SAN JUAN RIVER BASIN
RECOVERY IMPLEMENTATION PROGRAM

HYDROLOGY, GEOMORPHOLOGY AND HABITAT STUDIES

2008 ANNUAL REPORT

prepared by

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EXECUTIVE SUMMARY

HYDROLOGY

The 2008 flow in the San Juan River reflects an unusual reservoir operation pattern. Because of high reservoir level and a large early forecast inflow, releases began in February. These early releases resulted in the second highest February, March and April flows since the study began in 1991. The forecast high inflow did not materialize, so flows were dropped and a three-week peak release initiated in late May. This is the second year in a row that high winter reservoir content required an early release. The 2008 release was closest to the 1993 release, except that it was lower during May and June than in 1993.

All flow recommendations were met except the 10,000 cfs criterion which was missed by 110 cfs for 1 day. Flows fell below the 500 cfs minimum base flow for 8 days in August with a minimum flow of 440 cfs.

Two small storm runoff events occurred in late summer, but did not contribute as much sediment as the storm events in 2007.

Long-term trends in hydrology also influence habitat maintenance. Extended droughts do not provide sufficient flushing flows to remove fine sediments that accumulate as a result of summer and fall storm events and can contribute to channel simplification as fine sediments accumulate in low velocity areas and isolate secondary channels. An examination of 10-year antecedent flow of the San Juan River near Bluff shows that there has been an extended drought period during the 16 years of this study with 2007 being preceded by the driest 10-year average on record. In 2008, the trend reversed, but 2008 was still preceded by the second driest 10-year period on record.

DETAILED REACH STUDIES

Detailed reaches established at RM 82 and RM 137 in 2005 were surveyed again in 2008 to assess channel change with flow and update the River2D models developed in 2005. Water's edge surveys were also completed in June during high flow events. A two-pass fish survey was completed in both reaches in March and August 2008. Detailed mapping was completed coincident with the fish surveys. Colorado pikeminnow capture data from the small-bodied monitoring and non-native removal programs were included in habitat selection and association studies. The River2D model results were used to generate velocity and depth data throughout the detailed reaches over a range of flows from 500 to 8,000 cfs. These results were used to examine coarse sediment transport, relationships of mean velocity and wetted area with flow and identification of the characteristics and extent of shore-run habitat, which has not been specifically mapped.

These are the findings to date by study element:

Channel Change

- DR 82 demonstrated nearly 5 cm of net scour between August 2007 and August 2008, with both scour and deposition within the reach. Both cobble/gravel and sand were scoured from the reach in 2008, compared to a net increase for both in 2006.

- DR 137 demonstrated nearly 6 cm of net scour during the same time period with both scour and deposition within the reach. There was a net loss of both cobble/gravel and sand.
- The net scour is a result of the large volume of water released from Navajo dam from February through June, resulting in the flow for the period being 2.0 times the 2007 volume for the same period. During the 1991-2008 study period, only 1993 had higher total flow for this time (115% of 2008).

River2D Model

- River2D models have been developed and operated for DR 82 and 137 that cover ranges in flow from about 500 cfs to around 8,000 cfs for 2008.
- The models provide sufficiently reliable results to forecast depth, velocity and wetted area over a range of flows.
- Model results in 2008 indicate that DR 82 reaches maximum average flow velocity at about 7,000 cfs and bank-full conditions at 7,000 – 8,000 cfs. The maximum average velocity is about 1,000 cfs higher than predicted in 2007.
- For DR 137, average flow velocity stabilizes at about 5,000 cfs and bank-full conditions occur at about 7,000 cfs, similar to the results in 2007.

Coarse Sediment Transport

- There is no statistically significant difference in median cobble diameter between the reaches in 2008 or between 2007 and 2008 for DR 137. The D_{50} for DR 82 was significantly smaller in 2008, relative to 2007. The average D_{50} for the two reaches was about 5.5 cm in 2008.
- Boundary shear stress is adequate in both reaches to mobilize cobble into the reaches at flows near bank-full (6,000 – 8,000 cfs).
- Boundary shear stress at the outlet of DR 82 is adequate to transport cobble out of the reach, corresponding to the measurement of lost cobble during 2008.
- Computed boundary shear stress at the outlet of DR 137 shows only marginal capacity to move cobble out of the reach and drops at the highest flows due to a backwater condition at the confluence of the two channels. Measured change shows net export from the reach, suggesting that the hydraulic predictions of the model are not accurate at high flow in this area of the reach or that the mean size of cobble being transported is smaller than the sampling determined.

Detailed Reach Habitat

- A simplified habitat classification system is recommended that reduces the total number of habitat categories from 29 to 14, with an additional 12 classification categories for structural features (e.g. islands, cobble bars, sand bars). The change will improve repeatability of mapping and aid in habitat/fish relationship analysis.
- The detailed reaches exhibit similar habitat makeup as the average for the river reaches they are in. An important exception is that the detailed reaches now exhibit less backwater habitat area than the average for the river reach. Analysis of the reasons for this loss will be reported in the 2009 final report after the remaining habitat mapping can be completed.
- Comparing detailed to standard mapping resulted in the identification of two relationships that might be applied to the river-wide mapping to correct for findings in the detailed

mapping. Detailed mapping demonstrates a marginally significant increase in total low velocity habitat over standard mapping ($p=0.06$, ratio ≈1.50). More habitat polygons demonstrating higher habitat complexity are mapped in the detailed mapping than in standard mapping ($p = 0.002$, ratio = 2.30). These ratios may be applied to the overall river-wide dataset, but may not be valid for any individual reach or time period.

Model and Habitat Data Integration

- Availability of shore-run habitat was determined by applying depth/velocity criteria to establish a typical distance from shore as the break between shore-run and mid-channel run habitat types. In 2007, 2.5 m was found to best represent the transition between the two habitats based on data from the detailed reaches. Using 2 years of data, it appears that 3.0 m is a better representation of shore runs.
- Application of the 3.0 m offset for the detailed reaches resulted in about 13% of the run habitat being classified as shore-run.
- Shoreline discrimination for selection of appropriate edge conditions should be included in future definitions of shore run habitat.
- Forecast habitat availability at other flows will be developed after the 2009 habitat data are available and reported in the 2009 final report for this study.

Fish Survey

Three reaches were surveyed in four separate passes, two in March and two in August, in 2008. During the 2008 surveys 141 Colorado pikeminnow were captured, 89 in March and 56 in August. Following is a summary of findings to date:

- Younger (<100 mm) Colorado pikeminnow appear to select for lower velocity habitats with selection for backwaters, embayments and pools indicated. These habitats also tend to have fine substrates.
- Habitat associations within about 10 meters of the capture site for younger Colorado pikeminnow that include backwaters and slackwaters together and pools together with slackwaters and runs are also important. Beyond 10 meters, the correlation to habitats is weaker, indicating a limited range of movement.
- Older (>100 mm) Colorado pikeminnow appear to select for habitats with higher and more varied velocities (riffles and cobble shoals). They also show selection for cobble substrates.
- The habitat associations in the vicinity of the captures of older Colorado pikeminnow indicate an affinity for more varied habitat and a larger range. The relationship between habitat associations and Colorado pikeminnow capture strengthen with increased distance from the capture location up to 20 meters. Habitat associations that include cobble shoals, riffles and slackwaters appear important. Since many of the targeted riffle samples also included some slackwater or cobble shoal, the association of these habitats may be a contributing factor in the selection for riffles.
- Colorado pikeminnow that are large enough to be subject to electrofishing appear to be less selective in their habitat associations than smaller fish. In both 2007 and 2008 they seem to be associated more strongly with islands and island complexes. More fish were captured in 2008 than in 2007 and the sites were less specific to particular habitats or even to habitat complexity. Fall monitoring data showed affinity to a larger range of habitat types, but included the same associations as the non-native removal data.

- GPS locations of razorback sucker captures from the two electrofishing programs indicate an affinity for islands and island complexes, similar to the Colorado pikeminnow. However, both data sets indicate a correlation between more habitat types and overall habitat complexity for razorback sucker than for Colorado pikeminnow. In particular, riffle habitat types in the vicinity of capture show significance for razorback sucker but not for Colorado pikeminnow of this size.
- Differences in results between the non-native removal and large-bodied monitoring programs may be related to time of year, multiple-pass versus single-pass sampling and the total number of captures. Additional years of comparative data are needed to understand the significance of any habitat associations.
- Larval razorback sucker where highly correlated to backwater habitat and inundated vegetation. In 2008, 100% of the captures were in backwaters and 85% of those sites had inundated vegetation. In 2007 83% of the capture sites were backwaters and 59% had inundated vegetation. In both years backwaters and inundated vegetation were highly associated with sites with larval razorback sucker.
- 2008 was a much higher flow year during larval sampling than 2007 (140% greater mean flow during sampling). In 2008 captures were further down river compared to 2007 when captures were in approximate proportion to availability of habitat. The higher runoff may have contributed to the displacement.
- Additional years of larval pikeminnow data should be analyzed for habitat association, particularly the drought years, to verify the conclusions from these two years.

RIVER-WIDE HABITAT MAPPING

Aquatic habitat has been mapped in the San Juan River since 1992. This data set has played a major role in determining and evaluating flow recommendations. Twenty-seven habitat types in seven major categories are mapped annually on digital aerial photography and then processed into GIS coverage. Monitoring protocol established in 1999 specifies that the habitat be mapped at flows between 500 and 1,000 cfs, if possible, in the fall of the year following runoff with the results used to assess response of the habitat to spring runoff. This is the last year of river-wide habitat mapping, pending completion of a revised habitat monitoring plan. The following conclusions are drawn from the results of the habitat mapping in 2007:

- Relative abundance among habitat categories has not changed during the 15 years of data collection. Runs, riffles and slackwater still dominate.
- Backwater habitat reached a low in 2003 at about 20% of the peak value. The trend started to reverse in 2004 and increased even more in 2005. There is no significant difference in Reach 1-6 total backwater area since 2005.
- The channel is simplifying with time as evidenced by a loss of islands and reduction in total wetted area with time.
- The channel simplification is related to both the extended dry period and encroachment of non-native vegetation along main channel margins and within secondary channels.
- Reach 5 has experienced the greatest loss of islands over time, but the trend reversed in 2007.
- Reach 3 lost the greatest amount of backwater habitat over time, followed by Reach 5. In 2007, backwater area increased significantly in Reach 5, but dropped in Reach 3.
- The increase in island count and backwater area in Reach 5 is not explained by antecedent hydrology.
- Further investigation in Reach 5 is warranted to determine the sustainability of the recent trend shift in backwater area and channel complexity.

TEMPERATURE MONITORING

Seven temperature recorders are installed in the San Juan River from Navajo Dam to Mexican Hat, Utah and one is installed on the Animas River at Farmington. These recorders log temperature every 15 minutes and store data for about 8 months. They are read twice each year.

The Navajo Dam release started in early February caused a drop in water temperature of from 1 - 4° C in most of the river from about March 1 to June 20, 2008. Early in the period the suppression was the smallest. At times the water at Archuleta was 5-7° C cooler than the Animas River at Farmington. The temperature of the San Juan at Farmington ranged 1 - 5° C cooler than the Animas at Farmington, depending on the flow in the Animas. By the end of the fish release the San Juan and Animas Rivers at Farmington were approximately the same water temperature (15° C). The water temperatures in the San Juan and Animas Rivers at Farmington remained nearly the same until mid-August. After which, the water temperatures on the Animas River was 1 - 4° C warmer than the San Juan throughout the rest of the 2008 water year. This temperature suppression in 2008 was extended relative to other years due to the extended release.

CHAPTER 1: INTRODUCTION

Hydrology, geomorphology and habitat studies of the San Juan River began in 1992 as a part of the San Juan River Basin Recovery Implementation Program (SJRIP). The activities changed from research to monitoring beginning in 1999. Geomorphology monitoring changed in 2005 at the direction of the SJRIP Biology Committee. River cross-section measurement changed from pre- and post-runoff to post-runoff every 5 years with the next measurements in 2009. Due to funding limitations this was further postponed and will not occur before 2010. In 2005, two detailed reach studies were initiated. The reaches were selected and first surveyed in 2005. In 2007, Colorado pikeminnow surveys in the two detailed reaches were added. In 2008, funding was eliminated for river-wide habitat mapping. All elements of the study will be completed in 2009. The need for and nature of any future habitat monitoring will be determined in a series of workshops schedule for 2009.

This report summarizes data collected in 2008 as a part of the long-term monitoring program and compares these data to those collected since 1992. Data collected in the following areas are summarized here:

- Hydrology
- Detailed Reach Analysis
    - Geomorphology
    - Habitat Mapping
    - Fish Survey
- Aquatic Habitat Mapping from the confluence of the San Juan and Animas Rivers (RM180) to the Clay Hills Crossing (RM 2)
- Water Temperature

All data sets are from the 2008 field season except full-river habitat mapping. Due to the long data analysis time after the late fall data collection, there is a one-year lag in the habitat data.

Methods for each data set that are covered in the Long-Term Monitoring Plan are not described in detail in this annual progress report. The methods for detailed reach analysis are reported here as they are not included in the long-term monitoring plan. This report concentrates on data reporting with a minimum of data analysis, particularly between data sets. All analyses will be completed in 2009 and reported in the final report.

SAN JUAN RIVER STUDY AREA

The seven-year research program defined eight geomorphically distinct reaches in the San Juan River (Bliesner and Lamara, 2000; Figure 1.1). The bulk of the studies reported here occur within Reaches 1-6, as this encompasses the critical habitat for the endangered Colorado pikeminnow and razorback sucker. Some studies extend outside this range where necessary to define processes that affect the critical habitat. The study area for each data set is described with the summary of that data set.

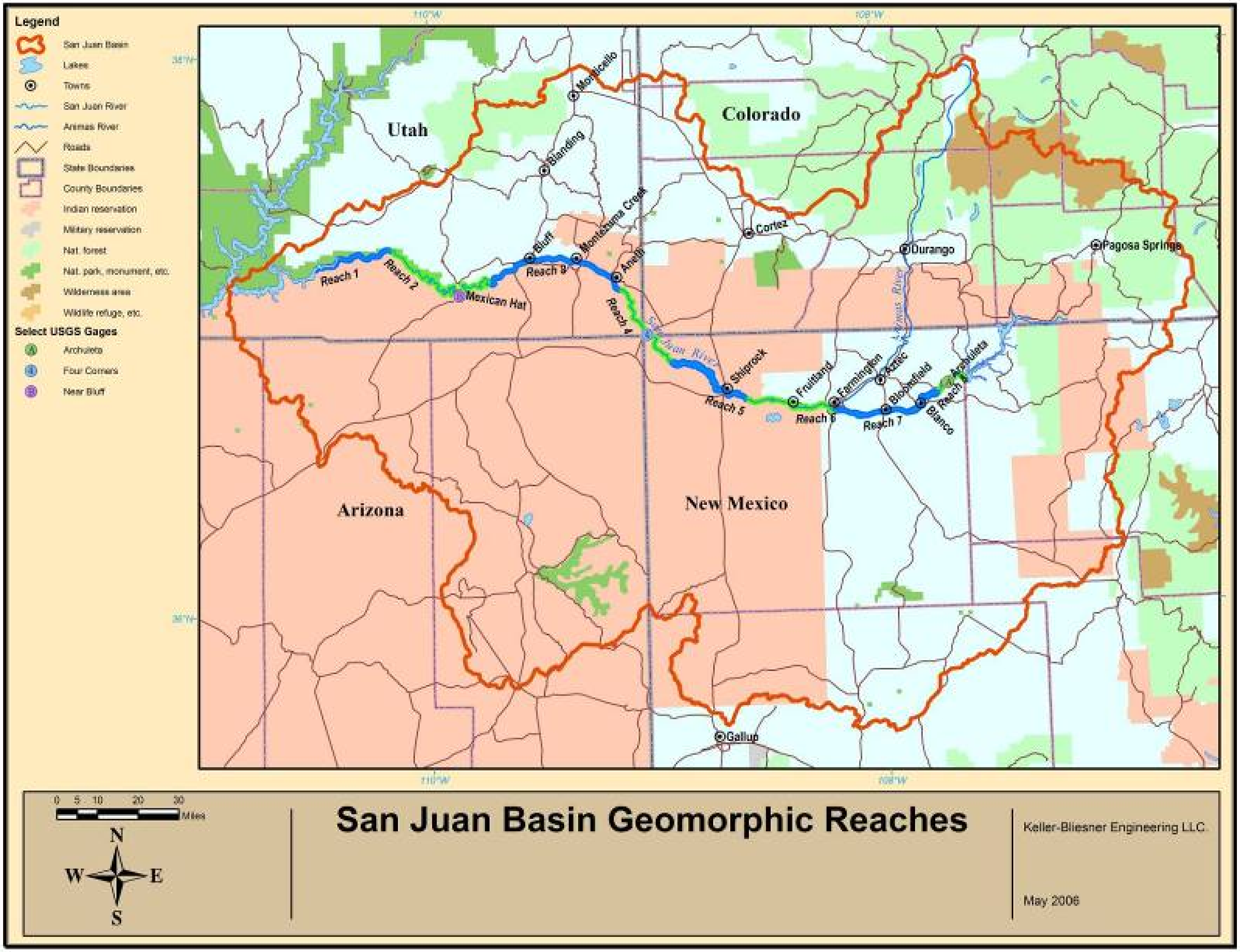

Figure 1.1. San Juan Basin location map showing geomorphic reaches

CHAPTER 2: HYDROLOGY

BACKGROUND

United States Geological Survey (USGS) flow records for the San Juan River begin in 1911, but are not consistent or complete until about 1929. By this time substantial irrigation development had occurred. While the pre-Navajo Dam hydrology is natural in shape, it is depleted in volume by about 16 percent from natural conditions due to irrigation development, with most of the depletion coming during the summer months. The depletion prior to Navajo Dam was relatively small during the runoff period and the flow was not regulated by major storage reservoirs. Therefore, the conditions during the pre-dam period (1929-1961) are used to judge effects of later development and the value of future modification of the hydrology for the benefit of the endangered fishes, particularly during the runoff period. The summer low-flow period must be assessed independent of the historical flows as they were much reduced from natural conditions by irrigation and were actually enhanced after reservoir construction.

Between 1993 and 1999 Navajo dam was operated to test a variety of flows during a research period directed toward developing a flow recommendation. The San Juan Recovery implementation program completed the flow recommendation in 1998 (Holden 1999). Since 1999, the operating rules recommended in the Flow Recommendation Report have been employed by Reclamation as far as restrictions would allow[1]. With the completion of the Navajo Dam Operations EIS and the issuance of the Record of Decision in July 2006, the Dam can be operated to meet the flow recommendations as written, subject to the physical limitations of the release works at the dam and the flood control limits between Navajo Dam and Farmington[2].

METHODS

Daily flow data recorded by the USGS from 1929 through the present are available for the key points on the San Juan River. These data have been used to analyze the 2008 hydrology and compare the statistics to previous years. The flow statistics in the SJRIP Flow Recommendation Report (Holden, 1999) are used as the basis for comparison. USGS gage records were used to assess the resulting hydrograph at Archuleta, Farmington, Shiprock, Four Corners, and Bluff.

For each release year, the operating rules are evaluated utilizing the anticipated water supply and the release criteria set. The design release pattern and the actual releases are compared. The statistics of each year are computed and the flow recommendation conditions that were met are indicated.

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[1] Prior to completion of the EIS, releases could not go as low as 250 cfs as recommended in the Flow Recommendation Report because the impacts to trout fishery and diverters had not been identified.

[2] Flood control limits do not allow flow in the River to exceed 5,000 cfs. If storm runoff enters any of the tributaries between Navajo Dam and the confluence of the San Juan and Animas Rivers, releases may have to be reduced below 5,000 cfs. Safe operating guidelines on the release works at Navajo Dam may limit magnitude or duration of high flows to accommodate maintenance and inspection requirements and findings.

RESULTS

Research releases from Navajo Dam were made every year from 1992 through 1998 (1991 was a control year with no modification to the release) to augment the unregulated flows from the Animas River and provide peak spring runoff flows mimicking a natural hydrograph in the San Juan River below Farmington, NM. Beginning in 1999, the operating rules presented in the Flow Recommendation Report were implemented.

Water year 2008 was an above average year with annual runoff at Bluff of 1,861,856 ac-ft (116% of the 1929-2008 average). The March through July runoff at Bluff was 1,272,000 ac-ft (123% of 1929-2008 average).

Spring releases from Navajo were started in early February due to the combination of a high forecast inflow volume and Navajo being 85% full. Releases were increased from 800 cfs to 3,000 cfs between February 10 and 13 and were maintained at approximately 3,000 cfs until March 9. Releases were ramped up to 4,000 cfs by March 11 and remained relatively constant until April 6 except for a two day gate inspection period. In response to a reduction in the forecast runoff, releases were adjusted downward between April 7 and April 12 and remained at approximately 2,400 cfs until May 11. Releases were again reduced to about 1,000 cfs until the fish release began May 19 with an 11-day ramp-up and a 21-day peak that averaged 5,080 cfs. During the 21 day peak, releases were dropped to 4,200 cfs for two days for gate inspection on June 10-11. The flows were ramped down in 7-days to 515 cfs on June 26.

The fish release hydrograph resulted in a total volume above base flow (600 cfs) of 262,900 ac-ft (Table 2.1). Table 2.1 also describes the nature of the release each year since 1991 for comparison. From a reservoir operation standpoint, the 2008 runoff season was a challenge to manage. The unexpected drop in the forecast resulted in releasing too much water too early. Navajo never exceeded the February 1, 85% capacity value during the runoff season. Additionally, the Animas had a dual peak (Figure 2.1). The first peak (6,080 cfs) occurred on May 21. The Animas flow then dropped to 2,030 cfs and peaked again (5,730 cfs) on June 3. In order to meet the 10,000 cfs flow criteria (5-days at 10,000 cfs) at Four Corners, Navajo peak releases need to coincide with the Animas peak. Flow data at Four Corners shows 4-days at 10,000 cfs or above, missing the criteria by 110 cfs on one day. All flow statistics are evaluated at Four Corners because it is considered to be the gage that most represents the flows in the habitat range.

To pick up additional days at 10,000 cfs at Four Corners, the 5,000 cfs Navajo release would have had to start 7 days earlier (May 22). However, the flow recommendations call for centering the release on June 4. An additional week at peak would have seen Navajo releases at 5,000 cfs starting May 24 or 25 which would have still missed the first Animas peak. Nearly a two week peak extension would have been required to pick up additional days at10,000 cfs.

The USGS Four Corners gage record shows the flow as being “estimated” throughout the peak flow period. This normally results from an equipment failure. There are 4 days between 9,500 and 10,000 cfs that are shown as “estimated”. One day was 9,890 cfs. It is possible that with a functioning gage the 10,000 cfs criteria would have been met. Flow statistics for the other primary flow criteria (2,500, 5,000 and 8,000 cfs) were met in 2008 (Table 2.2).

Base flow conditions of at least 500 cfs calculated as a running 7-day average were only met at the Farmington gage (Table 2.3) in 2008. Base flow criteria were not met at the Shiprock, Four

Table 2.1. Summary of Navajo Dam release hydrograph characteristics since the beginning of the research period, 1992 to 2006

Year	Ascending Limb	Peak	Descending Limb	Matched Animas River Peak	Volume Above 600 cfs Base ac-ft
1992	6 weeks starting April 13	2 weeks at 4,500 cfs	4 weeks ending July 15	Yes	409,740
1993	Starting March 1, rapid increase to 4,500 (compare with 1987)	split peak, 45 days at 4,500 cfs, 7 days at 4,500 cfs	4 weeks ending July 13	No	773,820
1994	4 weeks starting April 23	3 weeks at 4,500 cfs	6 weeks ending July 28	Yes	486,620
1995	3 weeks at 2,000 cfs in March, ramp to 4,500 over 6 weeks starting April 1	3 weeks at 5,000 cfs	4 weeks ending July 14 (summer flow increased by 200 cfs)	Yes	675,810
1996	1 week starting May 27	3 weeks at 2,500 cfs	1 week ending June 29	No	100,320
1997	3 weeks at 2,000 cfs in March, return to 600-cfs base for 31 days, 10 days starting May 12	2 weeks at 5,000 cfs	6 weeks ending July 16	Yes	433,580
1998	30 days starting April 23	3 weeks at 5,000 cfs	1 week ending June 18	Yes	340,850
1999	9 days starting May 24	8 days at 5000 cfs	9 days ending June 18	No	166,189
2000	8 days starting May 30	1 day at 4580	7 days ending June 13	No	61,484
2001	10 days starting May 15	26 days at 4300-5300 cfs	10 days ending June 28	No	265,527
2002	none	None	none	N/A	-
2003	none	None	none	N/A	-
2004	none	None	none	N/A	-
2005	April 28 – May 19	28 days at 4300-4670 cfs	9 days ending June 24	Yes	327,074
2006	9 days starting May 25	6 days at 4900 cfs	9 days ending June 16	No	113,583
2007	5 days starting April 30	13 days at 5,270 cfs	7 days ending 23 May	Yes	171,233
2008[3]	11 days starting May 19	21 days at 5080 cfs	7 days ending June 26	No	262,900

[3] Releases began in February based on high predicted inflow. The flow did not materialize, so the release was terminated in early May with the fish release starting as shown.

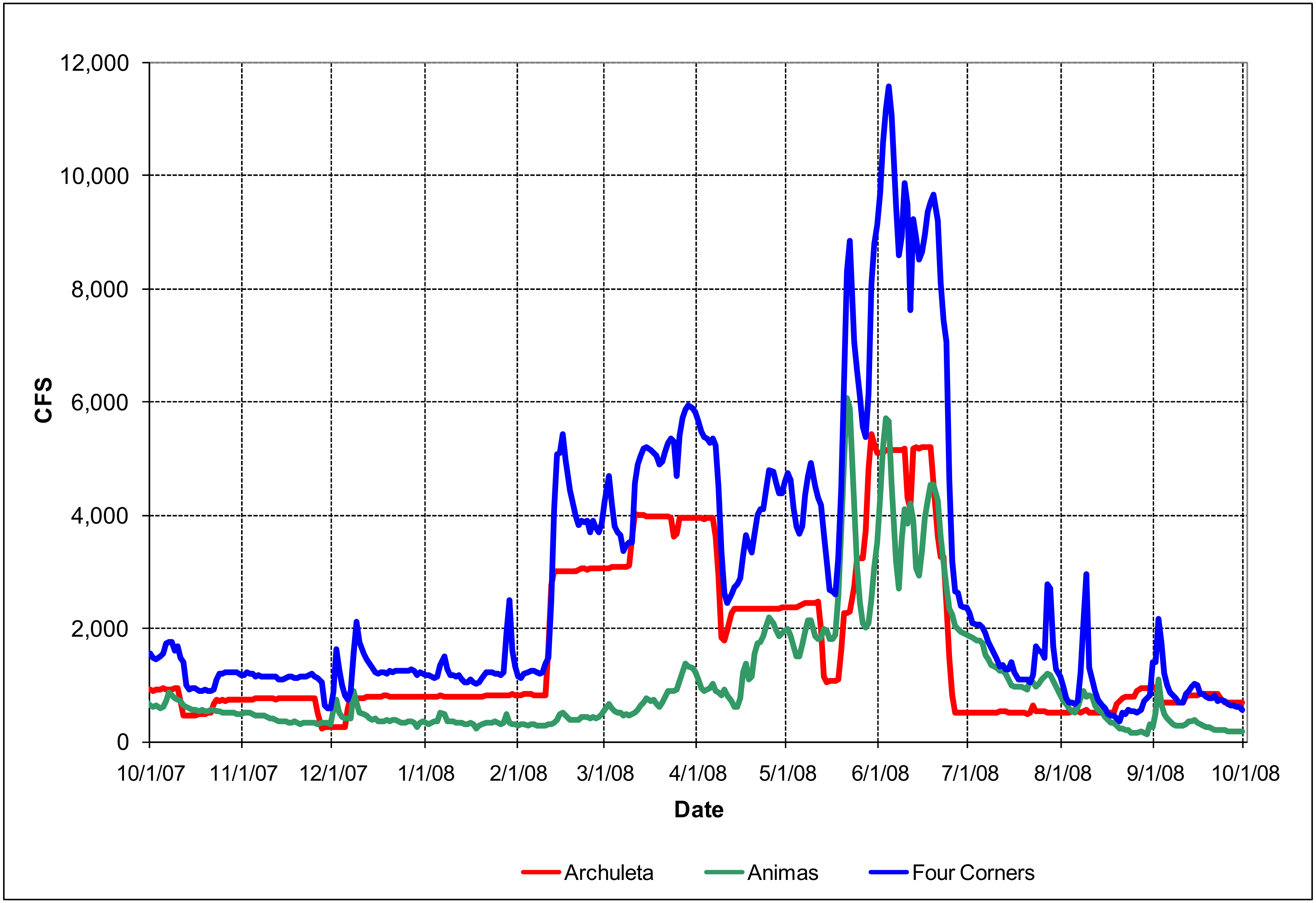

Figure 2.1. San Juan River near Archuleta, and Four Corners and Animas River near Farmington, 2008

Table 2.2. Flow statistics met in each year for 1992 through 2008

Condition (cfs)	Std	'92	'93	'94	'95	'96	'97	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07	'08
10,000 or more	5	0	1	0	**11**	0	**10**	0	0	0	0	0	0	0	**9**	0	0	4
8,000 or more	10	3	**16**	9	**27**	0	**33**	2	0	0	1	0	0	0	**18**	0	2	**25**
5,000 or more	21	**54**	**109**	**49**	**72**	0	**51**	**34**	**29**	3	**33**	0	0	1	**50**	7	**21**	**58**
2,500 or more	10	**81**	**126**	**68**	**135**	**36**	**103**	**65**	**72**	**37**	**55**	0	**13**	**23**	**84**	**25**	**54**	**118**
Years w/o meeting 10,000	10	6	7	8	0	1	0	1	2	3	4	5	6	7	0	1	2	3
Years w/o meeting 8,000	6	0	0	1	0	1	0	1	2	3	4	5	6	7	0	1	2	0
Years w/o meeting 5,000	4	0	0	0	0	1	0	0	0	1	0	1	2	3	0	1	0	0
Years w/o meeting 2,500	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0

Note: Values in **BOLD** are those that meet or exceed the minimum standard

Table 2.3. 2008 base flow statistics using a 7-day running average

Gage	Minimum 7-Day Average Flow	Days below Given Flow Rate		
		500 cfs	400 cfs	300 cfs
Farmington	714	0	0	0
Shiprock	427	8	0	0
Four Corners	446	7	0	0
Bluff	428	9	0	0
3-gage	440	8	0	0

Corners or Bluff gages or using the 3-gage rule. Depending on the gage, the baseflow violation lasted 7 to 9 days and occurred between August 19 and August 29, 2008.

The 2008 hydrographs for the San Juan River at Archuleta (release hydrograph) and Four Corners and the Animas River at Farmington show the influence of the somewhat unusual spring Navajo operations (Figure 2.1). The February monthly flow volume at Four Corners is greater than any other February flow since the study began in 1991 (Table 2.4). The dual Animas peak is also clearly visible. There are two storm events shown in late July and early August that may have had an effect on spawning and hatching success of Colorado pikeminnow eggs due to sedimentation of the spawning bars. These summer storms are not unusual and also occurred in 2006 and 2007 (Figure 2.2).

Long-term trends in hydrology also influence habitat maintenance. Extended droughts do not provide sufficient flushing flows to remove fine sediments that accumulate as a result of summer and fall storm events and can contribute to channel simplification as fine sediments accumulate in low velocity areas and isolate secondary channels. An examination of 10-year antecedent flow of the San Juan River near Bluff shows that there has been an extended drought period during the 16 years of this study with 2007 being preceded by the driest 10-year average flow on record (Figure 2.3). In 2008 the trend reversed, but 2008 was still preceded by the second driest 10-year period on record.

Table 2.4. Summary of flows for the research (1991-1998) and monitoring (1999-2008) periods, San Juan River at Four Corners, New Mexico

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Peak Runoff-cfs	5,160	8,900	10,300	9,090	12,100	3,540	11,900	8,580	7,970	5,210	8,340	926	3,900	5,110	13,500	6,200	8,530	11,600
Runoff - af (Mar - Jul)	600,510	1,076,680	1,717,333	1,004,047	1,627,775	432,670	1,340,886	931,107	876,847	548,424	848,626	174,282	294,401	475,970	1,205,506	433,755	769,371	1,418,697
Runoff - af (Tot. Ann.)	1,086,676	1,512,795	2,216,820	1,410,706	2,102,229	815,796	1,884,020	1,401,536	1,901,804	928,808	1,288,346	534,643	627,396	739,950	1,575,554	838,114	1,328,930	1,992,026
Peak Date	16-May	29-May	3-Jun	5-Jun	19-Jun	18-May	4-Jun	4-Jun	3-Jun	6-Jun	29-May	23-May	30-May	5-Apr	27-May	7-Jun	17-May	4-Jun
Days >10,000	0	0	1	0	11	0	10	0	0	0	0	0	0	0	9	0	0	4
Days >.8,000	0	3	16	9	27	0	33	2	0	0	1	0	0	0	18	0	2	25
Days >5,000	2	54	109	49	72	0	51	34	29	3	33	0	0	1	50	7	21	58
Days >2,500	46	81	126	68	135	36	103	65	72	37	55	0	13	23	84	25	54	118
Average Daily Flow for Month																		
October	1,447	767	826	919	1,107	1,089	1,273	1,404	1,533	1,141	1,273	829	720	633	873	1,351	2,676	1,252
November	1,125	1,354	909	1,202	1,076	1,137	881	1,175	1,494	910	1,154	836	744	612	796	908	979	1,086
December	1,078	1,086	955	1,129	958	1,087	700	1,154	1,031	940	966	848	657	517	689	790	887	1,261
January	1,171	858	1,356	1,056	916	783	788	1,208	947	935	915	835	569	524	838	740	837	1,251
February	1,299	1,263	1,522	852	1,084	874	695	1,239	976	931	1,039	732	574	578	1,295	583	989	3,141
March	994	1,171	5,454	948	2,777	765	2,251	1,267	969	1,186	1,329	663	698	1,016	1,285	583	1,278	4,799
April	1,807	3,716	6,178	984	3,472	606	2,524	1,910	1,174	2,263	1,680	582	580	2,020	3,082	861	1,318	4,111
May	3,733	6,622	7,285	5,255	6,108	2,146	5,990	5,831	3,439	2,995	5,146	713	1,619	2,485	7,694	1,974	5,787	5,185
June	2,575	4,835	7,688	7,212	9,351	2,920	8,499	4,542	5,986	2,293	4,984	501	1,371	1,754	6,382	2,721	3,174	7,779
July	799	1,442	1,773	2,195	5,178	714	2,899	1,802	2,925	330	877	411	583	586	1,468	1,031	1,101	1,583
August	555	925	1,346	534	1,561	491	2,306	1,073	6,135	708	1,315	482	672	440	940	1,266	1,614	818
September	1,441	997	1,432	1,078	1,193	891	2,361	574	4,852	733	646	1,443	1,611	1,100	762	1,058	1,287	883
Uniqueness	Control	Early Ave.	Early	Late Ave.	Late Peak	Dry	Narrow Runoff	Early Ave.	Large Summer Release	Dry	Early Ave.	Record Dry	Very Dry	Dry	Classic Hyrdro-graph	Dry	early average	High Spring Flows
		Storm @ Spawn					Storm @ Spawn	Storm @ Spawn	Storm @ Spawn				Sep. Peak > 10,000			Storm @ Spawn	Storm @ Spawn	Storm @ Spawn

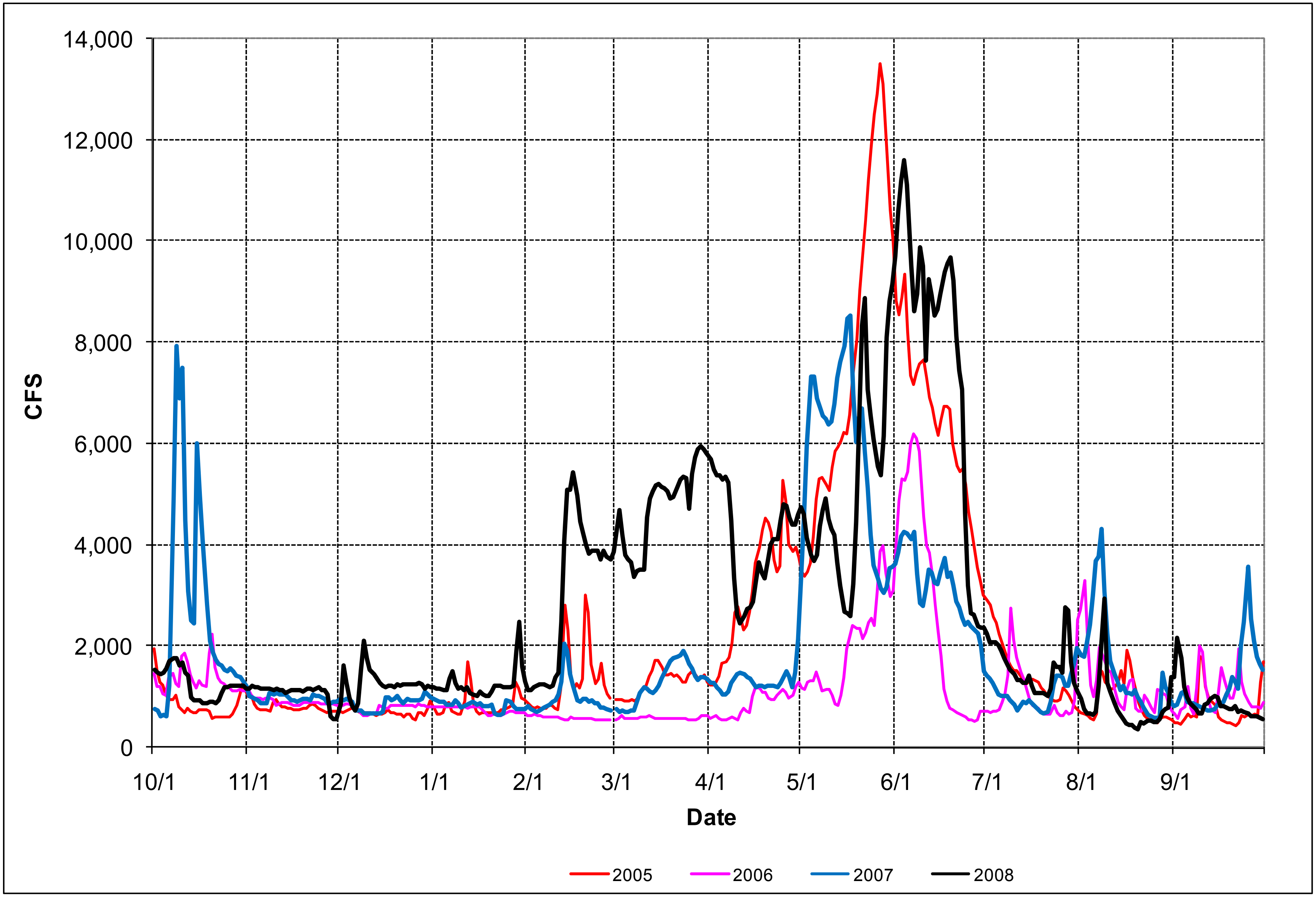

Figure 2.2. San Juan River at Four Corners, 2005-2008

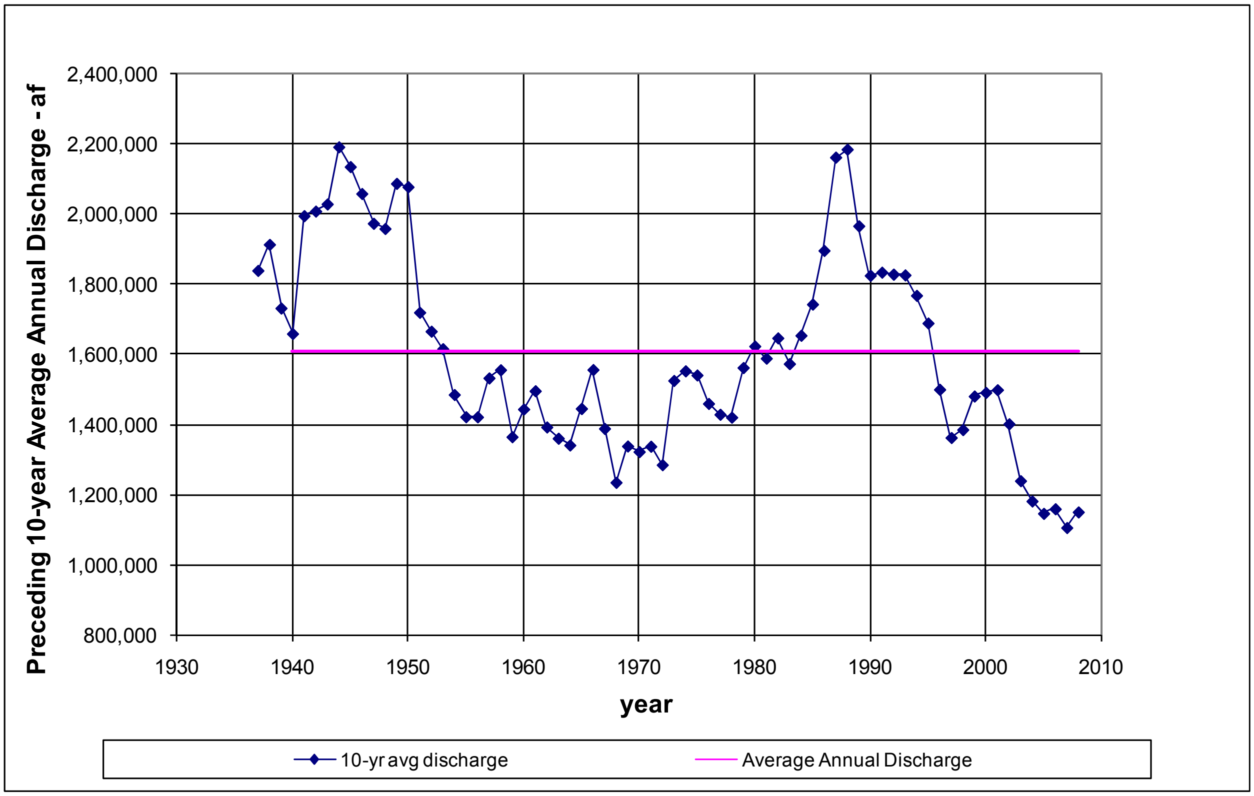

Figure 2.3. **10-year average antecedent flow in the San Juan River near Bluff, Utah 1937-2007**

CHAPTER 3: DETAILED REACH GEOMORPHOLOGY AND HABITAT

BACKGROUND

In the process of integrating the 1999-2003 monitoring data for the SJRIP, the Biology Committee determined that the information gained from semi-annual (pre- and post-runoff) surveys of the standard cross-sections in the river was not sufficient to warrant such regular survey. Further, it was determined that a more detailed look at the geomorphology and habitat of shorter reaches that contained elements that may be important to native and endangered fish was warranted. The change was made to better understand the mechanisms at work that maintain backwater and other low velocity habitats and channel complexity and to assess habitat in more detail related to actual captures of endangered fish.

