CITY OF ALAMEDA

THE RESPONSE OF THE SHALLOW GROUNDWATER LAYER AND CONTAMINANTS TO SEA LEVEL RISE

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Executive Summary

As sea levels rise and extreme storms become more frequent, communities are developing climate adaptation plans to protect communities from flooding. However, these plans often neglect an important potential flood hazard – emergent groundwater. The shallow groundwater surface in coastal communities will rise as sea levels rise. This slow but chronic threat can flood communities from below, damaging buried infrastructure, flooding below grade structures, and emerging aboveground as an urban flood hazard, even before coastal floodwaters overtop the shoreline. This study explores the links between sea level rise, precipitation, and the elevation of the shallow groundwater surface so that adaptation plans can consider all potential flood hazards. An integrated planning approach that addresses rising seas and groundwater simultaneously, from the vulnerability and risk assessment phase through to adaptation implementation, is recommended. A suite of potential adaptation strategies to address rising seas and rising groundwater are presented.

> *The areas at risk of flooding increases by up to 25 percent when considering both threats…*

The City of Alameda's Climate Action and Resiliency Plan (CARP) identified emergent groundwater as a potential future hazard and recommended additional analyses to better characterize the shallow groundwater layer and the response of this layer to sea level rise. The shallow groundwater layer contains known contaminants, and areas with emergent groundwater could bring these contaminants to the surface. In areas with high contaminant concentrations, this may cause unacceptable exposure levels to humans, particularly impacting sensitive populations such as the elderly and younger children, as well as pets and wildlife. Known contaminated lands are also examined. Although many of these sites are in the process of cleanup efforts, rising groundwater could impact longer-term remediation plans.

This study uses monitoring well data collected for the California State Water Resources Control Board to develop an estimate of the existing shallow groundwater surface and to evaluate contaminants with potential concentrations above human health benchmarks. Analysis of long-term groundwater trends highlighted the response of the shallow groundwater surface to large precipitation events, with the surface rising by five feet or more during wet winters. To estimate how high the present-day groundwater surface could be in relation to the ground, the monitoring well data collected during wet winters (between the year 2000 and the present) were selected for analysis. In areas with limited monitoring well data, geotechnical reports containing soil boring logs collected during wet winters supplemented the well data. The response of the existing shallow groundwater surface to seven sea level rise scenarios (i.e., 12, 24, 36, 48, 52, 66, and 108 inches) was evaluated, and areas with emergent groundwater were mapped. The areas at risk of flooding increased by up to 25 percent when considering both threats, and some areas were flooded by emergent groundwater long before coastal floodwaters overtopped the shoreline, highlighting the importance of considering groundwater hazards in adaptation planning.

> *… and some areas flood by emergent groundwater long before coastal floodwaters overtop the shoreline…*

Areas with emergent groundwater and existing contaminant concentrations above human health benchmarks were identified as potential areas of concern. However, several contaminants show decreasing concentration trends; making it difficult to assess if the contaminants will remain a concern in the future. The U.S. Navy and the City of Alameda are undertaking significant remediation efforts related to legacy contamination associated with its industrial past, which may help further reduce the future level of contaminants in the shallow groundwater layer.

Emergent groundwater flooding is expected to have consequences for the City of Alameda and its residents. During wet winters, emergent groundwater flooding will likely be sporadic and localized. Initially, rising groundwater levels will affect below-grade infrastructure such as building foundations, basements, and utilities. Many structures throughout the city are already affected by groundwater, and sump pumps are commonly found in basements and below-grade structures. Over time, building foundations will be increasingly susceptible to scour and soil erosion resulting in foundation subsidence and structural damage. Basements and below-grade living spaces will become more prone to flooding. Storm sewer systems will experience more inflow and infiltration, reducing the conveyance capacity of the storm sewer system during rainfall events. All electrical utilities and electrical connections are at risk of flooding damage. Efforts to mitigate these impacts include sealing basements and below-grade structures from water intrusion, installing specialized systems to remove volatilized contaminants, and dewatering or pumping groundwater around structures.

> *… highlighting the importance of considering groundwater hazards in adaptation planning.*

Larger-scale mitigation and adaptation measures could include modifying lagoon operations to help reduce the groundwater surface, increasing stormwater pumping capabilities, and wetproofing below-grade utilities. In the longer-term, additional measures such as filling low-lying neighborhoods, raising structures, and managed retreat could be necessary to ameliorate the longer-term effects of sea level rise and an elevated shallow groundwater surface.

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ACRONYMS / ABBREVIATIONS

Acronym	Definition
Act	AB 599 Groundwater Quality Monitoring Act of 2001
AMP	Alameda Municipal Power
BFE	Base Flood Elevation
CARP	Climate Action and Resiliency Plan
DEM	Digital Elevation Model
DTSC	California Department of Toxic Substances Control
DTW	Depth to Water
EBMUD	East Bay Municipal Utility District
FEMA	Federal Emergency Management Agency
FISCA	Fleet Industrial Supply Center, Alameda
GAMA	Groundwater Ambient Monitoring and Assessment Program
HHB	Human Health Benchmark
MCL	Maximum Contaminant Level
MTBE	Methyl-tert-butyl alcohol
NL	Notification Level
PAH	Polynuclear aromatic hydrocarbon
PERC/PCE	Tetrachloroethene or Tetrachloroethylene
RWQCB	San Francisco Regional Water Quality Control Board
SLR	Sea Level Rise
SMCL	Secondary Maximum Contaminant Level
SWRCB	California State Water Resources Control Board
TBA	Tert-butyl alcohol
TCE	Trichloroethene or Trichloroethylene
USGS	United States Geological Survey
VOCs	Volatile Organic Compounds

1 Introduction

The response of the shallow groundwater layer to sea level rise is a critical data gap associated with sea level rise and climate change adaptation planning (Michael et al. 2017). Sea level rise poses a direct threat to developments in low-lying areas around San Francisco Bay (Bay) and several agencies have mapped sea level rise and coastal storm surge inundation throughout the San Francisco Bay Area's (Bay Area) nine counties. As sea levels rise, the surface of the shallow groundwater table will also rise. This can result in damage to buried infrastructure and cause inland flooding where the groundwater surface emerges above the existing ground. In areas where buildings and infrastructure are built on unconsolidated sediment placed over historic wetlands or mudflats (i.e., "Bay Fill"), the potential for liquefaction during a seismic event could also increase with a higher groundwater level. Although awareness of the threat of rising groundwater levels is increasing, few climate adaptation plans include strategies to address this threat; however, a failure to acknowledge and plan for this threat could undermine adaptation success. It could even result in costly adaptation failures when areas protected by levees are flooded by emergent groundwater, or when rising groundwater levels result in higher rates of inflow and infiltration into flood control channels and stormwater pipelines, as this could reduce the stormwater conveyance capacity during periods of heavy rainfall and also increase the likelihood of inland urban flooding.

This study assesses and maps the response of the shallow groundwater layer to sea level rise and seasonal rainfall events within the City of Alameda and the surrounding areas. The existing shallow groundwater surface was established using groundwater monitoring well data collected for the California State Water Resources Control Board (SWRCB), and soil boring data collected for recent (i.e., post 2000) geotechnical investigations. This shallow groundwater layer is hydrologically connected to the Bay and can rise and fall with the tides in nearshore areas. For consistency with the *Adapting to Rising Tides*[1] sea level rise mapping, the response of the shallow groundwater layer to seven sea level rise scenarios was considered: 12", 24", 36", 48", 52", 66", and 108" of sea level rise (Vandever et al. 2017). This study maps the areas where the groundwater could become emergent under each sea level rise scenario.

The shallow groundwater layer contains various contaminants from the city's industrial past and from more recent commercial and industrial land use (e.g., gas stations, dry cleaners, machine shops, etc.). These contaminants could pose future health risks to humans, pets, and wildlife once the groundwater becomes emergent, either above ground or within subterranean structures such as basements and below ground living or working spaces. Using the SWRCB groundwater monitoring data, nine contaminants found in the shallow groundwater layer within the City of Alameda were analyzed. Of these, six that occur with concentrations above human health benchmarks in the current day period (2015-Present) were mapped. This study presents a summary of the contaminants, the human health benchmark for each contaminant, and the average concentrations of each contaminant as monitored under existing conditions. Areas with both early emergent groundwater under future sea level rise scenarios and high concentrations of potential

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[1] The Adapting to Rising Tides program provides planning guidance, tools, and information to help agencies and organizations understand, communicate, and begin to address complex climate change issues. http://www.adaptingtorisingtides.org/

contaminants are identified areas of potential concern. However, remediation efforts have resulted in a decline in the concentrations of many contaminant found in the shallow groundwater layer. If current trends continue, the existing contaminants may decline below levels that pose potential health or environmental concerns long before the groundwater becomes emergent.

2 Existing Groundwater and Contaminant Data

The SWRCB and the local San Francisco Bay Regional Water Quality Control Board (RWQCB) have a mission to preserve, enhance, and restore the quality of California's water resources and drinking water for the protection of the environment and public health. In the Bay Area, their jurisdiction includes San Francisco Bay, its tributaries, and all groundwater resources, including the shallow groundwater layer. The SWRCB and RWQCB regulate discharges into these waters, as well as the cleanup of unplanned or illegal discharges that impact these waters. The groundwater and contaminant mapping relied on the data submitted to the SWRCB, as well as geotechnical reports provided by the City of Alameda and the Port of Oakland for the Oakland International Airport on Bay Farm Island.

The contamination mapping and analysis also relied on information from the California Department of Toxic Substances Control (DTSC), part of the California Environmental Protection Agency (EPA), with a mission of protecting public health and the environment from toxic harm. The DTSC regulates hazardous waste treatment and storage facilities as well the cleanup of unplanned hazardous waste spills and legacy contamination, as discussed in Section 2.6. For many sites, the regulatory authority for cleanup of may overlap between the SWRCB and DTSC. Small underground storage tanks, such as residential oil tanks which can be found underneath or adjacent to historic Alameda homes, fall under the jurisdiction of the local enforcement agency, the City of Alameda. These underground storage tanks were not considered in this assessment.

2.1 Groundwater Monitoring (Depth to Water)

SWRCB created a data management system for public and private well data called GeoTracker Groundwater Ambient Monitoring and Assessment Program (GAMA) (SWRCB 2019) in response to the Groundwater Quality Monitoring Act (Act) of 2001 (AB 599 2001, Belitz et al. 2003). The Act identifies the importance of maintaining and monitoring groundwater supplies in the state. In support of this Act, thousands of groundwater monitoring wells are located throughout the Bay Area, typically near potential water quality hazards such as underground storage tanks containing hazardous chemicals (e.g., gas stations), facilities where hazardous chemicals are used or stored (e.g., dry cleaners, manufacturing industries), or locations of previous known spills (see Figure 2.1). The SWRCB and RWQCB oversee the remediation and monitoring of these sites.

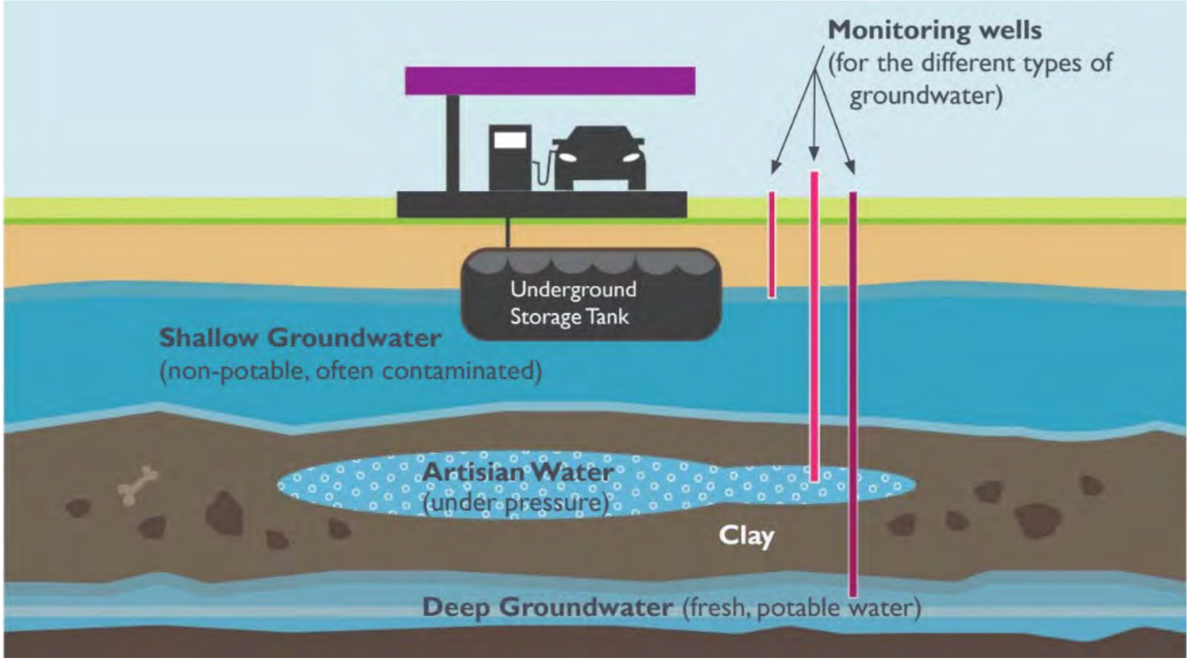

Figure 2.1 Groundwater Monitoring Wells

Regular monitoring observations of each active well include the depth to groundwater, relevant contaminant concentrations, and other factors based on a facility's permit requirements. In many cases, monitoring wells are sampled multiple times a year, providing an extensive data set to monitor changes in the groundwater elevation and water quality. Observation data from over 270,000 individual wells throughout the State are included in the GAMA database. Within the City of Alameda there are 144 individual well locations[2] (see Figure 2.2). 695 additional wells located nearby in Oakland, San Leandro, and within the Oakland International Airport, were also used to analyze the shallow groundwater layer within the City of Alameda.

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[2] Each contaminated site often includes multiple wells to better characterize the concentration and movement of contaminants; therefore, it may be difficult to identify 144 individual well locations at the scale of the map presented in Figure 2.2.

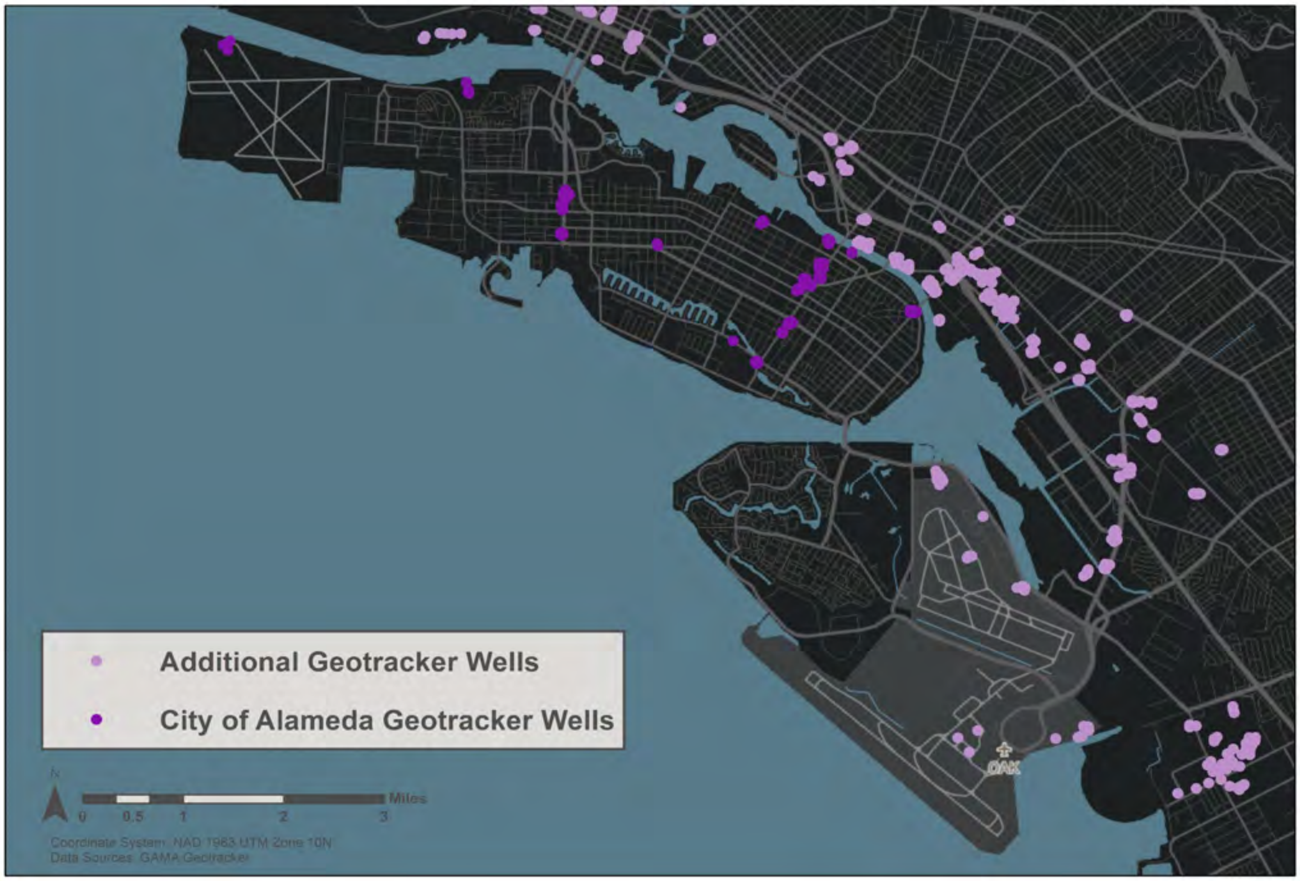
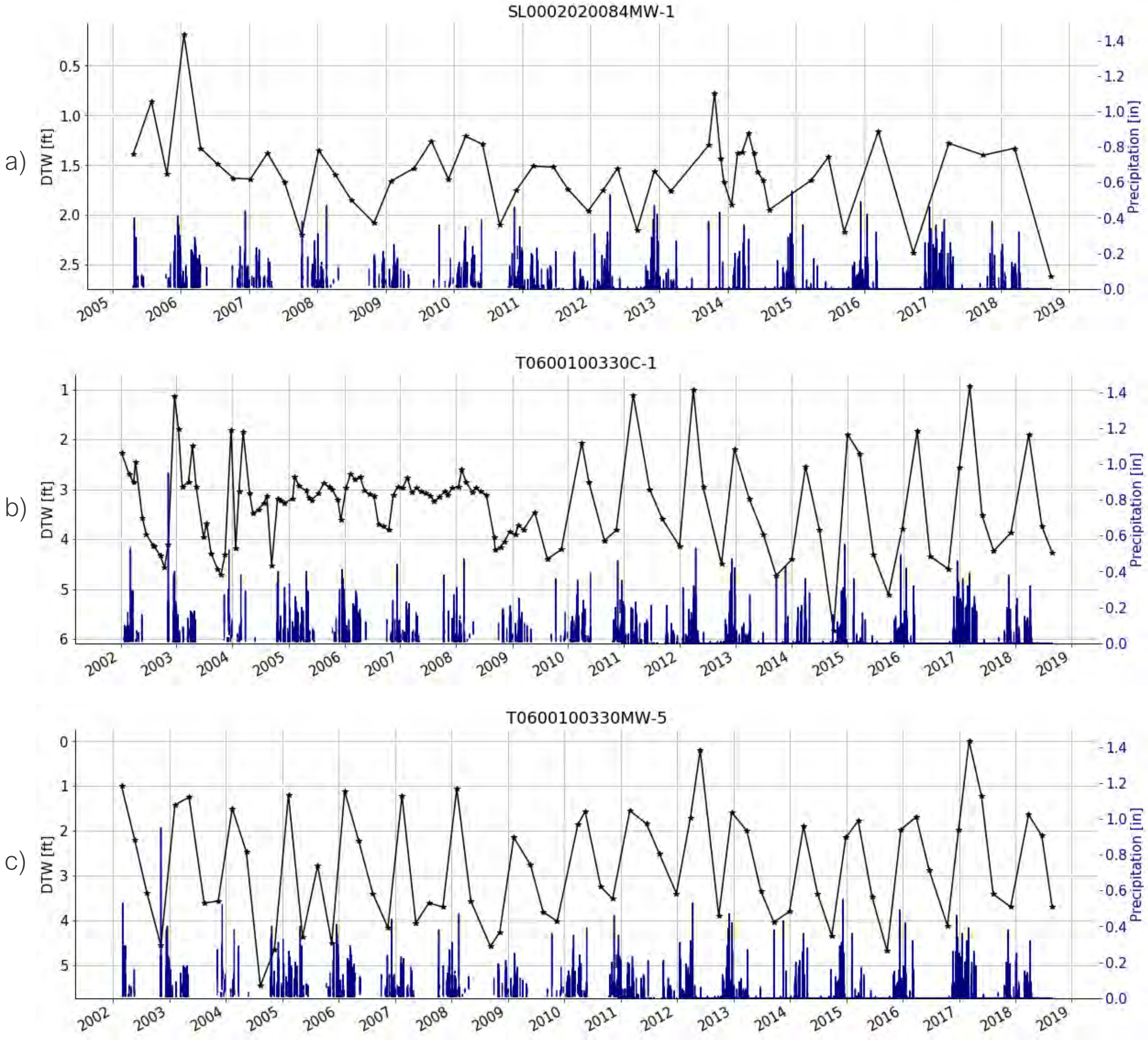


Figure 2.2 Groundwater Monitoring Well Locations

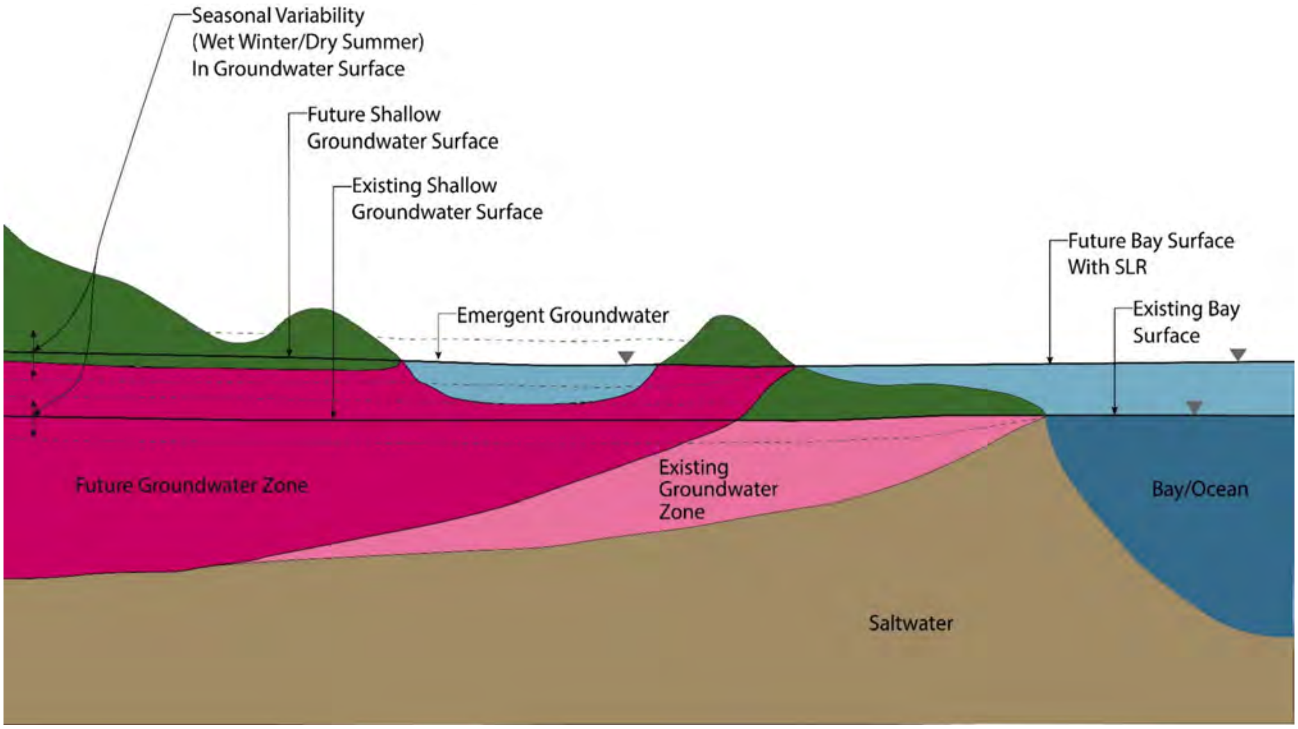
Groundwater is simply water found underground in the soil, either in the pores between soil particles or in crevices in rock. The groundwater layers found in the Bay Area are complex, with multiple porous layers of soil separated by more impervious layers. The clay areas limit the movement of groundwater from one layer to the other. The shallow unconfined aquifer (i.e., shallow groundwater layer) that lies closest to the ground surface is of interest for this assessment. This shallow groundwater layer is hydrologically connected to the Bay in nearshore areas and can rise and fall with the tides. The groundwater level can also rise rapidly in response to precipitation events as stormwater infiltrates through the ground and saturates the soils (see Figure 2.3). The shallow groundwater is at its highest level (i.e., closest to the ground surface) either during, or shortly after, large precipitation events, which usually occur during the winter. The groundwater then slowly falls to its lowest level (i.e., deeper below the ground surface) during the dry summer months when rainfall is scarce.



a) Doolittle Drive on Bay Farm Island, b) High Street and Gibbons Drive, c) High Street and Gibbons Drive

Figure 2.3 Shallow Groundwater Table Response to Precipitation

Because this layer is unconfined at its top, it can emerge above the surface of the ground and create surface flooding. To differentiate this flooding source from other flooding sources (e.g., coastal, riverine, urban stormwater), this is referred to as “emergent groundwater flooding”. At present, emergent groundwater flooding is not a serious concern for the City of Alameda, apart from groundwater seepage into basements and other subterranean areas. However, as sea level rise causes Bay water levels to rise, the surface of the hydrologically connected shallow groundwater layer will also rise (see Figure 2.4).



Source: Mohan et al. 2019

Figure 2.4 Shallow Groundwater Surface Response to Sea Level Rise

In contrast, the deeper groundwater aquifer generally does not have a direct hydrological connection to the Bay, and the groundwater surface fluctuates more slowly in response to longer-term patterns. The deeper groundwater aquifer often contains potable water (i.e., suitable as a drinking water source).

A third type of aquifer can also be found throughout the Bay Area – artesian aquifers. Artesian aquifers are confined and under positive pressure. A well drilled into an artesian aquifer is called an artesian well, and the water level in the well will often rise above the ground surface due to the pressure in the aquifer.

2.2 Geotechnical Soil Boring Data

Although the SWRCB GAMA data provides information on 144 wells across Alameda, the well data is limited to areas where contaminants are most likely present. Several areas have limited well coverage, including areas on the Main Island and Bay Farm Island that are primarily residential. To fill these data gap areas, 51 recent geotechnical reports (i.e., completed post 2000) were reviewed to identify soil borings with depth to water information. The reports were provided by the City of Alameda and the Port of Oakland for the Oakland International Airport on Bay Farm Island (see Section 7.2). The geotechnical reports were originally prepared to support construction and infrastructure projects. In total, the reports include data for 115 soil boring logs in the data gap areas. This information was not available in digital format, and the soil boring locations were hand digitized in ArcGIS as part of this study. Figure 2.5 presents the soil boring locations that were combined with the SWRCB GAMA data to better define the existing shallow groundwater layer surface.

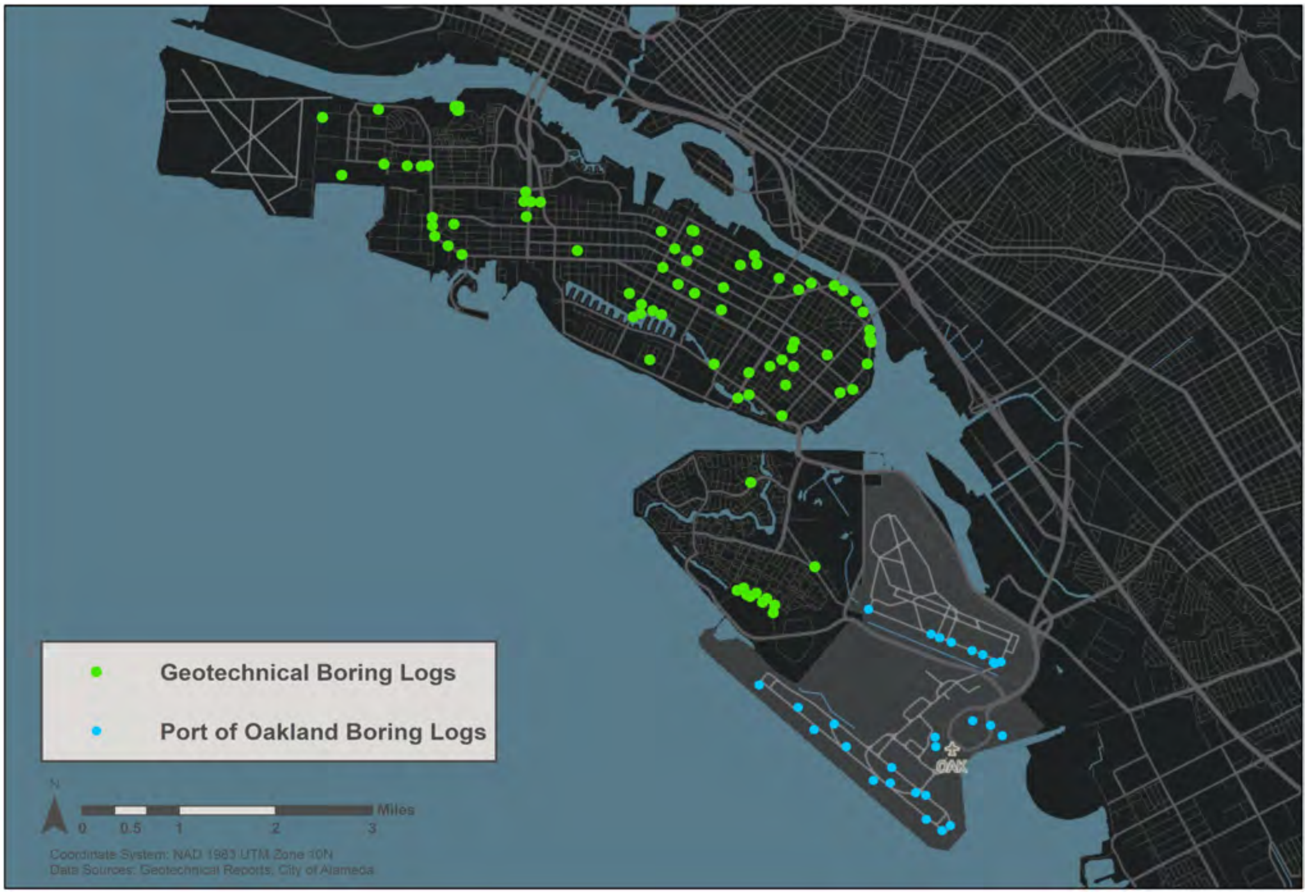


Figure 2.5 Location of Soil Boring Logs

Several of the geotechnical reports reference and include information on historical soil borings from the same general location. This allowed for a comparison of groundwater levels over many years and seasons. However, only depth to water measurements collected post 2000 were used in the analysis. In general, the geotechnical reports consistently note that groundwater levels in the City of Alameda fluctuate with seasonal precipitation and Bay tides.

2.3 Groundwater Monitoring (Contaminants)

The SWRCB GAMA data includes measurements of known chemicals and contaminants at each well (SWRCB 2019). Within California, more than 260 different chemicals are measured and monitored. These include both contaminants with known human health impacts and emerging contaminants. The groundwater samples collected at each well are analyzed by an accredited environmental laboratory for commonly observed chemical constituents such as bacteria (total and fecal coliform), inorganic constituents (metals, major anions and general minerals), volatile organic compounds (VOCs), and trace elements. Test results are compared against three public drinking water standards established by the California Department of Public Health: primary maximum contaminant levels (MCLs), secondary maximum contaminant levels (SMCLs), and notification levels (NLs) (Bennett 2018). These water quality standards are used for comparison purposes only. The water in the shallow groundwater layer is often brackish and not suitable as a drinking water source (i.e., non-potable). When contaminant concentrations exceed human health benchmarks, remediation efforts are generally required and overseen by the SWRCB, RWQCB, the local enforcement agency, or the DTSC.

The top ten contaminants monitored in California are shown in Table 2.1. Seven of the ten contaminants have been monitored in the City of Alameda; however, two contaminants have limited monitoring information available (e.g., 1,2,3-trichloropropane and chromium, hexavalent), and two contaminants do not pose a significant human health risk if present in emergent groundwater (e.g., nitrate and total dissolved solids). Therefore, only three of the top ten contaminants were assessed for this study (e.g., arsenic, tetrachloroethene, and trichloroethene). Table 2.1 presents additional information related to the top 10 contaminants relative to Alameda, including the benchmark concentration, maximum concentration measured, and notes relative to specific contaminant's inclusion or exclusion from the analysis.

