LAHAR FLOOD RISK MANAGEMENT FOR MUD MOUNTAIN DAM ON THE WHITE RIVER BELOW MT. RAINIER, WASHINGTON STATE

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Introduction

Lahars from the Mt Rainier volcano present an unusual risk to Mud Mountain Dam (MMD) located downstream on the White River in western Washington State. The current lahar potential at MMD can be described as a low probability, high impact event, with lahars potentially ranging from 10 million cubic yards (mcy) up to extremely large and rare lahars of billions of cubic yards caused by the melting of snow and ice by an eruption of Mt Rainier. The focus of this paper will be the Flood Risk Management Plan (FRMP) actions to reduce the impacts to MMD caused by what has been termed the operational lahar. The operational lahar is defined as largest lahar for which the FRM actions can mitigate impacts to MMD. This event is estimated to have a volume of 40 mcy of sediment and water, with a risk loosely defined as <1% annual exceedance probability (AEP). MMD is a single purpose flood regulation project and the reservoir is normally empty. Without implementing any FRMP actions, lahars in the 5-40 mcy range have the potential to deposit approximately 120-210 feet of mud, rocks, and trees around the MMD outlet structure. Such deposits could severally restrict gate operations and even threaten the stability of the trash rack and sustainability of the dam and reservoir.

A critical factor in developing this FRMP was identifying an "operational lahar". This is the maximum size lahar which FRMP measures would be formulated. There is no existing U.S. Army Corps of Engineers (USACE), or other guidance, for identifying an operational lahar. In this paper, the operational lahar is defined as the largest lahar for which FRMP actions can limit impacts to MMD. After an operational lahar the project would be able to return to operation after a short recovery period of days to weeks. Prior analysis (USACE, 2018) has estimated that a lahar in the 40-mcy range meets those criteria. Lahars in this range have the potential to cause significant damage if they reach the outlet structure at MMD unimpeded. Lahars over 100 mcy do not fit the operational lahar criteria because FRMP actions are unlikely to reduce the potential for those lahars to entirely bury the trash rack at MMD and fill most of the reservoir with sediment. This would cause extensive damage and leave the project inoperable for an extended period. The benefits, if any, of FRMP actions for lahars between 40 mcy and 100 mcy are too indeterminate to be identified at this time.

Lahar Characteristics: Lahars are slurries of water, soil, and rock that originate in volcanic areas and may reach solids concentrations of up to 60-80% by volume. Lahars can travel very fast. In the steep, narrow canyons of the White River, may reach flow velocities of over 50 ft/sec. Lahar hydrographs tend to raise very quickly and have durations of only a few hours. A common analogy for the nature and movement of a lahar is a wet-concrete slurry. Numerous lahars, some of them of catastrophic proportions, have occurred at Mt Rainier in the past 10,000 years. The largest ancient lahar identified at Mt Rainier, the Osceola mudflow, traveled through the White River basin to Puget Sound near Seattle around 5,700 years ago. That lahar had a volume estimated at one-half cubic mile (Crandell, 1971) and the deposits, averaging approximately 20 ft. deep, cover over 200 square miles.

Flood Risk Management Plan

This FRMP focuses on actions that can be taken to prepare for and respond to lahars in the range of 5-40 mcy that could be generated by an eruption of Mt Rainier. This size of lahar could be triggered by a small

eruption or as a secondary product of a large eruption directed to the south or west of the mountain. An eruption at Mt Rainier is likely to be proceeded by seismic warning signs and an eruption alert implemented by State and Federal emergency management agencies. An eruption alert could last for weeks to months and can have increasing threat levels. This FRMP describes emergency actions to be taken before, during, and after an eruptive period to reduce the lahar risks. The four phases of emergency management: mitigation, preparedness, response, and recovery are addressed below.

