Preliminary Discussion of the Hazards of Lahar-Induced Oil Spills at the Drift River Marine Terminal, Cook Inlet, Alaska

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Lahars inundate a portion of the Drift River Marine Terminal (DRMT), 2009. Source: Cyrus Reed, Alaska Volcano Observatory, USGS.

Introduction

Mt. Redoubt has erupted more than 50 times in the last 10,000 years. It has erupted at least 4 times since 1900 (Alaska Volcano Observatory). Each historic eruption has consisted of multiple explosions (for example, there were 20 separate explosions in 1989-90 eruption). These individual eruption periods have generated numerous lahars, by mechanisms including vent-clearing explosions and pyroclastic flows, causing lahar inundation of the both Drift River valley and the Crescent River valley (Waythomas et al. 2012, Dorava & Meyer 1995, Riehle et al. 1981). The Alaska Volcano Observatory forecasts the future of the Mt. Redoubt-Drift River system will be characterized by additional eruptions, lahars, floods, channel instability, and valley floor aggradation (Nye 2009).

The Drift River Marine Terminal (DRMT) oil storage facility is directly threatened by the lahars originating on Mt. Redoubt and flowing down the Drift River valley. During both the 1989-1990 and 2009 eruptions, lahars from Mt. Redoubt overtopped DRMT's protective berms and partly inundated the facility. Future eruptions may inundate the DRMT with lahars much larger than those from the 1966-68, 1989-90, and 2009 eruptions. It is also possible that the terminal could be inundated by a landslide-induced lahar or an outburst flood, in the absence of an eruption. The DRMT faces the threat of lahars overtopping or eroding through its dikes and berms, and/or excavating its buried pipeline. A lahar equivalent to, larger than, or even slightly smaller than the one seen in 2009 could overtop the protective berms, as occurred in 2009, or create local breaches in them. Additional protective measures installed since 2009, including sheet-pile berm reinforcement and a second diversion dike, help mitigate this hazard, but do not guarantee protection in all plausible scenarios.

Lahars that do not breach the containment still increase facility risk. Aggradation of lahar sediment on the valley floor progressively increases the facility's vulnerability to both lahars and flooding.

If a facility inundation or pipeline excavation occurs, the storage tanks or pipeline could be ruptured, introducing oil into a moving lahar. If such a spill were to occur, a large fraction of the oil would likely mix into the lahar itself, and be deposited both onshore and in Cook Inlet. Recovery of oiled sediment onshore could be difficult and expensive, requiring earth-moving machinery and sediment storage. While some marine oil would be expected to form a surface slick, and might be accessible to conventional marine response technologies, a large fraction might remain mixed with lahar sediment, making response and recovery difficult or impossible.

The total line fill for the pipeline system is roughly 122,000 barrels, although sections can be isolated and presumably a pipeline spill would release only a fraction of this. One tank (#3) at DRMT is currently in use for oil storage, holding 270,000 barrels of oil. CIPL has plans to use some additional capacity in tank 4, bringing the maximum oil stored at the facility to 443,537 barrels. Together, the tanks and pipeline could release a spill in excess of 450,000 barrels, much larger than the official estimate for the Exxon Valdez oil spill. The construction of mitigation measures based solely upon the size and behavior of recent lahars unreasonably discounts the broad variability of possible eruptive events, landslides, outburst floods, lahar sizes and lahar behavior. Considerably larger and more destructive lahars, or even smaller lahars channelized in unexpected ways, could potentially cause a major oil spill into Cook Inlet.

Part I: Geological Hazard of Lahars to the Drift River Marine Terminal

A lahar is a dense flow of water and sediment ranging from silt to boulders. Lahar flows can exceed 50% sediment by volume, and can entrain trees, boulders, ice blocks, and other debris. Most recently, the lahar of April 4, 2009 left 1 to 6 meter-thick deposits of sand and fine gravel over a large portion of the 125 km^2 it inundated (Waythomas et al, 2012), and overtopped the existing mitigation structures at DRMT.

Note on terminology: Throughout this document, various terms are used to refer to DRMT's protective earthworks, according to the CIPL conventions:

- **Diversion dike:** The "diversion dike" earthwork constructed outside DRMT, to the northwest (figure 3).
- **Berm, or protective berm:** The 32-foot, armored berms surrounding the active tank farm, as identified in figure 2.

Potential for larger-than-historic lahars

Given the volume of snow and ice available on Mt. Redoubt, a larger eruption than the 2009 and 1989-90 eruptions could cause a much larger individual lahar, or a quick succession of similar-sized lahars. The total volume of such a lahar(s) could exceed 2009 volumes by a factor of 10 or more. An estimated 2 cubic kilometers of perennial snow and ice sit on Mt. Redoubt slopes that drain into the Drift River drainage, in addition to large volumes of seasonal snow. Mudflows can be nearly half sediment, so if all of this ice were melted it could result in flows exceeding 4 cubic kilometers. This extreme is unlikely, but lahars approaching this are conceivable if an eruption produces a flank collapse such as seen in the 1980 St Helens eruption or prehistoric eruptions of Mt. Rainier. The Osceola Lahar from Mt. Rainer 5000 years ago was around 1 cubic kilometer (Vallance & Scott 2012).

