SAN JUAN RIVER BASIN
RECOVERY IMPLEMENTATION PROGRAM

HYDROLOGY, GEOMORPHOLOGY AND HABITAT STUDIES

2006 FINAL REPORT

prepared by

Ron Bliesner
Keller-Bliesner Engineering, LLC
78 East Center
Logan, Utah 84321
(435) 753-5651

and

Vince Lamarra
Ecosystems Research Institute
975 South Highway 89-91
Logan, Utah 84321
(435) 752-2580

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

HYDROLOGY

The 2006 flow in the San Juan River near Bluff, Utah was only 56% of the 1931-2006 average. The flow recommendation operating rules called for a small release since the reservoir level was high in the spring. The release in 2006 consisted of a 9-day ramp up, 6 days at 4,900 cfs with a 9-day ramp down, ending on June 16. The release in excess of 600 cfs totaled nearly 114,000 acre-feet. The resulting peak flow at Four Corners was 5,900 cfs. Only the 2,500 cfs duration requirements of the flow recommendation were met. This is in contrast to the 2005 water year when all flow recommendation statistics were met.

Two storm runoff events with peak discharge greater than 3,000 cfs occurred post-runoff (one in July and one in August). Numerous smaller storm events occurred throughout August and September. These events are typically sediment laden and increase turbidity and sediment deposition through the fall months. While late summer and fall storm events are common, July and early August storm events that could affect pikeminnow hatching success only occur about 30% of the time.

DETAILED REACH STUDIES

Detailed reaches established at RM 82 and RM 137 in 2005 were surveyed again in 2006 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. Standard and detailed habitat mapping were completed in March and November 2006. Endangered fish capture data from these reaches collected by other studies were included for comparison to habitat data. The River2D model results were used to predict availability of habitat over a range of flows.

Based on these studies, the following conclusions were reached:

Channel Change

- DR 82 demonstrated about 3 cm of net scour between November 2005 and August 2006, with both scour and deposition within the reach. Both cobble/gravel and sand had a net reduction in the reach.
- DR 137 demonstrated about 3 cm of net deposition during the same time period with both scour and deposition within the reach. Both cobble/gravel and sand had net import to the reach.
- The change in both reaches is statistically significant

River2D Model

- River2D models have been developed for DR 82 and 137 that cover ranges in flow from about 700 cfs to around 6,000 cfs.
- Channel change between 2005 and 2006 resulted in a deterioration of model accuracy in DR 82, requiring re-calibration using the 2006 survey data.
- Changes in flow during 2005 edge-of-water survey lead to poor calibration results in DR 137. 2006 calibrations are better.
- The models provide sufficiently reliable results to forecast depth and velocity over a range of flows.

Detailed Reach Habitat

- Detailed mapping identifies from 2 to 3 times as many habitat polygons as standard mapping.
- Changes between 2005 and 2006 at flows near 1,000 cfs are small.
- Interpretive difference between mappers of some habitat categories suggests a review of the classifications and training standards for future refinement.

Integrating Fish Monitoring Data

- Both reaches are used by Colorado pikeminnow and razorback sucker.
- Only the Colorado pikeminnow augmentation study provided site-specific data for endangered fish in these reaches.
- Neither the accuracy of GPS fish capture locations or of habitat map projections is sufficient to provide habitat-specific capture locations.

Model and Habitat Data Integration

- Differences in map accuracy between the survey-generated base for River-2D modeling and the projected digital videography frames for habitat mapping prevented intersection of the two data sets to calibrate velocity and depth to habitat type.
- Using depth-velocity-habitat relationships reported in 2000, the model can only predict change in habitat abundance by category with change in flow. It cannot accurately predict location or total area at any given flow. With additional calibration it may be able to reasonably predict total area at any given flow, but will not give the same spatial distribution as physical mapping.
- The modeled low velocity habitat is much greater than mapped, even when weighted for suitability based on depth and velocity. The difference is primarily along channel margins that are not mapped. Changes in mapping could identify these areas if found to be important to endangered fishes.
- Weighted usable area of low velocity habitat increases with flow above about 1,000 cfs, but is relatively constant as a percentage of the total wetted area. Weighted usable area is actually lower at 1,000 cfs than at 600-700 cfs.

The detailed reach studies provide some new insight into the relationships between hydrology, geomorphology, habitat and fish. Some of the lessons learned apply to the collection of data. Based on the 2006 findings the following recommendations for adjustments in the work plan are made:

- Collection of Wolman pebble count data (Wolman, 1954) should be added to allow large-particle sediment transport analysis to meet objective 5.
- More model calibration is required to eliminate isolated wetted areas, particularly at high flow, that are a result of modeling. These areas can result in over-predicting low velocity habitat availability unless removed from analysis, although the over-prediction is small (<5%).
- Endangered fish habitat use data should be collected simultaneously with habitat mapping to provide a linkage between habitat availability and habitat use.
- Habitat mapping categories should be refined to assure that conditions that exist at fish capture locations are adequately described and to assure that the habitat types can be identified with repeatability across mappers and with time.
- An agreed-upon set of habitat descriptions should be used by all studies and a training program should be instituted to assure that all field personnel with responsibility for determining habitat type have the same training.

- Effort should be placed on identifying the suitability of low velocity habitat along channel margins for endangered fish.
- If this edge habitat is found to be important, a process of mapping it should be developed.

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. The following conclusions are drawn from the results of the habitat mapping in 2005:

- Relative abundance among habitat categories has not changed during the 14 years of data collection. Runs, riffles and slackwaters still dominate.
- Backwater habitat reached a low in 2003 at about 20% of the peak value in 1995. The trend started to reverse in 2004 and increased even more in 2005.
- The 40% increase in backwater habitat area between 2004 and 2005 is attributed to the high flow year, during which the desired flow recommendation conditions were all met.
- Multiple high flow years will likely be required to achieve backwater conditions similar to 1995 (Bliesner and Lamarra, 2006).

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 made May 25, 2006 to June 16, 2006 caused an average drop of approximately 4 - 5° C over a two week period throughout the river system. At high flow, the temperature at Archuleta is suppressed to the dam release temperature and the temperature of the San Juan at Farmington ranged 1 - 6° C cooler than the Animas at Farmington. By the end of the fish release (June 16), the San Juan and Animas Rivers at Farmington were approximately the same water temperature (16° C). The water temperatures on the San Juan and Animas Rivers at Farmington remained nearly the same until June 29, 2006. After which, the water temperatures on the Animas River was 1 - 4° C warmer than the San Juan throughout the rest of the 2006 water year, coinciding with the period after spring runoff on the Animas River.

This temperature suppression is typical in years of low Animas flows during a release from Navajo Dam. During high-flow years the suppression is much less, as the larger volume of Animas runoff is typically cooler.

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. In 2005, two detailed reach studies were initiated. The reaches were selected and first surveyed in 2005.

This report summarizes data collected in 2006 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
- 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 2006 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 are covered in the Long-Term Monitoring Plan and are not described in detail in this annual progress report, except for the methods for detailed reach analysis. This report concentrates on data reporting with a minimum of data analysis, particularly between data sets.

SAN JUAN RIVER STUDY AREA

The seven-year research program defined 8 geomorphically distinct reaches in the San Juan River (Bliesner and Lamara, 2000). Figure 1.1 shows these reach locations. 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.

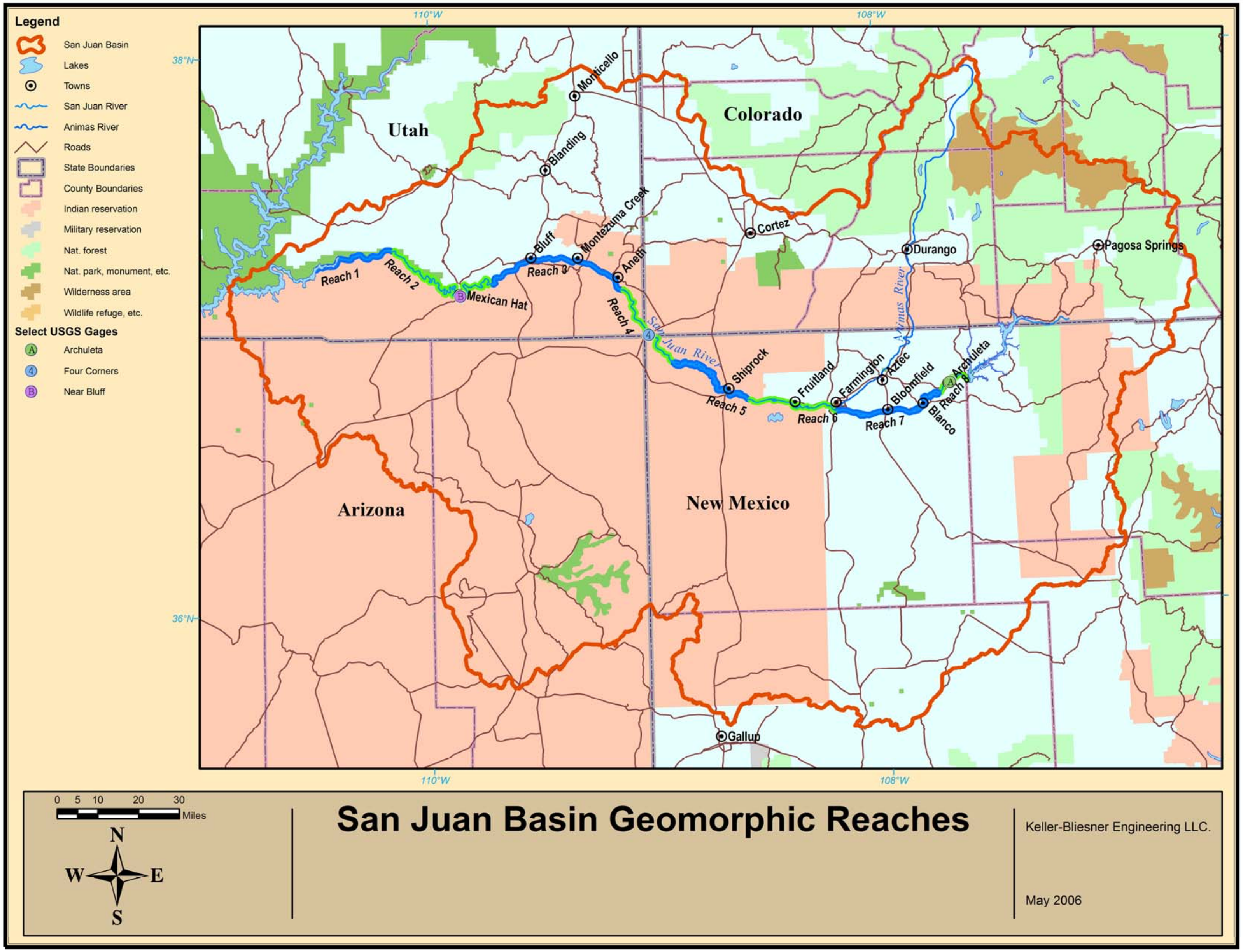

Figure 1.1. San Juan Basin location map showing geomorphic reaches

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 this 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 2006 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.

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

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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 the 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. Save 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.

Juan River below Farmington, NM. Beginning in 1999, the operating rules presented in the Flow Recommendation Report were implemented.

Water year 2006 was a dry year with annual runoff at Bluff just 56% of the 1929-2006 average. The March through July runoff at Bluff was 484,000 ac-ft (46% of 1929-2006 average). The fish release was limited to a 9-day ramp-up, a 6-day peak of 4,900 cfs, and a 9-day ramp-down resulting in a total release of 113,583 ac-ft above base flow (600 cfs) conditions (Table 2.1). This table also describes the nature of the release each year since 1991 for comparison. The volume of water released is that water in excess of an assumed base release of 600 cfs, the typical minimum historical release. In 2000, 2002, 2003 and 2004 there was not sufficient water to make a fish release.

Only 3 years since 1991 have met fewer of the flow statistics than 2006 (Table 2.2). Only the 2,500 flow statistic was met, although there were 7 days with flows above 5,000 cfs. The base flow conditions were met at each individual gage in 2006 as well as the minimum requirement using the three-gage rule (Table 2.3) as there were no 7-day running averages below 500 cfs.

The 2006 hydrographs for the San Juan River at Archuleta (release hydrograph), Four Corners, Bluff and the Animas River at Farmington show the influence of the small release from Navajo dam and the summer storm spikes beginning in July (Figure 2.1). The summer storm spikes are typically sediment laden and increase turbidity and sediment deposition in the river. The flow spikes in July and early august are of particular concern as they can affect hatching success of any spawning Colorado pikeminnow through sedimentation of the spawning bars.

The effects of the dry year and small release hydrograph can be seen in comparison to the relatively large runoff in 2005 and the very dry conditions with no release in 2003-2004 in Figure 2.2. 2005 had the highest peak flow and exhibited a classic pre-dam runoff hydrograph with only very small summer storm spikes in the late summer and fall (Figure 2.3). The flow statistics that apply to these hydrographs appear in Table 2.4. Since 2005 was the first time the flow statistics had all been met since 1997, the influence on habitat will be examined in Chapter 4. The Four Corners gage is considered the most representative gage for the habitat range and is used in all correlations reported.

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 in-creased 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

Table 2.2. Flow statistics met in each year for 1994 through 2006

Condition	Std	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
10,000 cfs or more	5	0	1	0	**11**	0	**10**	0	0	0	0	0	0	0	**9**	0
8,000 cfs or more	10	3	**16**	9	**27**	0	**33**	2	0	0	1	0	0	0	**18**	0
5,000 cfs or more	21	**54**	**109**	**49**	**72**	0	**51**	**34**	**29**	3	**33**	0	0	1	**50**	7
2,500 cfs or more	10	**81**	**126**	**68**	**135**	**36**	**103**	**65**	**72**	**37**	**55**	0	**13**	**23**	**84**	**25**
Years w/o meeting 10,000 cfs	10	6	7	8	0	1	0	1	2	3	4	5	6	7	0	1
Years w/o meeting 8,000 cfs	6	0	0	1	0	1	0	1	2	3	4	5	6	7	0	1
Years w/o meeting 5,000 cfs	4	0	0	0	0	1	0	0	0	1	0	1	2	3	0	1
Years w/o meeting 2,500 cfs	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0

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

Table 2.3. 2006 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	561	0	0	0
Shiprock	539	0	0	0
Four Corners	548	0	0	0
Bluff	607	0	0	0
3-gage	576	0	0	0

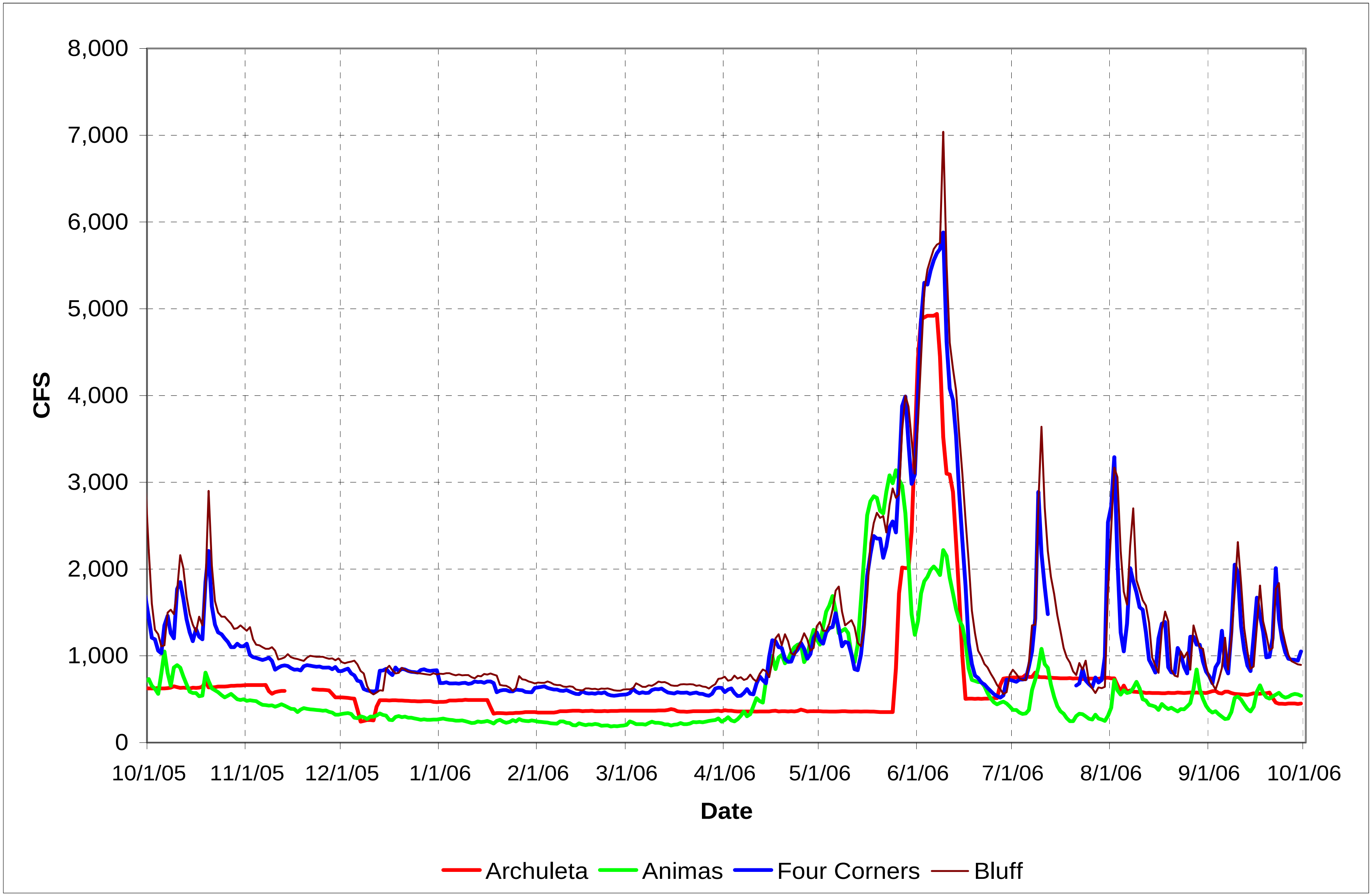

Figure 2.1. San Juan River near Archuleta, Four Corners and Bluff and Animas River near Farmington, 2006

