ANL/EVS-17/7

2016 Reassessment of Floodplain Wetland Connections in the Middle Green River, Utah

Environmental Science Division
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2016 Reassessment of Floodplain Wetland Connections in the Middle Green River, Utah

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NOTATION

ACRONYMS, INITIALISMS, AND ABBREVIATIONS

Argonne	Argonne National Laboratory
FWS	U.S. Fish and Wildlife Service
Recovery Program	Upper Colorado River Endangered Fish Recovery Program
USGS	U.S. Geological Survey
WAPA	Western Area Power Administration

UNITS OF MEASURE

cfs	cubic foot (feet) per second
cm	centimeter(s)
ft	foot/feet
h	hour(s)
km	kilometers(s)
mi	mile(s)
m^3	cubic meter(s)
s	second(s)

METRIC UNIT CONVERSIONS

1 cfs	0.0283 m^3/s
1 ft	30 cm
1 mi	1.61 km

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EXECUTIVE SUMMARY

The frequency, magnitude, and duration of seasonal overbank flooding in the Green River have been substantially reduced since completion of Flaming Gorge Dam in 1962. Flow recommendations (Muth et al. 2000) were developed to assist with conservation and recovery of endangered fish species in the Green River downstream from Flaming Gorge Dam. Among the objectives of these recommendations was to provide for floodplain wetland connection to the river at sufficient frequency and duration to support sustained recruitment of the endangered razorback sucker (*Xyrauchen texanus*). Although floodplain habitats are important for all four of the endangered Colorado River fishes,[1] the inundation of floodplain wetlands along the middle Green River is particularly important for providing important nursery habitat for young-of-the-year razorback suckers. Restoring or enhancing floodplain wetland connections to the river would provide access to these productive habitats and is expected to support the recovery of the four endangered fish species in the basin.

An uncertainty identified in the Larval Trigger Study Plan (Larval Trigger Study Plan Ad Hoc Committee 2012), a report that identified priorities for geomorphology research in the Upper Colorado River Basin (LaGory et al. 2003), and the Green River Study Plan (Green River Study Plan Ad Hoc Committee 2007) was interannual variability in the flow needed to connect floodplain wetlands and the effect of peak flows on these connecting flows. To address this uncertainty, we conducted reassessments of floodplain connections in 2012 and 2014 and found considerable differences from values presented in previous reports, which presumably resulted from the effects of intervening peak flows (LaGory et al. 2016a,b).

The 2015 peak flow (15,800 cfs and 14,800 cfs at the Jensen and Ouray gages, respectively) exceeded the estimated connection flow at several breaches surveyed in October 2014. A reassessment of these breaches was needed to determine whether connection in 2015 altered the breach or connection channel geomorphology that could influence future floodplain connection. The overall objective of our April 2016 survey (prior to the 2016 peak flow) was to determine whether or not relatively low-magnitude spring peak flows (<16,000 cfs) that connected mostly downstream breaches in 2015 would produce changes in subsequent connection flows through either scour or sediment deposition. Our specific objectives were to:

- Determine the minimum flow that would connect floodplain wetlands to the main channel river and allow for the entrainment of larval razorback suckers;

- Determine the minimum flow that would allow the passage of subadult and adult razorback suckers (minimum depth of 1 ft [30 cm] based on Burdick 1997) between the wetlands and the river; and

[1] In addition to razorback sucker, the Colorado pikeminnow (*Ptychocheilus lucius*), humpback chub (*Gila cypha*), and bonytail (*Gila elegans*), all listed as endangered, occur in the middle Green River.

- Compare our 2016 survey results with information collected in our 2012 and 2014 surveys (LaGory et al. 2016a,b), as well as information reported by Tetra Tech (2005) and Bestgen et al. (2011)[2] to determine the extent to which connection flow levels and conditions have changed since those studies were conducted.

In this report, we present the results of floodplain wetland connection surveys conducted in April 2016 at six priority floodplain wetlands along the middle Green River between Jensen and Ouray, Utah. Surveys were conducted only at breaches where the 2015 peak flow magnitude at Jensen and Ouray exceeded the 2014 connection flow estimate (LaGory et al. 2016b). At each site, surveys were conducted at levee breaches and within channels leading from the breaches to the wetlands (referred to here as connection channels) to characterize the flows needed to connect the river's main channel with the floodplain wetlands.

Our survey results will be used in conjunction with past survey results and other studies conducted under the Larval Trigger Study Plan and Green River Study Plan to resolve uncertainties associated with razorback sucker floodplain nursery habitats and factors contributing to recruitment of this species. The evaluation summarized here also will provide important input to the Upper Colorado River Endangered Fish Recovery Program's ongoing evaluation of the Muth et al. (2000) flow recommendations.

We conducted topographic surveys to determine the flows that would connect the main channel of the Green River to six priority floodplain wetlands along the middle Green River from April 18 through 21, 2016, between the U.S. Geological Survey (USGS) Jensen gage (USGS 09261000) and the USGS Ouray gage (USGS 9272400). We only surveyed the ten breach locations that had estimated connection flows in 2014 that were lower than the 2015 peak flows, and therefore were expected to have connected during the 2015 spring peak.

At each location, we determined elevations for the river edge (water surface elevation), and a series of cross sections of levee breaches and associated connection channels. We used this topographic information to determine minimum flows needed to overtop breaches and connect the floodplain wetlands to the river main channel, and compared those values to floodplain connection measurements we made in 2014 and 2012, and to other reported estimates of connection flows.

Our 2016 survey identified differences in connection flow from our 2012 and 2014 survey results and 2005 reported values. Aside from the Johnson Bottom breaches, which were intentionally modified in early 2015 (prior to the 2015 peak flow) to facilitate connection at lower flows, connection and passage flows at surveyed breaches showed relatively little change from 2014 values. With the Johnson Bottom breaches excluded, the mean difference in connection flow was -125 cfs (range -1,900 cfs to +1,000 cfs; Table 4) with 5 of the 8 breaches surveyed increasing slightly, and 3 decreasing. Most of the 2016 connection flow estimates (7 of 8) were lower than values we obtained in 2012 (mean difference -1,969 cfs with Johnson

[2] Bestgen (2011) reported connection flows based on several information sources including Tetra Tech (2005).

Bottom breaches excluded). Although the mean difference in connection flow of the six breaches surveyed in both 2016 and 2005 was low (mean difference -116 cfs), the range was great (-5,193 at ER-OUT to +2,400 cfs at AB-IN-3).

We assume the breaches surveyed in 2016 had the lowest connection flows of all breaches of the six priority floodplain wetlands in the middle Green River in that year. This is a reasonable assumption since these were the only breaches likely to have connected during the previous spring peak flow. Given this assumption, the mean estimated minimum floodplain connection flow (i.e., the lowest connection flow of any breach at a particular wetland) among the six floodplain wetlands surveyed in 2016 was 11,272 cfs (12,448 cfs with Johnson Bottom breaches excluded). This value is 1,402 cfs, 2,910 cfs, and 1,767 cfs lower than the estimates in 2014, 2012, and 2005, respectively (40 cfs, 1,350 cfs, and 307 cfs lower, respectively, with Johnson Bottom breaches excluded). However, there was considerable variation among the wetlands in estimated minimum connection flow in 2016, ranging from 5,390 cfs at Johnson Bottom to 15,900 cfs at Bonanza Bridge. There was less variation in 2014 (8,740 to 15,700 cfs) prior to the modification of JB-OUT-1.

Estimated passage flows were approximately 1,870 cfs to 2,500 cfs higher than connection flows in the Ouray National Wildlife Refuge wetlands (Johnson Bottom and Leota Bottom) and 2,680 cfs to 3,200 cfs higher than connection flows in the wetlands further upstream. In 2016, the mean passage flow for the breaches surveyed was 15,008 cfs (7,260 cfs to 19,100 cfs). The mean minimum passage flow for the floodplain wetlands surveyed (i.e., the lowest passage flow of any breach at a particular wetland) was approximately 13,980 cfs (7,260 to 19,100 cfs).

Estimated duration of connection and passage flows varied considerably among breaches and wetlands from 2013 through 2016. All floodplain wetlands connected at one or more breaches in all years during this period except in 2013 when peak flows were relatively low (11,000 cfs to 10,500 cfs at the Jensen and Ouray gages, respectively), ranging from < 1 day (Stirrup in 2015) to 58 days (Escalante Ranch in 2016); only the Above Brennan wetland connected in 2013, and only for 4 days. Passage flows were provided at the Escalante Ranch and Above Brennan wetlands in all years except 2013, ranging from 4 to 33 days at Above Brennan and 16 to 54 days at Escalante Ranch. Passage flows were achieved only during 2016 at Bonanza Bridge, Stirrup, and Johnson Bottom, and in 2014 and 2016 at Leota Bottom.

Suspended sediment concentration data are not currently available for the study area, but we expect that concentrations would have been lower during the lower magnitude 2015 flow compared to the higher magnitude 2014 and 2011 peak flows. A lower sediment load would have made the 2015 peak flow more erosive as the flow passed through upstream breaches. Water entering these breaches could have eroded old deposits while depositing less new sand, resulting in net erosion of older sand deposits. This is likely the reason that connection flow at AB-IN-1 decreased by 1,900 cfs after the 2015 peak flow; this is the largest change in connection flow observed in 2016.

Our 2016 survey results indicated that surveys to reassess floodplain connections may not be needed after relatively low-magnitude peak flows (<16,000 cfs), because little if any deposition occurred in most connected breaches at these flows.

We recommend the following:

- Resurvey floodplain wetland breaches and their connection channels following moderately high or higher peak flows (e.g., ≥ 18,600 cfs) that exceed previously determined connection flows to determine if those peak flows have altered connection flows. Our 2016 survey indicates that peak flows < 16,000 cfs have limited effect on subsequent connection flows, and may not require resurvey.

- Determine connection of floodplain wetlands annually by direct observation. Ideally, determinations should be made annually of initial connection flows at upstream and downstream breaches and the degree of filling and draining through the peak flow cycle.

- Determine the duration of peak flows needed to fill wetlands over a range of peak flow-magnitudes. The peak flow duration needed to fill wetlands will be inversely proportional to peak flow magnitude, and also dependent on the storage capacity and filling rate of wetlands. Recently collected lidar data should be evaluated to determine its suitability for making these estimates.

- Measure the surface area of floodplain wetlands after peak flows recede and through the summer and winter to determine if floodplain wetlands provide suitable habitat for razorback suckers between flooding events that reconnect the wetlands to the main channel.

- Consider modification of floodplain wetland breaches and connection channels to provide connection to the main channel river at a return frequency of 1.5 years (probability of about 67%) to mimic pre-dam flooding frequency.

- Consider modifications of wetlands to prevent sediment deposition from blocking inflow. These modifications could include (1) actively reconfiguring levee breaches, connection channels, and wetland topography to minimize the blockage of connection channels; (2) filling or allowing the filling of upstream breaches; (3) creating control structures such as those that have been successfully deployed at Stewart Lake, Johnson Bottom, and Old Charley Wash; and (4) managing vegetation encroachment that exacerbates sediment deposition in breaches and channels.

1 INTRODUCTION

The frequency, magnitude, and duration of seasonal overbank flooding in the Green River have been substantially reduced since completion of Flaming Gorge Dam in 1962. Flow recommendations (Muth et al. 2000) were developed to assist with conservation and recovery of endangered fish species in the Green River downstream of Flaming Gorge Dam. These recommendations identified target instantaneous annual spring peak flows in the middle Green River between the confluences of the Yampa River and White River of at least 18,600 cubic feet per second (cfs) (as measured at the Jensen gage) in 1 of 2 years, and flows of at least 18,600 cfs for at least 2 weeks in 4 of 10 years. The intent of these recommendations was to provide for floodplain wetland connection to the river at sufficient frequency and duration to support sustained recruitment of the endangered razorback sucker (*Xyrauchen texanus*), as well as maintenance of the Green River channel and ecosystem function.

Although floodplain habitats are important for all four of the endangered Colorado River fishes,[3] the inundation of floodplain wetlands along the middle Green River is particularly important for providing important nursery habitat for young-of-the-year razorback suckers. Restoring or enhancing floodplain wetland connections to the river would provide access to these productive habitats and is expected to improve the recovery of the four endangered fish species in the Green River Basin.

An uncertainty identified in the Larval Trigger Study Plan (Larval Trigger Study Plan Ad Hoc Committee 2012), a report that identified priorities for geomorphology research in the Upper Colorado River Basin (LaGory et al. 2003), and the Green River Study Plan (Green River Study Plan Ad Hoc Committee 2007) was interannual variability in the flow needed to connect floodplain wetlands and the effect of peak flows on these connecting flows.

Floodplain connection assessments following years with peak flows that exceed previous connection flows are important to understand changes in connection flows that may result from scouring or deposition of sediments or debris. In 2012, we conducted surveys to evaluate changes in floodplain connections following the 2011 high peak flows (LaGory et al. 2016a). The 2014 peak flow (Table 1) exceeded the 2012 estimated connection flow of many of the wetlands (LaGory et al. 2016a), and our 2014 survey identified differences from our 2012 survey results (LaGory et al. 2016b). Most of the 2014 connection flow estimates were lower than values we obtained in 2012 (mean difference -971 cfs), but still higher than reported values in 2005 (mean difference +3,536 cfs). All but 3 of the 19 breaches and associated connection channels surveyed had lower estimated connection flows than in 2012.

The 2015 peak flow (15,800 cfs and 14,800 cfs at the Jensen and Ouray gages, respectively; Table 1) exceeded the estimated connection flow at several breaches surveyed in October 2014. A reassessment of these breaches was needed to determine whether connection in 2015 altered the breach or connection channel geomorphology that could influence future

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[3] In addition to razorback sucker, the Colorado pikeminnow (*Ptychocheilus lucius*), humpback chub (*Gila cypha*), and bonytail (*Gila elegans*), all listed as endangered, occur in the middle Green River.

TABLE 1 Green River Annual Peak Streamflow at Jensen and Ouray, Utah, from 2005-2016

Year[a]	Jensen Gage Peak Flow (cfs)	Ouray Gage Peak Flow (cfs)
2005	19,900	NA[b]
2006	19,200	NA[b]
2007	12,700	NA[b]
2008	24,000	NA[b]
2009	19,600	16,400
2010	20,500	18,700
2011	32,200	28,600
2012	10,600	10,100
2013	11,000	10,500
2014	20,100	17,900
2015	15,800	14,800
2016	21,100	20,400

[a] Annual peak flow occurred each year in either May or June.

[b] NA=not available. Ouray gage was not in operation prior to 2009.

floodplain connection. The overall objective of our April 2016 survey (prior to the 2016 peak flow) was to determine whether or not relatively low-magnitude spring peak flows (<16,000 cfs) that connected mostly downstream breaches would produce changes in subsequent connection flows through either scour or sediment deposition. Our specific objectives were to:

- Determine the minimum flow that would connect floodplain wetlands to the main channel river and allow for the entrainment of larval razorback suckers;

- Determine the minimum flow that would allow the passage of subadult and adult razorback suckers (minimum depth of 1 ft [30 cm] based on Burdick 1997) between the wetlands and the river; and

- Compare our 2016 survey results with information collected in our 2012 and 2014 surveys (LaGory et al. 2016a,b), as well as information reported by Tetra Tech (2005) and Bestgen et al. (2011)[4] to determine the extent to which connection flow levels and conditions have changed since those studies were conducted.

In this report, we present the results of floodplain wetland connection surveys conducted in April 2016 at six priority floodplain wetlands along the middle Green River between Jensen and Ouray, Utah. Surveys were conducted only at breaches where the 2015 peak flow magnitude

[4] Bestgen (2011) reported connection flows based on several information sources including Tetra Tech (2005).

at Jensen and Ouray exceeded the 2014 connection flow estimate (LaGory et al. 2016b). At each site, surveys were conducted at levee breaches and within channels leading from the breaches to the wetlands (referred to here as connection channels) to characterize the flows needed to connect the river's main channel with the floodplain wetlands.

Our survey results will be used in conjunction with past survey results and other studies conducted under the Larval Trigger Study Plan and Green River Study Plan to resolve uncertainties associated with razorback sucker floodplain nursery habitats and factors contributing to recruitment of this species. The evaluation summarized here also will provide important input to the Upper Colorado River Endangered Fish Recovery Program's ongoing evaluation of the Muth et al. (2000) flow recommendations.

