Brownsville and Savage Rapids Dam Removal Effectiveness Monitoring

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Prepared by:
Desiree Tullos, Ph.D., PE
Biological and Ecological Engineering
Oregon State University
116 Gilmore Hall
Corvallis, OR 97331

Brownsville Dam (pre-removal)   Brownsville Dam (post-removal)

Savage Rapids Dam (pre-removal)   Savage Rapids Dam (post-removal)
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Introduction and Project Objectives

Background and project objectives
The often-dramatic channel changes following the removal of dams continue to intrigue scientists and water resources managers for both practical and academic reasons. Uncertainty exists regarding both the physical and ecological responses, though experience with and literature on (e.g., most recently Sawaske and Freyberg 2012, Major et al. 2012) dam removal is growing. This project is intended to contribute to this growing experience and knowledge on the physical and ecological responses to dam removal, with the specific objective of documenting dominant geomorphic, biological, and socio economic processes and responses to the Brownsville and Savage Rapids dam removals. Our research strategy included paired observations made prior to, during, and following the removals. While there is some variability in the methods and data collection at the two sites, observations generally included streamflow, bathymetry, substrate, benthic macroinvertebrates, and fish. In addition, a socio-economic study was performed at Brownsville dam removal and vegetation surveys were conducted in the former reservoir behind Savage Rapids dam. The results of the work have been published in peer-reviewed journals, student graduate theses and dissertations, at scientific conferences, at watershed council open houses, and online (See Appendix A for list of publications and presentations).

General site descriptions
The rivers basins and barriers (Brownsville Dam and Savage Rapids Dam) of the two study sites represent a range of the sizes present in Oregon (Table 1). The Calapooia River is one of the thirteen major tributaries of the Willamette River in the middle of the while the Rogue River is one of the major rivers in southern Oregon (Figure 1). Common features of the sites are that a) none of the downstream reaches were supply limited, b) all barriers were run-of-river projects, c) all barriers passed sediment, d) cohesive fines were absent or very low in upstream sediments, and d) stored sediment was composed primarily of resistant gravel. Each upstream reach stored the equivalent volume of approximately one to two years of sediment yield from the basin.

Extent of the study area varied between each site. At Brownsville dam, the study area included the reservoir (~385m), two consecutive 670 m (20 active channel widths) reaches downstream of the dam, and one 640 m control reach 1.6 km upstream of the dam. The Savage Rapids Dam survey area included a control reach starting 5.7 km upstream of the dam just below where Evans Creek flows in, the reservoir (~ 2500 m) and 20 km downstream to the confluence with the Applegate River.
Table 1: Site characteristics

<table>
<thead>
<tr>
<th>Site</th>
<th>Drainage area above barrier (km$^2$)</th>
<th>Year removed</th>
<th>Barrier height (m)</th>
<th>Active channel width (m)</th>
<th>Avg. Width: Depth</th>
<th>Slope (m/m)</th>
<th>Stored sediment volume (m$^3$)</th>
<th>D50$^R$ / D50$^D$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brownsville</td>
<td>404</td>
<td>2007</td>
<td>2.5</td>
<td>35</td>
<td>34</td>
<td>0.002</td>
<td>17,000</td>
<td>1.5</td>
</tr>
<tr>
<td>Savage Rapids</td>
<td>6369</td>
<td>2009</td>
<td>12</td>
<td>90</td>
<td>21</td>
<td>0.0026</td>
<td>543,000</td>
<td>0.18</td>
</tr>
</tbody>
</table>

Figure 1: Site locations

Brownsville Dam

Brownsville Dam was located on the Calapooia River, which runs east to west from Tidbits Mountain in the Western Cascade Range to the Willamette River at Albany, Oregon. The headwaters of the Calapooia River are comprised of steep (gradient of 0.44 to 1.94%) and highly dissected terrain consisting of basalt and andesite (Sherrod and Smith, 2000) and predominately private forest land use (Runyon et al 2004). Average annual precipitation in this area is 173 cm and falls primarily as rainfall between November and May.
Brownsville Dam was located, at RM 62, in a wider section of the valley with lower gradients (0.10 to 0.44%), a wider (35 m) active channel, and land comprised predominantly of agricultural and low-density urban uses. The dam was a 33.5 m long and 4.3 m wide concrete shell filled with sand and gravel with a hydraulic height of 1.8 m in winter and 3.4 m in summer with flash boards in place. The dam was removed in August 2007 in two stages: 1) A 4.5 m long section was removed with a jackhammer and excavator on river right (north side); 2) Flow was diverted into the breach and the remainder of the dam was removed behind a cofferdam (Martin, 2007). During removal of the dam, a historical log crib dam was found beneath the concrete dam but was not removed.