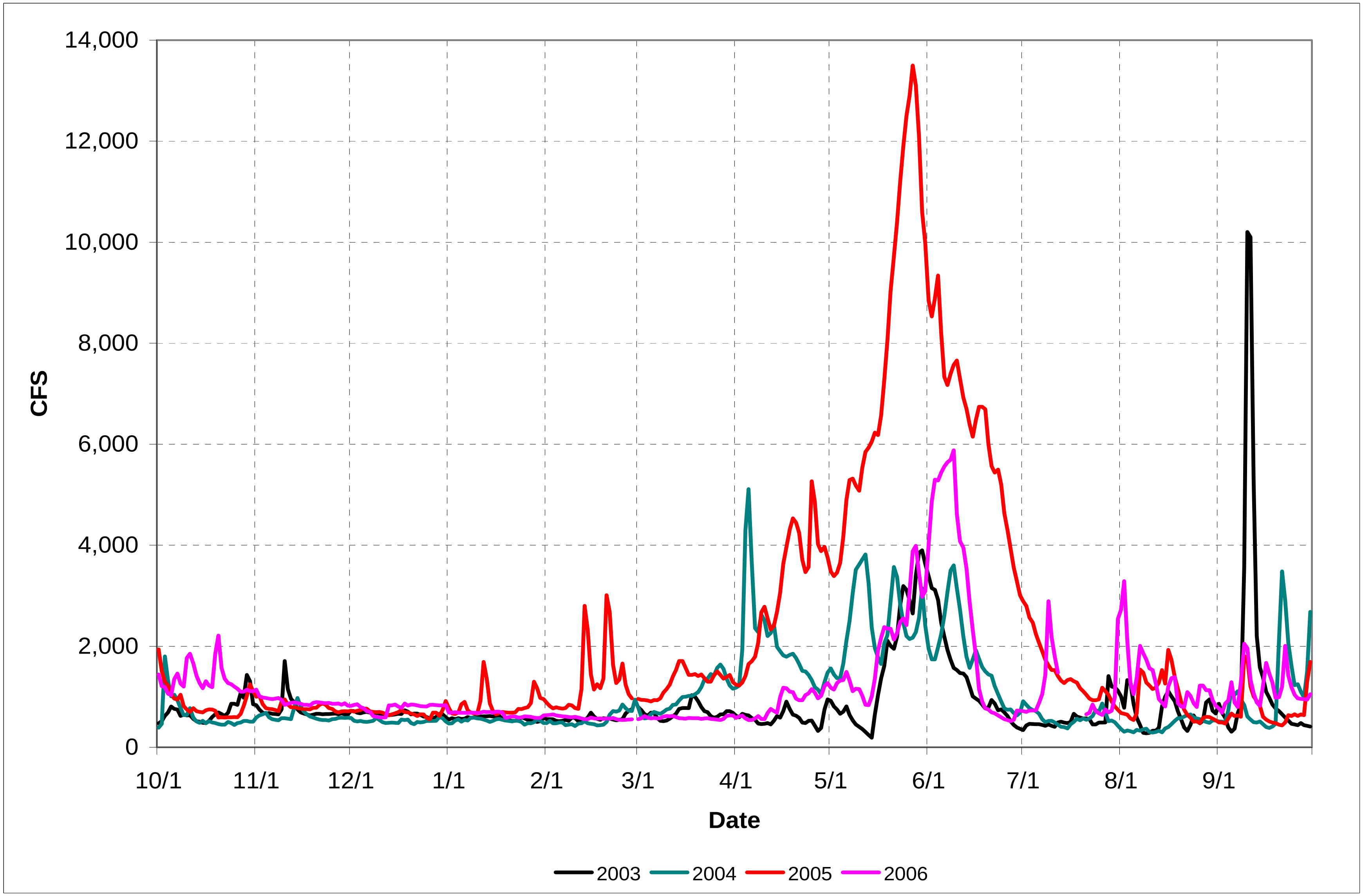

Figure 2.2. San Juan River at Four Corners, 2003-2006

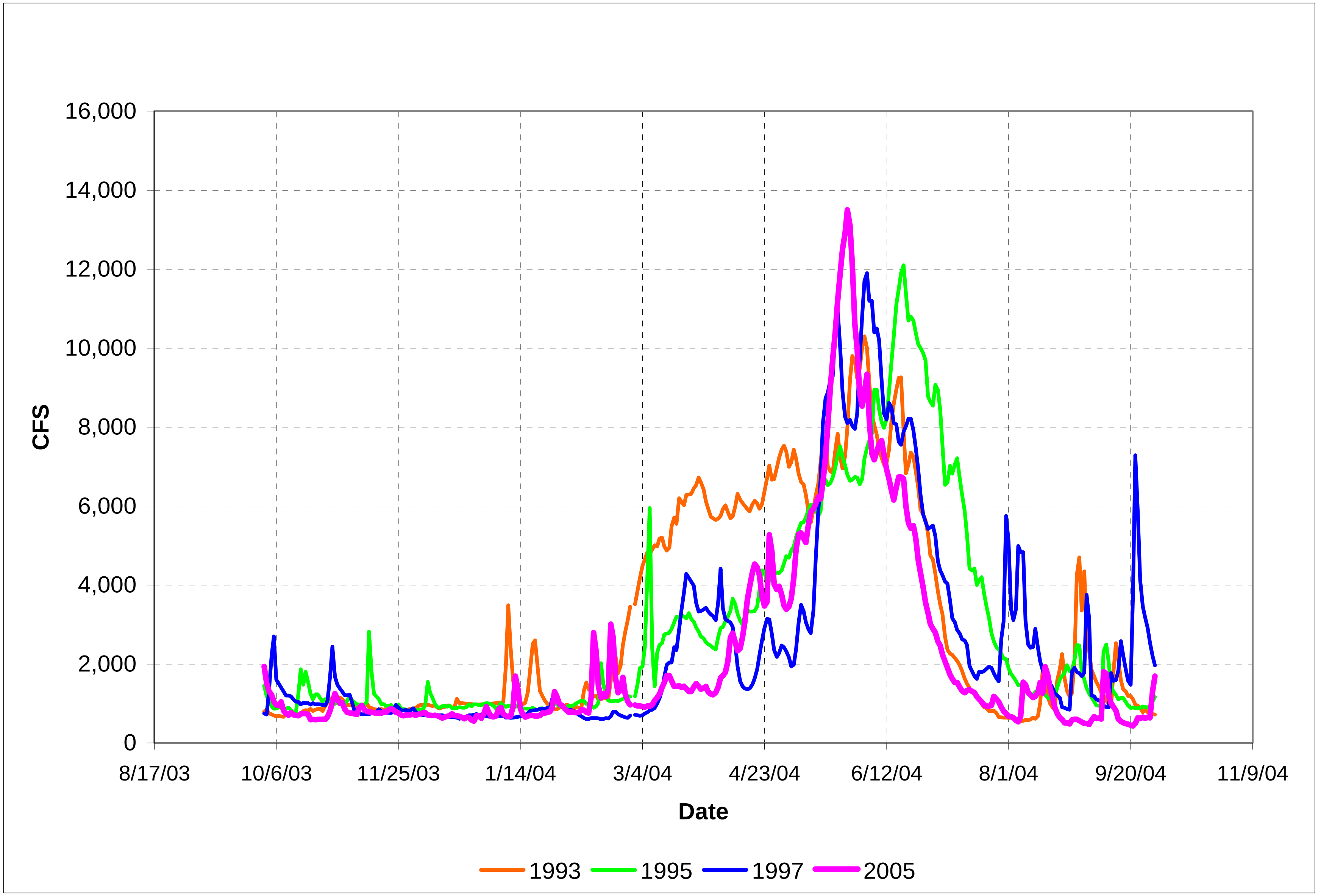

Figure 2.3. **San Juan River at Four Corners high flow year hydrographs since 1992**

Table 2.4. Summary of flows for the research (1991-1998) and monitoring (1999-2006) 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
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	5,880
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	417,909
Runoff - af (Tot. Annual)	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	825,150
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	9-Jun
Days >10,000	0	0	1	0	11	0	10	0	0	0	0	0	0	0	9	0
Days >.8,000	0	3	16	9	27	0	33	2	0	0	1	0	0	0	18	0
Days >5,000	2	54	109	49	72	0	51	34	29	3	33	0	0	1	50	7
Days >2,500	46	81	126	68	135	36	103	65	72	37	55	0	13	23	84	25
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	1,338
November	1,125	1,354	909	1,202	1,076	1,137	881	1,175	1,494	910	1,154	836	744	612	796	902
December	1,078	1,086	955	1,129	958	1,087	700	1,154	1,031	940	966	848	657	517	689	782
January	1,171	858	1,356	1,056	916	783	788	1,208	947	935	915	835	569	524	838	651
February	1,299	1,263	1,522	852	1,084	874	695	1,239	976	931	1,039	732	574	578	1,295	583
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
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	859
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	1,968
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	2,688
July	799	1,442	1,773	2,195	5,178	714	2,899	1,802	2,925	330	877	411	583	586	1,468	813
August	555	925	1,346	534	1,561	491	2,306	1,073	6,135	708	1,315	482	672	440	940	1,325
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	1,165
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
		Storm @ Spawn					Storm @ Spawn	Storm @ Spawn	Storm @ Spawn				Sep. Peak > 10,000			Storm @ Spawn

CHAPTER 3: DETAILED REACH ANALYSIS

BACKGROUND

In the process of integrating and evaluating the standardized monitoring data, 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 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.

Detailed reaches were established in 2005 at RM 137 and RM 82 as described in the 2005 annual report. They have been designated DR 137 and DR 82. Habitat surveys have been completed in 2005 and 2006 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 has been completed for fall survey flows in 2005 and 2006 and the model used to predict habitat availability at different flows.

OBJECTIVES

The objectives of the detailed reach study 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.

To accomplish these objectives, the following work elements are included in the scope of work:

1. <u>Channel Morphology Monitoring of Detailed Reaches</u>. Annually survey multiple cross-sections in each of the detailed reaches identified in 2005 at sufficient density to allow two-dimensional modeling of the hydrologic processes involved in forming and maintaining the reach and to identify change.

2. <u>Map Habitat in the Detailed Reaches</u>. Map habitat in the detailed reaches annually at a level of detail adequate to represent YOY fish sampling.

3. <u>Identify Habitat Use of YOY Endangered Fish and Correlate to Detailed Mapping</u>. Map sampled habitat during YOY fish surveys in these reaches to identify characteristics and scale of habitats important to these life stages. Utilize this information to refine scale of mapping in the detailed reach and allow better interpretation of the larger scale mapping of the entire river.

4. Update Two-Dimensional Steady State Model of Detailed Reaches. Based on the survey data collected under Objective 1, update the two-dimensional model for each reach developed in 2005 and compare results to those of the 2005 model.

5. Analyze Response of Channel Morphology and Habitat to Hydrology. The data collected will be used to better define the relationships between hydrology and habitat, both with stage and in response to antecedent conditions. Annually, the change in morphology and habitat from the previous year in response to antecedent runoff will be assessed.

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 2006 and areas where more detail was needed were surveyed in 2006. Based on findings from 2005, the survey pattern was changed from cross-sections to longitudinal survey lines 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 also surveyed during near peak flow in June 2006.

During 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.

Channel Change

Survey data from the fall 2005 and fall 2006 surveys were used to develop the topology of the channel and floodplain in each reach for each year. A three-dimensional surface was constructed in AutoCad for each survey. Scour and deposition in each detailed reach was determined by subtracting the three-dimensional surface created from the 2005 survey from that created from the 2006 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[3]. 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. Finally, River2D was used to visualize and interpret the results and perform PHABSIM type fish habitat analyses. In the San Juan River, habitat mapping data was compared to velocity and depth information generated by the model for interpretation at calibration points and extrapolation to other flow conditions. This is 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 is initially calibrated to measured water surface elevations at the time of survey. The roughness is adjusted to calibrate to water surface elevation. The model refinement and calibration is 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)[4] collected during survey. Additional calibration is accomplished by measurement of water surface elevation (water's edge) at higher stage flows during spring runoff.

The model has been 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 are calibrated to water surface at survey for each of the detailed reaches at 2005 and 2006 survey flows. Calibration is accomplished by adding breaklines 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.

Habitat Mapping

Habitat mapping of the detailed reaches was completed in the fall at the same time as the standardized mapping. Each reach is included in the standardized mapping and then each was

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

[4] 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.

mapped at a detailed level at the same time by a different mapper. Standard habitat mapping is completed at a scale of approximately 1" = 150 ft. Detailed mapping for the reaches is completed at a scale of 1" = 75 ft. The two data sets are then compared to determine differences in mapping detail. Detailed mapping is also completed in March near the time of the spring Colorado pikeminnow survey.

Integrating Fish Monitoring Data

Endangered fish capture data were obtained from the following studies:

- Pikeminnow Augmentation Evaluation (Bio-West)
- Adult Monitoring (FWS, Grand Junction)
- Larval Fish Study (UNM)
- Small Bodied Monitoring (NMGF)

All of these studies except the adult monitoring studies are site specific with GPS locations for the sampling sites. Locations from GPS readings for 2005 and 2006 from all pikeminnow augmentation evaluation and larval fish study sites within these reaches were included for analysis. The adult monitoring data were included for information, but are not site-specific and could not contribute to habitat assessment. The small bodied monitoring study did not capture any endangered fishes in these reaches. The work plan anticipated simultaneous mapping with fish sampling, but trip-scheduling challenges prevented that opportunity. Therefore, the GPS locations were used to assess general locations and mapped habitats in the vicinity.

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. 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.

Since low velocity habitat is of key concern, a habitat-suitability relationship was generated for low velocity habitat. This is not a literature based relationship, but is presented as an example of modeling capability. The location and abundance of this type habitat, based on depth and velocity was compared to the total mapped low velocity habitat and forecast at other flows to examine change with flow. The results are presented for discussion of applicability in future work plans.

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 2006 to compare to fall 2005 surveys and determine deposition and scour for each reach. There are 3,115 points for DR 82 and 3,148 for DR 137, all taken below the 2006 high water line (Figures 3.1 and 3.2). These data points 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 1,140 cfs for DR 82 and 799 cfs for DR 137. Water's edge at high flow was surveyed in June 2006 at a flow of 6,140 cfs (Bluff gage) for DR 82 (283 points) and 5,550 cfs (Shiprock gage) for DR 137 (418 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 2006 water surface overlain. The high flow water surface was used as the extent of analysis for channel change.

Channel Change Analysis

Figures 3.5 and 3.6 show the channel topology generated from the 2005 and 2006 surveys for DR 82 and DR 137, respectively. Scour and deposition between 2005 and 2006 surveys have been assessed for each reach by subtracting the 2005 surface from the 2006 surface. Figure 3.7 show the location and depth of scour and deposition for DR 82. The same information is shown in Figure 3.8 for DR 137. Table 3.2 shows substrate makeup from the 2005 and 2006 survey, the volume of scour and deposition and the net change in volume and depth between the two surveys for each detailed reach. Although there are locations of scour and deposition in each reach, DR 82 exhibited nearly 3 cm of net scour and DR 137 experienced about the same amount of deposition. This change is significant at the 99% level.

