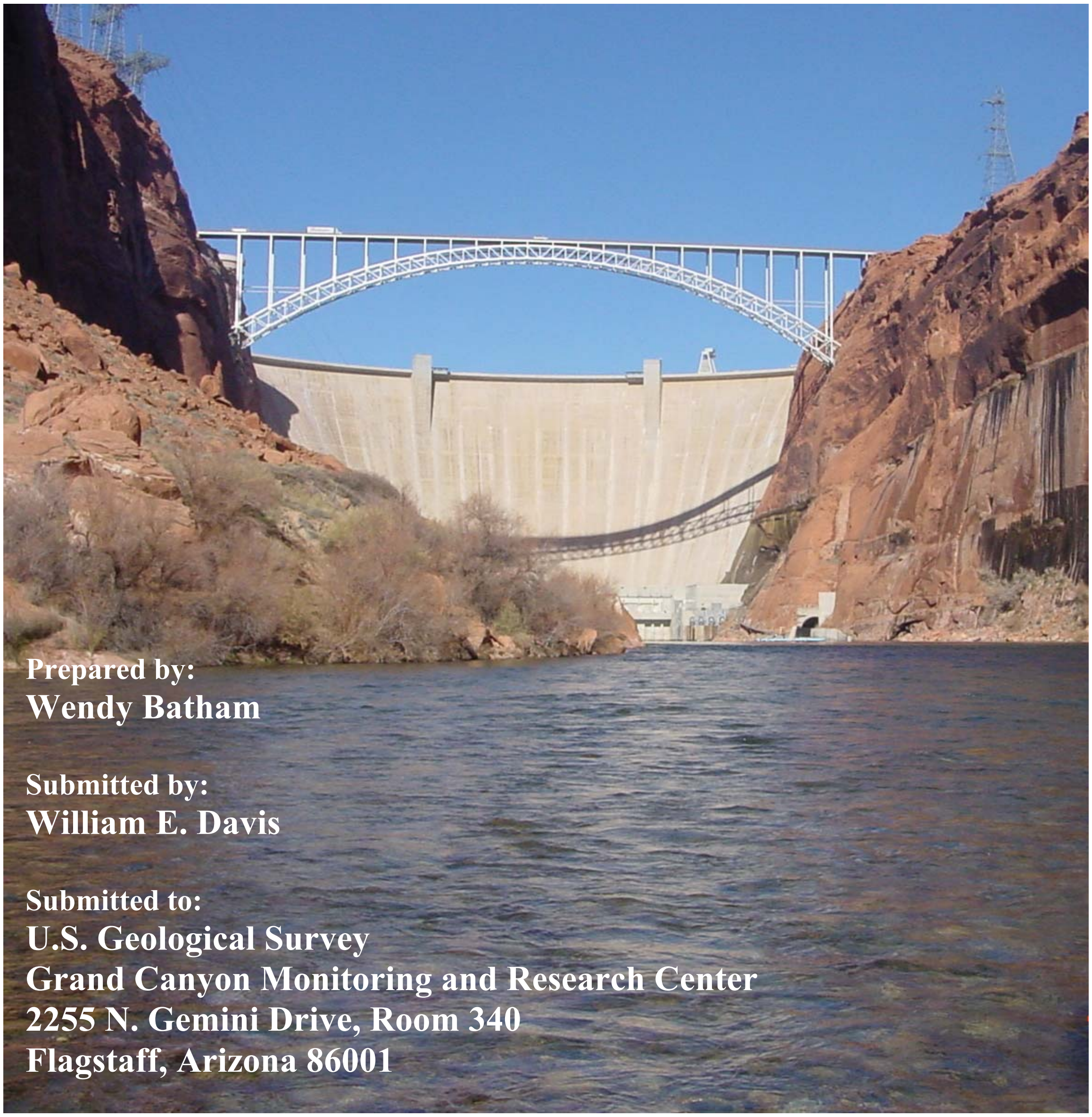
Stranding of Rainbow Trout during Experimental Fluctuating Releases from Glen Canyon Dam on the Colorado River



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Executive Summary

The purpose of this study was to determine the extent of stranding among non-native rainbow trout (RBT) within the Lees Ferry reach of the Colorado River resulting from fluctuating flow releases during a three-month period (January 2003 through March 2003) from Glen Canyon Dam. The fluctuating flows were part of an experiment intended to disrupt spawning and subsequent survival of rainbow trout. One expected, but unintended consequence of fluctuating releases during the experiment, was stranding of adult trout in shallow, lower flow areas.

EcoPlan Associates, Inc. estimated a total of 1,742 RBT adults became stranded during this three-month study. We estimated seven percent of stranded fish (125 fish) were dead or dying while 93 percent (1,617 fish) would have lived. The mean total length of rainbow trout found was 378 millimeters (SD = 63, n = 36), as compared to an average of 234 millimeters caught by Arizona Game and Fish during adult population surveys.

Stranding numbers observed during the 2003 experiment (503 fish)) differed from those observed in 1990 by Angradi *et al*. (1924 fish). We found stranded trout in approximately the same sites as Angradi but direct comparison of total numbers of stranded trout with the earlier stranding study was impossible due to differences in: 1) length of the study period (3 months vs. 18 months; 2) number of surveys; 3) flow conditions and ramping rates; and 4) water temperatures in stranding pools. Also, such a comparison was probably inappropriate since the Angradi study was set to determine if stranding took place over an 18-month period under a variety of seasonal conditions while this survey was intended to document the extent of stranding during a short, 90-day fluctuating flow experiment.

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1.0 Introduction

Scientists have recognized that the endangered Grand Canyon humpback chub population has been in decline for more than a decade. Highly fluctuating flows were curtailed in November of 1991 and some scientists suggest this change may be a reason for the decline. One hypothesis offered is that these flows helped to control numbers of non-native fish, especially rainbow (RBT) and brown trout. Trout prey upon, and compete with, native fish such as the endangered humpback chub and scientists reason that the reduction in fluctuations helped trout spawning and recruitment (U.S. Department of the Interior 2002b). An Environmental Assessment prepared for a 2003 experiment (*Experimental Releases from the Glen Canyon Dam and Removal of Non-native Fish)* states that the non-native trout population in the Grand Canyon has tripled since 1996 (U.S. Department of the Interior 2002a) and is approaching carrying capacity.

As part of this 2003-2004 experiment, the hypothesis that pre-1990 daily fluctuations and ramp rates suppressed natural recruitment of trout and present stabilized flows have benefited recruitment of trout and resulted in higher numbers will be tested. The 2003 experimental flow proposal included a daily high fluctuating flow element (a minimum of 5,000 cubic feet per second [cfs] beginning at 0100 and a maximum of 20,000 cfs beginning at 1200 with ramping down or up, respectively, prior to these times) starting January 1, 2003 and continued through March 31, 2003. The fluctuating flows were intended to disrupt spawning and subsequent survival of the non-native RBT. In addition to benefiting native fish, a secondary purpose of the experiment was to improve the quality of the Lees Ferry (River Mile[1] [RM] 0.0) trout fishery by reducing the numbers of RBT produced immediately below the dam [RM –15.80] with the expected result being larger fish. One expected, but unintended consequence of fluctuating releases during the experiment was stranding of adult trout in shallow, lower flow areas. In this part of the experiment, EcoPlan Associates, Inc. (EcoPlan) was asked to examine the spatial and temporal extent of trout stranding by determining the number of stranded fish in the 15.80-mile reach below Glen Canyon Dam (Lees Ferry Reach [Figure 1 and Figure 2]).

Until June 1990, flows were regulated by four power-related functions: to follow power system load changes, to produce peaking power, to regulate the power system or to respond to power system emergencies. Maximum releases were set by generation capacity, whereas ramp rates were unrestricted. As stated in Angradi *et al.* (1992), releases after August 1991 followed the *Interim Flows* criteria until 1996 when a Record of Decision (ROD) was reached in the *Final Environmental Impact Statement* (EIS) on the *Operation of the Glen Canyon Dam*. This decision modified how the dam was to be operated in order to protect downstream resources. During *Interim Flows*, maximum releases were reduced and ramp rates were set (upramp rate of 2,500 cfs/hour and a downramp rate of 1,500 cfs/hour). Under ROD flows, maximum release and ramp rates were similar to the *Interim Flows*. Flows during the 2003 90-day fluctuating flow portion

[1] River mile (RM) 0 in Grand Canyon occurs at Lees Ferry, coinciding with the dividing line between upper and lower Colorado River basins. River distances upstream from Lees Ferry are denoted by a minus sign to signify they occur upstream of the dividing line (e.g. RM –15.2).

Figure 1. Project location

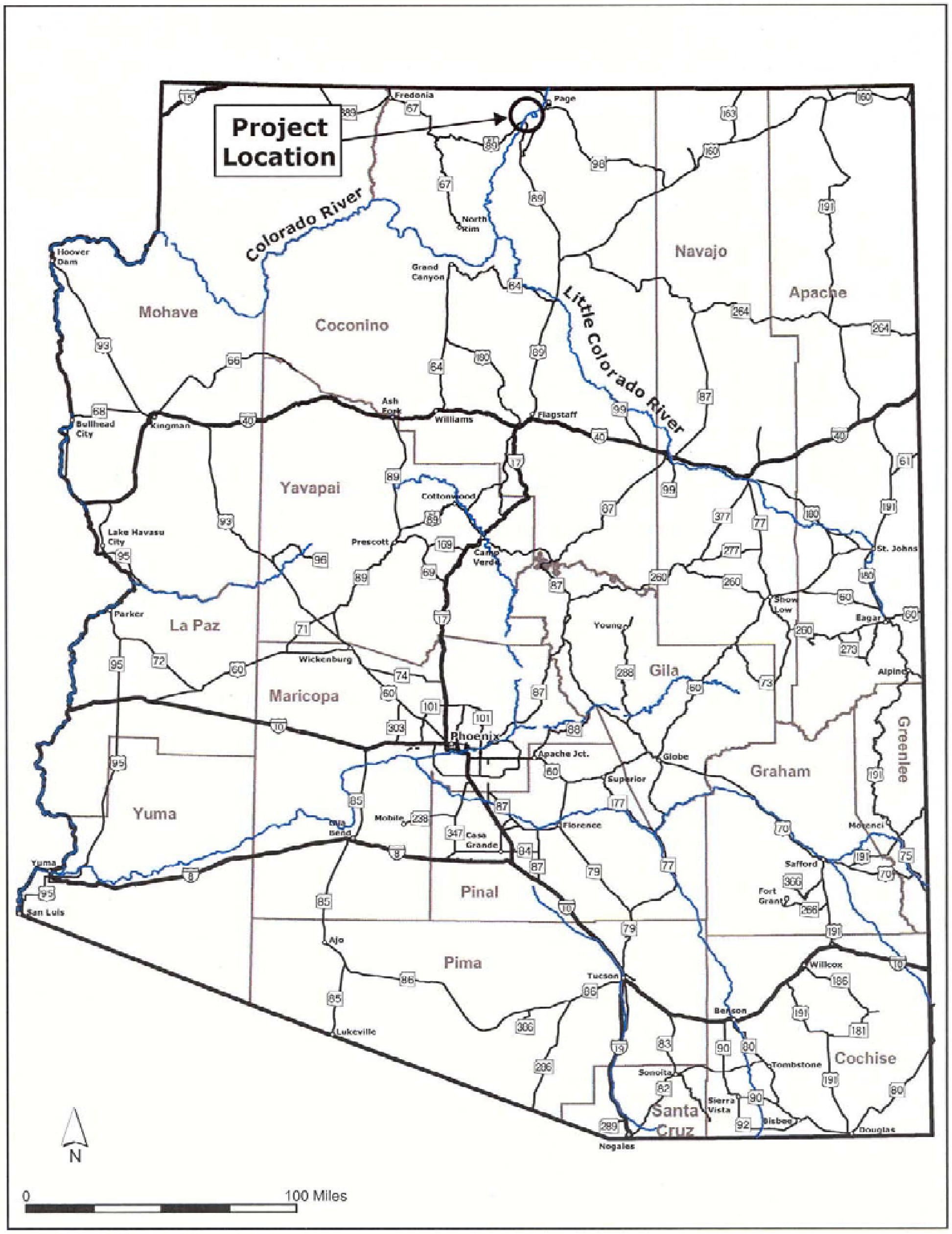


Figure 1. Project Location in Arizona.

Figure 2. Project vicinity

Figure 2. Project Vicinity Showing Sites Monitored for Stranded Trout.

of the experiment reached a daily maximum of 20,000 cfs and a minimum of 5,000 cfs with a maximum 5,000 cfs/hour upramp and 2,500 cfs/hour downramp (Figure 4).

Table 1. Various flow regime characteristics during the last 15 years.

Flow regime	Minimum releases (cfs)	Maximum releases (cfs)	Allowable daily fluctuations (cfs)	Ramp rate (cfs/hr)
No Action Alternative/ Pre-EIS (normal flows)	1,000 Labor Day to Easter 3,000 Easter to Labor Day	31,500	30,500 Labor Day to Easter 28,500 Easter to Labor Day	Unrestricted; 4,000 up (70% of the time) 4,000 down (70% of the time)
Interim Flows/ROD Flows	8,000 day 5,000 night	25,000	5,000; 6,000; or 8,000	2,500 up 1,500 down
2003 Experimental Flows	5,000	20,000	15,000	5,000 up 2,500 down

(cfs = cubic feet per second)

Rainbow trout in the Lees Ferry reach of the Colorado River spawn nearly every month of the year; however, the majority spawn December through April, with a peak occurring in late March to early April (Angradi *et al.* 1992). During spawning, RBT typically move to shallower, lower flow areas to construct their redds. Flows must remain at a suitable level to inundate the spawning areas for a period of time long enough for the RBT to build redds and lay eggs. For eggs to hatch, redds must remain moist and oxygenated. Fluctuating flow levels during the experiment are meant to disrupt and impede reproductive actions of RBT present within the system. During daily dewatering, desiccation of trout eggs, embryos, and fry are expected to occur (due to minimum flows). An unintended, but predictable consequence of daily dewatering was adult stranding in shallow, low flow areas.

