San Juan River Habitat Monitoring: 2017

Annual Report

Submitted To:

San Juan River Biological Committee
United States Fish and Wildlife Service

Submitted By:

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Executive Summary

During 2017 the San Juan River experienced a significant run-off event for the second time in two years. Flows reached a maximum for a short period of time, (8,310 cfs) and a sustained high flow of over 5,000 cfs for 50 days. The combination of these two factors, along with the high water year that occurred in 2016 contributed to the current geomorphic planform of the San Juan River. Aerial images were captured on September 11 and September 12 when the flow of the river was approximately 530 cfs. Images were processed using ESRI Arcmap 10.0 creating individual quantified polygons for wetted area, islands, non-wetted in-stream structures, embayments, and five types of backwaters. Due to the mapping at the 530 cfs low flow, total wetted area of the river decreased by 6% compared to the 2016 mapping effort (a loss of approximately 22 million m² of surface area). In a similar manner, island area (which is used as a surrogate of habitat complexity) was affected by the mapping at this low flow resulting in abandoned side channels, decreased island count and island area. A total number of 154 islands were mapped in 2017. The presence of wetted sand, recently deposited debris piles, and isolated pools within abandoned secondary channels indicated that side channels had been flowing. Backwaters and embayments in the San Juan River are low velocity habitats considered important to Colorado Pikeminnow and Razorback Sucker as nursery habitats and refugia. Inversely to wetted area and island area, low velocity habitats continued to increase in area despite mapping at the 530 cfs low flow. Overall low velocity habitats increased 11% from 94,001m² in 2016 to 105,064 m² in 2017. All reaches of the river gained low velocity habitat surface area except reach 4. An effort was made in 2017 to delineate low velocity habitat into 6 categories; secondary channel backwaters, river bank backwaters, embayments, island associated backwaters, in stream non-wetted area associated backwaters and point-bar associated backwaters. The reason for these delineations was to better understand formation dynamics, and location persistence. The count and area of these low velocity habitats were generally consistent and similar to 2016, except for secondary channel backwaters. They were only 3% of the total count but were 30% of the total area. This indicates that the cyclical nature of secondary channels which flow at high stage and become abandoned at the head of the island at lower baseflows, is an important mechanism for providing approximately 1/3 of all total backwaters that persist into base flow.

Introduction

Colorado Pikeminnow (*Ptychoheilus lucius*) and Razorback Sucker (*Xyrauchen texanus*) are two native fish species of the San Juan River listed as endangered in 1967 and 1991 respectively. A major component of the Endangered Species Act is the designation and protection of critical habitat including locations within the geographical area occupied by the species that contain physical or biological features essential to the conservation of the species. These physical or biological qualities are considered primary constituent elements (USFWS, 1998). The United States Fish and Wildlife Service determined critical habitat for Colorado Pikeminnow to be from Farmington, New Mexico to Neskahi Canyon, Utah. Critical Habitat for Razorback Sucker is located from Hogback Diversion, New Mexico to Neskahi Canyon, Utah. (USFWS, 1998).

Research in the upper Colorado River, Green River, and Yampa River have shown that low velocity type habitats and backwaters were critical to the development of both young-of-year and juvenile Colorado Pikeminnow and Razorback Sucker (Holden 1977; Joseph et al. 1977; Tyus and Karp 1989; Tyus and Karp 1990). Most recently, sampling conducted as part of the San Juan River Recovery Implementation Program (SJRIP), indicates both species have reproduced in the San Juan River with early life stages found in low velocity habitats such as backwaters and embayments. SJRIP is driven by several program guidance documents. The 2012 Monitoring Protocols (SJRIP 2012) state that the overarching goal for habitat monitoring is to:

"Quantitatively document effects of naturally occurring conditions, management actions, and other anthropogenic activities on aquatic habitat availability in the San Juan River. Use this information to recommend appropriate modifications to recovery strategies for Colorado Pikeminnow and Razorback Sucker in the San Juan River."

In Addition, there are statements in the Long Range Plan for specific tasks and objectives. The monitoring objectives relative to habitat are as follows:

1. Annually, following spring runoff, document abundance and distribution of key habitats and geomorphic features (backwaters, embayments, islands, and total wetted area) that indicate the response of the river channel and habitat to antecedent runoff conditions and specific management actions.
2. Track long-term trends of habitat availability.
3. Develop relationships between habitat availability and antecedent flow conditions, using key habitats for this analysis.

Methods

Aerial imagery of the San Juan River was obtained using a TU-206 Cessna fixed wing aircraft that maintained an altitude above 3,800 feet in order to achieve a 10 centimeter digital 4 band resolution. Images were captured using a UltracamLp high resolution camera. The contractor Blue Sky Consulting (BSC) took photographs of the San Juan River between September 11 and September 12, 2017 while the river was documented flowing at approximately 531 cfs measured at the four corners gauge (USGS station No. 09371010) (Figure 1). Digital images were imported and post-processed in the laboratory using ESRI Arcmap 10.0, and subsequently overlaid on 2011 georeferenced National Agriculture Imagery Program (NIAP) county mosaics for the full extent of the river floodplain boundaries in order to ensure geographic accuracy. Images were georeferenced and rectified by the contractor (BSC), resulting in an end product of high resolution (10 cm) mosaic images of the San Juan River from the confluence of the Animas River in Farmington, New Mexico to the Great Bend of the San Juan River in Lake Powel, Utah. This process of preparing the mapping photos was a similar process to the methods employed by Block (2014) on the Little Colorado River.

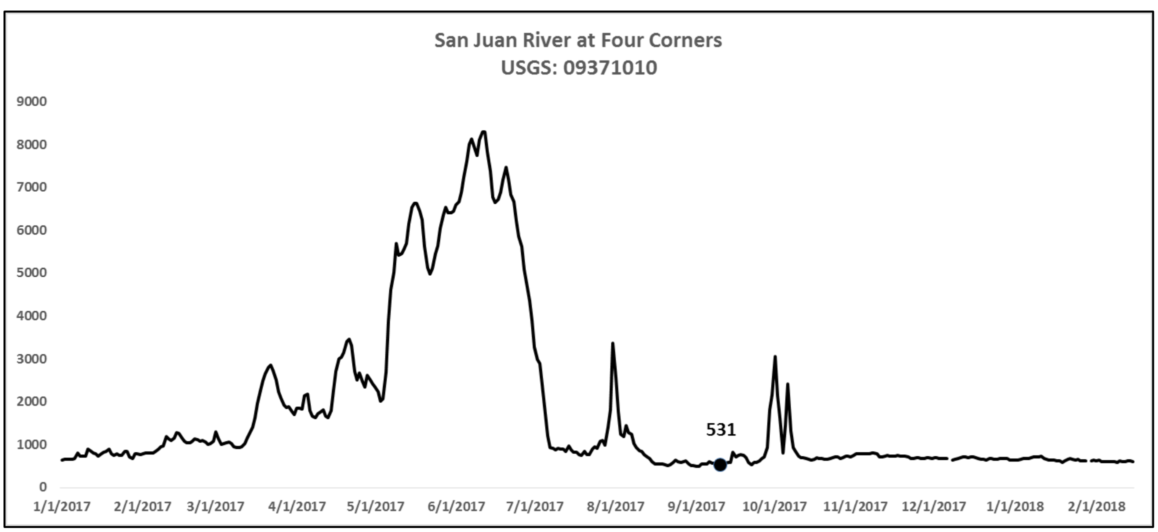

Figure 1 The 2017 hydrograph for the San Juan River at four Corners (Station 09371010), labeled point denotes sampling date and flow at mapping.

Total Wetted Area

Total wetted area for the San Juan River was determined by using the vector-editing program within Arcmap and the above-mentioned rectified, high resolution images from the 2017 data set. A vector image of the waters' edge was created for each river mile in the San Juan River using the polygon function. These vectors were then transformed into individual mile-specific polygons from which total wetted area could be quantified. Islands were delineated (defined as any in-stream, non-wetted structure with at least 50% vegetation coverage), as well as any non-wetted in-stream structures such as sand bars, cobble bars, or debris piles. These delineated polygon areas were subtracted from the total wetted area to estimate the actual wetted area for each river mile in the system. Island structures were delineated per mile, and uniquely identified as part of the comprehensive data set. Characteristics such as count, area, and perimeter were quantified. Backwater and embayment habitat types were delineated using the same polygon-editing tool as referenced above, creating a unique vector image for each individual habitat. Both habitat type areas counted towards total wetted area. In addition to the acquisition of new habitat data for 2016, a further effort was undertaken to differentiate and quantify backwaters dependent on locations within the river and formation methods. The following definitions were used to characterize backwater types.

1- **Secondary Channel Backwater**: Formed on the tail end of a previously flowing secondary channel.
2- **Bank Backwater**: Formed on the direct bank of the river.
3- **Island Backwater**: Formed on islands.
4- **Non-Wetted Area Backwater**: Formed on cobble-bars and sand-bars
5- **Point Bar Backwaters**: Formed on bends of rivers on bank point-bars.

Various hydrologic parameters were calculated from the hydrograph as gaged at the Four Corners USGS Station No. 09371010 (Table 1). These data were considered to be antecedent conditions prior to base-flow mapping. Antecedent conditions were calculated for the 2017 base-flow mapping and are compared to the previous 6 years of hydrologic characteristics (2011-2016).

Table 1: The antecedent flow conditions in the San Juan River in 2017. Data are from the USGS gage at Four Corners (No. 09371010).