Table 2.1 Top 10 Contaminants Monitored in California Groundwater

Contaminant	Monitored in Alameda?	Included in Analysis?	Benchmark Concentration	Maximum Concentration post 2000	Notes
1,2,3-Trichloropropane	Yes	No	0.005 µg/l	6.4 µg/l (10/24/2013)	Measured one time at 4 wells in Alameda in 2013 (between Pacific Avenue and Buena Vista Avenue on Park Street). Insufficient data is available for inclusion in this study.
1,2-Dibromo-3-chloropropane	No	No	0.2 µg/l	N/A	N/A
Arsenic	Yes	No	10 µg/l	120 µg/l (8/25/2003)	Concentrations measured at 25 wells in Alameda. Historic high measurement of 120 µg/l recorded in 2003. Ten wells monitored in 2013 with only 3 wells exceeding the benchmark. No Arsenic measurements were recorded at any well locations after 2013.
Chromium, Hexavalent (Cr6)	Yes	No	20 µg/l	58 µg/l (10/3/2014)	Concentrations measured at 33 wells in Alameda. Historic high measurement of 58 µg/l recorded in 2014 near Buena Vista Avenue and Park Street. No Cr6 measurements were recorded at any well locations after 2014.
Nitrate	Yes	No	10 mg/l	221 mg/l (8/29/2019)	Concentrations measured at 52 wells in Alameda. Historic high measurement of 221 mg/l recorded in 2019 near Santa Clara Avenue and Oak Street. Such concentration levels present an ecological toxicity risk. Infants exposed

Contaminant	Monitored in Alameda?	Included in Analysis?	Benchmark Concentration	Maximum Concentration post 2000	Notes
					to high nitrate levels could experience methemoglobinemia.
Perchlorate	No	No	6 µg/l	N/A	N/A
Tetrachloroethene	Yes	Yes	5 µg/l	7700 µg/l (3/3/2005)	Concentrations measured at 95 wells in Alameda. Historic high measurement of 7700 µg/l recorded between Chestnut Street and Stanford Street off Clement Avenue in 2005. The highest measured concentration in the past 3 years was 730 µg/l (3/7/2019).
Total Dissolved Solids	Yes	No	1000 mg/l	2206 mg/l (8/26/2003)	Concentrations were measured once at 22 wells located near Santa Clara Avenue and Oak Street in 2007, and near Oak Street and Clement Avenue in 2003. Insufficient data is available for inclusion in this study. Total dissolved solids do not pose a health risk if present in emergent groundwater.
Trichloroethene	Yes	Yes	5 µg/l	570 µg/l (10/3/2014)	Concentrations measured at 140 wells in Alameda. Historic high measurement of 570 µg/l recorded at 2 wells near Buena Vista Avenue and Park Street in 2014.
Uranium	No	No	20 pCi/l	N/A	N/A

Source: Groundwater Ambient Monitoring and Assessment Program (SWRCB 2019)

After reviewing all contaminants monitored within the City of Alameda, eight additional contaminants with known human health impacts were selected for analysis (See Table 2.2 and Appendix A). Table 2.2 includes the additional contaminants and the three contaminants selected from Table 2.1, organized by contaminant type. The contaminants were selected because more than 25 percent of the wells tested positive for the contaminant (between 2000 and 2019) and average concentrations were above human health benchmarks (HHB), the level at which a contaminant is known to cause adverse health impacts.

Table 2.2 Groundwater Contaminants in Alameda

Type	Contaminant	Health Benchmark	Value/Unit	Monitoring Period
Inorganic Constituents	Iron	SMCL	300 µg/L	2002-2019
Volatile Organic Compounds	Benzene	MCL	1 µg/L	2001-2019
	Methyl tert-butyl ether (MTBE)	MCL	13 µg/L	2001-2019
	Tert- butyl alcohol (TBA)	NL	12 µg/L	2001-2019
	Toluene	MCL	150 µg/L	2001-2019
	Trichloroethene (TCE)	MCL	5 µg/L	2001-2019
	Tetrachloroethene (PERC/PCE)	MCL	5 µg/L	2001-2019
Trace Elements	Arsenic	MCL	10 mg/L	2003-2013
	Chromium	MCL	50 µg/L	2010-2013
	Lead	NL	15 µg/L	2005-2010
	Manganese	SMCL	50 µg/L	2001-2019

Source: Groundwater Ambient Monitoring and Assessment Program (SWRCB 2019)

2.3.1 Inorganic Constituents

The only inorganic constituent analyzed is iron. Iron is a heavy metal that can accumulate in the body. Iron is an essential nutrient, but when there is too much iron in the body, this can disrupt normal body functions and negatively impact the liver, heart, and brain (Jaishankar et al. 2014). The highest concentrations of iron were found near Oak Street and Santa Clara Avenue (400,000 µg/l on 9/22/2007) and Park Street and Buena Vista Avenue (370,000 µg/l on 6/19/2014).

2.3.2 Volatile Organic Compounds

VOCs are organic chemicals that have many adverse human health impacts when present in drinking water and when mobilized in the environment (Rowe et al. 2007). Remediation to remove VOCs from an environment includes installing systems for soil vapor extraction and air sparging[3] to vent air with potentially high VOC concentrations away from locations where human exposure is likely (McCann et al. 1994). When found in groundwater, these compounds can seep through cracks in foundations and accumulate in the air within an enclosed structure, such as a basement or home.

The VOCs analyzed in this study include benzene, methyl tert-butyl ether (MTBE), tert-butyl alcohol (TBA), toluene, trichloroethene (TCE) and tetrachloroethene (PERC/PCE)[4].

Benzene is commonly found near gas stations and automobile repair shops. Most people are regularly exposed to small doses. However, in high concentrations it can become fatal, and repeated exposure to benzene in the air can cause leukemia and pediatric cancers (Smith 2010). Figure 2.6 presents monitored benzene concentrations at three locations where high concentrations were measured post 2000. Figure 2.6a shows concentrations measured near Oak Street and Santa Clara Avenue, with peak values in 2018. Figure 2.6b shows concentrations measured near Park Street and Buena Vista Ave, and Figure 2.6c shows concentrations measured near High Street and Fernside Avenue. Figure 2.6b and Figure 2.6c have peak concentrations measured before 2010, with lower concentrations in the present. Both figures also highlight that measured concentrations decrease during wet winters when rain infiltration can dilute the concentrations found in the shallow groundwater layer. The concentration of benzene increases over the drier summer months. Many contaminants are monitored in both the wet winter months (Jan-Feb-Mar) and the dry summer months (Jul-Aug-Sep) to account for this seasonal variation. At most well locations in Alameda, concentrations of benzene have decreased over historical high values (see Appendix A, Table A.7.1).

MTBE has a distinctive odor and is used as a fuel additive. MTBE has relatively short-term and minor health impacts (e.g., dizziness, nausea, skin irritation), but chronic and long-term exposure can impact the central nervous system, liver and kidneys (ATSDR 1996, EPA 2000a, Baehr et al. 2001). Figure 2.7 presents monitored MTBE concentrations at two locations where high concentrations were measured post 2000. Figure 2.7a shows concentrations measured near Park Street and Buena Vista Ave, and Figure 2.7b shows concentrations measured near Webster Street and Pacific Avenue. Concentrations show peak values prior to 2010, with decreasing concentrations in the present. In general, MTBE concentrations appear to have declined over historic high values (see Appendix A, Table A.7.2). MTBE is often persistent in groundwater (Peckhenham 2010).

TBA is highly mobile in soil due to its low affinity for soil organic matter and has the potential to persist in groundwater and soil. TBA is a metabolite of MTBE and has been shown to impact kidney and thyroid functions (EPA 2016). Figure 2.8 presents monitored TBA concentrations at two locations where high concentrations have been measured post 2000. Figure 2.8a shows concentrations measured near Park

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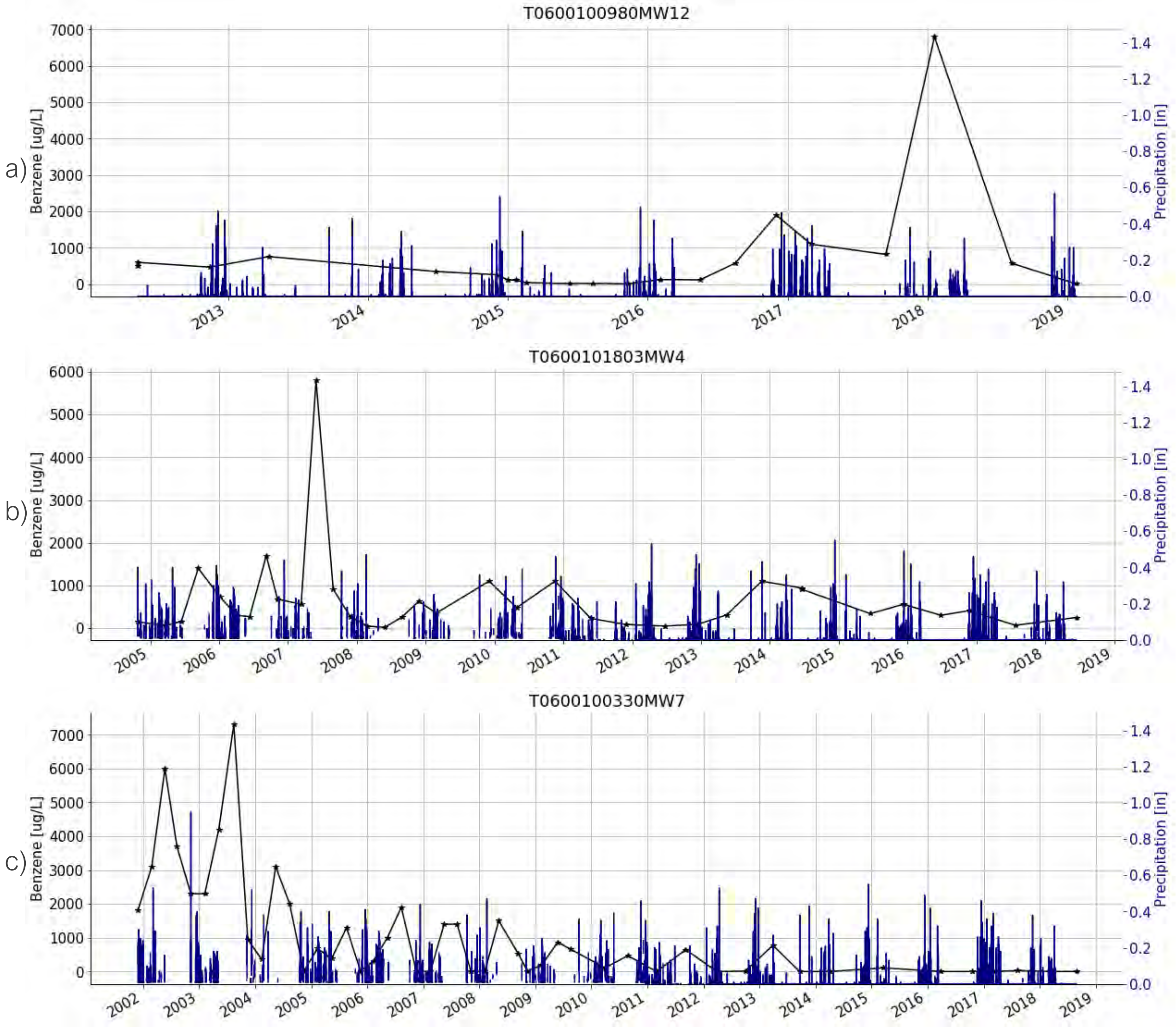
[3] Air sparging is a technique to remediate contaminated soils by forcing air through the soil column and venting through a soil vapor extraction system to capture and vent contaminant (VOC) laden air as it rises to the unsaturated soil zone (McCann et al. 1994, Braida and Ong 2000, Reddy and Tekola 2004).

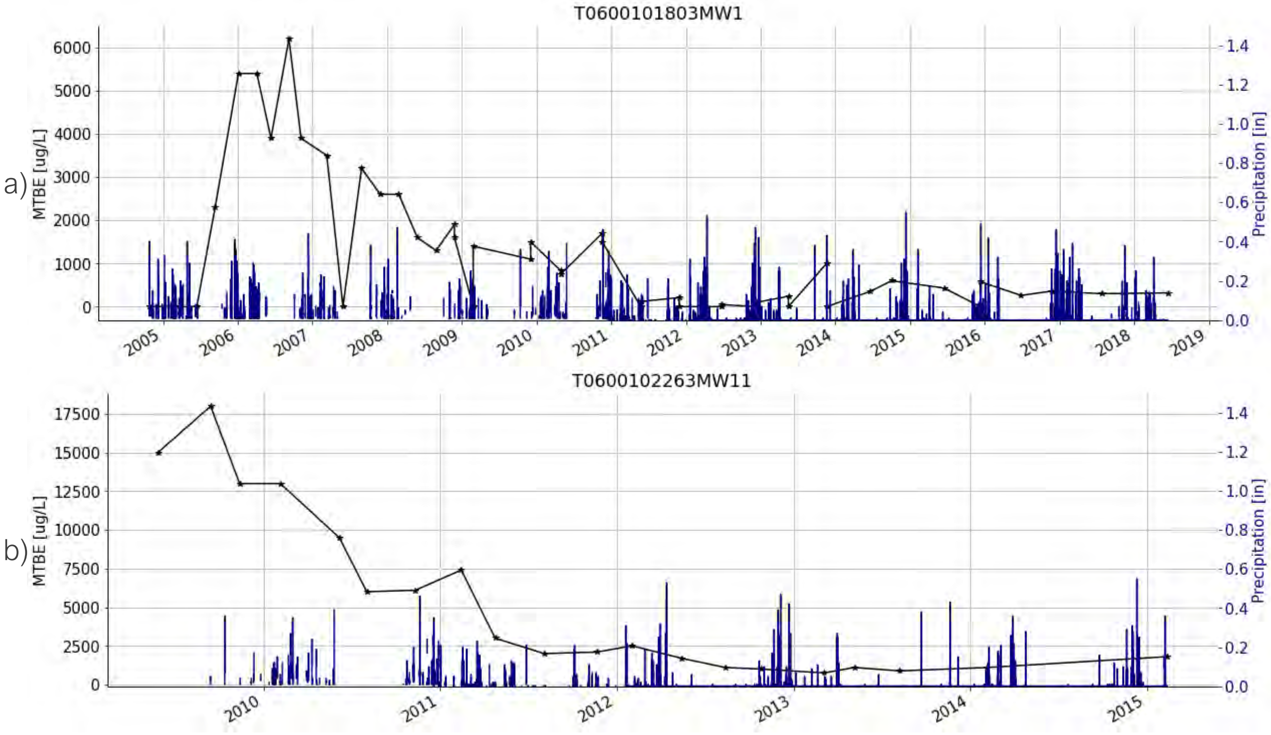
[4] TCE can refer to both trichloroethene and trichlorethylene, and PERC/PCE can refer to both tetrachloroethene and trichloroethylene

Street and Buena Vista Ave, and Figure 2.8b shows concentrations measured near Webster Street and Pacific Avenue.



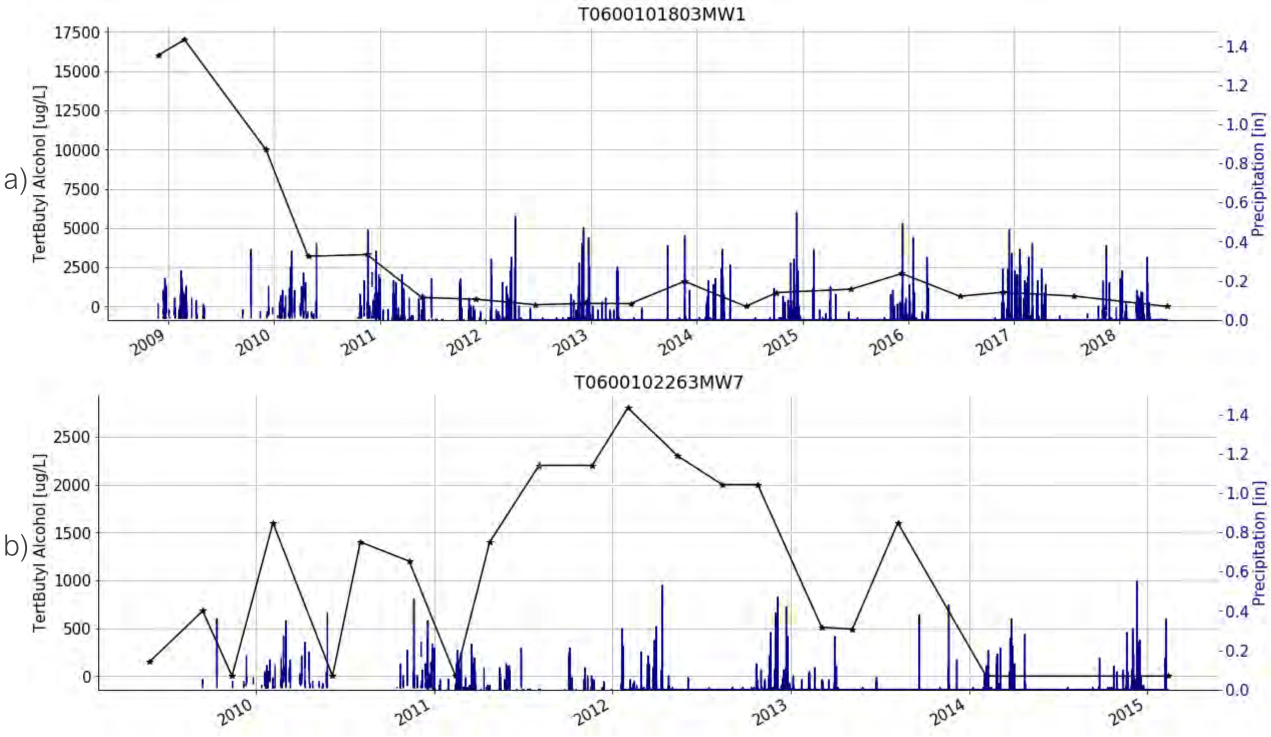
a) Oak Street and Santa Clara Ave, b) Park Street and Buena Vista Ave, c) High Street and Fernside Ave

Figure 2.6 Monitored Benzene Concentrations



a) Park Street and Buena Vista Ave, b) Webster Street and Pacific Avenue

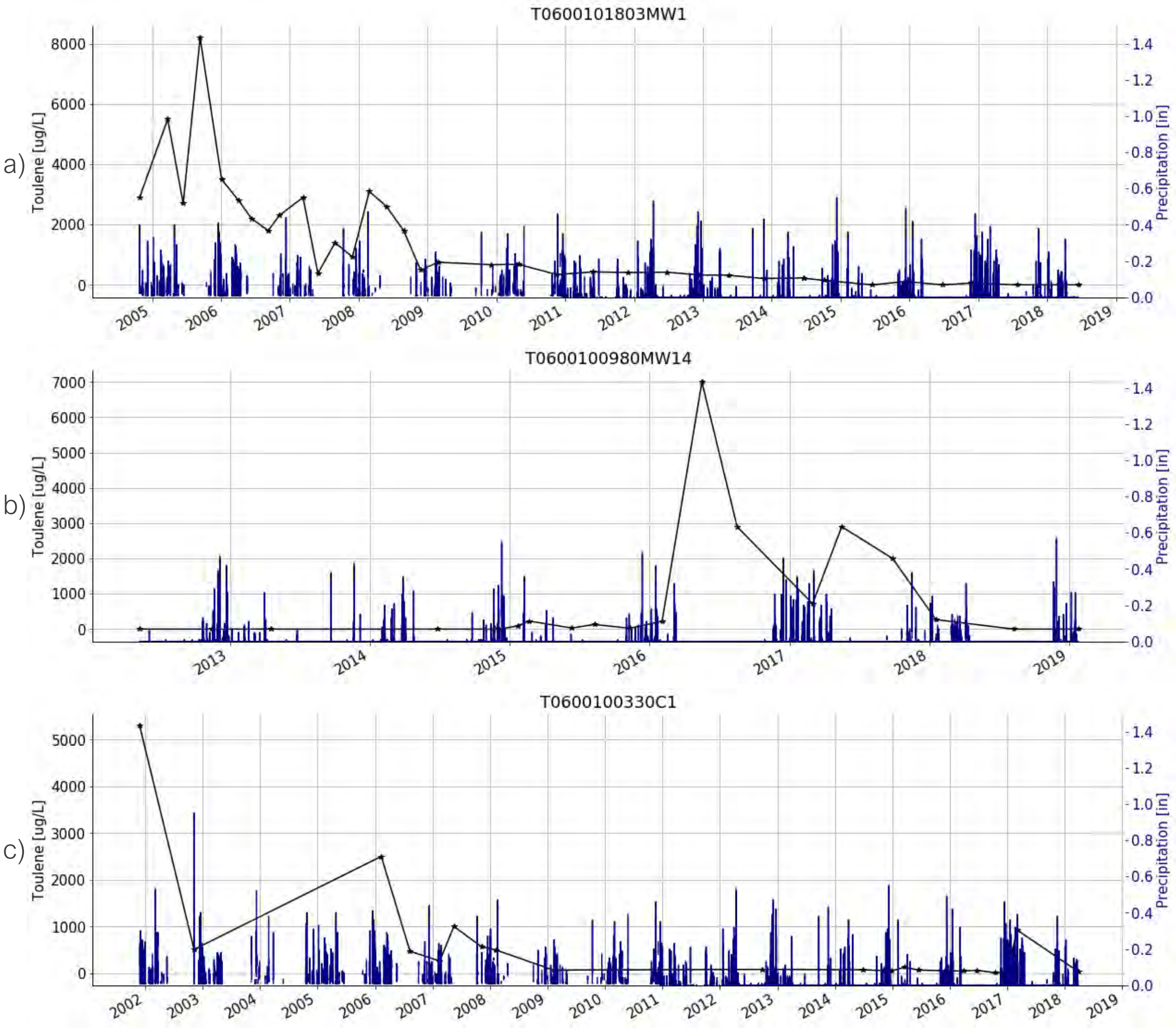
Figure 2.7 Monitored MTBE Concentrations



a) Park Street and Buena Vista Ave, b) Webster Street and Pacific Avenue

Figure 2.8 Monitored TBA Concentrations

Toluene is a common solvent used in the production of benzene, paint thinners and other chemicals. Toluene is commonly found in air samples throughout the United States. It breaks down quickly in the soil and the air, but it can become problematic when it concentrates in indoor environments. Exposure to high concentrations of toluene can have temporary impacts on the nervous system; however, repeated exposure can cause permanent cognitive impairment, as well as vision and hearing loss (EPA 2005, ATSDR 2015). Figure 2.9 presents monitored toluene concentrations at two locations where high concentrations were measured post 2000. Figure 2.9a and Figure 2.9b present concentrations measured near Park Street and Buena Vista Ave. Although both wells are located within the same block, the timing of the peak concentrations varies significantly. Figure 2.9c presents concentrations measured near High Street and Gibbons Drive. Concentrations at all three locations have decreased in recent years.



a) Park Street and Buena Vista Ave, b) Park Street and Buena Vista Ave, c) High Street and Gibbons Drive

Figure 2.9 Monitored Toluene Concentrations

TCE is a stable, colorless liquid with a chloroform-like odor. It was used in dry-cleaning prior to 1950 and is also used for degreasing metals. TCE is found in adhesives, paint-stripping formulations, paints, lacquers, and varnishes. Its use was discontinued in cosmetics, drugs, foods, and pesticides. TCE poses a potential human health hazard for toxicity to the central nervous system, kidney, liver, immune system, male reproductive system, and the developing fetus (EPA 2011). There is strong evidence that TCE can cause kidney cancer, and some evidence that it causes liver cancer and malignant lymphoma (a blood cancer). Relatively short-term exposure of animals to TCE can result in harmful effects on the nervous system, liver, respiratory system, kidneys, blood, immune system, heart, and body weight. In subsurface environments, TCE degrades slowly and may be relatively persistent. The maximum concentration of TCE was found near Buena Vista Avenue and Park Street (570 µg/l on 10/3/2014). Only six wells have measured TCE concentrations exceeding human health benchmarks in the past three years; four wells near Buena Vista Avenue and Park Street, and two wells near Chestnut Street and Clement Avenue.

PERC/PCE is widely used for dry-cleaning fabrics and metal degreasing operations. Acute (short-term) high-level exposure can cause irritation of the upper respiratory tract and eyes, kidney dysfunction, and neurological effects such as reversible mood and behavioral changes, impaired coordination, dizziness, headache, sleepiness, and unconsciousness. Chronic (long-term) exposure can cause neurological impacts, including impaired cognitive and motor neurobehavioral performance. PERC/PCE exposure may also cause adverse effects in the kidney, liver, immune system, and hematologic system, and on development and reproduction. Studies of people exposed in the workplace have found associations with several types of cancer including bladder cancer, non-Hodgkin lymphoma, and multiple myeloma. PERC/PCE is classified as likely carcinogenic to humans (EPA 2000b, Peckhenham 2010). The maximum concentration of PERC/PCE was found near Chestnut Street and Clement Avenue (7,700 µg/l on 3/3/2015). Only six wells have measured PERC/PCE concentrations exceeding human health benchmarks in the past three years; four wells near Buena Vista Avenue and Park Street, and two wells near Chestnut Street and Clement Avenue.

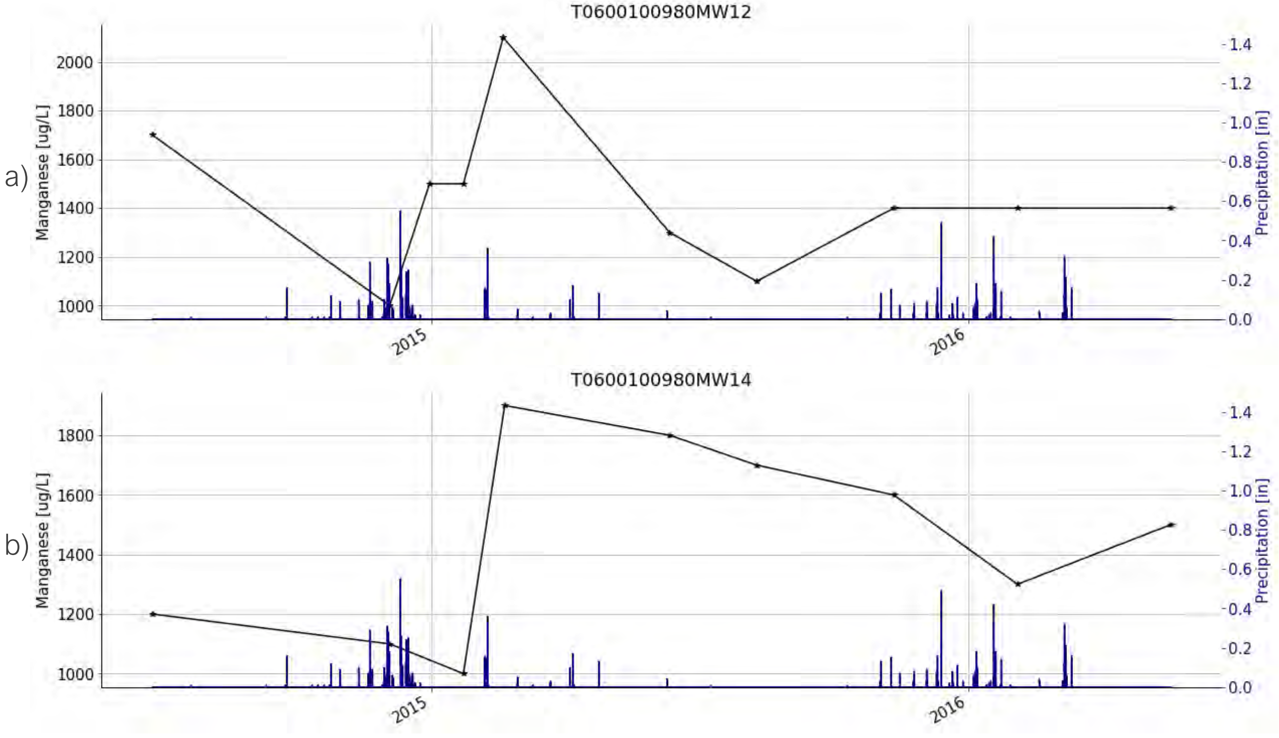
2.3.3 Trace Elements

The trace elements found in the City of Alameda include arsenic, chromium, lead, and manganese. An excess of arsenic can cause cardiovascular impacts and lead to hypertension, fatigue, and increased cancer risk; these risks are higher for children who live near contaminated sites (ATSDR 2007, Ngole-Jeme and Fantke 2017). Long-term exposure by children can result in reduced IQ scores. In areas where exposure is a concern, dense groundcover (e.g., thick lawn) and dust control (e.g., air filters, cleaning) can reduce exposure to contaminated soil (ATSDR 2007, Wuana and Okieimen 2011, Ngole-Jeme and Fantke 2017). Limited arsenic monitoring was completed within the City of Alameda, and no monitoring occurred after 2013.

Chromium strongly attaches to soil and is generally contained within the silt layer surrounding contaminated areas. Chromium is not classified as a carcinogen and is relatively unregulated. However, chromium at high concentrations is considered toxic. While chromium-3 is essential for human vascular and metabolic systems and treating diabetes, too much chromium-3 can result in severe skin rash, or other more serious symptoms. Other chromium compounds (e.g., Cr-6, monitored separately, see Table 2.1) are deemed carcinogenic and have health impacts similar to arsenic and other trace elements (ATSDR 2012, Wuana and Okieimen 2011, Ngole-Jeme and Fantke 2017). Although concentrations of chromium (Cr-6) that exceed human health benchmarks (50ug/L in California) were measured in Alameda, particularly near gas stations and automobile mechanic shops, no monitoring of chromium occurred after 2015.

Lead poisoning is particularly problematic for children as it can impair development, shorten attention spans, and cause mental deterioration. Lead exposure can impact many bodily systems including brain function, the nervous system, and kidney function. The most serious exposure can come from eating contaminated soil. Common heavy metal soil remediation techniques include capping, immobilization, and soil-washing. These techniques vary in cost and environmental impact (Wuana and Okieimen 2011). The highest concentration of lead was found between Eagle and Clement Avenues, and Oak Street and Park Street. No monitoring of lead has occurred after 2015.

Manganese exposure generally comes in the form of concentrated air in occupational environments (e.g. in steel production) and, if excessive, can cause a disease with Parkinson-like symptoms (Dobson et al. 2004, ATSDR 2008). Manganese is also an additive in unleaded gasoline to boost octane ratings. High concentrations of manganese were measured near Oak Street and Santa Clara Avenue in 2015 (see Figure 2.10).

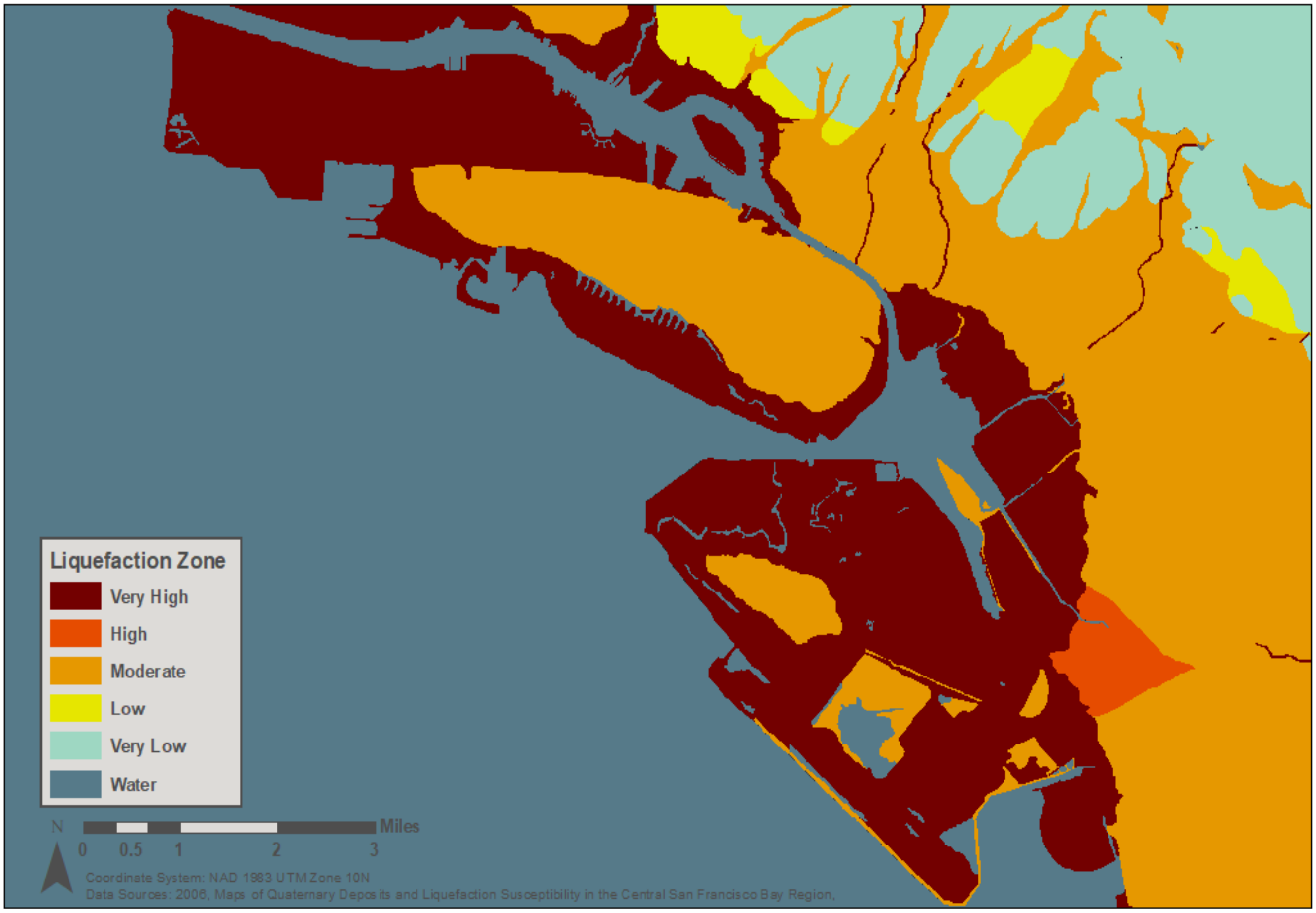


a) Oak Street and Santa Clara Avenue, b) Oak Street and Santa Clara Avenue

Figure 2.10 Monitored Manganese Concentrations

2.4 Bay Fill

Many areas along the Bay's shoreline, including the Main Alameda Island (i.e., Main Island) and Bay Farm Island, are built on fill that expanded the amount of developable land. Existing swamps, oyster farms, marshlands, and mudflats were filled using dredged material and other soils composed of a mixture of sand, gravel, and clayey materials. Construction debris and rubble from the 1906 earthquake were also used as fill material. This unconsolidated material of varying thickness comprises the majority of Bay Farm Island and much of the Main Island shoreline. Many of these areas experience subsidence, due to being built on fill of mixed quality, and due to the high shallow groundwater table elevation. These soils are all within a liquefaction zone (see Figure 2.11). A liquefaction zone is an area with soils that are at a very high risk of liquefying during an earthquake. When these soils are exposed to violent shaking during an earthquake, the groundwater and fill mix together and essentially turn into a liquid like quicksand that cannot support structures, compromising building foundations and structures that are not adequately anchored to the bedrock beneath the Bay fill. Rising groundwater levels may increase liquefaction risks, and this is a current topic of expanding scientific research. The City of Alameda is also within a high hazard seismic risk area (see Figure 2.12). The city is close to several fault lines and the probability of experiencing severe shaking is high.