**Savage Rapids Dam**

Savage Rapid dam was located on the Rogue River, which flows east to west from springs on Mount McLoughlin in the Cascade Range near Crater Lake through the Klamath Mountains to the ocean at Gold Beach, Oregon. The majority of the basin, except for in the headwaters where the river runs through Western and High Cascade volcanic geology (Cenozoic basaltic and andesitic rocks), is in the Klamath Mountain Accretionary Complex, which is composed of ophiolitic sequences and granitic, gabbro, meta-sedimentary, and meta-volcanic rocks (VanLaningham et al., 2008). Discharge for the Rogue River is rainfall-dominated, with approximately 1400 mm falling mainly between December and March with snow secondary (Jones et al. 2011). The majority of the basin is forested with small percentages of land in agriculture and urban areas.

Savage Rapids Dam was located at RM 107.6 in the lower part of the middle Rogue River basin, with a gradient of 0.14% (Jones et al. 2011) and active channel width of 90 m. Built in 1921 for an irrigation diversion, Savage Rapids Dam was a combination gravity and multiple arch concrete dam, a 152 m long spillway crest containing 16 bays including two 2.1 by 4.9 m radial gates (bays 10 and 11), a fish ladder on each side of the river, and a pumping plant with fish screens on the river right (north side) (USBR, 2001). During the non-irrigation season (mid-October to mid-May), the hydraulic height of the dam was 9.1 m and the dam created a backwater pool stretching 800 m upstream (USBR, 2001). “Stoplogs” were added for the irrigation season and increased the hydraulic height to 12.5 m and the backwater pool to 4000 m upstream of the dam (USBR, 2001). The dam was removed from June-October 2009, by first removing the nine bays on the north (river right) side of the river as well as both fish ladders in a dewatered section behind a cofferdam, and then creating a pilot channel on river right and decommissioning and removing remaining infrastructure on river left (USBR, 2009).
Methods

Field measurements

Brownsville Dam

Data collection for monitoring associated with the Brownsville Dam removal consisted of photo points in the reservoir, habitat surveys, topographic surveys, macroinvertebrate sampling, sediment sampling, and discharge gaging from 2007 (pre-removal) to 2009 (two years post-removal). Photos were taken from the north dam abutment facing upstream and downstream annually (Appendix B). As part of habitat surveys following the protocols of the Oregon Department of Fish and Wildlife’s Aquatic Inventory Project, channel units (riffles, pools, runs, and glides) were delineated within each reach annually at low flow (Moore et al., 1999) (The Calapooia River as primarily a wadeable river, was surveyed annually at low flow using a total station (Nikon DTM 352) and real time kinetic (RTK) global positioning system (GPS) (Topcon GR-3). Cross sections for the topographic surveys were located at the top, bottom, and two evenly spaced within each channel unit. Surveys also included a longitudinal profile and bar mapping.

Macroinvertebrate sampling occurred over one day annually at low flow following the U.S. Environmental Protection Agency’s (EPA) Environmental Monitoring and Assessment Program (EMAP) wadeable protocol (Peck et al., 2001) with three randomly located samples per riffle for three riffles per reach for both downstream reaches and the upstream control reach. These samples include 1m$^2$ kick net samples, collected in riffles by disturbing sediment in a 1m by 1m area in front of the kick net for 60 seconds. Samples were collected on July 18, 2007, August 4, 2008, and July 14, 2009, field-preserved in ethanol, and counted and identified at a laboratory in the Department of Fisheries and Wildlife of Oregon State University following Caton, 1991. Aquatic insects were identified to genus with the exception of Simuliidae that were left at family, and Chironomidae and Ceratopogonidae that were identified to subfamily or tribe. Non-insects were identified to the finest practical level, varying from class (e.g. for free-living flatworm) to genus (e.g. for amphipods and snails).

Figure 2). The habitat surveys included data collection on valley and stream geomorphic features at the reach and unit level including channel and valley form, riparian vegetation, land use, unit type and characteristics (length, width slope, shade, active channel height, active channel width, depth, substrate, bank erosion, etc.), and wood volume and distribution.