2.0 Methods

2.1 Physical Conditions

A study of trout stranding commenced January 7, 2003 and continued through March 31, 2003. The Lees Ferry Anglers (LFA) guides were used to safely access the sites at low flows and dark conditions due to their extensive knowledge of the Lees Ferry reach of the Colorado River. Use of the LFA guides provided a better understanding of recreational fishing activities within Glen Canyon, and created a working relationship with the angling and guiding community who are very concerned with the trout fishery upstream of Lees Ferry. Initially, the guides provided valuable input as to what areas of the river they believed posed the greatest threat of stranding to RBT based on their daily involvement with river conditions. This information was taken into account when sites were selected. In addition, the guides conveyed any information they gained on fish stranding during times that EcoPlan biologists were not present on the river. (The information gained from the guides regarding stranded fish was noted on data sheets, but was not used in the analysis for this project).

During the first visit, January 7, 2003, all gravel bars between Glen Canyon Dam and Lees Ferry were inspected at low flow (approximately 5,000 cfs) to assess the presence and quality of spawning gravel and their potential to strand trout. Using previous data (Angradi *et al.* 1992), angling guide suggestions, and current observations, ten different sites along the 15.80-mile stretch of the Colorado River were selected as study sites based on their potential for stranding. Recent observations about the stranding conditions at the different sites during previous months were provided by LFA. Several aspects were taken into consideration to determine if the site should be classified as a potential stranding area: 1) previous findings (Angradi *et al.* 1992), 2) quality and quantity of spawning gravel, 3) recent observations of spawning activity relative to the site, 4) extent of stranding conditions and, 5) likelihood of stranding (e.g., morphometry of the site, seepage rates, etc.). Throughout the project, site photographs were taken at both low and high water stages (Appendix A-Aerial Photographs depicting Stranding Areas, Appendix B-Photographs of Stranding Sites taken at 5,000 cfs, Appendix C-Photographs of Stranding Sited taken at 20,000 cfs).

The 2003 stranding survey encompasses the same river reach and, for the most part, the same stranding areas surveyed by Angradi *et al*. (1992). River Mile measurements from Lees Ferry have been more refined since 1989; hence there are slight discrepancies in the RM identification between the two studies. For clarity, we have used the most recent RM measurements in this report and refer the reader to Table 2 for any comparisons.

Although the study encompassed only a portion of the shoreline between Glen Canyon Dam and Lees Ferry, EcoPlan believes the weekly surveys provided a nearly complete inventory of stranded trout. Most of the shoreline contains no sites for stranding, consisting of vertical cliffs entering and lying well below the water surface. Smaller, less obvious gravel bars may have produced the occasional stranded trout, but since we examined the most likely sites, we assume few other trout were stranded other than those we counted.

Table 2. Comparison of river mile and maximum dimensions for stranding areas and sites between Glen Canyon Dam and Lees Ferry in this study and the Angradi study.

2003					Angradi *et al.* 1992			
RM	Subset	Max Length (m)	Max Width (m)	Max Depth (m)	RM	Max Length (m)	Max Width (m)	Max Depth (m)
-15.20	A	8.0	4.0	0.2	-14.83	29.0	14.0	0.2
	B	15.2	3.0	0	-14.82	4.0	7.0	0.3
	C	40.0	3.0	0	-14.81	4.0	7.0	0.3
	D	11.0	9.0	0	-	-	-	-
-14.50		79.35	30.5	0.2	-14.00	15.0	5.0	0.4
-13.20		76.0	11.0	0	-13.00	4.5	2.2	0.1
-		-	-	-		1.3	1.0	0.3
-		-	-	-		1.0	1.4	0.1
-		-	-	-		9.6	5.8	0.2
-		-	-	-		4.6	2.0	0.1
-12.20		198.0	61.0	0.2	-	-	-	-
-		-	-	-	-11.90	50.0	10.0	0.2
-11.85	A	12.2	11.0	0.2	-11.70	15.0	3.0	0.4
	B	15.2	9.0	0.2	-	-	-	-
	C	22.9	4.6	1.4	-	-	-	-
-11.15		79.3	79.3	0.2	-11.00	5.0	1.0	0.2
-9.90	A	48.8	12.2	0.2	-9.70	20.0	2.0	0.2
	B	91.4	6.1	0.2	-	-	-	-
	C	38.1	36.5	0.2	-	-	-	-
-8.70		105.0	30.0	0.2	-8.90	23.0	7.0	0.6
-		-	-	-		30.0	3.0	< 0.1
-		-	-	-		35.0	2.0	0.2
-8.25		470.0	50.0	0.3	-8.20	50.0	5.0	0.2
-3.90	A	400.0	40.0	0.2	-4.02	60.0	12.0	0.3
	B	45.0	120.0	0	-4.01	100.0	10.0	0.5
-		-	-	-	0.50	100.0	20.0	0.6

(m = meters)

Stranding areas were surveyed two days a week, usually at daybreak, weekly from January 7, 2003 through March 31, 2003 for a total of 26 days of observation. Morphometric measurements (length, width, and depth) of the stranding areas were recorded during the initial visit on January 7, 2003 (Table 2). Within four of the stranding areas (RM -15.20, -11.85, -9.90, and –3.90), subsets (A, B, C, and D) were identified as a result of a change in habitat over the larger area. Some of the subsets within the stranding areas were separated by areas of differences in habitat (e.g., pools, runs, flats, etc.); therefore, it made sense to separate these sites out from the others. During subsequent surveys, water and air temperatures were measured at each site

(Figure 3). Water temperatures were taken within water present in each of the stranding areas.

During 2003, flow measurements in the Lees Ferry reach of the Colorado River were obtained from gauges operated by the U.S. Geological Survey ([Lee's Ferry Gauge], USGS 2003). Daily air and water temperatures for each site were calculated as the mean of the daily water temperatures taken at each site (for the days surveyed).

2.2 Trout Stranding

During each visit to the ten sites, stranding areas were covered in a zigzag manner to ensure that no fish was overlooked. The numbers of fish dead, likely to live, or likely to die were recorded, as well as any relevant comments (i.e. predators, other animals observed, and number fishermen and guides present within the study stretch of the river). A fish was categorized as likely to live if it was stranded in a pool of water that covered a substantial portion of its body and it was postulated that the fish would endure until the water rose high enough for the fish to escape to deeper water. On the contrary, a fish was categorized as likely to die, if the fish was stranded either on dry land or in a pool of water that was insufficient to ensure its survival to next high water stage.

At a site, we first determined if any fish was likely to die and carefully collected and returned it to the river (no measurements were recorded on these fish). Second, any fish found dead was collected, placed in a numbered bag, and transported to the National Park Service fish cleaning station at Lees Ferry. Dead fish were weighed to the nearest gram (g) and measured to the nearest millimeter ([mm]; total length [TL] and fork length [FL]). The sex of the fish was then determined along with spawning condition (i.e., green, ripe and running, or spent). A fish was labeled as green if it was immature and there was no evidence of mature gonads. A fish was labeled as ripe and running (R/R) if it was full of eggs or milt and a fish was labeled as spent if there was evidence of gonads, but there was no evidence of either eggs or milt.

In both the eighth and ninth week of surveying, a temporary change in protocol occurred. Tuesday morning (2/25/03 and 3/4/03) visits to the sites were made earlier in the morning (approximately 0200) to coincide with dropping river level (Figure 4). This protocol change was implemented in an attempt to alleviate a potential source of error, i.e. predators (e.g. coyotes, ringtail cats, birds of prey, etc.) removing stranded fish from the study area before we arrived to conduct the site assessment. During these two pre-dawn surveys, there appeared to be no striking increase or decrease in the amount of stranded fish than were encountered during the earlier sampling periods, i.e. the numbers of stranded fish were within the range of numbers seen on earlier surveys. The February 25 visit resulted in two stranded fish: one dead and one likely to live. On March 4, approximately 32 fish likely to live were observed and only one dead fish was collected. No evidence (i.e. eye reflection and tracks) was observed during those early visits to indicate predators were out scavenging stranded fish at that time in the morning. On the March 11 sampling trip, the survey protocol returned to normal, and sites were visited starting at daybreak.

3.0 Results

3.1 Physical conditions

Ten potential stranding areas were identified earlier (Table 3) and RBT showed a particular susceptibility to stranding at three sites (RM -15.20, -13.20, and -11.85).

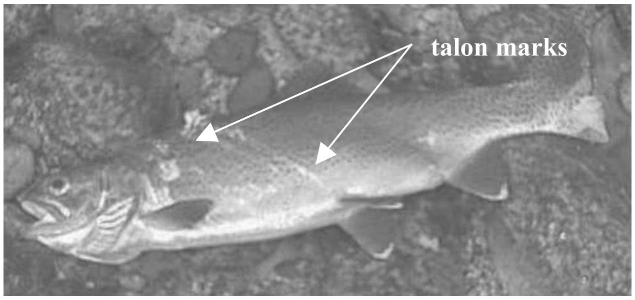
Throughout the experiment, air and water temperatures were collected at each site during each sampling day. The average water temperature was 6.68 degrees Celsius (VAR = 1) with the average air temperature being 7.28 degrees Celsius (VAR = 6.6) (Figure 3). Water temperatures remained nearly constant due to the deep hypolimnial release of water from Lake Powell through Glen Canyon Dam and the winter cooling of the epilimnion bringing the temperatures of the upper and lower water depths closer.

Table 3. Rainbow trout numbers observed in 2003 for stranding areas between Glen Canyon Dam and Lees Ferry.

RM	RBT likely to live	RBT likely to die	RBT dead	Total	Percent dead and likely to die
-15.20	19	2	19	40	53
-14.50	2	0	0	2	0
-13.20	27	0	7	34	21
-12.20	30	0	2	32	6
-11.85	386	0	2	388	0.5
-11.15	0	0	0	0	0
-9.90	1	0	1	2	50
-8.70	0	0	0	0	0
-8.25	0	0	1	1	100
-3.90	2	1	1	4	50

3.2 Trout Stranding

A total of 503 adult fish were found stranded during this three-month study. Seven percent (36 fish) of stranded fish were dead or dying (Figure 5). Stranded fish (dead) ranged from 200 mm to 455 mm TL (Figure 6) and from 85 g to 1,200 g in weight (Figure 7). Some (10 fish, 28 percent) of the stranded fish, both alive and dead, showed indications of predation, i.e. fish that were still alive had talon marks along their flanks, while dead fish had wounds that varied from talon marks (Photograph 1) along the flanks to missing portions of their anatomy (i.e. eyes, gills, and internal organs [Photograph 2]). It is unclear whether fish (dead) with talon marks or any other wounds, received these prior to or after their death. Bald Eagles and Osprey are present within the project area and could be responsible for the talon marks either before or after the fish had died.



Photograph 1. Stranded fish with talon marks present.

Photograph 2. Stranded fish that exhibits signs of predation.

The stranding site at RM –15.20 showed a high potential of stranding and mortality to those stranded fish. A total of 40 fish were seen over the span of the experiment at this site, 19 (48 percent) of those fish were dead. Ten of the 19 (53 percent) stranded fish were found at the top of the stranding area (subset A), in close proximity to a large boulder that created a place of refuge away from the main current. As the water level dropped, a small pool remained until approximately 0700, when the pool would completely disappear. A majority of the 19 stranded fish categorized as likely to live were observed in a pond at the southern end of the site (subset C). Contrasting the site at RM –15.20, is the site at RM –11.85. A total of 388 stranded fish were found and only two were dead. The difference at this site was gravel that sloped towards a 1.4 m deep pool, which enabled stranded RBT to survive until the water level rose to a sufficient level where they could migrate out to the river.

Even numbers of male and female fish died after becoming stranded over the 3-month period (16 male, 16 female, and one unknown fish [due to small size and age]). Seventy percent of the dead stranded fish were ripe and running (Figure 8).

4.0 Discussion

Sampling was conducted two days per week during the three-month period. An assumption was made that since the flow rates during the study period fluctuated between 5,000 cfs and 20,000 cfs consistently day to day, a sub-sample would be adequate to illustrate the stranding findings within the Lees Ferry stretch of the Colorado River; therefore, sampling was only conducted two days a week.

A total of 36 RBT were either placed into the categories of dead or likely to die during the 26 sampling days of the experiment while another 467 were stranded but likely to live. If we assume equal numbers of stranded fish would have been observed on any of the other days in the 90-day period then we can conclude 125 fish died or were likely to die over the entire period and an additional 1,617 would have been stranded but lived.

There was no significant trend between the size of stranded fish and time in which they were stranded (r^2 = 0.0004 [Figure 9]). Some of the stranded fish, both alive and dead, showed indications of predation; fish that were still alive had talon marks along their flanks, while in addition to talon marks, the dead fish had more lethal wounds (i.e. missing eyes, gills, and internal organs). It is difficult to discern if these wounds were a result of stranding or resulted in the fish being stranded. The fluctuating river level may have helped to increase predation pressure on the rainbow trout by reducing the amount of deep water that could be utilized by the fish as refuge from predators.

From November 1989 through April 1990 under high fluctuating flows, trout stranding was regularly surveyed by Angradi *et al.* (1992), then periodically until April 1991. During November 1989, stranding areas from Glen Canyon Dam downstream to Lees Ferry were identified, numbered, and morphometric measurements (length, width, and depth) were recorded. From February 1990 through April 1990, identified stranding areas were surveyed four times each month. May 1990 through March 1991, stranding areas were surveyed during each controlled flow and twice a month during all other flows. A total of 1924 adult fish were found stranded over the 18 month period with fifty-one percent of stranded fish either dead or dying.

The 1990 estimate of RBT numbers within the Lees Ferry reach of the Colorado River was approximately 114,000 Age II+ fish. In 2000, Arizona Game and Fish Department estimated the number of RBT present within the Lees Ferry reach to be approximately 160,000 Age II+ fish (Bill Persons 2003).

The mean total length (TL) of RBT found within the Lees Ferry reach in 2002 was 234 mm (SD = 88, n = 3409)(Joe Slaughter 2003), whereas the mean TL of stranded RBT was larger at 378 mm (SD = 63, n = 36). RBT lengths in 1991 were 352 mm (SD = 117, n = 228), but, like 2003, stranded fish also were larger at 437 mm (SD = 53, n = 496). Size of fish stranded in 2003 remained constant throughout the study (Figure 9).

