Lower Deschutes River Gravel Study Review

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1 INTRODUCTION

As part of Portland General Electric Company's (PGE's) FERC relicensing effort, several investigators evaluated the potential effects of the Pelton–Round Butte Hydroelectric Project ("Project") on the supply, transport, and deposition of sediment in the lower Deschutes River. Those studies examined watershed-scale geomorphic processes (e.g., O'Connor et al. 2003a), as well as Project effects on bedload transport and channel morphology (e.g., Grant et al. 1999, Fassnacht et al. 2003). After the license was issued in 2005, supplemental geomorphic and biological monitoring agreed upon during relicensing and incorporated into the Settlement Agreement (FERC 2005) was performed as part of the Lower River Gravel Study Plan (LRGS; Stillwater Sciences 2006). The investigations outlined in the LRGS were conducted from 2007 through 2014, and results were summarized in separate reports for geomorphic monitoring (Lower Deschutes River Gravel Study; Stillwater Sciences 2015) and biological monitoring (2008–2014 Salmonid Spawning Surveys Summary Report; Spateholts 2015).

The objective of the monitoring and augmentation study was to assess the impacts of the Pelton–Round Butte Hydroelectric Project on downstream gravel availability and channel morphology, and the objective of the experimental gravel augmentation program was to test the dynamics of augmented gravels and, in combination with the biological monitoring program described below, monitor their quality through time (FERC 2005). PGE's Pelton–Round Butte Hydroelectric Project license (FERC 2030), License Article 433, requires that a three-member expert panel (Panel) be selected to review studies and monitoring completed through 2014, and then provide a recommendation of whether gravel augmentation below the Project is needed. We (the authors of this report) were selected to serve as the Panel.

1.1 Objectives

The objective of the Panel is to review information summarized in the LRGS (Stillwater Sciences 2015), as well as pertinent information contained in other related lower Deschutes River geomorphic and biological investigations, to evaluate the three evaluation criteria listed in the Settlement Agreement and LRGS Study Plan Design (FERC 2005, Stillwater Sciences 2007):

Criterion #1: *Is the Project causing impacts that could be mitigated by gravel augmentation (to include examination of whether the Project may be having deleterious effects on channel bedforms and spawning gravel quantity and quality?*

Criterion #2: *Is the pilot gravel augmentation test adversely affected downstream bank stability or caused downstream pool filling?*

Criterion #3: *Would a gravel augmentation program be beneficial to fish habitat and fish populations (as indicated by the results of the biological monitoring program)?*

From these evaluations, the Panel is tasked with making one of the following recommendations:

1. The experimental gravel study should be continued;
2. The licensees should implement a long-term gravel augmentation program; or
3. No further study or augmentation is needed.

To make the recommendations required by the FERC license, the Panel has organized this report to first provide the setting at the beginning of the 2008 gravel augmentation experiment (Section 2), then summarize information pertinent to the three evaluation criteria listed above based on the available reports and our field observations of July 21–22, 2015 (Section 3), then evaluate the three evaluation criteria based on the available information (Section 4), and then conclude with recommendations based on our evaluation of the three evaluation criteria (Section 5). The recommendations in Section 5 focus on (1) whether the gravel study should be continued, ended, or transitioned into a long-term gravel augmentation program; (2) uncertainties with respect to future gravel augmentation; and (3) future monitoring and assessments that should guide the next phase of gravel augmentation experimentation.

2 BACKGROUND FOR 2008 GRAVEL AUGMENTATION EXPERIMENT

Dam operations can fundamentally change the hydrologic and sediment transport regime of rivers, leading to downstream changes in morphology and dynamics. Interpreting how changes in flow and sediment regimes translate into morphologic responses for any particular dam is complex, however, and often requires detailed historical and field studies to distinguish among different response trajectories. A full suite of such studies have been conducted on the Deschutes River over the past 20 years as part of the FERC relicensing process and subsequent settlement agreement. These studies provide a solid foundation for interpreting the effects of the dams on the downstream channel and associated aquatic habitats. Here we focus on the most recent (since 2007) studies to better understand the long-term effects of the dams on sediment transport and aquatic habitat in the Deschutes River (most notably, Stillwater Sciences 2015, Spateholts 2015, and R2 Resource Consultants 2015).

The broader context and results from prior studies are well developed in previous published work (O’Connor and Grant 2003, O’Connor et al. 2003a, and 2003b, Fassnacht et al. 2003, Grant et al. 2003, Huntington 1985, Aney et al. 1967). Following dam closure in 1957, sediment supply from the river upstream of the Pelton–Round Butte Dam complex was effectively cut off from the lower river, but the Project has had minor effects on the hydrograph because it is operated as a run-of-the-river facility and conveys inflows through the Project with minor modifications (Fassnacht et al. 2003). Large floods in 1964, 1983, and 1996 locally reshaped the channel in some places but overall had little effect on the channel morphology (O’Connor et al. 2003a and 2003b, Fassnacht et al. 2003). The Deschutes River is an unusual river, and its peculiarities need to be considered when interpreting gravel supply and transport rates in the lower river below the Pelton–Round Butte dams. Foremost among these characteristics is the extremely stable flow regime. As noted by Henshaw et al. (1914): "The flow of the river is more remarkably uniform than that of any other river in the United States comparable with it in size." As an example, the difference between the 1% and 99% exceedance flow is less than a factor of 3, whereas in most alluvial rivers, this range can vary by 1 to 2 orders of magnitude (Fassnacht et al. 2003).

This stable flow regime translates into a sediment transport regime that only occasionally exceeds the general threshold of transport, although low levels of partial transport (where only some of the bed is mobilized) are somewhat more common (Stillwater Sciences 2015, USGS 2011). Stable discharges also mean that the flow rarely accesses new sediment sources (i.e., floodplains, bars, and banks). While larger tributaries can locally deliver substantial volumes of sediment during floods, watershed-scale sediment supply to the Deschutes River is among the lowest values ever measured (O'Connor et al. 2003b). Larger inputs of sediment, including gravel, to the lower river occur at the confluences of Shitike Creek, Trout Creek, Warm Springs River, and White River (O'Connor et al. 2003b).

Finally, while most modern flows and floods do not result in substantial sediment delivery and transport, ancient floods owing to a variety of processes have had a distinct imprint on the river and its morphology. Many of the vegetated islands and higher surfaces that flank the river owe their origins to these "out-sized" floods, which can be up to an order of magnitude larger than current meteorological floods (O'Connor et al. 2003a, Beebee and O'Connor 2003, Curan and O'Connor 2003). These very large floods sculpt the valley bottom and leave remnant depositional features and boulders that resist erosion and transport under the modern flow regime.

For these and other reasons, the Deschutes River does not behave like many other alluvial rivers in terms of the frequency and magnitude of sediment transport. Alluvial rivers typically exhibit relatively frequent (e.g., every 1–2 years or so) movement of bed material, and the geomorphic and biological impacts of hydroelectric dams on these more dynamic alluvial rivers is often substantial (Collier et al. 1996). This disparity in behavior between more typical alluvial rivers and the Deschutes River, and consequently different geomorphic impact of upstream hydroelectric dams, undoubtedly underlies much of the concern that motivated the LRGS on the Deschutes River. Although studies prior to 2004 predicted that sediment transport rates on the Deschutes River below the hydroelectric dams would be low under most flow conditions, these predictions were based on models and other lines of evidence. Without direct measurements of sediment transport, the conclusion that the river bed was uncommonly stable with only infrequent transport represented a hypothesis (Fassnacht et al. 2003, Grant et al. 2003, Grant 2004). Alternative hypotheses of more frequent transport (Rovira and Kondolf 2008) and below-dam sediment deficit (Schmidt and Wilcock 2008) had been proposed, prompting the need to directly measure sediment transport and associated geomorphic changes.

To test between these two hypotheses, determine the effects of gravel augmentation, evaluate to what extent future augmentation is necessary, and provide long-term guidance for managing channel, sediment, and aquatic resources below the Pelton–Round Butte Dam complex, the LRGS was established in 2006 as part of the relicensing Settlement Agreement (FERC 2005, Stillwater Sciences 2006). The LRGS included direct measurement of bedload sediment transport, channel bed scour and morphologic change, bed particle size distributions, and aquatic habitat. These measurements formed the basis of the LRGS, culminating in the publication of final reports in 2015 (Stillwater Sciences 2015, Spateholts 2015, R2 Resource Consultants 2015).

2.1 Implementation of the Lower River Gravel Study in 2008

Implementation of the gravel augmentation sites was conducted in August 2008, and is described in detail in Stillwater Sciences (2009), and is briefly summarized here. Gravel augmentation was conducted at three sites: Jason Smith, Paxton, and Warm Springs (Figure 1). A total of 300 yd^3 of gravel augmentation was delivered to the three sites, but the actual volume placed as determined by topographic differencing was approximately 222 yd^3 due to particle settling after placement (Table 1). The grain size distribution of gravel augmentation ranged from 16 mm to 128 mm, with a D_{50} of 58 mm and D_{84} of 107 mm, both of which were finer than the underlying bulk samples at the augmentation sites and coarser than what is generally considered suitable for redband trout and steelhead (D_{50} of approximately 16 to 45 mm used in the spawning habitat mapping effort); however, these grain sizes are more suitable for Chinook spawning habitat.

The gravel augmentation guidelines were to “place gravel in bar shaped deposits in locations with flow depths and velocities that are similar to existing gravel bars,” with topography to mimic the existing topography at or near augmentation sites. Gravel augmentation at the three sites extended 1.0 to 1.5 feet above the baseflow water surface at the time of placement (see Appendix B in Stillwater Sciences 2009), but via a combination of settling and/or manual raking, the augmented gravels were just below the baseflow water surface elevation. The gravel was stockpiled on one of the banks and placed in the channel by a cable and a “gravel-o-matic” trolley car delivery system, and spread out by hand tools in the channel (Stillwater Sciences 2009). No heavy equipment was used to place the gravel.

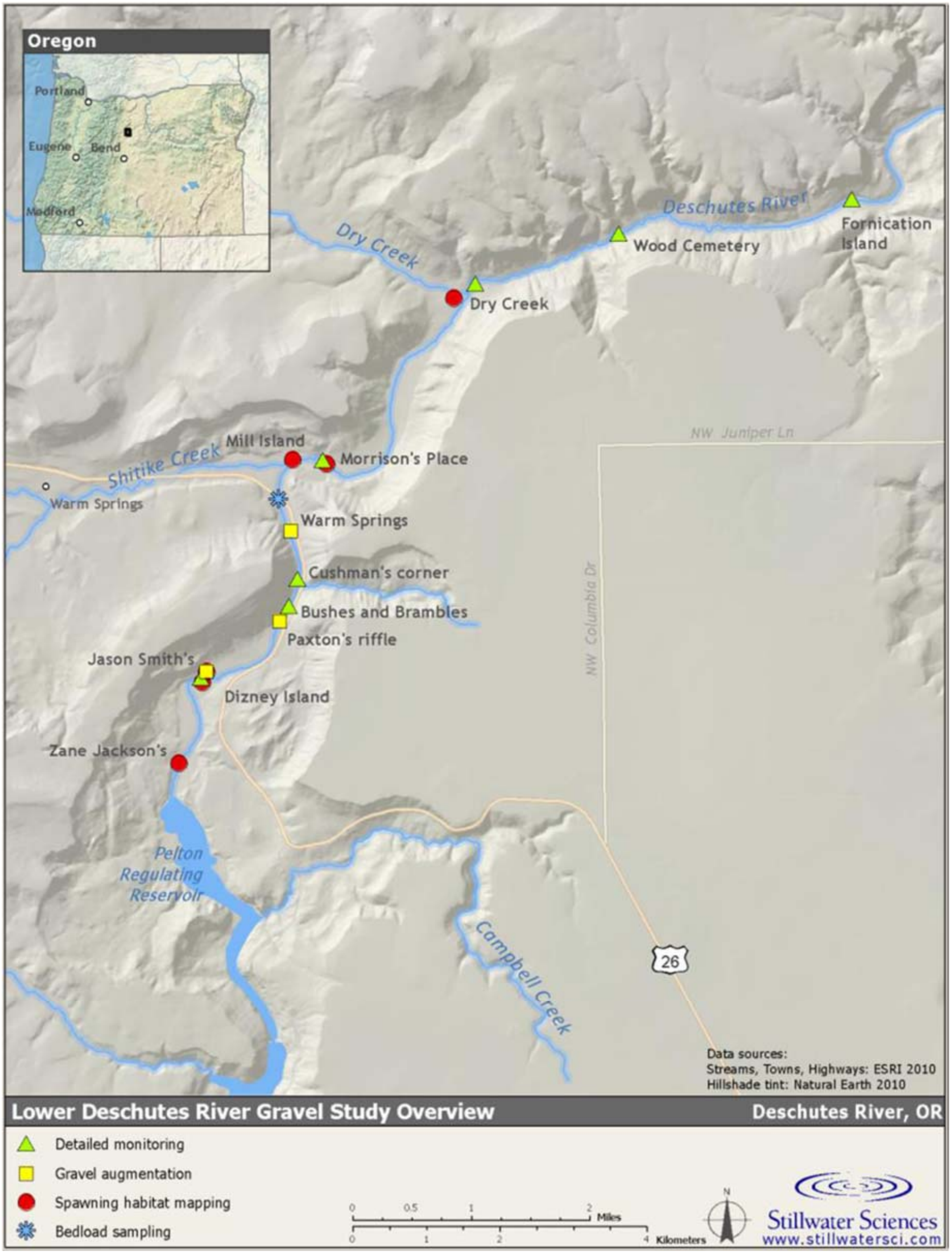

Figure 1. Overview of the LRGS study sites in the lower Deschutes River, from Stillwater Sciences (2015).

