HERRERA

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Subject: Petersburg Medical Center Inundation Analysis

Dear Mr. Jardine:

This letter documents an inundation analysis to support the master planning process for the Petersburg Medical Center (PMC) in Petersburg, Alaska. Per direction you provided, the inundation analysis focuses on the potential for tsunamis to inundate and impact the PMC. Due to the PMC being a regional medical center, it is important that it be located away from areas at risk of inundation, including rare events like tsunamis. In addition to examining tsunami inundation, we also agreed that we would briefly address sea level rise and storm surge as it applies to potential locations of the PMC.

Geographic Setting

Petersburg is located on the north end of Mitkof Island in the southeast Alaska archipelago. It is bordered to the north and west by Wrangell Narrows and to the east by the larger and deeper Fredrick Sound. The PMC is currently located on a single city block at elevations between 40 and 55 feet above mean lower low water (MLLW) (Ackley Jensen Architects, Inc. 1983).

Project Understanding

A recent Facility Condition Assessment of the PMC indicates that some of the building components and systems are nearing the end of their useful life. Accordingly, PMC has begun to explore renovation versus new construction alternatives. The alternative locations under consideration, along with the existing location of the PMC, are shown in Figure 1. Elevation is a key parameter for all of the location alternatives, at least with respect to inundation. Therefore, Table 1 lists the approximate elevations of the existing PMC site and the alternative sites.

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Alternatives 1 through 3 all exhibit a similar inundation hazard profile because the sites are all immediately upslope of the existing PMC and at comparable elevations. Alternative 4 is somewhat distinct in that its site is upslope of the northeast end of Petersburg and at an elevation only slightly higher than the existing PMC. The relatively low elevation of the Alternative 4 site subjects this location to an increased probability of inundation, particularly associated with tsunami and storm surge events originating in Frederick Sound.

