Study and Monitoring Plan to evaluate the potential effects of experimental endangered fish flow releases from Flaming Gorge Dam on downstream resources

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Abstract

The Upper Colorado River Endangered Fish Recovery Program is proposing experimental flow releases from Flaming Gorge Dam including (1) revised summer base flows to promote survival and recruitment of age-0 endangered Colorado Pikeminnow (*Ptychocheilus lucius*) (CPM), and (2) early summer flow spikes to disadvantage spawning invasive Smallmouth Bass (*Micropterus dolomieu*). The proposed revised base flows have the potential to stabilize summer base flows and are higher than base flows previously recommended in the dry and moderately dry hydrologic categories. They also restrict the range and variation of base flows both overall, and within most hydrologic categories. This has the potential to exacerbate a well-published long-term trend of channel narrowing on the Green River. The proposed annual on-the-ground monitoring of vegetation and topography will focus on selected sites with data tied to changes in vegetation and geomorphology related to that year's flow. On-the-ground monitoring will help to describe the mechanistic process behind why vegetation encroachment or scouring leading to channel narrowing or widening is taking place. We are also monitoring with remote sensing to follow channel widening and narrowing at two different scales. Gathering remote information at two different scales will give us the unique opportunity to evaluate fine scale differences in vegetation encroachment and scouring at a broad spatial scale centered first on the selected sites, and second on the entire reach. By merging data from these 2 scales with on-the-ground data we can understand how changes in flow can influence geomorphology and establishment and removal of riparian plant species. This will provide annual information on channel and plant dynamics for managers to consider along with other study results and input from other partners and water management interests in the Recovery Program's existing adaptive management cycle. This information will help aid recommendations by the Recovery Program for whether these experiments will continue, be revised, mitigated, or ceased if unacceptable impacts are observed to the affected resources.

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Introduction

The Upper Colorado River Endangered Fish Recovery Program (Program) was formed in 1988 for the dual purposes of recovering four endangered fish and allowing water development to continue in the upper Colorado River Basin above Lake Powell (Glen Canyon Dam). The four endangered fish are the Colorado Pikeminnow (*Ptychocheilus lucius*) (CPM), Razorback Sucker (*Xyrauchen texanus*), Humpback Chub (*Gila cypha*) and Bonytail (*G. elegans*); they are endemic to the Colorado River Basin and have populations in the mainstem Green and Colorado rivers as well as several major tributaries, and critical habitat was designated in several overlapping reaches of these rivers (USFWS 1994). Threats contributing to listing under the Endangered Species Act included water diversions, invasive fish introductions through predation and competition, invasive plant species, and dam operations that altered flow patterns by reducing spring peak flows and altering summer base flows. In the Green River below Flaming Gorge Dam (completed in 1963) these altered flows have contributed to channel narrowing (Graf 1978, Andrews 1986, Lyons et al 1992, Allred and Schmidt 1999, Grams and Schmidt 2002, Walker et al 2020), resulting in changes and potential loss of habitat (BOR 2006, Grippo et al. 2017).

Changes to dam operations were made beginning in 1992 (USFWS 1992) to improve conditions for the endangered fish, including recommended base flows and increasing spring peak magnitude to more closely emulate a natural hydrograph. Additional research in the early 1990's during these study flows further evaluated the dam operations and flow effects on the endangered fish and their habitats, which led to the "Flow and Temperature Recommendations for Endangered Fishes in the Green River downstream of Flaming Gorge Dam" (Muth et al. 2000). These recommendations were formalized and a plan for implementation was made under the 2005 Final Environmental Impact Statement (FEIS) and 2006 Record of Decision (ROD) for the Operation of Flaming Gorge Dam (BOR 2005, 2006). As research into flow effects continued (Bestgen et al. 2011), the Larval Trigger Study Plan (LTSP) was implemented beginning in 2012 to improve recruitment of Razorback Sucker (Lagory et al. 2012). Studies also found increased densities of age-0 CPM in autumn when summer base flows were within a range typically higher than Muth et al. (2000) recommended for drier hydrologies, suggesting that raising summer base flows in these years could improve recruitment of CPM (Bestgen and Hill 2016). Beginning in 2008 either the U.S. Fish and Wildlife Service (FWS) or the Program has requested the Bureau of Reclamation (BOR) target summer base flow recommendations in the higher end of the Muth et al. (2000) recommended ranges in years with average or drier hydrologies within the flexibility of the ROD. No base flow relationships have been developed specifically for Razorback Sucker, Humpback Chub or Bonytail; however, Day et al. (2000) investigated flow factors related to the three native Gila species (*G. cypha*, *G. elegans* and *G. robusta*) and recommended a more natural hydrograph with higher spring peaks and more stable base flows.

The Program is proposing additional experimental flow releases from Flaming Gorge Dam including (1) revised summer base flows to promote survival and recruitment of age-0 endangered CPM (Bestgen and Hill 2016a), and (2) early summer flow spikes to disadvantage spawning invasive Smallmouth Bass (*Micropterus dolomieu*) (SMB; Bestgen and Hill 2016b; Bestgen 2018). The proposed revised base flows have the potential to stabilize summer base flows at higher levels than base flows previously recommended in Muth et al. (2000) in the dry, moderately dry, and average-below median hydrologic categories. They also restrict the range and variation of base flows overall and within most hydrologic categories and curtail higher base flows in wetter years (Figure 1). This coupled with possible reductions in magnitude or duration of peak flows as a result of other associated flow experiments such as the LTSP, and the curtailment of spillway use (LaGory et al. 2019 *draft*) could exacerbate a long-term trend of channel narrowing associated with flow stabilization (i.e., less variability in the range of flows associated with lower peak flows and relatively higher and more consistent base flows) and changes in sediment dynamics on the Green River. The LTSP can potentially reduce the magnitude of peak flows if Razorback Sucker larvae emerge after the Yampa has peaked, because peak releases out of Flaming Gorge Dam to match the emergence of the larvae are not always matched to the peak of the Yampa.

There is a broad range of literature relating changes in flows to channel narrowing on the Green River. Allred and Schmidt (1999) identified a phase of narrowing in 1963 on the Green River that was related to flood control and increased base flows. Walker et al. (2020) found that while there was no change in annual flow volume, flood control at Flaming Gorge had reduced the spring peak (2-year recurrence flood is 47% less) and increased the annual minimum base flow by 18%. They found that that narrowing resulted from changes in flow regime and increases in vegetation on channel bars and incipient floodplains. They further stated that narrowing occurred during the mid-1980s during several years with low peak flow. Changes in the flow and sediment regime have led to proliferation of vegetation including invasive tamarisk (*Tamarix spp.*) along the channel and associated sediment deposits, channel narrowing, and channel simplification (Allred and Schmidt 1999, Grams and Schmidt 2005, Dean et al 2011, Manners et al. 2011, Manners et al. 2014, Friedman 2018).

The experimental flow spikes are intended to disadvantage smallmouth bass to reduce competition with, and predation upon young native fishes including Colorado Pikeminnow. However, the flow spikes could provide an extended opportunity for tamarisk to establish due to its long germination window and could add moisture to plants that germinate above the flow spike level during early growth when they are vulnerable to desiccation (Friedman 2018). Conversely, it is also possible that flow spikes could scour away first year tamarisk seedlings that were just beginning to establish. Less is known about the potential impact of flow spikes than of peak flows on establishment of Tamarisk and native Cottonwood (*Populus fremontii*), since they have occurred infrequently in the critical smallmouth bass period.

Channel narrowing and simplification threatens the health and diversity of a functioning river. Use of high flows to remove unwanted vegetation is constrained by current operational guidance for Flaming Gorge Dam, which limits use of the spillway (i.e., releases or bypasses greater than 8600 ft^3/s). Therefore, reversing vegetation encroachment is more likely to succeed if implemented while plants are still small, and vegetation is sparse; thus, annual monitoring to evaluate the effects of the experimental flows is recommended.

Peak flows in the range described in the 2006 ROD, particularly when combined with the more natural flows of the Yampa River, may be sufficient to remove new vegetation if they occur frequently enough. However, a series of dry years such as identified by Walker et al. (2020) in the late 1980s and the early 2000s could allow vegetation to grow large enough to resist scouring. Low base flows in some low water years helps to prevent vegetation establishment by desiccating young plants that can't reach the water table (Horton et al. 1960, Auble and Scott 1998, Shafroth et al. 1998, Horton and Clark 2001). Elevated base flows in all low water years may not allow this desiccation to take place. However, permanently wetted areas below the elevated base flows will not allow vegetation establishment in that zone, so the zone of potential vegetation establishment is fairly narrow and above the elevated base flows (Manners et al 2014). The proposed annual monitoring of near-channel vegetation and topography will focus on this sensitive zone at selected sites and attempt to describe changes in vegetation as they occur on an annual basis so that changes observed can be attributed to that year's flow. We may also be able to use data from an associated study on sediment balance (Topping et al. 2018) to help look at causation. We can combine this new monitoring with baseline monitoring at Dinosaur NM since 2011 and at Canyonlands since 2014 to follow changes in channel narrowing and widening. This information would enable managers to determine if the proposed flow experiments exacerbate vegetation encroachment and decrease in channel width (Friedman 2018), or if the proposed experiments have neutral or positive effects on vegetation encroachment and channel morphology.

In 2018, the Recovery Program Biology Committee approved a flow spike study plan that details the timing, magnitude and frequency of flow spikes and the expected response of the fish community, primarily the targeted SMB (Bestgen 2018). A similar study plan for revised summer base flows detailing the timing, magnitude and frequency of flows and the expected response of the fish community, primarily CPM larvae and juveniles, is expected to be finalized in 2020. A channel and vegetation monitoring study plan that can evaluate the physical effects of both flow spikes and revised summer base flows is needed to accompany these experiments. This plan addresses the needed channel and vegetation monitoring.

Friedman (2018) reviewed and summarized the underlying theories and mechanisms leading to the potential for the experimental flows to contribute to further vegetation encroachment and channel simplification. He also recommended components of a monitoring plan that would track changes through time, potentially allowing for experimental flows to be revised or reconsidered if unacceptable adverse resource impacts are observed. In an unrelated effort,

and as part of a NPS nationwide initiative to inventory and monitor resources at all park units, the National Park Service (NPS) (Northern Colorado Plateau Inventory and Monitoring Network – NCPN) implemented a Big Rivers monitoring program in Dinosaur National Monument (NM) in 2010 and in Canyonlands National Park (NP) in 2014 to track riparian vegetation and channel changes along the Green River (Perkins et al. 2018). We propose using the same methods as NCPN to address potential impacts of the proposed flow experiments on resources within Dinosaur NM and Canyonlands NP, and on adjacent lands outside NPS boundaries in areas where critical nursery habitat for CPM occurs.