Hydrograph Characteristics at 4-Courners Gage

Antecedent Condition	2011	2012	2013	2014	2015	2016	2017
Peak Runoff (cfs)	8,980	5,680	2,140	4,890	8,490	8,480	8,310
Runoff (Mar-July af)	545,803	388,502	223,358	189,779	585,358	816,094	529,298
Total Runoff (Annual af)	871,147	674,917	632,705	721,912	939,320	1,179,646	1,391,548
Peak Date	13-Jun	25-May	20-May	3-Jun	12-Jun	12-Jun	7-Jun
Days > 10,000 cfs	0	0	0	0	0	0	0
Days > 8,000 cfs	7	0	0	0	1	7	5
Days > 5,000 cfs	12	6	0	0	14	36	50
Days > 2,500 cfs	27	10	0	23	38	58	81
Days BT 500 & 1,000	255	278	253	251	232	220	199
Days BT 750 & 1,000	157	79	45	79	77	110	73
Days BT 1,000 & 1,500	37	52	33	46	55	75	42
Days BT 1,500 & 2,000	22	18	17	10	14	5	24
Days BT 2,000 & 2,500	11	2	2	10	16	7	18
Days BT 5,000 & 8.000	5	6	0	0	13	29	45
Days < 500	12	5	46	25	9	1	2
Days < 750	110	204	254	197	155	111	128
Days < 1000	267	283	299	276	241	221	201
Days < 1500	304	335	332	322	296	296	243
Days < 2000	326	353	349	332	310	301	267
Days < 2500	336	355	365	342	327	308	285
Maximum Daily Flow (cfs)	8,980	5,680	8,440	4,890	8,490	8,480	8,310
Minimum Daily Flow (cfs)	399	461	259	354	405	484	489
Assending RO (Mar 1-May 31) af	172,226	281,708	145,112	187,047	187,744	316,697	283,385
Decending RO (June 1-July 31) af	373,577	106,793	78,246	188,716	391,761	499,397	245,913

Results

Antecedent Conditions

Antecedent conditions for 2017 exhibited similar traits to that of 2016 as well as some marked differences. The maximum average daily flow measured for 2017 was 8,310 compared to 8,217 in 2016 (Table 1). In addition both years contained at least five days of flow over 8000 cfs. In 2016 there were 36 days of flow over 5000 cfs compared to 50 days in 2017. In 2016 there were 58 days above 2,500 cfs and 81 days in 2017. In addition, there were more days in 2017 below 1,000 cfs compared to 2016. Although the baseflows were lower in 2017, the numbers of days above 5,000 cfs were greater (14 days) compared to 2016. Lower summer baseflows were ameliorated by multiple monsoonal storm events after the run-off period (Figure 1).

Wetted Area

Total wetted area (TWA) of the river channel represents the accumulation of all wetted habitats and wetted channels within the river. The TWA is summarized (Table 2) by river reach, canyon and non-canyon reaches of the entire river (RM 2-180). Flow at mapping was approximately 200 cfs lower in 2016, (mapped at 531 cfs) compared to 750 cfs in 2016. Due to the lower observed discharge in the canyon bound and non-canyon reaches, the river lost 6% of total wetted area or approximately 22 million m² (Table 2).

Table 2: The total wetted areas (m²) in the San Juan River for 2016 and 2017.

Reach	River Miles	2016	2017	Difference
1	16-2	1,999,597	1,904,330	-95,267
2	67-17	3,674,051	3,395,005	-279,046
3	68-105	3,760,698	3,468,440	-292,258
4	106-130	2,446,947	2,325,030	-121,917
5	154-131	2,309,093	2,116,575	-192,518
6	155-180	2,109,804	2,056,469	-53,335
Canyon	67-2	5,673,648	5,299,335	-374,313
Non-Canyon	180-68	10,626,542	9,966,514	-660,028
River Total	180-2	16,300,190	15,265,849	-1,034,341
Flow at mapping		750	531	

Island Count and Area

Quantifying the island complexes in the San Juan River is part of the habitat monitoring program because islands represent a surrogate for habitat complexity in the river (Bliesner and Lamarra 1999). In 2017 there was 5.9 million m² of island area in 154 islands between river miles 68 to 180. Reaches 5 and 6 both contained the most islands at 44 for each reach with 2.669 million m² and .635 million m² respectively. Reach 3 contained the second most island complexes (36) comprising 1.082 million m². Reach 4 had the least number of islands (30) although the area was 1.485 million m² (Table 3). The overall reduction in island structures can be attributed to the decreased flows at mapping and the abandonment of secondary channels as the river is reduced in stage. Inspection of the videography indicated that the abandoned secondary channels did flow during run-off and at a slightly elevated base flow because of the presence of wetted sand, new debris piles, and isolated pools.

Table 3: The island area (m²) and island counts in the San Juan River for 2016 and 2017.

Reach	River Mile	Aug-16	Sep-18	Difference
1	16-2			
2	67-17			
3	105-68	1,586,880	1,082,879	-504,001
4	130-106	1,708,457	1,485,529	-222,928
5	154-131	4,531,692	2,699,351	-1,832,341
6	180-155	655,624	635,201	-20,423
Canyon	67-2			
Non-Canyon	180-68	8,482,654	5,902,960	
Flow at mapping		730	531	

Reach	River Mile	Aug-16	Sep-18	Difference
1	16-2			
2	67-17			
3	105-68	58	36	-22
4	130-106	38	30	-8
5	154-131	65	44	-21
6	180-155	38	44	6
Canyon	67-2	0	0	0
Non-Canyon	180-68	199	154	-45

Low Velocity Habitat (LVH)

Backwaters and embayments are considered important low velocity habitats for the early life stages of both endangered species in the San Juan River. Functionally, low velocity habitats (backwaters and embayments) are produced by different mechanisms in the canyon bound river reaches compared to that of the formation mechanisms in the non-canyon reaches. In the canyon, low velocity type habitats are associated with the mouths of dry washes and debris fans. In addition, Reach 1 (River miles 2-16) has large amounts of ephemeral sand bars and associated backwaters. As stated above, in the non-canyon portion of the San Juan River (Reaches 3 to 6), backwater type habitats are associated with temporally non-flowing secondary channels, cobble/sand bars, point-bars, the direct bank of the river, and on island complexes. In 2017 backwater habitat was high throughout the entire river. Total surface area (105,064 m²) and count (1,581) represented the highest densities of low velocity habitat since January 1996 (Figure 2). Compared to 2016 the river gained LVH surface area in all reaches of the river except 4 (-7,274 m²). Non-canyon reaches (except 4) saw the greatest gains of surface area ranging from 4,542 m² (reach 3) to 6,553 m² (reach 6). Canyon bound reaches (1 and 2) though gaining LVH area, remained relatively neutral compared to the upper reaches of the river. Reaches 1 and 2 gained 420 m² and 406 m² respectively (Table 4).

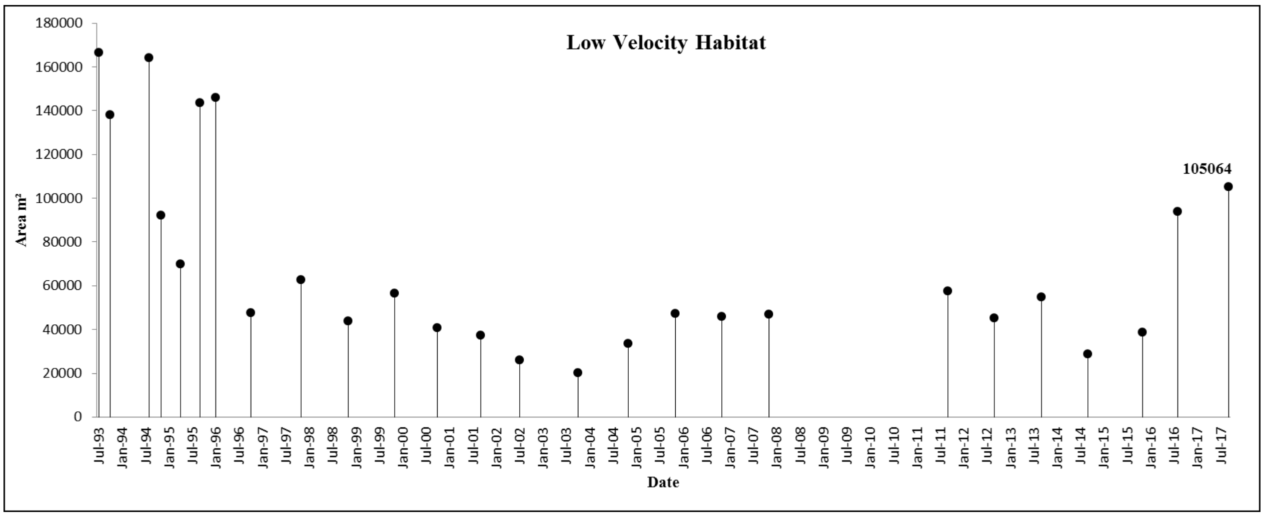

Figure 2: Total low velocity habitat area (m²) over time in the San Juan River from RM 2 to RM 180

Table 4: The backwater type areas (m²) in the San Juan River for 2016 and 2017.

Reach	2016	2017	Difference
1	15728.00	16148.00	420.00
2	4045.75	4452.65	406.90
3	26537.67	31080.02	4542.35
4	21784.75	14510.38	-7274.36
5	18192.39	24606.43	6414.04
6	7712.57	14266.33	6553.75
Total	**94001.14**	**105063.82**	**11062.68**

Low Velocity Type Analysis

Backwaters and embayments in the San Juan River can be divided into multiple categories depending on their location and method of formation. Depending on their locations and formation mechanisms, these low velocity habitats may provide persistent refugeia and nursery habitat for the endangered fishes of the San Juan. In some cases, the LVH may be too small and ephemeral for usage. Based upon their planform and spatial location, the LVH were placed into 6 separate categories (Figures 3 and 4). They were: (1) Bank associated type, (2) Embayments, (3) Island type, (4) Non-wetted area type, (5) Point-bar type and (6) Secondary channel associated type. Bank associated types comprised 29% of recorded surface area (31,083 m^2) and 32% of the total count (509 individual bank associated types identified). Embayments made up 28% of the total area with 29,103 m^2, and comprised 36% of the count (568). Island type backwaters consisted of 4% of the total area (4,029 m^2) and 9% of the count (140). Non-wetted types were 5% of area (4,905 m^2) and 18% of count (284). Point-bar types contained 4% of area (3,880 m^2) and 2% of the count (32). Secondary channel associated types account for 30% of all area (32,061 m^2) and 3% of the count (48). This analysis illustrates that low velocity habitat locations and formations are not distributed equally among the types, in particular the secondary channel associated type. With very low numbers but high area (Figures 3 and 4) may indicate that these types of backwaters are larger and may persist longer, providing stable nursery habitat and a refugia for small endangered fish.