The largest numbers of RBT became stranded during the Angradi *et al*. 1992 study at RM –3.90, -8.70, -9.90, and –13.20. The largest numbers of stranded fish during the EcoPlan study were found at RM -11.85, -12.20, -14.50, and -15.20. Total stranding numbers observed during the 2003 experiment were low compared to those observed in 1990 by Angradi *et al*. A total of 503 adult fish were found stranded during this three-month study. This is considerably lower than the 1924 adult fish found stranded during the 18-month Angradi *et al*. 1992 study. Fifty percent of the Angradi fish were either dead or dying when found whereas six and half percent (33 fish) of stranded fish were dead in this survey. We attribute the lower death rate to lower water temperatures in stranding pools during this survey than those found during the summer of 1990.

We believe the Angradi numbers would have been considerably higher had his team conducted more intensive, weekly sampling from April 1990 to April 1991; however, their goal to document that stranding took place differed from the goal for this survey which was to determine the extent of stranding.

One plausible explanation for the differences in stranding is low ramping rates (Saltveit *et al.* 2001). According to the EIS, over 70 percent of the time down ramp rates exceeded 4,000 cfs/hour and over 25 percent of the time they exceeded 6,000 cfs/hour. Gradual down ramping rates as seen in the 2003 experiment (2,500 cfs/hour) may be one key to the stranding rate seen within the system. Slower ramping rates give the fish present within these shallow areas more time to escape out to the deeper water of the river. Faster or unrestricted ramping rates may have a higher tendency to leave fish stranded. Also, some of the differences may be due to: 1) Angradi had large kills that could be accredited to high water temperature in stranding pools in May and June, whereas EcoPlan only surveyed during cool times; and 2) Angradi led 34 surveys over an 18-month period, whereas EcoPlan led 26 surveys over three months.

Low air and water temperatures present could account for the relatively small numbers of dead and dying stranded fish (36) that were seen during the 2003 experiment in comparison with those found in 1990. During the Angradi *et al.* 1992 study, high temperatures (up to 29 degrees Celsius) may have led to poor water quality and higher RBT mortality than seen in the 2003 experiment. One day in May 1990, 86 adult RBT died at RM –11.85 and 94 died at RM -14.50, more mortality than seen during the entire 2003 experiment. When RBT were stranded during the 2003 experiment, air temperatures were low enough that water quality of stranding pools never reached lethal levels.

In addition, antecedent conditions were different during the two experiment years. During fall and winter of 2002, flows were lower and more controlled than those preceding the study completed in 1990. In the time preceding the Angradi study, monthly flows varied from approximately 1,300 cfs up to 30,000 cfs. The lower, more consistent flows seen in the fall of 2002 may have conditioned the RBT not to enter shallower, lower flow areas and to stay in deeper regions of the river.

The angling public, more specifically guides of the Lees Ferry area, anticipated that fluctuating flows within the river would result a large number of stranded fish. Due to the possibility of stranded fish and the fact that the experiment was public knowledge, the guides were most concerned that these factors would result in a lower number of booked trips, thus resulting in a loss of business. Initially most of the guides expressed some concern over the expected outcome of the experiment. However, as the experiment progressed and few stranded trout were found, the guides seemed to sense that constant fluctuating flows may not be as great a threat as first perceived.

5.0 Conclusions

- Fish were stranded in select sites (not randomly) possibly because of site morphometry.

- A lower percentage of fish died in this survey compared with results in 1990.

- Cool winter temperatures may have prevented further loss of stranded fish in pools.
- Predation on stranded fish appeared to be minimal.
- A low down ramp rate appears to be a possible factor in preventing stranding of fish.
- Stranded fish apparently were substantially larger than the population norm.
- Male and female trout were equally susceptible to stranding.
- Concerns of the angling public and guides about stranding in 2003 were not as prevalent as anticipated.
- Antecedent conditions may play a role in the degree of vulnerability of trout to stranding.

6.0 Recommendations

Fluctuating flows similar to 2003 will commence January 2004 and last until the end of March 2004. Habitat conditions are likely to differ in the months preceding the fluctuating flows suggesting that further study of the stranding potential is needed to determine the role antecedent flows play in conditioning trout. Second, in addition to trout stranding, ramping rates are important to power generation and beach erosion. Further study is needed to refine the benefits and impacts of various ramping rates to trout, power generation, and beach erosion.

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Figure 3: Mean Daily Air and Water Temperatures Over the 2003 Experiment