2 METHODS

We conducted topographic surveys to determine the flows that would connect the main channel of the Green River to six priority floodplain wetlands along the middle Green River from April 18 through 21, 2016, between the U.S. Geological Survey (USGS) Jensen gage (USGS 9261000) and the USGS Ouray gage (USGS 9272400) (Figure 1). We only surveyed the ten breach locations that had estimated connection flows in 2014 that were lower than the 2015 peak flows, and therefore were expected to have connected during the 2015 spring peak. We provide a summary of survey times and flow conditions at each of the floodplain areas in Table 2. We estimated local flow conditions using the same methods as in our 2012 and 2014 studies (LaGory et al. 2016a,b), and based on calculated water travel times (i.e., lag-adjusted flows) and distance from the nearest Green River USGS gage station (Jensen or Ouray; Table 2).

We determined flow values that corresponded to the elevation of all survey points based on their elevation relative to the river elevation and flow at the time of survey, using the most recent stage-flow tables provided by USGS for the nearest Green River (Jensen or Ouray) gage. Stage-flow tables for each of the gages are provided in Appendix A of LaGory et al. (2016b). For wetlands closer to the Jensen gage and downstream of the Ashley Creek confluence, we added Ashley Creek flows (USGS 9266500) to Jensen flows to determine flow at the site. During the survey period, Jensen flow ranged from 5,250 and 7,970 cfs; Ashley Creek flows were approximately 25 cfs; and Ouray flows ranged from 5,250 and 8,420 cfs.

We surveyed the ten breach locations at the six floodplain wetland sites using the methods described in LaGory et al. (2016a). At each location, we determined elevations for the river edge (water surface elevation), and a series of cross sections of levee breaches and associated connection channels. Example photographs of survey locations are shown in Figure 2.

We used the survey data to determine the minimum elevation at each cross section. We identified the cross section with the greatest minimum elevation as the location that most limited connection, and the flow associated with that minimum elevation was identified as the connection flow. We compared those values to floodplain connection measurements made in 2014 (LaGory et al. 2016 b), 2012 (LaGory et al. 2016a), and other reported estimates of connection flows (Tetra Tech 2005; Bestgen et al. 2011).

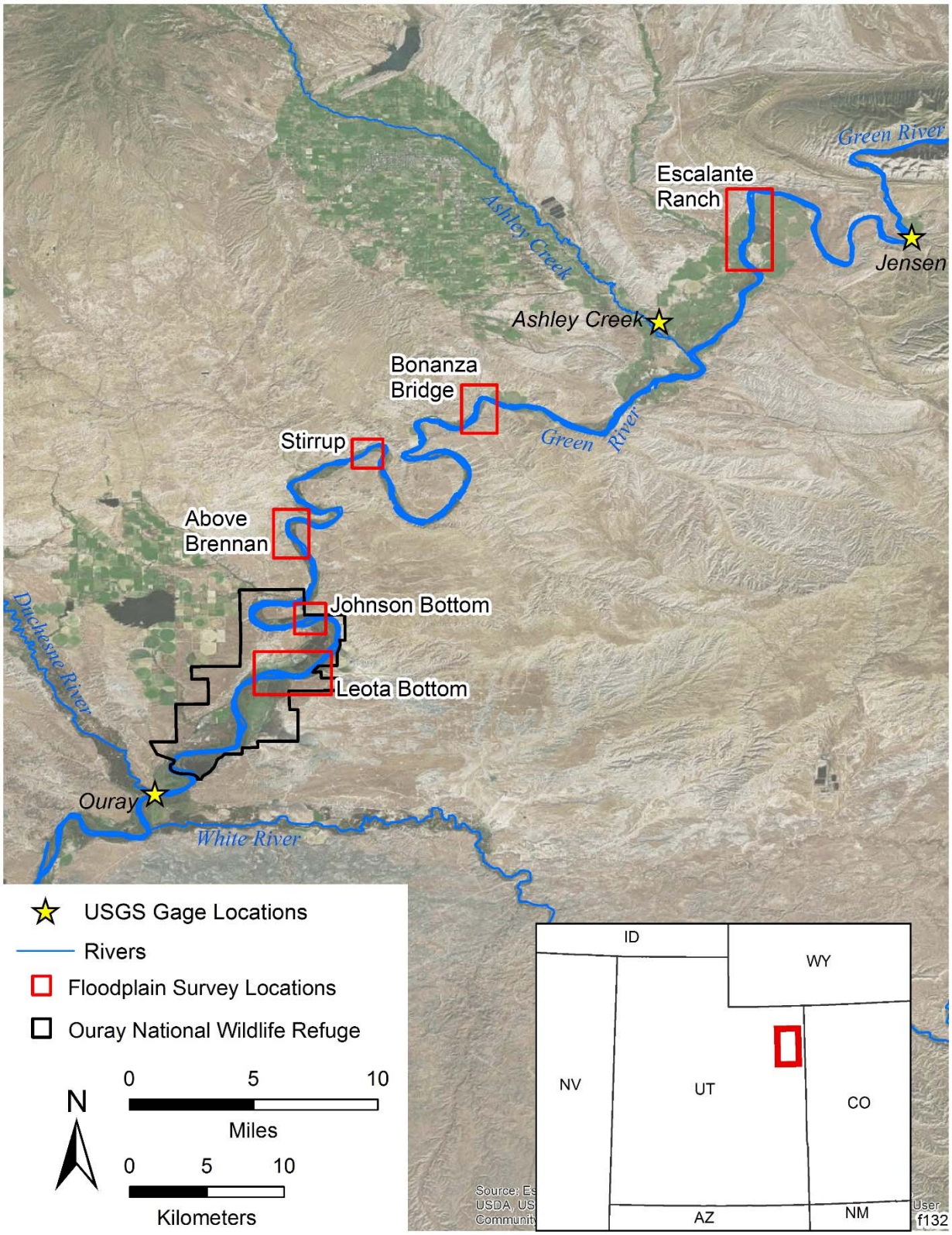

FIGURE 1 Green River Floodplain Survey Locations, April 2016

TABLE 2 Summary of Survey Dates and Estimated Local Flow Conditions at Surveyed Floodplain Wetland Breaches on the Middle Green River, Utah, in April 2016

Wetland Breach	Date	Time (h)	USGS Gage (distance, mi)[a]	Lag-Adjusted Gage Flow (cfs)[b]	Ashley Creek Flow (cfs)	Estimated Local Flow (cfs)[c]	Estimated Local Stage (ft)[d]
Escalante Ranch (ER-OUT)	April 21	11:30	Jensen (10)	6,210	NA[e]	6,210	4.90
Bonanza Bridge (BB-OUT)	April 18	15:00	Jensen (24)	7,370	25	7,395	5.36
Stirrup (ST-OUT)	April 19	10:00	Jensen (38)	6,540	25	6,565	5.04
Above Brennan (AB-IN-1)	April 19	13:30	Jensen (44)	6,460	25	6,485	5.00
Above Brennan (AB-IN-3)	April 19	14:45	Jensen (44)	6,390	25	6,415	4.98
Above Brennan (AB-OUT)	April 19	15:45	Jensen (44)	6,360	25	6,385	4.96
Johnson Bottom (JB-OUT-1)	April 20	11:00	Ouray (-12)	5,640	NA[f]	5,640	18.18
Johnson Bottom (JB-OUT-2)	April 20	11:00	Ouray (-12)	5,640	NA[f]	5,640	18.18
Leota Bottom (LB7-IN)	April 20	11:00	Ouray (-9)	5,810	NA[f]	5,810	18.26
Leota Bottom (LB7A-IN)	April 20	13:00	Ouray (-9)	5,730	NA[f]	5,730	18.22

[a] Values in parentheses indicate distance (miles) away from the nearest USGS stream gage. Positive values are locations downstream from the gage; negative values are locations upstream from the nearest gage.

[b] The lag-adjusted flow was determined by offsetting the gage flow by the lag time from the gage to the site. The lag time (hours [h]) was calculated as $h = 8.9441 \times D_w \times Q_{max}^{-0.3231}$, where D_w is the distance (mi) of the wetland from the nearest gage and Q_{max} is the maximum hourly flow (cfs) at the gage on the date of the survey.

[c] For sites associated with the Jensen gage, the local estimated flow was determined by adding the lag-adjusted Jensen flow (column 5) with the Ashley Creek flow (column 6).

[d] The local lag-adjusted stage was determined using the most current stage-flow tables for the Jensen and Ouray gages (2014 and 2012, respectively). Stage-flow tables are provided in Appendix A of LaGory et al. (2016b).

[e] NA = not applicable; Ashley Creek is downstream of the Escalante Ranch site.

[f] NA = not applicable; Ashley Creek flow is included in the Ouray gage flow.

Stirrup Wetland

Escalante Ranch Outlet (ER-OUT)

Leota Bottom (LB7A-IN)

Above Brennan Outlet (AB-OUT)

FIGURE 2 Example Floodplain Wetland Survey Photographs, April 2016

We estimated the duration of connection and passage flows at each of the 19 breaches of the six priority floodplain wetland sites using our survey data from 2012, 2014, and 2016, and the instantaneous peak flow and mean daily flow data from the Jensen and Ouray gages. We estimated durations in both 2013 and 2014 by comparing flow data in each of these years to the 2012 post-peak connection and passage flow estimates from our 2012 survey (LaGory et al. 2016a); peak flows in 2013 were relatively low (Table 1), and were expected to have minimal effect on the connection and passage flows estimated in 2012. We estimated durations in 2015 using the post-peak survey estimates from 2014 (LaGory et al. 2016b), and in 2016 using the pre-peak survey estimates from April 2016.

3 RESULTS

In this section, we provide a summary of our April 2016 survey results for each floodplain wetland, including estimated connection and passage flows, and descriptions of the breach and connection channel at each location (Table 3). In Tables 4 and 5, we present comparisons of 2016 connection and passage flow estimates, respectively, with values from 2005, 2012 and 2014. In Table 6, we present estimates of the duration of connection and passage flows for breaches from 2013 through 2016 based on our survey results. Appendix A contains maps of the connection channel between the river and the floodplain wetland at each location at the minimum connection flow.

In the descriptions below, we identify the following critical elevations and associated estimated flows for each levee breach and its connection channel:

- *River water surface elevation (flow)*: water surface elevation and associated flow as surveyed at river's edge nearest each levee breach;

- *Connection elevation (flow)*: minimum elevation and associated flow in the connection channel that would allow water to flow between the river and floodplain wetland as determined from a series of cross sections measured between the levee breach and the entrance to the floodplain wetland; and

- *Passage elevation (flow)*: minimum water surface elevation and associated flow that would provide at least 1 ft (30 cm) of depth along the entire connection channel. This is considered to be the minimum depth that would allow subadult and adult razorback suckers to swim between the wetland and river (Burdick 1997).

3.1 ESCALANTE RANCH

We surveyed the Escalante Ranch wetland on April 21, 2016, at an estimated local flow of 6,210 cfs (Table 2). The wetland was not connected to the river at the time of survey. We only surveyed the Escalante Ranch outlet (ER-OUT) (Figure 3) because this was the only breach at this wetland expected to connect during the 2015 peak flow based on its 2014 connection flow of 8,740 cfs (Table 4).

We surveyed 569 points at ER-OUT in 2016. The estimated mean river water surface elevation near ER-OUT was 4,735.2 ft. Hard-packed sand in the channel near the river and breach showed signs of scour (Table 3), and there was a water-filled scour hole (as observed in 2012 and 2014) located midway up the channel toward the wetland. The scour hole was larger in 2016 than in previous years with a cutbank on the adjacent sandbar. Areas of shallow standing water in the channel supported sedges and other wetland vegetation. Based on our 2016 survey, the estimated connection flow for ER-OUT was 7,240 cfs (4,735.6 ft), and the highest channel

TABLE 3 Summary of Middle Green River Floodplain Wetland Survey Results, April 2016[a]

Breach ID	Connection Flow (cfs)	Passage Flow (cfs)	Notes
ER-OUT	7,240	9,920	Hard-packed sand in channel near river and breach. Scour hole with standing water (as observed in 2012 and 2014) located midway up channel toward wetland; scour hole larger than in previous years with cutbank on adjacent sandbar. Other areas of standing water in channel with wetland vegetation (mostly sedges). Connection point about one-sixth of distance between breach and wetland, closer to the river than in previous years. Wetland was observed connected on April 18, 2016, when flow was 7,530 cfs. U.S. Fish and Wildlife Service (FWS) personnel observed connection and a depth of 54 cm in the breach on July 1, 2016, when flow was 10,600 cfs.
BB-OUT	15,900	19,100	Two shallow breach inlets and connection channels with loose sand. Connection occurs through upstream breach at lower flows than downstream breach; connection point about halfway between breach and wetland. Sand and gravel roads to breaches serve as main outlet channels. Several additional small roads cross broad forest swale near outlet, which also serves to connect wetland to river at high flows. FWS personnel did not observe connection on July 1, 2016, when flow was 10,700 cfs.
ST-OUT	15,100	18,200	Shallow breach and narrow incised channel of packed sand with no apparent new sand deposits. Connection point about two-thirds of the distance between the breach and wetland, closer to wetland than in 2014. No change from 2014 or 2012 in staff gage burial depth (0.8 ft). FWS personnel observed connection and a depth of 56 cm on June 6, 2016, when flow was 17,400 cfs. They observed connection and a depth of 7 cm in the breach on July 1, 2016, when flow was 10,700 cfs, and the wetland was draining.
AB-IN-1	13,300	16,400	Wide breach of hard-packed sand and thick growth of young willows opens to wide sandy channel with sparse young willows and annuals. Large pile of cut brush near wetland that could trap sediment and block fish passage. Connection point about halfway between breach and wetland, similar to 2014. No change in staff gage burial depth from 2014 or 2012 (0.6 ft). FWS personnel observed connection and a depth of 72 cm on June 6, 2016, when flow was 17,400 cfs.
AB-IN-3	15,400	18,600	Narrow breach of hard-packed sand with no apparent new deposits. Very narrow channel passes through dense willow thicket then opens to wide sandy channel. Connection point just past the breach as in 2014. FWS personnel did not record connection information for AB-IN-3 in 2016.
AB-OUT	10,700	13,600	Very narrow incised channel through a broad mud breach and wide channel vegetated with grasses. Beaver dam and large tree trunks across channel could obstruct flow, but no apparent sand deposits. Connection point about two-thirds of the distance between breach and wetland as in 2014. Staff gage was pushed over, so could not compare to previous years. FWS personnel did not observe connection on June 28, 2016, when flow was 12,900 cfs indicating that the beaver dam and other debris was preventing connection at lower flows.

Table 3 (Cont.)

Breach ID	Connection Flow (cfs)	Passage Flow (cfs)[b]	Notes
JB-OUT-1	5,390	12,700	Flow entry to wetland is controlled by gate that is located at the end of the connection channel. Channel modified in 2015 prior to spring peak to enhance connection to the river; vegetation had been removed and excavated soil placed on terraces along channel. On April 20, 2016 (Ouray gage flow 5,640 cfs), channel was filled with water to gate, which was closed. Connection point about two-thirds of the distance between breach and wetland. The gate was not opened for water entry in 2016.
JB-OUT-2	11,600	13,900	Broad breach armored with gravel-filled geocell; road runs length of breach. Broad channel slopes downward from breach to wetland. Connection point just past the breach toward wetland. Breach modified in 2015 prior to spring peak to enhance connection to the river. FWS personnel determined that Johnson Bottom was connected to river through JB-OUT-2 between May 9 (Ouray flow 10,700 cfs) and June 29, 2016 (Ouray flow 12,100 cfs).
LB7-IN	14,800	17,300	LB7 and LB7A are now internally connected as a single basin. Sand road runs length of wide breach; many young willows and herbaceous plants in breach. Broad heavily vegetated channel (herbaceous vegetation with many young cottonwood trees) slopes downward from breach to wetland. Large deposit of sand in wetland from 2011 now completely vegetated. Connection point just past breach on wetland side, closer to river than in 2014. FWS personnel did not record connection information for LB7-IN in 2016.
LB7A-IN	13,300	15,800	LB7 and LB7A are now internally connected as a single basin. Portion of breach is concrete; sand road runs length of breach. Broad heavily vegetated channel (mostly herbaceous with scattered young cottonwood trees) slopes downward from breach to wetland. Large sandbar between breach and river. Large deposit of sand in wetland from 2011 now completely vegetated. Connection point at wetland edge, farther from the river than in 2014. FWS personnel observed connection and a depth of 54 cm in the breach on June 6, 2016, when flow was 18,500 cfs.
Mean for all Breaches	12,273	15,552	

[a] Only breaches that were presumed to have been inundated by 2015 peak flows were surveyed (i.e., those with measured connection flows less than 15,800 cfs or 14,800 cfs at the Jensen and Ouray gages, respectively, dependent on the wetland's location). Other non-surveyed breaches were assumed to have not changed since 2014 because their connection flow was higher than the 2015 spring peak.