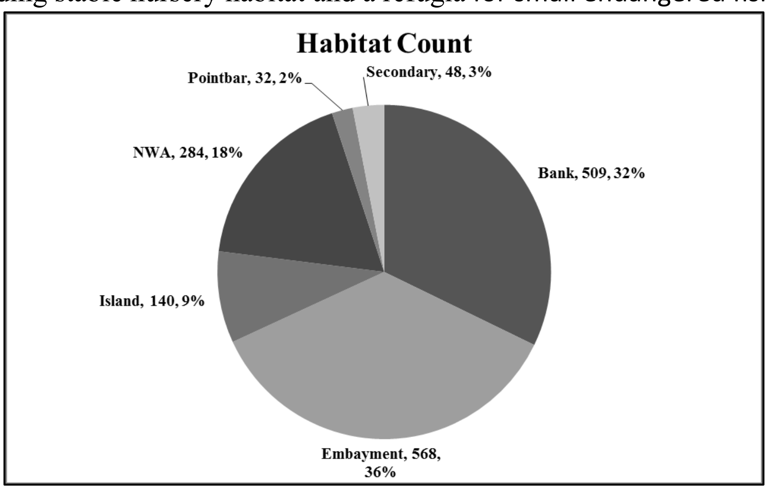

Figure 3: Low velocity habitat type counts in the San Juan River for RM 2 to RM 180 in 2017.

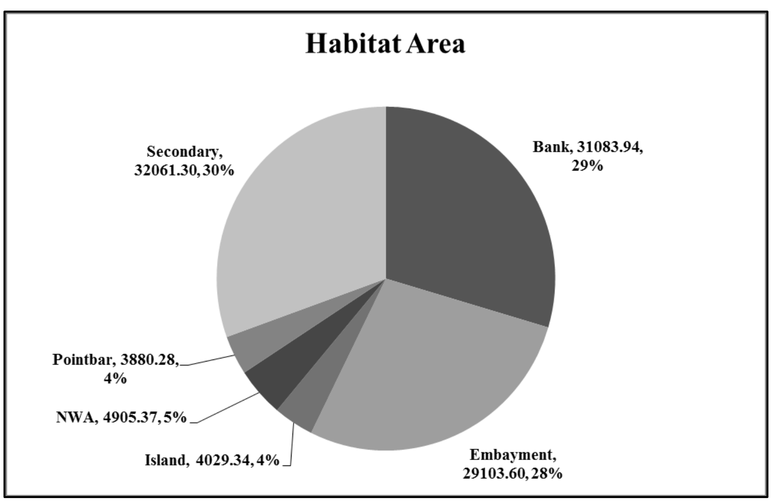

Figure 4: Low velocity habitat type areas in the San Juan River for RM 2 to RM 180 in 2017.

Discussion

The results of the 2017 habitat monitoring program indicated that the extensive changes seen in 2016 continued in 2017 as a result of another relatively high spring run-off event. Because of the timing of the aerial image acquisition (a low flow of 531 cfs), total wetted area and the number of islands were reduced. However, the images indicated that the non-flowing secondary channels (which define islands) had been recently flowing at a slightly higher stage.

The high flows during spring runoff in 2017 were sustained above 5,000 cfs resulting in 50 days at or above that flow compared to 36 days in 2016 and only 14 days in 2015. This trend of elevated high spring flows in 2017 may have continued to reshape the main and secondary channels similar to the results in geomorphic planform changes seen in 2016. Holden (2000) showed that the sustained flows above 5,000 could flush sand and silt from secondary channels into the main stem of the river to be redistributed. Additionally, sustained flows between 5,000 and 8,000 cfs were shown to mobilize cobble substrates in the San Juan River (Bliesner and Lamarra 1999). Although secondary channels were cleaned and material redeposited into the main channel (new cobble-bars and sand-bars were observed throughout the river in 2017), many island complex side channels were not flowing and abandoned. This is most likely due to the extremely low flow (531 cfs) at mapping. These abandoned secondary channels at low flow resulted in large backwaters forming on the downstream end of these side channels. Main channel low velocity habitats may have formed as a result of the redistribution of bed materials and the low flow at mapping. The rare low velocity habitats (only 0.7% of the total wetted area) continued the trend from 2016, with all but one reach of the river seeing large gains. These LVH features were widespread throughout the river and in locations that could benefit the small rare fish and provide reasonably stable habitat even at low stream flows.

Conclusion

In conclusion, due to above average, back to back sustained spring run-off events, the San Juan River experienced another year of geomorphic planform LVH alterations. The antecedent conditions associated with sustained high flows (50 days over 5,000) largely contributed to the cleaning and redistribution of cobbles, silt, and sand.

The cleaning of side channels and the building of new cobble/sand bars resulted in the continued development of low velocity habitats associated with these geomorphic features. Because of the timing of the acquisition of aerial images (at a flow of 531 cfs), island count and area were lower than that of 2016. Because of the resolution of the aerial images (11 cm) it was evident through observation of non-flowing secondary channels (wetted sand, new debris piles, and isolated pools) that these side channels were active at a slightly higher river stage at baseflow. Even at the observed low flows LVH increased throughout the river except in one reach, the amount of LVH surface area was the highest since January 1996. The habitats observed in 2017 were widespread and associated with multiple different river edge features. Most importantly, the secondary channels associated backwaters where 30% of the total low velocity backwater area but only 3% of the total LVH counts. This indicated that backwater persistence was occurring into late summer and available as refugia for juvenile Razorback Sucker and Colorado Pikeminnow even at a low baseflow.

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Appendix A

Response to Comments:

1. *I would suggest that the approach for evaluating morphologic change needs to be modified to account for the effects of differences in flow level at the time of mapping (unless these differences are very small, much less than 30%)*

   There is not a lot of literature on this topic, but the basic idea is to develop a relation (or series of relations) between discharge and wetted channel width (or wetted area=ave. wetted width x reach length). The plots on the next page show several examples, and references to the studies are listed at the end of this review. In each of these studies, estimates of wetted channel width (or area inundated) were determined for a range of discharges, and width (or area inundated) was plotted as a function of discharge. The relations between W and Q shown in these plots were developed from measurements of width at a given discharge for multiple cross sections within an individual reach (and similar relations were developed for other reaches). The mean values of section-specific widths are indicated by the solid points and fit with the following relations:

   $$W=15Q^{0.38}$$

   $$W=15Q^{0.34}$$

   The similarities in these two equations is interesting, but largely coincidental; the two river systems are, in fact, quite different. The important point to note here is that the relation between wetted channel width and discharge is nonlinear, such that width changes relatively rapidly from low to intermediate discharge, then more slowly from intermediate to high discharge. This is perhaps more evident in the relations presented Pitlick (2007) and wallick et al. (2010) which use linear, rather than logarithmic, scale for both the x and y axes. Relations such as these can be used to address the uncertainty associated with mapping at different flow levels. For example if the wetted width of the SJR follows a relation similar to one of those shown here, then a 30% difference in discharge between 2016 and 2017 would translate to about a 11-12% difference in mapped width (or wetted area). The observed difference in wetted area between 2016 and 2017 is reported at 6%, not to different from my hypothesized value. Going forward, it would be very useful if relations similar to the ones show below could be developed for the 6 individual reaches of the SJR that provide habitats for rare fish.

A significant effort was made to address the channel width of the San Juan River. Data sets from 1994, 2005-2007, and 2011-2017 underwent a post-hoc width analysis consisting of taking width transects at five locations per river mile from the confluence of the Animas River (RM180) to the mouth of the upper canyon (RM 68). Transects were taken at the beginning and end of each river mile, the middle of the river mile, and in between the beginning/end and the center. The size of this data set (n=568 per year) was advantageous in creating robust models of the entire river as well as for each reach or even individual river miles if need be. As recommended, table 1-A and figures 1-A through 6-A represent the relationship of average channel width and discharge at the time of mapping. Though different than those presented by Pitlick (2007) and Wallick et al. (2010) the overall trend is similar, where channel width increases quickly at lower discharges, and then stabilizes during intermediate discharge. Interestingly, at intermediate flows each reach increased in width at similar rates, but when higher flows are experienced, each reach reacts to the increased discharge independently of each other with reach 3 showing the greatest rate of change and reach 6 exhibiting the lowest rate of change. This most likely is related to increased sinuosity, and tributary input in lower reaches versus the channelization of reach 6.

Table 1-A: List of river sections with corresponding model formula and R^2 value.

Section	Formula	R^2
Reach 3:	$W=24.5Q^{0.2713}$	$R^2=0.97$
Reach 4:	$W=26.6Q^{0.2268}$	$R^2=0.92$
Reach 5:	$W=20.3Q^{0.3143}$	$R^2=0.94$
Reach 6:	$W=24.4Q^{0.2332}$	$R^2=0.90$
Whole River:	$W=23.9Q^{0.2628}$	$R^2=0.95$

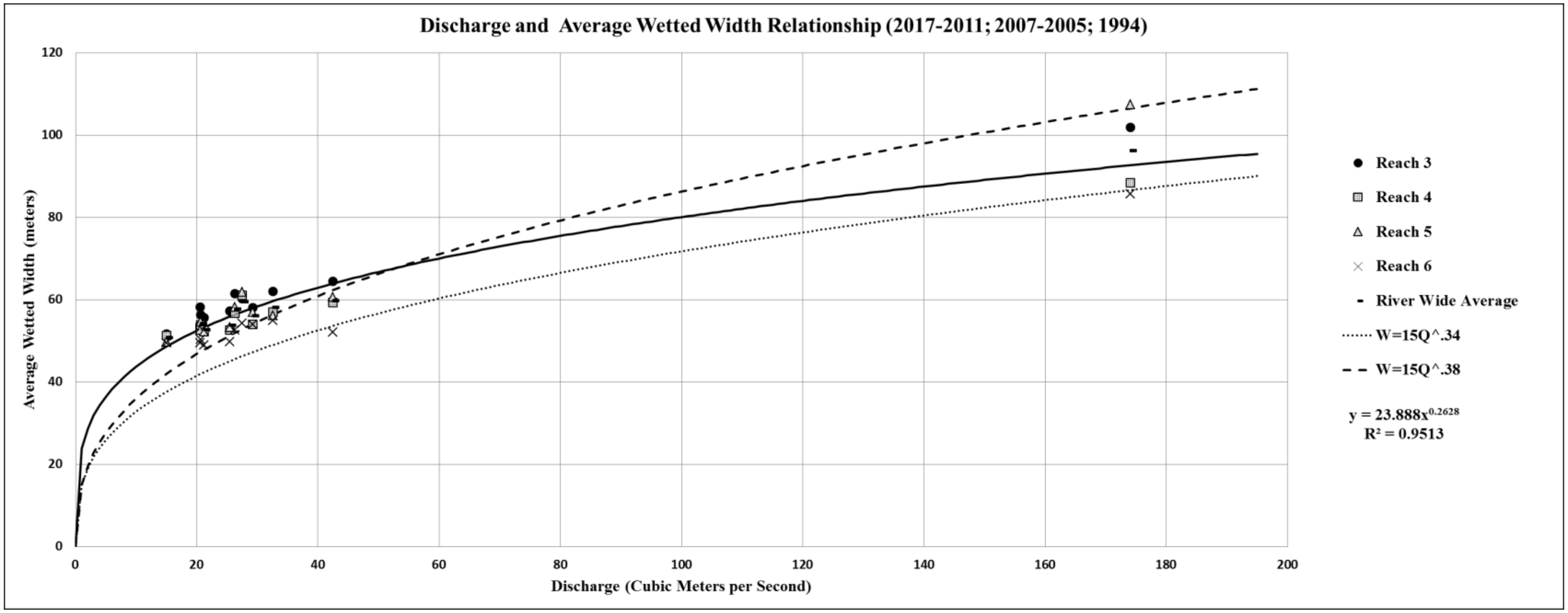


Figure 1-A: Average Wetted Width and Discharge Relationship (2017-2011; 2007-2005; 1994) Including similar river models from (Pitlick (2007) and Wallick et al. (2010).

