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June 21, 2021

To: Interested Parties

Through: G. Fenix Grange, Acting Program Manager
Hazard Evaluation and Emergency Response

From: Dr. Diana Felton, MD, State Toxicologist
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Subject: Risks of Sea Level Rise and Increased Flooding on Known Chemical Contamination in Hawaii (updated June 2021)

This memorandum discusses potential environmental concerns posed by anticipated increased flooding, groundwater inundation and disruption of contaminated lands in coastal areas due to climate change and rising sea levels.

It is anticipated that additional guidance, policies and regulations will be necessary to adequately prepare for and address impending impacts to human health and the environment from climate change. Comment and input from the public is welcome and should be provided to Diana Felton (diana.felton@doh.hawaii.gov) and Iris van der Zander (iris.vanderzander@doh.hawaii.gov).

Background

Hawaii has around 1,000 sites with known chemical contamination that are monitored and regulated by the Department of Health's Hazard Evaluation and Emergency Response (HEER) Office. Many of the contaminated sites are in low lying areas and along shorelines and are at risk for coastal erosion, as well as submersion and impact from flooding, ground water inundation and sea level rise. Common chemical classes contaminating shoreline areas include petroleum constituents, heavy metals, solvents, pesticides, and persistent organic pollutants (POPs). These contaminants are generally the result of historical industrial and agricultural uses and releases.

While hazards from contamination may be mitigated by removal, treatment or destruction of contaminated media, the most commonly used remedial option across the islands is to prevent exposure by managing contaminated materials in place. This is often done through a combination of physical containment, including protective caps or treatment, and institutional controls such as guidance or restrictions against reuse of sites for residential housing, playgrounds and schools. These protective, site specific controls are summarized in Environmental Hazard Management Plans (EHMPs), which are themselves institutional controls, and describe the specific mitigation strategies approved for preventing exposures and reducing risk for current and future uses.

However, these strategies have historically been viewed in the context of a static environment. The increasing impacts from climate change and sea level rise including more frequent flooding, accelerated erosion and related disruption of contaminated lands due to sea level rise, ground water inundation and an increase in storms and heavy rain events require an equal progression in the manner in which risk is evaluated and mitigated for these types of sites. Of particular concern are large, current or former industrial sites in coastal areas that are known to be heavily contaminated and are at high risk of climate change-related impacts. This includes many harbors, airports, bulk fuel terminals, and former landfills in the islands.

Specific concerns related to these contaminated areas result from the chemical changes induced by sea level rise, effects of barometric pressure changes and increased precipitation (e.g., storms), groundwater inundation and increased flooding. Risks to human health and the environment can increase significantly when these contaminants are moved from their current location to areas that did not previously contain contamination. This includes the possible release of contaminants into drinking water sources and the food chain via fish and shellfish.

Planning for Sea Level Rise

In the 2017 *Sea Level Rise Vulnerability and Adaptation Report* from the Hawaii Climate Change Mitigation and Adaptation Commission (HICCMAC 2017)[1], Recommendation 6 advises protection of nearshore water quality from sea level rise impacts and mentions the risks from underground storage tanks as well as hazardous waste storage facilities. However, this report does not account for the many areas across the state where chemical contamination is managed in place or where widespread residual contamination exists due to historical releases.

The report *Guidance for Sea Level Rise Exposure Area in Local Planning and Permitting Decisions* (Romine et al., 2020)[2] recommends that areas within 3.2 feet of current sea level should be used as the primary planning benchmark for chronic sea-level rise related effects. This reflects a predicted rise in sea level by mid to end of the century. A sea-level rise of 3.2 feet by 2100 is an intermediate scenario. Other plausible scenarios include projections of 2 meters (~6 feet) to a revised upper-bound "extreme" scenario of 2.5 meters (~8 feet) for global sea-

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[1] Hawaiʻi Climate Change Mitigation and Adaptation Commission. 2017. Hawaiʻi Sea Level Rise Vulnerability and Adaptation Report. Prepared by Tetra Tech, Inc. and the State of Hawaiʻi Department of Land and Natural Resources, Office of Conservation and Coastal Lands, under the State of Hawaiʻi Department of Land and Natural Resources Contract No: 64064.https://climate.hawaii.gov/wp-content/uploads/2019/02/SLR-Report_Dec2017-with-updated-disclaimer.pdf pg 241-245