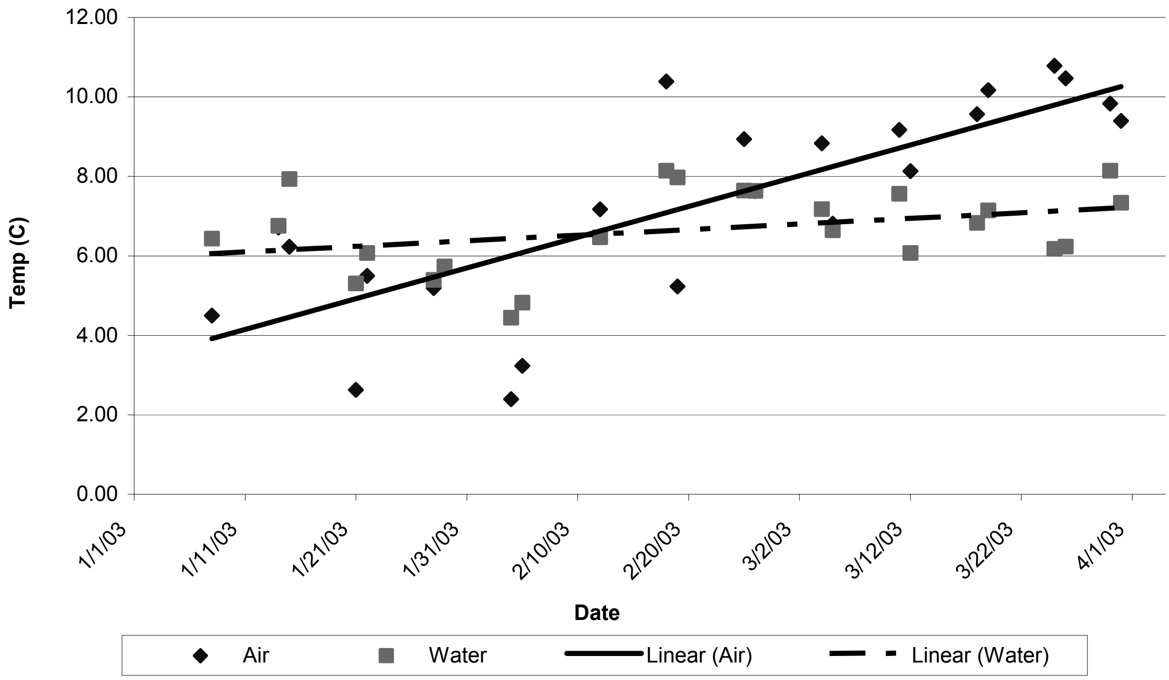


Figure 4: Typical Glen Canyon Dam Experimental Releases for the 2003 Experiment

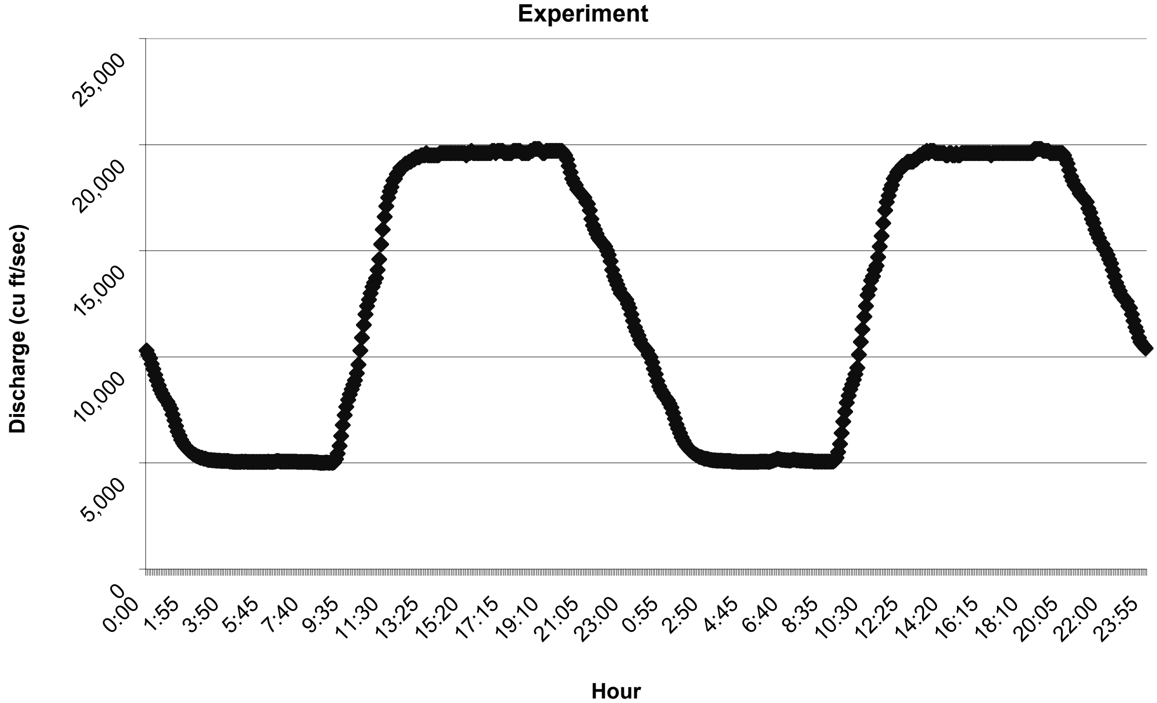


Figure 5: Numbers of Rainbow Trout Encountered During the Stranding Survey

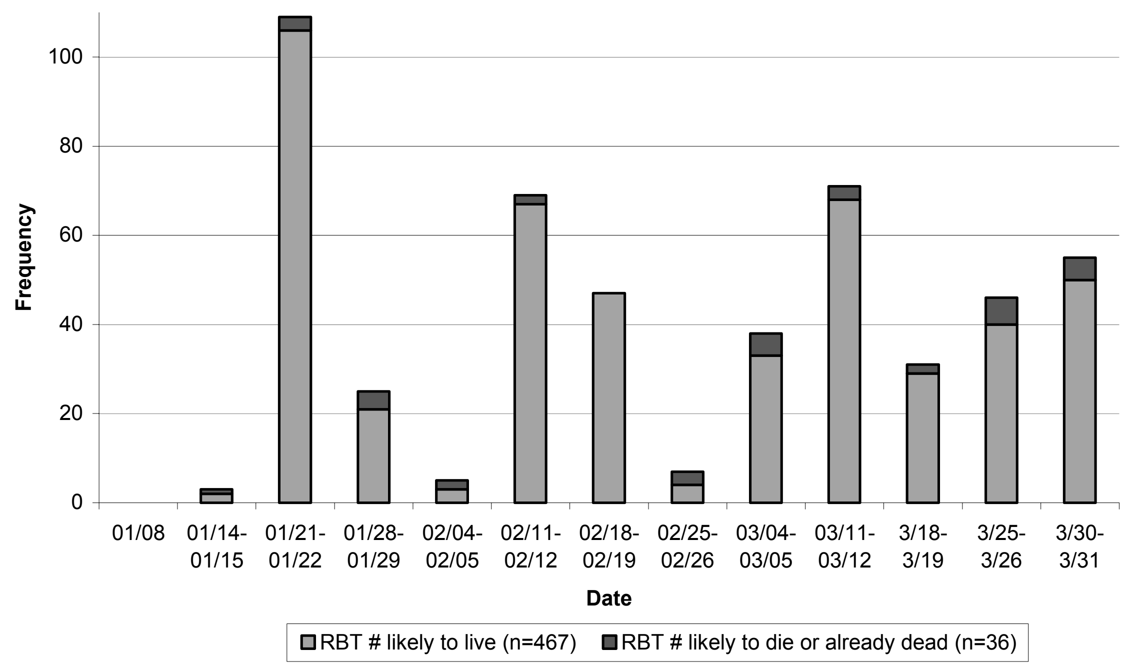


Figure 6: Length Frequency Distibution of Dead RBT

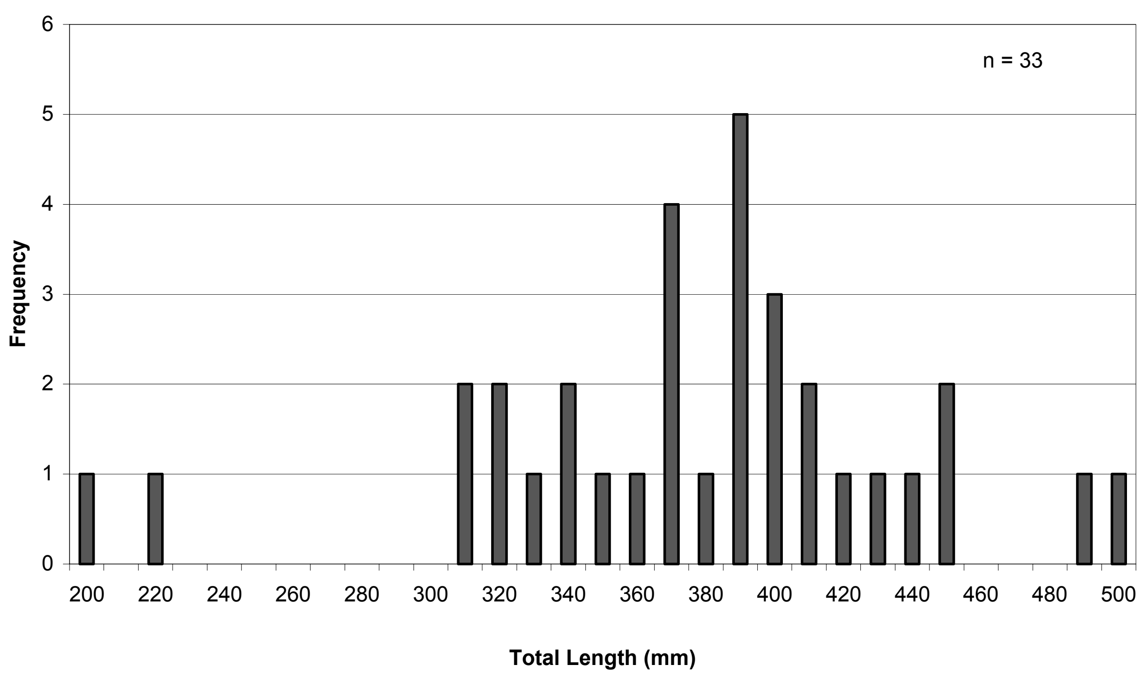


Figure 7: Length-weight Ratio for Stranded (dead) Fish

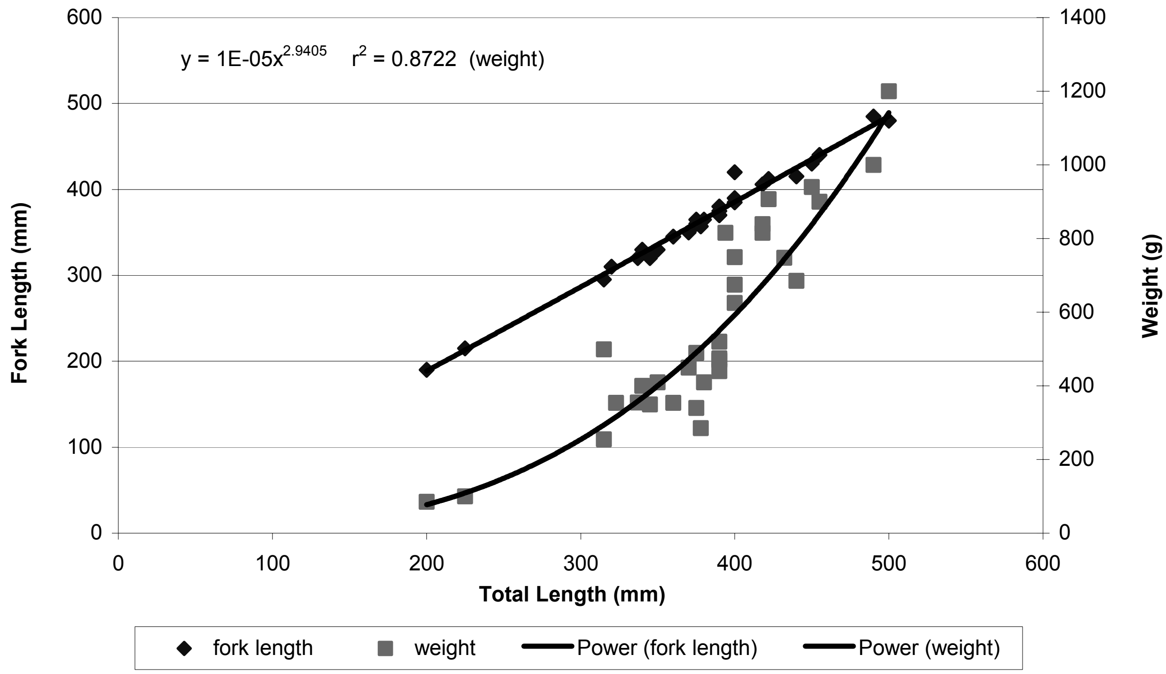


Figure 8: Spawning Condition and Sex of Stranded Rainbow Rrout

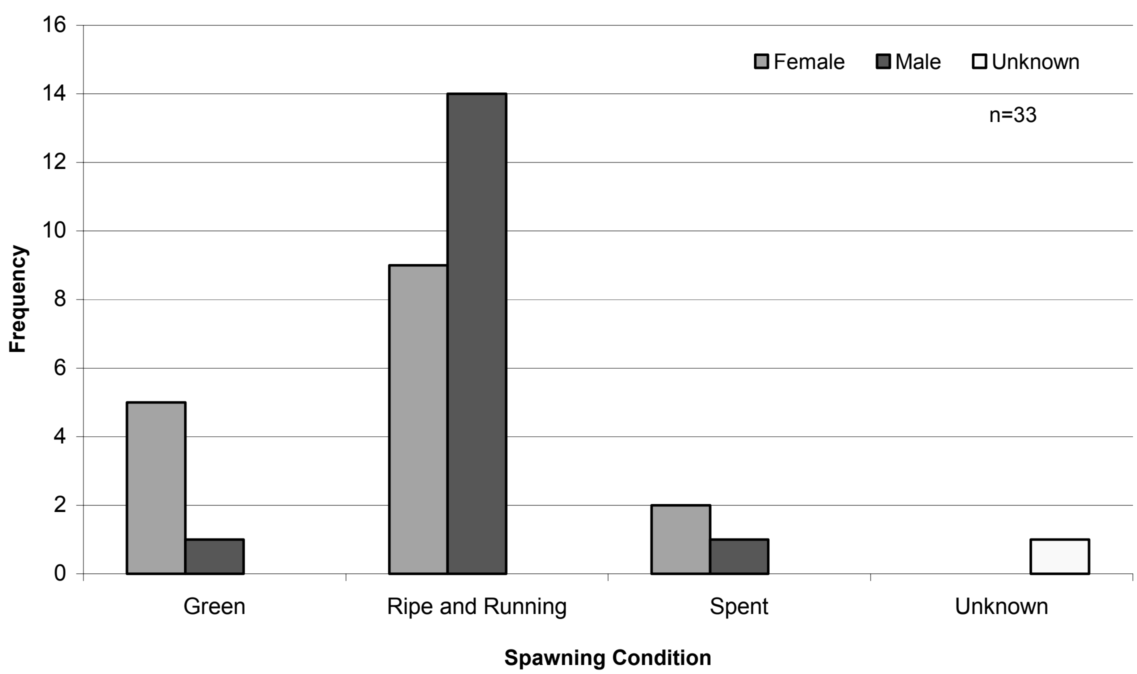
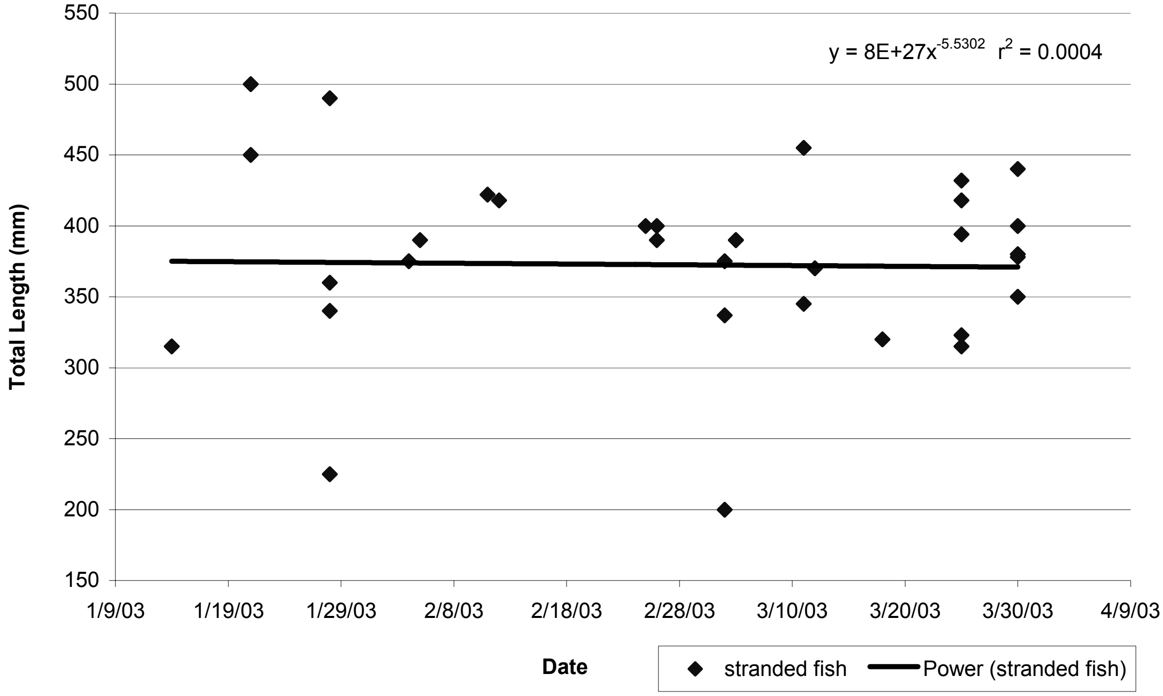


Figure 9: Size of Dead Stranded Rainbow Trout Over Time

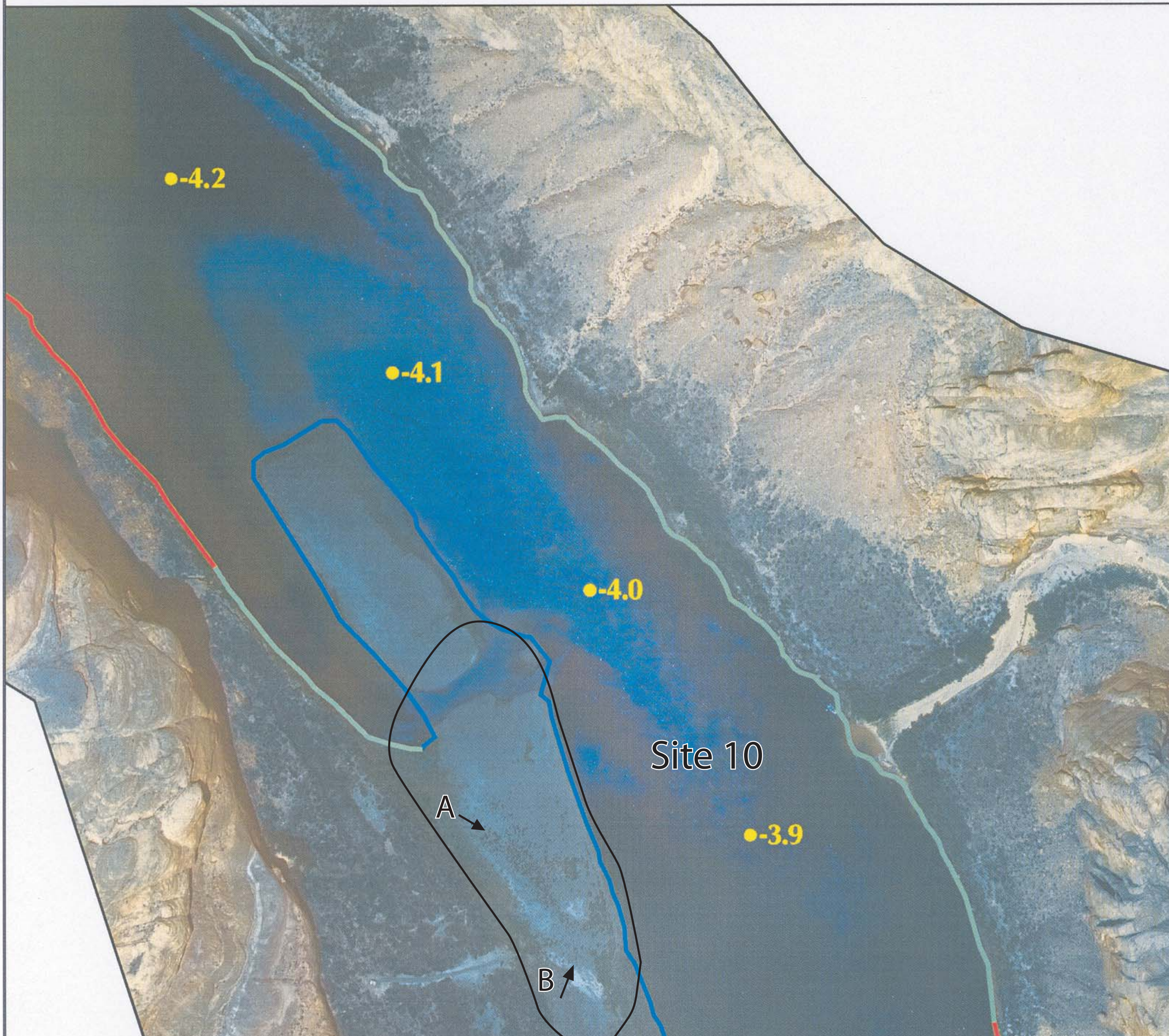


APPENDIX A

Aerial Photographs of Stranding Sites from Glen Canyon Dam to Lees Ferry

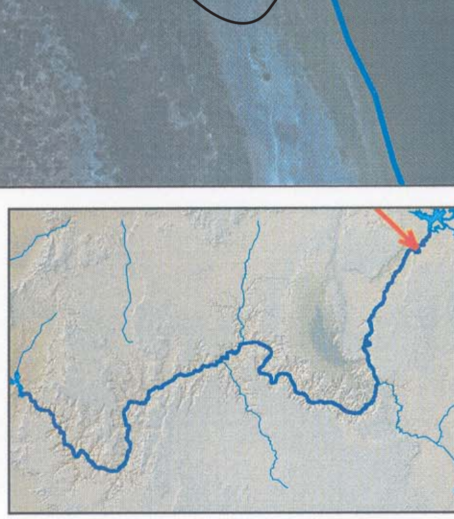
River Mile -4

Shoreline Fish Habitat with GCMRC Mile System



Shoreline Habitat Characterists

- Cobble Bar (CB)
- Talus (TA)
- Sand Bar(SB)
- Debris Fan(DB)
- Shadow(SH)
- Cliff Ledge(CL)



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KILOMETERS

Scale = 1:3000

Map location – I:/EXP_FLOW03/FISH/GLEN_MAPS/RM-4.MAP
Map created on December 20, 2002 by smietz