Table 2: Dates of data collection for Brownsville Dam

<table>
<thead>
<tr>
<th>Data collected</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Habitat</td>
<td>7/26, 8/10, 8/13, 9/4</td>
<td>9/2-9/5</td>
<td>8/6-8/7</td>
</tr>
<tr>
<td>Topography</td>
<td>8/15-8/29</td>
<td>7/28-8/29</td>
<td>8/10-10/4</td>
</tr>
<tr>
<td>Macroinvertebrates</td>
<td>6/18</td>
<td>8/4</td>
<td>7/14</td>
</tr>
<tr>
<td>Sediment</td>
<td>8/29, 9/3-9/4</td>
<td>8/19-8/21</td>
<td>7/13-7/14</td>
</tr>
</tbody>
</table>
The Calapooia River as primarily a wadeable river, was surveyed annually at low flow using a total station (Nikon DTM 352) and real time kinetic (RTK) global positioning system (GPS) (Topcon GR-3). Cross sections for the topographic surveys were located at the top, bottom, and two evenly spaced within each channel unit. Surveys also included a longitudinal profile and bar mapping.

Macroinvertebrate sampling occurred over one day annually at low flow following the U.S. Environmental Protection Agency’s (EPA) Environmental Monitoring and Assessment Program (EMAP) wadeable protocol (Peck et al., 2001) with three randomly located samples per riffle for three riffles per reach for both downstream reaches and the upstream control reach. These samples include 1m$^2$ kick net samples, collected in riffles by disturbing sediment in a 1m by 1m area in front of the kick net for 60 seconds. Samples were collected on July 18, 2007, August 4, 2008, and July 14, 2009, field-preserved in ethanol, and counted and identified at a laboratory in the Department of Fisheries and Wildlife of Oregon State University following Caton, 1991. Aquatic insects were identified to genus with the exception of Simuliiidae that were left at family, and Chironomidae and Ceratopogonidae that were identified to subfamily or tribe. Non-insects were identified to the finest practical level, varying from class (e.g. for free-living flatworm) to genus (e.g. for amphipods and snails).

Figure 2: Map of types and locations of data collected for the Brownsville Dam removal
Sediment sampling occurred annually at low flow as a combination of bulk samples (Rosgen, 1996) and pebble counts (Wolman, 1954). Bulk samples were collected and wet sieved at two bars and riffles for each reach (except the reservoir with no riffles) in 2007, and just at bars in 2008 and 2009. Pebble counts were performed at two to three riffles and bars per reach in 2008 and 2009.

Since the USGS has not gaged the Calapooia River since 1990, we installed a pressure transducer (vented Stevens PS 60) 5 km downstream from Brownsville Dam and approximately 30 m downstream of Brownsville Bridge near the town of Brownsville (Figure 1) (Buchanan and Somers, 1968). Starting September 29, 2007, we recorded water height in the Calapooia River every 15 minutes with a few gaps due to equipment failures. We built a rating curve to relate the water heights to discharge by taking wading and bridge based discharge measurements over a range of flows using USGS protocols (Figure 3) (Buchanan and Somers, 1969; Kennedy, 1984; Rantz et al., 1982a; Rantz et al., 1982b).

**Figure 3: 15 minute discharge for the Calapooia River at Brownsville Bridge**

In addition, a socio-economic study was conducted to evaluate the community impacts of the Brownsville Dam Removal. Two primary questions were investigated: 1) how has the Brownsville Dam removal affected the social and economic conditions of the community and 2) what indicators can be used to characterize and monitor the impacts? Twenty-nine semi-structured interviews were conducted with four community affiliations: 1) Canal Company
members; 2) Calapooia Watershed Council members; 3) City Officials; and 4) community residents.

**Savage Rapids Dam**

Data collection on the Rogue River for monitoring changes associated with the removal of Savage Rapids Dam included annual non-wadeable EMAP physical habitat (PHAB) measurements, bathymetric surveys of the main channel, topographic surveys of bars and the reservoir, sediment sampling on bars, and photo points and vegetation surveys in the reservoir (Table 3, Figure 4). The EMAP surveys consisted of 4 reaches (2 above the dam and 2 below the dam) with 11 transects collecting data on fish (size and species identification), macroinvertebrates, substrate, thalweg depth, riparian condition, and water chemistry. The only major deviation from the EMAP protocols is that benthic macroinvertebrate samples were not composited in order to evaluate within site variability for evaluating significance of any reach-scale changes.

Since the Rogue River is primarily non-wadeable, the main channel was mapped from a boat as a series of longitudinal profiles (1-3) using a Teledyne RD Instruments Workhorse Rio Grande Acoustic Doppler Current Profiler (ADCP) with network RTK GPS. Pre-removal bathymetry was collected by the U.S. Bureau of Reclamation in 1999 and 2002. Topography of bars and wadeable areas was surveyed by taking points at slope breaks using RTK GPS. Sediment was sampled on all bars surveyed using pebble counts (Wolman, 1954) of the margin, bottom third, or entire bar. Photos were taken annually from six locations to capture the reservoir, dam, and immediately downstream (Appendix B). Reservoir vegetation was sampled in randomly selected 1m² quadrats along ten transects across the reservoir. The dominant grain size class was noted for each sampling frame.