The three most recent Redoubt lahars, upon which current mitigation measures are based, have reached only a tiny fraction of the potential lahar volume, and are much smaller than documented prehistoric lahars. Precise measurements of all lahars haven't been done, but the total volume of individual lahars in the 66-68, the 89-90, and the 2009 eruptions likely never exceeded 0.1 cubic kilometer (Schaefer 2011), (Sturm, Benson, & MacKeith, 1986), (Trabant & Meyer, 1992), (Waythomas, Pierson, Major, and Scott, 2012).

Because past eruptions have removed a small proportion of the perennial ice on Redoubt, and because the perennial ice can be replenished in less than a decade (Sturm et al., 1986), future eruptions will have similar access to frozen water as past eruptions. There is no reason to expect future lahars to be smaller than past ones.

Lahar hazard mitigation in the past has been barely sufficient.

Existing mitigation structures at the DRMT were overtopped by the 1990 and 2009 lahars. Both events caused some facility inundation, and snow atop the berms in 2009 helped prevent more serious inundation in 2009 (Figure 1) (Schaffer 2011, Dorava & Meyer 1994, Waythomas et al 2012). Had the lahars developed an erosive flow along one of the berms, or channelized the Drift River against it, this could have created a breach in the structure, inundating the facility without overtopping the berms. A larger debris flow than occurred in 2009 could easily overtop and breach berms of comparable specification.

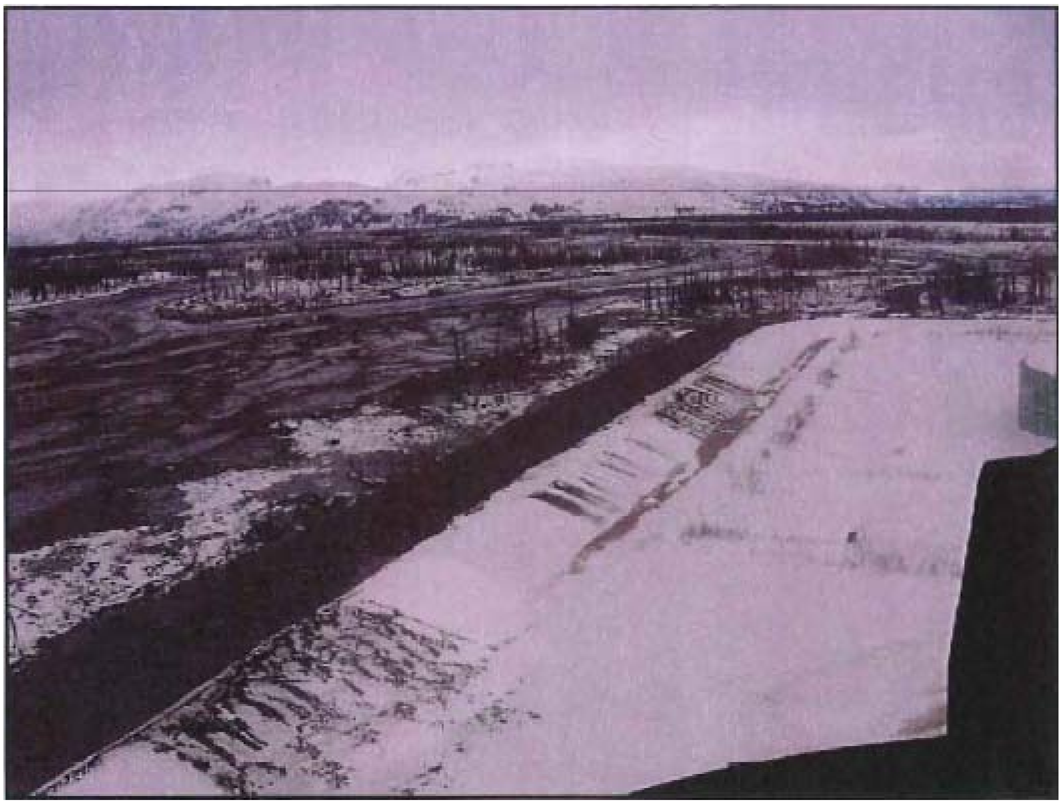

Figure 1: *Overtopping of the berms, 2009. Reproduced from (Flood RA)*

Increased facility vulnerability due to floodplain aggradation.

Accumulation of sediment across the broad floodplain outside the facility raises channel elevations, making the facility more vulnerable to future flooding. The 2009 lahars deposited large volumes of sediment around the facility (Schaefer, 2011) and over large areas of the floodplain (Waythomas, 2012). Future lahars can be expected to continue this process. Higher channel elevations relative to the facility floor will make it more vulnerable to conventional flooding and groundwater inundation, and make future lahar breaches more destructive.

Floodplain aggradation may be an acute concern if it occurs early in a sequence of lahars. Channel elevation during successive lahars might be several meters higher than at the time when dikes were designed, and eruption hazards or short intervals between lahars might prohibit dike modification to compensate for increased channel elevation.

