveys and a sand mass-balance model to quantify sediment conditions in Marble Canyon that existed prior to Water Year 1997 (Fig. 3). Methods for collection of empirical data and volumetric analysis are contained in Kaplinski et al. (1995) and Parnell et al. (1996). The sand-transport relations of Randle and Pemberton (1987) were used to examine the sediment transport capacity of alternative releases and to construct a sand mass-balance model similiar to that developed by Randle et al. (1993) for the GCD-EIS. Methods, assumptions, and estimates of error in the sand mass-balance model are provided in Randle et al. (1993) and Appendix D of the GCD-EIS (Bureau of Reclamation, 1995). For this analysis, cumulative storage of sand between Lees Ferry and the Little Colorado River was calculated as the sum of computed inputs from the Paria River minus the computed transport past the USGS streamflow-gaging station above the Little Colorado River (09383100 *Colorado River above Little Colorado River*). Daily sediment tranport was determined by multiplying mean daily discharge data for each day between June 1, 1990-March 3, 1997, by the appropriate sediment rating relation. The Paria River was assumed to be the only source of sand. Derived values for Paria River sand input were calculated from the daily mean flow at the USGS streamflow-gaging station (09382000 *Paria River at Lees Ferry*).

The sand mass-balance model was altered to accomodate estimates of future monthly release volumes, based on historic releases in previous water years, for Water Year 1997. These were provided by the Department of Interior and are depicted in Appendix 1. Each alternative water release pattern, was modified to contain a beach/habitat-building flow with an 18 hour peak of 90,000 ft^3/s. Three different beach/habitat-building flow scenarios are shown in Appendix 2. Sediment transport capability as a function of time and discharge for the sediment rating relation used in this analysis are included as Table 1 and graphically in Appendix 3. Future changes in riverbed sand storage during Water Year 1997, for each flow scenario, was assumed to begin with the estimated sand mass that existed in the Marble Canyon reach at the end of Water Year 1996. Future patterns of sand supply from the Paria for this analysis was determined from the the median annual sand input (4.8×10^5 Mg) from the Paria River for the 1941-1996 period (Fig. 1). A daily sediment load was calculated from the annual sediment yield and used as the sand input for the model during Water Year 1997.

Results

Sediment Storage Conditions and Tranport at the end of Water Year 1996

Figure 3a shows that there was significant accumulation of tributary derived sand between 1992-1996 but little accumulation during the GCES Phase II experimental discharge test flow program conducted between June, 1990-July, 1991. The daily mean discharge during interim flows, excluding the 1996 beach/habitat-building flow, was 12,500 ft^3/s. Despite the reduced transport capacity of interim flows, cumulative storage did not substantially increase until large tributary inflows in 1993 (Fig. 1). There was little accumulation between spring 1993-1995 (a period of low tributary inflow) because there was a balance between transport and supply. Tributary floods during the the winter of 1995 increased sand storage by about 2×10^5 Mg. However, a substantial decline in sand storage occurred between June-October, 1995 due to unusually high reservoir releases (nearly constant 20,000 ft^3/s), the 1996 beach/habitat-building flow, and because of high releases following the 1996 beach/habitat-building flow (average of 17,000 ft^3/s from April-July). This sequence of discharges removed two-thirds of the mass of sediment that had previously accumulated as a result of interim flow operating criteria.

The total range in the volume of sand stored in the river between 1990-Water Year 1997 was about 1.6×10^6 Mg (Fig. 3). In comparison, Randle et al. (1993) estimated that 6×10^5 Mg of sand accumulated between 1963-1982 for the same reach as Lake Powell filled. However, sand eroded from the reach during the high water years of 1983-1986 and below average supply from the Paria River resulted in a total net decrease in sand storage of 11×10^5 Mg, between closure of GCD and Water Year 1990 (Randle et al., 1993). The total mass of sand stored in 1984 on the bed and in eddies of the Colorado River between Lees Ferry and Phantom Ranch was estimated by J. Schmidt to be 38×10^6 Mg using the bed material maps of Wilson (1986) and assumptions of deposit thickness (Bureau of Reclamation, 1988). Assuming that sediment input from the Paria River is approximately one-fourth that of the Little Colorado River, a rough estimate of the total mass of sand stored in the Marble Canyon reach would be about 9×10^6 Mg for the same year. Randle et al. (1983) estimated that sediment storage in the Marble Canyon reach in 1989 was approximately 5×10^6 Mg lower than the amount stored in 1984. Therefore, we estimate that the total mass of sediment stored within the Marble Canyon reach at the start of Water Year 1997 was approximately 4.5×10^6 Mg (9×10^6 Mg to start with, minus 5×10^6 Mg at the end of 1988, plus 5×10^5 Mg that remained at the end of Water Year 1996).

