# Evaluating watershed response and increases in sediment loading to Willow Creek and Willow Creek Reservoir due to East Troublesome fire

**Kent L Collins**, Hydraulic Engineer, Bureau of Reclamation, Denver, CO, kcollins@usbr.gov

## Introduction

Willow Creek Dam and Reservoir are located on Willow Creek in Grand County in north-central Colorado approximately 2.5 miles upstream of the confluence of Willow Creek with the Colorado River, 60 miles northwest of Denver, CO, and 5 miles north of the town of Granby, CO (Figure 1). Operated by the Northern Colorado Water Conservancy District (Northern Water) as part of the Colorado Big Thompson Project, Willow Creek Dam captures about 33,700 acre-feet of excess Willow Creek flows annually for diversion to Lake Granby for storage.

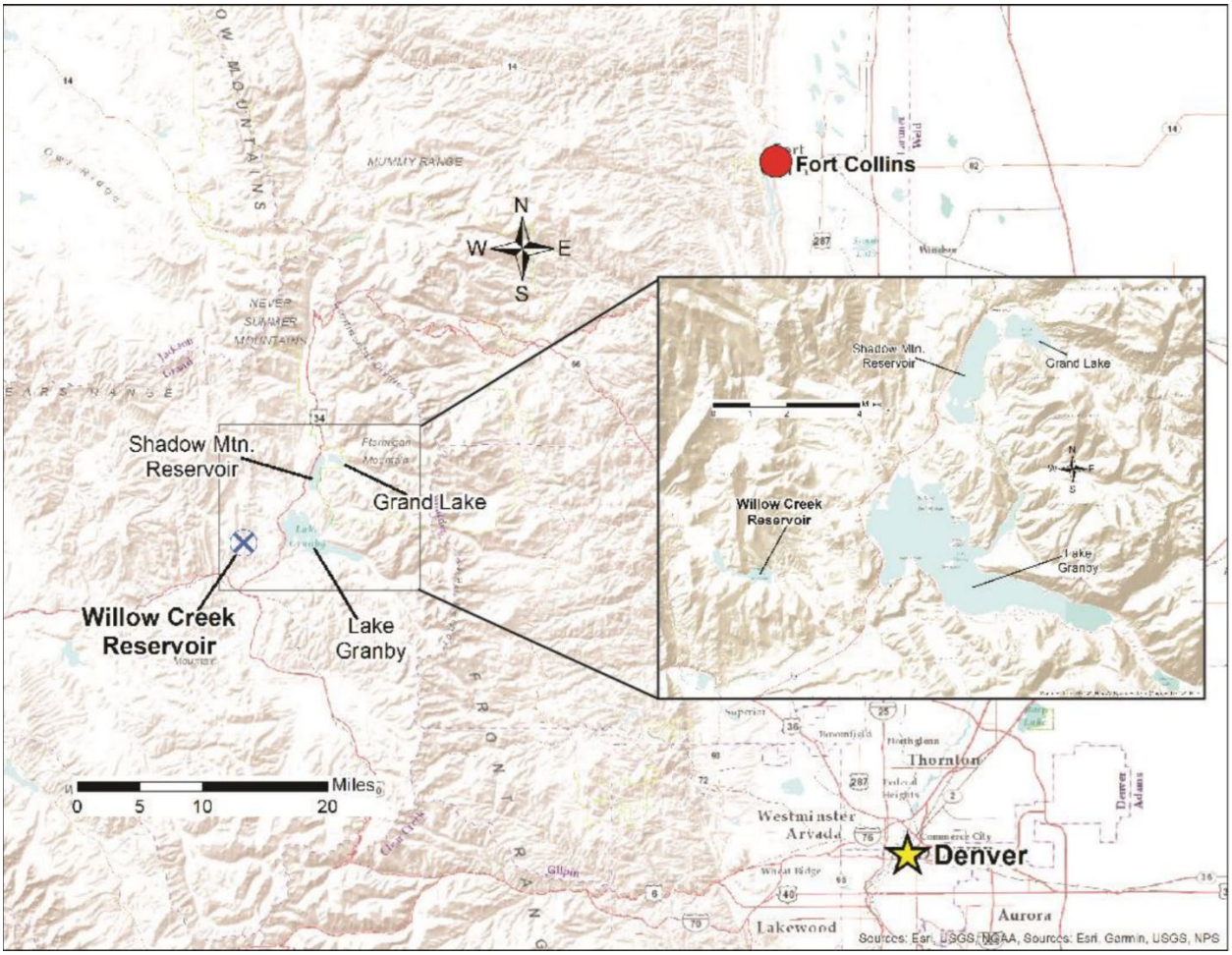


**Figure 1.** Location map showing Willow Creek Reservoir and surrounding area (Reclamation 2021)

In October and November 2020, the East Troublesome Fire burned 193,812 acres surrounding Willow Creek Reservoir including more than 91 percent of the watershed that feeds the reservoir. The second largest fire in Colorado history, it grew more than 150,000 acres in a

single 24-hour period driven by near-hurricane-force winds as it burned most of the 55-percent-forested watershed.