TABLE 4 Comparison of 2016 Floodplain Wetland Connection Flow Estimates to Previous Years[a]

	Estimated Connection Flow (cfs)				Change in Connection Flow (cfs)			
Breach ID	2016	2014[b]	2012[c]	2005[d]	2016-2014	2014-2012	2012-2005	2016-2005
ER-OUT	7,240	8,740	11,300	12,433	-1,500	-2,560	-1,133	-5,193
BB-OUT	15,900	14,900	17,400	>13,900	+1,000	-2,500	+3,500	+2,000
ST-OUT	15,100	15,700	16,900	13,000	-600	-1,200	+3,900	+2,100
AB-IN-1	13,300	15,200	16,400	13,000	-1,900	-1,200	+3,400	+300
AB-IN-3	15,400	14,600	18,500	13,000	+800	-3,900	+5,500	+2,400
AB-OUT	10,700	10,400	9,990	13,000	+300	+410	-3,010	-2,300
JB-OUT-1	5,390	13,600	16,100	13,000[e]	-8,210	-2,500	+3,100	-7,610
JB-OUT-2	11,600	14,100	16,400	13,000[e]	-2,500	-2,300	+3,400	-1,400
LB7-IN	14,800	14,500	17,600	NA[f]	+300	-3,100	NA[f]	NA[f]
LB7A-IN	13,300	12,700	13,400	NA[f]	+600	-700	NA[f]	NA[f]
Mean	12,273	13,444	15,399	13,042	-1,171	-1,955	+2,332	-1,213
Mean difference between years without Leota Bottom[g]					-1,576	-1,969	+2,332	-1,213
Mean difference between years without Johnson Bottom[h]					-125	-1,844	-2,026	-116

[a] Only breaches that were presumed to have been inundated by 2015 peak flows were surveyed (i.e., those with measured connection flows less than 15,800 cfs or 14,800 cfs at the Jensen and Ouray gages, respectively, dependent on the wetland's location). Other non-surveyed breaches were assumed to have not changed since 2014 because their connection flow was higher than the 2015 spring peak. Connection flow estimates represent the expected connection flow during the 2016 peak flow.

[b] Values from October 2014 survey reported in LaGory et al. (2016b). Connection flow estimates represent the expected connection flow during the 2015 peak flow.

[c] Values from October 2012 survey reported in LaGory et al. (2016a). Connection flow estimates represent the expected connection flow during the 2013 peak flow.

[d] Values reported in Tetra Tech (2005). Target flows are the flows that were targeted for connection when levee breaches were constructed. Tetra Tech (2005) made observations during the peak runoff period of 2005 to determine if connection was actually occurring at these flows by visiting sites at the following flows: Escalante Ranch: <10,000 cfs, 14,000 cfs, 16,700 cfs, and 19,600 cfs; Bonanza Bridge: <10,000 cfs, 13,900 cfs, 18,500 cfs, and 19,700 cfs; Stirrup: <10,000 cfs, 13,900 cfs, 18,500 cfs, and 21,600 cfs; and Above Brennan: <10,000 cfs, 15,000 cfs, 18,300 cfs, and 21,800 cfs. These visits allowed verification of target flows. Of the breaches surveyed in 2016, only BB-OUT had a connection flow higher than the target flow of 13,000 cfs. For this breach, Tetra Tech (2005) noted that connection did not occur at 13,00 cfs, but was observed at 18,500 cfs.

[e] Estimated connection flows from 2012, 2014, and 2016 surveys were compared to Bestgen (2011) because target connection value was not presented in Tetra Tech (2005).

[f] NA = not available.

[g] Mean of connection flows without Leota Bottom to enable comparison with the 2005 mean.

[h] Mean of connection flows without Johnson Bottom to enable comparison with the 2016 mean.

TABLE 5 Comparison of 2016 Floodplain Wetland Passage Flow Estimates to Previous Years[a]

	Estimated Passage Flow (cfs)				Change in Passage Flow (cfs)			
Breach ID	2016	2014	2012	2005[d]	2016-2014	2014-2012	2012-2005	2016-2005
ER-OUT	9,920	11,500	14,300	15,600	-1,580	-2,800	-1,300	-5,680
BB-OUT	19,100	18,100	20,800	17,300	+1,000	-2,700	+3,500	+1,800
ST-OUT	18,200	19,000	20,200	16,300	-800	-1,200	+3,900	+1,900
AB-IN-1	16,400	18,400	19,700	16,300	-2,000	-1,300	+3,400	+100
AB-IN-3	18,600	17,700	21,900	16,300	+900	-4,200	+5,600	+2,300
AB-OUT	13,600	13,300	13,000	16,300	+300	+300	-3,300	-2,700
JB-OUT-1	7,260	16,000	18,700	15,400	-8,740	-2,700	+3,300	-8,140
JB-OUT-2	13,900	16,500	19,000	15,400	-2,600	-2,500	+3,600	-1,500
LB7-IN	17,300	17,000	20,300	NA[e]	+300	-3,300	NA[e]	NA[e]
LB7A-IN	15,800	15,100	15,800	NA[e]	+700	-700	NA[e]	NA[e]
Mean	15,008	16,260	18,370	16,113	-1,252	-2,110	+2,338	-1,490
Mean difference between years without Leota Bottom[f]					-1,690	-2,138	+2,338	-1,490
Mean difference between years without Johnson Bottom[g]					-148	-1,822	+2,643	+380

[a] Only breaches that were presumed to have been inundated by 2015 peak flows were surveyed (i.e., those with measured connection flows less than 15,800 cfs or 14,800 cfs at the Jensen and Ouray gages, respectively, dependent on the wetland's location). Other non-surveyed breaches were assumed to have not changed since 2014 because their connection flow was higher than the 2015 spring peak. Passage flow estimates represent the expected connection flow during the 2016 peak flow.

[b] Values from October 2014 survey reported in LaGory et al. (2016b). Passage flow estimates represent the expected passage flow during the 2015 peak flow.

[c] Values from October 2012 survey reported in LaGory et al. (2016a). Passage flow estimates represent the expected passage flow during the 2013 peak flow.

[d] Passage flows for 2005 were estimated by the authors using the elevations associated with reported 2005 connection flows in Tetra Tech (2005) and Bestgen et al. (2011), adding 1 ft to the elevation, and determining the associated flow in the stage-flow table provided by USGS for 2005. Since the Ouray gage was not in place in 2005, we used the 2012 stage flow table for the Ouray gage to estimate passage flows for Johnson Bottom and Leota Bottom in that year.

[e] NA = not available.

[f] Mean of passage flows without Leota Bottom to enable comparison with the 2005 mean.

[g] Mean of passage flows without Johnson Bottom to enable comparison with the 2016 mean.

TABLE 6 Estimated Duration of Connection and Passage Flows from 2013 through 2016 in Middle Green River Floodplain Wetlands[a]

	Duration of Connection Flows (days)				Duration of Passage Flows (days)			
Breach ID	2013	2014	2015	2016	2013	2014	2015	2016
Escalante Ranch								
ER-IN-3	0	6	0	10	0	0	0	0
ER-IN-4	0	<1	0	3	0	0	0	0
ER-IN-5	0	11	0	5	0	<1	0	0
ER-IN-6	0	1	0	6	0	0	0	0
ER-IN-7	0	18	0	11	0	4	0	0
ER-OUT	0	28	39	58	0	21	16	54
Bonanza Bridge								
BB-IN-1	0	<1	0	4	0	0	0	0
BB-IN-2	0	0	0	1	0	0	0	0
BB-IN-3	0	0	0	0	0	0	0	0
BB-OUT	0	8	1	18	0	0	0	5
Stirrup								
ST-OUT	0	10	<1	22	0	0	0	10
Above Brennan								
AB-IN-1	0	11	<1	36	0	<1	0	15
AB-IN-2	0	1	0	5	0	0	0	0
AB-IN-3	0	4	1	20	0	0	0	9
AB-OUT	4	33	24	50	0	23	4	33
Johnson Bottom								
JB-OUT-1	0	10	2	66[b]	0	0	0	58[a]
JB-OUT-2	0	9	1	44	0	0	0	28
Leota Bottom								
LB7-IN	0	1	<1	21	0	0	0	12
LB7A-IN	0	22	6	32	0	10	0	15

[a] Durations in both 2013 and 2014 were determined by comparing flow data in each of these years to the 2012 post-peak connection and passage flow estimates from our 2012 survey (LaGory et al. 2016a); durations in 2015 were estimated using the post-peak survey estimates from 2014, and in 2016 using the pre-peak survey estimates from 2016.

[b] JB-OUT-1 was not opened in 2016 (Jones et al. 2016). Estimates of connection and passage flows for JB-OUT-1 assume the gate is left open during the entire peak flow period.

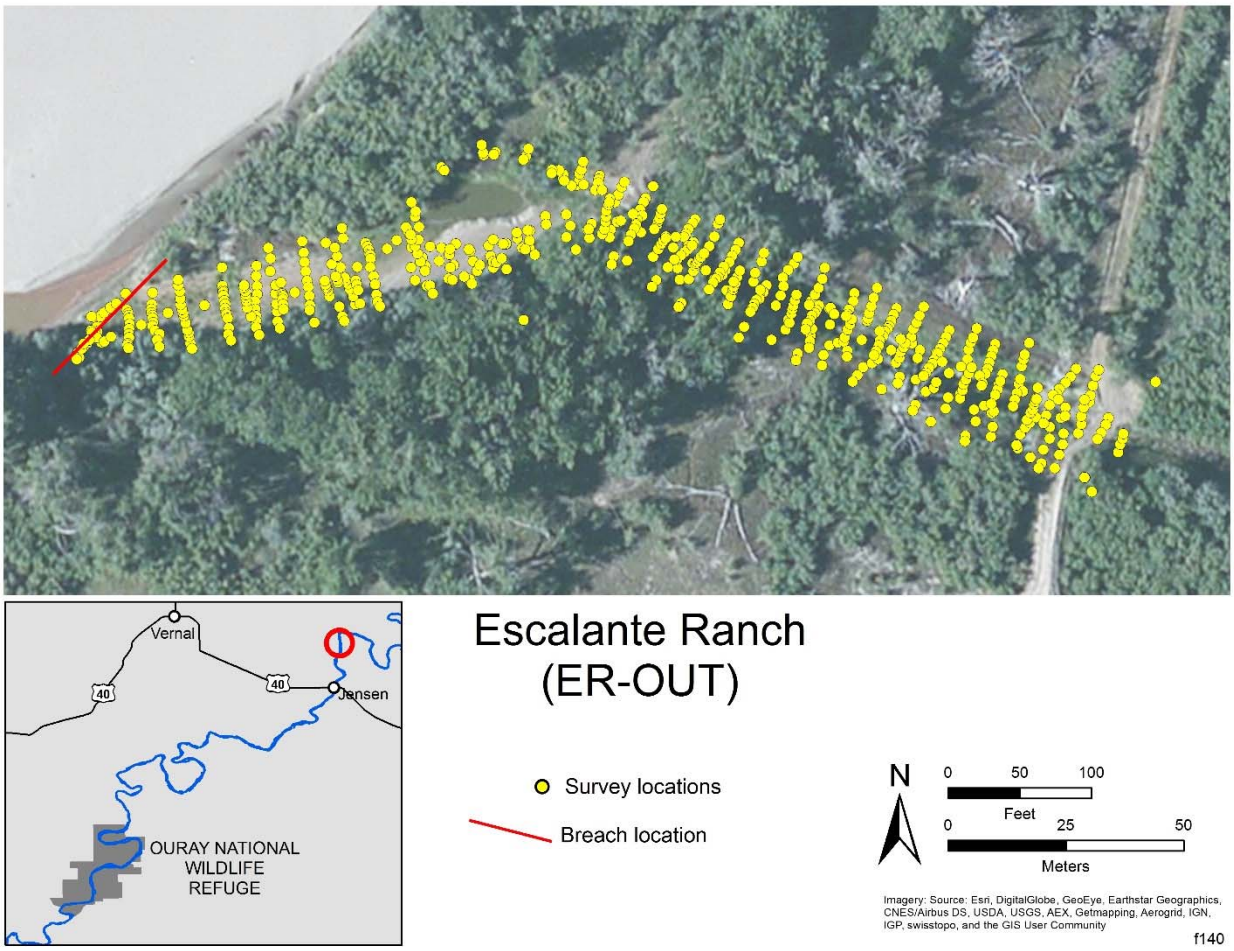

FIGURE 3 Escalante Ranch Floodplain Survey Locations in 2016. Date of the imagery differs from the date of the survey, and does not depict conditions at the time of the survey.

cross-section was about one-sixth of the distance between the breach and the wetland (Table 3; Figure A-1), which was closer to the river than in previous years. Connection flow in 2016 was approximately 1,500 cfs, 4,060 cfs, and 5,193 cfs lower than connection flow estimates in 2014, 2012, and 2005, respectively (Table 4). Estimated passage flows for ER-OUT in 2016 was 9,920 cfs (4,736.6 ft), which is approximately 1,580 cfs, 4,380 cfs, and 5,680 cfs lower than in 2014, 2012, and 2005, respectively (Table 5). The continuing decrease in connection and passage flow for ER-OUT is noteworthy (a net decrease of 5,193 cfs and 5,680 cfs, respectively, since 2005).

On our initial visit to this breach on April 18, 2016, the wetland was connected to the river and too deep to survey (local flow was 7,530 cfs). FWS personnel observed connection of ER-OUT with a measured depth of 54 cm in the breach on July 1, 2016, when flow was 10,600 cfs (T. Jones, FWS, personal communication).

Based on our survey results, we estimate that, from 2013-2016, peak flows in all years but 2013 provided connection and passage at the Escalante Ranch wetland, primarily through

ER-OUT (Table 6). Duration of connection flows for 2014-2016 ranged from 28 to 58 days; duration of passage flows for those years ranged from 16 to 54 days.

3.2 BONANZA BRIDGE

We surveyed the Bonanza Bridge floodplain wetland on April 18, 2016, at an estimated local flow of 7,395 cfs (Table 2). The wetland was not connected to the river at the time of survey. We only surveyed the Bonanza Bridge outlet (BB-OUT) (Figure 4) because this was the only breach at this wetland expected to connect during the 2015 peak flow based on its 2014 connection flow of 14,900 cfs (Table 4).

We surveyed 493 points at BB-OUT in 2016 (Figure 4). The estimated mean river water surface elevation near BB-OUT was 4,708.3 ft. BB-OUT consisted of two shallow breaches that were mostly filled with sand. Both breaches led to a network of unimproved dirt and gravel roads that served as connection channels to the wetland through a broad low woodland. Based on our 2016 survey, the estimated connection flow for BB-OUT was 15,900 cfs (4,711.3 ft), and the highest channel cross-section was about half of the distance between the breach and the wetland (Table 3; Figure A-2), similar to that in 2014. Connection flow in 2016 was approximately 1,000 cfs higher, 1,500 cfs lower, and 2,000 cfs higher than connection flow estimates in 2014, 2012, and 2005, respectively (Table 4). Estimated passage flow for BB-OUT in 2016 was 19,100 cfs, which was 1,000 cfs higher, 1,700 cfs lower, and 1,800 cfs higher than in 2014, 2012, and 2005, respectively (Table 5).

FWS personnel visited the location once in 2016 (on July 1) when flow was 10,700 cfs; they did not observe connection at this flow (T. Jones, FWS, personal communication).

Based on our survey results, we estimate that, from 2013-2016, peak flows in all years but 2013 provided connection at the Bonanza Bridge wetland, primarily through BB-OUT (Table 6). Passage flows were achieved only in 2016. Duration of connection flows for 2014-2016 ranged from 1 to 18 days; passage flows were achieved for 5 days in 2016.

3.3 STIRRUP

We surveyed the Stirrup floodplain wetland on April 19, 2016, at an estimated local flow of 6,565 cfs (Table 2). The wetland was not connected to the river at this flow. There is only one breach location at Stirrup (ST-OUT, Figure 5). We surveyed this breach because it was expected to have connected during the 2015 peak flow based on its 2014 connection flow of 15,700 cfs (Table 4).