Source: Witter et al. 2006

Figure 2.11 Liquefaction Zones

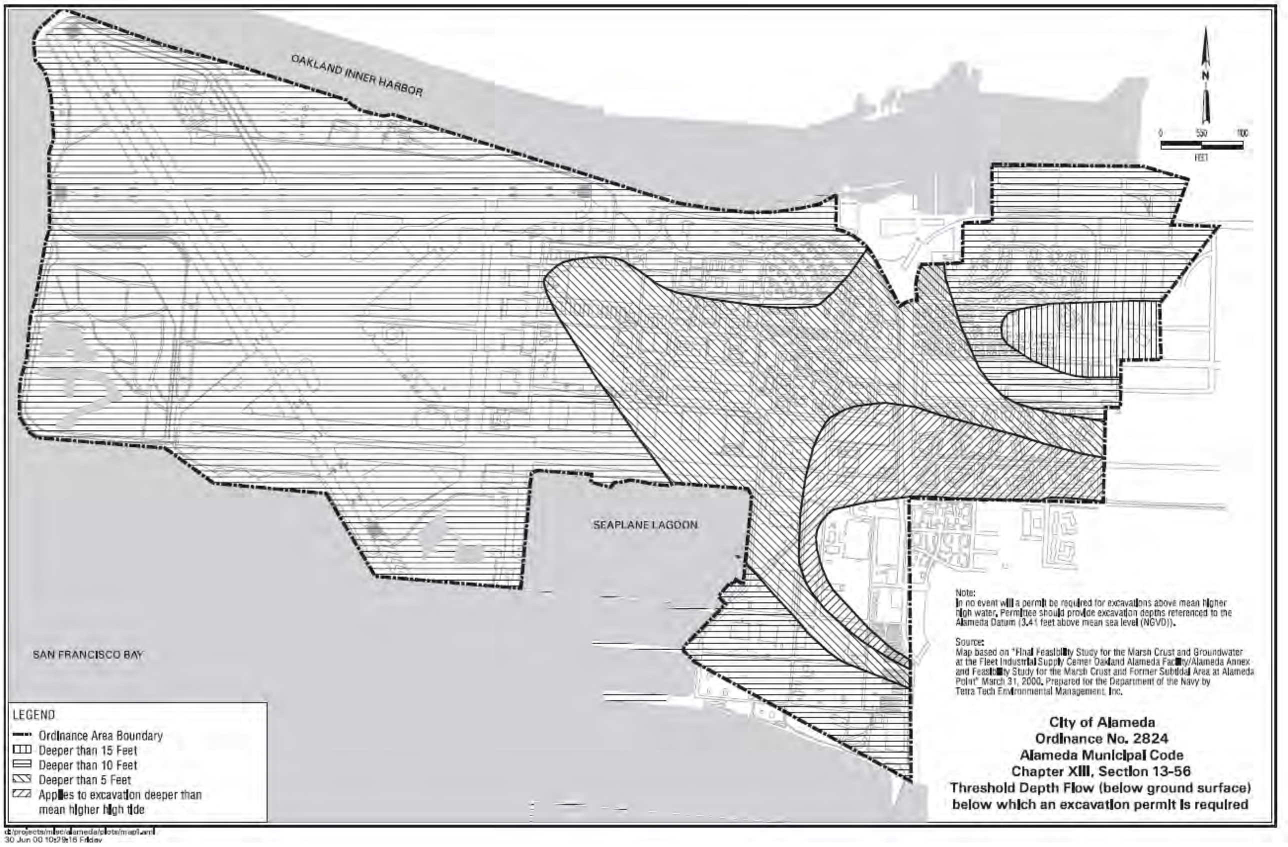
Source: Holzer et al. 2005

Figure 2.12 Seismic Hazard Zones, Modified Mercalli Intensity Scale

2.5 Marsh Crust

Oil refineries and manufactured gas plants operated in Alameda between 1887 and the 1920s. The adjacent marshlands are believed to have been contaminated by direct releases of petroleum products and wastes from these facilities (Tetra Tech 2000). The contaminated marshlands were essentially encapsulated by the placement of dredged fill material to create developable land between the late 1800s and 1975 (Tetra Tech 2000). Soil borings collected in the areas currently known as Alameda Point, Bayport, Alameda Landing, Admiral's Cove, and Coast Guard Housing contained a thin layer of contamination between the buried marshlands and the fill material (Tetra Tech 2000). This layer of contamination is commonly known as the marsh crust, and investigations completed to date have noted the presence of this contaminated layer over a geographic area that exceeds 700 acres (see Figure 2.13).

This marsh crust contains elevated levels of petroleum-related substances (e.g., high concentrations of SVOCs and total petroleum hydrocarbons (Tetra Tech 2000)), which may pose an unacceptable human health risk if excavated and brought to the surface. The marsh crust is located 4 to 15 feet below the existing ground surface today (ERM 2009). The Remedial Action Plan/Record of Decision for the marsh crust selected institutional controls as the remedy. These controls include environmental restrictions via deeds, a Covenant to Restrict Use of Property, and the City's Ordinance Number 2824 (Marsh Crust Ordinance). The controls prohibit the excavation and disturbance of the marsh crust without proper control to prevent potential adverse health and environmental consequences. Excavation requires a permit when proposed below defined threshold depths, and the threshold depth is defined as a depth 5 feet shallower (i.e., above) the actual depth at which marsh crust might be encountered (ERM 2009).



Note:
In no event will a permit be required for excavations above mean higher high water. Permittee should provide excavation depths referenced to the Alameda Datum (3.41 feet above mean sea level (NGVD)).

Source:
Map based on "Final Feasibility Study for the Marsh Crust and Groundwater at the Fleet Industrial Supply Center Oakland Alameda Facility/Alameda Annex and Feasibility Study for the Marsh Crust and Former Subtidal Area at Alameda Point" March 31, 2000. Prepared for the Department of the Navy by Tetra Tech Environmental Management, Inc.

City of Alameda
Ordinance No. 2824
Alameda Municipal Code
Chapter XIII, Section 13-56
Threshold Depth Flow (below ground surface)
below which an excavation permit is required

Source: Tetra Tech 2000

Figure 2.13 Marsh Crust Map for Alameda Point

2.6 Contaminated Lands

Both the SWRCB and DTSC are responsible for overseeing the evaluation and cleanup of contaminated lands, and both agencies maintain databases of contaminated lands that includes the status of cleanup efforts, remediation method(s) used for cleanup, contaminants present, and the past or current land use that led to the contamination. DTSC also tracks potentially contaminated sites where further investigation is required to assess if cleanup is needed.

The City of Alameda has multiple known contaminated sites under the jurisdiction of the SWRCB or DTSC, including historic sites for which cleanup and monitoring activities have been completed[5] (see Figure 2.14 and Table 2.3). The previous land uses that caused contamination are primarily industrial and manufacturing operations, including former military land use. The contaminants found include VOCs, benzene, lead, naphthalene and other polynuclear aromatic hydrocarbons (PAHs), and many others.

Although continued monitoring and reporting to the RWQCB for the Doolittle Landfill (also known as *Mount Trashmore*) on Bay Farm Island is no longer required, it was included as a contaminated site since it contains potential legacy contamination associated with trash disposal. The Pennzoil Company site and Fox-Collins property are both on DSTC's watch list; however, current remediation efforts have been completed under the jurisdiction of the of the RWQCB.

Additional contaminated sites, beyond those presented in Figure 2.14, are likely located within the City of Alameda and in various stages of contamination identification or remediation due to Alameda's industrial and military past. For example, potential legacy contamination at the large Del Monte Property and its historic 240,000 square foot warehouse built in 1927 was not investigated for this assessment. In addition, many small contaminated sites are associated with specific groundwater monitoring wells; specific sites with contamination levels that remain above human health benchmarks are discussed under Section 4.2.

The scope of this assessment was limited to readily available information, and additional investigations and analysis are likely warranted to fully characterize all contaminated areas in the city. The CARP recommended completing an assessment of the remediation timelines of contaminated sites (see Table 4-23 in City of Alameda 2019), and this assessment is the most comprehensive first step taken to address this recommendation.

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[5] The DTSC database was reviewed to remove duplicate records and potentially contaminated sites where investigations have not yet been completed to determine if cleanup is required. This assessment only includes sites with known existing or previous contamination.

Coordinate System: NAD 1983 UTM Zone 10N
Data Sources: DTSC Envirostor, Silvestrum Climate Associates

Figure 2.14 Contaminated Lands

The CARP identified environmental conditions that could influence how a contaminant responds to rising groundwater levels, including how different contaminants respond to changes in groundwater elevation, groundwater flow gradients, changes in geochemistry, and current land use (City of Alameda 2019). The impact of rising groundwater levels on the contaminated lands will vary based on the remediation method(s) used and the concentration of contaminants present. The most common remediation methods and respective potential effects from rising groundwater are:

- **Excavation and removal:** Contaminated soil is excavated and disposed of at an appropriate facility outside of Alameda. If all contaminated soil is successfully removed, rising groundwater levels would not adversely affect the site with respect to contamination.
- **In situ groundwater treatment:** Substrates, compounds, or microorganisms are injected into the contaminated soil and groundwater to break down the contaminant into non-toxic constituents. For example, biosparging is an in-situ remediation method that uses indigenous microorganisms to biodegrade organic constituents, such as chlorinated solvents or petroleum hydrocarbons, in a saturated zone. A monitoring program is required to assess remediation success, such as when the contaminant concentrations fall below a predefined threshold (typically a concentration that would no longer harm public health or the environment). If this remediation approach is successful, rising groundwater levels would not adversely affect the site with respect to contamination.

- **Capping**: Capping involves placing a physical cover over the contaminated land to prevent human exposure from the mobilization of contaminants by airborne dust, rainwater infiltration, or vaporizing gas releases. The cap often includes an impermeable concrete slab or clay cover, with gas collection mechanisms depending on the contaminants present. Caps may include an additional layer of soil and vegetative cover. Except for modern landfills[6], contaminated lands are only capped from above and not from below. As the groundwater table rises, contaminants could be mobilized. As the groundwater table becomes emergent, the cap itself could crack, break apart, or be lifted, increasing the potential for contaminant exposure.
- **Institutional controls**: Institutional controls are administrative and legal controls that help minimize the potential for human exposure to contaminants. These controls can restrict allowable land uses and construction or excavation activities. Institutional controls are rarely the sole remediation method used. They may be used to protect the integrity of another remediation method (e.g., a cap), to limit human exposure until another remediation method is complete (e.g., excavation or in situ treatment), or to minimize human and environmental exposure if residual contamination remains after cleanup efforts are complete. Contaminated lands with institutional controls generally require long-term monitoring to verify the controls' effectiveness at limiting exposure. Annual inspections are typically required, along with a more detailed evaluation every five years. Contaminated lands with institutional controls have the greatest risk of contaminant mobilization as the groundwater table rises. The impact on public health and the environment depends on the contaminant type and concentration. Consistent monitoring can help identify when and if the institutional controls require modification or if additional remediation measures are needed.

Table 2.3 Contaminated Lands and Remediation Status

ID[1]	Site	Acres	Remediation Method				Remediation Status
			Excavation and Removal	In situ Groundwater Treatment	Capping	Institutional Controls	
Alameda Naval Air Station							
1	*- 1943 – 1965 Disposal Area*	78	x			x	Complete, Ongoing Monitoring
2	*- West Beach Landfill and Wetlands*	110	x	x		x	Complete, Ongoing Monitoring
3	*- Operational Unit 2A*	39.1		x		x	Complete, Ongoing Monitoring
4	*- Operational Unit 2B*	33.2		x		x	In Progress, Ongoing Monitoring

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[6] Modern landfills are well-engineered facilities designed to receive specific kinds of waste, and they are constructed with sophisticated protective liners designed to prevent leachate from reaching the surrounding soil and groundwater. The EPA established federal standards for municipal solid waste landfills under Title 40 of the Code of Federal Regulations, including location requirements, design standards, and environmental protection.

ID[1]	Site	Acres	Remediation Method				Remediation Status
			Excavation and Removal	In situ Groundwater Treatment	Capping	Institutional Controls	
5	*- Operational Unit 5*	12	x			x	In Progress
6	Alameda East Housing	87[7]				x	Complete, Ongoing Monitoring
7	Jean Sweeney Open Space Park	25	x		x	x	Complete, Ongoing Monitoring
Fleet and Industrial Supply Center and Alameda Navy Supply Center Annex (FISCA)							
8	*- Shinsei Gardens*	2.5	x		x	x	Complete, Ongoing Monitoring
9	*- Stargell Commons*	1.1	x			x	Complete, Ongoing Monitoring
10	*- Cadence and Linear*	3.5	x	x[8]		x	Expected Completion 2020
11	*- Symmetry*	4.2					Expected Completion 2020
12	*- Target Parcel*	10.3	x		x	x	Complete, Ongoing Monitoring
13	*- Retail Center*	13.7	x		x	x	Complete, Ongoing Monitoring
14	Pennzoil Company	4.1					Open, Ongoing Monitoring
15	Kem Mil Company	0.1	x		x		Unknown
16	Alameda Naval Operation Center	12	x			x	Complete, No Further Action
17	2100 Clement Avenue	2.8	x				Complete, No Further Action
Former J.H. Baxter Property							
18	*- Dutra-Velodyne Property*	4.1	-	-	-	-	In Progress
19	*- Extra Space Storage*	4.1	x				In Progress
20	*- Fox-Collins Property*	4.1	x		x	x	In Progress
21	Lincoln Avenue Housing	0.5	x				Complete, No Further Action
22	Doolittle Landfill	40			x	x	Complete, No Further Action

[1] The ID numbers correspond to the numbers on Figure 2.14

Source: DTSC 2019a

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[7] The DTSC database reports the size of the Alameda Naval Air Station East Housing as 68 acres. However, alternate sources report the size of this site as 87 acres. The discrepancy in acreage was not investigated for this effort.

[8] This site is underlain by a benzene and naphthalene plume that is being remediated with in situ groundwater treatment.

The following sections describe the known contaminated lands in Alameda, along with the type of contaminants present and the remediation methods used.

2.6.1 Alameda Naval Air Station

The naval base located on the west end of Alameda operated from 1940 until it was officially closed in 1997. During its operation, industrial activities across the base resulted in soil and groundwater contamination that continues to be addressed today. Contaminants include petroleum hydrocarbons, metals, chlorinated solvents, semi-VOCs, and radiological isotopes. The U.S. Navy (Navy) is required to complete remediation activities under the oversight of the U.S. EPA, DTSC, and the San Francisco Regional Water Quality Control Board (RWQCB) before land can be transferred to the City of Alameda for development or alternate land uses (City of Alameda 2019). All four remediation methods have been used on the naval base, with the specific methods used at each location varying based on the contaminant type, concentrations, and the size of the site. The navy retains the responsibility for future cleanup and remediation efforts for all lands that have been transferred to the City of Alameda. The following sites are subareas of the Naval Air Station site that are recorded in the DTSC database[9]:

- **1943 – 1965 Disposal Area**: The 1943 – 1965 disposal area was a former burn disposal site with ash and other contaminants that were buried onsite. Remediation methods include soil excavation, removal, and replacement with three feet of clean fill. The surface of the soil was seeded with indigenous plants as an erosion control measure. A steel barrier containment system was placed along several hundred feet of the shoreline. The barrier extends ten feet below mean sea level to isolate and contain the residual contaminants. Annual monitoring of adjacent Bay waters and the shallow groundwater layer are ongoing. If the residual contaminants below the soil cover are re-mobilized in the future, the Navy remains responsible for additional cleanup efforts (Naval Facilities Engineering Command 2009, AMEC 2019). Institutional controls restrict the land use to open space and recreation uses, prohibit soil disturbance or excavation below 2 feet, and prohibit the extraction of groundwater.
- **West Beach Landfill and Wetlands**: West Beach landfill is a former 77-acre landfill with approximately 33 acres of wetlands. This site served as a primary disposal area between 1956 and 1978, receiving approximately 1.6 million tons of waste (BRAC 2016). Remediation methods included excavating contaminated soil from "hotspot" areas with measured radiation. This site is within a proposed Nature Reserve to provide long-term protection of habitat for the federally-endangered least tern and other wildlife (BRAC 2016). An animal intrusion barrier was placed below 1.5 feet of clean soil to discourage animals from burrowing on the site. The soil cover was hydroseeded to establish native vegetation. Institutional controls restrict the land use to open space and recreational uses, all land-disturbing activities are restricted, extraction of groundwater is prohibited, and excavation of soil below 1.9 feet is strictly prohibited due to the presence of

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[9] Additional areas on the Alameda Naval Air Station property may (or may not) have contamination concentrations that exceed human health benchmarks; however, only the subareas recorded in the DTSC database were included in this assessment.

radionuclides. Continued monitoring of potential contaminants in the shallow groundwater layer is also required (NAVFAC 2017).

- **Operational Unit 2A**[10]: This site once included a paint stripping facility, oil refinery, hazardous waste storage, and a plane defueling area. Remediation efforts include in situ bioremediation which has reduced the contamination plume size by a factor of four and contaminant concentrations by more than 90 percent (BRAC 2016). Institutional controls require annual monitoring, prohibit the domestic use of groundwater, and require that new residential construction include approved vapor control systems to minimize human exposure to residual contamination in some areas (DTSC 2017). The re-development plan for this site includes potential residential, commercial, industrial, and maritime land uses.
- **Operational Unit 2B:** This site included a fuel storage area, aircraft engine facility, engine test cell, and a ship fitting and engine repair facility. Five “hotspots” had elevated levels of chlorinated VOCs, and these areas were treated with in situ bioremediation. Soils contaminated with lead were excavated and removed. Soils contaminated with cobalt remain underneath an existing building. The shallow groundwater layer was contaminated with petroleum. The most recent monitoring shows a significant reduction in contaminant concentrations; however, it will likely take 25 to 30 years to reach the remediation goals for this site (US Navy 2015, NAVFAC 2018).
- **Operational Unit 5**: Historically, this site was used for residential housing (i.e., naval barracks) and open space known as Estuary Park. Estuary Park contains baseball and soccer fields, a sand volleyball court, a playground, and a physical fitness course. This site is in the process of redevelopment for residential use and open space for park areas and recreation. Contaminated soil was found at depths over 8 feet below the ground surface (BRAC 2016). Remediation included the removal of four feet of soil in 2000 and replacement with clean soil in the vicinity of the playground to address health risks to children. Additional soil was removed (to a depth of two feet) over a 2.8-acre portion of the site. Institutional controls will remain, including land use restrictions, and limitations on soil disturbance below a depth of four feet, as well as limitation on soil disturbance due to the presence of the marsh crust (Ninyo & Moore 2019).

2.6.2 Alameda Naval Air Station East Housing

The East Housing Area is an 87-acre property previously used for military housing[7]. Although no legacy contaminants are known to be present, the site is underlain by the marsh crust (see Section 2.5). In July 2000, the Navy transferred this property to the city for residential land use, including the Bayport housing development. The only remediation method used on this site are the institutional controls associated with the marsh crust.

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[10] The Navy identified toxic sites and organized them into Operational Units based on the contaminants present and the historic land uses(s). Although some clean-up sites have alternate names (e.g., West Beach Landfill and Wetlands), some sites retain only their Operational Unit designations.

2.6.3 Jean Sweeney Open Space Park

The City of Alameda created a public open space park on this 25-acre parcel in 2018. Historically the site included a railroad maintenance and storage facility operated by the Alameda Belt Line railroad. The site was purchased by the City in 2009. Site investigations found petroleum hydrocarbons and lead in localized areas and in the shallow groundwater. PAHs were also found in low concentrations within the soil. In 2017, 450 cubic yards of soil contaminated with metals and hydrocarbons were excavated and transported off-site for incineration. Lead-impacted soil (1,900 cubic yards) was consolidated and capped under a paved bike trail within the park. Institutional controls remain in place, including restricting the land use to open space and recreation, and continued groundwater monitoring (SLR 2018a, 2018b).

2.6.4 Fleet and Industrial Supply Center and Alameda Navy Supply Center Annex (FISCA)

The approximately 146-acre FISCA site was an airport in the 1930s. Contamination occurred when sediments were dredged from the adjacent Baylands and used to fill in the marshlands to create more developable land. The dredged sediments contained PAHs, a residual from the former aircraft operations. This site was later converted to a military warehouse facility and scrap yard. Multiple remediation methods were used, including the excavation and removal of 17,900 cubic yards of soil contaminated with polychlorinated biphenyls and cadmium. As cleanup efforts were completed, portions of the site were transferred to the City for redevelopment as Alameda Landing. Institutional controls include annual monitoring to confirm that residual contaminated soil and groundwater remain contained onsite and do not mobilize or expand into uncontaminated areas (BRAC 2016). The final Completion of Corrective Action[11] determination is scheduled for 2021 (DTSC 2019b). The following sites are subareas of the FISCA site:

- **Shinsei Gardens:** A 2.5-acre housing development completed in 2009. The development required a sub-grade vapor collection zone, multi-layered vapor seal blanketing below all building foundations, and passive venting systems to direct any soil vapor to the atmosphere to reduce the potential for human exposure. Institutional controls remain in place (in the form of an oversight plan) and include annual inspections.
- **Stargell Commons:** An approximately one-acre site located between Bette Street, Willie Stargell Avenue, and Fifth Street. Four feet of clean fill was placed over the site, and the development construction was completed in May 2017 in compliance with all land use regulations (a form of institutional controls) including restrictions on disturbance or excavation below the first four feet of soil (e.g., marsh crust is present at this site, see Section 2.5; ENGEO 2015). Vapor mitigation barriers were installed below the slab foundations because a portion of the development overlies the benzene and naphthalene groundwater plume (Barse 2019).
- **Cadence and Linear:** This 18-acre residential development with 255 homes is underlain by a benzene and naphthalene contaminated groundwater plume. Plume remediation remains the responsibility of the Navy. Four feet of soil were excavated, removed, and replaced with clean fill in

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[11] The Federal Environmental Protection Agency Completion of Corrective Action includes two milestones: the attainment of corrective action performance standards, both with or without controls, and the final completion of the corrective action process.

compliance with all land use covenants. The 2008 transfer of land from the Navy to the City for redevelopment did not require the installation of vapor mitigation systems below the structures. However, institutional controls required annual monitoring and inspections. In 2019, soil sampling found contaminated soil with concentrations exceeding human health benchmarks remaining onsite. A Remedial Action Completion Report that details how the remaining contamination was addressed is scheduled to be submitted to DTSC in March 2020, a final Land Use Restriction Determination is scheduled for May 2020. The current schedule includes receiving Completion of Corrective Action in late 2020 or early 2021. The need for continued institutional controls will be assessed as part of the completion process.

- **Symmetry at Alameda Landing:** This 4.2-acre development is located at Mitchell Avenue and Diller Street. Portions of this site are also associated with the Alameda Landing Waterfront and are currently under development. The Remedial Action Completion Report is scheduled to be submitted to DTSC in March 2020, with Completion of Corrective Action anticipated in June 2020. Details of the remediation methods used at this residential site were not readily found during the review of DTSC materials.
- **Target Parcel:** The Target Parcel is a 10.3-acre site within the Alameda Landing redevelopment area. To prevent exposure from VOCs in the soil, a barrier cap was installed in accordance with the 2008 Remedial Action Plan. Remediation is considered complete, and institutional controls remain in place, including annual monitoring and inspections, land use restrictions, restrictions on any soil disturbance, and monitoring of the concrete cap.
- **Retail Center:** The Retail Center is a mixed-use commercial development on Fifth street with businesses and grocery stores. Remediation methods included the removal of 19 cubic yards of contaminated soil. To prevent human exposure to potential contaminants, all native soils are required to be covered with buildings, pavement, or landscaping. Institutional controls include annual monitoring and reporting to DTSC, and land use restrictions that prevent the construction of residential housing, hospitals, or schools.

2.6.5 Pennzoil Company

The Pennzoil Quaker State Company has owned and operated this 4.1-acre site since 1951. The site includes a tank farm with 29 oil storage tanks and 48 above-ground bulk storage tanks, a blending and packaging warehouse, and truck loading and maintenance areas. Hazardous wastes generated at the facility include automatic transmission fluid, waste oil/water mixtures, and waste oil with heptane. The automatic transmission fluid and waste oil/water mixture are temporarily stored in a 2,200-gallon tank and 1,000-gallon sump, respectively, prior to pick-up and proper disposal by a licensed hazardous waste hauler. DTSC investigated the site in 1980, 1986, and 1995. The investigations recommended keeping the site in the DTSC database as an active potentially contaminated site; however, large-scale remediation may not be possible until the Pennzoil Quaker State Company ceases operations at this facility (DTSC 2019c).

The 48 above-ground tanks have a combined capacity of 3,045,758 gallons. Contaminated soil was discovered by the RWQCB and regular groundwater monitoring began in 1995. The RWQCB issued site cleanup requirements in 1998 (Order No. 98-121). Additional contaminated soil was discovered in 2002, prompting contaminated soil removal. However, some contaminated soil was left under aboveground storage tanks to maintain their structural integrity. Contamination at this facility is also attributed to former underground storage tanks at adjacent properties. Groundwater monitoring is ongoing at this site.

2.6.6 Kem Mil Company

This site was a U.S. Naval Reserve Shipyard and from 1967 to 1986, the site included a photochemical machine shop. In 1988, the County of Alameda Health Care Services Agency issued a Notice of Violation for the site, citing several violations of the California Health and Safety Code, and Title 22 of the California Code of Regulations. 1988 soil sampling identified elevated levels of cyanide, arsenic, and chromium beneath the machine shop. Remediation methods include the excavation of 28 cubic yards of contaminated soil. Following soil excavation beneath the structure, latex enamel paint was applied to the concrete surfaces to prevent contamination from leaching out of the concrete. The last record from DTSC was in 1991 and the need for additional remediation is unknown (DTSC 2019d).

2.6.7 Alameda Naval Operational Support Center

This site, formerly known as the Naval and Marine Corps Reserve Center, was filled as part of the Oakland Inner Harbor construction in 1919. Graving docks (i.e., an excavated shore dry dock for the repair and maintenance of ships) were constructed to support wartime purposes in 1942. Dredge material was placed between the graving docks to create embankments for access roadways. Hazardous constituents found in the groundwater and soils include gasoline, diesel, lead, and other metals. Remediation methods included removal of underground storage tanks and soil excavation, removal, and replacement with clean fill. Although remediation is complete, residual petroleum soil contamination remains deeper than 13.5 feet below the ground surface. Long-term institutional controls are in place, including land use restrictions (BECHTEL 2005a, 2005b, DTSC 2013).

2.6.8 2100 Clement Avenue

This site is adjacent to the Alameda Naval Operational Support Center. Remediation methods include soil excavation in areas where VOCs or soil vapor could pose a vapor intrusion risk to future residents. Previous military buildings were also demolished. DTSC determined that no further action is required (Stantec 2016), and a 2.8-acre residential development was completed in 2018.

2.6.9 Former J. H. Baxter Facility

From 1924 to 1969 this site contained a wood treatment facility that treated wood with coal tar derived creosote and fuel oil. The site also included a 6,000-gallon underground gasoline storage tank and a storage area for marine construction and dredging equipment. In 2003, a dark tarry substance was observed emanating from beneath a driveway in the north-eastern section of the site. Soil samples revealed the presence of various hazardous contaminants that exceeded DTSC regulatory screening levels. Three subareas of this site are in the process of remediation:

- **Dutra-Velodyne Property (2199 Clement Avenue):** Soil testing and groundwater sampling at this site found contaminants consistently above regulatory benchmarks; redevelopment cannot occur until all remediation is complete (Bureau Veritas North America 2009). A Removal Action Workplan is scheduled to be submitted to DTSC in April 2020. Ongoing groundwater monitoring, and monitoring of soil gas and vapor intrusion, will be required as part of the remediation efforts.

- **Extra Space Storage (2189 Clement Avenue)**: In 2008, a limited soil excavation (approximately 15 x 15 feet square, with depths ranging from 1 to 4 feet below the ground) was completed and an underground storage tank was removed (ARCADIS 2010). A Removal Action Workplan is scheduled to be submitted to DTSC in January 2020. A public notice for intended cleanup activities was scheduled for November 2019.
- **Fox-Collins Property (2201, 2229 Clement Avenue):** In 2013, 8,500 cubic yards of contaminated soil were excavated. An additional 200 cubic yards were excavated and removed in 2015. Once remediation is complete, this site could be redeveloped for residential housing and open space if human health impacts can be managed. Redevelopment will likely require the installation of a permeable reactive barrier, soil isolation and capping, and installation of vapor mitigation systems for residential housing (Sequoia Environmental Coporation 2010).

2.6.10 Lincoln Avenue Housing

This approximately 0.5-acre site was redeveloped to support an 18-unit affordable housing unit for adults with disabilities. Approximately 1,150 cubic yards of contaminated soil was removed and replaced with clean fill to depths of 2 to 4 feet below the ground surface. As of 2013, all remediation actions were complete and no land use restrictions were imposed (SLR 2013).

2.6.11 Doolittle Landfill

This former landfill was operated as a disposal site for municipal refuse from 1953 until its closure in 1978 (Harding-Lawson Associates 1979, RWQCB 1993). This landfill was not designed using today's standards for landfill siting, design, and operations, and was closed shortly after the Resource Conservation and Recovery Act was enacted in 1976 to govern the disposal of solid waste, and before the EPA established federal standards for municipal solid waste landfills under Title 40 of the Code of Federal Regulations. The approximately 40-acre site[12] is directly adjacent to San Leandro Bay on Bay Farm Island. The layer underneath the landfill is 25 to 35 feet thick and comprised primarily of Bay mud, underlain by stiff clays (Harding-Lawson Associates 1979). The shoreside barrier is a 10 to 20 ft wide levee with erosion control measures consisting of concrete riprap, soil, and inert waste building materials. The closure plan notes that a minimum 1-foot layer of clay was placed on top of the compacted refuse, and the clay layer was further compacted to create an "impermeable" layer (Harding-Lawson Associates 1979). On top of this impermeable layer, two additional feet of soils suitable for landscape development were placed (Harding-Lawson Associates 1979). These measures sufficed as a cap to seal in the refuse at the time of landfill closure. Levee repairs were completed in 1979 to eliminate subsurface flows between the landfill and the Bay in sections of the levee that were found to be porous (Harding-Lawson Associates 1979).

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[12] The acreage of the Doolittle Landfill varies between 40 and 44 feet throughout the reports that were reviewed.

The City of Alameda performed semi-annual groundwater monitoring until 2017 with consistently low or non-detectable concentrations of VOCs and inorganic contaminants. Continued groundwater monitoring and reporting to the RWQCB is no longer required. Monitoring has shown that leachate containing VOCs or metals have not infiltrated below or off the site into adjacent soils or surface waters (AMEC 2012). The city is currently investigating re-development plans, including using the site for a solar project with Alameda Municipal Power. Additional recapping or other measures may be required to convert the landfill for alternative land uses.

It has been noted that the Corica Golf Course was constructed on top of an old landfill site and groundwater monitoring has occurred quarterly since approximately 2013. At the time this groundwater assessment was completed, records of the old landfill and the respective groundwater monitoring data was not obtained. The Corica Golf Course has also changed substantially in recent years as fill has been imported and the site has been raised, re-graded, and improved. Re-evaluation of the golf course and any old landfill material underlying the site is recommended as a next step in Section 6.7.

3 Existing Condition Mapping

This section presents the methodology for creating the shallow groundwater surface for existing conditions, and for mapping the presence of contaminants within the shallow groundwater layer based on the RWQCB monitoring data presented in Section 2.

3.1 Shallow Groundwater Surface

To understand how the shallow groundwater surface responds to sea level rise, the existing shallow groundwater surface must first be characterized. The study builds upon a regional groundwater mapping effort led by the University of California at Berkeley in collaboration with Silvestrum Climate Associates (Plane et al. 2017, 2019).

3.1.1 Regional Mapping

A San Francisco Bay Area-wide map of the shallow groundwater layer was first developed by Plane et al (2017, 2019) using the SWRCB GAMA data. The shallow groundwater layer was mapped within 1 mile of the Bay shoreline. The well data was filtered to use measurements collected between 2000 and 2016 (i.e., focusing on the most recent epoch) for wells with depths to water less than 21 feet (i.e., to capture the shallow groundwater layer). Wells with negative depths to water were removed (i.e., wells with a depth to water above the ground surface are associated with artesian wells). From this filtered data set, the minimum depth to water measurement for each well was extracted. Selecting the minimum depth to water measurement is a proxy for the highest observed groundwater surface elevation, which typically occurs during wet winters in late winter and early spring. The depth to water measurements were translated to the

NAVD88[13] topographic datum using a digital elevation model developed by the USGS using LiDAR[14] data collected in 2010 and 2011(OPC 2010).

To connect the shallow groundwater surface with the Bay, tidal data from the San Francisco Bay Extreme Tide and Tidal Datum Study by the Federal Emergency Management Agency (FEMA) was used (May et al. 2016). This effort provides tidal datum information at over 900 points along the complex Bay shoreline. In areas with limited monitoring well information directly near the shoreline, this data helped approximate the natural slope of the shallow groundwater surface towards the Bay. The tides within the Bay rise and fall twice per day in a semi-diurnal cycle, and the shallow groundwater surface was estimated to connect to the Bay approximately 1-foot above mean tide level because freshwater usually lies above the mean tide line (Moss 2016).

Using a multi-quadratic radial basis interpolation technique in ArcGIS[15], the well water level elevations and FEMA tide points were transformed into a regional groundwater surface layer. Areas farther than 0.62 miles (1 km) from a known well location were not mapped. The response of the regional groundwater surface to 3.28 feet (1 meter) of sea level rise was also evaluated. This initial groundwater surface layer shows how high the shallow groundwater table can be in Bay Area coastal communities, providing a first look at areas where sea level rise adaptation efforts must consider rising groundwater.

The regional mapping also highlights areas where additional, finer-scale analysis is necessary to better understand the shallow groundwater layer. In some areas, the regional mapping shows that the existing groundwater surface is above the ground today; however, many of these areas do not currently have emergent groundwater concerns. In these areas, the local topography may constrain groundwater flow, and/or additional data is needed to refine the surface information due to sparse well data. Figure 3.1 presents the initial regional shallow groundwater surface for the City of Alameda and the surrounding areas.

