# Reservoir Delta Morphodynamics and Implications for Fish Passage in the Yakima River Basin

**Colin Byrne**, Hydraulic Engineer, Bureau of Reclamation, Denver, CO, cbyrne@usbr.gov
**Nathan Holste**, Hydraulic Engineer, Bureau of Reclamation, Denver, CO, nholste@usbr.gov
**Timothy Randle**, Hydraulic Engineer, Bureau of Reclamation, Denver, CO, trandle@usbr.gov
**Richard Visser**, Fish and Wildlife Administrator, Bureau of Reclamation, Yakima, WA, rvisser@usbr.gov

## Extended Abstract

## Introduction

Reservoir deltas form at the confluence of a stream with a reservoir pool that acts as base level control. While the formation of deltas within lakes is a natural process, deltas in reservoirs can also be subjected to large fluctuations in the managed reservoir pool water level. Delta surfaces are associated with deposition, especially large sediment clasts, and can be highly dynamic during flood events with considerable changes in channel location and form. Given the human influence on these systems, reservoir deltas are relatively new, novel ecosystems on the landscape as the surfaces grow and become more visible (Volke et al., 2015). Minimal geomorphic research has been conducted on reservoir deltas, especially those in mountainous regions where the deltas may not be subjected to typical deltaic processes due to large grain sizes in the rivers and higher gradient tributary streams.

In the Yakima River basin in the state of Washington, USA, the Endangered Species Act (ESA)-listed bull trout and other salmonids are prevented or impaired from migrating between the reservoirs and upstream spawning habitat because of the delta morphology and associated hydrology of the tributary and reservoir pool (Meyer, 2002). These fish passage issues include partial or complete dewatering of the delta stream channels, wide channels with insufficient flow depths for fish passage, lack of channel cover leading to increased predation, and channels flowing over bedrock ledges creating large hydraulic drops that fish are unable to jump over. In the western United States, where climatic variability is common, these conditions are even more pronounced during dry years. Current efforts to promote fish passage are on an annual basis in the Yakima basin, but the present solutions are labor intensive and unsustainable.

This study was undertaken to better understand geomorphic conditions on the delta surfaces in relation to bull trout fish passage and had two main objectives: 1) to develop a conceptual understanding of the geomorphic processes that contribute to reservoir delta evolution, and 2) quantify the specific conditions at select reservoir deltas across four Yakima River basin reservoirs (Keechelus, Kachess, Bumping, Rimrock). Two types of delta tributaries were identified and are the focus of the research: mainstem alluvial streams that enter the reservoir at the upstream end, and lateral tributaries that flow into to the reservoir but are not aligned with the downstream valley geometry. Using a combination of historical elevation datasets and newly collected field data, several topographic analyses were conducted to inform the conceptual model of reservoir delta fish passage at the tributary locations. Analyses included evaluating the evolution of long profiles and erosion-sedimentation patterns across each of the deltas.

## Site Description

The Yakima River is a tributary of the Columbia River in south-central Washington on the eastern side of the Cascade Mountains primarily in Kittitas and Yakima Counties. The Yakima River basin has become an important agricultural region due to the United States Bureau of Reclamation's (Reclamation) Yakima Project. The Yakima Project provides needed delivery flows for agricultural use in relatively arid lands west of the Cascade Mountains from five mountain reservoirs: Bumping, Cle Elum, Kachess, Keechelus, and Rimrock. Cle Elum, Kachess, and Keechelus were deep, glacially-carved lakes prior to construction of dams at the downstream end to provide increased storage and control over downstream flows. Five reservoir deltas were the focus of this study located on all reservoirs except Cle Elum (Fig. 1; Table 1).