[2] Romine, B.M.; Habel, S.; Lemmo, S.J.; Pap, R.A.; Owens, T.M.; Lander, M.; Anderson, T.R. 2020. Guidance for Using the Sea Level Rise Exposure Area in Local Planning and Permitting Decisions. Prepared by the University of Hawaii Sea Grant College Program with the Hawaiʻi Department of Land and Natural Resources - Office of Conservation and Coastal Lands for the Hawaiʻi Climate Change Mitigation and Adaptation Commission - Climate Ready Hawaiʻi Initiative. (Sea Grant Publication TT-20-01). https://climate.hawaii.gov/wp-content/uploads/2020/12/Guidance-for-Using-the-Sea-Level-Rise-Exposure-Area.pdf

level rise by 2100 (Sweet et al. 2017)[3]. Higher sea level rises than 3.2 feet by 2100 are now considered more likely due to the potential rapid melting of ice sheets.

The Romine et al. (2020) report suggests that less frequent, but more severe coastal flood events can be assessed per the guidance using the 1% Annual-Chance Coastal Flood Zone augmented with 3.2 feet of sea level rise (1% CFZ-3.2). Consideration of areas impacted by longer-term rises in sea level up to six feet or more might be necessary for sites impacted with persistent contaminants such as lead, arsenic, polychlorinated biphenyls (PCBs) and organochlorine pesticides.

Appendix A contains maps showing example areas around Honolulu Harbor that are at risk for projected sea level rise of 3.2 feet. Chronic sea level rise is shown in Figure 1, and less frequent, but more severe flooding risk in Figure 2. Comparison of HEER managed contaminated site maps with sea level rise projection maps reveals that over 300 chemically contaminated sites statewide are at risk for inundation due to 3.2 feet of sea level rise. When 1% annual-chance coastal flood zone and risk from rising groundwater or additional sea level rise up to six-feet is considered, the count of at-risk chemically contaminated sites rises dramatically.

Investigation of contamination is ongoing at some sites noted in the figures. In other cases, contamination is being managed in place under an Environmental Hazard Management Plan. Residual contamination at many sites in coastal areas around the islands may be relatively small and may not pose a significant individual risk due to future rises in sea level and other climate-related changes but evaluation of this risk requires investigation on a case-by-case basis. Other areas with significant contamination that could pose a future risk to human health and the environment from climate change mediated effects remain. In addition, the impact of cumulative contamination from small and intermediate sites, is unknown. Identification of the potential high-risk sites and development of short term and more thorough, long-term remediation and management strategies is needed.

Case Examples

Key among these concerns are former and current bulk fuel facilities and related pipeline networks, and current and former industrial areas with known, heavy contamination that is currently being managed in place. Climate change induced disruptions and related physical damage to these areas is likely to expose and spread petroleum contamination in soils and groundwater, posing risks to human health and the ecosystem including coral reefs. Leakage of petroleum, methane buildup and other events could also disrupt the safety and functionality of harbors, ports, fuel facilities, airports and other infrastructure and lead to significant economic impacts.

In one example, extensive areas of the shoreline in downtown Honolulu are underlain with fill material known to be contaminated with lead from former incinerator ash. This is the case for Kakaʻako Park and the area extending several hundred yards inland from the park. The contamination is currently being effectively managed under thick caps of clean soil or pavement. Future rises in sea level or storm surges could disrupt the caps and spread contaminated fill material along the shoreline and onto adjacent coral reefs.

Arsenic contamination in Wailoa River State Park in Hilo is a historical example of this type of weather-related impact. The park is the site of a former Canec plant that produced termite-resistant, arsenic-infused lumber in the early 1900s. Sediment in Waikea Pond within the park is known to be heavily contaminated with arsenic. Soil around the perimeter of the pond was

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[3] Sweet et al. 2017. Global and Regional Sea Level Rise Scenarios for the United States. NOAA Technical Report NOS CO-OPS 083, US Department of Commerce. https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf

discovered to be similarly contaminated. Further investigation suggests that contaminated sediment was flushed out of the pond and spread into the current park area during the tsunamis of 1946 and 1960. The contamination in the park and the pond are currently managed in place to prevent exposure but are at risk for further disturbance as sea level rises, flooding increases and large storms impact the island.

Other examples of high-risk sites where sea level rise and increased flooding are likely to spread chemical contamination include the Waianae High School Outdoor Air Rifle Range in west Oahu, and the Keehi Lagoon Canoe Facility, Increment II site in Honolulu Harbor (Appendix B, Figures 1 through 4).

The Waianae High School Outdoor Air Rifle Range was constructed in 1999 and the extensive use of lead shot has led to soil contaminated with high lead levels. The contamination is currently being managed in place with an EHMP and long-term plans to remediate the site are slow moving. The area is less than 1 meter above sea level and sea level rise and flooding will spread the lead contamination potentially exposing humans and aquatic organisms to the toxic effects of lead.

