Reservoir Regulation and Vegetation in the Draw-down and Delta Zones of the Duncan Lake Reservoir, British Columbia

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What happened?

The Duncan River provides the northern inflow into Kootenay Lake and was dammed in 1967 with the Duncan Dam, the first dam that followed the Columbia River Treaty between Canada and the United States. This earth-fill dam is 40 m tall and imposes an annual 30 m (100 ft) rise and fall in the level of the upstream reservoir (Figure 1). The dam is operated to trap inflow and fill the reservoir each spring and thus attenuate the peak in order to reduce flooding downstream along the Columbia River. The reservoir is full through much of the summer, and then drawn down through the winter season, to enable hydroelectricity generation when power demands are highest. There is no hydroelectric facility at the Duncan Dam but the released water flows through seventeen hydroelectric dams downstream along the Kootenay and Columbia Rivers.

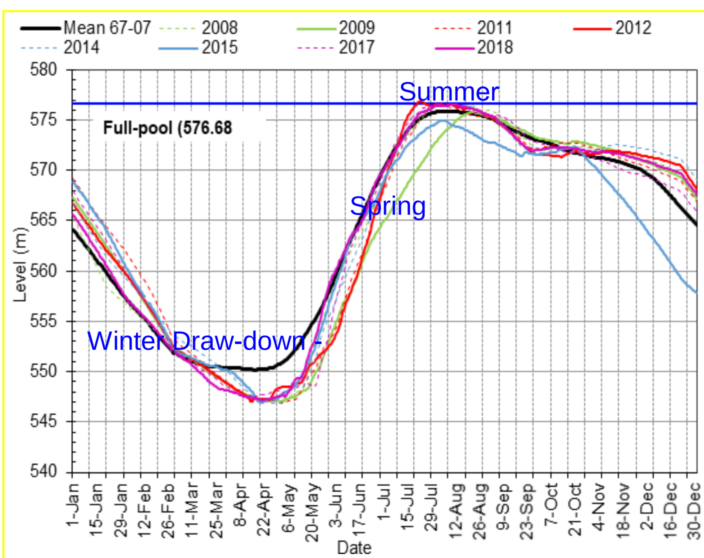

Figure 1. Annual patterns in the level of the Duncan Reservoir, with the average for the post-dam interval up to 2007, and then yearly patterns after the implementation of the new regime, Alt S73. There has been ~30 m annual fluctuation with draw-down through the winter and refilling into the summer (modified from Polzin and Rood, 2019).

What's new?

Following the Duncan Dam Project Water Use Plan (WUP), a new operational regime, Alternative S73 (Alt S73), commenced in 2008. This was intended to benefit riparian woodlands and fish along the lower Duncan River, downstream from the dam. This also resulted in changes in the patterns of reservoir draw-down and fill, which was predicted to decrease the suitability for vegetation around the reservoir. However, the actual changes in the annual patterns of reservoir drain and fill were relatively slightly changed over the decade following Alt S73 (Figure 1).

What we did.

To explore the consequences of the new, Alt S73 reservoir regime, we analyzed aerial photographs and undertook field studies in 2009, 2012, 2015 and 2018 to assess surface conditions and vegetation. We inventoried vegetation within the upper 10 m draw-down zone at 12 sites at alluvial fans from creek outflows, which would provide more favorable locations for riparian vegetation. Supporting the prediction, we found a decrease in vegetation; some areas that were sparsely vegetated in 2009 were relatively barren by 2018 (Polzin and Rood, 2019).

Species richness, the number of plant species, was highest near the full-pool shoreline and this band included shrubs and trees, including black cottonwoods (*Populus trichocarpa*). Within the draw-down zones that were inundated annually, the primitive plant, common horsetail (*Equisetum arvense*) was the most abundant species. The vegetation patterns at three year intervals are reported, and a final report coordinates the ten-year findings (Polzin et al., 2010; Polzin and Rood, 2013, 2016, 2019). These provide effective hydrogeomorphic models for vegetation cover (abundance) and richness (diversity), which consider the site locations, elevations and associated exposure durations, substrate texture and surface slope. Thus, vegetation in the reservoir draw down zones was sparse and followed somewhat predictable patterns based on the physical environment.

What was lost?

The Duncan River is within the Purcell Trench and along much of its length, steep rocky mountain slopes drop directly into the relatively narrow, 1.5 to 2 km wide river valley. Prior to damming, the valley included the 25 km long Duncan Lake, and extensive wetlands and riparian zones in the Duncan River valley downstream and especially upstream of that natural lake (Figure 2). Following damming, upstream flooding elevated the natural lake surface, and created the 45 km long Duncan Lake Reservoir ('Duncan Reservoir'). This inundated zones with the river and its biodiverse riparian floodplain, ecologically rich areas with inflows from the tributary creeks, and extensive wetland complexes with braided stream channels, shallow ponds and rich and diverse riparian woodlands. This loss of wetlands with the Duncan Reservoir was proportionally much more extensive than for the other regional reservoirs (Utzig and Schmidt, 2011).