We surveyed 429 points at ST-OUT in 2016. The estimated mean river water surface elevation near ST-OUT was 4,683.4 ft. ST-OUT was a narrow incised channel in a wider shallow breach of packed sand and silt. The connection channel was narrow, but did not have any apparent obstructions to flow. Based on our 2016 survey, the estimated connection flows for ST-OUT was 15,100 cfs (4,686.4 ft), and the highest channel cross-section was about two-thirds

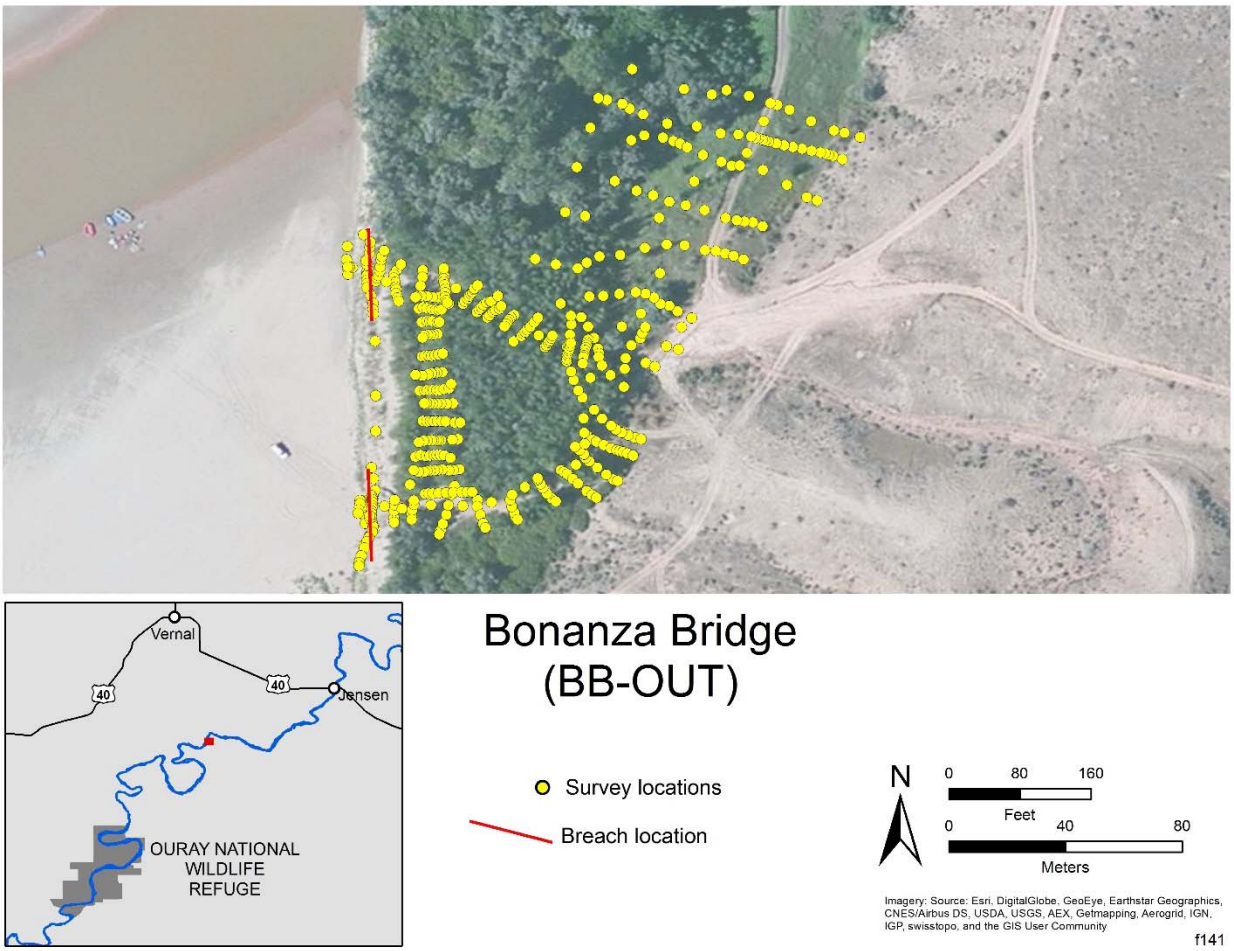

FIGURE 4 Bonanza Bridge Floodplain Survey Locations in 2016. Date of the imagery differs from the date of the survey, and does not depict conditions at the time of the survey.

of the distance between the breach and the wetland (Table 3; Figure A-3), which was closer to the wetland than in 2014. Connection flow in 2016 was approximately 600 cfs lower, 1,800 cfs lower, and 2,100 cfs higher than connection flow estimates in 2014, 2012, and 2005, respectively (Table 4). Estimated passage flow for ST-OUT in 2016 was 18,200 cfs (4,687.4 ft), which was 800 cfs lower, 2,000 cfs lower, and 1,900 cfs higher than in 2014, 2012, and 2005, respectively (Table 5).

FWS personnel observed connection of ST-OUT with a measured depth of 56 cm in the breach on June 6, 2016, when flow was 17,400 cfs (T. Jones, FWS, personal communication). They observed connection and a depth of 7 cm in the breach on July 1, 2016, when flow was 10,700 cfs; the wetland was draining at this flow.

Based on our survey results, we estimate that, from 2013-2016, peak flows in all years but 2013 provided connection at the Stirrup wetland through ST-OUT (Table 6). Passage flows were achieved only in 2016. Duration of connection flows for 2014-2016 ranged from <1 day

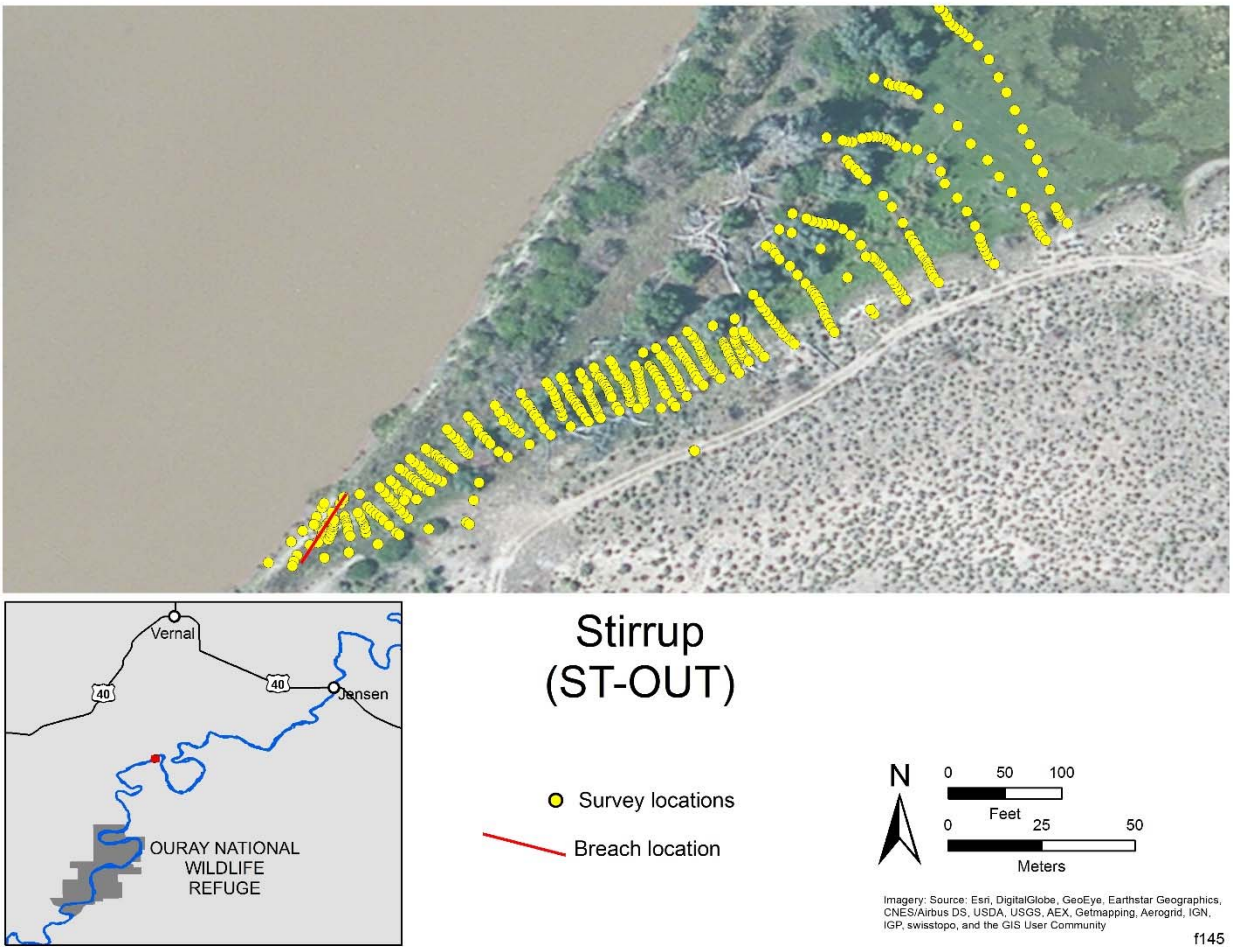

FIGURE 5 Stirrup Survey Locations in 2016. Date of the imagery differs from the date of the survey, and does not depict conditions at the time of the survey.

(connection flow threshold was only exceeded by the instantaneous peak flow in 2015) to 22 days; passage flows were achieved for 10 days in 2016.

3.4 ABOVE BRENNAN

We surveyed the Above Brennan floodplain wetland on April 19, 2016, at an estimated mean local flow of 6,428 cfs (Table 2). The wetland was not connected to the river at the time of survey. We surveyed three breach locations at Above Brennan in 2016: two upstream breaches (AB-IN-1 and AB-IN-3) and a downstream breach (AB-OUT) (Figure 6). These breach sites were chosen because they were expected to connect during the 2015 peak flow based on their 2014 connection flows of 15,200 cfs, 14,600 cfs, and 10,400 cfs, respectively (Table 4). Connection and passage flows at each of these breaches are provided below. The 2016 minimum connection flow at Above Brennan occurred at the downstream outlet (AB-OUT), and was estimated to be 10,700 cfs (Table 4).

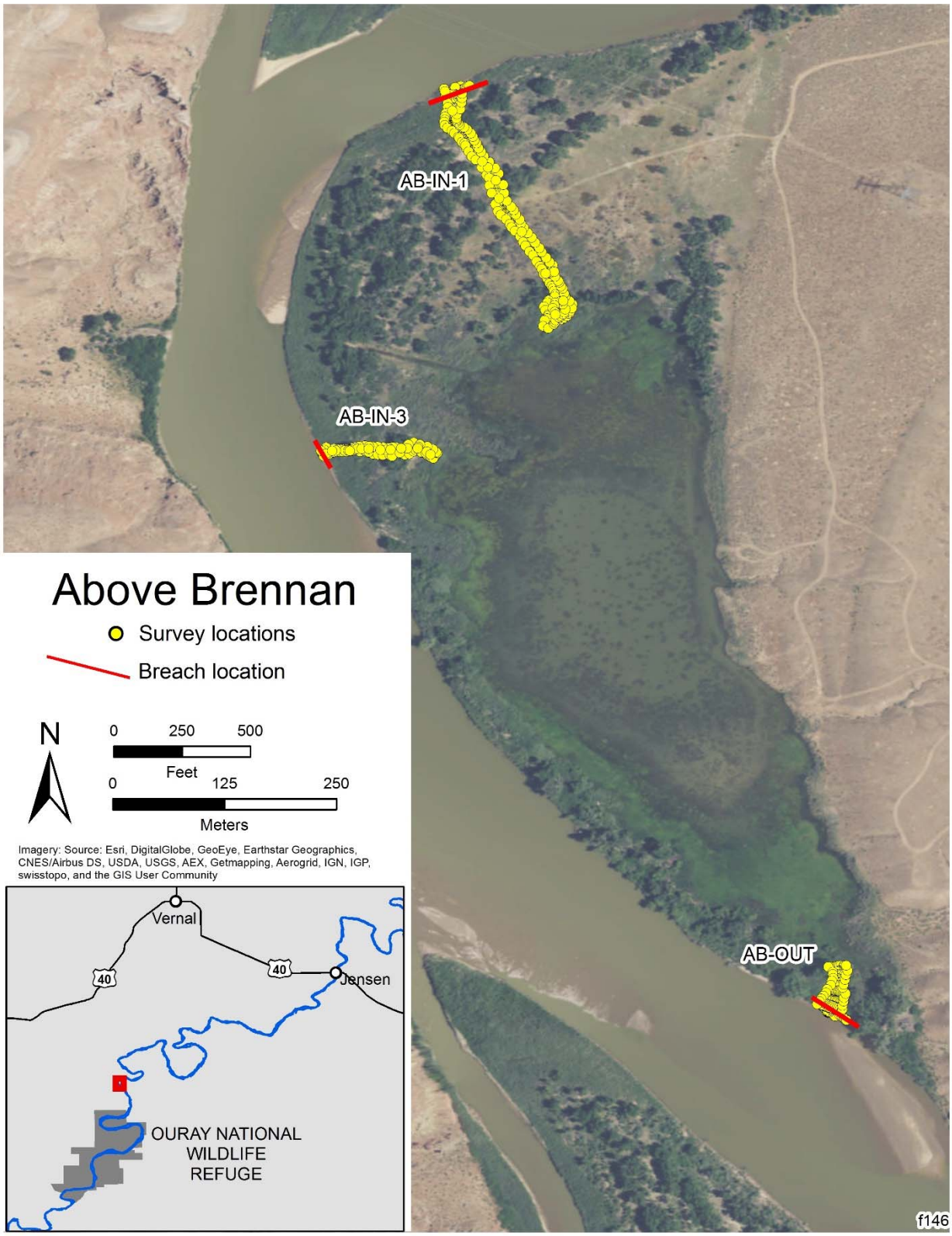

FIGURE 6 Above Brennan Survey Locations in 2016. Date of the imagery differs from the date of the survey, and does not depict conditions at the time of the survey.

Based on our survey results, we estimate that, from 2013-2016, peak flows in all years but 2013 provided connection and passage at the Above Brennan wetland, primarily through AB-OUT (Table 6). Above Brennan was the only wetland to connect (through AB-OUT) in 2013; connection duration in this year was 4 days. Duration of connection flows for 2014-2016 ranged from 24 to 50 days; duration of passage flows for those years ranged from 4 to 33 days.

AB-IN-1. We surveyed 602 points at AB-IN-1 in 2016. The estimated mean river water surface elevation near AB-IN-1 was 4,674.5 ft. AB-IN-1 was a fairly wide breach of hard-packed sand with a thick growth of young willows, which opens to a wide sandy channel with sparse growth of young willows and annuals. There was a large pile of cut brush near the wetland that could trap sediment and block fish passage. Based on our 2016 survey, the estimated connection flow for AB-IN-1 was 13,300 cfs (4,677.0 ft), and the highest channel cross-section was about half of the distance between the breach and the wetland (Table 3; Figure A-4), similar to that in 2014. Connection flow in 2016 was approximately 1,900 cfs lower, 3,100 cfs lower, and 300 cfs higher than connection flow estimates in 2014, 2012, and 2005, respectively (Table 4). Estimated passage flow for AB-IN-1 in 2016 was 16,400 cfs (4,678.0 ft), which was 2,000 cfs lower, 3,300 cfs lower, and 100 cfs higher than in 2014, 2012, and 2005, respectively (Table 5).

FWS personnel observed connection of AB-IN-1 with a measured depth of 72 cm in the breach on June 6, 2016, when flow was 17,400 cfs (T. Jones, FWS, personal communication).

AB-IN-3. We surveyed 202 points at AB-IN-3 in 2016. The estimated mean river water surface elevation near AB-IN-3 was 4,673.9 ft. AB-IN-3 was a narrow cut through packed sand and silt with no apparent new deposits of sand or debris. A very narrow channel passed through a dense thicket of willows before opening into a wide sandy channel with little vegetation. Based on our 2016 survey, the estimated connection flow for AB-IN-3 was 15,400 cfs (4,677.1 ft), and the highest channel cross-section was just past the breach as in 2014 (Table 3; Figure A-5). Connection flow in 2016 was approximately 800 cfs higher, 3,100 cfs lower, and 2,400 cfs higher than connection flow estimates in 2014, 2012, and 2005, respectively (Table 4). Estimated passage flow for AB-IN-3 in 2016 was 18,600 cfs (4,678.1 ft), which was 900 cfs higher, 3,300 cfs lower, and 2,300 cfs higher than in 2014, 2012, and 2005, respectively (Table 5).

FWS personnel did not record connection information for AB-IN-3 in 2016 (T. Jones, FWS, personal communication).