To address these issues, detailed reaches were established in 2005 at RM 82 and RM 137 as described in the 2005 annual report. They have been designated DR 82 and DR 137. Habitat surveys were completed in 2005, 2006 and 2007 at standard and detailed levels and the data correlated to fish utilization where fish data were available. Two-dimensional modeling of the flow in these reaches was completed for fall survey flows in 2005 and 2006 and the model used to predict habitat availability at different flows.

In 2007, characterization of the coarse sediment and analysis of coarse sediment transport in each reach was added to assess conditions necessary to move cobble within these reaches. The habitat mapping, combined with detailed channel topology measurements, hydraulic modeling and coarse sediment transport analysis, is intended to provide insight into the mechanism or process for creation and maintenance of these complex reaches and provide a better understanding of the loss or creation of backwater habitats and other low velocity habitats used by the endangered fishes.

OBJECTIVES

The objectives of the detailed reach geomorphology and habitat studies are:

1. Examine the response of the channel morphology and habitat of two typical complex reaches of the San Juan River that have a history of use by endangered fish to hydrology.

2. Identify habitat availability in these complex reaches at a scale compatible with fish sampling efforts to improve linkage of habitat use to habitat availability.

3. Develop methods to extrapolate the detailed mapping in these complex reaches to river-wide mapping.

4. Evaluate mapping protocol and make recommendations for changes that improve integration of fish and habitat data.

METHODS

Reach Survey

Each detailed reach was surveyed with sub-centimeter real time kinematic GPS equipment. Only areas up to the high water mark in 2008 and areas where more detail was needed were surveyed in 2008 to supplement the 2005, 2006 and 2007 survey points that were above high water. The surveys were completed with an average point density of about one point per 30 m^2. In areas of complexity, point density was increased as needed to describe the topology. In addition, break lines and waters-edge were surveyed. Water's edge was surveyed in DR 82 at 7,220 cfs on 6/14/08 and DR 137 at 8,530 cfs on 6/13/08 for high flow calibration.

During each survey, substrate was characterized as fines, gravel/cobble or bedrock. These are qualitative categories based on the material at the point of survey. Water depth prevented reliable assessment between cobble and gravel, so they were lumped.

Wolman pebble counts (Wolman, 1954) were completed at the same 10 locations in DR 82 and 9 in DR 137 that were sampled in 2007 to characterize the bed material. The minimum measurement was 1.0 cm. Locations with grain size smaller than 1.0 cm were recorded as <1.0 cm. Size distribution was computed two ways: using all readings and using just the coarse (all measurements above 1 cm) measurements.

Channel Change

Data from the fall 2008 surveys were used to develop the topology of the channel and floodplain using the same boundary conditions that were used for 2005, 2006 and 2007. A three-dimensional surface was constructed in AutoCad for 2008, similar to those in previous years. Scour and deposition in each detailed reach was determined by subtracting the three-dimensional surface created from the 2007 survey from that created from the 2008 survey. The difference represents average net change in elevation, with a positive difference indicating net deposition and a negative difference indicating net scour. Perspective images were generated showing locations of scour and deposition to identify where change occurred in response to antecedent flow conditions. Only the active channel up to the high water elevation from the June survey is included in the analysis.

The significance of the change in bed elevation was tested by determining the confidence limits around the computation based on 3,000 observations with a standard deviation of 5 cm (estimated accuracy of measurement combined with approximations of computing the surface). For 99% confidence, the deviation about the mean could be as much as ±0.24 cm. If the estimated accuracy is 10 cm, then the deviation would be ±0.47 cm. Since the 5 cm of estimated measurement accuracy is approximate, a value of 10 cm was used as an upper bound. Therefore, change in average elevation greater than ±0.47 cm was taken as significant. This confidence limit is based on the average surfaces. Assessing change at any given point is qualitative, identifying areas of scour or deposition, rather than quantitative due to both elevation and location errors at any point.

River2D Model

The resulting topology of the channel and floodplain in each reach described above was also used for hydrodynamic modeling. The model chosen for analysis is River2D[4]. River2D is a two dimensional depth averaged finite element hydrodynamic model that has been customized for fish habitat evaluation studies. Three of the four modules that are a part of the River2D model suite were used: R2D_Bed, R2D_Mesh and River2D.

The modules were used in succession. A preliminary bed topography file (text) was developed from the field survey data, then edited and refined using R2D_Bed. The resulting bed topography file was used in R2D_Mesh to develop a computational discretization as input to River2D. River2D was then used to solve for the water depths and velocities throughout the discretization. This was an iterative approach at various stages, including modification of the bed topography, for refinement and calibration of the model of the two reaches.

The model was initially calibrated to measured water surface elevations at the time of survey. The roughness was adjusted to calibrate to water surface elevation. The model refinement and calibration was an extensive process whereby the field data points are supplemented with the placement of break lines to best describe the topology and input of roughness height that is judged by the attributes of the bed (fines, gravel, cobble, or vegetation type)[5] collected during survey. Additional calibration was accomplished by measurement of water surface elevation (water's edge) at higher stage flows during spring runoff.

The model was configured using a 2.0 m nominal grid size with refinement in areas where more detail was required to match water surface elevations. This corresponds with the minimum polygon mapped at the detail level (1.7 m^2).

River2D models were calibrated to water surface at survey for each of the detailed reaches at the 2008 survey flow. After calibration at survey flow, the model was operated at the high flow waters-edge measurement and recalibrated to provide reasonable results across the range of flows anticipated. Calibration was accomplished by adding break lines or increasing grid resolution in key areas and by adjusting the roughness height both globally and locally. After reviewing the literature for comparable modeling efforts (Bovee, 1982, Pasternack, et al., 2004, Stamp, et al. 2005, Tarbet and Hardy, 1996), the following calibration criteria were set for the difference between modeled and measured water surface elevation as a percent of average elevation for the flow at survey: Mean difference - ±5%, standard deviation – 25%. For high flow calibration the mean difference should not exceed ±10% or the standard deviation 30%. These values are well within the range of the literature reviewed, particularly for complex river reaches. Comparisons were also made between the model results in previous years. In 2006 we found that we could not reliably use a model calibrated in a previous year to accurately represent depths and velocities in the current year due to topology change. Therefore, comparisons between years rely on results from the individual models in each year.

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[4] Developed by the University of Alberta. www.river2d.ualberta.ca

[5] These general classifications are made at the time of survey. The categories are based on qualitative assessment. No grain size measurements are made. Vegetative type is assessed for areas above normal water surface that are vegetated. These initial roughness heights may be adjusted later during the calibration process.

Coarse Sediment Transport Analysis

Bed sediment size distribution was determined by completing Wolman pebble counts (Wolman, 1954) at 10 locations in DR 82 and 9 in DR 137. Size distributions were computed for the full sample and then for just the coarse fraction (size > 1 cm). The full set was used to characterize the nature of the fine/coarse distribution. The coarse distribution was used for transport analysis. Sampling locations were limited to those that could be sampled by wading.

The thresholds for incipient and significant motion occur when boundary shear stress (τ_0) is greater than or equal to the critical shear stress of the median bed material diameter (τ_{c50}) thresholds (Equation 1). The average boundary shear stress is calculated using Equation 2.

$$\tau_{c50} = \tau_c^*(\gamma_s - \gamma_w)D_{50} \qquad (1)$$

$$\tau_o = \gamma_w \cdot h \cdot S_f \qquad (2)$$

Where τ_c^* is the critical dimensionless shear stress, γ_s is the specific weight of sediment, γ_w is the specific weight of water, D_{50} is the median sediment diameter, h is the flow depth, and S_f is the friction slope or energy gradient, calculated using Equation 3. All computations were completed in SI units.

$$S_f = S_o - \frac{u}{g}\frac{du}{dx} - \frac{dh}{dx} \qquad (3)$$

Where S_o is the channel bed slope, u is the mean column velocity, and *dx* is the change in distance downstream. There has been much discussion over appropriate values of τ_c^* and the reasons for its variation from river to river. There is evidence that the Colorado River bed material begins to move at τ_c^* = 0.03; however, very few particles of any size are moving and bed material transport rates are very low (Pitlick and Van Steeter 1998).

In this analysis, the three conditions of transport were examined using the median sediment diameter (D_{50}) of bed material with incipient motion occurring when τ_c^* is in the range of 0.02 (Andrews 1994) to 0.03 (Parker et al. 1982, Pitlick and Van Steeter 1998), average motion when τ_c^* = 0.030 to 0.045, and significant motion when τ_c^* =0.045 to 0.06 (Wilcock and Southard (1989) and Pitlick (1992). These values were used in Equation 1 to determine the flow at which the boundary shear stresses were high enough for incipient, average and significant or full motion.

Model output depth, velocity and bed elevation over a range of flow from 745 to 8,000 cfs were used in sediment transport calculations. Three locations were selected: near the entrance and exit of the reach and one intermediate location. Reference points were selected within these areas to extract depth, velocity, and bed elevation data from the model runs. All data within a radius of approximately 4-6 meters depending on the site were extracted at each reference point. The extracted depths and velocities at each reference point were averaged for boundary shear stress calculations. Slopes were determined between reference points. A linear trend analysis was performed to determine the bed slope for entrance and main channel analysis areas. Individual paired-point analysis was used to examine localized transport potential.

Habitat Mapping

Habitat mapping of the detailed reaches was completed during fish sampling in March and August. This detailed mapping for the reaches is completed at a scale of 1" = 75 ft. The mapped habitat was used to determine habitat availability and examine habitat associations that may be correlated to endangered fish capture. The methods follow those outlined in the standardized monitoring protocol.

Model and Habitat Data Integration

The original study design anticipated overlaying habitat mapping with modeled depth and velocity to characterize the depth and velocity by habitat type, using that correlation to forecast habitat availability at flows other than those mapped. Since the model is based on field survey and the habitat mapping on photo-interpretation, the two maps do not precisely overlay, making it difficult to accurately assess the depth and velocity of habitat types, particularly the small features and those affected by channel margin.

Since this approach did not work, an alternate approach was developed and implemented in 2006. Depth and velocity standards for habitat classifications developed in 1998 (Bliesner & Lamarra, 2000) were used to characterize the main habitat classifications. It was necessary to identify unique bins with non-overlapping depths and velocities to associate model results with habitat (Table 3.1). These categories were then applied to the model results to estimate habitat availability at different flows. The process was developed and demonstrated in 2006, but not repeated in 2007 or 2008. The intent is to use the 2005-2009 data together in 2009 to finalize the process of extending habitat description to other flows and examining availability of key habitat found to be important to the early life stages of Colorado pikeminnow (and razorback sucker to the extent it can be defined) across a range of flows. The values in Table 3.1 will be refined through calibration with mapped habitat and model results.

During the fish survey work in August 2008, shore runs were sampled but not separately mapped. Other fish sampling efforts have identified this habitat category (Golden et al. 2006, Robertson and Holden 2007). Shore runs are moderately low velocity habitats along the margin of runs characterized by shallower depths and lower velocities. The break line between shore run and mid-channel run is not easily discernable when mapping and is typically too narrow to map during standard mapping. The model was used in this study to identify a reasonable break point between shore and mid-channel runs based on observed depth and velocity in areas where shore-runs were sampled. Four locations (2 in each reach) representing seven fish samples were used for the analysis. Depth and velocity were plotted with distance from shore and a break point selected based on maximum velocity where Colorado pikeminnow were captured. A distance from shore was then defined for that average condition and the availability of shore run identified by intersecting this offset distance to the edge of all runs that contacted a shore line in the GIS.

Table 3.1. Depth and velocity categories by habitat

Habitat Category	Velocity – cm/sec		Depth - m	
	Min	Max	Min	Max
Backwaters (1,2,22)	0	0.1	0	3+
Low Velocity (3,4,5,6,7,16)	0.1	10	0	3+
Slackwater (20,35)	10	20	0.3	3+
Shoals (8A,8B)	10	43	0	0.3
Runs (9A,9B,10,11,12,13,14)	43	75	0	0.3
Runs (9A,9B,10,11,12,13,14)	20	100	0.3	3+
Riffles (15,17,18,19,30,32)	75	100	0	0.3
Riffles (15,17,18,19,30,32)	100	300+	0	3+
Vegetation (24,34)	n/a			
Other (21,29,33,37,39)	n/a			

Adapted from Hydrology, Geomorphology, Habitat final report, February 2000, pp 5-5 to 5-8

RESULTS

Reach Survey

Each reach was surveyed in the fall of 2008 to compare to fall 2007 surveys and determine deposition and scour for each reach. There are 3,611 points for DR 82 and 3,393 for DR 137, all taken below the 2008 high water line (Figures 3.1 and 3.2). These data points, in conjunction with data points collected above the 2008 high water mark collected in previous years, were used to generate the bed elevations used in channel change analysis and for River2D modeling. Water's edge was determined in these surveys at flows of 695 cfs for DR 82 and 512 cfs for DR 137. Water's edge at high flow was surveyed in June 2008 at a flow of 7,220 cfs (Bluff gage) for DR 82 (86 points) and 8,530 cfs (Shiprock gage) for DR 137 (101 points). The increased surface area and additional flowing secondary channels at high flow are shown in Figures 3.3 and 3.4 for DR 82 and DR 137, respectively, with the fall 2008 modeled water surface overlain. Actual high flow in 2008 was over 10,000 cfs, but at that flow, the water is out of the channel and cannot be accurately modeled. For DR 82, the high water survey model run is shown in Figure 3.3. For DR 137 the channel is out-of-bank at 8,530 cfs and the model is not accurate. A model run at 7,000 cfs is shown in Figure 3.4.

Channel Change Analysis

Figures 3.5 and 3.6 show the channel topology generated from the 2005, 2006, 2007 and 2008 surveys for DR 82 and DR 137, respectively. Scour and deposition between 2007 and 2008 surveys have been assessed for each reach by subtracting the 2007 surface from the 2008 surface (Figures 3.7 and 3.8, Table 3.2). Table 3.2 shows substrate makeup, the volume of scour and deposition and the net change in volume and depth between subsequent surveys for each detailed reach from 2005 through 2008. Although there are locations of scour and deposition in each reach, DR 82 exhibited 4.7 cm of net scour and DR 137 experienced 5.7 cm of scour. This change is significant at the 99% level.

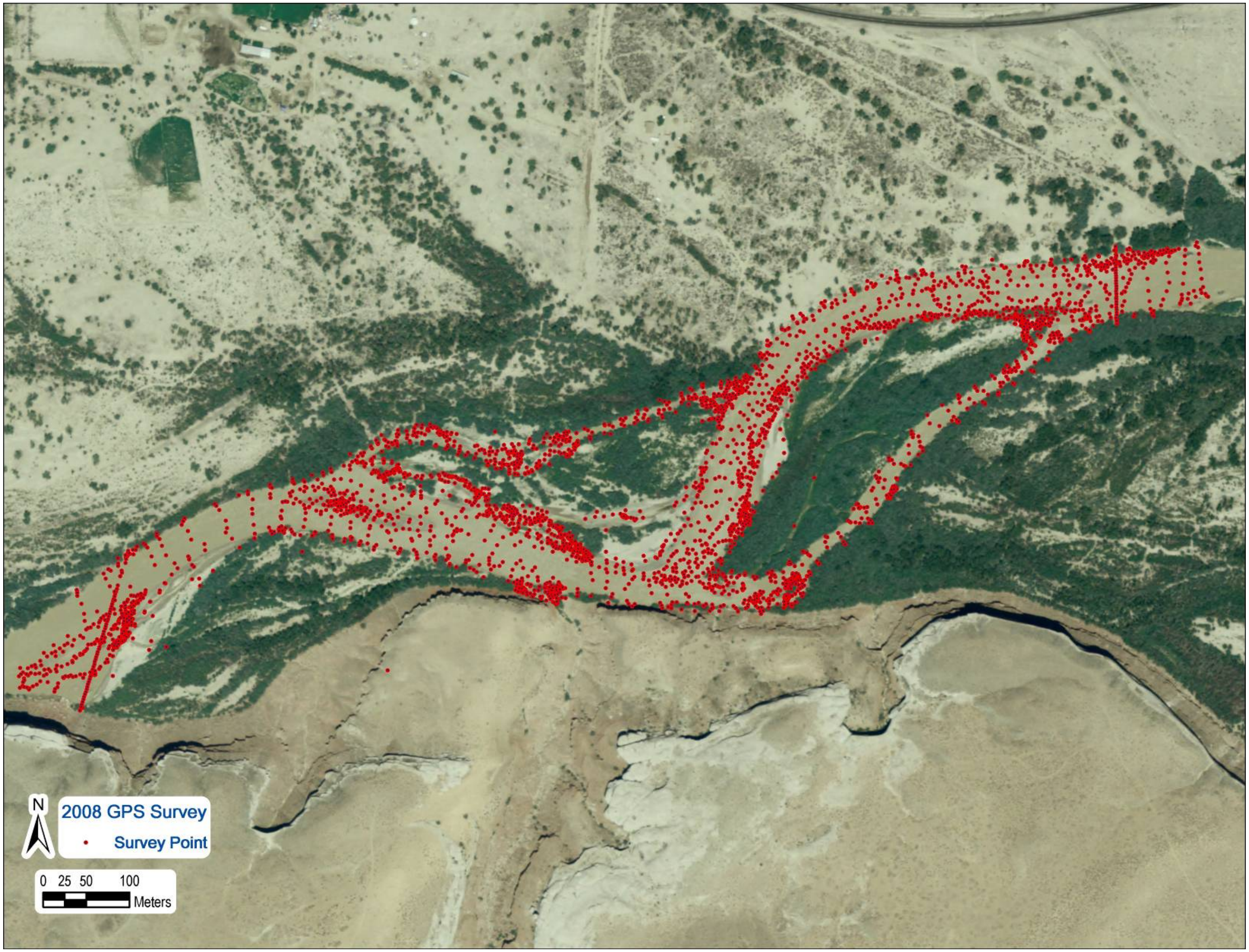

Figure 3.1. Point locations for August 2008 survey at DR 82

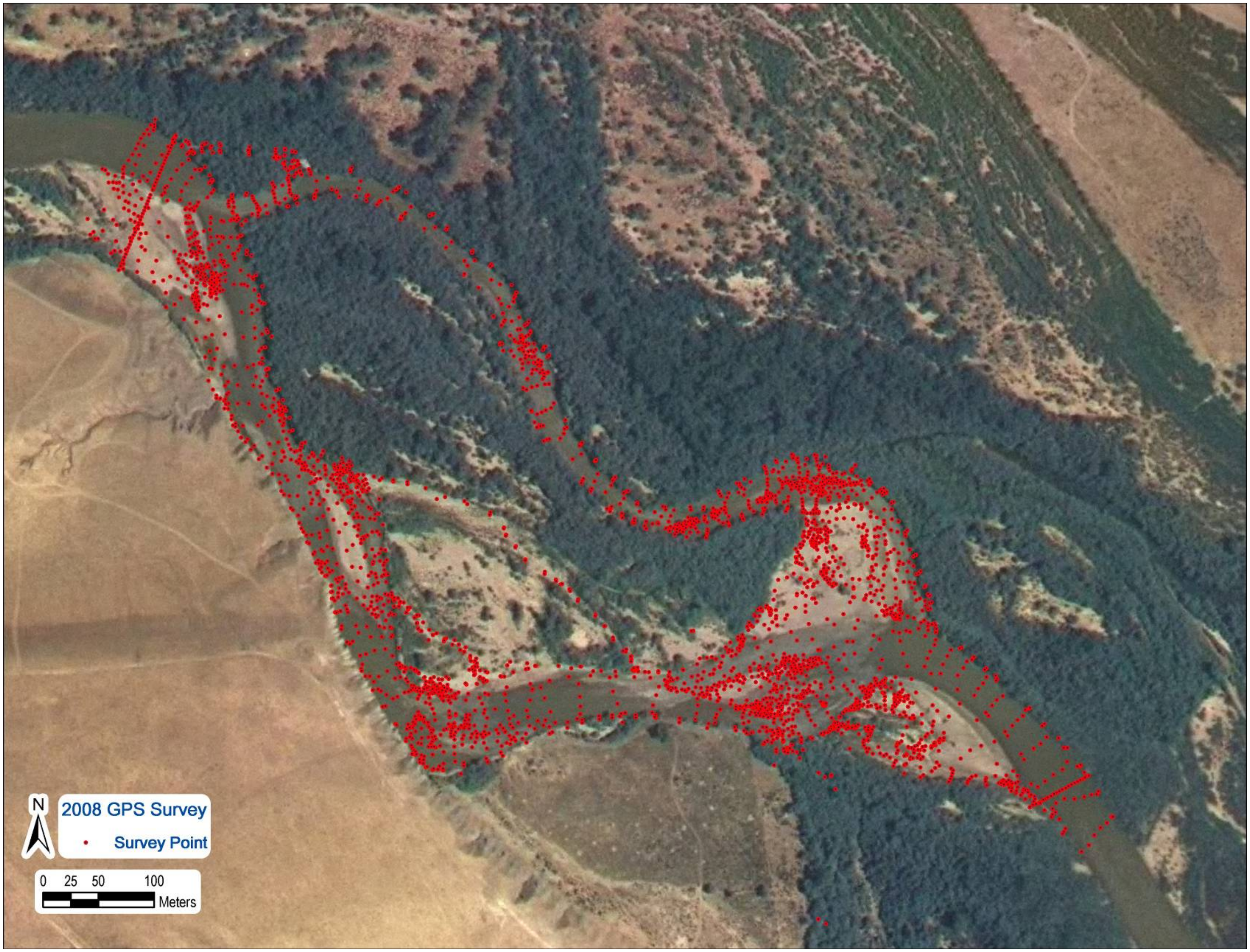

Figure 3.2. Point locations for August 2008 survey at DR 137

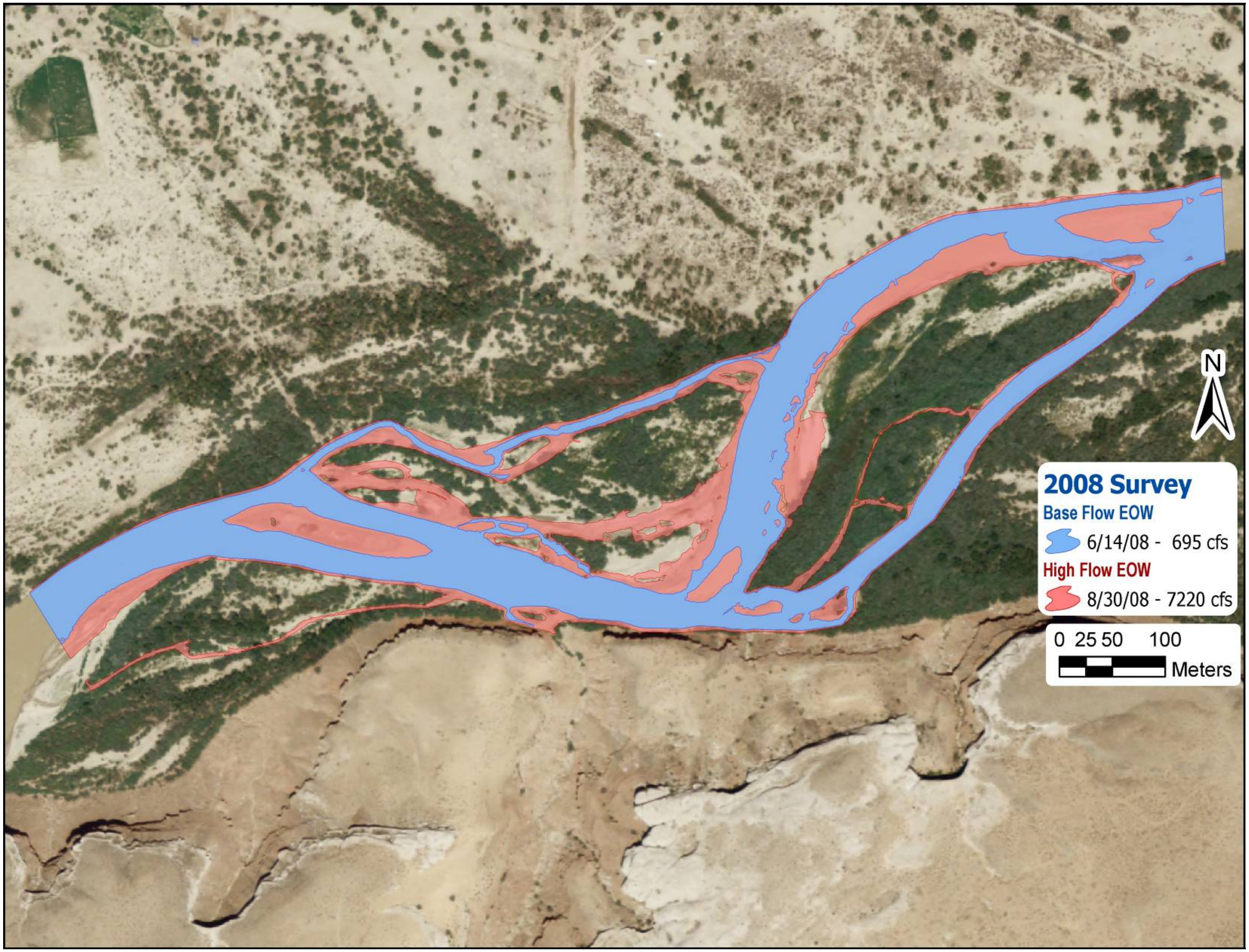

Figure 3.3. DR 82 water surface at 7,220 and 695 cfs (June 2008 high and August 2008 low flow surveys)

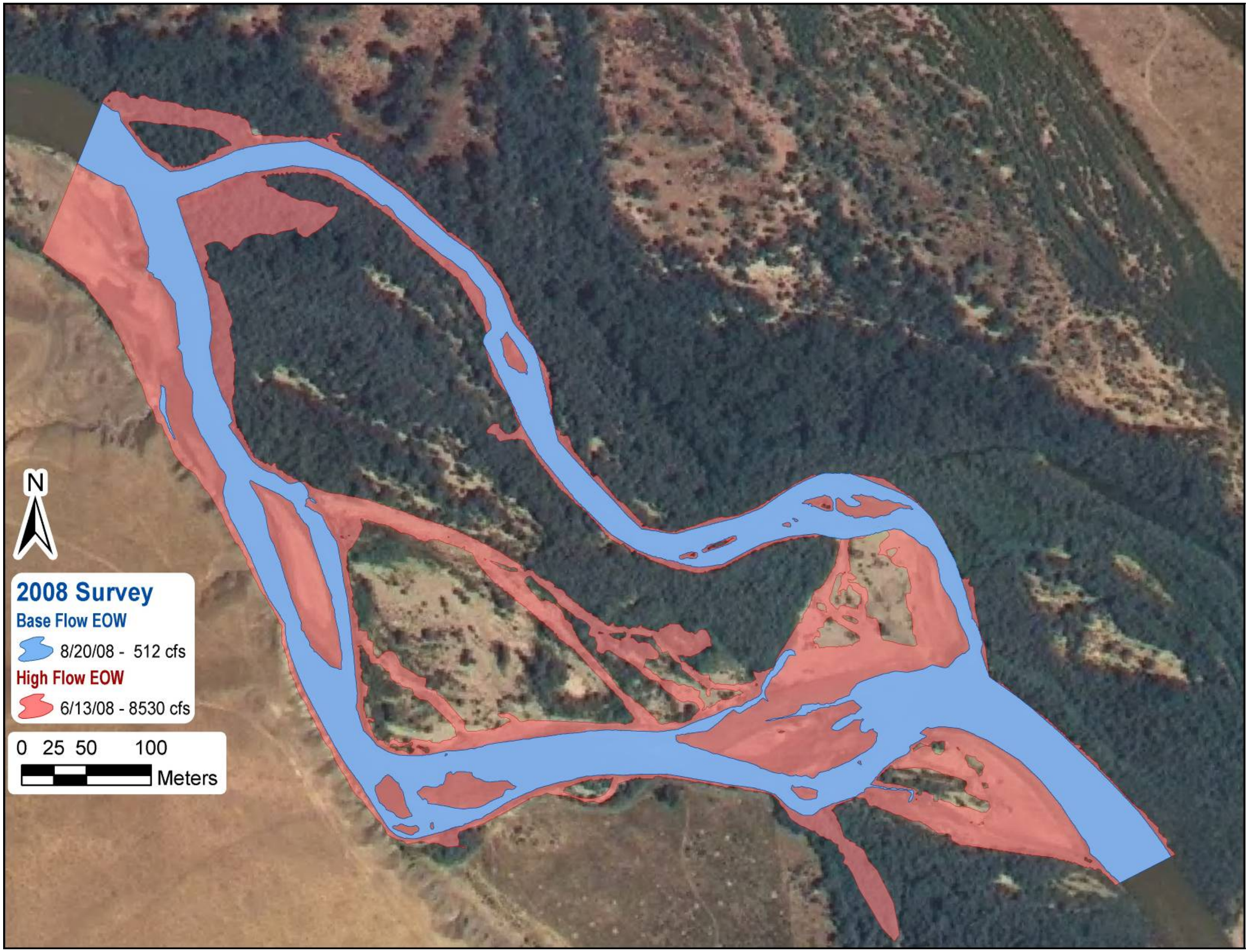

Figure 3.4. DR 137 water surface at 7,000 and 512 cfs (modeled high flow and August 2008 low flow surveys)

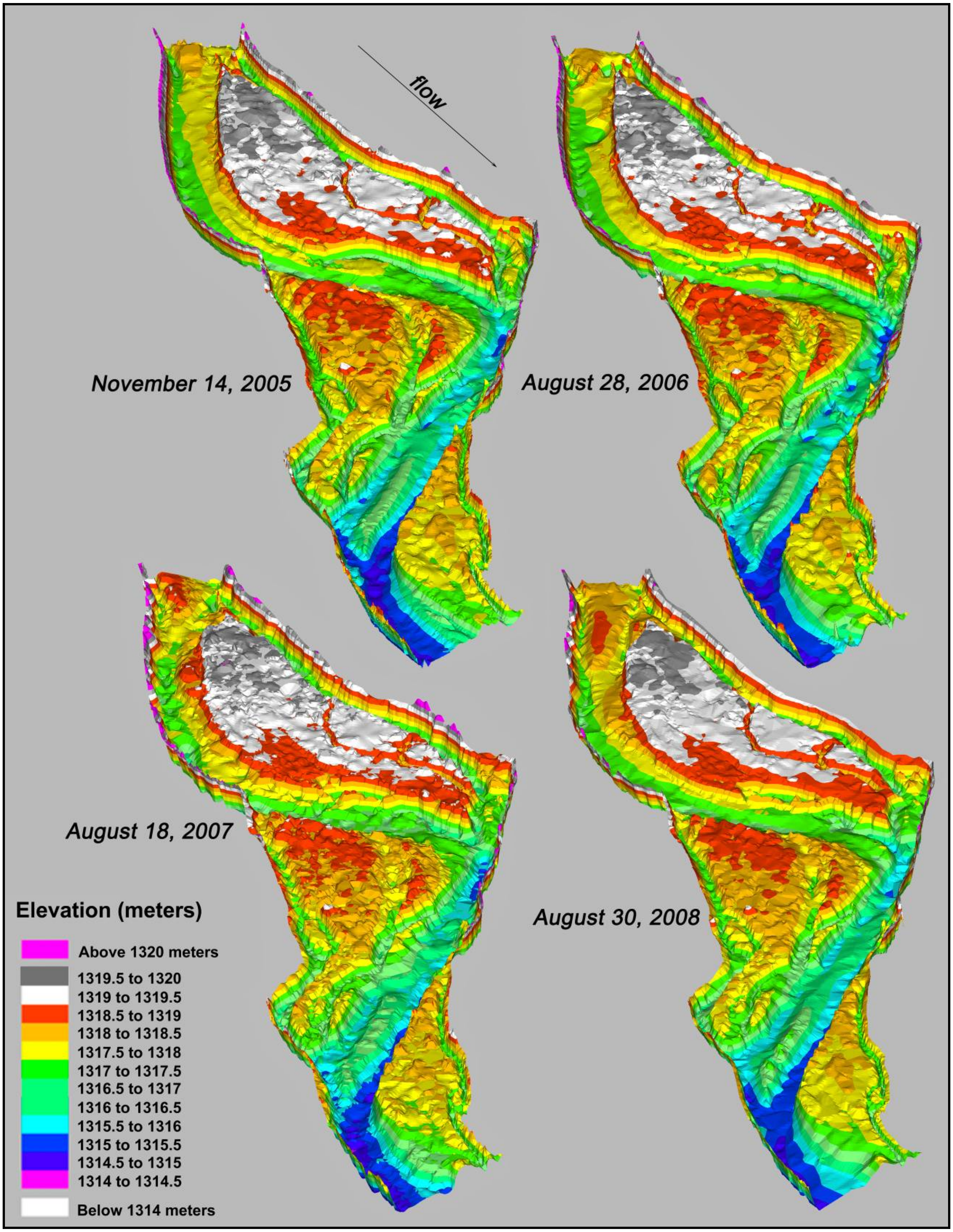

Figure 3.5. 2005, 2006 and 2007 channel topology generated from fall surveys for DR 82

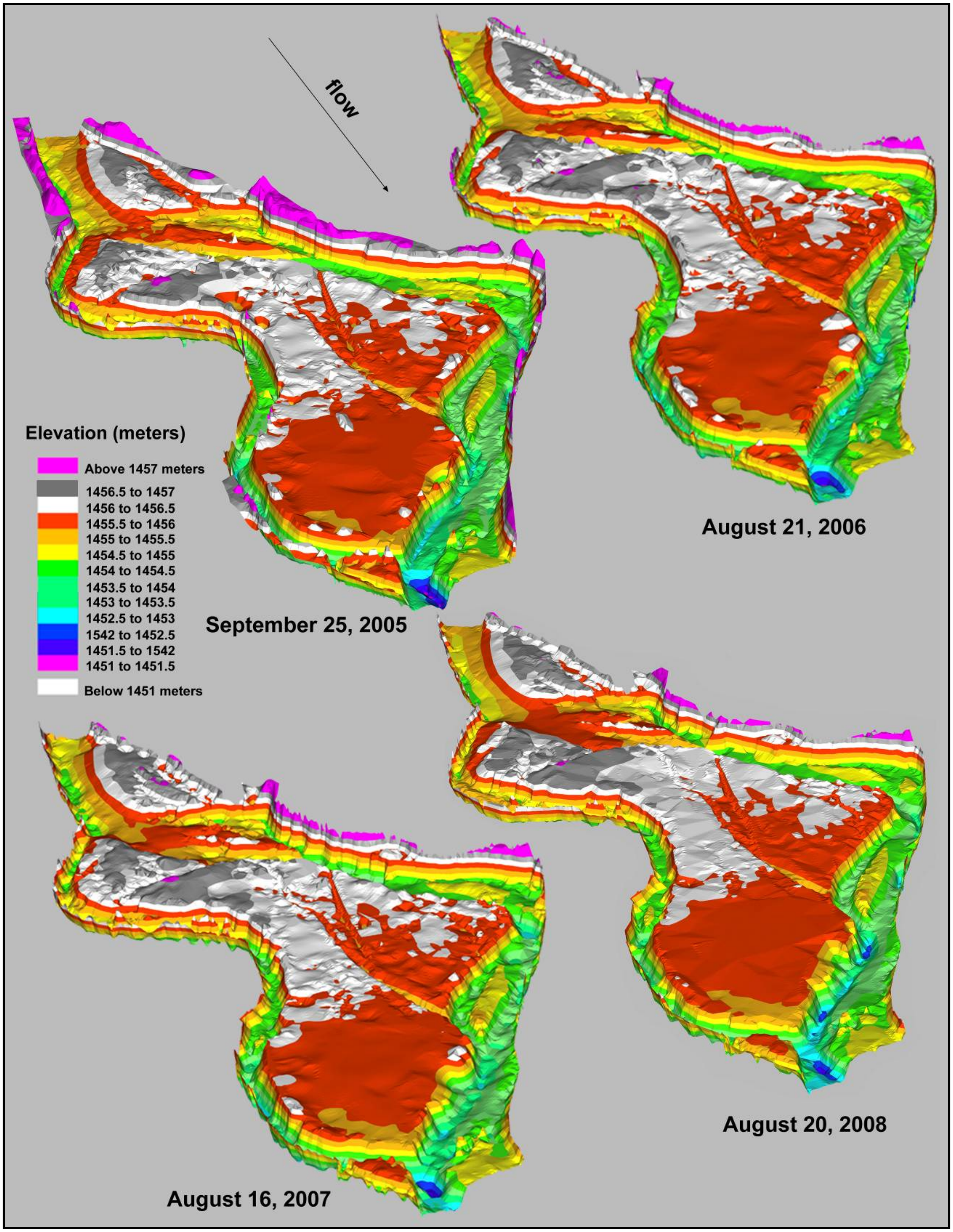

Figure 3.6. 2005, 2006 and 2007 channel topology generated from fall surveys for DR 137