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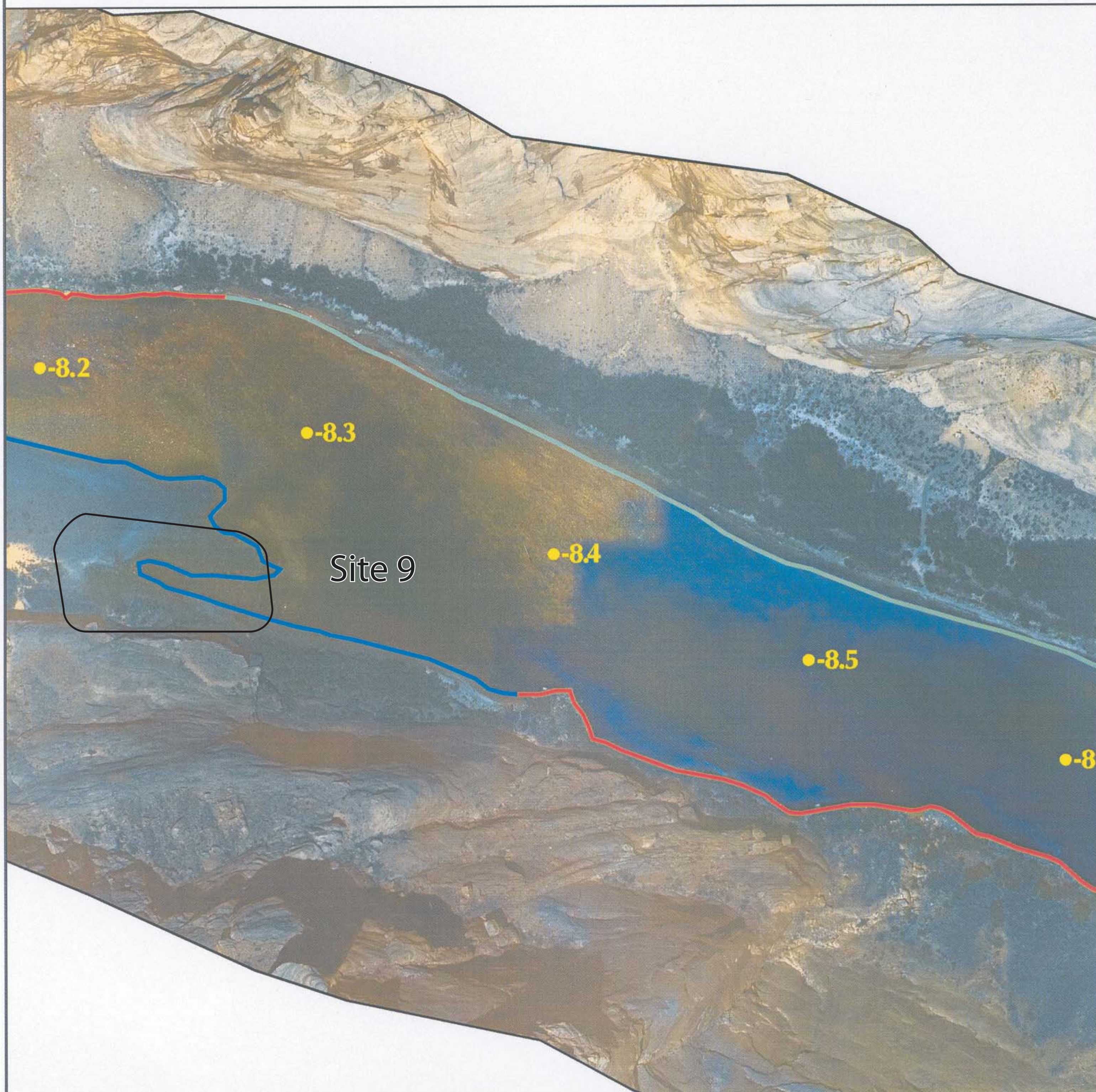
River Mile -8.4

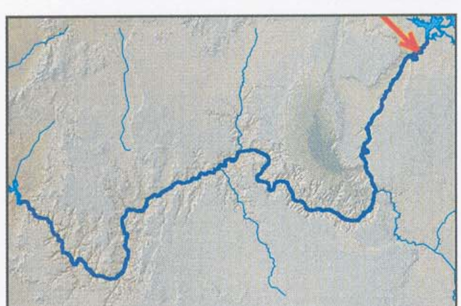
Shoreline Fish Habitat with GCMRC Mile System

GRAND CANYON MONITORING AND RESEARCH CENTER



Shoreline Habitat Characterists

- Cobble Bar (CB)
- Talus (TA)
- Sand Bar(SB)
- Debris Fan(DB)
- Shadow(SH)
- Cliff Ledge(CL)



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Map created on December 20, 2002 by smietz

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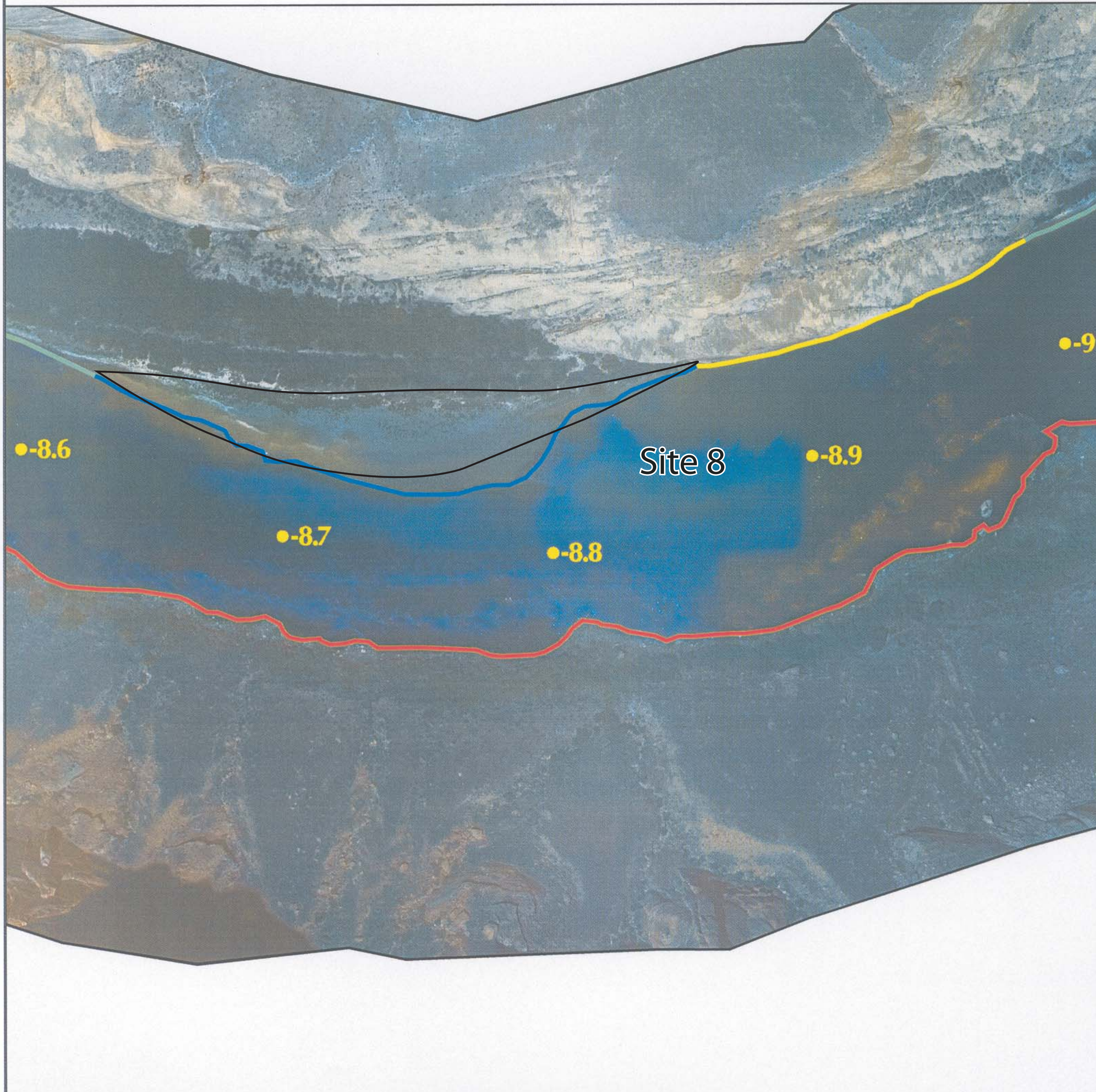
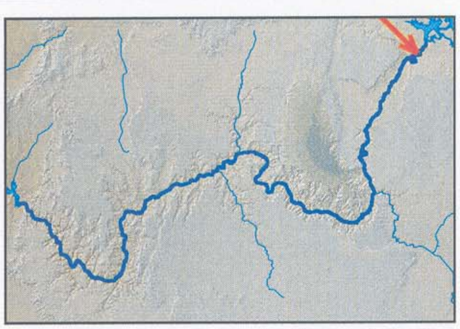
River Mile -8.8

Shoreline Fish Habitat with GCMRC Mile System



Shoreline Habitat Characterists

- Cobble Bar (CB)
- Talus (TA)
- Sand Bar(SB)
- Debris Fan(DB)
- Shadow(SH)
- Cliff Ledge(CL)



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Map created on December 20, 2002 by smietz

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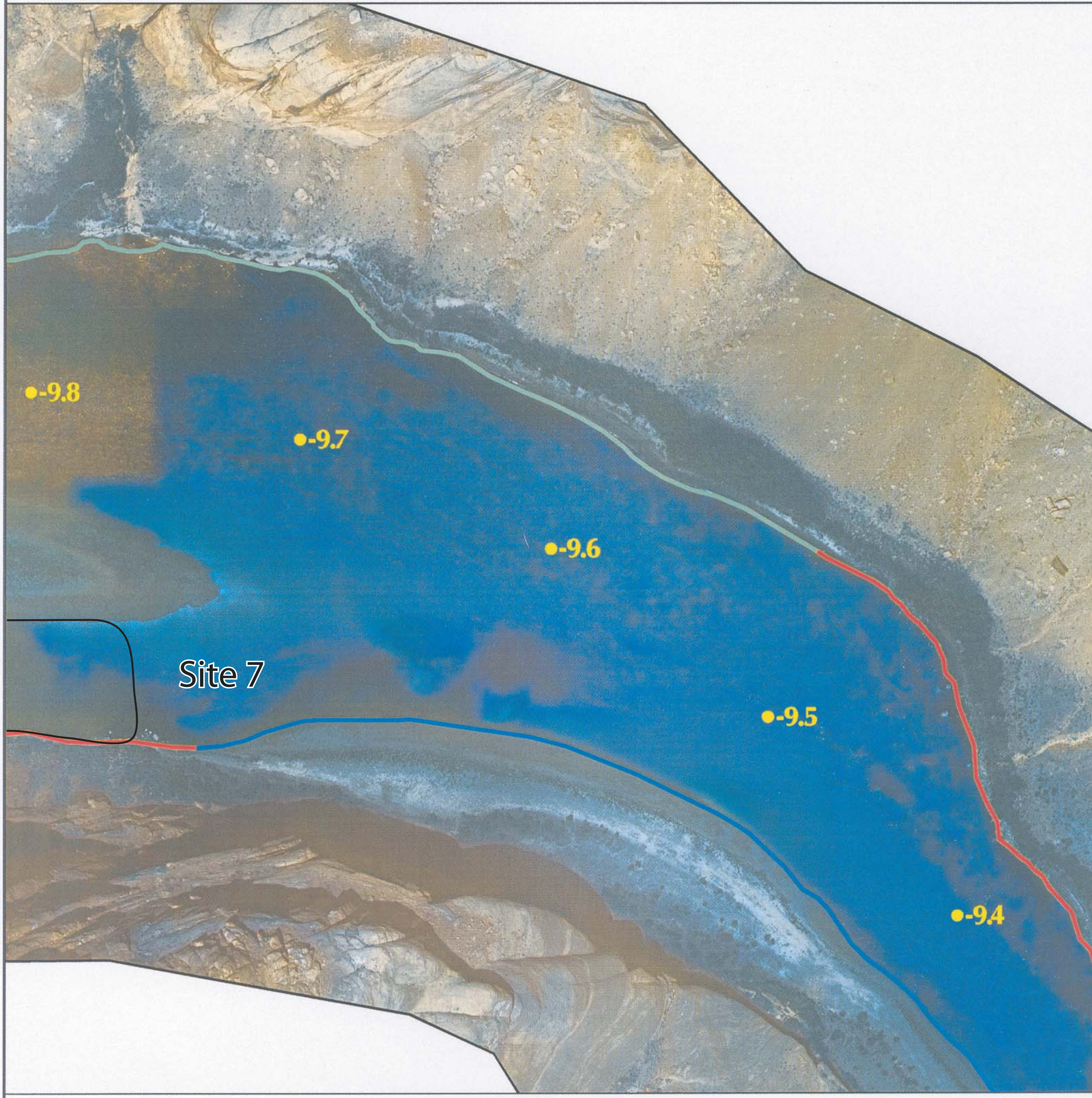
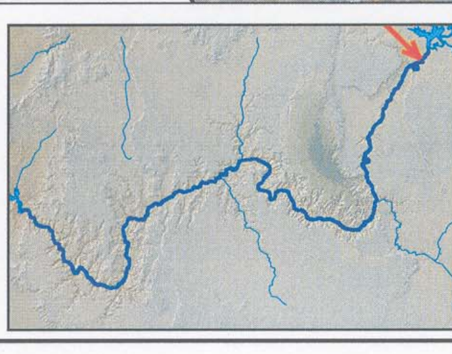
River Mile -9.6

Shoreline Fish Habitat with GCMRC Mile System



Shoreline Habitat Characterists

- Cobble Bar (CB)
- Talus (TA)
- Sand Bar(SB)
- Debris Fan(DB)
- Shadow(SH)
- Cliff Ledge(CL)



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KILOMETERS

N W E S

Scale = 1:3000

Map location = I:/EXP_FLOW03/FISH/GLEN_MAPS/RM-9_6.MAP
Map created on December 20, 2002 by smietz