Table 1. Summary of August 2008 gravel augmentation at three sites, from Stillwater Sciences (2009).

Augmentation Site	**Planned Gravel Augmentation Volume (yd^3)**	**Actual Gravel Augmentation Volume (yd^3)**
Jason Smith	75	57.2
Paxton	115	82.3
Warm Springs	110	82.4
Total	**300**	**222**

3 CONTEMPORARY OBSERVATIONS AND FINDINGS WITH RESPECT TO GRAVEL DYNAMICS

In the following section, we evaluate what the LRGS and previous studies have revealed with respect to evaluation criteria specified in the Settlement Agreement (FERC 2005), and what the implications are for short-term experimental and/or long-term gravel management of the lower Deschutes River. Specifically, we draw on these various reports, as well as additional analyses that we conducted, to develop the Panel's findings with respect to gravel dynamics, channel morphology, and implications for aquatic habitat that serve as the evidentiary basis for our responses to the evaluation criteria described in Section 1. We draw on published reports, notably the work by Stillwater Sciences, PGE staff, R2 Resource Consultants, and the US Geological Survey (USGS), as well as our own observations from field trips and our own data analysis. In discussing these findings, we identify our level of confidence in the conclusions, and caveats and uncertainties that should be considered in interpreting the results.

To help interpret results in the LRGS, it is important to recognize the context for the LRGS itself. The 8-year period from 2007–2015 during which measurements were made included a period when flows were relatively modest, with the largest flow event during the period having a peak flow of just over 9,000 cfs, an event with slightly less than a 3-year post-dam recurrence interval (Figure 2). The LRGS period also saw major increases in fall-run Chinook salmon spawning activity in the reaches below the dam, in unprecedented levels beyond those observed during the 1970s (Figure 3). As discussed below, this may have had significant impacts on gravel transport and availability that were not previously identified in prior geomorphic studies.

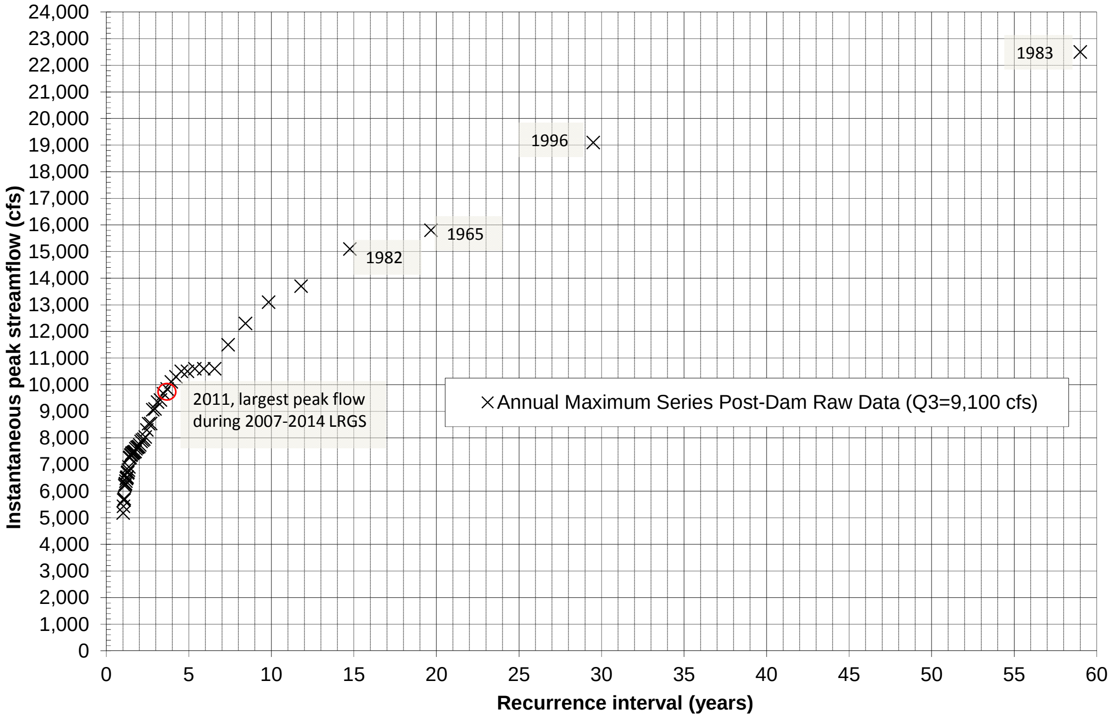

Figure 2. Plot of annual instantaneous peak flow data for the Deschutes River, Oregon near Madras (Stn 14-092500) under the post-dam period (1958–2015). The largest peak flow during the LRGS was 9,090 cfs in 2011, slightly less than a 3-year recurrence interval event.

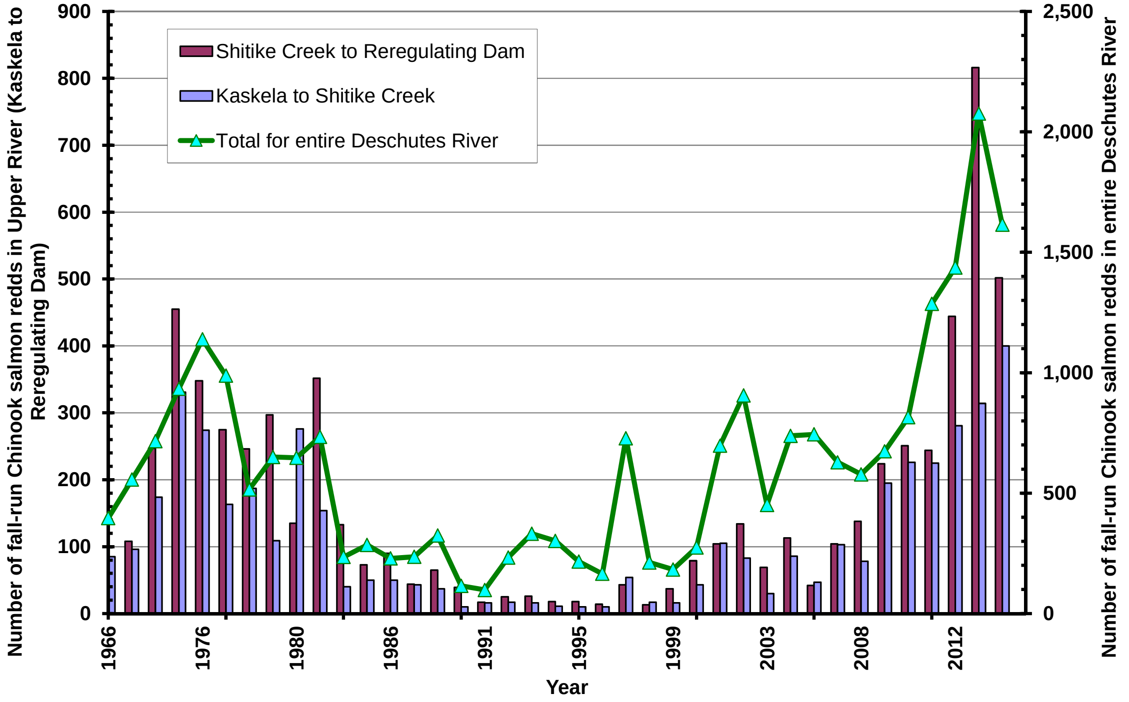

Figure 3. Plot of fall-run Chinook salmon redd counts in various reaches of the Deschutes River from annual helicopter surveys for 1966–2014 from Oregon Department of Fish and Wildlife and Confederated Tribes of the Warm Springs Reservation of Oregon data, as illustrated in Spateholts 2015 (no data available for 1967–1971, 1973, 1982, 1984, 1987, and 2004).

The primary findings from the aforementioned published reports and field observations are listed as follows:

3.1 Finding #1: The Deschutes River below Pelton–Round Butte and above Shitike Creek has unusually low sediment transport rates for a river of this size.

As summarized in Stillwater Sciences (2015):

> *Study results describe a relatively stable channel with partial bedload transport occurring at peak flows ranging from 6,500 to 9,000 cfs. Tracers were predominantly immobile, sampling captured little bedload material at flows up to 8,880 cfs, bed scour was typically limited to depths equal to or less than one D_{50} particle, and less than 25% of the channel width experienced erosion or deposition greater than the thickness of one D_{84} particle.*

The measured transport rates over the 2007–2014 period support the prior modeling work of Fassnacht (1997) and Fassnacht et al. (2003), who predicted that discharges around 12,000 cfs (approximately an 8-year event, Figure 2) would be required for general mobility of the bed. As summarized by Stillwater Sciences (2015):

> *The preponderance of findings suggests that the threshold for general channel bed mobility is near the 12,000 cfs upper limit predicted by Fassnacht (1997).*

As described above and in Stillwater Sciences (2015), this conclusion rests on multiple lines of evidence: direct measurement of transport at the Warm Springs Bridge (Highway 26) by the USGS at flows up to 8,880 cfs (USGS 2011), very limited movement of tracer rocks at flows up to 9,000 cfs, very limited scour and fill at these flows, and very limited entrainment of the gravel augmentation deposits. This finding also corroborates the earlier specific cableway cross section analysis by Fassnacht et al. (2003) for the multi-decade record from the USGS streamflow gage on the Deschutes River near Madras (Stn 14-092500), located 0.5 miles below the Pelton Reregulating Dam. These multiple lines of evidence support a high level of confidence in this finding. As discussed below in Finding #4, however, there appear to be higher transport rates for the finer gravel fraction (D_{50} = 16–45 mm); this has implications for availability of suitable spawning habitat for smaller fish (i.e., redband trout and steelhead).

3.2 Finding #2: In general, the channel morphology of the lower Deschutes River is quite stable with very limited cross-section change or evidence of scour and fill.

From Stillwater Sciences (2015):

> *Detectable bed elevation change (scaled to site D_{84}) and active bed width was limited during the LRGS…. Seventy-two of 94 (77%) of paired cross sections had an active bed width less than 25% for scour and fill scaled to D_{84}, while 28 of 94 (30%) never exceeded 10% active bed width. Much of the apparent detectable bed elevation change less than site D_{84} can be attributed to accepted levels of survey imprecision common in large, coarse-grained river systems.*

These results are consistent with the observed low transport rates (Finding #1). Extension of the specific gage analysis conducted by Fassnacht et al. (2003) at the Madras USGS gaging station to include the LRGS period suggested that the bed may actually be more stable in this region than suggested by earlier studies, possibly due to increased armoring (see Figure 10 in Stillwater Sciences 2015).

While we have high overall confidence in this finding, several caveats need to be highlighted. First, as noted above, the range of flows during the LRGS period did not exceed a 3-year event, although prior studies reaching the same conclusion regarding channel stability witnessed much larger (100-year) events in February 1996 (i.e., Curran and O'Connor 2003). Second, as discussed below in Finding #6, we did detect some topographic changes to the vegetated islands in the reaches immediately below Pelton Reregulating Dam that indicate multi-decadal erosion of islands.

3.3 Finding #3: Gravel augmentation to date has had little effect on the gravel transport rates, channel morphology, or availability of aquatic habitat.

In general, the gravel that has been added to the river has largely stayed in place, with very modest changes in the topography of the gravel augmentation deposits, as noted by Stillwater Sciences (2015, see Figure 11), who attribute much of the small topographic change measured as due to both settling of the augmented piles and fish spawning activity at these sites. Average changes in the surface elevations of the piles were on order of 0.1 to 0.2 m, which corresponds approximately to a grain diameter of a median bed particle. Although we have high confidence in the overall trend of limited erosion of the augmented gravel deposits, we cannot categorically separate the effects of settling and fish disturbance from the effects of gravel entrainment and transport.

3.4 Finding #4: Increased spawning use of the reaches immediately below the Pelton Reregulating Dam by large numbers of Chinook salmon has had an effect on gravel transport, channel morphology, and available aquatic habitat.

A key contextual observation is that the LGRS period coincided with a dramatic increase in Chinook escapement and spawning in the lower Deschutes River (Figure 3). For example, as few as 13 redds were observed in the reach between the Pelton Reregulating Dam and Shitike Creek during an extended period of low spawner escapements in the 1990s (in 1998), and as many as 816 redds in 2013, a 60-fold increase. The increased spawner activity and concentration may be having what we believe to be a measureable and significant local effect on gravel transport and channel morphology, with implications for the availability of patches of finer gravel suitable for redband trout and steelhead spawning. The increased fall-run Chinook salmon spawning activity removes the armor layer, exposing finer grained sediment to entrainment and transport. Although we cannot absolutely quantify the magnitude of this effect, it is suggested by several lines of evidence, including: (1) observed increases in fish utilization as indicated by the increase in the number of spawning redds, particularly for Chinook salmon (Figure 3); (2) distinctive redd-like features, dunes, and patches of material moved by fish on the downstream side of gravel augmentation sites; (3) fining of the bed surface in many spawning locations; and (4) a high proportion of fine gravel caught in USGS bedload samplers (no grains coarser than 64 mm caught in any samples for flows up to 8,880 cfs). As summarized by Stillwater Sciences (2015):

> *While results indicate infrequent general surface mobility, morphological change, or average bed lowering, results do indicate more frequent transport and turnover of finer gravel (D50=16–45 mm) suitable for trout and steelhead spawning. Transport and storage of this size fraction was expressed as bed surface fining and changes in mapped suitable gravel between WY2007 and WY2014, coincident with a period of increased fall-run Chinook salmon spawning. Surface fining is in large part a result of Chinook salmon spawning activity that disrupts the immobile armor layer and creates patches of finer-grained bed that can be utilized by spawning steelhead and redband trout.*

We are fairly confident that the fish are playing an increasingly important role in shaping their own habitat through spawning activities. This represents a new insight into the dynamics of the lower Deschutes River that was not previously captured by prior geomorphic studies, due to the fact that these studies occurred when Chinook salmon escapement numbers were low. We do not fully understand the long-term implications of this finding for management of the gravel resource in the lower Deschutes River, but we think that it should serve as a primary focus for any continued monitoring and gravel augmentation program.

