Coupled Upstream-Downstream Geomorphic Responses to Deep Reservoir Drawdowns at Fall Creek Dam, Oregon

Mackenzie K. Keith, Hydrologist, USGS, Portland, Oregon, mkeith@usgs.gov
J. Rose Wallick, Geomorphology Team Lead, USGS, Portland, Oregon, rosewall@usgs.gov
Laurel E. Stratton Garvin, Hydrologist, USGS, Baker City, Oregon, lstratton@usgs.gov
Gabriel W. Gordon, Geologist, USGS, Portland, Oregon, ggordon@usgs.gov

Abstract

The operation of 13 high-head dams in the Willamette River Basin, Oregon, affects important cultural, biological, and other natural or economic resources both upstream and downstream of the dams. Although the dams primarily are operated to control flooding, other authorized purposes include water-quality improvement, irrigation, fish and wildlife habitat, and recreation, all of which result in several meters of annual lake level fluctuations. Since 2011, deep reservoir drawdowns at Fall Creek Lake, Oregon were implemented to lower lake levels to the historical streambed elevation (herein streambed drawdowns) and facilitate downstream passage of ESA-listed juvenile spring Chinook salmon through the 55-meter-high dam. Temporarily lowering the lake has increased the mobilization and downstream transport of predominantly sand and finer sediment to the lower gravel-bed reaches of Fall Creek and the Middle Fork Willamette River. Modifications to dam operations may alter reservoir and downstream conditions and processes; therefore, understanding coupled upstream-downstream interactions will aid managers in their assessment of overlapping priorities.

Upstream of the Fall Creek Dam, reservoir characteristics, streamflows, weather conditions, and dam operations during a particular drawdown control the magnitude of reservoir sediment erosion. Reservoir mapping shows that well-defined channels for the two main tributaries allow efficient conveyance of water and sediment through the reservoir during low lake levels, despite over 50 years of sediment accumulation since dam construction. During streambed drawdowns, fluvial erosion of reservoir deposits delivers mostly fine-grained sediment to the regulating outlets.

Downstream of Fall Creek Dam, local deposition of fine-grained reservoir sediment in some low-velocity, off-channel areas along Fall Creek can be substantial, and cause reductions in wetted area and depth that lead to subsequent colonization and stabilization by vegetation. This stabilization reduces the likelihood of erosion and return to pre-drawdown conditions during future high flows. Loss of off-channel aquatic habitat is greatest along Fall Creek where drawdown sediment supply is high and the mixed bedrock–alluvial channel has few off-channel features. Downstream of the confluence with the larger Middle Fork Willamette River, sediment loads are diluted by increased discharge. Compared with Fall Creek, the Middle Fork Willamette River is a wider, alluvial river with larger and more numerous off-channel areas to accommodate fine-sediment deposition. Here, geomorphic changes are most apparent where reservoir sediment has accumulated in large eddies. However, direct linkages between drawdown operations and off-channel deposition in the Middle Fork Willamette River are challenging to establish.

Introduction

The operation of 13 U.S. Army Corps of Engineers (USACE) high-head dams in the Willamette River Basin, Oregon (**Figure 1**), affects important cultural, biological, and other natural or economic resources both upstream and downstream of the dams. While providing societal benefits, these dams also change geomorphic processes and influence aquatic and riparian habitats and associated species, cultural sites and artifacts, and infrastructure. Although the dams primarily are operated to control flooding, other authorized purposes include water quality improvement, irrigation, fish and wildlife habitat, and recreation. At Fall Creek Lake, these purposes result in 50 meters (m) of annual lake level fluctuations. Since 2011, deep reservoir drawdowns at Fall Creek Lake that lower lake levels to the historical streambed elevation were implemented to facilitate downstream passage of Endangered Species Act (ESA)-listed juvenile spring Chinook salmon through the 55-meter-high dam (**Figure 2**; **Figure 3**A). Temporarily lowering the lake has increased the mobilization and downstream transport of predominantly sand and finer sediment to the lower gravel-bed reaches of Fall Creek (**Figure 3**B) and the Middle Fork Willamette River. Modifications to dam operations may alter reservoir and downstream conditions and processes; therefore, understanding coupled upstream-downstream interactions will aid managers in their assessment of overlapping priorities.