The Keehi Lagoon Canoe Facility Increment II site in Honolulu Harbor was originally intended for development as part of the Keehi Lagoon Canoe Competition Center Master Plan in 1990. Increment II was planned as a public park area that would have areas for spectators and would restore existing salt ponds for bird habitat. This part of the development plan never occurred and during a 1994 site investigation, it was discovered the site has lead and polyaromatic hydrocarbons (PAHs) contaminating the soil and groundwater. A former asphalt plant in the area is suspected to be a source of the contamination as well as dumping of unclassified material into the lagoon to create 10 acres of land.

The 13-acre site is not currently considered a risk because public access to the area is very limited, and the contaminants present in the soil are unlikely to move through the ground into the ocean. However, the site is at very low elevation, directly adjacent to the lagoon and includes areas of stormwater run-off. Sea level rise and increased flooding will likely transport the contaminated soils from this isolated area to other areas with more usage, increasing the risk of human exposure. Movement of these contaminants also threatens nearby coral reefs and near-shore ecosystems.

Petroleum-Contamination

Management of coastal areas with soil and groundwater known to be contaminated with petroleum poses particular future challenges. Exposure of contamination due to flooding, rising groundwater and inundation of storm sewers and severe erosion due to wave action can be expected to cause impacts to coral reefs and other aquatic habitats as well as commercial shipping and recreation along coast lines.

An additional concern is the potential increased generation of methane and hydrogen sulfide gas from the submersion and anaerobic degradation of residual petroleum contamination. A strongly anaerobic environment conducible to methane and hydrogen sulfide gas production is typical in areas with petroleum contamination where oxygen is consumed (e.g., source areas) and petroleum contamination is submerged in water. Since water has a much lower oxygen content than the atmosphere, chronically submerged petroleum contamination and the associated establishment of a more anaerobic environment through sea-level rise, ground water inundation or acute flooding is expected through more frequent heavy storm and rain events.

Methane is not only a potent greenhouse gas, but also explosive if mixed with the right proportion of oxygen in the presence of a spark or flame. Hydrogen sulfide is flammable and toxic at low concentrations. The increased production of these gases due to the anaerobic environment created by the submersion of petroleum contamination presents significant health and safety hazards.

An example of this potential risk includes the Honolulu Harbor Area where years of petroleum releases from pipelines and storage tanks have led to areas with widespread petroleum contamination. Work has been done to remove pipelines and petroleum in this area, however, hydraulic recovery of petroleum has limits and widespread residual contamination remains. As long as the subsurface is sufficiently aerated and enough oxygen is present, methane oxidizing bacteria can degrade petroleum to CO_2. Unfortunately, as these areas become inundated from sea level rise, groundwater inundation or flooding, the oxygen supply decreases, leading to enhanced production of methane (Appendix A, Figures 3 and 4). Enhanced methane generation due to sea-level rise and/or related flooding of carbon-rich material has been predicted using modeling[4,5], and observed during laboratory experiments[6]. Oxygen circulation from the surface into the subsurface is further reduced by developed surfaces such as concrete and in the case of active fuel terminals, plastic liners. Methane can build up in areas under pavement and move along utilities or utility corridors, into confined spaces and accumulate in other subterranean pockets, creating a significant explosive hazard for utility workers and construction crews. Moreover, methane gas generation in vapors appears to be enhanced during low atmospheric (barometric) pressures (Appendix A, Figure 5). This indicates a heightened risk of high methane concentrations during storm events with low barometric pressure when conditions are difficult to control.

Changing conditions related to sea water inundation of petroleum contaminated soil will also likely result in the increased production of hydrogen sulfide gas due to resulting anaerobic degradation of residual fuel in the presence of sea water[7]. Progression of more sulfate rich seawater inland therefore increases the risk of hydrogen sulfide gas production at petroleum contaminated sites. Hydrogen sulfide gas and methane vapors can migrate laterally and vertically and potentially intrude into buildings, creating indoor air quality concerns and flammability/explosive hazards.

Recommendations

The risk of increased hazards from sea level rise, groundwater inundation and increased flooding due to climate change requires study and planning to understand and mitigate these hazards before they cause adverse health effects to the population and damage to the environment and the economy. Additional technical guidance, policies and regulations are needed to minimize the impacts and protect human health and the environment.