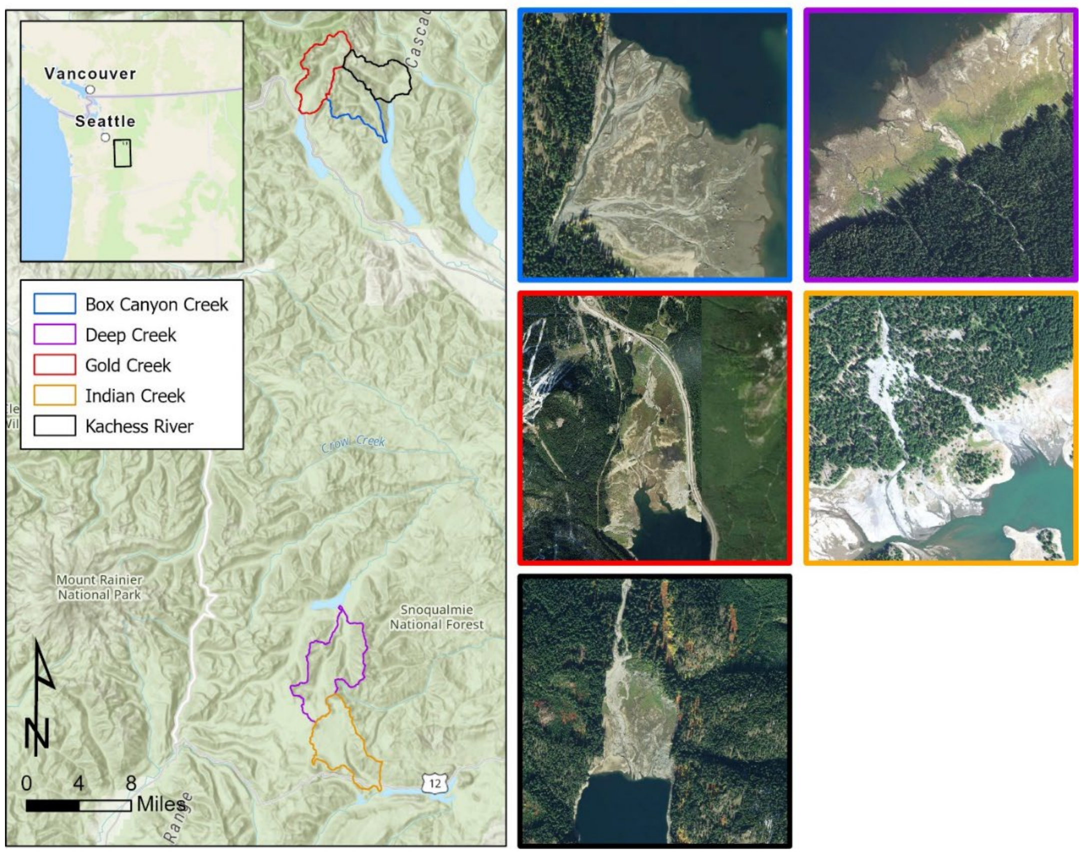


**Figure 1.** Watersheds and areal images of five reservoir deltas in the Yakima River basin.

**Table 1.** Five reservoir deltas where bull trout fish passage is of concern in the Yakima River basin.

| Tributary Name | Reservoir/Lake Name | Basin Location | Basin Area ($mi^2$) | Mean Basin Elevation (ft) | Longitudinal or lateral tributary | Topo-bathymetry years |
|---|---|---|---|---|---|---|
| Gold Creek | Keechelus | Upper basin | 13.94 | 4130 | Longitudinal | 2000, 2014 |
| Kachess River | Kachess | Upper basin | 11.15 | 4070 | Longitudinal | 2000, 2018 |
| Box Canyon Creek | Kachess | Upper basin | 12.19 | 3980 | Lateral | 2000, 2021 |
| Deep Creek | Bumping | Naches basin | 23.67 | 5000 | Lateral | 2000, 2014 |
| Indian Creek | Rimrock | Naches basin | 19.7 | 4780 | Lateral | 2000, 2018 |