Mitigation: The FRMP goal is to establish a general pool management plan that reduces the risk to MMD during an operational lahar (up to 40 mcy). The MMD pool is normally empty and lahars would travel unimpeded through the empty reservoir and directly impact the dam. Without any FRMP actions, lahars in the 5-40 mcy range have the potential to create a deposit approximately 120-210 feet deep of mud, rocks, and trees at the MMD outlet structure. Such deposits could severely restrict gate operations and even threaten the stability of the trash rack. Lahars over 30 mcy could completely bury the trash rack. One approach to mitigating the potential impacts to the MMD outlet structure from an operational lahar is to have a long pool in the reservoir to encourage lahar deposition upstream of the dam. A long pool would be established following the issuance of an eruption alert, and then maintained throughout the alert period; as the 1-2 hour lahar travel time from Mt Rainier would not be sufficient time to raise the pool once a lahar has begun. At elevation 1180 ft, the pool has a volume of 70,341 ac-ft and will take some time to fill under normal White River flows. During the low flow season (August, September, and October) average monthly streamflows are in the 600-850 cfs range and it could take three months to fill the reservoir to 1180 ft. depending on the minimum allowable outflow. During the November through July period when average monthly streamflows are around 1400-2100 cfs, it may require 25-35 days to fill to 1180 ft, assuming a minimum outflow of 500 cfs. Well before implementation of this FRMP there should be a careful examination of downstream flood risk management and dam safety issues.

The key to establishing a sustainable pool elevation is to balance the lahar risks and riverine flood risks. During the 1980 eruption of Mount St Helens, lahars formed in Pine Creek and Muddy River, and flowed into PacifiCorp's Swift No 1 reservoir. The volume and discharge rates of the lahars were examined by the U.S. Geological Survey- Cascade Volcanic Observatory (USGS-CVO), but there had been no prior analysis of the longitudinal distribution of the lahar deposits within the reservoir. USACE (2018) found that the 18-mcy lahar traveled 3.8 miles through Swift No. 1 reservoir during the Mount St. Helens eruption, demonstrating the ability of lahars to travel long distances underwater on valley slopes similar to those at MMD. The characteristics of the lahar that impacted the Swift No 1 reservoir are analogous to what may happen at MMD. Table 1 shows the MMD pool lengths and volumes at selected pool elevations between 1150-1200 ft. A sustainable pool elevation should provide as much distance as possible for lahar deposition, but still allow the reservoir to contain the lahar volume without uncontrolled outflow and provide some degree of riverine flood regulation. A 5.7 mi long full pool would provide the maximum lahar risk reduction, but would maximize downstream flood risks, as the project would have no storage capacity remaining to regulate outflows. Conversely, a 3.8 mi long pool would provide 75% of the original flood storage, but lahars over 20 mcy would likely reach the dam.

Table 1. Mud Mountain Dam Pool Lengths and Volumes

Elevation in Feet	Length in Miles	Storage Volume in Ac-FT	Storage Volume in MCY
1150	4.4	48,210	78
1160	4.6	55,000	89
1170	4.8	62,438	101
1180	5	70,341	113
1190	5.2	78,701	127
1200	5.4	87,624	141
1215	5.7	102,041	165

Additional analysis and coordination with a range of disciplines is required before any particular pool elevation can be identified as optimally balancing risk. Another factor to consider is the risk of a Tsunami being generated by a lahar as it enters the pool. A pool elevation of 1180 feet is the minimum pool elevation that is likely to absorb the operational lahar. Lower pool elevations would result in higher lahar risk but would provide greater flood storage. This elevation provides a 5.0 mi long pool and 32,000 ac-ft (52 mcy) of remaining storage available for flood regulation or to absorb an inflowing operational lahar before producing uncontrolled outflow. This is 1.2 mi longer than the 1980 deposit in Swift No. 1 reservoir, but those lahars only totaled 18 mcy, just 45% of the maximum 40-mcy lahar considered in this FRMP. From strictly the lahar risk perspective, it would be desirable to provide this longer travel distance given the potential for larger lahars at MMD.

