A BENEFIT-COST ANALYSIS OF

Hydraulic Mine Remediation in the Middle Yuba and Oregon Creek Watersheds

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Table of Contents

EXECUTIVE SUMMARY

This is a benefit-cost analysis (BCA) for the Yuba Water Agency (YWA) of three possible hydraulic mine remediation portfolios for two study areas in the Yuba Watershed: the Oregon Creek and Middle Yuba subwatersheds. These subwatersheds are home to 105 abandoned hydraulic mine sites covering 1,318 "impacted acres" or acres of abandoned mines that are considered highly erosive. Eroded sediment from these areas accumulates behind two diversion dams that are operated by the YWA – the Our House and Log Cabin diversion dams. This eroded sediment results in significant costs incurred by the YWA as this sediment must be physically removed so the dams can operate efficiently. The YWA expressed interest in understanding the economic benefits of remediating hydraulic mines on their budget because addressing these landscape features has forest health benefits in addition to reducing sedimentation behind their impoundments. Remediating these sites as part of watershed restoration would improve wildfire risk, wildlife habitat, water quality, and soil health.

The amount and type of erosion control treatments that are appropriate depends on the slope of the land. Of the 1,318 acres of hydraulicly mined acres, 923 acres have less than 50% slope, and 395 acres have >50% slope. Following erosion control all slope types would receive soil amendments and revegetation. The BCA considered four possible mine remediation investment portfolios.

- **The "Business-as-usual" portfolio:** assumes no treatments of hydraulic mines in the two study areas and that erosion continues at the same annual rate as today. This quantifies the current amount of sediment from hydraulic mines and provides a portfolio to compare the change in sedimentation with remediation done in the other three portfolios.
- **The "Low Remediation" portfolio:** (1,022 total acres) represents an approach to target high density fuel loads, erosion control, soil amendments, and revegetation on all acreages with <50% slope and one quarter of the acreages with ≥50% slope using erosion control treatments that can be done by hand. This results in:
  - **<50% slope: 923 acres of fuels reduction, erosion control treatments done by hand, soil amendments, and revegetation.**
  - **≥50% slope: 99 acres of erosion control treatments done by hand.**
- **The "Medium Remediation" portfolio:** (1,121 acres) includes the treatments described in the "Low Remediation" portfolio and in addition one quarter of the acreages with ≥50% slope treated for erosion control with equipment. This results in:
  - **<50% slope: 923 acres of fuels reduction, erosion control treatments done by hand, soil amendments, and revegetation.**
  - **≥50% slope: 198 acres of erosion control treatments done by hand and with equipment.**
- **The "High Remediation" portfolio:** (1,318 acres) includes the treatments described in the "Low Remediation" portfolio and in addition three quarters of the acreages having ≥50% slope receiving erosion control treatments using equipment. This results in:
  - **<50% slope: 923 acres of fuels reduction, erosion control treatments done by hand, soil amendments, and revegetation.**
  - **≥50% slope: 395 of erosion control treatments done by hand and with equipment.**

The analysis considered hydraulic mine acreages on both public and private lands within the Oregon Creek and Middle Yuba River subwatersheds to estimate the total benefits associated with mitigating sediment delivery from hydraulic mines to YWA facilities.

The analysis compared these investment portfolios with a business-as-usual portfolio which assumes no action is taken to remediate hydraulic mines to quantify the current amount of sediment from hydraulic mines and compare it to the change in sedimentation with remediation. Table ES-1 provides an overview of the avoided sediment that is possible with remediation under each scenario annually and over 30 years. Table ES-2 includes the percent contribution of sedimentation from hydraulic mines compared to the natural amount of sediment from the surrounding landscape.

Table ES-1 Annual avoided sedimentation (yd^3or cubic yard) for Oregon Creek above Log Cabin Dam and Middle Yuba above Our House Dam combined over the three Remediation Portfolios

Remediation Portfolio	Total Acres Treated	Total Annual Avoided Sediment for 105 Mine Sites (yd^3/year)	Total 30-Year Avoided Sediment for 105 Mine Sites (yd^3/year)
Business-as-usual	---	---	---
Low Remediation	1,022	20,573	466,148
Medium Remediation	1,121	41,056	930,212
High Remediation	1,318	82,004	1,857,976

Table ES-2. Annual sediment contributions (yd^3or cubic yard) from hydraulic mines compared to surrounding natural landscape for the Oregon Creek and Middle Yuba River watersheds above Log Cabin and Our House Dams.

Watershed	Current Sediment Yield (yrd^3/year)	Hydraulic Mine Sediment Contribution (yrd^3/year)	Natural Sediment Contribution (yrd^3/year)	% Hydraulic Mine Contribution
Oregon Creek (18,000 acres)	44,430	40,827	3,603	92%
Middle Yuba River (66,000 acres)	52,816	41,177	11,639	78%
Combined (84,000 acres)	97,246	82,004	15,242	84%

The BCA compared the costs of remediation treatments with the avoided sediment management costs for the YWA over a 30-year period and using YWA's preferred 4% discount rate.

Our analysis reveals that investing in the High Remediation Portfolio for hydraulic mine remediation for the 105 abandoned mine sites would generate substantial net gains for the YWA. As shown in Table ES-3, the High Remediation Scenario generates the highest net present value (NPV) at $112 million over 30 years, with a payback period of 11 years. The benefit-cost ratio (BCR) is 2.9, meaning the YWA can expect $2.9 dollars in benefits for every

dollar it invests in hydraulic mine remediation. This equates to a return on investment (ROI) of 195%. Furthermore, the Low and Medium Remediation portfolios also generate positive economic returns for almost every scenario in our sensitivity analysis.

The current cost of removing sediment from the two impoundments is estimated to be between $28-57 million over 30 years. Over the past five years, YWA has spent roughly almost $20 million to remove 140,000 yd^3 of sediment (see Appendix B for more details). Hydraulic mine remediation in the Oregon Creek and Middle Yuba watersheds represents a 48% - 195% return on investment. The investment pays for itself in 11-17 years depending on the remediation scenario implemented, with the high remediation scenario having the shortest payback period.

Table ES-2: 30-year Benefit-Cost Analysis results for all remediation portfolios in millions of dollars (M) discounted at 4%.

	Low Remediation Portfolio	Medium Remediation Portfolio	High Remediation Portfolio
Total benefits (discounted)	$42M	$85M	$169M
Total costs (discounted)	$29M	$41M	$57M
Net Present Value	$14M	$44M	$112M
Benefit-cost radio (BCR)	1.5	2.1	2.9
Return on Investment	48%	107%	195%
Payback period (yrs.)	17	14	11

As explored in the main body of the benefit cost analysis and Appendix B, a sensitivity analysis, which varied the remediation treatments and sedimentation management costs to account for uncertainty in these estimates, generated positive economic results in almost every scenario. Table ES-4 presents the range in net present value (NPV) results, from -$14 million to a positive $180 million over 30 years. The low end of the sensitivity analysis range assumes that remediation treatment costs are maximized, and sedimentation management costs are minimized; whereas the high end of the sensitivity analysis range assumes remediation treatment costs are minimized and sedimentation management costs are maximized.

Table ES-3: Sensitivity analysis results - 30-year Net Present Value (NPV) and 4% discount rate ($Millions)

Investment Portfolio	NPV (Average)	Sensitivity Analysis range in NPV
Low Remediation	$14	-$14 to +$38
Medium Remediation	$44	-$5 to +$84
High Remediation	$112	$39 to $180

The cost of gray or engineered infrastructure elements like closing an open adit or shaft or stabilizing a debris control dam were not included in this analysis. These can be determined once site surveys are completed, and a site plan is created. Given the high ROI of the remediation scenarios, however, there is significant room for investment in gray infrastructure.

Another omission is the costs in time and efforts associated with working with private landowners. Approximately 43% of hydraulic mines (570 acres) are on private lands and 57% of the hydraulic mines (748 acres) are on public lands owned by the Tahoe National Forest. Approaching a private landowner to conduct remediation projects could be met with hesitation and apprehension towards letting project staff on their land. This might be specifically true for landowners that are not private entities such as timber harvest organizations. A small private landowner could be difficult to contact or locate, may require a softer approach, and additional materials and meetings to outline project objectives, goals, and benefits. Though the minority percentage of hydraulic mine lands are on private lands within the project scope (43%), the additional time requirement to respectfully approach and work with landowners may represent costs that this analysis does not include. Future iterations of this analysis could include the costs associated with working with private landowners to ensure that 570 acres of mine impacted private lands can be remediated alongside the public lands. A revised analysis that included the cost of working with private landowners would benefit from a land use layer that identified the lands owned by timber industry. Given the incredibly high ROI values, there is plenty of room to add this and other elements and still achieve a positive economic result.

It is equally important to note that the analysis does not include other potential co-benefits from mine remediation such as reduced wildfire risk, improvements to water quality and soil health, improvements to habitat and biodiversity, and long-term below-ground carbon sequestration in soil from the use of biochar soil amendments.

In addition, the efficiency of coordinating fuels reduction efforts with hydraulic mine remediation efforts has also not been included in this analysis. For example, the access, mobilization and staging costs needed for fuel reduction and timber harvest efforts could be the same expenses as those needed to remediate hydraulic mines and therefore reduce the cost per acre estimates. This efficiency of coordinating and combining in the project plans surrounding fuel reduction efforts with hydraulic mine remediation efforts is especially true when it comes to using existing access roads, crews and equipment and have not been included in this analysis.

I INTRODUCTION

This paper details results from a benefit-cost analysis (BCA) conducted by The Sierra Fund with support from the World Resources Institute (WRI). The BCA examines the business case for investing in remediation of abandoned gold-rush era hydraulic mines located within the Tahoe National Forest (TNF) in two study areas located in the Yuba Watershed. The analysis compares the 30 -year costs of remediating hydraulic mines on both public and private lands using a novel set of treatments, to the benefits accrued to the Yuba Water Agency (YWA) in terms of avoided sediment management costs at two downstream diversion dams, the Our House Dam and Log Cabin Dam.

Abandoned hydraulic mines have long been a feature of the California landscape. An estimated 39,000 mine sites were dug during the gold-rush era in California from roughly 1854 to 1893, which were eventually abandoned as minerals and economies dried up. Abandoned mine sites are distributed across public and private lands (CDC 2000), and the majority of hydraulic mines are located in the Yuba and Bear River watersheds (Gilbert 1917). These sites are highly erosive and continue contribute significant amounts of sediment to downstream rivers and streams.

The two study areas include the Oregon Creek and Middle Yuba subwatersheds. Combined, these sites comprise 105 abandoned hydraulic mines and 1,318 "impacted acres" or acres that were denuded by hydraulic mining and today are highly erosive with unhealthy stressed fuels. Eroded soils from these mines flow downstream and are impounded behind two diversion dams managed by the YWA, resulting in increased sedimentation management costs. While not examined in this benefit-cost analysis, it is important to note that without remediation, these mine sites will continue to contribute to water runoff that has sediment and mercury and will remain hot spots for unhealthy forest fuels putting the area at risk of high intensity fire.

The objective of this analysis is to inform the YWA Board's water quality management strategy and business strategy and help them advance an integrated approach to watershed management that includes hydraulic mine remediation (HMR). As hydraulic mine remediation (HMR) is relatively new, the suggested set of treatments was defined by The Sierra Fund based on expert consultation and experience. The analytical approach for the BCA is based on WRI's Green-Gray Assessment (GGA) methodology from Gray et al. 2019. The GGA is an economic approach to identifying and comparing green and gray infrastructure investments to support water utilities in meeting their water security objectives. The GGA follows the steps of a traditional benefit-cost or cost-effectiveness analysis used in public policy and investment appraisals but aims to raise awareness of green infrastructure options and relevant costs and benefits.

In this section we provide an overview of the history and impacts of hydraulic mining, define hydraulic mine remediation treatments, and provide an overview of the study area and its water management challenges. **The following section presents the benefit-cost analysis assumptions and results including the project's return on investment and net present value over a 30-year period.**

1. Hydraulic mining history and impacts

Hydraulic mining was a form of mining practiced in California from around 1854 to 1893 to extract gold. The practice consisted of using large water cannons to wash away hillsides and process ancient riverbed deposits. Mercury was used to extract gold from mined materials. Hydraulic mining was unregulated during its almost 40-year stretch and produced an estimated 1.2 billion cubic yards of sediment in the Yuba and Bear River watersheds, leaving scars in the watershed that have lost soil structure and are highly erosive (James et al. 2019).

Hydraulic mining methods were targeted in 1884 by the Sawyer Decision after a lawsuit was filed by downstream farmers over damages to their land from floods of mud and debris. Hydraulic mining temporarily ceased. A decade later, the Caminetti Act of 1893 permitted hydraulic mining to resume under regulations requiring that sediment and mine debris be held back by debris control dams permitted by the California Debris Control Commission.