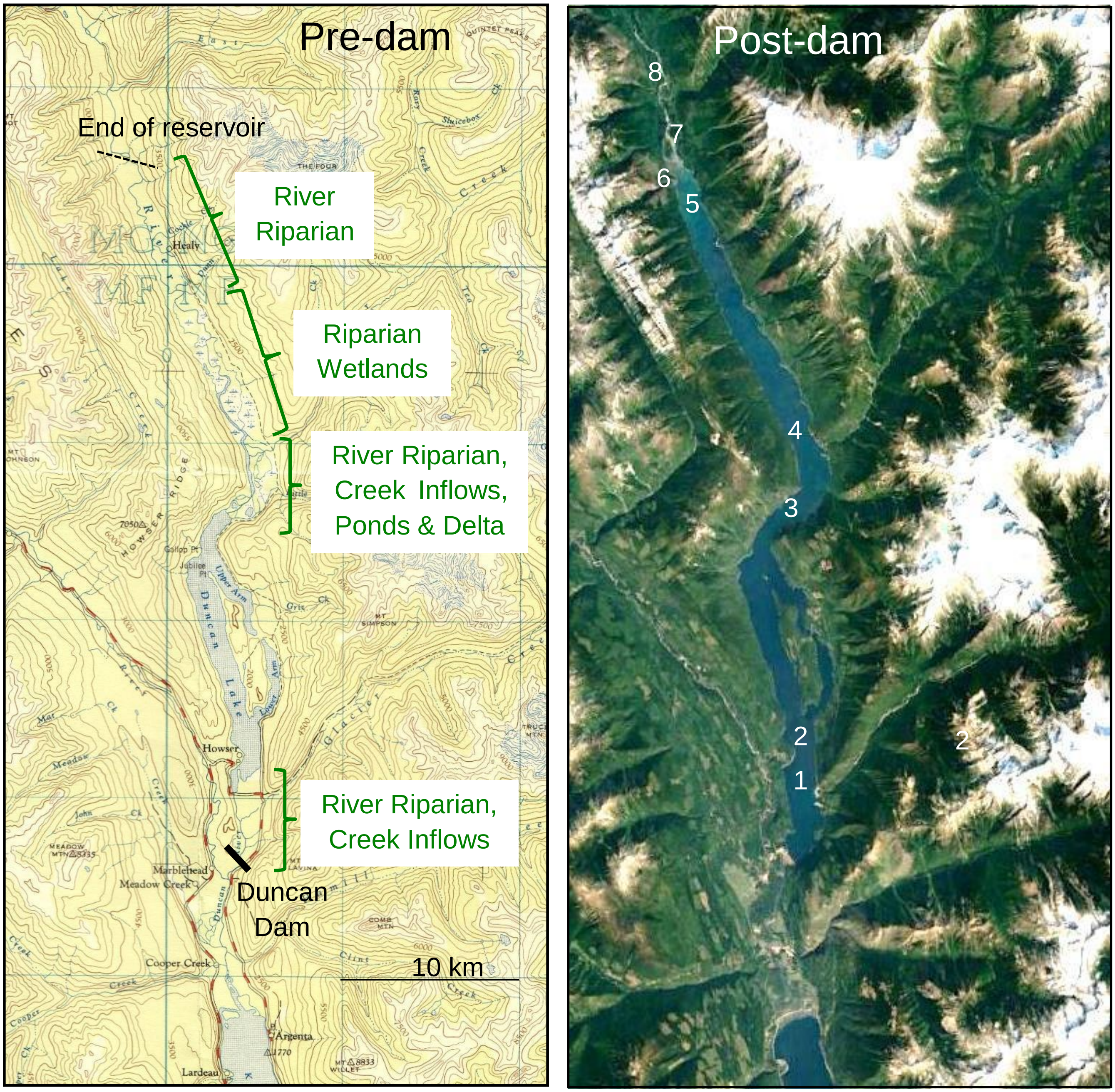

Figure 2. (left) Pre-dam conditions along the Duncan River valley displayed in the 1959 Canadian Surveys and Mapping Branch topographic map from 1953 air photos (82K Lardeau, 1:250,000, 500 ft contours) versus the filled Duncan Reservoir (Google Earth, Landsat composite, 2016), with numbers for photograph locations that follow.

What are the current conditions along the Duncan Reservoir?