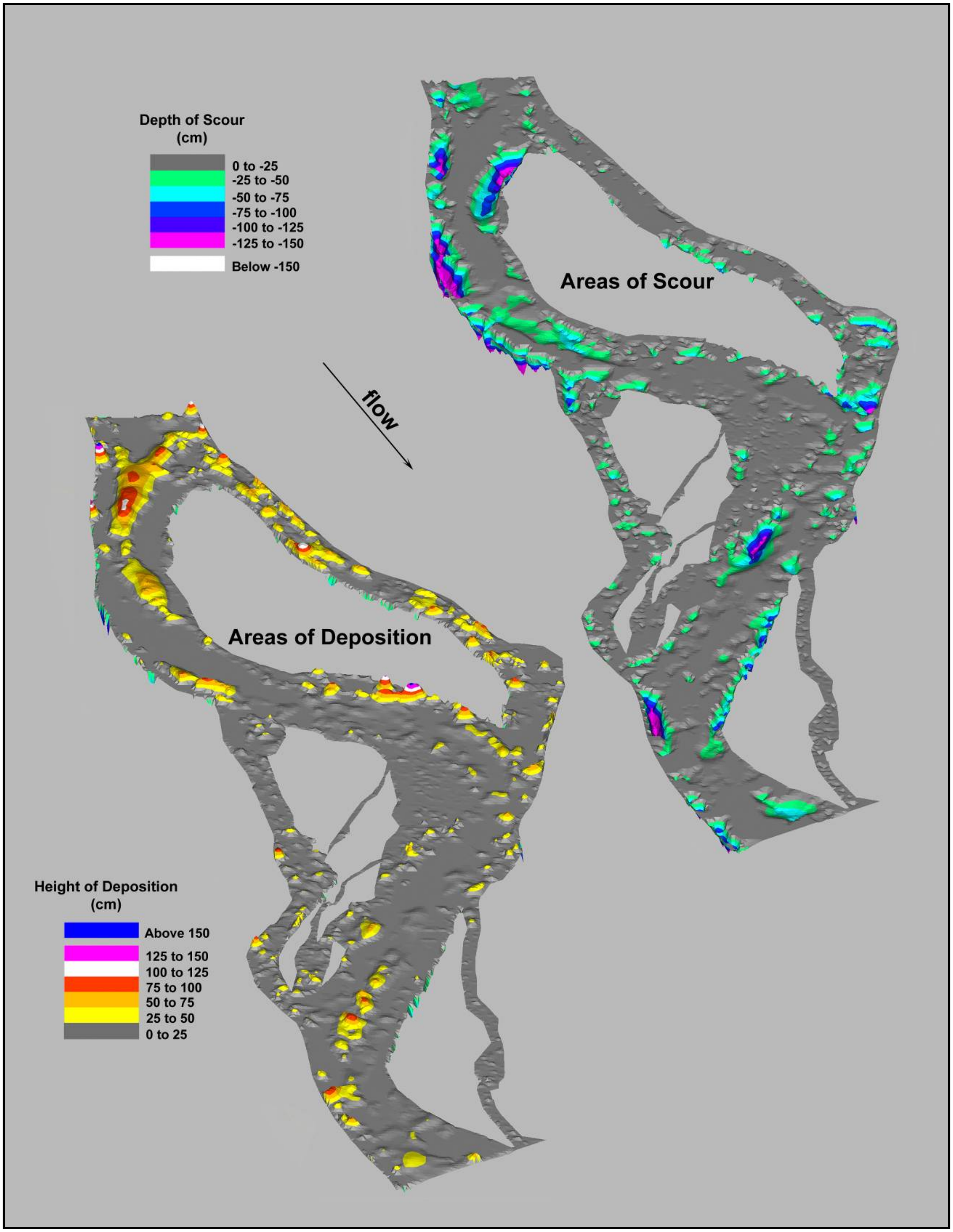

Figure 3.7. Location and depth of scour and deposition between 2007 and 2008 for DR 82

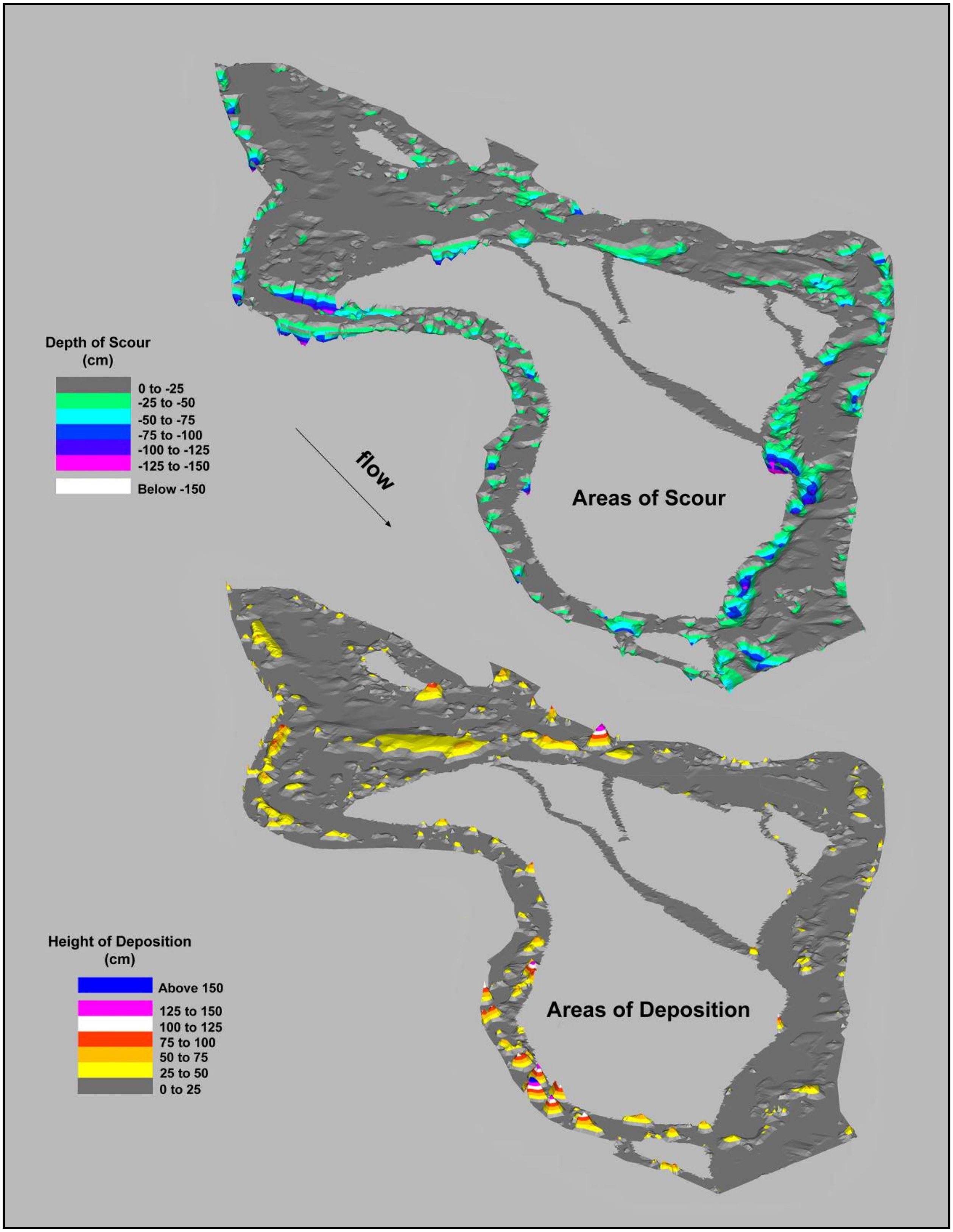

Figure 3.8. Location and depth of scour and deposition between 2007 and 2008 for DR 137

Table 3.2. Volume of scour and deposition between 2005, 2006, 2007 and 2008 surveys

Parameter	DR 82	DR 137	DR 82	DR 137	DR 82	DR 137
	'05-'06	'05-06	'06-'07	'06-07	'07-'08	'07-'08
Volume of scour – m^3	16,612	11,739	13,263	13,607	20,645	17,523
Volume of deposition - m^3	12,762	15,373	24,643	18,464	14,025	10,084
Net change (+deposition, -scour) - m^3	-3,850	3,634	11,380	4,858	-6,620	-7,439
Net change in depth - cm	-2.95	+2.94	+8.4	+4.7	-4.74	-5.69
Volume of cobble/gravel scour - m^3	7,326	4,766	5,207	4,735	11,000	10,034
Volume of sand scour - m^3	9,286	6,973	5,809	5,119	9,645	7,489
Volume of cobble/gavel deposition - m^3	5,309	6,580	7,258	6,070	6,540	5,035
Volume of sand deposition - m^3	7,453	8,793	15,530	12,347	7,485	5,049

Scour and deposition were also categorized as to bed material (Table 3.2). Only two categories of mobile substrate are categorized: sand and cobble/gravel. The original substrate is used for this characterization of scour, so even if cobble or gravel was present under the sand in a scour location, all the scour was considered to be sand. The post-runoff (2008 survey) substrate was used to characterize deposition.

More cobble/gravel was scoured in DR 82 than was deposited for a net export of cobble/gravel in 2008. More sand was scoured than deposited, also indicating net export. This is contrasted to observed net deposition of both coarse and fine substrate between 2006 and 2007 (Table 3.2).

About twice as much cobble/gravel was scoured in DR 137 as deposited, indicating a net export of cobble from the reach; 48% more sand was scoured than deposited, also indicating net export. Net deposition of both sand and cobble/gravel occurred in 2006 and 2007 (Table 3.2).

The portion of coarse substrate (cobble/gravel) increased from 2007 in DR 82, but was about the same in DR 137 (Table 3.3). Even though both reaches exhibited significant net scour, by the time surveys were completed in August, the coarse substrate portion had not returned to 2006 levels in either reach.

2008 was a high runoff year as a result of a large, extended release from Navajo Dam. The February 14 through June 30 flow at Four Corners totaled 1.45 million acre-feet in 2008, twice the total for 2007. The runoff volume and higher peak flows resulted in the net scour in these two reaches. There were two moderate storm events after runoff but before fall survey that likely contributed to the low abundance of coarse substrate relative to 2005 and 2006.

River2D Model

River2D models have been calibrated to water surface at survey for each of the detailed reaches for 2005-2007 survey flows (Tables 3.4 and 3.5). The 2008 calibration for DR 82 exceeded calibration standards for both base flow and high flow conditions (Table 3.4) and has consistently been easier to calibrate than DR 137. DR 137 calibration met the standards in 2008 for the low flow calibration except for the standard deviation standard (26% vs. 25% standard; Table 3.5). At high flow, the standards were not met. Surveyed waters-edge was at a flow rate that is above bank -full. The model predicted higher water surface than observed because it cannot deal with out-of-bank flow. It was better therefore to operate the model without re-calibrating at the 8,500 cfs flow to prevent inaccuracies in modeling below bank-full.

The model indicates that the mean velocity in DR 82 reaches maximum at about 7,000 cfs, at the point when the main island begins to flood and the wetted area increases more rapidly with increased flow (Figure 3.9). In 2007, this occurred at about 6,000 cfs. Model results and field observation indicate that the channel goes over-bank and outside the modeled area between 7,000 and 8,000 cfs. Model results above 8,000 cfs likely over-predict flow depth as the areas that are showing over-bank flow are contained to allow model continuity. Primary channel (portion of the reach that is flowing at 750 cfs) velocity continues to increase, but more slowly as flows exceed 7,000 cfs.

In DR 137, modeled mean velocity stabilizes at about 5,000 cfs, also corresponding with the initiation of island flooding, similar to 2007. The expansion of wetted area occurs at about the same point (Figure 3.10). Model results and field observation indicate that the flow begins to go over-bank on the north side of the model reach at around 7,000 cfs, so the 8,000 cfs model results likely over-predict depth somewhat. The difficulty in matching surveyed waters edge at 8,500 cfs confirms that the channel is out-of-bank at that flow.

Table 3.3 Cobble/gravel substrate percent for DR 82 and DR 137, 2005-2008

Year	Cobble/Gravel Substrate - % of total	
	DR 82	DR 137
2005	52%	50%
2006	52%	55%
2007	43%	45%
2008	48%	44%

Table 3.4. River2D model calibration results for DR 82

Parameter	2005	2006	2006 high flow	2007	2007 high flow	2008	2008 high flow
Flow - cfs	1,020	1,140	6,140	1,140	4,500	695	7,220
Average error – cm	.38	-1.8	-3.6	.35	-5.2	-0.8	-3.1
(% average depth)	(0.74%)	(4.9%)	(4.5%)	(0.92%)	(7.8%)	(2.2%)	(3.2%)
Standard deviation – cm	7.6	8.6	9.2	7.9	10.1	8.3	7.7
(%)	(14.8%)	(23.8%)	(11.6%)	(20.7%)	(15.2%)	(22.2%)	(8.1%)
95th percentile range -cm	±12.7	±12.3	±15.7	±13.4	±17.8	±12.5	±8.9

Table 3.5. River 2D model calibration results for DR 137

Parameter	2005	2006	2006 high flow	2007	2007 high flow	2008	2008 high flow
Flow - cfs	607	799	5,546	1,120	4,900	512	8,530
Average error – cm	1.1	1.9	-8.0	0.7	-6.2	-.9	16.8
(% average depth)	(3.5%)	(5.4%)	(11%)	(2.0%)	(8.9%)	(2.7%)	(22.8%)
Standard deviation – cm	15.6	7.8	11.0	10.2	11.2	8.2	11.1
(%)	(47.7%)	(22.9%)	(15.1%)	(27.2%)	(16.0%)	(26.1%)	(15.0%)
95th percentile range-cm	±24.8	±13.4	±17.4	±15.8	±18.7	±20.5	±35.3

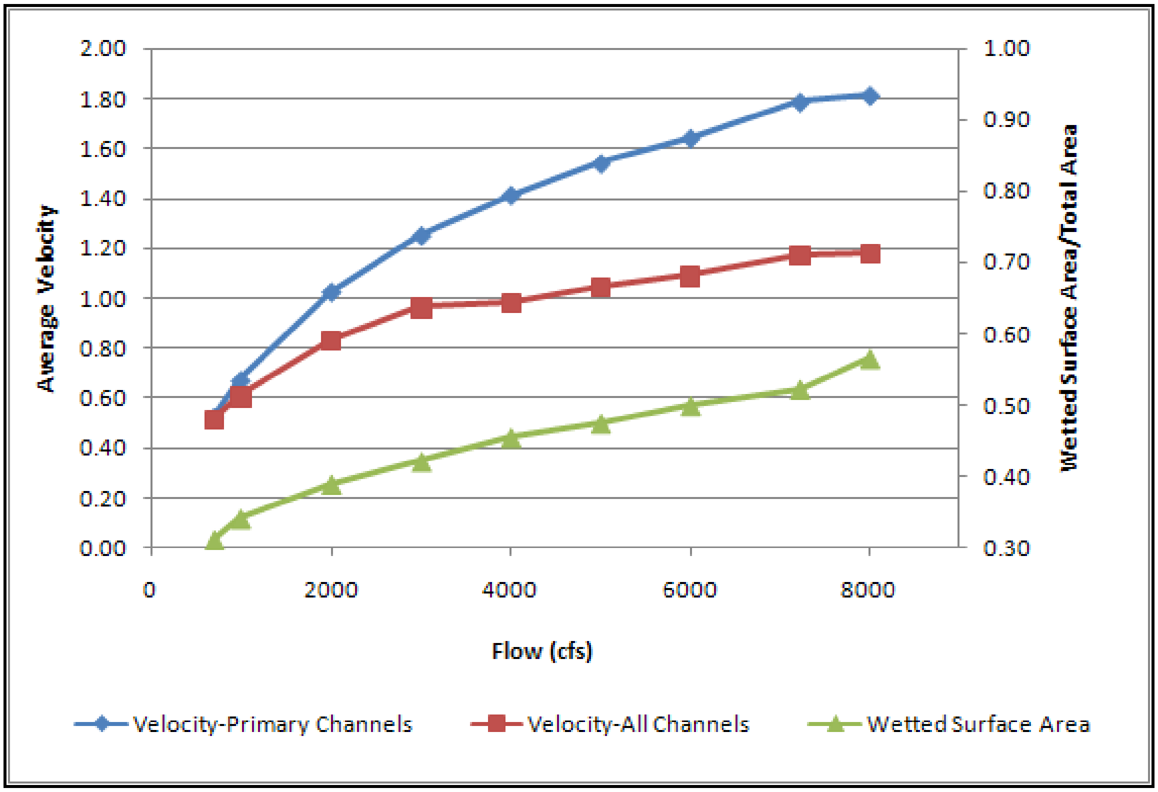

Figure 3.9. DR 82 modeled velocity and wetted surface area, 750 to 8,000 cfs

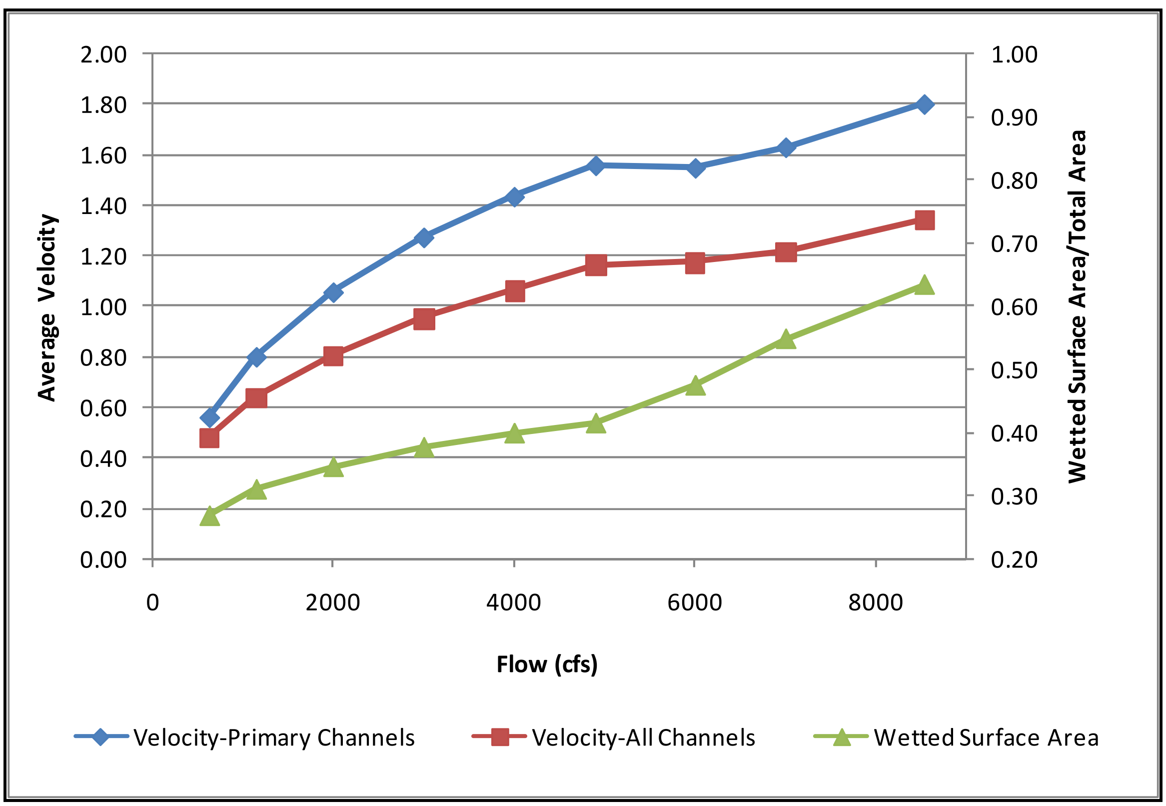

Figure 3.10. DR 137 modeled velocity and wetted surface area, 750-8000 cfs

Coarse Sediment Transport Analysis

Wolman pebble counts were completed at 10 locations in DR 82 and 9 in DR 137 (Figures 3.11 and 3.12). The mean D_{50} for the coarse fraction at DR 82 was 5.22 cm with a range of 4.9 to 6.1 cm (Table 3.6). The mean D_{50} at DR 137 was 5.78 cm with a range of 4.1 to 7.1 cm (Table 3.6). There is no significant difference between the two reaches (p=0.143). Between years, 2008 is significantly smaller (mean=6.55 cm vs 7.24 cm) for DR 82 in 2008 (p=.015), but there is no significant difference for DR 137. The distributions are more uniform in 2008 than in 2007. The count for individual samples is sufficiently low in some cases once the fine samples were removed that the distribution statistics may not be valid. Channel wide transport calculations were completed using the mean in each reach.

When all samples are included, 70% of the sites in DR 82 and 20% of those in DR 137 had a D_{50} of less than 1 cm (Table 3.7). When analyzed for sediment transport, material smaller than 1 cm was assumed to have a D_{50} of 5 mm. It represents the fine fraction of the bed and is called sand, although the upper end of the range and the D_{50} are in the range of fine gravel.

Boundary shear stress calculations were completed for three general reaches each in DR 82 and DR 137 (Figures 3.11 and 3.12). Reaches are defined as the area between paired points (Tables 3.8 and 3.9). Calculations were made for modeled conditions from 575 to 7,220 cfs in DR 82 and from 632 to 8,530 cfs in DR 137. Because of the out-of-bank condition in DR 137 at 8,530 cfs, results above 7,000 cfs are likely not accurate.

The average Wolman pebble count D_{50} for DR 82 of 5.22 cm was used for all of the shear stress estimates in this reach, since they are all general stream sections. The DR 82 river-left entrance channel (reach 1-2) boundary shear stress reaches incipient motion at approximately 2,000 cfs, average motion at 5,000 cfs and full motion between 6,000 and 7,220 cfs (Table 3.8). the channel in this area exhibited some scour on the point of the island, but no change in the remaining channel which is armored with vegetation on its banks and too deep to allow cobble measurement in the thalweg. The upper end of this reach exhibited net deposition as a result of cobble transport to this area.

Reach 3-4 of DR 82 represents the intermediate position in the right channel. Incipient motion begins at 2,000 cfs, like the left channel, but average motion occurs at 3,000 cfs. This channel does not achieve full motion (Table 3.8). This area demonstrated net scour between 2007 and 2008.

Boundary shear stress in reach 5-6 of the main channel is sufficient at flows between 1,000 and 5,000 cfs to have some transport with full motion beginning at about 6,000 cfs, (Table 3.8). This reach exhibited net scour of cobble this year with peak flows above 10,000 cfs with 23 days above 6,000 cfs. At flows above about 6,000 cfs, this reach could transport cobble out at a higher rate than it is transported in. Observed scour supports the model results.

The average cobble D_{50} for DR 137 of 5.78 cm (Table 3.7) was used to examine the potential for entrance channel cobble transport (Reach 1-2; Figure 3.12). While the survey did not extend upstream to capture the conditions in the channel approaching the detailed reach, the results for this reach indicates initial motion at as low as 1,500 cfs, and average motion at 3,000 cfs and above (Table 3.9). Full motion is not reached. Between 2007 and 2008 there was some bank scour in this reach but no net scour across the reach.

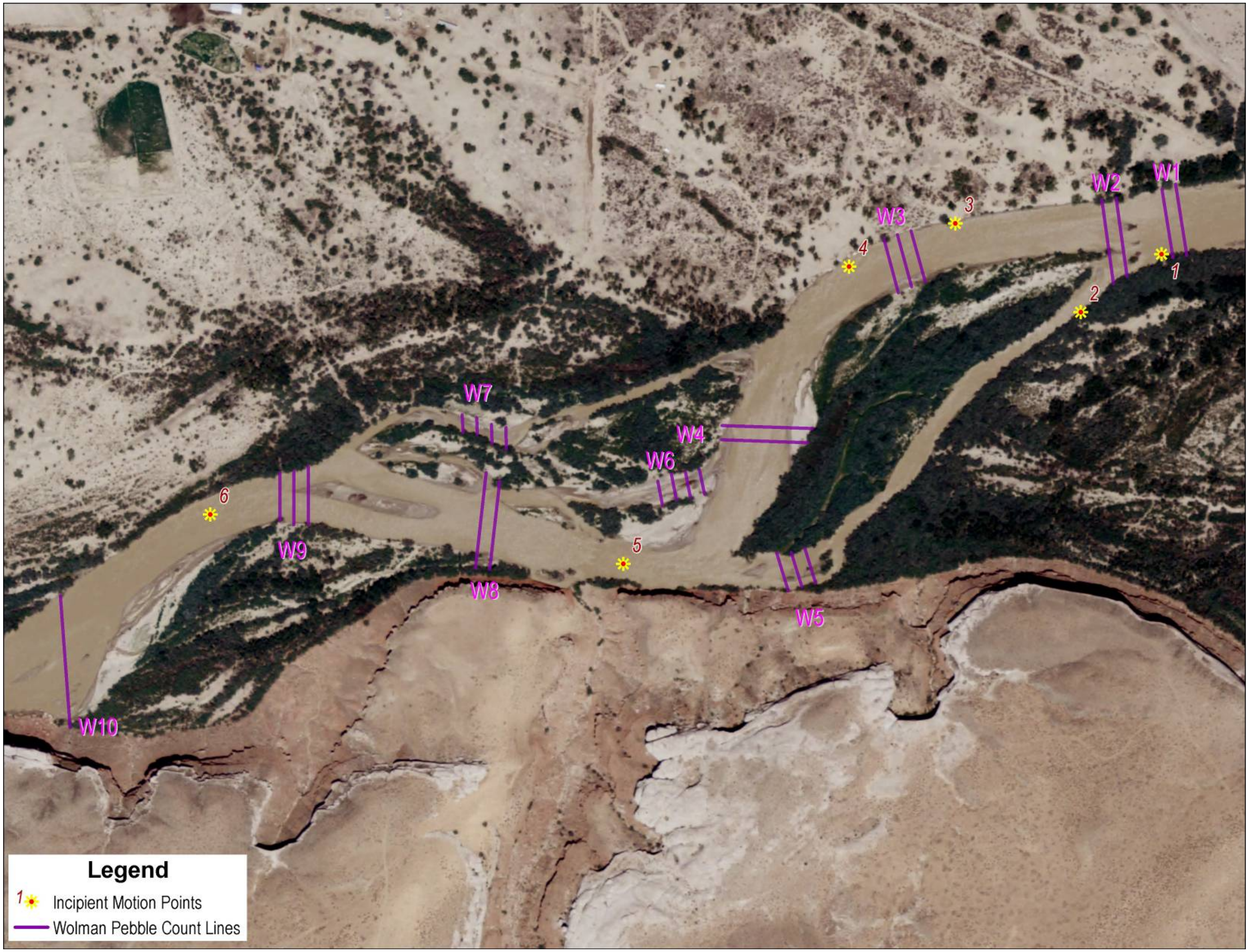

Figure 3.11. Wolman pebble count and shear stress calculation locations – DR 82. Shear stress calculations are for reaches between paired points

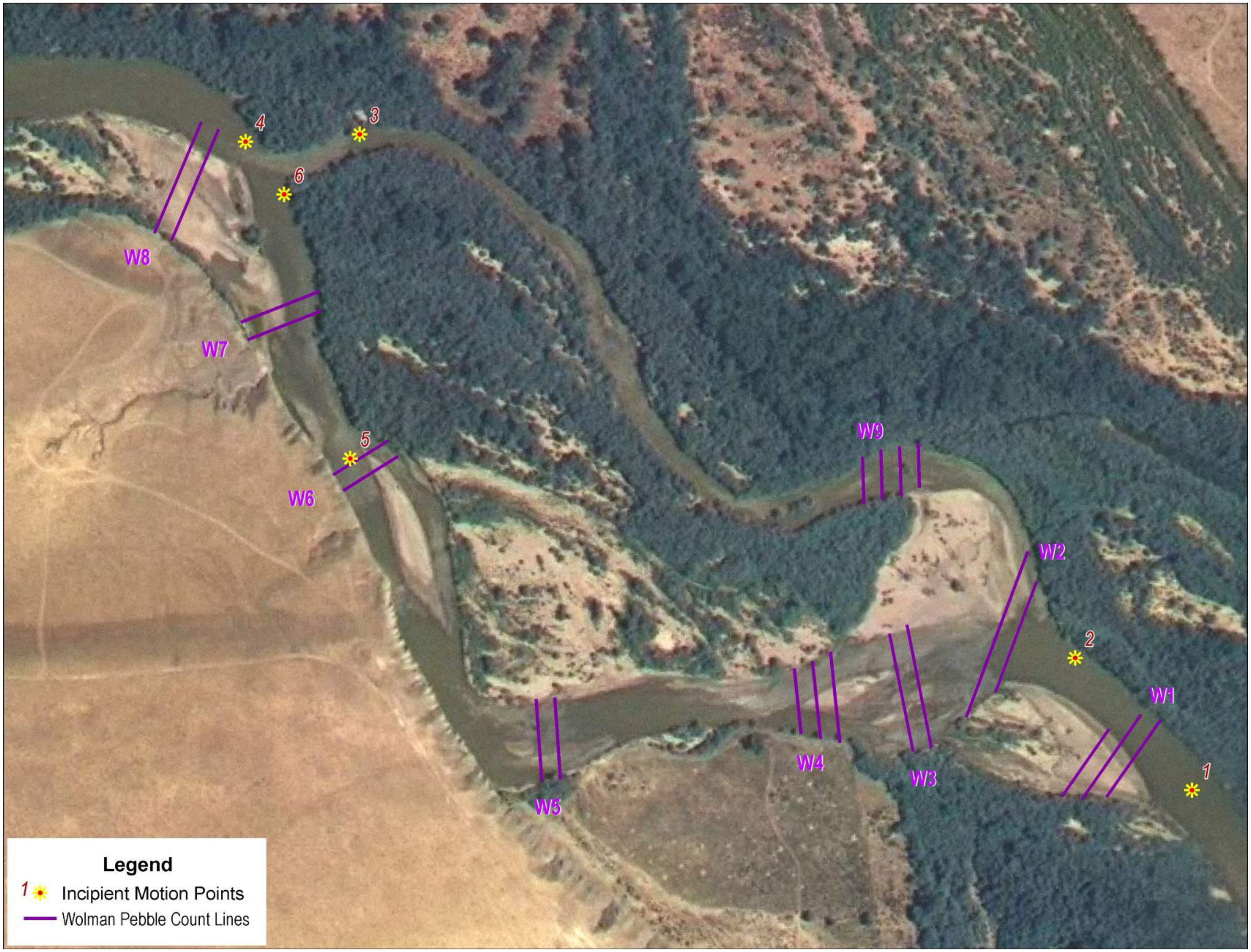

Figure 3.12. Wolman pebble count and shear stress calculation locations – DR 137. Shear stress calculations are for reaches between paired points

Table 3.6. Cumulative sediment size (cm) distribution from Wolman pebble counts for DR 82 and DR 137 with data <1 excluded

Location	Date	Sample Size	D84	D75	D50	D25	D16
DR 82 W1	9/16/08	21	0.00	6.75	5.10	3.13	2.59
DR 82 W2	9/16/08	62	9.87	9.07	5.18	0.00	3.46
DR 82 W3	9/16/08	34	9.28	7.75	5.00	2.94	2.56
DR 82 W4	9/16/08	42	7.92	7.50	6.00	4.58	3.86
DR 82 W5	9/16/08	85	9.08	7.11	5.17	3.75	3.24
DR 82 W6	9/16/08	58	8.72	6.81	4.91	3.10	2.48
DR 82 W7	9/16/08	40	7.40	6.50	4.20	2.67	2.27
DR 82 W8	9/16/08	73	10.66	9.47	6.07	3.41	2.53
DR 82 W9	9/16/08	22	9.65	8.33	5.50	3.25	2.63
DR 82 W10	9/16/08	53	8.76	6.94	4.93	2.93	2.45
DR 82 All	**9/16/08**	**490**	**9.29**	**7.57**	**5.22**	**3.46**	**2.78**
DR 137 W1	8/22/08	54	10.12	7.83	4.92	3.75	2.95
DR 137 W2	8/22/08	95	10.15	8.85	6.39	4.31	3.36
DR 137 W3	8/22/08	111	8.61	7.56	5.81	3.86	2.72
DR 137 W4	8/22/08	81	10.02	7.39	5.71	3.36	2.63
DR 137 W5	8/22/08	93	11.45	10.25	7.12	4.30	3.43
DR 137 W6	8/22/08	61	9.81	8.63	6.64	4.36	3.68
DR 137 W7	8/22/08	67	9.75	8.63	6.22	4.75	4.29
DR 137 W8	8/22/08	62	8.35	6.92	4.10	3.03	2.54
DR 137 W9	8/22/08	55	7.10	6.21	4.15	2.88	2.38
DR 137 All	**8/22/08**	**679**	**9.72**	**8.15 5.78**	**3.79**		**3.02**

Table 3.7. Cumulative sediment size (cm) distribution from Wolman pebble counts for DR 82 and DR 137

Location	Date	Sample Size	D84	D75	D50	D25	D16
DR 82 W1	9/16/08	110	2.60	<1	<1	<1	<1
DR 82 W2	9/16/08	132	7.29	5.00	<1	<1	<1
DR 82 W3	9/16/08	114	4.75	2.56	<1	<1	<1
DR 82 W4	9/16/08	100	6.83	5.50	<1	<1	<1
DR 82 W5	9/16/08	112	7.58	6.54	4.25	0.30	<1
DR 82 W6	9/16/08	110	6.43	5.07	1.20	<1	<1
DR 82 W7	9/16/08	109	4.71	2.97	<1	<1	<1
DR 82 W8	9/16/08	120	9.35	7.00	2.71	<1	<1
DR 82 W9	9/16/08	127	2.17	<1	<1	<1	<1
DR 82 W10	9/16/08	131	5.56	4.04	<1	<1	<1
DR 82 All	**9/16/08**	**1165**	**6.18**	**4.56**	**<1**	**<1**	**<1**
DR 137 W1	8/22/08	129	5.67	4.52	<1	<1	<1
DR 137 W2	8/22/08	119	9.49	8.35	5.39	2.22	<1
DR 137 W3	8/22/08	150	7.85	6.86	4.44	<1	<1
DR 137 W4	8/22/08	131	7.29	6.30	2.86	<1	<1
DR 137 W5	8/22/08	138	10.42	8.08	4.36	<1	<1
DR 137 W6	8/22/08	101	8.47	7.31	3.79	<1	<1
DR 137 W7	8/22/08	110	8.20	6.59	4.38	<1	<1
DR 137 W8	8/22/08	102	6.78	4.65	2.64	<1	<1
DR 137 W9	8/22/08	136	4.72	3.55	<1	<1	<1
DR 137 All	**08/15/07**	**1116**	**7.96**	**6.52**	**3.18**	**<1**	**<1**

Table 3.8. DR 82 boundary shear stress (τ_0) conditions at various locations and flow rates with the critical shear stresses required according to degree of transport and substrate D_{50}

									Critical Shear Stress (lb/ft^2)		
FigID .	FigID .	Flow (cfs)	Mean Vel. (mps)	Change in Vel. (mps)	Change in Depth (m)	Friction Slope	Cobble D_{50} (cm)	τ_0 (lb/ft^2)	Incip. Motion τ^*_c=0.02	Avg. Motion τ^*_c=0.03	Full Motion τ^*_c=0.045
5	6	722	1.04	-0.30	-0.21	0.00096	5.77	0.15	0.39	0.58	0.88
5	6	1,017	1.29	-0.28	-0.22	0.00111	5.77	0.20	0.39	0.58	0.88
5	6	2,000	1.53	-0.56	-0.19	0.00135	5.77	0.31	0.39	0.58	0.88
5	6	3,000	1.69	-0.64	-0.16	0.00133	5.77	0.36	0.39	0.58	0.88
5	6	4,075	1.83	-0.67	-0.17	0.00161	5.77	0.51	**0.39**	0.58	0.88
5	6	4,500	1.83	-0.75	-0.15	0.00166	5.77	0.55	**0.39**	0.58	0.88
5	6	6,000	1.94	-1.15	-0.09	0.00195	5.77	0.72	**0.39**	**0.58**	0.88
5	6	7,000	1.96	-0.43	-0.09	0.00005	5.77	0.02	0.39	0.58	0.88
7	8	722	1.11	-0.21	-0.07	0.00092	5.77	0.10	0.39	0.58	0.88
7	8	1,017	1.35	-0.27	-0.07	0.00100	5.77	0.14	0.39	0.58	0.88
7	8	2,000	1.65	-0.25	-0.10	0.00115	5.77	0.21	0.39	0.58	0.88
7	8	3,000	1.80	-0.17	-0.13	0.00122	5.77	0.28	0.39	0.58	0.88
7	8	4,075	1.93	0.06	-0.19	0.00131	5.77	0.35	0.39	0.58	0.88
7	8	4,500	1.83	0.03	-0.14	0.00115	5.77	0.34	0.39	0.58	0.88
7	8	6,000	2.01	0.40	-0.27	0.00140	5.77	0.46	**0.39**	0.58	0.88
7	8	7,000	1.92	0.24	-0.28	0.00157	5.77	0.63	**0.39**	**0.58**	0.88
9	10	722	0.87	0.32	-0.43	0.00325	5.77	0.55	**0.39**	0.58	0.88
9	10	1,017	1.09	0.34	-0.47	0.00332	5.77	0.66	**0.39**	**0.58**	0.88
9	10	2,000	1.47	0.35	-0.38	0.00304	5.77	0.77	**0.39**	**0.58**	0.88
9	10	3,000	1.71	0.18	-0.27	0.00279	5.77	0.86	**0.39**	**0.58**	0.88
9	10	4,075	1.92	0.10	-0.23	0.00270	5.77	0.92	**0.39**	**0.58**	**0.88**
9	10	4,500	1.94	0.00	-0.16	0.00257	5.77	0.93	**0.39**	**0.58**	**0.88**
9	10	6,000	2.11	-0.19	0.00	0.00222	5.77	0.93	**0.39**	**0.58**	**0.88**
9	10	7,000	1.94	-0.55	0.30	0.00157	5.77	0.78	**0.39**	**0.58**	0.88

Note: Bold = boundary shear stress is greater than the critical shear stress
See equation 3 for computation of boundary shear stress.

Table 3.9. DR 137 boundary shear stress (τ_0) conditions at various locations and flow rates with the critical shear stresses required according to degree of transport and substrate D_{50}

									Critical Shear Stress (lb/ft^2)		
Fig. ID.	Fig. ID.	Flow (cfs)	Mean Vel. (mps)	Change in Vel. (mps)	Change in Depth (m)	Friction Slope	Cobble D_{50} (cm)	To (lb/ft^2)	Cobble Incip. Motion T_c^*=0.02	Cobble Avg. Motion T_c^*=0.03	Cobble Full Motion T_c^*=0.045
1	2	632	0.57	0.07	0.46	0.00152	5.78	0.35	0.39	0.59	0.88
1	2	1150	0.86	0.12	0.45	0.00160	5.78	0.42	**0.39**	0.59	0.88
1	2	2000	1.25	0.21	0.41	0.00174	5.78	0.52	**0.39**	0.59	0.88
1	2	3000	1.64	0.31	0.37	0.00188	5.78	0.61	**0.39**	**0.59**	0.88
1	2	4000	1.96	0.42	0.32	0.00197	5.78	0.69	**0.39**	**0.59**	0.88
1	2	4900	2.24	0.49	0.28	0.00206	5.78	0.76	**0.39**	**0.59**	0.88
1	2	6000	2.33	0.31	0.41	0.00139	5.78	0.65	**0.39**	**0.59**	0.88
1	2	7000	2.50	0.21	0.42	0.00147	5.78	0.72	**0.39**	**0.59**	0.88
1	2	8530	2.69	0.01	0.46	0.00155	5.78	0.80	**0.39**	**0.59**	0.88
3	4	632	0.54	-0.99	0.46	0.00305	5.78	0.44	**0.39**	0.59	0.88
3	4	1150	1.04	-0.06	0.47	0.00368	5.78	0.74	**0.39**	**0.59**	0.88
3	4	2000	1.21	0.06	0.46	0.00376	5.78	0.98	**0.39**	**0.59**	**0.88**
3	4	3000	1.40	0.20	0.42	0.00347	5.78	1.05	**0.39**	**0.59**	**0.88**
3	4	4000	1.53	0.14	0.43	0.00355	5.78	1.23	**0.39**	**0.59**	**0.88**
3	4	4900	1.64	0.09	0.43	0.00344	5.78	1.28	**0.39**	**0.59**	**0.88**
3	4	6000	1.44	0.12	0.06	0.00052	5.78	0.22	0.39	0.59	0.88
3	4	7000	1.47	0.04	0.05	0.00066	5.78	0.30	0.39	0.59	0.88
3	4	8530	1.91	0.25	0.00	0.00073	5.78	0.34	0.39	0.59	0.88
5	6	632	0.57	-0.70	0.74	0.00101	5.78	0.16	0.39	0.59	0.88
5	6	1150	0.76	-0.59	0.78	0.00118	5.78	0.25	0.39	0.59	0.88
5	6	2000	0.94	-0.42	0.78	0.00120	5.78	0.33	0.39	0.59	0.88
5	6	3000	1.11	-0.37	0.76	0.00112	5.78	0.37	0.39	0.59	0.88
5	6	4000	1.16	-0.52	0.78	0.00113	5.78	0.41	**0.39**	0.59	0.88
5	6	4900	1.22	-0.63	0.79	0.00109	5.78	0.43	**0.39**	0.59	0.88
5	6	6000	1.23	-1.08	0.38	0.00101	5.78	0.41	**0.39**	0.59	0.88
5	6	7000	1.17	-1.49	0.41	0.00106	5.78	0.46	**0.39**	0.59	0.88
5	6	8530	1.56	-1.26	0.39	0.00017	5.78	0.08	0.39	0.59	0.88

Note: Bold = boundary shear stress is greater than the critical shear stress
See equation 3 for computation of boundary shear stress.