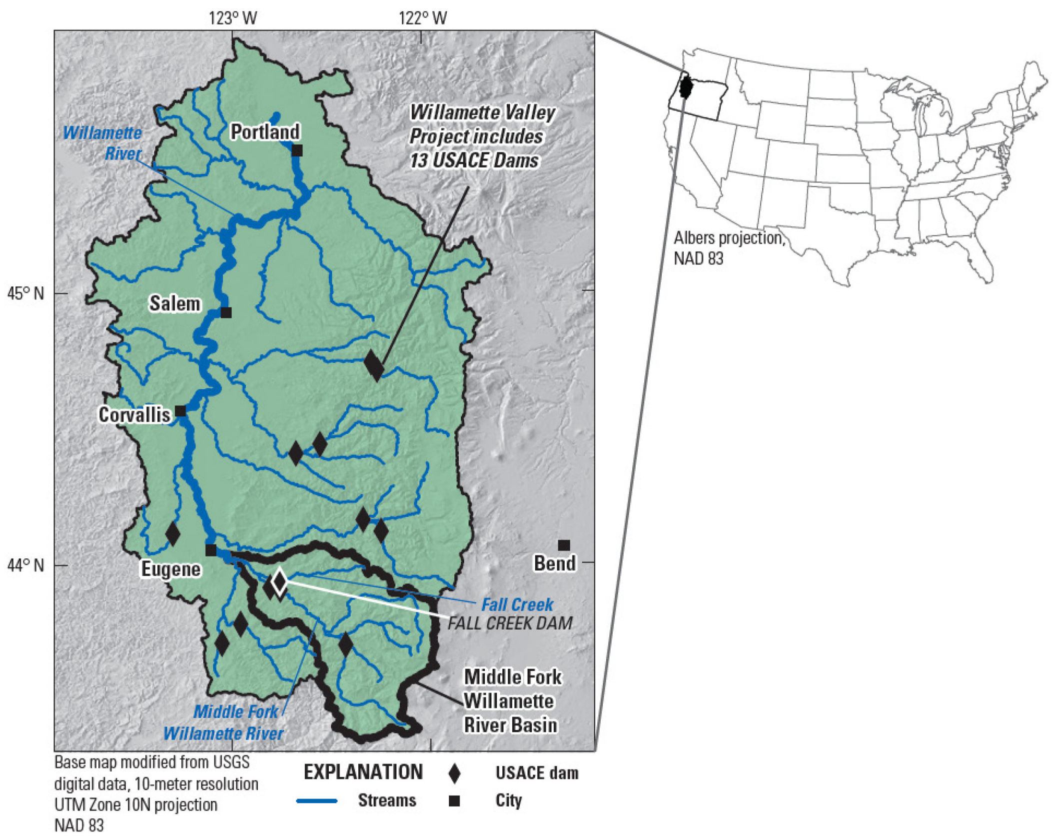

Figure 1. Willamette River Basin, Oregon, and large U.S. Army Corps of Engineers dams.

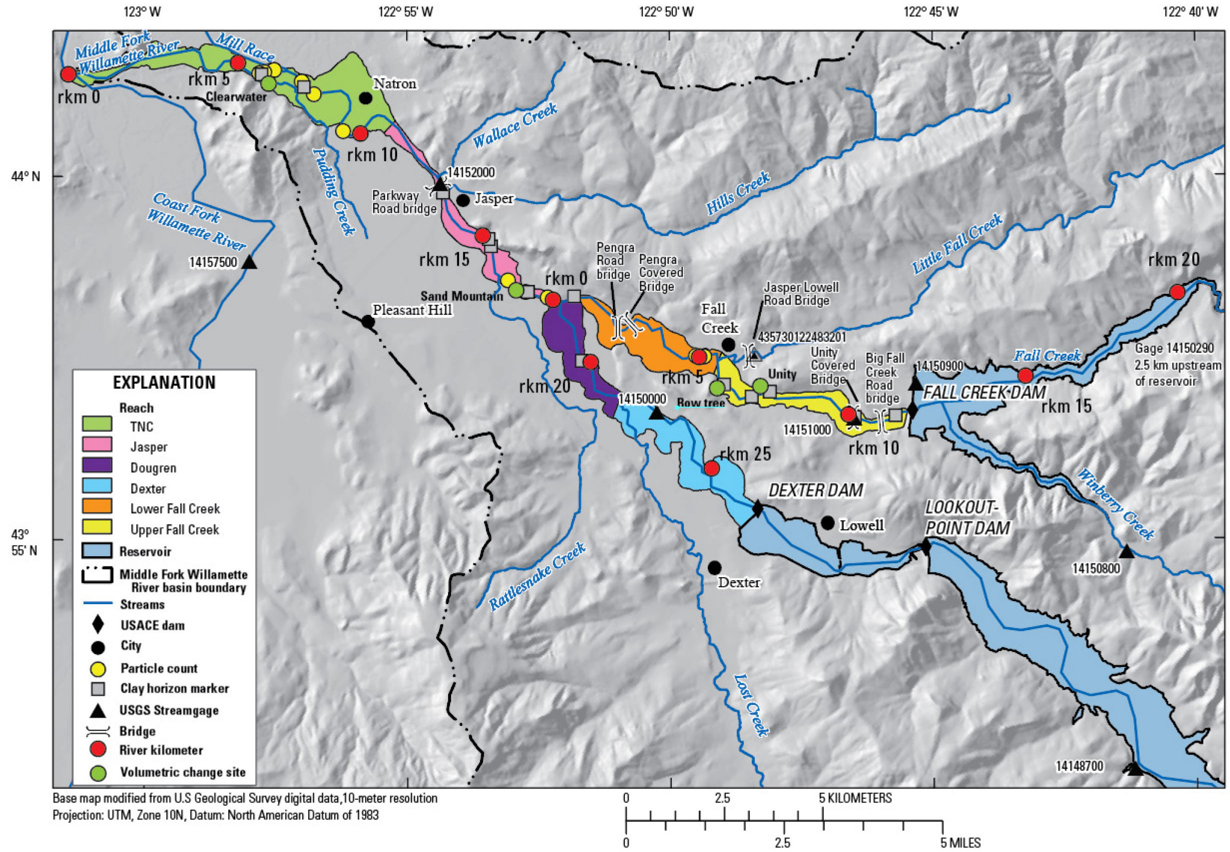

Figure 2. Fall Creek and Middle Fork Willamette River study area, Oregon.