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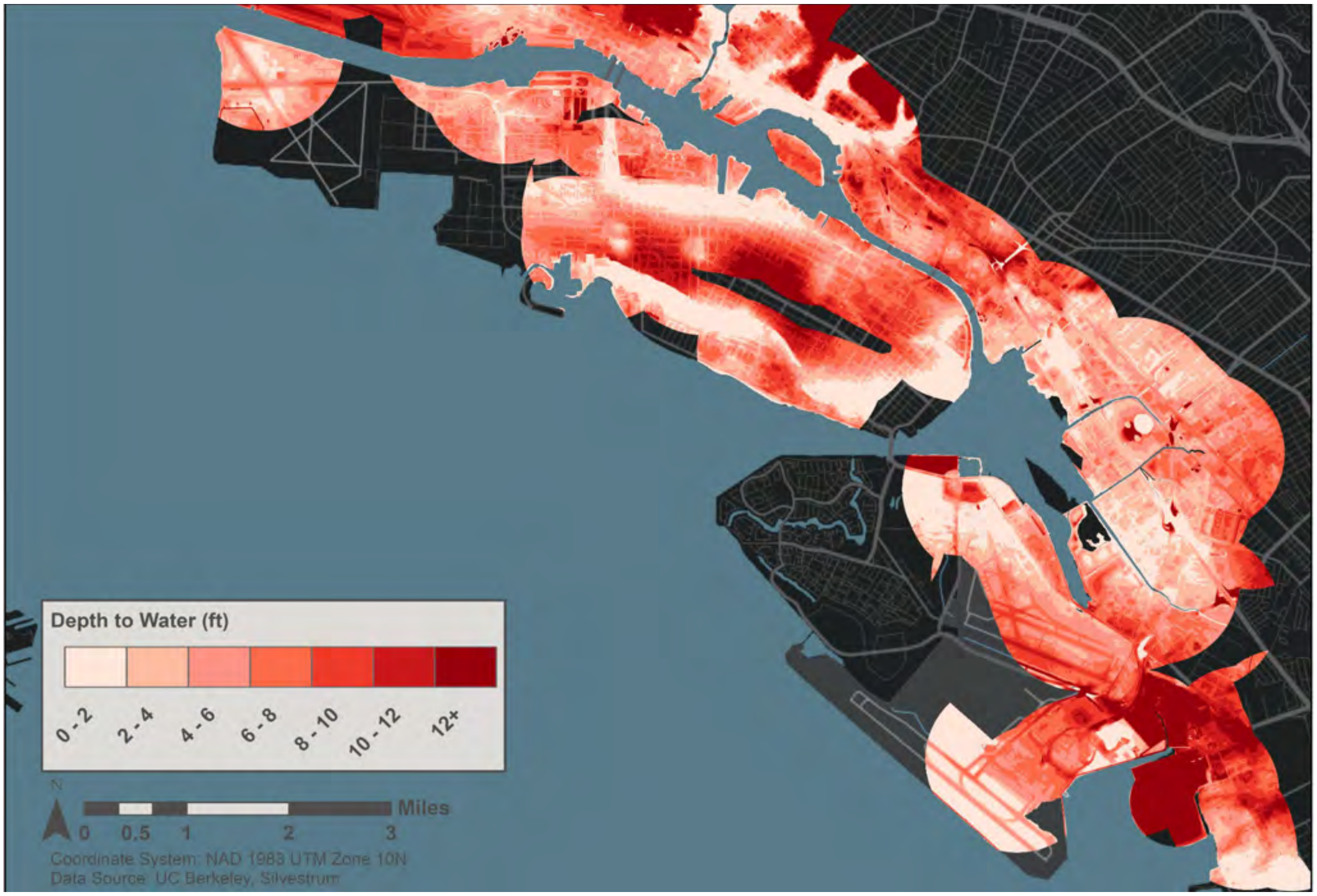
[13] The North American Vertical Datum of 1988 (NAVD88) is the vertical control datum established in 1991 by the minimum-constraint adjustment of the Canadian-Mexican-United States leveling observations.

[14] Light Detection and Ranging (LiDAR) is a surveying method that measures distance to a target by illuminating the ground with laser light and measuring the reflected light with a sensor. Differences in laser return times and wavelengths can then be used to make digital 3-D representations of the ground surface.

[15] ArcGIS is a geographic information system for working with maps and geographic information.



Source: Plane et al. 2017, 2019

Figure 3.1 Regional Shallow Groundwater Mapping

3.1.2 City of Alameda Mapping

To develop a more refined assessment of the existing shallow groundwater surface, additional analysis of the RWQCB GAMA data was completed. The well data was subsampled to only select wells with measurements collected during wet winters (generally December thru May) between 2000 and 2018. Although this subsampling reduces the number of wells available for interpolation, it removes potential bias from wells that were only sampled during the dry summer seasons, and wells with short-term data collection that did not include a wet winter. In areas with well clusters (i.e., areas with five or more wells closely spaced together) the well data was carefully reviewed and in select areas only the wells with the highest groundwater surface were retained (i.e., wells that were sampled shortly after large precipitation events). Between 2000 and 2018, California experienced more drought years than wet years, based on the National Oceanic and Atmospheric Administration's Palmer Drought Severity Index (PDSI), with the four-year drought occurring between 2011 – 2015 estimated as the worst drought in over a century (CADWR 2015).

The soil boring data was also filtered to select only soil boring logs collected post 2000 during wet winters (see Section 2.2). The soil boring logs were carefully reviewed to assess if the depth to water, noted in the geotechnical reports, had reached an equilibrium elevation. The soil boring data was used to provide groundwater elevation information for areas with sparse well data.

Similar to the regional approach, the refined approach also incorporates tide level elevations along the shoreline from the FEMA study (May et al, 2016). In areas where significant grade changes (e.g., hills) occurred between inland monitoring wells and the Bay shoreline, breaklines[16] were used to constrain the groundwater with the topography. Figure 3.2 presents the wet winter season well points, FEMA tide points, and the grade break points that were used to develop the existing shallow groundwater surface for the City of Alameda and the surrounding areas. Figure 3.3 presents the final existing shallow groundwater surface layer.

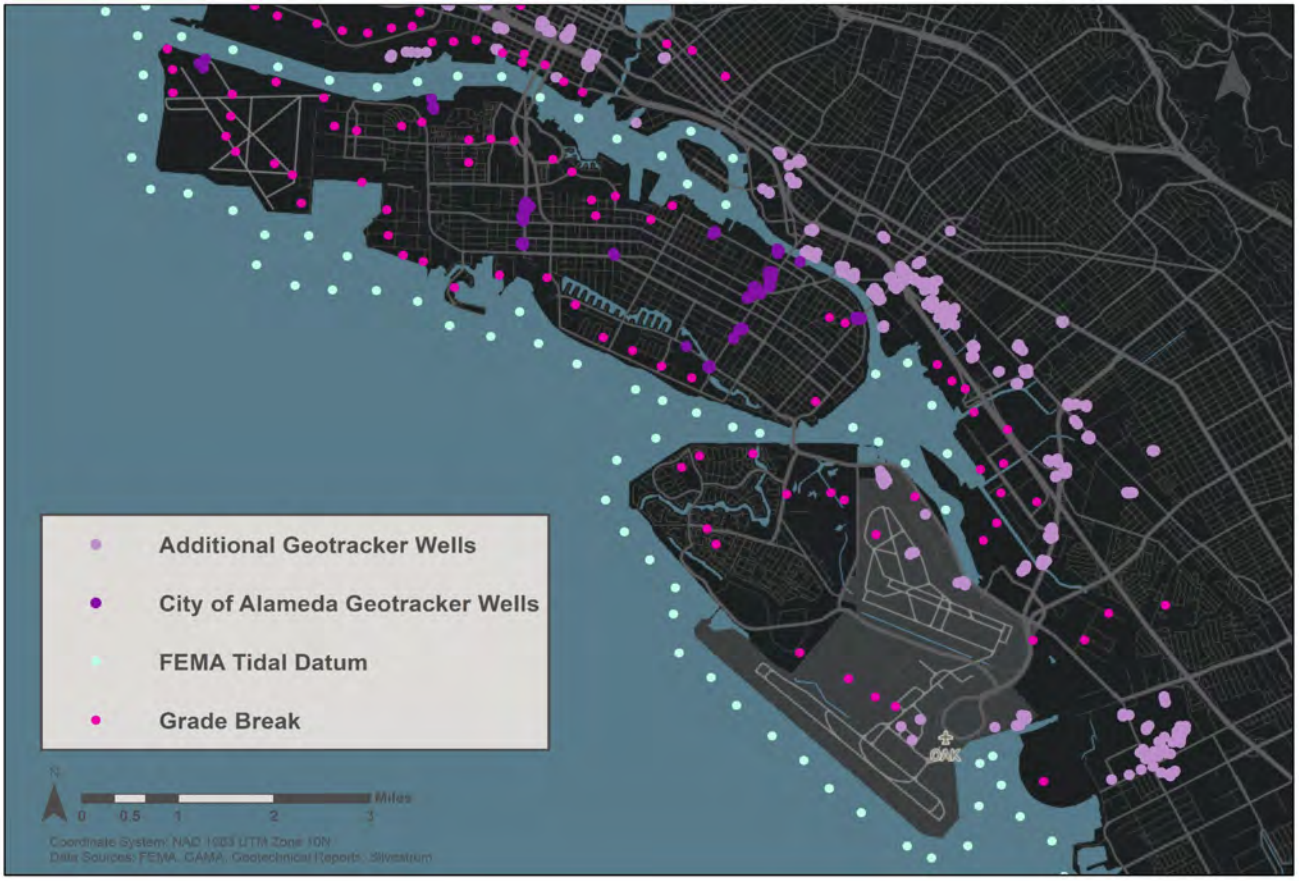


Figure 3.2 Well Points, Tide Points, and Grade Break Points

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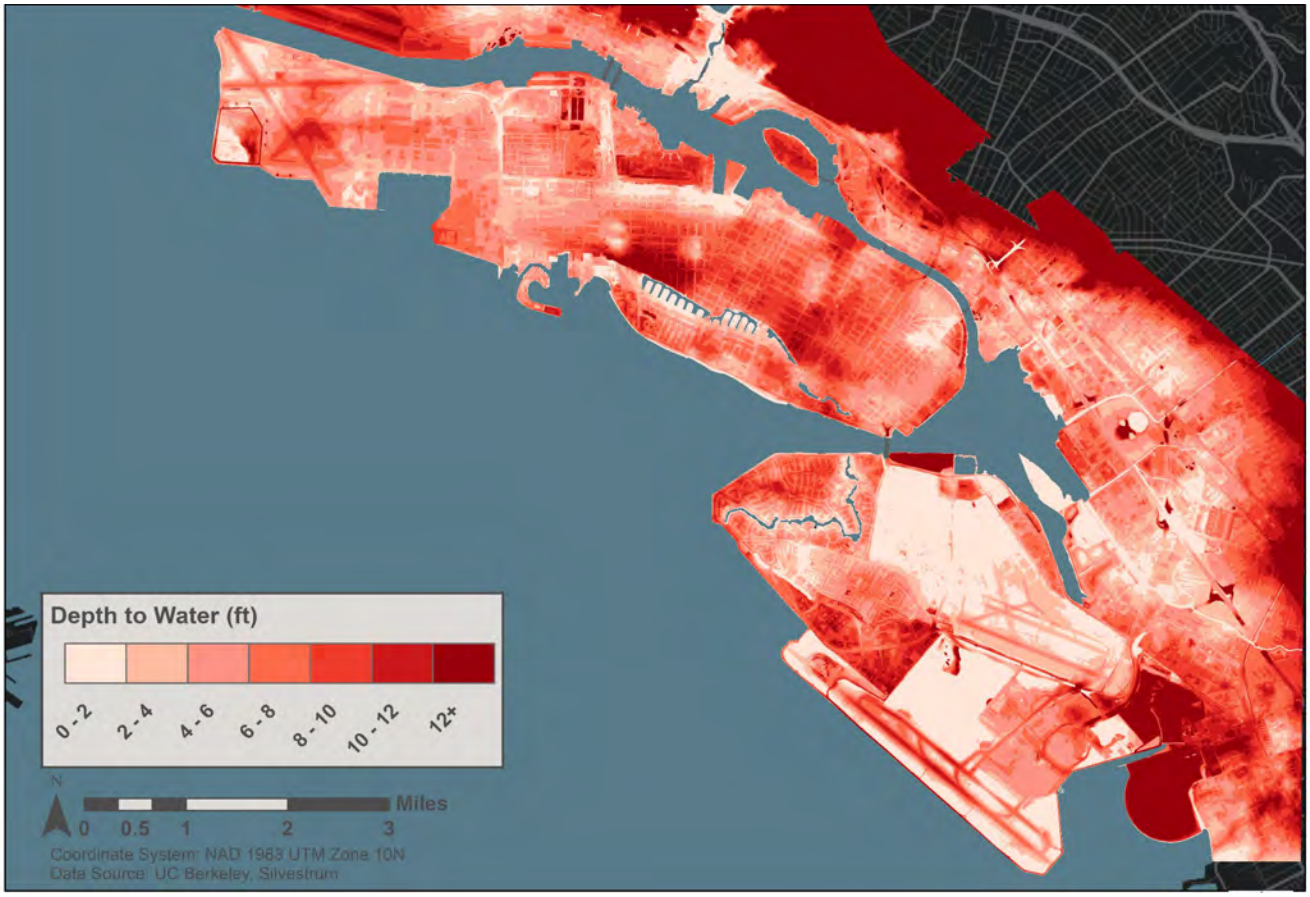
[16] Breaklines are imaginary lines created from a sudden increase or decrease in the ground surface elevation (e.g., at the base or crest of a hill). Breaklines are critical for creating an accurate surface model. Breaklines constrain the interpolation, preventing interpolation across the breakline to better represent grade changes.



Coordinate System: NAD 1983 UTM Zone 10N
Data Source: UC Berkeley, Silvestrum

Figure 3.3 Existing Shallow Groundwater Surface

3.1.3 Comparison

Figure 3.4 presents a comparison between the regional shallow groundwater mapping and the more refined mapping prepared for the City of Alameda. Initially, the regional mapping showed large areas of the city with the existing shallow groundwater layer at (or above) the existing ground surface. The updated mapping produced a surface that is generally lower (i.e., larger depth to water values) than the regional surface: it is representative of ground-truthed depth to water values based on soil boring data and on observations of emergent groundwater made during the wet rainy season over the 2018 – 2019 winter.

Both the regional mapping and the updated mapping relied on USGS LiDAR data collected in 2010 and 2011 (OPC 2010). The updated mapping also relied on a digital elevation model (DEM) (built from the 2010 LiDAR) that was updated through an extensive stakeholder effort as part of the Adapting to Rising Tides program (Vandever et al. 2017). However, some areas within the City of Alameda have had grade changes due to recent construction and development efforts, and these grade changes are not yet accounted for in the LiDAR data or DEM. Areas with known changes include the Chuck Corica Golf Course on Bay Farm Island (i.e., significant fill was brought in post 2011 to raise the grades within the golf course) and areas on the West End near Alameda Point where new development has occurred and additional development is in progress.

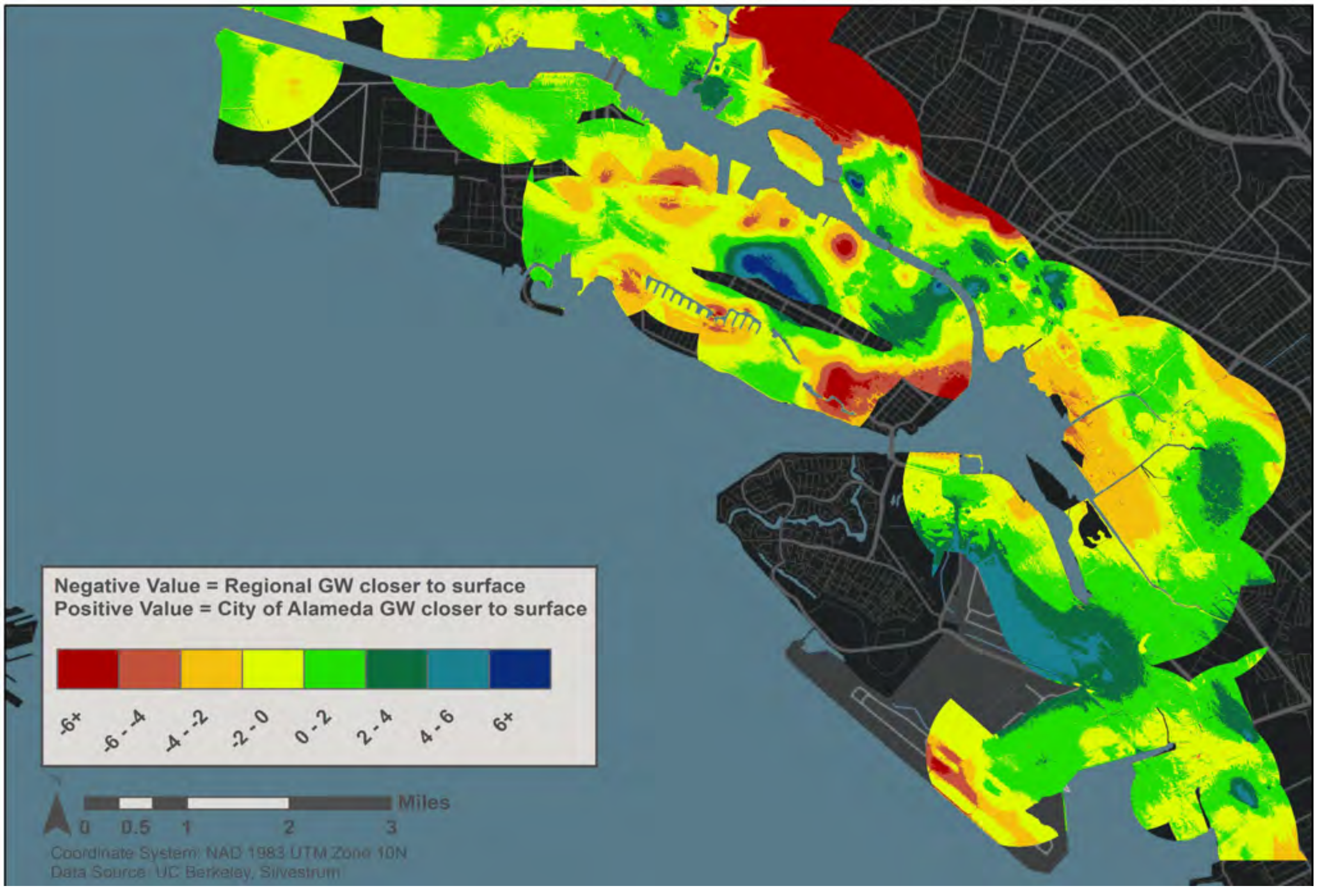
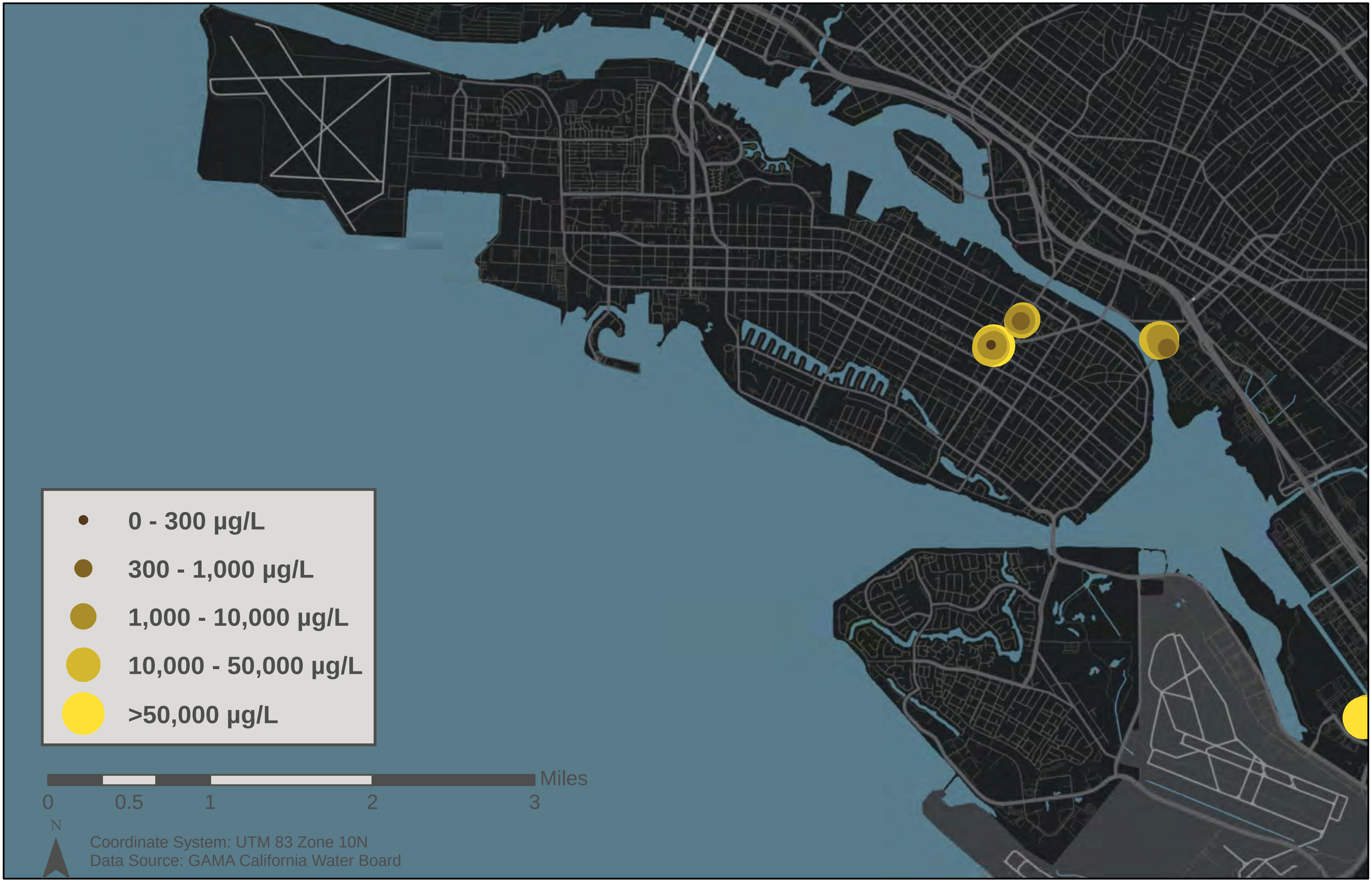


Figure 3.4 Comparison between Regional Mapping and City of Alameda Mapping

3.2 Groundwater Contaminants

For each contaminant in Table 2.2, the distribution within the City of Alameda was analyzed. During the years 2000 – 2015 many contaminants measured were present in high concentrations (i.e., well above human health benchmarks); however, between 2015 and 2019 the values were generally lower (see Appendix A). This difference could be because of the City's cleanup efforts, discontinuation of chemicals used, breakdown of the legacy contaminants in the groundwater and soils, or the movement of the contaminants toward or into the Bay in the direction of the groundwater flow. To represent current contamination levels, eight contaminants (i.e., iron, benzene, MTBE, TBA, toluene, TCE, PERC/PCE, and manganese) with 2015 – 2019 average concentrations above human health benchmarks were mapped (see Figure 3.5 through Figure 3.12). Additional details are presented in Appendix A and Section 2.5. The three contaminants no longer monitored (e.g., arsenic, chromium, and lead) were not mapped.

Unlike the creation of the groundwater surface, a "contamination surface" was not created. Instead, the average concentrations were mapped at the well location where they were measured. Not all contaminants were measured at each well. Appendix A includes tables for each contaminant, including information for each well where the contaminant was measured, the number of measurements taken, the historic high measurement and the date it was recorded, the historic average measurement (2000 – 2019), and the current average (2015 – 2019).



Coordinate System: UTM 83 Zone 10N
Data Source: GAMA California Water Board

Figure 3.5 Current Period (2015 – 2019) Average Iron Concentration

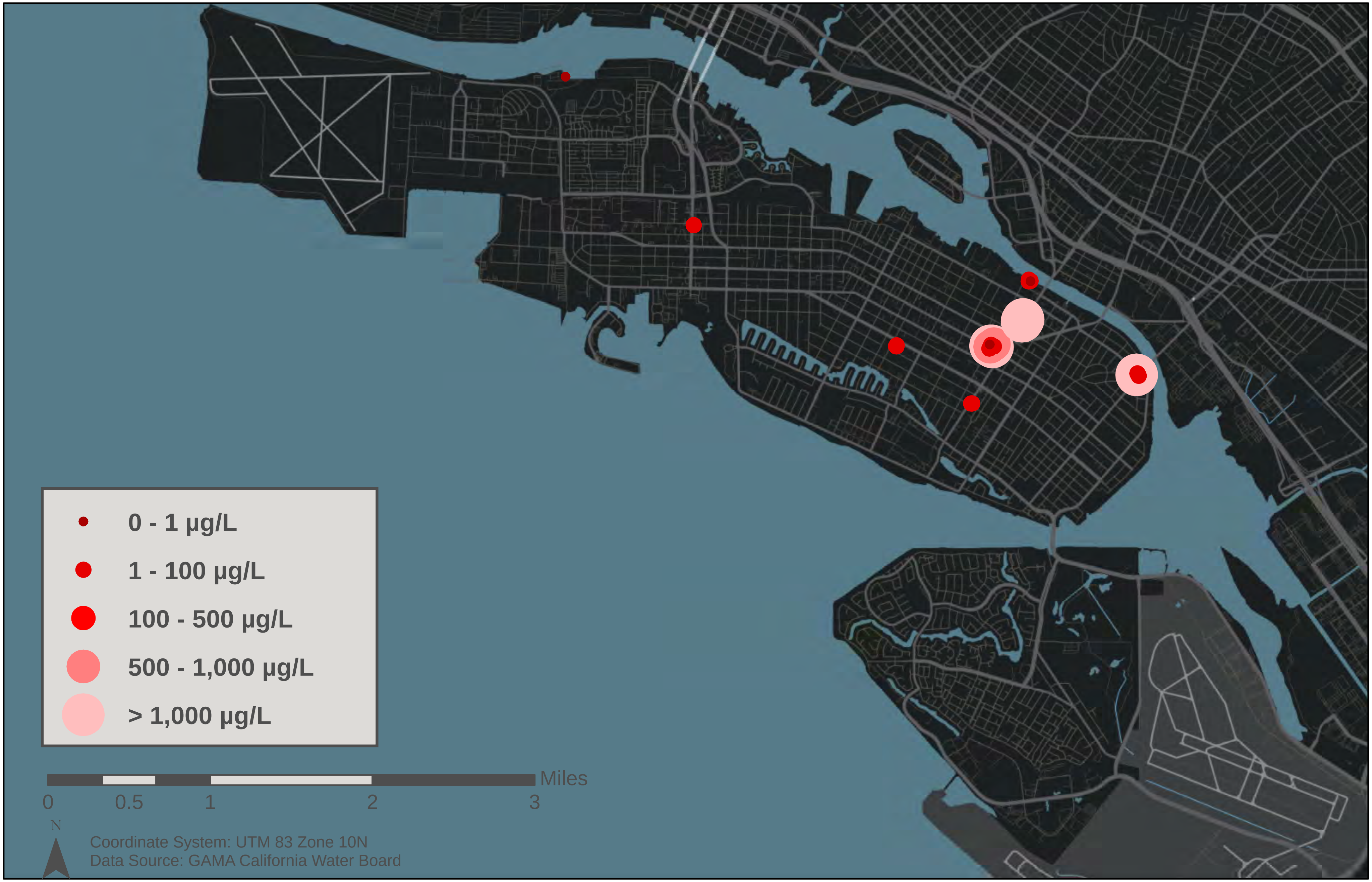


Figure 3.6 Current Period (2015 – 2019) Average Benzene Concentration

Figure 3.7 Current Period (2015 – 2019) Average Methyl-Tert-Butyl Alcohol (MTBE) Concentration

Figure 3.8 Current Period (2015 – 2019) Average Tert-Butyl Alcohol (TBA) Concentration

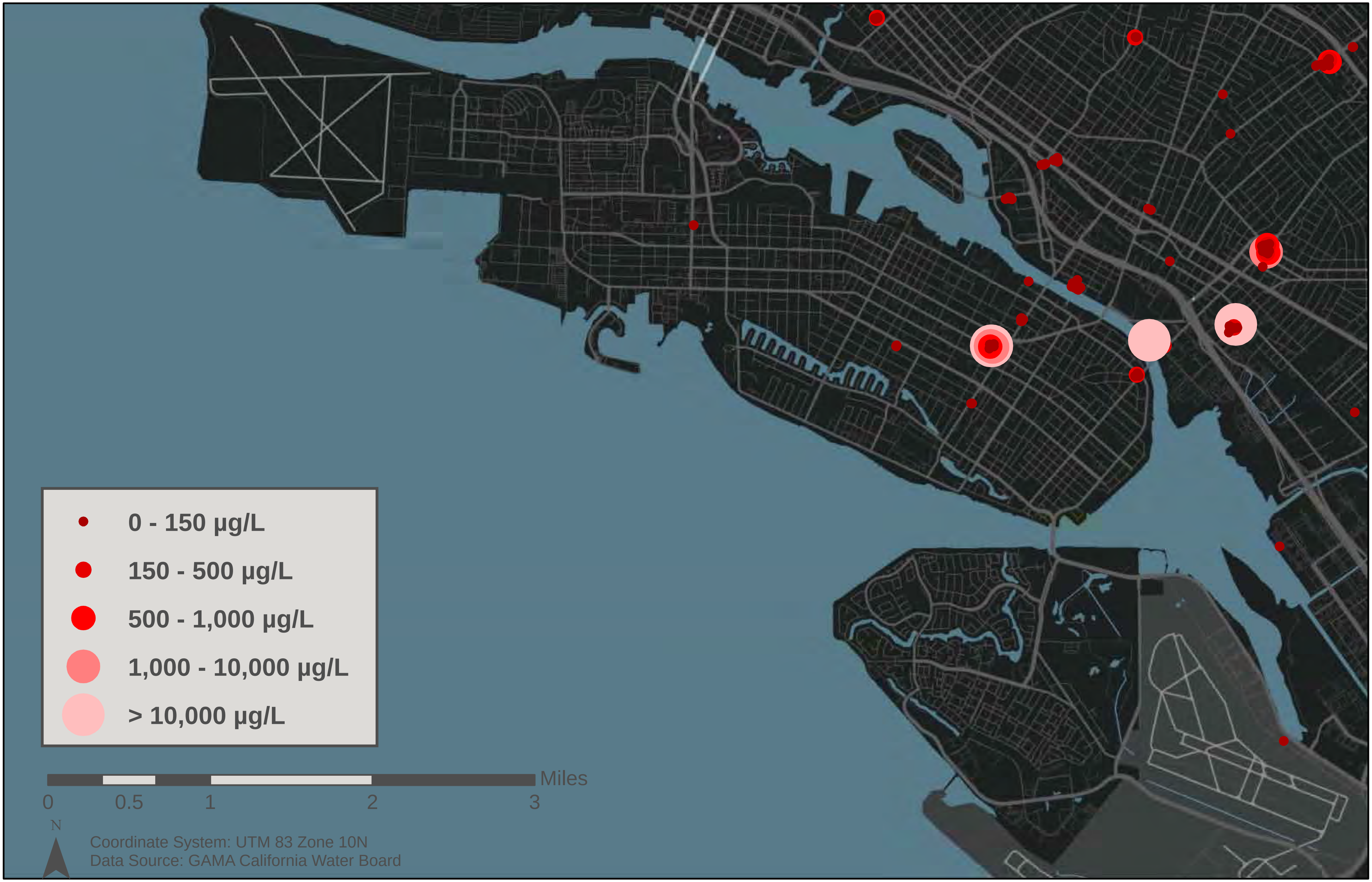


Figure 3.9 Current Period (2015 – 2019) Average Toluene Concentration

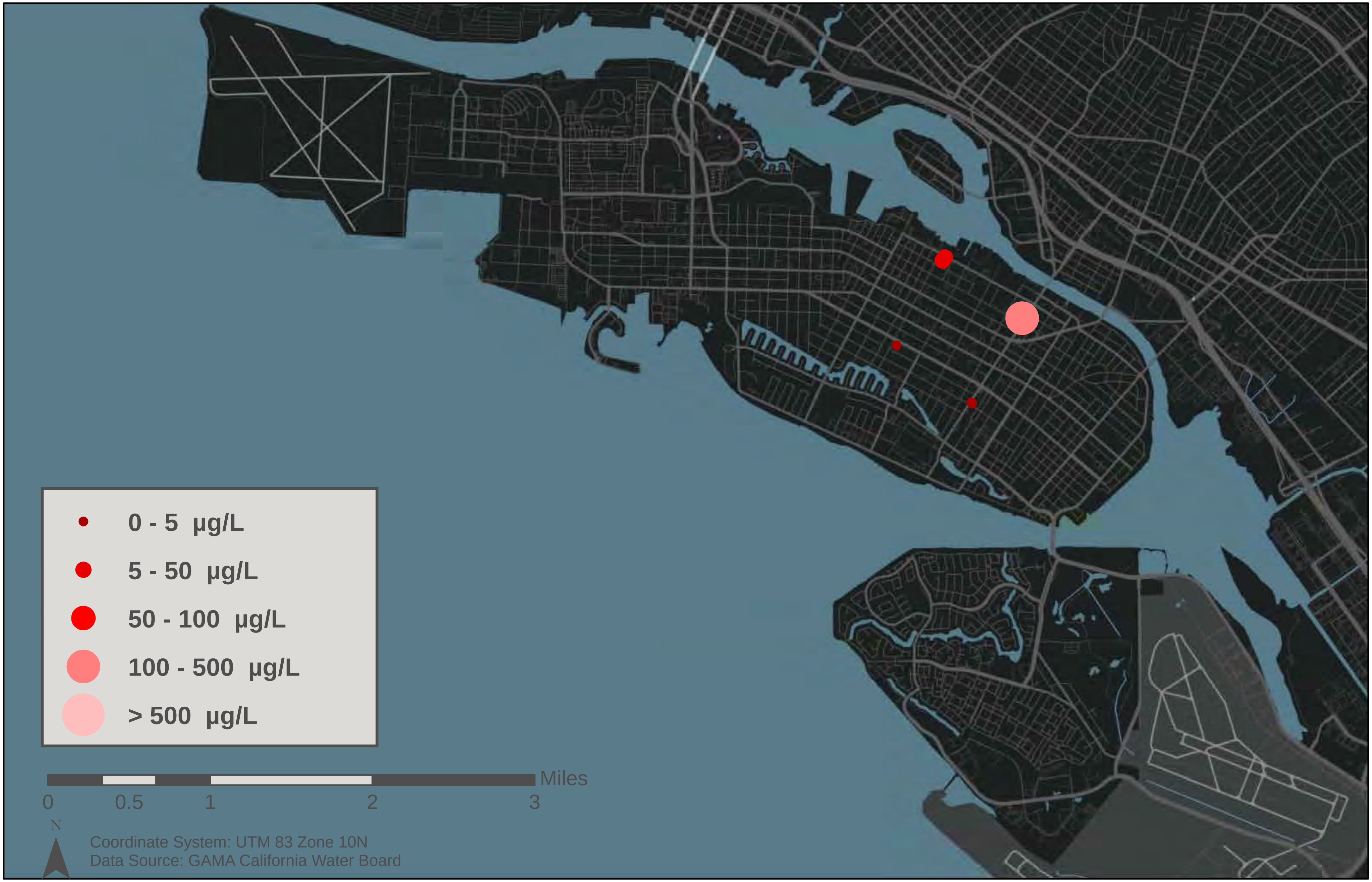


Figure 3.10 Current Period (2015 – 2019) Average Trichloroethene (TCE) Concentration