AB-OUT. We surveyed 212 points at AB-OUT in 2016. The estimated mean river water surface elevation near AB-IN-1 was 4,673.2 ft. AB-OUT was a narrow incised channel through a broad mud breach, with a wide connection channel that was vegetated with grasses. A beaver dam and large tree trunks cross the channel and could obstruct flow, but there were no sand deposits observed in the connection channel. Based on our 2016 survey, the estimated connection flow for AB-OUT was 10,700 cfs (4,674.9 ft), and the highest channel cross-section was about two-thirds of the distance between the breach and the wetland as in 2014 (Table 3; Figure A-6). Connection flow in 2016 was approximately 300 cfs higher, 710 cfs higher, and

2,300 cfs lower than connection flow estimates in 2014, 2012, and 2005, respectively (Table 4). Estimated passage flow for AB-OUT in 2016 was 13,600 cfs (4,675.9 ft), which was 300 cfs higher, 600 cfs higher, and 2,700 cfs lower than in 2014, 2012, and 2005, respectively (Table 5).

FWS personnel did not observe connection of AB-OUT on June 28, 2016, when flow was 12,900 cfs. This indicates that the beaver dam and other debris was preventing connection at lower flows (T. Jones, FWS, personal communication).

3.5 JOHNSON BOTTOM

We surveyed the Johnson Bottom floodplain wetland on April 20, 2016, at an estimated local flow of 5,640 cfs (Table 2). One of the two breaches (JB-OUT-1) was connected to the river at the time of the survey. We surveyed both breaches (JB-OUT-1 and JB-OUT-2; Figure 7) because both had been refurbished in early 2015 to enhance connection to the river, and they were known to have connected during the 2015 peak flow (LaGory et al. 2016b). Connection and passage flows at each of these breaches are provided below. The 2016 estimated minimum connection flow at Johnson Bottom was 5,390 cfs (JB-OUT-1), which was about 8,120 cfs and 10,710 cfs lower than the connection flow in 2014 and 2012, respectively.

Based on our survey results, we estimate that, from 2013-2016, peak flows in all years but 2013 provided connection at the Johnson Bottom wetland through both JB-OUT-1 and JB-OUT-2 (Table 6). Passage flows were provided only in 2016 after the breaches were modified. Estimated duration of connection flows for 2014-2016 ranged from 2 to 66 days; passage flows were provided for 58 days in 2016. The maximum value for connection and passage flow in 2016 would occur at JB-OUT-1; however, as noted below, the gate at this breach was kept closed during the 2016 peak flow period (Jones et al. 2016). Therefore, duration of connection and passage flows at Johnson Bottom during 2016 (through JB-OUT-2 only) was estimated to be 44 and 28 days, respectively.

JB-OUT-1. We surveyed 226 points at JB-OUT-1 in 2016. The estimated mean river water surface elevation near JB-OUT-1 was 4,669.3 ft. Flow entry to the wetland is controlled by a gate that is located at the end of the connection channel. The breach and channel were modified in 2015 prior to the spring peak to enhance connection to the river. Vegetation along the channel had been removed and excavated soil placed on terraces along the length of the channel. On the day of our survey, at a flow of 5,640 cfs, the connecting channel was filled with water to the gate, which was closed. Based on our 2016 survey, the estimated connection flow for JB-OUT-1 was 5,390 cfs (4,669.2 ft), and the highest channel cross-section was about three-fourths of the distance between the breach and the control gate (Table 3; Figure A-7), much closer to the gate than in 2014. Connection flow in 2016 was approximately 8,210 cfs, 10,710 cfs, and 7,610 cfs lower than in 2014, 2012, and 2005, respectively (Table 4). Estimated passage flow for JB-OUT-1 in 2016 was 7,260 cfs (4,670.2 ft), which was 8,740 cfs, 11,440 cfs, and 8,140 cfs lower than in 2014, 2012, and 2005, respectively (Table 5).

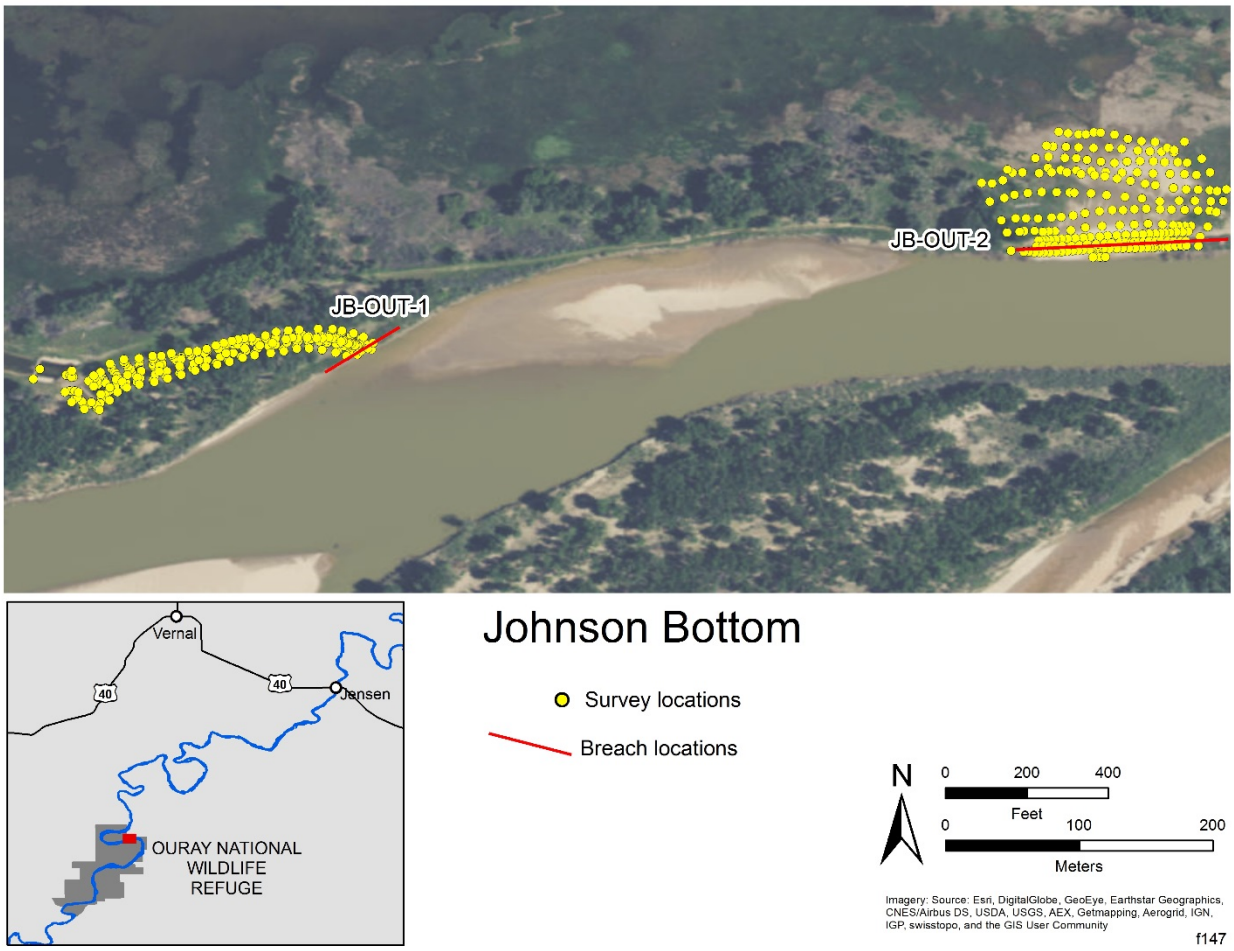

FIGURE 7 Johnson Bottom Survey Locations in 2016. Date of the imagery differs from the date of the survey, and does not depict conditions at the time of the survey.

FWS personnel did not open the control gate to allow water entry during the 2016 peak flow period (Jones et al. 2016).

JB-OUT-2. We surveyed 203 points at JB-OUT-2 in 2016. The estimated mean river water surface elevation near JB-OUT-2 was 4,669.3 ft. This broad breach and channel was modified in 2015 prior to the spring peak to enhance connection to the river. The breach was armored with gravel-filled geocell, and served as a portion of the road to the wetland gate. The broad connection channel sloped downward from the breach to the wetland. Based on our 2016 survey, the estimated connection flow for JB-OUT-2 was 11,600 cfs (4,672.2 ft), and the highest channel cross-section was just past the breach as in 2014 (Table 3; Figure A-8). Connection flow in 2016 was approximately 2,500 cfs, 4,800 cfs, and 1,400 cfs lower than in 2014, 2012, and 2005, respectively (Table 4). Estimated passage flow for JB-OUT-2 in 2016 was 13,900 cfs (4,673.2 ft), which was 2,600 cfs, 5,100 cfs, and 1,500 cfs lower than in 2014, 2012, and 2005, respectively (Table 5).

FWS personnel determined that Johnson Bottom was connected to the river through JB-OUT-2 between May 9 (Ouray gage flow 10,700 cfs) and June 29, 2016 (Ouray gage flow 12,100 cfs) (Jones et al. 2016). The May 9 flow is lower than our estimated connection flow of 11,600 cfs, but the local flow at the time of observation may have been higher than the mean daily gage flow of 10,700 cfs. Photographs taken of JB-OUT-2 in October 2016 show that a large volume of sand was deposited in the breach by the 2016 peak flow (20,400 cfs at the Ouray gage on June 12). Figure 8 shows the change in conditions after the spring peak flow receded compared to conditions during our April survey. Unless removed, this deposit is likely to increase the connection flow at this breach in the future.

3.6 LEOTA BOTTOM

We surveyed the Leota Bottom wetland on April 20, 2016 at an estimated mean local flow of 5,770 cfs (Table 2). The wetland was not connected to the river at the time of survey. We surveyed two downstream breach locations at Leota Bottom: LB7-IN and LB7A-IN (Figure 9); these two units, which used to be separated by an internal dike, are now connected internally as a single basin. These breach sites were chosen because they were expected to connect during the 2015 peak flow based on their 2014 connection flows of 14,500 cfs and 12,700 cfs, respectively (Table 4). Connection and passage flows at each of these breaches are provided below. The 2016 estimated minimum connection flow at Leota Bottom was 13,300 cfs (LB7A-IN), which was about 600 cfs higher and 100 cfs lower than the connection flow in 2014 and 2012, respectively.

Based on our survey results, we estimate that, from 2013-2016, peak flows in all years but 2013 provided connection at the Leota Bottom wetland through both LB7-IN and LB7A-IN (Table 6). Passage flows were achieved in 2014 in 2016. Estimated duration of connection flows for 2014-2016 ranged from 6 to 32 days; passage flows were achieved for 10 days in 2014 and 15 days in 2016.

LB7-IN. We surveyed 868 points at LB7-IN in 2016. The estimated mean river water surface elevation near LB7-IN was 4,666.0 ft. A sand road ran the length of the wide breach, and many young willows and herbaceous plants were growing in it. The channel was broad, heavily vegetated with herbaceous species and many young cottonwood trees, and sloped downward from the breach to the wetland. The large deposit of sand in the connecting channel from the 2011 peak flow was completely vegetated. Based on our 2016 survey, the estimated connection flow for LB7-IN was 14,800 cfs (4,670.2 ft), and the highest channel cross-section was just past the breach (Table 3; Figure A-9), closer to the river than in 2014. Connection flow in 2016 was approximately 300 cfs higher and 2,800 cfs lower than in 2014 and 2012, respectively; an estimate of the 2005 connection flow is not available (Table 4). Estimated passage flow for LB7-IN in 2016 was 17,300 cfs (4,671.2 ft), which was 300 cfs higher and 3,000 cfs lower than in 2014 and 2012, respectively (Table 5).

FWS personnel did not record connection information for LB7-IN in 2016 (T. Jones, FWS, personal communication).

a.

b.

FIGURE 8. Photographs of JB-OUT-2 on April 20, 2016 and October 25, 2016 (before and after the 2016 flood) Showing Sand Deposit in Breach. Both photographs are looking upstream toward grove of cottonwood trees on the adjacent levee.

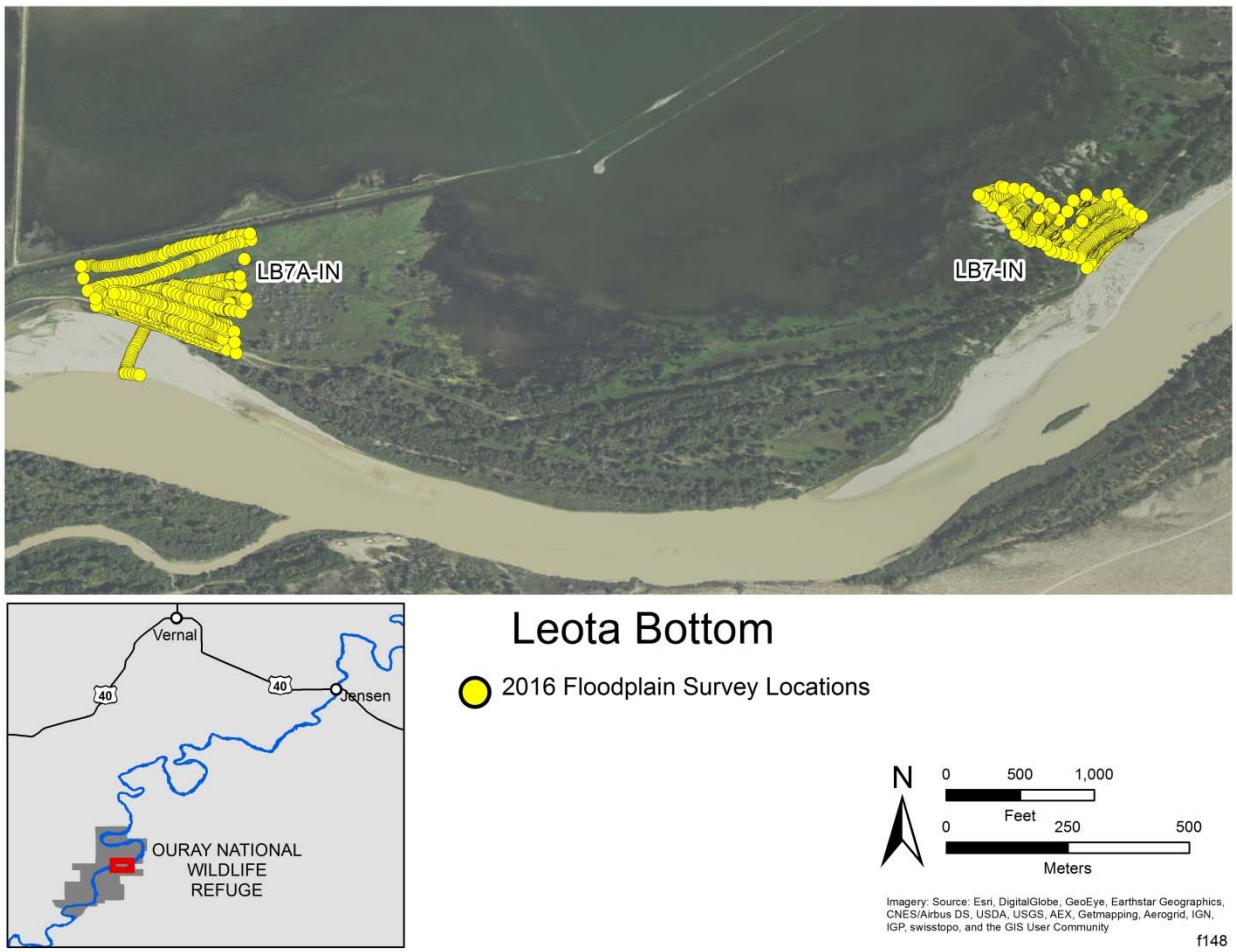

FIGURE 8 Leota Bottom Survey Locations in 2016. Date of the imagery differs from the date of the survey, and does not depict conditions at the time of the survey.

LB7A-IN. We surveyed 600 points at LB7A-IN in 2016. LB7A-IN was a broad breach of mostly loose sand that led to a broad connection channel to the wetland; a road traversed the length of the breach, part of which was concrete. The channel was broad, heavily vegetated with herbaceous species and scattered young cottonwood trees, and sloped downward from the breach to the wetland. The large deposit of sand in the connecting channel from the 2011 peak flow was completely vegetated. There was a large sandbar between the breach and the river edge. Based on our 2016 survey, the estimated connection flow for LB7A-IN was 13,300 cfs (4,668.3 ft), and the highest channel cross-section was near the wetland edge (Table 3; Figure A-10), farther from the river than in 2014. Connection flow in 2016 was approximately 600 cfs higher and 100 cfs lower than in 2014 and 2012, respectively; an estimate of the 2005 connection flow is not available (Table 4). Estimated passage flow for LB7A-IN in 2016 was 15,800 cfs (4,669.3 ft), which was 700 cfs higher than in 2014 and the same as in 2012 (Table 5).