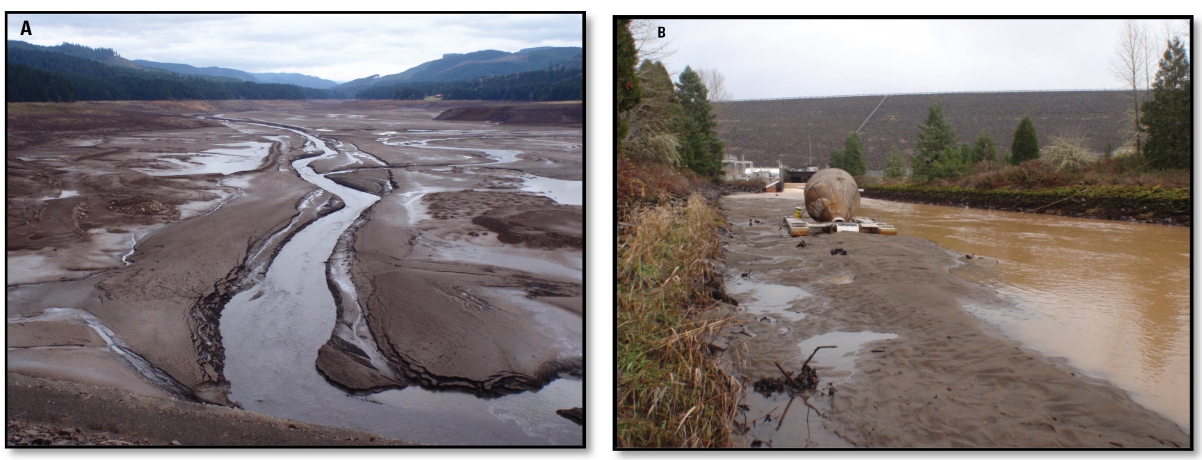

Figure 3. Photographs of Fall Creek reservoir reach facing upstream from the dam (A) and downstream reach facing upstream towards the dam and screw-trap (B) during November 2011 (WY 2012) streambed drawdown. Photographs courtesy of USACE.

Repeated releases of large amounts of reservoir sediments to the river corridors below Fall Creek Dam (Schenk and Bragg 2014, 2021) and observations of sediment accumulation in off-channel habitats (Bangs et al. 2011–2014) prompted questions regarding near- and long-term consequences of sediment delivery to downstream channel morphology and aquatic habitats along Fall Creek and the Middle Fork Willamette River. The magnitude, timing, and character of sediment released through drawdown operations influences deposition and erosion processes in downstream reaches. Therefore, understanding sedimentation and erosion processes within Fall Creek Lake under continued drawdown or other operational regimes is critical to understand downstream geomorphic responses and future trajectories of change. In coordination with USACE, the USGS conducted assessments of the Fall Creek reservoir and downstream reaches to 1) document the spatial and temporal geomorphic responses to streambed drawdowns and 2) provide considerations for how Fall Creek Lake operations and responses may or may not translate to other Willamette Valley reservoirs and rivers.

Methods: Documenting Spatial and Temporal Geomorphic Responses to Streambed Drawdowns

Reach-scale Geomorphic Mapping

Geomorphic mapping, particularly when repeated over multiple periods, enables detection and interpretation of hydrogeomorphic processes. Within the reservoir upstream of Fall Creek Dam, landform mapping units developed from structure-from-motion digital surface models and orthophotographs of the 2016 reservoir provide interpretive layers related to erosional and depositional processes. Three main reservoir process domains focus on channel, floor, and hillslope domains. Within those domains, multiple landforms and generalized substrates are also delineated. Mapping protocols and details are documented in Keith and Stratton (2019) and Keith and Stratton Garvin, (2021). Downstream of Fall Creek Dam, reach-scale changes in channel planform at 2- to 5-year intervals were evaluated with repeat geomorphic channel mapping from aerial photographs to assess incremental and cumulative changes in channel morphology that reflect multiple drawdowns spanning 2005–16. Similar to the upstream reservoir mapping, the mapping framework for the downstream channel includes process domains; however, these are focused on the floodplain and active channels. Mapping protocols are similar to other mapping efforts for western Oregon rivers (Wallick et al. 2011; Jones et al. 2012, 2016) and details are documented in Keith and Gordon, 2019.

Landform- and Site-scale Geomorphic Change Detection

Volumetric change analyses (commonly referred to as geomorphic change detection, GCD) are useful for quantifying the magnitude of erosion and/or deposition. Coupled with broader reach-scale mapping, interpretations of landforms and processes may be further linked. In the reservoir, net volumetric changes and patterns of sediment deposition and erosion for the period 2012–16 were assessed using digital surface models (DSMs) of Fall Creek Lake during full streambed drawdowns and acquired in January 2012 (lidar, Watershed Sciences, Inc., 2012) and November 2016 (Keith and Mangano, 2020). Quantitative comparisons between the DSM datasets were made with GCD Software (Riverscapes Consortium, 2018). Change detection analyses were focused on the reservoir floor and main channel domains within the lower 2.5 km of the reservoir where ground control coverage was greatest and where most observed changes have occurred. Downstream of Fall Creek Dam, topographic change analyses were completed at four gravel-bar features including the two sites on Fall Creek and two sites on the Middle Fork Willamette River. Lidar datasets were used to characterize an initial ‘baseline’ topography at each site, which was compared against topographic-bathymetric lidar data collected September 2015 (Quantum Spatial, 2016). The initial topographic lidar dataset for the Fall Creek and upstream Middle Fork site was acquired in February 2012 (Watershed Sciences, Inc., 2012). The initial topographic lidar surface for the downstream site on the Middle Fork was acquired March 2009 (Watershed Sciences, 2009) before annual streambed drawdowns began.