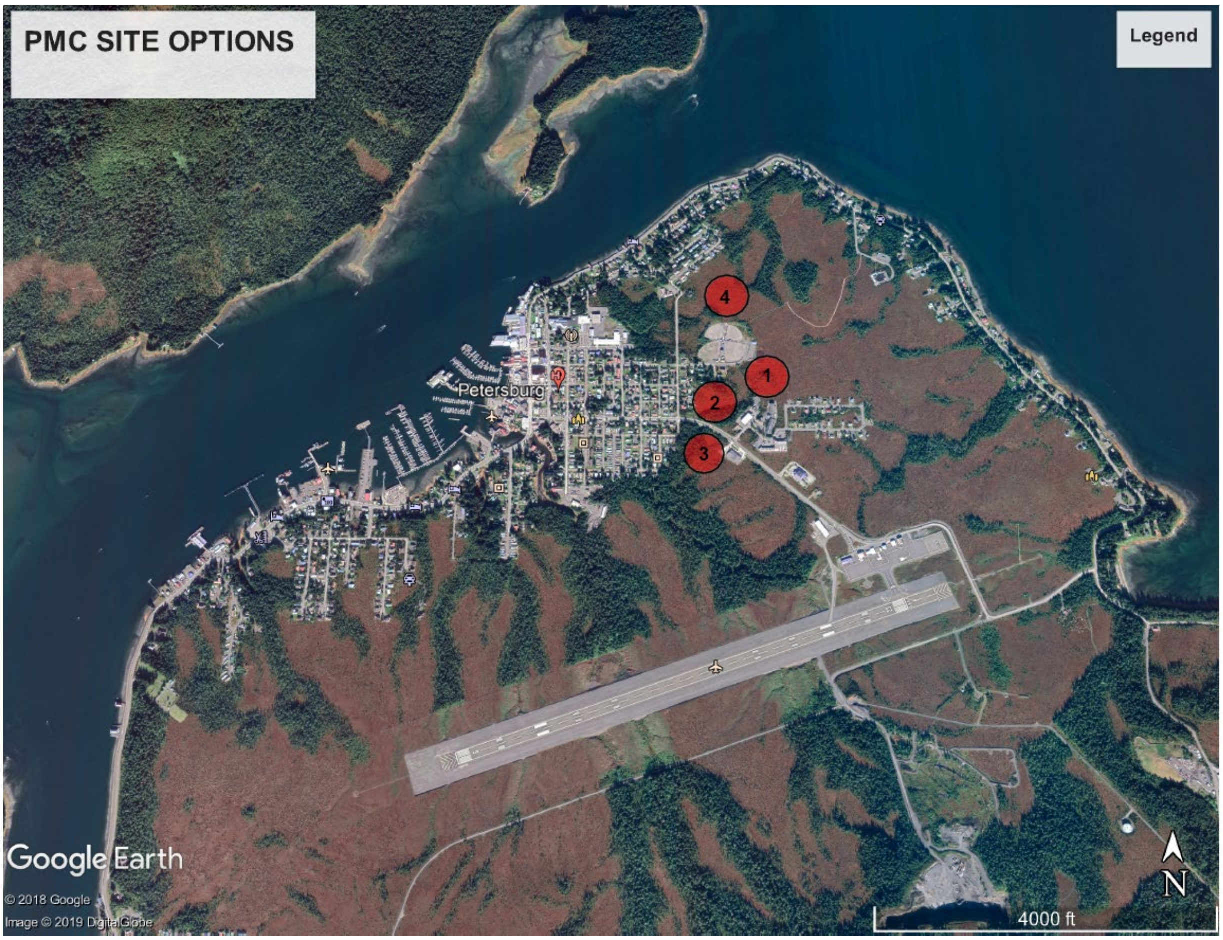

Figure 1. Map of the existing PMC and proposed alternative locations (from NAC Architecture). Small red H denotes the location of the existing PMC, while the numbered red circles indicate the alternative locations.

Table 1. Approximate Elevations of the Existing PMC Site and Proposed Alternative Sites.

Location	Elevation range in feet above MLLW
Existing PMC	40-55*
Alternative 1	80-90
Alternative 2	75-90
Alternative 3	70-80
Alternative 4	50-70

*From Ackley Jensen Architects, Inc. (1983)

Sea Level Rise

Sea level rise is an important consideration for a critical facility located close to marine waters, as is the case with the PMC. A key component in estimating future sea level rise is vertical land movement (Sweet et al. 2017). There is no vertical land movement data for Petersburg, but there is for Ketchikan. Ketchikan has not experienced any sea level rise in the historical record due to this effect (NOAA 2019b). The lack of historical sea level rise is a result of tectonic uplift associated with the collision of the Pacific and North American plates. Although Ketchikan is over 100 miles away from Petersburg, given its similar location with respect to the plate boundaries, it is expected that tectonic uplift will also mitigate some of the effects of sea level rise at Petersburg.

Even if no tectonic uplift occurs in Petersburg, the ground elevation at the existing PMC site is sufficient to avoid even the most extreme projected sea level scenarios prior to year 2150 (Sweet et al. 2017). The latest predictions suggest that even the most extreme predictions in 2200 will only inundate portions of the existing PMC. The other alternatives are higher than even the worst-case values in 2200.

Storm Surge

Storm surge refers to elevated sea level associated with wind and low atmospheric pressure. Waves often contribute to storm surge, but wave heights are modest in the Wrangell Narrows. Like other protected passages in the Pacific Northwest (Finlayson 2006), waves are mostly generated by local winds and boat wakes and are only a few feet high at the windiest times.

Storm surge is typically estimated from analyses of tide gages. Although a temporary gage was installed to understand the relationship between the tides at Petersburg compared to its reference station at Ketchikan (NOAA 2019a), none of that data is publicly available. The best data available for assessing storm surge at Petersburg are from the Ketchikan tide gage (NOAA 2019b). From this data, NOAA (2019b) estimates the 100-year (1% chance of exceedance in a given year) water level to be approximately 21 feet above MLLW. Because the lowest elevation of the existing PMC is 40 feet above MLLW, at least 19 feet of sea level rise is required to inundate the existing PMC in relation to atmospheric and oceanographic processes. Substantially more sea level rise would need to occur to inundate the alternative PMC sites.

TSUNAMIS

Many tsunamis have occurred within the last 100 years in Southeast Alaska. Even more have occurred in recent geologic time. Therefore, the threat of tsunami-induced inundation of a critical facility, such as a hospital, in southeast Alaska is real and serious. There are several mechanisms by which a tsunami could impact the Petersburg area. Each mechanism generates a different type of tsunami and the probability of each mechanism is dramatically different. Therefore, each mechanism is discussed separately below.