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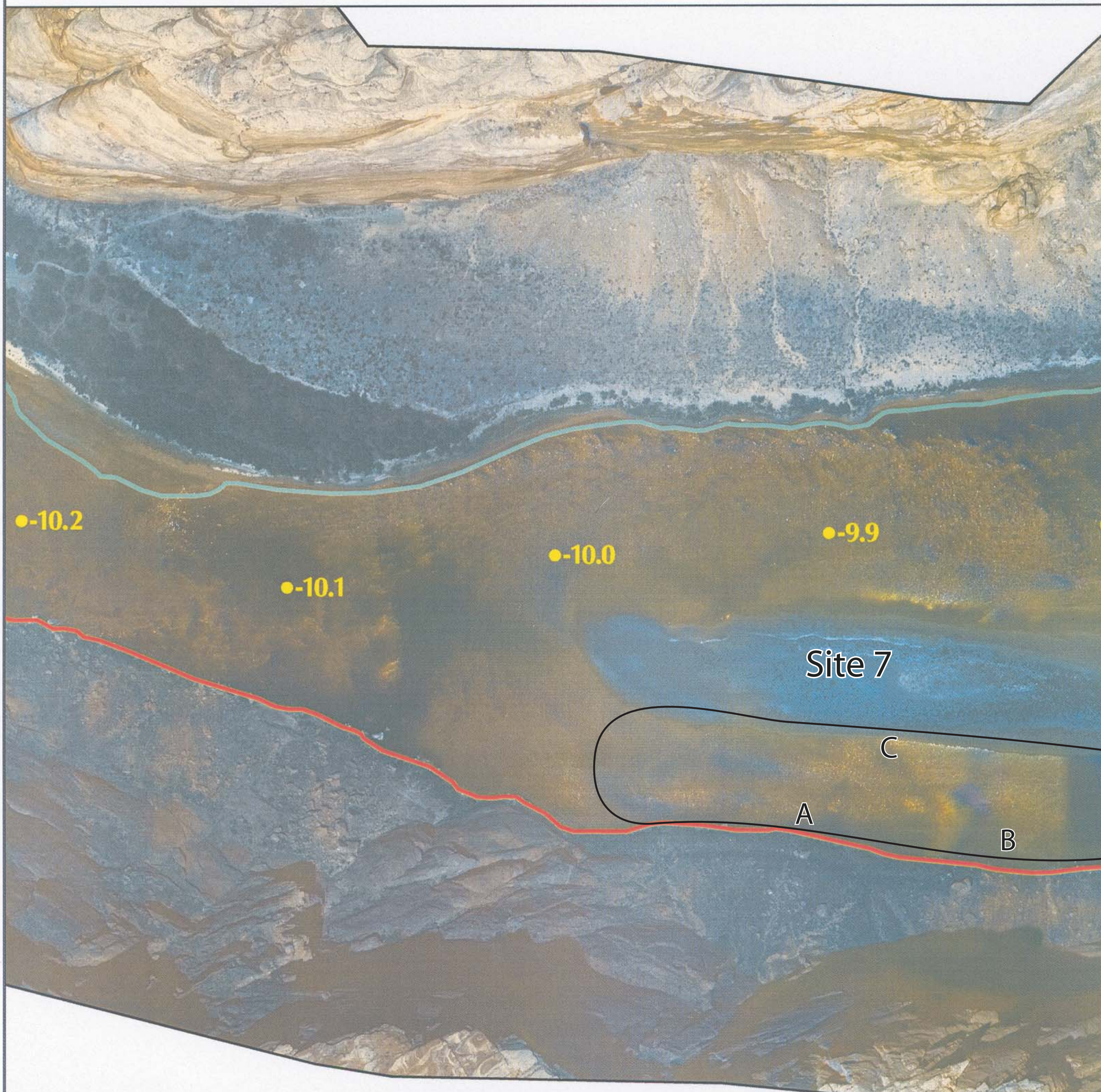
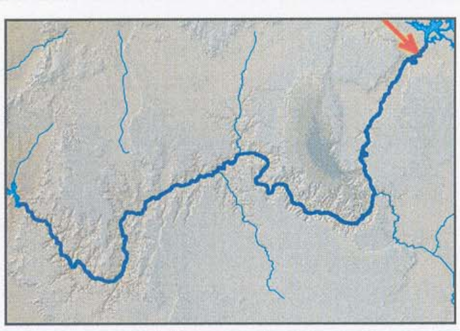
River Mile -10

Shoreline Fish Habitat with GCMRC Mile System



Shoreline Habitat Characterists

- Cobble Bar (CB)
- Talus (TA)
- Sand Bar(SB)
- Debris Fan(DB)
- Shadow(SH)
- Cliff Ledge(CL)



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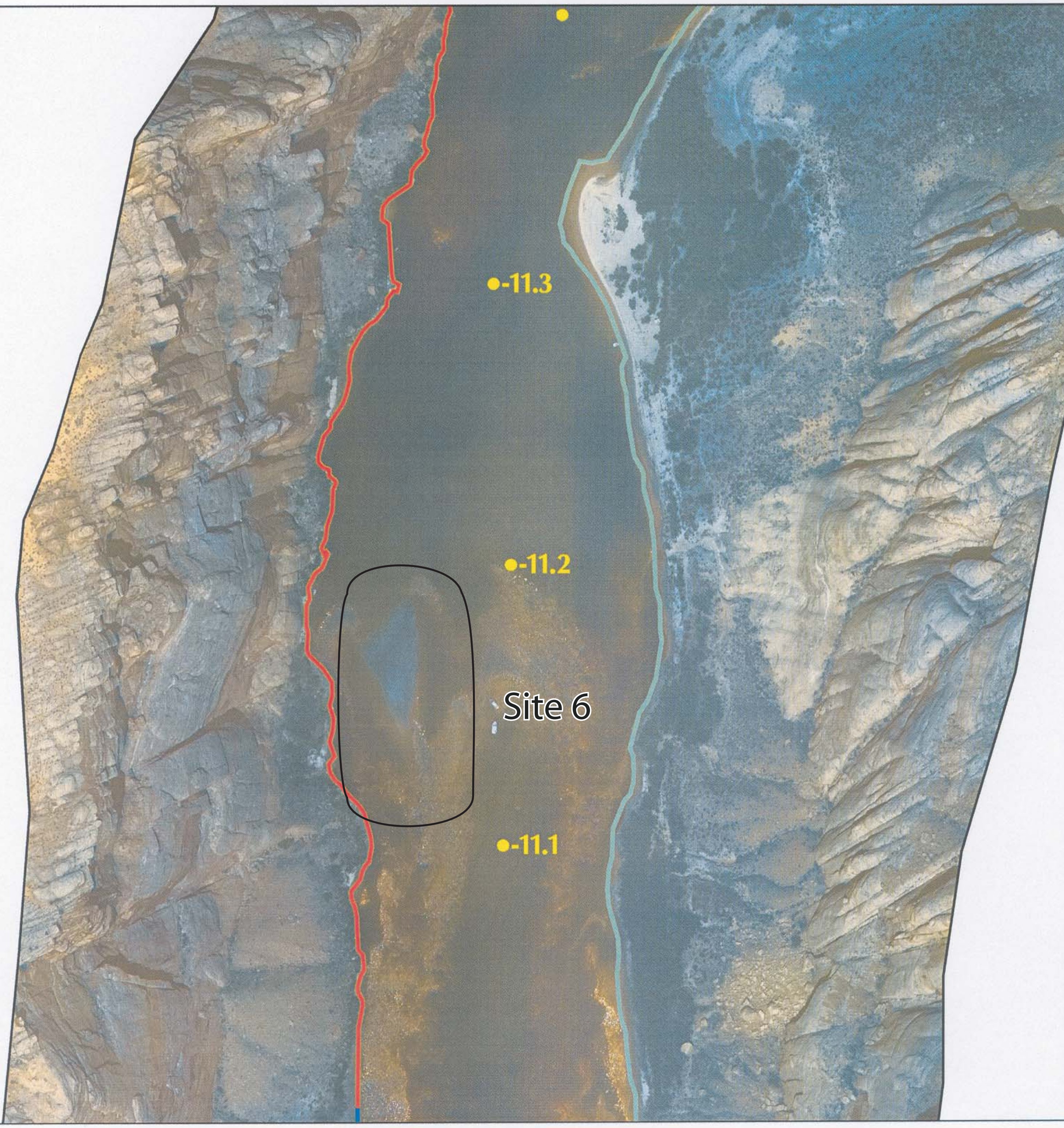
Map created on December 20, 2002 by smietz

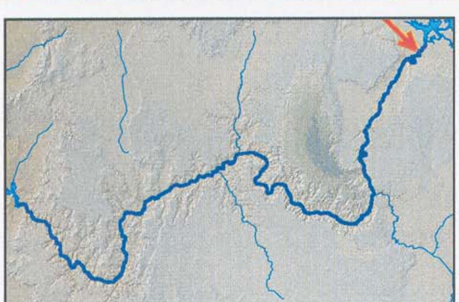
River Mile -11.2

Shoreline Fish Habitat with GCMRC Mile System



Shoreline Habitat Characterists

- Cobble Bar (CB)
- Talus (TA)
- Sand Bar(SB)
- Debris Fan(DB)
- Shadow(SH)
- Cliff Ledge(CL)



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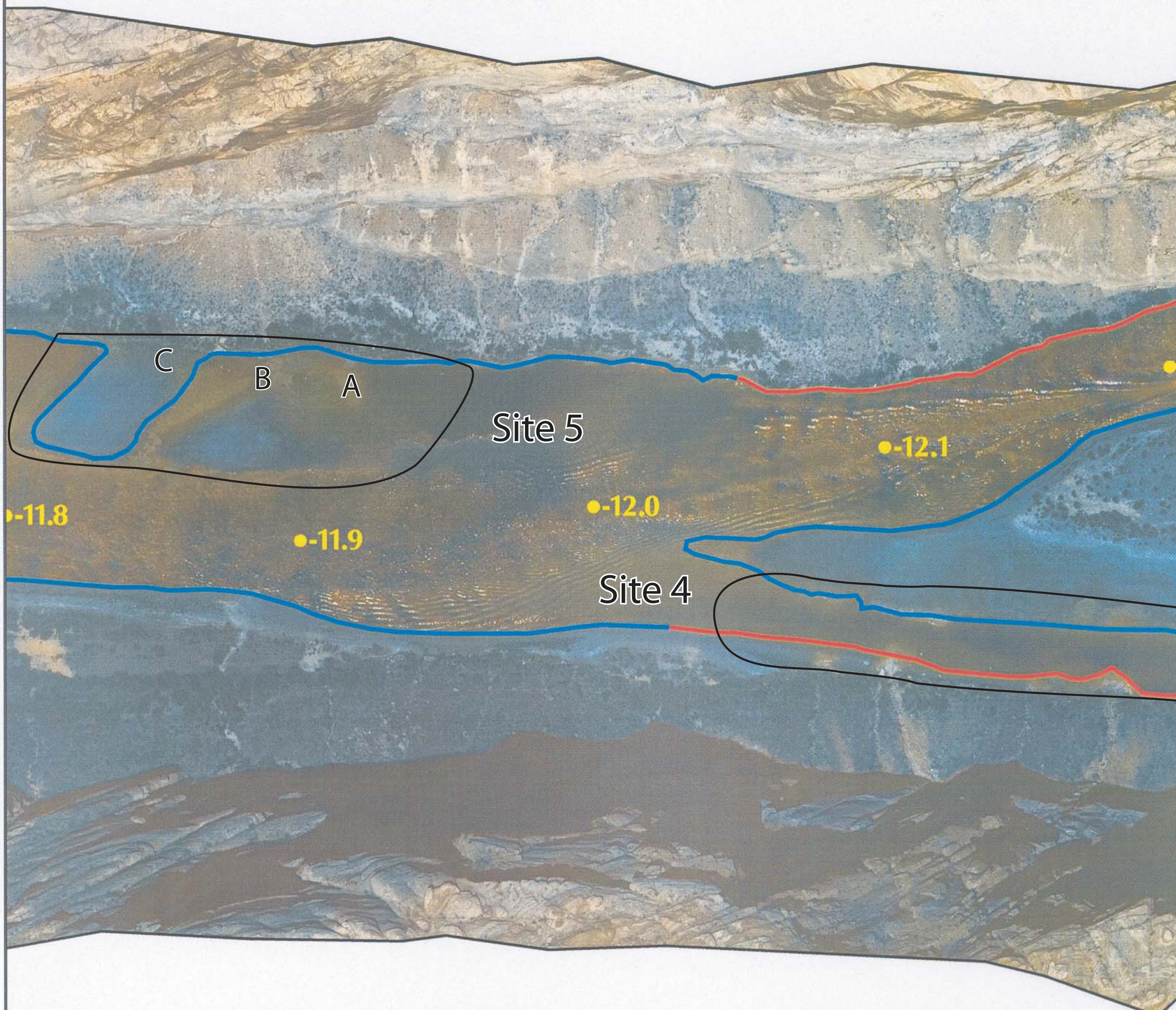
Map created on December 20, 2002 by smietz

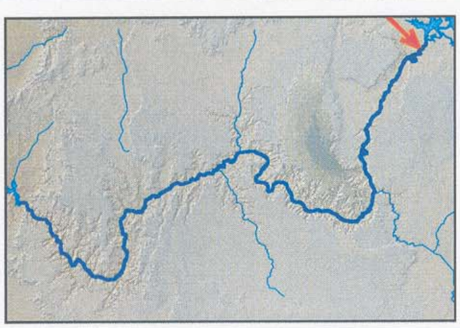
River Mile -12

Shoreline Fish Habitat with GCMRC Mile System



Shoreline Habitat Characterists

- Cobble Bar (CB)
- Talus (TA)
- Sand Bar(SB)
- Debris Fan(DB)
- Shadow(SH)
- Cliff Ledge(CL)



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Map created on December 20, 2002 by smietz