The lahar deposition in the Swift No 1 reservoir can be used in a couple of ways to estimate the deposition potential of a 5 mi long pool at MMD. The simplest way is to scale up the deposition based on the total lengths and volumes of deposition: 5 mi at MMD divided by 3.8 mi at Swift times 18 mcy at Swift equals roughly 25 mcy at MMD. Another way is to look only at the main deposition zone at Swift and scale that up to MMD. This approach requires an estimate of the Swift's main deposit volume and an assumption as to the length of the deposition in the MMD reservoir. The main Swift reservoir deposit had a length of 1.8 mi and an estimated volume of around 15 mcy. Assuming significant deposition does not start until the lahar becomes submerged in the MMD pool, about ½ mi downstream of the upstream pool boundary, and that only a limited volume of deposition in the narrow channel in the first 1/3 mile upstream of the dam, the length of deposition at MMD is estimated to be 4.2 mi. Given these conditions, somewhere around of 25-35 mcy (5/3.8 x 18 and 4.2/1.8 x 15) of lahar could be deposited in the MMD pool. There are topographic differences between the two reservoirs that are likely to produce different depositional patterns that cannot be accounted for in this simplified analysis. The major difference is that overall the MMD reservoir is narrower than the Swift reservoir and will not let the lahar spread as far laterally, potentially reducing deposition through the upstream end of the MMD reservoir, but with increased longitudinal distance.

While significant lahar deposition can be expected to occur in a 5 mi long pool, it is likely that some portion of any lahar would reach the MMD outlet structure. The volume and/or composition of any lahar reaching the dam cannot be reliably determined from the available information, but both are expected to be considerably smaller than without the long pool. A lahar may remain a high concentration slurry of rocks, boulders, and other debris as it travels through the reservoir, or it could be transformed at some point into a lower concentration hyper-concentrated flow. If the lahar degrades to hyper-concentrated flow, it is likely to be transporting mostly sand and smaller material, with some gravel and few boulders. Most of a hyper-concentrated flow reaching the dam would probably pass through the outlets. However, if it is still a lahar when it reaches the dam, with large amounts of rock and debris, it is likely to block at least portions of the outlets. A study is needed to determine the effects of holding a lahar mitigation pool on Water Management ability to adequately reduce flood peaks, and what reservoir management strategies might be effective in advance of a storm prediction.

Preparedness: In this FRMP, preparations for a lahar focus on actions that can be taken to reduce the risk to MMD, but the final FRMP must also incorporate the potential impacts and responses around the region during and after a Mt. Rainier eruption. The MMD lahar FRMP should be coordinated with other eruption response plans including the Pierce County Mount Rainier Volcanic Hazards Plan and any plans developed by King County or the State of Washington.

Part of being prepared for a lahar is to have a warning system in operation so FRMP can be implemented in time. A lahar warning system is in place on the west side of Mt Rainier, operated by Peirce County, State of Washington, University of Washington, and the USGS-CVO. Those agencies have plans to expand the lahar monitoring system to the White and West Fork White rivers in the next few years.

The USGS-CVO plans to install new Lahar Detection stations on the White and West Fork White rivers at sites that border the northeast side of Mt Rainier National Park (USGS-CVO, 2018). The sites under consideration are approximately 30 miles upstream of MMD and are shown on the USGS map in Figure

1. The sites would be on U.S. Forest Service (USFS) land. USGS-CVO plans to begin the permitting process in 2019 and construction in 2020 or 2021. They plan 2 digital stations with broadband seismic sensors, trip wires, GPS receiver, and a radio transmitter on each river. The seismic sensors will be able to detect seismic activity on Mt Rainier and lahar flows in the river. The trip wires would provide an indication of the size of a lahar. It is estimated that these monitoring stations could provide MMD with a one-hour warning of an approaching lahar.