Earthquake Generated Tsunamis

The most common type of tsunami is generated by large, distant (outside the northeast Pacific Ocean) earthquakes. These types of tsunamis occur every few years on average. The most recent large tsunami of this type occurred in March 2011 as a result of the Tohoku event in Japan (Allan et al. 2012). However, as detailed by Suleimani et al. (2018), interior portions of Southeast Alaska, like Ketchikan, are protected from these events by large islands to the west. In the 2011 Tohoku event, the tsunami height at Ketchikan was only 0.11 meter (0.4 foot). Like Ketchikan, Petersburg is much more protected from open ocean tsunamis than other Southeast Alaska locations, so it is likely that the tsunami height at Petersburg stemming from the Tohoku event was smaller than the small tsunamis observed in outer Southeast Alaska (e.g., at Craig where it was approximately 1 foot high). Since the Tohoku event occurred due to the fourth largest earthquake in recorded history, and it is highly unusual for earthquakes to be any larger than that earthquake, it is impossible for a standard, distant tectonic event to produce a tsunami that could inundate the existing PMC.

Considerable modeling has been performed recently on local subduction earthquakes in Southeast Alaska. Unlike distant earthquakes such as the Tohoku event off the coast of Japan, local subduction earthquakes can produce significant tsunamis in the area. In particular, Suleimani et al. (2018) provide insight into the propagation of tsunami waves from these local events. Although the focus of their study was at Port Alexander, Craig and Ketchikan and did not include Petersburg, Suleimani et al. (2018) document a range of simulations that indicate earthquake tsunamis can be produced that exceed 10 feet in height in developed areas of outer Southeast Alaska, where tsunamigenic (tsunami producing) earthquakes occur. However, for protected interior areas, such as Petersburg, tsunami heights generated by these types of earthquakes are much smaller. Suleimani et al. (2018) ultimately use a maximum runup height of 1.43 meters (or slightly less than 5 feet) for Ketchikan. Since Petersburg is at least as protected as Ketchikan, it is not possible for a local subduction earthquake to generate a tsunami that would inundate the existing PMC.

Pro-glacial Tsunamis

Pro-glacial tsunamis occur when a large landslide or ice sheet calving occurs amid a tidewater glacier. The wave generated by the landslide and/or ice displacing sea water causes run-up of sea water on to nearby land. A recent pro-glacial tsunami occurred in 2015 in Taan Fiord, an arm of Icy Bay, approximately 375 miles northwest of Petersburg (Higman et al. 2018). The maximum run-up of this tsunami was 192 meters (approximately 630 feet). The glacial landslide occurred due to rapid retreat of Tyndall Glacier, a tidewater glacier, in addition to the melting of permafrost on adjacent slopes, causing those slopes to destabilize (Higman et al. 2018). The giant 1958 Lituya Bay tsunami, which produced the largest runup of any historical tsunami known, was also a pro-glacial tsunami (Higman et al. 2018), though its initiation mechanism was somewhat complex because the landslide was triggered by a large earthquake (Doser 2010).

As pointed out by recent analysis of the Taan Fiord event, these types of events are probable and likely to increase in frequency with climate change (Higman et al. 2018). The nearest tidewater glaciers to Petersburg are the Baird Glacier in Thomas Bay and the Le Conte Glacier in Le Conte Bay. Both are approximately the same distance from Petersburg (about 20 miles) and both are geographically similar to Tyndall Glacier. There is an ongoing risk of a tsunami occurring near the terminus of either glacier within the confines of either bay.

Based upon the analogy with the Taan Fiord tsunami, it is likely that if a tsunami were to occur in either of these bays, inundation in Petersburg would be minimal. In the absence of modeling both the landslide and the tsunami, it is difficult to speculate about inundation extents, but the tsunami generated in Taan Fiord did not propagate far into Icy Bay, despite its exceptionally large peak runup in Taan Fiord. This is understandable because Icy Bay is large and deep and capable of dissipating even large waves in a smaller arm of the bay. In fact, the tsunami impacts were unidentifiable just 5 kilometers (about 3 miles) from the mouth of Taan Fiord (Higman et al. 2018). The equivalent in the case of both possible pro-glacial tsunami source areas in Thomas Bay and Le Conte Bay would be impacts no more than 3 miles from the mouths of these bays into Frederick Sound. Frederick Sound is even larger and deeper than Icy Bay and Petersburg is more than 12 miles from the mouths of either bay. Therefore, a tsunami generated in either Thomas or Le Conte bay would have to be orders of magnitude larger than the Taan Fiord event to even reach Petersburg, let alone to inundate the existing PMC. It is thus highly unlikely that a pro-glacial tsunami would inundate the existing PMC or any of the alternative PMC sites.