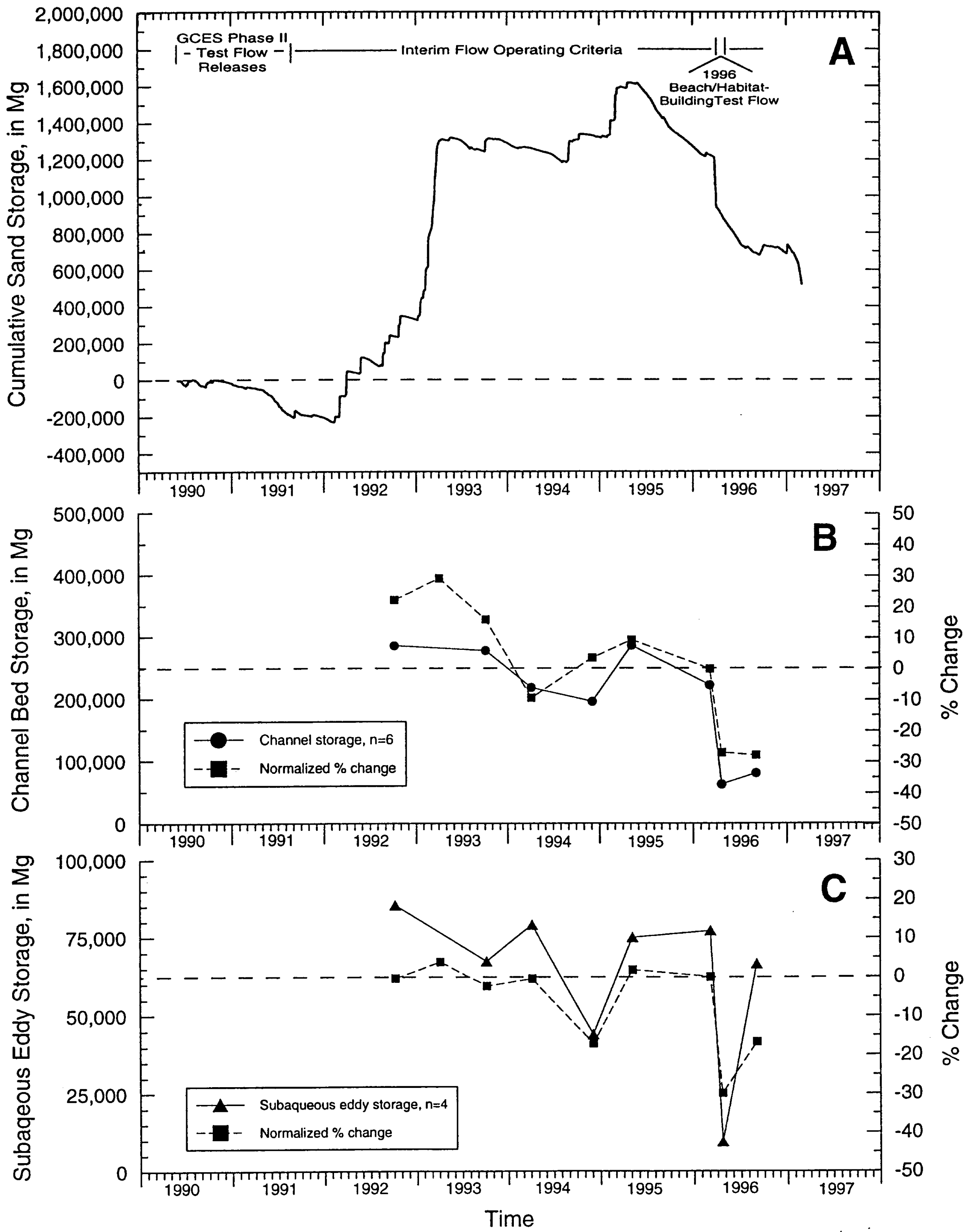


Fig. 3. Cumulative sediment storage in the Marble Canyon reach between 1990-1997. A) sand mass-balance model using the sediment transport relations of Randle and Pemberton (1987), and measured sediment storage below the 5,000 ft^3/s stage elevation from the B) main channel, and C) eddy systems at selected study sites monitored by Parnell et al. (1996).

Table 1. Flow releases and corresponding sediment transport

Alternative (1 mo.~31 days)	Release (1000 Acre Feet)	Transport per/mo (1000 Mg)
steady flow		
20000	1230	101
27000	1660	265
31500	1937	436
33200	2041	516
45000	2767	1158
65000	3997	2517
90000	5534	5004
Beach/habitat- building flow		
90000 for 18 hr	1617	467
65000 for 2 days	1559	404
45000 for 1 wk	1651	383

Figure 3b and c shows the pattern of main channel and eddy sediment storage at selected sites in Marble Canyon between 1992 and Water Year 1997. Comparison with the sand mass-balance model (Fig. 3a) suggests that when annual sand inputs from the Paria River are low or even when the sand load appears to be in balance with tributary supply, main channel bed storage declined during interim flows. For example, despite a 2 year balance (1993-1995) between transport capacity and annual sand input from the Paria River the sediment stored in the main channel declined by 38%. Following this period of deficit, there was a 13% increase in channel storage in 1995 as a result of sand inputs from the Paria River the preceding winter. Channel storage again declined by 9% as a result of the nearly constant 20,000 ft^3/s releases from June-October, 1995 and at the time of the survey just prior to the 1996 beach/habitat-building flow, 29% of the sediment in storage in 1993 had been removed from these sites. Subaqueous storage in the deeper parts of eddies, typically upstream from reattachment bars, however, was relatively unaffected by dam releases between 1992-1996. In comparison, regardless of fluctuations in river-stored sand during this same period, subaerially exposed sand bars continued to erode regardless of reach (Fig. 2).