Hydraulic mining resumed after 1893 but never to the same scale that it was at prior to the Sawyer Decision. The price of gold was fixed after World War I and it became increasingly difficult to get enough gold to be profitable using this highly industrialized technique that required a significant amount of capital to operate the monitors, process material, and build a dam to hold the debris back. **The hydraulic mine sites were never cleaned up, in part because there was an expectation that they would be reopened. That did not occur, and as a result, the hydraulically mined areas have been eroding for the past 170+ years.**

Today, hydraulic mine-scarred lands across the forest share many of the same site characteristics because they were created using similar mining methods and techniques. They are denuded landscapes that are highly erosive with poor soil structure. Hydraulic mine sites still pose safety and environmental hazards today:

- open shafts or adits pose physical safety risks;
- mine sites often have stressed shrubs and trees that represent a significant fire hazard;
- runoff discharged can contain trace levels of mercury that was once used in gold extraction; and
- high erosion rates lead to downstream sedimentation of reservoirs and blockage of water supply infrastructure.

There are several ways to estimate the amount of eroded material coming from these sites that have been used by researchers:

1) using direct measurements over time on a site-by-site basis with terrestrial LiDAR (Howle et al., 2019),
2) using erosion prediction models that are based on soil types, topography, and climate (Robichaud et al., 2016; Quinn et al., 2018; Brooks et al., 2016) and
3) using a combination of these approaches.

There are as much as 395 acres of steep slopes (>50%) within the two study areas alone. Direct measurements from terrestrial LiDAR indicate that steep slopes (>50%) could be eroding as high as 529± 211 yrd^3/acre/year (Howle et al., 2019). A commonly used erosion prediction model, the Watershed Erosion Prediction Project, or WEPP model, was developed for forestry applications and can be used to quantify runoff and sediment yield over a range of conditions based on changes in land management, changes in soil texture, changes in vegetation type, burned vs unburned catchments, slope, and estimates secondary deposition and transport capacity to a selected point. By combining site specific measurements from terrestrial LiDAR for steep slopes with WEPP modeling outputs for slopes and associated sediment deposition rates downstream, we can create slope weighted soil loss estimates that are both unique to hydraulic mine site conditions and measure anticipated improvements with remediation scenarios that include natural landscape erosion. *See Appendix A for details of this approach.*

2. Hydraulic Mine Remediation (HMR) objectives and treatments

The principal goals of hydraulic mine remediation are to:

- reduce erosion to protect and secure water supply facilities,
- reduce fuels to reduce the risk of high-severity wildfire, and
- amend soils and revegetate for forest health and watershed resilience.

To date, only a handful of hydraulic mine sites have been remediated in part because until now they have been in the middle of nowhere (out of site and out of mind). Now that forest health and fuels reduction work is taking place in the region, crews are in and around these sites. But unfortunately, the mine sites are still being avoided. The United States Forest Service (USFS) is opting to flag and avoid these sites because they require site-specific cultural resource surveys before work can take place on them. The TNF has limited capacity to conduct these cultural resources surveys and has asked The Sierra Fund to help get sites “ready to proceed” by hiring outside archeologist consultants to conduct these surveys. Once the cultural resources survey is complete these sites need site specific plans to meet remediation goals and avoid impacting any significant cultural resources. This upfront planning work, that typically does not increase the value of a timber sale, has not been part of business as usual. **Our hope is that by quantifying the benefits of hydraulic mine remediation to downstream beneficiaries, hydraulic mine remediation and the benefits of doing it will be better understood by more land managers and become a normal part of all Forest Health projects.**

Based on The Sierra Fund’s experience, a literature review, and expert consultation, we have defined a set of treatments and phases to conduct restoration on denuded forests and remediate hydraulic mine sites:

Phase I: Conduct cultural surveys, site plan development and permitting. To begin, an initial investment in planning and permitting is needed, specifically, for cultural surveys by an archeologist and a site plan by an engineer. Without this initial investment in planning, the hydraulic mine sites will be left out of implementation to ensure no disturbance of potential culturally significant resources occur and no action will occur on these ‘flagged and avoided’ sites during surrounding Forest Health projects. When a cultural survey is done and if a site does *not* have potentially significant cultural resources, then the site is considered not eligible for listing under Section 106 of the California Cultural Resources Code and work can proceed without mitigation of impacts to these resources under the National Environmental Policy Act (NEPA). The majority of these hydraulic mine sites are not anticipated to have cultural resources of significance.

When a project manager decides to conduct an archaeological survey at the site, rather than flag and avoid the hydraulic mine site, a cultural archeologist must be hired to survey the property. The landowner would send the completed cultural survey and recommendation to SHIPO, the State Historic Preservation Officer to concur on the determination of eligibility as part of NEPA.

If SHIPO (State Historic Preservation Officer) determines that the site is ineligible for Section 106, the hydraulic mine site can be included in treatment scenarios and fuels reduction work planned in the surrounding forest. If the site is determined to be eligible, additional surveys and archaeological evaluation of the site plan and potential mitigation measures may be needed prior to treatment, which can increase the costs of the project. Once the site plan and cultural resource surveys are completed these sites can be included in the surrounding NEPA permitting documents and CEQA efforts as needed.

It is possible that a Determination of NEPA Applicability (DNA), will need to be completed for each hydraulic mine site by the District Ranger, stating that the work proposed fits appropriately within the larger NEPA permit. A site plan that describes the work that is proposed is one way to communicate NEPA applicability to the USFS, because it allows the work that is planned to be located on the site as part of a workplan, and if needed can show how any culturally significant features are being avoided/protected.

Phase II: Gain site access. After Phase I, it may be necessary to conduct road improvements to access each site and to create a designated staging area. Almost all hydraulic mine sites were once accessed by roads that were built a long time ago. **For this BCA, we anticipated having to improve these roads for many of the sites. We assumed at least 1 mile of road work for each site**, but a site could require as much as 10 miles of road improvements for site access and staging. Much of this road improvement work is already taking place as part of surrounding fuel treatment work, but if it is not, road improvements will be needed just to access the mine impacted areas.

We also anticipate the need to both get forest fuels out to reduce wildfire hazard as well to bring materials in, such as soil amendments to conduct the mine remediation. This typically means trucks need access. If equipment is needed to recontour steep slopes on the site, then that equipment needs to be brought in on trailers and off loaded in a staging area. **The mobilization and staging of equipment are part of the cost estimate**. It is assumed that ongoing maintenance of the sites will not require equipment to be brought back out to the site but can be done with hand treatments and therefore the costs of long-term maintenance of access roads was not included in our estimates.

Some temporary roads and road improvement on existing roads will be needed to gain site access and will contribute to the sediment load in the watershed. We estimate that between 105-1,050 miles of roads may be constructed to access hydraulic mines sites resulting in ~2,800yrd^3/year to 28,000 yrd^3/year (4,300 tons/year to 43,000 tons/year) of sediment. These values of additional sediment are significant and additional roads are considered a huge problem for watersheds. However, **we did not include the additional sediment from roads in our model because of the following considerations;** 1) These roads are considered temporary and will be decommissioned at the end of the project and not maintained and so the sediment input is temporary, 2) The vast majority of the roads that will be used for this effort already exist from when the mines were operated and will require improvements but not new cut roads, 3) The majority of the roads that need improving or to be built are already included in the scope of the surrounding fuels reduction projects.

Phase III: Implement remediation treatments. Table 1 provides an overview of applicable hydraulic mine remediation treatments and their relevant geographic areas as defined by slope. Generally, areas with higher slope (>50%) will be more difficult to access and treat and will require slope contouring using equipment in lieu of erosion control treatments by hand. Remediation would likely start with fuel reduction treatments. In areas with less steep slopes, fuel reduction would be followed by erosion control treatments done by hand or with equipment. After erosion control and slope contouring, soil amendments with biochar and/or wood chips and seeding treatments would be necessary to increase water infiltration and promote revegetation growth. The BCA includes all remediation treatments referenced in this table as part of the cost estimates.

Table 1: Hydraulic Mine Remediation Treatments (Phase III) and Sequencing

Remediation treatment	Description	Applicable Areas
1. Fuel reduction treatments	Reduce fuel load and fire severity by variable density thinning to achieve target stand density (75-100 BA-ft^2/acre), eliminate ladder fuels, improve tree species composition, and promote gap dynamics with a mosaic of landscape conditions.	Slopes < 50% with fuel densities greater than 100 BA-ft^2/acre.
2. Erosion control	Erosion control treatments done by hand, include installing structures to slow runoff and promote sediment aggradation such as: wattles, logs on contour, post assisted log structures (PALS), gully stuffing, Zuni bowls and one rock dams.	Slopes < 50%, with channel incision and drainage ditching.
3. Slope contouring	Erosion control treatments done with equipment, slopes, roads, ditches impacting site runoff would be realigned or reconstructed to reduce sediment transport using mechanized equipment.	Slopes ≥ 50% and areas of severe channel incision and drainage ditching.
4. Soil amendments	Amend soil with biochar, wood chips and seeding treatments. Residual slash from treatments would be chipped or burned to create biochar and applied as a broadcast to increase infiltration and promote revegetation.	Denuded soils on all slopes
5. Revegetation with native seeds	Appropriate California native erosion control seed mixtures would be broadcasted across hydraulic mine land footprints.	All areas

Phase IV: Perform gray infrastructure treatments when needed. Engineered, or gray infrastructure treatments like closing an open adit or shaft or stabilizing a debris control dam, may be needed but can only be determined after site access is gained and on a site-by-site basis. **We do not explore gray**

infrastructure treatments in this analysis, but it is possible a later version of this study could include these estimates.

3. Study area overview: The Middle Yuba and Oregon Creek watersheds

The Oregon Creek and Middle Yuba watersheds sit within the surrounding YWA project referred to as The Yuba River Development Project. The nearest cities are Camptonville, located approximately three miles east of New Bullards Bar Reservoir. The Yuba River Development Project serves multiple uses including hydropower, flood control, water supply, and environmental resources.

Flows in the Middle Yuba River watershed, including Oregon Creek, primarily originate from snow runoff and rain accumulated at Jackson Meadows Reservoir in Sierra County, California (YCWA, 2010). Oregon Creek is the largest tributary to the Middle Yuba River and joins the Middle Yuba River ~8.5 miles below Our House Dam. A portion of Middle Yuba River flows are diverted to the Log Cabin Dam on Oregon Creek through the Lohman Ridge Tunnel at Our House Dam. A portion of Oregon Creek flows are diverted to New Bullards Bar Reservoir through the Camptonville Diversion Tunnel at Log Cabin Dam.

The scope of this BCA is the Oregon Creek subwatershed above Log Cabin Dam and Middle Yuba subwatershed above Our House Dam (Figure 1). **These two subwatersheds were selected because of the locations of YWA impoundments, Log Cabin and Our House diversion dams, and the 105 hydraulic mines within them.**