Results

Geomorphic Mapping Results within Fall Creek Lake

The main channel spatial domain is 9 percent (0.63 km^2) of the mapped reservoir area and contains the wetted channels of Fall and Winberry Creeks and associated landforms such as bars, in-channel bedrock, channel banks, and slumping banks (**Figure 4**A). Alluvial landforms with gravel or sand/mud substrate compose 19 and 25 percent (respectively) of this domain. Bars are mapped along channel margins throughout the length of the reservoir and are typically less than 400 m^2, but range in size up to about 2,400 m^2 near the middle of the reservoir. Channel banks locally are made up of pre-dam hillslope/pre-impoundment soils, mostly in the upper reservoir. Slumping channel banks are about 4.5 percent of the area mapped as channel banks, are entirely composed of sand/mud substrate, and were identified from orthophotograph coverage. Although the wetted channel comprises only 4.3 percent of the total mapped area within the reservoir, it is the main conduit of streamflow and sediment during low lake levels.

The reservoir hillslope domain of Fall Creek Lake encompasses steeply sloping surfaces that extend from the reservoir floor to the mapping boundary at maximum pool (254 meters [m] NAVD 1988). Reservoir hillslopes comprise about 36 percent (2.58 square kilometers [km^2]) of the total mapped area. The dominant landform category is undifferentiated reservoir hillslope (**Figure 4**B), generally identifiable by wave-built terracettes on relatively steep slopes. Most landforms within the reservoir hillslope domain lie above minimum conservation pool (94 percent above elevation 223 m).

The reservoir floor domain comprises about 55 percent (3.91 km^2) of the total mapped area (**Figure 4**C). Broad, planar topography with sand/mud substrate dominates this domain, though these surfaces are crossed by channels, infrastructure, and other mapped landforms. The dominant landform, pelagic reservoir floor, is relatively flat, has a smooth appearance in aerial imagery, and is more deeply inundated by water than the littoral reservoir floor as indicated by adjacent hillslope areas. The littoral reservoir floor is similarly broad and flat but is less deeply inundated and has no adjacent reservoir hillslope extending up to the maximum pool mapping boundary. Drawdown channels, drawdown terraces, and drawdown distributary zones are a related set of mapped landforms within the reservoir floor domain that show evidence of recent erosion, fluvial sediment transport, and re-deposition. Drawdown channels originate near the margins of the reservoir floor but lack an obvious stream channel source. Drawdown terraces border drawdown channels of Fall and Winberry Creeks and are typically elongated, planar surfaces inset within the reservoir floor. Drawdown channels, terraces, and distributary zones are almost exclusively mapped with sand/mud substrate.