FWS personnel observed connection of LB7A-IN and a depth of 54 cm in the breach on June 6, 2016 when flow was 18,500 cfs at the Ouray gage (T. Jones, FWS, personal communication).

3.7 RESULTS SUMMARY

Our 2016 survey identified differences in connection flow from our 2012 and 2014 survey results (LaGory et al. 2016a,b) and 2005 reported values (Tetra Tech 2005; Bestgen et al. 2011; Table 3). Aside from the Johnson Bottom breaches, which were intentionally modified in early 2015 (prior to the 2015 peak flow) to facilitate connection at lower flows, connection and passage flows at surveyed breaches showed relatively little change from 2014 values. With these two breaches excluded, the mean difference in connection flow was -125 cfs (range -1,900 cfs to +1,000 cfs; Table 4) with 5 of the 8 breaches surveyed increasing slightly, and 3 decreasing. Most of the 2016 connection flow estimates (7 of 8) also were lower than values we obtained in 2012 (mean difference -1,969 cfs with Johnson Bottom breaches excluded). Although the mean difference in connection flow of the six breaches surveyed in both 2016 and 2005 was low (mean difference -116 cfs), the range was great (-5,193 at ER-OUT to +2,400 cfs at AB-IN-3).

We assume the breaches surveyed in 2016 had the lowest connection flows of all breaches of the six priority floodplain wetlands in the middle Green River in that year. This is a reasonable assumption since these were the only breaches likely to have connected during the previous spring peak flow period. Given this assumption, the mean estimated minimum floodplain connection flow (i.e., the lowest connection flow of any breach at a particular wetland) among wetlands surveyed in 2016 was 11,272 cfs (12,448 cfs with Johnson Bottom breaches excluded). This value is 1,402 cfs, 2,910 cfs, and 1,767 cfs lower than the estimates in 2014, 2012, and 2005, respectively (40 cfs, 1,350 cfs, and 307 cfs lower, respectively, with Johnson Bottom breaches excluded). However, there was considerable variation among the wetlands in estimated minimum connection flow in 2016, ranging from 5,390 cfs at Johnson Bottom to 15,900 cfs at Bonanza Bridge. There was less variation in 2014 (8,740 to 15,700 cfs) prior to the modification of JB-OUT-1.

Estimated passage flows were approximately 1,870 cfs to 2,500 cfs higher than connection flows in the Ouray National Wildlife Refuge wetlands (Johnson Bottom and Leota Bottom) and 2,680 cfs to 3,200 cfs higher than connection flows in the wetlands further upstream. In 2016, the mean passage flow for the breaches surveyed was 15,008 cfs (7,260 cfs to 19,100 cfs). The mean minimum passage flow for the floodplain wetlands surveyed (i.e., the lowest passage flow of any breach at a particular wetland) was approximately 13,980 cfs (7,260 to 19,100 cfs).

Estimated duration of connection and passage flows varied considerably among breaches and wetlands from 2013 through 2016 (Table 6). All floodplain wetlands connected at one or more breaches in all years during this period except in 2013 when peak flows were relatively low (Table 1), ranging from < 1 day (Stirrup in 2015) to 58 days (Escalante Ranch in 2016); only the Above Brennan wetland connected in 2013, and only for 4 days. Passage flows were provided at the Escalante Ranch and Above Brennan wetlands in all years except 2013, ranging from 4 to 33 days at Above Brennan and 16 to 54 days at Escalante Ranch. Passage flows were achieved only during 2016 at Bonanza Bridge, Stirrup, and Johnson Bottom, and in 2014 and 2016 at Leota Bottom.

4 DISCUSSION

We reassessed floodplain wetland connection of six priority wetlands in the middle Green River in 2016 to estimate connection and passage flows following the relatively low-magnitude 2015 peak flow (15,800 cfs and 14,800 cfs at the Jensen and Ouray gages, respectively). Knowing the actual connection flows in any given year is critical to defining the target peak flows during the runoff season to meet the biological objectives identified in Muth et al. (2000) and in the Larval Trigger Study Plan (Larval Trigger Study Plan Ad Hoc Committee 2012). We wanted to determine whether or not relatively low spring peak flows (<16,000 cfs) that connected predominantly downstream breaches would produce changes in subsequent connection flows through either scour or sediment deposition.

Although our 2016 survey identified some changes since our 2014 survey (LaGory et al. 2016b), the net mean change was only 125 cfs indicating that the relatively low-magnitude 2015 peak flows did not result in much if any net change in breaches that connected in that year. Suspended sediment concentration data are not currently available for the study area, but we expect that concentrations would have been lower during the lower magnitude 2015 flow compared to the higher magnitude 2014 and 2011 peak flows. A lower sediment load would have made the 2015 peak flow more erosive as the flow passed through upstream breaches. Water entering these breaches could have eroded old deposits while depositing less new sand, resulting in net erosion of older sand deposits. This is likely the reason that connection flow at AB-IN-1 decreased by 1,900 cfs after the 2015 peak flow; this is the largest change in connection flow observed in 2016.

Our 2016 survey results indicate that surveys to reassess floodplain connections may not be needed after relatively low-magnitude peak flows (<16,000 cfs) because little if any deposition occurred in most connected breaches.

Sufficient connection of floodplain wetlands to the river main channel is important to ensure the filling of wetlands and adequate entrainment of larval razorback suckers. The topography of connection channels determines the rate at which wetlands can fill, and wetland topography determines the volume of water that can be stored. The durations needed to fill each wetland and entrain sufficient numbers of larvae currently are not known, but are affected by a number of factors including peak flow magnitude (affects volume), the topography of connection channels (affects filling rate), topography of the wetland (affects storage capacity and amount of habitat), and the larval drift period (affects entrainment rate and total).

Muth et al. (2000) identified peak flow duration targets of 14 days or more, at least in part to fill wetlands and entrain razorback sucker larvae. The Escalante Ranch and Above Brennan wetlands consistently provided 14 days or more of connection from 2014-2016 over a range of peak flows of 15,800 cfs to 21,100 cfs at Jensen and 14,800 cfs to 20,400 cfs at Ouray. Over this same period, the remaining wetlands provided connection for at least 14 days in one year (Bonanza Bridge, Stirrup, and Johnson Bottom in 2016) or two years (Leota Bottom in 2014 and 2016). Given its recent modifications, the Johnson Bottom wetland should also be able to connect consistently over this same range of flows.

Recently collected lidar data for the middle Green River could be used to identify the peak flow magnitude and duration needed to achieve the physical requirements of filling wetlands. This information could be used to refine connection and passage flow duration targets to achieve objectives related floodplain wetland nursery habitat.

5 CONCLUSIONS

- In April 2016 (prior to the 2016 peak flow), we surveyed 10 breaches in six priority wetlands that were connected to the river by the 2015 peak flow. Our survey identified differences in connection flow from our 2012 and 2014 survey results and 2005 reported values. Aside from the Johnson Bottom breaches, which had been intentionally modified to facilitate connection at lower flows, connection and passage flows at surveyed breaches showed relatively little change from 2014 values.

- Mean minimum connection flow (i.e., the lowest connection flow of any breach at a particular wetland) for all six surveyed wetlands in 2016 (including Johnson Bottom) was 11,272 cfs compared to 12,673 cfs in 2014 and 14,182 cfs in 2012; these connection flows represented decreases of 1,402 and 2,910 cfs from 2014 and 2012, respectively. With Johnson Bottom excluded, the mean minimum connection flows were 12,448 cfs, 12,488 cfs, and 13,798 cfs in 2016, 2014, and 2012, respectively, representing reductions of 40 cfs and 1,350 cfs from 2014 and 2012 values.

- Five of the breaches showed an increase in connection flow while five showed a decrease compared to 2014. The mean change was a decrease of 1,171 cfs with the Johnson Bottom breaches included but only a 125 cfs difference with them excluded. This finding indicates that surveys to reassess floodplain connections may not be needed after relatively low-magnitude peak flows (<16,000 cfs).

- Estimated minimum passage flows were approximately 1,870 cfs to 2,500 cfs higher than connection flows in the Ouray National Wildlife Refuge wetlands (Johnson Bottom and Leota Bottom) and 2,680 cfs to 3,200 cfs higher than connection flows in the wetlands further upstream.

- Mean passage flow for the breaches surveyed was 15,008 cfs (7,260 cfs to 19,100 cfs). Mean minimum passage flow for the floodplain wetlands surveyed (i.e., the lowest of all levee breaches in each wetland) was approximately 13,980 cfs (7,260 to 19,100 cfs).

- Estimated duration of connection and passage flows varied considerably among breaches and wetlands from 2013 through 2016. All floodplain wetlands connected at one or more breaches in all years during this period except in 2013 when peak flows were relatively low (11,000 cfs and 10,500 cfs at Jensen and Ouray, respectively). Passage flows were provided at the Escalante Ranch and Above Brennan wetlands in all years except 2013, but only during 2016 at Bonanza Bridge, Stirrup, and Johnson Bottom, and in 2014 and 2016 at Leota Bottom.

6 RECOMMENDATIONS

- Resurvey floodplain wetland breaches and their connection channels following moderately high or higher peak flows (e.g., ≥ 18,600 cfs) that exceed previously determined connection flows to determine if those peak flows have altered connection flows. Our 2016 survey indicates that peak flows < 16,000 cfs have limited effect on subsequent connection flows, and may not require resurvey.

- Determine connection of floodplain wetlands annually by direct observation. Ideally, determinations should be made annually of initial connection flows at upstream and downstream breaches and the degree of filling and draining through the peak flow cycle.

- Determine the duration of peak flows needed to fill wetlands over a range of peak flow-magnitudes. The peak flow duration needed to fill wetlands will be inversely proportional to peak flow magnitude, and also dependent on the storage capacity and filling rate of wetlands. Recently collected lidar data should be evaluated to determine its suitability for making these estimates.

- Measure the surface area of floodplain wetlands after peak flows recede and through the summer and winter to determine if floodplain wetlands provide suitable habitat for razorback suckers between flooding events that reconnect the wetlands to the main channel.

- Consider modification of floodplain wetland breaches and connection channels to provide connection to the main channel river at a return frequency of 1.5 years (probability of about 67%) to mimic pre-dam flooding frequency.

- Consider modifications of wetlands to prevent sediment deposition from blocking inflow. These modifications could include (1) actively reconfiguring levee breaches, connection channels, and wetland topography to minimize the blockage of connection channels; (2) filling or allowing the filling of upstream breaches; (3) creating control structures such as those that have been successfully deployed at Stewart Lake, Johnson Bottom, and

Old Charley Wash; and (4) managing vegetation encroachment that exacerbates sediment deposition in breaches and channels.

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APPENDIX A:

MIDDLE GREEN RIVER FLOODPLAIN WETLAND CONNECTION MAPS FOR 2016

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APPENDIX A:

MIDDLE GREEN RIVER FLOODPLAIN WETLAND CONNECTION MAPS FOR 2016

This appendix presents overlays of modeled flow connections on aerial imagery of levee breaches and connection channels for floodplain wetlands surveyed in April 2016. Elevations of survey points are presented in feet. The flow and cross section at which connection is estimated to occur is presented on each figure. For all images shown, the date of the aerial imagery differs from the date of the survey, and aerial imagery does not depict conditions at the time of the survey.

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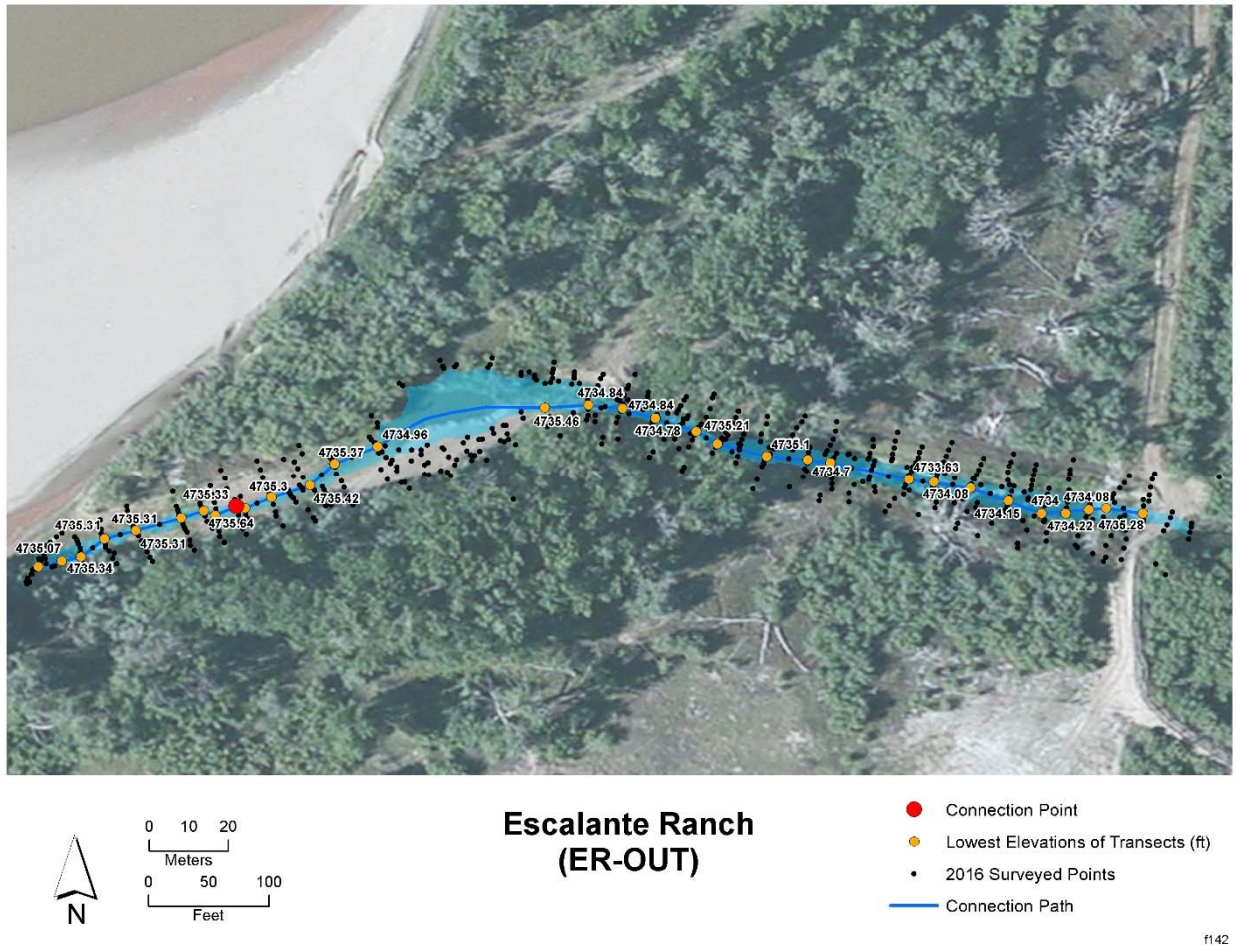

FIGURE A-1 ER-OUT Connection Channel at Minimum Connection Flow (7,240 cfs) in 2016