Danger of an outburst flood scenario

Lahars are not the only risk to the DRMT. A volcanic landslide or glacial surge could create a debris-dammed or ice-dammed lake in the upper Drift River valley. A destructive outburst flood could then threaten the DRMT, possibly of a size comparable to recent lahars (Dorava 1994). A dammed lake could accumulate on the order of a cubic kilometer of water from normal precipitation and volcanic melting of ice and snow. Landslide dammed lakes often fail abruptly, producing a violent flood. Similar events occurred prehistorically at St. Helens (Scott, 1989) and elsewhere. Such a flood could threaten the oil storage facility, either by simply overtopping berms during extreme flooding, or through rapid erosion. Because an outburst flood like this would start with less sediment than a lahar, it would tend to be more erosive than a lahar. The timespan for the development of such a lake, and the ensuing outburst flood, might be too short for engineered controlled release, especially if access was limited by eruptions.

In a more extreme scenario, a pyroclastic flow from the summit crater could initiate an outburst flood. Since this event would likely generate a lahar on the upper mountain as well, the upper-mountain lahar and outburst flood could compound.

Danger of a Sudden-Onset Eruption and Lahar

CIPL's Oil Discharge Prevention and Contingency Plan (C-Plan) calls for the evacuation by tank vessel of all oil at DRMT as a spill-prevention measure, in the event of serious volcanic activity. Within 24 hours of the Alaska Volcano Observatory changing color-code of Mt. Redoubt from Green (Normal) to Yellow (Advisory), CIPL will schedule a tank vessel to evacuate the facility's oil. The tanker will upload the stored oil "as soon as possible". Reasonably, the delay in evacuating oil will include transit time, mooring time, and oil-transfer time for the tanker. Environmental conditions such as ice and ashfall may further delay the tanker. A minimum of several days will likely be necessary.

Successful evacuation of oil from DRMT is likely to require several days or more between the AVO identifying Mt. Redoubt's status as Yellow, and the initiation of a lahar and/or an eruption which prevents the emptying of the facility (for instance, by heavy ashfall at DRMT). This time may not be available. The eruption and lahar of December 15, 1989, occurred less than 36 hours after the AVO warning of increased activity.

Lahars can occur without an associate volcanic eruption. Volcanoes such as Mt. Redoubt are constructed by successive eruptions, and therefore consist of piled masses of poorly cohesive volcanic rock. Additionally, such volcanoes weather internally, as water and volcanic gases combine to form acids that attack and weaken the rock. This makes large volcanoes subject to periodic landslides, earth movements, and flank collapses, which can generate massive lahars – one of the most well-known being the prehistoric Osceola mudflow, which originated on Mt. Rainier, WA, and covered more than 200 km^2 of lowland (Vallance & Scott, 2012).

Significant volcanic eruptions, while sometimes preceded by obvious signs of increasing activity risk (such as flank swelling and earthquake tremors), can also occur with little warning. Mt. Redoubt has erupted with little serious warning in the past.

Dike and Berm Erosion

Plans to raise re-establish the berms at 32 feet and improve the armoring along their perimeter would improve the facility's ability to survive lahars. However, these improvements will not mitigate all reasonable scenarios. Sheet pile can be damaged by debris like boulders and ice blocks, and the possibility for dramatically larger or more erosive lahars, or simply lahars channeled differently, may still breach the levees. Proposed design improvements should be juxtaposed with reasonable "worst case" scenarios, like lahars ten times larger than historic incidents, or outburst flooding.

General Potential for Erosion at DRMT

A lahar has the potential to directly erode into the dikes and berms, or to infill existing drainages and channelize the

Drift River itself against DRMT's berms. During the 2009 lahars, for instance, the Drift River channel was completely infilled upstream of the DRMT, and the primary river flow diverted into Rust Slough. (CIPL 2012). A single very large lahar could inflict a complex regimen of erosion, deposition, and debris impacts on the facility. A rapid series of smaller lahars could restructure local topography, causing subsequent lahars to more severely impact DRMT than is currently expected.

Physical Protections at DRMT

Current lahar protections and improvements to the facility (CIPL 2012) include:

- Re-establishment of the heights of the protective berms at 32 feet.
- External armoring of the berms.
- Use of sheet pile to form an additional protective wall in some areas.
- Construction of a 22-foot diversion dike north of the facility, to slow lahar flow from the upstream direction.

Lahar Erosion Dynamics

Lahar erosion potential can be influenced by the speed, energy, and turbulence of the flow, by the sediment capacity of the flow, by the vulnerability of bed and bank material to erosion, and by the presence of large debris (such as logs, icebergs, and boulders) in the flow.

Lahars cause erosion by undercutting and scouring into their banks, and by bed scouring. Of the identified erosion mechanisms, bank undercutting and side-cutting has been identified as probably the most important way that lahars erode (Vallance 2000). This is the primary mechanism of erosion that threatens the berms and dikes at DRMT.