Steps to begin to address these needs include:

- Summarize the potential environmental concerns associated with impacts of sea level rise and related conditions to contaminated sites in coastal areas.
- Design and implement pilot studies to examine and measure changing contaminant conditions in high risk areas and explore innovative mitigation approaches that can be implemented to reduce methane risks and reduce potential build-up of methane vapors.

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[4] Lu, X., Zhou, Zhoung, Q., Prigent, C, Liu, Y., & Teuling, A. (2018). Increasing methane emissions from natural land ecosystems due to sea-level rise. Journal of Geophysical Research: Biogeosciences, 123, 1756-1768. https://doi.org/10.1029/2017JG004273.

[5] King, G. M. and Henry, K (2019). Impacts of Experimental Flooding on Microbial Communities and Methane Fluxes in an Urban Meadow, Baton Rouge, Louisiana. Front. Ecol. Evol. 7:288. Doi:10.3389/fevo.2019.00288.

[6] King, G. M. and Henry, K (2019). Impacts of Experimental Flooding on Microbial Communities and Methane Fluxes in an Urban Meadow, Baton Rouge, Louisiana. Front. Ecol. Evol. 7:288. Doi:10.3389/fevo.2019.00288.

[7] Suthersan, S.S (2001), Natural and enhanced remediation systems, CRC Press, August 6, 2001, 440 Pages.

- Develop criteria for identification of sites at high-risk of causing significant harm due to rising sea level and related events. Example scenarios where closer evaluation is needed include former dump sites and landfills, areas with extensive cover of contaminated fill material, current and former bulk fuel terminals and related pipeline networks with extensive petroleum contamination and other areas of heavy contamination associated with past industrial activity.
- Develop additional guidance, policies and associated regulations to address anticipated short- and long-term impacts to the areas and mitigate adverse impacts to the environment and human health.
- Identify high-risk sites for focused attention and resources in order to mitigate potential hazards in a timely manner.

Actions to mitigate impacts will necessarily be site specific and must take into consideration both risk to human health and the environmental, timing of anticipated events and economic limitations. **Potential examples include:**

- Incorporation of sea level rise risk factors into site ranking criteria.
- Incorporation of the impacts of sea level rise and related effects on contamination in State, County, and Local Masterplans, including harbors.
- Consideration of sea level rise, rising groundwater and increased flooding related events in the awarding of building permits and development in affected zones. In addition to limiting new construction in some areas, measures might include requiring additional remediation to address existing contamination as well as engineering controls to address the potential buildup of vapors under the structure. This includes areas of widespread petroleum contamination that could be subject to increased vapor emissions and the buildup of methane and hydrogen sulfide gas.
- Evaluation and prioritization of the potential impacts of sea level rise and related events on areas with chemical contamination in state and county disaster and hazard mitigation planning.
- Additional requirement for responsible parties of high-risk sites to take into account the potential impacts of sea level rise and increased flooding due to climate change as they make plans for remediation and the future management of their sites.
- Incorporation of the increased risks of chemical contamination due to sea level rise and related events in the State Sustainability Plan and any updates to the 2017 Sea Level Rise Vulnerability and Adaptation Report from the Hawaii Climate Change Mitigation and Adaptation Commission.
- Additional requirement for consideration of sea level rise and related events in HEER Office approvals for management in-place remedies located in the inundation zones that meet the high-risk criteria.
- Review and re-evaluation of high-risk sites previously awarded No Further Action with Institutional Controls (NFA-IC) determinations letters in potentially affected areas. Review should include changes in transport and fate of contaminants and new associated hazards they may pose in response to sea-level rise and climate change.

It is important that State, County, and Local agencies as well as environmental experts and potentially affected private entities work collaboratively to develop a better understanding of the potential effects of climate change on Hawaii’s people, environment and economy. Proper planning, policy changes and new approaches to address the impact of climate change on environmental chemical hazards are critical to protecting Hawaii’s health, unique natural environment, and economy. As we learn more, targeted state and county changes to Statutes and Rules should be considered to mitigate avoidable effects from the increasing and changing risks of chemical contamination due to climate change.