Monitoring sediment deposition in the reservoir over multiple years is underway to determine and possibly predict the watershed and reservoir response to large-scale wildfires. Repeat hydrographic surveys (including above and below water data collection) and sediment sampling following spring runoff, are being used to measure the volume and distribution of sediment deposits from the burn area and assess the effectiveness of sediment management activities undertaken prior to runoff. Potential impacts to the Colorado-Big Thompson Project and operations at Willow Creek Reservoir will be identified through this research.

Reclamation's Sedimentation and River Hydraulics (Sedimentation) Group is conducting repeat hydrographic surveys of Willow Creek Reservoir following the 2021, 2022, 2023, and 2024 spring runoff. The Sedimentation Group is collecting the bathymetry using Acoustic Doppler Current Profiler (ADCP) and multibeam sonar integrated with a Real-Time Kinematic Global Positioning System (RTK GPS) to measure underwater changes while Northern Water contractor River Science repeats November 2020 and fall 2021 and 2022 aerial drone surveys to capture the above-water changes, anticipated to be primarily in the upper delta. The Sedimentation Group then processes the bathymetry data and combines it with the drone data to generate a continuous surface of the reservoir bottom up to the dam crest elevation. Surface and core samples are also being collected in the reservoir delta to determine the thickness, gradation, and source of sediments delivered to the reservoir.

## Data Collection

Reclamation's Sedimentation Group, River Science, and the Northern Water Conservation District (Northern Water) have collaborated to acquire all data collected since the East Troublesome Fire in 2020. The first two years of data collection (2020-2021) were funded by Northern Water, Reclamation's Missouri Basin Region, and supplemental funding from Reclamation's Science and Technology (S&T) Program. Years 3-5 (2022-2024) are funded by Northern Water and a separate research grant from Reclamation's S&T Program.

### Bathymetry

Bathymetric surveys were conducted in November 2020 and August 2021 and 2022. The 2020 bathymetry was collected using an ADCP while the 2021 and 2022 surveys used multibeam sonar. The primary difference between the ADCP and multibeam transducers is the detail and amount of coverage that can be obtained. The ADCP used emits 5 beams at a 50-degree swath angle while the multibeam system used can emit up to 512 beams at maximum swath angle of 210 degrees. Figure 2 shows the difference in bathymetric coverage between the 2020 ADCP and 2021 and 2022 multibeam surveys.

### Aerial Photogrammetry

During the 2020 bathymetric survey and following the 2021 and 2022 bathymetric surveys, River Science collected aerial photogrammetry using a high-resolution camera mounted to a drone to map the above water areas of Willow Creek Reservoir. Overlapping aerial images were collected with 80% overlap on two sides, resulting in a resolution of 1.13 inches per pixel

(Javernick, 2023). Water levels were too low during the 2020 and 2021 bathymetric surveys to provide overlap with the drone photogrammetry, requiring supplemental data (ice surveys) to be collected and interpolation to be performed to fill the gap between the two data sets.

## Ice Surveys

Ice surveys were conducted during February of 2021 and 2022 to supplement topography and fill data gaps near the upstream end of the narrows (Figure 2), where the survey boat was unable to access and the UAS photogrammetry could not penetrate the water surface. Using a motorized ice auger, holes were drilled in the ice at a 100-foot grid spacing and a measuring tape with a weight attached was lowered through each hole to measure the distance from the top of the ice to the reservoir bottom. The elevation of the top of the ice and horizontal coordinates of each hole were measured with RTK GPS. Measured distances from the top of the ice were then subtracted from GPS elevations to determine the reservoir bottom elevation at each hole. The resulting ice survey data is shown in Panels B and C of Figure 2 below.

River Science combined processed data from the bathymetric, aerial, and ice surveys to generate a Digital Elevation Models (DEM) of the reservoir banks and bottom at a 1-foot grid spacing for each year of survey. Reclamation computed updated surface areas and storage capacities for 2020-2022 from the DEM's. The DEM's were also compared to each other to determine sediment deposition volumes and distributions.