Bed scouring, while probably a less important factor in a sediment-rich lahar, has the potential to expose the buried pipeline, or to contribute to the undercutting of berm armor and (in the event of berm armor failure), the exposure of the sheet-pile foundations. Lake outburst floods, mentioned earlier are a potential threat. A flood of this type may cause much greater erosion than a typical lahar, and could occur in conjunction with an eruption cycle and associated lahars.

Potential for Channel Avulsion (River Re-routing)

Lahars could channelize their flows against the DRMT berms, or displace the Drift River itself to flow against the berms. This is because lahars erode, transport, and deposit large volumes of sediment. Lahars are typically most erosive during their waxing and peak flow periods, actively deposit after peak flow, and terminate in a more watery, erosive waning flow. The final stage is frequently observed to carve new channels into freshly deposited lahar debris. (Vallance 2000). They can infill existing channels, raise (aggrade) entire floodplains, and reroute river channels (channel avulsion). An individual lahar can be simultaneously both erosive and depositional at different locations (Vallance 2000). A series of successive lahars can greatly alter channel geometries (Waythomas et al. 2012), presenting flood scenarios that are very different from those used in planning. Pre-existing drainages and terrain cannot be used to predict where a lahar will focus erosion.

Sufficiency of Berm Armoring and Sheet Pile Reinforcement

The effectiveness of the berm armoring is key to their ability to resist lahar erosion, since their earthen structure is otherwise vulnerable. The dense, cement-like material of a lahar can be highly abrasive, and can drive large debris objects (such as logs, boulders, and icebergs) into nearby obstructions with great force. This should be considered in a geotechnical evaluation of the revetments, since heavy impacts and scouring by a dense, debris-rich lahar (during its waxing, peak, and falling periods) might plausibly be followed by an erosive, watery stage, which has the potential to exploit vulnerabilities created by damage. The waxing and peak stages themselves can also be highly erosive, creating a complex regimen of erosion, deposition, and debris impacts throughout a single lahar.

In CIPL's diagram (Figure 2), the armored berm may be compromised by bed erosion by a highly erosive lahar or hyperconcentrated flow, which undercuts and scours behind the berm armor. Such an erosive event might cause the armor to collapse. The sheet pile wall itself is shown to be more securely buried into underlying sediments (and backed by supporting berm material), but the horizontal extent of the sheet pile is not clear. Therefore its general vulnerability to erosion and circumvention is difficult to assess.

Finally, the sufficiency of the berm armoring and pile reinforcement could be rendered moot if the berm is overtopped by a lahar or flood. This could be caused by a large lahar or rapid series of lahars that aggrade the floodplain, lowering the effective height of the berms. Overtopping could alternately be caused by a lahar larger than has been observed in the past few decades. Both scenarios are quite plausible.

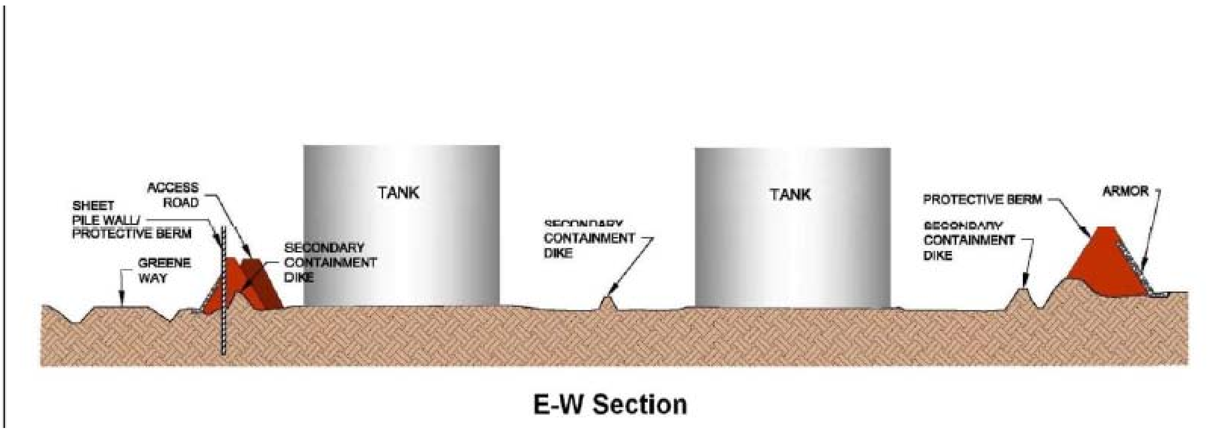

Figure 2: DRMT protective berms and secondary dikes. Reproduced from Cook Inlet Pipe Line Company's (CIPL's) Oil Discharge Prevention and Contingency Plan (CIPL 2012)

Hazard of dike & berm circumvention

Instead of protecting the facility from strong flows, diversion dikes and berms may be circumvented by the flow, or actually cause the flow to impinge upon the facility. Aggradation of surrounding terrain may cause unexpected flow patterns for both lahars and ordinary water drainage, including that of the Drift River. The Northwest side of the tank farm is most vulnerable to channelized flow, and the diversion dike has been constructed in this location to provide extra protection. However, existing drainage channels to the East and West of the tank farm could also be infilled or blocked by lahar debris, resulting in channelized flow that has the potential to circumvent the diversion dike and the sheet pile berm reinforcement along the northern aspect of the tank revetments. If the river channels were to shift due to lahar filling, the full force of the flooding Drift River or Rust Slough would not be slowed by the diversion dike, and might flow directly into the tank farm revetments.