3.5 Finding #5: Gravel quality remains good, but there have been gradual reductions in spawning gravel quantity since 2008.

In studies summarized by Campbell (2015) and Spateholts (2015), the recent quality of spawning gravel in the lower Deschutes River above and below the Shitike Creek confluence was examined using methods very similar or identical to those used during previous post-dam work by Aney et al. (1967) and Huntington (1985). The recent studies examined gravel permeability, inter-gravel dissolved oxygen levels, substrate size compositions, and multiple model predictions of embryo incubation survival rates. The recent studies generally found spawning gravel quality to be good at the sites evaluated. There is little or no evidence that we know of that gravel quality has either declined or improved significantly within the areas studied above Shitike Creek since the 1960s.

With respect to spawning gravel quantity, recent monitoring studies by Stillwater Sciences (2015) measured the spatial extent of spawning gravel suitable for use by redband trout and steelhead in six of the most important salmonid spawning areas within upper segments of the lower river, three above the Shitike Creek confluence and three below the Shitike Creek confluence. Measurements of the quantity of gravel suitable for use by redband trout and steelhead in these same areas had also been made during the 1960s by Aney et al. (1967) and in 1984 by Huntington (1985), but only those made in 1984 used methods similar enough to those of the recent monitoring work to be considered comparable.

Figure 4 compares recent measurements of the spatial extent of gravel suitable for use by spawning redband trout and steelhead at the six study sites to those made back in 1984. The measurements suggest that the combined quantity of spawning gravel available for redband trout and steelhead at the three Deschutes River sites above Shitike Creek is at least as great as that of 1984, but that during the most recent years there have been within-site declines in the spatial extent of gravel suitable for use by these fish. Over the 2008–2014 period, the Stillwater Sciences data show a decrease in spawning gravel area at all three sites above Shitike Creek (Figure 4). The methodology for mapping suitable spawning gravel area was refined in 2010 to be more accurate (GPS, subdivision of spawning dunes), which may explain some of the recent decrease in spawning gravel area. However, we suspect that the most recent apparent declines reflect modest surveyor variability, possibly some level of expanded growth by aquatic macrophytes, and substantial disturbances of the surface composition and contours of monitored sites by the spawning activity of high escapements of fall-run Chinook salmon. Similar but less extensive disturbances of these sites by fall-run Chinook salmon were seen and documented by Huntington (1985).

There have apparently been mixed patterns of change in the spatial extent of gravel suitable for use by spawning redband trout and steelhead at the three monitored sites below the Shitike Creek confluence (Figure 4). The extent of suitable gravel areas in 1984 fell within the range of conditions measured recently at two of the three sites (Mill Island and Dry Creek), but not at the third site (Morrison's) at River Mile (RM) 96.4. There has been a substantial reduction in the quantity of gravel suitable for use by redband trout and steelhead at the Morrison's site, where most of a gravel bar that was once among those most heavily used by these fish has been colonized by riparian vegetation.

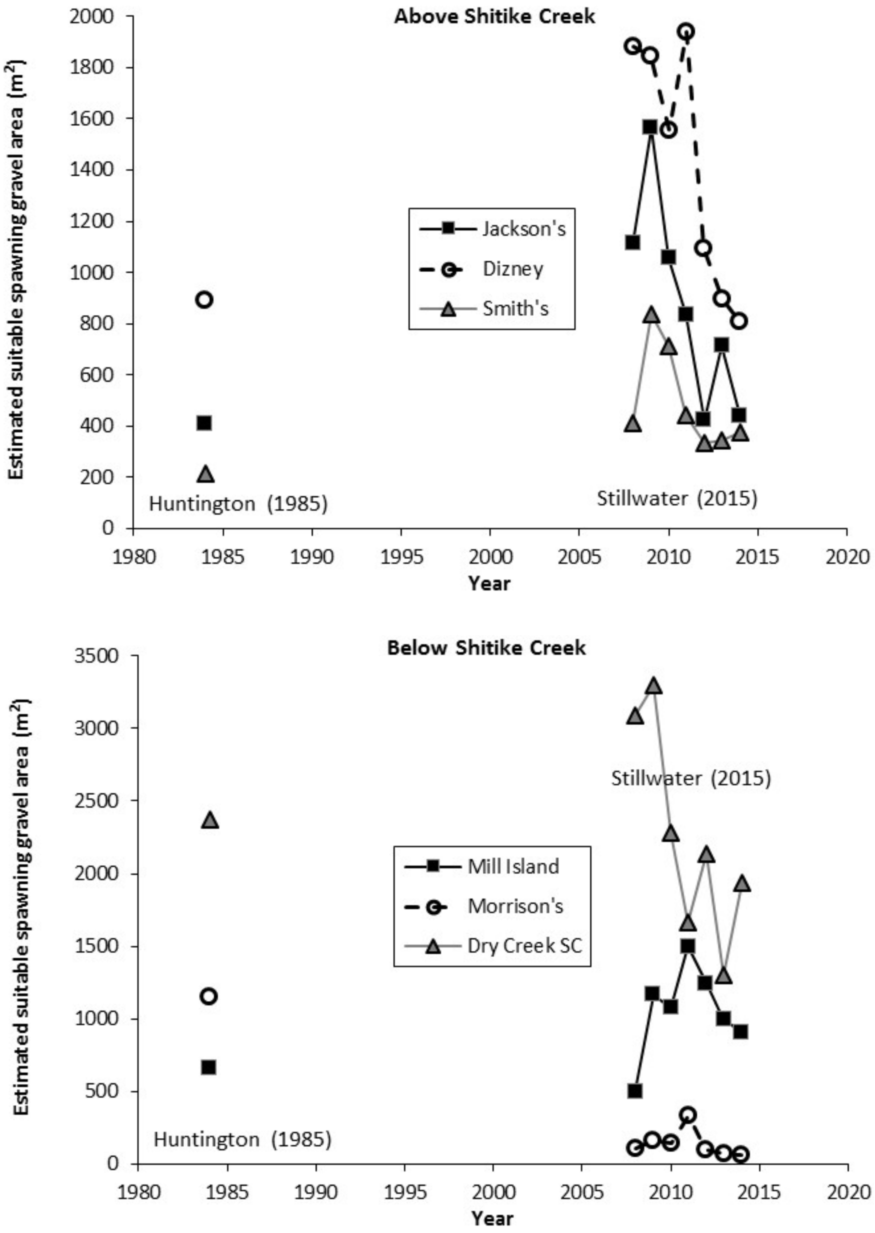

Figure 4. Plot of suitable spawning gravel areas for redband trout and steelhead at comparative sites above and below Shitike Creek in 1984 (adapted from Huntington 1985) and between 2008-2014 (Stillwater Sciences 2015).

There has been no apparent shift since 1984 in the proportion of redband trout and steelhead spawning at the three monitored sites above the Shitike Creek confluence versus those below the confluence (Figure 5), although it is unclear to what extent there have or have not been changes in redband trout and steelhead spawning activity outside the monitored sites. Similarly, Spateholts (2015; Figure 6) has shown that there has been no significant shift in the proportion of fall Chinook salmon spawning activity in the lower Deschutes River above Kaskela (RM 79.5) that occurs above the Shitike Creek confluence (RM 96.8).

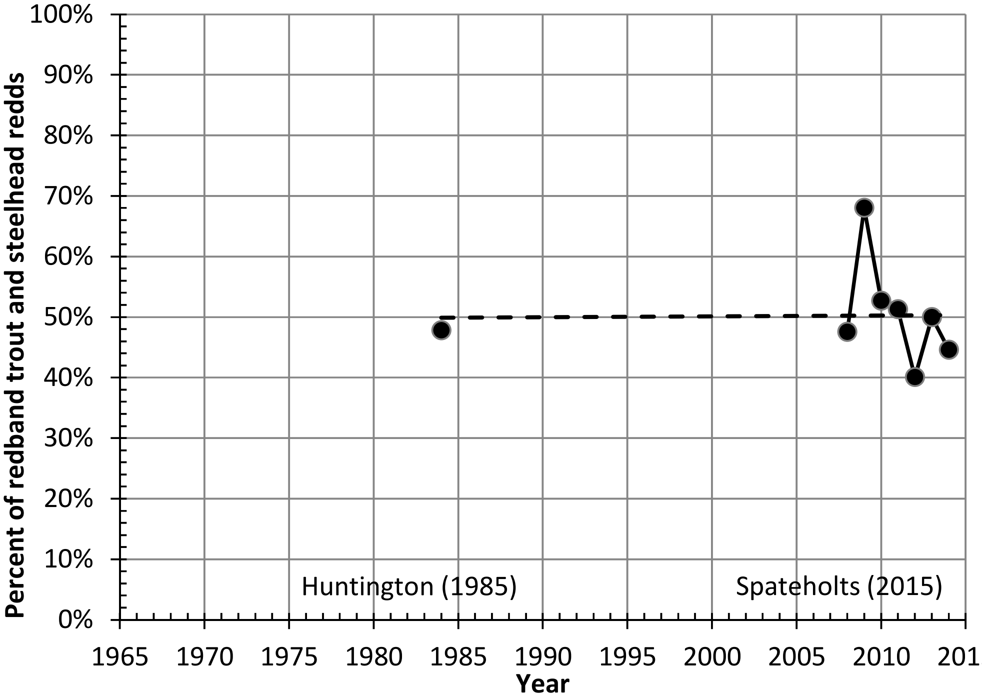

Figure 5. Percentage of the annual count of redband trout and steelhead redds at six monitored lower Deschutes River sites above the Trout Creek confluence (Jackson's, Dizney, Smith's, Mill Island, Morrison's, and Dry Creek) contributed by three of these sites that are upstream of the Shitike Creek confluence.

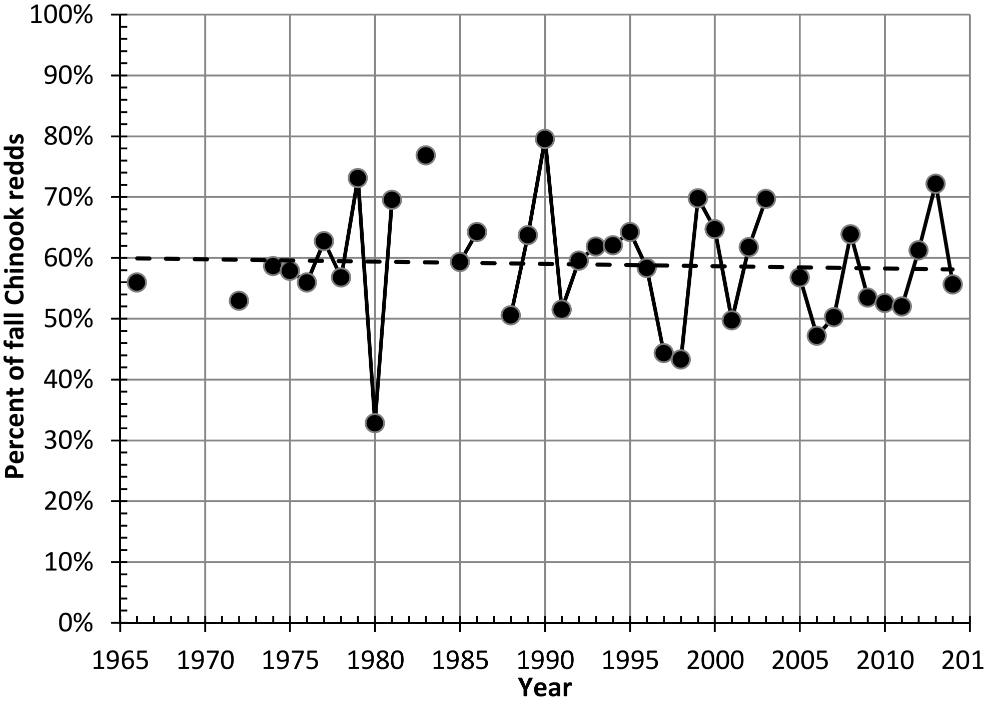

Figure 6. Percentage of fall-run Chinook salmon redds above Shitike Creek for the reach between Pelton Reregulating Dam (RM 100.1) and Kaskela (RM 79.5), using data illustrated in Spateholts 2015 (no data available for 1967–1971, 1973, 1982, 1984, 1987, and 2004).

The lack of a clear long-term shift in the broad-scale spawning distribution of either species is consistent with the idea that there have not yet been consequential changes in the quantity and quality of suitable spawning area for salmonids in the river above Shitike Creek associated with a reduction in natural gravel supply. This is not to say, however, that such changes might not occur in the future nor that it would not be beneficial to develop effective methods for mitigating such changes before or as they occur.