Our goal is to design a simple, cost-effective monitoring program that builds on the existing body of work by NCPN that includes baseline information from Dinosaur NM and Canyonlands NP and that can be deployed elsewhere along the Green River to effectively track leading indicators of resource change and capture the potential effects associated with the Recovery Program proposed flow experiments. This study is based on annual measurements of vegetation and geomorphology that are tied to flow and can tie into existing monitoring in place elsewhere on the Green River.

Study Area

The current NCPN work focuses exclusively on park lands and only addresses channel conditions and riparian vegetation at a handful of locations within NPS boundaries. We recognize it is necessary to expand the existing monitoring to encompass lands outside the park in important age-0 Colorado pikeminnow nursery habitat areas. With this expanded monitoring we will have a total of 17 sites on the Green River to evaluate the effects of these flows. Monitoring efforts will focus on three reaches of the Green River from the upstream boundary of Dinosaur NM, downstream to the confluence with the Colorado River in Canyonlands NP.

1. New Monitoring - Jensen to Ouray:

    - Five new sites (based on current funding) will be established in CPM nursery habitat to evaluate the effects of the revised summer base flow experiments as part of this monitoring plan. Age-0 CPM nursery habitat in the Green River is most abundant below Split Mountain Canyon, with a high concentration of good habitats from Jensen, UT, downstream to the top of Desolation Canyon (near Sand Wash boat ramp). The upper portions of this reach are largely within BLM and USFWS ownership; consequently, there are no existing NPS-NCPN monitoring sites in this reach. New sites were selected based primarily on potential sensitivity to channel narrowing and widening, as well as ease of access and secondarily on the availability of relevant legacy data. The flow spike is not expected to affect this reach and the spike will have attenuated by the time it reaches Canyonlands NP.

2. Existing NCPN Monitoring at Dinosaur NM – Canyon of Lodore through Split Mountain Canyon:

    - SMB can be abundant within Dinosaur NM, and spawn in reaches above and below the confluence with the Yampa River. Upstream of Dinosaur NM stream temperatures are generally too cold to support thriving SMB populations; reaches downstream of Dinosaur NM do not consistently provide good spawning habitat. Hence, flow releases to disadvantage SMB will focus on reducing reproduction within Dinosaur NM in average to dry hydrology years (Bestgen 2018), and monitoring efforts relative to the flow spike experiments will be concentrated within this reach. This reach is currently monitored at 6 sites by NCPN for vegetation and channel changes as part of ongoing Big-River Program; the existing sites will be used to monitor effects of the proposed flow experiments on vegetation. This reach will also be monitored for potential changes associated with the revised summer base flow experiment. Funding from this project will only cover the pre-spike monitoring, post-spike monitoring will occur as part of NCPN's normal monitoring program.

3. Existing NCPN Monitoring at Canyonlands NP:

    - This reach is also known CPM nursery habitat and currently is monitored by NCPN at 6 sites for vegetation and channel changes as part of the on-going Big-River Program. The existing sites will be used to evaluate the potential effects of the revised summer base flow experiments. The flow spike is not expected to affect this reach as the spike will have attenuated by the time it reaches Canyonlands NP.

Methods

Revised Base Flow Monitoring at Sentinel Sites

Study Framework

We propose to monitor site topography using the existing NCPN monitoring protocols (Perkins 2018). Repeated surveys using partial transects with real-time kinematic (RTK) equipment during low (base) flows, which will allow us to survey 75–90% of the active channel excluding only those portions too deep to safely wade. Survey measurements including position and ground elevation are taken along the transects every 3 m and at elevation break points. For the portions too deep to safely wade, we anticipate that changes in the deeper parts of the channel due to river incision (or the progressive disconnection from the floodplain) will become evident on the banks and near-shore areas where the surveys will be conducted. As vegetation becomes established it can divert flows into the channel causing incision in the deeper part of the channel that concentrates flow near the thalweg instead of the margins and side channels. This is then indicated by vegetation slowing the water at the margins and side channels, which

traps sediment, resulting in floodplain construction and further disconnecting it from the channel. Each 3-m survey point will also serve as the center point for a vegetation plot. The survey and plot results will be used to document changes in channel topography and vegetation.

Information Gaps Addressed

While there is a wealth of published literature on the geomorphology of this reach of the Green River, when NCPN initiated its long-term monitoring there was no annual monitoring of vegetation and geomorphology that was tied to annual flows. In developing their annual monitoring protocol, NCPN reviewed and evaluated other aridland riparian methods which were determined to be of insufficient rigor, too expensive, or lacking repeatability (Perkins et al. 2018). Complete channel and floodplain transects with bathymetry are probably the optimal method for measuring geomorphic changes along a river; however, the associated labor and equipment is too cost-prohibitive at the desired spatial scale for these experiments. Water-penetrating LiDAR can be effective at obtaining bathymetry, but does not work in sediment-laden rivers, such as those found on the Colorado Plateau. Given these constraints, the extensive lengths of rivers in remote settings within NCPN parks, and the limited resources available for monitoring, we sought to focus most of their effort on detailed annual monitoring at a select number of sites (sentinel sites, see below) that we hypothesized were sensitive to potential changes in streamflow. This detailed information at sentinel sites provides flow specific information on the observed changes in vegetation and geomorphology. However, since these sites are subjectively selected, the monitoring approach also incorporates remote sensing that collects coarse information across a broad spatial scale to capture any changes that might be occurring outside the sentinel sites.

Sentinel Site Selection

Under the current NPS-NCPN Big Rivers Monitoring protocol, the primary sampling unit is a "*sentinel site*", which is often a discrete geomorphic feature (e.g., an island, side channel, eddy deposit, floodplain with or without adjacent backchannel etc.). The existing sentinel sites were chosen based on sensitivity to fluvial geomorphic change and subsequent channel narrowing and widening, as well as logistics, safety, presence of legacy data, value to endangered fish, and significant park resources. As such, they are expected to show leading indicators of vegetation and geomorphic change and serve as early warning signals for channel narrowing and widening. As sites specifically selected to be more sensitive to vegetative encroachment and channel narrowing, they should not necessarily be considered representative of the entire Jensen-to-Ouray river reach, and the monitoring results should be interpreted accordingly. Due to the nature in which sentinel sites are selected, we are also conducting monitoring over the entire reach (see "Revised Base Flow Monitoring with Remote Sensing" section below.

Sentinel sites are monitored annually. Measurements of vegetation, hydrologic, and geomorphic drivers are co-located at each sentinel site and monitored concurrently. The size of a sentinel site is dependent on the size of the geomorphic feature(s), which is often a function

of peak and annual flows, and geologic controls (e.g., canyons) that allow or restrict channel movement. Currently, NCPN has nine sentinel sites in Dinosaur NM (six on the Green River and three on the Yampa) and nine sites at Canyonlands NP (six on the Green and three on the Colorado). New sample sites for this monitoring plan were chosen with similar criteria, including presence of complex channel morphology that can show channel narrowing or widening. In addition, the presence of more persistent backwater sites was considered in selecting the sentinel sites in the Jensen to Ouray reach. Examples of sites for potential selection were examined before and during initial reconnaissance trip and are listed in Table 1, and shown in Figures 2 and 3 (Appendix A). Figure 2 shows potential sites against a background of imagery taken in 2015 (from Google Earth). Final site selection was accomplished on a trip conducted from August 26-28, 2019, using the most recently available Worldview imagery from 2017, and rapid assessments of each potential site based on potential for narrowing or widening, current and historical backwater presence, accessibility, land ownership, expert advice from local biologists from UDWR and USFWS, and other factors (Table 1).

Sentinel Site Transect Design and Data Collection

For each site, the NCPN protocols call for establishing several (5-10 depending on size of site) permanent transects stretching across the river to the upland boundaries. Transects are placed systematically across the feature and are perpendicular to flow in the main channel (Figure 4). During the initial survey, transects are extended into the uplands to account for possible future channel migration, but it is only necessary to survey from the inactive floodplain boundary (or high water mark in high water years) to inactive floodplain boundary on the opposite river side on an annual basis unless a large channel migration occurs. Topographic surveys on these transects will be conducted annually. Permanent vegetation plots ($1m^2$) will be established along the transects every three meters, similarly to how sites were established in Canyonlands NP (Perkins et al. 2018). At each plot, total cover and percent cover by plant species, as well as modal sediment grain size will be assessed and recorded. Indicator plant species (Scott et al. 2018) have been identified for active channel, active floodplain and inactive floodplain surfaces. Changes in presence and abundance of these indicator species will also be assessed. For example, an increase in frequency of an active floodplain indicator species on an active channel surface could be an indication that the area is narrowing. Each plot will also be surveyed with RTK to determine elevation. Water transducers will be permanently located above and below sentinel sites and paired with an air transducer to determine hydrologic characteristics of each plot (e. g., the number of days per year of inundation on each plot) (Figures 5 and 6). Days of inundation is a key factor influencing types of vegetation presence and absence. A thorough description of methods to establish the transects and survey plots, data collection and storage, and analysis is given in Perkins et al. (2018).

Annual sampling of sentinel sites will allow us to detect the effects of annual flows within one year after they occur (i.e., see Figures 7 and 8). Sampling of vegetation and geomorphology will occur during summer base flow, after vegetation has reached peak growth (July– September). Surface water will be continuously monitored with transducers at all sites so that we can build

models to determine the number of days of inundation for each plot (see Figures 9 and 10). Information from the transducers is downloaded once each year. Additional flow information can be gathered from nearby USGS gages.

Metrics Monitored – The following metrics will be monitored at sentinel sites: change in percent cover in active channel and active floodplain by flow regimes (# of days plot is inundated), change in frequency of indicator species in active channel, active floodplain or flow regimes.