Reach 3-4 is at the outlet of the right channel (Figure 3.12). The model suggests that cobble transport would begin at about 1,150 cfs and full motion at flows between 2,000 and 5,000 cfs (Table 3.9). Above 5,000 cfs, a backwater condition develops in the model from high water surface elevation in the main channel and the model predicts that no cobble would be transported at 6,000 cfs and above.

Reach 5-6 is at the lower end of the left channel, upstream of the confluence with the right channel. The model predicts insipient motion between about 4,000 and 7,000 cfs, with no average or full motion expected at any flow rate modeled. This is inconsistent with observed conditions that show localized scour in this reach.

This analysis demonstrates minimal to moderate cobble transport capacity for DR 137 at the flows experienced in 2008, yet the surveys show a net scour of cobble somewhat greater than DR 82, for which greater transport capacity was computed.

Habitat

Detailed and standard habitat mapping completed in 2005 through 2007 for the two reaches was reviewed for consistency, importance of mapping and correlation with fish captures. It was determined that some of the transitional habitats (e.g. run/riffle) were difficult to consistently map. Others were rarely used. In order to simplify analysis, all habitat categories were reviewed and a revised list prepared (Table 3.10). Also shown in Table 3.10 are the habitat classifications that are recommended for removal and the associated habitat to which they would translate. Detailed reach habitat discussed in Chapter 4 uses these new classifications. River-wide mapping discussed in Chapter 5 and used for analysis of habitat association with GPS positions of endangered fish use the old habitat classifications.

For 2008, the detailed mapping was completed four times for each reach, twice in March and twice in April, corresponding with the fish sampling passes. In previous years, the habitat was mapped once for the two sampling passes as the flows were stable between passes. The separate mapping was required in 2008 because of flow rate change between passes.

The habitat mapped in the detailed reaches from 2005 through 2008 generally reflects the habitat distribution of the river reaches in which the detailed reaches are located (Tables 3.11 and 3.12). These reaches were selected because of the persistence of backwater habitats shown in previous habitat mapping. DR 137 had backwater habitat consistently for all years of mapping. DR 82 had both consistent and ephemeral backwaters. Historically the backwater habitat abundance of these reaches equalled or exceeded the average of the reach. That has not been the case since the detailed mapping began, with both reaches having less backwater habitat than the average of their respective river reaches. A key objective of this study is to identify the processes that lead to the loss and creation of backwater habitats. The modeling and habitat mapping datasets will be integrated in the final 2009 report to examine this response. That will allow the inclusion of the 2009 mapping data for analysis.

Table 3.10. Recommended revised habitat classifications

Habitat Features	
HABITAT	**DEFINITION**
1 Backwater	Typically a body of water off-channel in an abandoned secondary mouth, behind a bar or in a bank indention, water depth from <10 cm to >1.5 m, no perceptible flow, substrate typically silt or sand and silt. Little or no mixing of backwater and channel water.
3 Pool	Area within channel where flow not perceptible or barely so; water depth usually ≥ 30 cm; substrate silt, sand, or silt over gravel, cobble, or rubble.
6 Eddy	Same as pool, except water flow is evident (but slow) and direction typically opposite that of channel or circular.
8A Sand Shoal	Generally shallow (≤25 cm) areas with laminar flow (very slow to slow velocity: ≤5 cm/sec) over sand substrate
8B Cobble Shoal	Same as 8A except over cobble substrate
10 Run	Typically moderate or rapid velocity water 10-30 cm/sec with little or no surface disturbance. Depths usually 10-74 cm but may exceed 75 cm. Substrate usually sand but may be silt in slow velocity runs and gravel or cobble in rapid velocity runs.
15 Riffle	Area within channel where gradient is moderate (5 cm/m), water velocity usually moderate to rapid (10 to 31 cm/sec), and water surface disturbed. Substrate usually cobble and rubble and portions of rocks may be exposed. Depths vary from <5 to 50 cm, rarely greater.
19 Chute	Rapid velocity (⩾30 cm/sec) portion of channel (often near center) where gradient ⩾10 cm/m. Channel profile often U- or V-shaped. Depth typically ⩾30 cm. Substrate large cobble or rubble and often embedded.
20 Slackwater	Low velocity habitat usually along inside margin of river bends, shoreline invaginations, or immediately downstream of debris piles, bars or other in-stream features, but deeper than shoals (>25 cm).
21 Isolated Pool	Small body of water in a depression, old backwater, or side channel, not connected to the channel as a result of receding flows.
22 Embayment	Open shoreline depression similar to a backwater but that faces upstream. Typically at the top end of abandoned secondary channels or bars.
32 Rapid	Deep, high gradient, high velocity areas often with standing waves
35 Pocket water	Low velocity water similar to slack water, but in boulder fields. These usually occur in channel margins in the canyon reaches.
41 Plunge	The transition area below a riffle or chute where the channel deepens into a run with transition from high to low velocity.

Other Mapping Features	
25 Cobble bar	34 Inundated vegetation
26 Root wad pile	36 Boulders
28 Sand bar	37 Waterfall
29 Tributary	38 Bridge/pier
31 Island	39 Irrigation Outflow (diverted Water)
33 Irrigation return	40 Diversion Structure

Discontinued Habitat Classifications

Old Category		New Category		Old Category		New Category	
2	Backwater Pool	1	Backwater	13	Undercut Run	10	Run
4	Debris Pool	3	Pool	14	Run/Riffle	15	Riffle
5	Root wad Pool	3	Pool	16	Riffle Eddy	6	Eddy
7	Edge Pool	3	Pool	17	Shore Riffle	15	Riffle
9 A	Sand Shoal/Run	8A	Sand Shoal	18	Riffle/Chute	19	Chute
9B	Cobble Shoal/Run	8B	Cobble Shoal	24	Overhang Vegetation		removed
11	Scour Run	10	Run	27	Abandoned Channel (dry)		removed
12	Shore Run	10	Run	30	Shoal/Riffle	15	Riffle

Note: Shore runs may be noted as such during sampling, but will be post-processed for mapping.

Table 3.11. Relative abundance of habitats for DR 82, 2005-2008 compared to Reach 3

	DR 82							Reach 3		
Category	**Nov-05**	**Mar-06**	**Nov-06**	**Aug-07**	**Oct-07**	**Mar-08**	**Aug-08**	**Nov-05**	**Nov-06**	**Oct-07**
Flow - cfs	**951**	**621**	**1,190**	**880**	**931**	**3,693**	**1,256**	951	1,190	931
Backwater	0.10%	0.25%	0.00%	0.29%	0.13%	0.32%	0.34%	0.09%	0.41%	0.22%
Pool	0.49%	0.00%	0.68%	0.71%	0.57%	0.00%	0.55%	0.18%	0.37%	0.14%
Eddy	0.15%	0.08%	0.00%	0.10%	0.05%	0.25%	0.08%	0.01%	0.02%	0.02%
Run	54.9%	76.6%	63.8%	62.4%	56.3%	79.3%	71.7%	81.6%	76.8%	71.0%
Riffle	25.3%	14.4%	22.4%	17.2%	21.9%	11.8%	13.2%	8.1%	14.6%	15.4%
Chute	2.07%	0.05%	0.00%	0.05%	0.87%	0.00%	0.00%	0.28%	0.07%	0.05%
Slackwater	0.61%	0.61%	3.70%	7.79%	4.77%	2.96%	6.82%	1.15%	1.88%	1.08%
Isolated Pool	0.00%	0.10%	0.04%	0.09%	0.06%	0.00%	0.37%	0.11%	0.16%	0.35%
Embayment	0.12%	0.12%	0.00%	0.06%	0.12%	0.00%	0.00%	0.05%	0.03%	0.07%
Cobble bar	3.44%	5.28%	2.31%	5.77%	6.18%	1.00%	6.97%	3.89%	4.08%	6.69%
Root wad pile	0.15%	0.30%	0.37%	0.36%	0.29%	0.53%	0.32%	0.10%	0.16%	0.13%
Sand bar	2.20%	6.50%	7.49%	5.66%	5.10%	2.09%	5.31%	5.89%	8.74%	9.40%
Island	51.3%	34.6%	41.7%	41.6%	40.9%	34.4%	37.2%	26.4%	22.6%	22.8%
Rapid	1.23%	0.00%	0.00%	0.00%	0.00%	2.79%	0.00%	0.00%	0.02%	0.00%
Inundated vegetation	0.00%	0.00%	0.00%	0.00%	0.00%	0.63%	0.00%	0.00%	0.00%	0.00%
Pocket water	0.07%	0.13%	0.11%	0.22%	0.05%	0.00%	0.33%	0.01%	0.01%	0.00%
Boulders	0.02%	0.01%	0.00%	0.01%	0.01%	0.02%	0.01%	0.01%	0.01%	0.02%
Plunge	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Sand Shoal	7.47%	5.37%	8.65%	4.50%	10.26%	0.58%	3.95%	6.36%	4.96%	9.40%
Cobble Shoal	7.40%	2.29%	0.55%	6.56%	4.87%	0.46%	2.68%	2.11%	0.65%	2.28%

Note: Wet habitats shown as % of total wet area. Dry habitats as % of total mapped area

Table 3.12. Relative abundance of habitats for DR 82, 2005-2008 compared to Reach 3

	DR 137						Reach 5		
Habitat	**Mar-06**	**Nov-06**	**Aug-07**	**Oct-07**	**Mar-08**	**Aug-08**	**Nov-05**	**Nov-06**	**Oct-07**
Flow - cfs	**542**	**1,084**	**880**	**871**	**3,693**	**1,310**	951	1,084	871
Backwater	0.10%	0.16%	0.23%	0.00%	0.09%	0.27%	0.65%	0.19%	0.41%
Pool	1.76%	0.00%	0.00%	0.02%	0.16%	0.62%	1.67%	0.70%	1.29%
Eddy	0.73%	0.08%	0.35%	0.08%	0.13%	0.09%	0.11%	0.03%	0.05%
Run	67.3%	68.3%	70.8%	66.1%	62.6%	68.8%	68.6%	66.2%	66.6%
Riffle	12.2%	21.2%	16.2%	21.6%	27.3%	18.1%	17.9%	22.5%	21.5%
Chute	0.30%	0.00%	0.33%	1.72%	0.20%	0.07%	1.77%	0.01%	0.38%
Slackwater	2.63%	6.40%	5.28%	4.07%	4.83%	6.60%	0.42%	5.11%	1.26%
Isolated Pool	0.06%	0.01%	0.08%	0.12%	0.04%	0.36%	0.17%	0.08%	0.17%
Embayment	0.05%	0.63%	0.21%	0.45%	0.61%	0.00%	0.04%	0.03%	0.05%
Cobble bar	6.76%	2.67%	2.43%	3.33%	1.05%	7.68%	1.67%	1.52%	3.54%
Root wad pile	0.24%	0.09%	0.18%	0.11%	0.20%	0.21%	0.02%	0.07%	0.03%
Sand bar	2.95%	1.29%	3.20%	3.08%	1.72%	0.98%	0.97%	2.32%	1.75%
Island	58.2%	58.3%	58.3%	55.8%	52.3%	54.6%	63.9%	64.4%	62.7%
Rapid	0.00%	0.00%	0.00%	0.00%	0.57%	0.00%	0.00%	0.00%	0.00%
Inundated vegetation	0.00%	0.00%	0.00%	0.00%	0.12%	0.00%	0.00%	0.00%	0.00%
Pocket water	0.00%	0.00%	0.00%	0.00%	0.01%	0.00%	0.01%	0.01%	0.00%
Boulders	0.03%	0.00%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Plunge	0.00%	0.00%	0.05%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Sand Shoal	11.57%	0.85%	3.36%	1.63%	1.89%	1.28%	6.30%	3.52%	4.59%
Cobble Shoal	3.15%	2.30%	3.08%	4.24%	1.14%	3.84%	2.35%	1.62%	3.66%

Note: Wet habitats shown as % of total wet area. Dry habitats as % of total mapped area

Funding for standardized habitat mapping was terminated in 2008, so no comparison of standard to detailed mapping was possible. The original scope anticipated attempting a correlation between the two levels of detail to allow post-processing the standardized mapping to reflect results gained from a higher level of detail. With only three years of data (two years for DR 137), there are no statistically significant relationships for individual habitat types or reaches. By combining backwaters and other low velocity habitats together for both detailed reaches and all years there is a marginally significant difference between mean total area for detailed and standard mapping (p=0.06; Table 3.13). The detailed to standard ratio is 1.64. This would not be valid for any single year or individual reach. However, it might be inferred that the actual low velocity habitat in the river is about 1.5 times that indicated by river-wide habitat mapping.

The number of habitat polygons mapped is significantly greater for detailed than standard mapping (p=0.002, ratio=2.3) based on the combined data for all years and both reaches. All significance tests utilize two-tailed student t-test for unequal variance.

Table 3.13. Low velocity habitat area comparison from detailed and standard mapping

		Backwater m^2		Low Velocity m^2		Combined	
Reach	**Date**	**Detailed**	**Standard**	**Detailed**	**Standard**	**Detailed**	**Standard**
DR 137	Nov-06	623	200	64	0	687	200
	Oct-07	369	181	81	68	450	250
DR 82	Nov-05	180	0	549	410	729	410
	Nov-06	0	0	728	751	728	751
	Oct-07	275	278	661	261	936	538
Total		289	132	417	298	706	430
Ratio detailed / standard		2.20		1.40		1.64	
p-value		0.23		0.56		0.06	

Model and Habitat Data Integration

Runs from which fish samples were collected and identified as shore runs were intersected with the modeled depth and velocity for the flow closest to sampling flow in both 2007 and 2008 (Figures 3.13 and 3.14). The velocity distributions are similar, but the depths are quite different in the two years. In 2008, the selection of runs was limited to those listed as shore runs when sampled, which may explain the shallower depths.

In 2007 the threshold velocity for Colorado Pikeminnow capture was about 0.6 m/sec. In 2008 it was 0.7 m/sec. The velocity trend line reaches this range at between 3 and 4 m from shore in both years. The depth trend line ranges from 0.4 to 0.6 m in 2008, but from 0.5 to 0.7 m in 2007 whereas the bulk of the Colorado Pikeminnow captures were at depths of 0.6 m or less.

In 2007 a width of 2.5 m was used to define shore runs. Using both year's data it appears that 3.0 would be a better selection, which would increase the portion of the runs classified as shore runs from 10.7% to about 13%.

This value is achieved by using the linear edge of all runs that contacts the shore. In application, this approach needs some refinement as all shorelines are not equal. For example, runs next to a cut bank will typically be deep and swift, not meeting the desired velocity and depth conditions. Screening of bank conditions could improve the availability estimate. For application to mapping, it is recommended that a classification for shoreline condition be developed and the shore lines that fit the criteria be marked during mapping. In processing, only these reaches would be used to assess availability of shore run, if this habitat category is important to endangered fish.

CONCLUSIONS AND RECOMMENDATIONS

Analysis of the first four years of data from the detailed reaches has led to some important findings, substantially enhanced by the addition of the fish survey in 2007. The objectives of the study are being met, although some of the original methods have been changed. Following are the detailed findings and recommendations:

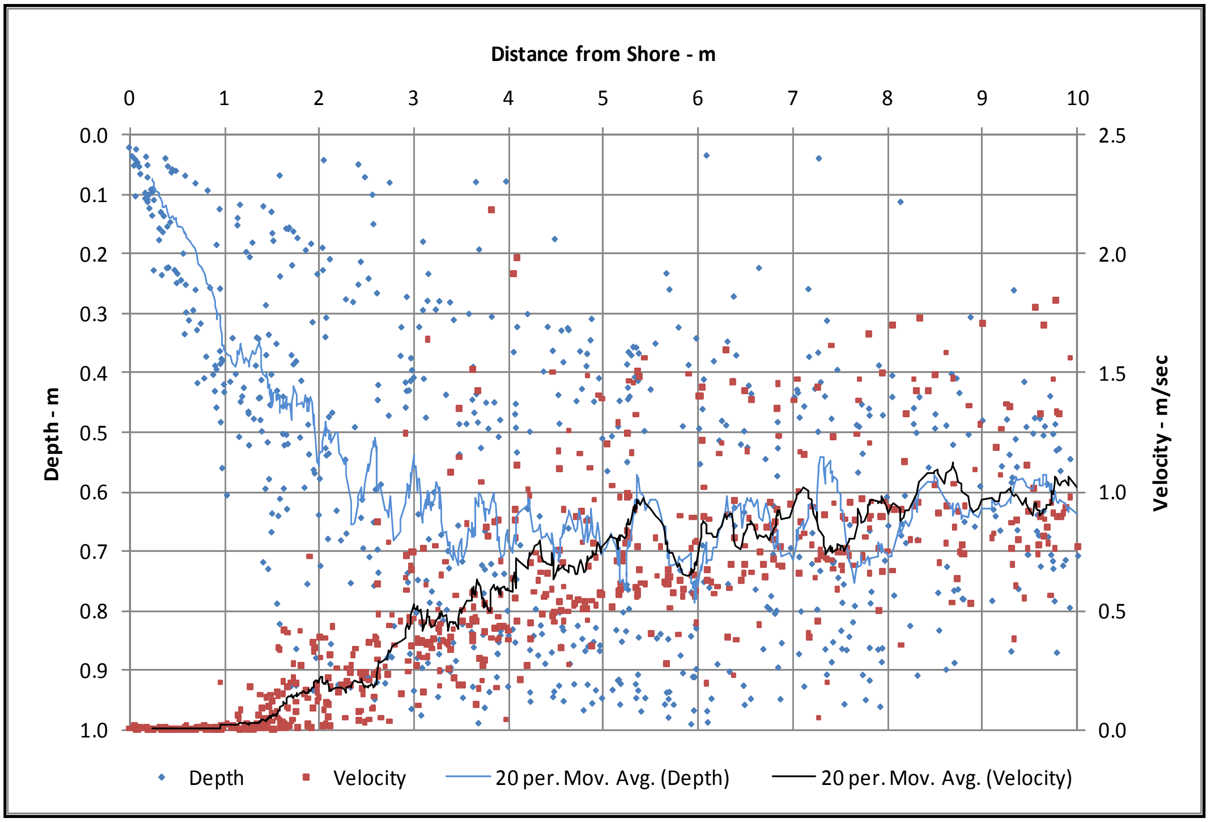

Figure 3.13. Depth and velocity in selected runs with distance from shore –DR 82 and DR 137, August 2007

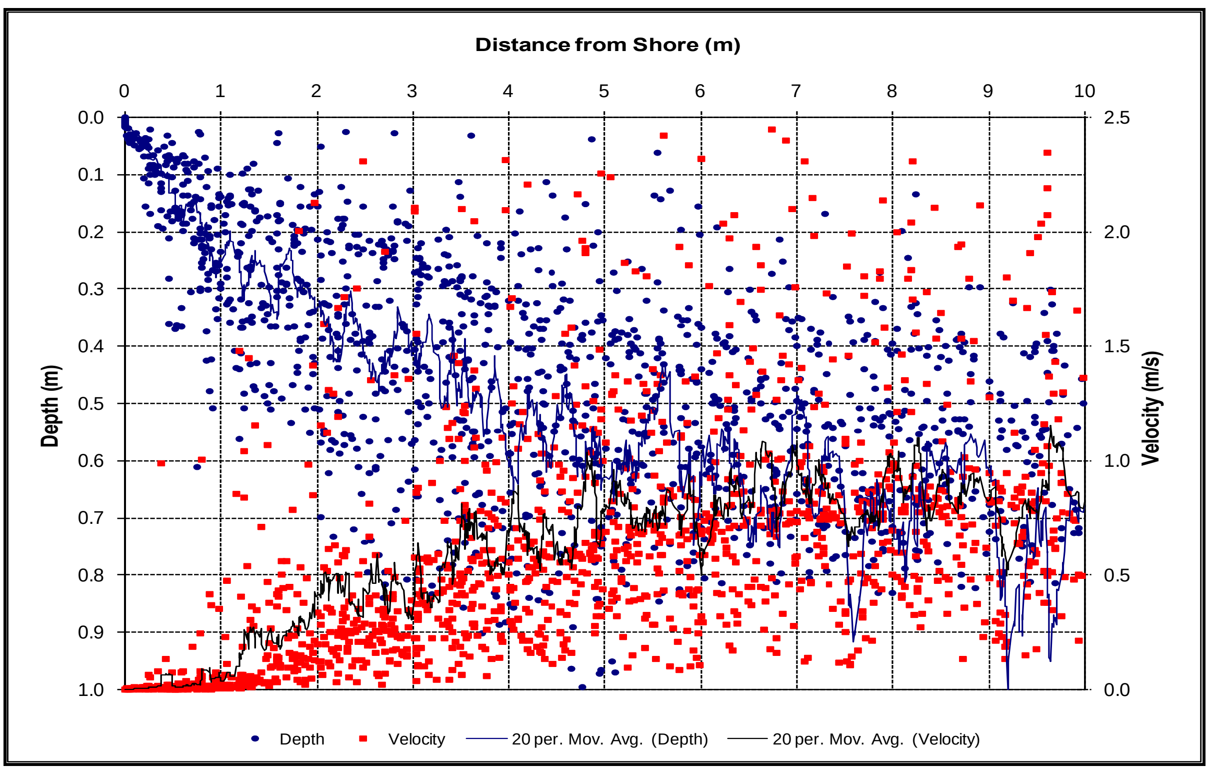

Figure 3.14. Depth and velocity in selected runs with distance from shore –DR 82 and DR 137, August 2008

Channel Change

- DR 82 demonstrated nearly 5 cm of net scour between August 2007 and August 2008, with both scour and deposition within the reach. Both cobble/gravel and sand were scoured from the reach in 2008, compared to a net increase for both in 2006.
- DR 137 demonstrated nearly 6 cm of net scour during the same time period with both scour and deposition within the reach. There was a net loss both cobble/gravel and sand.
- The change in bed elevation is statistically significant for both cobble and sand.
- The net scour is a result of the large volume of water released from Navajo dam beginning in February which resulted in the flow for the period being 2.0 times the 2007 volume for the same period.

River2D Model

- River2D models have been developed and operated for DR 82 and 137 that cover ranges in flow from about 500 cfs to around 8,000 cfs.
- The models provide sufficiently reliable results to forecast depth, velocity and wetted area over a range of flows.
- Model results in 2008 indicate that DR 82 reaches maximum average flow velocity at about 7,000 cfs and bank-full conditions at 7,000 – 8,000 cfs. The maximum average velocity is about 1,000 cfs higher than predicted in 2007.
- For DR 137, average flow velocity stabilizes at about 5,000 cfs and bank-full conditions occur at about 7,000 cfs, similar to the results in 2007.

Coarse Sediment Transport

- There is no statistically significant difference in median cobble diameter between the reaches in 2008 or between 2007 and 2008 for DR 137. The D_{50} for DR 82 was significantly smaller in 2008 than in 2007. The average D_{50} for the two reaches was about 5.5 cm in 2008.
- Boundary shear stress is adequate in both reaches to mobilize cobble into the reaches at flows near bank-full (6,000 – 8,000 cfs).
- Boundary shear stress at the outlet of DR 82 is adequate to transport cobble out of the reach, corresponding to the measurement of lost cobble during 2008.
- Computed boundary shear stress at the outlet of DR 137 shows only marginal capacity to move cobble out of the reach and drops at the highest flows due to a backwater condition at the confluence of the two channels. Measured changes shows net export from the reach, suggesting that the hydraulic predictions of the model are not accurate at high flow in this area of the reach.

Detailed Reach Habitat

- A simplified habitat classification system is recommended that reduces the total number of habitat categories from 29 to 14, with an additional 12 classification categories for structural features (e.g. islands, cobble bars, sand bars). The change will improve repeatability of mapping and aid in habitat/fish relationship analysis.
- The detailed reaches exhibit similar habitat makeup as the average for the river reaches they are in. An important exception is that the detailed reaches now exhibit less habitat

area than the average for the river reach. Analysis of the reasons for this loss will be reported in the 2009 final report after the remaining habitat mapping can be completed.

- Comparing detailed to standard mapping resulted in the identification of two relationships that might be applied to the river-wide mapping to correct for findings in the detailed mapping. Detailed mapping demonstrates a marginally significant increase in total low velocity habitat over standard mapping ($p=0.06$, ratio ≈1.50). More habitat polygons demonstrating higher habitat complexity are mapped in the detailed mapping than in standard mapping ($p = 0.002$, ratio = 2.30). These ratios may be applied to the overall river-wide data set, but may not be valid for any individual reach or time period.

Model and Habitat Data Integration

- Availability of shore-run habitat was determined by applying depth/velocity criteria to establish a typical distance from shore as the break between shore-run and mid-channel run habitat types. The transition between the two habitats occurred at 3 m, based on data from the detailed reaches.
- Application of the 3 m offset for the detailed reaches resulted in about 13% of the run habitat being classified as shore-run.
- Shoreline discrimination for selection of appropriate edge conditions should be included in future definitions.
- Shore-run habitat definition should be refined after receiving input from the Biology Committee.

CHAPTER 4: SAN JUAN RIVER DETAILED REACH FISH SURVEY (2007-2008)

INTRODUCTION

The integration of San Juan River Basin Recovery Implementation Program (SJRIP) monitoring data from 1999-2003 highlighted the difficulties in relating fish and fish habitat data given that these two data sets were based on data collections at different levels of detail and different times (Miller 2005). Adult fish monitoring data were too coarse to allow correlation with habitat data while habitat mapping units were too large to see details that were often the focus of sampling by larval and juvenile fish sampling programs. While larval and small-bodied fish sampling collect habitat data, the habitat categories do not consistently match those in the habitat mapping program. Also, the sampling and mapping are completed at different times and different flows than the fish sampling programs, making correlation difficult. Finally, although GPS locations are provided for recently collected larval and small-bodied fish sampling programs and for endangered fish captures from large-bodied sampling, the accuracy is not adequate to place them on the habitat maps with sufficient precision to correlate the two data sets.

Backwater habitat has been suggested as important to young endangered fishes (Tyus and Haines 1991, Modde et al. 1996, 2001). Backwater habitat is low in abundance in the San Juan River and has declined substantially since 1995 (Bliesner and Lamarra 2006). However, sampling for age-0 and age-1 Colorado pikeminnow in the last several years has indicated that they use other low velocity habitat that may not be mapped at adequate detail to be representative of availability by the standard mapping program (Golden et al. 2006, Bliesner et al. 2008).

The goal of the detailed reach fish survey is to identify the habitat(s) utilized by young endangered fishes and to provide information to allow this habitat to be mapped more broadly in the San Juan River. Specific objectives include:

1. Sample for young-of-year Colorado pikeminnow and razorback sucker within at least two complex reaches to assess habitat use of endangered fishes.

2. Map habitat in each complex reach each time fish sampling occurs to assess habitat availability.

3. Use supplemental data on young Colorado pikeminnow and razorback sucker captures of any size class throughout the San Juan River from other SJRIP sampling efforts and use these data to add to the habitat use information in the complex reaches.

Habitat mapping combined with detailed channel topology measurements and hydraulic modeling, would also provide insight into the mechanism or process for creation and maintenance of these complex reaches and provide a better understanding of the loss or creation of backwater habitats or other low velocity habitats used by the endangered fishes.

METHODS

Fish were intensively sampled along 2 complex reaches in August 2007 and along 3 complex reaches in March and August of 2008. Reaches sampled in 2007 included Detailed Reach 82 (DR 82) located at river mile 82 (RM 82) and DR 137, located at RM 137. In addition to these reaches, a third detailed reach (DR 131) located at RM 131 was also sampled in 2008. Each reach was sampled twice within a six day period. Typically the first sampling event occurred over the course of one day; with the second sample taking place after two days of "rest". This “rest” period was intended to allow displaced fish to redistribute among available habitats. “Block” seining was the primary method used to capture fish in August sampling events. This method involved using two 2m x 9m double weighted seines with a 6mm mesh. To sample a particular location, one seine was dragged downstream through the sample area while the other was held in place at the downstream end and pivoted towards the shore behind the first seine. Samples were also collected using a single seine of the same size or smaller (i.e., 2m x 3m seine with a 3mm mesh size) as appropriate based on habitat area and flow conditions. Similarly, a single seine (2m x 3m with 6 mm mesh) was typically used during March sampling events.

Total and standard lengths were recorded for all Colorado pikeminnow and razorback sucker captured in each of the complex reaches. For other species captured, length measurements of up to 50 individuals of each species were recorded. A PIT tag reader was used to scan all Colorado pikeminnow and razorback sucker over 150 mm TL for PIT tags. Numbers of PIT tags detected were recorded and a new tag was inserted when detection did not occur. All Colorado pikeminnow that were less than 150 mm TL were marked with a VIE tag (marking color and location: pink right dorsal) during the first pass. Mark and recaptured data were used to estimate the population size of Colorado pikeminnow by reach.

The selection of sampling habitats was intended to be proportional to the occurrence of habitats within the two complex reaches. However, previous sampling has shown that pikeminnow with total length greater than 100mm (TL > 100 mm) tend to use fairly complex portions of the river with some current, while smaller Colorado pikeminnow (TL < 100 mm) occur more commonly in backwaters and shoals (Golden et al. 2006, Robertson and Holden 2007). Based on this evidence, some habitats were sampled in a relative lower or higher proportion than they occurred in each reach. Backwaters, embayments, and eddies are relatively uncommon and all or the majority of these low-velocity habitat types were sampled. Conversely, runs are among the most common habitat types but only a small area of this habitat type was sampled. Water depth and velocity also prevented sampling this (and other habitat types) in proportion to their occurrence. For these reasons, the assessment of habitat selection by fish, described below was based on the area sampled by habitat type rather than on the total area present.

Prior to the field data collection, a plan for selecting sample sites was developed based on previous mapping efforts and anticipated number of samples that could be collected in the allocated sample period. It was anticipated that approximately 40 samples could be collected during a single day/pass. After the initial sampling pass, the habitats sampled were reviewed and the second pass was intended to sample habitats that were missing and/or that were not sampled in approximate relative proportion during the initial sampling pass. The second pass also served to increase the number of seine hauls pulled, to boost pikeminnow captures, and if possible, to calculate endangered fish mark-recapture population estimates.

Approximate site locations were selected in advance (except for backwaters and other low-velocity habitats) using maps from the previous year as well as a grid and random number generator. In the field, many of these sites were no longer in the same habitat category or were not suitable to sampling with seines. Thus, sample sites were adjusted as needed. Overall, despite detailed planning, the final allocation of sampled habitat types was more closely associated with habitat conditions observed in the field than the anticipated sample locations determined from previous mapping efforts.

In all sample efforts, a single habitat type was targeted for sampling. However, effective sampling of small habitat features often required beginning a seine haul in one habitat feature, passing through the targeted habitat, and completing the sample in the second or even possibly a third habitat feature. In such cases, effort was focused on minimizing the area sampled in adjacent habitats. All captured organisms were presumed to have been captured in the target habitat for data analysis. The habitat association study examined the association between all habitats within each seine haul and Colorado pikeminnow capture.

Physical characteristics recorded at each habitat sampled included multiple depth and velocity measurements, primary and secondary substrate types, and primary and secondary cover features (if present). The habitat type, area sampled (width and length of seine haul) and water temperature were also recorded. Depth and velocity measurements were collected in 3 to 5 locations per site and were chosen to be representative of the range of conditions within the site. Velocity measurements were collected at 60 percent below the water surface in all locations with depth less than 2.5 feet and at 20, 60, and 80 percent below the surface with depth greater than 2.5 feet. In these locations, velocity was averaged for the three values to generate a mean velocity value for that location. Depth and mean velocity for each of the 3-5 locations were then averaged to find a mean depth and velocity for the sample site. Substrate was classified as silt, sand, fine gravel (<1 in.), coarse gravel (1-3 in.), small cobble (3-6 in.), large cobble (6-10 in.), or boulder (>10 in.). Categories for cover included inundated vegetation, roots, small woody debris, large woody debris, overhanging vegetation/roots, boulders, and bedrock shelves.

Sample locations were identified on an ortho-rectified digital photograph base map on which were drawn habitat features collected at the same time as fish sampling. GPS coordinates were recorded at each sampling site. Habitat types follow Bliesner et al. (1999).

Other San Juan River fish studies were also reviewed for the potential to use them in the habitat selection analysis. Data from the larval fish, non-native fish removal, adult monitoring, and small-bodied monitoring studies were evaluated. These studies were also reviewed as part of the habitat association analysis discussed below.

DATA ANALYSIS

All available habitats were mapped in the complex study reaches (DR 82, DR131, and DR 137) and categorized by habitat unit type. For each habitat type, the total area mapped, sample frequency, and total area sampled were calculated.

Habitat selection of fishes in the complex study reaches was analyzed by examining the proportional use of individual habitat types (number of fish collected divided by total number of fish caught) in relation to their proportional availability (amount of that habitat sampled divided by the total amount of habitat sampled). Habitat selection analyses were conducted for Colorado pikeminnow, as well as for the entire fish assemblage, the native fish assemblage, the non-native fish assemblage, and other individual fish species of interest (i.e., bluehead sucker- *Catostomus discobolus*, flannelmouth sucker- *Catostomus latipinnis*, speckled dace-

Rhinichthys osculus, channel catfish- *Ictalurus punctatus*, fathead minnow- *Pimephales promelas*, and red shiner- *Cyprinella lutrensis*). Analyses of Colorado pikeminnow habitat selection were conducted by individual reach and by combining the use and available habitat of all complex study reaches. Analyses of habitat selection for DR 82 were not conducted separately because of the small number of Colorado pikeminnow captured in this reach.

Two types of chi-square analysis were used to test the null hypothesis that fish are randomly selecting habitats in proportion to their availability. These tests of "no selection" included the Pearson chi-square statistic (χ^2_p), which is driven by differences between the observed and expected number of used resource units of each type and the Log-likelihood statistic (χ^2_l), which is based on the ratio of the observed and expected resource units used. Significant chi-square values ($p<0.05$) are indicative that selection occurs (Manly et al. 1993).

Selection of particular habitat unit types was determined by the proportional use and availability (given by the area of habitat sampled) of each habitat type. Resource selection ratios (w) were calculated for each habitat type by dividing the proportion of fish using the habitat type by the proportion of habitat sampled (Manly et al. 2002). The selection ratio statistic allowed for the determination of habitat selection. Selection ratios equal or close to one ($w=1$ or $w\approx1$) indicate no selection. Values much smaller than one ($w<1$) suggest selection against a particular habitat type and ratios greater than one ($w>1$) indicate selection. Selection becomes increasingly stronger as the statistic increases further from one. The Z-squared statistic was used to test the hypothesis that a particular selection ratio equals one. Statistical significance ($p<0.05$) of this test is based on p-values calculated using the chi-squared distribution minus one degree of freedom. All habitat selection analyses were conducted using the Stats-Alive RSTool program developed by Ken Gerow (2007) of the University of Wyoming.

In addition to analyses of habitat availability and use, basic fish information for the complex reaches sampled including fish captured; capture per unit of effort (CPUE), and endangered fish size information were also summarized. Colorado pikeminnow population estimates by reach were also calculated using the Lincoln-Petersen estimator as described in Young and Young (1998).

The potential relationship between Colorado pikeminnow fish capture and habitat associations was also explored. In 2008, the seine haul area of each sample was recorded in the field and digitized. Using digitized habitat and seine haul location datasets, buffer distances of from 5 to 20 m around each seine haul site were set and habitat types within that buffer identified, along with the habitats within the seine haul. Combinations of habitats (habitat associations) within each buffer zone were then examined in relation to the capture of Colorado pikeminnow. The average availability of each combination for sites with and without Colorado pikeminnow capture was determined and the ratios of availability for each category (with and without pikeminnow) computed. When ratios are greater than 1.0, preference is indicated. Significant differences between samples with and without Colorado pikeminnow were determined using a two-tailed t-test for non-equal variance. P-values of 0.05 and less are considered significant. P-values between 0.05 and 0.10 are considered marginally significant.

Further, the GPS location data for Colorado pikeminnow capture collected in 2008 in the non-native removal and large bodied monitoring programs provide the opportunity to examine capture location on a resolution greater than 1 mile for electrofishing data. While the accuracy of the GPS data and the nature of electrofishing do not allow specific habitat use data, it is possible to refine the analysis to 0.1 mile segments. An analysis similar to that described above for the detailed reach fish sampling locations was performed to examine the potential relationship between habitat complexity (number of habitats per tenth of river mile) and capture of Colorado pikeminnow by electrofishing during the non-native removal program. The abundance of individual habitats types and habitat classes were also examined. GPS locations and dates of pikeminnow captures were obtained from the non-native removal program (Davis, Pers. Com. 2008) and the large-bodied monitoring program (Ryden, Pers. Com. 2008). The locations were tabulated to the nearest 1/10 mile. Habitat abundance and complexity for each 1/10 mile from the 2007 river-wide habitat survey (latest survey for which data were available) was computed by using a 220 m buffer around each 1/10 river mile mark in the SJRIP GIS. This buffer allows for possible GPS location error and fish movement that might be outside the 1/10 mile range. The abundance of individual habitats and habitat complexity of the 1/10 river mile segments for which Colorado pikeminnow were captured was compared to those for which there were no captures using a two-tailed student t-test for non-equal variance to test the hypothesis that the mean habitat complexity for the two cases are different. The analysis range was RM 70.2 to RM 166.6 for the non-native removal data and RM 3.2 to RM 181 for the adult monitoring data.

Habitat association data from the larval fish study (Brandenburg, Pers. Com. 2008) was used to assess habitat use of larval razorback sucker. The distribution of larval razorback sucker captures was compared to the distribution of backwater and low velocity habitat sampled.

RESULTS

Habitat Utilization

Fish sampling efforts in August 2007 and March and August of 2008 resulted in the capture of 169 young Colorado pikeminnow from a variety of habitats (Table 4.1). A total of 24, 89, and 56 Colorado pikeminnow where captured along all reaches sampled in August 2007, March 2008, and August 2008, respectively. Colorado pikeminnow captured ranged in size from 39 mm to 269 mm total length (TL; Figure 4.1). Most of the pikeminnow captured in March had total lengths of 100 mm or less (TL<100 mm) whereas pikeminnow captured in August sampling events were between 100 mm to 200 mm TL. Given that only 11 of the pikeminnow captured had total lengths greater than 200 mm, all fish with total lengths greater than 100 mm were pooled for the purposes of habitat selection analyses by fish size.

In total, 3,649 fish (natives and non-natives) were collected from multiple habitats during the three sampling events conducted during 2007 and 2008 (Table 4.2). Most of the fish were collected in slackwater, run, and shoal habitat types (Table 4.2). In addition to Colorado pikeminnow, other native fishes captured along the reaches sampled included bluehead sucker, flannelmouth sucker, and speckled dace. No razorback suckers were captured. Non-natives included channel catfish, red shiner, and fathead minnow.

Capture Per Unit of Effort

Of the total 699 habitat units sampled across all reaches and sampling events, habitat types sampled more frequently included slackwater (241 seine-hauls), shore-run (142 seine-hauls), riffle (87 seine-hauls), sand shoal (75 seine-hauls), and cobble shoal (69 seine-hauls; (Table 4.3). The frequency in which these habitat types were sampled reflects their dominance of the overall habitat observed across all reaches. A total of 22, 12, 6, and 30 seine-hauls were completed in rarer backwater, eddy, embayment, and pool habitat, respectively.