There do appear to have been some potentially consequential localized shifts in the distributions of spawning salmonids in the lower river above Shitike Creek, but these may be unrelated to changes in the natural gravel supply. More spatially expansive spawning activity by fall-run Chinook salmon near islands and in side channels may be having local effects on habitat suitability for spawning redband trout and steelhead as noted earlier, and thus the spawning sites selected by the trout. Detailed spatial data on redband trout and steelhead redd distributions collected by Stillwater (2015) establish a partial basis for future evaluation of this situation if it is deemed important. However, although there would be value in collecting more spatially resolute data on Chinook salmon redd distributions within the river, annual monitoring of these redds above Shitike Creek has become less spatially resolute over time. Because of the pronounced degree to which the Chinook salmon are modifying riverbed contours in this section of river, detailed analysis of high-resolution air photos should probably be considered as way to add resolution to both past and future monitoring of the Chinook salmon redds.

Gravel augmentation experiments summarized by Spateholts (2015) did not yield strong responses from salmonids spawning in the river. Per Spateholts (2015), and consistent with observations we made during our field tour, the gravels added to the river were of a larger size at the upper end of suitability for fall-run Chinook salmon spawning, but were placed in channel positions where late-season flows were probably inadequate to make all but their edges available as spawning habitat for these fish. In addition, an underlying objective of the 2008 gravel augmentation experiment was to place known volumes of material with grain size distributions similar to the adjacent channel, thus the augmentation deposits were not specifically intended to act as spawning habitat enhancement structures. Accordingly, the grain size of the 2008 gravel augmentation experiment was much larger than that suitable for redband trout and steelhead spawning. Therefore, if spawning habitat enhancements were adopted as a future objective (not included in the original LRGS), these future gravel augmentation experiments could place gravels in channel positions with deeper and faster water, and add smaller gravels to locations likely to be used by redband trout and steelhead.

3.6 Finding #6: We see some evidence for slow and likely punctuated (i.e., during large floods) erosion of the vegetated islands in the reach below the Pelton Reregulating Dam; the scale of this erosion is modest but potentially cumulative over decadal timescales.

Vegetated islands within the lower Deschutes River are important ecological features because they contribute channel complexity, and their margins and side channels provide a substantial portion of the preferred spawning and early rearing habitat for redband trout and steelhead (Zimmerman and Ratliff 2003). The amount and/or aerial extent of islands also provides an index on alluvial storage in the lower Deschutes River, and how storage may be changing over time in response to changes in sediment supply, hydrology, channel processes, land use, and other factors. The abundance and total area of these features is greatest in the upper-most segments of the lower Deschutes River, below the Pelton Reregulating Dam (Curran and O’Connor 2003), a distribution that coincides with the highest intensities of spawning activity by summer steelhead, resident redband trout, and fall-run Chinook salmon (Aney et al. 1967; Huntington 1985). Consistent with this pattern, Huntington (1985) found that at multiple scales most spawning by redband trout and steelhead in the lower Deschutes occurred in habitat associated with islands. Similarly, Zimmerman (2000) observed during 1995 that 68% of the spawning by steelhead in the river between the Pelton Reregulating Dam and Trout Creek occurred in side channels behind islands, even though these features were found along less than 10% of the length of this section of river. The abundance of juvenile redband trout and steelhead rearing in the Deschutes River tends to be greatest in relatively shallower habitat close to shorelines (Zimmerman and Ratliff 2003), suggesting that selections of spawning sites near islands by redband trout and steelhead may be related to the habitat needs of young fish, as well as for proper egg incubation conditions.

Because of their ecological importance and potential sensitivity to changes in sediment supply, hydrology, and bedload transport, vegetated islands within segments of the lower Deschutes River nearest to Pelton Reregulating Dam may provide a valuable and sensitive long-term index of conditions important to the river’s salmonids in this area and whether these conditions may be changing in response to dam-related shifts in gravel supply. We would expect that island erosion, if and when it occurs, would be episodic and not continuous because of the river’s unique morphological stability and its dependence on infrequent flood events for most bedload transport, as described by Fassnacht et al. (2003) and Curran and O’Connor (2003). Huntington (1985) suggested that islands had begun slowly eroding within this section of river after Project completion, and a more recent analysis by Curran and O’Connor (2003) indicated net island erosion due to the 1996 flood. However, Curran and O’Connor (2003) indicated no longitudinal pattern over the long-term (1944–1996), possibly due to a broader focus on channel morphology along the entire 100.1 mile length of the lower river rather than the short reach between Pelton Reregulating Dam and Shitike Creek, where island loss may be more pronounced.

Stillwater Sciences (2015) has suggested that it might be informative to quantify the lower river's current natural sources of gravel upstream from Shitike Creek. Similarly, we felt a more focused analysis of island area changes in the reach between Pelton Reregulating Dam and Shitike Creek may provide insights on island evolution in this important reach of the Deschutes River. We made a relatively quick test of the utility of this exercise by qualitatively interpreting air photos of the area taken in 1956 and 1968 (each 1:20,000 scale black-and-whites), and in 2014 (NAIP 2014 color image with 1 meter resolution). We had the images scanned at 1,800 dpi, selected a few channel segments containing important island complexes, rectified digital images of these segments using a rubber-sheeting process, and then carefully digitized the island and channel margins within each image. Sequences of all photos are illustrated in Appendix A.

Our preliminary evaluation of the images resulted in the following observations:

- As described in Section 2, the amount of change in the islands (with the exception of the islands immediately below Shitike Creek) is extremely small, often within the uncertainty bounds due to digitizing judgements with respect to vegetative cover and potential inaccuracy of the aerial photo rubbersheeting process. This generally corroborates the findings of Curran and O'Connor (2003).
- The margins digitized for the 1956 and 1968 images had modest levels of uncertainty or error due to overhanging vegetation and the photo scales. The 2014 images were at a better scale and thus had less uncertainty.
- Changes between individual time periods were less certain than the overall changes that occurred between 1956 and 2014, with most locations showing a gradual reduction in island area. One of the largest changes over this 58-year time period was evident in an image covering the islands within Stillwater Sciences gravel study areas at Dizney and Smith's (Figure 7 and Figure 8). While the acreage changes from the digitized polygons have been computed and tabulated, we do not present them here due to the uncertainty in the precision of these numbers. However, to give a sense of scale of the potential volume of erosion from one of the clearer examples of island erosion, the area of the four islands in Figure 7 has been reduced by 42,000 ft^2, and if we assume that the island was 3 feet high, then approximately 4,700 yd^3 would have been lost over the 58-year time period (80 yd^3/year). Again, these rates are very low, and indicate a very slow decay of islands immediately below Pelton Reregulating Dam.

- Due to the biological importance of these islands and uncertainty in the rubbersheeting process, a more detailed and quantitative evaluation of islands in the reach between Pelton Reregulating Dam and Shitike Creek using orthorectified aerial photos would likely provide more definitive results of island evolution in this important reach. In addition, future monitoring of island evolution should be conducted given their biological importance.

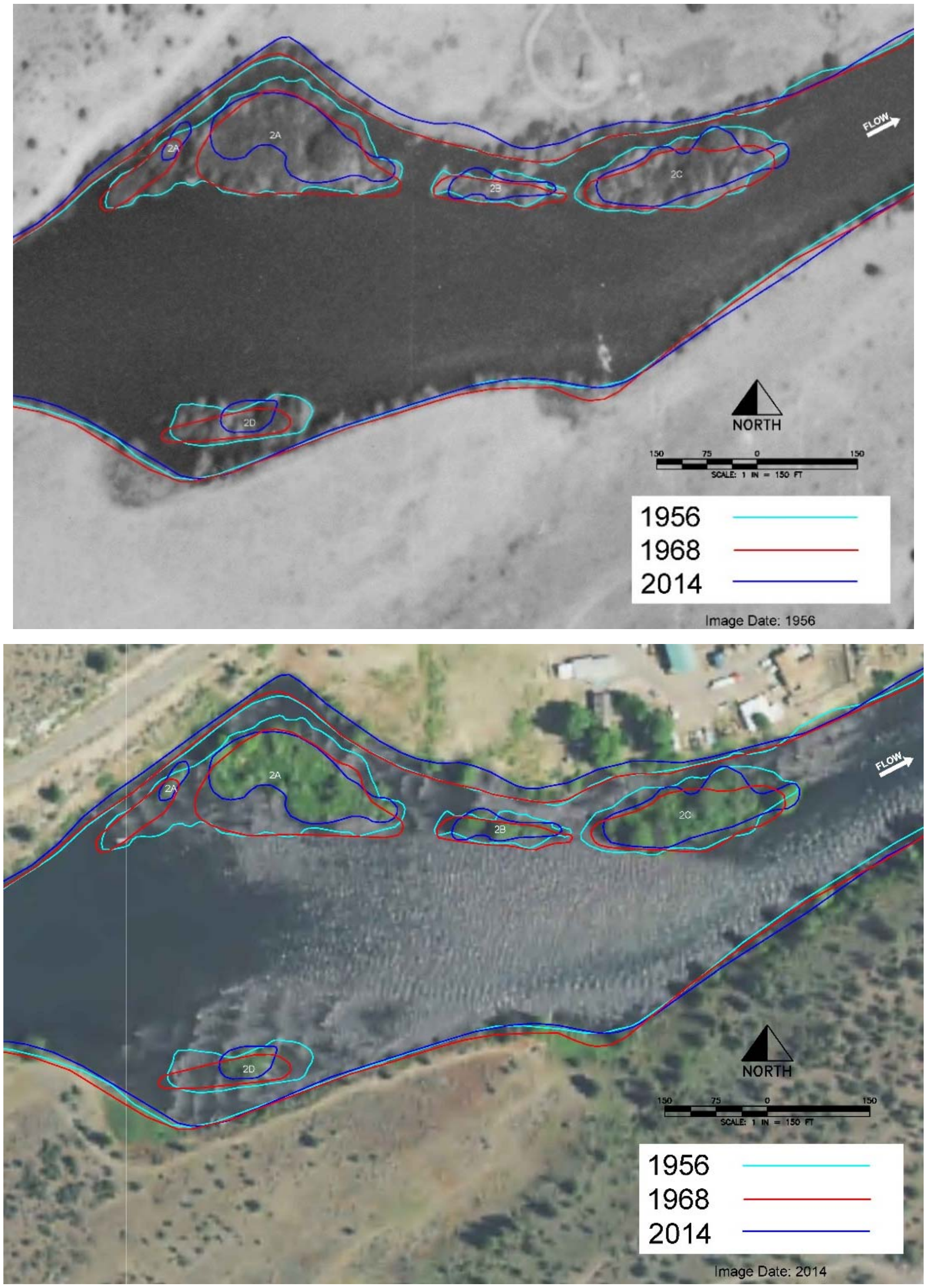

Figure 7. Comparisons of 1956 (top) and 2014 (bottom) aerial photographs and island polygons at the Jason Smith's (north side of river) and Dizney (south side of river) sites, showing slow rates of island attrition since 1956.

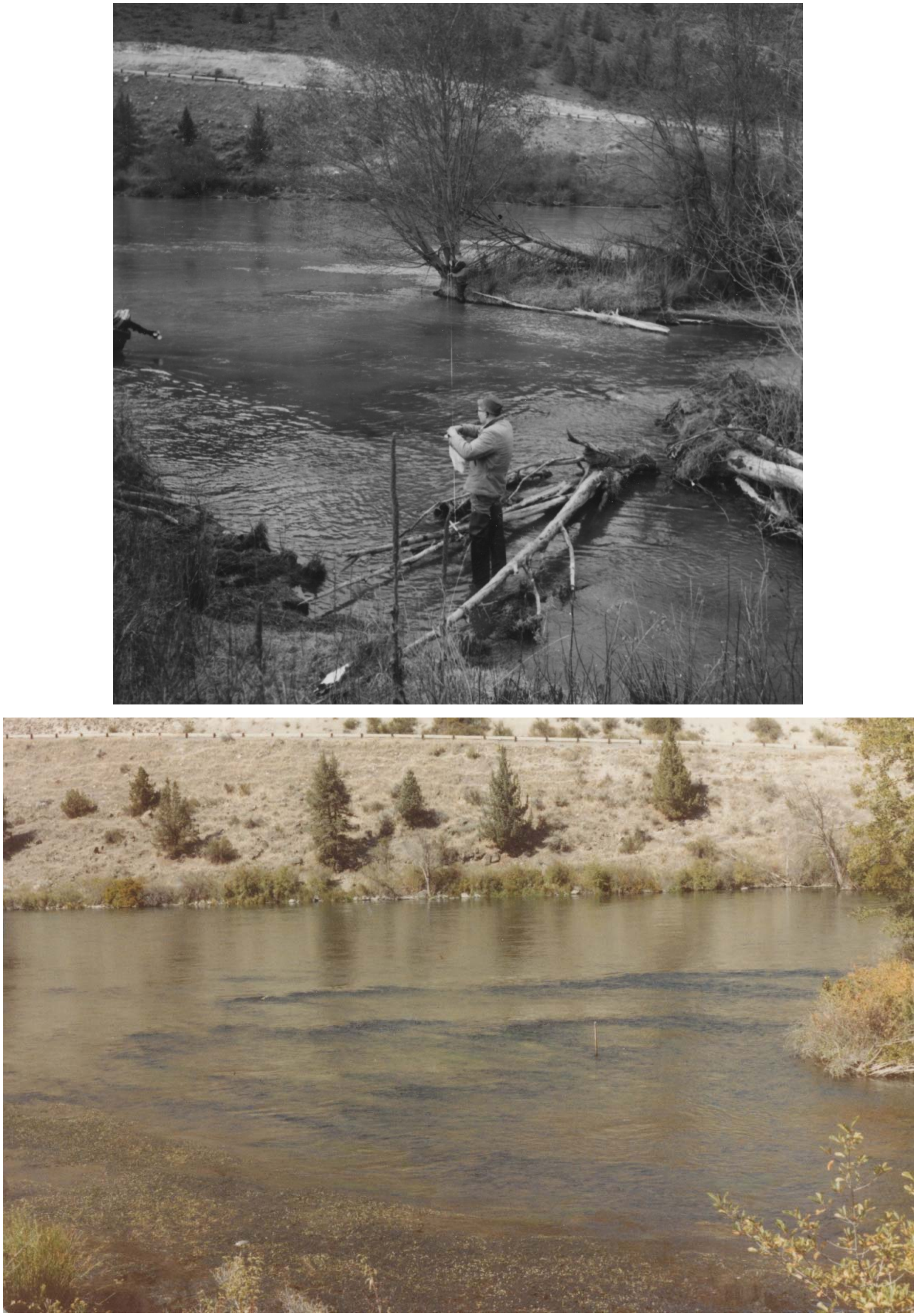

Figure 8. Comparisons of 1960s (top, exact year unknown) and 1984 (bottom) photos at the upstream end of Dizney site from Huntington (1985), showing erosion of upstream end of island, and reduction in large wood storage.