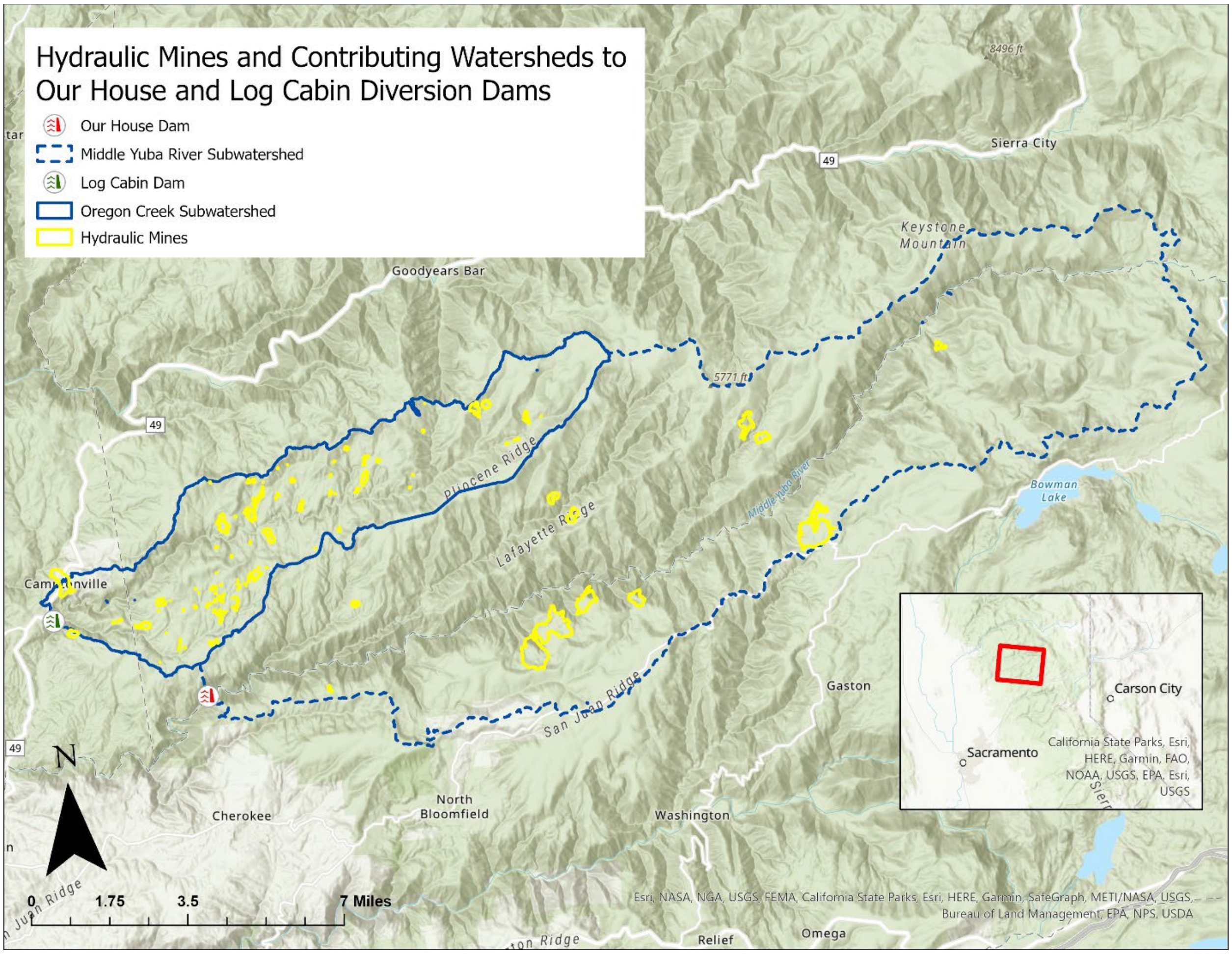


Figure 1. Contributing watersheds to the Log Cabin Dam on Oregon Creek (green) and Our House Diversion Dam on the Middle Yuba River (red). LiDAR derived Hydraulic mines delineated in yellow (Hydraulic Mine Inventory, 2019).

A. Oregon Creek subwatershed and the Log Cabin dam.

The Oregon Creek subwatershed above Log Cabin Dam is 18,000 acres and home to 95 hydraulic mine sites with 396 “impacted acres” or acres considered highly erosive due to historic mining activities (Hydraulic Mine Inventory, 2019) (see Table 2). Tahoe National Forest owns about 60% or ~11,000 of the 18,000 acres within the Oregon Creek subwatershed and 50% of the 396 acres of hydraulic mine lands (198 acres), while the other half are privately owned lands (198 acres) (Figure 2). Lands owned and managed by the TNF are primarily managed for timber, grazing, and recreation. At elevations above 3,000 feet there are other landowners including private corporations such as timber companies (NMFS 2014).

Log Cabin Diversion Dam is in Yuba County along Oregon Creek, approximately one mile south of the town of Camptonville. At ~15 river miles long, the 18,000-acre Oregon Creek subwatershed contributing to the Log Cabin Diversion Dam ranges from ~5,750 feet in elevation, at its eastern edge, to 1,925 feet at its western terminus (Figure 2). Approximately 90% of the Oregon Creek subwatershed is located within Sierra County, CA while the remaining 10% is within Yuba County, CA.

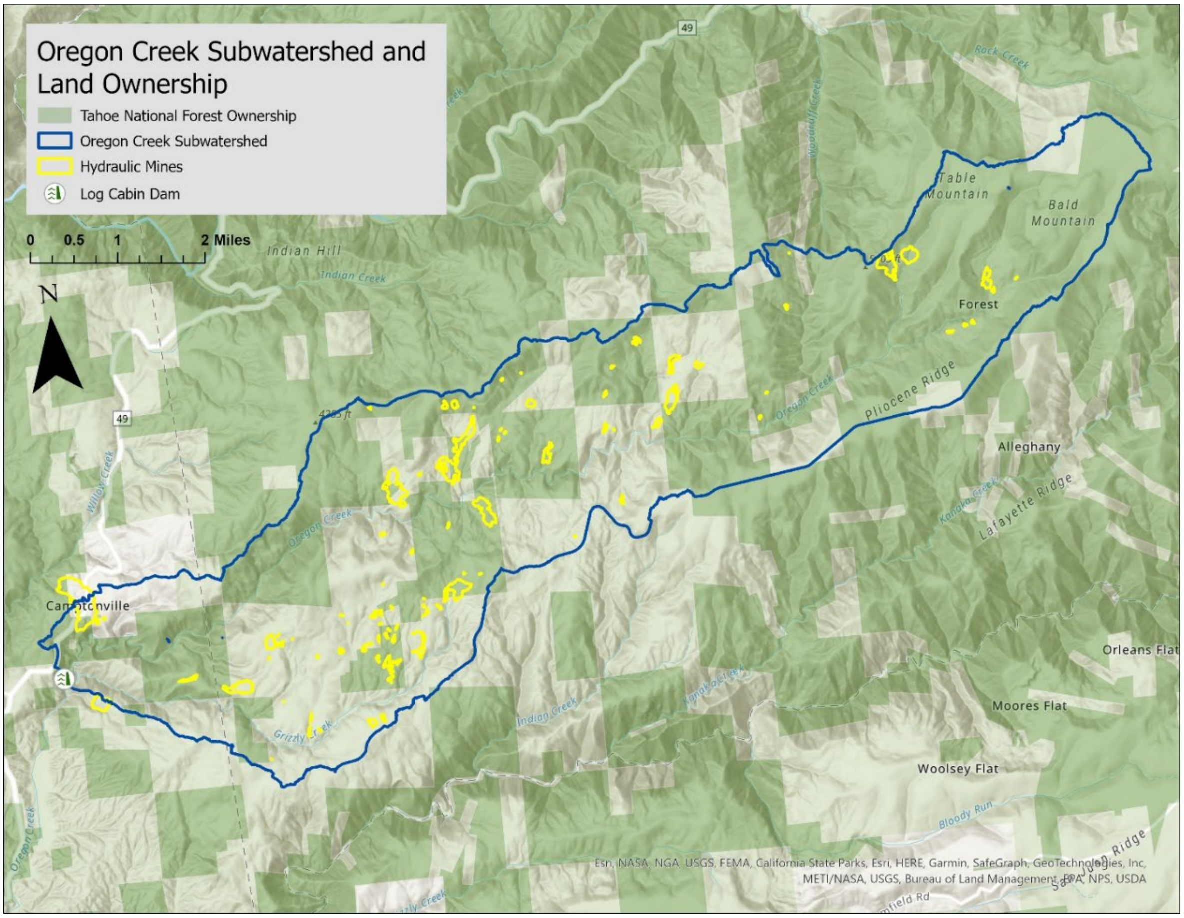


Figure 2. Land ownership within the Oregon Creek subwatershed and hydraulic mines.

Log Cabin Diversion Dam has two outlets to Oregon Creek in addition to a spillway (Figure 3). One outlet is a 5-foot diameter steel pipe that acts as a low-level outlet with a maximum capacity of 800 cubic feet per second (cfs) at an elevation 1,938 feet (YCWA, 2010). The second outlet is an 18-inch diameter release pipe with a maximum capacity of 13 cfs and is located just above the low-level outlet. The dam can divert ~ 1,100 cfs of water from Oregon Creek to New Bullards Bar Reservoir to provide water in part for power generation, irrigation and domestic needs, flood control, and recreation (YCWA, 2010).

Figure 3. Log Cabin Diversion Dam on Oregon Creek. Source: YCWA (2010).

B. Middle Yuba subwatershed and the Our House dam.

The Middle Yuba watershed above Our House Dam has 66,000 acres and is home to 10 hydraulic mine sites and 922 impacted acres (Hydraulic Mine Inventory, 2019) (see Table 2). Tahoe National Forest owns ~37,000 of the 66,000 acres within the Middle Yuba River subwatershed and 60% of the 922 acres of hydraulic mine lands (~ 550 acres), while the remaining 40% are privately owned lands (367 acres) (Figure 4).

Our House Diversion Dam is located along the Middle Yuba River, the dividing feature between Nevada and Sierra County, CA, and is approximately five miles southeast of the town of Camptonville. The Middle Yuba River subwatershed as defined for the scope of this analysis is limited to the river miles between Our House Diversion Dam and the next upstream impoundment, Milton Reservoir Diversion Dam. At 34 river miles long, the 66,000-acre Middle Yuba River subwatershed contributing to Our House Dam ranges from ~5,700 feet in elevation, at its eastern edge, to ~1,980 feet at its western terminus (Figure 4). Approximately 50% of the Middle Yuba River subwatershed lies within Sierra County on the northern slopes and 50% within Nevada County on the southern.

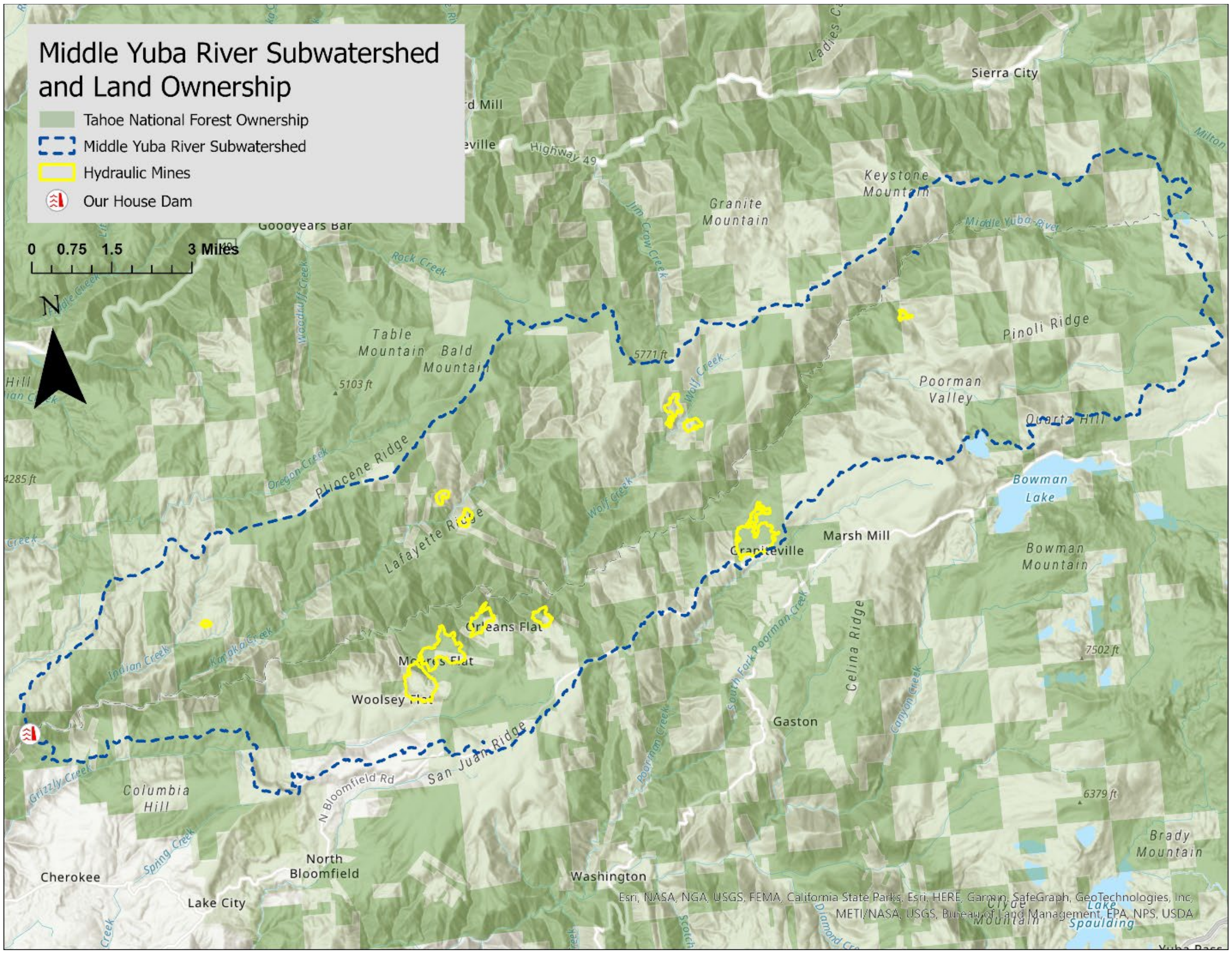


Figure 4. Land ownership within the Middle Yuba River subwatershed and hydraulic mines.