The 1996 beach/habitat-building flow resulted in a 27% decrease in the remaining channel sand storage. Although Fig. 2 shows that sand bars were significantly aggraded by the 1996 beach/habitat-building flow, sand storage in eddies was reduced by 30% indicating that there were areas within eddies in Marble Canyon that were a significant source of sand during the experiment. At the close of Water Year 1996, 6 months after the 1996 beach/habitat-building flow, eddies that were scoured during the test flow had recovered over half of the sand mass evident after the test flow. There had been no significiant tributary input up to this time (Fig. 1) and most of this aggradation must be from upstream eroding bars and channel margin deposits. There was little accumulation (<1%) in main channel storage at this time. These data suggest that even during a period of reduced flow fluctuation such as interim flows there was significant variation in river-stored sand. There remains a stored sand surplus but it appears that a substantial amount of it resides in eddies.

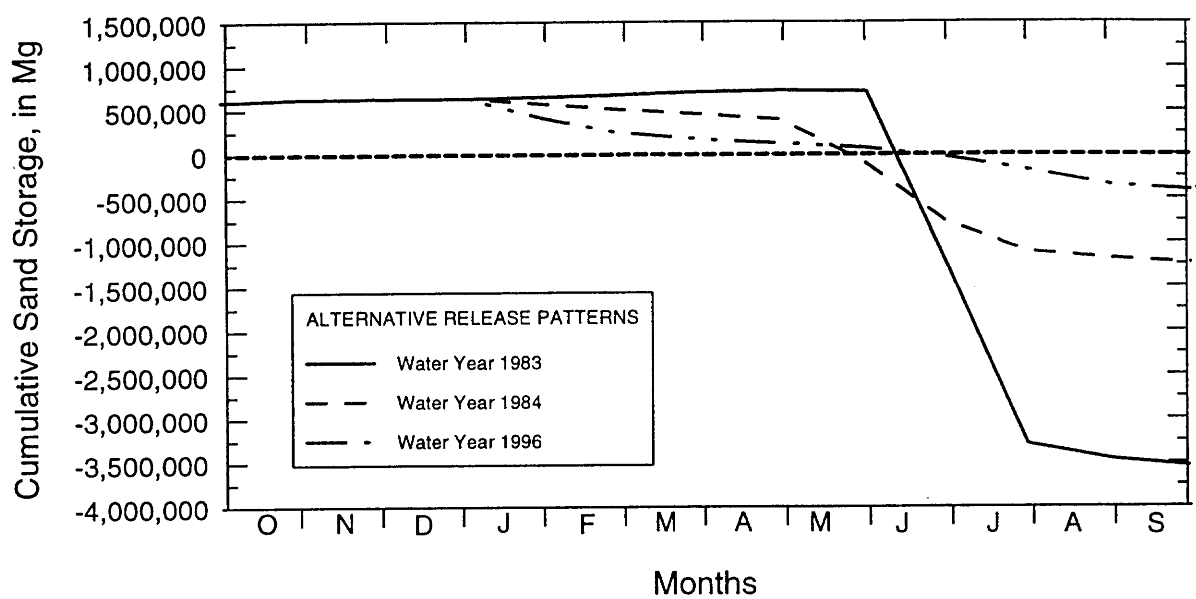
Impacts of Alternative Water Release Patterns in Water Year 1997

Figure 4 depicts the impacts of the three different release alternative in Appendix 1 on sand storage. A flow scenario based on Water Year 1996 would minimize sand transport out of the canyon (Fig. 4a). However, this scenario is also likely to erode bars built during the 1996 beach/habitat-building flow by transferring sand from high-elevation locations to the main channel and submerged eddies. Observations of our study sites this February confirm that high-steady flows below powerplant capacity (~27,000 ft^3/s) increased erosion rates of high-elevation sand gained during the 1996 beach/habitat-building flow. A release scenario based on Water Year 1983 would result in a 3 fold decrease in cumulative sand storage over impacts that would result from the other alternatives (Fig. 4a). This alternative may build bars with the remaining surplus of sand in storage, but would simultaneously deplet the sand budget to a value that is lower than the value estimated by Randle et al. (1993) to exist in Marble Canyon reach after the high flows between 1983-1986. Because sediment transport capacity is exponentially proportional to discharge, steady flows below powerplant capacity will result in less transport than a high release of short duration later in the Water Year. However, these flows could potentially erode sand stored at higher bar elevations.

The flow alternatives were altered to include the 90,000 ft^3/s beach/habitat-building flow depicted in Appendix 2 (Fig. 4b). This bar-building flow hydrograph has a stair-stepped, falling limb with the purpose of rebuilding areas of bars that may have potentially been scoured during the high peak discharge and to stabilize the bars by depositing sediment at lower elevations. This may result in increased stability of newly rebuilt bars. It is advantageous that such a flow occur early in the Water Year, such as April, while a sand surplus still remains. Notice that this scenario for Water Year 1983 would lessen the deficit produced in Fig 4a by approximately 1 x 10^6 Mg at the end of the Water Year. The other flow alternatives remain relatively unchanged by the addition of a bar-building flow. If the forecast strongly indicates a need to spill, it would be best to do it early in the Water Year so that bar-building has a greater chance of being successful and sand in storage can be deposited in eddies rather than being lost to downstream transport.

The sand mass-balance model assumes that the actual sediment load delivered to the Marble Canyon reach during Water Year 1997 approximates that of the median annual load for the Paria River. Impacts to sand storage in this analysis would be much greater if Paria River input was similiar to that supplied in Water Year 1996 (Fig. 1). As of March 1, 1997, 5 months into Water Year 1997, sediment input from the Paria River had supplied 14% of the annual mean and 21% of the annual median sand input, respectively. Conversely, impacts to sand storage would be reduced if Paria River input were above average.