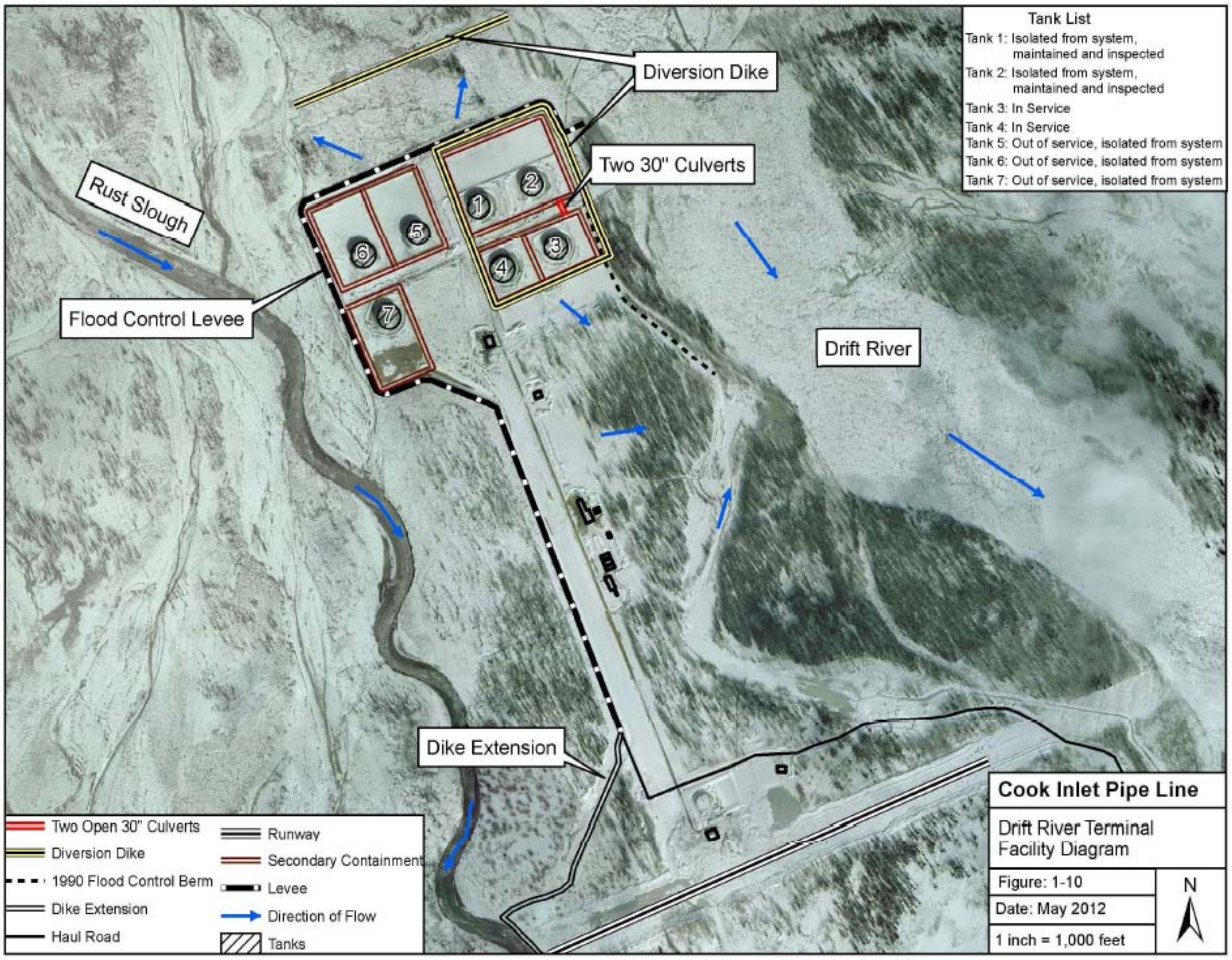

Figure 3: DRMT protections & facilities diagram. Reproduced from Cook Inlet Pipe Line Company's (CIPL's) Oil Discharge Prevention and Contingency Plan (CIPL 2012)

Hazard of pipeline excavation and rupture

The DRMT pipeline is buried to a minimum depth of 4 feet. The pipeline is 20 inches in diameter, and the majority of it is constructed of ¼" steel. Where the pipeline crosses rivers, it is constructed of ½" steel with a 4" concrete casing.