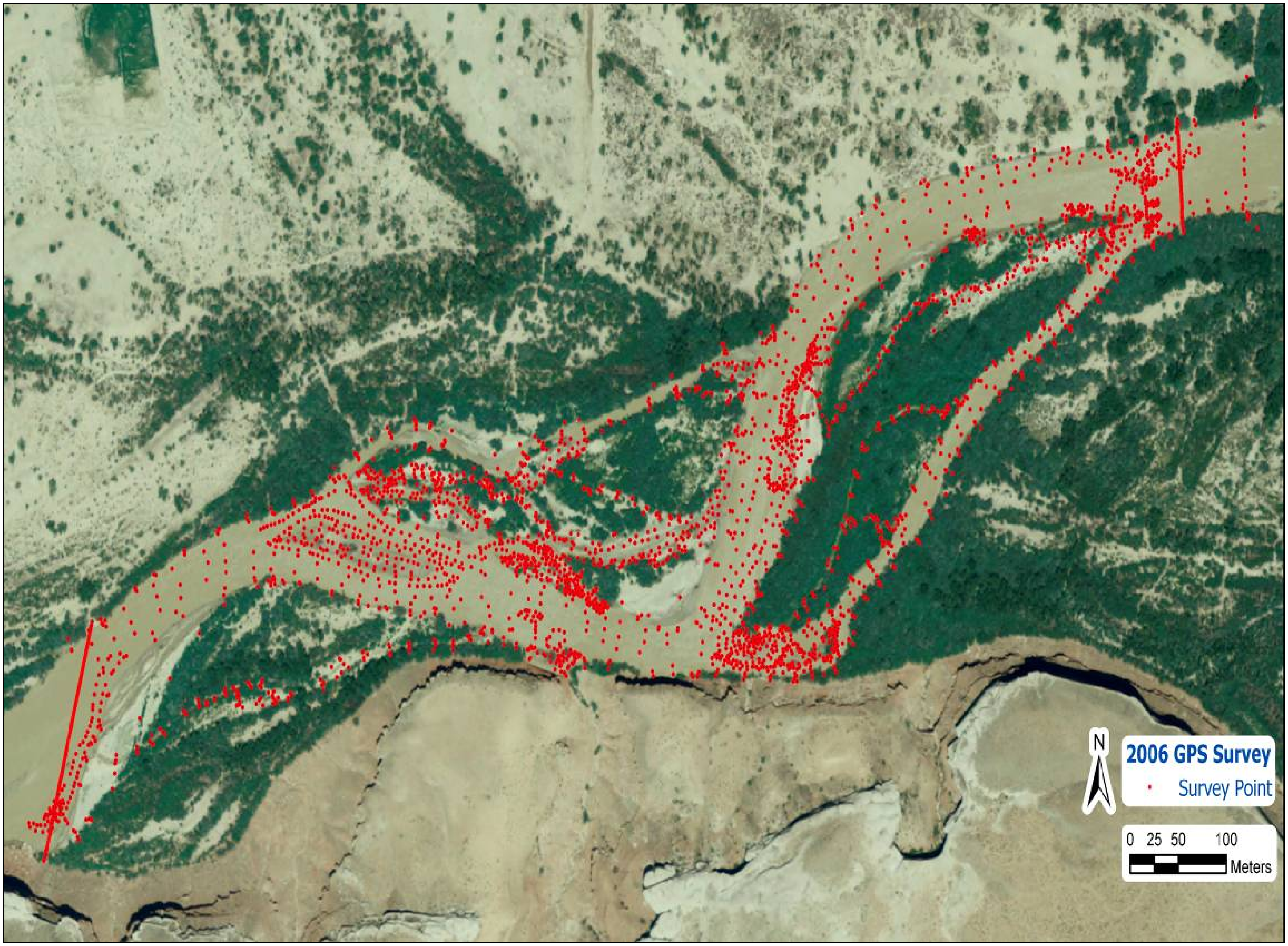

Figure 3.1. Point locations for August 2006 survey at DR 82

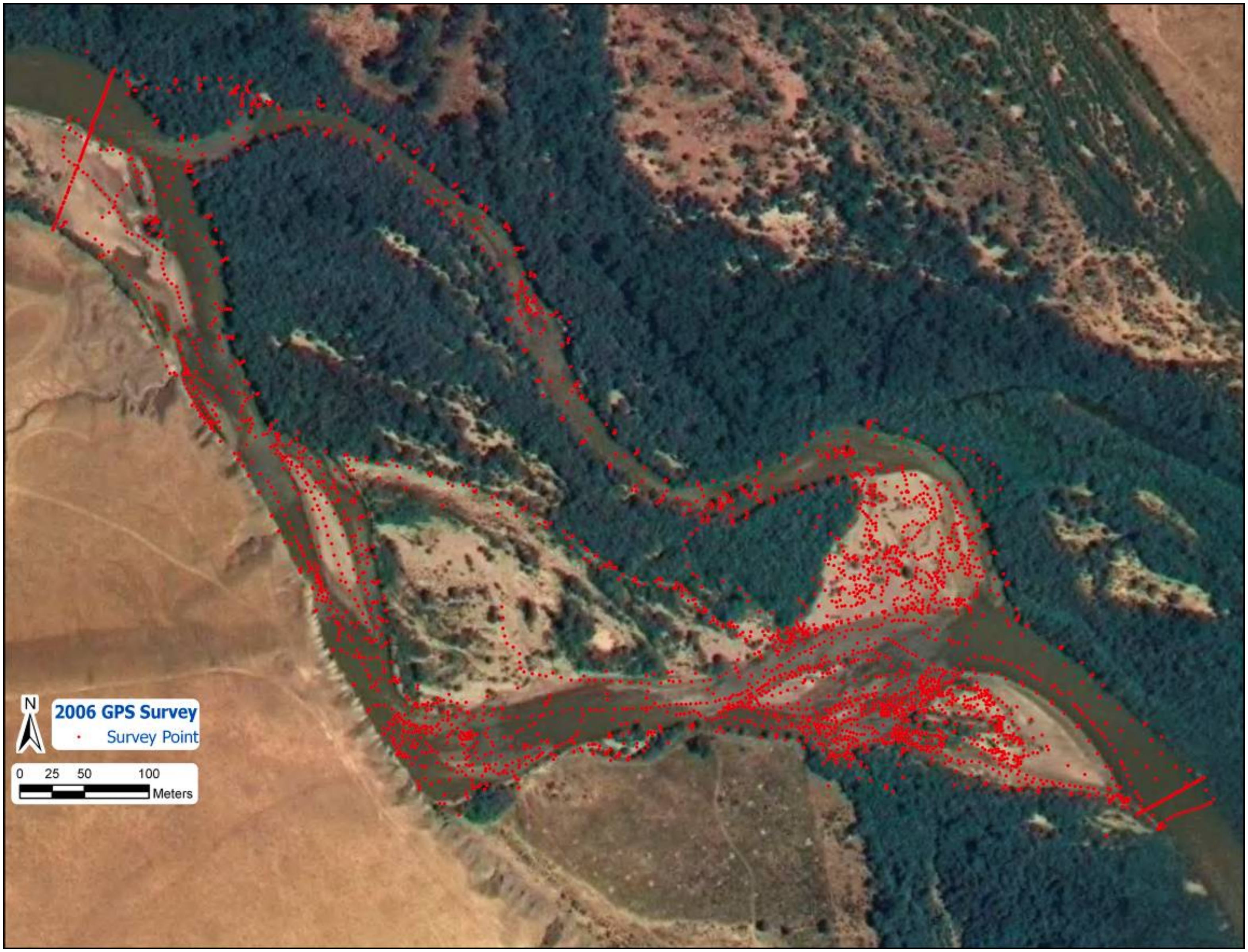

Figure 3.2. Point locations for August 2006 survey at DR 137

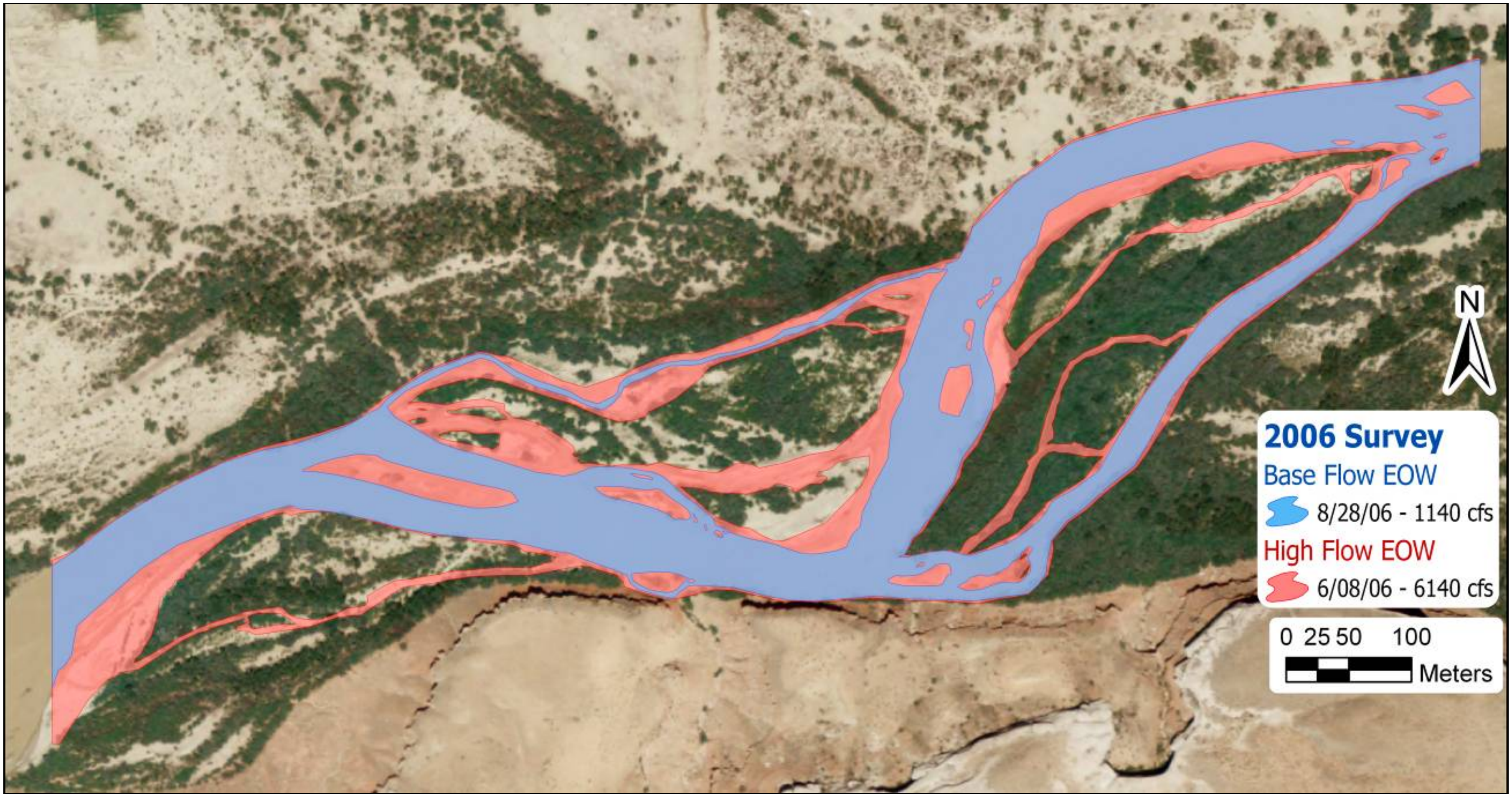

Figure 3.3. DR 82 water surface at 6,140 and 1,140 cfs (June and August surveys)

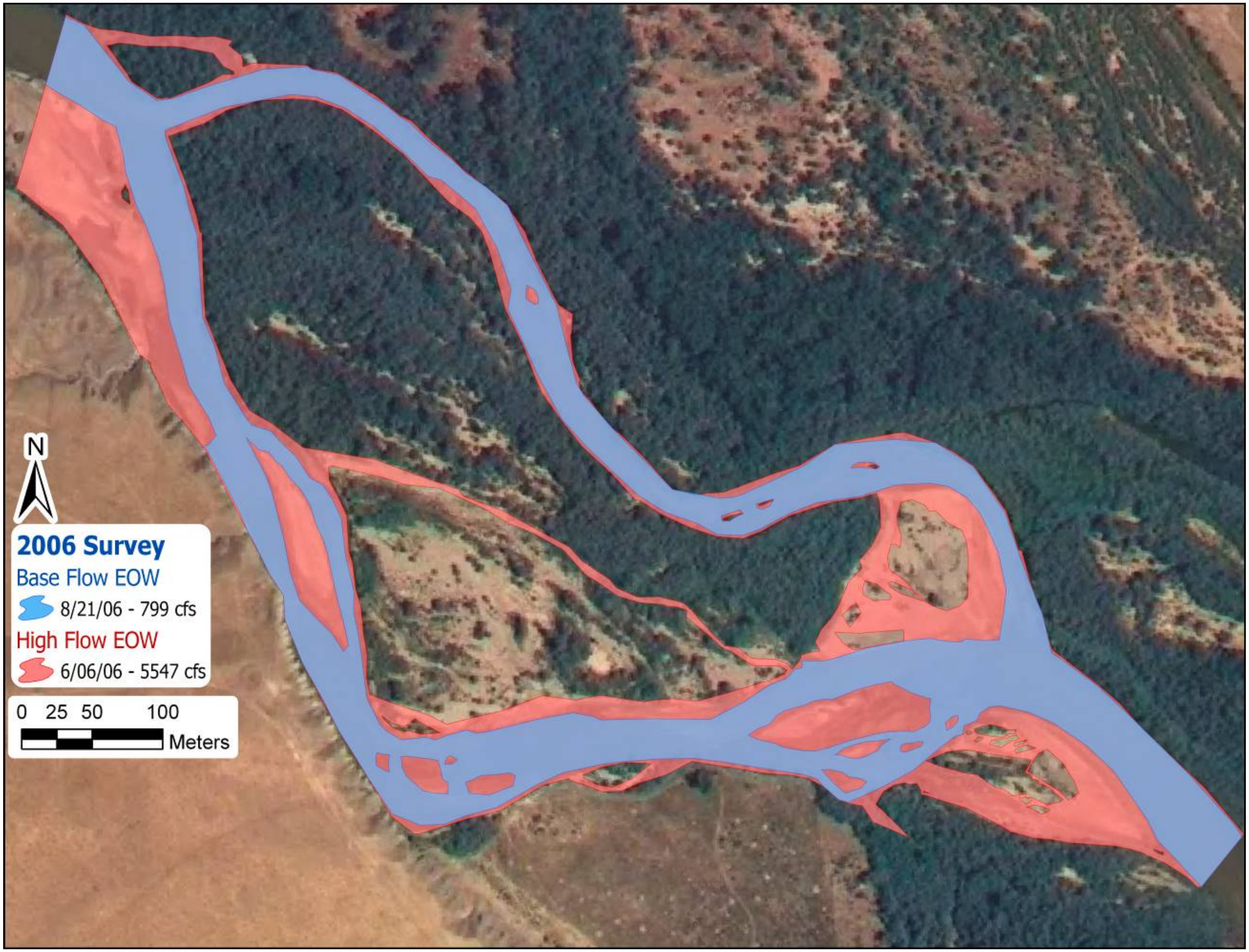

Figure 3.4. DR 137 water surface at 5,550 and 1,080 cfs (June and August 2006 surveys)

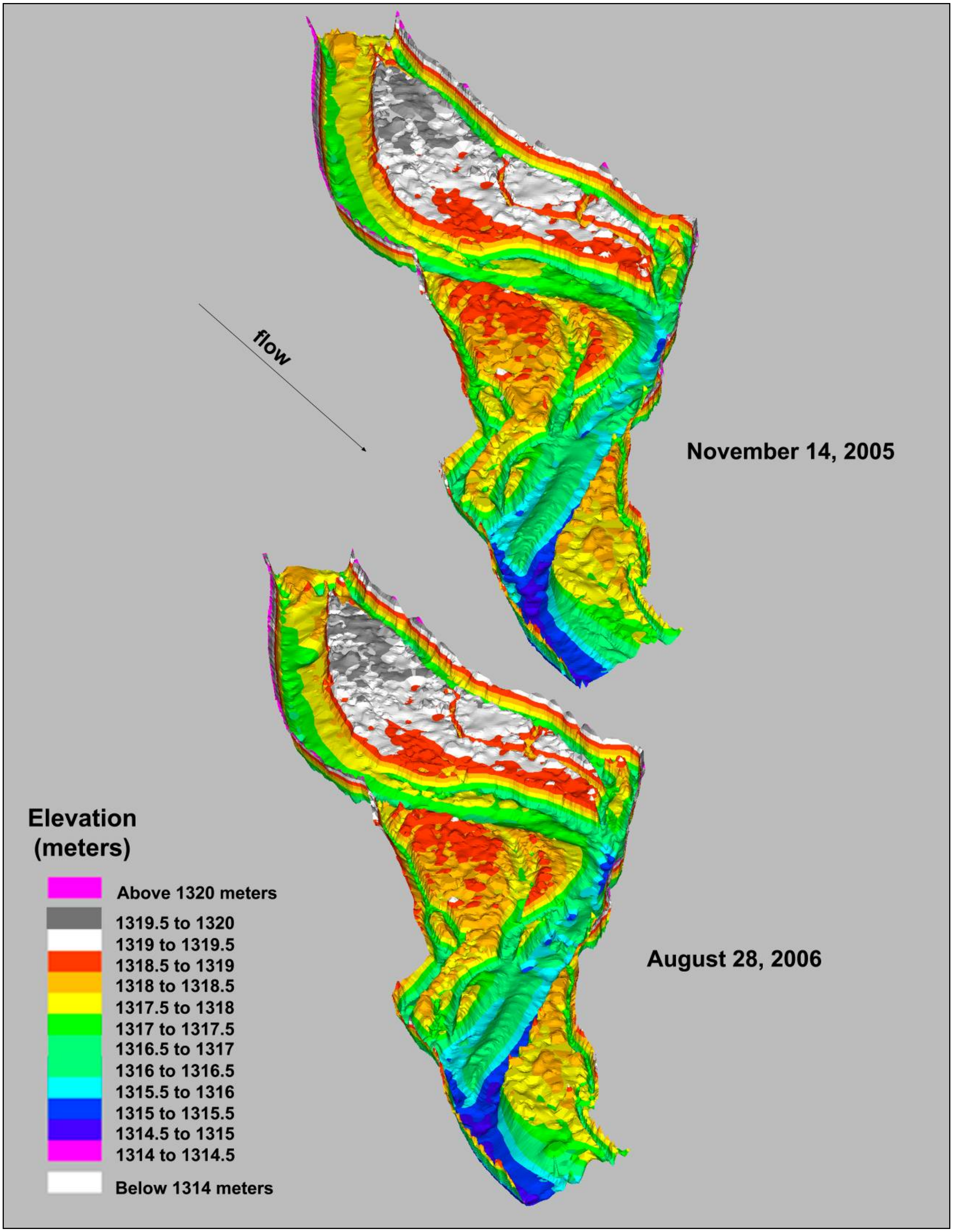

Figure 3.5. 2005 and 2006 channel topology generated from fall surveys for DR 82

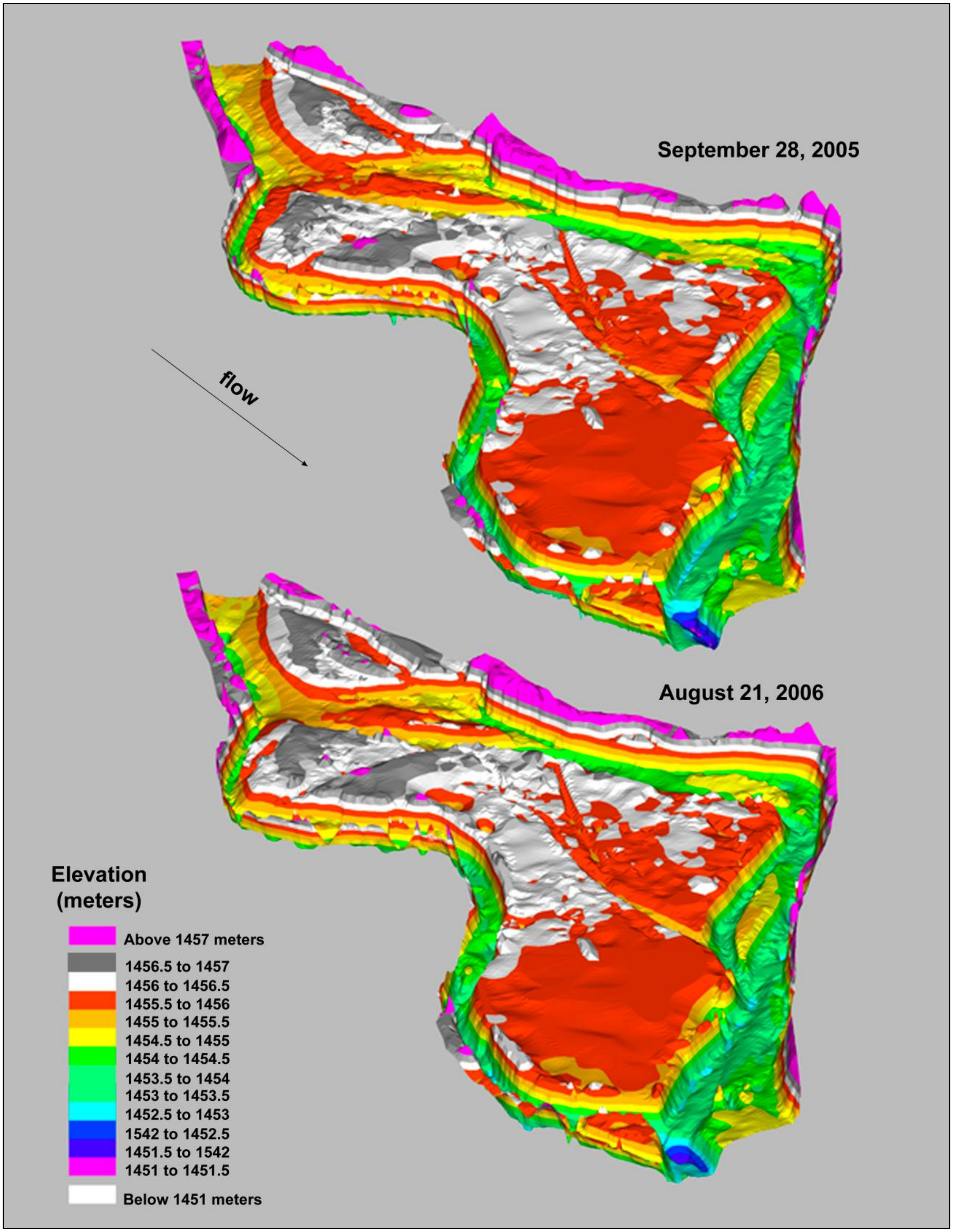

Figure 3.6. 2005 and 2006 channel topology generated from fall surveys for DR 137

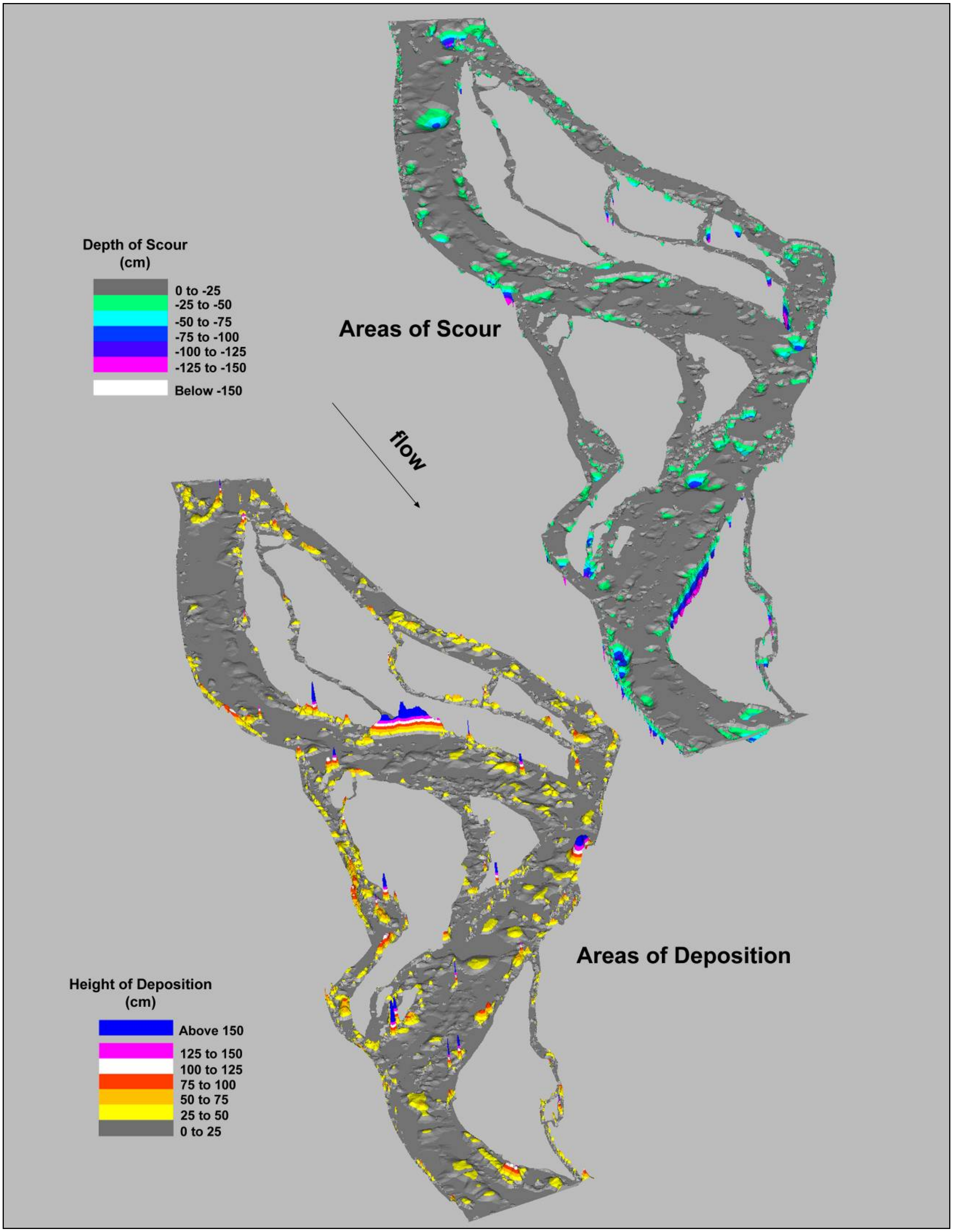

Figure 3.7. Location and depth of scour and deposition between 2005 and 2006 for DR 82