A. Modified Historic Releases



B. Modified Historic Releases With a 90,000 cfs Beach/Habitat-Building Flow

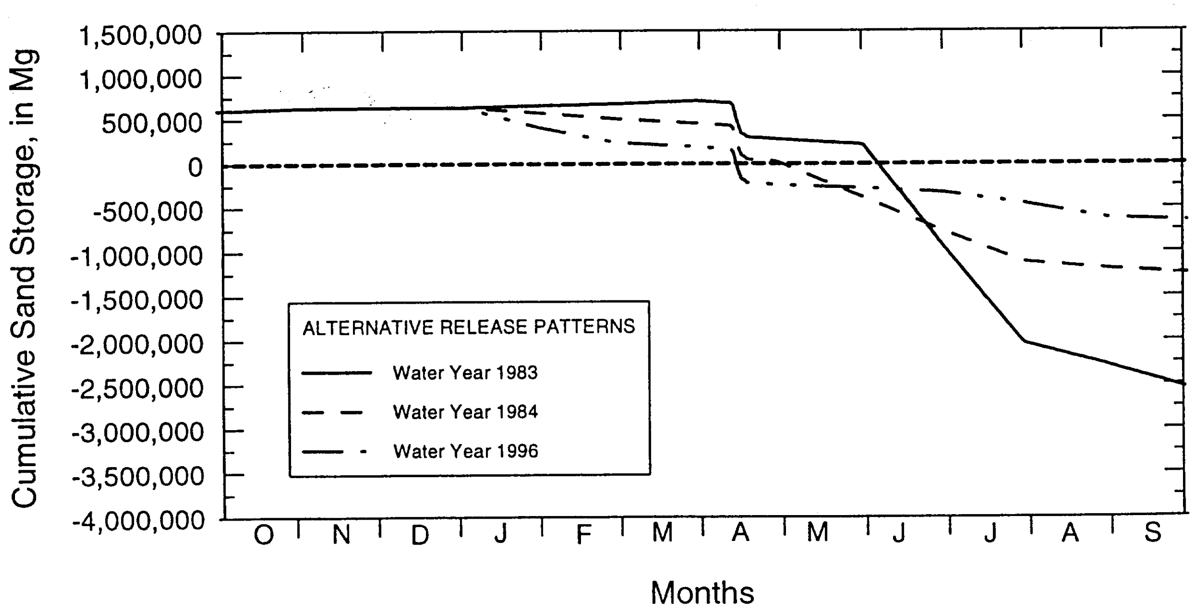


Fig. 4. Cumulative sediment storage in the Marble Canyon reach in Water Year 1997 using historic releases modified to the 10-11 MAF release level for April-July, approximately 130-140% of normal. A) steady monthly releases and B) modified operations with an 18 hour, 90,000 ft^3/s peak, beach/habitat-building flow in April.

Discussion and Recomendations

The impacts of the different flow alternatives depends on the magnitude and duration of monthly releases in each alternative and the supply of sand in eddies and the main channel prior to Water Year 1997. The sand mass-balance model and empirical data suggest that, at the start of Water Year 1997, sediment conditions in Marble Canyon are similiar in magnitude to the remaining amount of sediment stored in the channel following the high discharges between 1983-1986. The entire sequence of nearly steady 20,000 ft^3/s releases for 4 months in 1995, the 1996 beach/habitat-building flow, and flows with an annual mean of 16,000 ft^3/s in 1996 removed the sand that had accumulated between 1991-1995. In addition, tributary input from the Paria was below average during the interim flow period. These data also support the conclusion of Schmidt (1992) that erosion of bars can occur when mass accumulation is occurring in the system.

In the planning of flow releases in Water Year 1997 that are intended to accomplish release objectives from Lake Powell, scenarios that will result in long-term sediment depletion in Marble Canyon should be minimized so that sand-dependent resources are not lost. If it is desireable to preserve some of the sand in surplus by depositing it at higher locations or to scour and restore critical habitats for endangered fish then timing is of utmost importance. There must be sufficient sediment available in order to to build bars (Rubin et al., 1994). A higher release later in the year may accomplish other objectives but will scour bars without sand in storage. If the primary source of sediment in the Marble Canyon reach is the river channel, than bar-building floods can be repeated in successive years. However, if the predominate portion of the sand mass in storage is in eddies and bars, then floods have a great potential to be net erosive (Schmidt et al., 1993). For example, the high flows in 1983 aggraded sand bars but because these flows also transported much of the available sediment out of the system, the discharges between 1984-1986 deposited little sediment on bars and these flows were net erosive (Rubin et al., 1994). Our data suggest that at the close of Water Year 1996 most of the sand in Marble Canyon was stored in eddies, rather than in main channel pools. Pools and eddies were scoured during the 1996 beach/habitat-building flow. Eddies recovered rapidly following the test flow and were relatively full within 6 months. Main-channel pools, however, had not recovered and will remain in a scoured condition until main channel transport capacities are less than the mean input from tributaries. We attribute this disparity in sand storage and recovery to the greater efficiency of eddies as sediment traps. The lack of significiant tributary input in 1996 indicates that deposition on low-elevation bars in eddies must be from upstream erosion of unstable bars and channel margin deposits deposited by the 1996 beach/habitat-building flow or from channel pools that were not fully evacuated by the test flow. There may not be sufficient sand available for future transport if the flows of Water Year 1997 result in long-term depletion from the canyon. If the canyon becomes depleted of sand, it may take decades to replenish the sand budget.