Erosive flow from a lahar or outburst flood could excavate the buried pipeline, as was observed in 1990 (Waythomas et al. 2012). Particularly since lahar flow is not constrained to current river channels, erosion could occur at any location in the Drift River floodplain. While undercutting and bank erosion are probably the most important mechanisms of sediment entrainment in a moving lahar, bed erosion can also be significant (Vallance 2000). If the buried pipeline was excavated, it could be ruptured by the force of the sediment-rich lahar flow, possibly in combination with impact of entrained debris, such as ice. The pipeline itself traverses the floodplain parallel to the shore of Cook Inlet (Figure 4), making an exposed pipeline section directly vulnerable to the force of a lahar moving transversely across it.

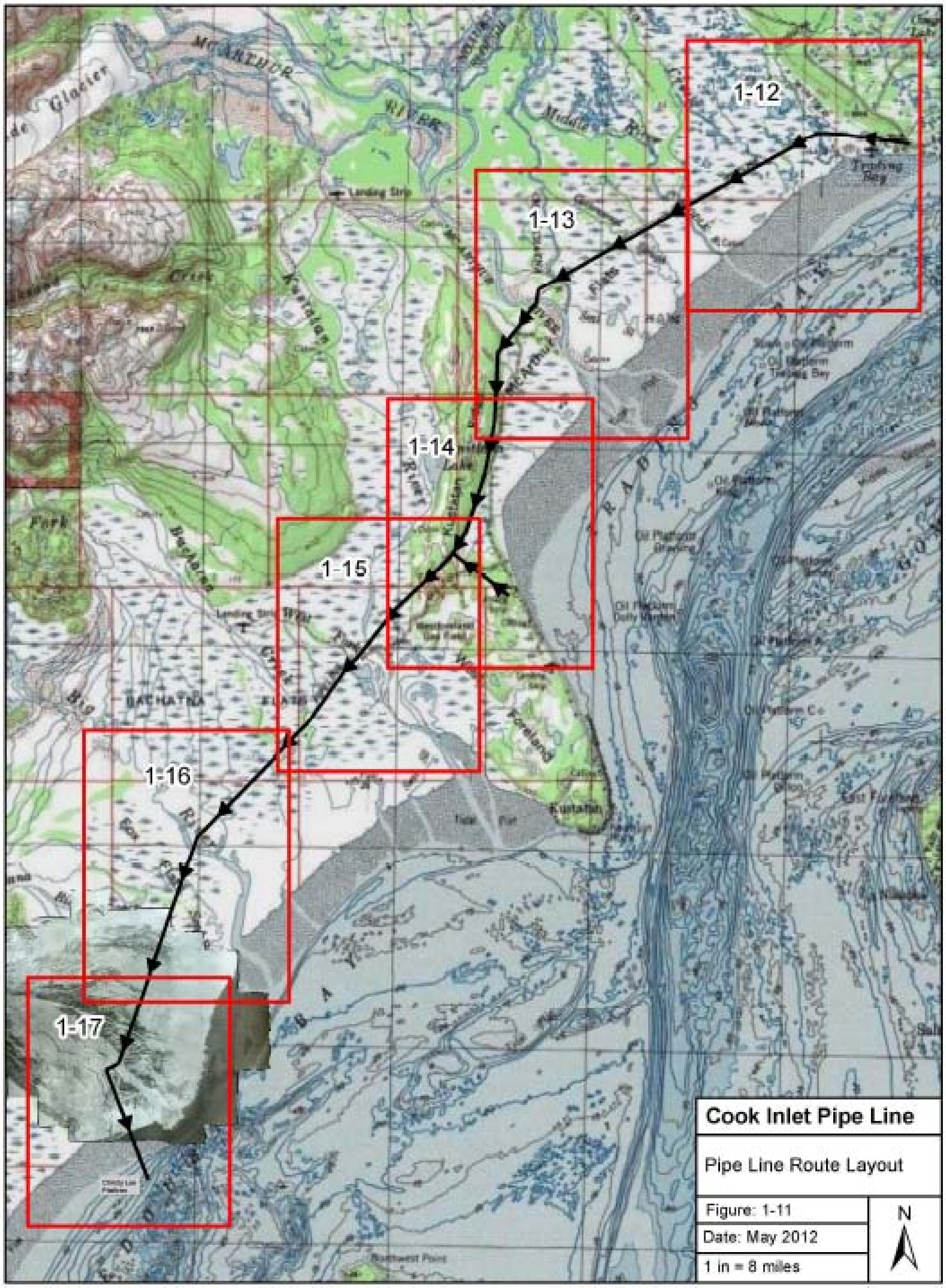

Figure 4: Cook Inlet Pipe Line, reproduced from (CIPL part 1)

Part II: Implications of a Lahar-Caused Oil Spill

Broadly speaking, a spill triggered by a Drift River lahar would likely be impossible to clean up before it reaches Cook Inlet. Oiled lahar sediment would be difficult to clean up, and would probably need to be entirely removed. Ashfall and pyroclastic flows could delay or impair response by grounding aircraft, restricting the movement of tankers and response vessels, rendering machinery non-operational, reducing visibility, and creating human respiratory threats.