Appendix A

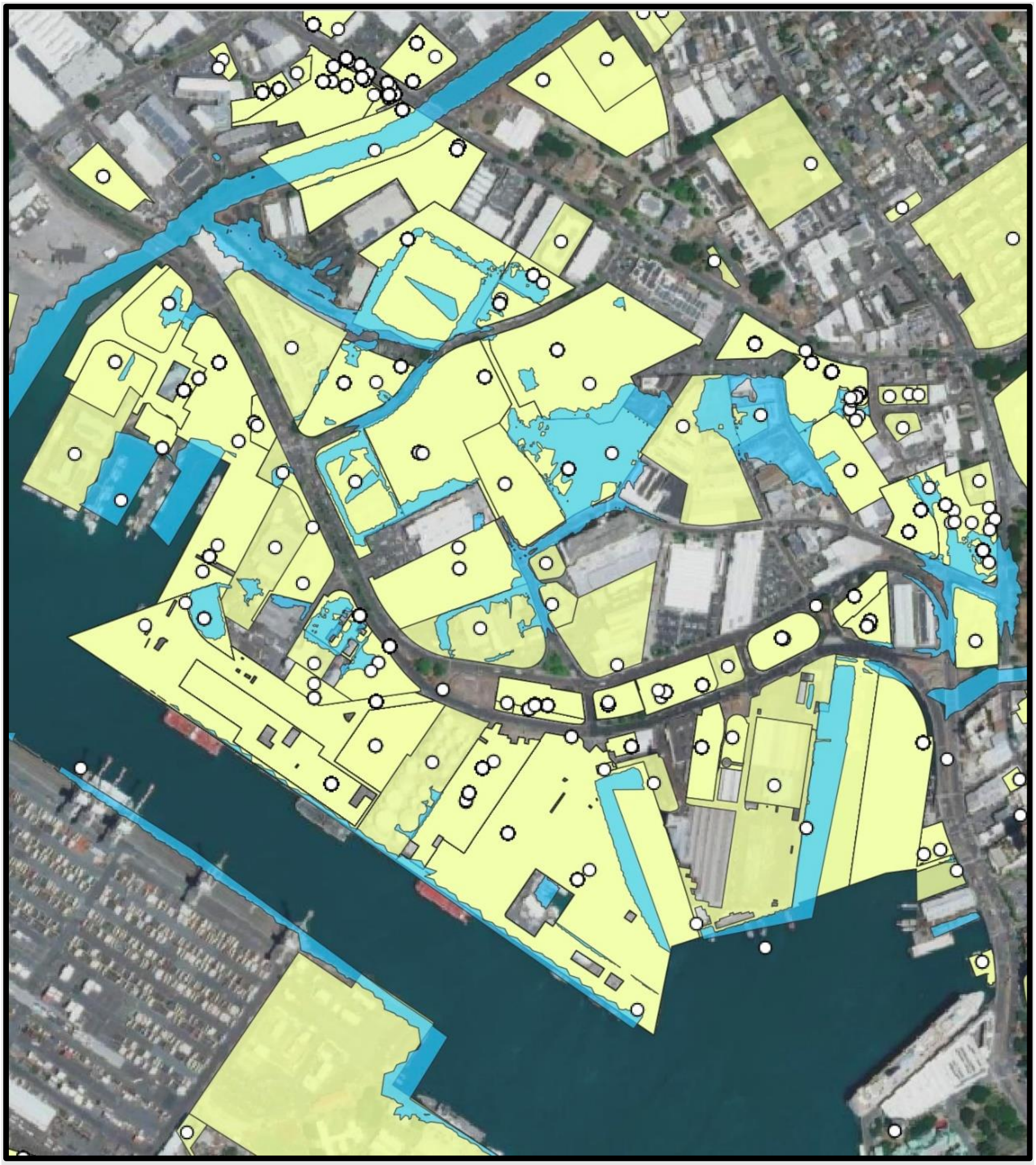

Figure 1: HEER sites in the Honolulu Harbor Area in relationship to the sea level rise exposure area at 3.2 feet of Sea level Rise. The exposure area is shown in blue and a combination of three modeled effects: sea-level-rise induced passive flooding expressed at the surface; coastal erosion, and annual high wave flooding. White circles= HEER site centroids, yellow=HEER site outline.

Figure 2: HEER sites (centroids only; white circles) in the Honolulu Harbor Area in relationship to the area affected by 100-year flood event in addition to 3.2 feet of SLR (purple).

Figure 3: Top panel show the concentration of methane in groundwater from wells at an active fuel terminal at Honolulu Harbor from 2007 to 2021. The bottom panel shows the monthly mean variation of the Mean Sea Level (MSL) from the NOAA Honolulu Harbor Station (Station ID 1612340) during the same time frame. In 2013 a liner was installed at the surface of the fuel terminal and active petroleum recovery stopped. Concentrations of methane in groundwater started to rise after 2014 and parallel with the MSL.