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APPENDIX 1

GLEN CANYON DAM WATER RELEASE SCENARIOS

WATER YEAR 1983

Month	Forecast Rel. Curr mo.-July (1000 AF)	Forecast Rel. Jan.-July (1000 AF)	Forecast Change (1000 AF)	Actual Release (1000 AF)	Actual Release (cfs)
Jan	4906	4906		914	14865
Feb	4145	5059	153	853	15359
Mar	3110	4877	-182	660	10734
Apr	3813	6240	1363	951	15982
May	3388	6766	526	1259	20476
Jun	3125	7762	996	4417	74230
Jul	4609	13663	5901	4609	74958
Aug				1942	31584
Sep				1600	26889
Tot Apr-Jul				**11236**	
Tot Jan-Sep				**17205**	

Modified Table for 10-11 MAF Release Level (Apr-Jul)

Month	Forecast Rel. Curr mo.-July (1000 AF)	Forecast Rel. Jan.-July (1000 AF)	Forecast Change (1000 AF)	Actual Release (1000 AF)	Actual Release (cfs)
Jan	3925	3925		731	11889
Feb	3316	4047	122	682	12280
Mar	2488	3902	-145	528	8587
Apr	3050	4992	1090	761	12789
May	2710	5413	421	1007	16377
Jun	2500	6210	797	3534	59391
Jul	3687	10930	4720	3687	59963
Aug				1554	25273
Sep				1280	21511
Tot Apr-Jul				**8989**	
Tot Jan-Sep				**13764**	

APPENDIX 1--CONT.

WATER YEAR 1984

Month	Forecast Rel. Curr mo.-July (1000 AF)	Forecast Rel. Jan.-July (1000 AF)	Forecast Change (1000 AF)	Actual Release (1000 AF)	Actual Release (cfs)
Jan	11631	11631		1555	25290
Feb	9336	10891	-740	1487	25852
Mar	6914	9956	-935	1493	24281
Apr	5658	10193	237	1507	25326
May	5682	11726	1533	2554	41537
Jun	4388	12964	1238	2752	46249
Jul	2652	14000	1036	2332	37926
Aug				1628	26477
Sep				1450	24368
Tot Apr-Jul				**9145**	
Tot Jan-Sep				**16758**	

Modified Table for 10-11 MAF Release Level (Apr-Jul)

Month	Forecast Rel. Curr mo.-July (1000 AF)	Forecast Rel. Jan.-July (1000 AF)	Forecast Change (1000 AF)	Actual Release (1000 AF)	Actual Release (cfs)
Jan	9305	9305		1244	20232
Feb	7469	8713	-592	1190	20688
Mar	5531	7965	-748	1194	19419
Apr	4526	8154	189	1206	20268
May	4546	9381	1227	2043	33226
Jun	3494	10371	990	2202	37006
Jul	2122	11200	829	1866	30348
Aug				1302	21175
Sep				1160	19494
Tot Apr-Jul				**7317**	
Tot Jan-Sep				**13407**	

APPENDIX 1--CONT.

WATER YEAR 1996

Month	Forecast Rel. Curr mo.-July (1000 AF)	Forecast Rel. Jan.-July (1000 AF)	Forecast Change (1000 AF)	Actual Release (1000 AF)	Actual Release (cfs)
Jan	6225	6225		972	15808
Feb	6632	7604	1379	807	14030
Mar	6771	8550	946	1123	18264
Apr	5418	8320	-230	1092	18352
May	4462	8456	136	1051	17093
Jun	3224	8269	-187	1033	17360
Jul	1395	7473	-796	984	16003
Aug				910	14800
Sep				829	13932
Tot Apr-Jul				**4160**	
Tot Jan-Sep				**8801**	

Modified Table for 10-11 MAF Release Level (Apr-Jul)

Month	Forecast Rel. Curr mo.-July (1000 AF)	Forecast Rel. Jan.-July (1000 AF)	Forecast Change (1000 AF)	Actual Release (1000 AF)	Actual Release (cfs)
Jan	8715	8715		1680	27323
Feb	9285	10646	1931	1470	25556
Mar	9479	11970	1324	1260	20492
Apr	7585	11648	-322	1155	19410
May	6247	11838	190	1190	19353
Jun	4514	11577	-261	1330	22351
Jul	1953	10462	-1115	1505	24476
Aug				1540	25046
Sep				1191	20015
Tot Apr-Jul				**5180**	
Tot Jan-Sep				**12321**	