Our House Diversion Dam has two outlets to the Middle Yuba River in addition to a spillway (Figure 5). One outlet is a 5-foot diameter steel pipe that acts as a low-level outlet and has a maximum capacity of 800 cfs at an elevation of 1,990 feet. The second outlet is a 24-inch diameter release pipe with a maximum capacity of 60 cfs and is located just above the low-level outlet. Our House Dam can divert about 810 cfs of water from the Middle Yuba River to Oregon Creek through the Lohman Ridge Diversion Tunnel. Flows that are not diverted continue downstream and contribute towards Englebright Dam where releases are administered for hydroelectric power generation, irrigation, and maintenance of downstream riverine ecosystems.

Figure 5. Our House Diversion Dam on the Middle Yuba River. Source: YCWA (2010).

Table 2. Summary of each subwatershed acreage, the associated impoundment, number of hydraulic mines, the acres of hydraulic mines and the number of areas in each slope class.

Watershed	Watershed Acreage	Impoundment	# Of Hydraulic Mines	Hydraulic Mine Acreage	HM* Acreage <50%Slope	HM* Acreage ≥50%Slope
Oregon Creek	18,000	Log Cabin Dam	95	396	311	85
Middle Yuba River	66,000	Our House Dam	10	922	612	310
Combined	**84,000**	**Combined**	**105**	**1318**	**923**	**395**

** HM = Hydraulic Mine*

4. Water management challenges faced by YWA.

Accumulation of sediment behind the Our House and Log Cabin Diversion Dams is a present and ongoing phenomenon that the YWA continually manages. Depending on the climatic regime and precipitation amounts, **YWA mechanically removes accumulated sediments behind these impoundments every 2-10 years**. During removal efforts YWA has typically aimed to remove ~50,000 – 70,000 yrd^3 of sediment behind Our House Dam at total costs generally ranging from \$6.7 - \$8.6 million USD (2022) per removal event; and ~10,000 yrd^3 of sediment behind Log Cabin Dam at total costs ranging from \$1.8 – 2.5 million USD (2022) per removal event for Log Cabin Dam.

Sediment removal behind these impoundments is primarily initiated in response to YWA efforts to maintain flows and transfers through the Lohman Ridge Diversion Tunnel (Middle Yuba River to Oregon Creek) and the Camptonville Diversion Tunnel (Oregon Creek to New Bullards Bar Reservoir) as part of YWA's Yuba River Development Project (FERC P2-2246). **Sediment management at these impoundments ensures the proper management of flows for power production, flood control, water supply, and fish habitat maintenance in the lower river below New Bullards Bar Reservoir. In addition to sediment encroaching on release valves, sediment removal actions can be triggered if sediment levels become a threat to dam safety and structural ability and the delivery of environmental flows for fish habitat.**

Improving watershed resilience upstream of infrastructure is a strategy that has been adopted by several forward-thinking agencies, including YWA. The long-term management and maintenance of the watershed contributing areas is complicated by the fact that the land is often not owned by the agencies downstream. The Forest Resilience Bond was a groundbreaking strategy for YWA because it quantified the benefit of fuels reduction projects in the watersheds upstream of their impoundments and the associated avoided costs of wildfire. The North Yuba Forest Partnership connected the downstream agency, YWA, with the upstream landowners, Tahoe National Forest, and associated implementation partners. **This analysis expands that relationship to include the benefits of not just avoided wildfire risk to avoided sedimentation behind impoundments.** <u>**Simply put, this analysis quantifies the benefit of addressing the source of the sedimentation problem, the hydraulic mine sites, compared to the costs of sediment removal at the water supply facilities downstream.**</u>

II GREEN-GRAY ASSESSMENT FRAMEWORK, ASSUMPTIONS AND RESULTS

We conducted a benefit-cost analysis following WRI's Green-Gray Assessment (GGA) six-step approach (see Figure 6) by comparing the costs of remediating all hydraulic mine sites within the two watersheds with the avoided costs (or benefits) in terms of avoided sedimentation management costs for the YWA. This section follows the order of those steps.

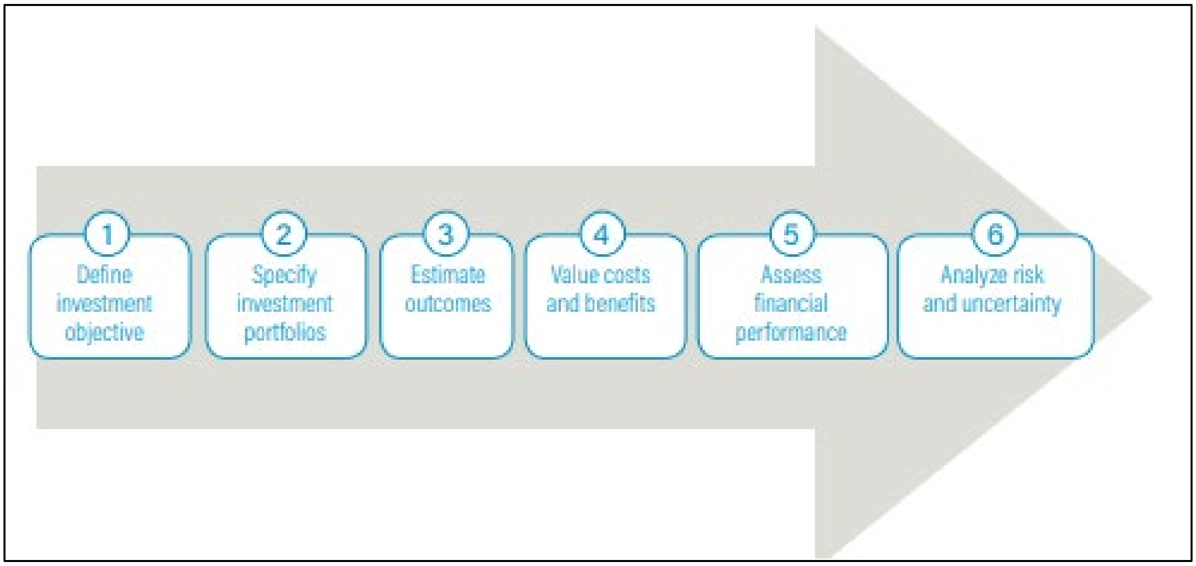


Figure 6. World Resource Institute's Green-Gray Assessment Steps (Gray et al. 2019).

1. Define the investment objective.

YWA is the targeted beneficiary for this analysis. The investment objective based on the water management challenges and interest in addressing hydraulic mines, is for YWA to maximize the net present value or return on investment of mine remediation over a 30-year period.

2. Specify investment portfolios.

The analysis team defined four possible remediation scenarios. It is important to note all portfolios attempt to remediate all 105 mines located within the two subwatersheds, irrespective of land ownership type. This is because we wanted to quantify the total effect and sediment contributions to YWA facilities that are directly associated with hydraulic mines. The remediation portfolios vary in terms of the total acres treated based primarily on slope. Areas with >50% slope require slope contouring measures and are generally more expensive to treat and less accessible. The four investment portfolios are described below and in Table 3:

- **"Business-as-usual" portfolio**: Assumes no treatments of hydraulic mines in the two study areas and that erosion continues at the same annual rate as today. Climate change and wildfire are anticipated to increase erosion rates and sediment transport but did not factor these increased risks into the analysis.

- **“Low Remediation” portfolio**: includes treating slopes that are less than 50% with fuels reduction and treating one quarter of the areas having slopes ≥50% with erosion control treatments that can be done by hand, followed by soil amendments (woodchips/biochar), and revegetation with native seed. This portfolio represents an approach to target high density fuel loads and improve soil conditions on hydraulic mine acreages with <50% slope. Erosion control measures for high slope areas include the use of straw wattles, post assisted log structures, logs on contour, Zuni bowls, and one-rock dams. Fuels reduction efforts on acreages having <50% slope would be the first treatment component to occur on hydraulic mine sites and then would need to reoccur every four years as needed. In conjunction with biochar, wood chips created during fuels reduction efforts would be applied to landscapes having <50% slope as soil amendments as one time application. Following soil amendment application, native seed mixes would be broadcasted across amended soil and repeated once a year for three years.
- **“Medium Remediation” portfolio**: includes the treatments described in the “Low Remediation” scenario, but with one quarter of the acreages having ≥50% slope being treated for erosion control via techniques done by hand and one quarter of the acreages having ≥50% slope being treated for erosion control via heavy equipment for slope recontouring. Recontouring or slope recontouring would only take place once and means shaping the landscape to provide natural drainage network and maximize hydrologic function. It may include “cut and fill”, cutting areas that are over steepened and using the material to fill areas of depression, to make a smoother even sloped ground surface that can receive soil amendments and revegetation. Recontouring may also include terracing steep cliffs to reduce mass wasting potential. These terraces would receive soil amendments and native seed following completion. Fuels reduction activities would be conducted first followed by recontouring one-quarter of the hydraulic mine acres with ≥50% slope using equipment. Then the erosion control by hand treatment would take place followed by soil amendments and revegetation. This scenario assumes that some areas with greater than 50% slope would be too difficult for recontouring by any reasonable means and would remain untreated.
- **“High Remediation” portfolio**: includes the treatments described in the “Medium Remediation” scenario with erosion control techniques that can be done by hand on all hydraulic mine acreages, and recontouring three-quarters of the areas having slopes that are ≥50%. The “High” remediation scenario would include treatments described in the “Low” and “Medium” remediation scenarios except it would include recontouring and subsequent soil amendment and revegetation applications on three-quarters of hydraulic mine acres having steep slopes (≥50%). Like the “Medium” scenario, the “High” scenario recontouring efforts would be a one-time effort. This is the most optimistic scenario because it assumes that all areas of the hydraulic mine site can be accessed and remediated with reasonable levels of effort. The extent to which this is possible will in large part be determined by the conditions of the site itself.

In addition to these treatments, we assume that each site would need Phase I and Phase II treatments (i.e., cultural surveys and site planning and permitting, and road work and staging). For Phase II road work and staging treatments, the Low Remediation investment portfolio we assume 1 mile of work for each site, and then 5 and 10 miles, respectively, for the Medium and High investment portfolios.

Table 3. Summary of Phase III remediation treatments by investment portfolio.

Watershed	Portfolio	Treatments	Slope Assumption	Treated Acres
LOG CABIN DAM (OREGON CREEK)	Business-as-usual	No remediation interventions	n/a	0
	Low Remediation	Fuels reduction	<50% & >50%	333
		Erosion control	<50%	312
		Erosion control	>50%	21
		Revegetation with native seeds	<50% & >50%	333
		Soil amendments with biochar and woodchips	<50% & >50%	333
		Slope contouring	>50%	0
	Medium Remediation	Fuels reduction	<50% & >50%	354
		Erosion control	<50%	312
		Erosion control	>50%	21
		Revegetation with native seeds	<50% & >50%	354
		Soil amendments with biochar and woodchips	<50% & >50%	354
		Slope contouring	>50%	21
	High Remediation	Fuels reduction	<50% & >50%	396
		Erosion control	<50%	312
		Erosion control	>50%	21
		Revegetation with native seeds	<50% & >50%	396
		Soil amendments with biochar and woodchips	<50% & >50%	396
		Slope contouring	>50%	63
OUR HOUSE DAM (MIDDLE YUBA)	Business-as-usual	No remediation interventions	n/a	0
	Low Remediation	Fuels reduction	<50% & >50%	689
		Erosion control	<50%	612
		Erosion control	>50%	78
		Revegetation with native seeds	<50% & >50%	689
		Soil amendments with biochar and woodchips	<50% & >50%	689
		Slope contouring	>50%	0
	Medium Remediation	Fuels reduction	<50% & >50%	767
		Erosion control	<50%	612
		Erosion control	>50%	78
		Revegetation with native seeds	<50% & >50%	767
		Soil amendments with biochar and woodchips	<50% & >50%	767
		Slope contouring	>50%	78
	High Remediation	Fuels reduction	<50% & >50%	922
		Erosion control	<50%	612
		Erosion control	>50%	78
		Revegetation with native seeds	<50% & >50%	922
		Soil amendments with biochar and woodchips	<50% & >50%	922

		Slope contouring	>50%	233
Combined Sites	Business-as-usual	No remediation interventions	n/a	n/a
	Low Remediation	Fuels reduction	<50% & >50%	1022
		Erosion control	<50%	923
		Erosion control	>50%	99
		Revegetation with native seeds	<50% & >50%	1022
		Soil amendments with biochar and woodchips	<50% & >50%	1022
		Slope contouring	>50%	0
	Medium Remediation	Fuels reduction	<50% & >50%	1121
		Erosion control	<50%	923
		Erosion control	>50%	99
		Revegetation with native seeds	<50% & >50%	1121
		Soil amendments with biochar and woodchips	<50% & >50%	1121
		Slope contouring	>50%	99
	High Remediation	Fuels reduction	<50% & >50%	1318
		Erosion control	<50%	923
		Erosion control	>50%	99
		Revegetation with native seeds	<50% & >50%	1318
		Soil amendments with biochar and woodchips	<50% & >50%	1318
		Slope contouring	>50%	296

3. Estimate biophysical outcomes.

The remediation investment portfolios were compared to the Business-as-usual portfolio to estimate the change in sediment yields or sediment delivery to the Log Cabin and Our House diversion dams. We used the Water Erosion Prediction Project (WEPP) model for (Un)-Disturbed sites in the United States (Ver. 2021.05.18.01). The WEPP model allows for users to make comparisons between the effects of land management changes on surface flows and sediment yield and delivery. In this study, the WEPP model allowed us to analyze changes in erosion and draw comparisons between current conditions and hypothetical remediated scenarios to quantify the benefit in avoided sediment accumulations and management costs behind YWA's impoundments. Details on the WEPP Model and our modeling assumptions can be found in Appendix A.