# Methodology

## Field-collected Reservoir Delta Data

Indian Creek, Gold Creek, and Box Canyon Creek deltas were surveyed in October 2022 using Trimble Real-Time Kinematic (RTK) equipment. Field surveys focused on collection of longitudinal transects along the active channel and observable dry channels as well as cross-sections of the delta surface. Post-processing of RTK data, including solving for final OPUS solutions, was conducted using Trimble Business Center. Data were then imported into ESRI's ArcGIS Pro to calculate longitudinal distances along the thalweg of each reservoir delta channel. Profiles were developed from the calculated longitudinal distances and field-surveyed elevations

## Remotely Sensed Reservoir Delta Data

Channel profiles at the Kachess River and Deep Creek were developed using publicly available 2018 and 2014 lidar data, respectively. Lidar was downloaded from the Washington Lidar Portal (WADNR, 2023). Both locations had multiple years of lidar available. Because the lidar data were collected under different reservoir conditions, the lidar data with the lowest reservoir pool elevation was used to develop the channel profiles, which allowed for the furthest downstream extents of the channel to be analyzed. Lidar data were brought into ArcGIS Pro and lines were digitized along observable channels. A channel profile was developed from these digitized lines.

Elevation differences at each reservoir delta were calculated between the 2000 Yakima River lidar and the most recent high-resolution topo-bathymetry data. Except for Box Canyon Creek, where a 2021 sonar-collected bathymetric survey was used, the remaining recent delta surfaces were derived from lidar data (Table 1). The 2000 lidar was subtracted from the more recent data to calculate elevation change only on the delta surface and sampled across a 25-foot grid. Because different reservoirs had different lidar resources, elevation differences were divided by the total years between 2000 and the most recent topo-bathymetry to calculate a comparable, average annual elevation change on the surfaces.

# Results

Reservoir delta channels displayed slopes between 0.6% at Gold Creek and 2.6% at Indian Creek (Fig. 2). Although a small sample size, reservoir delta channel slopes were not clearly dependent on lateral or longitudinal orientation of the tributary, upstream watershed area, or mean watershed elevation. The active channel at the Indian Creek delta was the most perched channel on all delta surfaces indicating the dynamic nature of the steepest delta surface of the study. Gold Creek exhibits a relatively consistent longitudinal profile in the form of a pool-riffle system.

Topo-bathymetric differences indicated surfaces are subjected to both erosional and depositional processes. All upper basin deltas (e.g. Gold Creek, Box Canyon Creek, and Kachess River) displayed more erosion during the years of analysis than deposition while the Naches basin deltas (e.g. Indian and Deep Creeks) displayed more deposition than erosion (Fig. 3). While general aggregational and degradational trends differed between deltas, all surfaces showed local channel scour indicating migrating flow paths. Gold Creek exhibited locations with the greatest erosional and depositional amounts, often associated with channel migration along cut-bank locations and bar development.

# Discussion

The reservoir deltas within the Yakima River basin were found to have slopes predominantly in the range of pool-riffle systems (Montgomery and Buffington, 1997), though slopes and drainage basin areas are also within the range observed for alluvial fans (Parsons and Abrahams, 1994). The steepest tributary systems, Box Canyon and Indian Creeks, were most likely subjected to alluvial fan processes before the construction of Reclamation dams and remain representative of fan systems. Both deltas exhibit locations where the active channel is perched above another flow path and the control of the active flow path is at the most upstream end of the delta. Indian Creek was subjected to a large amount of deposition at the point of valley expansion which likely substantially altered flow direction between 2000 and 2018. In contrast, Gold Creek and the Kachess River exhibit a dominant channel with a less clear opportunity for channel piracy to alter the delta flow path substantially. Instead, these longitudinal deltas seem to be governed by fluvial channel evolution dynamics. However, reservoir pool management prevents large woody, vegetation growth, which likely increases the erodibility of these systems. Finally, Deep Creek, while also a lateral tributary like Box Canyon and Indian Creeks, displays a more distributary nature. Where Deep Creek exits a more confined valley, the delta exhibits a fan-like form, but as it continues downstream toward the reservoir, the parallel stream channels and contours are more representative of a pediment-like erosional surface.