Revised Base Flow Monitoring with Remote Sensing

NCPN work to-date from repeated digital analysis of historic and more recent aerial photography has tracked vegetation along the Green River at Canyonlands and in the alluvial parks at Dinosaur using freely available remote imagery (Figures 11-13). However, high resolution photographic imagery is not available every year. Advances in satellite imagery are allowing for higher resolution (<1m^2) imagery to be acquired. Through the Commercial Remote Sensing Space Policy (CRSSP), commercial satellite imagery can be requested and made available through the USGS/EROS. Therefore, in addition to monitoring sentinel sites, we propose to use available imagery to calculate the vegetated area and the change in vegetated area each year at two different scales.

1. We will collect annual high resolution (<10cm/pix) natural color aerial mapping using small Unmanned Aircraft Systems (sUAS) in two different reaches encompassing the 5 sentinel field sites established by NPS along the Green River between Jensen and Ouray, UT. The first reach is located around Horseshoe Bend from Collier Draw to the Stirrup and the second reach is located at the Ouray National Wildlife Refuge. In January, 2020, the federal drone fleet was grounded indefinitely for cyber security concerns (S.O. 3379). A waiver may be obtained on an annual basis, but if waivers are not granted remote imagery will only be obtained through the Worldview satellite service.

2. We will submit annual Data Acquisition Requests (DARS) through the CRSSP Imagery-Derived Requirements (CIDR) Tool for acquiring high resolution aerial imagery using 'worldview' satellites that offer <50cm/pix resolution. This will be done for the section from the Highway 45 bridge southwest of Jensen, UT, to the Highway 88 bridge in Ouray, UT, approximately 40 river miles. It is anticipated this imagery will be available in most years during the August-September base flow timeframe, and usually during the specific week the physical monitoring occurs, barring uninterrupted cloud cover, or other unavailability of satellite coverage. By gathering remote sensing information at two different scales it will give us the unique opportunity to evaluate fine scale differences in vegetation encroachment and scouring at a broad spatial scale centered first on the sentinel sites in conjunction with the on-the-ground field measurements, and second on the entire

reach scale by comparing the results from satellite imagery analysis with that obtained using the finer resolution UAS data centered around the sentinel sites.

Image Interpretation

The UAS river-bend scale data can relate changes in cover of broad vegetation types to changes in flow and geometry, but only for small sections of the river that may not be representative of larger reaches. The satellite imagery at the long-reach scale can relate changes in cover of broad vegetation types to changes in flow and quantify horizontal changes in channel size and location for the entire reach of interest but does not have a vertical component.

Only by merging data from these two scales with on-the-ground data can we understand how changes in flow and sediment load influence establishment and removal of riparian plant species, resulting in changes in channel and floodplain at different points along the river. The sentinel sites give us the "why" things are changing with potential information about how an annual flow is influencing a specific site, while the remote sensing data gives us large scale changes in the river reach should the sentinel sites be poorly selected or telling a different story then the entire river reach.

Metrics Monitored – The following metrics will be monitored with remote sensing: hectares of vegetated area, bare sand, and water, and annual change in hectares of these areas (See Figures 11-13).

Flow Spike Monitoring

Possible Processes of Tamarisk Encroachment

The primary concern of the flow spike experiment is that it could re-wet the germination and/or rooting zone of non-native tamarisk that have taken root just above the flow spike maximum and power plant capacity of 4,600 cfs along the Green River in Dinosaur NM. It is also possible that the spike flow could scour new tamarisk seedlings. Tamarisk are known to have a longer germination period than cottonwood (Warren and Turner 1975, Stromberg 1997, Ralston et al. 2014). For example, at Island Park in 1993 and at Browns Park in 1994 and 1995, tamarisk seed dispersal along the Green River began in early to mid-July and continued until early September (Cooper et al. 1999). The flow spike, as currently prescribed, will most often occur after cottonwood germination period so it could potentially remove newly established cottonwood seedlings, while providing additional new germination sites and opportunities for tamarisk. In low flow years this is less likely to be an issue as next year's peak flow will likely scour any new seedlings of cottonwood or tamarisk. However, if there are multiple low peak flow years and stabilized base flows over a number of years, there is the potential for tamarisk to establish just above the maximum power plant capacity and grow sufficiently large to resist scour from higher peak flows. Since the LTSP was implemented, the frequency of spring releases greater than 4,600 cfs has increased, as bypass releases are used more often to meet the LTSP flow targets in the Green River below the Yampa River (Reach 2; Muth et al. 2000) even in drier hydrologies. This increase in the frequency of flows above 4,600 cfs likely

diminishes the risk of the flow spikes' differential effect on tamarisk establishment; however, this aspect will be studied by NPS/NCPN. The primary area of concern for the flow spike is Dinosaur NM as the effects of the flow spike will attenuate and be minimized below Dinosaur NM.

Method/Timing of Observations

Monitoring associated with the flow spike experiments would require pre- and post-flow spike sampling. Each year at the end of the spring peak and prior to the onset of the flow spike experiment (typically late June) crews would visit existing sentinel sites that are most favored for long-term cottonwood and tamarisk establishment within Dinosaur NM (Brown's Park, Echo Park, and Island Park). The pre-spike trip will focus on vegetation plots and the presence of newly established woody vegetation. The pre-spike trip should occur as close to the flow spike as logistics allow. We will visit existing plots below the high-water line. A post flow spike trip will occur later that same year, in conjunction with regular NCPN sampling trips in July/August; the same sentinel sites would be sampled to document the effects of the flow spike experiment by examining woody species survival rates.

Metrics Monitored – The following metrics will be tracked with flow spike monitoring: mortality rates and frequency of woody vegetation (primarily willow, cottonwood, and tamarisk) based on areas affected and not affected by the smallmouth bass spike flow. Note that these are new types of data being collected from the existing NCPN monitoring, so we do not have example data to share.

Analysis, Reporting, and Implementation

Annual Metrics Reported

Annual information on vegetation and geomorphology is the only way to determine the effects of annual flows. We will deliver annual metrics including change in percent cover of vegetation by geomorphic surface (Figure 7), percent of plots that have no vegetation (Figure 8), change in indicator species frequency and percent cover (Figure 7), change in elevation along transects (Figure 10), and change in total vegetated and unvegetated area along the Jensen to Ouray reach (Figures 12 and 13). These metrics from sentinel sites can be further binned into categories of days of inundation (Figure 6) to show how each plot is affected by the experimental flows.

'Families' of Plot Types for Distinguishing Vegetative Trends

In any given year, the population of plots sampled will include all plots that were affected (inundated) by the annual peak flow (i.e., those plots below the annual high-water or peak flow stage as determined hydrologic data and from ground evidence of leaf litter, rack lines etc.) A subset of these plots will then necessarily have experienced flows associated with the flow

spike and/or the revised base flows for that year. Thus, in any given year, there will be families of plots that were: (a) affected only by the peak flow, (b) affected by both the peak flow and the flow spike, and (c) affected by the peak flow, the flow spike, and the revised base flows. Each group of plots will then have characteristic signature hydrologies that reflect that year's flows, which in turn will influence the presence and abundance of the key indicator species described earlier. Comparing plant presence and abundance across these different families of plots would allow evaluation of vegetation response to the different flow experiments that occurred that year.

After 6 years of monitoring, NCPN has found in preliminary analysis at Canyonlands NP that active floodplain plots are inundated no more than 20% of the time, while inundation more than 25% of the time generally result in active channel plots that have less than 5% vegetation cover. By watching these zones of active channel, active floodplain, and inactive floodplain change over time, we can assess changes in channel narrowing and widening. The number of days of inundation can be a useful indicator of active vs inactive floodplain.

The combination of hydrologic and plant data can give unique information about the establishment of different species and potential leading indicators of channel narrowing. For example, 2017 was a year with a late peak and high July flows (Table 2). This was a relatively poor year for cottonwood establishment. Cottonwoods established on only 6% plots that were inundated between 6 and 60% of the time between April 1 and August 30 at our Upper Tuxedo site in Canyonlands NP. In this same year tamarisk was able to establish on 46% of plots that were inundated between 0 and 60% of the time. Tamarisk, unlike cottonwoods, can establish in places that do not get inundated. In addition tamarisk established on some plots that dried out as late as August 24. In 2018 when peak and July flows were lower and the peak came earlier, cottonwood recruitment was higher (29%) of plots (Figure 14) and they established plots that were inundated between 6 and 68% of the time. Tamarisk establishment remained similar to 2017 establishing at 39% of plots that were inundated between 4 and 94% of the time. In 2019 we had a higher later peak r and had higher July flow than 2017 and cottonwoods only established in 1% of plots, while tamarisk established in 46% of plots. Tamarisk recruitment has been relatively stable from 2014 to 2019 regardless of the timing and size of the peak, demonstrating its ability to germinate in a wide range of conditions. These results show that tamarisk can establish very late in the season and potentially take advantage of spike flows or increased water table from modified base flows. Cottonwoods did not establish in any plots that were inundated after July 14 in 2018 and June 30 in 2017. We will follow the establishment of woody species in each year. It is likely that some of these seedlings will be wiped out with higher peak flows in the following year, so we will also follow their recruitment in subsequent years.

Models to Assess Response With/Without Experimental Flows

Models using data similar to the above paragraph can be designed to show what plots were inundated by the revised base flows, versus what would have been inundated if revised flows

were not in place (see Table 2 for list of current flows). Table 3 shows the level of detail that can be achieved to determine the optimum areas for seedling germination for different species. Models could take this data and show how species would respond at different elevations with and without the experimental flows. By showing the vegetation response on plots that had elevated base flows and spike flows compared to plots that did not, we can model how vegetation would have responded if the base and spike flows were not implemented.

Possible Indicators of Transition Between Active and Inactive Surfaces

NCPN (Scott et al. 2018) determined that certain plant species found along the Yampa and Green rivers were consistent indicators of whether a geomorphic surface is active or inactive. Annual species indicated the active channel, while other species are indicative of the active and inactive floodplain. As vegetation patterns transition from one state to another, this indicates transition from active to inactive surfaces. Bare sandbars (active channel) are scoured of vegetation each year while inactive floodplains are disconnected from the river by dense stands of perennial woody plants that have stabilized banks. The transition of indicator plants from active channel to active floodplain and inactive floodplain are indicators of channel narrowing. The vegetation plots will allow quantification of patterns in the extent and composition of riparian vegetation across the range of active and inactive surfaces at each site. Multivariate analyses will be used to quantify differences in vegetation patterns across the geomorphic surfaces at each site and compared to the conceptual model developed by Scott et al. (2018) to aid in the early identification of such transitions. Lastly changes in modal sediment size can be indicators of state level changes.