4 CONSIDERATION OF EVALUATION CRITERIA

Based on findings in Section 3, we now revisit the evaluation criteria introduced in Section 1.

4.1 Criterion #1

Is the Project causing impacts that could be mitigated by gravel augmentation, including examination of whether the Project may be having deleterious effects on channel bedforms and spawning gravel quantity and quality?

There are two parts to this question: (1) is the Project causing impacts? and (2) could these be mitigated by gravel augmentation? In answer to the first, we conclude that the Project is likely causing some downstream impacts, but as discussed in previous sections, the scale of these impacts is very small, their progression slow, and their detectability challenging. Available data are insufficient to assign Project specific impacts to spawning gravel quantity and quality from pre-dam to contemporary conditions; however, recent reductions (2008–2014) in spawning gravel quantity may be indicative of a Project-related effect. Increased spawning activity by Chinook salmon is also likely causing increased gravel movement downstream and some of the reduction in spawning habitat quantity. At first glance, increased spawning use is a desirable outcome and not a Project effect, yet the Pelton Reregulating Dam increases the concentration of spawners immediately downstream (e.g., 33% to 83% of all fall-run Chinook spawning activity above Kaskela occurs in this 3.3 mile reach). In addition, assessment of island area changes between Pelton Reregulating Dam and Shitike Creek illustrated in Section 3.6 could also be attributed to a Project impact, but uniquely assigning the scale of Project responsibility versus long-term channel dynamics is uncertain.

In answer to the second part, and as discussed under Criterion #3, some but not all of these impacts could probably be mitigated by gravel augmentation. For example, targeted gravel augmentation in the finer size classes could increase availability of spawning habitat for smaller fish. We are less confident that gravel augmentation could be used to rebuild islands or prevent further erosion, although we think that an experimental program to explore this is warranted (discussed under Recommendations).

From a biological standpoint, the slow loss of island area and spawning gravel area between Pelton Reregulating Dam and Shitike Creek seems likely to become a growing concern during the license term, due to potential declines in habitat for aquatic and riparian-dependent species. The Project may at times be influencing the distribution of habitat for redband trout and steelhead by truncating the spawning distribution of the lower river's fall-run Chinook salmon and causing very high densities of the salmon to spawn between Pelton Reregulating Dam and Shitike Creek. When the Chinook salmon spawning densities are high, these fish are altering the riverbed in side-channels important to redband trout and steelhead. There are, however, no data indicating that this has limited the abundance of redband trout and steelhead in the area (Criterion #3). The gradual reduction of spawning gravel quantity, combined with sustained or increasing fall-run Chinook salmon spawners, could also be problematic due to potential redd superimposition during higher escapement years, especially when a large proportion of the Chinook spawn above Shitike Creek.

In summary, Project-induced deleterious effects are likely very low (extremely low compared to most other regulated alluvial rivers) and difficult to detect, and occur over a very long time scale (multi-decadal) or during rare floods. So mitigation efforts, if implemented, should also be commensurately modest due to the small impacts and slow rate of change in the river (i.e., we are not recommending large scale augmentation that creates an unnaturally dynamic river). Based on the available evidence, we do not see strong evidence in support of a continuous, long-term, and/or large-scale volume gravel augmentation program.

4.2 Criterion #2

Is the pilot gravel augmentation test adversely affecting downstream bank stability or caused downstream pool filling?

No. Given the stability of the bed (including augmented gravels), small volume of augmented gravels (220 yd^3), and stability of nearly all banks due to boulders and riparian vegetation, there have been no findings to suggest that the gravel augmentation test has caused any adverse effects to downstream bank stability or pool filling.

4.3 Criterion #3

Would a gravel augmentation program be beneficial to fish habitat and fish populations (as indicated by the results of the biological monitoring program)?

This criterion is evaluated in two parts: fish habitat and fish populations. With respect to fish habitat, a gravel augmentation program could likely increase physical fish habitat if grain sizes and placement locations were carefully planned such that gravel augmentation locations would be suitable for spawning and rearing. Small amounts of gravel augmentation could be implemented to increase and improve spawning habitat. Supplementation (maintenance) of islands for both spawning and rearing habitat could be implemented with modest amounts of gravel augmentation. However, gravel augmentation to address the formative processes of islands would require large volumes and we believe it would be difficult to achieve the objectives given the stability of the river and infrequent flows capable of forming these islands. Some degree of experimentation to explore this issue does seem warranted, however.

With respect to fish populations, the Panel has no evidence to evaluate this criterion, as none of the gravel studies addressed whether the pilot program would benefit fish populations. In the absence of Deschutes-specific analysis, some discussion may be useful on this topic. First, while gravel augmentation can increase physical fish habitat, whether or not those habitat improvements translate into production or population-level response is highly uncertain, and probably unlikely except for some rare scenarios. For example, spawning habitat is probably not limiting fish production or populations in the basin in most years. However, given the large proportion of total redds in the reach between the Pelton Reregulating Dam and Shitike Creek (33% to 80%, while only 16% of the reach length), there could be some population-level benefits to fry production by increasing spawning habitat and rearing habitat via island maintenance upstream of Shitike Creek, particularly during high escapement years when superimposition losses could be high and density dependent limitations on fry rearing may occur. But we have no data or models to evaluate these population scale effects, and thus this question cannot be answered. A program focused on supplementing vegetated islands and specific spawning areas might be beneficial to fish production and populations, particularly over the long term, but further experimentation and assessment would be needed to identify physically effective methods and their biological benefits.

5 RECOMMENDATIONS

Based on the Settlement Agreement evaluation criteria listed above, and the task of the Panel to "make a recommendation to the Fish Committee regarding the implementation of a long-term gravel augmentation program," the Panel first provides recommendations on the long-term gravel augmentation program, then recommends priority assessments to address uncertainties discussed in preceding sections.

5.1 Long-term Gravel Augmentation Program

Based on our review of the historical literature, LRGS, and our own analyses, the panel concludes that there is not sufficient evidence to recommend a specific long-term gravel augmentation program at this time. However, this does not necessarily mean that a long-term gravel augmentation program is not needed, as additional management considerations that were not prioritized in the LRGS study plan may be more important into the future. We have confidence in the substantial empirical and modeling evidence that transport and associated channel changes on the lower Deschutes River occur infrequently, and that the Pelton–Round Butte Project has had only minor impacts on gravel supply and dynamics downstream of Pelton Reregulating Dam to date. However, as summarized in Section 3.5 and 3.6, changes in gravel storage and spawning habitat are occurring, albeit at a very slow rate, and long-term implications to fish habitat upstream of Shitike Creek could be important, particularly if the dramatic improvements in fall-run Chinook salmon escapement continue into the future. Therefore, our primary recommendation is that a Phase II experimental gravel augmentation program be designed and implemented, with redirected focus on the reach between Pelton Reregulating Dam to Shitike Creek (the reach most sensitive to Project-induced changes to sediment supply and gravel dynamics). This Phase II experimental gravel augmentation program should have greater focus on islands, spawning areas (particularly if the Fish Committee decides that spawning habitat limitations may sometimes occur), and closely associated habitats (i.e., rearing habitat). Two primary future gravel augmentation experimental objectives could be as follows, which are different than the 2007 LRGS gravel augmentation objectives:

<u>Island gravel and large wood supplementation (spawning and rearing habitat focus)</u>: Enhance 1–2 islands with variable size classes of gravels and large wood pieces to (1) increase fall-run Chinook salmon spawning habitat at the head of the island via coarser gravels and small cobbles, (2) increase redband trout and steelhead spawning habitat on island flanks with medium and small gravels, and (3) increase hydraulic influence of island via cobbles, small boulders, and large wood pieces at the upstream end of the island to increase hydraulic and topographic complexity (natural

obstructions, see top photo in Figure 8). The scale of a 1-time gravel augmentation for this objective would likely be on the order of 300–1,000 yd^3 for a given island (e.g., supplementing the existing Dizney site, the Jason Smith's site, the head of Jackson's island, or the Valve site just downstream of Jackson's on right bank). It might be valuable to precede any island enhancements with sampling of the particle composition of an existing island or two, so as to better understand how or whether one might be able to encourage the formation of new vegetated islands within the river channel via gravel augmentation (i.e., develop a design grain size distribution that could foster vegetative growth on supplemented island).

<u>Riffle/side channel gravel supplementation (spawning habitat focus)</u>: Supplement existing riffles with variable size classes of gravels to (1) increase fall-run Chinook salmon spawning habitat in the center of the riffle/side channel via coarser gravels and small cobbles, and (2) increase redband trout and steelhead spawning habitat on riffle/side channel margins with medium and small gravels. The scale of gravel augmentation for this objective would likely be on the order of 100–500 yd^3 for a given riffle (e.g., supplement existing side channel at Jackson's island, main channel between Dizney and Jason Smith's sites).

The Phase II experimental gravel augmentation experiment design should be developed, implemented, and assessed for the objectives chosen by the Fish Committee, and the experimental design should clearly describe the placement locations, methods, grain sizes, and volumes, as well as linkages between the placement design, objectives, and hypotheses. Given that most potential augmentation locations are on private lands, implementation would require appropriate continued cooperation and permission from landowners. A corresponding monitoring and assessment design should accompany the gravel augmentation design to evaluate the hypotheses and underlying objectives, as well as the evaluation criteria outlined in the Settlement Agreement that informs the foundational question of whether a long-term gravel augmentation program is warranted. We specifically recommend additional focus on Criterion #3 (fish habitat and potential benefits to production), and a new criterion that evaluates long-term island evolution (e.g., can modest gravel supplementation on islands with appropriately scaled grain sizes and key large wood pieces slow or eliminate the slow attrition of islands observed immediately below Pelton Reregulating Dam?). Evaluation of these refined criteria should then be used in 5–7 years to re-address the need for a long-term gravel augmentation program.

Based on the potential objectives listed above, specific recommendations for the Phase II experimental gravel augmentation are as follows:

1. Placement of gravel grain size distribution suitable for fall-run Chinook salmon, redband trout, and steelhead in channel positions appropriate for these fish species (i.e., use smaller grain sizes than the 2008 gravel augmentation for redband trout and steelhead, and deeper placements at locations with water velocities are likely to be suitable for use by spawning fall-run Chinook salmon);
2. Placement of experimental gravel (size, location, topography) in a way that mimics natural fluvial sorting processes, achieves multiple habitat objectives, and/or addresses management uncertainties as described above. Given the naturally infrequent general mobility of the lower Deschutes River bed surface, placement of smaller gravels and embedding large wood pieces at the upstream ends of islands should provide moderate to long-term habitat benefits.
3. Placement of experimental gravels should be larger scale than was done in 2008 (222 yd^3) to better enable measurement of geomorphic and habitat change, but modest given the natural stability of the river and the small amount of island loss described in Section 3.6.

For clarity, the Panel <u>does not recommend</u> the following:

- Gravel augmentation downstream of Shitike Creek because the intensity of spawning activity by fall-run Chinook salmon, redband trout, and steelhead is greatest upstream of Shitike Creek and coarse sediment supply to the Deschutes River is much higher downstream of the Shitike Creek confluence.
- Large scale and/or large volume gravel augmentation intended to cause new bars to form during common high flows, as the amount of gravel augmentation needed to form new bars would be very large and did not occur prior to the Project except during exceptionally large floods.
- Large scale engineered wood structures or other unnatural features, as these types of features did not exist prior to the Project.

5.2 Management Uncertainties Associated with Gravel Augmentation

Based on our review of the foundational gravel augmentation assessments, as well as assessment of the three evaluation criteria, the Panel has developed the following list of priority uncertainties based on implications to future gravel augmentation management.