The sediment in the Oregon Creek sub watershed flows into the Log Cabin Dam impoundment. The Log Cabin Dam has 90AF of storage space which is approximately equivalent to 145,200 yrd^3 of sediment storage. The business-as-usual scenario estimates that ~44,000 yrd^3/year is eroded from hydraulic mines in the Oregon Creek sub watershed. According to this sedimentation rate it would take Log Cabin Dam 3.3 years to fill up. Similarly, Our House Dam has 280 AF of water storage which is approximately equivalent to 451,733 yrd^3 of sediment storage. The business-as-usual portfolio estimates that ~53,000 $yrds^3$/year is eroded from hydraulic mines in the Middle Yuba Watershed. According to this sedimentation rate it would take Our House Dam 8.5 years to fill up.

Based on these modeling efforts, Table 4 below provides the theoretical avoided sediment benefits with remediation of all 105 hydraulic mine sites for each scenario. Table 5 provides an overview of annual avoided sediment yields over a 30-year period that incorporates our implementation schedule for treating hydraulic mine lands for each scenario (we assume 9 sites can be treated per year for 11 years with the final 6 sites treated in year 12).

Table 4. Business-as-usual Portfolio Annual Sediment Yield and Avoided Sediment Yield Results with Hydraulic Mine (HM) Remediation.

Investment Portfolio	Watershed	HM Acres	HM Acres <50%	HM Acres >50%	Current Sediment Yield (yrd^3/year)	Remediated Sediment Yield (yrd^3/year)	Avoided Sediment Benefit (yrd^3/year)*
Business-as-usual	Oregon Creek	396	311	85	44,430	0	0
	Middle Yuba River	922	612	310	52,816	0	0
	TOTAL				**97,246**		
Low Remediation Portfolio	Oregon Creek	396	311	85		34,181	10,249
	Middle Yuba River	922	612	310		42,491	10,325
	TOTAL						**20,573**
Medium Remediation Portfolio	Oregon Creek	396	311	85		23,989	20,441
	Middle Yuba River	922	612	310		32,207	20,609
	TOTAL						**41,050**
High Remediation Portfolio	Oregon Creek	396	311	85		3,603	40,827
	Middle Yuba River	922	612	310		11,636	41,177
	TOTAL						**82,004**

** Sediment Yield and Sediment Yield Benefits are estimated assuming all 105 Hydraulic Mine sites have received remediation treatments.*

Table 5. Total Sediment Yield benefits over 30-year period for the, Low, Medium, and High Remediation Portfolios.

Investment Portfolio	Watershed	HM Acres	HM Acres <50%	HM Acres >50%	Current Sediment Yield (yrd^3/year)	30-yr Avoided Sediment Benefit (yrd^3)*
Business-as-usual	Combined	1,318	923	395	97,246	0
Low Remediation						**617,199**
Medium Remediation						**1,231,501**
High Remediation						**2,460,106**

** 30-yr Avoided Sediment Benefit (yrd^3) accounts for implementation schedule of 9 sites per year for 11 years (year 3 through 13) and 6 sites in year 12 to complete remediation of all 105 hydraulic mine sites.*

4. Benefit-Cost Analysis Results

This section provides information on the methods employed to value and compare the costs of the HMR portfolios vs. the benefits (e.g., avoided sediment management costs for the YWA). All values are in 2022 dollars. This section also discusses the sensitivity analysis with more details available in Appendix B.

A. Hydraulic mine remediation implementation costs.

Hydraulic mine remediation treatments are relatively new, so we conducted a literature review and consulted with experts (e.g., with engineers from Great Lakes Dredge & Dock Company, National Forest Representatives, Teichert Construction, and National Forest Foundation) to define and value. We considered four main types of costs (Gray et al. 2019):

- **Upfront investment costs** – "Initial project expenditure costs for land and capital equipment associated with implementing the investment portfolio."
- **Recurring operation and maintenance (O&M) costs** – "Costs of labor, equipment, and materials needed to ensure that infrastructure investments are maintained and operating well."
- **Transaction costs** – "Costs associated with the time, effort, and resources to search out, initiate, negotiate, and complete a deal and monitor and enforce that deal."
- **Opportunity costs** – "Forgone value from implementing the investment portfolio."

We assume that there are zero opportunity costs as the abandoned mine impacted acreages are currently not used for economic use. The remaining costs are summarized in Table 6.

Table 6: Hydraulic mine remediation costs (including sensitivity range)

Treatments	Units	Assumptions	Average cost	Minimum cost	Maximum cost	Sources
Permitting: Cultural surveys, Site plan, etc.…	$/site	Only occurs once	$150,000	$75,000	$225,000	*Sierra Fund knowledge*
Staging and road work	$/mile	Only occurs once to gain site access. Assume 1 mile access needed for Low Remediation sites, 5 miles access needed for Medium Remediation sites, and 10 miles access needed for High Remediation sites.	$27,500	$10,000	$45,000	Thomson and Pinkerton 2008
Fuel reduction upfront costs	$/acre		$4,408	$1,740	$7,076	Jones et al. 2017
Fuel reduction recurring costs	$/acre	Occurs every 4 years assuming 20% of upfront costs	$882	$348	$1,415	
Erosion control	$/acre	Erosion control treatments done by hand. Includes waddles, post-assisted structures, logs on contour, Zuni bows and one rock dams.	$2,035	$700	$4,000	Bales and Conklin 2020
Revegetation with native seeds upfront costs	$/acre		$300	$150	$750	*Sierra Fund knowledge*
Revegetation with native seeds recurring costs	$/acre	Occurs every year for 3 years, assuming 20% of upfront costs.	$60	$30	$150	

Soil amendments - biochar/woodchips	$/acre	Includes cost of biochar and application cost. Chips are made on site as part of fuels work. This assumes 10 tons/acre on average, low estimate is for 5 tons/acre, and high is for 20 ton/acre	$3,580	$ 1,790	$ 7,160	USU 2021
Slope recontouring	$/acre		$5,000	4,000	6,000	Thomson and Pinkerton 2008
Transaction costs (contract management and monitoring)	%	% of total annual costs	18%	15%	20%	*Sierra Fund knowledge*

Implementation schedule

We assumed that HMR treatments would be implemented over a 12-year period with nine sites remediated per year for the first 11 years, and 6 sites remediated in the final year. We assume remediation starts immediately in 2022. We assume that for each site, remediation happens within the given year and that sedimentation benefits are available immediately.

B. Benefits – Avoided sediment management costs.

To determine the cost savings to YWA due to a reduction in sediment loading at both dams, we worked with YWA (Crawford 2022) to identify avoided costs based on historic sediment removal events and determined a $/yd3 estimate for each cost line item (see Appendix B for more information). Table 7 provides an overview of the estimated costs including the sensitivity analysis range. The analysis assumes that at some point in the near future, a new stockpiling site would be needed.

Table 7: Avoided sedimentation management costs (average and sensitivity analysis range)

	Our House ($/yd^3)			**Log Cabin ($/yd^3)**		
		Sensitivity analysis range			**Sensitivity analysis range**	
Cost Components	**Average**	**Minimum**	**Maximum**	**Average**	**Minimum**	**Maximum**
Mobilization	$4	$1.33	$7.02	$10.92	$8.12	$13.71
Control of water	$10	$2.78	$17.55	$28.13	$20.18	$36.08
Sediment excavation & stockpiling	$39	$26.68	$51.68	$48.97	$52.32	$45.62
Sedimentation, erosion control, and hydro seeding	$1	$0.95	$0.95	$3.32	$3.32	$3.32
Internal Labor	$1	$0.50	$1.46	$0.72	$0.71	$0.73
Construction	$59	$40.03	$77.20	$89.68	$80.62	$98.74
Permitting and compliance	$10	$8.24	$11.30	$27.12	$18.97	$35.27
External Project Management	$6	$6.30	$5.71	$12.27	$8.23	$16.31
New stockpiling site	$1.67	$1.25	$2.08	$1.67	$1.25	$2.08
TOTAL COSTS ($/yd^3)	**$131.50**	**$88.06**	**$174.94**	**$221.13**	**$189.14**	**$249.79**

Due to data limitations regarding current reservoir sedimentation levels and what triggers a sediment removal event, we assume that all new sediment within a year will be removed. This approach has been used in similar financial analyses of green-gray infrastructure for urban water security (Ozment et al. 2018). These costs were then applied to the annual erosion yield benefit to estimate total annual costs.

Costs are multiplied by the total avoided sediment modeled in Step 3. As the full sedimentation benefits are not realized until all 105 sites are remediated, we multiplied the total annual avoided sediment benefit by the ratio of acres that received treatment in each year.

C. Comparison of costs and benefits.

Time horizon and discount rate

The Benefit-Cost Analysis (BCA) is conducted over a 30-year time horizon and assumes hydraulic mine remediation treatments will be implemented beginning in 2022. A 30-year time horizon has been used by previous analyses of hydraulic mines in California (USDA 2007), is relevant for water authorities like YWA (YWA) in terms of typical water infrastructure lifespans. Additionally, it is more appropriate for green infrastructure benefits than a 10- or 20-year time horizon due to the long-term provision of benefits identified by forest ecosystems (Gray et al. 2019).

The discount rate is the interest rate used to determine the present value of future cash flows. We assume a discount rate used by YWA of 4%. YWA provided cost estimates for two sediment removal events per site, as well as the amount of sediment removed.

Decision Criteria

Benefits and costs were compared using four metrics (Gray et al. 2019):

- **Net present value –** "compares the present value of costs to the present value of benefits. A positive NPV indicates a net gain for the investor(s)."
- **Benefit-cost ratio –** "divides total present value benefits by total present value costs. A ratio greater than one indicates a net gain."
- **Return on investment** – "measures the gain or loss of an investment by dividing the net discounted benefits by the discounted investment costs. This is calculated as a percentage."
- **Payback period** – "(years) expresses how long it takes to recover investment costs."

Results:

Table 8 presents results for each decision criterion, along with the sensitivity analysis range. As shown in Tables 6 and 7, we develop a minimum, average, and maximum value for each cost and benefit component. The low end of the sensitivity analysis range assumes the maximum values for remediation treatment costs and the minimum value of benefits (or minimum sedimentation management costs). The high end represents the minimum values for remediation costs and the maximum values for benefits.

Table 8: Benefit-Cost Analysis sensitivity analysis results –30-year analysis

Investment portfolio	**NPV* – Average (US$ Millions)**	**NPV* - Sensitivity Analysis Range (US$ Millions)**
Low Remediation	$14	-$14 to +$38
Medium Remediation	$44	-$5 to $84
High Remediation	$112	$39 to $180
	BCR - Average**	**BCR** - Sensitivity Analysis Range**
Low Remediation	1.5	0.7 to 4

Medium Remediation	2.1	0.9 to 5.7
High Remediation	2.9	1.4 to 8.4
	ROI *- Average**	**ROI*** - Sensitivity Analysis Range**
Low Remediation	48%	-30% to 298%
Medium Remediation	107%	-7% to 468%
High Remediation	195%	41% to 739%
	Payback period – Avg (yrs.)	**Payback period - Sensitivity Analysis Range (yrs.)**
Low Remediation	17	9 to 28 years
Medium Remediation	14	7 to 23 years
High Remediation	11	5 to 17 years

**NPV – Not Present Value, ** BCR – Benefit-cost radio, ***ROI – Return on Investment*

III CONCLUSIONS

Results from Table 8 show that almost every remediation portfolio and sensitivity analysis scenario presents a positive business case for investment for YWA in hydraulic mine remediation. **If we assume YWA's investment objective is to maximize the Not Present Value (NPV) and Return on Investment (ROI), then the best business case is to invest in the High Remediation Portfolio. Based on the average scenario in the sensitivity analysis, this portfolio generates the highest net present value (NPV) at $112 million over 30 years, with a payback period of 11 years. The benefit-cost ratio (BCR) is 2.9, meaning the YWA can expect $2.9 dollars in benefits for every dollar it invests in hydraulic mine remediation. This equates to a ROI of 195%.** This portfolio also generates the highest sedimentation reduction (see Table 5) – almost twice that of the medium scenario and quadruple that of the low remediation scenario. This indicates that treating higher sloped areas is economically beneficial.