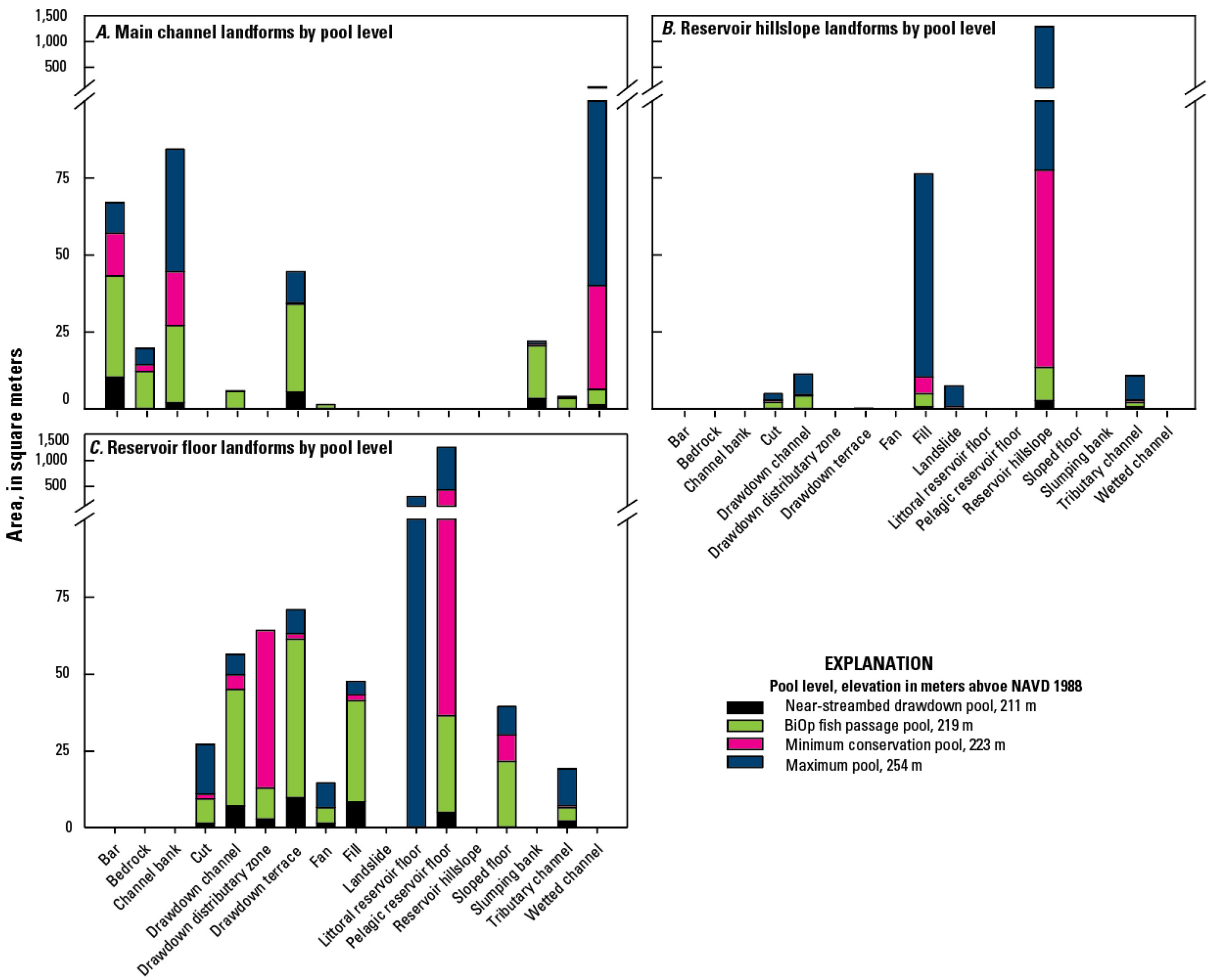

Figure 4. Graph of the distribution of mapped geomorphic landform units as a function of pool elevations at Fall Creek Lake, Oregon, for the A) main channel, B) reservoir hillslope, and C) reservoir floor mapping domains (data from Keith and Stratton Garvin, 2021, analyses show provisional data, subject to revision).

Geomorphic Mapping Results in the Channels Downstream of Fall Creek Dam

The Upper and Lower Fall Creek reaches (**Figure 2**) were laterally stable between 2005 and 2016 with most variation in mapped features owing to changes in the locations, morphology, and vegetative cover of gravel bars. Bar landforms flanking the main channel were predominantly covered in herbaceous and woody vegetation in all periods 2005–16; though more bare bars were present in the Lower Fall Creek reach (**Figure 5**). In the Upper Fall Creek reach, total bar area (including vegetated and unvegetated bars) increased by about 9 percent from 2005 to 2016, which was primarily driven by increases in vegetated bar area as areas that mapped as main channel or secondary water features in 2005 became bars with either herbaceous and woody vegetation by 2016. From 2005 to 2011, prior to implementation of annual streambed drawdowns, changes in mapped bar areas were negligible and likely within the range of mapping uncertainty. From 2011 to 2012 (spanning the WY 2012 streambed drawdown), mapped bar area increased by 2,500 m^2 (or about 4 percent), due mainly to increases in unvegetated bars and bars with herbaceous cover. The unvegetated gravel bars mapped in the 2012 photographs were not detected in the 2014 photographs, leading to small decreases in overall mapped bars (about 2 percent) during that period which spanned two streambed drawdowns. Between 2014 and 2016, also encompassing two streambed drawdowns (WY 2014 and 2015), mapped vegetated and unvegetated bar area collectively increased by 5,200 m^2 (about 8 percent). General temporal patterns in bar changes were similar for the Lower Fall Creek reach. Some of the adjustments in bar area between 2005 and 2016 likely reflect higher streamflows represented in the aerial photographs from 2005 and 2014 compared with other years.