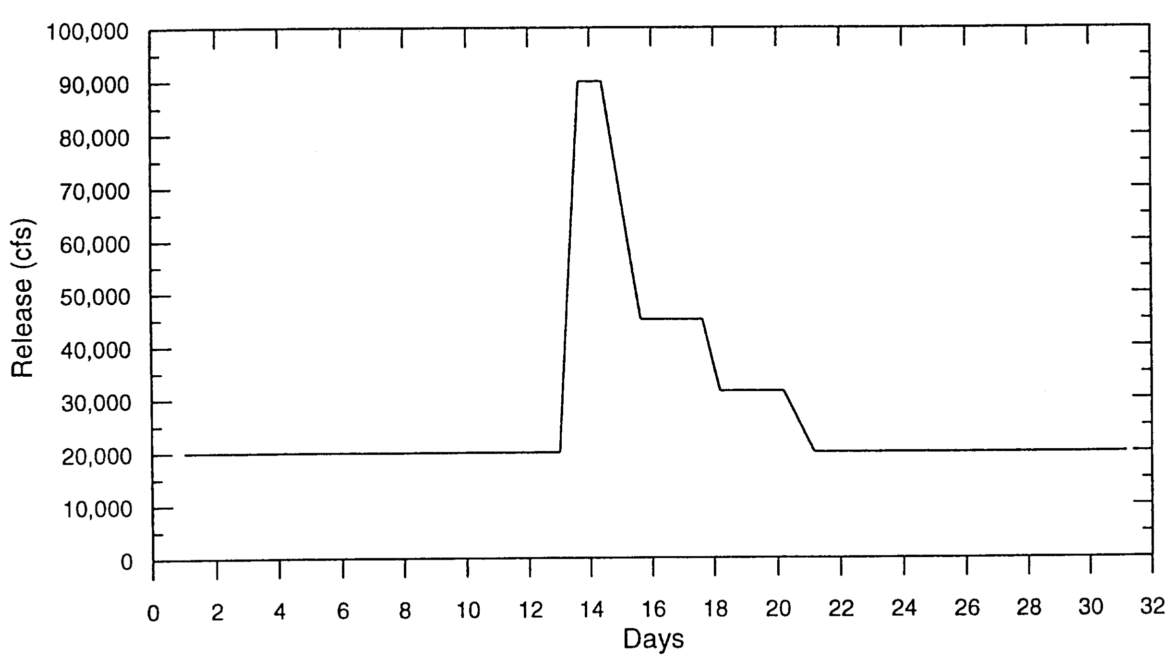
APPENDIX 2

BEACH/HABITAT BUILDING FLOWS

Peak	90000	
Up ramp	4500 cfs/hr	
Down ramp	1,500	90000 to 45000
	1,000	45000 to 31500
	500	31500 to 20000

DAY	CUM HOURS	FLOW (CFS)	INCRE. HOURS	RELEASE (1000 AF)	CUM. VOL (AF)	SAND TRANSPORT PER DAY	
1.00	0.00	20000		40	40.00	3346	
2.00	24.00	20000		40	79.67	3346	
3.00	48.00	20000		40	119.34	3346	
4.00	72.00	20000		40	159.01	3346	
5.00	96.00	20000		40	198.68	3346	
6.00	120.00	20000		40	238.35	3346	
7.00	144.00	20000		40	278.02	3346	
8.00	168.00	20000		40	317.69	3346	
9.00	192.00	20000		40	357.36	3346	
10.00	216.00	20000		40	397.02	3346	
11.00	240.00	20000		40	436.69	3346	
12.00	264.00	20000		40	476.36	3346	
13.00	288.00	20000		40	516.03	3346	
13.65	303.56	90000	15.56	71	586.74	38047	
14.40	321.56	90000	18	134	720.62	124555	
15.65	351.56	45000	30.00	167	887.98	113078	
17.65	399.56	45000	48	179	1066.49	76850	
18.21	413.06	31500	13.50	43	1109.17	15213	
20.21	461.06	31500	48	62	1171.65	28933	
21.17	484.06	20000	23.00	49	1220.59	7241	
22.17	508.06	20000		40	1260.26	3346	
23.17	532.06	20000		40	1299.93	3346	
24.17	556.06	20000		40	1339.60	3346	
25.17	580.06	20000		40	1379.27	3346	
26.17	604.06	20000		40	1418.94	3346	
27.17	628.06	20000		40	1458.61	3346	
28.17	652.06	20000		40	1498.28	3346	
29.17	676.06	20000		40	1537.95	3346	
30.17	700.06	20000		40	1577.62	3346	
31.17	724.06	20000		40	1617.29	3346	
						480882	Total

Beach/Habitat-Building Flow
90,000 cfs peak for 18 hours

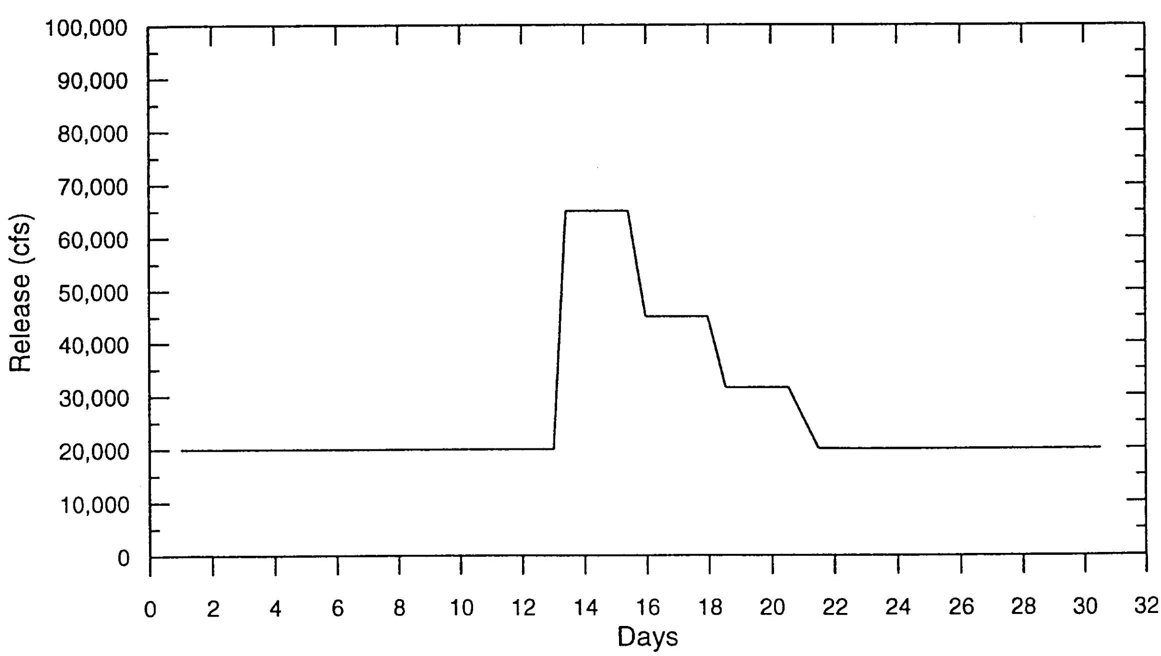


APPENDIX 2--CONT.