Through the summer interval of July and August, when recreation use is highest, the Duncan Reservoir is near full pool, with the water approaching the ring of coniferous woodland persists around the reservoir from the pre-dam interval. The reservoir is drawn down through the autumn and especially the winter season to the lowest levels in early May and these are displayed in the ground level photos that follow, with numbering as in Figure 2.

Figure 4. Photographs of the Duncan Reservoir at full draw down (May 7, 2019). (1) The alluvial fan at Glacier Creek, with an extensive area this is only slightly below the full pool elevation. (2) Sloping bank and boat launch near the town of Howser. (3) A steep slope drops directly into the former Duncan Lake and the draw down zone provides a near-vertical bedrock band. (4) Perhaps the greatest ecological loss was the wetland zone upstream of the prior lake. Here, Howser Creek inflows from the left and will join the Duncan River along the right bank. The wetland zone was quite flat along the transverse (valley wall to valley wall) and longitudinal (along river corridor) axes, and surface sediments were finer, with fewer large trees (stumps following clearing).

Figure 5. More photographs of the Duncan Reservoir, extending upstream (northward, 5 & 6 May 2019). (5) The elevation of the reservoir bottom progressively increases to the upstream end and consequently the depth and interval of inundation decline. Associated with this, vegetation increase as with this fairly complete ground cover of grass. (6) Puddingbowl Creek (study Site 13, aerial view) provides the most upstream inflow and its alluvial fan supports abundant shrugs and trees. Extending into the inundated zone, horsetail (*Equisetum arvense*) was prolific. (7) The most abundant woody vegetation was situated at the upstream end of the reservoir with the inflow delta from the upper Duncan River (aerial view with the reservoir near full pool, July 2018). This delta zone included braided distributaries from the river, which created a mosaic of wetland and riparian patches with abundant cottonwoods, willows (*Salix* species) and alder (*Alnus incana*) and could be deserving of conservation such as through ecological reserve designation. (8) Upstream from the delta, the upper Duncan River is free-flowing and relatively pristine (July, 2018).

Could vegetation be enhanced around the Duncan Reservoir?

Yes, but there would be costs and trade-offs. And due to irreversible influences, such as introductions of non-native plant species, even with the removal of the Duncan Dam, the reservoir zones would not fully return to the natural complex of riparian woodlands and wetlands that existed prior to the clearing and flooding in the 1960s. More favorably, relatively slight changes in the reservoir level patterns might benefit some vegetation and particularly perennial woody shrubs and trees such as cottonwoods and willows (*Salix* species), which are especially important for wildlife habitat, and benefit the broader riparian and aquatic ecosystems.

The prior challenge for vegetation has been that the post-dam regime provided conditions with the reservoir being: (1) too high, (2) for too long, and (3) too often. The inundation creates anoxic root conditions that are lethal for most terrestrial plants. Even for willows and other plants with aerenchyma that enable root oxygenation, inundated shoots are unable to survive. Hydrophytes are better able to survive inundation but they are highly susceptible to drought. The annual reservoir pattern imposes inundation and then complete drying, a combination of stresses that excludes all perennial plant species from the lower draw down zones.

Some perennial plants survive near the full pool elevation around Duncan Reservoir and these zones experience shorter intervals of shallower inundation. This band of woody vegetation should be promoted and expanded downwards if the reservoir: (1) was not filled to full pool, (2) experienced shorter intervals near full pool, and/or (3) had occasional, rather than annual filling to full pool. Some combination of these changes would reduce the magnitude, duration and frequency of inundation, and provide more favorable conditions for vegetation.

The most promising locations would continue to be on the alluvial fans from inflowing creeks, such as in Figure 4, photo 1; and towards the upstream end of the reservoir as in Figure 5, photos 5, 6 and 7. These locations provide more gradual slopes that would expand the exposed surfaces, and are at relatively higher elevations with reduced inundation depth and duration. Additionally, the inflowing creeks or river provide alternative alluvial groundwater sources when the reservoir is deeply drawn down.

The deliberate regulation of water stage has been successfully implemented to restore river riparian vegetation along a number of dammed rivers in western North America and the ecophysiological foundation is well established (Cooper et al., 1999; Dixon, 2003; Rood et al., 2005; Polzin and Rood, 2006; Shafroth et al., 2017). It would be expected that the same principles and parameters would apply to reservoir zones but experiments or restoration applications have been uncommon and this application would be more novel and less certain.

The prospect of changing reservoir regulation for environmental and social benefit, including vegetation enhancement, has also been proposed for Arrow Lakes Reservoir (Thompson et al., 2016). That system might have a higher priority than the Duncan Reservoir, due to the increased human use and adjacent towns, along with differences in the valley topography. If implemented, lessons from the Arrow Lakes Reservoir changes would benefit planning for environmental management of the Duncan Lake Reservoir.

Acknowledgements

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