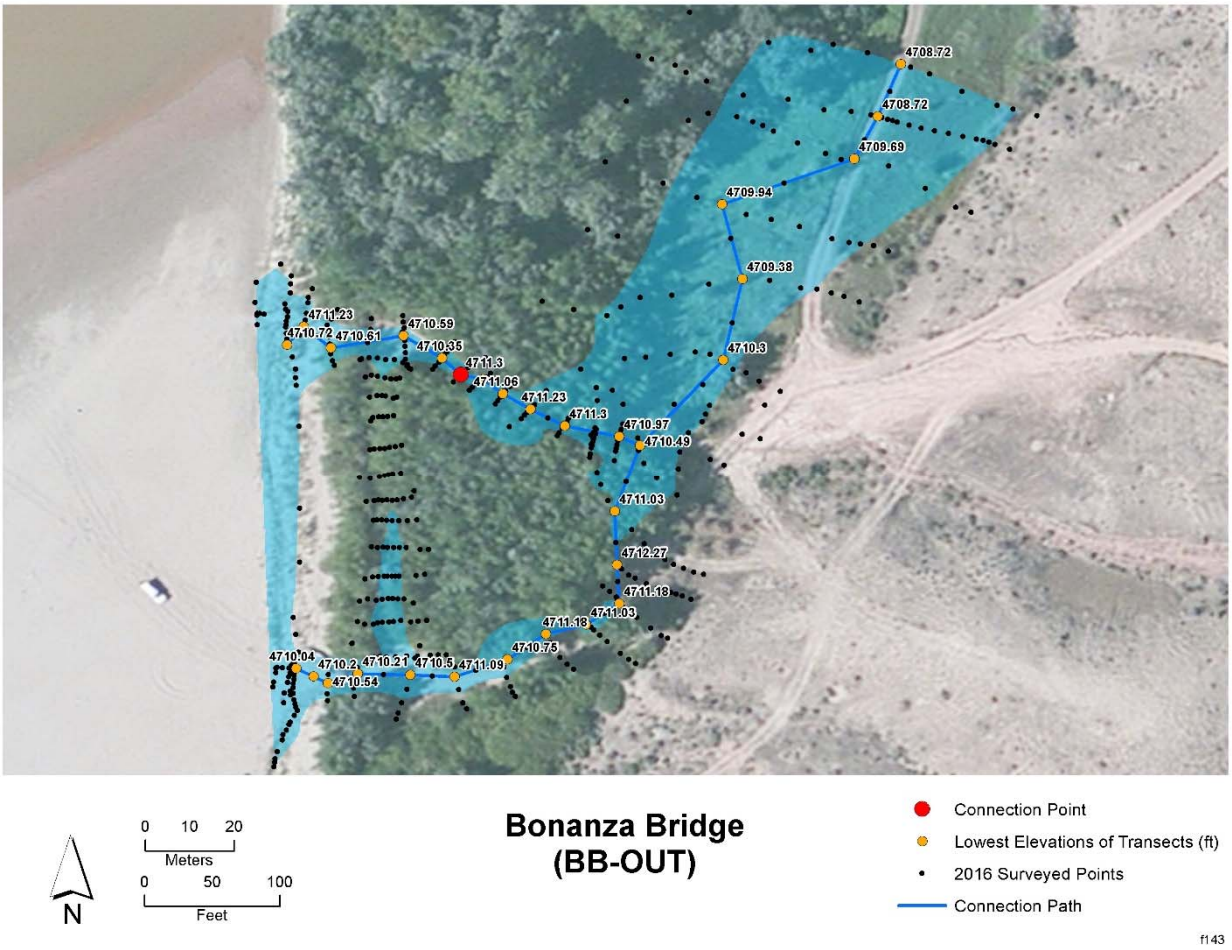

FIGURE A-2 BB-OUT Connection Channel at Minimum Connection Flow (15,900 cfs) in 2016

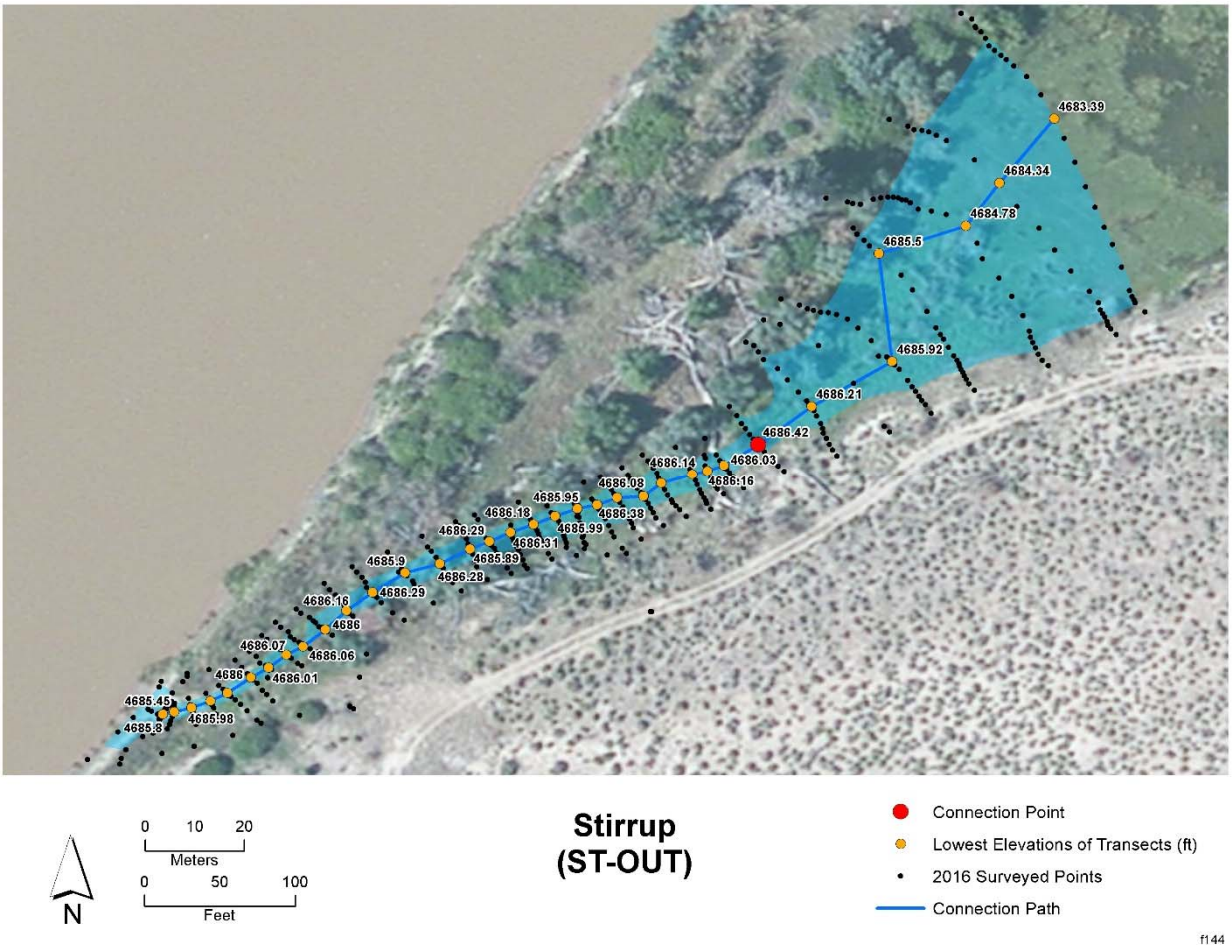

FIGURE A-3 ST-OUT Connection Channel at Minimum Connection Flow (15,100 cfs) in 2016

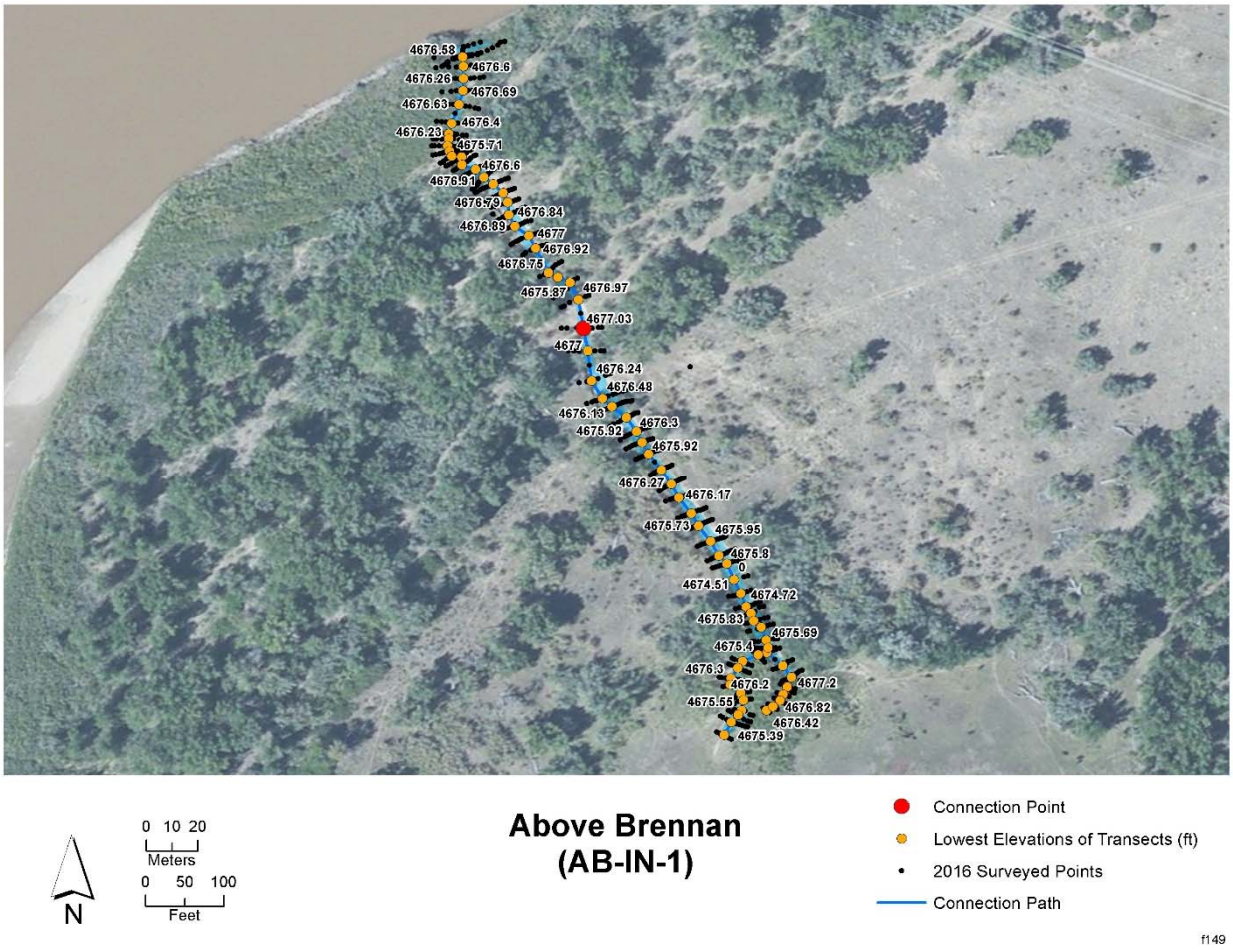

FIGURE A-4 AB-IN-1 Connection Channel at Minimum Connection Flow (13,300 cfs) in 2016

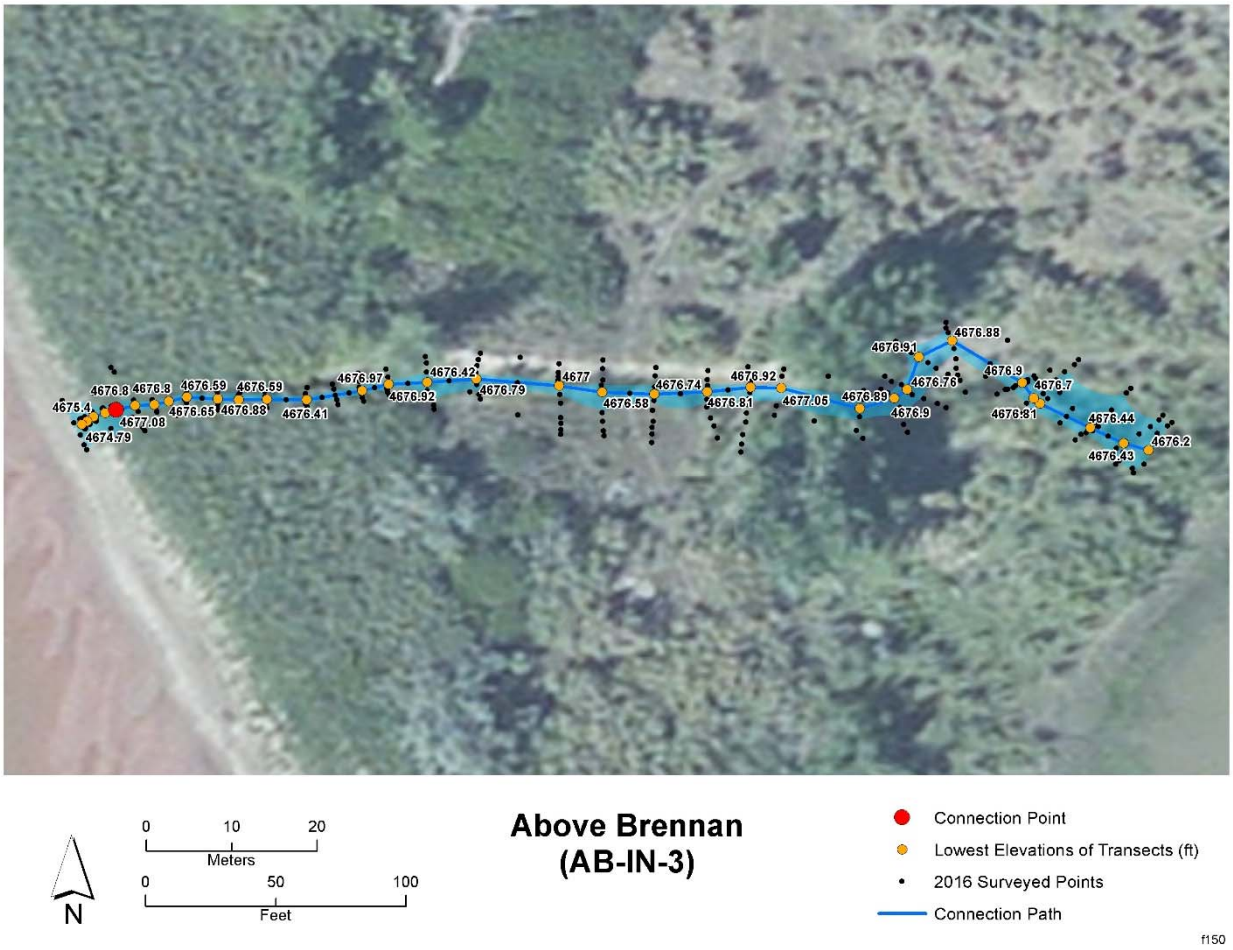

FIGURE A-5 AB-IN-3 Connection Channel at Minimum Connection Flow (15,400 cfs) in 2016

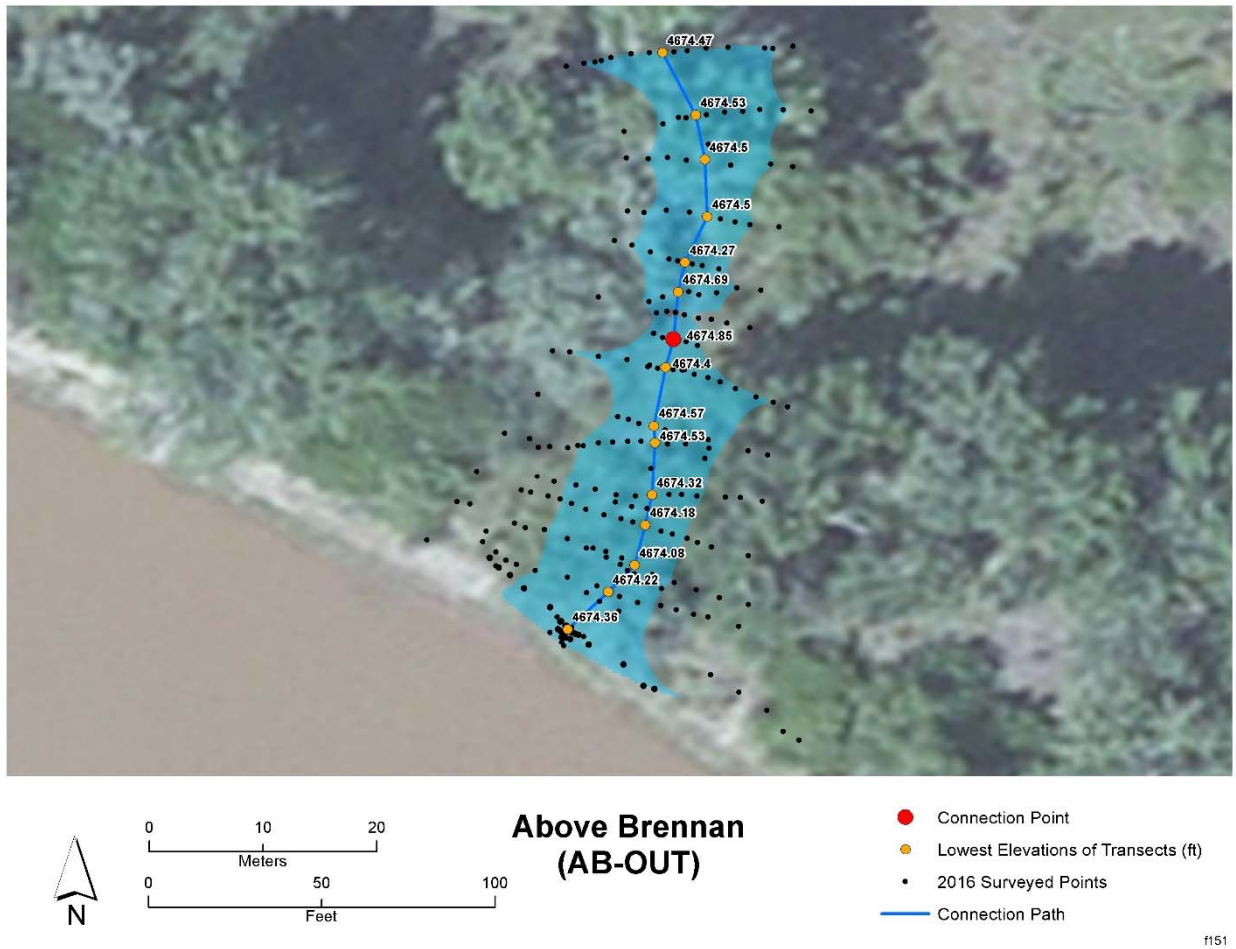

FIGURE A-6 AB-OUT Connection Channel at Minimum Connection Flow (10,700 cfs) in 2016