**Table 3: Dates of data collection for Savage Rapids**

<table>
<thead>
<tr>
<th>Data collected</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMAP</td>
<td>9/24-9/26</td>
<td>7/29-7/30</td>
<td>8/17-8/19</td>
<td>7/25-7/27</td>
</tr>
<tr>
<td>Bathymetry</td>
<td>--</td>
<td>--</td>
<td>8/17</td>
<td>6/14, 6/17, 6/27</td>
</tr>
<tr>
<td>Bar topography and sediment sampling</td>
<td>9/25</td>
<td>9/14-9/17</td>
<td>9/7-9/9</td>
<td>9/6-9/8, 10/11</td>
</tr>
<tr>
<td>Reservoir topography</td>
<td>--</td>
<td>4/8, 11/10</td>
<td>2/25, 9/7-9/8</td>
<td>2/10, 9/6-9/8</td>
</tr>
<tr>
<td>Photo points</td>
<td>--</td>
<td>9/17</td>
<td>2/25</td>
<td>7/13</td>
</tr>
<tr>
<td>Vegetation</td>
<td>--</td>
<td>--</td>
<td>7/6-7/8</td>
<td>7/11-7/13</td>
</tr>
</tbody>
</table>

**Figure 4: Location and types of data collected for Savage Rapids: a. 2009, b. 2010, c. 2011**
Analysis

All field data underwent extensive post-processing and validation. In addition, individual datasets were analyzed using approaches appropriate to each dataset.

For example, we analyzed field observations of channel bathymetry in three ways: 1) longitudinal changes in thalweg elevation and D50, 2) differencing Digital Elevation Model (DEM) surfaces, and 3) longitudinal changes in sediment volumes relative to impounded sediment derived from the differenced DEMs. In order to analyze elevation changes relative to pool and riffle locations, we plotted thalweg elevation and median grain size with distance downstream.

For differencing DEMS, we created and compared error-filtered DEM surfaces using Geomorphic Change Detection (GCD) software and approach (Wheaton et al. 2010). Surfaces were first created from error-checked survey points in ESRI’s ArcMap10 as Triangular Irregular Networks (TINs) interpolated using Delauney Triangulation and linearly resampled to a regular grid with a 1 m cell size for subsequent analyses. For each site, each post-removal surface was subtracted on a cell by cell basis from the pre-removal surface in order to create a differenced DEM of cumulative post to pre changes in channel elevation. To calculate the uncertainty in the change in elevation for each grid cell, we applied Wheaton et al.’s (2010) default Fuzzy Inference System (FIS) for elevation uncertainty based upon point density and slope. This spatially variable error surface was then used to threshold the differenced DEM at the 95%
confidence interval to remove any cells with elevation changes below their error values. Because geomorphic change typically occurs in a spatially contiguous fashion, we subsequently applied a “spatial coherence” filter to the error-thresholded DEM to add back in cells with elevation change values below the error threshold but consistent with the type of change (erosion or deposition) of a 5 by 5 window of neighboring cells. Finally, to calculate volume and net depth of erosion and deposition, we used surface masks to clip the thresholded DEM, with spatial coherence, into consecutive sections of one channel width lengths.

We evaluated volumetric changes relative to a pre-dam surface. In the absence of pre-dam channel data for any of the sites, we estimated the upstream pre-dam channel surface by constructing trapezoidal cross sections with thalweg elevations based upon the equilibrium slope or sediment depth data, and banks based upon pre-removal surveys. For Savage Rapids, the pre-barrier surface within the first 870 m upstream from the dam was created by the U.S Bureau of Reclamation as part of a pre-removal study where sediment depths were determined by drilling (USBR, 2001). For Brownsville, sediment depth was determined with seismic refraction by Northwest Geophysical Associates at three lines within the first 120 m upstream of the dam. Upstream of drilling or seismic data at Savage Rapids and Brownsville, the pre-dam thalweg was also based upon the equilibrium slope. Thus, net changes in volume are calculated for the reservoir as two sets of surfaces: 1. "Pre-dam" surface vs. pre-removal surface for the pre-removal estimates, and 2. pre-removal surface vs. each post-removal surface for the post removal volume estimates. In contrast, net volume changes are presented for the downstream reach only as pre-removal surface vs. each post-removal surface.

Analytical approaches for habitat data followed those outlined by the EMAP and ODFW habitat inventory protocols. To investigate changes in the benthic macroinvertebrate community, we calculated the species richness as the number of species at the genus taxonomic level. Each species was also assigned functional traits (Poff et al. 2006), and the distribution of functional traits at each site was plotted over time. We estimated the percentage of each functional trait in each sample by first calculating species richness for each sample unit (SU) and then calculating the fraction of taxa with each functional trait in the SU. That is, we multiplied a matrix of species richness for each SU by a binary matrix of functional to yield a matrix of the fraction of functional traits present at each SU.