The order of magnitude of these net benefits over 30 years ($14 – $112 million) is in the same order of magnitude as the cost of recent sediment removal events at the two diversion dams. Over the past five years alone, YWA has spent roughly almost $20 million to remove 140,000 yd^3 of sediment (see Appendix B for more details).

Additionally, a sensitivity analysis which varied the remediation treatment and sedimentation management costs to account for uncertainty in these estimates, also generated positive economic results in almost every scenario.

The analysis could be strengthened in future iterations by incorporating additional considerations. For example, the analysis did not include any gray infrastructure elements and assumed remediation treatments can take place on private as well as public lands. Approximately 57% of hydraulic mine acreages (748 acres) lie within public lands and the remaining 43% of hydraulic mines (570 acres) are within private lands. A large proportion of private lands are assumed to be private corporations, such as timber companies and could be potential partners in this effort. Given the incredibly high ROI values, there is plenty of room to add gray infrastructure elements and still achieve a positive economic result.

Finally, the benefit-cost analysis economic model did not include the many potential co-benefits of hydraulic mine remediation such as benefits from reduced fire risk, soil-carbon sequestration, habitat and biodiversity improvement, and reduce heavy metal contamination of soils and water bodies. Instituting monitoring protocols to evaluate the potential co-benefits with hydraulic mine remediation would provide the data to quantify ecosystem and monetary benefits for future investments in surrounding regions.

BIBLIOGRAPHY

Bales, R. and Conklin, 2020. Restoring California's forests to reduce wildfire risks will take time, billions of dollars and a broad commitment. The Conversation. Available at: https://theconversation.com/restoring-californias-forests-to-reduce-wildfire-risks-will-take-time-billions-of-dollars-and-a-broad-commitment-146532.

Crawford, K. 2022. Email communications between Kurtis Crawford, YWA and the Sierra Fund and WRI.

Gilbert, G.K., 1917, Hydraulic-mining debris in the Sierra Nevada: U.S. Geologic Survey Professional Paper 105, 155 p.

Hydraulic Mine Inventory, 2019. Hydraulic mine and mine feature geospatial database; developed using the 2013 and 2014 aerial Light Detection and Ranging (LiDAR) remote sensing data from the US Department of Agriculture (USDA), US Forest Service (USFS), Tahoe National Forest by The Tahoe National Forest and The Sierra Fund, 2019.

James, A., Monohan, C. and B. Ertis. 2019. Long term Hydraulic Mining Sediment Budgets: Connectivity as a Management Tool. Science of the Total Environment. (651) 2024-2035.

Jones 2017

Ozment et al. 2018. Natural Infrastructure in São Paulo's Water System. World Resources Institute. Washington, DC.

National Marine Fisheries Service (NMFS), 2014. Upper Yuba River Anadromous Salmonid Reintroduction Plan. Prepared by R2 Resource Consultants and Stillwater Sciences, Inc. in collaboration with NOAA/NMFS.

Reid, L.M.; Dunne, T. 2011. Sediment production from forest road surfaces. Paper #G28 in DeWalle, D.R. (ed.): Forest Hydrology (IAHS Benchmark Papers in Hydrology Series). International Association of Hydrological Sciences. (1984 paper reprinted from Water Resources Research 20(11), 1753 1761)

Thomson, C.J., and C. Pinkerton, 2008. Habitat restoration cost references for salmon recovery planning. NOAA. Available at: https://repository.library.noaa.gov/view/noaa/4516.

USDA 2007

USU (Utah State University), 2022. Biochar impacts on crop yield and soil water availability. Available at: https://extension.usu.edu/crops/research/biochar-impacts-on-crop-yield-and-soil-water-availability.

Yuba County Water Agency (YCWA). 2010. Yuba River Development Project, FERC Project No. 2246, Pre-Application Document. Marysville, CA http://www.ycwa-relicensing.com

APPENDIX A:
WEPP Model Overview and USGS Erosion Rates

The Watershed Erosion Prediction Project (WEPP) model was initially developed in 1985 by the USDA-ARS National Soil Erosion Research Laboratory (NSERL) and has since been updated, as recently as 2021. The WEPP model is a physically based hydrology and erosion model (Flanagan and Nearing, 1995, Flanagan et al., 2007) that estimates the spatial and temporal distribution of soil erosion, deposition, transport, and sediment yield based on slope, soil type or land use classification, and climate. The WEPP model is based on the fundamentals of hydrology, plant science, hydraulics, and erosion mechanics (Flanagan and Nearing, 1995). Other scientific literature related to the development of the WEPP model, validation, and applications include Nearing et al. (1989a), Zhang et al. (1996), Ascough et al. (1997), Liu et al. (1997), Tiwari et al. (2000), Laflen et al. (2004), Clark et al. (2006), Cruse et al. (2006), Pieri et al. (2007), Moore et al. (2007), and Abaci and Papanicolaou (2009).

The WEPP model allows for users to make comparisons between the effects of land management changes on surface flows and sediment yield. In this study, the WEPP model allowed us to analyze changes in erosion and draw comparisons between current conditions and hypothetical remediated scenarios to quantify the benefit in avoided sediment accumulations and management costs behind YWA's impoundments.

Below are brief descriptions model components and processes used for this study:

- Watershed delineations were performed using the Topographic Parameterization (TOPAZ) tool to derive topographic features such as slope length, width, aspect, and slope using Digital Elevation Models (DEM) and characterizes the watershed as the sum of multiple representative hillslopes or sub-catchments, channels, and the linkage between them (Garbrecht and Martz, 1997).
- Managements or the dominant "Landuse" is determined for the entirety of the delineated watershed on a per hillslope or sub-catchment basis derived from the 2019 National Land Cover Database (NLCD). Different managements or "Landuse" types can be applied or refined by the user to provide better representation of management practices or inform land managers on the effects of land management changes on runoff and sediment yield such as this study.
- Soils were derived using the Soil Survey Geographic database (SSURGO) which refers to digital soils data produced and distributed by the Natural Resources Conservation Service (NRCS) as collected by the National Cooperative Soil Survey (NCSS) over the course of a century. Soils were assigned for the delineated watershed on a hillslope or sub-catchment basis.
- Climate predictions (years = 50) for the model were made using CLIGEN, which is a stochastic weather generator that produces typical climatic parameters such as daily estimates of precipitation, temperature, dew point, wind, and solar radiation. Additionally, CLIGEN produces and individual storm parameter estimates, including time to peak, peak intensity, and storm duration. The CLIGEN weather generator predicted climatic regimes based on the NSERL CLIGEN database of weather station data using a "Multi-Factor Ranking" considering distance, elevation, and climate of the delineated watershed. The NSERL CLIGEN station selected for climate predictions for the Our House Dam watershed was the "BOWMAN DAM CA 41018" station and the "DOWNIEVILLE RS CA 42500 0" station for the Log Cabin Dam Watershed.

- Hillslope erosion is represented in two ways: 1) detachment and delivery of soil particles by raindrop impact and shallow sheet flow on interrill areas, and 2) soil particle detachment, transport, and deposition by concentrated flow in rill areas. Rill erosion is modeled as a function of flow capacity to mobilize soil versus existing sediments loads in flow. WEPP uses a steady-state sediment continuity equation for erosion calculations, or when hydraulic shear stress exceeds the critical shear stress of soil and when sediment load is less that sediment transport capacity. Deposition and or sediment transport capacity is calculated using a modified Yalin equation that describes when the sediment load in flow is greater than sediment transport capacity.
- Channel erosion is like hillslope erosion with the exception that flow shear stress is calculated using regression equations that approximate the spatially varied flow equations, and only entrainment, transport, and deposition by concentrated flow are considered (i.e., channel flow rather than sheet flow).

Soil surface cover or “Land use” is one of the WEPP model parameters for simulating soil erosion rates, where specific “Land use” types reference a land cover classification system. This is called the Anderson Land Cover Classification System and it is broadly used by USGS National Land Cover Database (NLCD). For hydraulic mine landscapes with slopes less than 50%, the “Current Sediment Yield” and erosion rates were calculated using the WEPP model output for “Bare Rock/Sand/Clay” land use designation. The “Bare Rock/Sand/Clay” land use class was selected and used to represent the baseline or current conditions associated with the hydraulic mined lands having slopes less than 50%. The “Bare Rock/Sand/Clay” land use class is defined as; areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material with vegetation accounting for less than 15% of total cover (Anderson et al., 1976).

For portions of the hydraulic mine landscapes with slopes greater than or equal to 50%, a United States Geological Survey (USGS) derived erosion rate for hydraulic mine landscapes with steep slopes (≥ 50%) (Howle et al. 2019) was assigned into the WEPP model for sediment delivery calculations. The USGS erosion rate was adopted from a geomorphic analysis that utilized Terrestrial-Light Detection and Ranging (t-LiDAR) technology to estimate erosion rates from steep sloping pit walls of a hydraulic Mine at the Malakoff Diggins State Historical Park, Nevada County, CA (Howle et al., 2019).

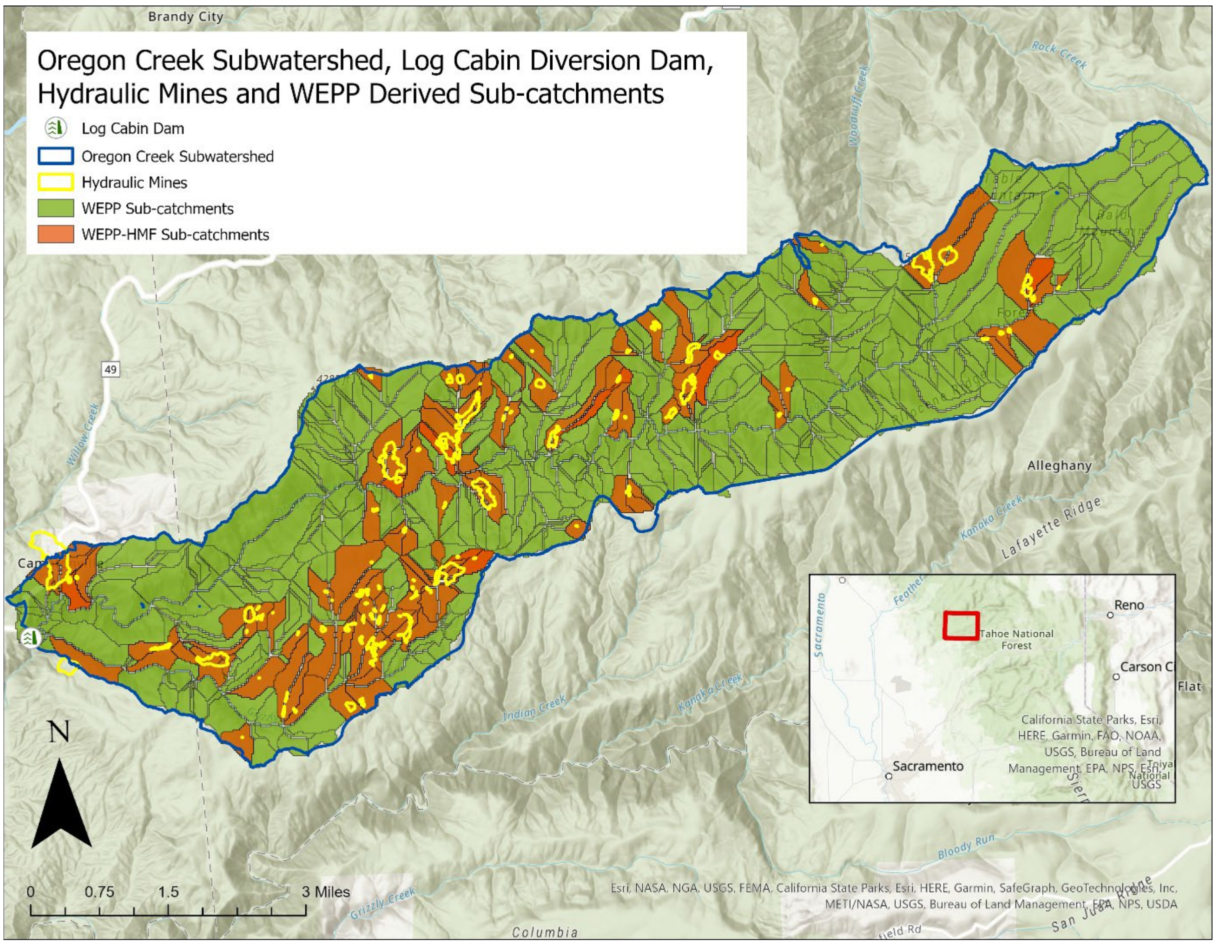
At Malakoff Diggins, the USGS collected annual high-resolution terrestrial laser scanning surveys (t-LiDAR) from 2014 to 2017, measuring centimeter-scale topographic changes to quantify the volume of sediment eroded from outcrops. The terrestrial laser scanning enabled the construction of three-dimensional maps of the complex topography on site, which could not be mapped non-destructively or in sufficient detail with traditional survey methods. Net eroded sediment volumes from discrete sedimentary units, across a range of steep sloping outcrops, were calculated at four study sites throughout the mine pit. Through their analysis, Howle estimated that the average annual erosion rate of all sites surveyed was 0.1±0.04 m^3/m^2/year or 529± 211 yrd^3/acre/year.