Peak	65000	
Up ramp	4500 cfs/hr	
Down ramp	1,500	65000 to 45000
	1,000	45000 to 31500
	500	31500 to 20000

DAY	CUM HOURS	FLOW (CFS)	INCRE. HOURS	RELEASE (1000 AF)	CUM. VOL (AF)	SAND TRANSPORT PER DAY	
1.00	0.00	20000		40	40.00	3346	
2.00	24.00	20000		40	79.67	3346	
3.00	48.00	20000		40	119.34	3346	
4.00	72.00	20000		40	159.01	3346	
5.00	96.00	20000		40	198.68	3346	
6.00	120.00	20000		40	238.35	3346	
7.00	144.00	20000		40	278.02	3346	
8.00	168.00	20000		40	317.69	3346	
9.00	192.00	20000		40	357.36	3346	
10.00	216.00	20000		40	397.02	3346	
11.00	240.00	20000		40	436.69	3346	
12.00	264.00	20000		40	476.36	3346	
13.00	288.00	20000		40	516.03	3346	
13.42	298.00	65000	10.00	35	551.16	14190	
15.42	346.00	65000	48	258	809.01	167065	
15.97	359.33	45000	13.33	61	869.61	32612	
17.97	407.33	45000	48	179	1048.13	76850	
18.53	420.83	31500	13.50	43	1090.80	15213	
20.53	468.83	31500	48	62	1153.28	28933	
21.49	491.83	20000	23.00	49	1202.23	7241	
22.49	515.83	20000		40	1241.90	3346	
23.49	539.83	20000		40	1281.57	3346	
24.49	563.83	20000		40	1321.24	3346	
25.49	587.83	20000		40	1360.91	3346	
26.49	611.83	20000		40	1400.58	3346	
27.49	635.83	20000		40	1440.24	3346	
28.49	659.83	20000		40	1479.91	3346	
29.49	683.83	20000		40	1519.58	3346	
30.49	707.83	20000		40	1559.25	3346	
						415722	Total

Beach/Habitat-Building Flow
65,000 cfs peak for 2 days

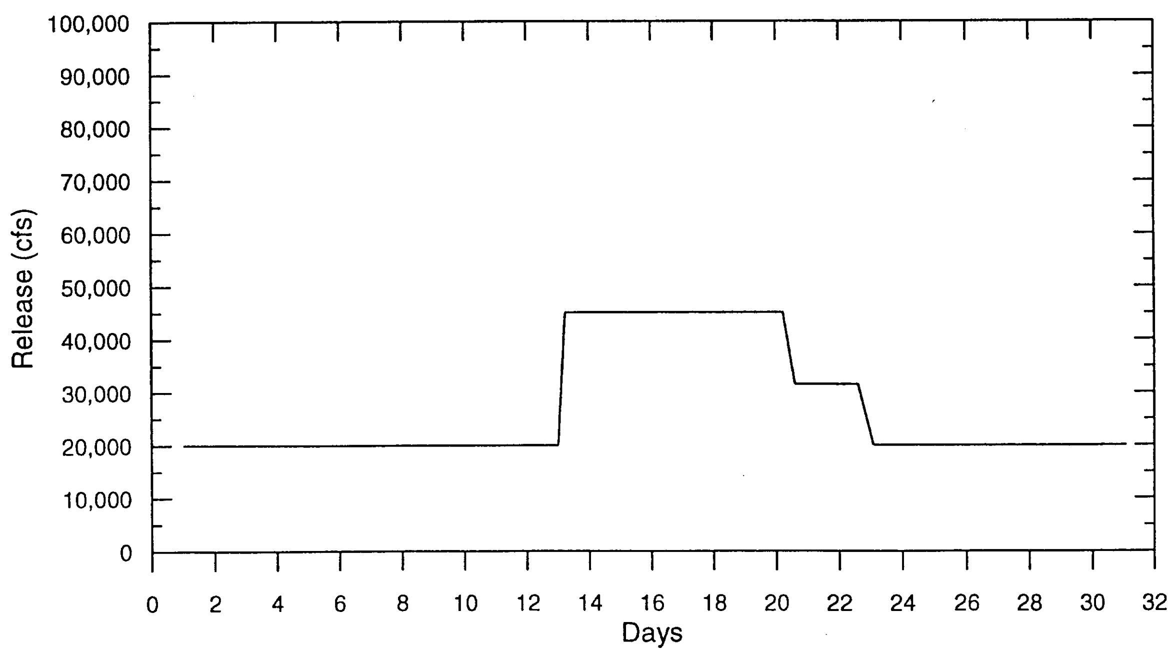


APPENDIX 2--CONT.