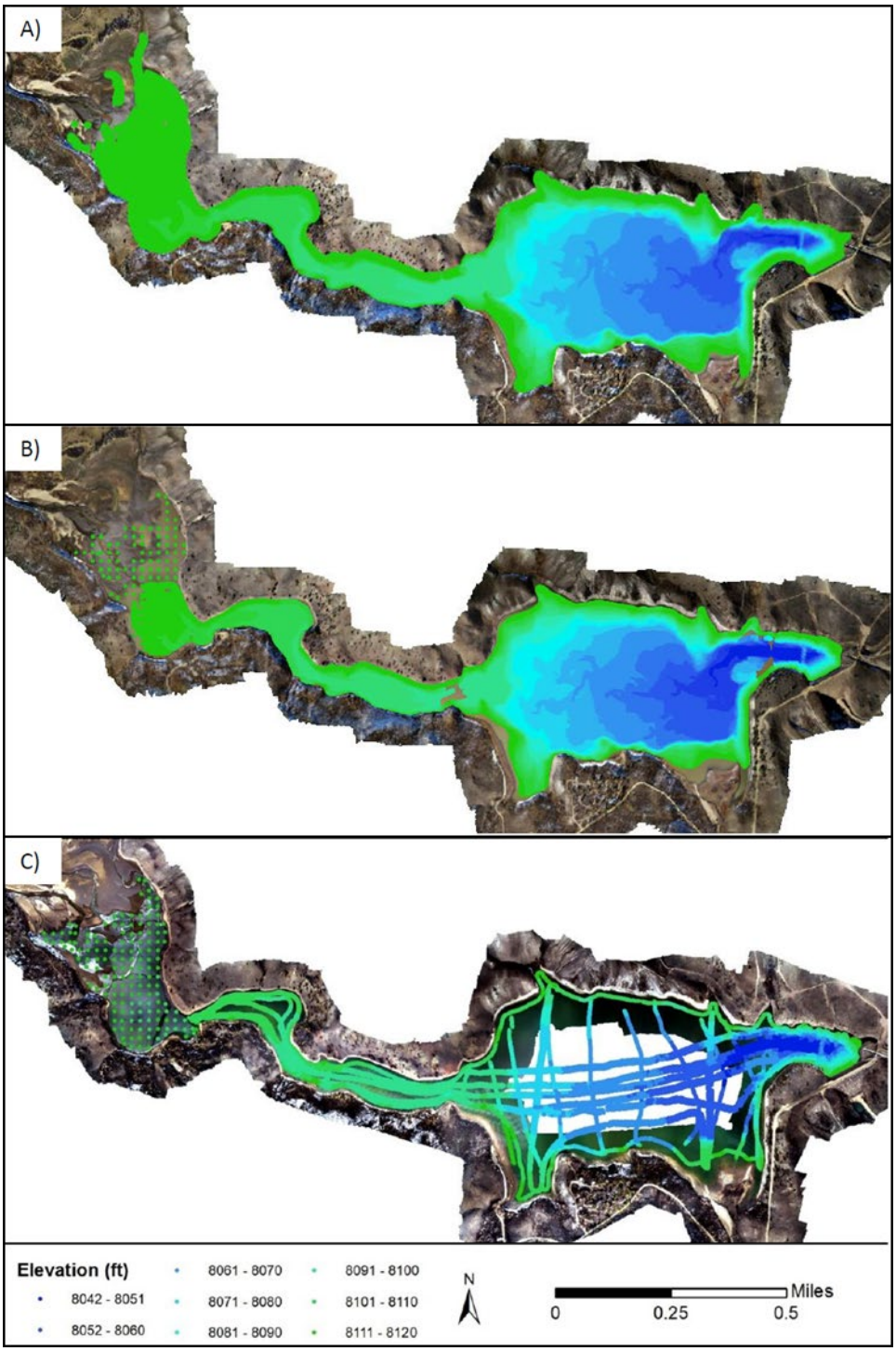


**Figure 2.** Panels showing total bathymetric coverage (ADCP or multibeam and ice survey) for each year of survey: (A) 2022; (B) 2021; (C) 2020 (Javernick, 2023)

Note the difference in coverage detail between the 2020 ADCP (Panel C) and 2021 and 2022 multibeam (Panel B and A) surveys. The sparser ADCP bottom coverage requires more interpolation over greater distances between bottom measurements.