The WEPP model was run twice across the Oregon Creek and Middle Yuba River watersheds, where differences in model outputs correlated to the avoided sediment yield benefit associated with remediation efforts. The first WEPP execution was run with the “Landuse” parameter declared as “Evergreen Forest” to simulate remediated soil erosion rates and the “Remediated Sediment Yield”. The second WEPP execution was run using the “Land use” parameter declared as “Bare Rock/Sand/Clay” to represent areas having <50% slope and combined with the USGS derived erosion rate for steep slopes

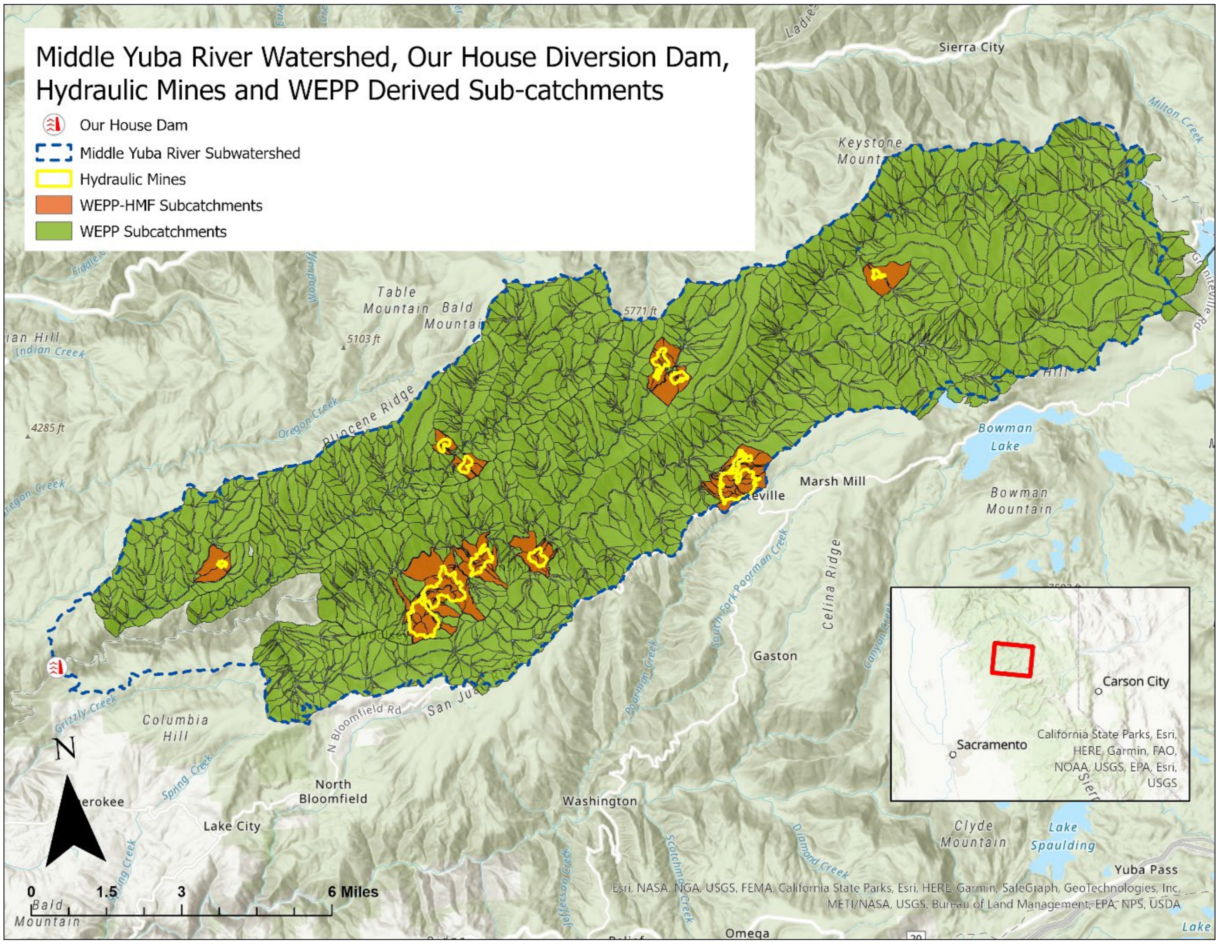
(≥50%) to simulate the current non-remediated soil erosion rates and “Current Sediment Yield”. The difference between these two erosion rates or sediment yield is the restoration potential for avoided sediment accumulations at downstream impoundments following treatments.

Using this modified WEPP-USGS model allowed us to be more accurate with our soil loss estimates from hydraulic mines landscapes. In other words, instead of assuming an entire hydraulic mine area could be represented by and erosion rate derived by a general landuse class (Bare Rock/Sand/Clay), we incorporated a regionally relevant erosion rate for steep slopes within a hydraulic mine, assigning different erosion estimates according to slope (< or ≥ 50%). Adding this distinction provided additional hydraulic mine site detail and erosive characteristics that would not have been captured without.

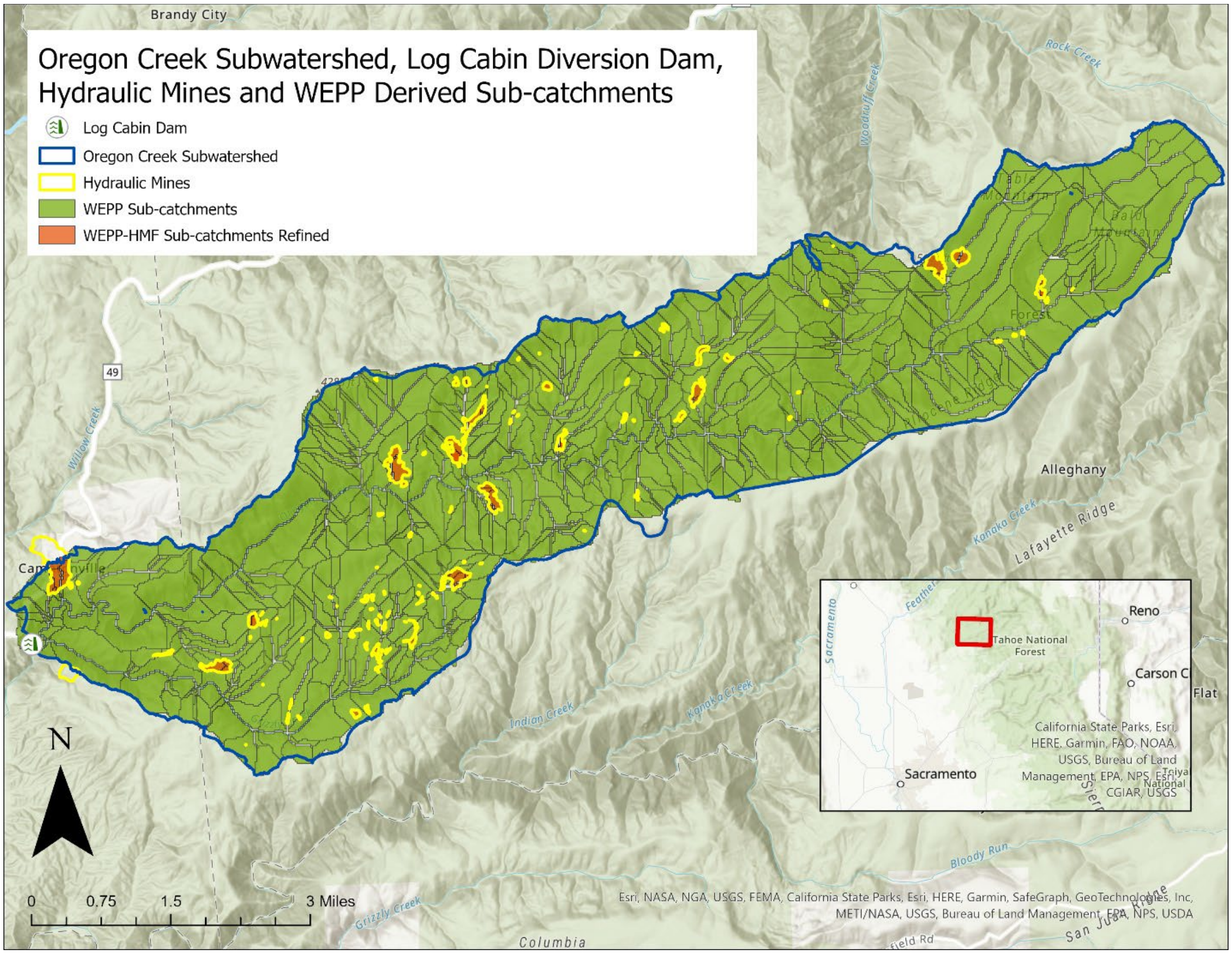
To capture and isolate the WEPP model soil loss estimates for just the hydraulic mine areas, we overlaid the full WEPP output for the watershed that was comprised of smaller sub-catchments onto the hydraulic mine delineations (Figure AP-A 1 & 2) and then clipped the WEPP layer to the hydraulic mine delineation (Figure AP-A 3 & 4).



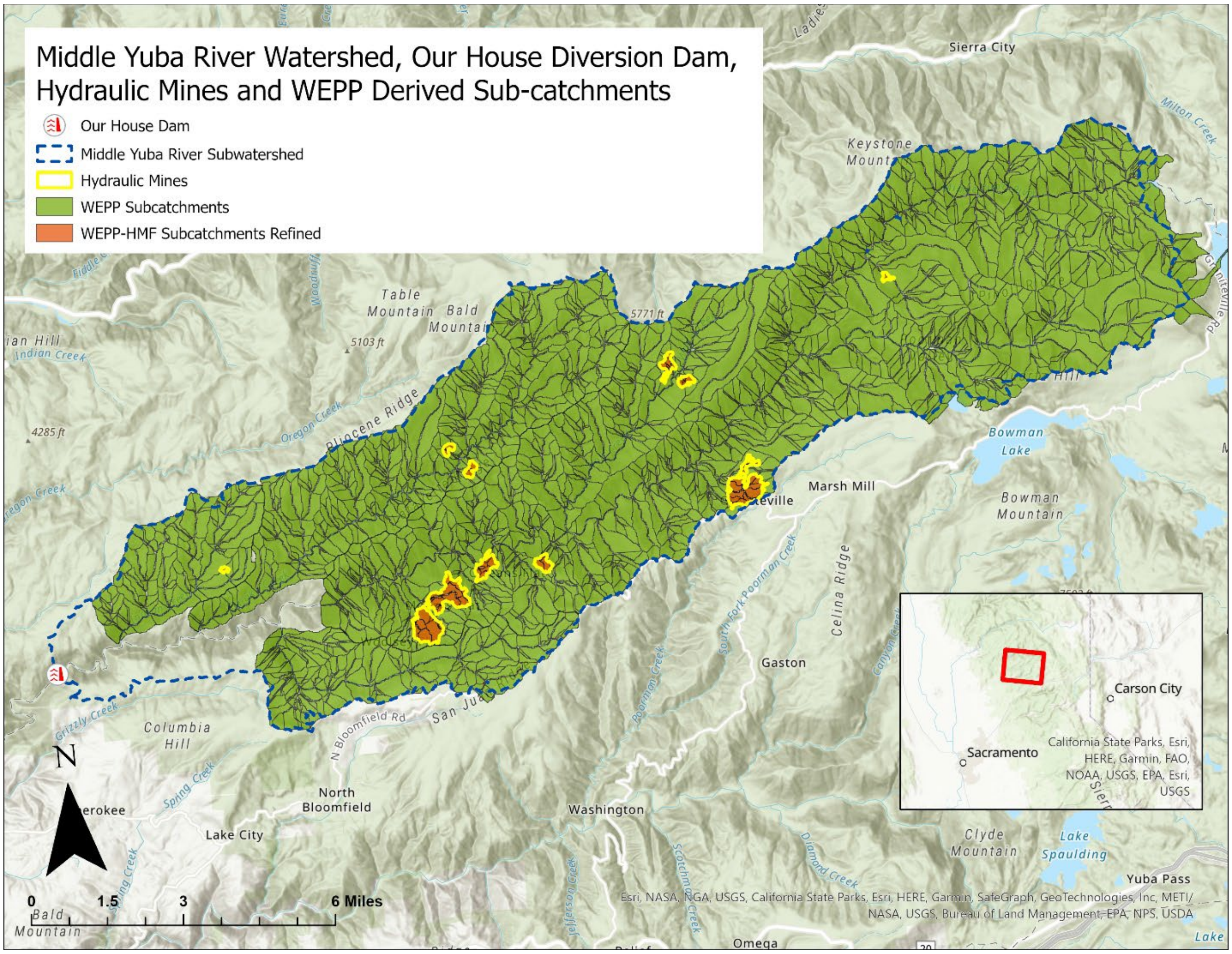
AP-A 1. WEPP Derived Sub-Catchments (green), Overlaid LiDAR Derived Hydraulic Mine Footprints (yellow), and Isolated WEPP Derived Sub-Catchments (orange) Within the Oregon Creek Subwatershed.