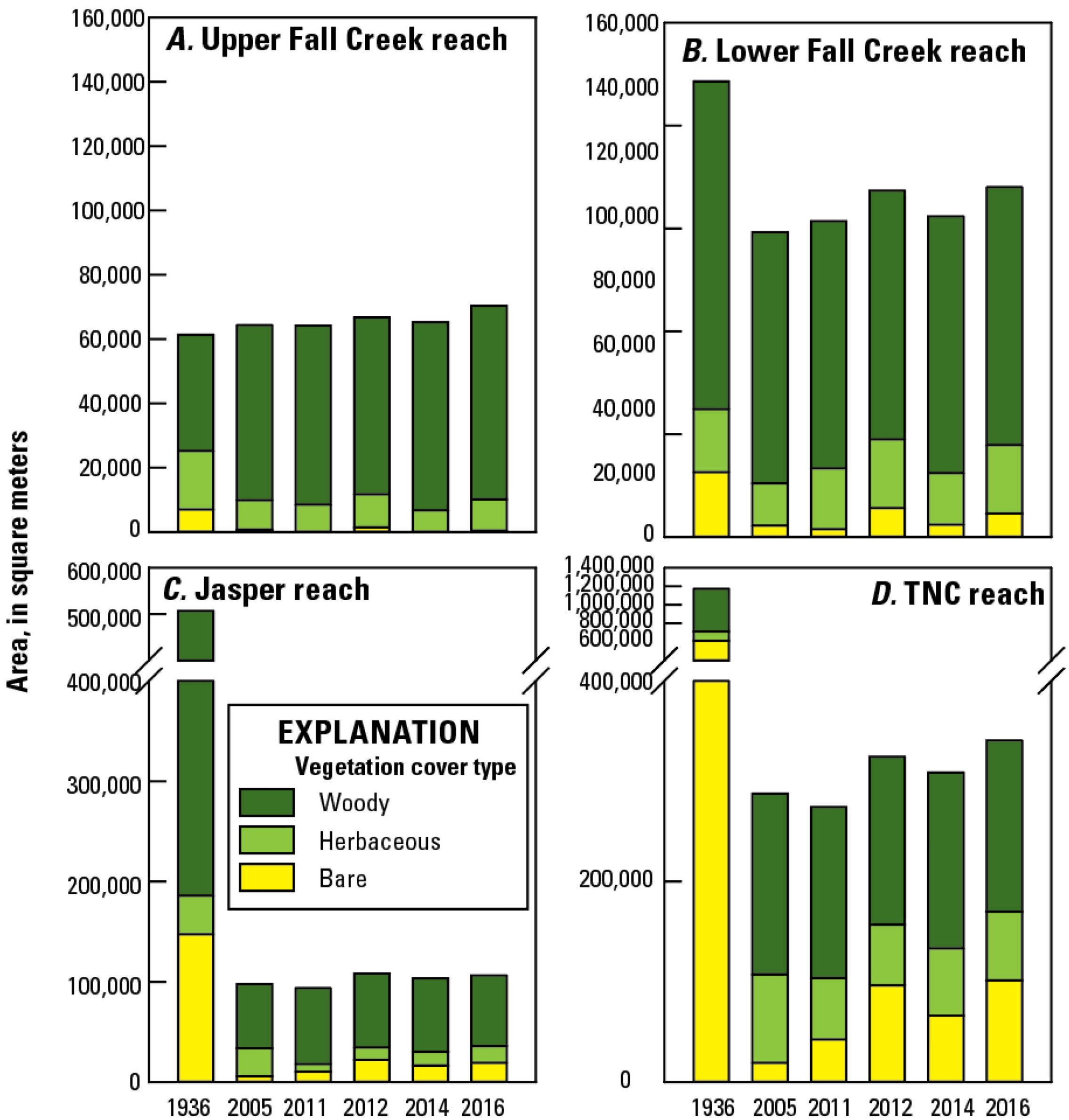

Figure 5. Mapped bar areas split by vegetation cover type from aerial photographs for reaches of Fall Creek (A, B) and the Middle Fork Willamette River (C, D) (data from Keith and Gordon, 2019, analyses show provisional data, subject to revision).

Volumetric Erosion and Deposition Changes within Fall Creek Lake

Within the lower reservoir of Fall Creek Lake, topographic change analyses show 143,200 m^3 erosion and 13,700 m^3 of deposition between 2012 and 2016 (**Table 1**). Total net erosion is 129,500 m^3, which suggests an annual average net erosion rate over the five-year analysis period of about 25,900 m^3/year. However, field measurements downstream (Schenk and Bragg, 2014, 2015, 2021), indicate that larger amounts of sediment were eroded during earlier streambed drawdown periods (WY 2012–13) than during later drawdowns suggesting later streambed drawdowns are shifting towards being supply limited as sediments from accessible reservoir supply are exhausted. Comparison of the reservoir changes from 2012–16 with mapped reservoir landforms shows erosion was focused in the main channels of Fall and Winberry Creeks. The area with greatest lowering of the reservoir topography was about 0.7 km upstream of the dam where the change in channel bed elevations decreased by up to 3.8 m. Areas with a net increase in vertical elevation were few and mainly located along the channel margins where bar formation or sediment delivery from slumping banks resulted in deposition of less than a meter.

Table 1. Table summarizing erosion, deposition, and net changes in the lower Fall Creek Lake between 2012 and 2016.

Approach	Propagated error using default survey uncertainty*	+/- error volume or depth, in cubic meters or meters
Total area analyzed, in square meters	1,425,309	NA
Area of detectable change, in square meters	275,127	NA
Average erosional depth change, in meters	0.60	0.19
Average depositional depth change, in meters	0.38	0.19
Erosion volume, in cubic meters	143,200	45,855
Deposition volume, in cubic meters	13,700	6,995
Net volume change, in cubic meters	-129,500	46,400

Volumetric Erosion and Deposition Changes Downstream of Fall Creek Dam

Overall, detectable topographic changes at the four sites along Fall Creek and the Middle Fork Willamette River primarily showed deposition; although, smaller localized instances of erosion were also identified at all sites (**Table 2**). Comparison of the 2012 and 2015 lidar at the Unity, Row Tree, and Sand Mountain locations shows broad-scale deposition encompassing substantial parts of the gravel bars and low-elevation floodplain with depositional volumes ranging from about 526±325 m^3 at the Sand Mountain site to about 1,560±1,040 m^3 at the Unity site. Locally, the greatest deposition detected over the 2012–15 measurement period within a single cell (1 m^2 area) within the Unity, Row Tree, and Sand Mountain sites was 1.55, 1.80, and 1.14 m thick, respectively. At the Downstream Clearwater site where topographic change was measured for the 2009–15 period, detected volumetric change are much greater, revealing 7,240±3,590 m^3 of deposition across the site and local deposition as great as 1.75 m.

Table 2. Table summarizing erosion, deposition and net changes at four sites downstream of the Fall Creek Dam on Fall Creek (FC) and the Middle Fork Willamette River (MF), (M. Keith, unpublished data, 2023; provisional data, subject to revision).