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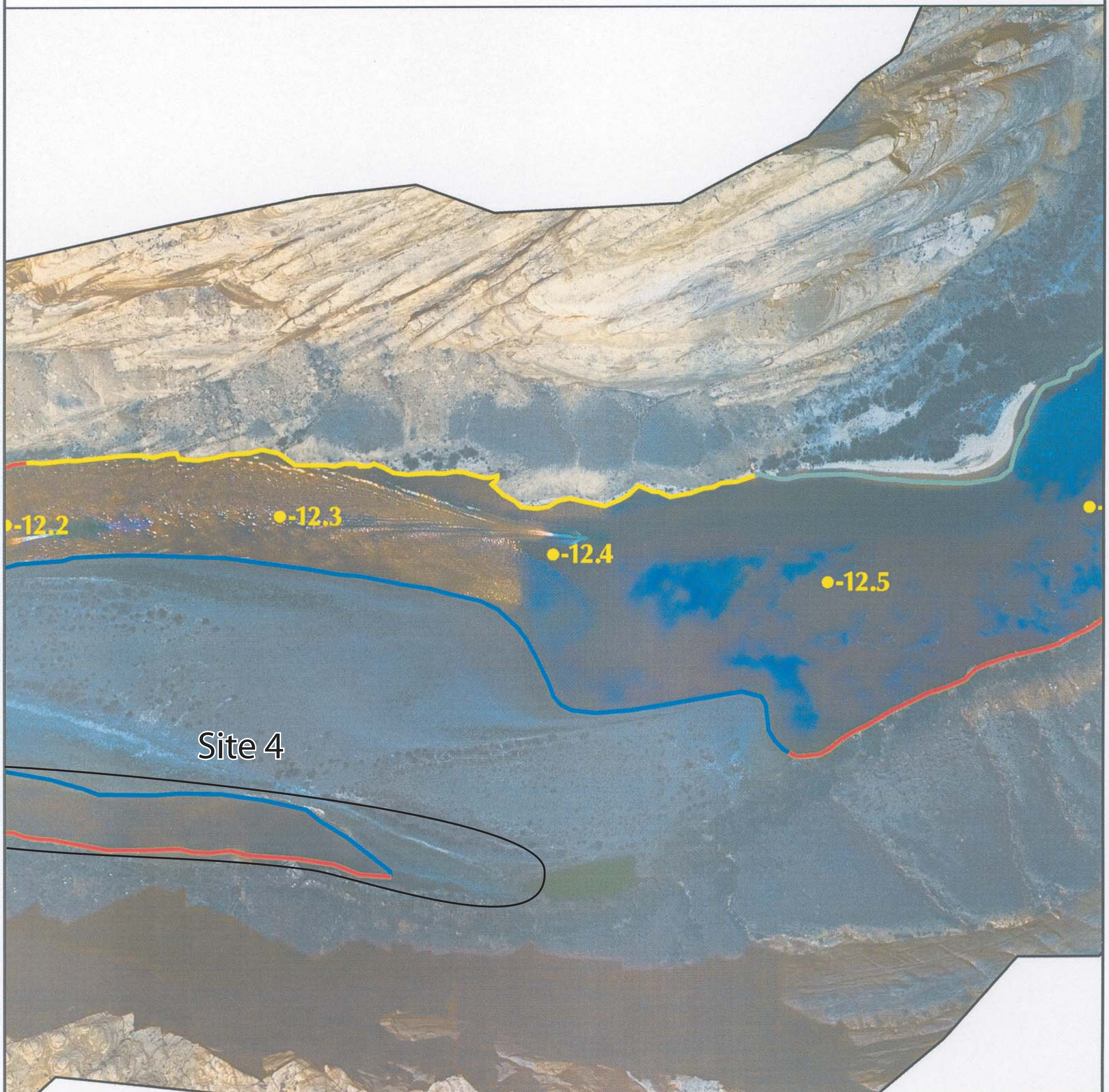
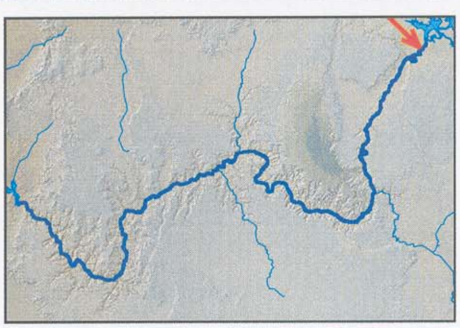
River Mile -12.4

Shoreline Fish Habitat with GCMRC Mile System



Shoreline Habitat Characterists

- Cobble Bar (CB)
- Talus (TA)
- Sand Bar(SB)
- Debris Fan(DB)
- Shadow(SH)
- Cliff Ledge(CL)



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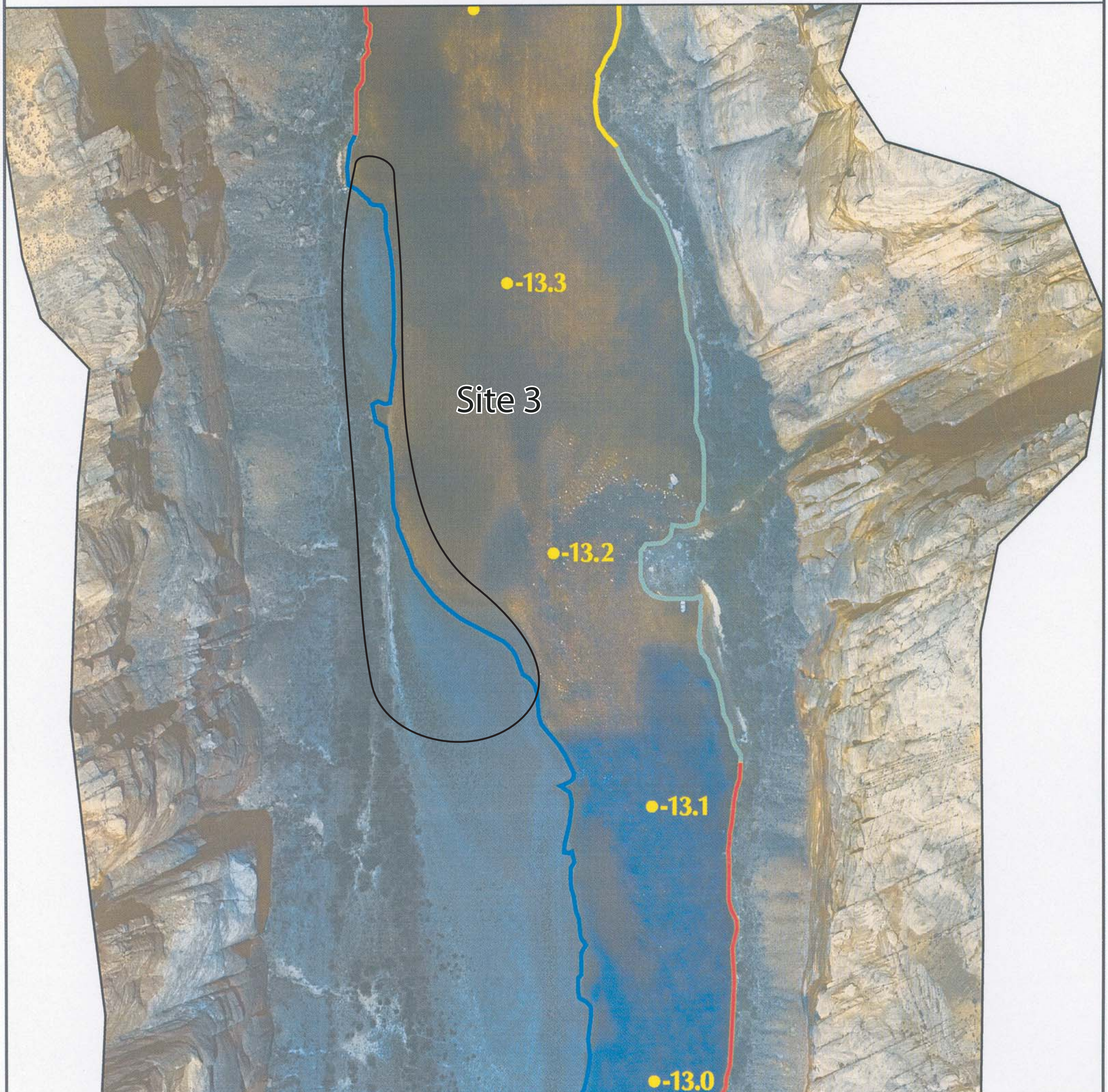
Map created on December 20, 2002 by smietz

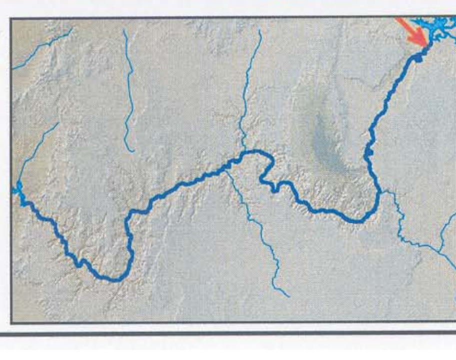
River Mile -13.2

Shoreline Fish Habitat with GCMRC Mile System



Shoreline Habitat Characterists

- Cobble Bar (CB)
- Talus (TA)
- Sand Bar(SB)
- Debris Fan(DB)
- Shadow(SH)
- Cliff Ledge(CL)



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Map created on December 20, 2002 by smietz

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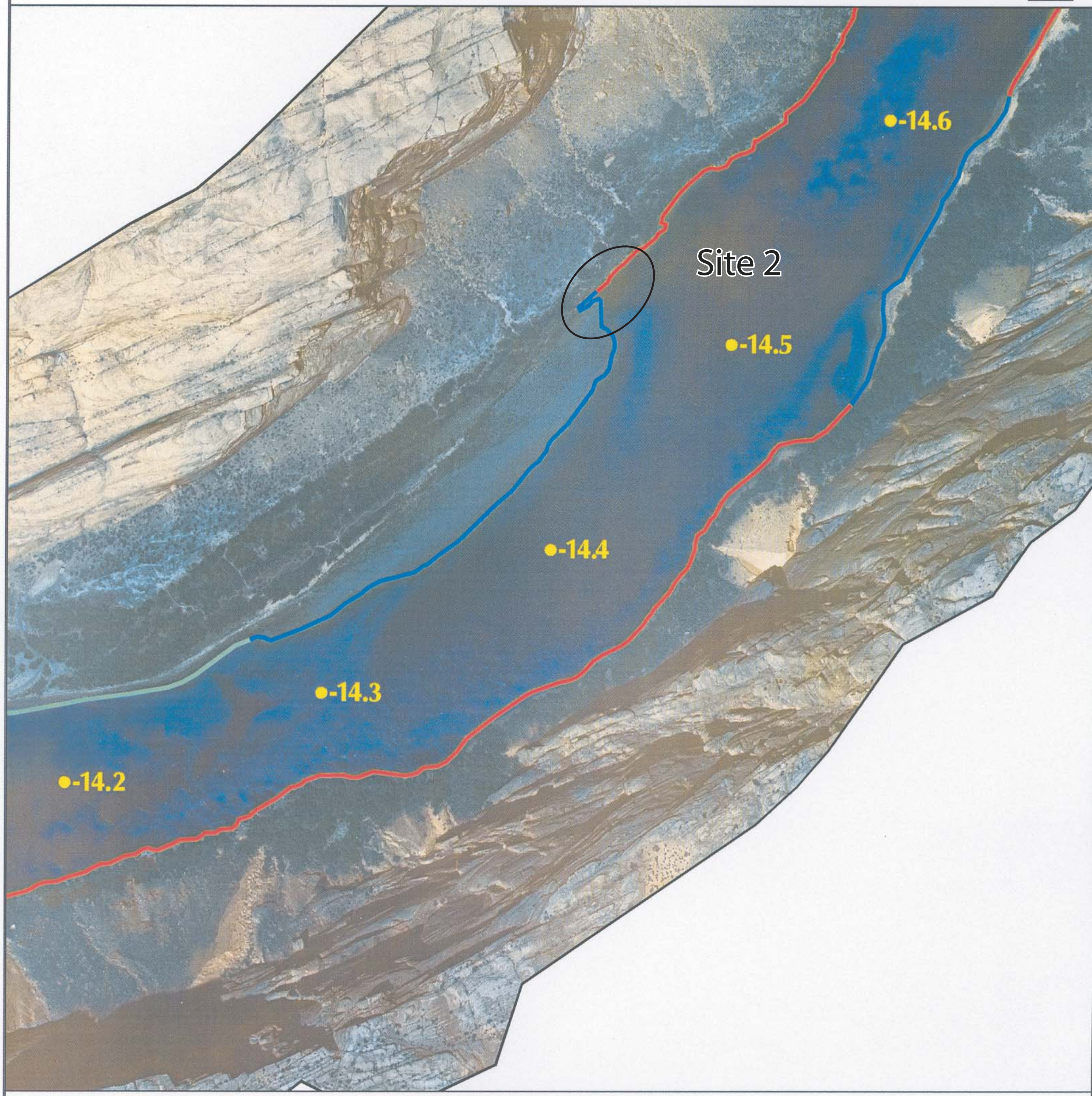
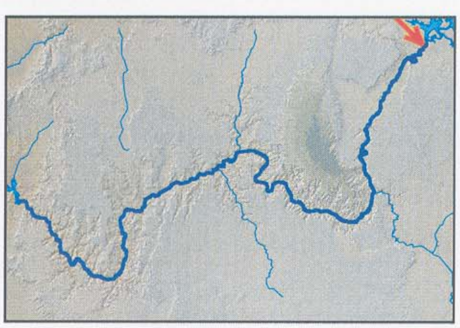
River Mile -14.4

Shoreline Fish Habitat with GCMRC Mile System



Shoreline Habitat Characterists

- Cobble Bar (CB)
- Talus (TA)
- Sand Bar(SB)
- Debris Fan(DB)
- Shadow(SH)
- Cliff Ledge(CL)



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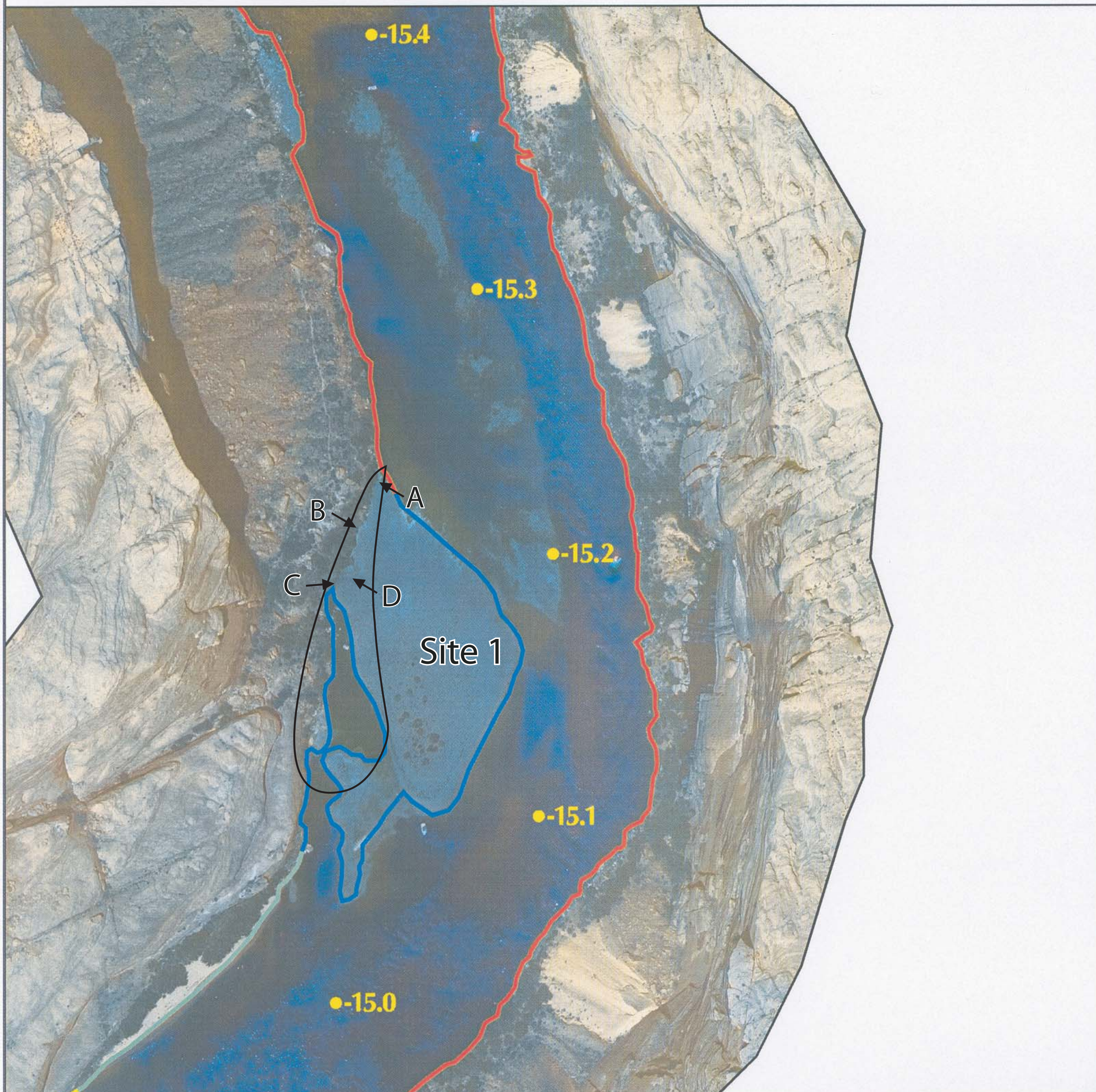
Map created on December 20, 2002 by smietz