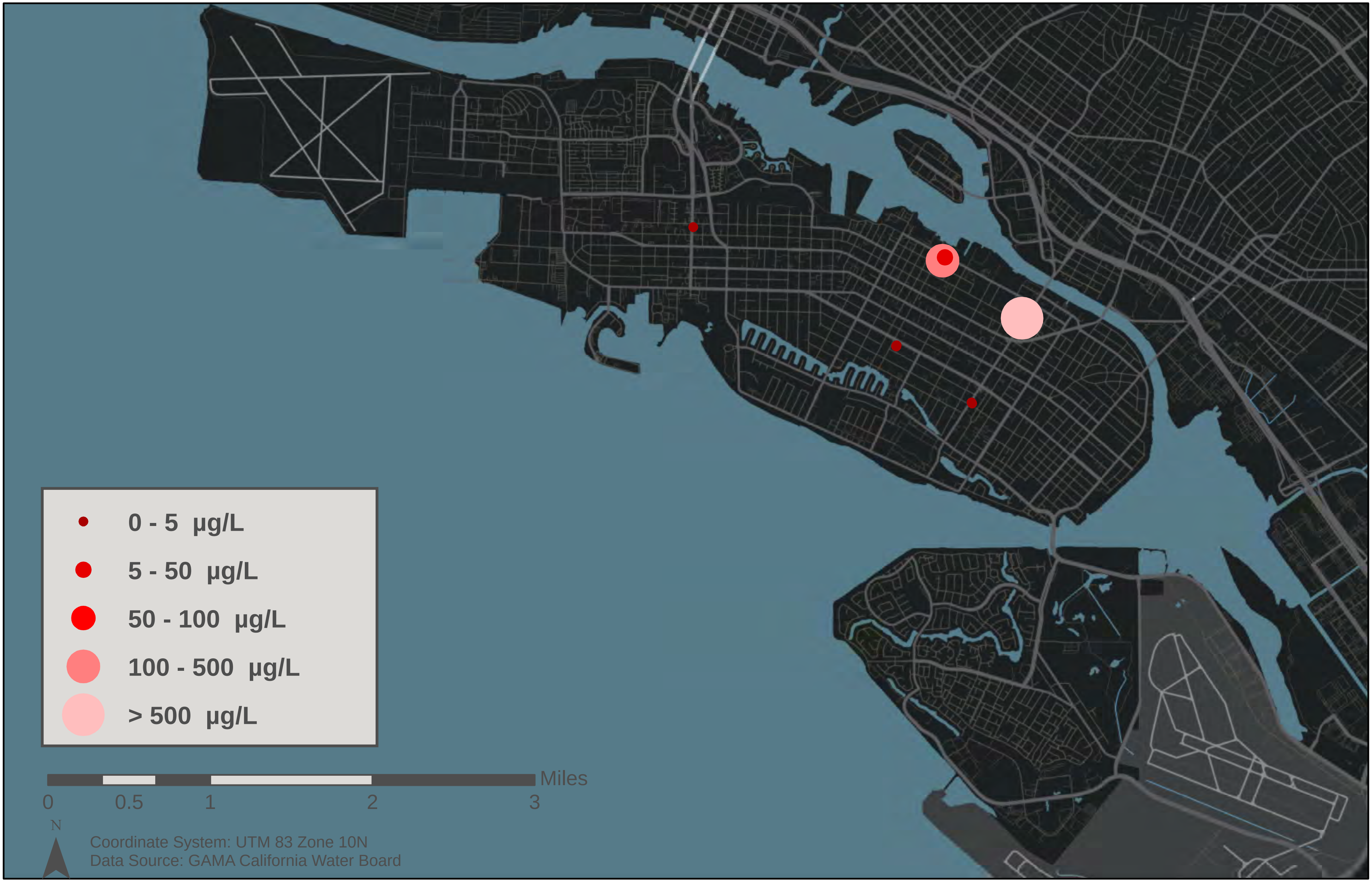
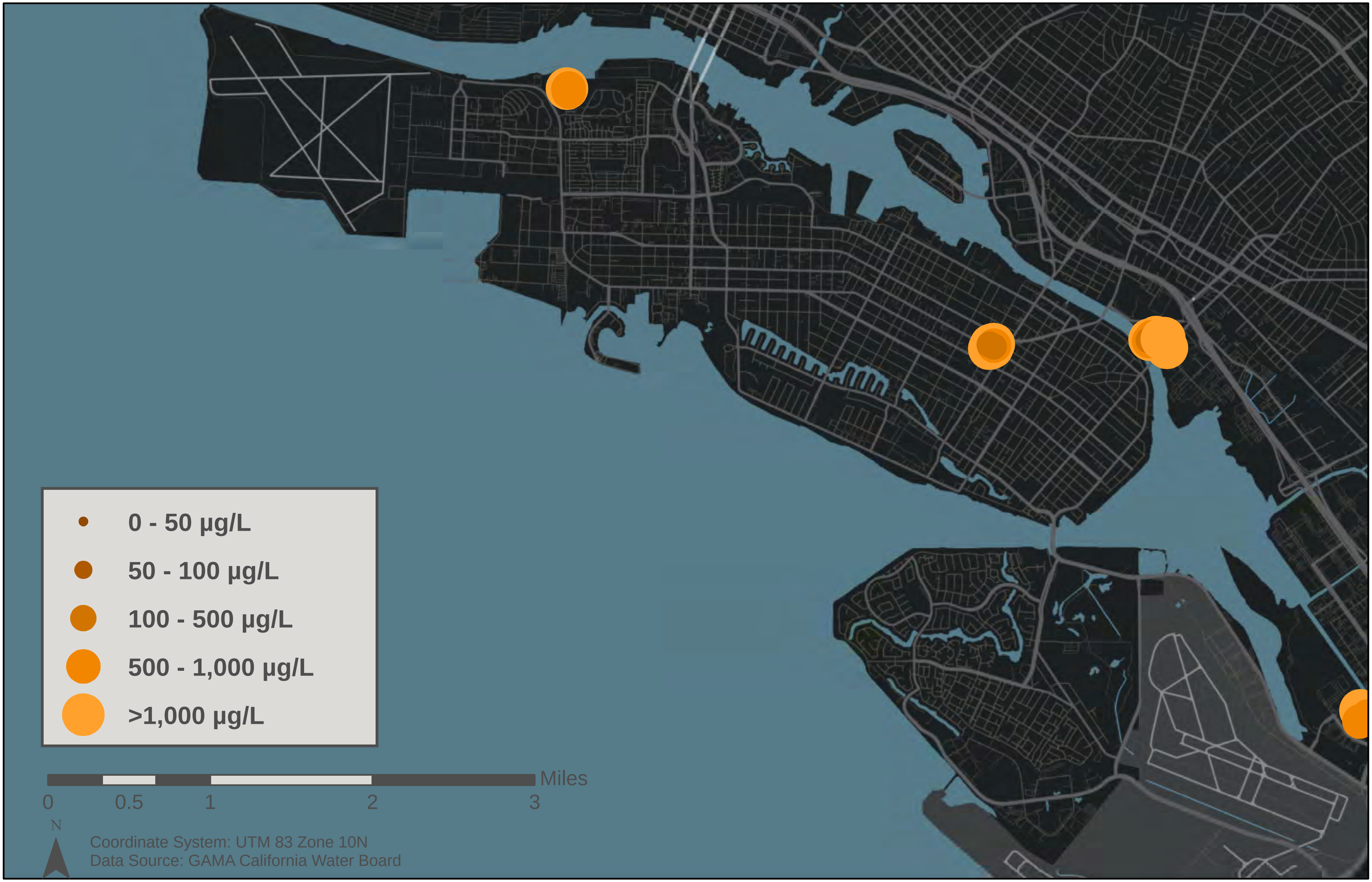


Figure 3.11 Current Period (2015 – 2019) Average Tetrachloroethene (PERC) Concentration



Coordinate System: UTM 83 Zone 10N
Data Source: GAMA California Water Board

Figure 3.12 Current Period (2015 – 2019) Average Manganese Concentration

4 Future Condition Mapping and Analysis

As the shallow groundwater table rises, contaminants that are in the groundwater, trapped in the soil, or buried in historic fill sites, can mobilize and rise to the surface. Although some contaminants may break down when exposed to air or have short-term exposure impacts, some can be distributed in shallow floodwaters and volatized into the air. The health effects from exposure to these contaminants could be hazardous to human health, particularly to seniors, small children, or people with chronic health conditions (Naidu et al. 2016). VOCs could also accumulate in subterranean structures such as basements. There is evidence of groundwater exposure in these structures, as many basements in Alameda already have sump pumps. Basements that have been converted to living spaces will need to monitor the potential for contaminated floodwaters and VOCs, particularly near areas with known VOC groundwater contamination. Exposure to trace elements, metals, and other contaminants can also be found in playgrounds, parks, picnic areas, and home backyards (Guney et al. 2010).

Understanding when and where shallow groundwater could become emergent over time, and what contaminants could be present, is important for developing plans to mitigate and reduce potential health risks. This section presents the methodology for creating the future condition shallow groundwater surface layer, and for identifying potential areas of concern related to groundwater contamination and current and former DTSC sites.

4.1 Future Shallow Groundwater Surface

In "flux-controlled" systems, where the rate of groundwater discharge is constant as sea level rises, sea level rise causes landward migration of the saltwater toe, otherwise known as saltwater intrusion (Werner and Simmons 2009, Chesnaux 2016). This saltwater intrusion causes the overlying fresh groundwater layer to rise (Chang et al. 2011). Therefore, sea level rise causes an increase in the height of the water table, or a decrease in the measured or modeled depth to water (Nuttle and Portnoy 1992, Masterson and Garabedian 2007, Chang et al. 2011, Michael et al. 2013, Rotzoll and Fletcher 2013, Chesnaux 2016, Hoover et al. 2017).

The rate of rise in the groundwater surface in response to sea level rise depends on many factors, including the tidal range, salinity, aquifer geology, soil characteristics, coastline change, shore slope, surface permeability, and precipitation (Rotzoll and Fletcher 2013, Chesnaux 2016, Hoover et al. 2017). The relationship between sea level rise and water table rise is unlikely to be exactly linear, especially near tributaries, streams, and rivers (Nuttle and Portnoy 1992, Masterson and Garabedian 2007). However, as a conservative approximation, a 1:1 correlation between sea level rise and water table rise can be assumed within the study area (Nuttle and Portnoy 1992). This approximation is only applicable in the zone where sea level and tidal fluctuations have an influence on the shallow groundwater aquifer; therefore, this study focuses only on the nearshore areas within approximately five kilometers of the shoreline (Rotzoll and Fletcher 2013). This relationship can be improved in the future, with additional analysis after the release of the United States Geological Survey's shallow groundwater modeling for the state of California, expected in 2020.

The existing shallow groundwater surface was modified to account for sea level rise using seven of the ten sea level rise scenarios mapped as part of the Adapting to Rising Tides program: 12”, 24”, 36”, 48”, 52”, 66”, and 108” of sea level rise (Vandever et al. 2017). Not all ten sea level rise scenarios were considered, because the Adapting to Rising Tides inundation mapping uses a “One Map, Many Futures” approach to showcase a range of sea level rise and storm surge scenarios.

> *The shallow groundwater surface can rise and fall by five feet or more between wet winters and the dry summer season.*

For the purposes of this study, only the response of the shallow groundwater layer to sea level rise is of concern. As the response of the shallow groundwater layer to storm surge scenarios would likely be limited and temporary, the range of 12” to 66” of sea level rise is within the bounds of the most recent sea level rise studies and State guidance (NRC 2012, Griggs et al. 2017, CCC 2018). The 108” scenario was mapped as it is the closest surrogate sea level rise scenario for the H++ scenario (i.e., 122” of sea level rise) presented in the State Sea Level Rise Policy Guidance (CCC 2018). The H++ scenario is an extreme scenario that represents a future scenario with rapid Antarctic ice sheet mass loss, under the premise that the physics governing ice sheet mass loss will change after mid-century due to overall warmer global temperatures (Griggs et al. 2017, CCC 2018). The H++ scenario is, at present, highly uncertain and is a topic of ongoing scientific research.

Figure 4.1 presents the existing (i.e., present day) shallow groundwater surface as it can occur during wet winters. As shown in Figure 2.3, the shallow groundwater surface can rise and fall by five feet or more between wet winters and the dry summer season (i.e., heavy rainfall can result in a significant rise in the shallow groundwater layer). For the future condition groundwater mapping, only the areas where the groundwater could become emergent under each sea level rise scenario was mapped (see Figure 4.2 through Figure 4.7). The future condition groundwater mapping represents a wet winter scenario, as groundwater flooding is likely to occur first during wet winters, exacerbating flooding and stormwater drainage, and maximizing the potential distribution of contaminants. As the shallow groundwater surface rises, the saturated soils and water can also damage the surrounding infrastructure (e.g. buried pipes or building foundations) and increase the liquefaction risk in the event of an earthquake (Quilter et al. 2015, Risken et al. 2015).

Figure 4.8 and Figure 4.9 present the emergent groundwater flooding along with the sea level rise inundation that could also occur for 36” and 66” of sea level rise, respectively. Both scenarios result in a greater amount of flooded area when both emergent groundwater and sea level rise are considered. In the near term, emergent groundwater flooding would occur sporadically during wet winters. This hazard could occur with higher frequency and longer durations as the sea level rises and extreme storms become more intense.

> *Groundwater flooding is likely to occur first during wet winters, exacerbating flooding and stormwater drainage, and maximizing the potential distribution of contaminants.*

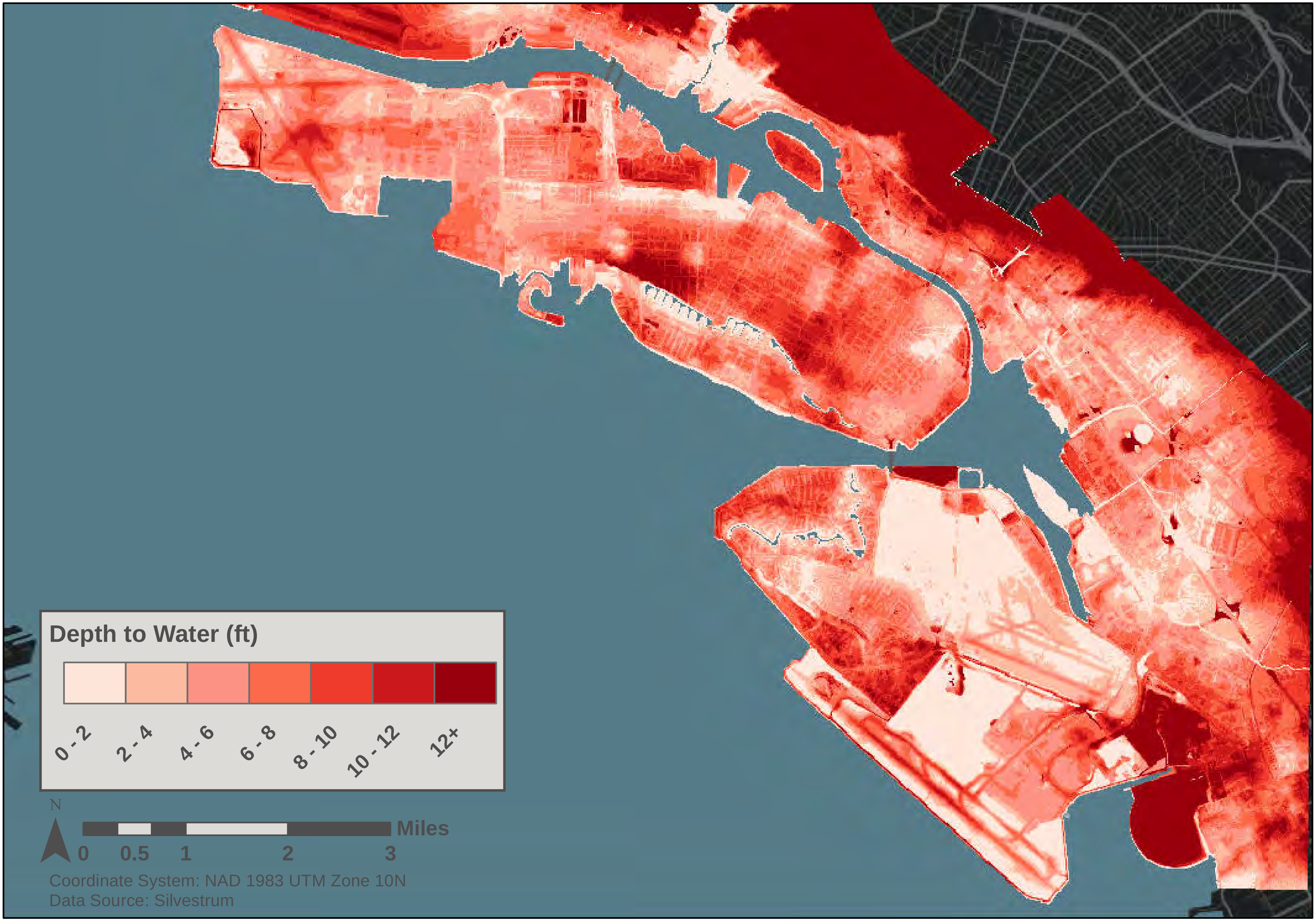


Figure 4.1 Existing Shallow Groundwater Surface

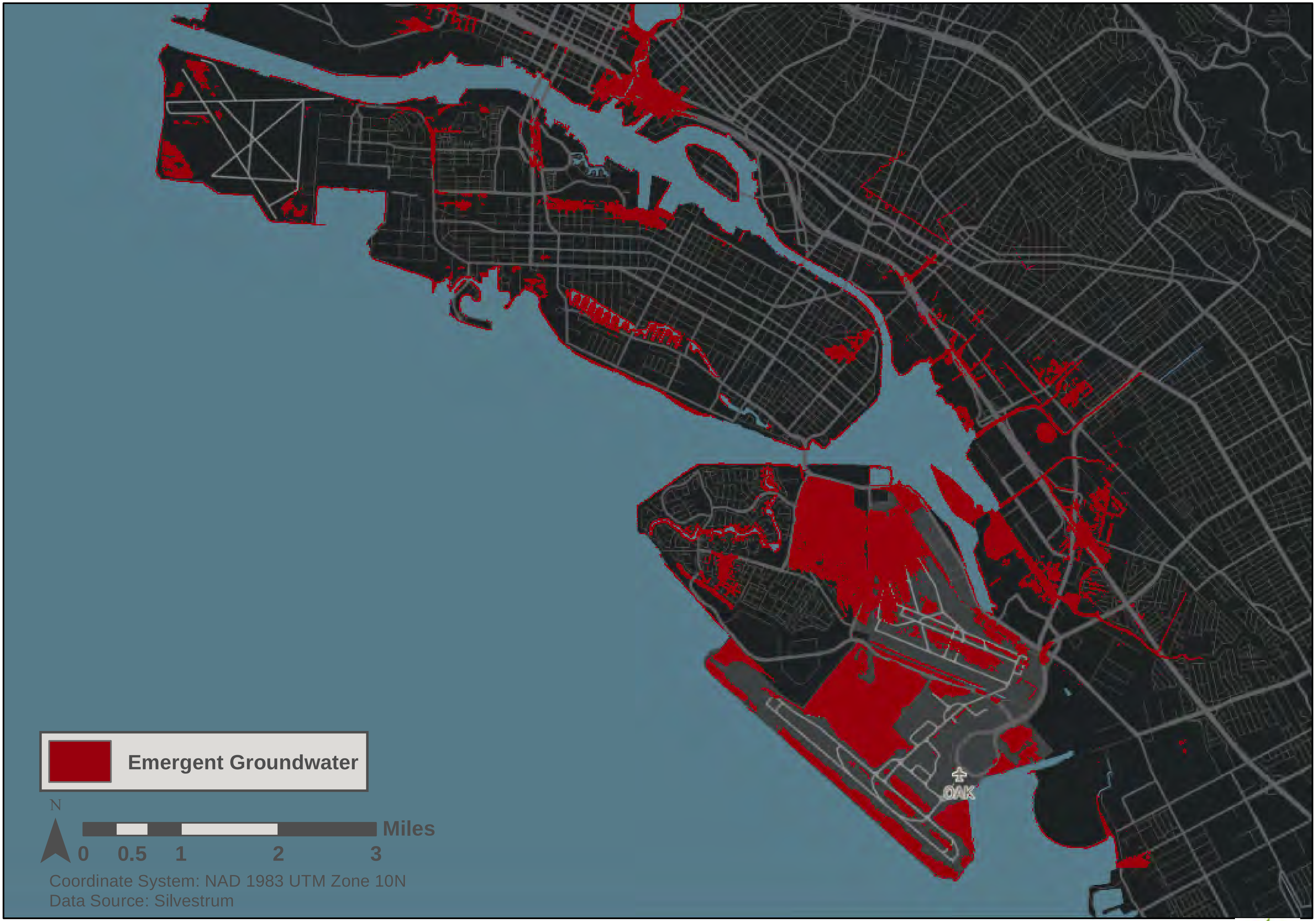
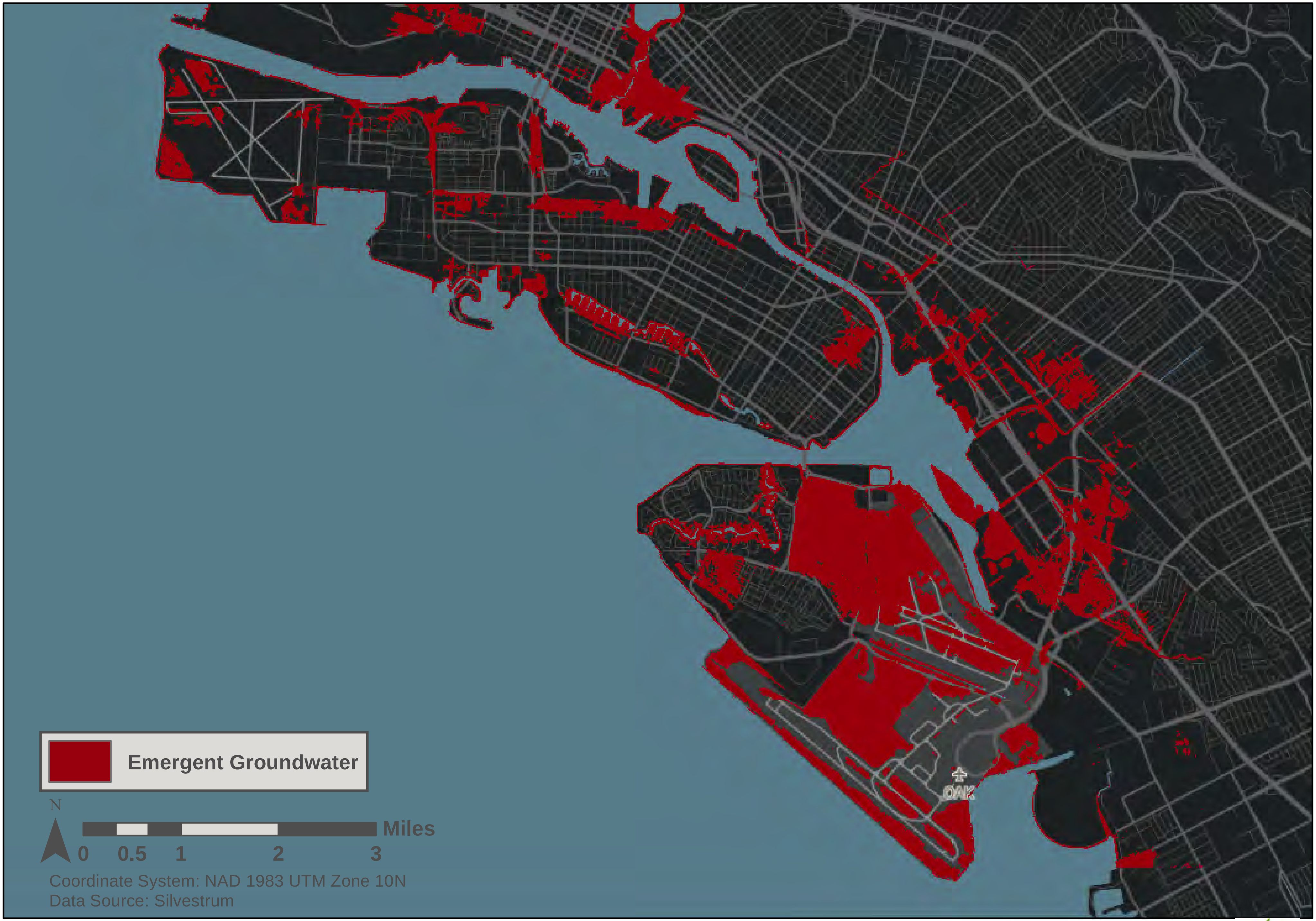


Figure 4.2 Emergent Groundwater with 12" of Sea Level Rise



Coordinate System: NAD 1983 UTM Zone 10N
Data Source: Silvestrum

Figure 4.3 Emergent Groundwater with 24" of Sea Level Rise

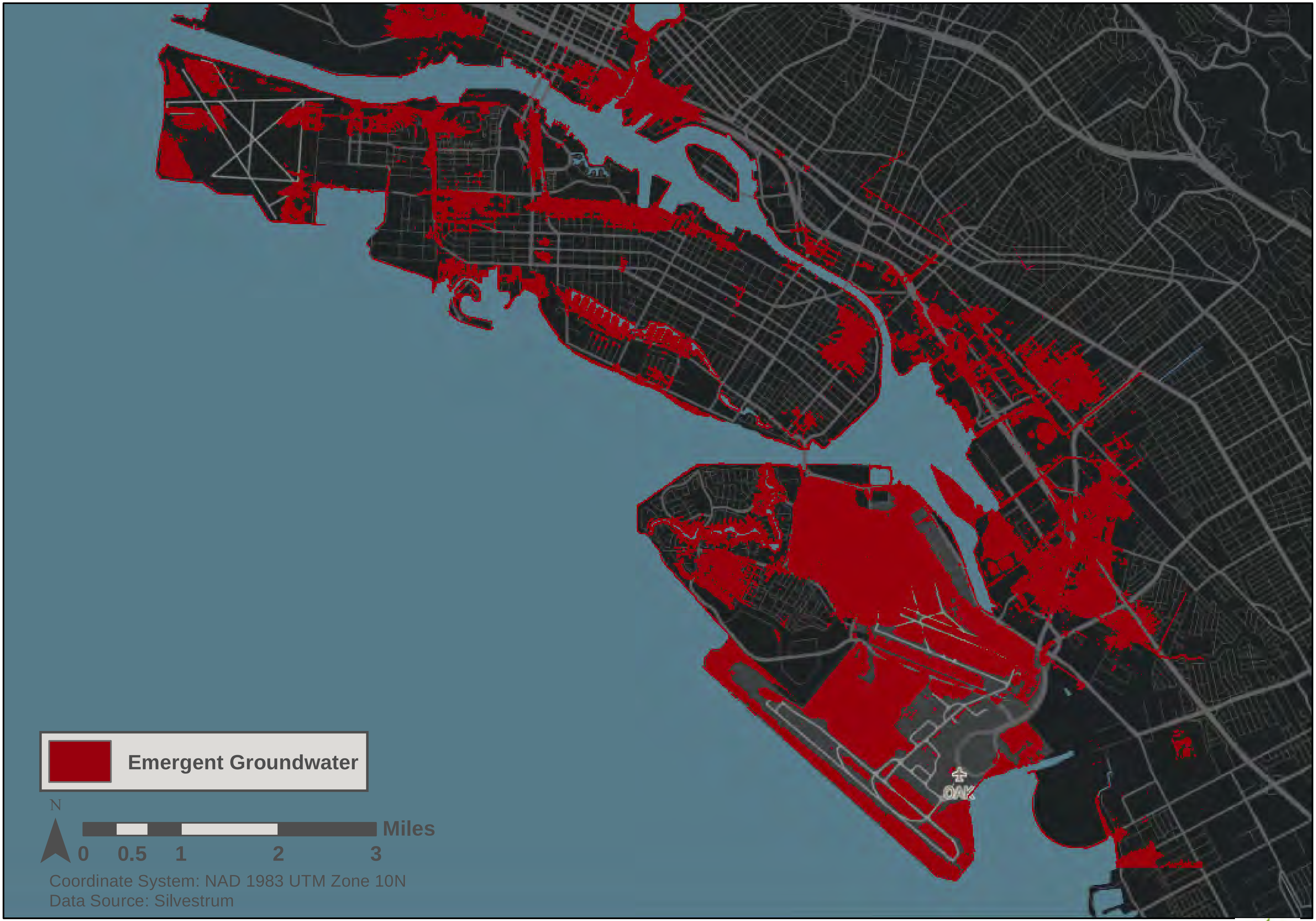
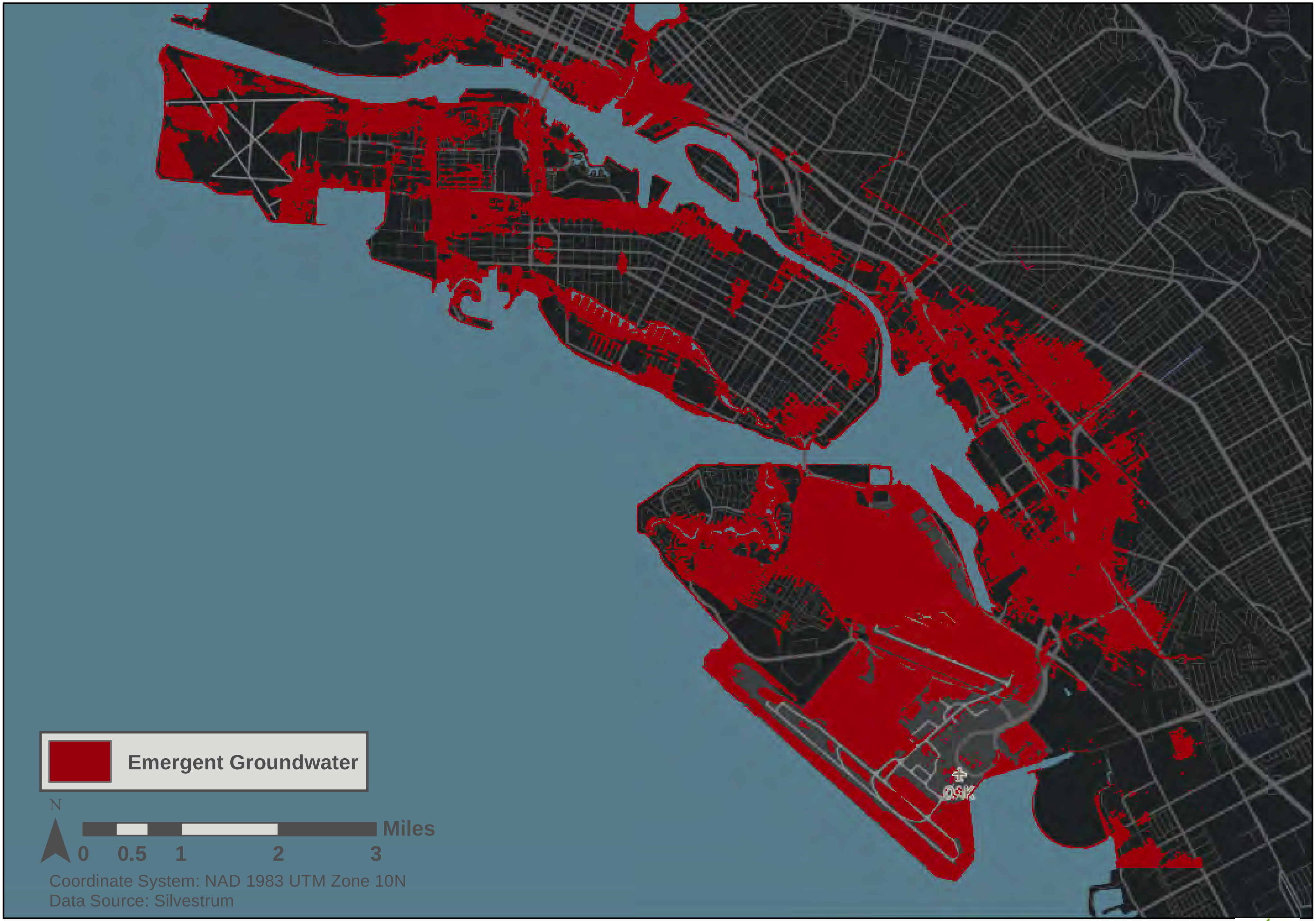