### Sediment Samples

PONAR derived surface grab samples of reservoir bottom deposits were collected at 16 repeat locations during the 2021 and 2022 bathymetric surveys. The sediment lab at the Colorado School of Mines is analyzing samples for gradation, organic content, and phosphorus levels. The goal of the sediment analysis to try to determine the source of deposited in the sediment in the reservoir as well as tracking changes in soil properties due to erosion or deposition processes.

During the final bathymetric survey in fall 2024, the Sedimentation Group will collect sediment core samples, up to 8 feet in length, at multiple locations along the delta where most of the deposition occurs. These samples will be analyzed for the same properties and constituents as the PONAR surface samples. The core samples will be used determine sediment sources, validate the repeat surveys, and to measure or track various short term or seasonal hydrologic events.

### Watershed Assessment

During the 2022 bathymetric survey, staff from the Sedimentation Group and USGS conducted a qualitative assessment of the Willow Creek Reservoir watershed to characterize sediment types and general erodibility. The watershed assessment will be repeated in 2023 and 2024 to track changes. This multi-year effort is intended to describe the increase in sediment available to be transported due to wildfire. One driving force behind this effort is the need to assess the risk of debris flows or landslides in the watershed that may impact sediment delivery or dam safety. Sediment deposition in the watershed or river corridor upstream of Willow Creek Reservoir may be delaying delivery to the reservoir.

Surface sediment samples were collected from debris fans, sediment deposits in the river corridor, and landslides to determine properties of sediment that may be transported to the reservoir. Those samples are also under analysis at the Colorado School of Mines sediment lab.

## Results

Results of the 2020, 2021, and 2022 surveys were analyzed by comparing Digital Elevation Models generated from the combined survey data and through comparison of longitudinal profiles. Updated surface areas and storage capacities were also computed from the DEM's for each year of survey. Figure 3 shows the difference surfaces that were calculated by subtracting the DEM representing one survey from the DEM representing the subsequent year's survey. The resulting surfaces in Figure 3 show the magnitude and distribution of vertical change between the surveys due to sediment deposition and erosion. The green areas (positive values) in both panels of Figure 3 represent areas of measured deposition while the magenta areas (negative values) represent measured erosion. Darker colors, indicate greater magnitudes of erosion or deposition. White areas represent regions of little-to-no measured vertical change between the two surveys.

Both the 2020-2021 and 2021-2022 DEM comparisons indicate that the bulk of the sediment deposition since the East Troublesome Fire has occurred in the lower delta area just upstream of the reservoir narrows. More than 3 feet of deposition was measured in that area between 2020 and 2021 with an additional 3+ feet of deposition measured between 2021 and 2022.