Use of Data in Annual Flow Request Development

The results of this study will be evaluated annually within the Program's existing adaptive management cycle with other partners and consider other study results and water management interests. We note that there are many studies documenting long-term channel narrowing in the Green River since Flaming Gorge was completed (Allred and Schmidt 1999, Cooper et al. 1999, Merritt and Cooper 2000, Grams and Schmidt 2002, Walker et al 2020). There are also some hydrologic classifications where the Muth et al. recommended flows (2000) and the proposed flows (Bestgen and Hill 2016a) are very similar. This could make it difficult to tease apart changes that are attributable to the experimental flows as opposed to long-term characteristics. However, the combination of on-the-ground hydrologic, geomorphic, and botanical monitoring, reach scale information from remote sensing and the baseline data collected by NCPN at 12 other locations on the Green River as well as information on reach scale narrowing obtained from remote imagery and other published studies give us the opportunity to assess annual flows in the larger context. Flows in a range of hydrologic classifications will also be helpful in evaluating the proposed flows.

To inform the development of the Program's annual Flow Request Letter (required by Reclamation by the end of February), preliminary results of this study will be provided to the Recovery Program by mid-December. All of the above information will help aid

recommendations by the Recovery Program for whether these experiments will continue, be revised, mitigated, or halted if unacceptable impacts are observed to the affected resources.

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Table 1. Potential and final sites considered for establishing long term channel morphology and vegetation status near Colorado Pikeminnow nursery habitat in the Green River, Jensen to Ouray reach. Green highlight indicates the final sites selected for inclusion as sentinel sites, while blue highlight are potential sites not selected at this time. Sites were evaluated and rated by Dusty Perkins and Melissa Trammell (NPS).

Potential Site	Size (meters)	BLM/FWS on both sides?	Persistence	Vegetated Island?	Backwater Habitat Associated?
Jensen #1	700	One side	Moderate	No	Good
Jensen #2	515	None	Yes	Yes	Good
Jensen #3	800	One side	Yes	Yes	Good
Jensen #4	1100	Both sides	Yes	Yes	Some
Jensen #5	450	One side	Yes	Yes	Good
Jensen #6	640	None	Yes	Large Solid Veg	Good
Jensen #7	675	Both sides	Yes	Yes	Good
Jensen #8	500	One side	Moderate	Yes	Some
Jensen #9	1125	Both sides	Yes	Large Solid Veg	Good
Jensen #10	770	Both sides	Yes	Large Solid Veg	Some
Jensen #11	2025	Both sides	Yes	Large Solid Veg	Some
Jensen #12	600	Both sides	Yes	No	Good
ONWR #1	850	Both sides	Yes	Large Solid Veg	Good
ONWR #2	1065	Both sides	Yes	Large Solid Veg	Good
ONWR #3	1070	Both sides	Yes	Large Solid Veg	Good
ONWR #4	1250	Both sides	Yes	Large Solid Veg	Good
ONWR #5	720	Both sides	Yes	No	Good
ONWR #6	930	Both sides	Yes	Yes	Good
Ouray #1	510	Both sides	Yes	Yes	Some
Ouray #2	1275	Both sides	Yes	Large Solid Veg	Some
Ouray #3	800	One side	Yes	Yes	Good
Ouray #4	870	None	Yes	Yes	Good

Table 2. Average daily flow (ADF), peak flow, date of peak flow and percentiles for the Green River at Green River, UT (#09315000) stream gage, 2013–2019.

		Annual				Daily		Daily	
Date of Peak	Percentile	Peak Flow	Percentile	Daily Flow	Percentile	July Flow	Percentile	August Flow	Percentile
June 10, 2014	70	20,800	29	4,259	23	3,957	28	3,326	58
May 24, 2015	29	16,200	18	4,680	28	4,162	30	2,287	29
June 15, 2016	82	24,400	45	5,479	39	4,954	36	2,243	28
June 10, 2017	70	22,100	34	7,008	72	6,260	52	3,185	52
June 10, 2018	70	13,000	12	4,062	21	2,245	15	2,070	23
June 19, 2019	90	28,800	91	5,946	55	9,346	73	2,978	49

Table 3. Preliminary data showing frequency of seedlings for cottonwoods and tamarisk and % of the growing season that plots were innundated from the Upper Tuxedo site in Canyonlands National Park, 2018.

				Innundation April 1 – August 30	
Elevation (m) Plots	Plots	% with Cottonwood Presence	% with Tamarisk Presence	Minimum	Maximum
<1190.5	26	0.0%	0.0%	100%	100%
1190.5-1191	36	0.0%	0.0%	100%	100%
1191-1191.5	27	62.9%	62.9%	52.7%	99.8%
1191.5-1192	13	53.8%	84.6%	29.2%	52.7%
1192-1193.5	11	9.1%	9.1%	0.0%	29.2%
1193.5-1194	11	0.0%	54.5%	0.0%	0.0%
>1194	9	0.0%	44.4%	0.0%	0.0%

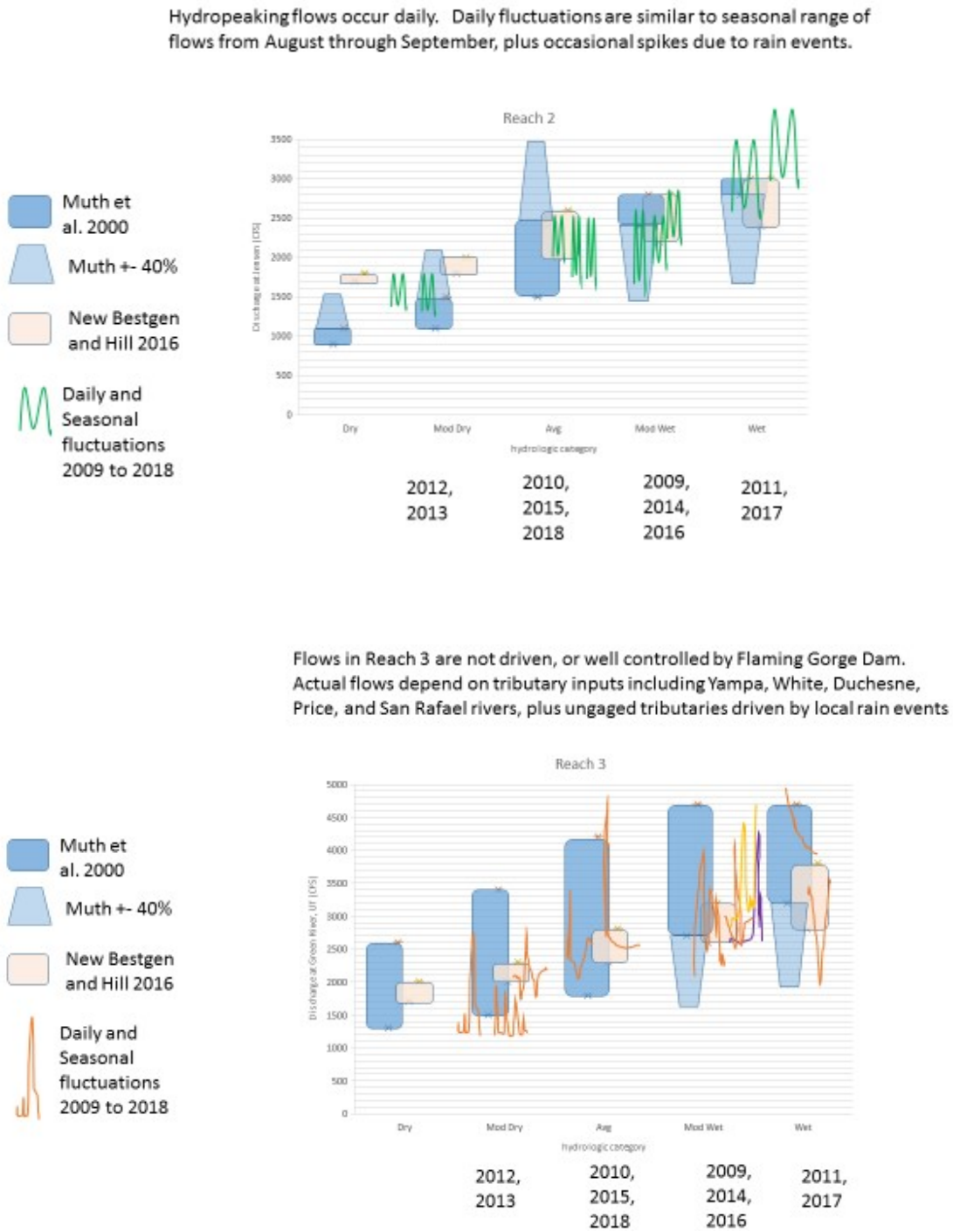

Figure 1. Old (Muth et al. 2000) and new proposed (Bestgen and Hill 2016) base flow recommendations for Reaches 2 (top) and 3 (bottom), in the Green River, UT. Also shown are the range of the +-40% of flows based on Muth et al. (2000) and the 2006 ROD. Also shown are the ranges of daily and seasonal fluctuations that have occurred during the most recent 10 years by hydrologic category.