Table 4.1. Summary of habitat use by Colorado Pikeminnow in DR 82, RM 131, and DR 137 (total pikeminnow captured)

DATE	August_07			March_08				August_08				
REACH	**82**	**137**	**82 & 137 Combined**	**82**	**131**	**137**	**82-131-137 Combined**	**82**	**131**	**137**	**82-131-137 Combined**	**Grand Total**
Backwater				3		8	11			2	2	13
Cobble Shoal	2	6	8					1	3	5	9	17
Eddy		3	3									3
Embayment						12	12					12
Pool					12	9	21	1		2	3	24
Riffle				1	1		2	1	13	7	21	23
Sand Shoal		3	3	3	3		6	1	1	2	4	13
Shore Run	1	1	2	8	5	14	27	1	2		3	32
Slackwater	2	6	8	4	1	5	10	2	5	7	14	32
Grand Total	5	19	**24**	19	22	48	**89**	7	24	25	**56 169**	

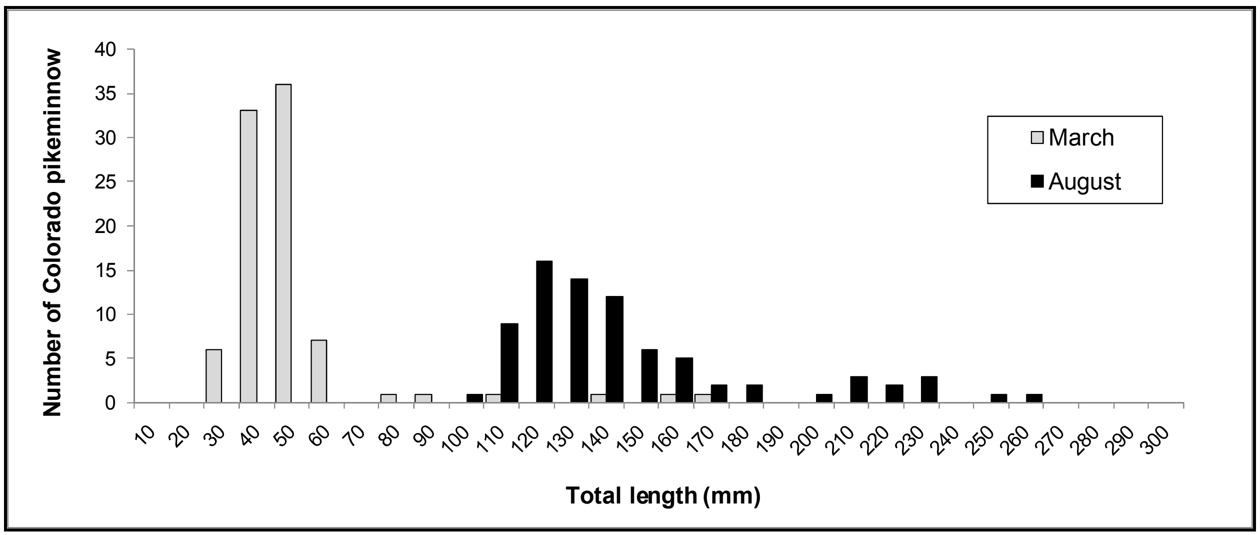

Figure 4.1. Length-frequency distribution of Colorado pikeminnow captured in DR 137, DR 131 and DR 82 of the San Juan River during detailed fish surveys conducted in the March 2008, and August 2007 and August 2008

Table 4.2. Summary of overall fish habitat use in DR 82, DR131, DR 137 (total fish captured)

DATE	August_07			March_08				August_08				Grand Total
REACH	82	137	82 & 137 Combined	82	131	137	82-131-137 Combined	82	131	137	82-131-137 Combined	
Backwater	83		83	5	0	11	16	37	53	59	149	248
Cobble Shoal	48	12	60	0	7	26	33	65	9	16	90	183
Eddy	2	24	26			0	0	8		2	10	36
Embayment						19	19		6	1	7	26
Isolated Pool	26		26			99	99	12		2	14	139
Plunge	9	2	11							2	2	13
Pool	151		151		15	16	31	149		46	195	377
Riffle	18	6	24	7	9	7	23	27	40	36	103	150
Sand Shoal	128	13	141	9	240	14	263	49	13	7	69	473
Shore Run	57	15	72	24	9	39	72	240	13	18	271	415
Slackwater	378	130	508	33	622	32	687	336	20	38	394	1,589
Total	900	202	**1,102**	78	902	263	**1,243**	923	154	227	**1,304 3,649**	

Table 4.3. Sample frequency (number of seine hauls by habitat) during August 2007, March 2008, and August (2008) surveys in DR 82, DR131, and DR 137 in the San Juan River.

DATE	August_07			March_08				August_08				Grand Total
REACH	82	137	82 & 137 Combined	82	131	137	82-131-137 Combined	82	131	137	82-131-137 Combined	
Backwater	3		3	5	1	1	7	4	3	5	12	22
Cobble Shoal	12	9	21	1	3	10	14	12	11	11	34	69
Eddy	1	6	7			1	1	2	1	1	4	12
Embayment						2	2		3	1	4	6
Isolated Pool	1		1			2	2	5		2	7	10
Mid-Channel Run		1	1									1
Plunge	1	2	3							1	1	4
Pool	9		9		4	4	8	7		6	13	30
Riffle	5	8	13	9	5	11	25	14	19	16	49	87
Sand Shoal	10	7	17	9	16	11	36	15	4	3	22	75
Shore Run	15	12	27	27	18	24	69	16	16	14	46	142
Slackwater	49	43	92	32	16	26	74	21	27	27	75	241
Total	106	88	**194**	83	63	92	**238**	96	84	87	**267 699**	

Across all reaches, a total of 1,102, 1,243, and 1,304 fishes were captured in August 2007, March 2008, and August 2008, respectively (Table 4.4). In August 2007, the total catch included 788 non-native and 314 native fishes, of which 24 were Colorado pikeminnow. The largest numbers of native fishes (1098 fishes including 89 Colorado pikeminnow) were captured in March 2007. In August 2008, 701 native fishes (including 59 Colorado pikeminnow) and 603 non-native fishes were captured.

Colorado pikeminnow CPUE values for March 2008 ranged from 0.0054 fish/m^2 in DR 82 to 0.0113 fish/m^2 in DR 137 (Table 4.4; Figure 4.2). Lower Colorado pikeminnow CPUE were observed for August sampling events. Pikeminnow CPUE for August 2007 ranged from 0.0004 fish/m^2 in DR 82 to 0.0016 fish/m^2 in DR 137. Pikeminnow CPUE was slightly higher in August 2008 ranging from 0.0009 fish/m^2 in DR 82 to 0.003 fish/m^2 in DR131. Overall, Colorado pikeminnow CPUE was substantially larger in March 2008 than in August of both years and also appeared to be higher in upper reaches (DR131 and DR 137) than in the lower-most reach (DR 82; Figure 4.2).

The overall CPUE for the entire fish assemblage was also higher in March 2008 (0.1165 fish/ m^2) than in both August sampling events (0.0470 fish/m^2 and 0.0526 fish/m^2 in 2007 and 2008, respectively) (Table 4.4; Figure 4.3). This difference in CPUE was mainly driven by the large native fish CPUE in DR131 during March 2007 (0.3093 fish/m^2).

Among the native fishes captured, speckled dace was the dominant species with a CPUE ranging from 0.0060 fish/m^2 in DR 82 to 0.258 fish/m^2 in DR131 during March 2008 (Table 4.4, Figure 4.4). CPUE for bluehead sucker was typically larger in March than in August. Conversely, larger CPUE for flannelmouth sucker were observed during August sampling events (Figure 4.4). On the other hand, fathead minnow dominated the overall non-native fish captures in March 2007 (0.0112 fish/m^2), while channel catfish dominated the overall catch in August sampling events (0.0225 fish/m^2 in 2007 and 0.0212 fish/m_2 in 2008; Table 4.4, Figure 4.5).

Colorado Pikeminnow Population Estimate

Lincoln-Petersen mark-recapture population estimates were calculated for Colorado pikeminnow in reaches where at least 10 percent of the total fish captured during the second pass were fish marked during pass 1. Estimates were calculated for August 2007 - RM 137, March 2008 - DR131, and August 2008 - RM 131 and 137. Estimates ranged from 52 fish/reach (95%CI: 13 to 92 fish/reach) in August 2008 – RM 131 to 59 fish/reach (95% CI: 13 to 105 fish/reach) in August 2008 - DR 137 (Table 4.5). A population of 53 fish/reach was estimated for August 2007 - DR 137 and March 2008 -DR131.

Habitat Selection Analysis

Analysis of habitat selection suggested that young Colorado pikeminnow do select for particular habitat types. Analyses of habitat selection were conducted for each year, sampling event (March, August), and reach, as well as for both August sampling events combined (Table 4.6). Sample sizes of Colorado pikeminnow in DR 82 were typically too small during August sampling events to assess habitat selection.

Table 4.4. CPUE Summary

Sampling Trip/Year	August_2007					March_2008					August_2008				
Species	**Area Sampled (m^2)**	**Number of seine hauls**	**Number of fish captured**	**CPUE (fish/ m^2)**	**CPUE (fish/seine)**	**Area Sampled (m^2)**	**Number of seine hauls**	**Number of fish captured**	**CPUE (fish/ m^2)**	**CPUE (fish/seine)**	**Area Sampled (m^2)**	**Number of seine hauls**	**Number of fish captured**	**CPUE (fish/ m^2)**	**CPUE (fish/seine)**
DR 82															
All Fish Assemblage			900	0.0774	8.4906			78	0.0222	0.9398			923	0.1184	9.6146
All Native Fish			185	0.0159	1.7453			56	0.0159	0.6747			405	0.0519	4.2188
All Non-Native Fish			715	0.0615	6.7453			22	0.0063	0.2651			518	0.0664	5.3958
Pikeminnow			**5**	**0.0004**	**0.0472**			**19**	**0.0054**	**0.2289**			**7**	**0.0009**	**0.0729**
Flannelmouth sucker	11624	106	93	0.0080	0.8774	3514	83	9	0.0026	0.1084	7798	96	63	0.0081	0.6563
Bluehead sucker			8	0.0007	0.0755			7	0.0020	0.0843			5	0.0006	0.0521
Speckled dace			79	0.0068	0.7453			21	0.0060	0.2530			330	0.0423	3.4375
Channel catfish			474	0.0408	4.4717			3	0.0009	0.0361			496	0.0636	5.1667
Red Shiner			111	0.0095	1.0472			10	0.0028	0.1205			18	0.0023	0.1875
Fathead minnow			126	0.0108	1.1887			8	0.0023	0.0964			0	0.0000	0.0000
RM 131															
All Fish Assemblage			NS	NA	NA			902	0.3107	14.3175			154	0.0193	1.8333
All Native Fish			NS	NA	NA			898	0.3093	14.2540			120	0.0151	1.4286
All Non-Native Fish			NS	NA	NA			4	0.0014	0.0635			34	0.0043	0.4048
Pikeminnow			**NS**	**NA**	**NA 22**				**0.0076**	**0.3492 24**				**0.0030**	**0.2857**
Flannelmouth sucker	NS	NS	NS	NA	NA	2904	63	1	0.0003	0.0159	7970	84	8	0.0010	0.0952
Bluehead sucker			NS	NA	NA			126	0.0434	2.0000			0	0.0000	0.0000
Speckled dace			NS	NA	NA			749	0.2580	11.8889			88	0.0110	1.0476
Channel catfish			NS	NA	NA			0	0.0000	0.0000			25	0.0031	0.2976
Red Shiner			NS	NA	NA			0	0.0000	0.0000			7	0.0009	0.0833
Fathead minnow			NS	NA	NA			4	0.0014	0.0635			1	0.0001	0.0119

Table 4.4. CPUE Summary (continued)

Sampling Trip/Year	August_2007					March_2008					August_2008				
Species	Area Sampled (m^2)	Number of seine hauls	Number of fish captured	CPUE (fish/m^2)	CPUE (fish/seine)	Area Sampled (m^2)	Number of seine hauls	Number of fish captured	CPUE (fish/m^2)	CPUE (fish/seine)	Area Sampled (m^2)	Number of seine hauls	Number of fish captured	CPUE (fish/m^2)	CPUE (fish/seine)
RM 137															
All Fish Assemblage			202	0.0171	2.2955			263	0.0619	2.8587			227	0.0251	2.6092
All Native Fish			129	0.0109	1.4659			144	0.0339	1.5652			176	0.0195	2.0230
All Non-Native Fish			73	0.0062	0.8295			119	0.0280	1.2935			51	0.0056	0.5862
Pikeminnow			**19**	**0.0016**	**0.2159**			**48**	**0.0113**	**0.5217**			**25**	**0.0028**	**0.2874**
Flannelmouth sucker	11809	88	22	0.0019	0.2500	4252	92	5	0.0012	0.0543	9041	87	35	0.0039	0.4023
Bluehead sucker			8	0.0007	0.0909			8	0.0019	0.0870			11	0.0012	0.1264
Speckled dace			80	0.0068	0.9091			83	0.0195	0.9022			105	0.0116	1.2069
Channel catfish			53	0.0045	0.6023			0	0.0000	0.0000			5	0.0006	0.0575
Red Shiner			15	0.0013	0.1705			11	0.0026	0.1196			33	0.0037	0.3793
Fathead minnow			3	0.0003	0.0341			108	0.0254	1.1739			3	0.0003	0.0345
Combined															
All Fish Assemblage			1102	0.0470	5.6804			1243	0.1165	5.2227			1304	0.0526	4.8839
All Native Fish			314	0.0134	1.6186			1098	0.1029	4.6134			701	0.0283	2.6255
All Non-Native Fish			788	0.0336	4.0619			145	0.0136	0.6092			603	0.0243	2.2584
Pikeminnow			**24**	**0.0010**	**0.1237**			**89**	**0.0083**	**0.3739**			**56**	**0.0023**	**0.2097**
Flannelmouth sucker	23433	194	115	0.0049	0.5928	10670	238	15	0.0014	0.0630	24808	267	106	0.0043	0.3970
Bluehead sucker			16	0.0007	0.0825			141	0.0132	0.5924			16	0.0006	0.0599
Speckled dace			159	0.0068	0.8196			853	0.0799	3.5840			523	0.0211	1.9588
Channel catfish			527	0.0225	2.7165			3	0.0003	0.0126			526	0.0212	1.9700
Red Shiner			126	0.0054	0.6495			21	0.0020	0.0882			58	0.0023	0.2172
Fathead minnow			129	0.0055	0.6649			120	0.0112	0.5042			4	0.0002	0.0150

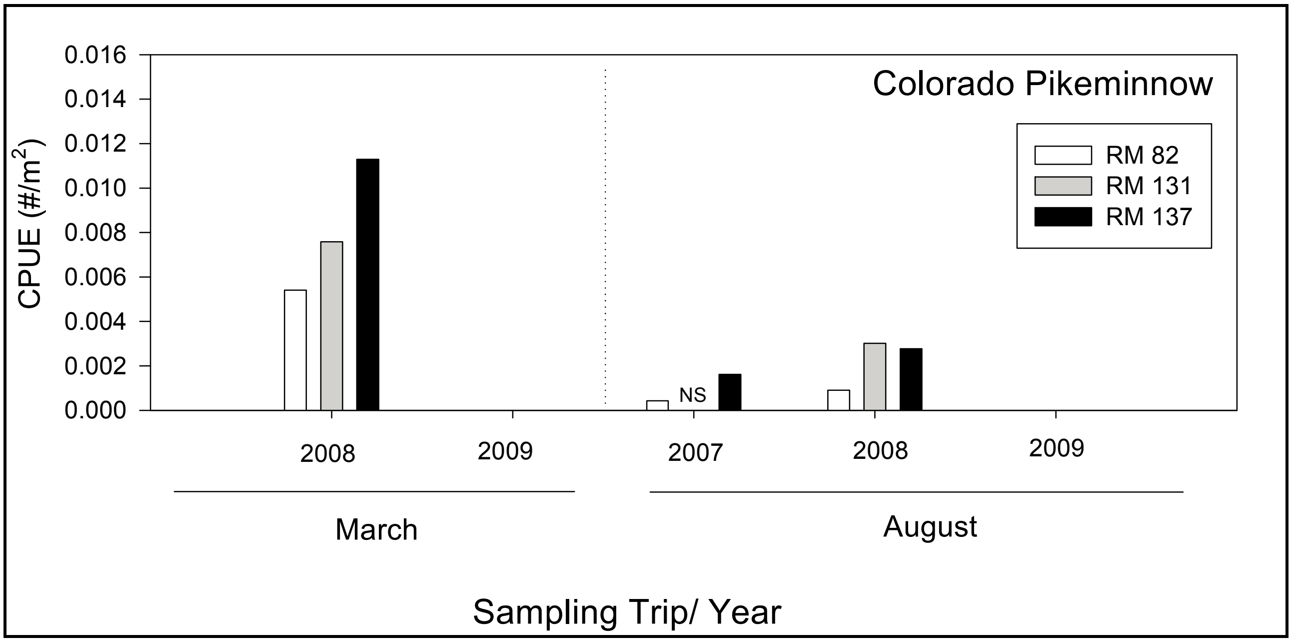

Figure 4.2. Colorado pikeminnow CPUE during surveys conducted in DR 82, DR131, and DR 137 during March and August of 2007 and 2008. NS indicates reach not sampled. 2009 data are not yet available.

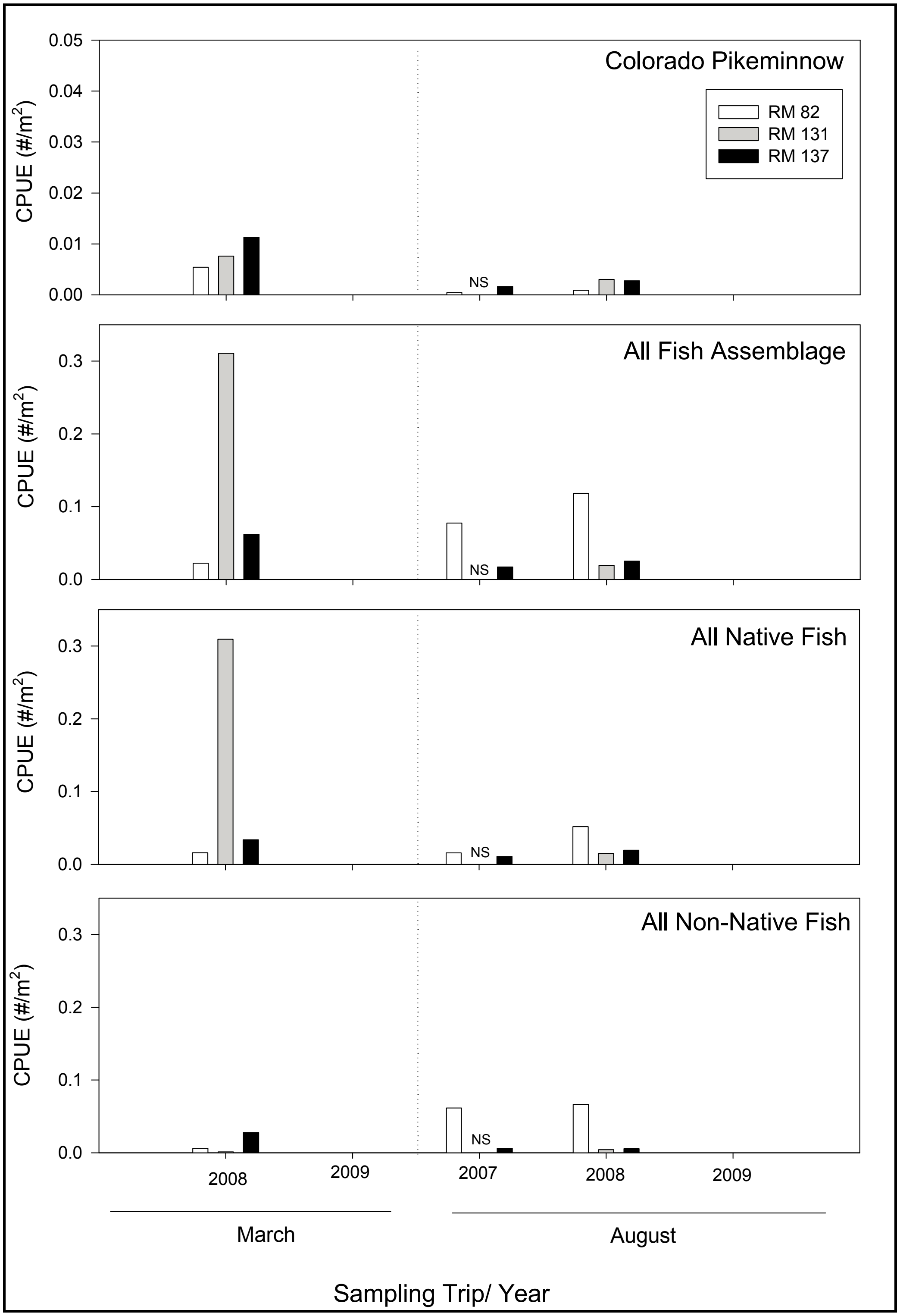

Figure 4.3. CPUE for Colorado pikeminnow, all fishes , all native fishes, and all non-native fishes during surveys conducted in DR 82, DR131, and DR 137 during March and August of 2007 and 2008. NS indicates reach not sampled. 2009 data are not yet available.

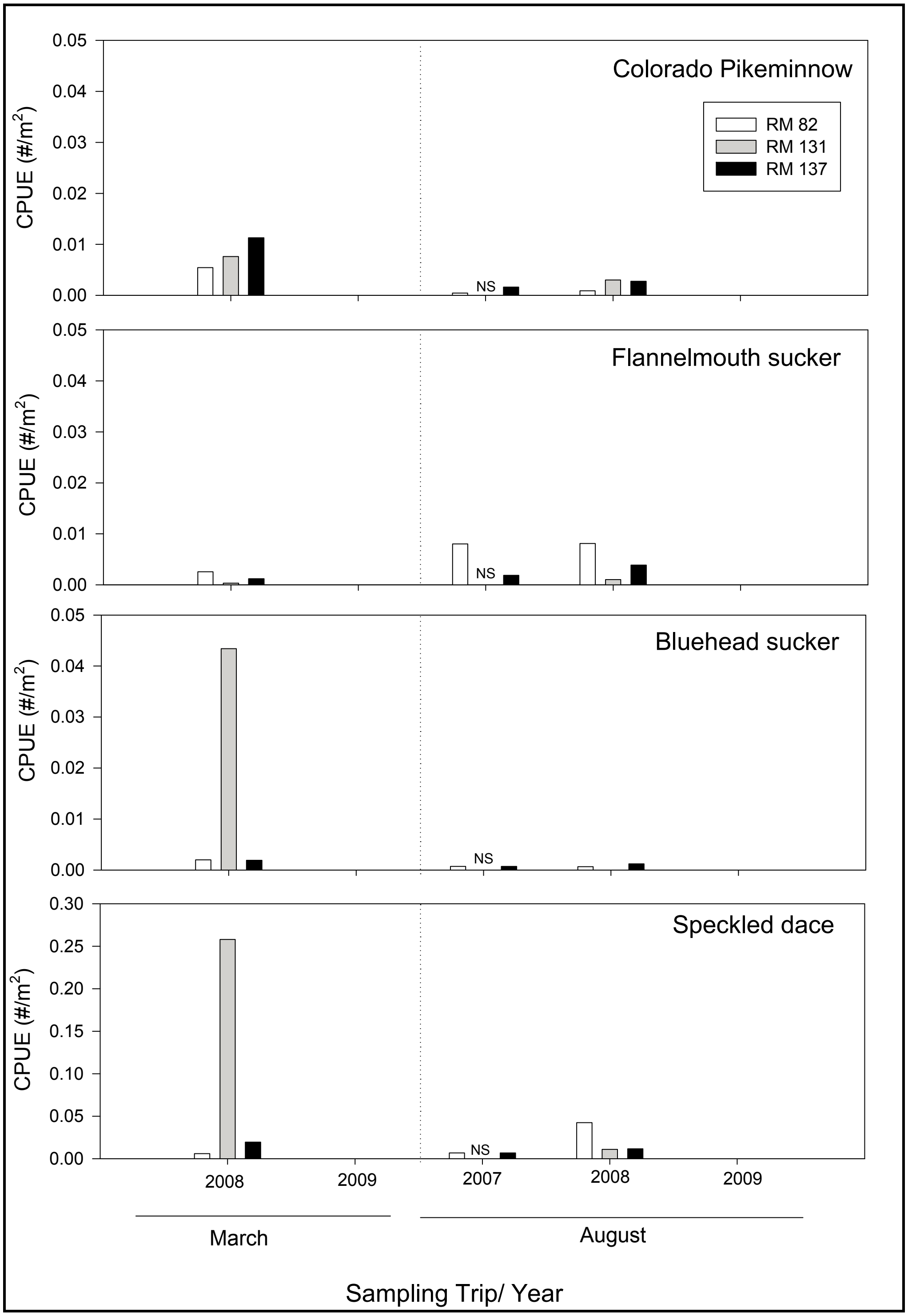

Figure 4.4. CPUE for Colorado pikeminnow, flannelmouth sucker, bluehead sucker, and speckled dace during surveys conducted in DR 82, DR131, and DR 137 during March and August of 2007 and 2008. NS indicates reach not sampled. 2009 data are not yet available.

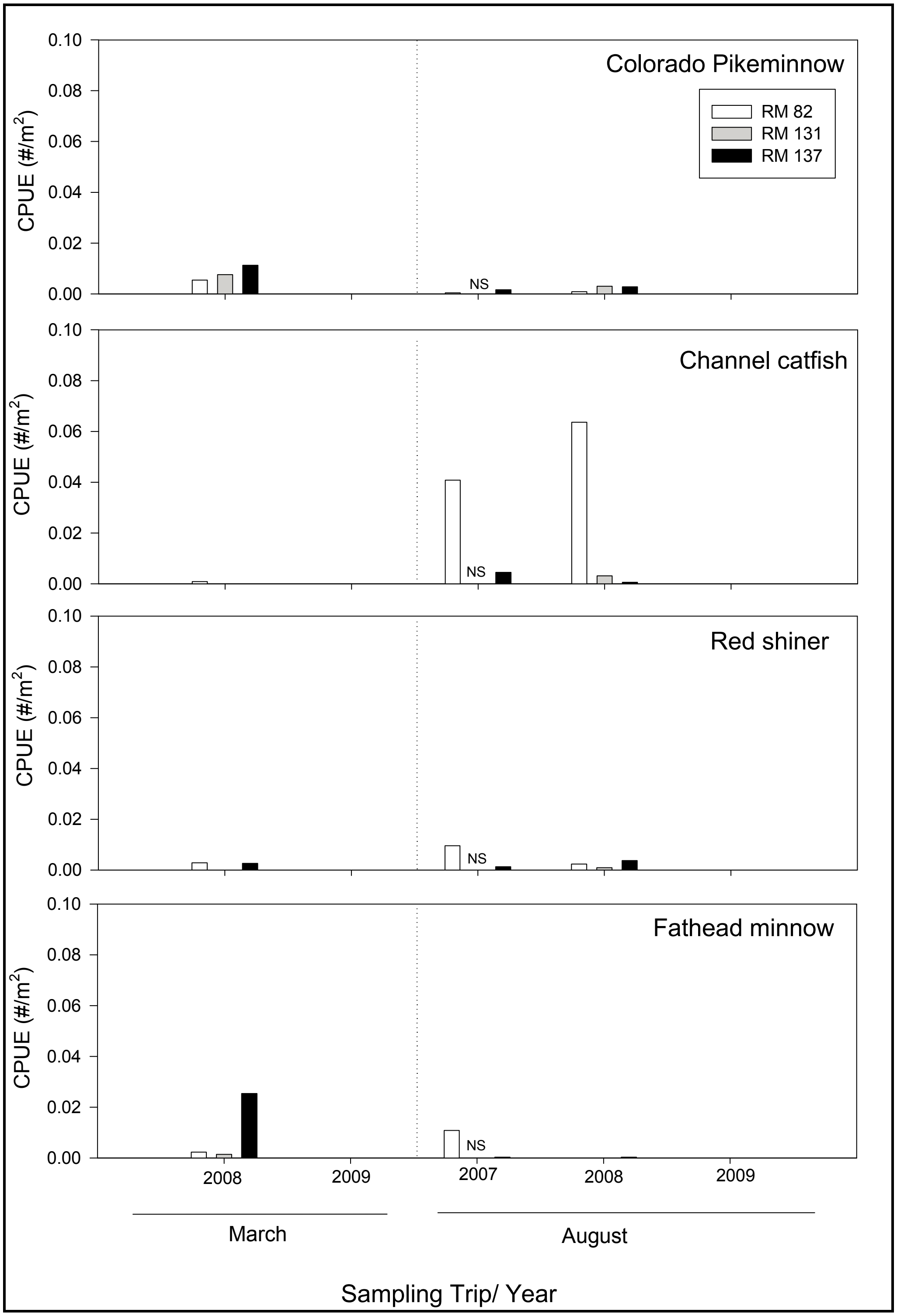

Figure 4.5. CPUE for Colorado pikeminnow, channel catfish, red shiner, and fathead minnow during surveys conducted in DR 82, DR131, and DR 137 during March and August of 2007 and 2008. NS indicates reach not sampled. 2009 data is not yet available.

Table 4.5. Summary of population estimates for Colorado pikeminnow based on mark-recapture data collected during detailed reach fish surveys conducted in August 2007, March 2008, and August 2008 in DR 82, DR131, and DR 137 of the San Juan River

DETAILED REACH	DR 82	DR131	DR 137
AUGUST_2007			
Marked Pass 1 (M)	2	NA	11
Recaptured Pass 2 (C)	0	NA	1
Total Captured Pass 2 (R)	3	NA	8
Population Estimate (N)	NA	NA	53
Variance			630
Standard Deviation			25
95 % CI			4-102
MARCH_2008			
Marked Pass 1 (M)	8	17	43
Recaptured Pass 2 (C)	1	1	0
Total Captured Pass 2 (R)	11	5	5
Population Estimate (N)	NA	53	NA
Variance		576	
Standard Deviation		24	
95 % CI		6-100	
AUGUST_2008			
Marked Pass 1 (M)	3	9	14
Recaptured Pass 2 (C)	0	2	2
Total Captured Pass 2 (R)	4	15	11
Population Estimate (N)	NA	52	59
Variance		404	540
Standard Deviation		20	23
95 % CI		13-92	13-105

Population estimates for reaches where recaptures accounted for at least 10 percent of the total catch in the second sample were calculated using the Lincoln-Petersen method.
NA: Not enough fish were marked and/or recaptured to estimate population size.

Table 4.6. Summary of Colorado Pikeminnow Habitat Selection by Year, Month, and Reach*

Year	Month	Reach	n	Pearson Chi^2	p-value	Log-likelihood Chi^2	p- value
2007	August	82	5	NA	NA	NA	NA
		137	19	15.20	0.02	14.57	0.02
		Combined	24	19.09	0.02	16.59	0.055
2008	March	82	19	6.45	0.26	5.76	0.33
		131	22	106.13	0.00	44.64	0.00
		137	48	172.18	0.00	103.18	0.00
		Combined	89	296.7	0.00	141.72	0.00
2008	August	82	7	NA	NA	NA	NA
		131	24	16.14	0.02	15.21	0.03
		137	25	13.27	0.21	16.97	0.07
		Combined	56	23	0.01	24.8	0.00
2007-2008	August	Combined	80	28.17	0.00	28.77	0.00

*Significant ($p<0.05$) Chi^2 values suggest selection for particular habitat types occur. Non-significant values indicate no selection.
NA: Selection analysis not conducted due to small sample size (n).

Colorado pikeminnow captures along all reaches in March 2008 suggested selection for embayment (w= 11.7, p<0.05), pool (w=7.97, p<0.05), and backwater (w=3.99, p<0.05) habitats while showing selection against riffle (w=0.18, p<0.05), sand shoal (w=0.43, p<0.05), and slackwater (w=0.4, p<0.05) habitats (Table 4.7). Captures of Colorado pikeminnow in August (all reaches, both years combined) suggested selection for riffle habitat (w=2, p<0.05) and selection against run (w=0.3, p<0.05) and slackwater (w=0.7, p<0.05) habitats (Table 4.8). The selection for cobble shoal in August was only marginally significant (w=1.53, p< 0.058).

Given that Colorado pikeminnow captures in March were predominantly less than 100 mm TL but also contained larger pikeminnow, and that captures of this species in August were predominantly greater than 100 mm TL but also included smaller fish, an assessment of habitat selection by Colorado pikeminnow was also conducted by fish size using the same data. This assessment provided evidence of habitat selection by Colorado pikeminnow of less than 100 mm TL (n= 85, χ^2_p= 453, p=0.00; χ^2_l= 189; p=0.00; Table 4.9) and Colorado pikeminnow greater than 100 mm TL (n=81, χ^2_p= 24.3, *p*=0.00; χ^2_l= 24.4; p=0.00). As expected and consistent with the analysis by sampling event (i.e., March versus August), while the smaller fish appeared to select for embayments (w=15.5, p<0.05), pools (w=10.6, p<0.05), and backwaters (w=8.06, p<0.05), selection against was evident for cobble shoal (w=0.09, p<0.05), riffle (w=0.18, p<0.05) and slackwater habitats (w=0.25, p<0.05; Table 4.9). Larger fish appeared to select for riffles (w=1.90, p<0.05) and cobble shoals (w=1.59, p<0.05) while selecting against run habitat (w=0.42, p<0.05). In addition, this assessment was also conducted by adjusting the Colorado pikeminnow sample size so that only one individual from each sample was accounted regardless of the total number of pikeminnow captured in the seine haul. In general, this assessment of selection with fish with total length less than 100 mm was consistent with results that included all pikeminnow captured (Table 4.9); riffle habitat was not selected against under this scenario. However, when the sample size for larger fish (TL>100mm) was adjusted there was no evidence of selection (n= 67, χ^2_p= 14.8, p=0.13; χ^2_l= 15.3; p=0.12; Table 4.9).

Table 4.7. Summary of habitat selection ratios for Colorado pikeminnow captured in March 2008

Month/Year	March_08	March_08	March_08
Reach	**131**	**137**	**82-131- 137**
HABITAT	**RATIO (n=22)**	**RATIO (n=48)**	**RATIO (n=89)**
Backwater		6.95	3.99
Cobble Shoal		0	0
Eddy	NS		
Embayment	NS	8.64	11.7
Isolated Pool	NS		
Run			
Pool	10.15	4.99	7.97
Riffle		0	0.18
Sand Shoal		0	0.43
Slackwater	0.2	0.41	0.4

Only significant selection ratios (p<0.05) are shown.
Ratio value greater than one indicate selection for, ratios below one indicate selection against, and ratios equal to one indicate no selection.
NS= Habitat not sampled

Table 4.8. Summary of habitat selection ratios for Colorado pikeminnow captured in August 2007 and 2008

Month/Year	August_07	August_08	August_07 & 08
Reach	**82 & 137**	**82-131- 137**	**82-131- 137**
HABITAT	**RATIO (n=24)**	**RATIO (n=56)**	**RATIO (n=80)**
Backwater			
Cobble Shoal	2.4		1.53 m
Eddy	4.3		
Embayment	NS		
Isolated Pool			
Run		0.3	0.3
Plunge			
Pool			
Riffle		2.1	2.0
Sand Shoal			
Slackwater			0.7

Only significant selection ratios (p<0.05) are shown.
Ratio value greater than one indicate selection for, ratios below one indicate selection against, and ratios equal to one indicate no selection.
NS= Habitat not sampled

Table 4.9. Summary of habitat selection ratios for Colorado pikeminnow by size

COLORADO PIKEMINNOW	INCLUDING ALL CAPTURES*		ADJUSTING SAMPLE SIZE**	
TOTAL LENGTH	TL <100 mm	TL> 100 mm	TL <100 mm	TL> 100 mm
HABITAT	Ratio (n=85)	Ratio (n=81)	Ratio (n=29)	Ratio (n=67)
Backwater	8.06		6.44	
Cobble Shoal	0.09	1.59	0.00	
Eddy				
Embayment	15.5		7.57	
Isolated Pool				
Plunge				
Pool	10.6		5.94	
Riffle	0.18	1.9		
Sand Shoal				
Run		0.42		
Slackwater	0.25		0.46	
Pearson Chi^2 ***	453 (p=0.00)	24.3 (p=0.00)	52.3 (p=0.00)	14.8 (p=0.13)
Log-likelihood Chi^2 ***	189 (p=0.00)	24.4 (p=0.00)	33.9 (p=0.00)	15.3(p=0.12)

* Analysis of selection conducted with all Colorado pikeminnow captured.
** Analysis of selection accounting for a single Colorado pikeminnow in samples that contained more than one individual of this species.
**Significant (p<0.05) Chi^2 values suggest selection for particular habitat types occur.
Only significant selection ratios (p<0.05) are shown.
Ratios greater than one indicate selection for, ratios below one indicate selection against, and ratios equal to one indicate no selection.

The assessment of habitat selection also provided evidence of selection for particular habitat types by the entire fish assemblage, all native fishes, all non-native fishes, and most single native and non-native fish species (Table 4.10, Table 4.11). Based on March surveys across all reaches (DR 82, DR131, and DR 137 combined), the selection for embayment habitat by Colorado pikeminnow was also shared by the non-native fish assemblage (w=2.99, p<0.05), flannelmouth sucker (w=11.57, p<0.05), and fathead minnow (w=3.61, p<0.05; Table 4.10). Red shiner selection for backwater (w=4.61, p<0.05) and pool (w=8.04, p<0.05) habitat also appeared to overlap with the selection for these habitats by Colorado pikeminnow. On the other hand, while Colorado pikeminnow captured during August surveys appeared to select for riffle habitat, no other fish species selected for this habitat type (Table 4.11). Results of habitat selection analysis by individual years, sampling events, and reaches are provided in Appendix A1.

Habitat Availability

A total of 171,989 m^2 , 640,644 m^2 , and 490,940 m^2 of aquatic habitat was mapped within the complex study reaches in August 2007, March 2008, and August 2008, respectively (Table 4.12). Of the total area mapped, the dominant habitat type observed across all reaches was mid-channel run (65%) followed by riffle (17%), shore run (7%), and slackwater (5 %). Low water velocity habitats such as backwater (0.2%), eddy (0.25), and pool (0.3%) accounted for only a small fraction of the total mapped area.

The proportion sampled of the total area mapped along all reaches during August 2007, March 2008, and August 2008, was 14 %, 2%, and 5 %, respectively (Table 4.13). Roughly, 30 to 40 percent of mapped backwater (38%), eddy (35%), pool (34%), and slackwater (33%) habitat were sampled. A considerable area of mapped cobble shoal (23%), embayment (28%), isolated pool (26%), sand shoal (17%), and shore-run (13%) habitat was also sampled. Habitats not sampled or sampled in lower proportions (e.g., riffle - 3%, mid-channel run - 0.1%) were typically too swift, too deep, or presented debris that precluded effective seining. Percentages greater than 100 (e.g., plunge- 374%) are the result of replicate sampling within rare habitats types and/or due to the total actual area sampled (i.e., seine haul area) being larger than the mapped area.

In terms of proportional habitat availability that was used for the habitat selection analysis, the percentages allocated to each habitat type were based on the actual habitat sampled and not the area mapped. On this basis, slackwater (37%) accounted for the largest proportion of habitat sampled followed by run (21%), riffle (13%), cobble shoal (12%), and sand shoal (9%; Table 4.14). Backwater (1.6%), eddy (1.6%), embayment (0.9%), isolated pool (0.7%), pool (2.3%), accounted for less than 8 percent of the total area sampled across all reaches and sampling events.

Other SJRIP Studies

Other SJRIP studies were reviewed for use in determining habitat selection. The general criteria to determine if the data could be used to assess habitat selection was that fish sampling locations and habitats needed to be known and most, or all habitats were represented in the sampling. In 2007, the larval fish studies collected 54 age-1 pikeminnow (TL <100 mm) primarily in April, May, and June and primarily from backwaters and other low velocity habitats. Three pikeminnow over 100 mm were collected, one each in a backwater, embayment, and pool habitat. In 2008, no fish with total length less than 100 mm were captured and three larger pikeminnow (TL> 100 mm) were collected in DR 137 in pool and embayment habitat. This study primarily targets low velocity habitats to sample larval fishes so not all habitats were sampled. Therefore, these data could not be used for habitat selection but will be discussed later. Similarly, given that electrofishing techniques are used for the capture of the rare fish during non-native removal and adult monitoring studies, the exact location and specific type of habitat are not known. Data from these studies did not meet the general criteria and could not be used for habitat selection analyses. However, since the non-native removal studies collected GPS locations when Colorado pikeminnow were netted, habitat association in the localized area of capture was analyzed and will be discussed in a later section.