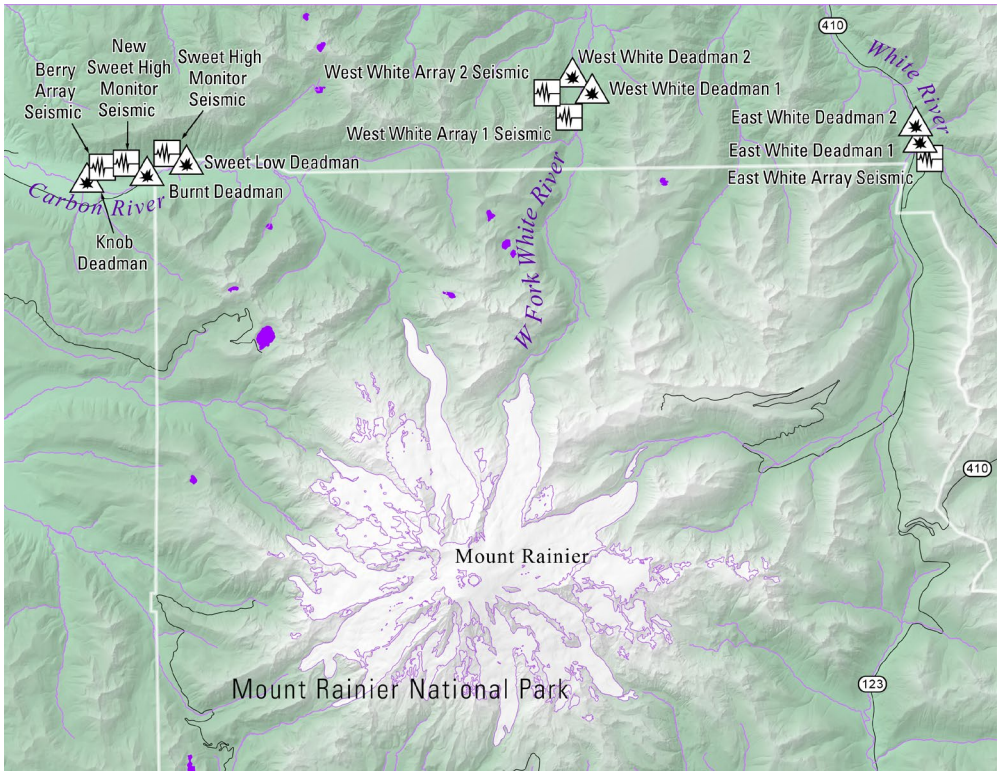

Figure 1. Map showing potential USGS-CVO lahar monitoring sites on the White and West Fork White rivers. (USGS-CVO, 2018)

Response: During a lahar, the lahar warning system discussed above could provide MMD with roughly a one-hour warning before the lahar arrives at the dam. An evacuation of the entire facility (staff, visitors, etc.) should begin immediately upon receipt of the warning. Prior to leaving, MMD staff could raise the one open gate (R1 or R2) to 80 or 100% and leave the other gates closed. This minimizes the risk of all the gates being blocked by rocks in the lahar and would not cause a significant downstream flood risk. The open gate would provide a 9.2-11.5 ft. high by 27 ft. wide opening that should allow rocks and boulders that pass through the trash rack's 1.67 ft. openings to pass out through the gate and into the 23-ft. tunnel. Water outflows at 80% gate opening would be about 6,400 cfs, exceeding the 6,000 cfs discharge target creating a minor downstream flood threat around Pacific and Sumner. At 100% gate opening the water outflow would be 10,000 cfs, enough to create a significant downstream flood threat. Opening the gate to 80-100% could also allow more of the lahar to pass downstream of MMD and perhaps reduce deposition near the outlet structure. It is likely that the lahar sediment passing through the trash rack will be mainly sand and finer material, and that it will mix with reservoir water to become hyper-concentrated flow. However, those lahar sediments are likely to deposit in the downstream channel, increasing flood risks and possibly aggravating any other eruption caused river problems. The tradeoffs between lahar risks and flood risks are beyond the scope of this paper and need to be evaluated before a final FRMP is adopted. Also beyond the scope of this paper are any predictions about blockages or restriction to flow caused by lahar material interacting with the trash rack, mixing chamber, gates, or tunnels. There is likely to be much confusion and uncertainty about the ongoing eruption and lahar activities, so to be safe, a total evacuation of the project may need to be completed. If reliable information becomes available indicating that the lahar the does not pose a threat to MMD, staff may return to the project to observe events and begin recovery.

Prior to a lahar, Seattle District Water Management would be actively managing MMD discharges to maintain the pool and regulate discharges. During a lahar Water Management would monitor pool elevations and advise other agencies as to the discharges that might be expected from MMD, similar to normal flood operations. Monitoring is remote from the Seattle District office (provided the pool sensors at the project remain working). If the gate is opened to 80-100% during a lahar, Water Management should immediately notify the appropriate emergency management agencies. This response is only related to the lahar risk and does not account for all eruption risks. When an eruption alert is issued, MMD activities should be coordinated with the Washington State Emergency Operations Center, Pierce County, USGS-CVO, and other emergency management agencies. MMD is 21 mi from Mt Rainier and could possibly fall within an eruption exclusion zone, requiring complete evacuation of the project for extended periods during an eruption alert.