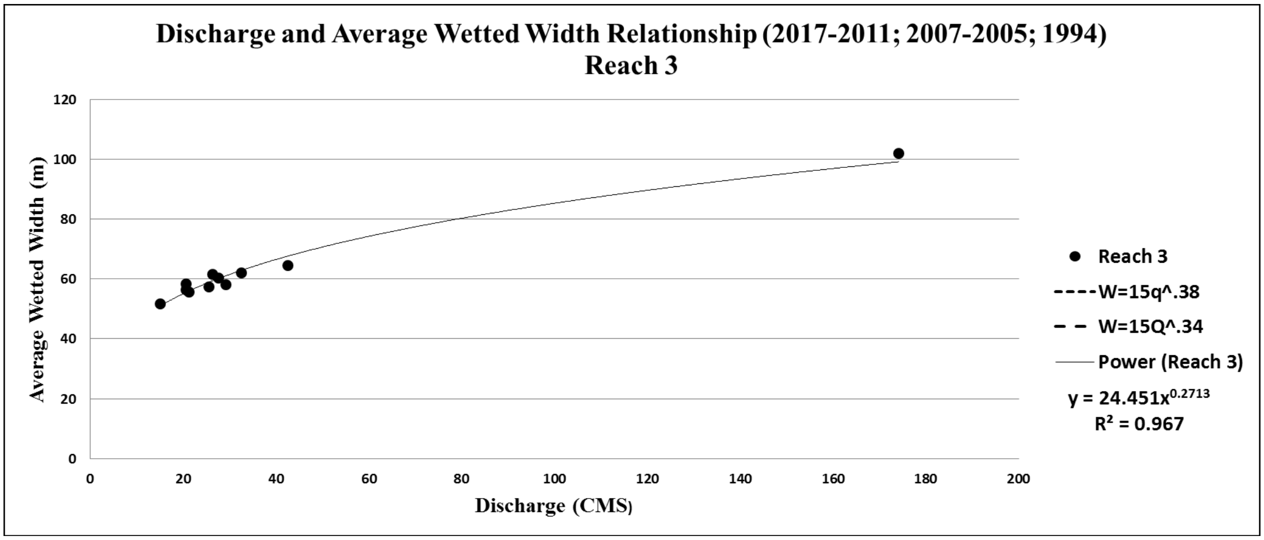


Figure 2-A: Average Wetted Width and Discharge Relationship (2017-2011; 2007-2005; 1994) Reach 3.

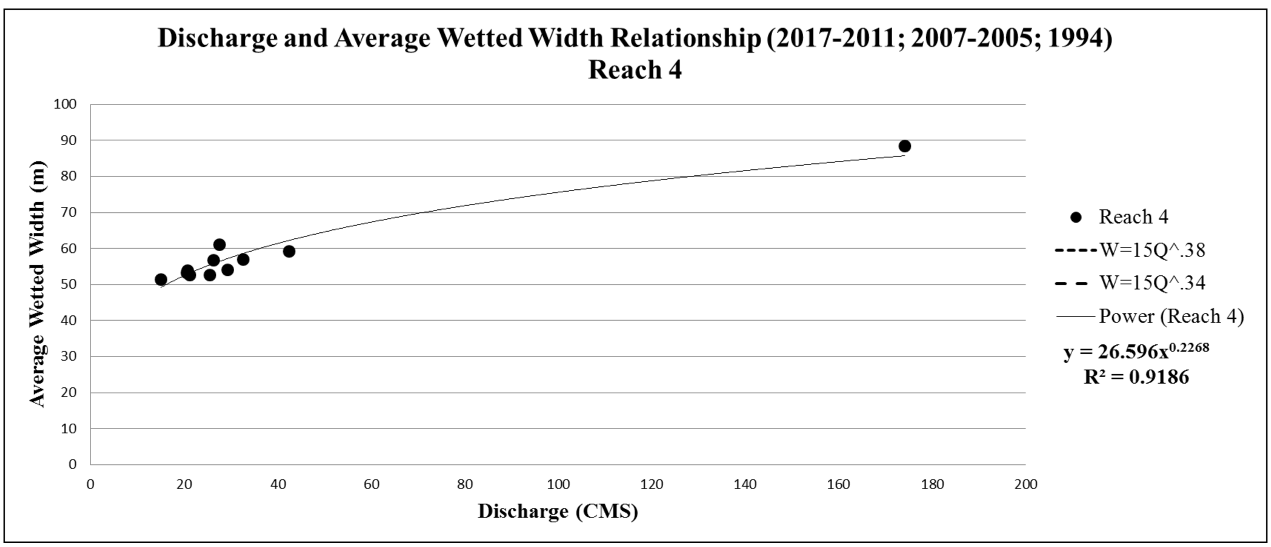


Figure 3-A: Average Wetted Width and Discharge Relationship (2017-2011; 2007-2005; 1994) Reach 4.

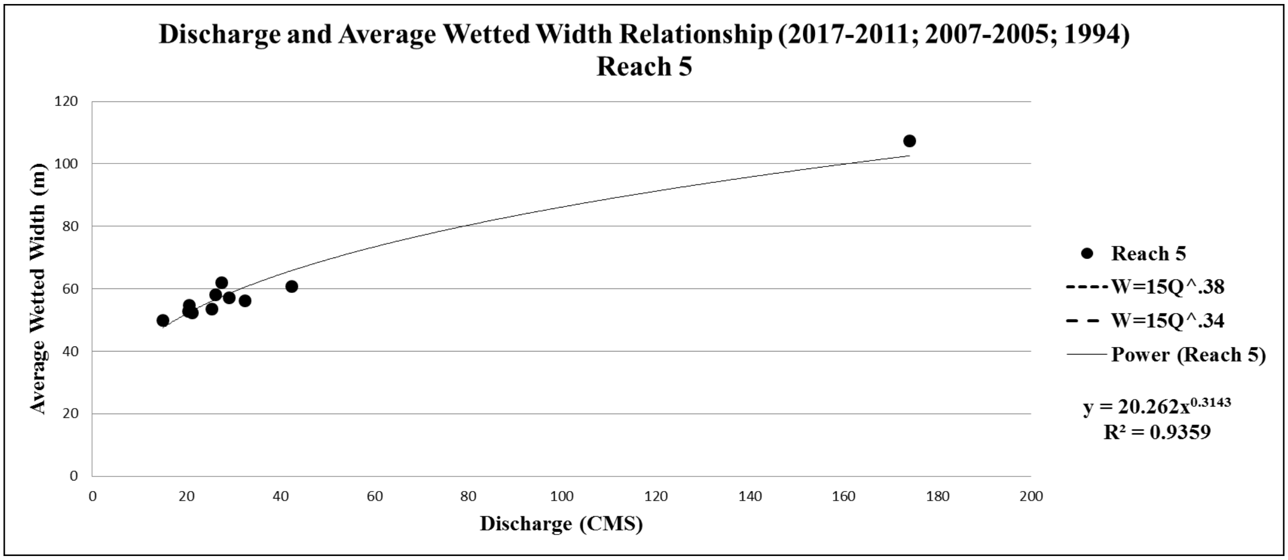


Figure 4-A: Average Wetted Width and Discharge Relationship (2017-2011; 2007-2005; 1994) Reach 5.

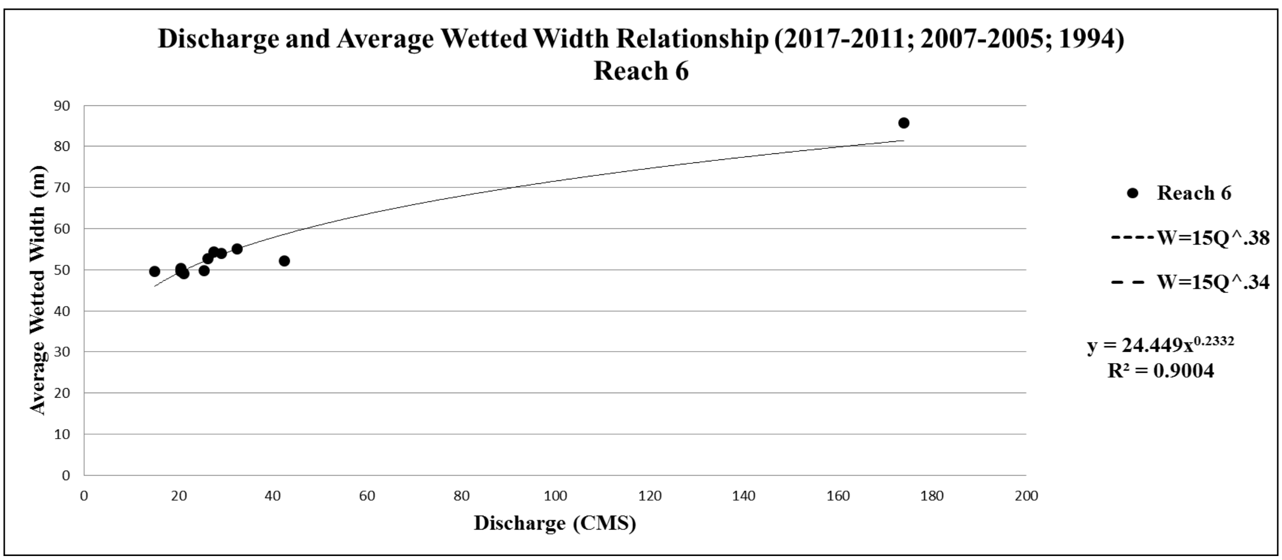


Figure 5-A: Average Wetted Width and Discharge Relationship (2017-2011; 2007-2005; 1994) Reach 6.