Table 4.10. Summary of habitat selection ratios: March 2008 - DR 82, 131, and 137 (combined)

SPECIES/ FISH GROUP *	PM	ALL FISH	ALL NATIVE	ALL NON-NATIVE	BHS	FLM	SPD	RS	FHM	CAT
HABITAT	RATIO (n=89)	RATIO (n=1243)	RATIO (n=1098)	RATIO (n=145)	RATIO (n=141)	RATIO (n=15)	RATIO (n=853)	RATIO (n=21)	RATIO (n=120)	RATIO (n=3)
BACKWATER	3.99	0.42	0.32		0.00		0.00	4.61		
COBBLE SHOAL	0.00	0.48	0.48		0.12		0.60			
EDDY										
EMBAYMENT	11.70			2.99		11.57	0.00		3.61	
ISOLATED POOL		11.66	0.00	99.93			0.00		120.75	
RUN		0.19	0.17	0.34	0.20		0.07		0.19	
POOL	7.97						0.12	8.04		
RIFFLE	0.18	0.15	0.17	0.00	0.00		0.18		0.00	
SAND SHOAL	0.43	1.35	1.52	0.04	0.13		1.89		0.00	
SLACKWATER	0.40	1.97	2.19	0.25	3.23	1.90	2.22		0.09	
Pearson Chi^2 **	296.7 (p=0.00)	1707 (p=0.00)	851.3 (p=0.00)	9786 (p=0.00)	293.8 (p=0.00)	27.45 (p=0.00)	829.2 (p=0.00)	45.13 (p=0.00)	11856 (p=0.00)	NA
Log-likelihood Chi^2 **	141.7 (p=0.00)	1171 (p=0.00)	923 (p=0.00)	855 (p=0.00)	272.35 (p=0.00)	17.87 (0.04)	967.2 (p=0.00)	27.31 (p=0.00)	915 (p=0.00)	NA

* PM: Colorado pikeminnow; BHS: Bluehead sucker; FML: Flannelmouth sucker; SPD: Speckled dace; RS: Red shiner; FHM: Fathead minnow; CAT: Channel catfish.

** Significant ($p<0.05$) Chi^2 values suggest selection for particular habitat types occur.

Only significant selection ratios ($p<0.05$) are shown.

Ratios greater than one indicate selection for, ratios below one indicate selection against, and ratios equal to one indicate no selection.

Table 4.11. Summary of habitat selection ratios: August 2007 and August 2008- DR 82, 131, and 137 (combined)

SPECIES/ FISH GROUP *	PM	ALL FISH	ALL NATIVE	ALL NON-NATIVE	BHS	FLM	SPD	RSH	FHM	CAT
HABITAT	RATIO (n=80)	RATIO (n=2406)	RATIO (n=1015)	RATIO (n=1391)	RATIO (n=32)	RATIO (n=221)	RATIO (n=682)	RATIO (n=184)	RATIO (n=133)	RATIO (n=1053)
Backwater		3.84	7.27	7.78			4.91	6.50	23.37	
Cobble Shoal	1.53 m	0.49	0.52	0.40			0.24	0.17	0.06	0.52
Eddy		2.38					2.34			2.88
Embayment		0.43		0.08						0.00
Isolated Pool				3.13		2.05 m	0.28		7.29	0.25
Run	0.34	0.74	0.87 m	0.70		0.02		0.11	0.00	0.86
Plunge						17.24				
Pool		3.20	4.92	7.81		1.71	2.48	8.23	4.52	3.00
Riffle	2.00	0.26	0.81	0.11		0.70	0.48	0.11	0.04	0.07
Sand Shoal		2.75	0.77	1.41		3.57		2.23		4.04
Slackwater	0.69	1.10	0.92				1.15		0.20	1.29
Pearson Chi^2 **	28.2 (p=0.00)	1667.9 (p=0.00)	901 (p=0.00)	2533.8 (p=0.00)	10 (p=0.44)	515.7 (p=0.00)	435.3 (p=0.00)	657.9 (0.00)	1924.7 (p=0.00)	787.8 (0.00)
Log-likelihood Chi^2 **	28.8 (p=0.00)	1315.8 (p=0.00)	444.5 (p=0.00)	1301 (0.00)	10 (p=0.44)	219 (p=0.00)	318.7 (p=0.00)	360.2 (p=0.00)	588.7 (p=0.00)	725 (p=0.00)

* PM: Colorado pikeminnow; BHS: Bluehead sucker; FML: Flannelmouth sucker; SPD: Speckled dace; RS: Red shiner; FHM: Fathead minnow; CAT: Channel catfish.

** Significant ($p<0.05$) Chi^2 values suggest selection for particular habitat types occur.

Only significant selection ratios ($p<0.05$) are shown.

Ratios greater than one indicate selection for, ratios below one indicate selection against, and ratios equal to one indicate no selection.

Table 4.12. Summary of area (m^2) mapped by habitat during August 2007, March 2008, and August (2008) surveys in DR 82, DR131, and DR 137 in the San Juan River

DATE	August_07			March_08				August_08				Grand Total*
REACH	**82**	**137**	**82 & 137 Combined ***	**82**	**131**	**137**	**82-131-137 Combined ***	**82**	**131**	**137**	**82-131-137 Combined ***	
Backwater	93	174	267 (.02%)	797	90	195	1,083(0.2%)	665	46	453	1,164 (0.2%)	2,514(0.2%)
Cobble Shoal	5,630	4,334	9,964 (5.8%)	276	2,137	2,422	4,835(0.8%)	5,231	5,229	6,731	17,191(3.5%)	32,008(2.5%)
Eddy	103	267	370(0.2%)	693	881	285	1,859(0.3%)	148	102	148	398(0.1%)	2,626(0.2%)
Embayment	60	159	219(0.1%)	0	44	1,306	1,350(0.2%)	0	335	0	335(0.1%)	1,904(0.1%)
Isolated Pool	72	63	135(0.1%)	0	0	84	84(0.01%)	719	38	606	1,364(0.3%)	1,583(0.1%)
Mid-Channel Run	51,790	48,550	100,339(58%)	179,132	126,218	119,646	424,996(66%)	129,496	83,191	103,224	315,911(64%)	841,245(65%)
Plunge		36	36 (0.08%)	0	0	0	0 (0%)	0	0	18	18(0.004%)	54(0.004%)
Pool	734		734 (0.4%)	0	772	349	1,121(0.2%)	1,075	34	1,036	2,145 (0.4%)	3,999(0.3%)
Riffle	14,009	14,849	28,857(16.8%)	33,173	32,768	58,105	124,047(19.4%)	25,728	17,418	30,171	73,316 (15%)	226,220(17.4%)
Sand Shoal	5,138	2,569	7,707(4.5%)	1,620	5,815	4,035	11,470(1.8%)	7,712	2,781	2,137	12,629(2.6%)	31,806(2.4%)
Shore Run	5,754	5,394	11,149(6.5%)	19,904	14,024	13,294	47,222(7.4%)	14,388	9,243	11,469	35,101(7.1%)	93,472(7.2%)
Slackwater	7,828	4,383	12,211(7.1%)	8,333	3,949	10,298	22,579(3.5%)	13,334	7,007	11,027	31,367 (6.4)	66,157(5.1%)
Total	91,210	80,779	**171,989**	243,926	186,698	210,019	**640,644**	198,496	125,423	167,021	**490,940**	**1,303,573**

* Number in parenthesis is the proportion of habitat mapped in relation to the total area (all reaches combined)

The small-bodied monitoring program conducted by New Mexico Game and Fish Department met the general criteria for habitat selection analysis. Overall, 23,228 m^2 encompassing 13 habitat types were sampled during the 2007and 2008 small-bodied monitoring program (New Mexico Department of Fish and Game, unpublished data). Runs and shoals were the habitat types sampled more frequently during these efforts accounting for 47% and 18% of the total area sampled, respectively (Table 4.15). Riffles (12%), backwaters (7%), and eddies (8%), represented approximately 27 percent of the total area sampled. The remaining proportion of area sampled (approximately 3%) encompassed eight other habitat types (Table 4.16).

A total of 31 pikeminnow with total length greater than 100 mm (TL>100mm) were captured during the small bodied sampling efforts in 2007 (Paroz et al. 2008). As noted in Bliesner et al. (2008), analysis of habitat selection based on small-bodied monitoring data indicated that habitat selection by pikeminnow was likely. Significant ratios indicating selection for particular habitats were estimated for riffle-eddy, pool and debris pile. Habitat selection was also evident for the 28 pikeminnow with total length less than 100 mm captured during small-bodied monitoring efforts in 2007. Significant ratios for the smaller pikeminnow indicated selection for backwater, slackwater, and overhanging vegetation habitats and selection against run and shoal habitat (Bliesner et al. 2008).

Small-bodied sampling efforts in 2008 resulted in the capture of 10 pikeminnow ≥ 100 mm from run (7 pikeminnow), backwater (2 pikeminnow), and plunge (1 pikeminnow) habitats (New Mexico Department of Fish and Game, unpublished data). No pikeminnow less than 100 mm (TL) were captured. The small sample size precluded the assessment of habitat selection for this individual sampling event. Habitat selection analyses were conducted by pooling the habitat use and availability data for larger pikeminnow (TL > 100 mm) from both sampling events. However, this analysis did not provide evidence of habitat selection (Table 4.15).

Physical Characteristics

Analyses of physical characteristics indicated that the highest mean velocity for most of the samples containing pikeminnow with total lengths under or above 100 mm was below 0.7 m/sec and 1.3 m/sec, respectively. However, a difference in mean depth across sites with pikeminnow from the two size classes was not observed. Typically, the mean depth of habitats where pikeminnow occurred was below 0.6 m (Figure 4.6).

Not surprisingly, given the results of habitat selection by pikeminnow with total length under 100 mm (i.e., embayment, pool, and backwater; Table 4.9) and larger pikeminnow (i.e., eddy, riffle), substrate selection by this species was apparent. While smaller pikeminnow selected for sand/silt and against cobble/gravel, the opposite was observed for fish in the larger size class (Table 4.16).

Table 4.13. Summary of area (m^2) sampled by habitat type during August 2007, March 2008, and August (2008) surveys in DR 82, DR131, and DR 137 in the San Juan River

DATE	August_07			March_08				August_08				Grand Total*
REACH	**82**	**137**	**82 & 137 Combined***	**82**	**131**	**137**	**82-131-137 Combined***	**82**	**131**	**137**	**82-131-137 Combined***	
Backwater	118		118 (44%)	193	36	102	331 (31%)	168	102	227	497 (43%)	946 (38%)
Cobble Shoal	1,784	1,491	3,276 (33%)	41	137	410	587 (12%)	1,185	1,088	1,159	3,432 (20%)	7,295 (23%)
Eddy	68	613	681 (184%)	NS	NS	25	25 (1%)	84	73	57	214 (54%)	920 (35%)
Embayment	NS	NS	NS	NS	NS	123	123 (9%)		353	61	414 (123%)	537 (28%)
Isolated Pool	6	NS	6 (4%)	NS	NS	73	73 (87%)	187		140	327 (24%)	406 (26%)
Mid-Channel Run	NS	140	140 (0.1%)	NS	NS	NS	NS	NS	NS	NS	NS	140 (0.1%)
Plunge	13	126	139 (383 %)	NS	NS	NS	NS	NS	NS	64	64 (356%)	203 (374%)
Pool	401	NS	401 (55%)	NS	156	160	316 (28%)	245		406	651 (30%)	1,368 (34%)
Riffle	519	1,254	1,773 (6%)	416	302	611	1,329 (1%)	974	1,748	1,822	4,544 (6%)	7,646 (3%)
Sand Shoal	965	971	1,936 (25 %)	393	834	448	1,675 (15%)	1,219	253	287	1,759 (14%)	5,370 (17%)
Shore Run	2,162	1,534	3,696 (33%)	1,208	778	1,226	3,212 (7%)	1,523	1,778	1,740	5,041 (14%)	11,948 (13%)
Slackwater	5,588	5,679	11,268 (92%)	1,264	661	1,074	2,999 (13%)	2,212	2,575	3,080	7,867 (25%)	22,133 (33%)
Total	11,624	11,809	**23,433 (14 %)**	3,514	2,904	4,252	**10,670 (2%)**	7,798	7,970	9,041	**24,808 (5%)**	**58,911 (5%)**

* Numbers in parenthesis indicate the proportion of habitat sampled in relation to the area mapped.

Table 4.14. Proportional Habitat Availability: percent area sampled by habitat type based on total areas sampled during August 2007, March 2008, and August (2008) surveys in DR 82, DR131, and DR 137 in the San Juan River

DATE	August_07			March_08				August_08				Grand Total
REACH	82	137	82 & 137 Combined	82	131	137	82-131-137 Combined	82	131	137	82-131-137 Combined	
Backwater	1.0	0.0	0.5	5.5	1.2	2.4	3.1	2.2	1.3	2.5	2.0	1.6
Cobble Shoal	15.4	12.6	14.0	1.2	4.7	9.7	5.5	15.2	13.7	12.8	13.8	12.4
Eddy	0.6	5.2	2.9	0.0	0.0	0.6	0.2	1.1	0.9	0.6	0.9	1.6
Embayment	0.0	0.0	0.0	0.0	0.0	2.9	1.2	0.0	4.4	0.7	1.7	0.9
Isolated Pool	0.0	0.0	0.0	0.0	0.0	1.7	0.7	2.4	0.0	1.5	1.3	0.7
Run	18.6	14.2	16.4	34.4	26.8	28.8	30.1	19.5	22.3	19.2	20.3	20.5
Plunge	0.1	1.1	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.3	0.3
Pool	3.5	0.0	1.7	0.0	5.4	3.8	3.0	3.1	0.0	4.5	2.6	2.3
Riffle	4.5	10.6	7.6	11.8	10.4	14.4	12.5	12.5	21.9	20.2	18.3	13.0
Sand Shoal	8.3	8.2	8.3	11.2	28.7	10.5	15.7	15.6	3.2	3.2	7.1	9.1
Slackwater	48.1	48.1	48.1	36.0	22.8	25.3	28.1	28.4	32.3	34.1	31.7	37.6

Values shown are percentages of the total area sampled by reach or reach combinations.

Table 4.15. Summary of areas sampled by habitat type, Colorado pikeminnow captures, and tests of No Selection based on small-bodied monitoring sampling in August 2007 and 2008

Habitat	Area (m^2)	Frequency (# of seine hauls)	Percent of total area (%)	Pikeminnow TL>100mm (n)	Pikeminnow TL<100mm (n)
Backwater	1728	86	7.44	5	23
Eddy	1958	102	8.43	5	0
Embayment	163	7	0.70	0	0
Isolated Pool	107	8	0.46	0	0
Plunge	234	11	1.01	1	0
Pool	493	41	2.12	2	0
Riffle	2733	169	11.77	1	1
Run	10939	463	47.09	23	1
Slackwater	509	23	2.19	0	1
Shoal	4199	156	18.08	3	1
Debris Pile	118	18	0.51	1	0
Overhanging Vegetation	22	1	0.09	0	1
Chute	23	1	0.10	0	0
Total	23228	1086	100	41	28
Pearson Chi^2 *				15.05 (p=0.2388)	NA
Log-likelihood Chi^2 *				16.35 (p=0.1757)	NA

Table 4.16. Summary of substrate selection ratios for Colorado pikeminnow by size. Based on detailed habitat fish surveys conducted in 2007 and 2008

COLORADO PIKEMINNOW	TL < 100 mm	TL > 100 mm
HABITAT	Ratio (n=84)	Ratio (n=80)
Sand/Silt	1.42	0.56
Cobble/Gravel	0.08	1.96
Pearson Chi^2	32.71 (p<0.00)	33.3 (p<0.00)
Log-likelihood Chi^2	47.37 (p<0.00)	30.24 (p<0.00)

* Significant ($p<0.05$) Chi^2 values suggest selection for particular habitat types occur.

Only significant selection ratios ($p<0.05$) are shown.

Ratios greater than one indicate selection for, ratios below one indicate selection against, and ratios equal to one indicate no selection.

Habitat Association

Detailed Reach Analysis

In 2008, the seined area of each sample was mapped on the habitat base maps, allowing an intersection with the habitat mapping to determine the habitats that were seined in each sample. Often the seined area extends beyond the target habitat, especially for small habitats. On average about 75% of the seined area consists of target habitat, ranging from 26% to 100% by habitat type (Table 4.17)[6]. An analysis of the habitats that are significantly related to capture within the seine hauls was completed that considered all habitats sampled. The seine haul boundary was used as the offset boundary for 5, 10, 15 and 20 m buffers to look at habitat associations that might also be important to pikeminnow capture.

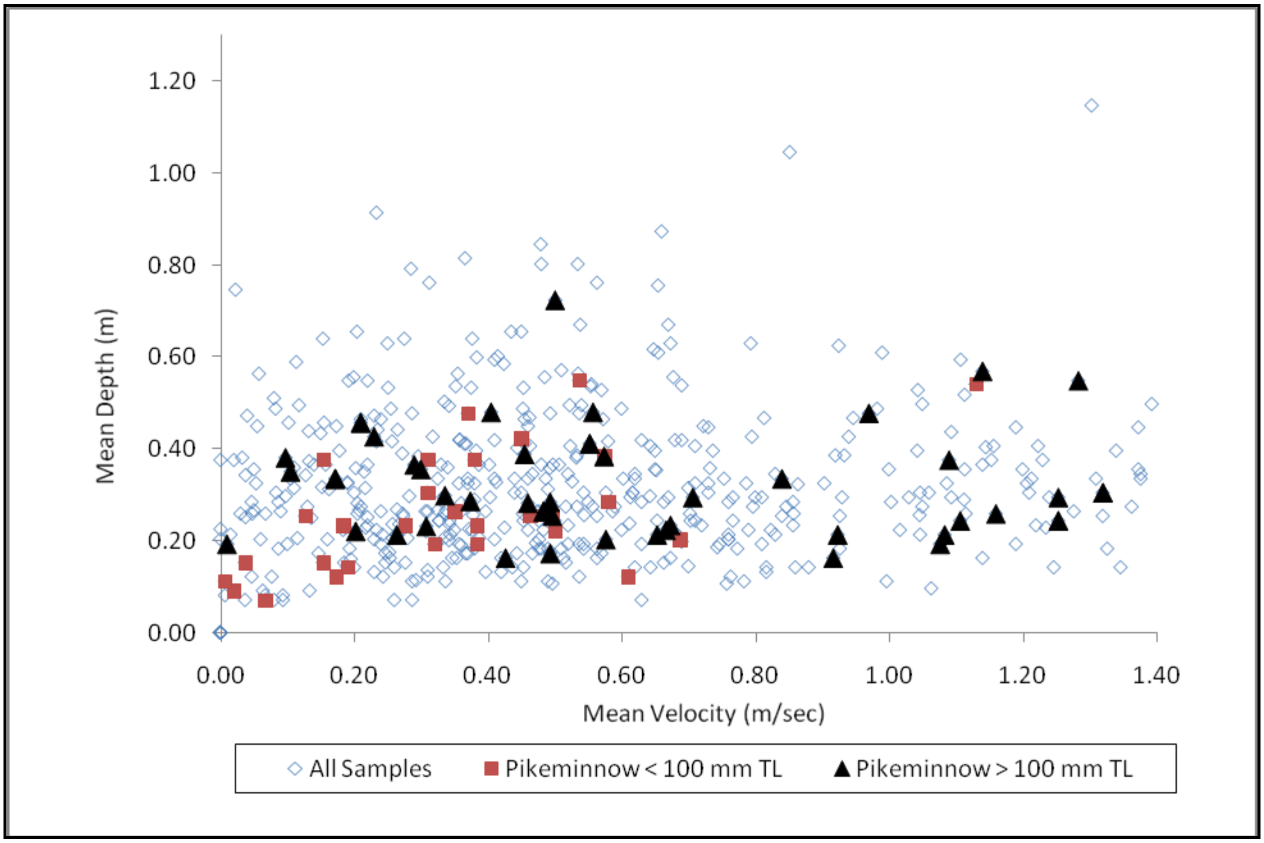

Figure 4.6. Scatter plot of mean velocity and depth for all samples and for those with Colorado pikeminnow

[6] We have discovered some mapping differences between those reported in the targeted habitat study and those on the habitat maps that cause these percentages to be lower than actual. This will be corrected in the final report.

Table 4.17. Target habitats and their average portion of the total seine haul area for March and August 2008 samples (to be reviewed for final report)

	Count		Percent in Seine Haul	
Target Habitat	**Mar 08**	**Aug 08**	**Mar 08**	**Aug 08**
Backwater	7	12	93%	75%
Cobble shoal	14	34	65%	67%
Eddy	1	4	46%	80%
Embayment	3	4	52%	57%
Isolated Pool	2	7	100%	100%
Plunge pool	0	1	n/a	26%
Pool	8	13	99%	83%
Riffle	27	49	64%	65%
San shoal	34	22	72%	74%
Shore run	70	46	76%	84%
Slackwater	71	74	81%	75%
Total	237	266	76%	74%

As with the target habitat analysis, the results of the habitat association study had different results for the March and August samples. In March, pools and backwaters in the buffer areas are significantly related with pikeminnow capture as well as five associations: backwater plus run, backwater plus slackwater, pool plus slackwater, backwater plus run plus slackwater and pool plus run plus slackwater (Table 4.18). Two habitats were significantly associated with no pikeminnow captures (root wads and eddies). The level of significance varies with buffer distance and tends to be lower within the seine haul than at some distance from the seine haul. These results are similar to the results from the targeted habitat analysis, except the significance is lower for embayment and backwater habitats and the habitats that are strongly correlated to no captures are different.

In August, the following individual habitats and associations were significantly correlated with pikeminnow captures among the range of buffers tested (Table 4.19):

- Riffle
- Slackwater
- Cobble Shoal
- Slackwater plus cobble shoal
- Run plus cobble shoal
- Run plus slackwater plus cobble shoal
- Run plus riffle
- Run plus riffle plus slackwater
- Riffle plus cobble shoal
- Riffle plus slackwater
- Riffle plus slackwater plus cobble shoal
- Riffle plus cobble bar plus cobble shoal

Table 4.18. Portion of samples with and without Colorado pikeminnow captures that contain certain habitats and the significance of the difference for March 2008 samples.

Radius m	Colorado Pikeminnow Captured	Back-water	Embay-ment	Pool	Rood Wad	Eddy	Back-water + Run	Back water + Riffle	Back-water + Slack-water	Back-water + Sand Shoal	Pool + Run	Pool + Riffle	Pool + Slack-water	Pool + Sand Shoal	Back-water + Run + Slack water	Pool + run + Slack water
Seined area	no	*3.9%*	0.5%	*2.5%*	**11.8%**	*1.5%*	1.5%	1.0%	2.0%	0.5%	0.0%	0.5%	0.5%	0.0%	1.0%	0.0%
	yes	*15.2%*	6.1%	*15.2%*	**3.0%**	*0.0%*	9.1%	0.0%	6.1%	3.0%	0.0%	3.0%	3.0%	3.0%	0.0%	0.0%
	ratio yes/no	*3.86*	12.36	*6.18*	**0.26**	*0.00*	6.18	0.00	3.09	6.18	n/a	6.18	6.18	n/a	0.00	n/a
	p-value	*0.092*	0.199	*0.056*	**0.024**	*0.083*	0.148	0.158	0.350	0.414	n/a	0.414	0.414	0.325	0.158	n/a
5	no	6.4%	1.5%	**3.4%**	**31.9%**	**2.9%**	4.9%	2.9%	3.9%	2.5%	0.5%	2.5%	*0.5%*	0.5%	3.4%	*0.0%*
	yes	18.2%	6.1%	**21.2%**	**6.1%**	**0.0%**	12.1%	3.0%	12.1%	9.1%	9.1%	3.0%	*12.1%*	6.1%	6.1%	*9.1%*
	ratio yes/no	2.85	4.12	**6.18**	**0.19**	**0.00**	2.47	1.03	3.09	3.71	18.55	1.24	*24.73*	12.36	1.77	*n/a*
	p-value	0.102	0.293	**0.021**	**0.000**	**0.014**	0.234	0.978	0.175	0.210	0.102	0.858	*0.053*	0.199	0.554	*0.083*
10	no	**9.3%**	2.5%	**4.4%**	**48.0%**	**5.4%**	**8.8%**	5.4%	**7.4%**	3.4%	0.5%	2.9%	*2.5%*	1.5%	**6.9%**	**1.5%**
	yes	**27.3%**	6.1%	**24.2%**	**21.2%**	**0.0%**	**27.3%**	9.1%	**24.2%**	12.1%	3.0%	3.0%	*15.2%*	9.1%	**24.2%**	**15.2%**
	ratio yes/no	**2.93**	2.47	**5.49**	**0.44**	**0.00**	**3.09**	1.69	**3.30**	3.53	6.18	1.03	*6.18*	6.18	**3.53**	**10.30**
	p-value	**0.034**	0.413	**0.015**	**0.002**	**0.001**	**0.029**	0.491	**0.037**	0.150	0.414	0.978	*0.056*	0.148	**0.032**	**0.040**
15	no	*12.7%*	2.9%	**6.4%**	**56.9%**	**7.4%**	*12.7%*	3.9%	*10.8%*	4.4%	1.0%	3.9%	*4.4%*	2.5%	10.8%	*4.4%*
	yes	*27.3%*	6.1%	**27.3%**	**36.4%**	**0.0%**	*27.3%*	9.1%	*24.2%*	12.1%	3.0%	9.1%	*18.2%*	9.1%	24.2%	*18.2%*
	ratio yes/no	*2.14*	2.06	**4.28**	**0.64**	**0.00**	*2.14*	2.32	*2.25*	2.75	3.09	2.32	*4.12*	3.71	2.25	*4.12*
	p-value	*0.085*	0.481	**0.014**	**0.031**	**0.000**	*0.085*	0.332	*0.096*	0.203	0.514	0.332	*0.056*	0.210	0.096	*0.056*
20	no	*13.2%*	2.9%	**6.4%**	**62.3%**	*11.3%*	*13.2%*	8.3%	*11.8%*	4.4%	1.0%	3.9%	**4.9%**	4.4%	*11.8%*	**4.9%**
	yes	*30.3%*	6.1%	**27.3%**	**42.4%**	**0.0%**	*30.3%*	15.2%	*27.3%*	12.1%	3.0%	9.1%	**21.2%**	12.1%	*27.3%*	**21.2%**
	ratio yes/no	*2.29*	2.06	**4.28**	**0.68**	**0.00**	*2.29*	1.82	*2.32*	2.75	3.09	2.32	**4.33**	2.75	*2.32*	**4.33**
	p-value	*0.051*	0.481	**0.014**	**0.040**	**0.000**	*0.051*	0.310	*0.066*	0.203	0.514	0.332	**0.034**	0.203	*0.066*	**0.034**

Note: Bolded values indicate significance (p≤0.05) and italics indicates marginal significance (p>0.05 and ≤0.10). Red values indicate habitats correlated with no pikeminnow captures.

Table 4.19. Portion of samples with and without Colorado pikeminnow captures that contain certain habitats and the significance of the difference for August 2008 samples.

Radius-m	Colorado Pikeminnow Captured	Riffle	Slack-water	Embay-ment	Rood Wad	Cobble Shoal	Slack-water + Cobble Shoal	Run + Cobble Shoal	Run + Slack-water + Cobble Shoal	Run + Riffle	Run + Riffle + Slack-water	Run + Slack-water + Root Wad	Riffle + Cobble Shoal	Riffle + Slack-water	Riffle + Slack-water + Cobble Shoal	Riffle + Cobble Bar + Cobble Shoal
Seined area	no	*29%*	*51%*	2%	7%	**33%**	**18%**	19%	*10%*	18%	11%	4%	**9%**	*15%*	**5%**	*6%*
	yes	*42%*	*67%*	2%	11%	**60%**	**42%**	29%	*22%*	27%	20%	2%	**27%**	*29%*	**18%**	*16%*
	ratio yes/no	*1.48*	*1.30*	1.23	1.53	**1.84**	**2.33**	1.56	*2.23*	1.51	1.84	0.61	**2.95**	*1.93*	**3.27**	*2.64*
	p-value	*0.093*	*0.052*	0.864	0.446	**0.001**	**0.003**	0.163	*0.068*	0.212	0.158	0.586	**0.014**	*0.059*	**0.044**	*0.095*
5	no	**44%**	65%	1%	21%	**49%**	**32%**	**37%**	*27%*	36%	28%	11%	**24%**	31%	*17%*	**20%**
	yes	**60%**	73%	4%	27%	**76%**	**56%**	**56%**	*40%*	47%	33%	16%	**47%**	42%	*31%*	**42%**
	ratio yes/no	**1.35**	1.13	3.27	1.25	**1.53**	**1.75**	**1.50**	*1.47*	1.31	1.21	1.43	**1.91**	1.37	*1.81*	**2.07**
	p-value	**0.040**	0.183	0.340	0.351	**0.0004**	**0.004**	**0.021**	*0.100*	0.153	0.426	0.340	**0.006**	0.145	*0.058*	**0.006**
10	no	**51%**	76%	2%	28%	**57%**	**44%**	**48%**	**40%**	45%	40%	16%	**32%**	*43%*	**27%**	**25%**
	yes	**67%**	82%	4%	29%	**76%**	**64%**	**64%**	**56%**	56%	49%	18%	**53%**	*58%*	**47%**	**51%**
	ratio yes/no	**1.30**	1.08	1.96	1.03	**1.33**	**1.47**	**1.33**	**1.40**	1.24	1.23	1.09	**1.68**	*1.34*	**1.72**	**2.05**
	p-value	**0.035**	0.196	0.507	0.770	**0.010**	**0.009**	**0.037**	**0.046**	0.160	0.230	0.703	**0.007**	*0.059*	**0.014**	**0.001**
15	no	**57%**	**80%**	2%	36%	**61%**	**49%**	*54%*	**45%**	*50%*	**47%**	23%	**38%**	**50%**	**33%**	**31%**
	yes	**76%**	**89%**	4%	31%	**76%**	**71%**	*67%*	**64%**	*64%*	**62%**	22%	**62%**	**69%**	**58%**	**56%**
	ratio yes/no	**1.34**	**1.12**	1.96	0.86	**1.25**	**1.46**	*1.24*	**1.42**	*1.29*	**1.34**	0.98	**1.66**	**1.37**	**1.75**	**1.81**
	p-value	**0.007**	**0.040**	0.507	0.629	**0.033**	**0.003**	*0.086*	**0.014**	*0.055*	**0.044**	0.942	**0.002**	**0.014**	**0.002**	**0.002**
20	no	**62%**	**83%**	3%	43%	*64%*	**54%**	**59%**	**52%**	**57%**	**54%**	29%	**43%**	**57%**	**39%**	**36%**
	yes	**78%**	**93%**	4%	36%	*76%*	**76%**	**73%**	**73%**	**73%**	**73%**	24%	**62%**	**76%**	**62%**	**58%**
	ratio yes/no	**1.25**	**1.12**	1.40	0.82	*1.18*	**1.40**	**1.25**	**1.42**	**1.29**	**1.35**	0.86	**1.45**	**1.34**	**1.60**	**1.60**
	p-value	**0.015**	**0.009**	0.702	0.415	*0.085*	**0.003**	**0.042**	**0.003**	**0.021**	**0.008**	0.660	**0.015**	**0.007**	**0.004**	**0.007**

Note: Bolded values indicate significance (p≤0.05) and italics indicates marginal significance (p>0.05 and ≤0.10).

The ratios (indicators of importance to pikeminnow capture) and significance increase for several of the combinations over the individual habitats. The largest ratios and strongest significance is for riffle plus slackwater plus cobble shoal within the seined area and for most buffer distances. These findings generally support the conclusions of the targeted habitat analysis with the addition of slackwater. Since slackwaters are associated with riffles, they appear in most seine hauls for riffles, but were not considered in these cases in the targeted habitat analysis.

Non-Native Removal and Large-Bodied Monitoring Razorback Sucker and Colorado Pikeminnow Habitat Association

Using the non-native removal program data, the abundance of run, riffle and island habitats and habitat complexity are all significantly greater for reaches with razorback sucker than those without (Table 4.20). Sand shoals and boulders are significantly more abundant in reaches without razorback sucker than those with. Tributary habitat abundance is marginally greater for reaches where razorback sucker were captured.

For Colorado pikeminnow, only island abundance is significantly related to their capture (Table 4.20.). Pocket water is significantly more abundant in reaches without pikeminnow. In 2007 habitat complexity and abundance of low velocity habitats, root wad piles and sandbars were positively related to reaches with pikeminnow captures. These did not show significance in 2008. Islands were common to both years.

In 2008, gps position data were available for Colorado pikeminnow and razorback sucker from the adult monitoring program. This is a single-pass effort with two boats and covers reaches 1-6. Because of problems with the GPS unit on the Utah boat below Bluff and problems with GPS signals in the canyon reaches only data above RM 58 were included and only the Colorado FWS boat data were used to maintain distribution consistency. Thirty-three razorback sucker captures were located with GPS positions in 23 locations (1/10 mile reaches). These capture locations were significantly correlated with 2 habitat categories, number of runs and islands (Table 4.21). Shoal/riffles were associated with locations that did not have razorback sucker captures, but the abundance is so low that the association may not have meaning.

A total of 115 Colorado pikeminnow were identified by GPS in 84 locations in the large-bodied monitoring program. These capture locations were significantly associated with two habitat categories (isolated pools and Islands; Table 4.21). The association with isolated pool is an indication that the sites are in proximity to a secondary channel that has recently stopped flowing. This corresponds with the association with islands. Sites without Colorado pikeminnow captures were significantly associated with five habitats (debris pools, eddy, slackwater, shoal/riffle and pocket water). Low abundance of all but slackwater habitats may diminish the meaning of the association.

Table 4.20. Habitat associations for razorback sucker (ZYRTEX) and Colorado Pikeminnow (PTYLUC) captures by non-native removal study resolved to 0.1 mile river reaches

Habitat	Habitats per 0.1 mi With XYRTEX	Habitats per 0.1 mi W/O XYRTEX	Ratio with / without	T-test p- value	Habitats per 0.1 mi With PTYLUC	Habitats per 0.1 mi W/O PTYLUC	Ratio with / without	T-test p-value
Backwater	0.06	0.08	0.80	0.53	0.08	0.07	1.06	0.84
Pool	0.05	0.06	0.94	0.89	0.07	0.05	1.54	0.19
Debris Pool	0.01	0.00	3.77	0.47	*0.000*	*0.004*	*0.000*	*0.08*
Eddy	0.11	0.07	1.53	0.36	0.07	0.07	1.03	0.94
Sand shoal	***0.57***	***0.74***	***0.77***	***0.03***	0.76	0.70	1.09	0.34
Cobble shoal	1.10	0.94	1.17	0.20	1.05	0.92	1.14	0.14
Sand shoal/run	0.52	0.42	1.25	0.23	0.41	0.44	0.94	0.60
Cobble shoal/run	0.13	0.11	1.26	0.48	0.12	0.10	1.15	0.59
Run	**1.66**	**1.43**	**1.16**	**0.01**	1.48	1.45	1.02	0.54
Undercut Run	0.02	0.01	1.68	0.59	0.02	0.01	2.18	0.43
Run/riffle	0.54	0.48	1.12	0.39	0.45	0.50	0.90	0.29
Riffle	**1.13**	**0.69**	**1.64**	**0.0003**	0.73	0.75	0.98	0.80
Riffle/chute	0.12	0.05	2.23	0.08	0.06	0.06	1.11	0.76
Chute	0.05	0.05	1.08	0.87	0.04	0.05	0.87	0.67
Slackwater	0.56	0.48	1.15	0.34	0.43	0.51	0.84	0.14
Isolated Pool	0.09	0.05	1.64	0.27	0.08	0.05	1.57	0.20
Embayment	0.02	0.04	0.47	0.16	0.04	0.03	1.09	0.83
Overhanging Vegetation	0.21	0.19	1.11	0.69	0.21	0.19	1.15	0.48
Cobble bar	0.92	0.84	1.09	0.51	0.85	0.85	1.00	0.99
Root wad pile	0.23	0.32	0.73	0.18	0.31	0.30	1.02	0.90
Sand bar	0.93	0.80	1.17	0.22	0.76	0.83	0.92	0.39
Tributary	0.03	0.00	22.62	0.10	0.01	0.00	2.61	0.41
Shoal/riffle	0.05	0.06	0.84	0.70	0.05	0.07	0.72	0.31
Island	**0.92**	**0.57**	**1.61**	**0.001**	0.69	0.58	1.19	0.06
Pocket water	0.02	0.02	0.75	0.68	***0.01***	***0.03***	***0.26***	***0.02***
Boulders	***0.03***	***0.10***	***0.27***	***0.05***	0.09	0.09	1.00	0.99
Cobble types	0.69	0.68	1.01	0.88	2.02	1.88	1.08	0.34
Sand types	0.71	0.72	0.98	0.76	1.94	1.97	0.99	0.84
All low velocity types	0.21	0.20	1.05	0.82	0.27	0.24	1.09	0.58
All riffle types	**0.70**	**0.57**	**1.23**	**0.01**	1.76	1.92	0.92	0.25
Complexity (wet types)	**6.97**	**5.99**	**1.16**	**0.02**	6.19	6.07	1.02	0.68
Total Fish Captured	231				447			
Total 0.1 mile reaches	113	852			267	698		

Note: Bold=significant (p<.05), italics=marginally significant (p>.05 and <.10), blue = higher with endangered fish, pink = higher without endangered fish.

Table 4.21. Habitat associations for razorback sucker (ZYRTEX) and Colorado Pikeminnow (PTYLUC) captures by large-bodied monitoring study resolved to 0.1 mile river reaches

Habitat	Habitats per 0.1 mi		Ratio	T-test	Habitats per 0.1 mi		Ratio	T-test
	With XYRTEX	W/O XYRTEX	with / without	p-value	With PTYLUC	W/O PTYLUC	with / without	p-value
Backwater	0.12	0.07	1.65	0.40	0.08	0.07	1.02	0.95
Pool	0.06	0.04	1.45	0.60	0.07	0.04	1.82	0.27
Debris Pool	0.02	0.00	7.00	0.40	*0.00*	*0.00*	*0.00*	*0.08*
Eddy	0.06	0.06	0.93	0.90	**0.03**	**0.07**	**0.37**	**0.02**
Sand shoal	0.49	0.58	0.84	0.44	0.62	0.57	1.10	0.51
Cobble shoal	1.14	0.91	1.24	0.23	1.03	0.90	1.15	0.29
Sand shoal/run	0.33	0.35	0.95	0.85	0.41	0.33	1.23	0.23
Cobble shoal/run	0.16	0.08	2.07	0.18	0.13	0.07	1.70	0.18
Run	**1.71**	**1.48**	**1.16**	**0.05**	1.46	1.50	0.98	0.66
Undercut Run	0.04	0.01	4.66	0.27	0.00	0.01	0.00	0.01
Run/riffle	0.57	0.54	1.05	0.82	0.49	0.55	0.89	0.36
Riffle	0.94	0.80	1.18	0.39	0.80	0.80	1.00	0.98
Riffle/chute	0.06	0.04	1.35	0.66	0.05	0.04	1.21	0.69
Chute	0.08	0.03	2.54	0.22	0.07	0.03	2.42	0.10
Slackwater	0.59	0.58	1.02	0.94	**0.44**	**0.60**	**0.73**	**0.04**
Isolated Pool	0.10	0.05	1.89	0.29	0.12	0.04	2.72	0.06
Embayment	0.04	0.04	0.93	0.92	0.04	0.04	1.01	0.99
Overhanging Vegetation	0.14	0.16	0.88	0.74	0.19	0.15	1.29	0.37
Cobble bar	0.90	0.82	1.10	0.60	0.78	0.83	0.94	0.59
Rootwad pile	0.24	0.26	0.90	0.79	0.24	0.26	0.89	0.72
Sand bar	0.65	0.75	0.87	0.42	0.63	0.76	0.83	0.14
Shoal/riffle	**0.02**	**0.09**	**0.22**	**0.00**	*0.05*	*0.09*	*0.55*	*0.09*
Island	**0.78**	**0.48**	**1.63**	**0.01**	**0.72**	**0.46**	**1.57**	**0.00**
Pocket water	0.04	0.06	0.62	0.42	**0.03**	**0.07**	**0.37**	**0.03**
Boulders	0.04	0.10	0.38	0.17	0.04	0.11	0.39	0.14
Cobble types	2.20	1.81	1.22	0.20	1.94	1.81	1.07	0.50
Sand types	1.47	1.68	0.88	0.39	1.66	1.66	1.00	0.98
All low velocity types	0.29	0.22	1.33	0.35	0.21	0.23	0.93	0.72
All riffle types	1.67	1.45	1.15	0.38	1.43	1.46	0.98	0.84
Complexity (wet types)	7.04	6.37	1.11	0.26	6.39	6.38	1.00	0.99
Total Fish Captured	33				115			
Total 0.1 mile reaches	23				84			

Note: Bold=significant (p<.05), italics=marginally significant (p>.05 and <.10), blue = higher with endangered fish, pink = higher without endangered fish.