Recovery: The immediate post-lahar situation at MMD will be highly uncertain. The magnitude of the impacts to MMD will depend on the size and nature of the lahar, the performance of the outlet structure, and to a large extent, chance. This recovery plan will focus on the aftermath of the 40-mcy operational lahar. Larger, more destructive lahars are possible, but are outside the scope of this FRMP.

At a pool elevation of 1180 ft, MMD reservoir will capture nearly all of the 40-mcy lahar. Lahar deposition will occur throughout the 5 mi long pool, with most of the deposit likely to settle within the 4.5 mi upstream of the dam. The depth of the deposits could range from less than 10 ft. at the upstream end, to conceivably over 150 ft. about a mile upstream of the dam. There could possibly be upwards of 1 mcy deposited up to 200 ft. deep in the 0.3 mile immediately upstream of the dam. Because of the upstream deposition, it is likely that as the lahar approaches the dam it will be a hyper-concentrated flow composed mostly of sand and finer materials, rather than a full lahar with lots of gravel and up to 10-20% boulders. The hyper-concentrated flow is likely to pass through the outlet works without causing any blockages. A large amount of floating woody debris may reach the dam, but most rocks and boulders are expected to deposit upstream. The lahar of 40 mcy could raise the pool level to around elevation 1208 ft, the water would be very turbid, and there would be a large amount of floating debris throughout the reservoir. There is some possibility of at least a partially blocked trash rack by debris, and possibly some coarse lahar deposits near the outlet structure. Damage to and the safety of the trash rack and elevator/stair tower would be unknown, limiting immediate access to the gate structure. For this FRMP, it will be assumed that one gate is open 80% and discharging 6,400 cfs. The open gate might be operable.

The primary recovery action at MMD should be to restore and/or maintain the capacity to regulate discharges. A 40-mcy lahar flowing into a pool already at elevation 1180 ft, would quickly reduce the storage available below the spillway crest to only about 7,000 ac-ft. The first step should be to check how much flow is being discharged from the outlet of the 23-ft. tunnel. This will give an indication of how efficiently the sediment-laden flow is moving through the outlet works. The next step is to determine if the open gate is operable. If this gate is operable, there will be some immediate capacity to regulate MMD water and sediment releases. If the lahar is a hyper-concentrated flow at the dam there is a good chance that it will have caused minimal structural damage to the trash rack. The high concentrations of sand and gravel in a hyper-concentrated flow can be very abrasive, but they are not likely to block the trash rack or discharge tunnels. If there is access to the gate control structure, the radial and emergency gates should be tested to determine if they could be opened.

The lahar deposit will eventually have to be removed if MMD is to be returned to full flood regulation capacity. One option would be to excavate the sediment and possibly dispose of it on the bluff above the reservoir. Another option would be to allow the sediment to erode and move downstream. This could probably remove most of the gravel and finer materials from the deposit, but 10-20% of the material could be boulders that would remain in the reservoir. Allowing the deposit to erode would produce much higher than normal sediment loads, and very likely cause serious channel deposition and flooding problems downstream of the dam, especially in the White River near Pacific and Sumner, in the Puyallup River in Tacoma.

Summary

Lahars from Mt Rainier pose a serious, but low probability risk to MMD. Having a FRMP in place before a lahar occurs is critical to safety at MMD and downstream populations. A preliminary lahar FRMP has been proposed that involves installation of a lahar warning system, providing a 5 mi long pool to encourage lahar deposition, adopting an evacuation plan with final gate settings, and identifying some initial recovery steps. A plan needs to be developed for managing the reservoir in the immediate post-lahar period. This plan only offers a starting point for the development of a comprehensive lahar FRMP. Much more study and evaluation of lahar risks, flood risk management, and dam safety issues are necessary before a FRMP can be finalized. There are many issues that remain to be resolved before this FRMP can be implemented. Some of the more significant issues are: lahar flow/deposition within the reservoir, lahar versus flood risks, hydraulic and geotechnical dam safety concerns with a prolonged high pool level, and potential downstream impacts.

References

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