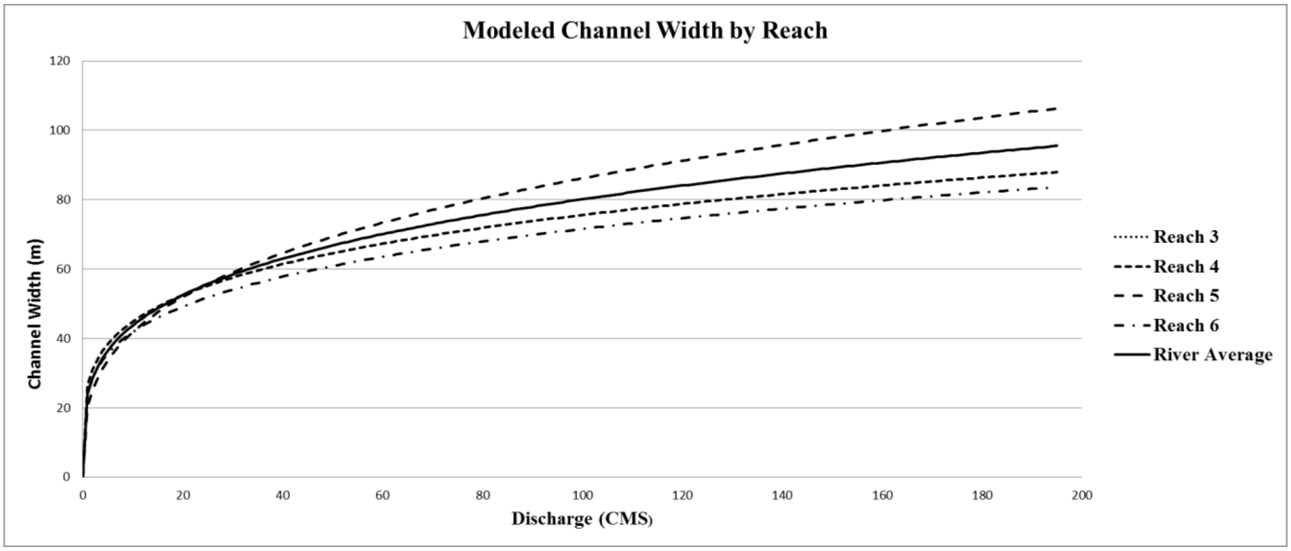


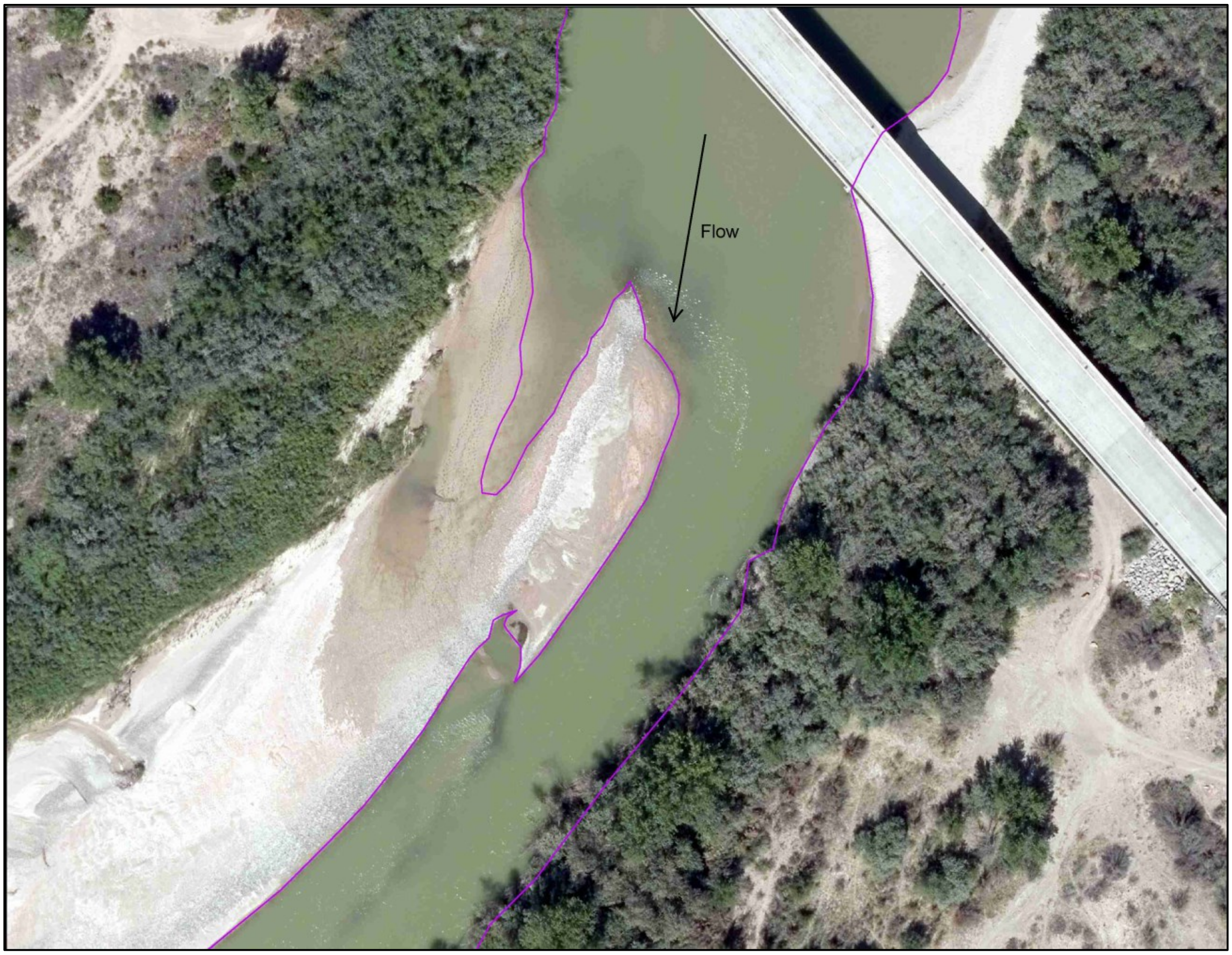
Figure 6-A: Modeled Channel Width by Reach.

2: It would be very helpful if the authors could present some figures (images) illustrating how different channel features were delineated. I am especially interested in seeing how low velocity habitats were delineated, particularly bank backwaters and embayments. First, what defines an "embayment"? This feature is not listed among the others listed on p.6 lines 179-184. Second, because embayment and bank backwaters make up roughly 60% of the area of all low velocity habitats, it is important to show how these features are delineated with respect to the flow in the main channel. Where/how does one draw a boundary between the channel-side part of a bank backwater and the main channel from looking at an aerial photograph? How repeatable are these measurements?

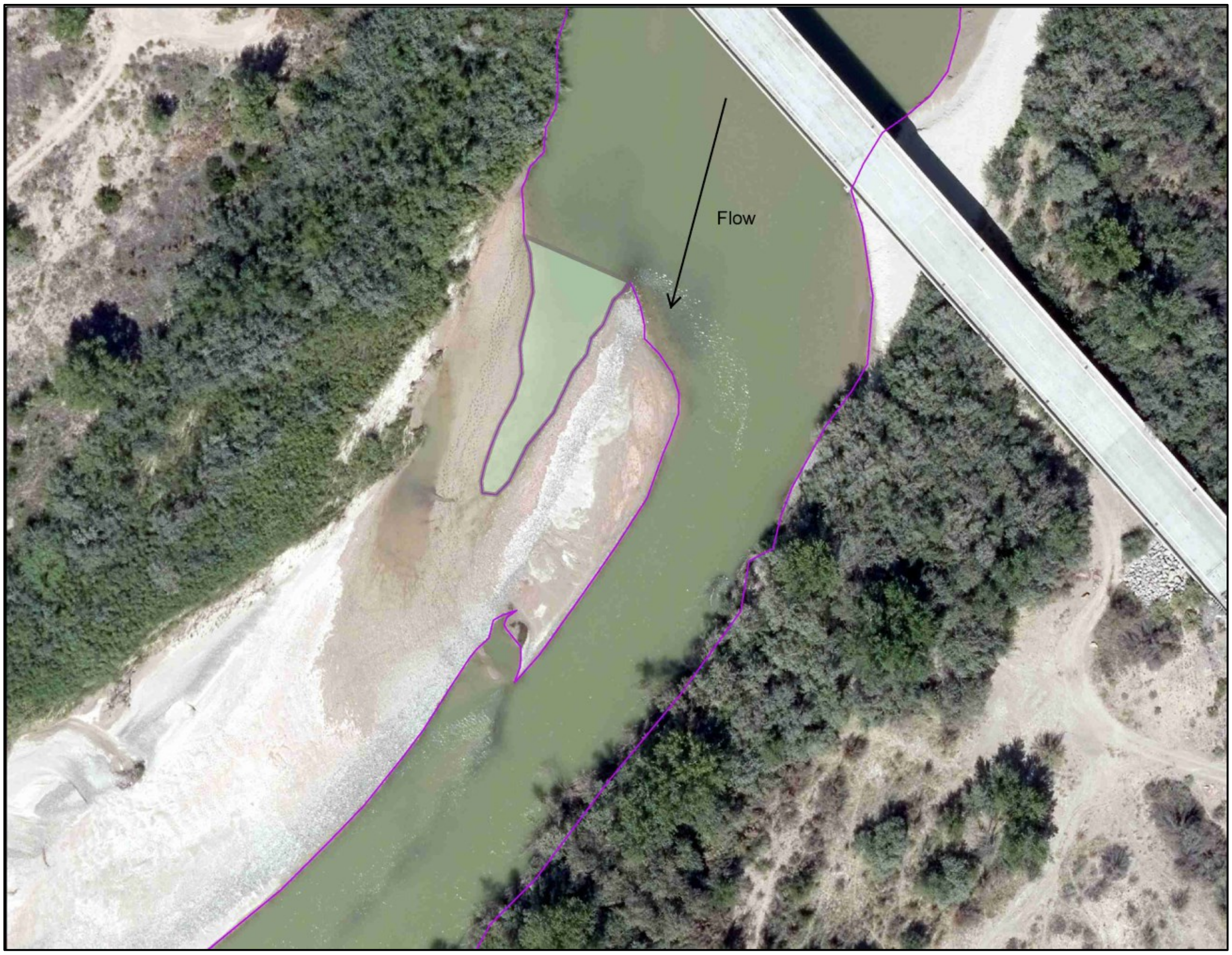
The figures provided below illustrate the process of defining, delineating, and identifying the boundary of backwaters and embayments. These figures represent a variety of types of backwaters and embayments along with their orientation to flow. The process of delineation is outlined in a series of three photographs according to the order in which low velocity habitat is identified and defined. The first photograph is simply the raw image we receive from contractors. The second photograph shows where the wetted edge of the river is defined. The third and last image is a combination of the first two photos with the boundary of the low velocity habitat defined. The low velocity habitat vector polygon is traced onto the vector line of wetted area insuring consistency between the wetted area edge, and the low velocity polygon.