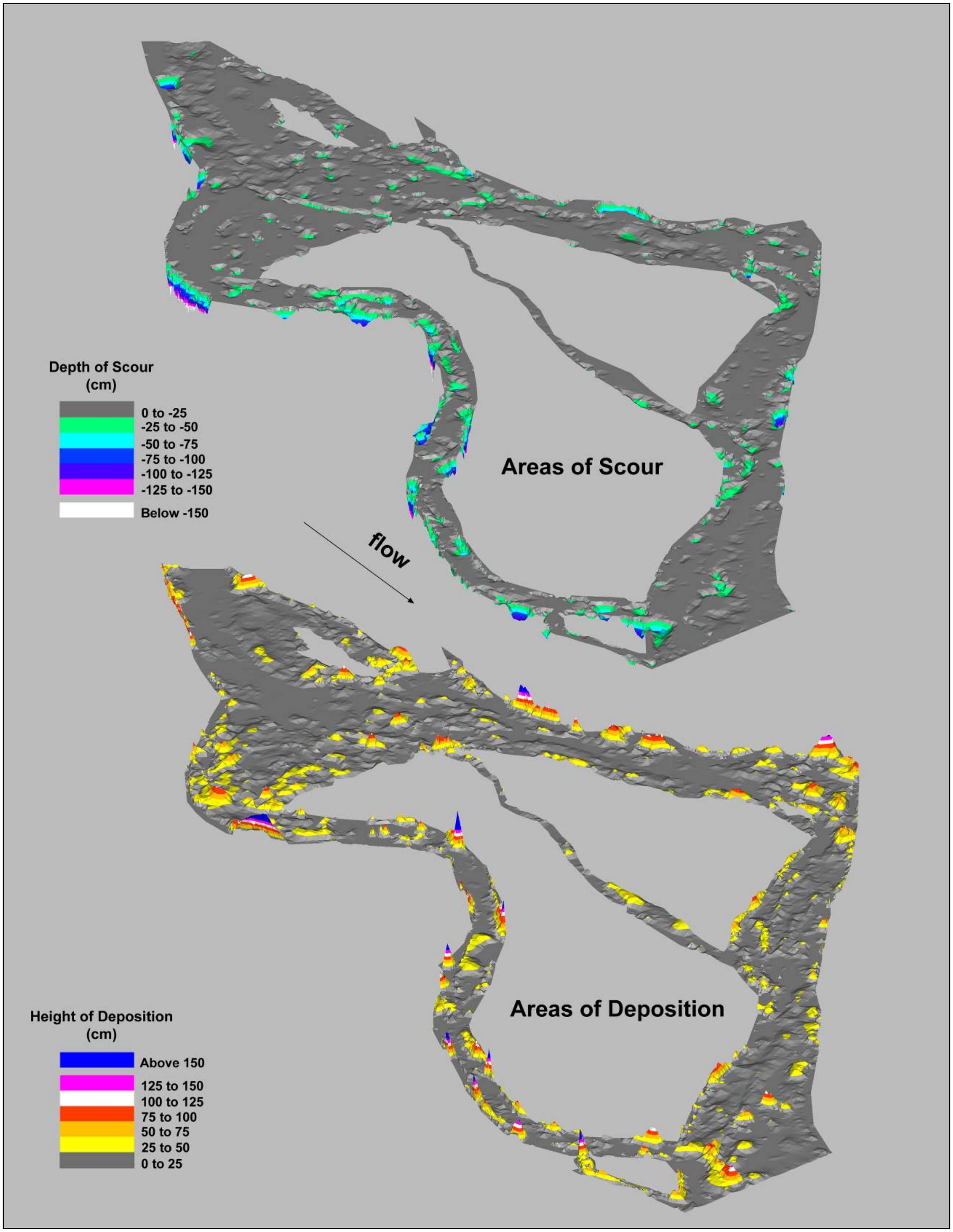

Figure 3.8. Location and depth of scour and deposition between 2005 and 2006 for DR 137

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

Parameter	DR 82	DR 137
Volume of scour – m^3	16,612	11,739
Volume of deposition - m^3	12,762	15,373
Net change (+ = deposition, - = scour) - m^3	-3,850	3,634
Net change in depth - cm	-2.95	+2.94
Portion of substrate that is cobble/gravel in 2005 - %	52.4	50.3
Portion of substrate that is cobble/gravel in 2006 - %	51.8	55.0
Volume of cobble/gravel scour - m^3	7,326	4,766
Volume of sand scour - m^3	9,286	6,973
Volume of cobble/gavel deposition - m^3	5,309	6,580
Volume of sand deposition - m^3	7,453	8,793

Scour locations are typically associated with local obstructions or high gradient areas of the channel (Figures 3.7 and 3.8). For example, a large scour hole developed in the DR 82 main channel around a large tree and root wad pile transported from up-river. Depositional areas tend to be in lower gradient areas down-slope of scour locations, channel junctions where secondary channels rejoin the main channel, on the inside of bends or in other areas of low velocity during high flow.

Scour and deposition were also categorized as to bed material. Table 3.2 also shows the volume of scour and deposition by substrate type. Only two categories of mobile substrate are categorized: sand and cobble/gravel. The original substrate is used for this characterization, so if cobble or gravel was present under the sand in a scour location, all the scour was considered to be sand.

Cobble and gravel constitute about one-half of the bed material in DR 82 and make up 42-44% of the material moved. There was no change in the percent of cobble/gravel substrate between 2005 and 2006. 38% more cobble/gravel was removed from the reach than was deposited for a net export of cobble/gravel from the reach. 25% more sand was scoured than deposited, also indicating net export.

Cobble and gravel also constitute about one-half of the bed material in DR 137 and make up 40% of the material that moved. There was a net increase in cobble/gravel substrate from 2005 to 2006. 38% more cobble/gravel was deposited than scoured, indicating a net import of cobble to the reach. 26% more sand was deposited than scoured, also indicating net import. The ratio of cobble/gravel to sand movement in each reach is about the same, although one reach gained material and the other lost.

River2D Model

River2D models have been calibrated to water surface at survey for each of the detailed reaches at 2005 and 2006 survey flows (Tables 3.3 and 3.4). The model flow depth and mean column velocities are shown in Figures 3.9 through 3.11 for DR 82 for 2005 and 2006 fall survey and 2006 high flow conditions, respectively. Figures 3.12 through 3.14 show the same information for DR 137.

The 2005 calibration for DR 82 exceeded the calibration standards with less than 1% error in mean water surface elevation (Table 3.3). Achieving this accuracy required many model runs over an extended period of time. To test the need for re-calibration after spring high flows, the 2006 surveyed water surface was tested at the 2006 flow using the 2005 model configuration, including bed-form and calibrated roughness values. The resulting calibration did not meet the standards set (Table 3.3). The mean predicted water surface is 3.9 cm lower than measured. The standard deviation is also worse, as would be expected with differential scour and deposition throughout the reach. Recalibration is necessary to meet calibration requirements.

The 2006 survey data was used to develop a new bed-file and the model was re-operated with the 2006 surveyed water surface elevation. While the calibration was not as good as the 2005 calibration, it was completed with much less modeling effort and is within calibration standards (Table 3.3).

The model configured with the 2005 bed elevation was also tested at the high flow water surface. The calibration meets the calibration standard indicating reasonable accuracy over a range of flows without recalibration.

The 2005 calibration for DR 137 is not as good as that for DR 82 and does not meet calibration requirements for standard deviation (Table 3.4). Flow changes during water's edge survey in 2005 resulted in more variation in the measured water surface than would normally occur at a constant flow. When using the 2005 model calibration with the 2006 water surface, the results are actually improved. The 2006 calibration is much better than for 2005, meeting the calibration requirements.

Table 3.3. River2D model calibration results for DR 82

Parameter	2005	2005 model, 2006 survey	2006	June high flow
Flow - cfs	1,020	1,140	1,140	6,140
Average error – cm(% average depth)	.38(0.74%)	-3.9(10.4%)	-1.8(4.9%)	-3.6(4.5%)
Standard deviation – cm (%)	7.6(14.8%)	17.8(47%)	8.6(23.8%)	9.2(11.6%)
95th percentile range - cm	±12.7	±30.4	±12.3	±15.7

Table 3.4. River 2D model calibration results for DR 137

Parameter	2005	2005 model, 2006 survey	2006	June high flow
Flow - cfs	607	799	799	5,546
Average error – cm(% average depth)	1.1 (3.5%)	1.3 (4%)	1.9(5.4%)	-8.0 (11%)
Standard deviation – cm (%)	15.6(47.7%)	9.3(27.5%)	7.8(22.9%)	11.0(15.1%)
95th percentile range - cm	±24.8	±15.5	±13.4	±17.4

The high-flow test for DR 137 using the 2005 model configuration did not quite meet the calibration requirement for mean water surface elevation, indicating a need to adjust calibration for high flow conditions (Table 3.4). Additional calibration, particularly adjustment in roughness height for the channel above the survey flow rates, is warranted.

The modeled depths and velocities for DR 82 are shown in Figures 3.9 through 3.11. Figure 3.9 is based on the flow rate and surveyed bed in the fall of 2005. The results in Figure 3.10 are for the flow rate and surveyed bed established in August 2006. Figure 3.11 is based on June high flow (6,140 cfs) and fall 2005 calibrated model. In each case there are what appear to be isolated pools that are remnants of the modeling process and are not included in data analysis. This is particularly true for the high flow model where detailed calibration has not been completed. Other than these anomalies, there is good agreement between the surveyed and modeled wetted area (compare Figures 3.3 and 3.10), and reasonable accuracy in matching water surface as indicated by the calibration statistics in Table 3.3. There are only very subtle differences between 2005 and 2006 (compare Figures 3.9 and 3.10). The high flow modeled water surface agrees will with the surveyed surface (compare Figures 3.3 and 3.11), although the isolated pools and pools adjacent to the channels resulting from the modeling are more extensive, requiring data filtering before analysis.

Figures 3.12 through 3.14 present the same information for DR 137 for the corresponding time periods and bed survey data. The flows are different because of different survey dates and location on the river. The water surface agreement is good between survey and modeled conditions although the accuracy of water surface elevation is not as good as for RM 82. This reach has been more difficult to model, resulting in less accuracy in matching water surface elevation.

Comparing Figure 3.14 to Figure 3.4 shows a difference in the location of a small secondary channel through the island. Sometime after the high water survey and the fall bed-survey, the upper channel became bermed off and the lower channel cut through, causing a change in routing. The difference is not a model error, but a changed condition between surveys.

The model is more accurate in representing the main channel and larger secondary channels than the small, shallow channels. This is due both to the limitations of the model and the survey. Specific locations in these shallow channels may be imprecisely modeled, but as a whole they are represented adequately for the purposes of this study.

Small details, such as root-wad piles or boulders are also difficult to represent given the 2 m grid size and the survey point density. Therefore, the model under-represents conditions around these small channel features.