Figure 4.4 Emergent Groundwater with 36" of Sea Level Rise



Coordinate System: NAD 1983 UTM Zone 10N
Data Source: Silvestrum

Figure 4.5 Emergent Groundwater with 48" of Sea Level Rise

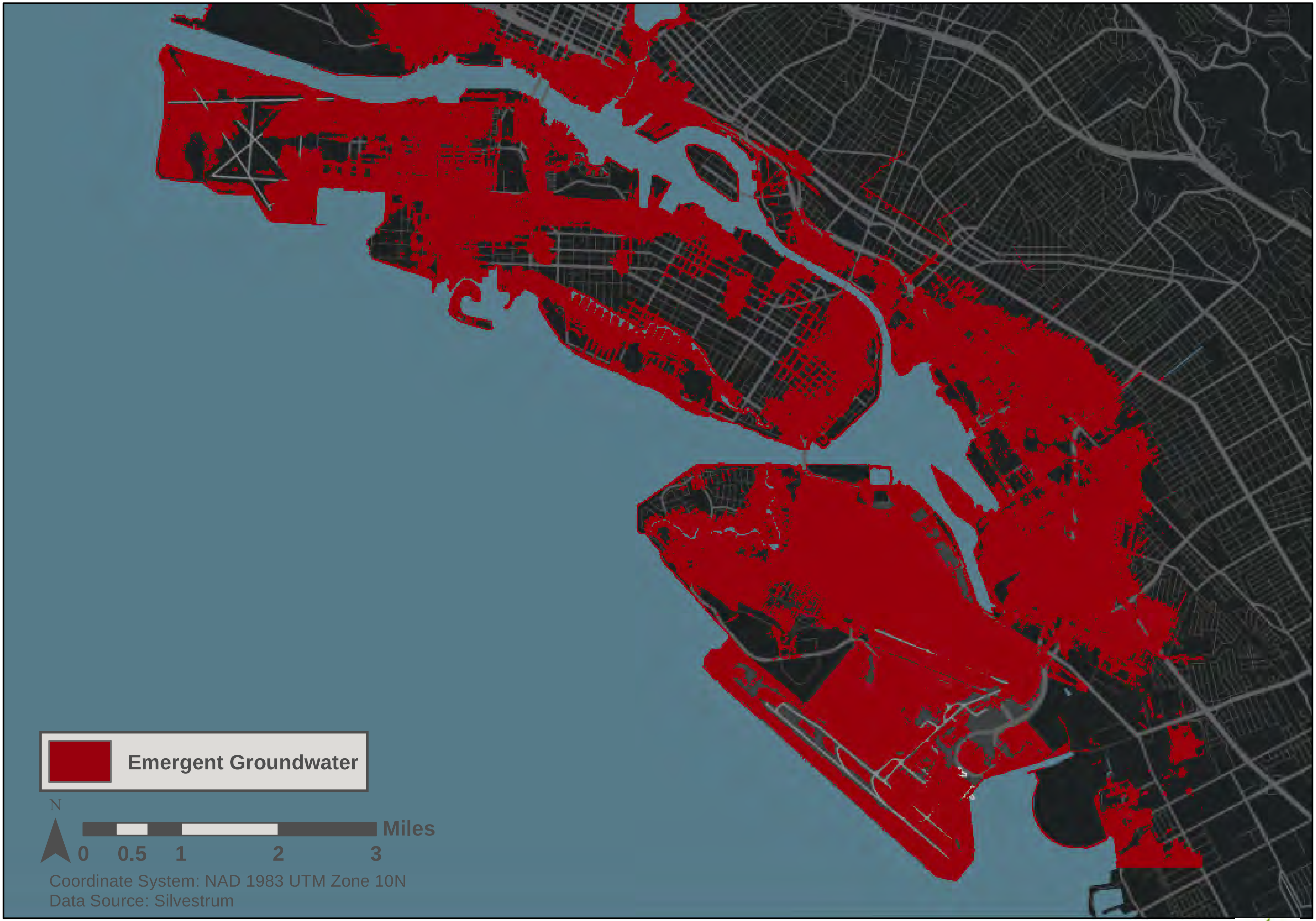


Figure 4.6 Emergent Groundwater with 66" of Sea Level Rise

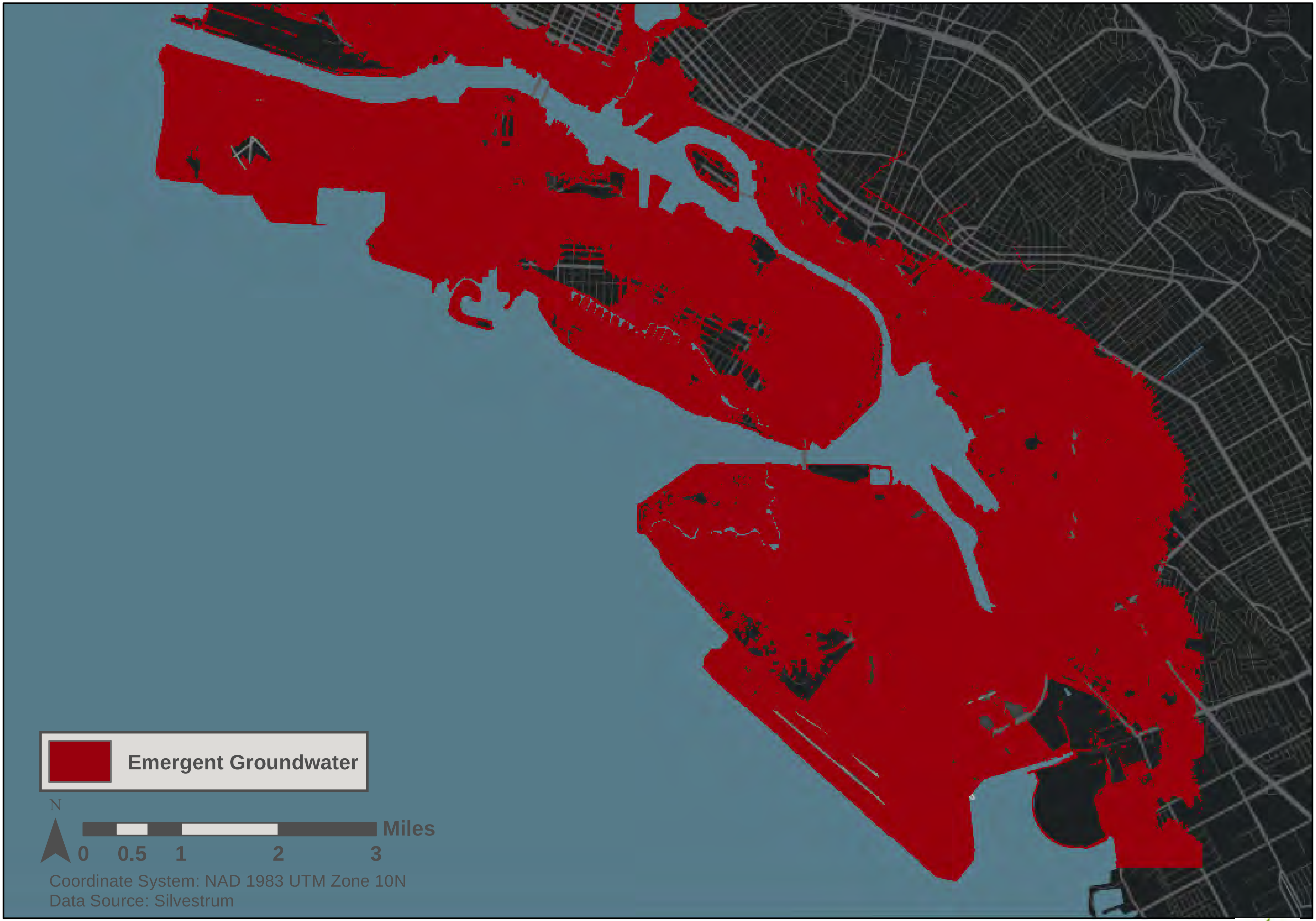


Figure 4.7 Emergent Groundwater with 108" of Sea Level Rise

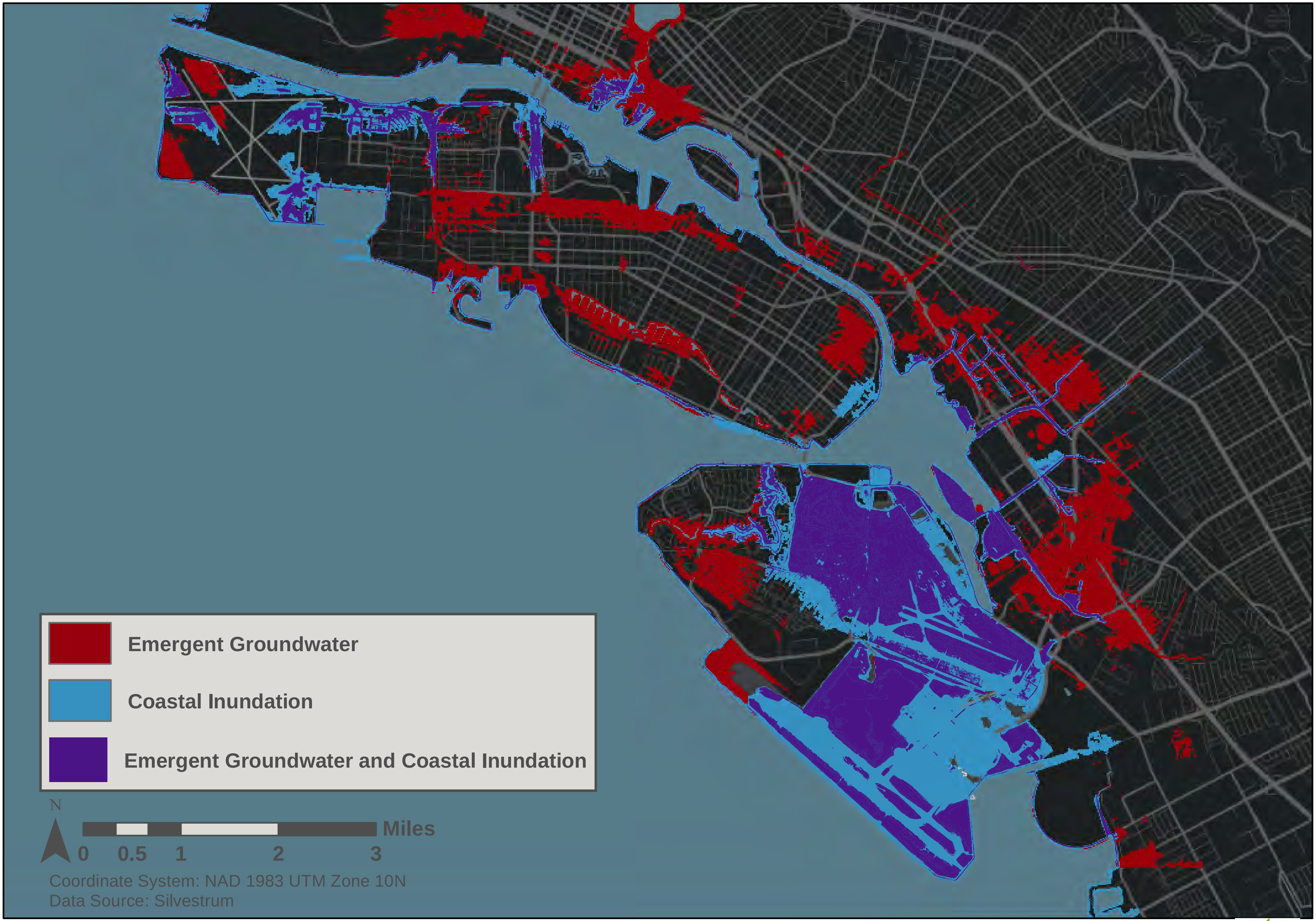


Figure 4.8 Emergent Groundwater and Sea Level Rise Inundation (36" of Sea Level Rise)

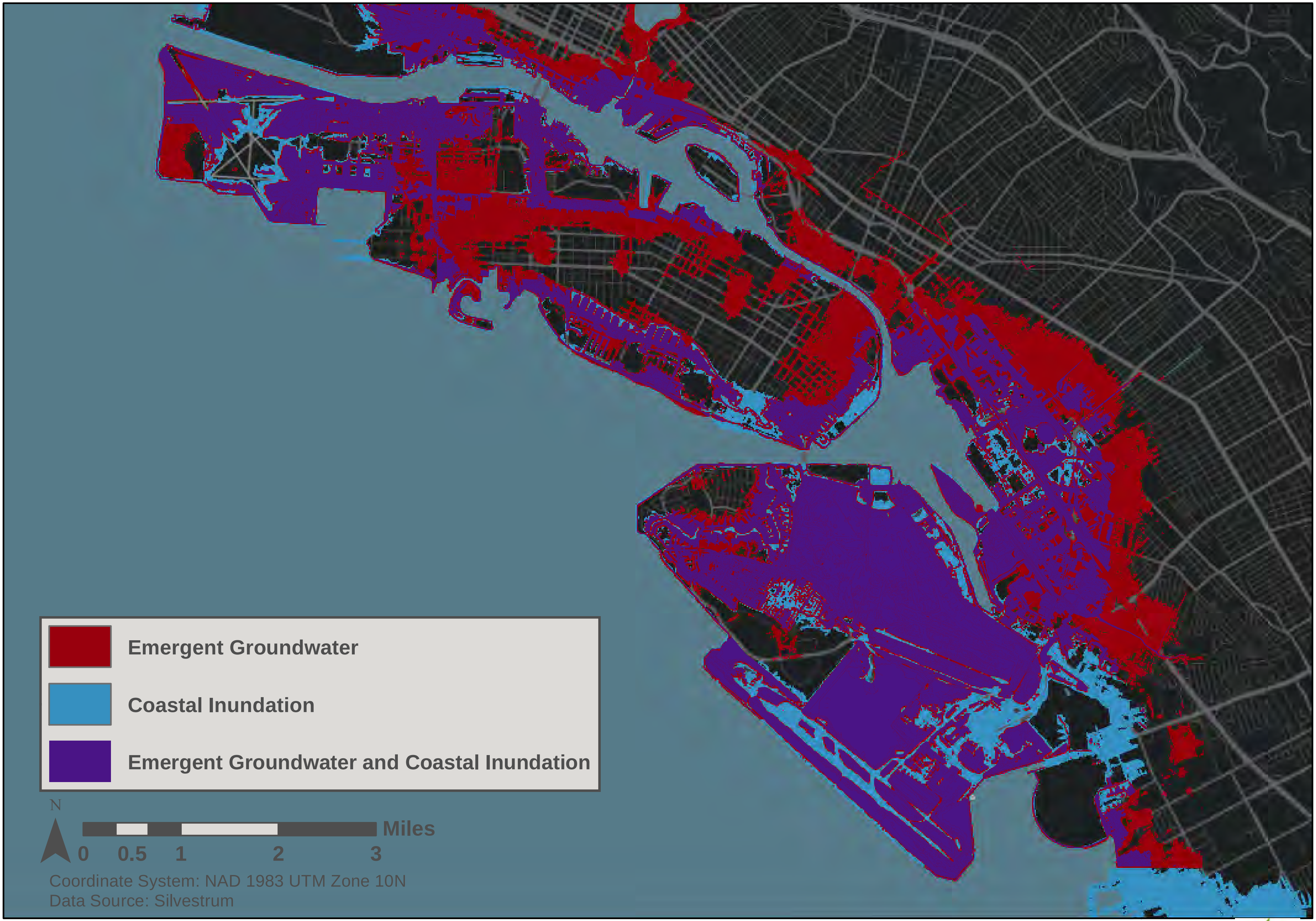


Figure 4.9 Emergent Groundwater and Sea Level Rise Inundation (66" of Sea Level Rise)

4.2 Groundwater Areas of Potential Concern

As the groundwater table rises, contaminants within the shallow groundwater will rise closer to the ground surface and may become emergent. The potential for contaminants to become emergent was assessed for the groundwater contaminants monitored at the wells in the SWRCB GAMA database (as discussed in Section 2.3 and shown in Table 2.2). Each monitoring well was evaluated individually to identify which well locations have had contaminant concentrations that exceed human health benchmarks within the past 5 years (i.e., between 2015 and 2019). The contaminant concentration at the time of groundwater emergency was estimated considering the most recent concentration, the previous concentration trend, the sea level rise scenario when groundwater becomes emergent at the well location, and an extrapolated future concentration if sufficient monitoring data was available for this estimation. Only wells with contaminant concentrations between 2015 and 2019 above human health benchmarks were included in this assessment.

- **Concentration A:** Using a conservative approach, the contaminant concentration when the groundwater first becomes emergent is assumed to be equal to the most recent measured concentration (i.e., no contaminant remediation or degradation is considered). This represents a reasonable upper bound estimate of the future contaminant concentration. The Recent Concentration (A) for wells with contaminants above human health benchmarks is presented in Table 4.1 thru Table 4.6.

- **Concentration B:** Using an alternative approach, the contaminant concentration is assumed to change over time based on the trend observed between 2000 and 2019. For example, a declining trend may be indicative of remediation efforts to date, natural degradation, and/or potential groundwater flow away from the well location. A "best fit" exponential degradation curve was fit to the observed contaminant concentration trend and projected forward to 2100. The Future Concentration presented in Table 4.1 thru Table 4.6 is also based on the timing of when the groundwater is likely to become emergent at each well[17]. If insufficient well observations are available to fit an exponential degradation curve, the Future Concentration is assumed to be equal to the Recent Concentration.

  For example, Table 4.1 shows that benzene concentrations of 13,000 µg/l were measured on 2/6/2008, and 2,300 µg/l were measured on 3/15/19 (many additional measurements occurred between this 12-year period to establish a trend). Groundwater could become emergent at this location with 12 inches of sea level rise, which is likely to occur before 2050, and potentially as early as 2035-2040[18]. Extrapolating the declining trend between 2008 and 2019 out to 2040 leads to a

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[17] Sea level rise is assumed to assumed to track with the upper end probability (1-in-200 chance) associated with the RCP 8.5 scenario presented in Rising Seas (Griggs et al. 2017) which was adopted by the State of California as best available science. RCP 8.5 1-in-200 chance is appropriate when considering the potential for high risk to public health and safety.

[18] Based on the State of California Sea Level Rise Policy Guidance, 12 to 24 inches of sea level rise is projected to occur by 2050 (CCC 2018)

potential future concentration of 1,800 µg/l for benzene when the groundwater first becomes emergent.

The following sections provide a summary of the contamination concentrations present in the SWRCB GAMA data for well locations where existing contamination concentrations are above human health benchmarks *and* the shallow groundwater table is expected to become emergent before 2100. Each location has an associated table with the potential range in future concentrations (Concentrations A and B) presented for each contaminant.

Figure 4.10 to Figure 4.17 present potential locations of concern where emergent groundwater may contain contamination. These figures are independent of the concentration values presented in Table 4.1 and Table 4.6. Each well location is colored based on the sea level rise scenario when the shallow groundwater layer could first become emergent (e.g., well locations colored red could experience emergent groundwater with 12 inches of sea level rise, whereas a well location colored purple would not experience emergent groundwater until 66 inches of sea level rise). The size of the dot represents the urgency – the larger the dot, the sooner the groundwater at that location may become emergent (e.g., the red dot showing groundwater emergent at 12 inches of sea level rise is also the biggest). Differentiating the dots based on both color and size was also necessary due to the close proximity of many of the well locations to each other.

For example, Figure 4.10 presents four well locations with benzene concentrations that currently exceed human health benchmarks. Two locations in Oakland near Bay Farm island have benzene concentrations that exceeding human health benchmarks with 12 inches of sea level rise (i.e., the two locations have large red dots). One location on the Oakland side of the High Street bridge has high benzene concentrations that could become emergent with 24 inches of sea level rise (i.e., smaller orange dot), and one location within the City of Alameda that could become emergent with 66 inches of sea level rise (i.e., smallest purple dot).

The sections below describe the locations where the monitoring wells are located, the historic land use and reason for the presence of contamination, and the remediation activities that have taken place (if available). All information presented in this section is publicly available on the SWRCB GeoTracker Groundwater Information System website.[19]

4.2.1 Gibbons Drive, Fernside Boulevard, and High Street

A former commercial petroleum fueling facility was once located near the intersection of Gibbons Drive, Fernside Boulevard, and High Street near the High Street Bridge. The facility began operations in 1930 and was demolished in 1986. An unauthorized release of contamination was reported during the demolition following the removal of five underground storage tanks (two with waste oil and three with gasoline). A single-family residence was constructed on the site in 1989.

Environmental monitoring began in 1986 and has continued to the present with ten groundwater monitoring wells. Several rounds of soil sampling have occurred, and soil vapor and indoor air pollution were monitored

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[19] https://gamagroundwater.waterboards.ca.gov/gama/gamamap/public/Default.asp

at the single-family residence in 2018. Contaminants of concern at this location include **benzene**, diesel, gasoline, lead, methane, other petroleum, **toluene**, xylene, ethylbenzene, and naphthalene (only the bolded contaminants are assessed in this report, the other contaminants of concern at this location are noted for information only). Multiple remediation actions have been implemented, including aeration of the soil, groundwater pump and treat, oxygen injections, hydrogen peroxide injections, and groundwater batch extractions. Additional corrective actions are warranted and are presented in a Corrective Action Plan dated August 19, 2019, including the installation of vapor mitigation measures for the single-family residence.

Table 4.1 presents the maximum measured concentrations, most recent measured concentrations, and the projected future concentration of the contaminants with 12 inches of sea level rise. Toluene is likely to be below the human health benchmark (i.e., both Concentration A and B are below this benchmark), while benzene is anticipated to remain above the human health benchmark (i.e., both Concentration A and B remain above this benchmark). The depth to the groundwater table varies between 0.5 feet and 6 feet below the ground surface, and emergent groundwater first occurs at this location with 12 inches of sea level rise. Benzene is the contaminant that is most likely to remain above the human health benchmark based on current trends. However, remediation efforts are continuing and may become more effective.

Table 4.1 Contaminant Concentrations at Gibbons Drive, Fernside Boulevard, and High Street

Contaminant	Benchmark Concentration (µg/l)	Maximum Concentration (µg/l)	Date	Concentration A (µg/l)	Date	Concentration B at 12” SLR
Benzene	1	13,000	2/6/2008	2,300	3/15/2019	1,800
Toluene	150	5,300	11/27/2001	60[1]	3/15/2019	10

[1] Toluene concentrations have fluctuated up and down significantly since 2012, but have generally stayed below 1000 (µg/l)

4.2.2 Clement Avenue and Chestnut Street

This location is currently occupied by the Next Level Softball and Baseball Academy. TCE and PERC/PCE were detected in soil vapor and groundwater at this location, and a phytoremediation project was implemented in June 2005. Groundwater monitoring has continued to assess the effectiveness of the phytoremediation project. The historic use that led to this contamination is not listed on the GeoTracker website; however, the responsible party is listed as the Cargill Salt Company and the investigation began in 1993.

Table 4.2 presents the maximum measured concentrations, the most recent measured concentrations (Concentration A), and the projected future concentration (Concentration B) of the contaminants with 12 inches of sea level rise. For PERC/PCE, both Concentration A and B are above the human health benchmark, suggesting additional remediation may be necessary. For TCE, Concentration A is above the benchmark, while Concentration B is just below the benchmark. The depth to groundwater at this location varies between approximately 1 foot and 7.5 feet, and emergent groundwater first occurs at this location with 12 inches of sea level rise. Both PERC/PCE and TCE are declining with the most significant decline occurring for PERC/PCE. Remediation efforts are still in progress at this location; therefore, it is possible that the "best fit" trend approach for estimating the future Concentration B may underestimate the effectiveness potential for continued remediation success.

Table 4.2 Contaminant Concentrations at Clement Avenue and Chestnut Street

Contaminant	Benchmark Concentration (µg/l)	Maximum Concentration (µg/l)	Date	Concentration A (µg/l)	Date	Concentration B at 12" SLR
PERC/PCE	5	7,700	3/3/2005	24	2/28/2019	12
TCE	5	81	3/3/2005	8.4	2/28/2019	4.2

4.2.3 2900 Main Street

In April 1990, four underground storage tanks and approximately 50 cubic yards of contaminated soil was removed and disposed of offsite. Elevated levels of petroleum hydrocarbon contamination were detected in the soil and groundwater during the removal. Groundwater monitoring wells were installed in 1992. Significant levels of contamination were still present in 2001. Between December 2016 and January 2017 approximately 20,000 gallons of contaminated groundwater was pumped from the site and processed through an on-site treatment system at the Bay Ship & Yacht wastewater treatment facility and disposed of under their facility permitted waste discharge requirements. Approximately 485 cubic yards of contaminated soil was excavated and disposed of offsite.

Additional groundwater monitoring in September 2017 did not show elevated levels of petroleum hydrocarbon contamination. However, the concentration of manganese that was measured exceeded the human health benchmark (see Table 4.3). No additional monitoring or remediation efforts are noted by the SWRCB; therefore, Concentration B is assumed equal to Concentration to A. Additional monitoring may be warranted at this location.

Table 4.3 Contaminant Concentrations at 2900 Main Street

Contaminant	Benchmark Concentration (µg/l)	Maximum Concentration (µg/l)	Date	Concentration A (µg/l)	Date	Concentration B at 12" SLR
Manganese	50	1,200	9/7/2017	1,200	9/7/2017	1,200

4.2.4 Park Street and Blanding Avenue

From 1930 until approximately 1961, a petroleum bulk plant was operated at this location. The bulk plant was removed between 1957 and 1963. The site later served as a construction materials yard, and from 1973 to 1983 the site was reportedly used for boat repair activities. In 1995, soil and groundwater investigations were conducted at the site and petroleum hydrocarbons were detected in the soil and groundwater. Eight groundwater monitoring wells were installed to monitor groundwater contamination. The primary contaminants of concern at this location include **benzene**, diesel, ethylbenzene, gasoline, **toluene**, and xylene (only the bolded contaminants are assessed in this report, the other contaminants of concern at this location are noted for information only).

Table 4.4 presents the maximum measured concentrations, the most recent measured concentrations (Concentration A), and the projected future concentration (Concentration B) of the contaminants with 48 inches of sea level rise. Emergent groundwater first occurs at this location with 48 inches of sea level rise. Both benzene and toluene appear to have been successfully remediated at this location. However, concentrations of diesel and gasoline, which were not evaluated in this assessment, remain elevated at this location.

Table 4.4 Contaminant Concentrations at Park Street and Blanding Avenue

Contaminant	Benchmark Concentration (µg/l)	Maximum Concentration (µg/l)	Date	Concentration A (µg/l)	Date	Concentration B at 48” SLR
Benzene	1	1,300	1/18/2012	0	8/14/2019	0
Toluene	150	22	10/28/2010	0	8/14/2019	0

4.2.5 Webster Street and Buena Vista Avenue

This site is a 7,000 square foot parcel located on the southeastern corner of the intersection of Webster Street and Buena Vista Avenue. A commercial fueling station has operated at this location since 1948. On September 6, 2013, a 1,000-gallon waste oil underground storage tank was removed, and soil and groundwater sampling indicated that an unauthorized release had occurred. Contaminants of concern at this location include acetone, **benzene**, ethylbenzene, gasoline, **MTBE**, naphthalene, xylene, **TBA**, and other contaminants (only bolded contaminants are assessed in this report, the other contaminants of concern at this location are noted for information only). Under the current land use, except for limited areas along the eastern property margin and several additional minor landscaped areas, the site is entirely paved resulting in a low potential for direct contact exposure. Although concentrations remain above human health benchmarks for benzene and other contaminants, the case was closed. This case would need to be re-investigated if the land use is changed or redevelopment occurs.

This site is also approximately one block from an active commercial service station located at 1601 Webster Street. In August 2004, a 10,000-gallon underground storage tank was accidentally punctured during station upgrades, releasing an estimated 2,048 gallons of gasoline. Emergency response efforts recovered approximately 1,997 gallons of gasoline within three months following the release. Groundwater monitoring continued through 2015 and indicated that a MTBE contaminant plume from the former gas station located at 1629 Webster Street had migrated to this location. At this location, MTBE could be found in emergent groundwater with 66 inches of sea level rise (see Figure 4.12). Multiple contaminant plumes have likely co-mingled along this stretch of Webster Street.

Table 4.5 presents the maximum measured concentrations and the most recent measured concentrations (Concentration A) of contaminants. Due to the limited length of monitoring, projected future concentrations with 48 inches of sea level rise could not be reasonably extrapolated; therefore, Concentration B is assumed to equal Concentration A. Since remediation efforts have ceased, the most recent concentrations measured in 2018 are assumed to remain in place. Emergent groundwater first occurs at this location with 48 inches of sea level rise. The depth to the groundwater table varies between approximately 4 feet and 8.5 feet below the ground surface. Benzene is the contaminant that is most likely to remain above the human health benchmark based on current trends. No additional remediation is planned, and all cases along this stretch of Webster Street are closed. Due to the complexity of past groundwater contamination and the number of service stations in this area, and the measured concentrations in 2018 for benzene and MTBE, continued monitoring may be warranted. TBA appears to have been remediated as it is no longer found at this location.

Table 4.5 Contaminant Concentrations at Webster Street and Buena Vista Avenue

Contaminant	Benchmark Concentration (µg/l)	Maximum Concentration (µg/l)	Date	Concentration A µg/l)	Date	Concentration B at 48" SLR
Benzene	1	71.6	8/30/2018	71.6	8/30/2018	71.6
MTBE	13	51.3	2/25/2016	12.1	8/30/2018	12.1
TBA	12	34.5	2/25/2016	0	8/30/2018	0

4.2.6 Park Street and Buena Vista Avenue

In April 1994, four underground storage tanks containing gasoline and diesel were removed from the parcel at 1701 Park Street, and a fifth underground storage tank containing heating oil was removed from the adjacent parcel at 2329 Buena Vista Avenue. Multiple groundwater monitoring wells were installed, and soil and groundwater samples have been collected since 1994. Numerous remedial actions and pilot studies have been implemented at this location but have not been effective at reducing the concentrations below human health benchmarks. However, most contaminant concentrations have generally decreased since 2005. Ozone injection is the next remedial action to be implemented. Multiple contaminants of concern are present at this location, including **iron**, **benzene**, diesel, **MTBE**, **TBA**, **PERC/PCE**, **TCE**, gasoline, heating oil, **toluene**, xylene, ethylbenzene, and naphthalene (the bolded contaminants are assessed in this report, the other contaminants of concern at this location are noted for information only).

Table 4.6 presents the maximum measured concentrations, the most recent measured concentrations (Concentration A), and the projected future concentration (Concentration B) of contaminants with sea level rise (five contaminants with 66 inches and two contaminants with 52 inches of sea level rise). Emergent groundwater first occurs at this location between 52 inches and 66 inches of sea level rise, depending on the location within the parcel. The depth to the groundwater table varies between 4.5 feet and 8.5 feet below the ground surface. Benzene, PERC/PCE, and TCE are all likely to remain above the human health benchmark based on existing concentration levels (Concentration A) and projected future concentrations

(Concentration B). Concentrations of iron and MTBE are challenging to estimate at this location due to past fluctuations; however, given the overall past trends, it is likely that Concentration B will be below the human health benchmarks before the groundwater becomes emergent. Remediation efforts at this location are ongoing and may become more effective over time. Given the fluctuations observed in the MTBE contaminant concentrations, additional monitoring wells over a larger geographic area could clarify groundwater plume movement in this area.

Table 4.6 Contaminant Concentrations at Park Street and Buena Vista Avenue

Contaminant	Benchmark Concentration (µg/l)	Maximum Concentration (µg/l)	Date	Concentration A (µg/l)	Date	Concentration B at 66” SLR
Iron	300	370,000	6/19/2014	4,700	6/18/2015	< 300
Benzene	1	8,800	1/4/2006	2,100	3/7/2019	200
MTBE	13	6,200	9/8/2006	130[1]	3/7/2019	< 13
TBA	12	17,000	2/25/2009	0	3/7/2019	0
Toluene	150	8,200	9/12/2005	0	3/7/2019	0
						Concentration B at 52” SLR
PERC/PCE	5	1,000	6/18/2015	730	3/7/2019	110
TCE	5	570	10/3/2014	320	3/7/2019	85

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[1] MTBE concentrations have fluctuated up and down between 1000 µg/l and 0 µg/l since 2011