Embayments can be defined as an open shoreline depression similar to a backwater, with little flow change. The mouths of embayments typically are wide and oriented up stream. The majority of embayments form at the beginning of a point bar, or at the head end of island complexes. Examples of embayments at river miles 75,141 and 150 can be found in figures below.

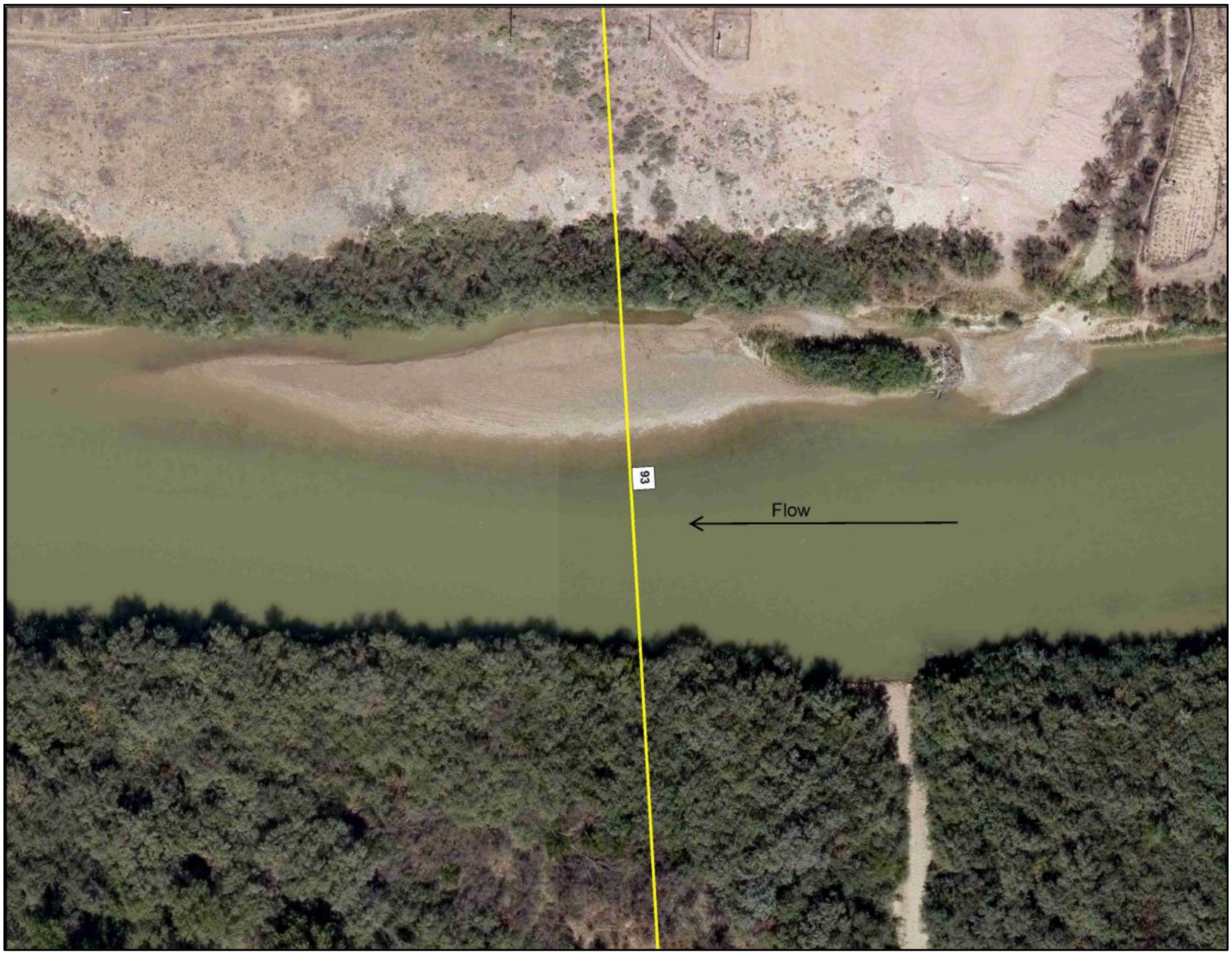
Picture 1: River Mile 75, Raw Image.



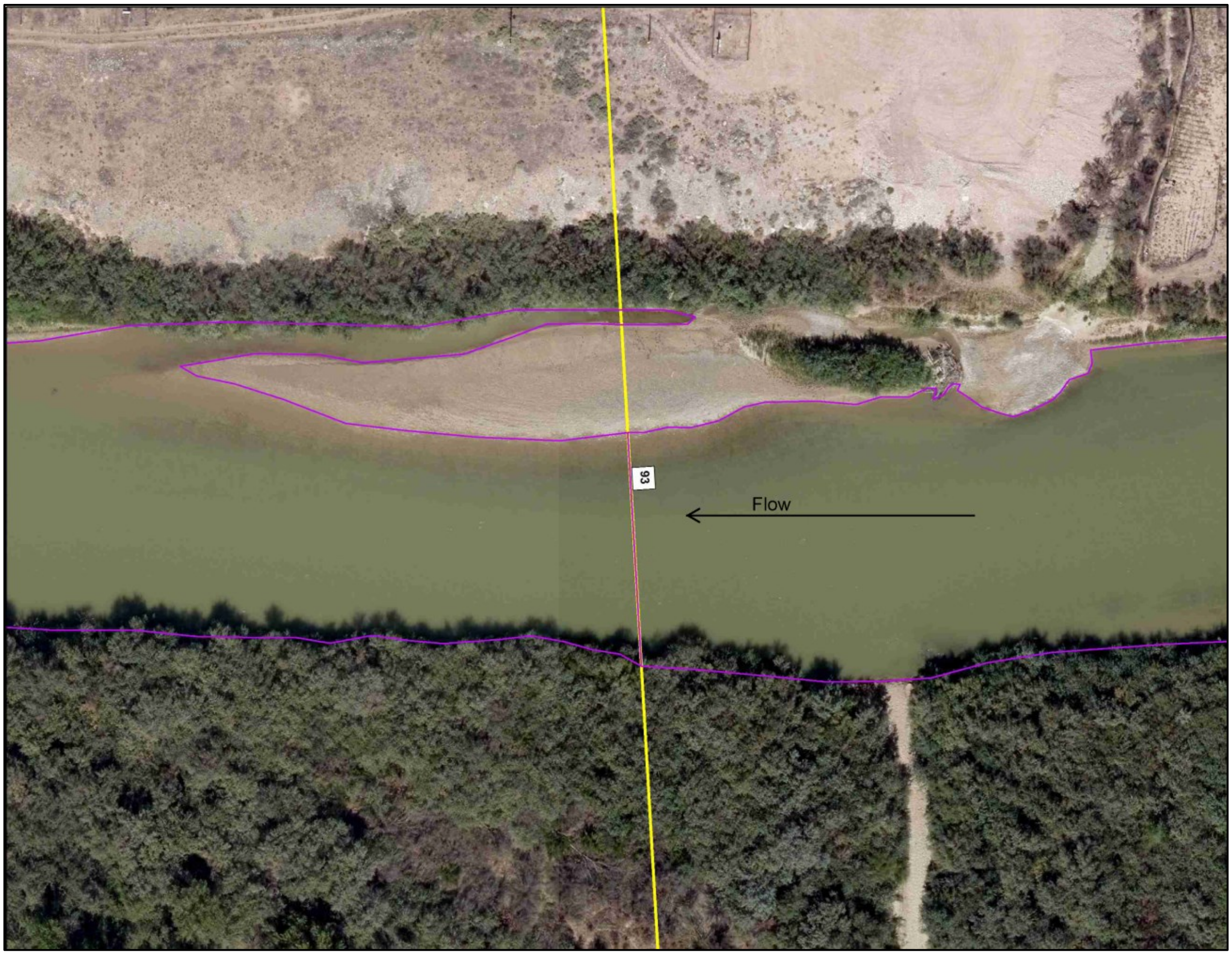
Picture 2: River Mile 75, Wetted Edge Defined.



Picture 3: River Mile 75, Embayment Boundary Defined.