The physical characteristics of the reservoir deltas likely indicate that different fish passage solutions will be needed for the different types of deltas. On alluvial fan-type deltas, solutions that promote a stable flow path and consistent erosional maintenance of that flow path are more likely to promote fish passage. In contrast, at longitudinal deltas, bank stability solutions representative of vegetation and floodplain stabilization may help to decrease channel instability in these observable pool-riffle systems. Results from this study will be used to inform future modeling efforts to develop and test longterm solutions to fish passage. Future work will include sediment transport modeling to test how fish passage solutions may impact channel evolution.

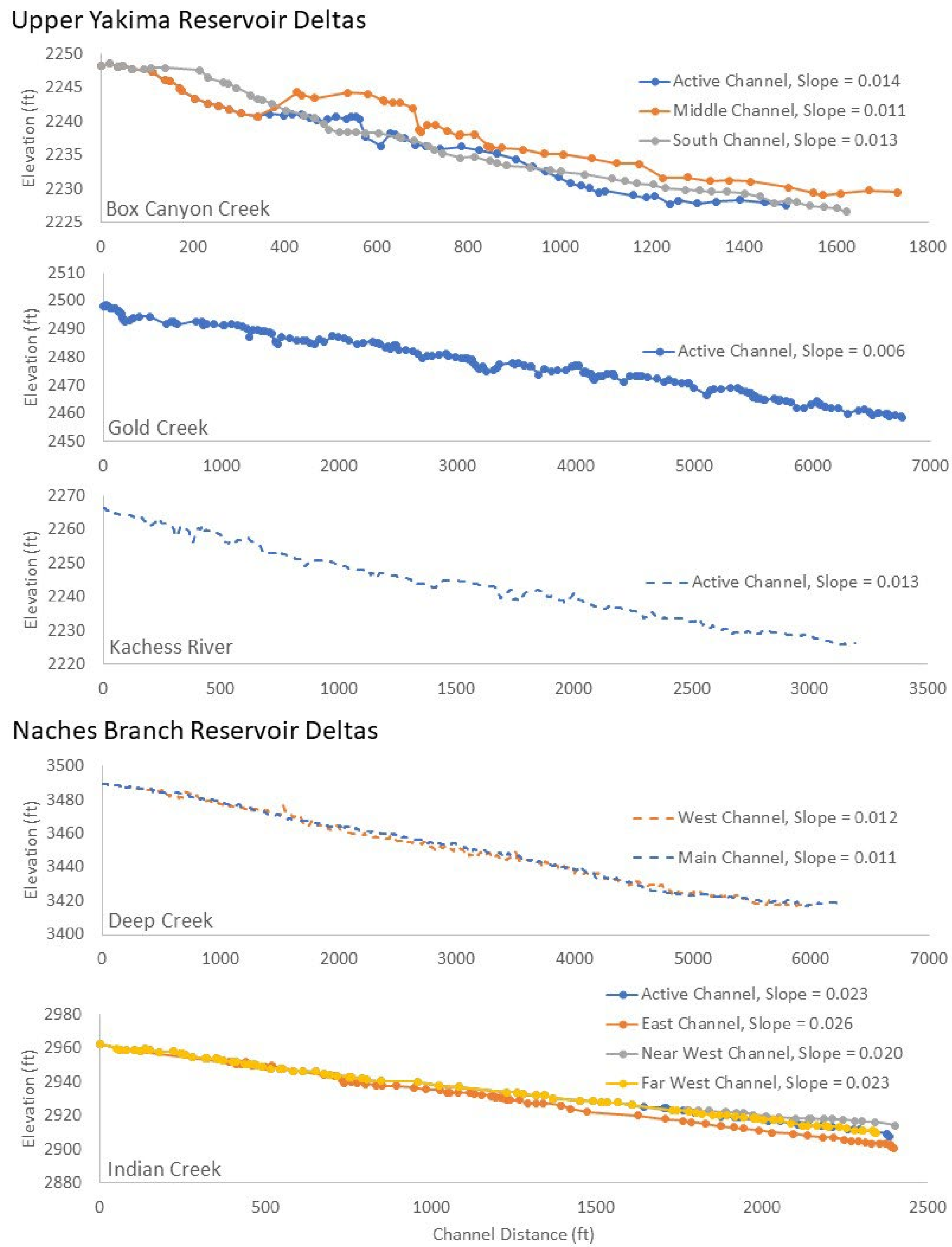


**Figure 2.** Channel profiles on Upper Yakima and Naches Branch reservoir deltas. Solid and dashed lines indicate field-collected and GIS-derived delta profiles, respectively.