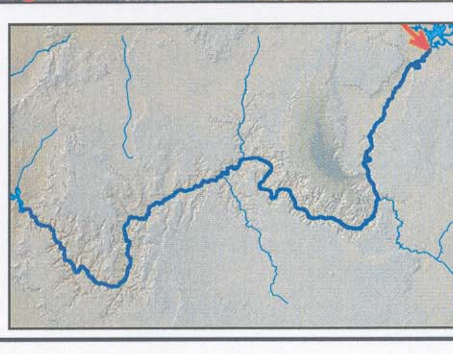
River Mile -15.2

Shoreline Fish Habitat with GCMRC Mile System



Shoreline Habitat Characterists

- Cobble Bar (CB)
- Talus (TA)
- Sand Bar(SB)
- Debris Fan(DB)
- Shadow(SH)
- Cliff Ledge(CL)



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Map created on December 20, 2002 by smietz

APPENDIX B

Site Photographs of Stranding Sites taken at 5,000 cfs

Photo 1. View looking south from the top of Site 1 (RM–15.20).

Photo 2. View looking south toward Location A (red arrow) of Site 1.

Photo 3. View looking south at Location B of Site 1.

Photo 4. View looking south at Location C of Site 1.

Photo 5. View looking north toward Location D (grassy area) of Site 1.

Photo 6. View looking at a pool immediately south of Location C of Site 1. The pool has a river connection.

Photo 7. View looking south at Site 2 (RM–14.50).

Photo 8. View looking north from the bottom of Site 2.

Photo 9. View looking south at Site 3 (RM–13.20).

Photo 10. View looking closer at Site 3 from the top.

Photo 11. View looking at the middle of Site 3. The rock has been an area of stranding (red arrow).

Photo 12. View looking south from the top of Site 4 (RM–12.20).

Photo 13. View looking north from the bottom of Site 4.

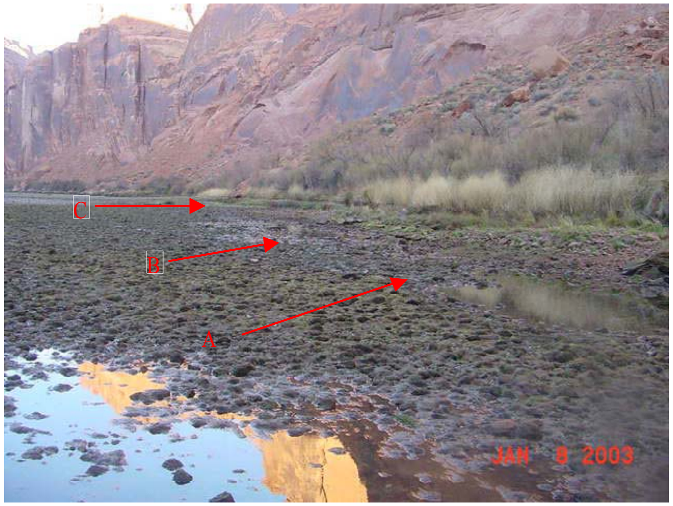

Photo 14. View looking south from the top of Site 5 (RM–11.85).

Photo 15. View looking closer at Location B in Site 5.

Photo 16. View looking north at Location C in Site 5.

Photo 17. View looking south at the large pool just south of Location C in Site 5. The pool traps fish, but is deep enough for them to survive.

Photo 18. View looking north at Site 6 (RM–11.15).

Photo 19. View looking south from the top of Location A in Site 7 (RM–9.90).

Photo 20. View looking north from the bottom of Location A in Site 7.

Photo 21. View looking south from the top of Location B in Site 7.

Photo 22. View looking north from the bottom of Location C in Site 7.

Photo 23. View looking north from the top of Site 8 (RM –8.70).

Photo 24. View looking south from the top of Site 8.

Photo 25. View looking southeast from the middle of Site 8.

Photo 26. View looking north from the top of Site 9 (RM–8.25).

Photo 27. View looking south from the top of Site 9.

Photo 28. View looking at the southern portion of Site 9.

Photo 29. View looking south at the pond that is found along the inside of Site 9.

Photo 30. View looking north from the top of Location A of Site 10 (RM –3.90).

Photo 31. View looking south from the top of Location A of Site 10.

Photo 32. View looking north from the bottom of Location A of Site 10.

Photo 33. View looking south from the top of Location B of Site 10.

APPENDIX C

Site Photographs of Stranding Sites taken at 20,000 cfs

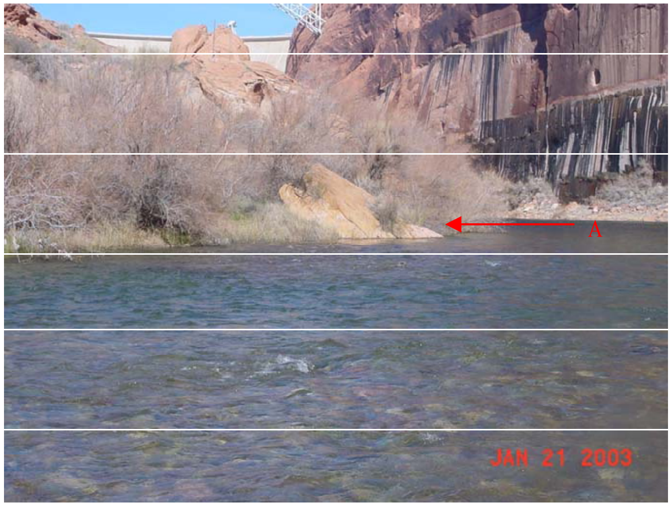

Photo 1. View looking north towards Location A of Site 1 (RM –15.20).

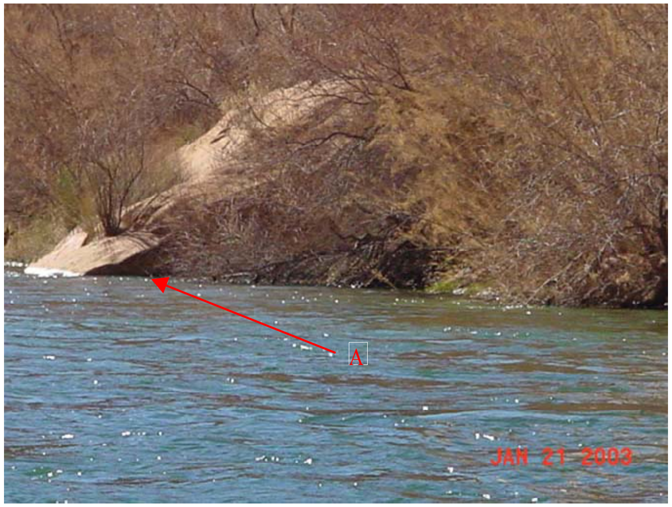

Photo 2. View looking south at Location A of Site 1.

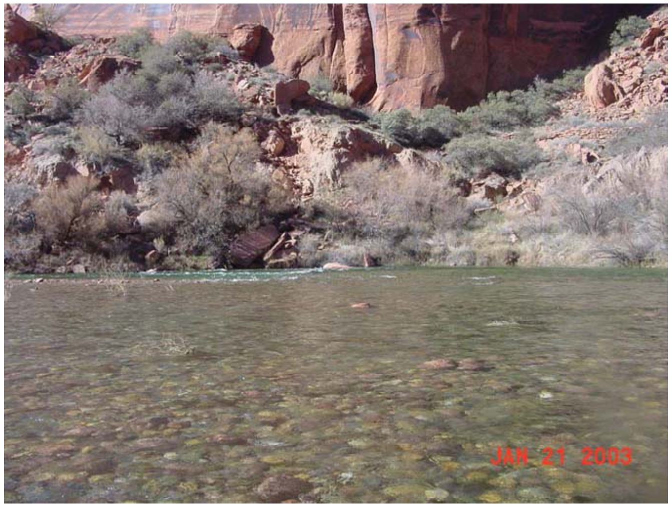

Photo 3. View looking west at Locations B, C, and D from the main part of the gravel bar.

Photo 4. View looking south from Locations B of Site 1 toward Location C and the main part of the river.

Photo 5. View looking south from the top of Site 3 (RM–13.20).

Photo 6. View looking south from the middle of Site 3.

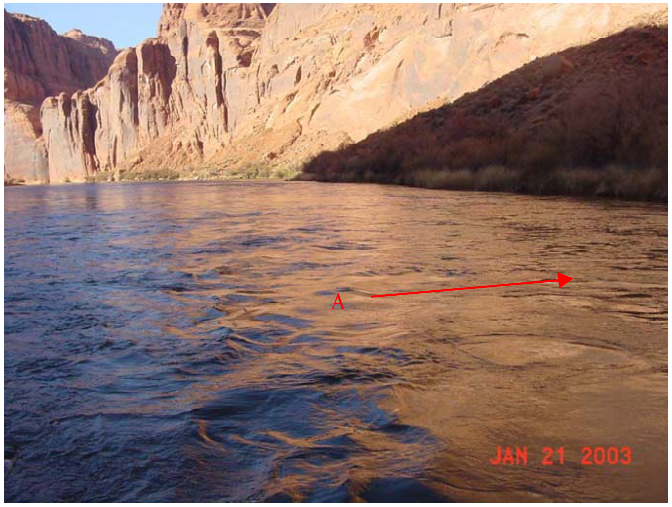

Photo 7. View looking south from the top of Site 5 (RM–11.85). Location A is to the right of the picture.

Photo 8. View looking south from the top of Site 5.

Photo 9. View looking north at Location C in Site 5.

Photo 10. View looking north at Location C in Site 5.

Photo 11. View looking south from the top of Location A in Site 7 (RM–9.90).

Photo 12. View looking south toward Location C in Site 7.

Photo 13. View looking west at Site 7.

Photo 14. View looking north from the bottom of Location C in Site 7.

Photo 15. View looking south from just above Site 8 (RM–8.70).

Photo 16. View looking south from the top of Site 8.

Photo 17. View looking north from the top of Site 9 (-8.25).

Photo 18. View looking north from the top of Site 9.

Photo 19. View looking south from the top of Site 9.

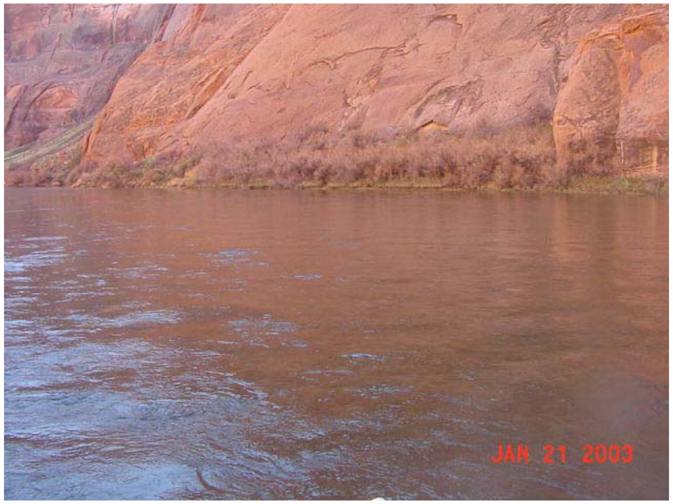

Photo 20. View looking north from the bottom of Site 9.

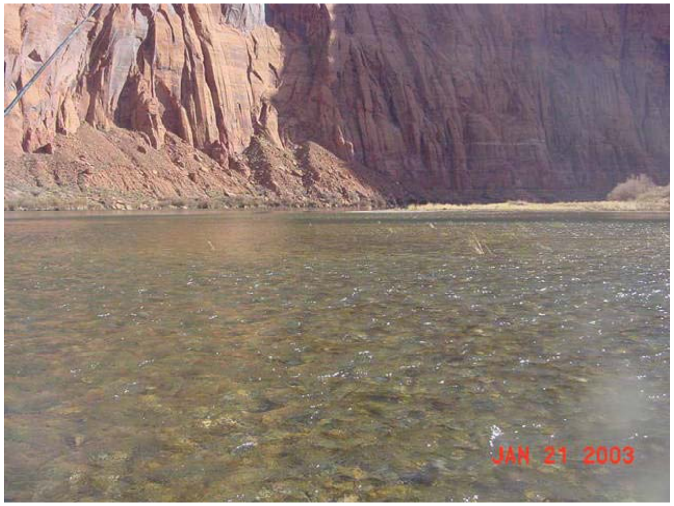

Photo 21. View looking south from the top of Location A of Site 10 (-3.90).

Photo 22. Another view looking south from the top of Location A of Site 10.

Photo 23. View looking west toward Location A of Site 10.

Photo 24. View looking west toward Location B of Site 10.