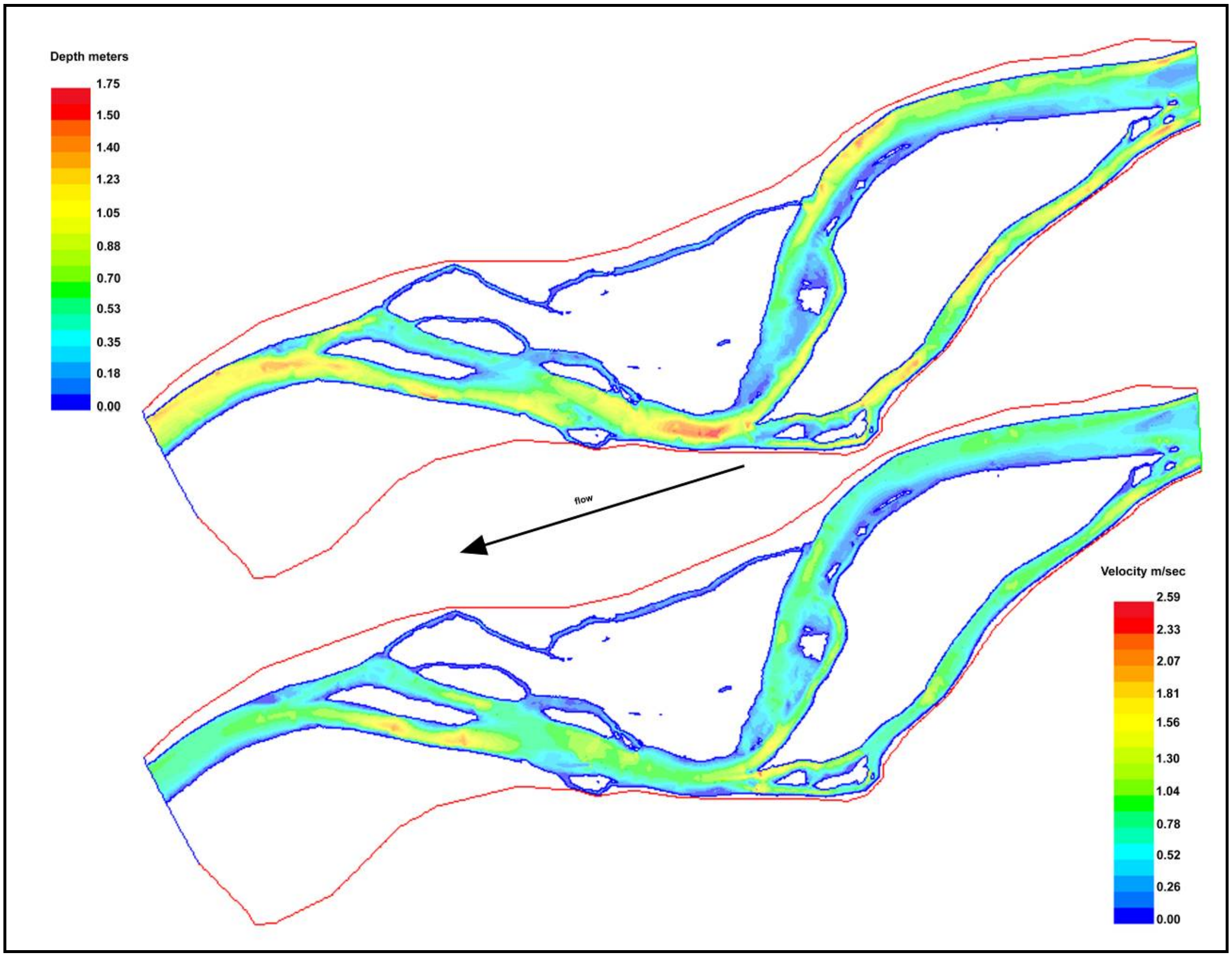

Figure 3.9. DR 82 modeled depth and velocity at 1,020 cfs with 2005 survey data

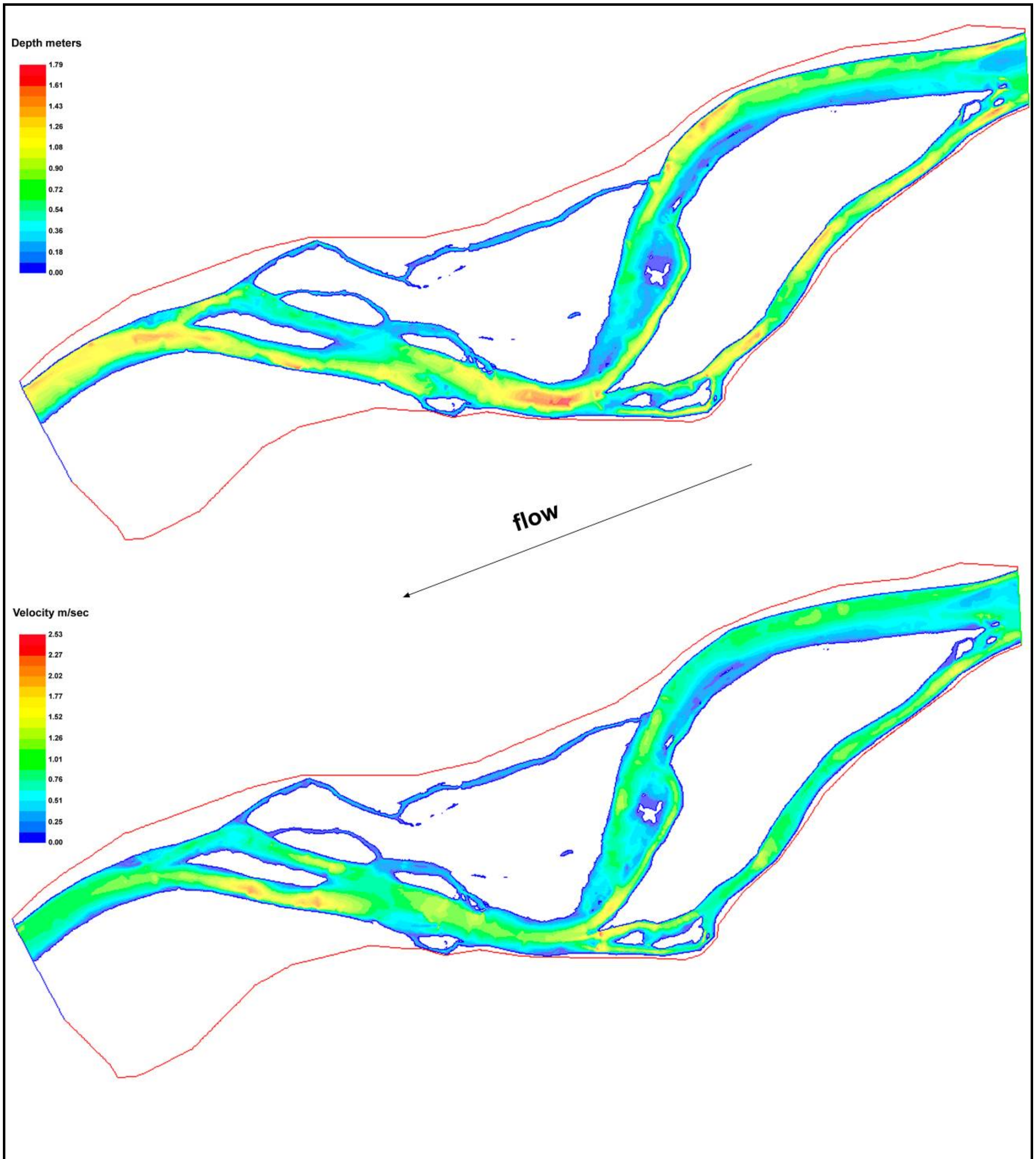

Figure 3.10. DR 82 modeled depth and velocity at 1,140 cfs with 2006 survey data

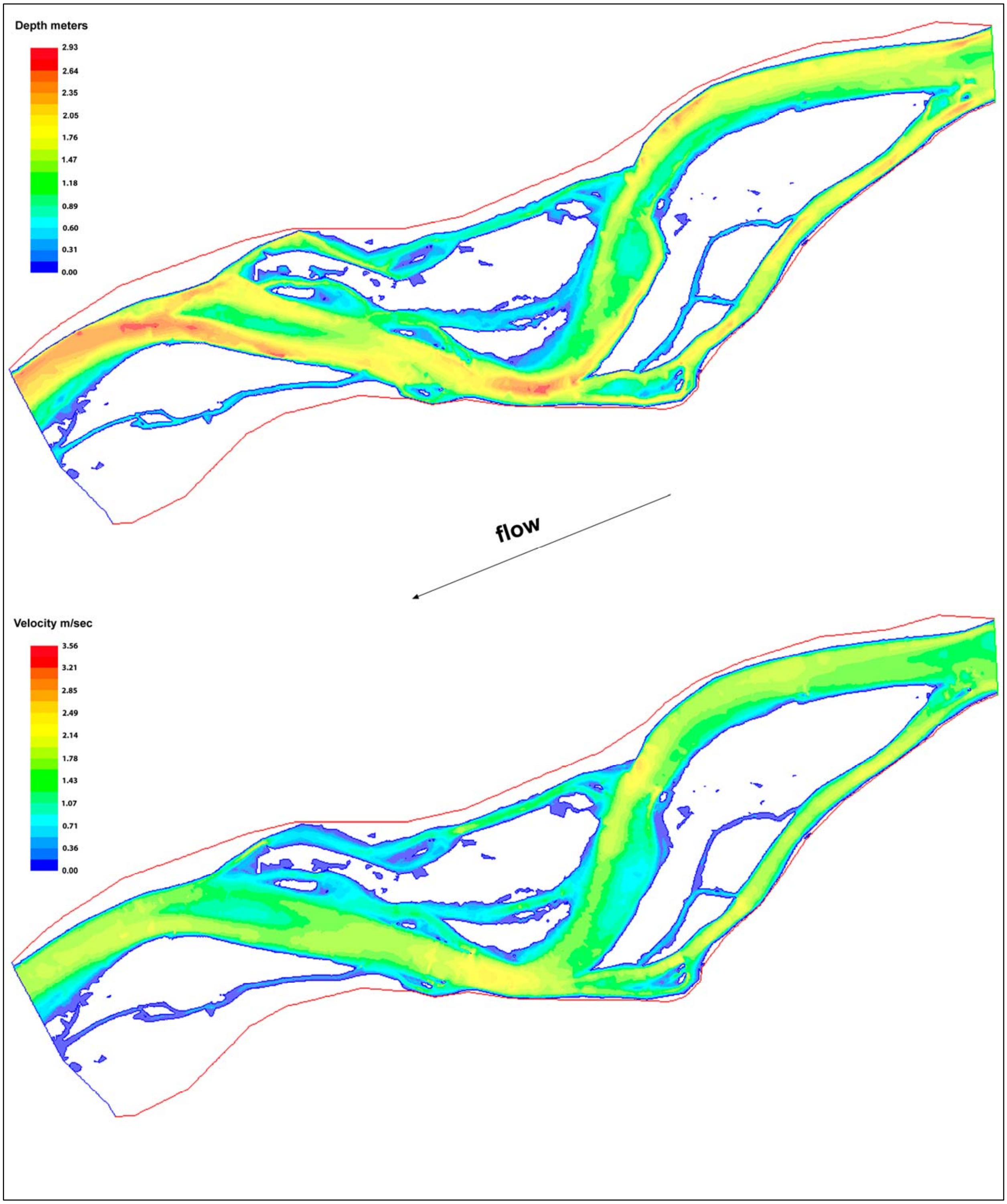

Figure 3.11. DR 82 modeled depth and velocity at 6,140 cfs with 2006 survey data

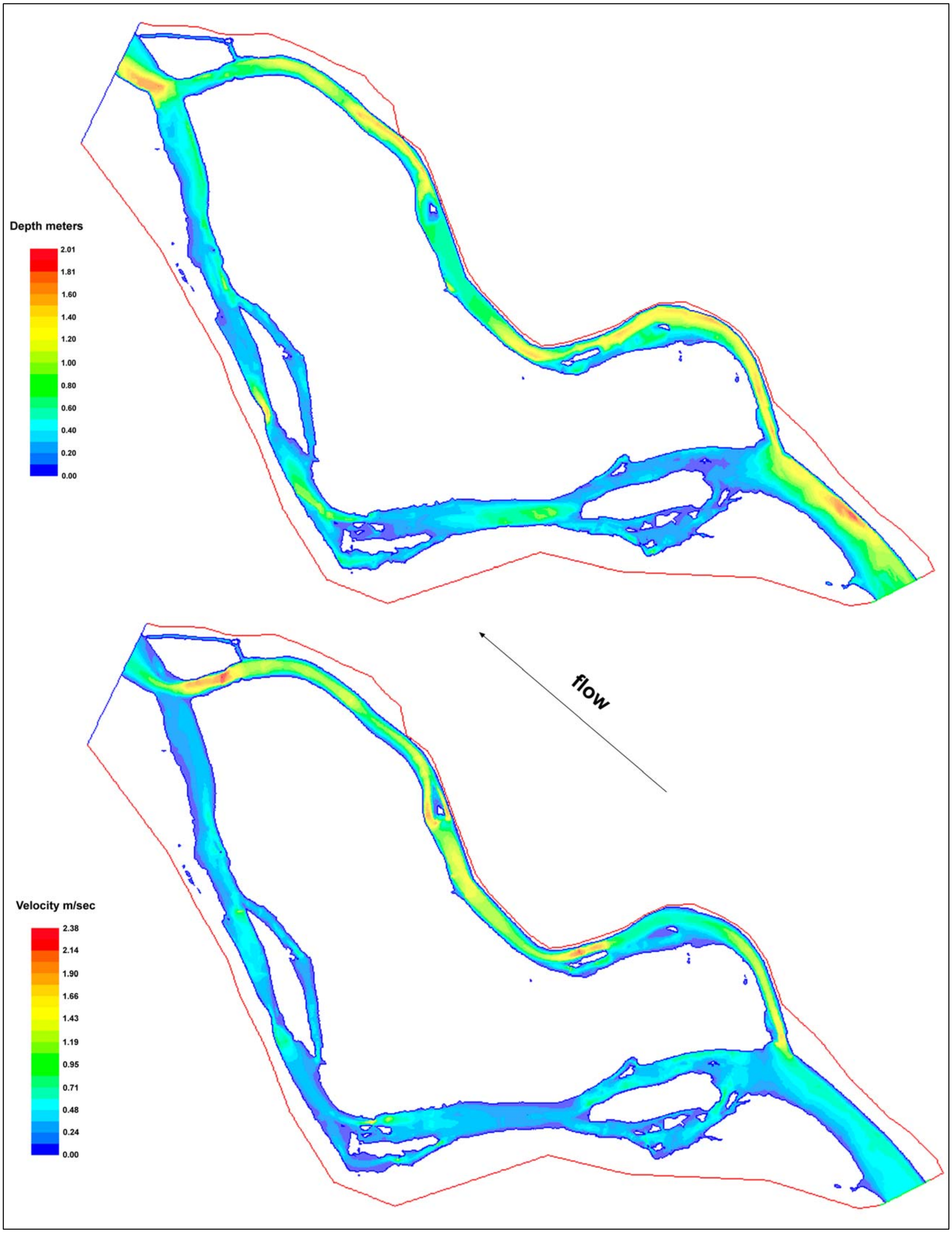

Figure 3.12. DR 137 modeled depth and velocity at 607 cfs with 2005 survey data

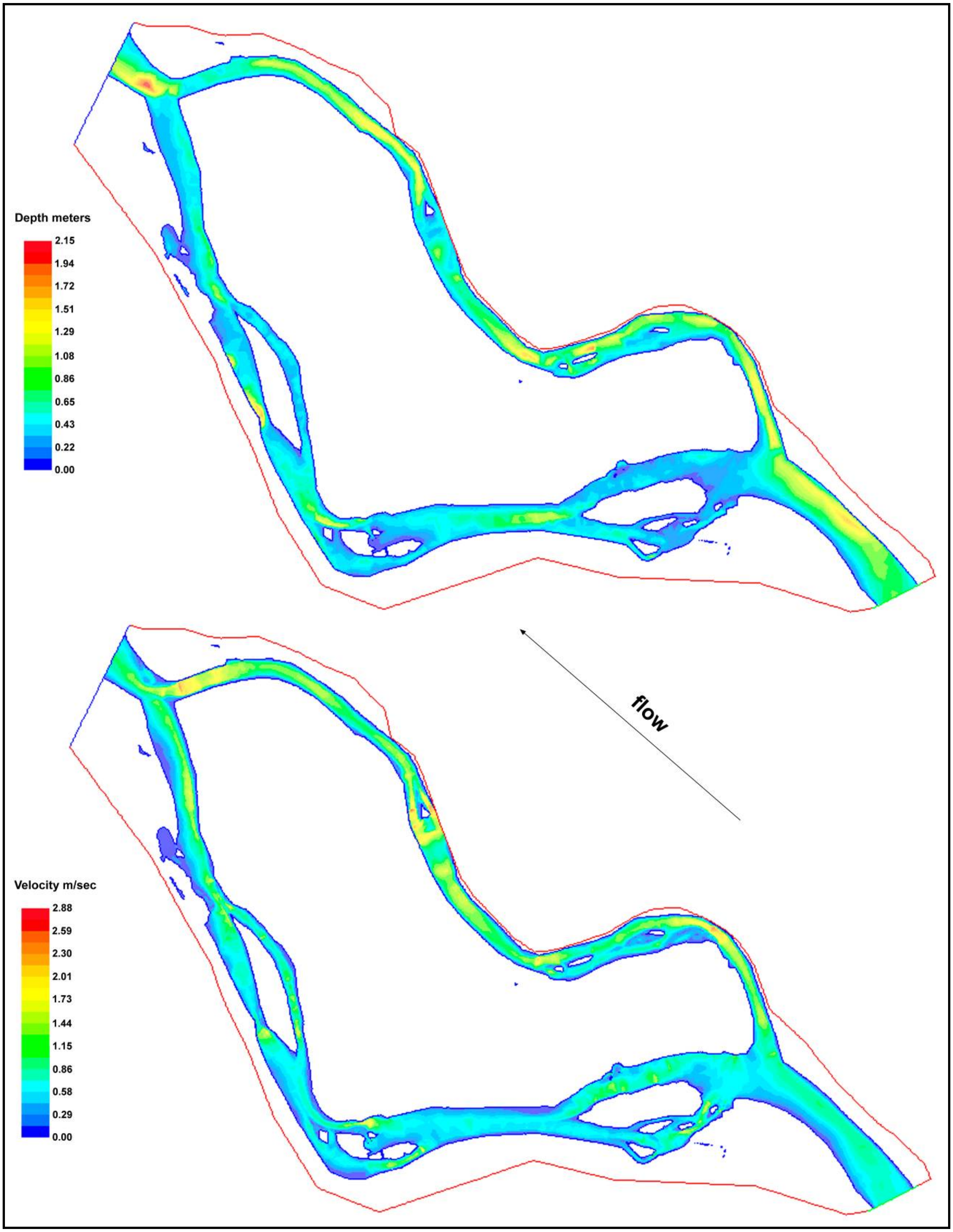

Figure 3.13. DR 137 modeled depth and velocity at 799 cfs with 2006 survey data

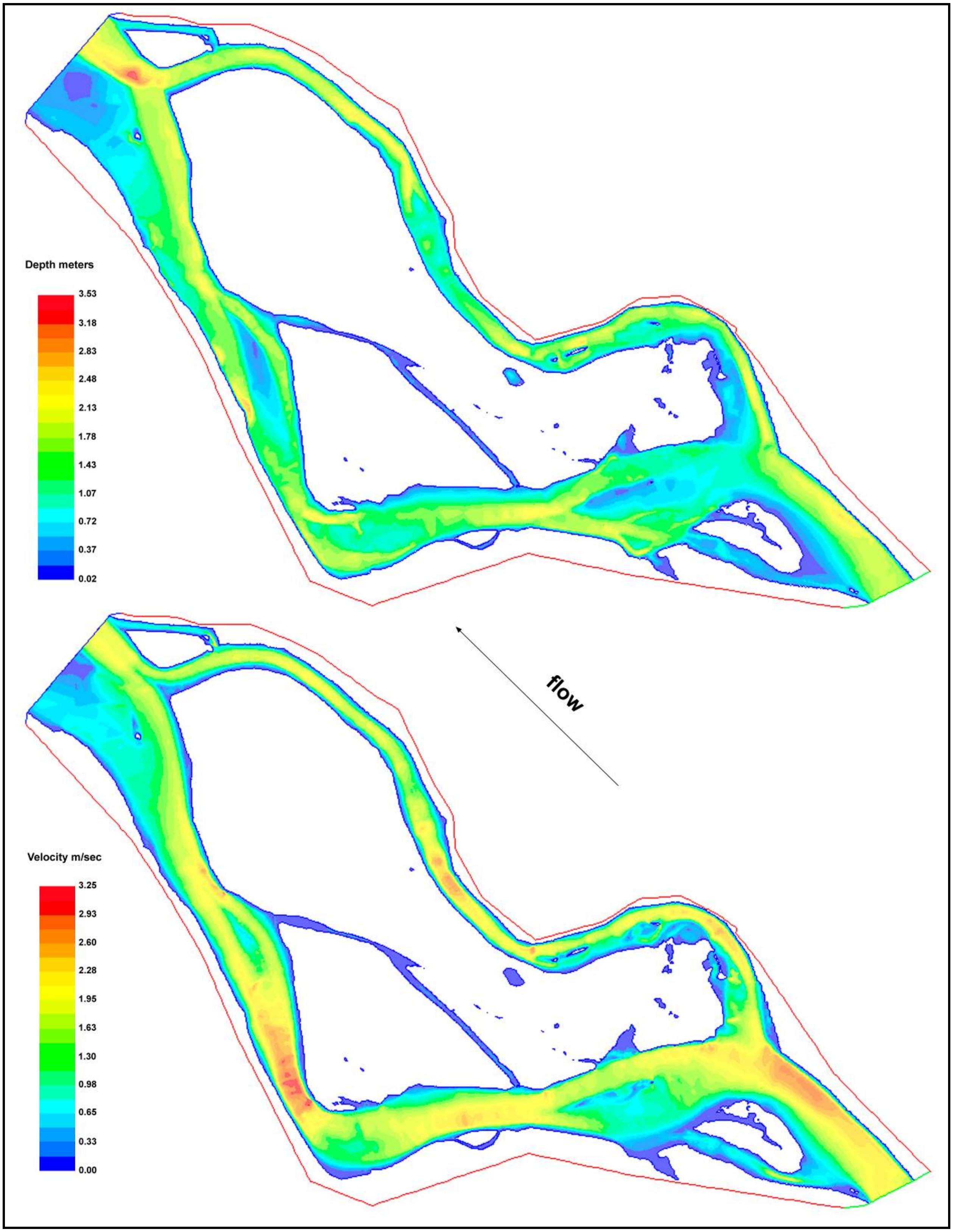

Figure 3.14. DR 137 modeled depth and velocity at 5,550 cfs with 2006 survey data.

Habitat

For both 2005 and 2006, the detailed mapping provides much finer resolution, with 2.1 to 3.7 times as many habitat polygons mapped compared to the standard mapping (Tables 3.5 and 3.6). This is particularly important in the smaller habitats that may be of importance to the endangered fishes. For example, root wad piles were mapped at four times the abundance in the detailed mapping. These features enhance habitat complexity and are often associated with endangered fish captures. Characterizing these features more accurately may improve the ability to assess habitat for endangered fish.

Fewer polygons were mapped in 2006, compared to 2005 for the detailed mapping. The 2006 mapping found no backwater habitats from detailed or standard mapping and indicates a reduction in other low velocity habitat polygons, but an increase in area. Also, slackwater increased substantially between 2005 and 2006, with about the same relationship between detailed and standard mapping. The mapping sets in both years show a substantial difference in run, riffle and shoal habitats between standard and detailed mapping (Figures 3.15 and 3.16, Tables 3.5 and 3.6). These are typically large polygons that would not be as subject to differences in map scale as backwaters and low velocity habitats that are sometimes very small and below the standard mapping scale.

In the study design, different mappers were assigned to the detailed and standard mapping to avoid interpretive bias. This also allowed a test of interpretive differences between mappers. These general categories of run, riffle and shoal are actually summations of several sub-categories that are actually mapped in the field as shown in Table 4.1. Several of these subcategories are transitional between major categories. For example, run/riffles or shoal/riffles vary primarily in velocity, and to a lesser degree in depth, from riffles and shoals, yet they are grouped with runs and riffles. One mapper may interpret a run/riffle as a riffle, putting it in the riffle category rather than the run category. The differences between mapping can be ascribed to the larger map scale, the ability to more carefully map when standing on the bank rather than floating by in a boat and the interpretive differences between mappers. Following is an assessment of the differences seen and what can be ascribed to these differences between standard and detailed mapping:

Differences attributed to improved mapping scale and the ability to more carefully map:

- Increase in low velocity, backwater and vegetation habitat types in detailed mapping
- Increase in number of polygons mapped
- Identification of key features too small to map reliably on standard maps (e.g. root wad piles and boulders):

Differences attributed to mapper interpretation

- Different number of polygons mapped between years at similar flow and river condition
- Differences in area of riffles, runs and shoals because of the subtle differences in depth and velocity in transitional habitats

There may also be some differences in interpretation that is induced by the speed of mapping. Standard mapping is completed while floating by in a raft. Detailed mapping is completed from the bank. In high velocity reaches, such as these detailed reaches, the limited time to map likely influences the accuracy of the characterization and may partly explain the differences attributed to different mappers.

Table 3.5. Comparison of detailed and standard habitat mapping for DR 82, 2005-2006

Habitat Category	2005 Count		Area – m^2		2006 Count		Area – m^2	
	Detail	Standard	Detail	Standard	Detail	Standard	Detail	Standard
Backwater	5	0	180	0	0	0	0	0
Other Low Velocity	18	1	549	410	4	2	728	751
Runs	29	13	71,412	66,701	25	23	73,664	77,093
Riffles	29	15	10,315	8,612	16	13	6,524	9,199
Shoals	39	27	8,580	16,400	31	20	4,453	5,113
Slackwater	47	2	517	240	33	5	3,924	1,732
Vegetation	49	0	1,777	0	45	10	773	212
Total wetted area	216	58	93,330	92,362	154	73	90,066	94,100
Islands	6	5	92,208	91,665	6	5	89,587	91,999
Sand Bar	28	20	4,023	9,238	35	24	12,404	10,095
Cobble Bar	18	9	6,181	6,841	19	15	4,442	6,107
Rootwad piles	48	19	356	785	40	10	770	505
Boulders	6	0	29	0	3	0	8	0
Total mapped area	322	111	196,128	200,890	257	127	197,276	202,807
Flow - cfs			951	891			1,190	1,190
Date			11/14/05	11/18/05			39,024	39,024
Map Scale ft/inch			75	150			75	150

Table 3.6. Comparison of detailed and standard habitat mapping for DR 137, 2006

Habitat Category	Count		Area – m^2	
	Detail	Standard	Detail	Standard
Backwater	8	2	623	200
Other Low Velocity	3	0	64	0
Runs	25	14	46,520	41,936
Riffles	30	12	6,210	13,998
Shoals	29	14	2,389	6,410
Slackwater	62	20	5,110	4,551
Vegetation	68	19	1,286	1,602
Total wetted area	225	81	62,203	68,697
Islands	4	4	125,115	123,886
Sand Bar	7	6	643	2,967
Cobble Bar	12	6	5,592	4,292
Rootwad piles	22	7	170	310
Boulders	0	0	0	0
Total mapped area	270	104	193,724	200,152
Flow - cfs			1,084	1,084
Date			11/1/06	11/1/06
Map Scale ft/inch			75	150