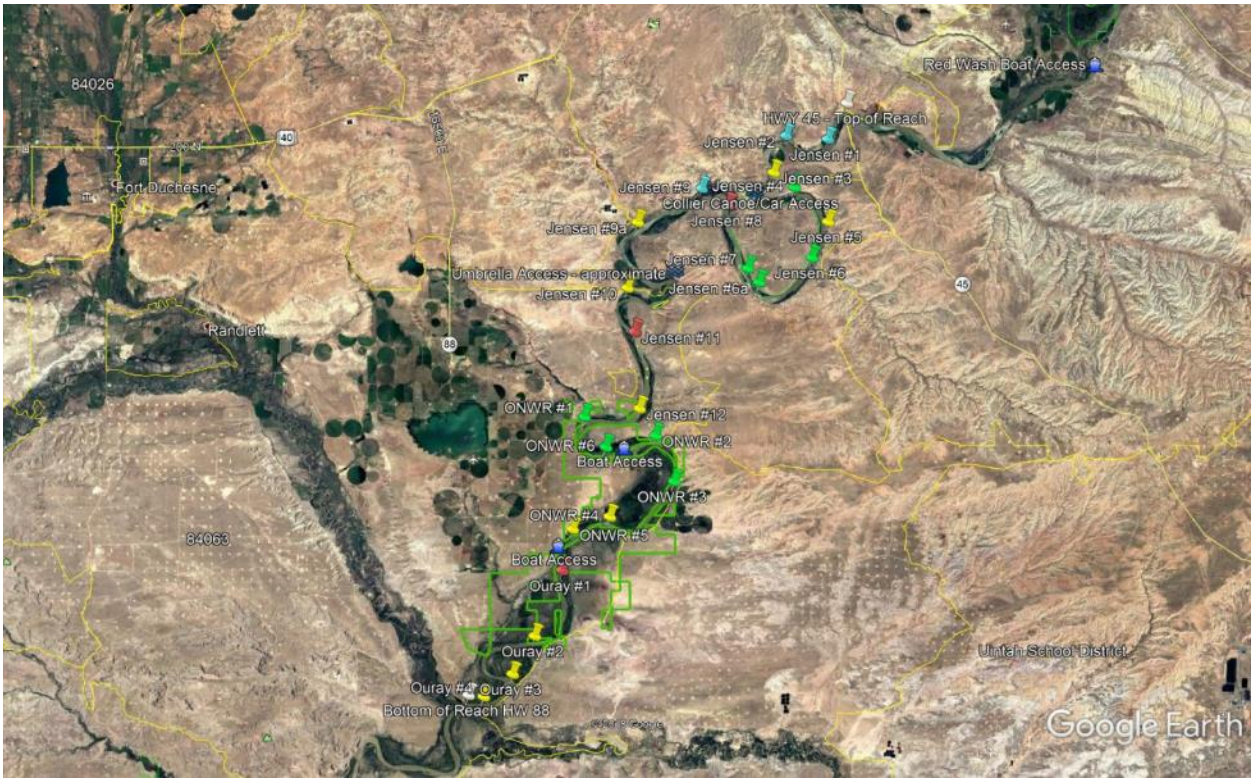

Figure 2. Overview of potential sites in the Jensen to Ouray reach of the Green River, UT, RM 300 to 249. Image is taken from Google Earth, June 2015 imagery (most recent Google imagery). Sites identified as having 'good' potential are in green, 'medium' in blue, and 'low' in yellow pins. Sites are labeled 'Jensen' above the Ouray National Wildlife Refuge (ONWR), as ONWR within the refuge and 'Ouray' below the refuge boundary.

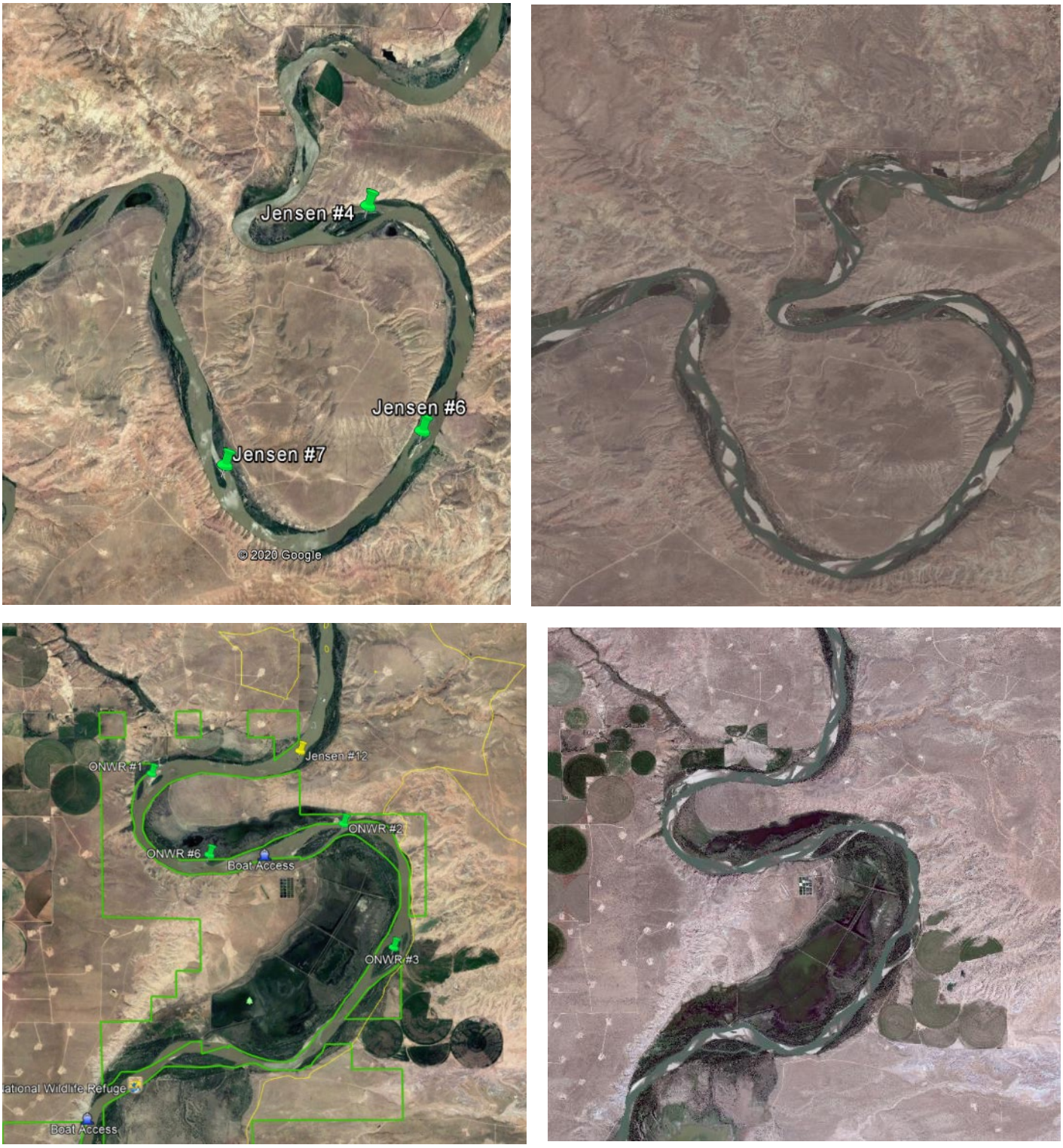

Figure 3. Close-up of potential Colorado Pikeminnow experimental backwaters on Ouray NWR lands from June 2015 Google Earth imagery (left) and August 21, 2019 Worldview imagery (right).

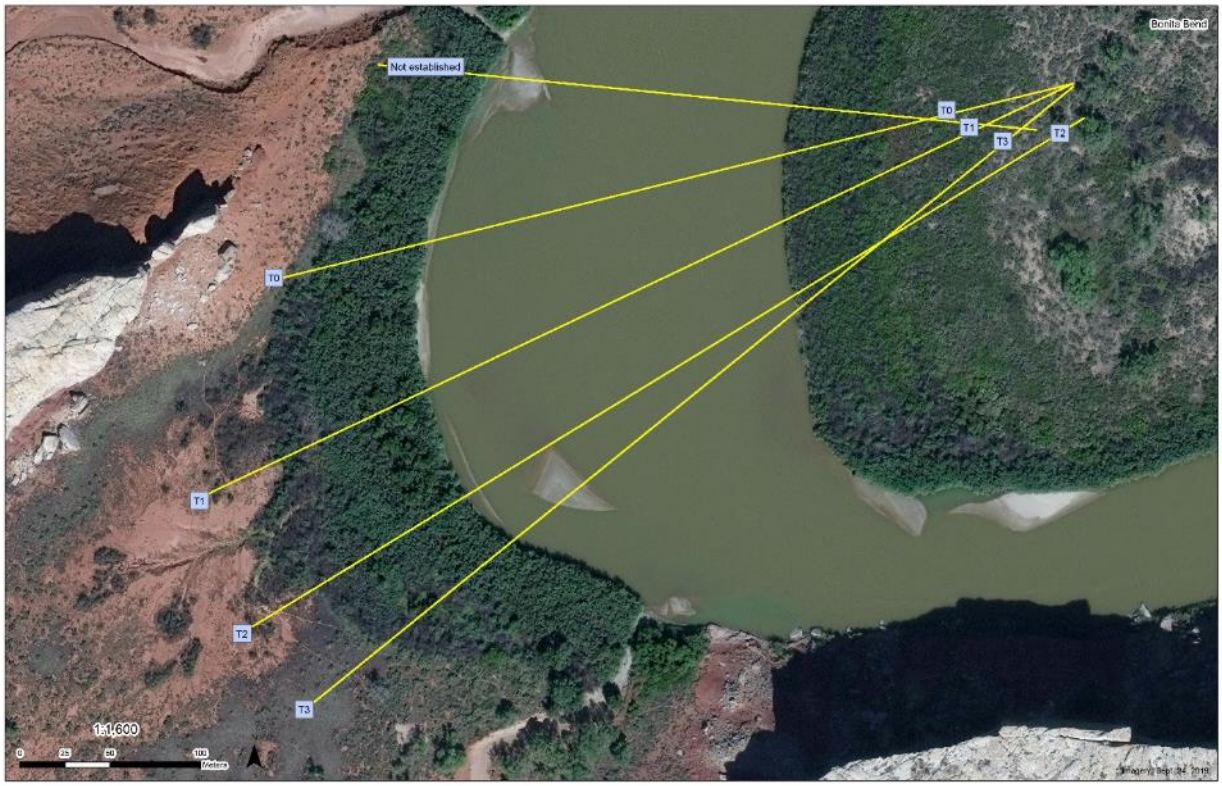

Figure 4. Example of transects established on a long-term monitoring site (sentinel site) in Canyonlands National Park at Bonita Bend. Transects are established roughly perpendicular to the prevailing direction of flow.