Site	Site description	Survey dates	Total area analyzed, in square meters	Area of detectable change, in square meters	Maximum deposition, in meters	Maximum erosion, in meters	Change in volume, in cubic meters	Error volume, in cubic meters
FC-Unity	Large alcove and low floodplain area occupying former side channel behind floodplain island	2012-2015	24,800	5,590	1.55	-0.93	1,560	1,040
FC-Row tree	Downstream segment of a low flow alcove and high-flow side channel	2012-2015	11,900	4,130	1.80	-1.69	1,470	843
MF-Sand Mountain	Vegetated gravel bar that grades to low floodplain and alcove along unvegetated bar	2012-2015	4,080	1,410	1.14	-0.42	526	325
MF-Clearwater	Large bare gravel bar that grades into vegetated bar and low floodplain	2012-2015	20,300	15,500	1.75	-0.99	7,240	3,580

Discussion of Coupled Upstream-Downstream Responses

Construction and operation of Fall Creek Dam has transformed the river corridors upstream and downstream. In the reservoir, Fall Creek (and the adjacent valley floor) have been transformed from a single thread, semi-alluvial stream flanked by floodplain and terraces to a lacustrine environment dominated by fine-grained sediment deposition. Downstream of Fall Creek Dam, Fall Creek flows through a relatively confined valley reflected by a narrow, semi-alluvial channel that efficiently conveys water. Unlike many gravel-bed rivers below large dams (Grant 2012), the morphology of Fall Creek has changed very little in the six decades following dam construction (for example, **Figure 5**). Farther downstream, the Middle Fork Willamette River was historically laterally dynamic with multi-thread and single-thread channels flanked by large, shifting gravel bars prior to dam construction and other channel modifications in the mid-20th century (Gregory et al. 2007; Dykaar, 2005, 2008; Wallick et al. 2013); the lower reaches of the Middle Fork Willamette River have become more stable and encompass a narrower floodplain corridor.

Upstream of the Fall Creek Dam, reservoir characteristics, streamflows, weather conditions, and dam operations during a particular drawdown control the magnitude of reservoir sediment erosion. Reservoir mapping shows that well-defined channels for the two main tributaries allow efficient conveyance of water and sediment through the reservoir during low lake levels, despite over 50 years of sediment accumulation since dam construction. During streambed drawdowns, fluvial erosion of reservoir deposits delivers mostly fine-grained sediment to the regulating outlets. Changes in the lower reservoir topography between January 2012 and November 2016 indicate overall net erosion. During streambed drawdowns, the most prominent changes were along the channel in the lowermost reservoir where inferred incision, lateral migration, and slumping banks result in vertical and lateral adjustments to channel position. Minimal change was detectable within the reservoir floor domain except where erosion was associated with mapped drawdown related features.

During most of the year when Fall Creek Lake fluctuates between minimum and maximum pool levels, lacustrine conditions dominate in the pool below minimum conservation level. When the lake is temporarily lowered during the drawdown, fluvial conditions dominate, and the pre-dam channel becomes a free-flowing channel subject to fluvial processes. Geomorphic mapping of the reservoir floor reveals four key categories of landforms and sediment processes within Fall Creek Lake related to lake level operations:

- **Reservoir floor deposits:** Lacustrine sedimentation expressed in the reservoir floor occurs during relatively high pool levels. Where reservoir floor is mapped as pelagic, smooth, muted topography indicates burial of pre-dam topography.
- **Erosional features related to drawdowns:** Erosion and formation of channel-like features created by the deep reservoir drawdowns occur primarily within reservoir floor and main channel deposits as the lake is draining. Erosional drawdown channel and terrace landforms are carved through underlying, unconsolidated sediments are prominent in the lower reservoir. Sediment generated from the formation of and conveyance within these drawdown landforms can be transported to main or tributary channels and is more likely to be transported through and out of the reservoir than sediment deposited along valley floor landforms distant from channels. As lake levels fall below minimum conservation pool to streambed, sediment is eroded from reservoir deposits below minimum conservation pool and then flows to the lower reservoir near the dam through the main channel and small drainage channels that cross the reservoir floor.
- **Main reservoir channels:** Fluvial erosion and deposition within historical stream channels occurs during streambed drawdowns and in free-flowing portions at higher pool levels. Well-defined channels for Fall and Winberry Creeks allow efficient conveyance of water and sediment through the reservoir during low lake levels. During streambed drawdowns, fluvial erosion of reservoir deposits delivers mostly sand and finer-grained sediment to the regulating outlets than can be exported downstream.
- **Reservoir hillslopes:** Erosion on reservoir hillslopes is driven by wave interaction at lake levels and gravitational processes at relatively lower lake levels.