There is no published case history of oil spills comingled with lahars. Usual methods of containment, storage, and recovery may not apply in lahar-caused discharge, when oil is expected to be heavily mixed with both water, sediment, and volcanic ash. There is no established literature or practice on responding to oiled lahars. Existing oil spill response plans, such as those outlined in STARS (Spill Tactics for Alaska Responders) and the Prince William Sound contingency plans, do not address what tactics would work for oil spills mixed into a water-sediment slurry, and deposited both onshore and underwater in the slurry.

Figure 5: 2009 Lahars in the Drift River valley and delta, entering Cook Inlet. Reproduced from: Earth Observatory, earthobservatory.nasa.gov/NaturalHazards/view.php?id=37800

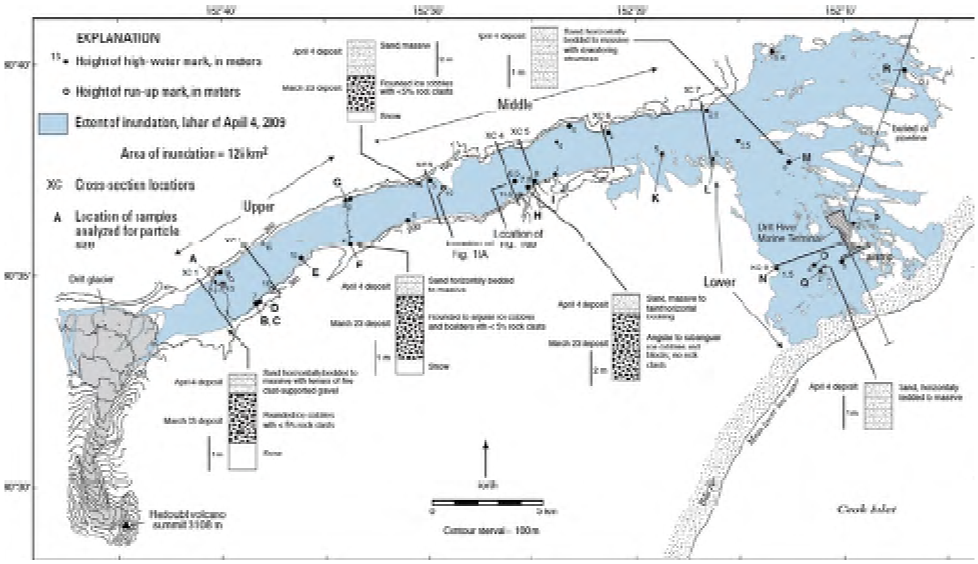

Figure 13. Map of lahar inundation associated with lahar 20 on April 4, 2009. Minimum flow depths (closed circles) and flow run up (open circles) as determined by laser rangefinder measurements of high-water marks and mud lines on trees also are shown. Location of channel cross sections used for discharge estimates, and generalized stratigraphic profiles also are shown. Locations of samples analyzed for particle-size distribution are indicated by letters A–R.

Figure 6. Reproduced with caption from Waythomas et al. 2012.

Probability of Oil Entering Cook Inlet

A lahar which strikes DRMT with sufficient flow to breach the protective berms or to excavate and rupture the pipeline is almost certain to enter Cook Inlet as well. Such a lahar will at that time have traveled more than 22 miles from its source, on Mt. Redoubt, and will be less than 2 miles from entering Cook Inlet. Recent lahars entered Cook Inlet, as is visible in imagery (Figure 5, Figure 6), and lahars larger than these are possible. In cases where sediment-rich lahars do not enter Cook Inlet, their water will nonetheless drain into local drainages and sloughs, and ultimately enter the Inlet. It would be nearly impossible for a lahar-induced oil discharge *not* to reach the Inlet.

To the extent that oil is discharged and escapes the immediate DRMT, it will flow into Rust Slough, the Drift River, or alternate drainage channels newly created by the lahar itself. It will be carried directly into a marine waters, or be deposited in porous lahar sediments on the ~1.75 x 0.5 mile strip of land between the shore and surrounding rivers and streams. If it is deposited onshore, oil which drains from the debris is likely to enter the fluvial and marine environments.

Oil Entrainment into a Lahar

Given the nature and dynamics of lahar flow, it should not be assumed that oil spilled in a lahar will behave as if it were spilled in a water flood. A professional opinion prepared by JWS Consulting (Short, 2012) suggests that large volumes of oil may become entrained within a lahar, coating individual sediment grains. The degree to which oil is entrained rather than forming a surface slick may depend on the source of the oil (buried pipeline or surface tank rupture), and behavior of the lahar. It is expected that some fraction of the spilled oil, possibly the majority, will become entrained within the lahar and adhere to sediment. (Short 2012).

Recovery of oil intermixed with a large sediment component is difficult, since a large fraction of the spilled oil may not form a skimmable surface slick, although oiled sediments may release oil back into the environment and form slicks when eroded, disturbed, or agitated. Degradation of the oil itself may be retarded, and the oil may be persistent in the environment. Unlike in a situation where oil is spilled on the ground surface and contaminates only the upper centimeters of earth, oiled lahar material may be contaminated throughout its entire depth. (Short, 2012). Where it is accessible on land, recovery of oiled lahar sediment would likely require earth-moving equipment. Conventional spill response tactics, such as booms, sorbents, and skimmers, will only be applicable for that fraction of the oil that forms an on-water surface slick.