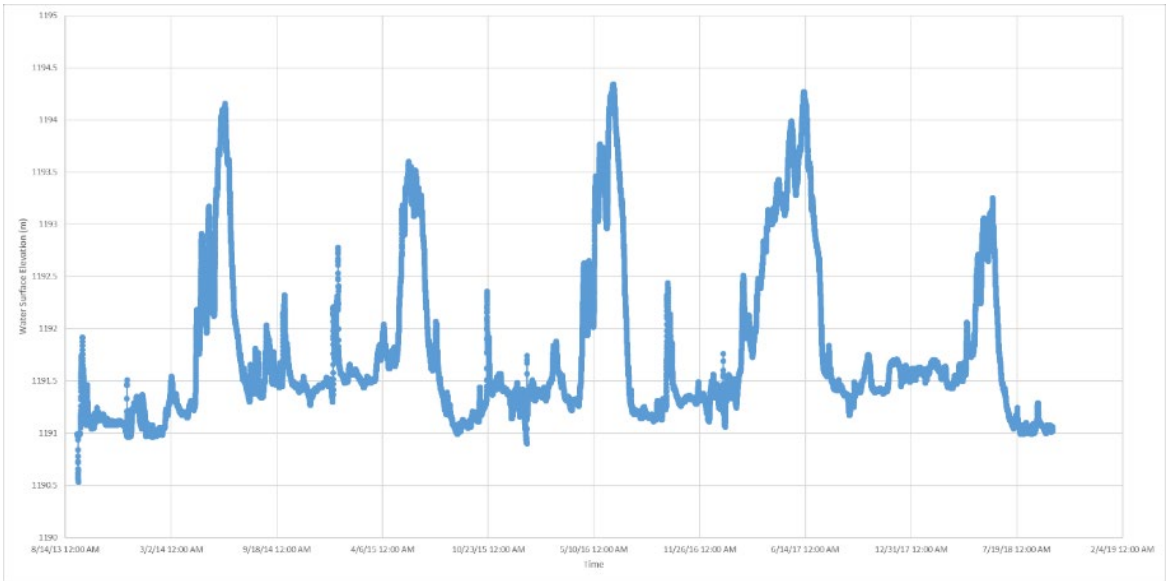

Figure 5. Example data showing the hydrograph at the Upper Tuxedo site in Canyonlands National Park from August 4, 2013 to September 30, 2019.

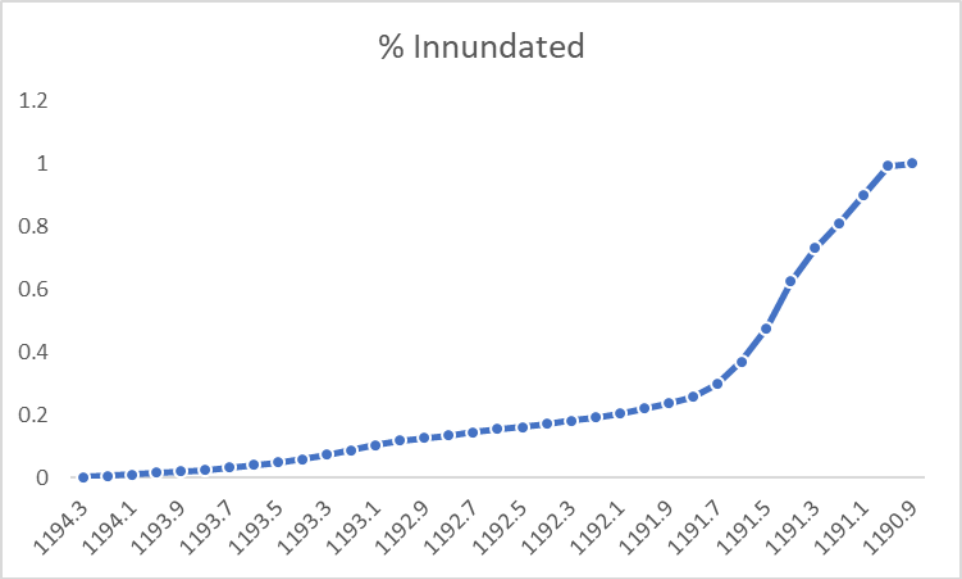

Figure 6. Example data from Upper Tuxedo site in Canyonlands National Park showing percent of time each elevation was inundated with water from August 4, 2013 to September 30, 2019.

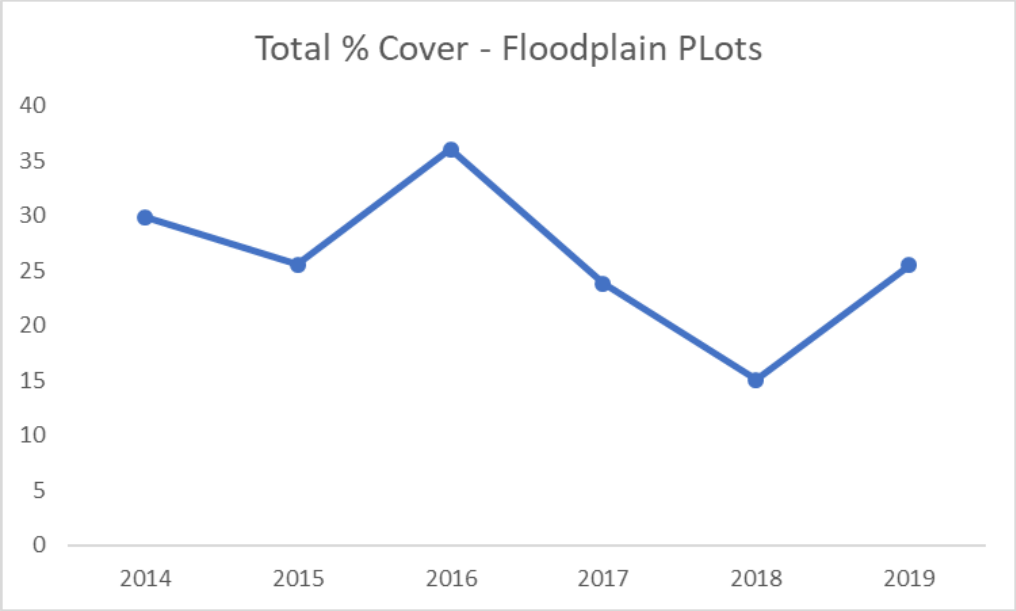

Figure 7. Example data of percent cover of vegetation is relatively stable in the floodplain plots from the Upper Tuxedo site in Canyonlands National Park, 2014-2019.

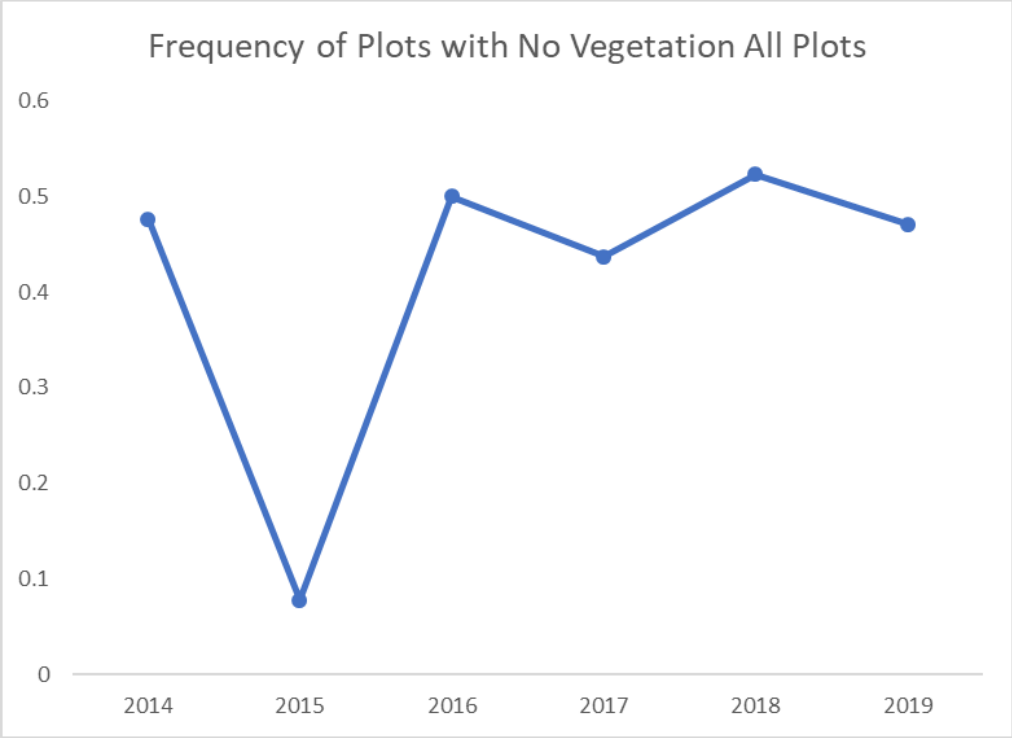

Figure 8. Example data of percent frequency of plots with no vegetation from the Upper Tuxedo site in Canyonlands National Park, 2014-2019. Figure shows how plots with no vegetation was reduced in 2015 when the peak was low and the earliest date of the peak of the monitoring period.

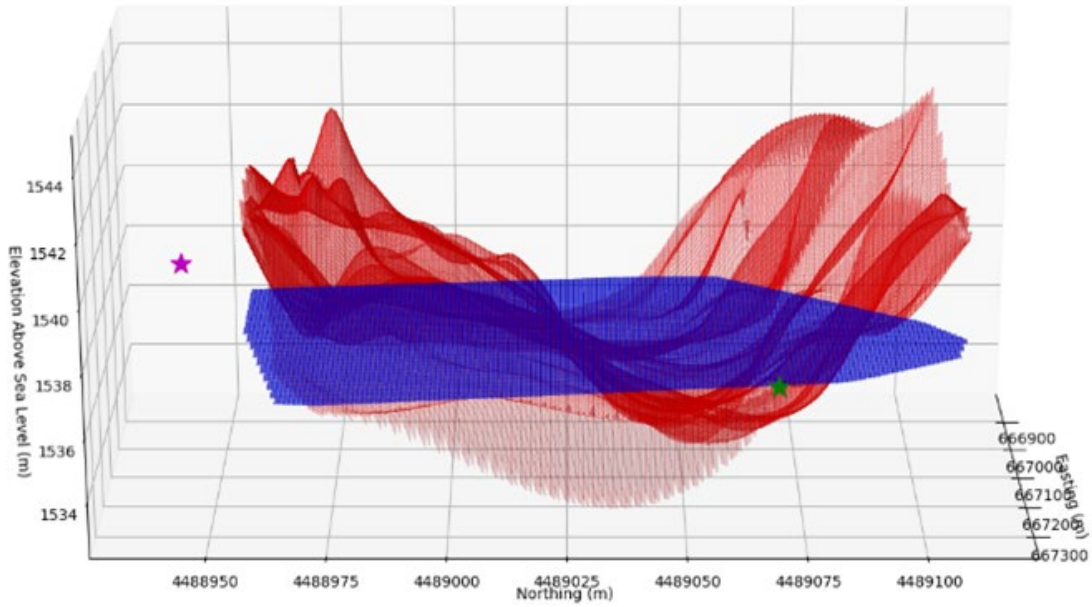

Figure 9. Example of the calculated water surface elevation plane for one timestep relative to the geomorphology of the Seacliff site of Dinosaur National Monument in 2015. The blue shows the range of water surfaces across the red elevation map. The green and magenta stars indicate the upstream and downstream transducer locations, respectively.