Results of the socio-economic interviews were summarized in a master’s thesis and were used to develop a matrix of impacts and indicators specific to small dam removal. A participatory social impact assessment (SIA) approach was used to validate existing and/or emergent impacts and indicators. The local impacts and indicators were operationalized and measured. Also part of this project, a geo-referenced database of PNW dam removals was generated based on a comprehensive literature review.
Summary of Results

Bathymetry and substrate

In the cases of both the Brownsville and Savage Rapids dam removal, channel response was rapid and included an initial period of channel change followed by a period of channel recovery. More detailed documentation of channel responses are given in Walter (2009), Walter and Tullos (2009), Kibler (2011), Kibler et al. (2011a), Kibler et al. (2011b), and Tullos et al. (forthcoming).

Following the Brownsville dam removal, sediment was rapidly evacuated from the reservoir, as indicated by the differences in the thalweg profiles between the pre-removal and first post-year survey (
Figure 5a). Material continued to erode over the following year, though the log crib dam acted as a grade control to limit the extent of total incision. The eroded sediment deposited within the first ~600 m downstream of the dam, with little detectable change in the channel beyond this distance. One year after dam removal, substrates of bars and riffles within 400 m downstream of the dam coarsened and a dominance of gravel and cobble sediments replaced previously hardpan substrate. New bars formed and existing bars grew (Figure 6a) such that bar area and volume increased substantially, and a pool-riffle structure formed where plane-bed glide formations had previously dominated. The sizes of these structures were reduced in the subsequent years as some of the sediment was eroded during winter flows and relative grain size (
Figure 5a) also decreased in the second year following dam removal. Based on relative changes in eroded and deposited volumes (Figure 7a), the gravel wave appears to have decayed in place, rather than translated downstream (Lisle 2008).

Following the Savage Rapids dam removal, reservoir sediments eroded just upstream of the dam during the first survey period (
Figure 5b). Subsequent surveys illustrate how the erosive front migrated upstream during higher flows in 2011 (Figures 5b, Figure 6b). In the first year following removal, the first pool downstream of the former dam was filled with sediment, whereas the second pool was filled by 2011 (}
Figure 5b). The development of depositional features, as was seen at Brownsville, was not evident downstream of the former Savage Rapids Dam. Relative volume changes (Figure 7b) illustrate that both dispersion and translation may have occurred at the Savage Rapids site, with the peak of erosion moving downstream over time.
Figure 5: Longitudinal profiles and D50 for a) Brownsville, and b) Savage Rapids
Figure 6: Bed elevation changes based on geomorphic change detection analysis for a) Brownsville, and b) Savage Rapids.
Figure 7: Net longitudinal changes in volume relative to impounded sediment for a) Brownsville, and b) Savage Rapids.
Benthic macroinvertebrates.

At the Brownsville site, the richness of the benthic macroinvertebrate community (Figure 8a) increased at all sites in each subsequent year. Because the richness varied more by year across all sites, including control, than in the upstream-downstream direction, it appears that the richness was more strongly influenced by annual variability in streamflow, temperature, and other environmental factors than by any changes in habitat induced by the dam removal. Similarly, functional traits (Figure 8b) did not
strongly vary between upstream and downstream sites (Figure 9a). The lack of increase in disturbance-related traits (e.g. multi-voltinism, smaller size, higher mobility, fast development, armoring, etc.) indicates that the dam removal did not act as an ecological disturbance (sensu Resh et al. 1988) in the timeframe represented by our samples.

At the Savage Rapids Dam removal site, richness of the benthic macroinvertebrate community (Figure 8b) declined at all sites, including the control, in the first year post-removal. Subsequent years show no clear pattern of increase or decrease in richness. Functional traits do not appear to vary substantially in an upstream-downstream direction, and the presence of disturbance-related traits does not appear to increase in the downstream reaches (Figure 9b). Similar to the Brownsville site, these results offer no evidence that the removal of Savage Rapids dam introduced an ecologically-significant disturbance.

**Figure 8: Richness of benthic macroinvertebrate samples at a) Brownsville, and b) Savage Rapids**
Figure 9: Functional traits of benthic macroinvertebrate community at a) Brownsville, and b) Savage Rapids.