Subaerial Landslide Generated Tsunamis

Landslide-generated tsunamis in the absence of recent deglaciation are extremely rare but have been known to occur. Although the cause of the tsunami event in 1958 Lituya Bay is considered to be a pro-glacial landslide, the mechanism by which it was generated (i.e., earthquake-triggered liquefaction) could occur anywhere where there is seismicity and steep terrain, like Petersburg.

At Petersburg, Petersburg Mountain is probably the only source of a landslide sufficient to produce a tsunami that could potentially impact the existing PMC. The mountain rises over 2700 feet in approximately one mile distance from Wrangell Narrows. The steepness of the mountain indicates potential for a catastrophic slope failure that could generate a large landslide mass, but the likelihood of such a failure is entirely unknown and speculative. Unlike at Lituya Bay, which has seen two different tsunami events in historical time (Higman et al. 2018), there is no evidence for past catastrophic landsliding on Petersburg Mountain. There is also no evidence of past flank collapses anywhere on the mountain (either in historical time or in the geologic past), and there are no mapped landslides in the geologic map of the area (Brew et al. 1984). Therefore, a flank collapse at Petersburg Mountain would be an unexpected event and highly unlikely to occur. If it were to occur, it could inundate the entire populated area of Petersburg, including the existing PMC and all proposed alternatives.

Submarine Landslide Generated Tsunamis

A final possibility for a tsunami mechanism in the Petersburg area is a submarine landslide, like the one that occurred in Skagway in 1994 (Suleimani and Dickson 2018). However, submarine landslides are highly unlikely in the Wrangell Narrows. Unlike Taiya Inlet near Skagway, Wrangell Narrows is relatively shallow (between 20 and 30 feet deep for the reach adjacent to Petersburg: National Ocean Survey 1978). The shallow water depth does not allow for a significant mass of submarine sediment to move laterally at fast speed. Also, the dominant sediment supply to this portion of the Wrangell Narrows, Petersburg Creek, is modest compared to the Skagway River. The type of tsunami that occurred in Taiya Inlet in 1994 requires a large accumulation of recently deposited sediment to suddenly slump into deeper water. In the Wrangell Narrows, sediment is well dispersed and does not form a large delta. While it is possible that a failure of a submarine slope into deep portions of Fredrick Sound could produce a tsunami, it is unlikely. The potential for an event of this type to generate a tsunami height that could reach the elevation of the existing PMC or any of the alternative PMC sites is negligible.

Conclusions

Table 2 summarizes the threats of inundation to the existing PMC and the proposed alternative PMC locations. The risk of inundation, particularly with respect to other locations in southeast Alaska, is extremely low at the current location of the PMC. While some of the alternative locations (Alternatives 1 through 3 in Figure 1) provide a modest reduction in probability of inundation due to their higher ground elevations relative to the existing PMC site, the most severe type of tsunami that could occur in the Petersburg area (a tsunami generated from a large flank collapse of Petersburg Mountain that is seemingly extremely unlikely) could cause inundation of all the proposed alternative sites.

Table 2. Inundation Analysis Summary

Event	Probability of Occurrence	Inundation at Site		
		Existing PMC	Alternatives 1-3	Alternative 4
Sea level rise and storm surge	Certain	None before 2150	None before 2200	None before 2200
Distant earthquake tsunami	Certain and frequent	None	None	None
Local earthquake tsunami	Certain but infrequent	None	None	None
Pro-glacial tsunami	Possible	Highly unlikely	Extremely unlikely	Highly unlikely
Petersburg Mountain flank collapse tsunami	Highly unlikely	Total inundation potential	Total inundation potential	Total inundation potential
Submarine landslide tsunami	Highly unlikely	Highly unlikely	Extremely unlikely	Highly unlikely

Caveats to the Analysis

This analysis was based on an examination of the scientific literature and publicly available information. Tsunamis and other geophysical processes are fundamentally unpredictable phenomena. No on-site survey was performed of the south flank of Petersburg Mountain, the primary area where a large-scale landslide could conceivably occur that could in turn initiate a tsunami capable of inundating the existing PMC. Minor flooding from local surface water runoff was not considered but could easily occur at the existing PMC site if not addressed, particularly in light of aging stormwater infrastructure and anticipated sea level rise.