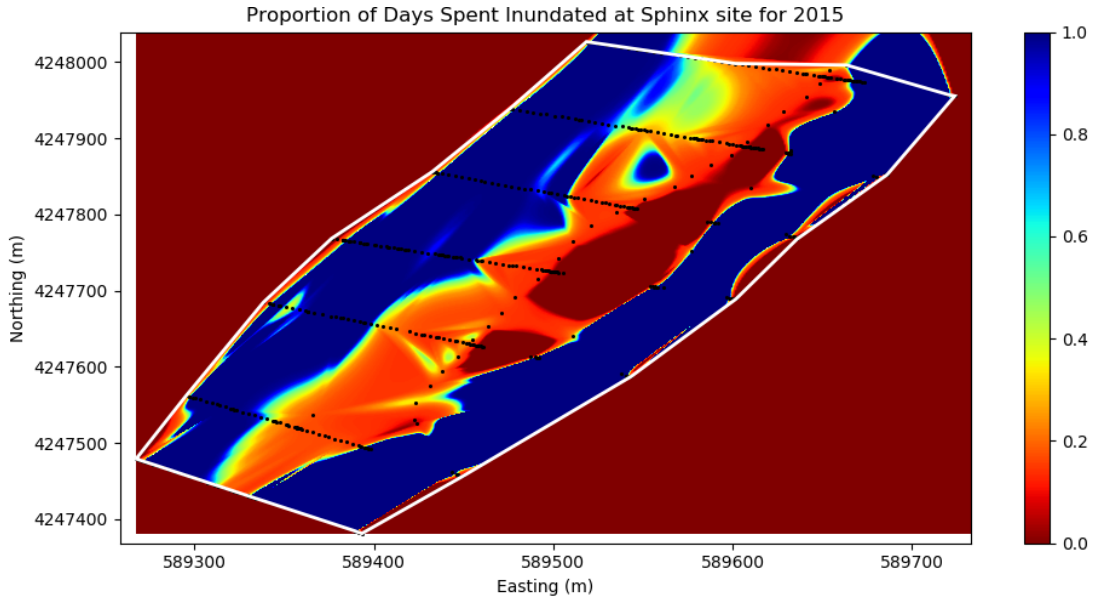

Figure 10. Example showing surveyed surfaces elevations along transects (black circles) and proportion of days inundated from the the Sphinx monitoring site in Canyonlands National Park in 2015. Locations that were submerged throughout the year are displayed in dark blue while locations that remained above water throughout the year are displayed in dark red.

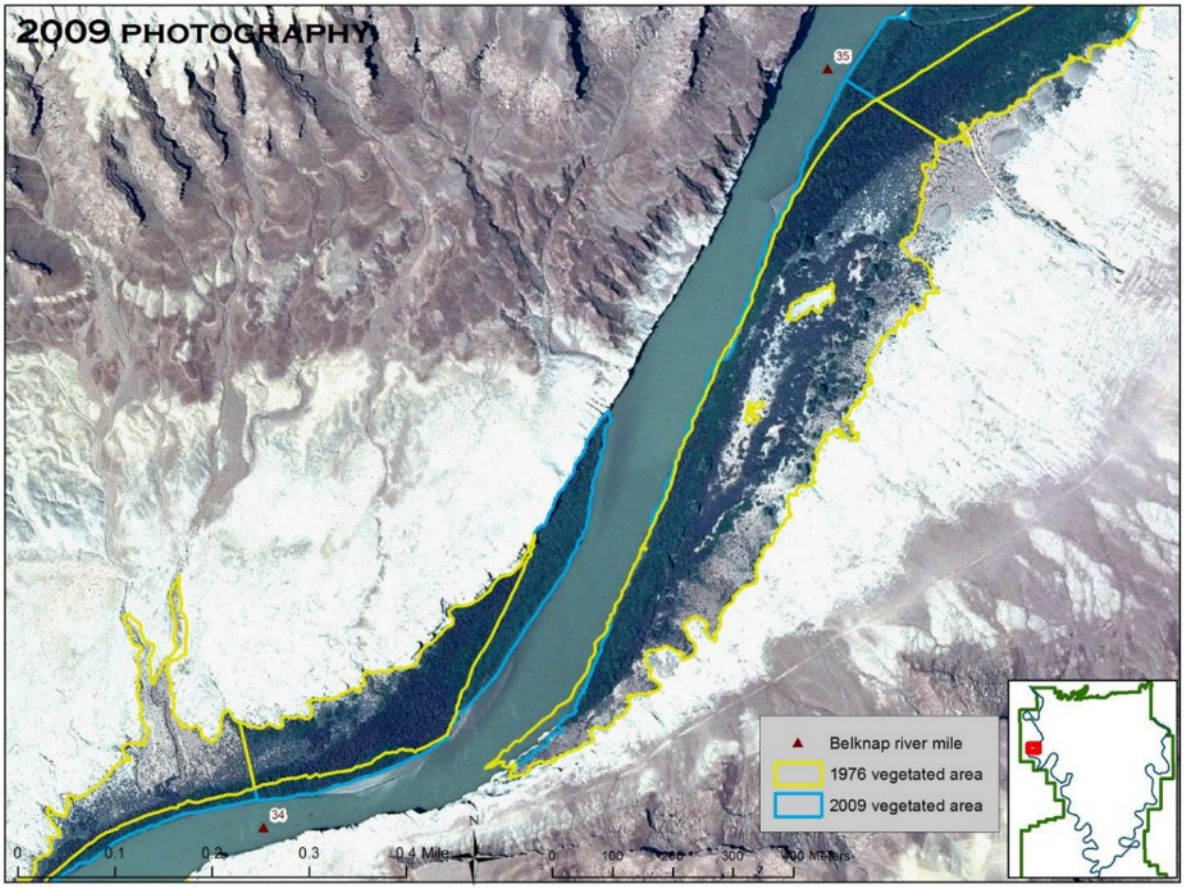

Figure 11. Example of polygons of vegetated areas along the Green River in Canyonlands National Park in 1976 and 2009.

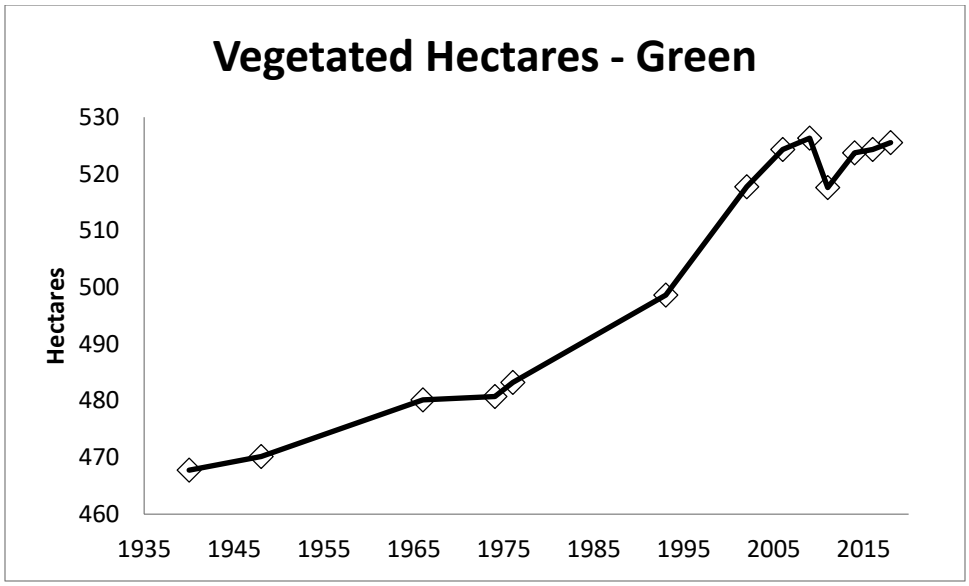

Figure 12. Change in vegetated hectares over 16 river miles of the Green River in Canyonlands National Park with consistent imagery from 1940 to 2018.

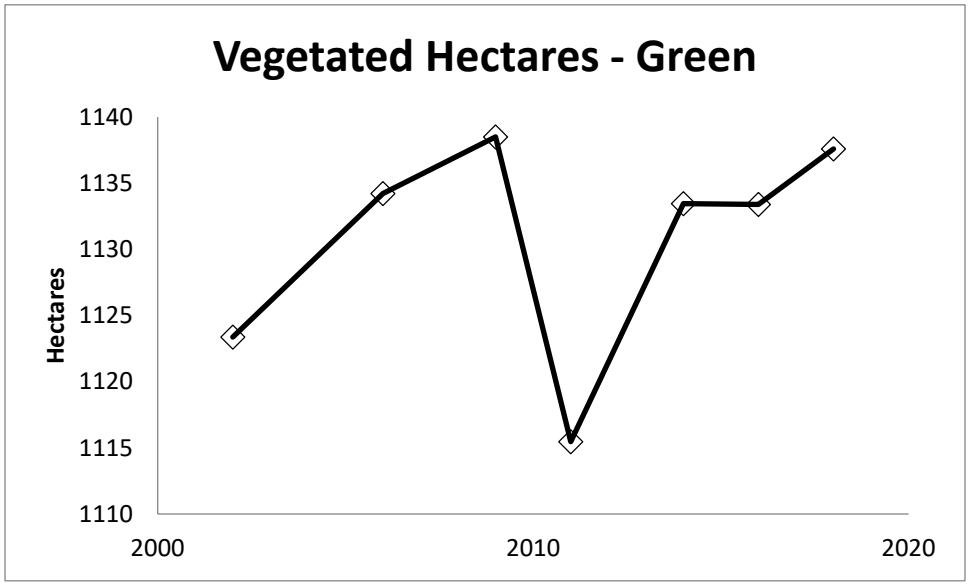

Figure 13. Change in vegetated hectares over all 47 river miles of the Green River in Canyonlands National Park with consistent imagery from 2002 to 2018.