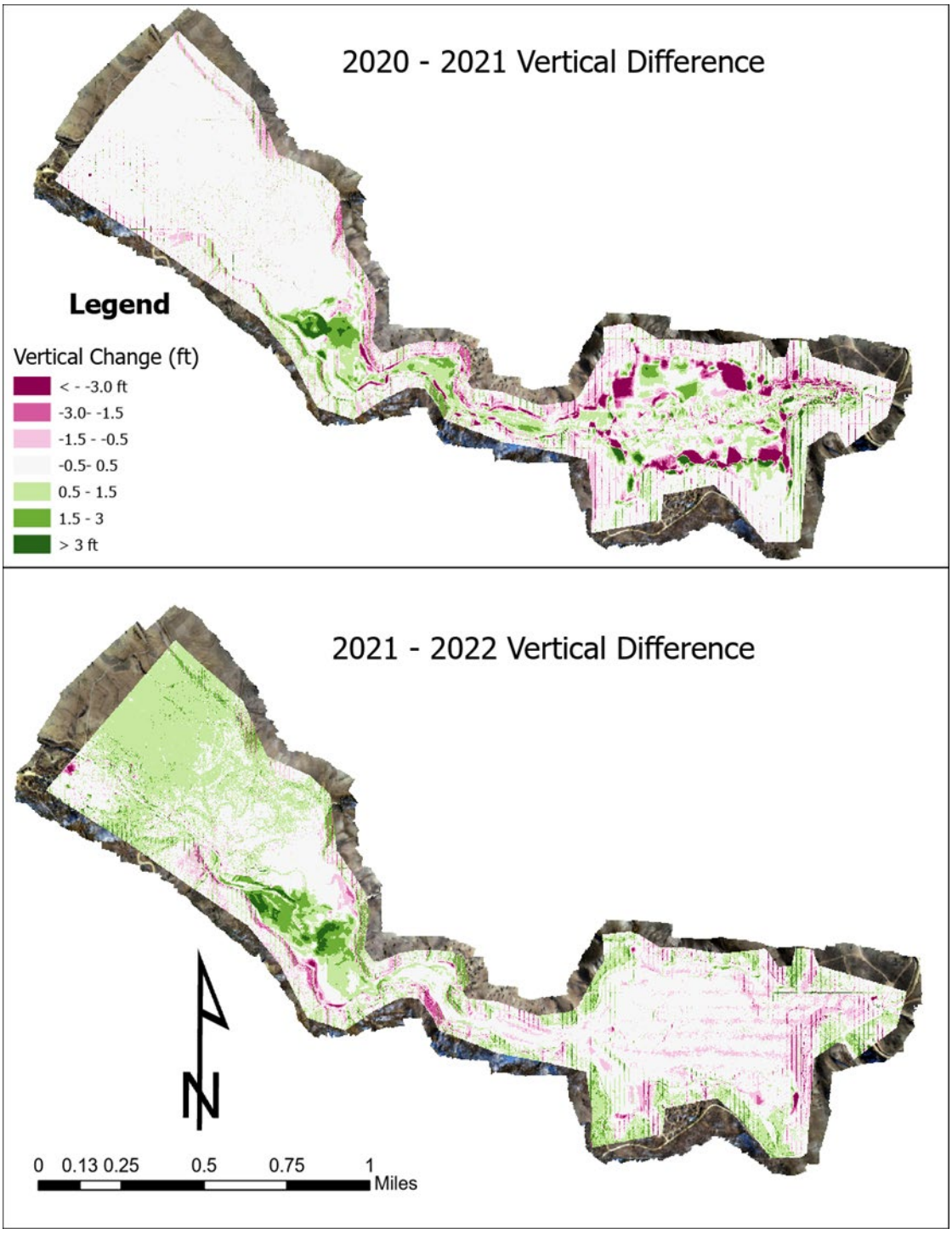


**Figure 3.** Measured vertical difference between 2020 and 2021 (top panel) and 2021 and 2022 surveys (bottom panel) of Willow Creek Reservoir

Areas in lower reservoir indicating measured erosion (magenta) between the 2020 and 2021 surveys do not represent actual erosion but are due to differences in survey methods resulting in relatively large gaps between bathymetric data. The 2020 survey data was collected using an ADCP at much lower resolution (especially in wider areas of the reservoir, Figure 2) than the

2021 and 20222 surveys and topography had to be interpolated over long distances, potentially misrepresenting the existing topography at the time of the survey. However, in the upper reservoir where the 2020 bathymetric survey achieved more complete bottom coverage (Figure 2), the measured vertical change is more accurate, validating the comparison to the 2021 survey and volume computations in that area where most of the deposition occurs.

Longitudinal profiles show depositional areas along the axis of the reservoir (Figure 4). Matching the vertical difference surfaces in Figure 3, the longitudinal plots show the bulk of the deposition since the East Troublesome Fire has occurred upstream of the narrows between elevations 8108 and 8122 feet, showing over 7 feet of deposition there since 2020. The longitudinal profiles show two distinct deltas: one upstream of the narrows, 9800 feet upstream of the dam; and another at the downstream end of the narrows, 4400 feet from the dam. The downstream delta formed prior to 2020 as the reservoir widens sharply, decreasing flow velocities, resulting in coarser sediments depositing there. No measurable change has occurred downstream of the narrows since 2020 according to the profiles.

The longitudinal profiles also show a slight increase in bed elevation upstream of maximum water surface/full pool elevation 8132 feet. Deposition upstream of the reservoir pool must be considered as it can have negative impacts such as increased flood risk. Deposition in the upstream channel indicates sediment is continuing to be transported downstream from the watershed.