Figure 4.10 Wells (Iron > HHB, 2015 – 2019) within Emergent Groundwater

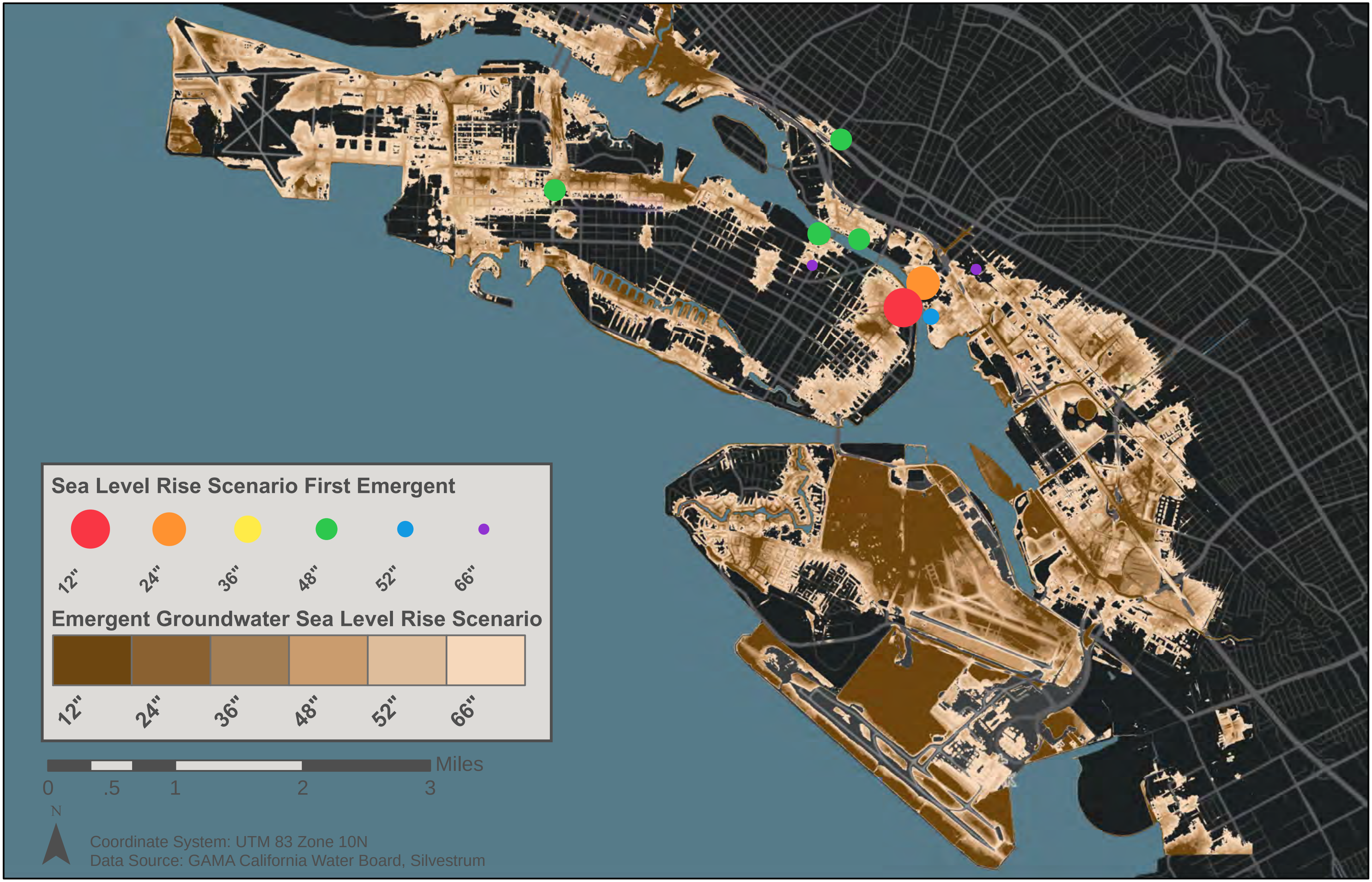


Figure 4.11 Wells (Benzene > HHB, 2015 – 2019) within Emergent Groundwater

Figure 4.12 Wells (MTBE > HHB, 2015 – 2019) within Emergent Groundwater

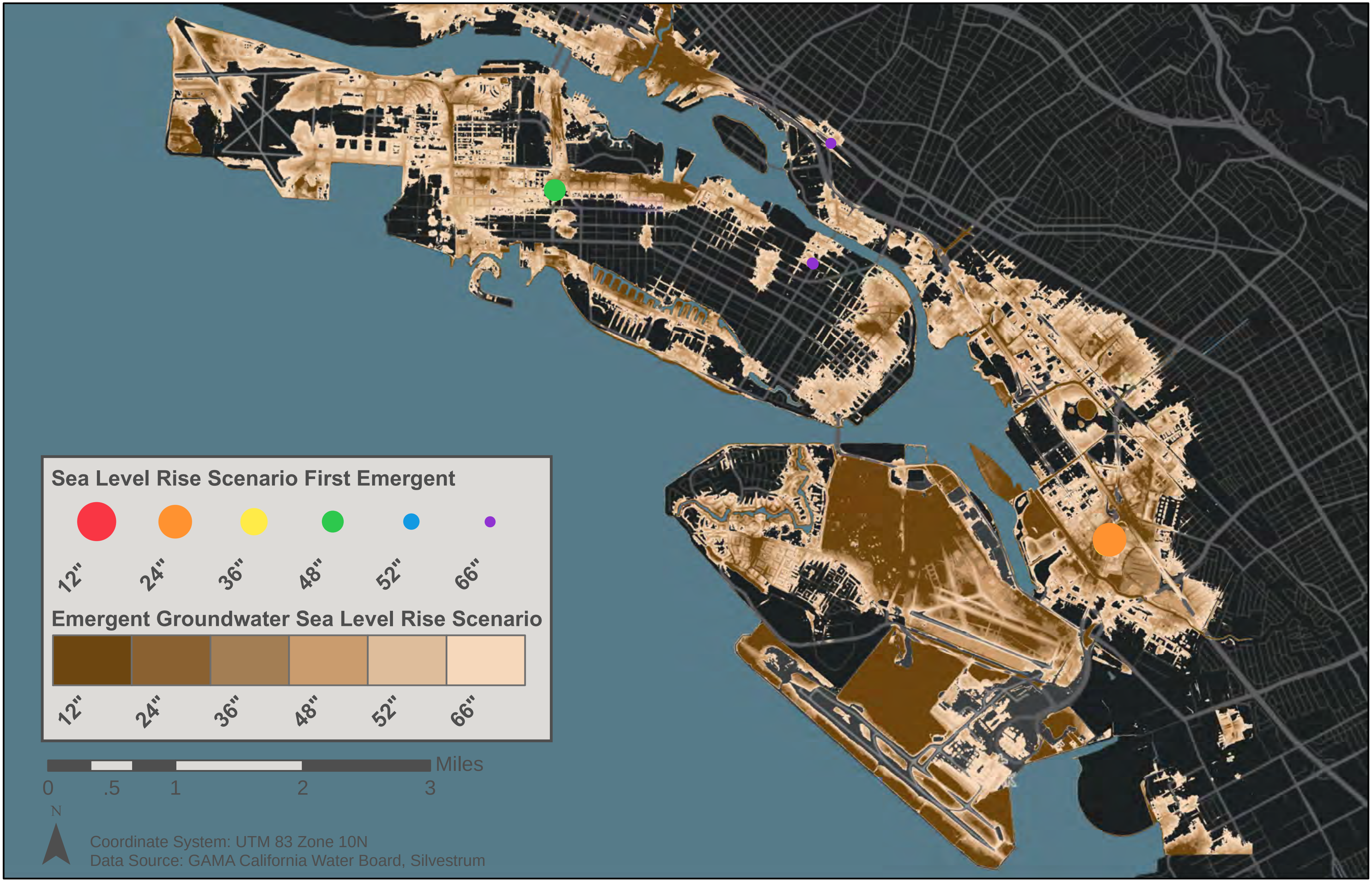


Figure 4.13 Wells (TBA > HHB, 2015 – 2019) within Emergent Groundwater

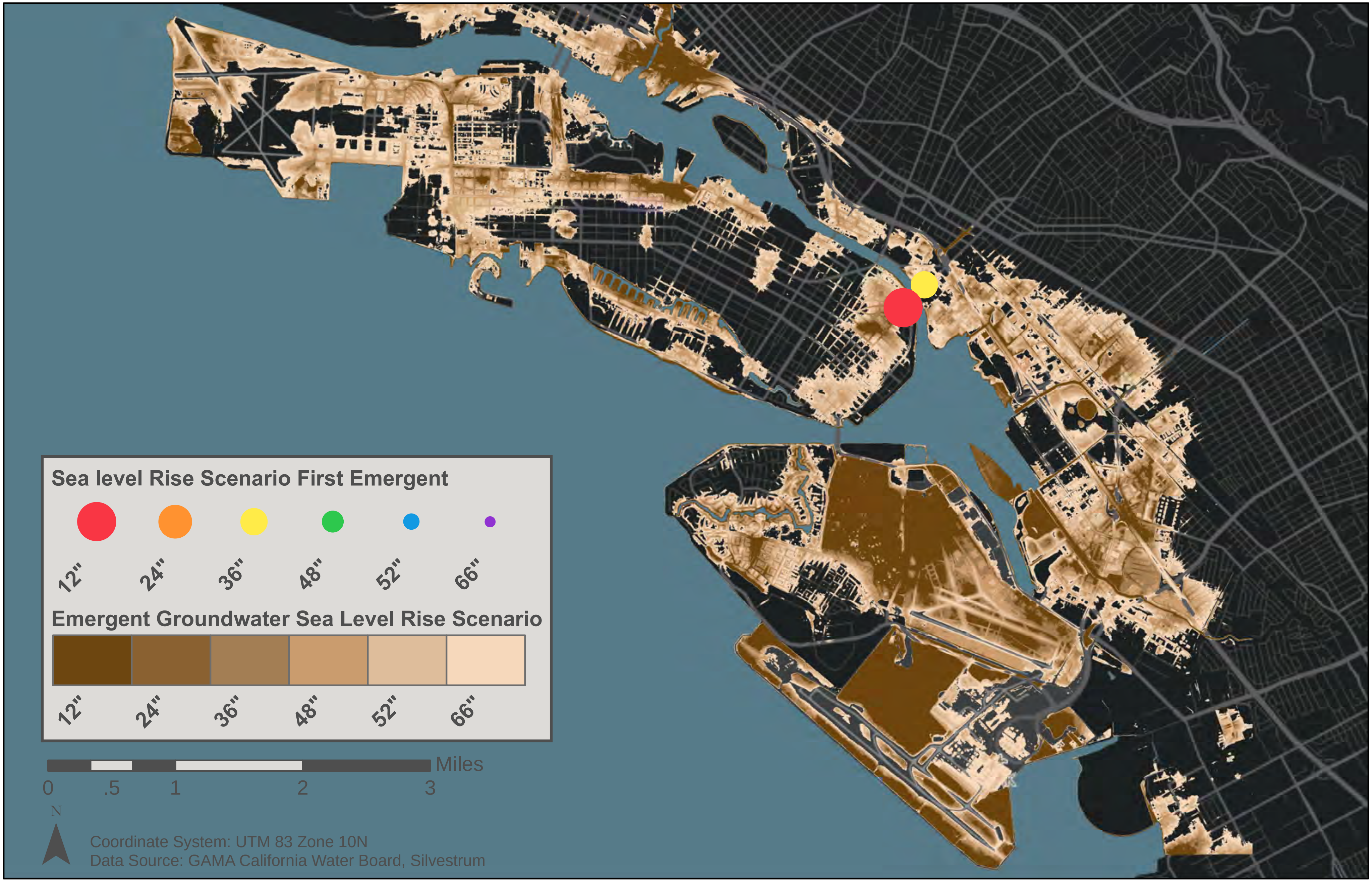
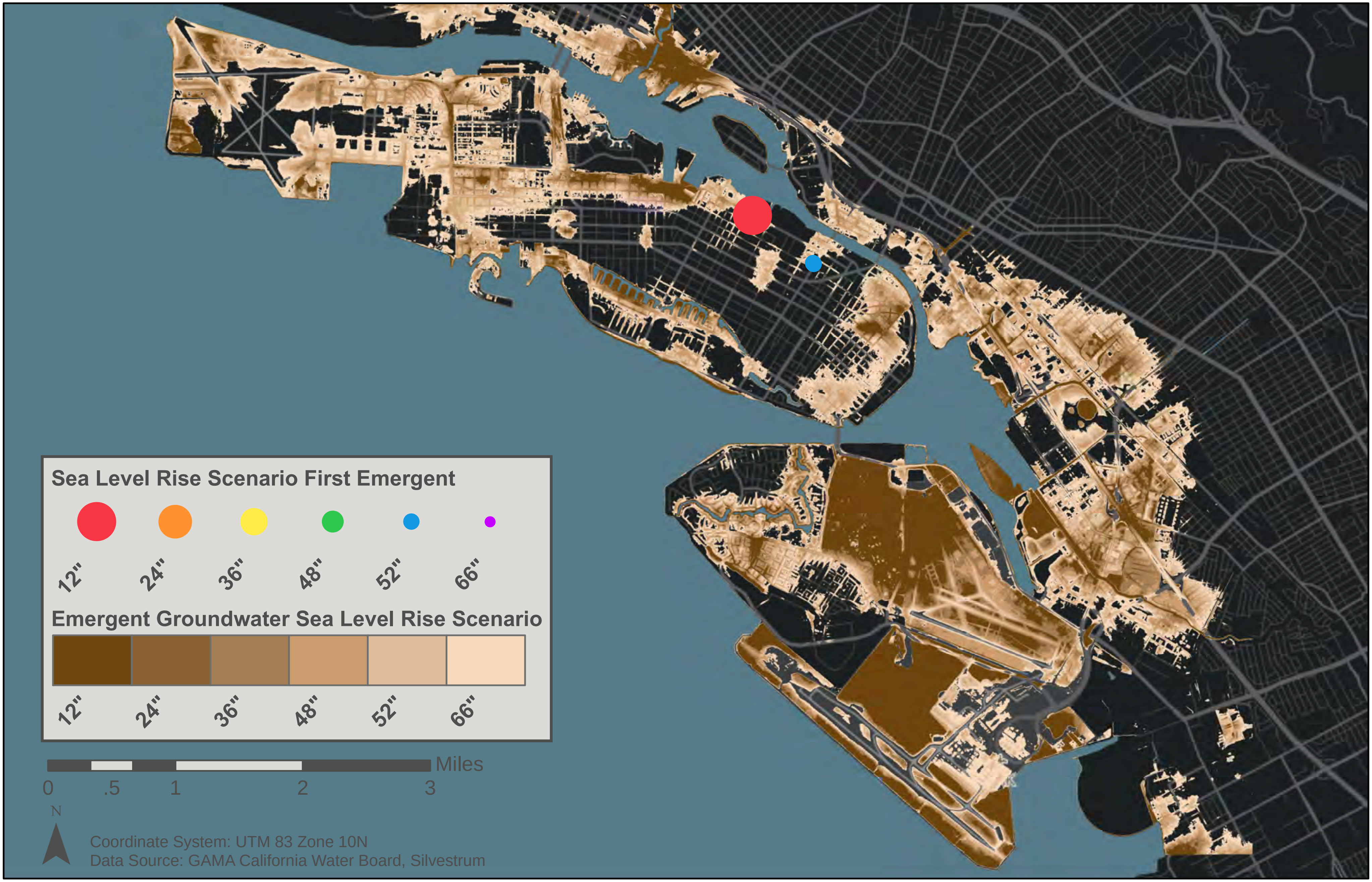


Figure 4.14 Wells (Toluene > HHB, 2015 – 2019) within Emergent Groundwater



Coordinate System: UTM 83 Zone 10N
Data Source: GAMA California Water Board, Silvestrum

Figure 4.15 Wells (TCE > HHB, 2015 – 2019) within Emergent Groundwater

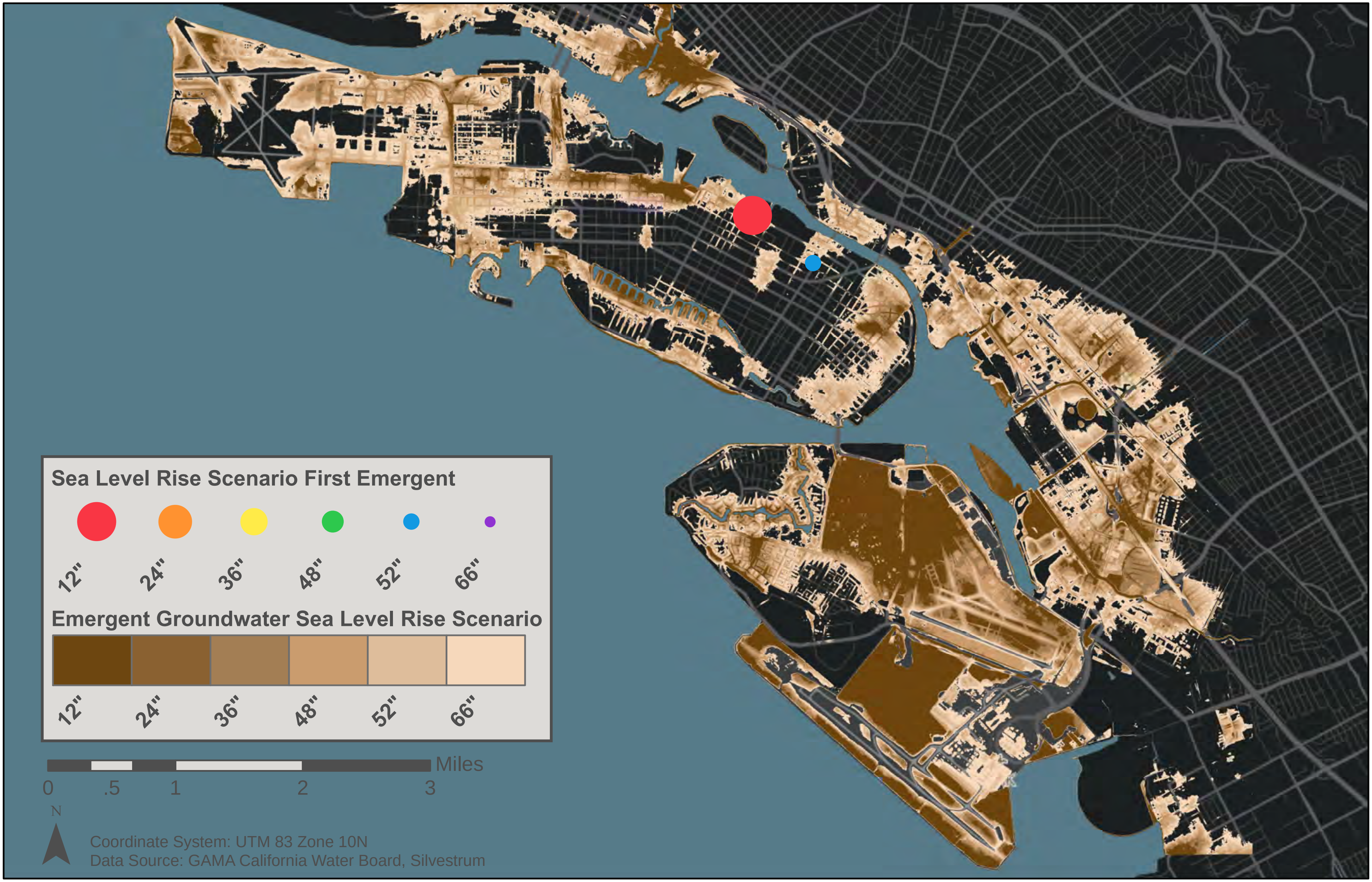
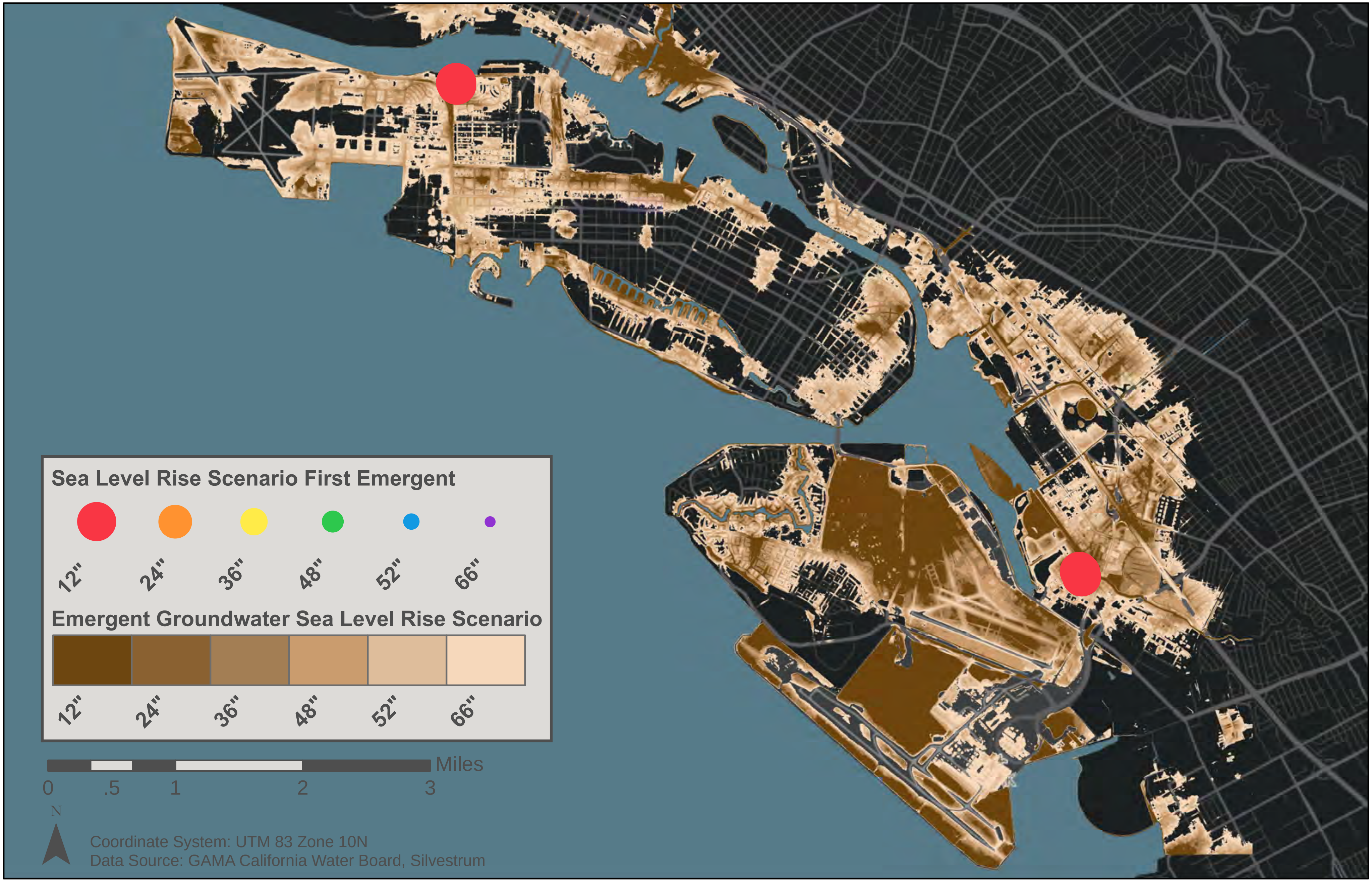


Figure 4.16 Wells (PERC/PCE > HHB, 2015 – 2019) within Emergent Groundwater



Coordinate System: UTM 83 Zone 10N
Data Source: GAMA California Water Board, Silvestrum

Figure 4.17 Wells (Manganese > HHB, 2015 – 2019) within Emergent Groundwater

4.3 Contaminated Lands of Potential Concern

Most of the contaminated lands (see Section 2.6) have either had clean-up efforts completed, or are in the process of having the contaminants found in the soil and groundwater cleaned-up (see remediation status, Table 2.3). However, residual (i.e., legacy) contaminants often remain on sites after remediation efforts are complete. Institutional controls such as land-use restrictions, soil disturbance restrictions, monitoring requirements, etc. will remain in place indefinitely if contamination is detectable above defined thresholds. Institutional controls are intended to protect human health and/or the environment, reducing the risk of human and environmental exposure to residual contamination; thereby allowing the site to be re-developed for an appropriate land use. However, institutional controls are developed based on existing conditions, and they do not consider the changing environmental conditions that could occur with climate change. As the groundwater table rises in response to sea level rise, residual contaminants could be re-mobilized and brought to the surface. In some cases, this re-mobilization could create a human health or environmental hazard. As awareness increases in the regulatory community, remediation methods and institutional controls may be revised to better consider a changing climate and related hazards.

The primary institutional controls, and their effectiveness when rising groundwater and emergent groundwater are considered, include:

- **Land use restrictions:** The type of land use allowed on a remediated site depends on the residual contaminant concentrations. In most instances, complete contamination removal is challenging and costly; therefore, some level of contamination will likely remain.
    - Re-development that includes residential housing, schools, and/or hospitals requires a high degree of contaminant removal (i.e., minimal legacy or residual contamination is present). These land uses could expose households, children, and people with compromised immune systems to chronic harmful exposure if contaminants above human health benchmarks are present and mitigation measures (e.g., vapor intrusion barriers) cannot reduce the health risk. These land uses are not allowed if contamination concentrations remain above a certain benchmark.

      If a site is remediated with minimal residual contamination and re-developed for these land uses, the rising groundwater table will result in a minimal risk of contaminant exposure. If a site is remediated and redeveloped for these land uses with mitigation measures required (e.g., vapor intrusion barriers or venting systems), the rising groundwater table may increase the human exposure risk over time. Ongoing monitoring should be required to monitor changes in the water table and contaminant concentrations to assess changes in health risks.
    - Re-development that includes commercial or industrial land use (e.g., retail, office space, hotel, machine shop, manufacturing facility) can have a higher concentration of legacy or residual contamination remaining on site. Residual contamination levels and human health exposure risks are typically based on adult exposure (e.g., employees). Use of these facilities by children, seniors, and people with compromised immune systems is generally more transitory, reducing the likelihood of chronic exposure. If residual contamination

concentrations are above the threshold(s) that prohibit residential housing, the rising groundwater table may increase the human exposure risk over time. Ongoing monitoring should be required to monitor changes in the water table and contaminant concentrations to assess changes in health risks.

- **Soil disturbance restrictions:** If soil below a certain depth (typically greater than 3 feet) remains contaminated, or if contaminants could be re-mobilized with activities such as excavation for utility maintenance that requires soil excavation (e.g., trenching) or large tree planting, institutional controls will restrict soil disturbance. The institutional controls may establish procedures, such as obtaining a permit and conducting soil and groundwater sampling, if soil excavation and disturbance are required. All sites with soil disturbance restrictions could exhibit an increased human health risk as the groundwater table rises. The increase in health risks will vary based on the contaminant; its affinity to soil, water, or air; and its concentration. Ongoing monitoring should be required to monitor changes in the water table and contaminant concentrations to assess changes in health risks.
- **Monitoring:** In general, most remediated sites require (at least) annual monitoring if residual concentrations of contaminants remain above levels that allow for unlimited use and unrestricted exposure. The need for ongoing monitoring is generally reviewed every five years to ensure protection of human health and the environment. Regular monitoring should also consider the changing water table elevation and its potential effect on the contaminants. Any potential increase in health risks will vary based on the contaminant; its affinity to soil, water, or air; and its concentration.

> *Regular monitoring should consider the changing water table elevation and its potential effect on the contaminants.*

Table 4.7 presents the contaminated sites, the remediation method(s) used, the institutional control(s) that remain in place, and the status of the remediation efforts (reproduced from Table 2.3). For most contaminated sites, residual contamination remains in the soil and/or groundwater, requiring institutional controls to protect humans and the environment from potential contaminant exposure. For the sites without completed remediation efforts, the best available information on the remediation timeline is included as a footnote. Table 4.7 also presents the size of the contaminated site in acres, and average (i.e., mean) depth to groundwater during summer conditions and minimum depth to groundwater that generally occurs after a heavy rainfall event. Based on the winter season groundwater table elevation, the percentage of the site that could be flooded with emergent groundwater was calculated for each sea level rise scenario evaluated (from 12-inches to 108-inches).

Table 4.7 presents a qualitative risk assessment for potential human (H) and environmental (E) exposure to contaminants in emergent groundwater. Additional details on each site are presented below Table 4.7). As noted in 2.6, additional contaminated sites are likely located within the City of Alameda and in various stages of contamination identification or remediation due to Alameda's industrial and military past. Therefore, Table 4.7 is not a comprehensive evaluation of all potential contamination site in the city.

Table 4.7 Groundwater Exposure of Contaminated Lands

ID	Site	Remediation Method				Institutional Controls				Contaminated Emergent Groundwater Risk	Acres	Existing Depth to Water (feet)		Percent of Site with Emergent Groundwater						
		Excavation and Removal	In situ Treatment	Capping	Complete (Y/N)	Land-use Restrictions	Soil Disturbance Restrictions	Vapor Barrier Required	Monitoring			Mean	Min.	12”	24”	36”	48”	52”	66”	108”
Alameda Naval Air Station																				
1	*- 1943 – 1965 Disposal Area*	x			Y	x	x		x	Moderate (E)[1]	78	5.1	0	1%	4%	20%	42%	51%	76%	98%
2	*- West Beach Landfill and Wetlands*	x	x		Y	x	x		x	High (E)	110	5.1	0	15%	24%	34%	44%	47%	57%	81%
3	*- Operational Unit 2A*		x		Y			x	x	Moderate/Low (H)[2]	39.1	5.5	1.0	–	–	2%	11%	14%	43%	100%
4	*- Operational Unit 2B*		x		N[20]				x	Moderate/Low (H)	33.2	5.2	2.4	–	–	–	7%	14%	61%	100%
5	*- Operational Unit 5*	x			N[21]	x	x		x	Low (H)	12	5.3	0	1%	5%	12%	29%	38%	76%	100%
6	Alameda East Housing				Y		x		x	Low (H)	87[7]	5.3	0.8	–	–	2%	12%	19%	58%	100%
7	Jean Sweeney Open Space Park	x		x	Y	x			x	High (E, H)	25	7.6	0	2%	10%	15%	20%	21%	26%	58%
Fleet and Industrial Supply Center and Alameda Navy Supply Center Annex (FISCA)																				

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[20] Remediation completion will likely take 25 to 30 years (see Section 2.6.1)

[21] Remediation completion data was not readily found (see Section 2.6.1)

ID	Site	Remediation Method				Institutional Controls				Contaminated Emergent Groundwater Risk	Acres	Existing Depth to Water (feet)		Percent of Site with Emergent Groundwater						
		Excavation and Removal	In situ Treatment	Capping	Complete (Y/N)	Land-use Restrictions	Soil Disturbance Restrictions	Vapor Barrier Required	Monitoring			Mean	Min.	12”	24”	36”	48”	52”	66”	108”
8	*- Shinsei Gardens*	x		x	Y			x	x	Low (H)	2.5	9.0	4.6	–	–	–	–	–	1%	45%
9	*- Stargell Commons*	x			Y		x	x	x	Low (H)	1.1	8.1	4.9	–	–	–	–	–	4%	79%
10	*- Cadence and Linear*	x	x[22]		N[23]				x	Moderate (H)	3.5	8.1	2.9	–	–	–	–	6%	19%	68%
11	*- Symmetry*[24]	-	-	-	N[25]					Moderate (H)	4.2	7.4	1.9	–	–	1%	4%	9%	27%	72%
12	*- Target Parcel*	x		x	Y	x	x	x	x	Moderate (H)	10.3	9.3	1.6	–	–	6%	12%	16%	24%	43%
13	*- Retail Center*	x		x	Y	x	x		x	Moderate (H)	13.7	8.4	2.4	–	–	4%	11%	13%	22%	62%
14	Pennzoil Company				N[26]					Unknown	4.1	3.6	2.2	–	–	12%	81%	94%	100%	100%
15	Kem Mil Co	x		x	N[27]					Unknown	0.1	3.9	0.8	–	–	–	–	–	96%	100%

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[22] This site is underlain by benzene and naphthalene plume that is being remediated with in situ groundwater treatment. The long-term institutional controls are still being assessed. See Section 2.6.4.

[23] Remediation completion is estimated by 2021. See Section 2.6.4.

[24] The remediation methods and institutional controls were not readily found. See Section 2.6.4.

[25] Remediation completion is estimated by 2020. See Section 2.6.4.

[26] This site remains in use by the Pennzoil Company and remediation has not begun. Remediation may not occur until this site is transitioned to an alternate land use. See Section 2.6.5.

[27] Contamination remains onsite. The need for additional remediation is unknown. See Section 2.6.6

ID	Site	Remediation Method				Institutional Controls				Contaminated Emergent Groundwater Risk	Acres	Existing Depth to Water (feet)		Percent of Site with Emergent Groundwater						
		Excavation and Removal	In situ Treatment	Capping	Complete (Y/N)	Land-use Restrictions	Soil Disturbance Restrictions	Vapor Barrier Required	Monitoring			Mean	Min.	12”	24”	36”	48”	52”	66”	108”
16	Alameda Naval Operation Center	x			Y	x			x	Low (H)	12	9.0	4.6	–	–	–	–	–	1%	45%
17	2100 Clement Ave.	x			Y					Low (H)	2.8	6.9	3.5	–	–	–	–	1%	10%	100%
Former J.H. Baxter Property																				
18	*- Dutra-Velodyne Property*				N[28]					Low (H)	4.1	10.7	1.0	–	–	–	–	–	–	5%
19	*- Extra Space Storage*	x			N[29]					Low (H)	4.1	11.0	8.8	–	–	–	–	–	–	–
20	*- Fox-Collins Property*	x		x	N[30]					Low (H)	4.1	11.1	6.1	–	–	–	–	–	–	1%
21	Lincoln Avenue Affordable Housing	x			Y					Low (H)	0.5	6.4	4.3	–	–	–	–	–	9%	100%
22	Doolittle Landfill[31]			x	Y					Unknown	40	27.2	0	–	1%	2%	5%	6%	10%	16%

[1] E = Primary exposure risk is to the environment and wildlife (e.g., the site has been designated as a nature preserve or open park space)

[2] H = Primary exposure risk is to humans (e.g., the site has been re-developed for commercial, residential, or recreational use)

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[28] Remediation efforts have not begun; remediation is expected to begin soon. See Section 2.6.9.

[29] Limited remediation completed; remediation is expected to begin soon. See Section 2.6.9.

[30] Remediation is in progress. The completion date is unknown, and institutional controls will likely be required. See Section 2.6.9.

[31] Institutional controls may be required to convert the landfill for alternative land use. See Section 2.6.11

4.3.1 Alameda Naval Air Station

The following contaminated sites listed in the DTSC database were evaluated relative to rising groundwater. Additional areas on the Alameda Naval Air Station property may (or may not) have contamination concentrations that exceed human health benchmarks; however, only the subareas recorded in the DTSC database were included in this assessment.

- **1943 – 1965 Disposal Area:** The risk of emergent contaminated groundwater on the environment is considered **moderate** due to the presence of legacy contamination at the site and the early risk of emergent groundwater with 12- and 24-inches of sea level rise. Land use at this former military disposal area is restricted to open space and recreational use. Contamination remains on site, and institutional controls prohibit soil disturbance below two feet and extraction of shallow groundwater. The steel barrier containment system that extends 10 feet below mean sea level may reduce the response of the shallow groundwater layer to sea level rise. However, if the shallow groundwater table rises, the 3-foot clean soil cover could be exposed to contamination, and the contamination could be become emergent. Seasonal wetlands are present on site, and contamination within these areas could have environmental impacts on wildlife. Ongoing monitoring of the shallow groundwater layer will inform future remedial actions, as required. Periodic soil sampling should assess if the clean soil cover becomes contaminated over time.
- **West Beach Landfill and Wetlands:** The risk of emergent contaminated groundwater on the environment is considered **high** due the presence of legacy contamination and the early risk of contaminated emergent groundwater. With 24-inches of sea level rise 24% of the site could exhibit emergent groundwater during the winter rainy season. The site is currently proposed as part of a Nature Preserve for endangered species and other wildlife. Contamination remains on site, and institutional controls restrict land use to open space and prevent soil disturbance below 1.9 feet due to the presence of radionuclides. This site is directly adjacent to the Bay and does not have a steel barrier containment system as found along the 1943 – 1965 Disposal Area. The rising groundwater table is likely to mobilize contaminants that remain below the clean soil, multi-layer cover. The human exposure risk at this site is likely low due to land use restrictions; however, if contaminated groundwater enters the Bay, persons who fish recreationally could be exposed to the legacy contamination by consuming contaminated fish (BRAC 2016). Ongoing monitoring of the shallow groundwater layer will inform future remedial actions, as required. Periodic soil sampling should assess if the clean soil cover becomes contaminated over time.
- **Operational Unit 2A:** Remediation efforts at this site have been successful at reducing benzene and ethylbenzene concentrations with in situ bioremediation (BRAC 2016). It is anticipated that concentrations will continue to decrease over time. However, USEPA expressed concerns about the continued success of the biodegradation of these contaminants due to likely increases in the water table associated with El Niño and winter storms which can hinder bioremediation (BRAC 2016). Long-term monitoring is recommended to ensure that contaminant rebound does not occur. The RWQCB expressed concerns over remaining legacy tarry refinery waste. Parcels that contain this waste are still being regulated by RWQCB. Emergent groundwater is not expected to occur

until 36 inches of sea level rise (see Table 4.7). If remediation continues and is successful, the exposure risk to humans and the environment could be **low**. However, currently, residential land uses would require the installation of vapor intrusion barriers, indicating a potentially elevated risk. As the groundwater tables rises, the human exposure risk could be **moderate**.

- **Operational Unit 2B:** Remediation is still in progress at this site. Soil and groundwater contamination could remain above human health benchmarks for 25 to 30 years. Soil contaminated with cobalt is present underneath a building and has not been excavated and removed (BRAC 2016). Emergent groundwater first occurs on this site with 48 inches of sea level rise; therefore, the human exposure risk is **moderate** to **low** since emergent groundwater is unlikely to occur until later in this century (see Table 4.7). The contamination may be fully remediated (with some level of residual contamination remaining on site) before 48 inches of sea level rise occurs. However, full remediation plans for this site and the potential alternative land uses for this site were not readily found.
- **Operational Unit 5:** Redevelopment is in progress at this site. However, legacy contamination is present in soils below a depth of eight feet, and institutional controls restrict soil disturbance below four feet to manage the long-term risks and minimize exposure. Additional contaminated soil may need to be excavated and removed when the existing structures are demolished as part of the redevelopment efforts. Approximately one percent of the site could be flooded by emergent groundwater during a winter storm with 12 inches of sea level rise. Five percent of the site could be flooded by emergent groundwater with 24 inches of sea level rise (see Table 4.7). Contamination in the deeper layers of soil could be mobilized into the areas of clean fill with the rising groundwater table. Ongoing monitoring of the soil and groundwater should assess the potential for contaminant mobilization. Based on the information reviewed, and the depth of the legacy contamination relative to the ground surface, the risk of contaminated emergent groundwater appears **low**; however, adaptation measures will be required to reduce the potential for emergent groundwater during the winter rainy season.