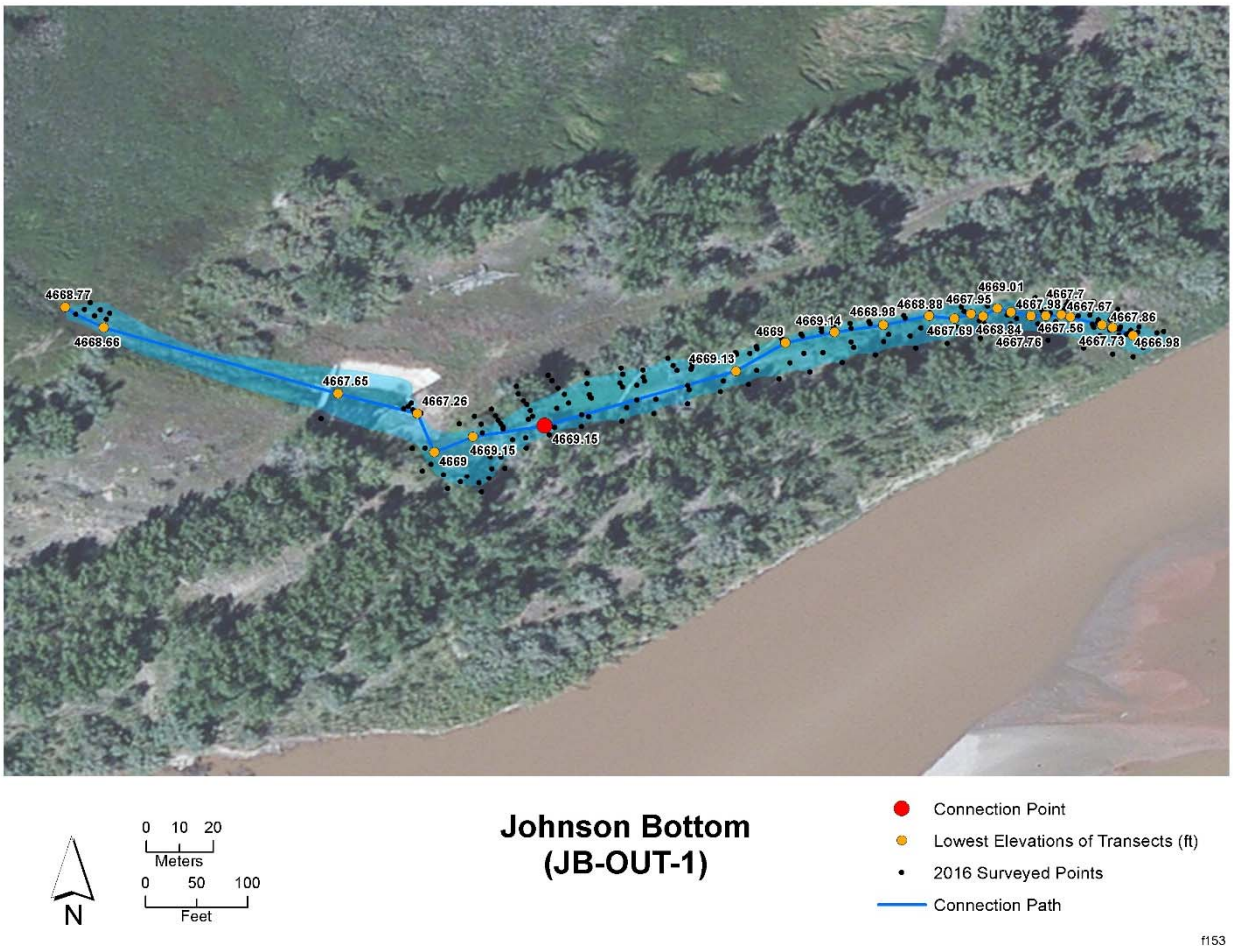

FIGURE A-7 JB-OUT-1 Connection Channel at Minimum Connection Flow (5,390 cfs) in 2016

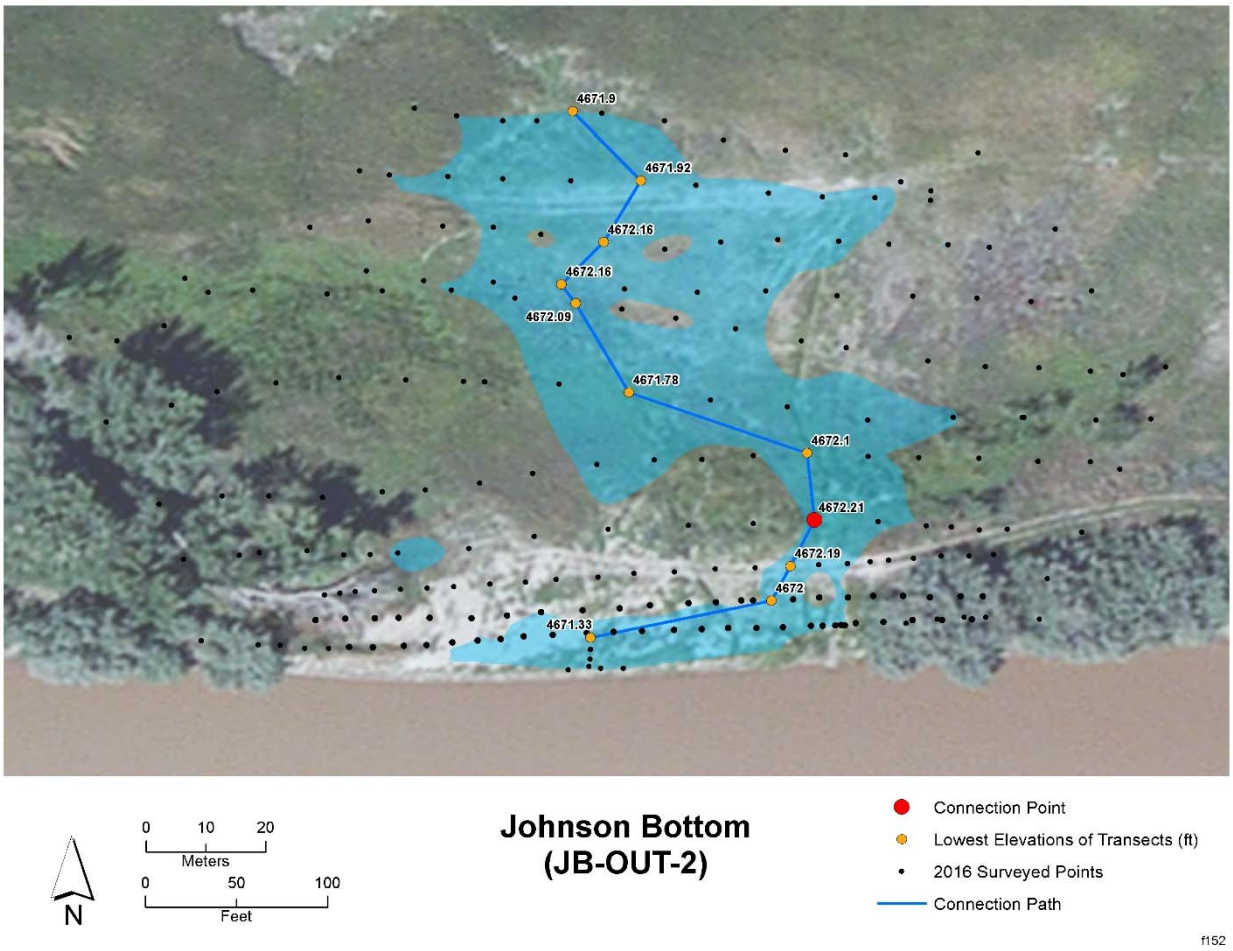

FIGURE A-8 JB-OUT-2 Connection Channel at Minimum Connection Flow (11,600 cfs) in 2016

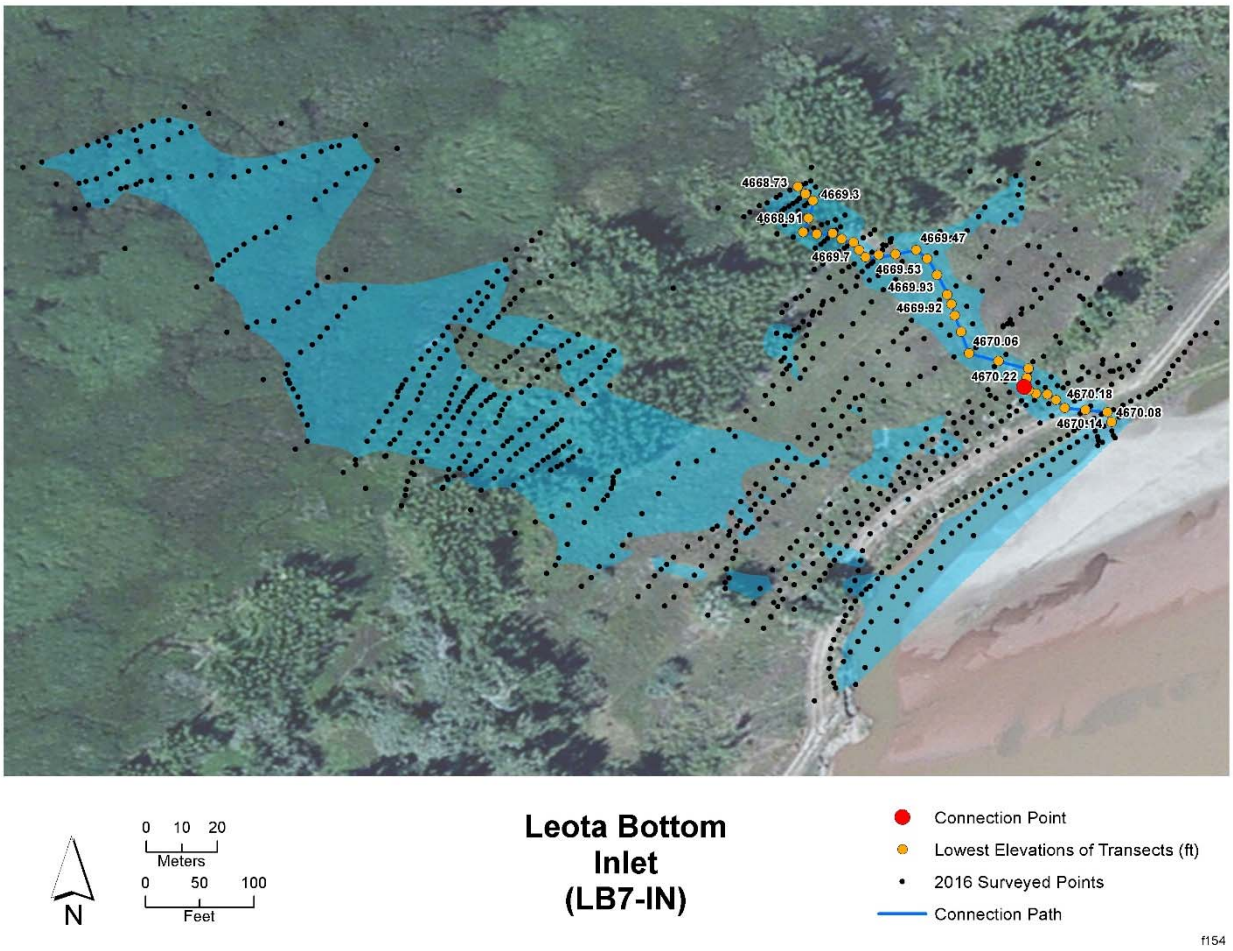

FIGURE A-9 LB7-IN Connection Channel at Minimum Connection Flow (14,800 cfs) in 2016

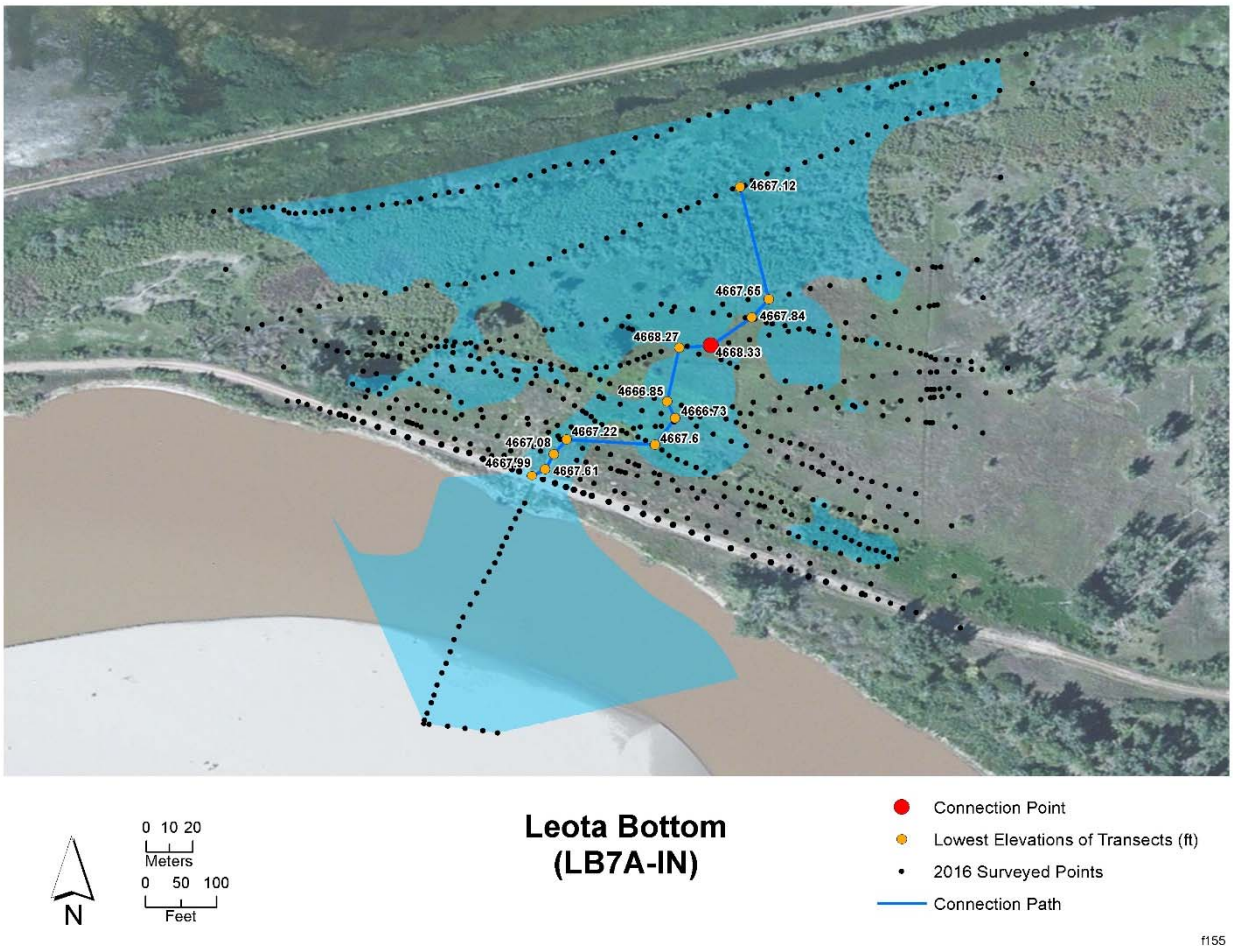

FIGURE A-10 LB7A-IN Connection Channel at Minimum Connection Flow (13,300 cfs) in 2016

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