Please let me know if you have any questions regarding the information presented in this letter.

Sincerely,

Herrera Environmental Consultants, Inc.

Jeff Parsons, PhD, PE
Geomorphologist

REFERENCES

Ackley Jensen Architects, Inc. 1983. Petersburg General Hospital Plans. Prepared for City of Petersburg. April 1983.

Allan, J.C., P.D. Komar, P. Ruggiero, and R. Witter. 2012. The March 2011 Tōhoku Tsunami and Its Impacts along the U.S. West Coast. Journal of Coastal Research 28(5):1142-1153.

Brew, D.A., A.T. Ovenshine, S.M. Karl, and S.J. Hunt. 1984. Preliminary Reconnaissance Geologic Map of Petersburg and Parts of the Port Alexander and Sumdum 1:250,000 Quadrangles, Southeastern Alaska. USGS Open File Report 84-405.

Doser, D.I. 2010. A Reevaluation of the 1958 Fairweather, Alaska Earthquake Sequence. Bulletin of the Seismological Society of America 100(4):1792–1799.

Finlayson, D. 2006. The Geomorphology of Puget Sound Beaches. PhD Thesis. University of Washington, Seattle.

Higman, B., D.H. Shugar, C.P. Stark, G. Ekström, M.N. Koppes, P. Lynett, A. Dufresne, P.J. Haeussler, M. Geertsema, S. Gulick, A. Mattox, J.G. Venditti, M.A.L. Walton, N. McCall, E. Mckittrick, B. MacInnes, E.L. Bilderback, H. Tang14, M.J. Willis, B. Richmond, R.S. Reece, C. Larsen, B. Olson, J. Capra, A. Ayca, C. Bloom, H. Williams, D. Bonno, R. Weiss, A. Keen, V. Skanavis, and M. Loso. 2018. The 2015 landslide and tsunami in Taan Fiord, Alaska.

Miller, I.M., H. Morgan, G. Mauger, T. Newton, R. Weldon, D. Schmidt, M. Welch, and E. Grossman. 2018. Projected Sea Level Rise for Washington State – A 2018 Assessment. A collaboration of Washington Sea Grant, University of Washington Climate Impacts Group, Oregon State University, University of Washington, and US Geological Survey. Prepared for the Washington Coastal Resilience Project.

NOAA. 2019a. Petersburg, AK Gage #9451439 Tides and Currents website. Available at: https://tidesandcurrents.noaa.gov/stationhome.html?id=9451439.

NOAA. 2019b. Ketchikan, AK Gage # 9450460 Tides and Currents website. Available at: https://tidesandcurrents.noaa.gov/stationhome.html?id=9450460.

National Ocean Survey. 1978. Alaska, Wrangell Narrows Hydrographic Survey H-9791.

Suleimani, E. and I. Dickson. 2018. Landslide tsunamis: Why they’re different and how to prepare. Alaska Earthquake Center website. Available at: <https://earthquake.alaska.edu/landslide-tsunamis-why-theyre-different-and-how-prepare>. June 10, 2018.

Suleimani, E., D.J. Nicholsky and R.D. Koehler. 2018. DRAFT Regional Tsunami Hazard Assessment for the Communities of Port Alexander, Craig and Ketchikan in Southeast Alaska. Available at: <http://earthquake.alaska.edu/sites/default/files/SE_Report_v0_FORMATTED_10-24-18.pdf>.

Sweet, W.V., R.E. Kopp, C.P. Weaver, J. Obeysekera, R.M. Horton, E.R. Thieler, and C. Zervas. 2017. Global and Regional Sea Level Rise Scenarios for the United States. NOAA Technical Report NOS CO-OPS 083. January.