Handling and Storage of Oiled Sediment on Land

If lahar sediment becomes heavily oiled, it will require different handling and storage than fluid oil, or even viscous oil-water emulsions. Lahar sediment includes gravel and other material that cannot be pumped like fluids and emulsions. Earth-moving equipment would be necessary for the collection and transport of oiled lahar material. Additionally, the volume of oiled material would be much larger than the recovered oil volume, perhaps by an order of magnitude or more, since the oil will coat sediment grains.

A lahar that breaches protective berms and enters the DRMT with sufficient force to rupture oil tanks would almost certainly fill open ditches and depressions. Even after a lahar subsided, it would leave secondary containment largely filled with sediment. While these areas may be available for oil storage during an oil spill resulting from equipment failure or another non-catastrophic cause, they are unlikely to be available for oil storage after a lahar inundation. The deposition of lahar material within the facility itself, and around the storage tanks, may also bury pumps or other equipment, preventing the use of other tanks for the storage of liquid oil.

Marine Recovery of Oiled Sediment and Non-Floating Oil

If oil adheres to the sediment particles of a lahar, large volumes of oil will become heavier than water. Some of this oiled lahar material may be deposited in the nearshore marine environment. Oil would then be contained in submarine sediments. If this were the case, recovery of such oil would require non-floating oil recovery equipment and methods. For instance, dredges might be required to excavate oiled sediment in river channels or in Cook Inlet itself. While there have been some recent developments in the submerged oil recovery (Michel 2006), the science of submerged oil recovery is embryonic (DeCola 2011), and remains difficult, inefficient, and expensive. Recovery of oiled sediment and non-floating oil might be impractical, especially in the presence of ongoing volcanic hazard or lahar activity, and in the wake of severe damage to DRMT.

The 2010 Kalamazoo River spill in Michigan may provide a useful analogue. In this spill, an estimated 32,000 barrels of dense diluted bitumen was spilled into a waterway. The oil formed a challenging and complex response problem without historical precedent, as a fraction of the oil submerged in the river. Oils were carried downriver in surface waters, and were also entrained into river-bottom sediments. Classic containment methods were ineffective, and the only effective containment was provided by natural catchments. As of August 2012, the Kalamazoo cleanup was still ongoing, 2 years after the spill (Murray & Korpalski, 2010, The Huffington Post). (Note crude oil mixed with dense lahar debris is not diluted bitumen. The purpose of this comparison is to illustrate the challenges of sunken oil.)

If oil is entrained into a lahar, some fraction may remain essentially fluid and even remain at the surface, and some fraction will almost certainly adhere to sediment grains that are denser than water. The lahar will likely continue in its flow pathway, and oil will be introduced into whatever environment the lahar enters. Some of this oil will likely be at the water surface, or mixed with turbid waters. Some fraction will be intermingled with sediment, somewhat analogous to the “sunken oils” of Kalamazoo.

Conclusions

DRMT faces a complex threat from Mt. Redoubt’s lahars and eruptions. Mt. Redoubt has the potential to generate larger lahars than have been observed in recent history, and without warning. Based on current evidence, the following general conclusions can be made:

- Lahars larger than the 2009 and 1989-1990 lahars may be generated.
- Alaska Volcano Observatory may not be able to provide warning sufficiently in advance of a lahar-generating eruption to allow the removal of oil from the storage tanks. No provision for removal of oil from the vulnerable pipeline sections has been planned.
- Rupture of the pipeline or storage tanks could create a spill which defies conventional oil spill response tactics, is difficult or impossible to clean up, and results in long-term persistent oil in the environment.
- Rupture of the pipeline would likely lead to oil discharge into the floodplain and Cook Inlet. Size of the discharge would depend on the section of pipeline ruptured, the nature of the rupture, and whether valves were successfully closed, but would likely exceed 10,000 barrels.
- Rupture of the DRMT storage tanks could release greater than 400,000 barrels of oil into the floodplain and Cook Inlet, if they are not successfully emptied beforehand. If plumbing arrangement prevents the complete emptying of tanks, then a spill of unidentified size would occur, even with a successful emptying of the facility tanks.
- A lahar-induced oil spill at DRMT is almost certain to enter Cook Inlet.
- Independent geotechnical and geological assessment of the sufficiency of DRMT’s protections is recommended. Protection that could resist the most severe eruptive or flank collapse events is likely impractical or impossible to construct.
- The potential of Mt. Redoubt to generate more catastrophic eruptions, larger lahars, and lahars which flow directly against the tank farm revetments or excavate and flow against the pipeline as it crosses the floodplain should be considered, prior to permitting future use of the facility.
- The proposed re-routing of the pipeline to totally avoid the Drift River floodplain appears to be a more rational solution than testing statistical probabilities of severe eruptive events or unpredictable lahar behavior.

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