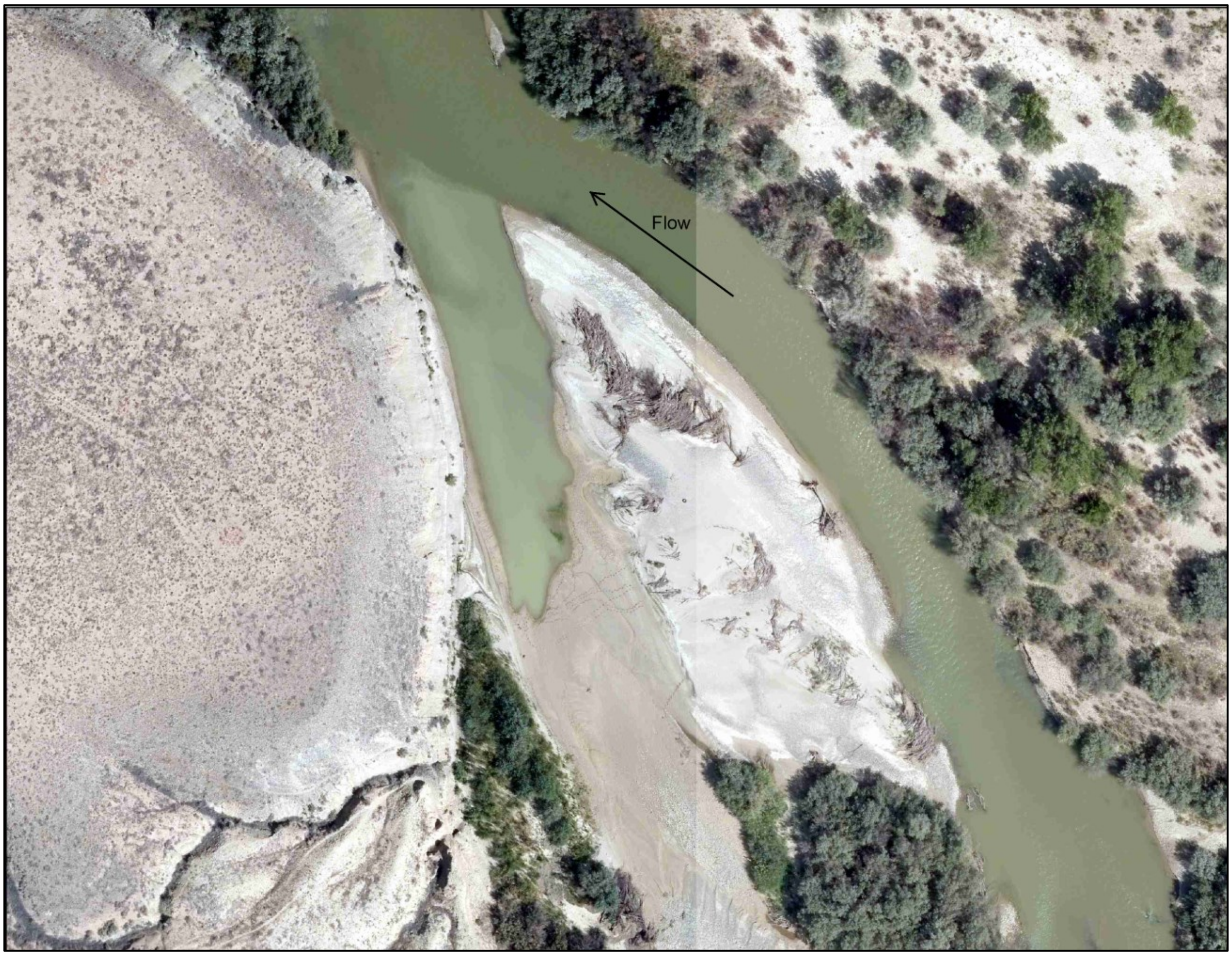


Picture 4: River Mile 93, Raw Image.



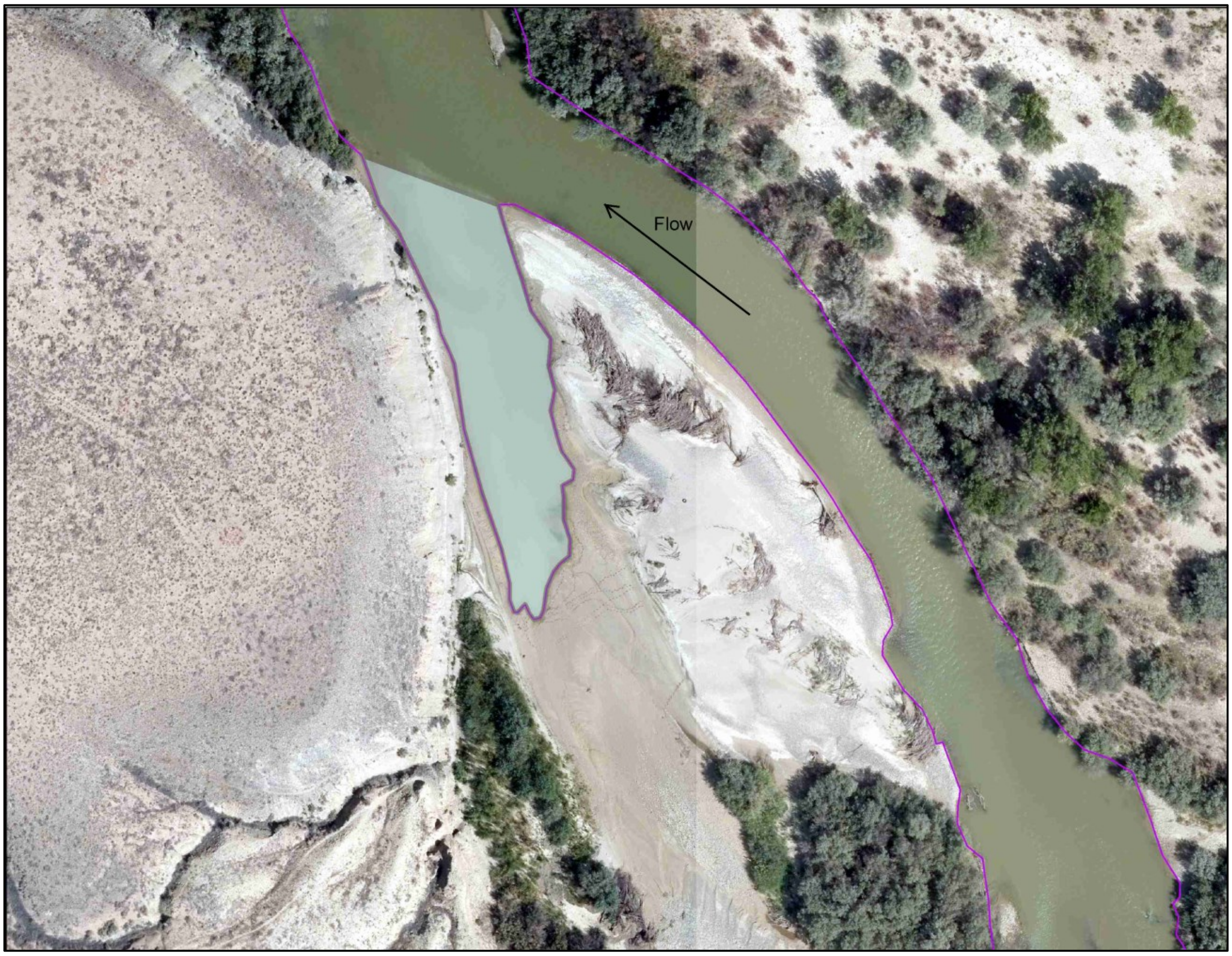
Picture 5: River Mile 93, Wetted Area Defined.

Picture 6: River Mile 93, Bank Backwater Boundary Defined.



Picture 7: River Mile 134 Raw Image.

Picture 8: River Mile 134, Wetted Area Defined.



Picture 9: River Mile 134, Secondary Channel Backwater Boundary Defined.

Picture 10: River Mile 141, Raw Image.

Picture 11: River Mile 141, Wetted Area Defined.

Picture 12: River Mile 141, Embayment Area Boundary Defined.

Picture 13: River Mile 150 Raw Image.

Picture 14: River Mile 150, Wetted Area Defined.

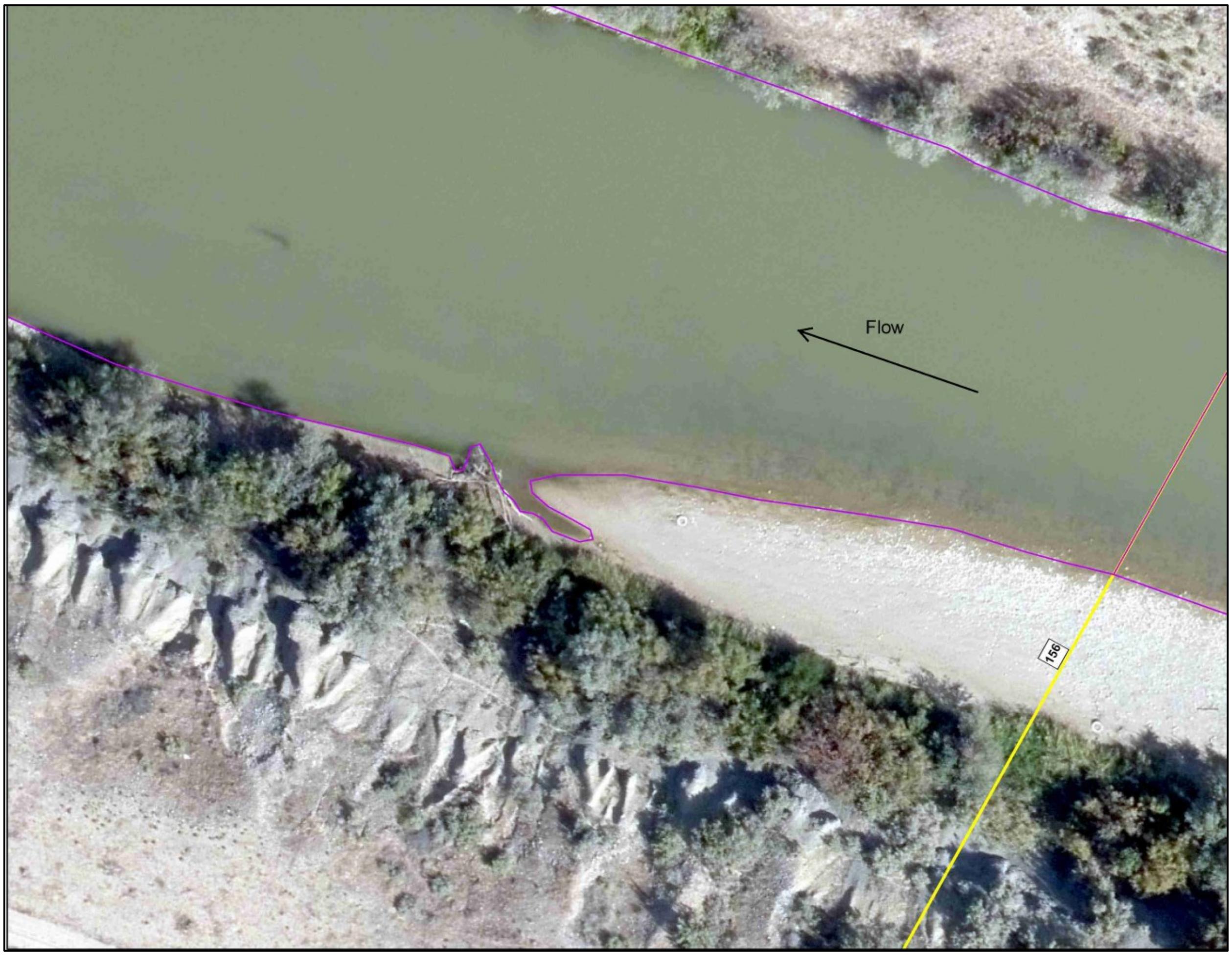
Picture 15: River Mile 150, Embayment Area Boundary Defined.