**Fish**

The fish community in the Rogue River was sampled in an upstream-downstream design prior to and following the removal of Savage Rapids dam. We present the results tabulated by the species list (Table 4) and as percent native (Figure 10). From the species list (Table 4), we find no clear evidence for an effect of the dam report in the variability in community composition or abundance over time or in space. Sample abundance is consistently higher in the sites above the dam, though abundance is not a reliable measure of the effect of the dam or its dam removal. Richness is a more robust measure and shows no pattern in space or time. No trend is apparent in the percent native species (Figure 10) for the site above the dam, but it appears to increase with time since the dam removal at the below above the dam.

Table 4. Species list for fish sampling above and below the former Savage Rapids dam on the Rogue River.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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</thead>
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<td>CHINOOK SALMON</td>
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<td>1</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>LARGEMOUTH BASS</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>PUMPKINSEED</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>RAINBOW TROUT</td>
<td>11</td>
<td>3</td>
<td>83</td>
<td>23</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>REDSIDE SHINER</td>
<td>71</td>
<td>2</td>
<td>50</td>
<td>43</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>RETICULATE SCULPIN</td>
<td>37</td>
<td>0</td>
<td>163</td>
<td>60</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>SPECKLED DACE</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>26</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>UMPQUA PIKEMINNOW</td>
<td>32</td>
<td>22</td>
<td>73</td>
<td>203</td>
<td>12</td>
<td>26</td>
</tr>
<tr>
<td>UNKNOWN SUNFISH</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>YELLOW PERCH</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

| Abundance | 178 | 28  | 431 | 394 | 95  | 65  |
| Richness  | 10  | 4   | 15  | 14  | 8   | 9   |
Vegetation surveys were conducted in the former reservoir at Savage Rapids during the first 2 years post removal (2010 and 2011). 1X1 meter plots (quadrats) were sampled along 10 cross sections (see Figure 12). Information collected included dominant substrate type, stem counts of all present woody species, % cover of the 5 most dominant species, and a complete account of species present. A summary of changes in vegetative cover from 2010 to 2011, broken down by plot and cross section, is shown in Figure 13. Vegetative cover increased slightly in many plots already containing vegetation, but many un-vegetated plots from 2010 remained un-vegetated in 2011, indicating a slow colonization of vegetation in the sediments of the former reservoir. Contrary to expectations, overall vegetation patterns were similar in 2010 and 2011.
Figure 11. Vegetation survey locations in the former reservoir at Savage Rapids.

Quadrat labels on the left bank start at the upland quadrat (Q1L) and progress to the riparian quadrat (Q5L in this case). A similar naming convention was used on the right bank, and for each cross section. Each quadrat in XS1 is labeled above, but remaining labels are excluded for clarity.
Figure 12. Vegetative cover changes in Savage Rapids reservoir: 2010-2011.
**Socio-Economic impacts at Brownsville.**

Social and economic impacts appear to have been minimal in this case of the small dam removal at Brownsville. However, the dam removal did appear to have enhanced the capacity of the community to resolve complex decisions. Detailed results are summarized in Elston (2009).

This research suggests that when collaboration is extended beyond a unidirectional flow of information (which is often the case in a traditional SIA), issues and concerns are open to deliberation in a non-threatening arena. The Calapooia Watershed Council served as the forum through which the residents of Brownsville were able to enhance their participation in decision making. This also contributed to a learning process that in the end furthered the community’s understanding of the Calapooia River. The case also demonstrated that collective learning is a reflective process of adjustment to the changing circumstances in which the community came to perceive, interpret, and act upon their interest. With a growing number of collaborative partnerships of watershed based management, distinguishable by their decentralized, participatory engagement of stakeholders, it may be likely that these place-based mechanisms will become the nexus to the successful coordination of small dam removal deliberation in the future.

However, as is often the case with dam removal, availability of local socio-economic data at Brownsville is limited. This study demonstrates several ways in which the traditional SIA framework can be improved through the engagement of the community. This work resulted in the development of a set of common social impacts and indicators for evaluating the presence of those impacts (Table 5) at small dam removals within and outside of Oregon.
Table 5. Matrix of validated and emergent social impacts of small dam removal, with indicators for evaluation.

Bold font indicates indicators of impacts validated by respondent; the *italic font* indicates emergent indicators (i.e. not represented in a *priori* matrix). The shaded boxes represent the impact indicators most frequently mentioned by respondents.