<u>Criterion #1: Are there Project impacts on bedforms, and could gravel augmentation mitigate impacts?</u>

The primary uncertainties identified by the Panel are the long-term evolution of island features, and the role of fall-run Chinook salmon spawning on overall gravel transport rates. With respect to island features, our analysis indicates a gradual net reduction in island area between the Pelton Reregulating Dam and Shitike Creek. There is uncertainty in the causal mechanism for this gradual reduction, whether it is Project-induced or a natural variable process of island building and decay caused by the stochastic sequencing of rare large flood events and more frequent small flood events. Given the potential importance of islands in spawning and rearing habitat, and the potential of future gravel augmentation to help mitigate these impacts, more detailed monitoring of island dynamics is warranted, particularly upstream of Shitike Creek. Second, given that natural coarse sediment transport rates are infrequent and small, the increased fall-run Chinook spawning activity in between the Pelton Reregulating Dam and Shitike Creek may play a meaningful role in overall coarse sediment transport of spawnable-sized gravel. At minimum, a reconnaissance-level assessment of annual gravel movement by spawning fall-run Chinook salmon should be conducted, then compared to fluvial gravel transport rates to see if this biologically-induced gravel movement is substantial with respect to fluvial transport rates.

<u>Criterion #2: Is pilot gravel augmentation causing pool filling or impacting bank stability?</u>
No uncertainties are associated with this criterion. The monitoring reports have confirmed that the bed surface is rarely mobilized, and when mobilized, bed particles typically move only short distances. In addition, the pilot gravel augmentation volumes and the scale of recommended future experimental gravel augmentation volumes described above are very small compared to pool depths, and nearly all channel margins are well protected by riparian vegetation and/or boulders.

<u>Criterion #3: Could gravel augmentation be beneficial to fish habitat or fish production?</u>
As discussed in Section 4.3, gravel augmentation can likely increase physical fish <u>habitat</u>. However, whether those benefits to habitat will translate to improvements in fish <u>production</u> or fish <u>populations</u> is highly uncertain. The lower river gravel studies were not designed to evaluate benefits to fish production, so the potential benefits of gravel augmentation to fish productivity or populations is uncertain. In most cases, spawning gravel quantity and quality do not limit fish productivity in a river. One exception is in cases where spawning habitat is limited and escapement is very large, potentially causing superimposition of redds and reduced fry production. However, fry and/or juvenile rearing habitat (density dependent limitations) and/or downstream water quality and/or productivity constraints often limit overall fish production, despite potential superimposition impacts during high escapement years. Therefore, the net benefits of gravel augmentation to fish productivity is highly uncertain, even in years with high spawner numbers.

In addition, initial study results may indicate a relationship between gravel augmentation and the polychaete host of *Ceratomyxa shasta*. Given the importance of *C. shasta* to fish health and survival in the Deschutes River, careful examination of this potential relationship is warranted.

5.3 Monitoring and Assessment

A monitoring and assessment strategy should be refined and conducted to assess habitat improvement effectiveness (Criterion #3), the long-term evolution of islands (new Criterion), and the primary management uncertainties described above. This monitoring and assessment strategy should focus on avoiding additional losses of islands and potential reductions in associated habitats, including spawning and rearing habitat for redband trout and steelhead. The monitoring strategy should also address concerns that might develop regarding interactions among gravel augmentation, the polychaete host of *C. shasta*, and possible outbreaks of the parasite. In addition, the monitoring and assessment should include the following components:

- Clear articulation of the gravel augmentation goals and objectives, with clear linkage between the monitoring and assessment components and these goals and objectives. Note that these future objectives will likely be different or expanded from those used in the 2007 LRGS study plan (Stillwater Sciences 2008).
- Extensive empirical and modeling studies have now given us a sound basis for predicting when bedload transport occurs in the Deschutes River. We know, for example, that the bed is only partially mobilized and transports very small volumes of bedload at flows below 9,000 cfs, and it is likely that full mobilization of the bed only occurs at flows at or above 12,000 cfs. These flow thresholds can be incorporated into future monitoring and utilized to define when any future bedload transport is measured and when channel or habitat changes involving gravel transport are likely. In addition, using event thresholds should reduce the cost of monitoring physical processes by focusing our monitoring resources only when we predict meaningful changes will occur. For example, if experimental gravel augmentation includes smaller grain sizes as recommended above, then topographic and/or tracer rock monitoring should be conducted after a >10,000 cfs flow event. If no changes are observed, then increase the monitoring threshold to a 12,000 cfs event.
- Re-occupying tracer rock arrays are cost-effective ways of estimating net bed mobility for different flows, and could be continued in the future under a threshold-based monitoring scheme described above. Each fall or early spring (prior to the high flow season), the tracers can be visually checked and refreshed if needed, then monitored only if a flow

threshold of 10,000 cfs is exceeded. If the flow threshold is not exceeded, no monitoring would occur in the late spring, but the tracer rock arrays would be checked and refreshed if needed for the upcoming high flow season.

- Given the importance of islands to spawning and rearing habitat, there should be a more robust and accurate historical assessment of island changes in the reach between Pelton Reregulating Dam and Shitike Creek using orthorectified aerial photographs (i.e., conduct a more accurate analysis of historic island area changes discussed in Section 3.6). Documentation of future changes to island areas in the reach between Pelton Reregulating Dam and Shitike Creek should also be done using RTK GPS of island margins (i.e., water surface edges at a common flow after a threshold flow event). Repeat surveys of existing or new cross sections through the islands could also be used, but cross sections typically do not provide a robust assessment of island evolution, and landowner access may be problematic. Terrestrial LiDAR flights could provide an alternative topographic method for documenting island evolution, provided proper filtering was applied to reduce topographic variability from vegetation.
- If a better determination of the flow conditions under which full mobility of the bed is achieved is deemed useful, bedload transport measurements from the Highway 26 Bridge just downstream of the Warm Springs Boat Ramp should only be conducted during flows greater than 10,000 cfs. Previous sampling has been conducted with a BL-84 sampler with a 3-inch by 3-inch square opening; a TR-2 type bedload sampler with wider nozzle should be used because it is better designed to capture the potential grain sizes in transport at these higher flows.
- A reconnaissance-level assessment of the scale of spawning gravel movement by fall-run Chinook salmon under different escapement scenarios, and comparison to fluvial gravel transport rates during rare high flow events (e.g., are the salmon moving more gravel than high flow events?).
- An assessment of the importance of biologically-created dune features (fall-run chinook spawning activity) on the riverbed as juvenile salmonid rearing habitat, and responses (if any) to changes (if any) to such features during Phase II gravel augmentation experiments.
- Monitoring and evaluation of the response (if any) of juvenile salmonids to physical changes to habitat subsequent to augmentation.

- Revisiting the methodology for mapping spawning habitat area, given the difficulty in consistent, repeatable survey methods. For example, photographic techniques to determine grain size distribution continue to evolve and improve, and may provide opportunity for future comparative use. A standardized grid sampling procedure, combined with geo-referenced mapping of bar wetted perimeters, might offer a way to avoid several sampling difficulties (macrophyte growth, pronounced alterations of bed contours by spawning fall Chinook salmon, and others) that have been experienced over the years when mapping gravels suitable for use by the fish.
- Revisiting the methodology for assessing how gravel augmentation may affect the *C. shasta* polychaete host, given the importance to fish growth and health on the lower Deschutes River.
- Geomorphic and biological monitoring associated with gravel augmentation should be focused upstream of Shitike Creek, as the sensitivity of geomorphic and biological responses to high flow and gravel management actions will be greater upstream of Shitike Creek.

The end result of this monitoring and assessment of Phase II gravel augmentation experiments would be to address the need for a long-term gravel augmentation program as envisioned by the Settlement Agreement. If a long-term gravel augmentation program is recommended, the monitoring and assessment should be conducted in a way that develops and prioritizes multiple lines of evidence that would inform gravel augmentation locations, volumes, frequency and/or triggers for placement, and size classes. Potential information sources for these parameters may include:

- Coarse sediment transport rates as measured by USGS;
- Topographic changes of Phase II gravel augmentation areas (how much is being transported and not replaced by upstream sources);
- Spawning gravel transport rates caused by fall-run Chinook salmon spawning;
- Existing estimates of coarse sediment yield from the upper watershed that is trapped by the Project;
- Refined estimates of island volume loss between Pelton Reregulating Dam and Shitike Creek using a combination of existing data (aerial photographs and cross sections) and new data recommended above; and
- Estimates of gravel transport thresholds and rates based on tracer gravel results.

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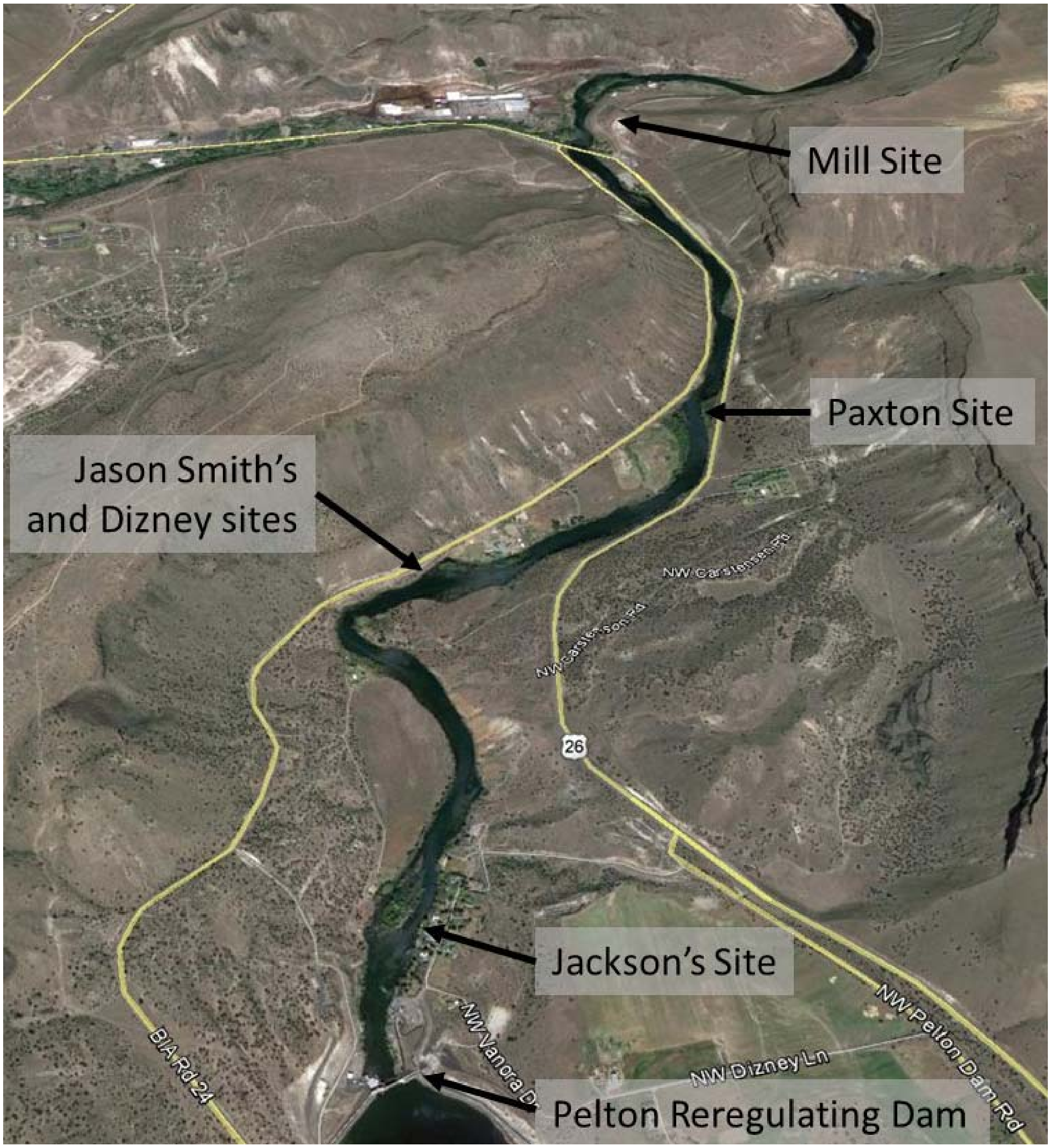
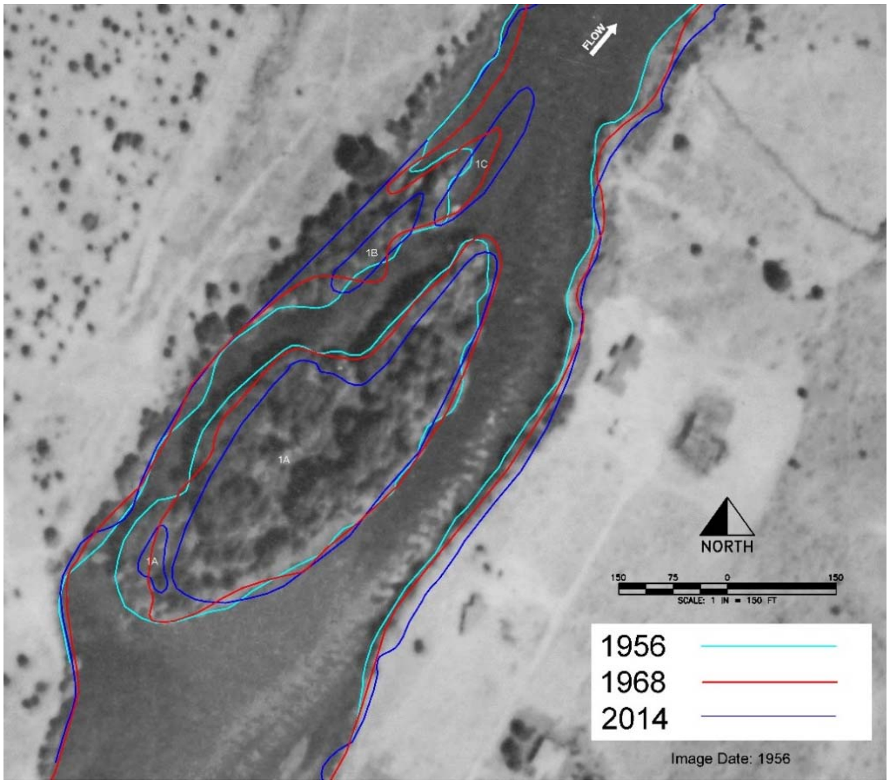
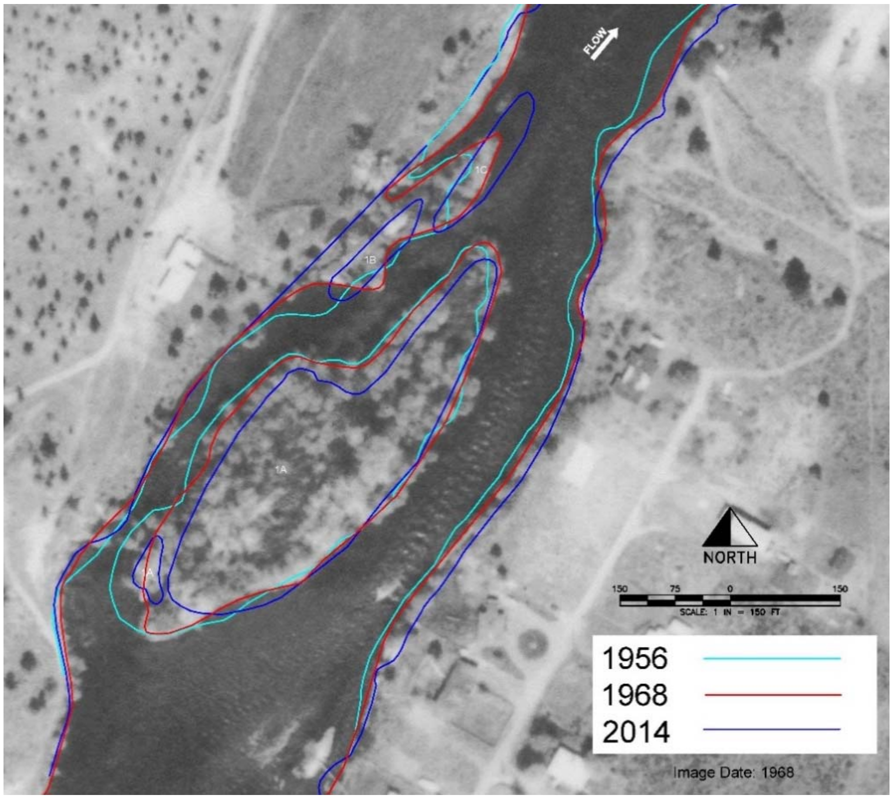
7 APPENDIX A: AERIAL PHOTOGRAPH ANALYSIS OF ISLAND AREAS IMMEDIATELY DOWNSTREAM OF PELTON REREGULATING DAM



