Comparative Cost Estimate for Reservoir 3 Option 3.

Work Item	Quantity	Unit Price	Cost
Mob/Demob	1	LS	$700,000
Drill & Cast Landslide Shoring Wall	70 shafts	LS	$3,500,000
410 Anchors (9-strand, 155-ft. avg.)	63,550 ft	$80/ft	$5,084,000
Excavate & Dispose Soil Offsite(1)	43,000 cy	$25/cy	$1,075,000
Temporary Soldier Pile Wall Shoring	12,000 ft^2	$75/$ft^2$	$900,000
Drain Aggregate	10,000 cy	$35/cy	$350,000
Compressible Inclusion (3-ft. thick)	2,600 cy	$150/cy	$390,000
Import Structural Fill	36,000 cy	$30/cy	$1,080,000
810 Micropiles (250-k allow. 70-ft avg.)	56,700 ft	$125/ft	$7,087,500
Contingency (25%)			$5,042,000
TOTAL COST			**$25,208,500**

(1) Includes cut to reach base of subgrade drain elevation 256 feet
(2) Costs for reservoir, piping, and other features not included

Advantages.

- Provides active landslide stabilization
- Construction within existing reservoir footprint

Disadvantages.

- Anchors are expected to be damaged during a 2,475-year earthquake event
- Specialty contractor required
- High likelihood of damaging drainage tunnels
- Measures to prevent tunnel damage would add cost to construction
- Settlement from backfilling reservoir may impact historic structures

6.5 Reservoir 3 Option 4 – Shear Piles

Option 4 involves resisting landslide forces with reinforced concrete shear piles installed along Sherwood Boulevard. This option would maintain the west slope of the existing reservoir at its current slope and grade, but would require excavating into the east slope of the existing reservoir similar to Option 1.

Shoring. Excavation shoring for Option 4 would be similar to that described above for Options 1 and 2.

Foundations. Option 4 would require foundations for the reservoir and reflecting pool as described above for Option 1. Piles would need to compensate for downdrag loading due to settlement of the Reworked Portland Hills Silt/Alluvium deposit.

Settlement. Settlements for the new reservoir with Option 4 would be similar to that described above for Option 1.

Subdrainage. A subdrain system similar to that described above for Option 1 would be required for Option 4.

Fill. Fill material for Option 4 should be as described above for Option 1.

Impacts to Tunnels. There is a high likelihood that existing drainage tunnels would be adversely impacted by shear piles. While the cement used to backfill piles is less mobile than grout for ground anchors, the shaft diameter is larger and could potentially reduce the tunnel cross section. In addition, intercepting a gravel-filled tunnel would be very problematic for the contractor. Casing would likely be necessary to stabilize the formation. Horizontal drains would likely be required to mitigate any tunnels impacted by shaft construction.

Seismic Performance. Seismic displacements for the 475 and 2,475-year ground motions are likely within the tolerable range for heavily-reinforced shear piles. Detailed structural and geotechnical analysis will be required during final design if Option 4 is the preferred mitigation option.

Comparative Cost Estimate for Reservoir 3 Option 4.

Work Item	Quantity	Unit Price	Cost
Mob/Demob Excavation Operation	1	LS	$700,000
Shear Piles (10-ft dia., 160-ft avg.)	30 shafts	LS	$17,600,000
Excavate & Dispose Soil Offsite(1)	43,000 cy	$25/cy	$1,075,000
Temporary Soldier Pile Wall Shoring	34,500 ft^2	$\$75/ft^2$	$2,587,500
Drain Aggregate	10,000 cy	$35/cy	$350,000
Compressible Inclusion (3-ft. thick)	2,100 cy	$150/cy	$315,000
Import Structural Fill	42,000	$30/cy	$1,260,000
810 Micropiles (250-k allow. 70-ft avg.)	56,700 ft	$125/ft	$7,087,500
Contingency (25%)			$7,744,000
TOTAL COST			**$38,719,000**

(1) Includes cut to reach base of subgrade drain elevation 256 feet
(2) Costs for reservoir, piping, and other features not included

Advantages.

- Stabilization work performed outside reservoir footprint
- Can likely tolerate 2,475-year earthquake deformations

Disadvantages.