AP-A 2. WEPP Derived Sub-Catchments (green), Overlaid LiDAR Derived Hydraulic Mine Footprints (yellow), and Isolated WEPP Derived Sub-Catchments (orange) Within the Middle Yuba River Watershed.

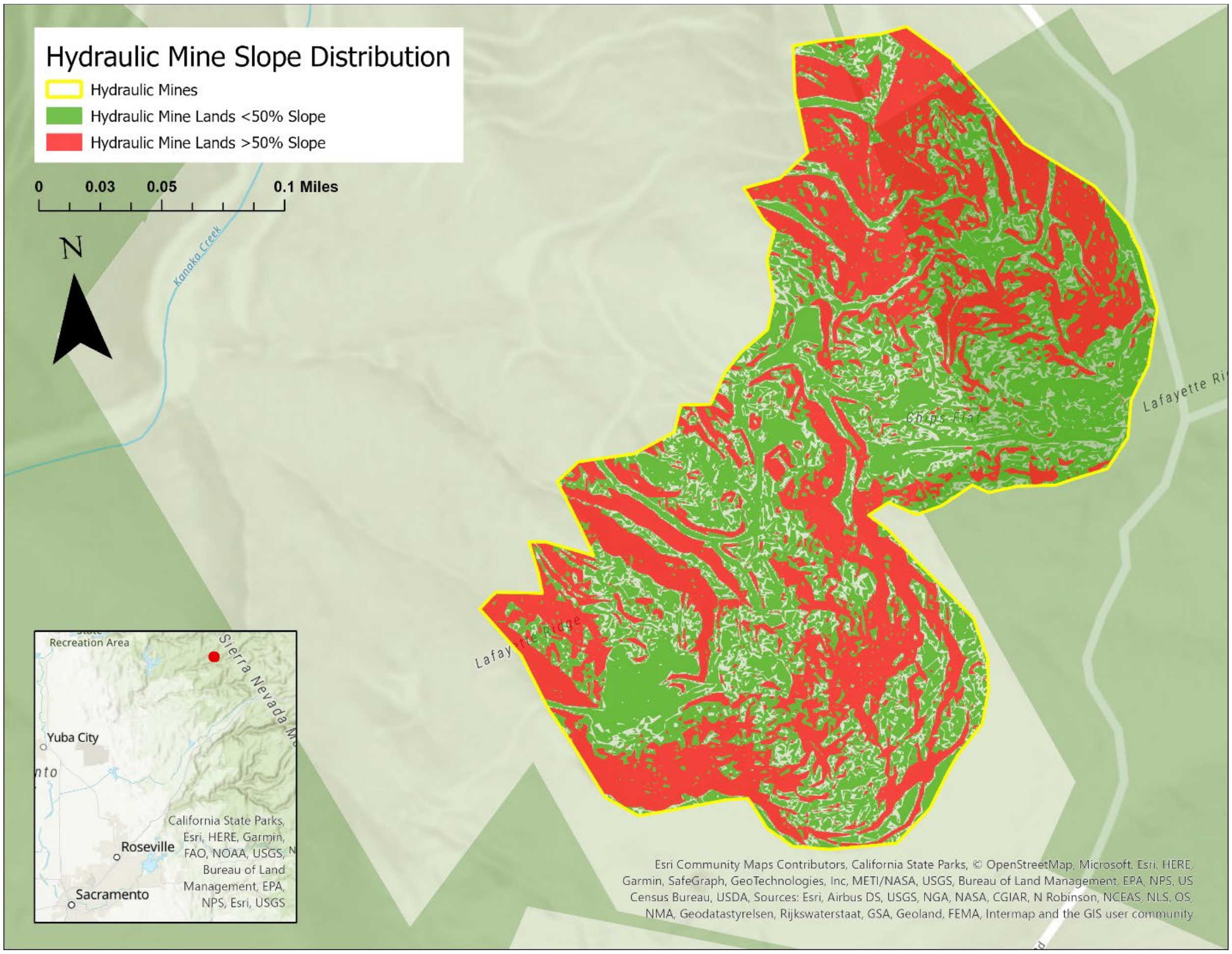


AP-A 3. Refined WEPP Derived Sub-Catchments (green), Overlaid LiDAR Derived Hydraulic Mine Footprints (yellow), and Isolated WEPP Derived Sub-Catchments (orange) Within the Oregon Creek Subwatershed.



AP-A 4. Refined WEPP Derived Sub-Catchments (green), Overlaid LiDAR Derived Hydraulic Mine Footprints (yellow), and Isolated WEPP Derived Sub-Catchments (orange) Within the Middle Yuba River Watershed.

The percent coverage of hydraulic mine areas over the WEPP sub-catchments were calculated and then multiplied by the assigned soil loss estimate for each sub-catchment to isolate the sediment yields originating from hydraulic mines and eliminate sediment yields from the surrounding landscape. Hydraulic mine site acreages were then binned into two slope classes, less than 50% and greater than or equal to 50% (Figure AP-A 5). Final sediment yields were then calculated using the corresponding percentage of hydraulic mine areas having <50% slope and ≥50% slope by multiplying their respective percentages by the WEPP derived soil loss estimates for areas having <50% slope and the USGS derived erosion rate on areas having ≥50% slope. Sub-catchment level soil loss estimates, which included unique ratios of sediment delivery, for each subwatershed were then summed to calculate the total sediment yield for Log Cabin Dam within the Oregon Creek subwatershed and Our House Dam within the Middle Yuba River subwatershed.



AP-A 5. Distribution of Slope on a Hydraulic Mine Site. Areas having <50% slope represented in green and areas having ≥50% slope represented in red. Percent coverage of slope class used for sediment yield calculations of WEPP and USGS derived erosion rates.

The difference in erosion rate and sediment yield or “Sediment Yield Benefit” for each watershed comprises the benefits to the YWA in terms of avoided sediment at the Log Cabin and Our House diversion dams. The “Sediment Yield Benefit” was determined for each scenario and watershed by quantifying the difference in sediment yield from the WEPP derived “Remediated Sediment Yield” and the sediment yield from the modified WEPP and USGS derived “Current Sediment Yield”. These calculations were made with the assumption that the erosion rates and sediment yields associated with the modified WEPP-USGS model for “Current Sediment Yield” resemble the current conditions, and the erosion rates and sediment yields associated with the WEPP model for “Remediated Erosion Yield” resemble conditions following interventions and treatments.

Use of the WEPP model for watershed and hillslope erosion and sediment yield data have been validated in previous studies; Robichaud et al., 2016 and Quinn et al., 2018, with acceptable accuracy and is suggested to expect a 50% modeling output variability for explicit model accuracy. In comparison, observed soil erosion rates from duplicate hillslope experimental plots often result in 50% variability (Brooks et al., 2016). Terrestrial LiDAR measurements are being collected by USGS from two hydraulic mines sites, Grizzly Creek and Tippecanoe, within the Oregon Creek subwatershed to get site specific measurements and increase the modified WEPP model applicability to the region.

APPENDIX B:
Sensitivity Analysis

To account for data uncertainty, we conducted a sensitivity analysis whereby we varied:

- **HMR implementation costs:** As there are very few circumstances of HMR in practice in the region, our estimates are based on a literature review and engineers' estimates for the practices on an individual scale. There may very well be economies of scale for implementation that would result in these costs being reduced, or site implementation complexities that result in costs being higher.
- **Sedimentation management costs:** YWA provided two data points for each site for sediment management costs based on four sediment removal events total. These values were converted to 2022 USD; the event with the lower of the two costs was used for the "low" estimate and the event with the higher of the two costs was used for the "high" estimate. The low and high estimates were averaged for the average scenario. The sediment removal events had varying cost line items. Based on conversations with YWA, we assume that all line items apply, so where data are missing we filled the gaps based on estimates from the other site or events.

Sedimentation management costs were based on the following data provided by YWA (Crawford 2022). All cost items were put into $ 2022 price per cubic yard values so we could estimate avoided cost values using output units from the WEPP model (cubic yards). We assumed all cost values were in the year relevant to the sediment removal period, and then converted them to 2022 values using the Bureau of Labor Statistics inflation calculator (https://www.bls.gov/data/inflation_calculator.htm). We divided all total cost values by the amount of sediment removed.

Figure 7: Historic YWA sedimentation management costs

2017 Our House Sediment						
Construction Costs	**Cost**	**Price per Yd³**		**Sediment Removed cub**	**Cost 2022**	**Price per yd3**
Mobilization	80,000		fixed		$92,800	$1
Control of Water	168,000		fixed		$194,880	$3
Sediment Excavation and Stockpiling	1,610,000	$	23.00	70000	$1,867,600	$27
Sedimentation and Erosion Control	30,000		fixed		$34,800	$0
Hydroseeding	27,500		fixed		$31,900	$0
Up to 20,000 Additional Cubic Yards	500,000	$	25.00		$580,000	$8
Internal labor	30,287				$35,133	$1
Construction	2,415,500				$2,801,980	$40
Permitting/compliance	497,074				$576,606	$8
External project mgmt	380,086				$440,900	$6
Totals					$6,656,599	$95
2021 Our House Sediment Removal Event						
Construction Costs	**Cost**	**Price per Yd³**		**Sediment Removed cub**	**Cost 2022**	**Price per yd3**
Mobilization	328,000		fixed		$350,960	$7
Control of Water	820,000		fixed		$877,400	$18
Sediment Excavation and Stockpiling	2,415,000	$	48.30	50000	$2,584,050	$52
Sedimentation and Erosion Control	44,500		fixed		$47,615	$1
Internal Labor	68,065				$72,830	$1
Construction	3,607,500				$3,860,025	$77
Permitting/Compliance	527,891				$564,843	$11
External Project Mgt	266,601				$285,263	$6
Totals					$8,642,986	$173
2017 Log Cabin Sediment Removal Event						
Construction Costs	**Cost**	**Price per Yd³**		**Sediment Removed cub**	**Cost 2022**	**Price per yd3**
Mobilization	70,000		fixed		$81,200	$8
Control of Water	174,000		fixed		$201,840	$20
Sediment Excavation and Stockpiling	451,000	$	45.10	10000	$523,160	$52
Internal Labor	6,096				$7,071	$1
Construction	695,000				$806,200	$81
Permitting/Compliance	163,514				$189,677	$19
External Project Mgt	70,919				$82,266	$8
Total					$1,891,414	$189
2018 Log Cabin Sediment Removal Event						
Construction Costs	**Cost**	**Price per Yd³**		**Sediment Removed cub**	**Cost 2022**	**Price per yd3**
Mobilization	121,365		fixed		$137,142	$14
Control of Water	319,305		fixed		$360,815	$36
Sediment Excavation and Stockpiling	403,700	$	40.37	10000	$456,181	$46
Sedimentation and Erosion Control	14,600		fixed		$16,498	$2
Hydroseeding	14,800		fixed		$16,724	$2
Internal Labor	6,468				$7,309	$1
Construction	873,770				$987,360	$99
Permitting/Compliance	312,151				$352,731	$35
External Project Mgt	144,343				$163,107	$16
Total					$2,497,867	$250

Source: Kurtis Crawford, YWA