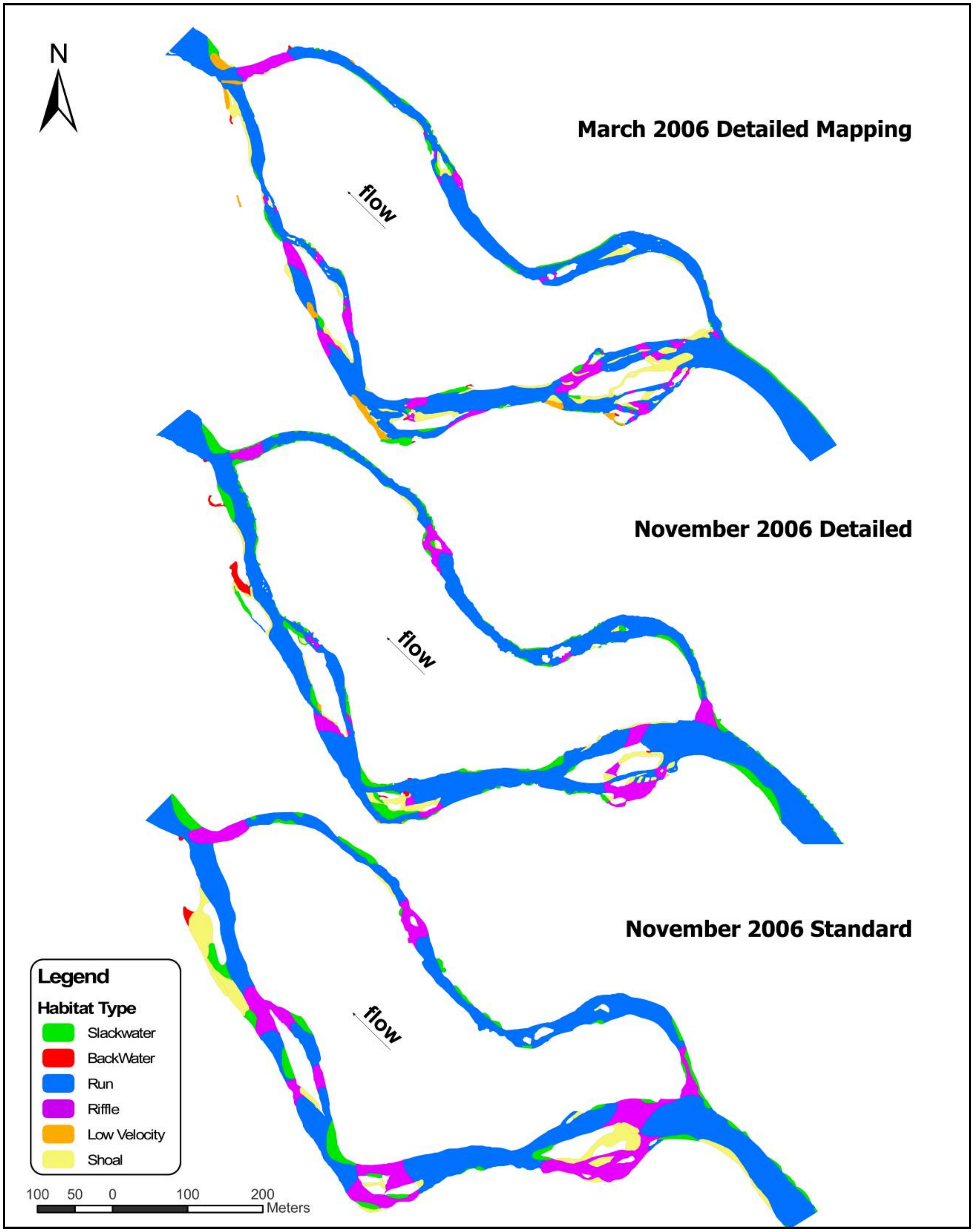

Figure 3.15. Comparison of detailed and standard 2006 habitat mapping for DR 137

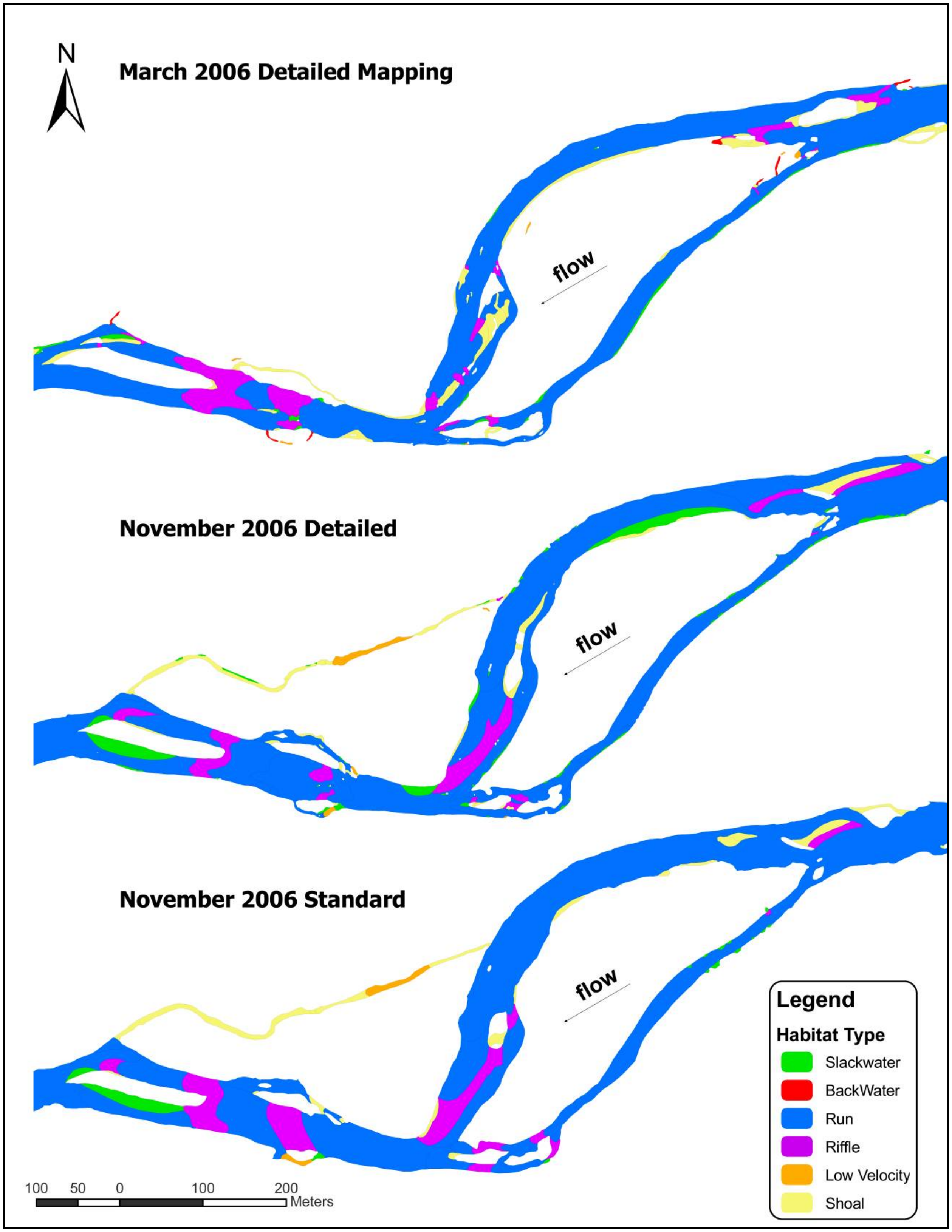

Figure 3.16. Comparison of detailed and standard 2006 habitat mapping for DR 137

The mappers used were carefully and uniformly trained. It is just that some differences are so subtle that they are subject to interpretive differences. Since riffles, runs and shoals make up the bulk of the habitat areas and are not limiting, differences in mapper interpretation is not critical to habitat assessment. However, any differences in these categories from year-to-year and from standard to detailed mapping should not be interpreted as response to flows or change in habitat unless the magnitude of the change is larger than shown in Tables 3.4 and 3.5 when mapped by different mappers. The fact that some mappers include more detail than others on the detailed mapping can be resolved by additional training. The habitats that are of greatest concern and least abundance (backwaters, slackwaters and other low velocity habitats) do not seem to be particularly affected by mapper interpretation.

Of key importance is that the more detailed mapping identifies more locations and smaller habitat polygons of features that represent habitat complexity and low velocity habitat. This greater detail may be important to correlating habitat availability to habitat use.

Extrapolation of this higher resolution mapping to the full standard data set would be possible if a relationship could be established between the high resolution mapping and the standard mapping. With only two years of data there are insufficient data points to develop habitat specific relationships. Grouping habitats in any regression analysis creates an accuracy bias towards the more abundant habitats and diminishes the predictive accuracy for categories with low abundance. Habitat specific relationships will be required and will be possible with five years of data, as originally planned.

Integrating Fish Monitoring Data

Adult monitoring and Colorado pikeminnow augmentation studies have documented use of these reaches by endangered fish (Table 3.7). The other monitoring studies did not capture endangered fish in these reaches, did not sample them or did not analyze the data on a resolution adequate to assess location within the reaches. Only the Colorado pikeminnow augmentation assessment provided site-specific endangered fish captures that could be directly correlated to the habitat mapping data.

Table 3.7. Endangered fish capture data for detailed reaches, 2005-2006

Reach	RM 137		RM 82	
Year	2005	2006	2005	2006
Adult Monitoring				
Colorado pikeminnow	0	1	0	6
Razorback sucker	2	3	0	1
Colorado Pikeminnow Augmentation				
March	n/a	n/a	4	1
July/Aug	n/a	n/a	2	1
November	n/a	n/a	4	n/a

Figure 3.17 shows the sampling and Colorado pikeminnow captures for RM 82 for 2005 and 2006 using gps coordinates for sampling location. At this scale, it is clear that the optical registration of the habitat base map and the level of gps accuracy result in a difference of location that does not allow the two data sets to be joined for identification of habitat use at the specific sampling location. Figure 3.18 is an enlargement of the circled area on Figure 3.17 that also shows the habitat described by the sampling crew. For this location, mapping accuracy is something less than 8-12 meters, making it impossible to determine the habitat type from the map location. General vicinity to complex reaches can be determined, but not specific location. As was found during 2005 when fish sampling and habitat mapping occurred on the same day, the habitat descriptions used by the sampling crew are different and more specific than used by the habitat mappers. Also of note is that the fish sampling crew describes greater detail than is mapped, even at the detailed level. For example, the sampling site and capture location indicated as main, embayment, debris pile is located in an area that is main channel, but shows no embayment or debris pile in the vicinity.

The Colorado pikeminnow augmentation study does not sample RM 137. However, abundant fish captures either side of the reach (Figure 3.19) indicate that captures would be probable if sampled. The 2005 habitat/geomorphology report recommended changing locations to include RM 137 in the sampling, but no change was made.

Model and Habitat Data Integration

Habitat classification based on the velocity/depth categories shown in Table 3.1 are shown for DR 82 in Figure 3.20 compared to the 2005 detailed habitat map, showing just the broader habitat categories listed in Table 4.1. Table 3.8 summarizes the results numerically. The ratios of modeled to detail mapped areas indicate similar accuracy as the detailed to standard mapping for all categories except low velocity for DR 82. The large difference in low velocity habitat is due to channel margin, which fits the modeled low velocity habitat definition, but is not mapped separately. Also, the location and shape of the habitat categories differ (Figure 3.20).

The relationships are not as good for DR 137 (Table 3.8). The model over-predicts shoals and under-predicts runs relative to the detailed mapping. However, there is also a large difference between detailed and standard mapping for shoals. The river left channel through this reach is quite shallow. With a model limit of 0.3 m for shoals, areas that are mapped as runs are being modeled as shoals. Additional calibration will be needed to improve this prediction. Modeled low velocity habitat is much larger than mapped for the reasons stated in the DR 82 discussion above.

Presently, model-predicted habitat areas can be used to assess change in habitat with flow, but will not as accurately represent the actual habitat availability at any particular flow. With additional calibration, total area by habitat category at a specific flow in a reach can be adequately represented, but individual habitats will not be spatially accurate within the reach.

A sample habitat suitability relationship for low velocity habitat availability was developed to demonstrate a refinement option for use of model results (Table 3.9). The DR 82 fall 2006 model utilizing this relationship predicts a weighted usable area of low velocity habitat of 2,898 m^2, or 3.8% of the wetted area, predominantly along channel margins (Figure 3.21). This represents about 5 times as much as is mapped. The difference is likely real if low velocity edge habitat is usable for early life stages of endangered fishes. This approximation is presented as an example. With further refinement it could provide a better estimate of available habitat than is presently mapped if it is found that this edge habitat is usable and important.

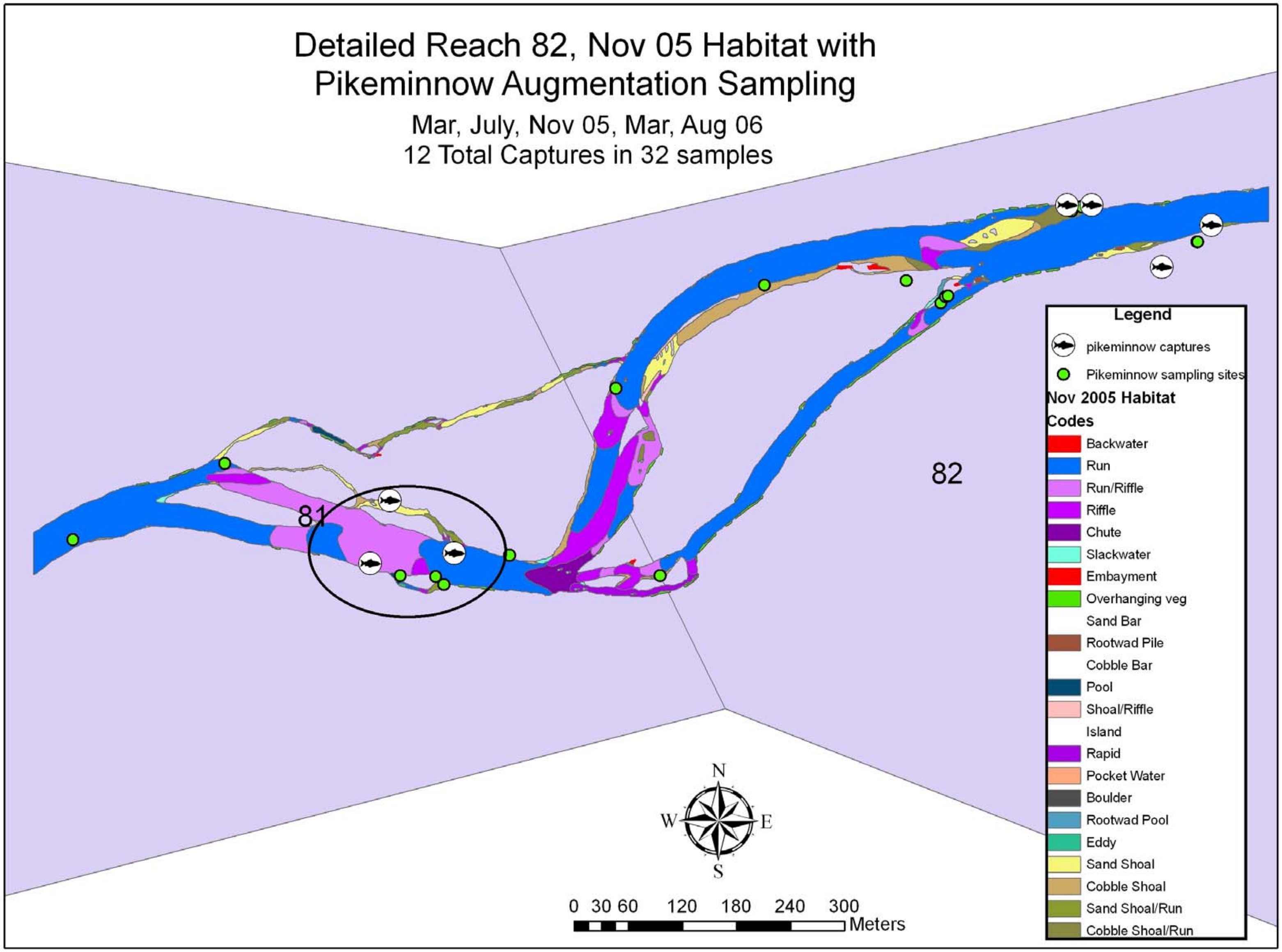

Figure 3.17. DR 82 November 2005 habitat map with Colorado pikeminnow augmentation survey sites and capture locations for 2005-2006

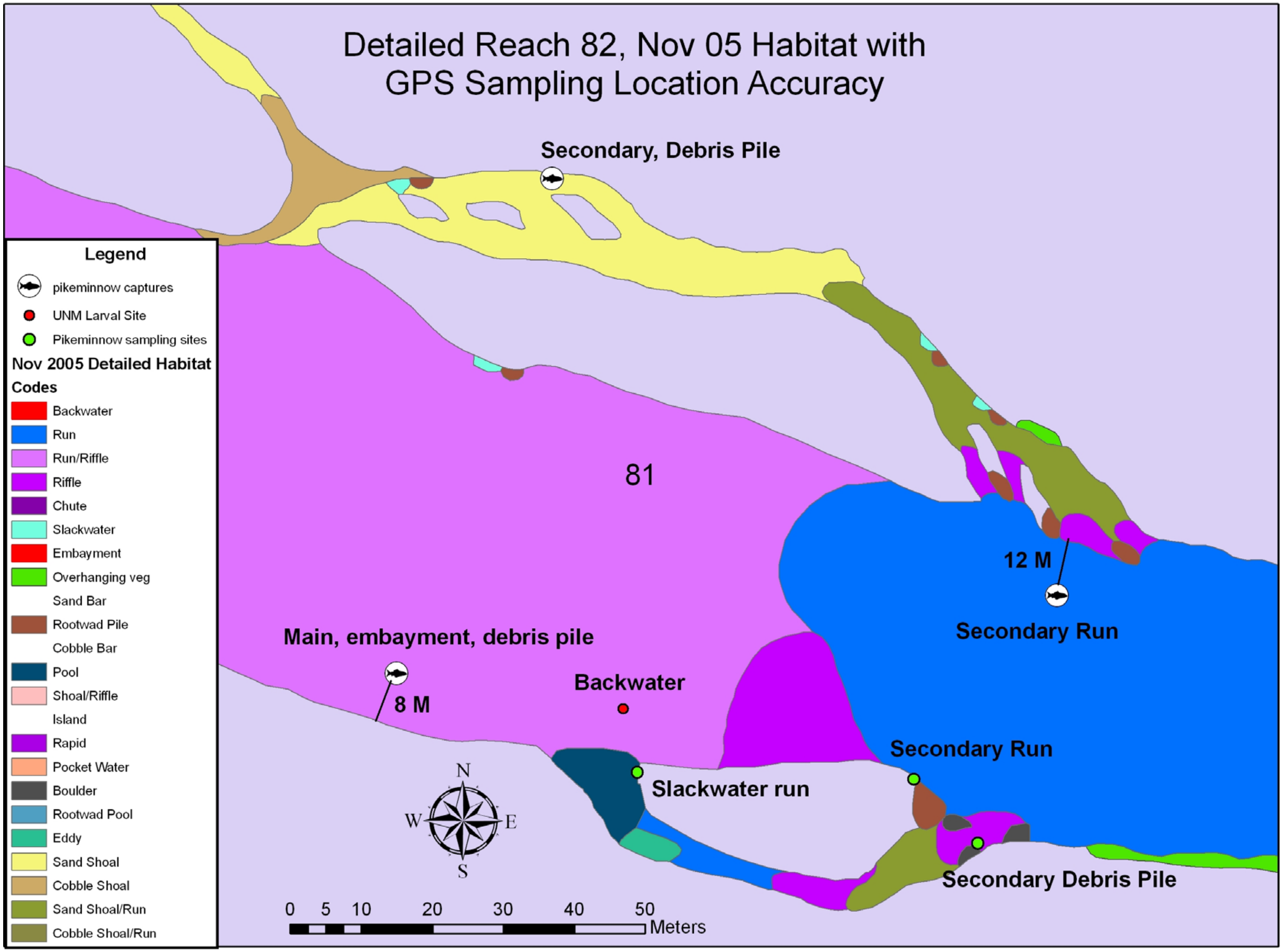

Figure 3.18. **DR 82 enlargement from Figure 3.17 comparing gps and mapping locations with habitat descriptions**

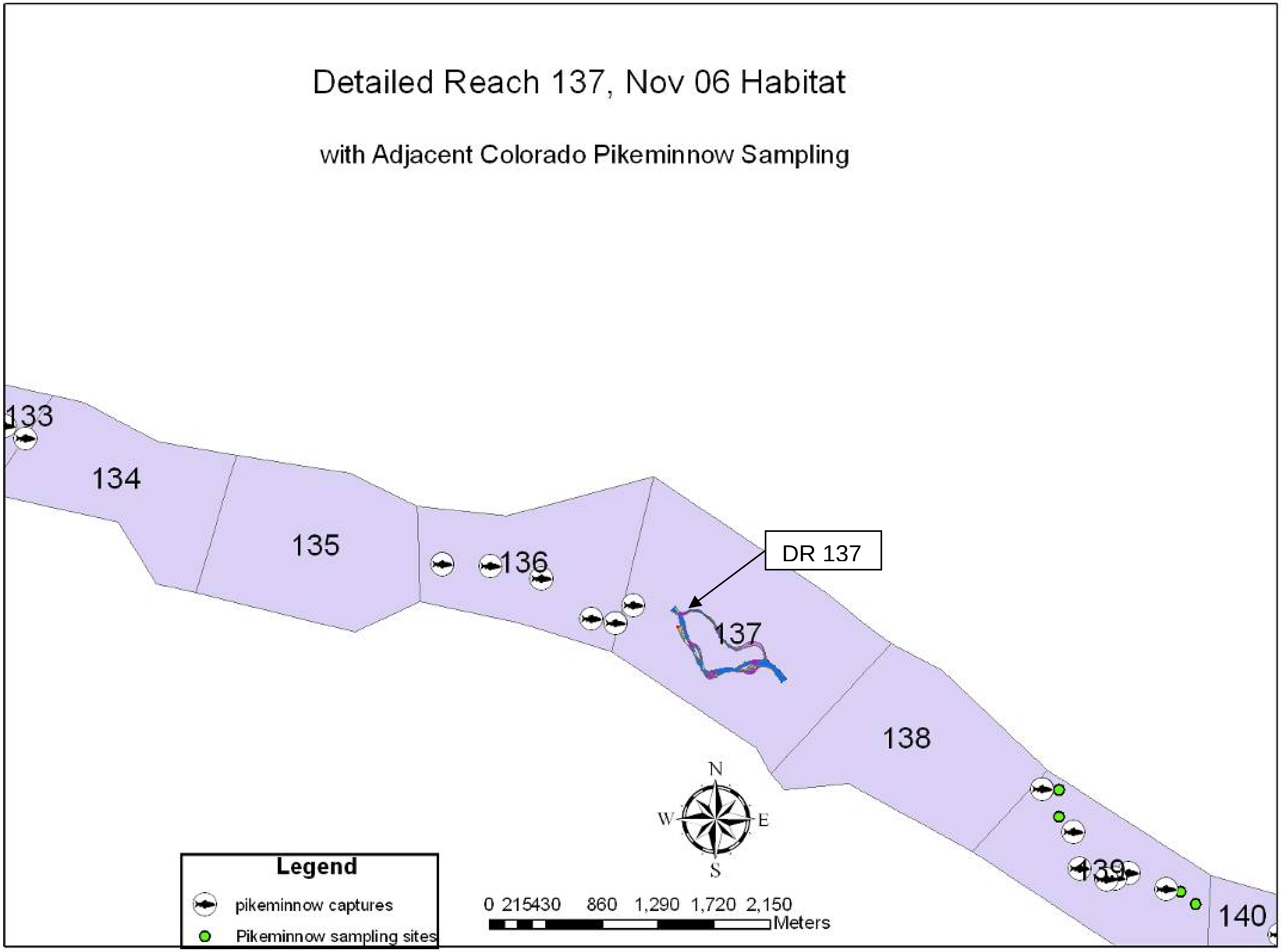

Figure 3.19. Colorado pikeminnow 2005-2006 capture locations in the vicinity of DR 137