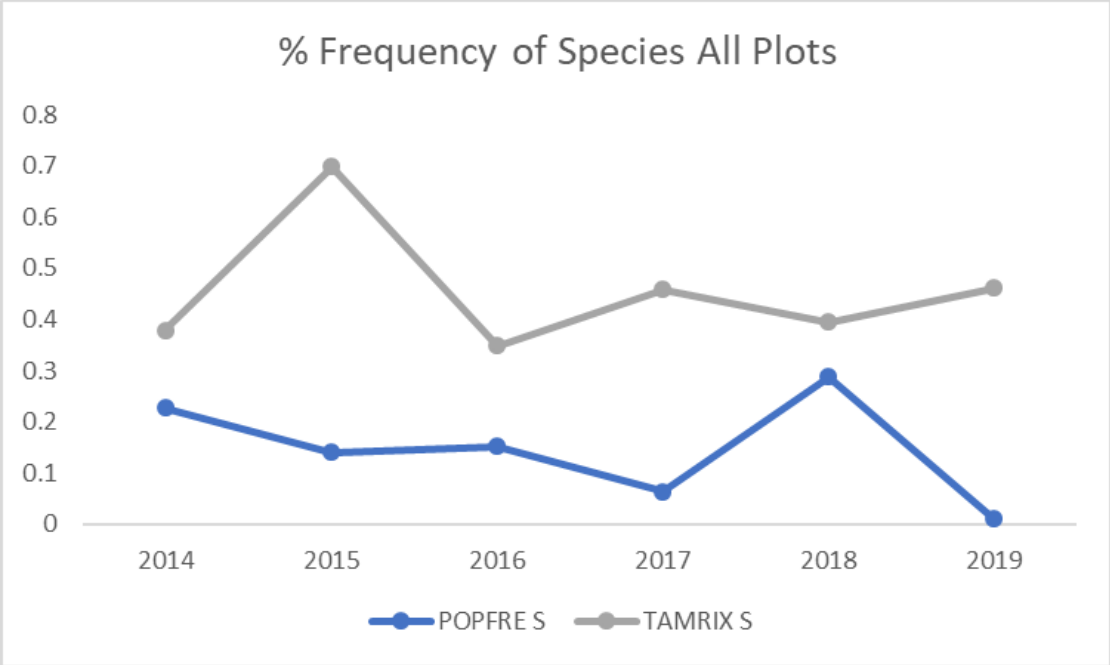

Figure 14. Percent frequency of *Tamarisk sp.* and *Populus fremontii* seedling presence in plots at the Upper Tuxedo site on the Green River in Canyonlands National Park, 2014-2018.

APPENDIX A

A reconnaissance trip was conducted in August 2019 during base flows to field check potential sites identified via Google Earth, earlier studies, and conversations with local fish biologists. Notes were taken for each site as appear below.

Sites – This takes into account the site visit, meeting with Matt Breen (UDWR) and Dan Schaad (ONWR) and previous discussions with Tildon Jones (FWS-RP)

Jensen #1 – Good CPM habitat during visit. Persistent with 2019 conditions, iPad and printed maps. Tributary on river left that provides sediment. Good base location on public land. Would need to get top of bank (TOB) and bottom of bank (BOB) measurements on river right on private land – Mike Partlow thought this would be ok. Good transducer rock locations. Matt Breen thought this site was not a consistent site. Good site for narrowing. BLM land on RL, private on RR. 700 m.

Jensen #2 – Moderate CPM habitat during visit. All private land on both sides of river with lots of activity. Would need TOB and BOB on private late, probably not good. Not a lot of rocks for transducers. Would need to put base in island. Only use this site if we decide we really like Jensen #1. Breen said there is consistent CPM habitat downstream of island on river left and a point bar on river left. Good site for narrowing. 515 m.

Jensen #3 – Low CPM habitat during visit. Private residence on river right. Has been good habitat in the past. Good site for narrowing with 2 islands. Breen – not a consistent fish site. BLM on RL, private on RR. 800 m.

Jensen #4 – Moderate fish habitat during visit. Bottom of site has “quintessential” CPM habitat, deep backwater. Huge site, 1,100 m, good for narrowing. No transducer locations, plenty of base station locations. Some CPM habitat at top and on river right. This has a horseshoe vortex (site where water hits upstream end of island creating sandbars on each side of island with a backwater between the sand bar and the island). Breen – consistent fish habitat. BLM on both sides

Jensen #5 – Low fish habitat during visit. House on RR US of site. Plenty of base station locations, no transducer locations. Little island. Moderate site for narrowing. Breen – not a consistent site.

Jensen #6 – Good fish habitat during visit, good vegetation narrowing. Near Baeser Wash so tributary input. Some cobbles present. Potential habitat at top of site, good habitat at bottom of site. Good US transducer location. Good base stations. Breen – consistent site, Baeser Wash flashes a lot. State land on RR, mix of private and state on RL. 640m.

Jensen #6a – New site. Good fish habitat during visit. Point bar. No island but a bend in river. Transducer rocks, public land on both sides. Good base. Good to tie in with #6. Blends into 7.

Breen – this site changes a lot. 840m. This site combined with #6 could show a good comparison between somewhat stable sites vs sites that are ephemeral and 'change a lot'

Jensen #7 – Good fish habitat during visit. Good base station location and transducer rocks present. Potential backwater on RL US end. Good narrowing site. Good base locations. Breen – not a consistent site. Public land on both sides. 675.

Jensen #8 – Good fish habitat during visit. Ok for narrowing. Private land on RR. US and DS (down aways) transducer locations. Good base locations. Breen – a weirdo owns the land on river right, nice, but odd. He suggests staying away from this site.

Jensen #9 – Moderate fish habitat during visit. Island complex, good narrowing site. Horseshoe vortex at top of island with fish habitat. Some ephemeral fish habitat. Access across from Stirrup. Good base locations. Near pond on river left at Stirrup Wetlands, good razorback habitat in some years, could potentially get that area with drone. Breen – Island always has habitat, some habitat will always be here just not in the same spot. Tildon – site has potential for good fish habitat. 1125 m. Public on both sides except for DS end on RR.

Jensen #9a – New site. One really good backwater during visit. 2 small islands, upper one is better for narrowing than bottom one. Isolated from other sites. Public land on RL, not on RR. Good base station, no transducer rocks. Breen – not a consistent site for fish. Public on RL, private on RR. 700m.

Jensen #10 – Low fish habitat during visit. DS and US transducer rocks. Major island with large cottonwoods. Horseshoe vortex at US end of island. Good base station. Breen – not consistent for fish. 770m. Public land on both sides. Moderate site for narrowing

Jensen #11 – Low fish habitat during visit. Huge site. Two main channels, not a great narrowing site. US transducer rocks. Good base station. Breen – not consistent for fish. 2025m.

Jensen #12 – Moderate fish habitat during visit. Transducer rocks. Not a great narrowing site. Good base station. Breen – not consistent for fish. 600m. Public land both sides.

ONWR #1 – Low fish habitat during visit. Two islands, good narrowing site, especially upper island. Transducer locations DS at refuge intake. Good base locations. Breen – almost always habitat on river right, but changes location. One of the better ONWR sites. Tildon – good habitat. Public both sides., except for maybe US end on RR. 850m.

ONWR #6 – Moderate fish habitat during visit. Potential US and DS (intake) transducer site. Good base but would need to be up high to get it. Breen – narrow and long habitat. One of the better ONWR sites. Tildon – Good habitat. Good site for narrowing

ONWR #2 – Moderate fish habitat during visit. US transducer sites at refuge intake. Good base locations Island complex. Main island is large with mature cottonwoods, good narrowing site at the bottom. Maybe just do bottom of island. Good transducer rock a ways DS on RL. Breen –

not consistent, but always some habitat at bottom – which is one of the better ONWR sites. Tildon – good site. 1065m. Refuge land both sides.

ONWR #3 – Moderate fish habitat during visit. Good transducer rock on RL US. Good base station. Transducer location DS on control structure is private, don't use. US island is good narrowing site. Larger DS island has mature cottonwoods. Good backwater on RR. Maybe just do DS end of island? Or skip middle of island? Good narrowing at the US and DS end of site. Breen – consistent habitat at DS end. One of the better ONWR sites. Tildon – good habitat. 1070 m. Public on RR, private on part of RL.

ONWR #4 – Moderate fish habitat during visit. Potential US transducer rocks on by buildings on RL. Potential downstream transducer on sheet metal above Wyasket pump. Good narrowing site. But is narrowing confounded by rip rap placed by refuge staff on RR – we think so. Large vegetated island with mature cottonwoods. Smaller island is better for narrowing. Not transducer rocks, good base station. Sand bar potential for narrowing on RL. Breen – RR is not consistent, but some habitat will be there. Tildon – good habitat. 1250m. Refuge land both sides

ONWR #5 – Moderate fish habitat during visit. Good base station. No transducer rocks. Just sand bar potential for narrowing on RL. Breen – not consistent habitat. Tildon – moderate habitat. 720m. Refuge land both sides.

Ouray #1 – Low fish habitat during visit. There is a Palisade structure on RL that is for the oil and gas pipeline, so that rules this site out. Two islands. No transducer rocks. This site is a concern to Dan Schaad at refuge due to potential narrowing and driving the river towards RR and towards the refuge road. Breen – not consistent. 510 m. Refuge land both sides.

Ouray #2 – Moderate fish habitat during visit. Large island with mature cottonwoods. Deep back channel. Good base. Cows present. No transducer rocks. Good backwater on RL of main channel mid way up island. Breen – not consistent fish habitat. Good site for narrowing. 1275 m. Refuge land on RR, private on RL.

Ouray #3 – Good fish habitat. Good narrowing site. Best site of Day 2. No transducer rocks, good base. Good backwater on RR of right channel. Good road on RL. Good back water on RL of left channel at top of island. Old Charlie wash is a pond good for razorback suckers. RL is tribal but part of refuge 10 year lease, RR is tribal but not part of lease, Dan Schaad thought that might be a problem. Tildon said that if both sides of the river were tribal than the islands would also be tribal since that occurred before the state hood, Tildon suggested staying away from here as well. Breen – always habitat here. Breen did not share concerns that Dan/Tildon had about RR and access. 800m.

Ouray #4 – Moderate fish habitat. Side channel on RL usually flows. Moderate for narrowing. Would need temporary base unless we could reach it from ONWR base. This year it has sand. 870 m. Private on both side. Same land access issues as Ouray #3.