- Expensive
- Requires landslide movement to mobilize pile resistance
- Specialty contractor required
- High likelihood of damaging drainage tunnels
- Settlement from backfilling reservoir may impact historic structures

6.6 Reservoir 4 Option 1 – Backfill Reservoir

Option 1 for Reservoir 4 involves backfilling the abandoned reservoir to replace stability removed by the original reservoir excavation. Two backfill geometries have been evaluated: fill option A involves filling the existing reservoir limits to approximately elevation 230 feet; and fill option B involves placing additional fill above the existing reservoir to attempt to replace a portion of the slope that was excavated for original reservoir construction.

Shoring. No shoring would be required for Option 1.

Foundations. Option 1 would not require foundations for new infrastructure.

Settlement. Reservoir fill would induce settlement; however, we understand that no new structures are proposed for Reservoir 4. There is no subsurface data under Reservoir 4, but settlements on the order of 6-12 inches would be expected if conditions are similar to those under Reservoir 3.

Subdrainage. A subdrain system would be necessary to maintain groundwater at or below the base of the reservoir fill. Groundwater in the reservoir fill would lower the calculated FS for the mitigation and result in higher lateral loads acting on Reservoir 4 concrete dam. For planning purposes, we anticipate that the subdrain would consist of at least 2 feet of free-draining granular material wrapped in nonwoven geotextile extending across the base and up the west slope of the existing reservoir. The subdrain should include a series of perforated pipes to collect and drain water to an outlet at the dam. A section view of the proposed Reservoir 4 subdrain is shown in Figure 14. At this time, it appears that the existing concrete liner could be left in place with this option.

Fill. Fill material used to backfill the reservoir should be placed as structural fill. The final design of the fill should accomplish the objectives of preventing groundwater from rising above the base of the existing reservoir and have a friction angle of at least 35 degrees. Due to the large volume of fill required, non-premium structural fill would likely be acceptable above the subdrain provided it can be suitably compacted.

Impacts to Tunnels. Option 1 would not impact existing drainage tunnels.

Impacts to Dam. Provided that subdrainage measures maintain groundwater levels at or below the base of the existing reservoir, lateral load on the dam would be less for a backfilled reservoir than it currently experiences under hydrostatic load. To prevent hydrostatic loads within the backfill, a zone of free-draining material should be placed against the dam. The free-drainage fill should be hydraulically connected to the subdrainage system. For planning purposes, we anticipate that a zone of free-drainage fill should extend at least 3 feet from the face of the dam. A penetration through the dam would be required to dispose water collected by the subdrainage layer.

Seismic Performance. Displacement estimates for the mitigated portion of the landslide mass at Reservoir 4 range from less than ½ inch for the 475-year ground motion to approximately 3 inches for the 2,475-year motion. The proposed mitigation measures for Option 1 should tolerate these movements with little or no damage. The extension of the landslide shear surface through the proposed reservoir fill would likely daylight before reaching Dam 4.

Comparative Cost Estimate for Reservoir 4 Option 1.

Work Item	Quantity	Unit Price	Cost
Mob/Demob	1	LS	$100,000
Drain Aggregate	10,000 cy	$35/cy	$350,000
Import Structural Fill (Option A)	80,000 cy	$30/cy	$2,400,000
Additional Fill (Option B)	60,000 cy	$30/cy	$1,800,000
Contingency (25%)			$1,155,500
TOTAL COST			**$5,777,500**

Advantages.

- Relatively inexpensive
- Accommodates 2,475-year earthquake induced landslide movements
- Simple construction techniques

Disadvantages.

- Large fill volume will likely need to be imported
- Local traffic impacts due to the number of trucks required
- Fill Option B would require removal of large trees and change the aesthetics of the site
- Settlement from backfilling reservoir may impact historic structures

6.7 Reservoir 4 Option 2 – Anchor Block Wall

Option 2 for Reservoir 4 involves resisting landslide forces with post-tensioned ground anchors. Due to the geometry of the landslide toe at Reservoir 4, ground anchors would need to be located on the slope above the existing reservoir. Ground anchors would react against concrete blocks placed along the existing slope between the upper and lower legs of the reservoir access road. Anchor construction would require removal of several sizeable trees on the slope.

Shoring. No shoring would be required for Option 2.

Foundations. Option 2 would not require foundations for new infrastructure.

Settlement. No settlement is anticipated for Option 2.

Subdrainage. No subdrainage system would be required if the reservoir remains in its current condition.

Fill. No significant amount of fill is planned for Option 2. Native material removed to place anchor blocks could be replaced to permanently cover the anchor blocks.