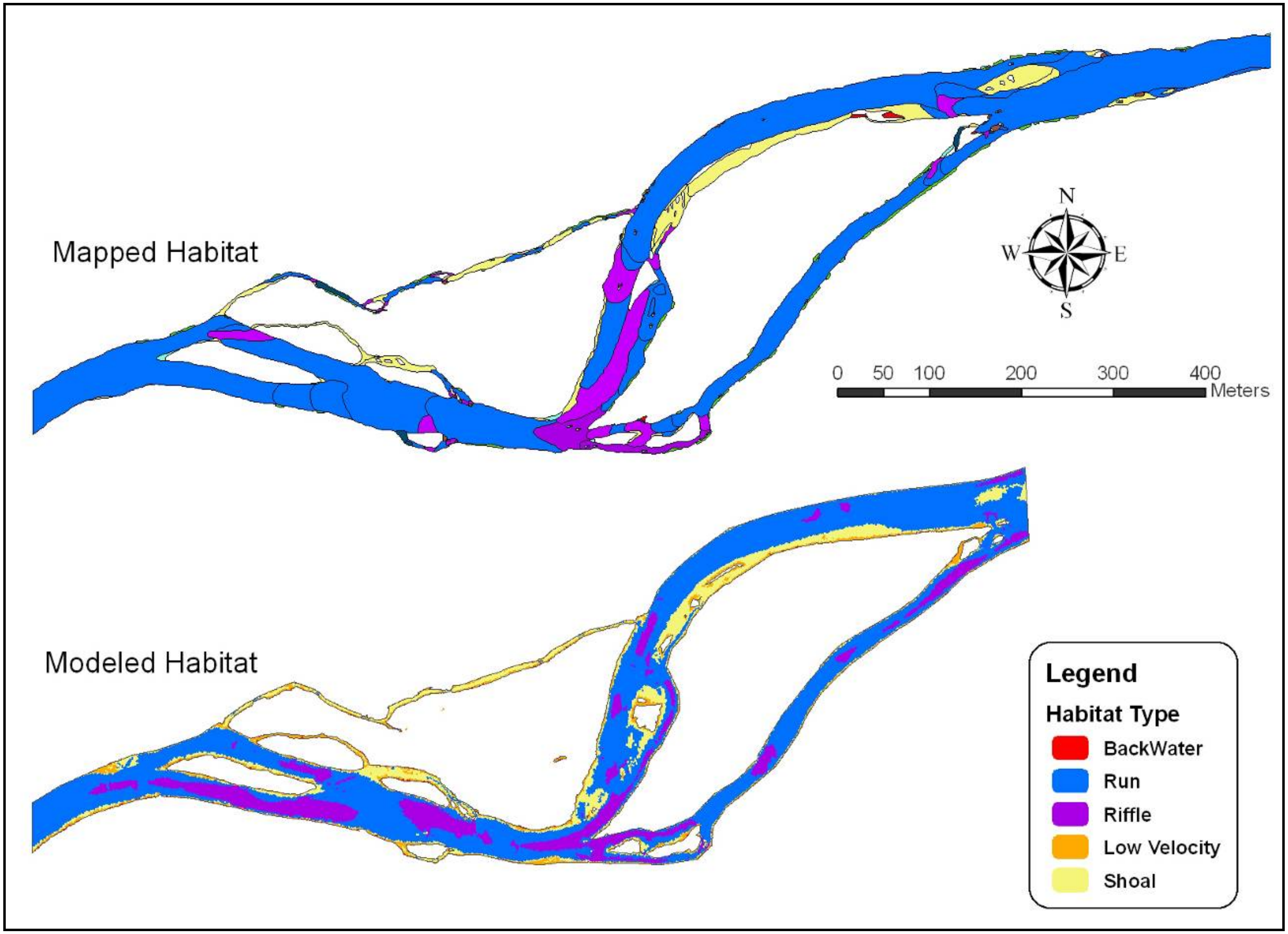

Figure 3.20. 2005 predicted and mapped habitat for DR 82

Table 3.8. Model-predicted habitat availability in DR 82 and DR 137 compared to November 2005 mapping

Habitat	Detail	Standard	Detail / Standard	Model	Model / Detail
			DR 82		
Backwater	180	-		392	2.18
Low Velocity	429	410	1.05	7,946	18.50
Slackwater	467	240	1.95	958	2.05
Shoal	7,552	13,753	0.55	10,427	1.38
Run	57,553	52,973	1.09	50,157	0.87
Riffle	10,315	8,538	1.21	13,328	1.29
Total	76,496	75,913	1.01	83,208	1.09
			DR 137		
Backwater	623	200	3.12	1,033	1.66
Low Velocity	64	-		8,755	132.11
Slackwater	5,110	4,551	1.12	3,359	0.66
Shoal	2,389	6,410	0.37	12,216	5.11
Run	46,520	41,936	1.18	29,559	0.64
Riffle	6,210	13,998	0.44	7,962	1.44
Total	62,203	68,697	0.91	62,884	1.01

Table 3.9. Habitat suitability definition for low velocity habitat

Velocity		Depth	
cm/sec	Index	m	Index
0.00	1.00	5.00	1.00
3.00	0.90	0.30	1.00
6.00	0.50	0.15	0.60
9.00	0.20	0.10	0.25
10.00	0.00	0.05	0.00

This sample weighted usable low velocity habitat area is relatively constant with flow when expressed as a percentage of the total habitat in the range of 600 to 6,000 cfs for both reaches (Table 3.10), although the total weighted area does increase. Since low velocity edge habitat is included, the increase in area with flow reflects the increase in linear edge as more secondary channels flow.

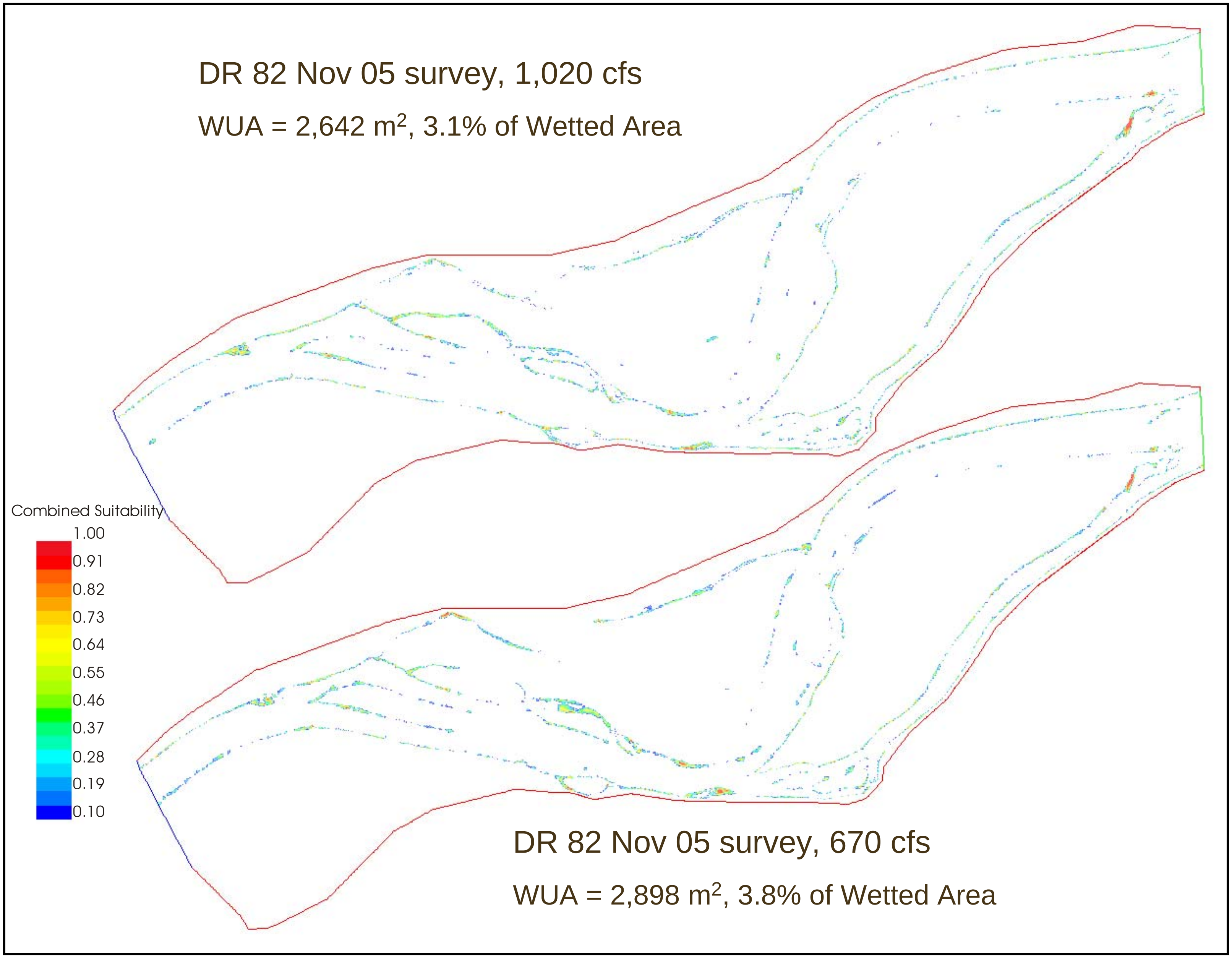

Figure 3.21. Weighted usable area of low velocity habitat in DR 82 for November 2005 mapping

Table 3.10. Modeled low velocity weighted usable area for DR 82 and DR 137 with flow

Reach	Flow - cfs	Weighted Usable Low Velocity Habitat – m^2	Total Wetted Area m^2	% WUA
DR 82	671	2,898	76,409	3.79%
	1,020	2,642	85,019	3.11%
	3,000	4,018	108,425	3.71%
	6,140	5,181	131,531	3.94%
DR 137	607	3,704	64,423	5.75%
	799	3,604	65,775	5.48%
	5,547	5,080	112,696	4.50%

This sample weighted usable low velocity habitat area is relatively constant with flow when expressed as a percentage of the total habitat in the range of 600 to 6,000 cfs for both reaches (Table 3.10), although the total weighted area does increase. Since low velocity edge habitat is included, the increase in area with flow reflects the increase in linear edge as more secondary channels flow.

CONCLUSIONS AND RECOMMENDATIONS

Analysis of the first two years of data from the detailed reaches has lead to some important findings. The objectives of the study are being met, although some of the original methods have been changed. The study has identified a need to establish common nomenclature for habitats among studies to allow better integration and a need to refine some additional habitat classifications for better repeatability. It also has identified low velocity habitat in association with channel margins and can assist in defining a method for mapping it river wide if it is found to be important to the endangered fish. Following are the detailed findings and recommendations:

Channel Change

- DR 82 demonstrated about 3 cm of net scour between November 2005 and August 2006, with both scour and deposition within the reach. Both cobble/gravel and sand had a net export in the reach.
- DR 137 demonstrated about 3 cm of net deposition during the same time period with both scour and deposition within the reach. Both cobble/gravel and sand had net import to the reach.
- The change is statistically significant.
- Collection of Wolman pebble count data (Wolman, 1954) should be added to allow large-particle sediment transport analysis to meet objective 1.

River2D Model

- River2D models have been developed for DR 82 and 137 that cover ranges in flow from about 600 cfs to around 6,000 cfs.
- Channel change between 2005 and 2006 resulted in a deterioration of model accuracy in DR 82, requiring re-calibration using the 2006 survey data.
- Changes in flow during 2005 edge-of-water survey lead to poor calibration results for DR 137. 2006 calibrations are better.
- The models provide sufficiently reliable results to forecast depth and velocity over a range of flows.

- More work needs to be done to eliminate isolated wetted areas, particularly at high flow, that are a result of modeling. These areas can result in over-predicting low velocity habitat availability unless removed from analysis.

Detailed Reach Habitat

- Detailed mapping identifies from 2 to 3 times as many habitat polygons as standard mapping.
- Changes between 2005 and 2006 at flows near 1,000 cfs are small.
- Interpretive difference between mappers of some habitat categories suggests a review of the classifications and training standards for future refinement.

Integrating Fish Monitoring Data

- Both reaches are used by Colorado pikeminnow and razorback sucker.
- Only the Colorado pikeminnow augmentation study provided site-specific data of endangered fish in these reaches.
- GPS fish capture locations in conjunction with projected habitat maps are not sufficiently accurate to provide habitat-specific locations.
- Simultaneous mapping of habitat and fish location is recommended for correlation of habitat availability to use.
- Since the Colorado pikeminnow augmentation study ended in 2006, endangered fish monitoring should be instituted with direct linkage to habitat mapping to meet the full objectives of this study.

Model and Habitat Data Integration

- Differences in map accuracy between the survey-generated base for River-2D modeling and the projected digital videography prints for habitat mapping prevented intersection of the two data sets to calibrate velocity and depth to habitat type.
- Using depth-velocity-habitat relationships reported in 2000, the model can only predict change in habitat abundance by category with change in flow. It cannot accurately predict location or total area at any given flow. With additional calibration it may be able to reasonably predict total area at any given flow, but will not give the same spatial distribution as physical mapping.
- The modeled low velocity habitat is much greater than mapped, even when weighted for suitability based on depth and velocity. The difference is primarily along channel margins that are not mapped. Changes in mapping could identify these areas if found to be important to endangered fishes.
- Weighted usable area of low velocity habitat increases with flow above about 1,000 cfs, but is relatively constant as a percentage of the total wetted area.
- Effort should be placed on identifying the suitability of low velocity habitat along channel margins for endangered fish.
- If this edge habitat is found to be important, a process of mapping it can be developed.

CHAPTER 4: 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.

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 4.1, summarized into seven general categories.

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.

Table 4.1. 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
pool	shoal/run	riffle	backwater	sand shoal	slackwater	overhanging vegetation
debris pool	run	shore riffle	backwater pool	cobble shoal	pocket water	Inundated vegetation
rootwad pool	scour run	riffle chute	embayment			
eddy	shore run	shoal/riffle				
edge pool	undercut run	chute				
riffle eddy	run/riffle	rapid				

Reported here are the results from 2005 mapping. Processing time is such that there is a one-year lag in reporting results.

RESULTS

2005 Mapping Summary

The mapping dates and ranges of flow rates for mapping between RM 2 and RM 180 are shown in Table 4.2 for 2002-2005. In 2005, 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 three previous years (Figure 4.1). These distributions can be seen in Figure 4.2 and the results in terms of the percent of total wetted area are summarized in Table 4.2. Run habitats, which have the most surface area, had a range of 78.6% to 82.0% of the total wetted area (TWA) and 80.9 % for 2005. Riffles had the second largest surface area (ranging from 9.0% to 11.8% between 2002 and 2004) with 8.5% of the total wetted area. The third most plentiful habitat was shoal types. This habitat ranged between 4.7% and 6.4% in the three previous years but increased to 8.1% in 2005. Slackwaters are the fourth dominant habitat with a range between 1.6% and 3.8%, with 2005 falling within that range (1.7%). Backwaters made up only 0.25% of the surface area of habitats in 2005 but reflected a continued increase which started in 2003 (0.13% of TWA).

The spatial distribution of these same general categories can be seen in Figures 4.2 and 4.3 for 2005. Figure 4.3 truncates the vertical scale to allow better viewing of the subdominant habitat distribution. Backwater habitats were distributed throughout the river but are in moderate amounts in Reach 1 (6,200 m^2), lowest in reach 2 (2,800 m^2) and relatively constant in reaches 3, 4 and 5 (9,800 to 10,900 m^2). Reach 6 had approximately 6,500 m^2. Low velocity habitat types had a patchy distribution (Figure 4.3) and were found to be most plentiful between RM 103 and RM 138. 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. Slackwater habitats are most abundant between RM 15 and RM 83 and are associated with riffle complexes within the canyon bound reach of the river.

Table 4.2. Summary of mapping dates, flows and habitat distribution for 2002-2005

Year	Dates	Flow - cfs	Runs	Riffles	Shoals	Slack-water	Back-water	Low Velocity	Veg.
2002	7/23-8/04	329-704	82.0%	9.0%	6.4%	1.6%	0.17%	0.62%	0.09%
2003	10/20-24	337-511	80.6%	11.0%	4.8%	3.2%	0.13%	0.21%	0.11%
2004	11/03-08	758-891	78.6%	11.2%	5.7%	3.8%	0.21%	0.25%	0.25%
2005	11/12-18	830-1,020	80.9%	8.5%	8.1%	1.7%	0.25%	0.51%	0.03%

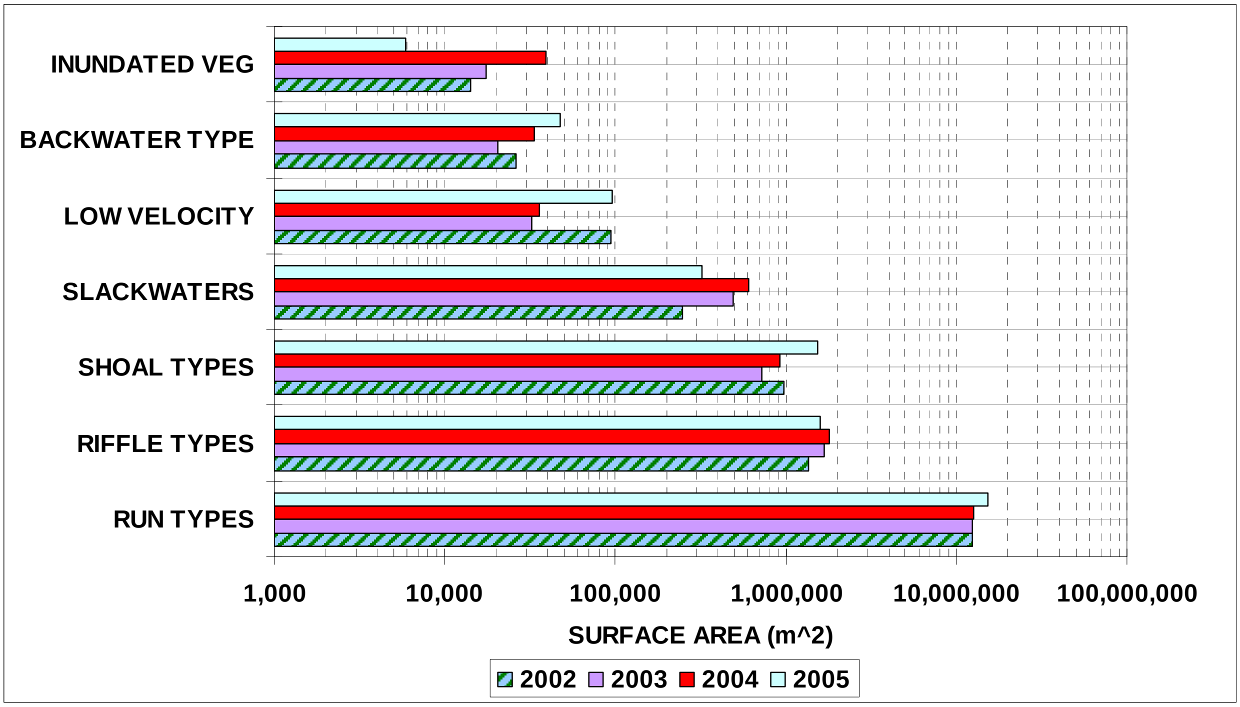

Figure 4.1. A comparison of the amount of surface area by general habitat type in the San Juan River (RM2 to RM180) for 2002 – 2005