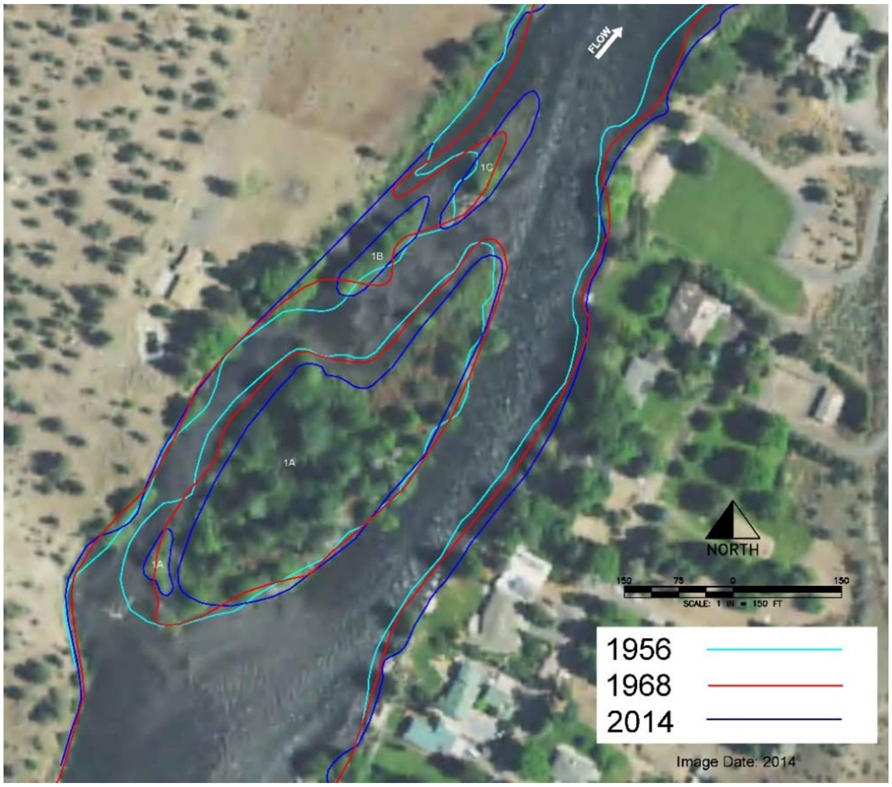
Jackson's site (center island)



1956 Photograph

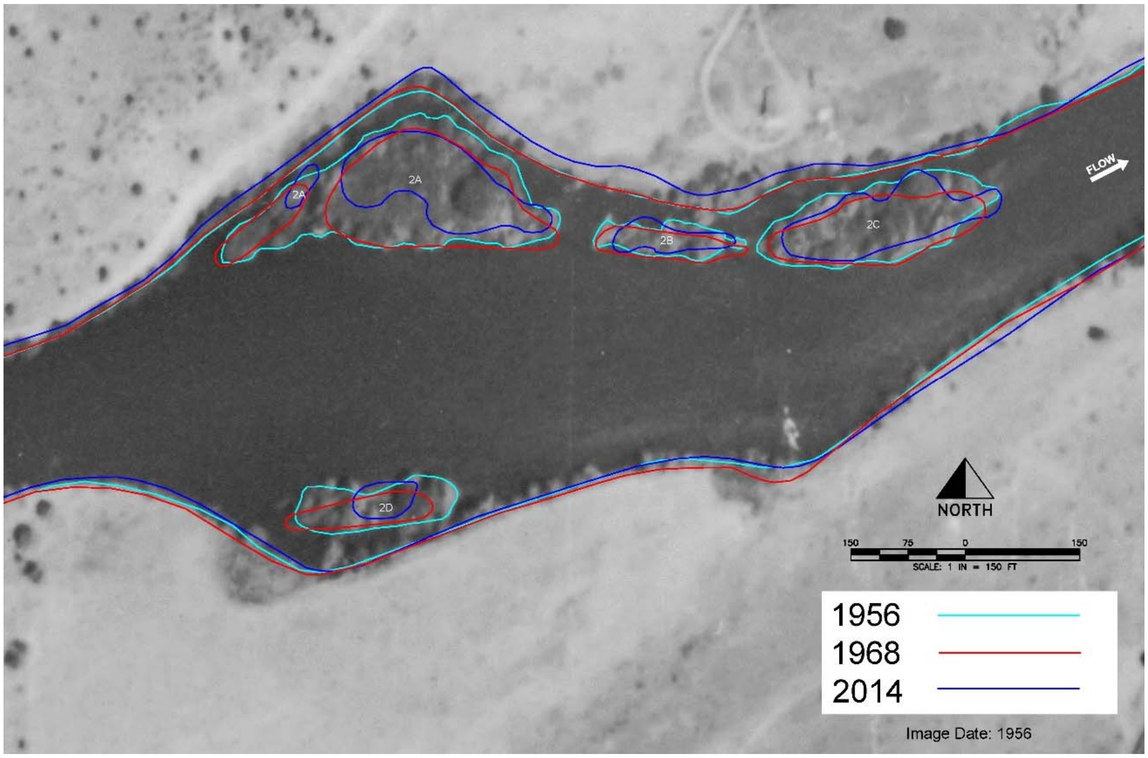


1968 Photograph

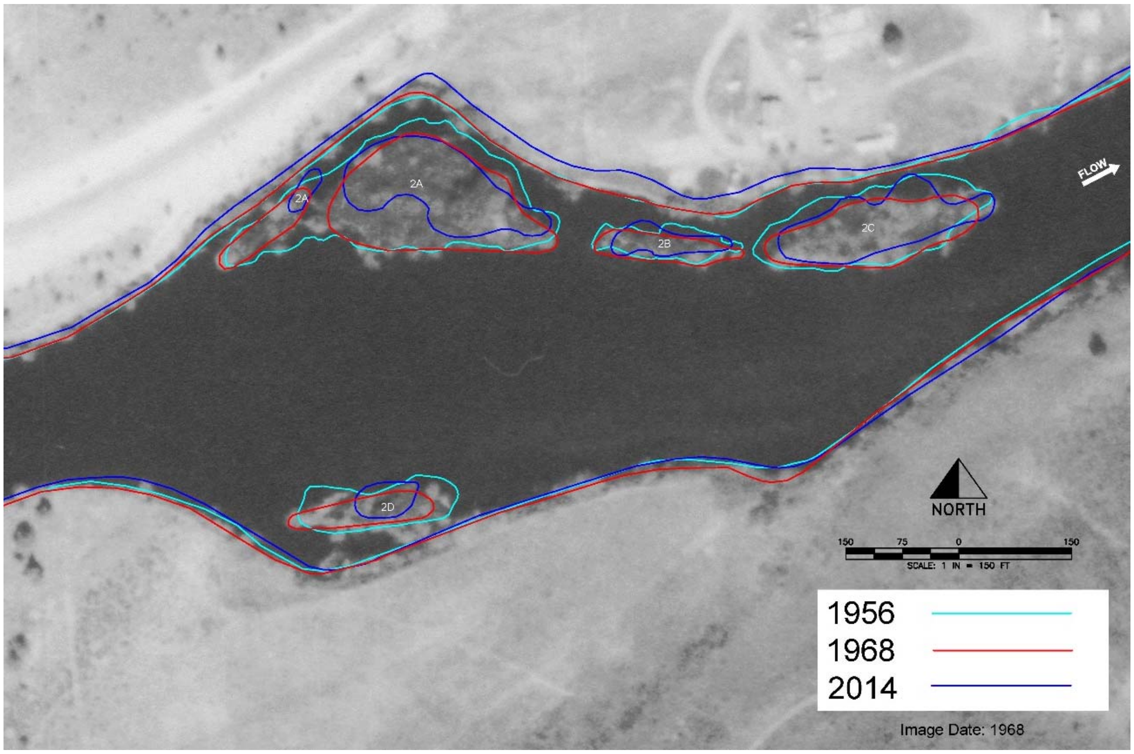


2014 Photograph

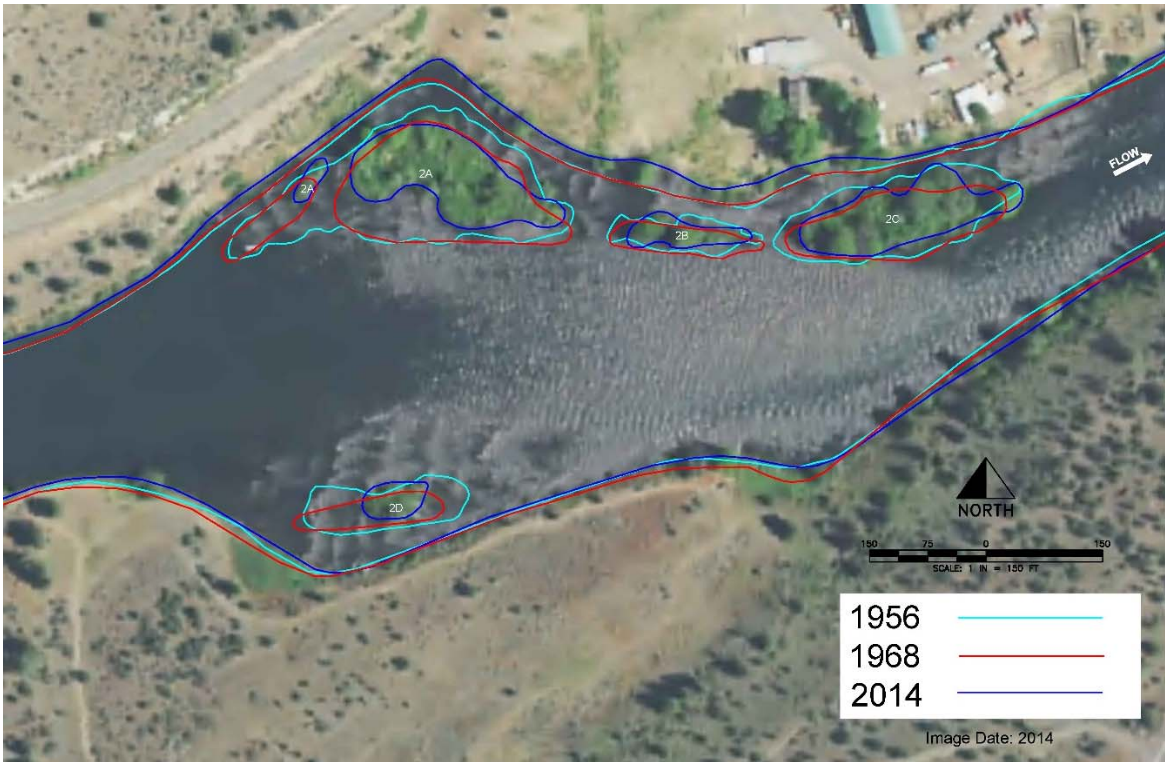
Jason Smith's site (top 3 islands) and Dizney site (bottom island)