Peak	45000	
Up ramp	4500 cfs/hr	
Down ramp	1,500	45000 to 31500
	1,000	31500 to 20000

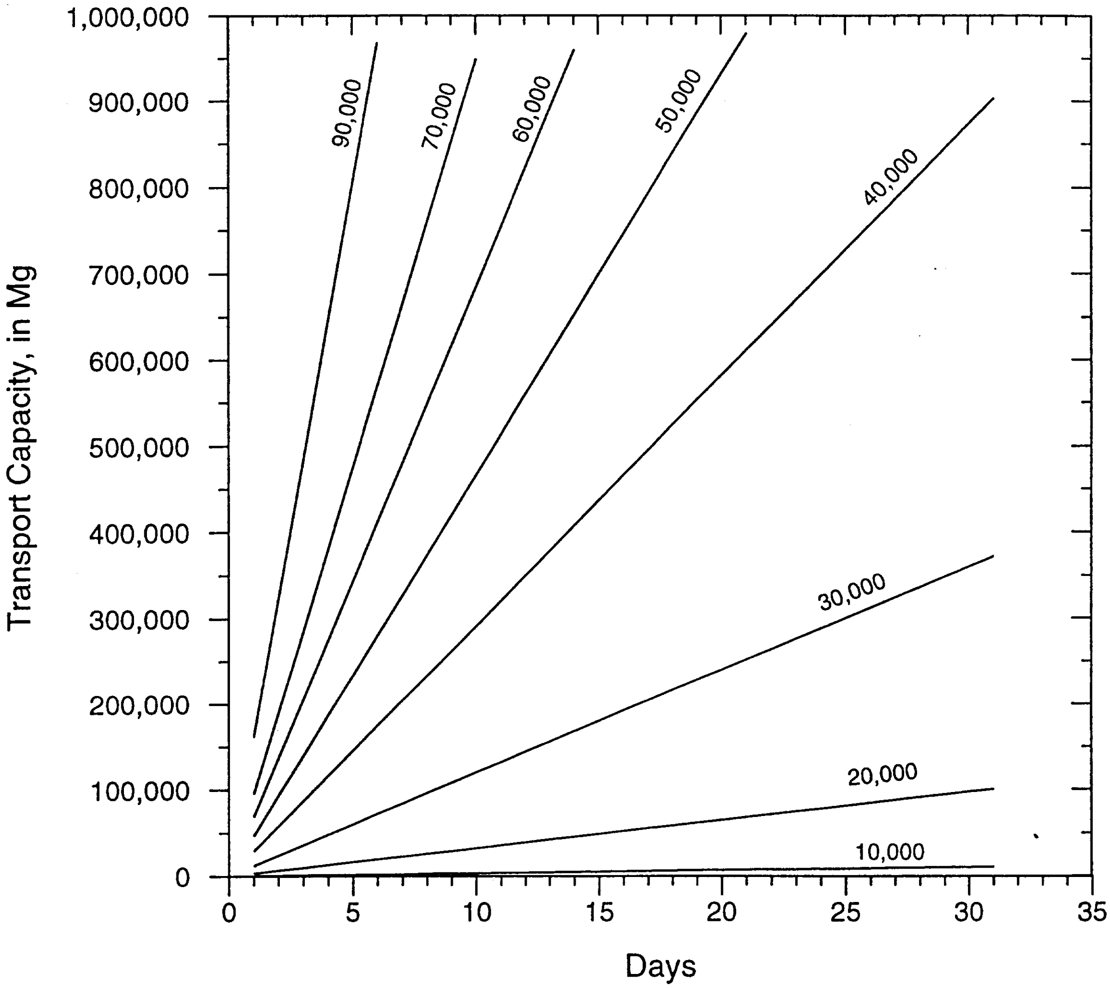
DAY	CUM HOURS	FLOW (CFS)	INCRE. HOURS	RELEASE (1000 AF)	CUM. VOL (AF)	SAND TRANSPORT PER DAY	
1.00	0.00	20000		40	40.00	3346	
2.00	24.00	20000		40	79.67	3346	
3.00	48.00	20000		40	119.34	3346	
4.00	72.00	20000		40	159.01	3346	
5.00	96.00	20000		40	198.68	3346	
6.00	120.00	20000		40	238.35	3346	
7.00	144.00	20000		40	278.02	3346	
8.00	168.00	20000		40	317.69	3346	
9.00	192.00	20000		40	357.36	3346	
10.00	216.00	20000		40	397.02	3346	
11.00	240.00	20000		40	436.69	3346	
12.00	264.00	20000		40	476.36	3346	
13.00	288.00	20000		40	516.03	3346	
13.23	293.56	45000	5.56	15	530.96	4474	
20.23	461.56	45000	168	625	1155.75	268976	
20.61	470.56	31500	9.00	28	1184.20	10224	
22.61	518.56	31500	48	125	1309.16	36186	
23.09	530.06	20000	11.50	24	1333.63	3620	
24.09	554.06	20000		40	1373.30	3346	
25.09	578.06	20000		40	1412.97	3346	
26.09	602.06	20000		40	1452.64	3346	
27.09	626.06	20000		40	1492.31	3346	
28.09	650.06	20000		40	1531.98	3346	
29.09	674.06	20000		40	1571.65	3346	
30.09	698.06	20000		40	1611.32	3346	
31.09	722.06	20000		40	1650.99	3346	
						393752	Total

Beach/Habitat-Building Flow
45,000 cfs peak for 1 week



Appendix 3

Sand Transport as a Function of Discharge and Time



-end of report-