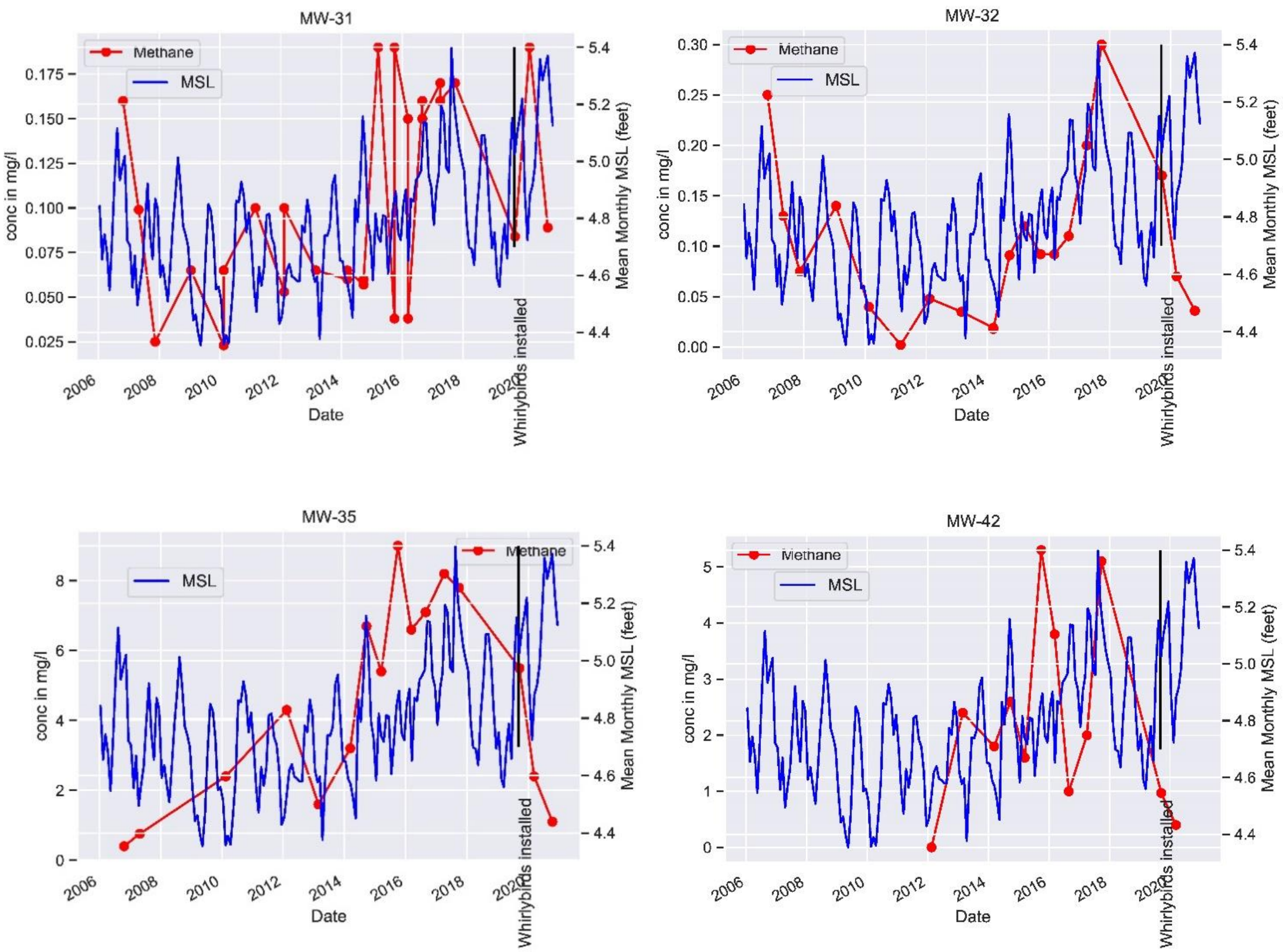

Figure 4: Methane Concentration in groundwater from four different wells at an active fuel terminal in the Honolulu Harbor area. In all four wells methane concentration covaries with average monthly mean sea level (MSL). MW-31 and MW-32 are located close to the shoreline and have lower average concentration. MW-35 and MW-42 have higher methane concentrations in groundwater and are located closer to Nimitz Highway.