<table>
<thead>
<tr>
<th>Health and Social Well-Being Impacts</th>
<th>Quality of the Living Environment (Livability) Impacts</th>
<th>Economic Impacts and Material Well-Being Impacts</th>
<th>Cultural Impacts</th>
<th>Family and Community Impacts</th>
<th>Institutional, Legal, Political, and Equity Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncertainty – being unsure of the effects or meaning of dam removal</td>
<td>Change in leisure and recreational activities and opportunities</td>
<td>Change in property values/real estate sales</td>
<td>Cultural integrity-degree to which local culture is respected and likely to persist</td>
<td>Changes in social tension-conflict within the community</td>
<td>Participation in decision-making</td>
</tr>
<tr>
<td>Hazard to Public Safety</td>
<td>Perceived/actual quality of the living environment</td>
<td>Replacement costs of environmental services</td>
<td>Loss of cultural or natural heritage-areas of recreational value</td>
<td>Strength of social networks</td>
<td>Fulfilled legal or regulatory obligation of administrative order</td>
</tr>
<tr>
<td>Annoyance – experiences due to disruption of life</td>
<td>Perception of personal safety, hazard exposure, and fear of crime</td>
<td>Maintenance cost alleviated/eliminated/Created a financial obligation to operate pumps</td>
<td></td>
<td>Lack of participatory involvement</td>
<td>Meeting State and Federal agency objectives</td>
</tr>
<tr>
<td>(Location for) delinquent behavior/ Elimination of location for delinquent behavior</td>
<td>Shared vision for the watershed</td>
<td>Access to public goods &amp; services/ Changes in the cost of recreation shift</td>
<td>Change in cultural traditions</td>
<td>Community identification; Sense of belonging; attachment to place; loss of community identification</td>
<td>Conflicting agency agendas</td>
</tr>
<tr>
<td>Dissatisfaction – due to failure of removal to deliver promised benefits</td>
<td>Fire Control</td>
<td>Liability risks eliminated Liability Risk Created</td>
<td>Historic structure-place of interest</td>
<td>Perceived and actual community cohesion</td>
<td>Formation of special interest groups as a result of institutional priority to certain groups</td>
</tr>
<tr>
<td>Sense of Identity/Place</td>
<td>Habitat Restoration</td>
<td>Changes to tourism industry</td>
<td></td>
<td></td>
<td>Lack of participatory involvement</td>
</tr>
<tr>
<td>Aesthetic qualities</td>
<td>Aesthetic qualities</td>
<td>Litigation</td>
<td>Aesthetic/Spiritual qualities</td>
<td>Community Safety</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Local employment opportunity</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Discussion and conclusions.**

At both of the study sites, the effects of the dam removals on the physical habitat appear to be temporary and of little to no ecological significance. The sediment released from behind the small, gravel-filled dams initially makes small changes over a short extent of the channel; Deposition lead to development and enlargement of bars downstream of Brownsville Dam but was concentrated in pools downstream of the Savage Rapids Dam. Because these small dams do not trap sediment, and thus do not modify the sediment or discharge regimes, it is reasonable to expect that, over time, the deposited sediment is likely to erode and return the channel to its pre-removal state. This sequence represents what we have observed downstream of Brownsville Dam (illustrated Figure 13).

Invertebrate richness and functional traits offer no evidence of effect of the dam removal on this trophic level of the ecosystem. Richness of fish samples at Savage Rapids similarly indicate no effect of the dam removal. Percent of the community composed of native species did increase downstream of the dam with time, whereas the percent native upstream of the dam did not similarly increase. It is possible that the dam removal triggered this trend, but the results are statistically inconclusive.

Socio-economic impacts of small dam removal also appear to be small. However, lack of data and a robust analytical framework for evaluation of impacts make the task challenging and we have introduced a new matrix of impacts for analysis at other small dam removals. Qualitative analysis indicates that, in the case of the Brownsville Dam removal, the project appears to have generated additional capacity for the community to collective resolve complex water and environmental resources problems and emphasizes the important role that watershed councils play in providing that capacity.

In summary, we have documented the physical, ecological, and socio-economic effects of the removal of the Brownsville and Savage Rapids dams. Most of the data indicate that, across all three realms, the measurable effects are negligible or transient. In future dam removal cases where site conditions are similar (e.g. small, gravel-filled dams that pass sediment), concerns regarding degradation of habitat are likely unwarranted. Socio-economic impacts are likely to vary by site but remain small. Identifying dam removals that will impose significant ecological risks remains an important area of research, though ongoing efforts are developing frameworks (Bountry et al. 2011) to make this task more manageable and the results more reliable. Further analysis is ongoing and additional publications are forthcoming.
Figure 13. Benchmark stages of channel change downstream of Brownsville Dam (Kibler et al. 2011b).
Literature Cited


Major, J.J., O'Connor, J.E., Podolak, C.J., Keith, M.K., Grant, G.E., Spicer, K.R., Pittman, S.,
Response of the Sandy River, Oregon, to Removal of Marmot Dam. U.S. Geological Survey:
Professional Paper 1792, 64 pp.