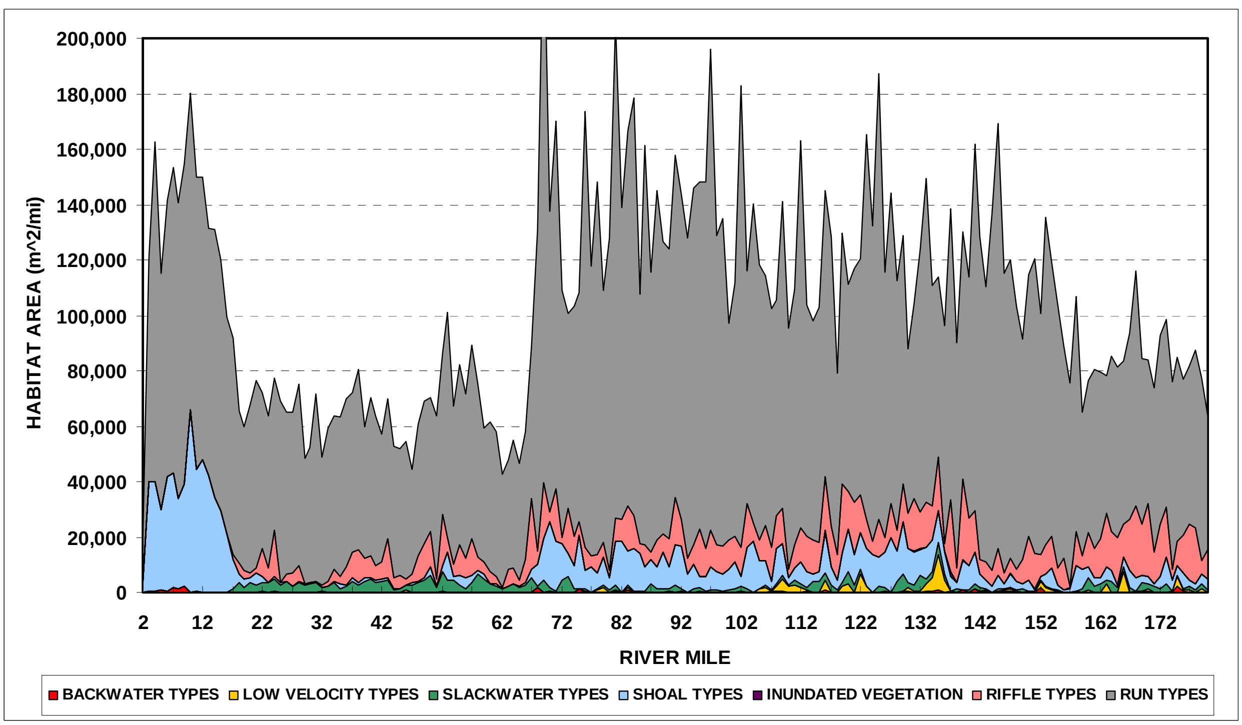

Figure 4.2. The spatial distribution of major habitat types in the San Juan River for 2005

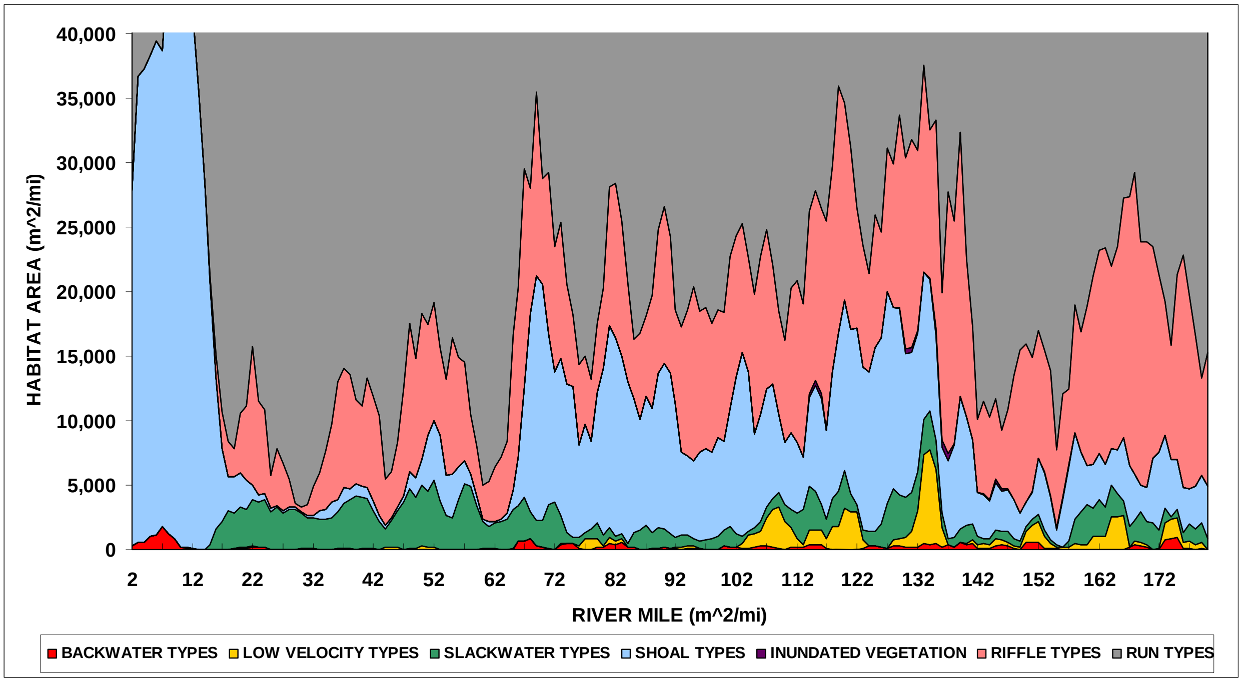

Figure 4.3. The spatial distribution of major habitat types in the San Juan River in 2005, scaled to better show subdominant habitat distribution

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 2005 (47,296 m^2) compared to previous years is shown in Figure 4.4 for surface area and in Figure 4.5 for the count (numbers) of backwaters. The data indicate that after reaching a maximum in 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 in 2005. Backwater habitat increased from 33,500 m^2 in 2004 to 46,600 m^2 in 2005, an increase of nearly 40%, with only a slight increase in flow at mapping. The increase occurred in all reaches, with the greatest increase (145%) in Reach 4. Other low velocity habitat followed the same trend, increasing 70% over 2004. The backwater count in 2005 was 111, about the same as 2004. The count in 2006 was 133, the highest since 1999 (Figure 4.5). Backwater areas have not been determined yet for 2006 as previously noted.

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 values 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. Only habitat data sets with flows under 1,200 cfs and for which reaches 1-6 were sampled are included. This relationship is shown in Figure 4.6. The relationship is significant with a downward trend through 2003, showing loss of habitat with time and then an increase to 2005 showing a

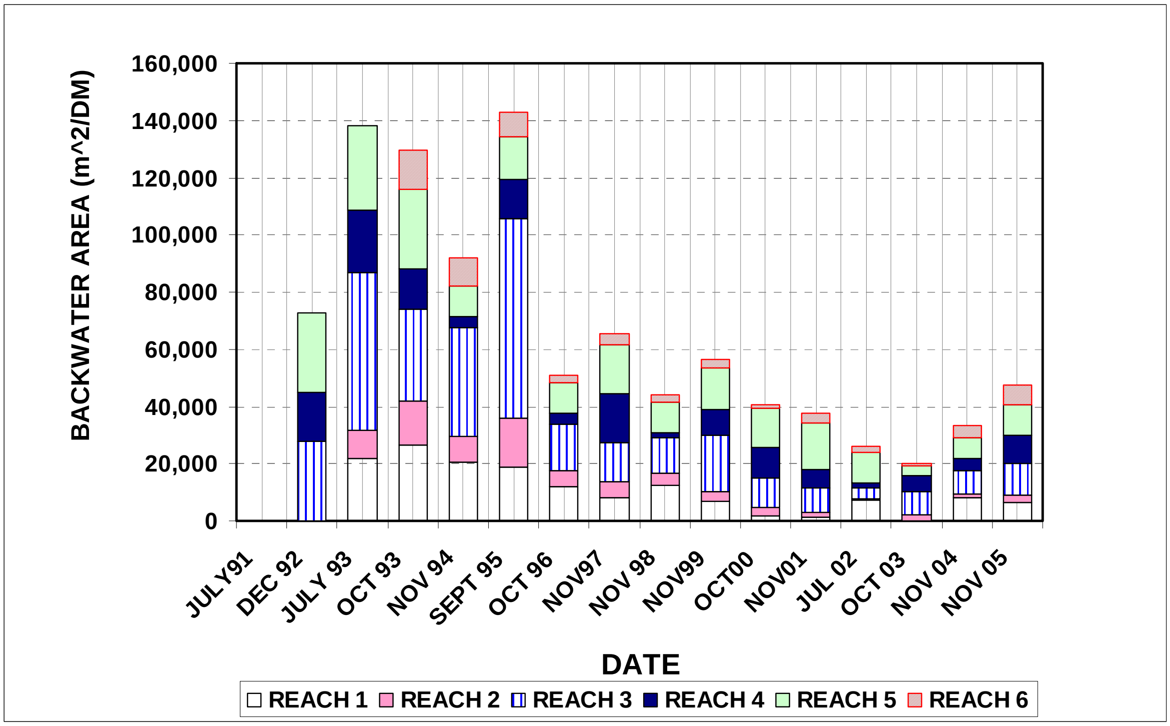

Figure 4.4. **A comparison of the backwater surface areas mapped at approximately the same flow in the San Juan River since 1991 (450-1200 cfs)[5]**

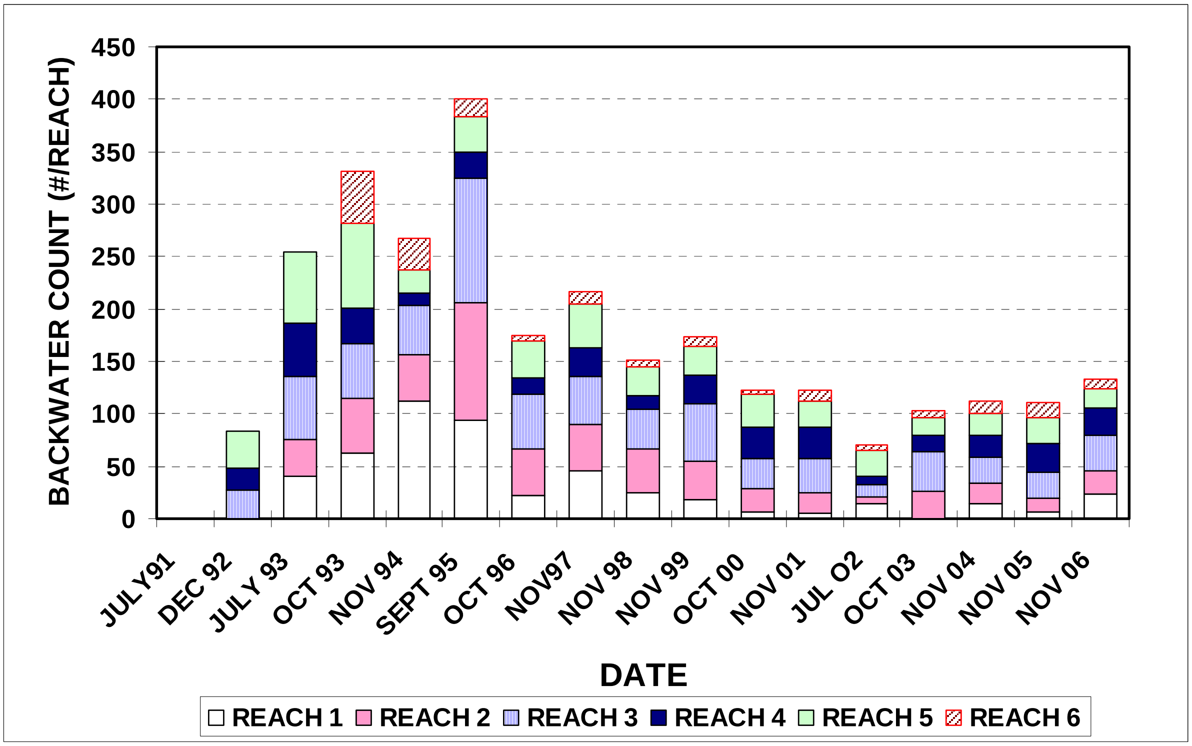

Figure 4.5. **A comparison of the number of backwaters in the San Juan River mapped at approximately the same flow since 1991 (450-1200 cfs). [2]**

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

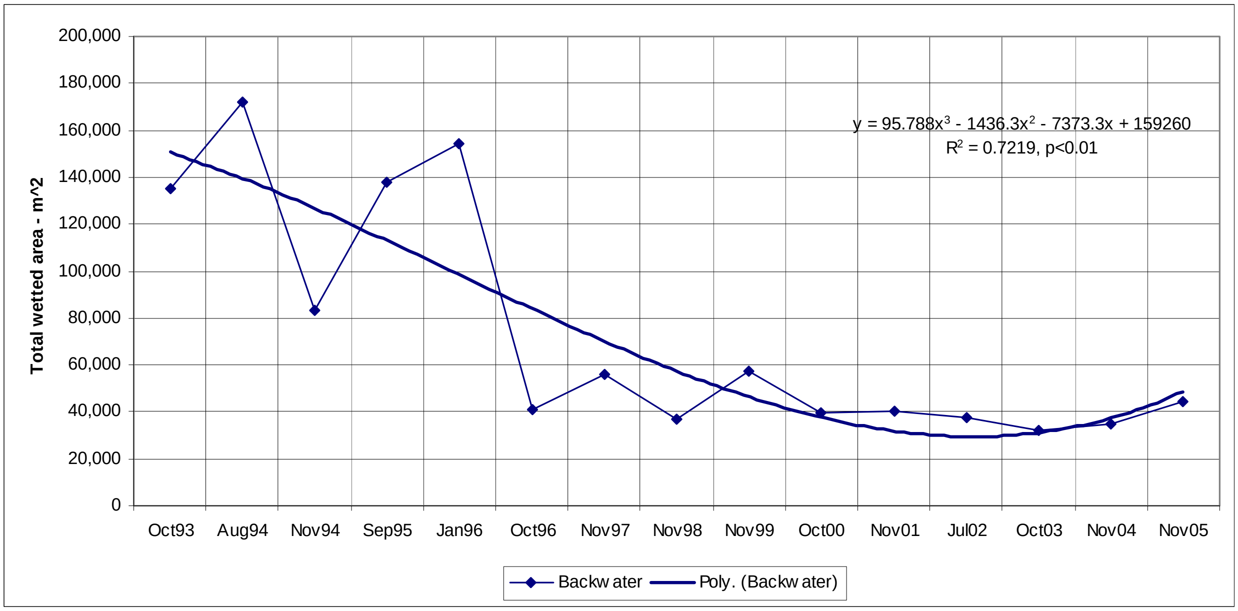

Figure 4.6. Backwater area residual (adjusted to yield mean habitat area) from habitat-flow regression

reversal in the trend. When corrected for flow, the trend from October 1996 through November 2004 is nearly flat with an increase in 2005 to levels seen in 1998-1999.

The increase in backwater and low velocity habitat in 2005 is in response to the high flows during 2005 spring runoff when all of the desired flow statistics were met. While backwater habitat area has not returned to 1995 levels, the increase is significant. As noted in the historical backwater study (Bliesner and Lamarra, 2006), it may take several sequential high flow years to produce the backwater abundance seen in 1995.

CONCLUSIONS

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

- Relative abundance among habitat categories has not changed during the 14 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.
- The 40% increase in backwater habitat area between 2004 and 2005 is attributed to the high flow year, during which the desired flow recommendation conditions were all met.
- Multiple high flow years will likely be required to achieve backwater conditions similar to 1995 (Bliesner and Lamarra, 2006).

CHAPTER 5: 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 5.1. 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 5.1 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 5.1 with their period of record.

RESULTS

Plots of the 2006 water temperature data for all monitored sites are shown in Figure 5.1. There was a malfunction in the Mexican Hat recorder between August 1, 2006 and September 16, 2006. A new HOBO Water Temp Pro recorder was installed on October 12, 2006. During this time, no temperature data were recorded at Mexican Hat as shown in Figure 5.1. The Montezuma Creek sensor was stolen some time between March 11, 2005 and October 8, 2005. A new logger was installed the end of October 2005. Thus, there are no temperature data at Montezuma Creek between March 11, 2005 and October 30, 2005.

The hydrograph at the Four Corners gage plotted with the temperature profiles illustrates the direct negative correlation between flow and water temperature (Figure 5.1). The Navajo Dam release made May 25, 2006 to June 16, 2006 caused an average drop of approximately 4 - 5°C over a two-week period throughout the river system. At high flow, the temperature at Archuleta is suppressed to the dam release temperature and the temperature of the San Juan at Farmington ranged 1 - 6°C cooler than the Animas at Farmington. By the end of the fish release (June 16), the San Juan and Animas Rivers were approximately the same water temperature (16°C). The water temperatures on the San Juan and Animas Rivers at Farmington remained nearly the same until June 29, 2006. After which, the water temperatures on the Animas River was 1 - 4°C warmer than the San Juan throughout the rest of the 2006 water year, coinciding with the period after spring runoff on the Animas River.

In years of low Animas flows it is typical to see suppression in temperature throughout the San Juan River during a release from Navajo Dam. In years with high Animas River flows there is less temperature suppression in the San Juan River below the confluence with the Animas during a Navajo Dam release, as the larger volume of Animas runoff is typically cooler.

Table 5.1 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
Archuleta - San Juan at USGS Gage Location	218.6	7/23/92 to 9/15/06
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
Shiprock - San Juan at USGS Gage Location	148.0	7/8/99 to 9/16/06
Four Corners - San Juan at USGS Gage Location	119.4	10/7/94 to 3/11/96*, 7/9/99 to 10/19/06
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
Mexican Hat - San Juan near Bluff Gage Location	52.1	7/9/99 to 3/27/02 , 9/18/02 to 8/1/06
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
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.

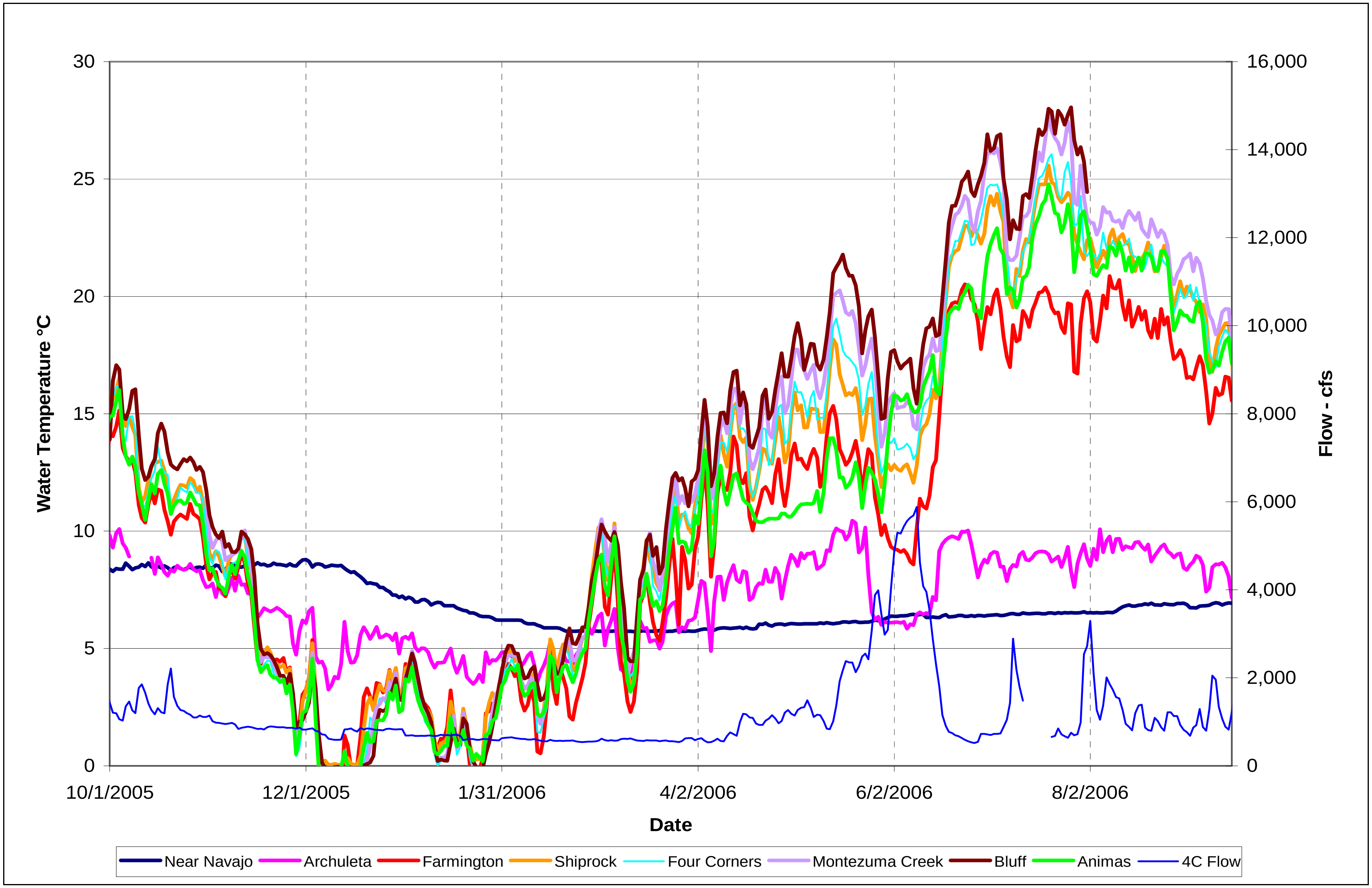

Figure 5.1. San Juan Basin Average Water Temperature Data, 2006

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