1956 Photograph

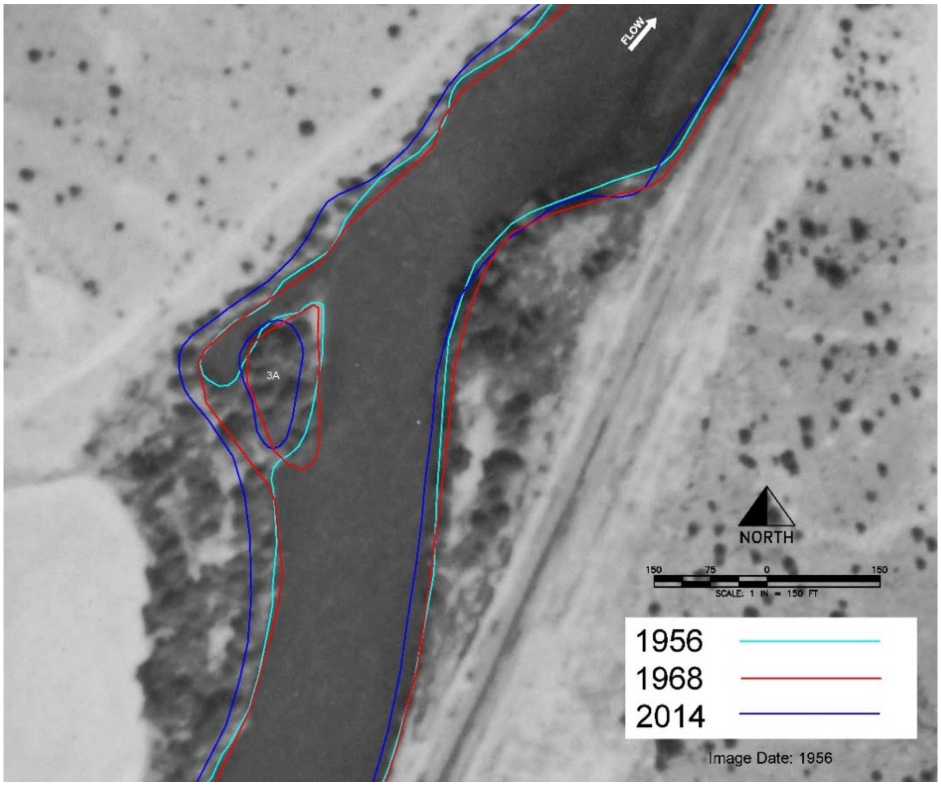


1968 Photograph

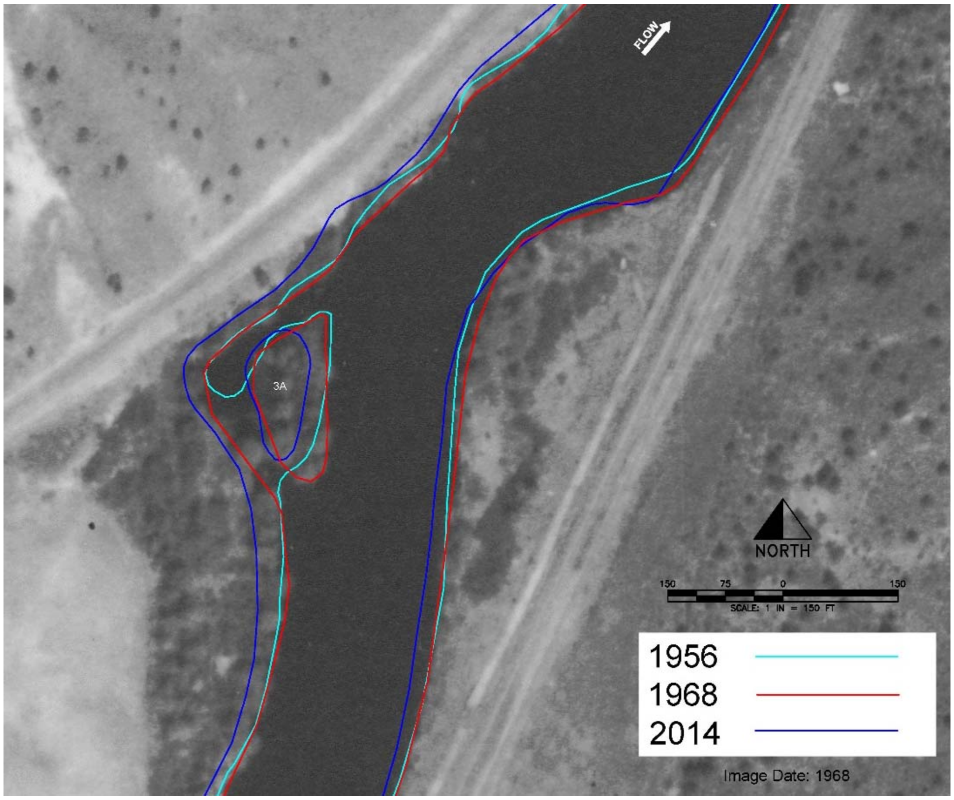


2014 Photograph

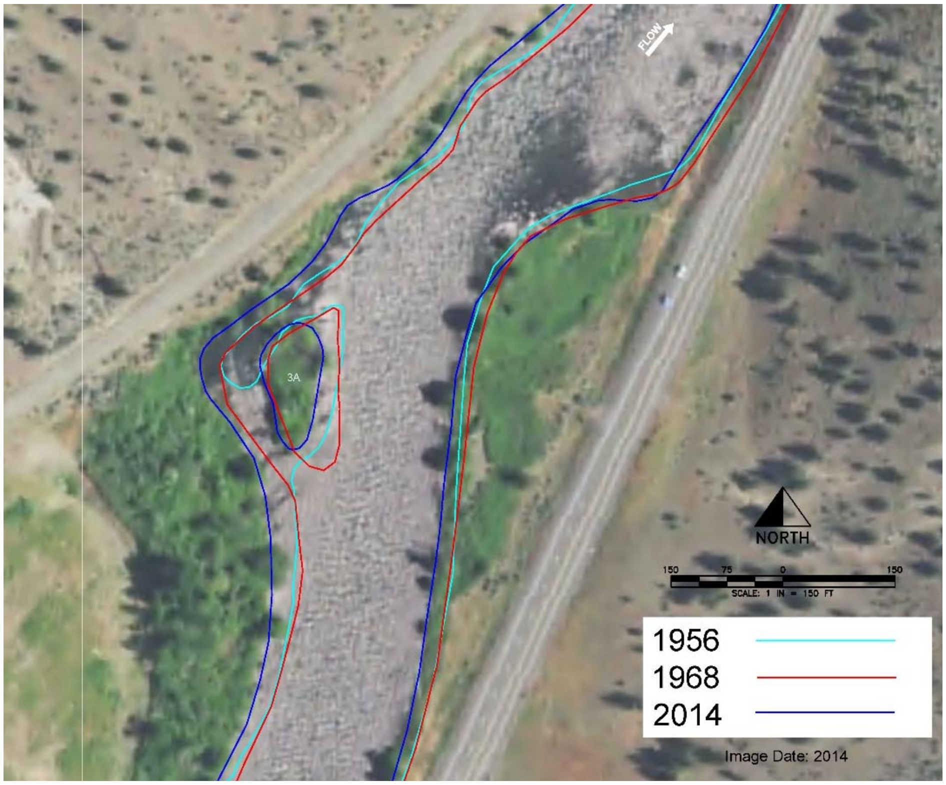
Paxton site (left island)



1956 Photograph

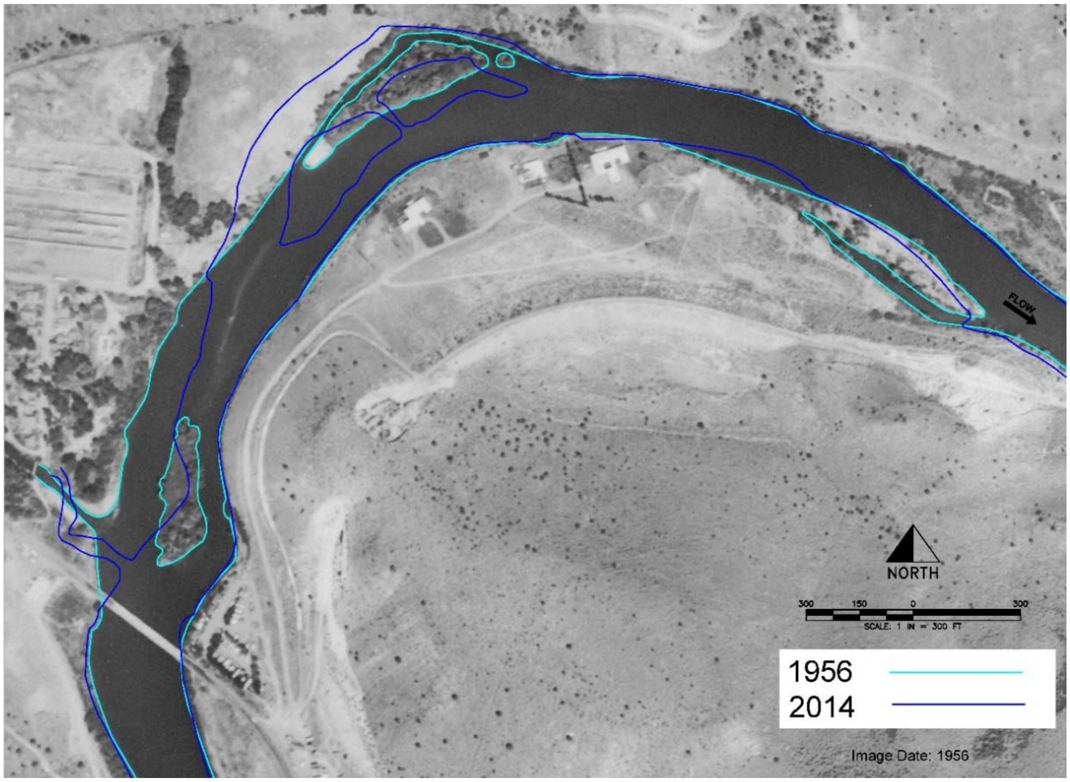


1968 Photograph

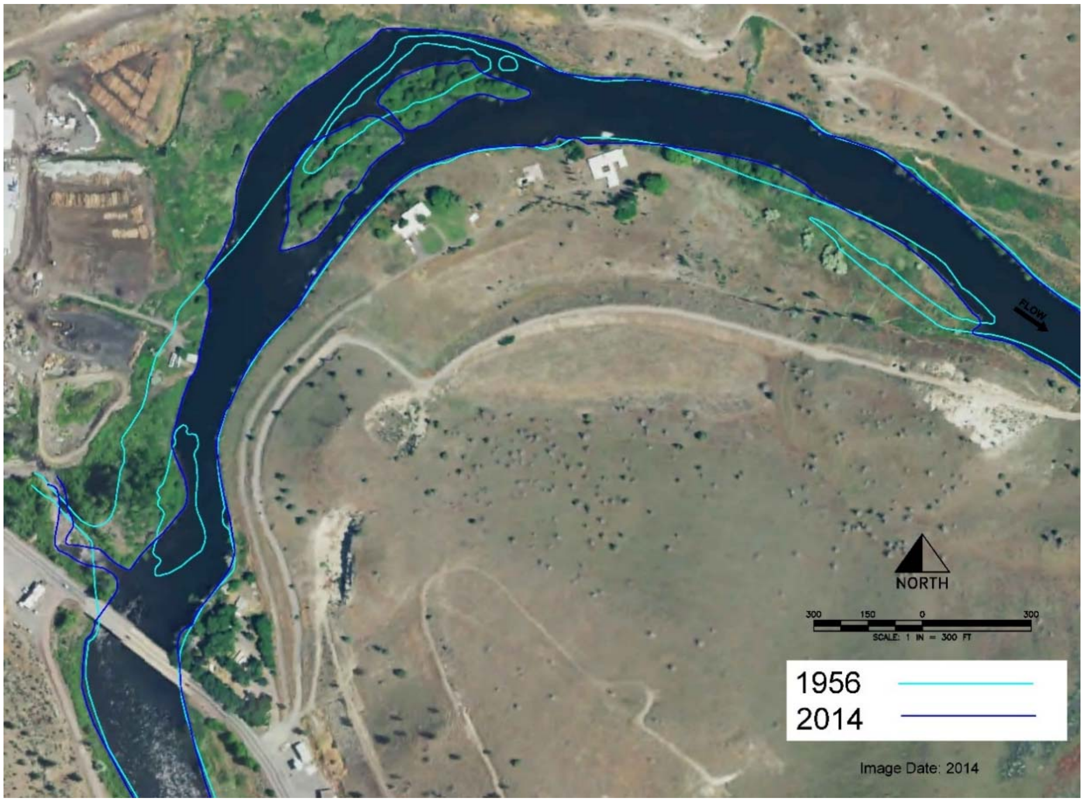


2014 Photograph

Mill site (two islands + channel migration)



1956 Photograph



2014 Photograph