Although the Fall Creek reaches immediately below Fall Creek Dam received influxes of fine-grained sediment from annual streambed drawdowns between 2011 and 2016, repeat mapping of the active channel from 2005 to 2016 suggests that reservoir sediments are having minor influence on reach-scale patterns of channel change, and that geomorphic changes potentially attributable to the drawdown are mostly focused along the channel margins and in off-channel areas. Repeat mapping of bars on Upper Fall Creek reach indicates that widespread increases in gravel bars did not result from the five streambed drawdowns encompassed by the 2005-16 mapping. The main change from 2011 to 2016 potentially attributable to sediment releases from Fall Creek Lake were localized increases in vegetated bar area particularly where channel margin areas were converted to herbaceous or woody bars. Mapped losses in secondary water features between 2005 and 2016 may partly owe to lower discharges in 2016 but some of these losses were validated with visual inspection of aerial photographs and field visits. The area of water features and gravel bars is influenced by streamflow and inundation during aerial photograph acquisition (for example, see analyses on the Chetco and Umpqua Rivers [Wallick and others, 2010, 2011; Curtis and Guerrero, 2015; Curtis and others, 2015]). Primary changes along the Lower Fall Creek reach include a) a 6.4 percent decrease in area of secondary water features between 2011 and 2016 spanning Fall Creek Lake streambed drawdowns owing to decreases in the area of side channels and conversion of some side channels to alcoves, and b) a nearly two-fold increase in the area of unvegetated bars while vegetated bar area remained approximately similar. Although other datasets from this study and accounts from other researchers (Oregon Department of Fish and Wildlife, ODFW surveys [Bangs et al. 2020], and landowners [J. Baumann, oral commun., November 2015 and other dates]) indicate local deposition can exceed 1 m, those local changes are seldom detectable with repeat mapping from aerial photographs conducted at one to three year intervals, because: a) the scale of deposition is smaller than photograph resolution, b) deposition along channel margins is obscured by vegetation, and c) temporary deposition during the early months following fall streambed drawdowns typically dissipated before aerial photographs were collected (typically summer).

At the landform-scale, comparison of bar and floodplain topography at four sites where cumulative landform-scale patterns of erosion and deposition were evaluated using repeat lidar surveys shows that these landforms were primarily evolving by net deposition though some localized erosion was also detected. Deposition thickness and spatial patterns were variable, including sites with dispersed but measurable deposition ranging from a few mm to over 1 m as well as sites where deposition was highly localized and exceeding 1 m in depth. Although topographic changes could not be quantified in channel areas that were below the water surface at the time of topographic lidar acquisition (2012 or 2009), field observations of these sites indicate that deposition could be substantial. Average annual deposition at the four sites ranges from 175–1,207 m^3/year. The measured deposition at Fall Creek sites most likely is from reservoir sediments released from Fall Creek Lake during streambed drawdowns because the geomorphic stability of this river and limited tributary inputs provide few other sediment sources. Likewise, sediment deposited at the Sand Mountain site on Middle Fork Willamette River also likely originates from Fall Creek Lake, but small tributaries and modest channel changes upstream on the Middle Fork Willamette River could also be contributing to sediment to this site. Sources of sediment deposited at the Clearwater site on the Middle Fork Willamette River at the downstream end of the study area are more confounded and could reflect sediment sourced from nearby bank erosion as well as Fall Creek Lake streambed drawdown operations or other upstream sources. Additionally, hydraulic conditions at the Clearwater site could be especially conducive to deposition of suspended sediment because comparatively wide active channel, large channel-flanking bars, and vegetation promote deposition processes at moderate to high streamflows.

Downstream of Fall Creek Dam, local deposition of fine-grained reservoir sediment in some low-velocity, off-channel areas along Fall Creek can be substantial, and cause reductions in wetted area and depth that lead to subsequent colonization and stabilization by vegetation. This stabilization reduces the likelihood of erosion and return to pre-drawdown conditions during future high flows. Loss of off-channel aquatic habitat is greatest along Fall Creek where drawdown sediment supply is high and the mixed bedrock–alluvial channel has few off-channel features. Downstream of the confluence with the larger Middle Fork Willamette River, sediment loads are diluted by increased discharge. Compared with Fall Creek, the Middle Fork Willamette River is a wider, alluvial river with larger and more numerous off-channel areas to accommodate fine-sediment deposition. Here, geomorphic changes are most apparent where reservoir sediment has accumulated in large eddies. However, direct linkages between drawdown operations and off-channel deposition in the Middle Fork Willamette River are challenging to establish.

Conclusions

This study informs management operations at Fall Creek Lake, Oregon for downstream fish passage and downstream sediment management. Overall, fish passage and the ecological benefits of streambed drawdowns have been deemed successful, and many of the hypothesized channel and ecological changes were short-term or transient. However, in reaches downstream of Fall Creek Dam, vegetation colonization on recently deposited patches of reservoir sediment or sediment deposition in off-channel features, and potential long-term reductions in those features may have longer-term effects. Multiple factors influence magnitude and type of geomorphic responses to streambed drawdowns, both upstream and downstream of Fall Creek Dam, and while the patterns observed here are specific to Fall Creek Lake, the approaches and findings from this study can support a broader understanding of reservoir drawdowns for other purposes, such as sediment management or construction elsewhere. Furthermore, these findings support understanding of the present-day conditions within the study area and predict the longer-term geomorphic responses downstream of Fall Creek Dam. While the purpose for drawdown operations and the drivers of reservoir erosion at Fall Creek Lake may differ from other reservoirs, the approaches linking process-based mapping and interpretation of erosional landforms to volumetric analyses could be modified to inform drawdown operations at other reservoirs to support sediment management for reservoir sustainability. Considering the geomorphic changes related to the streambed drawdowns between WY 2012 and 2018 documented at Fall Creek, future monitoring could be used to address outstanding questions about the effects of continued annual streambed drawdowns on key habitats or management issues (such as flood conveyance and loss of flood storage in the downstream channel, as well as response to land disturbances in reservoir watersheds such as wildland fire) and might encompass repeat reach-scale mapping, topographic surveys, ground-based observations at select sites, or hydraulic modeling.

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