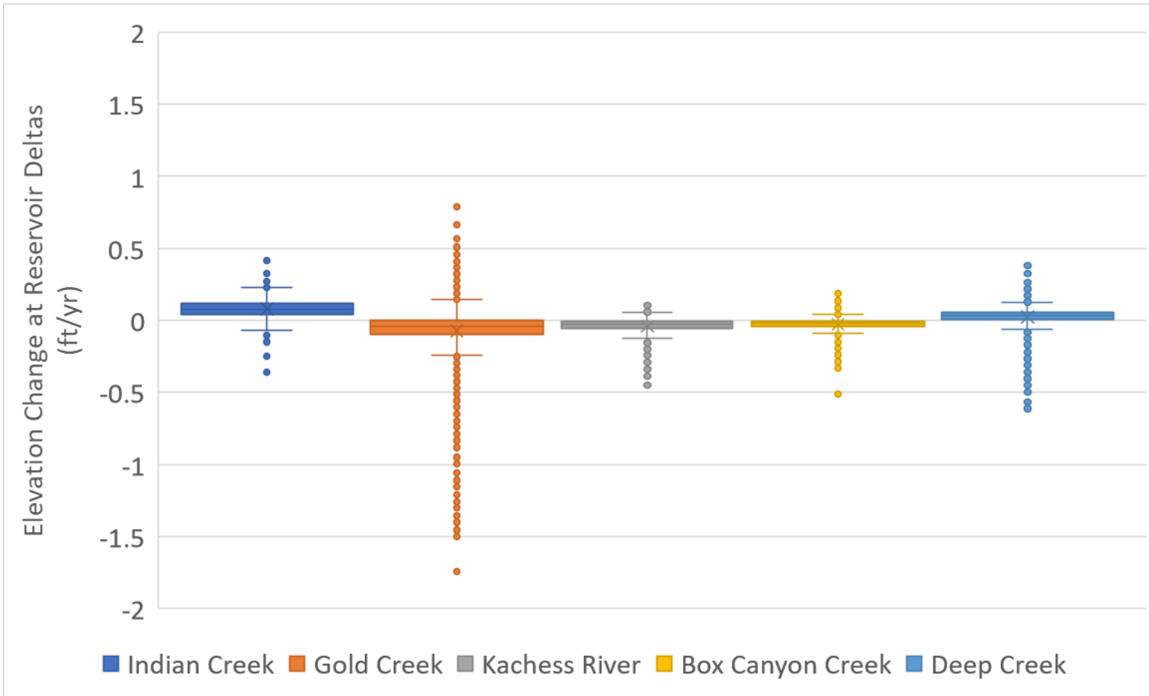


**Figure 3.** Differences in reservoir delta surface elevations.

## References

Meyer, W.R. 2002. "The effects of seasonal stream de-watering on three age classes of bull trout," Central Washington University.

Montgomery, D.R. and Buffington, J.M. 1997. "Channel-reach morphology in mountain drainage basins," GSA Bulletins, v.109, no. 5, pp 596-611.

Parsons, A.J. and Abrahams, A.D. 1994. Geomorphology of Desert Environments. Springer, Dordrecht.

Volke, M. A., Scott, M. L., Johnson, W. C. & Dixon, M. D. 2015. "The Ecological Significance of Emerging Deltas in Regulated Rivers." BioScience 65, 598–611.

Washington State Department of Natural Resources (WADNR), 2023. Washington Lidar Portal. lidarportal.dnr.wa.gov