Larval Razorback Sucker Habitat Association

In the April to June sampling period for larval fish, there were 177 samples collected in 138 different locations between RM 3.3 and 140.7 (pers. com. Brandenburg, 2009). While 10 habitat types were sampled, larval razorback suckers were captured in only backwaters (Table 4.22.). Backwaters made up 61% of the samples (108 of 177) with 26 of these samples (24%) containing larval razorback suckers. Larval razorback sucker were significantly ($P < 0.01$) associated with inundated vegetation; 22 of the 26 samples with larval razorback sucker (85%) had inundated vegetation while only 46% of the samples without larval razorbacks had inundated vegetation. In 2007 backwaters made up 49% of the sample sites but 83% of the capture locations. The presence of inundated vegetation was also significant in 2007 ($p=0.05$); 59% of capture sites had inundated vegetation, compared to 35% of non-capture sites.

The average flow during sampling for 2008 was 40% greater than 2007 (average flow of 4,590 vs 3,500 cfs). The total flow during the entire sampling period (mid-April to mid-June) was 145% greater in 2008 than in 2007. The higher flows increase the probability of inundated vegetation and abundance of backwaters. Higher flows also increase flow velocity and may speed larval drift.

The 2008 distribution of the samples with inundated vegetation was compared to the distribution of samples with larval razorback sucker (Figure 4.7). While the distribution of samples with inundated vegetation during this high flow sampling year was quite uniform, the distribution of larval fish was not. The slope of the distribution of larval razorbacks is flatter than the habitat availability through most of the river with a sharp increase beginning at RM 24.5. In 2007, the slope of the larval fish curve more closely matches the inundated vegetation curve (Figure 4.8.). Both figures show no larval fish captures in the canyon reach between about RM 25 and 50, even though sample sites with inundated vegetation occur here.

Table 4.22. Larval samples by habitat during the April to June 2008 sampling period with and without larval razorback suckers.

Habitat	Total Samples	Samples with razorback sucker
Backwater	108	26
Cobble Shoal	2	0
Debris Pool	1	0
Edge Pool	12	0
Embayment	5	0
Pocketwater	1	0
Pool	7	0
Sand Shoal	5	0
Shore Run	4	0
Slackwater	32	0
Total	177	26

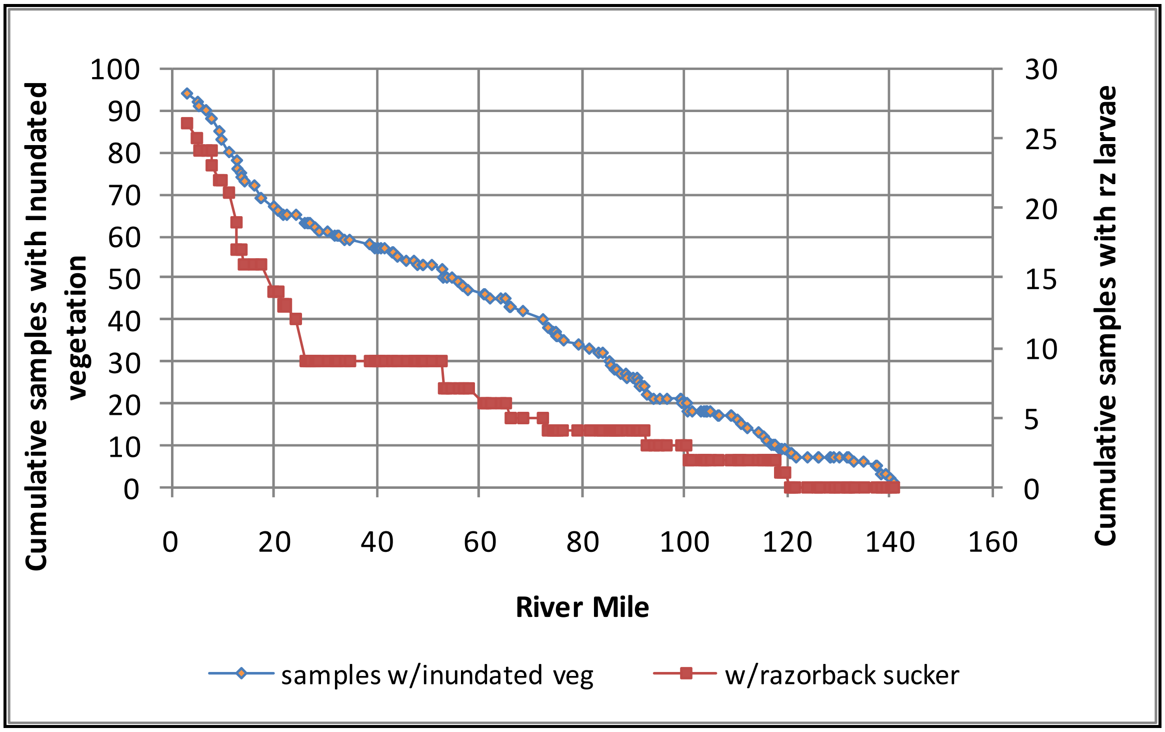

Figure 4.7. **Distribution of larval samples with inundated vegetation and with larval razroback sucker, April – June 2008.**

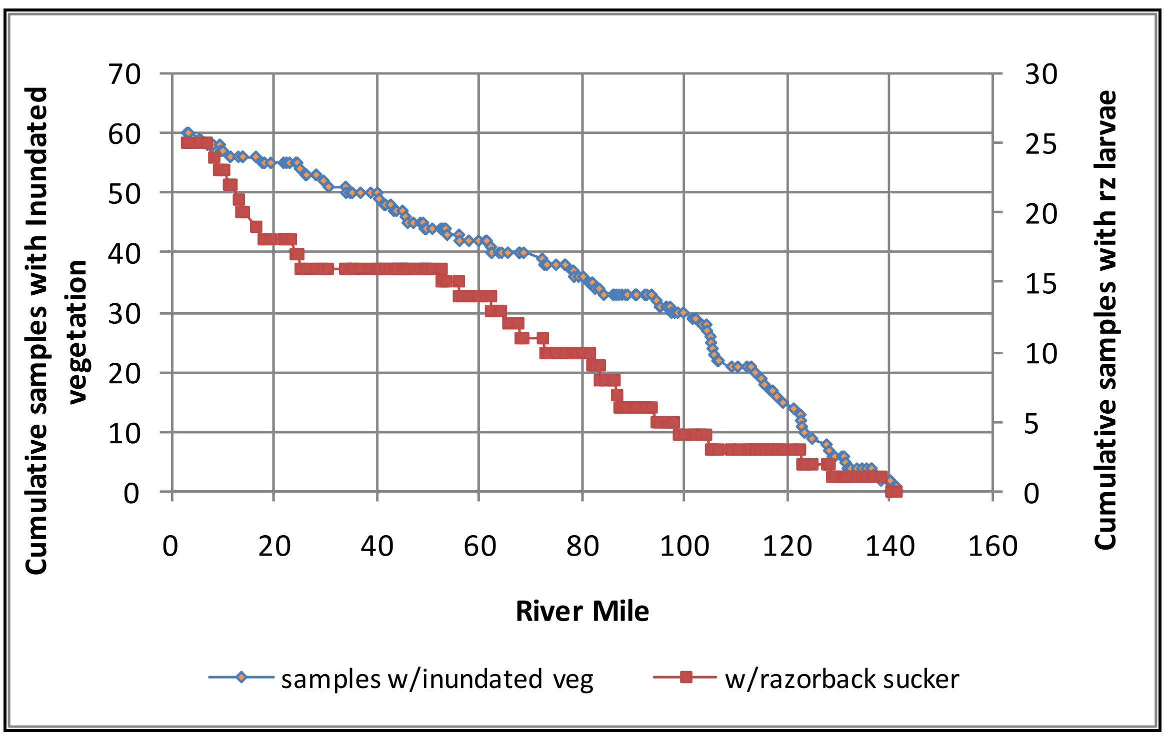

Figure 4.8. **Distribution of larval samples with inundated vegetation and with larval razroback sucker, April – June 2007.**

DISCUSSION

The 2008 results combined with those from fish and habitat surveys in detailed reaches conducted in 2007 (Bliesner et al. 2008) suggest that young Colorado pikeminnow select for specific habitat types. Pikeminnow in the smaller size class (TL < 100 mm) appear to select for low water velocity habitats including embayment, pool, and backwaters while selecting against riffle, cobble shoal, and slackwater. Alternatively, pikeminnow in the larger size class (TL > 100 mm) appear to select for riffle and cobble shoal habitats, and select against run habitat. Relatively high water velocities in riffle habitat lead us to question the selection for riffle habitat by pikeminnow with total length over 100 mm. However, it is possible that pikeminnow may have been captured in habitats adjacent to riffles when riffle was the target habitat. The discussion of habitat associations (below) will provide more insight into the selection for particular habitat types.

Consistent with Bliesner et al. (2008), the selection for cobble shoal habitat by pikeminnow >100 mm TL was supported by both 2007 and 2008 survey data. However, given that no pikeminnow were captured in eddy habitat during 2008, the reported selection for eddy by pikeminnow in this size class was not supported with the addition of the 2008 data. As noted in Bliesner et al. (2008), whereas summer 2007 surveys provided some insight into habitat selection by young pikeminnow those results were considered statistically weak and preliminary. The larger sample sizes in 2008 allowed for a better assessment of habitat selection and the comparison of selection by pikeminnow in two different size classes.

Although the assessment of habitat selection based on small-bodied 2008 monitoring data did not provide evidence of habitat selection, largely due to the small number of pikeminnow captured, the data collected in 2007 suggested that pikeminnow larger than 100 mm TL selected riffle-eddy, pool, and debris pile habitats (Bliesner et al. 2008). The riffle-eddy habitat selection is similar to the eddy and riffle selection shown in the detailed reach study. We also collected a small number of pikeminnow in this size class (TL > 100 mm) in pools during August 2008 but selection was not significant. On the other hand, small-bodied monitoring data from 2007 suggested that habitats selected by smaller pikeminnow (TL < 100 mm) included backwater, slackwater, and overhanging vegetation. Although the selection for backwater habitat by smaller pikeminnow (TL <100 mm) is consistent with our results, the selection for slackwater appeared contradictory. Also consistent with our results, is the selection against shoals by pikeminnow in the larger size class. Further, the larval study captured a number of pikeminnow with total length over 100 mm in backwaters and other low velocity habitats, typical habitats for pikeminnow in this size class (Golden et al. 2006), but since not all habitat types were sampled it is difficult to determine if those data support the habitat selection from other studies. The similarities and differences in habitat selection by Colorado pikeminnow based on detailed reach and small-bodied monitoring surveys will be explored further when data collection is completed in 2009.

Overall, preliminary results from detailed reach and small-bodied fish studies support findings from previous research that indicate Colorado pikeminnow with total length over 100 mm typically use habitats with some current, while smaller fish tend to use slow-water habitat types such as backwaters and slackwaters (Golden et al. 2006, Robertson and Holden 2007). The differences in habitat selection by pikeminnow in the two size classes are noted particularly in the detailed reach study. Shifts in habitat use of this nature have also been documented for other species (Gido and Propst 1999, Mullen and Burton 1995). For Colorado pikeminnow, differences in habitat use across age classes could be associated to shifts in diet composition. As Franssen et al. (2007) point out, age-0 Colorado pikeminnow feed mainly on insects and may require shifting to piscivory by age-1 for optimal growth and survival. Although previous research has pointed out the importance of low water velocity habitat for small Colorado pikeminnow, the detailed reach fish survey has provided more insight into the types of low water velocity habitats (e.g., backwater, embayment, pool) that are used by Colorado pikeminnow under 100 mm in total length and differences in habitat selection between this size class and larger fish. These differences will be explored further once detailed reach data collection is completed in 2009.

In terms of habitat selection overlaps by Colorado pikeminnow and other native and non-native fishes, results from the detailed reach survey in March 2008 suggest that pikeminnow < 100 mm TL, flannel mouth sucker, the non-native fish assemblage, and fathead minnow selected for embayment habitat. Backwater habitat was selected for by both pikeminnow < 100 mm TL and red-shiner, and selected against by the overall and all-native fish assemblages. While both pikeminnow under 100 mm and red shiner selected for pools, speckled dace appeared to select against this habitat type.

Analysis of habitat selection based on the combined August 2007 and 2008 data suggested pikeminnow was the only species selecting for riffle habitat. This analysis did not support the selection for eddy habitat by Colorado pikeminnow reported in Bliesner et al. (2008). However, this analysis shows that while the selection for cobble shoal by pikeminnow captured in August was only marginally significant, speckled dace appeared to select against both cobble shoal and riffle habitat. These results are consistent with predator-prey experiments that have indicated a strong preference of age-1 pikeminnow for small native prey (Franssen et al. 2007). It could be hypothesized that speckled dace are not typically found in riffle and cobble shoal habitat due, at least in part, to the presence of pikeminnow.

More generally, the detailed reach survey in March 2008 revealed little overlap in habitat selection by native and non-native fishes. Conversely, the observed pattern of selection for and against particular habitat types by native and non-native fish assemblages during surveys conducted in August provided evidence of the high overlap in resource use during low flow conditions (Table 4.11). Both groups (native and non-native fishes) appeared to select for backwater and pool habitats, while selecting against cobble shoal and riffle habitats. Selection against run habitat by native and non-native fishes may also occur. These results support findings from previous studies that have documented overlaps in resources used by native and non-native fishes in the San Juan River. For example, the food web dynamics study of Gido et al. (2006) in the San Juan River confirmed a high degree of overlap in diet composition and suggested that most native and non-native species fed on macroinvertebrates (particularly chironomids) in low-velocity habitats. Gido and Propst (1999) also documented high levels of habitat overlap between native and non-native fishes in secondary channels of the San Juan River, particularly among juvenile and larval fishes. These noted patterns of habitat selection and overlap highlight the potential for negative interspecies interactions (e.g., competition) between native and non-native fishes.

As noted in Bliesner et al. (2008), despite efforts to sample representative areas of the habitats mapped, the selection of sampling habitats during the detailed reach fish survey was typically not proportional to their occurrence for various reasons. For example, sampling mid-channel run and riffle was very limited due to waters that were too swift or too deep. Samples from some areas were not collected because depth, vegetation, and/or debris prevented effective seining. However, given that the majority of habitats mapped were sampled, it is unlikely that limited sampling in the dominant habitat types (particularly along mid-channel run) biased the results of our habitat selection analyses. More importantly, results of habitat mapped and sampled highlight the lack of low water velocity habitats that are used by pikeminnow under 100 mm in total length (e.g., backwater, embayment, pool; Table 4.12).

Analyses of physical characteristics show that pikeminnow with total length > 100 mm TL were not captured in habitats where mean velocity exceeded 1.3 m/sec. It also appears that there is a threshold in velocity below which pikeminnow < 100 mm TL are captured (approximately 0.6m/sec). We will continue to assess a potential upper velocity limit and establishment of depth/velocity preference with the inclusion of 2009 survey results.

Combinations of certain habitats within the proximity of Colorado pikeminnow captures also appeared to be important. In March, the 10 m buffer had the strongest relationship between pikeminnow capture and combinations of habitats. Four combinations were significant: backwaters plus runs, backwaters plus slackwaters, backwaters plus runs plus slackwaters and pools plus runs plus slackwaters. The combination of pools plus slackwaters was marginally significant. Root wad and eddy habitats were significantly related to samples without pikeminnow for all buffer distances.

In August, three single habitats (riffles, slackwaters and cobble shoals) and nine habitat combinations were significantly greater in relative abundance for the samples with pikeminnow captures for at least some of the buffer distances. Within the seine haul area, cobble shoals, slackwater plus cobble shoals, riffles plus cobble shoals and riffles plus slackwater plus cobble shoals were significant. Riffles, slackwaters, runs plus slackwaters plus cobble shoals, riffles plus slackwaters and riffles plus cobble bars plus cobble shoals were marginally significant. The greatest number of significant relationships occurred at 20 meters (11) and reduced successively with each smaller buffer size, with four significant categories included in the seined area. The August samples differed in the regard from the March samples. The greatest number of significant categories occurred at 10 meters in march with six categories. It appears that the younger fish are more limited in the range and complexity of habitats.

The habitat association data generally support the conclusion of the targeted habitat analysis. The smaller fish (March samples) tend toward lower velocity habitats while the larger fish (August samples) use a broader range of habitats that are of higher and more varied velocity. As noted previously, cobble substrate appears important to the fish in the larger size class (TL > 100 mm), but not to the smaller fish.

GPS data were analyzed for razorback sucker for the first time in 2008. The analysis shows that areas where razorback sucker are captured tend to be more complex, are closer to islands and have more riffles. In other words, complex channel and habitat areas appear to be important. The non-native removal and large-bodied monitoring data show similar trends although there are fewer associated habitat in the large-bodied monitoring data. The smaller number of fish, the single pass sampling and the time of year could contribute to the differences.

In 2008, the non-native removal GPS data for Colorado pikeminnow indicated that they had less affinity for complex areas than in 2007, but did tend to be more abundant where there were islands. They were more uniformly distributed among the habitats in the river than in 2007 and than razorback sucker in 2008. The large-bodied monitoring samples show similar results.

The larval fish data indicate selection by larval razorback suckers for backwater habitats and inundated vegetation in both 2007 and 2008, with stronger selection for both in 2008. In 2008, the larval razorback sucker tended to be shifted down river relative to 2007, possibly as a result of the higher flows during spawning. Comparison to results in 2002 and 2003 would show if these preferences hold during drought years.

Conclusions

The following preliminary conclusions may be reached from these studies:

- Younger (<100 mm) Colorado pikeminnow appear to select for lower velocity habitats with selection for backwaters, embayments and pools indicated. These habitats also tend to have fine substrates.
- Habitat associations within about 10 meters of the capture site for younger Colorado pikeminnow that include backwaters and slackwaters together and pools together with slackwaters and runs are also important. Beyond 10 meters, the association with habitats is weaker, indicating a limited range of movement.
- Older (>100 mm) Colorado pikeminnow appear to select for habitats with higher and more varied velocities (riffles and cobble shoals). They also show selection for cobble substrates.
- The habitat associations in the vicinity of the captures of older Colorado pikeminnow indicate an affinity for more varied habitat and a larger range. The association of habitat complexes with Colorado pikeminnow capture strengthen with increased distance from the capture location up to 20 meters. Habitat associations that include cobble shoals, riffles and slackwaters appear important. Since many of the targeted riffle samples also included some slackwater or cobble shoal, the association of these habitats may be a contributing factor in the selection for riffles.
- Colorado pikeminnow that are large enough to be subject to electrofishing appear to be less selective in their habitat associations than smaller fish. In both 2007 and 2008 they seem to be associated more strongly with islands and island complexes. More fish were captured in 2008 than in 2007 and the sites were less specific to particular habitats or even to habitat complexity. Fall monitoring data showed similar results.
- GPS locations of razorback sucker captures from the two electrofishing programs indicate an affinity for islands and island complexes, similar to the Colorado pikeminnow. However, both data sets indicate that razorback sucker are associated with more habitat types and overall habitat complexity compared to Colorado pikeminnow. In particular, riffle habitat types in the vicinity of capture show significance for razorback sucker but not for Colorado pikeminnow of this size.
- Differences in results between the non-native removal and large-bodied monitoring programs may be related to time of year, multiple-pass versus single-pass sampling and the total number of captures. Additional years of comparative data are needed to understand the significance of any habitat associations.
- Larval razorback sucker where highly associated with backwater habitat and inundated vegetation. In 2008, 100% of the captures were in backwaters and 85% of those sites had inundated vegetation. In 2007 83% of the capture sites were backwaters and 59% had inundated vegetation. In both years backwaters and inundated vegetation were highly associated with sites with larval razorback sucker.
- 2008 was a much higher flow year during larval sampling than 2007 (140% greater mean flow during sampling). In 2008 captures were further down river compared to 2007 when captures were in approximate proportion to availability of habitat. The higher runoff may have contributed to the displacement.
- Additional years of larval pikeminnow data should be analyzed for habitat association, particularly the drought years, to verify the conclusions from these two years.

CHAPTER 5: RIVER-WIDE HABITAT MAPPING

BACKGROUND

River-wide habitat mapping began in 1991 as part of the seven-year research study. Results of the habitat mapping and response of habitat to flow became a key part of the flow recommendations formulated in 1999 (Holden 1999). Annual mapping of habitat in reaches 1 through 6 became a part of the standardized monitoring plan in 1999. River-wide habitat mapping was terminated after 2007 until monitoring protocol could be evaluated and revised.

OBJECTIVES

The objectives of river-wide habitat mapping are:

1. Annually monitor habitat abundance (count and total area) in the lower six reaches of the San Juan River.
2. Determine the relationship between habitat abundance and flow.

METHODS

Habitat quantity was determined using airborne videography as previously described by Bliesner and Lamarra (2000) and as established as part of the Long Range Monitoring Program. In 2005 the registration process was changed to digitally register and rectify the mapping images to 1997 digital orthophoto quads. Habitat types mapped can be seen in Table 5.1, summarized into seven general categories. After a detailed review of these groupings during the detailed reach mapping, it was determined that run/riffles function more like riffles than runs and should be summarized in that manner. This is a change in reporting for the 2006 habitat data reported here and the change has been made in all previous summaries for comparison.

Trend analysis was completed for the period of record by regressing the backwater habitat area with flow at mapping and then plotting the residuals of this relationship with time after shifting the values to preserve the mean habitat area.

Reported here are the results from 2007 mapping. Mapping is completed in late autumn. After mapping, the photos must be rectified and digitized. Processing time is such that this cannot be completed by the report date deadline so there is a one-year lag in reporting results.

Table 5.1. Seven General Categories of Habitat Types on the San Juan River

Low Velocity Types	Run Types	Riffle Types	Back-Water Types	Shoal Types	Slack-Water Types	Vegetation Associated Habitat Types
				sand		overhanging
pool	shoal/run	riffle	backwater	shoal	slackwater	vegetation
debris pool	run	shore riffle	backwater	cobble	pocket	Inundated
root wad	scour run	riffle chute	pool	shoal	water	vegetation
pool	shore run	shoal riffle	embayment			
eddy	undercut	rapid				
edge pool	run	chute				

RESULTS

2007 Mapping Summary

In 2007 mapping was completed in September and October at a higher mean flow under 1,000 cfs (Table 5.2 for 2002-2007). In 2007, the sequence of dominant to subdominant habitat types based upon the amount of surface area between RM 2 to RM 180 had the same distribution as the five previous years, except that inundated vegetation was slightly greater than backwaters for the first time (Figure 5.1). The results in terms of the percent of total wetted area are summarized in Table 5.2. Run habitats continue to dominate with 76.2% of the total wetted area (TWA), an increase from 2007. Riffles had the second largest surface area with 14.3% of the total wetted area. The third most plentiful habitat was shoal types with 6.7% of TWA. Slackwaters are the fourth dominant habitat at 1.5%, the lowest in the last six years. Backwaters made up only 0.28% of the surface area of habitats in 2007, the second highest percentage in the last six years.

The spatial distribution of these same general categories can be seen in Figures 5.2 and 5.3 for 2007. Figure 5.3 truncates the vertical scale to allow better viewing of the subdominant habitat distribution. Backwater habitats were distributed throughout the river but are highest in total area in Reaches 5, 4 and 1 (17,000 m^2, 9,800 m^2 and 7,500 m^2, respectively), moderate in Reach 3 (5,500 m^2), and lowest in Reaches 6 and 2 (4,100 m^2 and 3,000 m^2, respectively).

Other low velocity habitat types (Figure 5.3) were found to be most plentiful in Reach 5 (44,100 m^2), followed by Reach 4 (22,500 m^2), then Reach 6 (10,100 m^2) and Reach 3 (7,700 m^2). This habitat group is in greatest abundance in reaches of the highest complexity (Reaches 3, 5 and 6). In 2007, low velocity habitat types in Reach 3 dropped in abundance to less than ½ the 2006 level, similar to the change in backwater habitats. They dropped in Reach 6 by a similar amount. Low velocity habitats increased in Reaches 4 and 5 to about 2.5 times the 2006 level. The distribution of other low velocity habitat types was more similar to 2005 than 2006. Overall, the abundance of other low velocity habitat types increased by about 25% over 2006 levels, but was about the same as in 2005.

Shoals which are the third most dense habitat type are found throughout the river system but are a major habitat feature in the lower 19 miles of the San Juan River where it is influenced by the backwater effects of Lake Powell. In this reach all shoals have sand substrate. In Reaches 2-5 sand substrate dominates this habitat type (about 75%), but in Reach 6, cobble substrate dominates (63%). These changes depending on spring runoff volumes and the number of summer storm events. For example, 2006 had a higher portion of sand substrate than 2007, while 2005 had a lower portion.

Slackwater habitats are most abundant in Reaches 2 and 6, but are also plentiful in Reaches 4 and 5. They are associated with riffle complexes.

Table 5.2. Summary of mapping dates, flows and habitat distribution for 2002-2007

Year	Dates	Flow – cfs Range	Flow – cfs Average	Runs	Riffles	Shoals	Slack-water	Back-water	Low Velocity	Veg.
2002	7/23-8/04	329-704	431	77.1%	13.8%	6.4%	1.6%	0.17%	0.62%	0.09%
2003	10/20-24	337-511	448	75.1%	16.3%	4.7%	3.2%	0.13%	0.21%	0.11%
2004	11/03-08	758-891	811	71.3%	18.4%	5.7%	3.8%	0.21%	0.23%	0.25%
2005	11/12-18	830-1,020	928	68.8%	19.1%	9.1%	2.0%	0.29%	0.56%	0.04%
2006	9/18-10/19	865-1,187	1,068	70.3%	19.6%	5.5%	3.5%	0.27%	0.41%	0.20%
2007	9/06-10/16	906-1,079	972	76.2%	14.3%	6.7%	1.5%	0.28%	0.51%	0.34%

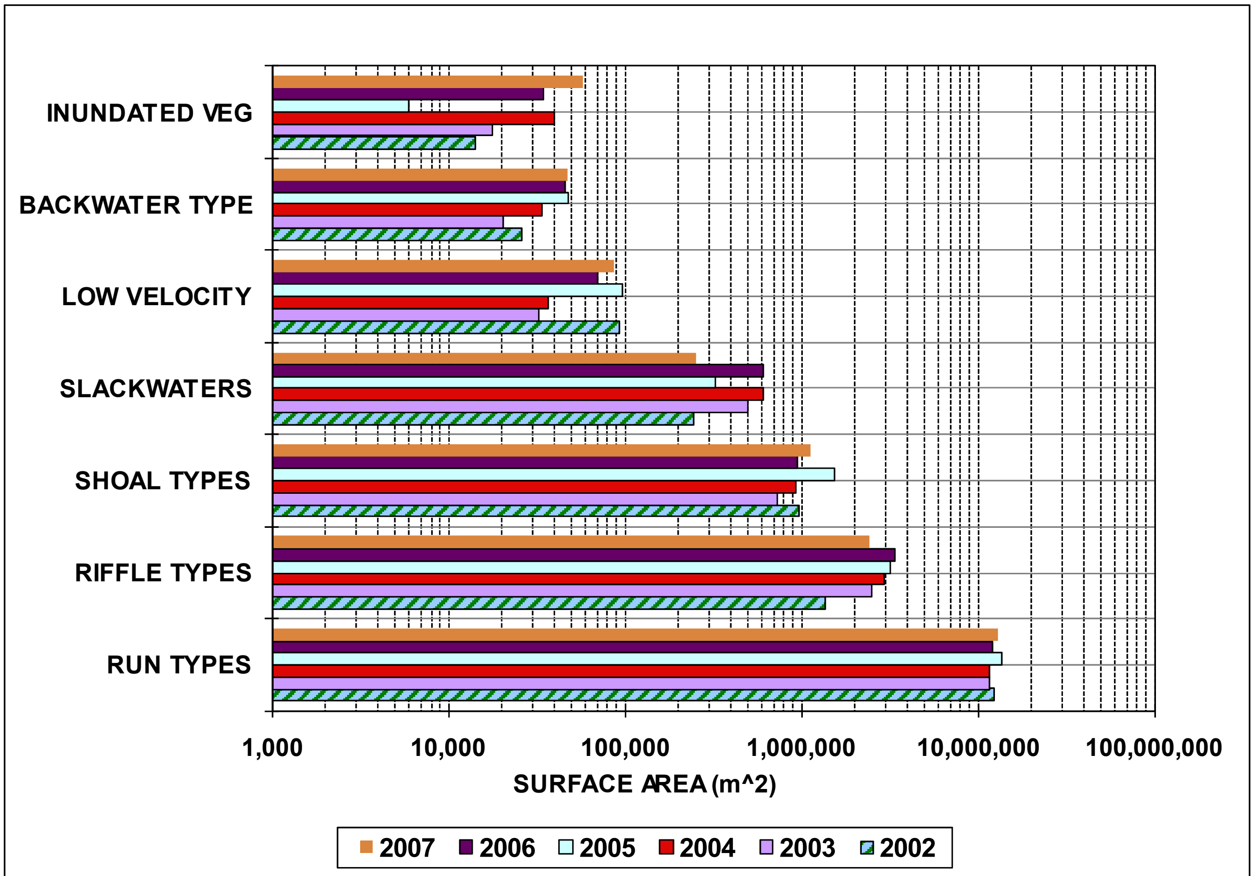

Figure 5.1. A comparison of the amount of surface area by general habitat type in the San Juan River (RM2 to RM180) for 2002 – 2007

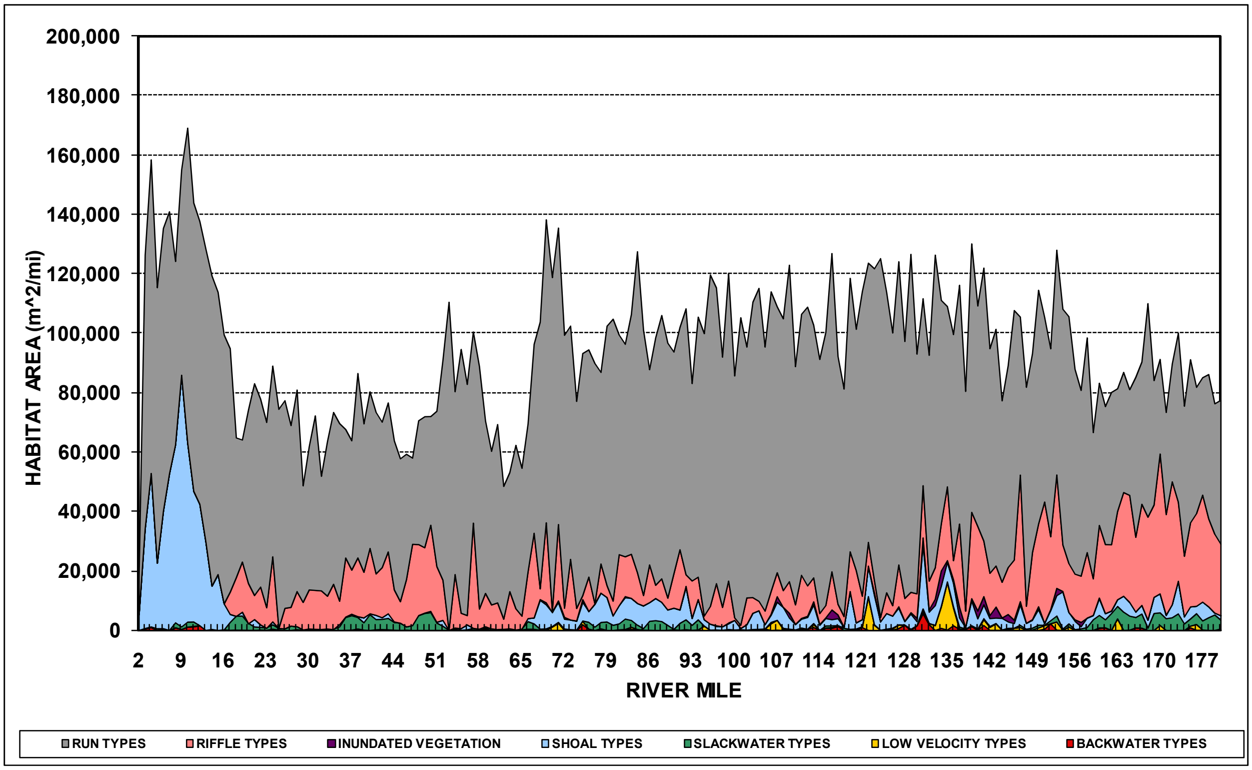

Figure 5.2. **The spatial distribution of major habitat types in the San Juan River for 2007**

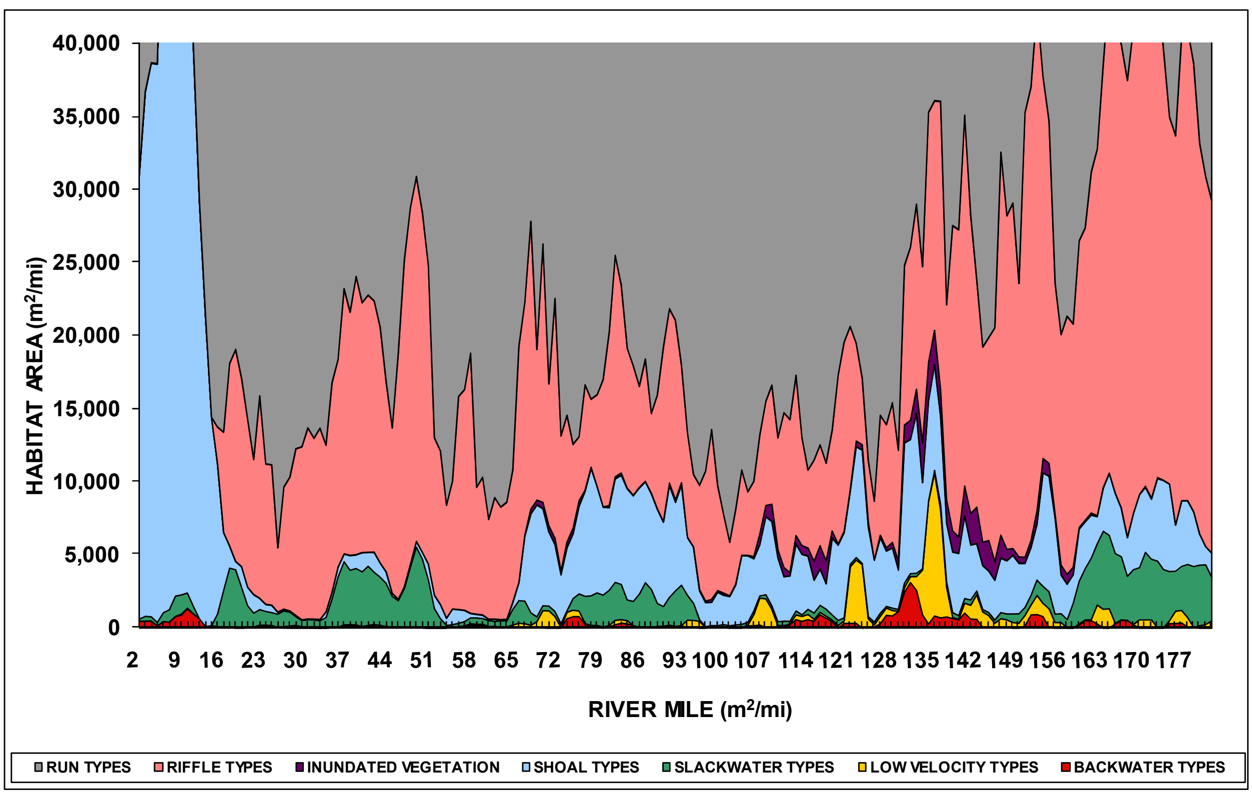

Figure 5.3. **The spatial distribution of major habitat types in the San Juan River in 2007, scaled to better show subdominant habitat distribution**

Backwater Trend Analysis

Backwater habitats represent an important component of the life cycle of many of the native species found in the San Juan River. Because of this fact, the temporal trend in the magnitude of surface area of this habitat type is used as a monitoring indicator to assess influences of flows on habitat quantity. As noted in previous investigations (Bliesner and Lamarra 2000), the magnitude of backwater habitats are influenced by their location in the river, flow magnitude, and summer storm events. A summary of the total surface areas for 2007 (47,000 m^2) compared to previous years is shown in Figure 5.4 for surface area and in Figure 5.5 for the count (numbers) of backwaters. The data indicate that after reaching a maximum surface area of 143,000 m^2 (373 backwaters) between RM 2 and RM 180 in 1995, there was a decrease to 26,000 m^2 (53 backwaters) in the summer of 2003. Since that time, backwaters have shown an upward trend which continued through 2005, flattening off in 2006. Backwater habitat area was essentially the same in 2007 as 2005 at similar flow. However, individual reaches exhibited more change. Reaches 1, 2, 5 and 6 all increased relative to 2006, with Reach 5 increasing the most (330% of 2006). Reaches 3 and 4 both decreased relative to 2006 (31% and 73% of 2006, respectively). The backwater count has continued to increase since 2005 and is the highest since 1999 (Figure 5.5).

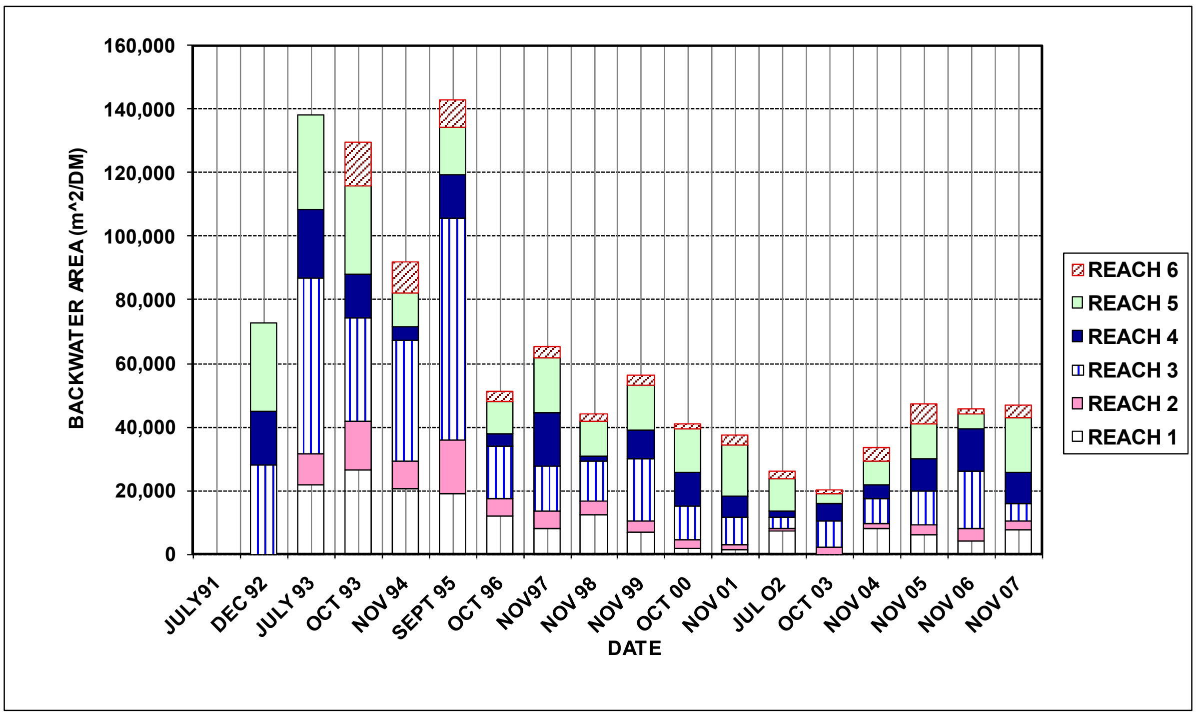

Figure 5.4. A comparison of the backwater surface areas mapped at low flow in the San Juan River since 1991 (450-1200 cfs)[7]

[7] Reach 1 not surveyed in December 92. Reach 6 not surveyed in December 92 or July 93.