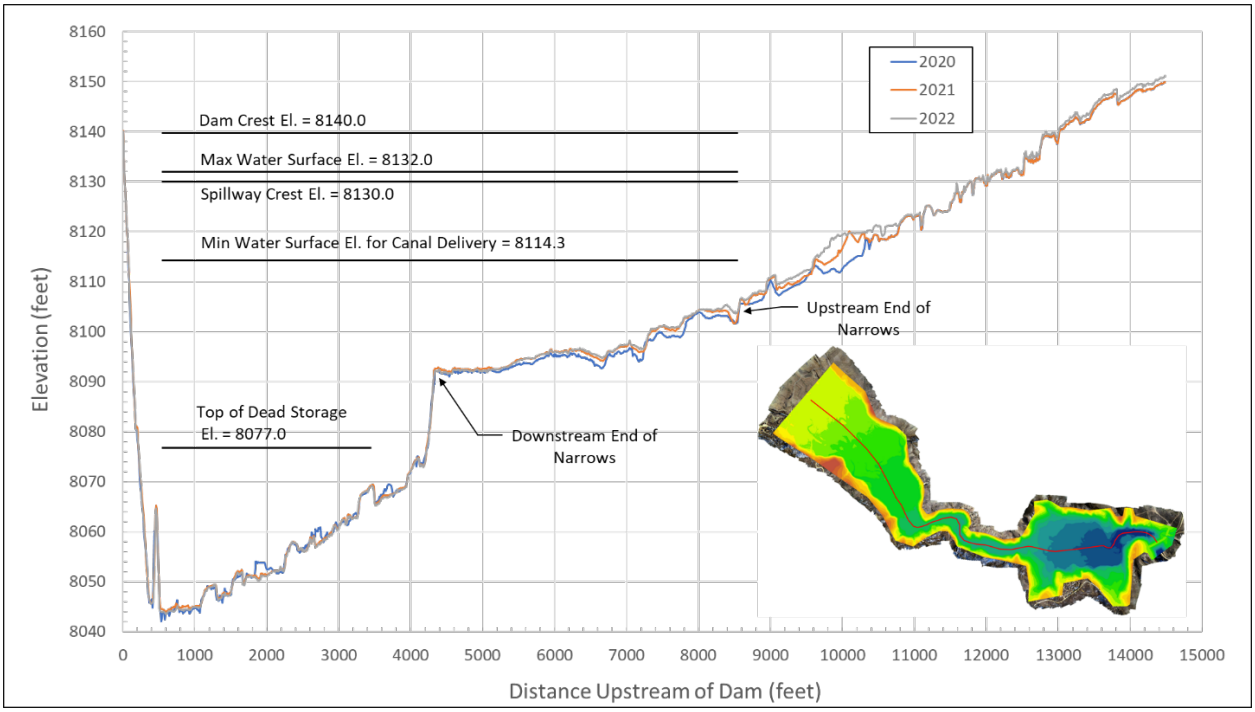


**Figure 4.** Longitudinal profiles of Willow Creek Reservoir bottom for 2020-2022. Graphic in lower right corner of plot shows profile alignment line along reservoir axis

In their comparison of the surveys, the Sedimentation Group computed 51.1 acre-feet of deposition upstream of the narrows between 2020 and 2021 (Reclamation, 2021), and Javernick 2023 computed 50.5 acre-feet between 2021 and 2022. Ignoring the changes attributed to

different survey methods in the lower reservoir shown in Figure 3, the computation of deposition volumes upstream of the narrows confirms results shown in the vertical difference surfaces (Figure 3) and longitudinal profiles (Figure 4). The deposition rates calculated in the analysis of the 2020-2021 and 2021-2022 data sets are nearly 5 times greater than the calculated pre-fire average annual deposition rate of 11.8 acre-feet per year.

## Conclusions

Comparison of the 2020-2021 and 2021-2022 data sets shows that sediment deposition rates may have increased by a factor of five in the upper reservoir since the East Troublesome Fire in October and November of 2020. Area and capacity computations, surface comparisons, and longitudinal profiles all indicate similar volumes of sediment deposition.

Differences in bathymetric survey methods make it difficult to compare results in the lower reservoir, particularly when comparing to the 2020 survey results. The lack of resolution resulting from the 2020 ADCP survey required more interpolation of topography over greater distances to generate a DEM when compared to subsequent multibeam surveys. Various interpolation schemes for the 2020 surface should be evaluated to see if topography more representative of actual reservoir bottom geometry might be produced.

Based on the initial watershed assessment, significant volumes of sediment initially mobilized after the fire may continue to be stored in the watershed upstream of the reservoir, delaying its delivery downstream. Deposits not mobilized for long periods of time may consolidate and/or vegetate and partially stabilize, making them less accessible to transport by flood flows.

Additional surveys using the same methods, continued monitoring of the upstream watershed, and collection and analysis of sediment samples is expected to further clarify the sediment balance picture and help quantify the impacts of the East Troublesome Fire on sediment transport throughout the Willow Creek Reservoir watershed.

## References

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