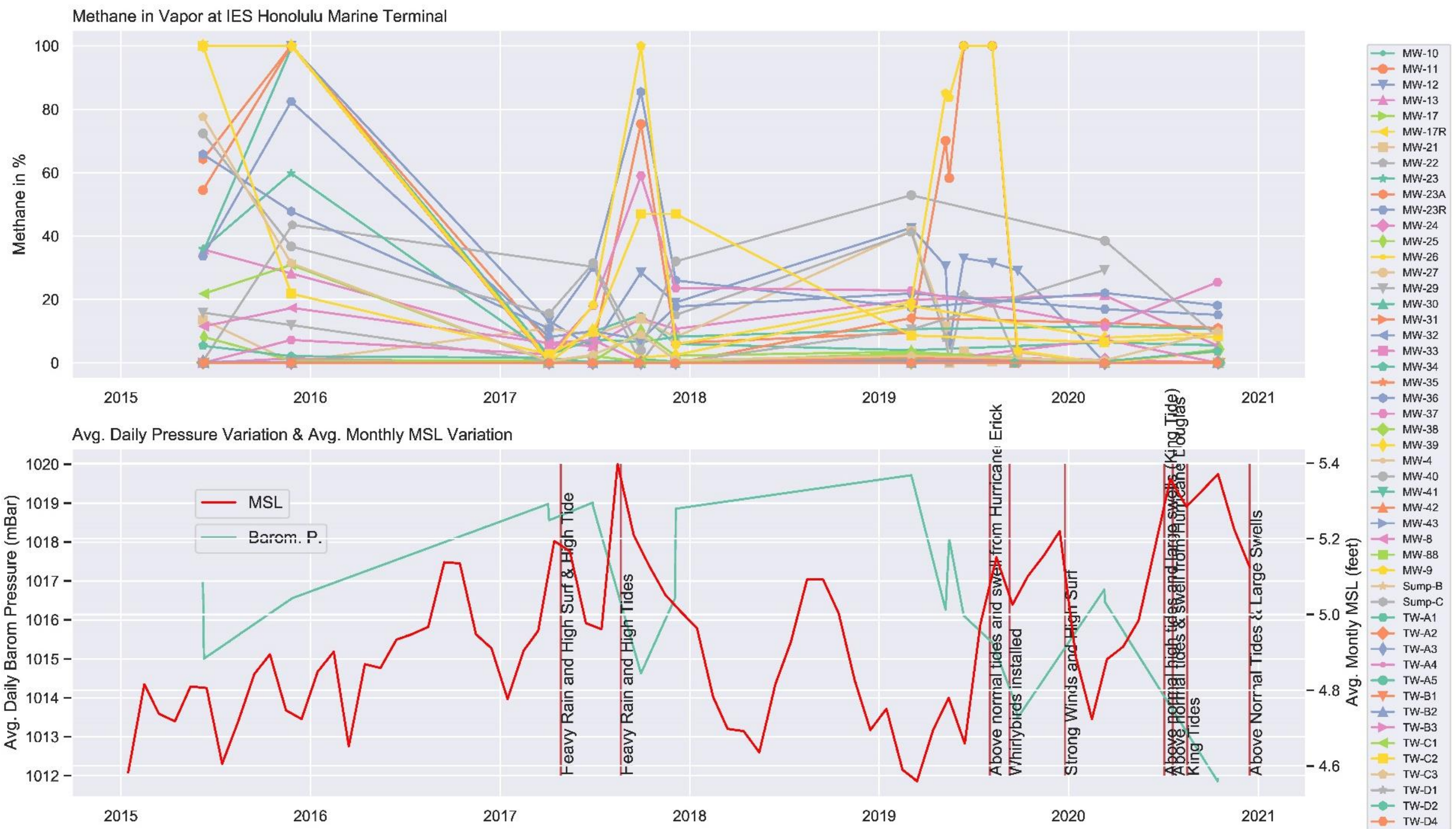

Figure 5: Top panel shows percentage of methane gas in vapor from wells of the same fuel terminal as in Figure 4 from 2015 to 2020. The bottom panel shows the variation of mean monthly sea level (red line) and average daily barometric pressure (green line). Methane concentrations in wells appear to increase with low barometric pressure. This presents especially a risk of increased methane gas generation in the subsurface under low barometric pressure conditions as typical during storms.