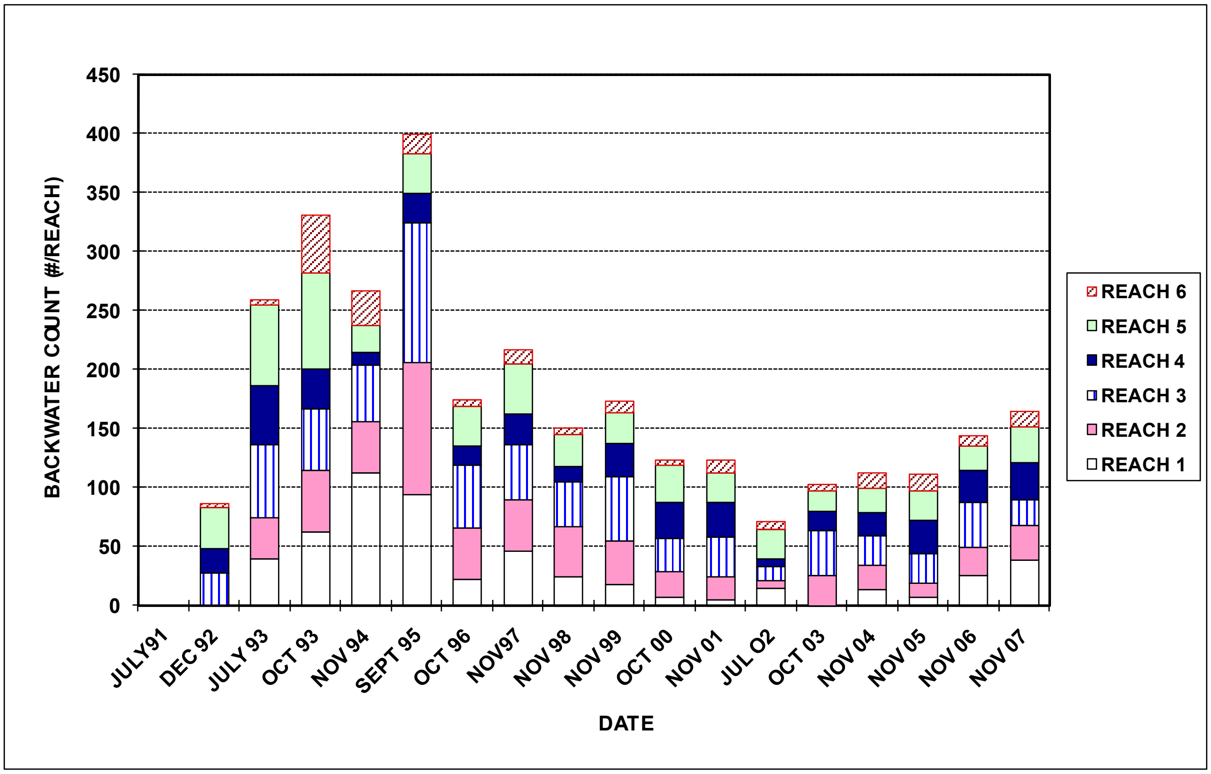

Figure 5.5. A comparison of the number of backwaters in the San Juan River mapped at low flow since 1991 (450-1200 cfs) [7]

Even though all these mappings occurred at low flow, there was still a relatively large range in flow at mapping (450 to 1,200 cfs). To better determine the change with time, the backwater areas were normalized by regressing habitat area against flow at mapping and then plotting the residuals of this relationship (adjusted to preserve the mean habitat area) with time (Figure 5.6). Only habitat data sets with flows under 1,200 cfs and for which reaches 1-6 were sampled are included. The relationship is significant with a downward trend through 2003, showing loss of habitat with time and then an increase to 2005 showing a reversal in the trend. Analyzing just the October 1995 through September 2007, there is no significant trend. However, there was a marginally significant increase in backwater area between 2004 and 2005 ($p=0.08$). There has been no significant change since 2005.

The increase in backwater and low velocity habitat in 2005 was in response to the high flows during 2005 spring runoff when all of the desired flow statistics were met. In 2006, only the 2,500 cfs criterion was met. In 2007 both the 2,500 and 5,000 cfs criteria were met, but not the 8,000 cfs and 10,000 cfs criteria. There is no significant difference in total backwater area among these years, although individual reaches did show significant change.

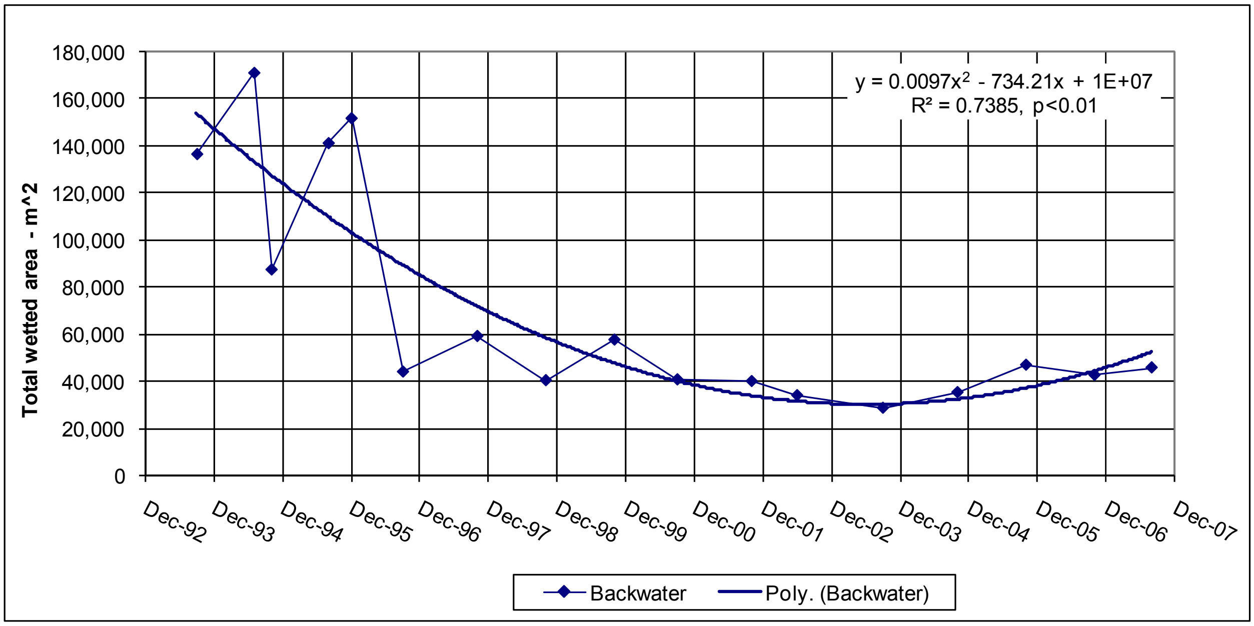

Figure 5.6. Backwater area residual (adjusted to yield mean habitat area) from habitat-flow regression with time

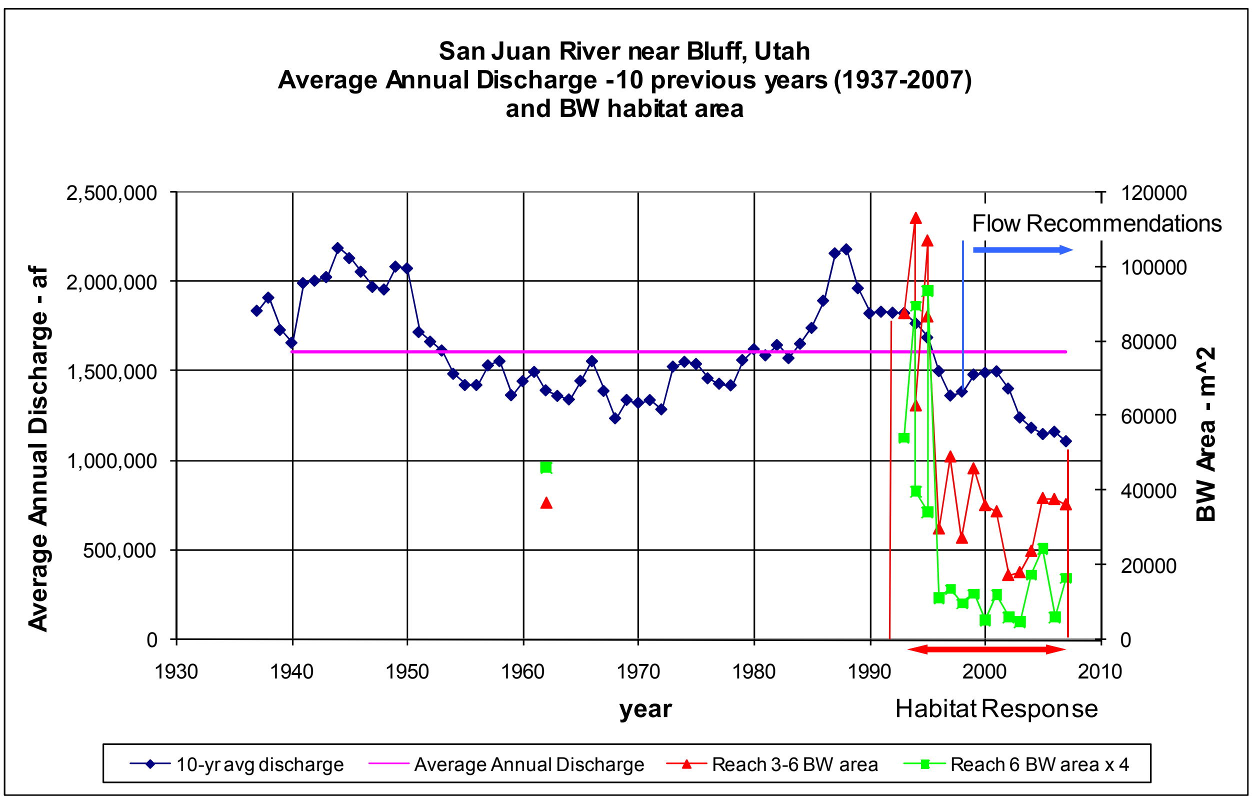

Figure 5.7. 10-year antecedent flow and backwater habitat area

The trend in backwater area was plotted with the 10 year average antecedent runoff and compared to the 1962 backwater area (Figure 5.7). The 1962 backwater area was determined from aerial photography at flows in the range of 500-1,000 cfs. 1962 was during an extended drought, but the 10-year antecedent flow was higher than that seen in the last 5 years. The Reach 3-6 backwater area is about the same in 2007 as it was in 1962. In Reach 6, however, it is much lower, coinciding with observed channel armoring and simplification in this reach that is heavily influenced by adjacent irrigation, some physical channel modifications and heavy bank vegetation.

Channel Complexity

Island count is used as an indicator of channel complexity as it represents the number of multiple channels in a given reach. The island count, normalized for flow at mapping shows a significant ($p=<0.01$) downward trend with time, indicating channel simplification (Figure 5.8). A second and related relationship of total wetted area with time, normalized for flow at mapping, shows the same trend (Figure 5.9). In the 15 years since mapping began there has been a cumulative reduction in island count at low flow of about 25%. During the same time the total wetted area has decreased by about 10%. In 2007, there was an increase in total island count, with the total count adjusted for flow at mapping about the same as in 1999.

The loss of islands has not been uniform among reaches. A comparison of island count by reach with time during years when flows at mapping were similar shows that a number of the reaches have stabilized, but Reach 5 continued to decline through 2006 (Table 5.3). In 2007, the trend reversed in all reaches except Reach 6. Reach 5 increased the most (35%). There was also an increase in total island area in 2007. Both island count and total area was greater in 2007 than any year since 1998.

This is the first reversal in trend in Reach 5 during the study. A careful inspection of the 2006 and 2007 habitat maps indicated that the increase was distributed throughout the reach. Most (80%) of the changes were caused by secondary channels flowing in 2007 that were dry in 2006, even though the mapping flow was higher in 2006 than in 2007. The remainder of the changes resulted from cobble bars, sand bars or root wad piles in 2006 being mapped as islands in 2007. That can happen as vegetation establishes on islands or deposition occurs around root wad piles. From the detailed reach studies there was more deposition between 2006 and 2007 than between 2005 and 2006, primarily as a result of a long-duration storm event in August. This sedimentation could have increased the bed elevation of the main channel and caused additional small channels to flow relative to 2006. If the sedimentation leads to increased island count, it will not likely sustain. However, since no habitat mapping was completed in 2008, there is no monitoring program in place to determine if this reversal will persist or if it was anomalous.

The channel simplification indicated by the reduction in islands over time may be attributed to two possible causes: extended drought and encroachment of non-native vegetation, primarily Russian olive and salt cedar. The 10-year antecedent average runoff has been decreasing since the beginning of this study (Figure 5.7). Examination of island count normalized for flow at mapping with 10-year antecedent flow shows a significant relationship (Figure 5.10). The channel simplification could be a result of the extended drought, unprecedented in hydrologic record.

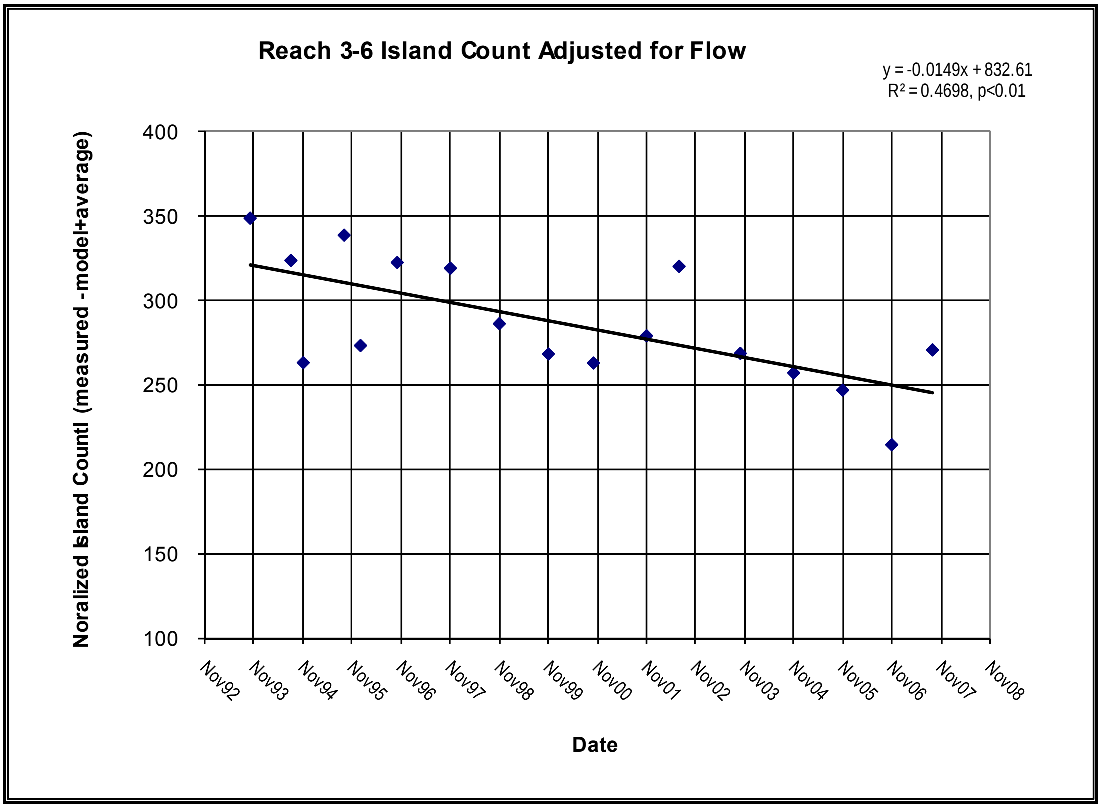

Figure 5.8. Change in normalized island count (residual from flow-island count relationship plus the average island count) with time

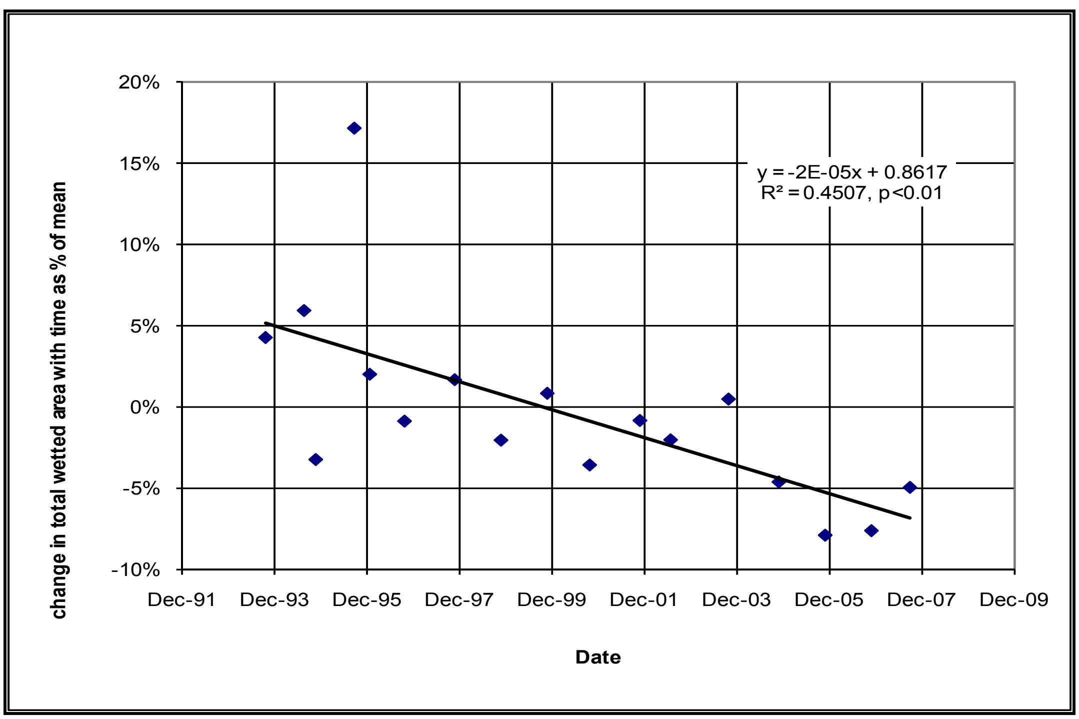

Figure 5.9. Change in normalized total wetted area (residual from flow-island count relationship plus the average island count) for reaches 3-6 with time

Table 5.3. Island count by reach for select years with similar flows, 1993-2007

Reach	1993	1999	2004	2005	2006	2007
3	98	60	58	63	66	76
4	83	58	48	48	49	61
5	105	88	77	78	72	97
6	77	54	60	64	63	61
Total	**363**	**260**	**243**	**253**	**250**	**295**
Flow - cfs	944	828	798	900	1,048	998

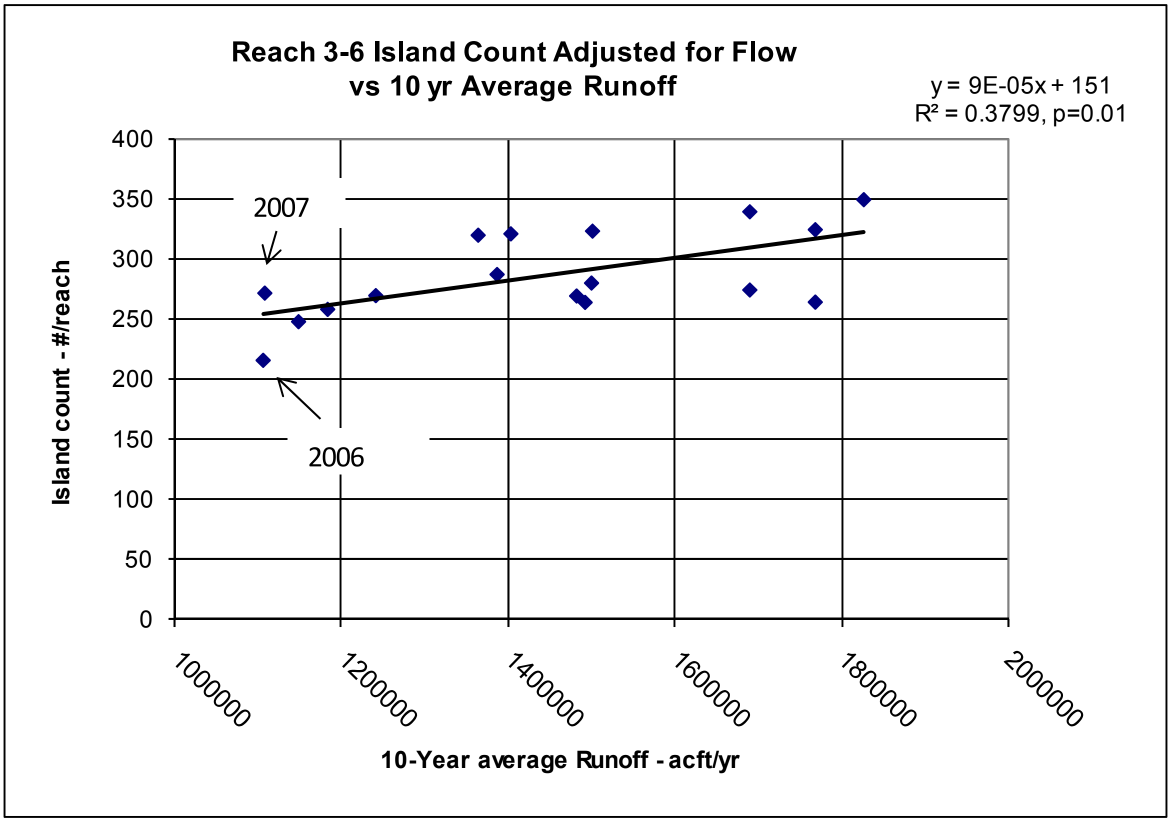

Figure 5.10. Island count adjusted for flow as influenced by the 10-year average antecedent flow in the San Juan River near Bluff, Utah

Encroachment of salt cedar and Russian olive has been observed during mapping over the past 15 years. This is exacerbated during dry periods when flow in secondary channels is inadequate to remove young vegetation. Once the vegetation is established it becomes an effective trap for fine sediments by creating increased channel roughness and low boundary velocities. With this established vegetation on main channel margins and within secondary channels it is more difficult for those channels to be flushed and for new ones to be created during high flow years. Stamp et al. (2006) observed these conditions in Reach 6 and recommended testing removal of non-native vegetation in the mouths of secondary channels as a mechanism for increasing low velocity habitat.

Bliesner et al. (2007) recommended studying the feasibility of non-native vegetation removal in channel mouths in Reach 5, if increased low velocity habitat was deemed important to the recovery of the endangered fish. The long-term trends in channel simplification and loss of low velocity habitat in Reach 5 support that recommendation. Further investigation is recommended to see if the reversal of trend in Reach 5 seen in 2007 is being sustained.

CONCLUSIONS

The following conclusions can be drawn from river-wide habitat mapping:

- Relative abundance among habitat categories has not changed during the 15 years of data collection. Runs, riffles and slackwater still dominate.
- Backwater habitat reached a low in 2003 at about 20% of the peak value. The trend started to reverse in 2004 and increased even more in 2005. There is no significant difference in Reach 1-6 total backwater area since 2005.
- The channel is simplifying with time as evidenced by a loss of islands and reduction in total wetted area with time.
- The channel simplification is related to both the extended dry period and encroachment of non-native vegetation along main channel margins and within secondary channels.
- Reach 5 has experienced the greatest loss of islands over time, but the trend reversed in 2007.
- Reach 3 lost the greatest amount of backwater habitat over time, followed by Reach 5. In 2007, backwater area increased significantly in Reach 5, but dropped in Reach 3.
- The increase in island count and backwater area in Reach 5 is not explained by antecedent hydrology.
- Further investigation in Reach 5 is warranted to determine the sustainability of the recent trend shift in backwater area and channel complexity.

CHAPTER 6: WATER TEMPERATURE

METHODS

Eight temperature recorders are presently installed in the San Juan and Animas rivers and have been in place since summer of 1992 at the locations shown in Table 6.1. From 1992-1999, OMNIDATA DP-230 data pod loggers sampled water temperature every 10 minutes and stored maximum, minimum and mean temperature for each day. Optic StowAway temperature loggers from Onset Corporation were utilized from 1999-2006. In 2006, these recorders were replaced with Onset Corporation HOBO Water Temp Pro loggers. They record water temperature every 15-minutes. Table 6.1 also shows the periods of record at each site. The missing data were caused by equipment problems or vandalism.

The recorders are inspected and read twice each year, once in the spring and once in the fall. Battery condition is monitored and loggers changed out when the battery life falls below that required to continue until the next reading point.

The records are maintained in a Microsoft Access Database. Also included in the database are temperature data from other sites that have been measured in the past or from USGS records. These sites are also shown in Table 6.1 with their period of record. All sites except Four Corners are missing data between September 16 and October 11-12, 2006. The storage space was exceeded on these recorders prior to servicing. The Animas at Farmington recorder malfunctioned and is missing data from September 16, 2006 to April 25, 2007.

RESULTS

The temperature profiles plotted with the hydrograph at the Four Corners (4C) gage illustrate the negative correlation between flow and water temperature (Figure 6.1). The Navajo Dam release started in mid-February caused a drop in water temperature of from 1 - 4° C from about March 1 to June 20, 2008. Early in the period the suppression was the smallest. At times the water at Archuleta was 5-7° C cooler than the Animas River. The temperature of the San Juan at Farmington ranged 1 - 5° C cooler than the Animas at Farmington, depending on the flow in the Animas. By the end of the fish release the San Juan and Animas Rivers at Farmington were approximately the same water temperature (15° C). The water temperatures on the San Juan and Animas Rivers at Farmington remained nearly the same until mid-August. After which, the water temperatures on the Animas River was 1 - 4° C warmer than the San Juan throughout the rest of the 2008 water year. This temperature suppression in 2008 was extended relative to other years due to the extended release.

Table 6.1. Water Temperature Monitoring Locations and Period of Record

Location	RM	Period of Record
Active Temperature Recording Sites		
Near Navajo Dam	225.0	7/9/1999 to 9/15/06, 10/12/06 to 9/30/08
Archuleta - San Juan at USGS Gage Location	218.6	7/23/92 to 9/15/06, 10/12/06 to 9/30/08
Farmington - San Juan at USGS Gage Location	180.1	8/5/92 to 1/16/96, 7/8/99 to 11/4/01, 10/3/02 to 9/15/06, 10/11/06 to 9/30/08
Shiprock - San Juan at USGS Gage Location	148.0	7/8/99 to 9/16/06, 10/11/06 to 9/30/08
Four Corners - San Juan at USGS Gage Location	119.4	10/7/94 to 3/11/96*, 7/9/99 to 9/30/08
Montezuma Creek - San Juan at Montezuma Creek Bridge	93.6	8/9/92 to 1/11/93, 2/25 to 3/14/93, 4/14 to 5/10/93, 5/28/93 to 3/11/05, (sensor stolen. Replaced 10/31/05) 10/31/05 to 9/16/06, 10/12/06 to 9/30/08
Mexican Hat - San Juan near Bluff Gage Location	52.1	7/9/99 to 3/27/02 , 9/18/02 to 8/1/06, 10/12/06 to 9/30/08
Farmington - Animas at USGS Gage Location	n/a	8/5/92 to 4/14/97, 5/7/97 to 8/26/97, 10/15/97 to 6/4/98, 7/8/99 to 9/15/06, 4/25/07 to 9/30/08
Other Temperature Records in Database		
Blanco - San Juan at US-64 Bridge	207.1	8/7/92 to 2/28/95 (missing 11/21 - 12/9/92)
Bloomfield - San Juan at Highway 44 Bridge	195.6	2/27/93 to 7/17/98
Lee Acres - San Juan at Lee Acres Bridge	188.9	8/8/92 to 12/2/92, 2/26/93 to 4/15/93, 5/27/93 to 9/6/94, 3/9/95 to 10/10/95
USGS Data - San Juan at Archuleta	218.6	10/1/50 - 9/30/68 with some missing data
USGS Data - San Juan at Shiprock	148.0	10/1/51 - 9/30/86,9/7/91 - 3/3/93 with some missing data
USGS Data – Animas at Farmington	n/a	10/1/52 - 9/30/90 with some missing data
Cedar Hill - Animas at USGS Gage nr Cedar Hill, NM	n/a	8/7/92 to 9/22/98

Note: All locations missing October 1992 data.

* Installed 8/10/92 but bad data were logged until thermistor was changed in October 1994. Prior to this time it was thought sediment accumulation was causing the warmer readings instead of a bad thermistor.

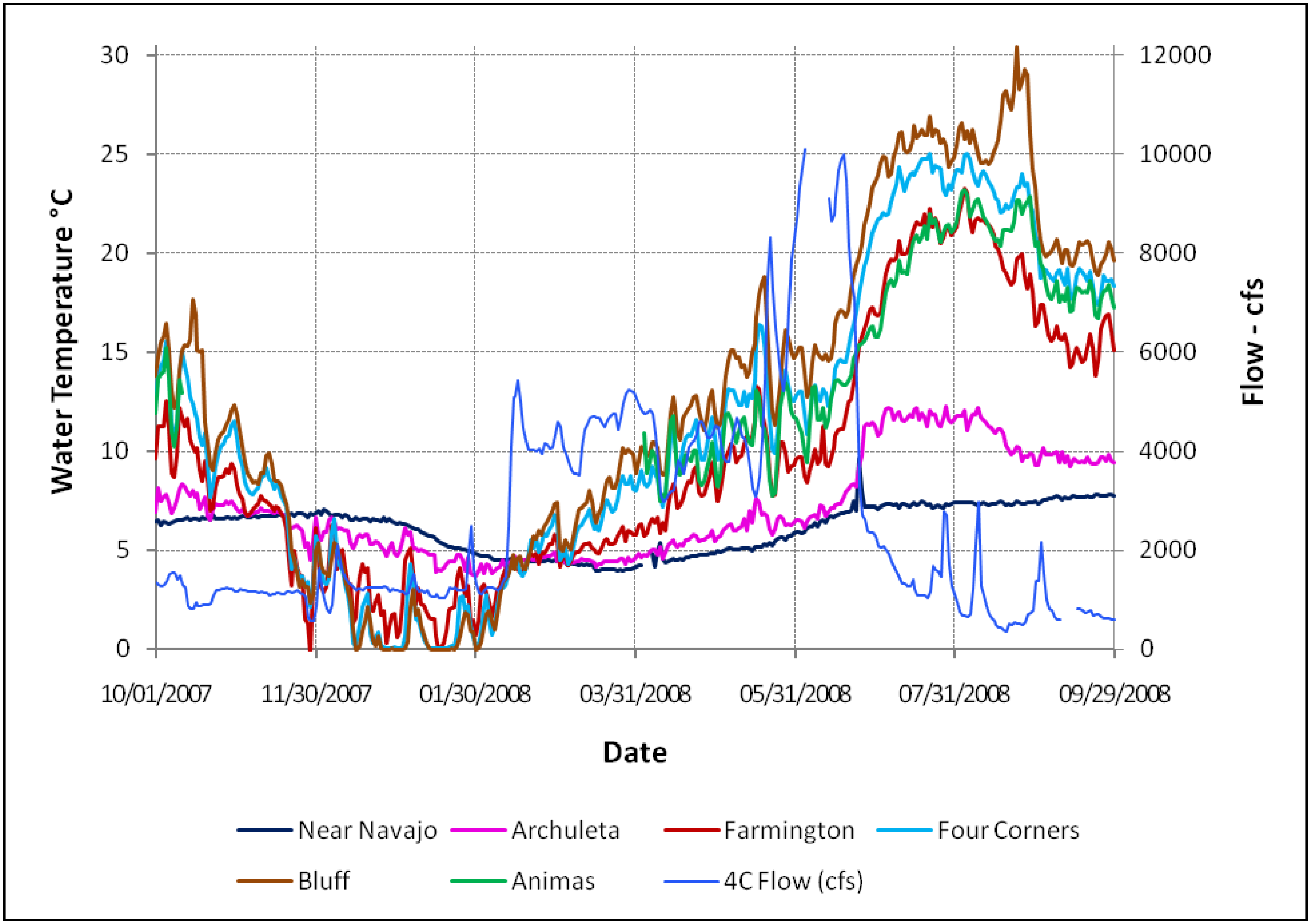

Figure 6.1. **San Juan Basin Average Water Temperature Data, 2008**

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APPENDIX A

Table A1. Summary of habitat selection ratios: March 2008 - RM 137

SPECIES/ FISH GROUP *	PM	ALL FISH	ALL NATIVE	ALL NON-NATIVE	BHS	FLM	SPD	RSH	FHM	CAT
HABITAT	**RATIO (n=48)**	**RATIO (n=263)**	**RATIO (n=144)**	**RATIO (n=119)**	**RATIO (n=8)**	**RATIO (n=5)**	**RATIO (n=83)**	**RATIO (n=11)**	**RATIO (n=108)**	**RATIO (n=0)**
Backwater	6.95		2.32							
Cobble Shoal	0.00		1.80	0.09			3.00		0.10	
Eddy										
Embayment	8.64	2.50	3.36							
Isolated Pool		21.96		48.52					53.47	
Run		0.51		0.12			0.59		0.06	
Pool	4.99	1.62	2.03	1.12					0.00	
Riffle	0.00	0.19	0.34	0.00					0.00	
Sand Shoal	0.00	0.51		0.00					0.00	
Slackwater	0.41	0.48		0.07					0.04	

*PM: Colorado pikeminnow; BHS: Bluehead sucker; FML: Flannelmouth sucker; SPD: Speckled dace; RS: Red shiner; FHM: Fathead minnow; CAT: Channel catfish.

Only significant selection ratios ($p<0.05$) are shown.

Ratio value greater than one indicate selection for, ratios below one indicate selection against, and ratios equal to one indicate no selection.

Table A2. Summary of habitat selection ratios: March 2008 - RM 131

SPECIES/ FISH GROUP *	PM	ALL FISH	ALL NATIVE	ALL NON-NATIVE	BHS	FLM	SPD	RSH	FHM	CAT
HABITAT	RATIO (n=48)	RATIO (n=263)	RATIO (n=144)	RATIO (n=119)	RATIO (n=8)	RATIO (n=5)	RATIO (n=83)	RATIO (n=11)	RATIO (n=108)	RATIO (n=0)
Backwater		0.00	0.00				0.00			
Cobble Shoal		0.17	0.09		0.00		0.11			
Run		0.04	0.04		0.00		0.02			
Pool	10.15	0.31	0.29		0.15		0.02			
Riffle		0.10	0.10		0.00		0.10			
Sand Shoal					0.00					
Slackwater	0.20	3.03	3.04		4.36		2.90			

* PM: Colorado pikeminnow; BHS: Bluehead sucker; FML: Flannelmouth sucker; SPD: Speckled dace; RS: Red shiner; FHM: Fathead minnow; CAT: Channel catfish.

Only significant selection ratios ($p<0.05$) are shown.

Ratio value greater than one indicate selection for, ratios below one indicate selection against, and ratios equal to one indicate no selection.

Table A3. Summary of habitat selection ratios: August 2007 - RM 137

SPECIES/ FISH GROUP *	PM	ALL FISH	ALL NATIVE	ALL NON-NATIVE	BHS	FLM	SPD	RSH	FHM	CAT
HABITAT	**RATIO (n=19)**	**RATIO (n=202)**	**RATIO (n=129)**	**RATIO (n=73)**	**RATIO (n=8)**	**RATIO (n=22)**	**RATIO (n=80)**	**RATIO (n=15)**	**RATIO (n=3)**	**RATIO (n=53)**
Cobble Shoal	2.50	0.47		0.33			0.30			0.15
Eddy	3.04	2.29	1.94	2.90			2.17			3.27
Run		0.52	0.55				0.44			
Plunge										
Riffle		0.28	0.44	0.00						0.00
Sand Shoal										
Slackwater		1.34	1.27	1.45			1.40			1.49

* PM: Colorado pikeminnow; BHS: Bluehead sucker; FML: Flannelmouth sucker; SPD: Speckled dace; RS: Red shiner; FHM: Fathead minnow; CAT: Channel catfish.

Only significant selection ratios ($p<0.05$) are shown.

Ratio value greater than one indicate selection for, ratios below one indicate selection against, and ratios equal to one indicate no selection.

Table A4. Summary of habitat selection ratios: August 2007 - RM 82 and 137 (combined)

SPECIES/ FISH GROUP*	PM	ALL FISH	ALL NATIVE	ALL NON-NATIVE	BHS	FLM	SPD	RSH	FHM	CAT
HABITAT	RATIO (n=24)	RATIO (n=1102)	RATIO (n=314)	RATIO (n=782)	RATIO (n=16)	RATIO (n=115)	RATIO (n=159)	RATIO (n=126)	RATIO (n=129)	RATIO (n=527)
Backwater		14.97		20.93				6.31	117.09	
Cobble Shoal	2.38	0.39	0.71	0.26			0.13	0.11	0.06	0.35
Eddy	4.30			0.57			1.95		0.00	
Isolated Pool		95.98	38.87	118.74		106.13		96.86	473.05	7.72
Run		0.40	0.43	0.39		0.37	0.46	0.05	0.00	0.57
Plunge			2.69				5.32			
Pool		8.00	5.95	8.82		5.58	7.34	23.17	12.22	4.65
Riffle		0.29		0.05				0.00	0.00	0.08
Sand Shoal		1.55		1.74		1.89	0.38		0.09	2.30
Slackwater				0.92			1.16		0.15	1.13

* PM: Colorado pikeminnow; BHS: Bluehead sucker; FML: Flannelmouth sucker; SPD: Speckled dace; RS: Red shiner; FHM: Fathead minnow; CAT: Channel catfish.

Only significant selection ratios ($p<0.05$) are shown.

Ratio value greater than one indicate selection for, ratios below one indicate selection against, and ratios equal to one indicate no selection.

Table A5. Summary of habitat selection ratios: August 2008 - RM 131

SPECIES/ FISH GROUP *	PM	ALL FISH	ALL NATIVE	ALL NON-NATIVE	BHS	FLM	SPD	RSH	FHM	CAT
HABITAT	RATIO (n=24)	RATIO (n=154)	RATIO (n=120)	RATIO (n=34)	RATIO (n=0)	RATIO (n=8)	RATIO (n=88)	RATIO (n=7)	RATIO (n=1)	RATIO (n=25)
Backwater		26.94	23.48	39.14			32.02			50.10
Cobble Shoal		0.43	0.49				0.33			0.00
Eddy										
Embayment										
Run		0.38	0.26				0.20			
Riffle	2.47		1.41							0.00
Sand Shoal		2.66	2.89				3.58			
Slackwater		0.40	0.39	0.46			0.28			

* PM: Colorado pikeminnow; BHS: Bluehead sucker; FML: Flannelmouth sucker; SPD: Speckled dace; RS: Red shiner; FHM: Fathead minnow; CAT: Channel catfish.

Only significant selection ratios ($p<0.05$) are shown.

Ratio value greater than one indicate selection for, ratios below one indicate selection against, and ratios equal to one indicate no selection.

Table A6. Summary of habitat selection ratios: August 2008 - RM 82, 131, and 137 (combined)

SPECIES/ FISH GROUP *	PM	ALL FISH	ALL NATIVE	ALL NON-NATIVE	BHS	FLM	SPD	RSH	FHM	CAT
HABITAT	**RATIO (n=56)**	**RATIO (n=1304)**	**RATIO (n=701)**	**RATIO (n=603)**	**RATIO (n=16)**	**RATIO (n=106)**	**RATIO (n=523)**	**RATIO (n=58)**	**RATIO (n=4)**	**RATIO (n=526)**
Backwater		5.70	6.69	4.55		3.77	8.02	22.38		1.99
Cobble Shoal		0.50	0.43	0.58			0.25	0.25		0.60
Eddy										
Embayment		0.32		0.10						0.00
Isolated Pool						2.86				
Run	0.26							0.25		1.18
Plunge										
Pool		5.70	4.19	7.46		5.76	4.08	11.83		7.25
Riffle	2.05	0.43	0.67	0.15			0.52	0.38		0.12
Sand Shoal		0.75	0.64			1.73	0.40			
Slackwater						0.48		0.16		

* PM: Colorado pikeminnow; BHS: Bluehead sucker; FML: Flannelmouth sucker; SPD: Speckled dace; RS: Red shiner; FHM: Fathead minnow; CAT: Channel catfish.

Only significant selection ratios ($p<0.05$) are shown.

Ratio value greater than one indicate selection for, ratios below one indicate selection against, and ratios equal to one indicate no selection.