Picture 16: River Mile 155, Raw Image.

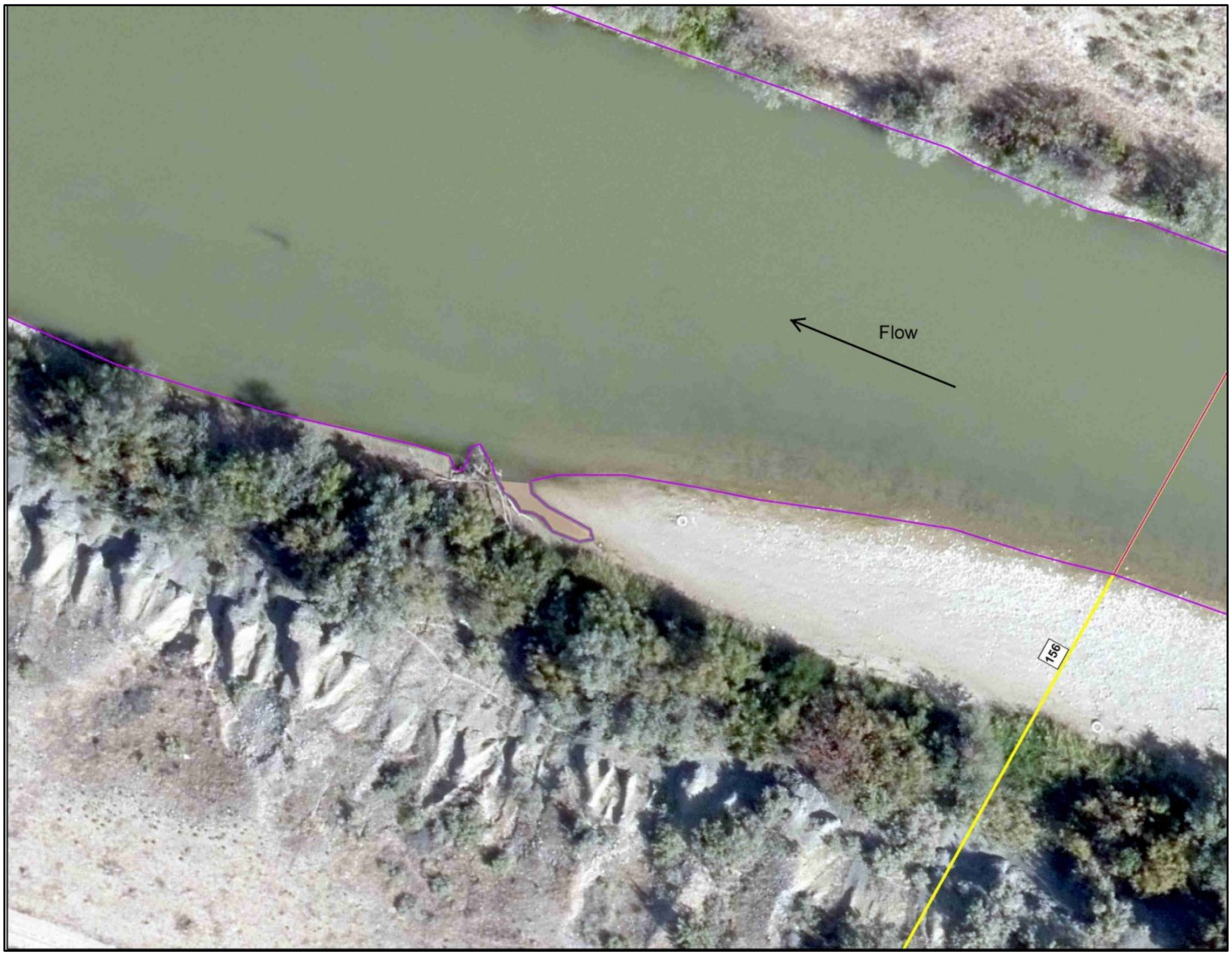
Picture 17: River Mile 155, Island Area Defined.

Picture 18: River Mile 155, Island Backwater Area Boundary Defined.

Picture 19: River Mile 156, Raw Image.



Picture 20: River Mile 156, Wetted Area Defined.



Picture 21: River Mile 156, Bank Backwater Boundary Defined.

3. *In several previous reviews I have asked for an analysis discussion of errors associated with the acquisition, geo-referencing, and delineation of geomorphic features. The reporting of errors is standard practice in studies of change detection that rely on analysis of aerial photographs.*

The following is a section from the 2014 final Habitat Monitoring Report:

As part of the 2013 mapping of the San Juan River, an attempt was made to estimate the reproducibility of the mapping protocols as a measure of parameter variability. Variability was determined by mapping the embayments and backwater at two separate times using the same mapper. The mapping efforts were separated by three months. Both area and count of the two habitat types were considered in this analysis. The results are shown in Table 2-A. The first mapping produced a count of 2714 embayments and backwaters while the second effort had 2385 habitats. The second mapping was only 87.9 % of the first mapping. For the surface area of the two habitat types, the duplicate mapping also showed a decline from the first to the second mapping. However, the reduction was only 1.1%. The major difference between count and area variability was the variation in count with backwater and embayment size (Figure 7-A). The smaller the size of these two habitats, the higher the variability between counts. The highest difference between the first and second mapping counts was in the size category 1 to 5 m^2 (Figure 8-A). There were no count differences after the 20 to 30 m^2 binn. This is consistent with the observations made in the 2011 and 2012 habitat monitoring reports (Lamarra and Lamarra 2012). In those reports it was noted that compared to the 2007 monitoring protocols, the 2011 and 2012 data had higher resolution imagery and more time to define the smaller sized backwater and embayment habitats. This has resulted in higher counts of smaller backwaters compared to the previous *in situ* mapping. Surface area of backwater type habitats was relatively unaffected by methodology. (Lamarra & Lamarra 2014).

We utilized the QA/QC data to refine our protocols to only include low velocity habitats greater than 30 m^2. This allows a comparison to data collected prior to 2011.

Table 2-A: The Summary of the backwater type quality control for the toal count (total number and total area after two separate mappings.

	RIVERWIDE COUNT	RIVERWIDE AREA (m^2)
FIRST MAPPING	2714	66,342
SECOND MAPPING	2385	65,607
DIFFERENCE (% of FIRST MAPPING)	87.9%	98.9%

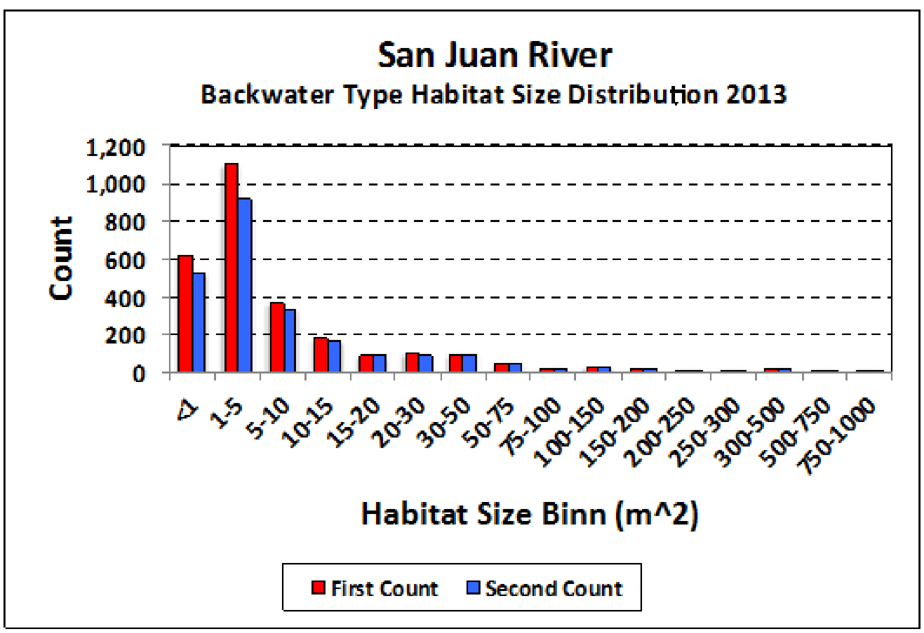


Figure 7-A: The size distribution of backwater type habitats on the first and second count for the purpose of quality control.

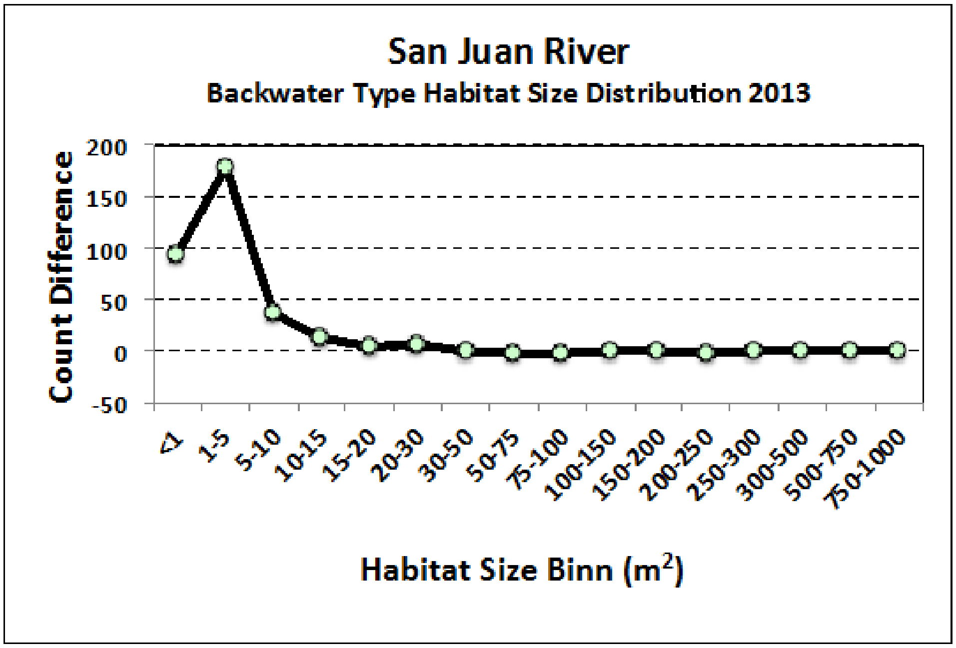


Figure 8-A: The size distribution of the backwater and embayments that were mapped in the first run but were not mapped in the second run. A positive value indicates that the habitat was mapped initially but not mapped in the second effort.