Appendix B

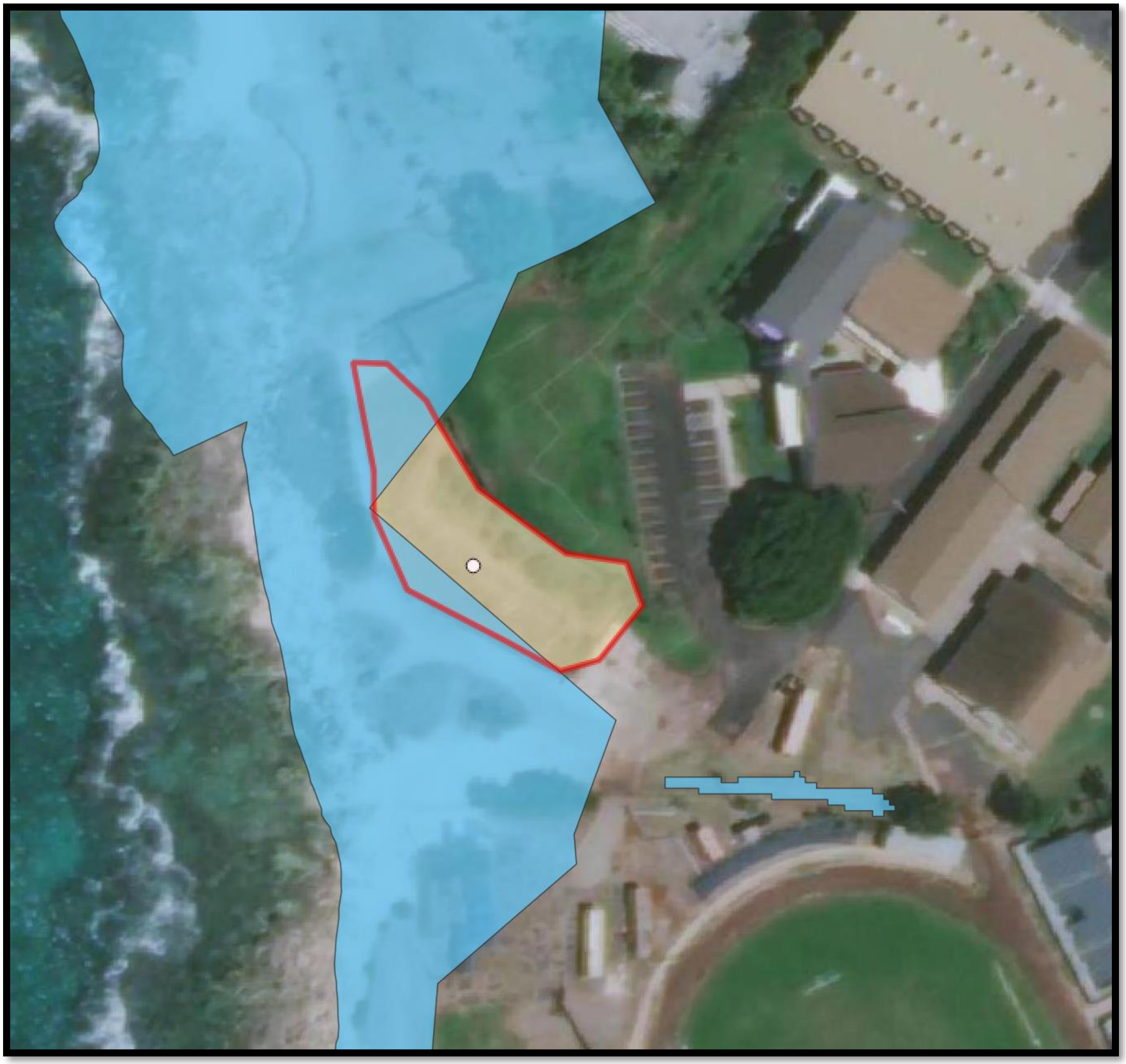

Figure 1: HEER site Waianae High School Outdoor Air Rifle Range in west Oahu in relationship to the sea level rise exposure area at 3.2 feet of Sea level Rise. The exposure area is shown in blue and a combination of three modeled effects: sea-level-rise induced passive flooding expressed at the surface; coastal erosion, and annual high wave flooding. White circle= HEER site centroids, red outline= Waianae High School Outdoor Air Rifle Range Site.

Figure 2: HEER site Waianae High School Outdoor Air Rifle Range on west Oahu (red outline) in relationship to the area affected by 1% Annual-Chance Coastal Flood Zone in addition to 3.2 feet of SLR (purple).

Figure 3: HEER site Keehi Lagoon Canoe Facility, Increment II in Honolulu Harbor in relationship to the sea level rise exposure area at 3.2 feet of Sea level Rise. The exposure area is shown in blue and a combination of three modeled effects: sea-level-rise induced passive flooding expressed at the surface; coastal erosion, and annual high wave flooding. White circles= HEER site centroids, yellow area with red outline= Keehi Lagoon Canoe Facility, Increment II in Honolulu Harbor.

Figure 4: HEER site Keehi Lagoon Canoe Facility, Increment II in Honolulu Harbor (yellow area with red outline) in relationship to the area affected by 1% Annual-Chance Coastal Flood Zone in addition to 3.2 feet of SLR (purple).