Impacts to Tunnels. Historic site plans indicate that drainage tunnels are located west of the existing reservoir. There is a high likelihood that existing drainage tunnels would be adversely impacted by the installation of ground anchors. If a tunnel is encountered during drilling, grout placed around the anchor would likely flow into the drainage tunnel. One method to prevent grout infiltration would be to install permanent casing in the portion of the hole between the ground surface and a point beyond the tunnel. Casing would increase the cost of the mitigation work. Horizontal drains may be required to mitigate tunnels impaired by anchor construction.

Impacts to Dam. Option 2 would have no impacts on the dam in Reservoir 4.

Seismic Performance. The anchors proposed for Option 2 would span a very narrow shear zone and bond into bedrock below. The seismic performance of the anchors is highly dependent on the amount of shear displacement that occurs along the landslide shear zone. Predicted landslide displacements for the 475-year earthquake are small enough that the anchors probably would be undamaged, but predicted displacements for the 2,475-year earthquake are expected to damage the anchor tendons at or near the shear zone. If the anchor tendons are damaged, the landslide could resume moving at a slow creep rate.

Comparative Cost Estimate for Reservoir 4 Option 2.

Work Item	Quantity	Unit Price	Cost
Mob/Demob	1	LS	$300,000
Excavate for Pads & Dispose Offsite	27,500 cy	$25/cy	$687,500
580 Anchors (9-strand, 165-ft avg.)	95,700 ft	$80/ft	$7,656,000
Backfill Anchor Pads	27,500 cy	$40/cy	$1,100,000
Contingency (25%)			$2,436,000
TOTAL COST			**$12,179,500**

Advantages.

- Provides active landslide stabilization

Disadvantages.

- Specialty contractor required
- High likelihood of damaging drainage tunnels
- Anchors are expected to be damaged during a 2,475-year earthquake event
- Requires tree removal on slope west of Reservoir 4
- Measures to prevent tunnel damage would add cost to construction

6.8 Reservoir 4 Option 4 – Shear Piles

Option 4 for Reservoir 4 involves resisting landslide forces with reinforced concrete shear piles. Stability analyses completed for Option 4 assumed the slope west of the existing reservoir would remain at its current slope and grade.

Shoring. No shoring is required for Option 4.

Foundations. Option 4 would not require foundations.

Settlement. Not applicable.

Subdrainage. No subdrainage system would be required if the reservoir remains in its current condition.

Fill. No significant amount of fill is planned for Option 4.

Impacts to Tunnels. There is a high likelihood that existing drainage tunnels would be adversely impacted by shear piles. While the cement used to backfill piles is less mobile than grout for ground anchors, the shaft is larger and could potentially reduce the tunnel cross section. In addition, intercepting a gravel-filled tunnel would be very problematic for the contractor. Casing would likely be necessary to stabilize the gravel that was used to backfill the tunnels. Horizontal drains may be required to mitigate damage to tunnels.

Seismic Performance. Seismic landslide displacements for the 475 and 2,475-year ground motions are expected to be tolerated by heavily-reinforced shear piles. A more detailed structural and geotechnical analysis will be required during final design if Option 4 is the preferred mitigation option.

Comparative Cost Estimate for Reservoir 4 Option 4.

Work Item	Quantity	Unit Price	Cost
Mob/Demob Shear Pile Operation	1	LS	$300,000
Shear Piles (10-ft dia., 160-ft avg.)	45 shafts	LS	$26,300,000
Contingency (25%)			$6,650,000
TOTAL COST			**$33,550,000**

Advantages.

- Can likely tolerate 2,475-year earthquake deformations

Disadvantages.

- Expensive
- Specialty contractor required
- High likelihood of damaging drainage tunnels
- Impacts traffic
- Requires landslide movement to mobilize pile resistance

6.9 Preferred Mitigation Option

Several factors will influence the selection of landslide mitigation including cost, seismic performance, risk tolerance, and construction impacts. Table 6-1 ranks the different mitigation options on a subjective basis for several different criteria.

The comparison in Table 6-1 assumes that PWB will design the new structure to the 475-year earthquake motion. Estimated seismic displacements for the 2,475-year ground motion are approximately one order of magnitude larger than the 475-year ground motion, and would likely damage ground anchors used in Options 2 and 3. This would require a significant future expenditure to replace the anchors and re-stabilize the landslide.