Streams “A Snapshot In Time”: Aquatic Inventory Project Training Materials and Methods

Monitoring and Assessment Program -Surface Waters: Western Pilot Study Field Operations
Manual for Wadeable Streams. EPA/XXX/X-XX/XXXX. U.S. Environmental Protection
Agency, Washington, D.C.

Poff, N.L., Bledsoe, B.P., and Cuhaciyan, C.O. 2006. Hydrologic variation with land use across
the contiguous United States: Geomorphic and ecological consequences for stream


Resh, V.H., Brown, A.V., Covich, A.P., Gurtz, M.E., Li, H.W., Minshall, G.W., Reice, S.R.,

385 pp.

Calapooia Watershed Council: Brownsville, OR.

sediment-impacted systems in the U.S. Geomorphology, 151-152, 50-58.

Sherrod D.R., and Smith J.G. 2000. Geologic map of upper Eocene to Holocene volcanic and
related rocks of the Cascade Range, Oregon. U.S. Geological Survey Geological


Appendix A: Project publications and presentations

Theses/dissertations:


Papers:

Tullos, D. and Walter, C. Patterns in and site characteristics contributing to behavior of asymmetric sediment waves following the removal of three small, gravel-filled barriers in Oregon. (in preparation, to be submitted to Earth Surface Processes and Landforms)

Tullos, D. and Cervantes, J.H.F. Impact and recovery of invertebrate and habitat changes follow the disturbance of dam removal: Evidence from three case studies in Oregon (in preparation, to be submitted to Freshwater Science)


Zunka, J., Tullos, D., and Lancaster, S. Effects of sediment pulses on bed relief in bar-pool channels (in preparation, to be submitted to Water Resources Research)


Walter, C., and Tullos, D. 2010. Downstream Channel Changes after a Small Dam Removal:

**Presentations:**


Tullos, D. 2008. Investigating geomorphic and ecological recovery following the disturbance of dam removal. Presentation to USGS.

**Posters:**


Appendix B: Photo point photos
Brownsville Dam: Facing upstream (East)
Pre-removal with flashboards: 5/26/2007 taken by CES
Pre-removal without flashboards: 8/20/2007 taken by CES
Post-removal: 9/17/2007 taken by CES
1 year post: 10/19/2008 taken by OSU
Brownsville Dam: Facing downstream (West)
After dam notching: 8/29/2007 taken by CES

Post-removal: 10/08/2007 taken by OSU
1 year post: 10/18/2008 taken by CES

2 years post: 07/13/2009 taken by OSU

3 years post: 08/24/2010 taken by OSU
Savage Rapids: Photo point 1 (Downstream edge of pumping station platform): Facing downstream

9/17/2009

11/10/2009

2/25/2010

7/13/2011
Savage Rapids: Photo point 1 (Downstream edge of pumping station platform): Facing upstream
9/17/2009

11/10/2009

2/25/2010

7/13/2011
Savage Rapids Photo point 2 (Upstream edge of pumping station platform): Facing downstream

9/17/2009

11/10/2009

2/25/2010

7/13/2011
Savage Rapids Photo point 2 (Upstream edge of pumping station platform): Facing cross-stream

9/17/2009

11/10/2009

2/25/2010

7/13/2011
Savage Rapids Photo point 2 (Upstream edge of pumping station platform): Facing upstream/cross-stream
9/17/2009

11/10/2009

2/25/2010

7/13/2011
Savage Rapids Photo point 2 (Upstream edge of pumping station platform): Facing upstream
9/17/2009

11/10/2009

2/25/2010

7/13/2011
Savage Rapids Photo point 2 (Upstream edge of pumping station platform): Facing upstream/river left

9/17/2009

11/10/2009

2/25/2010

7/31/2011
Savage Rapids Photo point 3 (On ramp to pumping station platform): Facing upstream

9/17/2009

11/10/2009

2/25/2010

7/13/2011
Savage Rapids Photo point 3 (On ramp to pumping station platform): Facing cross-stream

9/17/2009

11/10/2009

2/25/2010

7/13/2011
Savage Rapids Photo point 4 (On high voltage platform with USGS monument): Facing upstream

9/17/2009

11/10/2009

2/25/2010

7/13/2011
Savage Rapids Photo point 5 (From road upstream of dam): Facing downstream
9/17/2009

11/10/2009

2/25/2010

7/13/2011
Savage Rapids Photo point 5 (From road upstream of dam): Facing cross-stream

9/17/2009

11/10/2009

2/25/2010

7/13/2011
Savage Rapids Photo point 6 (From road upstream of dam at edge of guardrail): Facing upstream

9/17/2009

11/10/2009

2/25/2010

7/13/2011