4.3.2 Alameda Naval Air Station East Housing

Approximately two percent of the site could be flooded by emergent groundwater with 36 inches of sea level rise (see Table 4.7). However, this site has limited contamination beyond the marsh crust. As the groundwater tables rises, the human exposure risk is likely **low**.

4.3.3 Jean Sweeney Open Space Park

Portions of this site could be flooded by emergent groundwater with 12 inches of sea level rise (see Table 4.7). The lead-contaminated soil that is currently consolidated and capped under a paved trail could pose a **high** environmental and human health exposure risk. Contamination under the cap could be mobilized as the groundwater table rises. The risk of contaminated emergent groundwater at this site is high. Removal of the contaminated soil should be considered.

4.3.4 Fleet and Industrial Supply Center and Alameda Navy Supply Center Annex (FISCA)

The following contaminated sites recorded in the DTSC database were evaluated relative to rising groundwater. Additional areas on the FISCA property may (or may not) have contamination concentrations that exceed human health benchmarks; however, only the subareas recorded in the DTSC database were included in this assessment.

- **Shinsei Gardens:** Emergent groundwater is not anticipated until 66 inches of sea level rise; therefore, the human exposure risk is likely **low** (see Table 4.7). Residual contamination is present and vapor mitigation systems were required for residential housing. Ongoing monitoring should track if contamination is mobilized to the clean, upper layer of soil.
- **Stargell Commons:** Emergent groundwater is not anticipated until 66 inches of sea level rise ; therefore, the human exposure risk is likely **low** (see Table 4.7). Residual contamination is present and vapor mitigation systems were required for residential housing. The development overlies the benzene and naphthalene groundwater plume, and ongoing monitoring should track if contamination is mobilized to the clean, upper layer of soil.
- **Cadence and Linear:** Approximately six percent of this residential site could be flooded by emergent groundwater with 52 inches of sea level rise (see Table 4.7). Although remediation is near completion, new contaminated areas were discovered in 2019 during regular sampling activities. This site is also underlain with the benzene and naphthalene plume. The residential housing did not require vapor mitigation structures. As the shallow groundwater table rises, the VOCs in the plume could rise closer to the ground surface and contaminate the clean upper layers of soil. Ongoing monitoring should track if contamination is mobilized to these upper soil layers. The human exposure risk is considered **moderate** for this site; however, the exposure risk may be **low** if no additional contaminated areas are found during sampling activities.
- **Symmetry at Alameda Landing:** Approximately one percent of this residential site could be flooded by emergent groundwater with 36 inches of sea level rise (see Table 4.7). The details of the remediation methods were not readily available; therefore, the human exposure risk is considered **moderate** with rising groundwater levels. Additional review is required to better assess the exposure risk at this location.
- **Target Parcel:** Approximately six percent of this retail parcel could be flooded by emergent groundwater with 36 inches of sea level rise (see Table 4.7). Contaminants were remediated to levels consistent with commercial land use (i.e., residential land use is prohibited), and soil disturbance is restricted. VOCs are present under a barrier cap. Caps prevent direct contact between humans and/or wildlife and the contaminated soil and groundwater below the cap. As the groundwater table rises and becomes emergent, the VOCs could mobilize, rise to the surface, and vent to the atmosphere around the barrier cap. Ongoing monitoring should track the rise in the groundwater surface and monitor the potential for VOCs to be released. The human exposure risk for this site is likely **moderate** since emergent groundwater is not likely until after 2050 (36 inches of sea level rise could occur between 2050 and 2100 depending on global greenhouse gas emissions).

- **Retail Center:** Approximately four percent of this retail parcel could be flooded by emergent groundwater with 36 inches of sea level rise (see Table 4.7). Contaminants were remediated to levels consistent with commercial land use (i.e., residential land use is prohibited), and soil disturbance is restricted. All native soils require land cover by buildings, pavement, or landscaping to prevent human exposure to contaminants. As groundwater becomes emergent, contamination below the covered surface will likely be present in the emergent groundwater. Emergent groundwater will be present in landscaped areas initially. However, emergent groundwater can also occur above paved areas through cracks in the pavement. Emergent groundwater can also create or enlarge cracks in paved areas, establishing human exposure pathways. The human exposure risk for this site is likely **moderate** since emergent groundwater is not likely until after 2050 (36 inches of sea level rise could occur between 2050 and 2100 depending on global greenhouse gas emissions).

4.3.5 Pennzoil Company

Approximately 12 percent of this site could be flooded by emergent groundwater with 36 inches of sea level rise (see Table 4.7). Contaminants are likely present at this site, and no remediation has occurred to date as this site remains in active use. This risk of human exposure to soil and groundwater contamination is currently unknown. Regular monitoring of this site is recommended to inform the human exposure risk and the need for future remediation. The impact of emergent groundwater on the current land use is **unknown**.

4.3.6 Kem Mil Company

This site could be almost entirely flooded by emergent groundwater with 66 inches of sea level rise (see Table 4.7). Some remediation (i.e., excavation of contaminated soils) was completed thirty years ago, and the need for additional remediation is unknown. This risk of human exposure to soil and groundwater contamination is currently **unknown**. Additional investigations are likely needed if this site is redeveloped in the future.

4.3.7 Alameda Naval Operational Support Center

Approximately one percent of this site is projected to be inundated with emergent groundwater during winter storms with 66 inches of sea level rise (see Table 4.7). Residual soil contamination exists at depths of 13.5 feet below the ground surface, and the mean shallow groundwater surface is at a depth of approximately 9 feet. Contamination is currently found in the saturated soils well below the ground surface. As the shallow groundwater table rises, the contamination may rise closer to the surface. However, the risk of human and/or environmental exposure to the contamination is considered **low** for the foreseeable future.

4.3.8 2100 Clement Avenue

Approximately one percent of this site could be flooded by emergent groundwater with 52 inches of sea level rise, and ten percent could be flooded with 66 inches of sea level rise (see Table 4.7). This site has been remediated and redeveloped for residential housing. Soil and vapor testing in 2016 found residual VOCs contamination, with concentrations below residential screening levels (Stantec 2016). The high-density residential use resulted in most of the site being covered with structures or paving, with minimal landscaping constructed with imported clean topsoil. As the shallow groundwater table rises, the residual contamination may rise closer to the surface. However, the risk of human exposure to contamination in emergent groundwater is considered **low**.

4.3.9 Former J. H. Baxter Facility

The three properties evaluated for this site (e.g., Dutra-Velodyne Property, Extra Space Storage, Fox-Collins Property) are not anticipated to exhibit emergent groundwater in this century. Emergent groundwater may first occur with 108 inches of sea level rise (see Table 4.7). The risk of human exposure to contamination in emergent groundwater is **low** for all three properties.

4.3.10 Lincoln Avenue Housing

This 0.5-acre site was remediated and redeveloped with affordable housing. No institutional controls or restrictions remain for this site, and emergent groundwater is not anticipated until 66 inches of sea level rise (see Table 4.7). The risk of human exposure to contamination in emergent groundwater is likely **low** based on the information reviewed and the timing of exposure.

4.3.11 Doolittle Landfill

Although portions of this site could exhibit emergent groundwater within this century, most of it is elevated well above the surrounding landscape and is unlikely to be flooded. However, the landfill is constructed directly adjacent to San Leandro Bay. The impact of sea level rise and potentially increased wave exposure on the Bay Area's many coastal landfills is currently unknown. Coastal erosion along the shoreline edge of the landfill could create a pollution risk to the Bay as sea levels rise. This is a potential risk that requires additional study (see Section 6.7). Assessing this risk was outside the scope of the current study.

4.4 CARP High Priority Areas for Adaptation

The CARP identified eleven high priority areas for adaptation, based on future exposure to sea level rise inundation and coastal flooding, as well as exposure to urban flooding that can occur today during a 25-year rainfall event[32] (City of Alameda 2019). These areas, and the important assets within them, are exposed to coastal floodwaters in the near term (i.e., with 24 to 36 inches of sea level rise) with a high potential for consequences from flooding. Figure 4.18 presents the approximate locations of these high-priority areas. These locations were evaluated for their exposure to emergent groundwater, to understand if they could be exposed before the shoreline is overtopped by coastal floodwaters. Table 4.8 presents the locations of these high-priority areas, the sea level rise scenario at which an area or asset is first inundated due to sea level rise, and the sea level rise scenario that first results in emergent groundwater. If the

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[32] Alameda's storm sewer pipelines are designed to carry the stormwater runoff from a 10-year rainfall event, and a 25-year rainfall event should be contained within the streets without exceeding the curb height (Schaaf & Wheeler 2017). However, several areas within the city currently experience flooding during a 25-year rainfall event (City of Alameda 2019).

emergent groundwater scenario is lower than the sea level rise inundation scenario, the location or asset could be vulnerable earlier than presented in the CARP.

Half of the high priority areas could experience emergent groundwater surface flooding before sea level rise inundation occurs (see Table 4.8). For example, the area near Posey and Webster Tube entrances could exhibit emergent groundwater with 12 inches of sea level rise, although sea level rise is not projected to inundate the site until 36 inches of sea level rise. However, a 50- to 100-year flood event today could overtop the shoreline and cause temporary coastal flooding that occupies a similar extent to the permanent flooding caused by 36 inches of sea level rise using the ART one map equals many futures approach (Vandever et al. 2017). Differentiation between temporary coastal flooding and sea level rise inundation, along with the risks for wave hazards and coastal erosion, should be revisited for the high priority areas for adaptation.

Additional locations or assets (i.e., in addition to those presented in Figure 4.18 and Table 4.8) could become high-priority areas for adaptation when emergent groundwater is considered. However, a comprehensive review of the City of Alameda's assets relative to emergent groundwater was not undertaken as part of this assessment. This task is recommended as a next step (see Section 6.1).

Figure 4.18 CARP High Priority Areas for Adaptation with 36 inches of Sea Level Rise

Table 4.8 Exposure at CARP High Priority Areas for Adaptation

ID	Area or Asset Name	Exposure			Notes
		Sea Level Rise Scenario	Emergent Groundwater Scenario	Precipitation (25-year Storm, flooding > 1 foot)	
1	Shoreline adjacent to Webster and Posey Tubes	36”	36”	N/A	
2	SR260 and Posey/Webster Tube Entrance Locations	36”	12”	Yes	Monitoring wells are recommended at this location to better characterize the existing groundwater table elevation and its seasonal variability, see Section 6.3.
3	Crown Beach and Bird Sanctuary	12”	12”	N/A	Bay water levels and the shallow groundwater table elevation are closely related along this coastal beach. Coastal wave hazards and beach erosion are likely the dominant hazard.
4	Bay Farm Island Bridge Touchdown (Main Island)	36”	36”	N/A	Bay water levels and the shallow groundwater table elevation are closely related at this location. However, wave hazards and bridge scour may be the dominant hazard at this location.
5	Eastshore Drive	36”	36”	N/A	Bay water levels and the shallow groundwater table elevation are closely related at this location. However, wave hazards may increase with sea level rise and become the dominant hazard at this location.
6	Critical and High-use Roadways (also with high public transit use)	> 48”	36”	Yes	The critical and high-use roadways in the West End (e.g., Webster Street, Main Street, and Lincoln Avenue) could exhibit emergent groundwater before coastal floodwaters overtop the shoreline and inundate inland areas.
7	Bayview Weir and Outfall	24”	24”	N/A	Bay water levels and the shallow groundwater table elevation are closely related at this location.
8	SR61 (a.k.a., Doolittle Drive)	36”	12”	Yes	A high groundwater table is evident in the marshes inland of Doolittle Drive. Culverts may be present under Doolittle Drive to connect the marshes with Bay waters.

ID	Area or Asset Name	Exposure			Notes
		Sea Level Rise Scenario	Emergent Groundwater Scenario	Precipitation (25-year Storm, flooding > 1 foot)	
9	Bay Farm Island Lagoon Outlet Gate and Seawall	> 48”	12”	N/A	Emergent groundwater is observed along the lagoon. Managing the lagoon water levels may eliminate emergent groundwater with 12 – 36 inches of sea level rise. The addition of monitoring wells in this area would better characterize the groundwater table in this area (see Section 6.3)
10	Veteran’s Court Seawall	36”	12”	N/A	This area already experiences a high groundwater table during heavy rain events and high Bay tides. Water can be seen spouting from low-lying manholes near the shoreline.
11a	Storm Sewer Pipelines	36”	N/A	N/A	Storm sewer pipelines are impacted by the shallow groundwater before the groundwater becomes emergent.
11b	Storm Sewer Pump Stations	36”	Varies	Varies	Exposure is location dependent. Individual pump station exposure was not evaluated. Most pump stations have significant below grade infrastructure which may already be impacted by the shallow groundwater layer.

5 Adaptation Strategies

Levees and hardening shorelines will not protect Alameda from emergent groundwater flooding from below. To solve this challenge, innovative solutions are needed to adapt structures and utilities already in place; and the city will need to collaborate with other low-lying coastal communities to develop and identify new ways to adapt to this continually and increasingly changing environment.

Unfortunately, adaptation strategies that address rising and emergent groundwater are still in their infancy when compared to sea level rise adaptation. Rising groundwater levels in response to sea level rise first entered the national discussion in 2012; with a USGS publication on the response of the shallow groundwater table to sea level rise in New Haven, Connecticut (Bjerklie et al. 2012). Since 2012, this phenomenon has been studied in other cities, and the impacts that could occur within low-lying coastal communities have been investigated, but the development of adaptation strategies has lagged. However, humans have been building infrastructure below the groundwater table for centuries. Strategies to address groundwater generally include lowering the groundwater table, diverting the groundwater flows elsewhere, and adapting the infrastructure. Building in this environment requires water-tight structures, addressing buoyancy forces, and using materials that can withstand the damp and often corrosive subterranean environment. Below-ground structures require regular inspections to address leaks and sump pumps to remove excess water when leaks are pervasive. The challenge for today includes using these techniques in areas that are not below the groundwater table today, but that could be below the groundwater table in the foreseeable future. In addition, new techniques that are more cost effective and widely applicable may be required.

> *As the groundwater table rises, the pumping requirements will increase.*

To date, pumping remains the most common approach for addressing groundwater hazards. Pumping involves extracting groundwater, which can depress (i.e., lower) the groundwater table. The extracted groundwater must then be routed elsewhere, such as to another water body, a storage facility, or potentially to a treatment facility, if contaminant concentrations exceed regulatory standards for direct release. Groundwater pumping is used every day to address flooding in subterranean structures. The New York Metropolitan Transportation Agency pumps 13 million gallons of groundwater to keep the subway system running on a regular dry day (Nir 2018). As the groundwater table rises, the pumping requirements will increase. Pumping can also require an extensive and continuous supply of electricity. Keeping water out of the subway tunnels has driven innovation, and the agency has been replacing older concrete with a different type of concrete that is embedded with impermeable plastic membranes to reduce groundwater intrusion (Nir 2018). If groundwater leaks into the subway system can be reduced, regular pumping needs can also be reduced. As successful techniques and innovations are discovered, they can be shared and implemented across other sectors and cities around the world, increasing the collective knowledge base of solutions.

For a city like Alameda, which is surrounded by water on all sides, large-scale groundwater pumping to address rising groundwater levels using current technology may prove challenging. In the near term, individual properties and structures can use sump pumps and limited groundwater extraction to address rising groundwater levels – and many structures with subterranean areas (e.g., basements) in Alameda already use sump pumps to address this hazard. Over the longer term, larger-scale groundwater extraction pumping would need to be carefully implemented and coordinated with shoreline structures that also address coastal flooding and sea level rise.

The following sections provide examples of how existing utilities and structures could be vulnerable to rising groundwater elevations and provide potential strategies to address these vulnerabilities. Appendix C provides a compendium of additional strategies that can address rising groundwater tables.

5.1 Utilities

The city's stormwater and wastewater collection systems are managed by the City of Alameda, the wastewater regional interceptor and treatment system by the East Bay Municipal Utility District (EBMUD), and the electrical utilities by Alameda Municipal Power (AMP). This section assesses the different utility components that are projected to be impacted by groundwater and discusses potential strategies for adaptation that could be adopted or considered. The CARP presents a series of strategies for increasing the resilience of utilities to sea level rise and surface flooding (see Table 4-24 in City of Alameda 2019). Suggested additions to the CARP's recommendations are presented in Appendix D.

5.1.1 Stormwater Drainage System

The CARP identified the stormwater drainage system as a high priority for adaptation to sea level rise, noting that 36 inches of sea level rise could result in significant impacts (see Table 4.8). The rising groundwater table could impact the stormwater drainage system even before 36 inches of sea level rise occurs. In fact, in some areas of the city, the high groundwater table may already be impacting stormwater runoff conveyance capacities and increasing the likelihood of localized urban flooding.

Alameda's stormwater drainage system consists of ten pump stations, 126 miles of buried pipelines, several lagoons with tide gates, and 278 outfalls (Alameda City Council 2019). The system is designed to convey stormwater runoff from roads, roofs, and impervious surfaces, until it is ultimately discharged to the Bay through outfalls. The lagoons serve as stormwater retention and treatment ponds for portions of Alameda, and the stormwater sewers in these areas drain directly into the lagoons. The water levels in the lagoons can be lowered in advance of heavy rainfall events to increase stormwater storage capacities. The water levels are also managed in coordination with the Bay tides to maintain adequate water quality.

Alameda's stormwater pipelines are designed to carry the stormwater runoff from a 10-year rainfall event, and a 25-year rainfall event should be contained within the streets without exceeding the curb height (Schaaf & Wheeler 2017). However, several areas within the city currently experience flooding during a 25-year rainfall event, with flood depths in excess of one foot (City of Alameda 2019). To function as designed, the stormwater pipelines must be free of breaks or cracks to minimize infiltration of groundwater, and have the capacity to convey the 10-year discharge flow rate for stormwater runoff, or store excess runoff volumes, for the duration of the rainfall event. Current stormwater guidance includes keeping storm drains clear of leaf litter and trash to maximize the movement of runoff through the system and reduce the likelihood of localized flooding from clogged storm drains (Clean Water Program 2016). The City is in the process of implementing improvements to the stormwater drainage system as part of the Storm Drain Master Plan Update (Schaaf & Wheeler 2017).

WHY IS IT VULNERABLE? The rising groundwater table can increase infiltration into the stormwater pipelines through cracks, pipe joints, and connections. This inflow can reduce the capacity of the stormwater drainage system to convey stormwater runoff associated with the 10-year design storm, resulting in an increased risk of urban flooding. Groundwater and Bay inflows to the stormwater drainage system can also result in flows exiting manholes in low-lying areas. Flows out of the manholes already occur in Alameda, most demonstrably near Veterans Court on Bay Farm Island, where outflows can form a small fountain at the manhole location.

Rising groundwater elevations can also result in subsidence, soil swelling, and loss of bedding support around the pipelines, potentially causing the separation of pipe joints, leaks, breaks, and sewer collapse. The dramatic rise and fall of the water table in response to heavy rainfall events can also create voids around pipelines that can lead to sinkholes. Corrosion due to saltwater intrusion or contaminated groundwater can damage buried infrastructure, manholes, and other metal components (Chisolm and Matthews 2012).

WHAT ARE STRATEGIES TO ADDRESS RISING GROUNDWATER LEVELS? The primary methods for reducing groundwater infiltration are grouting the leaks in the pipelines and/or replacing or lining problematic pipelines. Grout can be applied using remote-controlled equipment and is effective at creating a watertight collar that seals cracks or joints and prevents groundwater infiltration. Lining a stormwater pipe can effectively rehabilitate a pipeline without any digging. A flexible liner is inserted into a pipeline and cured, forming a new, watertight pipe inside the existing pipe. The new pipe is jointless, which seals off any points of entry for infiltration.

Regular inspection and maintenance of stormwater drainage infrastructure can extend the life of existing pipelines and help thwart potential issues before they become significant problems. Identifying infiltration points can help maintain the conveyance capacity of the system. The same techniques used to identify infiltration points for sanitary sewer systems can be used for stormwater drainage systems, including using a closed-circuit television truck that can send a robotic camera through the pipelines to observe potential defects, or using smoke testing to identify potential leaks and cracks. With smoke testing, non-toxic smoke is pumped into the sewer system, and observers watch for smoke to be visible above the ground. Infiltration is most likely occurring in areas where smoke is visible. Stormwater pipelines that retain water outside of the wet weather season are also potential sources of groundwater infiltration.

When pipelines are replaced, utility trenches can be over-excavated and filled with crushed rock below the elevation of the pipelines. This strategy can help maintain the integrity of the utilities as the water level table rises and falls. Curb and gutter underdrains can also help minimizes flooding during a heavy precipitation event when the groundwater table is at the ground surface and soils are waterlogged. The installation of an underdrain network and collection system should be considered in new development areas; but may be cost prohibitive in existing neighborhoods.

> *Maintenance, rehabilitation, and upgrades to the sewer system should consider rising groundwater levels.*

The City recently increased stormwater fees (2019 Water Quality and Flood Protection Fee) to fund improved maintenance and upgrades to the stormwater drainage system. Maintenance, rehabilitation, and upgrades should consider rising groundwater levels.

5.1.2 Sanitary Sewer System

The City of Alameda's sanitary sewer system includes 142 miles of sewer mains and 42 pump stations. The wastewater flows are conveyed to EBMUD's regional conveyance and treatment facilities. Over the past 40 years, the City has worked with other Bay Area communities within EBMUD's service area to reduce wet weather sanitary sewer overflows to community streets, waterways, and the Bay. Sanitary sewer rehabilitation efforts have been targeted at replacing old, cracked sewer pipes to decrease the amount of groundwater and rainwater infiltration entering the sanitary sewer system. Groundwater and stormwater that infiltrates into sanitary sewer pipelines is conveyed to the wastewater treatment plant, increasing the cost of treating wastewater flows and potentially exceeding the capacity of the treatment plant. When this occurs, partially treated wastewater effluent is discharged directly to the Bay. A regional effort is underway to inflow and infiltration under a Federal Consent Decree. The City is replacing 2.6 miles of sanitary sewer main each year and completing other improvements to reduce inflow and infiltration. However, as inflow and infiltration improvements are implemented, the demand to convey these flows is shifted from the sanitary sewer system to the stormwater drainage system (described in Section 5.1.1).

If the volume of flow conveyed to the wastewater treatment plant is significantly higher during wet weather as compared to dry weather, groundwater inflow and infiltration is likely occurring within the system and should be addressed. The strategies for addressing inflow and infiltration for sanitary sewers are the same as those suggested for the storm sewer system (see Section 5.1.1).

5.1.3 Electrical System

The City of Alameda's electricity is supplied by Alameda Municipal Power (AMP). AMP maintains a network of underground and above ground electrical lines that operates and maintains the assets up to the meter or point of service. Individual homeowners are responsible for the electrical lines from the meter to the home. The City owns and maintains the streetlight facilities, including the underground service conduit and pull boxes.

AMP began its underground utility program in 1984 to place overhead lines (e.g., telephone, electric, cable) underground. The underground utilities were designed and built to withstand wet conditions, using the guidelines set forth by FEMA (FEMA 2017). The underground system also uses looped underground distribution to provide redundancy. Transformers, switches, and other aboveground electrical components are generally very sensitive to any type of flooding; therefore, AMP has been mounting these structures on pads above previous FEMA base flood elevations[33] to reduce the potential for power outages during a flood event. This elevation also reduces the risk of flooding due to elevated groundwater levels. However, older electrical infrastructure throughout the city may be in potentially vulnerable locations.

WHY IS IT VULNERABLE? If designed and built correctly, the underground electric utilities are likely resilient to rising groundwater levels. The underground cables manufactured for AMP are designed to function in wet (i.e., submerged) applications.

Electrical components that are located at or below grade could be vulnerable to rising groundwater levels if they have not been designed for a wet environment. For example, pull boxes[34], such as those used for the city's streetlights, are generally located at or near grade and they are specifically designed to allow for rainwater drainage through the box. The pull box itself is not watertight, and rainwater can enter the box from above. To allow rainwater to exit the box, the bottom of the box allows for rainwater drainage into the soils below. This prevents the box from filling with rainwater and impacting the electrical conduit. However,

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[33] The FEMA base flood elevation is the elevation that could be reached by the 1-percent annual chance flood event. FEMA released new flood maps depicted updated base flood elevations for the county of Alameda in 2016, and the maps became effective on December 21, 2018. The new base flood elevations are higher than previous base flood elevations. Pad mounted utilities installed prior to 2018 may no longer be above FEMA base flood elevations.

[34] A pull box is a metal box with a removeable cover that is installed in an accessible place along a run of electrical conduit to facilitate the pulling in of wires and cables.

as the groundwater table rises, the bottom opening will allow groundwater intrusion into the pull box. As groundwater intrusion into the box becomes more frequent, streetlight outages and disruption could occur.

WHAT ARE STRATEGIES TO ADDRESS RISING GROUNDWATER? Pull boxes in areas with existing wet winter groundwater elevations within one to two feet of the ground surface are excellent candidates for replacement with watertight alternatives. Various manufacturers make watertight and weatherproof pull boxes that might be preferable as emergent groundwater begins to impact these structures more regularly. A pilot replacement program could test the alternative pull boxes at select locations to ensure they perform as desired. Transformers, switches, and other electrical control panels should be elevated above new effective FEMA base flood elevations, which will also reduce the risk of power outages associated with elevated groundwater levels and other potential flood hazards.

5.2 Structures

Although building codes can be modified to increase the resilience of new structures to climate change, adapting existing structures can be challenging and costly. The city has a population of approximately 80,000 people, and hosts numerous commercial, industrial, and maritime industries, including two downtown corridors with walkable retail businesses and restaurants along Webster Street on the West End, and Park Street on the East End. The structures that support and house the population and businesses were constructed between the mid-1800s and today, representing a wide range of changing building codes, building materials, and construction techniques.

WHAT IS VULNERABLE? Below-grade structures (e.g., a home's basement) are the most vulnerable to rising groundwater. Although modern houses in Alameda are constructed as slab on grade, many of the homes built before 1930 have full or partial basements, and some of these basements have been converted into below-grade living areas. Many of the historic (non-residential) buildings also have below-grade facilities. As the groundwater rises, it can enter below-grade areas through cracks in the concrete. As the groundwater table rises and falls, the water can continue eroding the concrete foundation until new cracks form, old cracks enlarge, and the flow of water into the structure increases. Many Alameda homes with basements have sump pumps to redirect the groundwater under their basement to the yard or to the street. It is common to hear the sump pumps working continuously during wet weather when the groundwater table is high, and many sump pumps continue working long after the storms subside. Although sump pumps are adequate to prevent nuisance flooding in below-grade structures, they will not be able to permanently address the longer-term problems that rising groundwater can create.

> *It is common to hear the sump pumps working continuously during wet weather when the groundwater table is high, and many sump pumps continue working long after the storms subside.*

During a large storm event, saturated soil surrounding a building with a basement can cause uplift, where the building becomes buoyant with the upward pressure from the water table (NYC EDC 2019). Soil erosion can cause scour which can further weaken and damage building foundations. When the groundwater table recedes, buildings can settle and create structural instabilities within the structure's frame (Toll et al. 2012). In the event of an earthquake, saturated soil is more susceptible to liquefaction which can cause catastrophic consequences for buildings located in these zones (Quilter et al. 2015).

WHAT ARE STRATEGIES TO ADDRESS TEMPORARY FLOODING? Strategies to address temporary flooding are readily available (FEMA 2012, 2013, 2014, BPDA 2019). The first line of defense for any structure is waterproofing below-grade areas and waterproofing all areas below the FEMA base flood elevation. Adding two to three feet above the FEMA base flood elevation is recommended to account for larger storms, sea level rise, and uncertainties in the calculation of the FEMA base flood elevations. Sump pumps are often a necessary part of the internal drainage system for below grade structures. Appendix D (modified Table 4-18 from the CARP 2019) provides recommendations on residential sump pump requirements.

The second line of defense is relieving the water pressure against the below-grade walls and floors. Relieving the water pressure can reduce groundwater infiltration and reduce the risk of building instabilities. The installation of drain tile can help reduce the water pressure on the exterior of the structure. Excavation is required to waterproof the exterior of the structure and install either a drain tile or French drain system. The water should be properly diverted away from the structure (e.g., it should not be diverted in a way that adversely impacts another structure). Professional contractors are required, and all appropriate permits must be obtained before work can begin. Many contractors have experience with foundation repair, replacement, and basement repair and drainage improvements in Alameda. It has become commonplace to see older homes elevated so the foundation can be replaced. Many older (pre-1930s) homes used sand from the Bay in the concrete mixture[35] that comprises the foundation. The salt in the Bay sand reacts with moisture in the surrounding soils to accelerate deterioration of the concrete. These same older homes were generally not constructed with reinforcing bars within the concrete. As the foundation settles, cracks can occur and spread quickly (rebar helps to prevent cracks from spreading), increasing the potential for basement flooding.

> *As the groundwater table becomes elevated more frequently and for longer periods of time, basements may become challenging to keep dry.*

As the groundwater table becomes elevated more frequently and for longer periods of time, basements may become challenging to keep dry. If the overall structure is at risk of being compromised, the below-grade area can be structurally separated from the structure and filled. This option eliminates the groundwater problem (if the water table remains below the surface). This requires breaking up the below-grade floor to relieve water pressure and filling all below-grade areas with fill and/or rock as needed. The addition of drainage elements below the new lowest floor is recommended.

In the City of Alameda, high water tables are already occurring throughout most of the island. New below-grade basements and living spaces should not be permitted. Building codes could be modified to require

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[35] Concrete is made from a mixture of water, cement, sand, and aggregate (rock). The exact mixture varies depending on the application, environment, and strength desired.

contractors (for remodels/substantial modifications or new development) to plan for higher groundwater tables, and to plan for groundwater tables that can vary by five feet or more seasonally.

Large buildings with below-grade floors should be assessed for stability and drainage issues. The strategies available for residential and light-commercial structures may not be adequate for large multi-story facilities. However, the heavier weight of large buildings helps to minimize some of the foundation and structural instabilities more prevalent in residential and light-commercial structures.

The CARP presents a series of strategies for increasing the resilience of buildings to sea level rise and surface flooding (see Table 4-18 in City of Alameda 2019). This report fulfills one of the strategy recommendations, and suggested additions to the CARP's recommendations are presented in Appendix D.

5.3 Lagoon Operations

The City of Alameda has several lagoon systems that provide recreation, wildlife, and aesthetic benefits while also serving as stormwater retention and treatment ponds. The Alameda West Lagoon is located on the Main Island and is comprised of five lagoons connected with culverts. Saltwater is pumped from the Bay into the westernmost lagoon segment, and the water flows by gravity through the lagoons and out to the Bay through a weir and outfall located along the easternmost lagoon.

Bay Farm Island includes two separate lagoon systems. The larger system (in the Harbor Bay Isle neighborhood) includes 3 lagoons connected by culverts under Robert Davey Junior Drive and Aughinbaugh Way. Tide gates are located at either end of the lagoon system, with one near the Bay Farm Bridge and the other near Shoreline Park. Water can be moved passively (via gravity) through the lagoon system by managing the tide gates in coordination with the tides. A smaller two lagoon system is located between the commercial area and the residential area near the end of Harbor Bay Parkway, with a culvert under Bay Edge Road.

The water levels in the lagoons are managed in coordination with the tides to maintain adequate water quality. In the wet season, the lagoon water levels are lowered to accommodate additional stormwater runoff from the adjacent neighborhoods. The future condition groundwater mapping was developed without considering maintaining or modifying the lagoon water levels to help mitigate the rise of the groundwater table in response to sea level rise. Therefore, areas along the lagoon shoreline are shown with emergent groundwater with 12 inches of sea level rise (see Figure 4.2). However, water levels in the lagoons will influence the shallow groundwater table near the lagoons. Maintaining lower water levels in the lagoon could help depress the shallow groundwater table near the lagoons and prevent or reduce the likelihood of emergent groundwater in the early sea level rise scenarios (12 to 36 inches). However, how far from the lagoon the groundwater levels would remain depressed in response to modified lagoon operations is unknown. Monitoring for the effectiveness of this strategy is recommended as a next step (see Section 6.3).

5.4 Shoreline Strategies

Shoreline strategies such as levees, floodwalls, and seawalls are designed to address surface flooding (e.g., shoreline overtopping due to coastal storm surge, waves, and sea level rise). However, in areas with a shallow groundwater table or insufficient internal drainage capacity, pumps are likely required in addition to reduce the potential for flooding on the inland side of these structures. In Alameda, the groundwater table can rise by five feet or more in response to a heavy precipitation event (see Figure 2.3), and this groundwater slowly drains to the Bay overtime after the rainfall event subsides. In addition, surface flows from precipitation events are conveyed by the city's stormwater drainage system and discharged into the lagoons and the Bay through multiple outfalls. The City of Alameda is currently updating the Alameda Point Master Infrastructure Plan, and groundwater pumping in combination with levees, floodwalls, seawalls, and cutoff walls[36] will be added as future adaptative measures.

A series of distributed groundwater pumping wells and monitoring wells could be used to maintain a lower groundwater table and support the interior drainage system behind levees and floodwalls. The groundwater pumps should be set to activate when a threshold groundwater table level is exceeded, and to de-activate when the groundwater table is sufficiently lowered. In the near term, the pumps may only activate during and after large storm events when the groundwater table is high. In the longer term, if the shoreline protection structures do not prevent the inland groundwater table to rise in response to sea level rise, the pumps may operate more frequently, including outside of the rainy winter season.

Cutoff walls may be effective at reducing the rise of the inland groundwater table in response to sea level rise; however, pumping would still be required to address the rise in groundwater due to precipitation events and to support the discharge of stormwater runoff collected within the stormwater drainage system. Along the Alameda Point shoreline, deep soil mixing[37] is being used to stabilize the soils and reduce seismic and liquification risks. Deep soil mixing can also be used for groundwater control. At the Port of Oakland and the Oakland International Airport, cement deep soil mixing was used for ground stabilization and to limit lateral spreading and deformation during earthquake conditions (Yang et al. 2004). At the Airport, cement deep soil mixing was used to construct cutoff walls by overlapping mixing shafts with a diameter of 90 centimeters to provide permanent groundwater seepage control (Yang et al. 2004). This application may prevent an inland rise in the groundwater table by severing the connection between the Bay and the inland shallow groundwater layer. Both Alameda Point and the Oakland International Airport are primarily constructed on former tidelands and shallow water areas that were filled to create more developable land; therefore, applications that are successful at the Airport may also be successful at Alameda Point.

In areas without cutoff walls, a system of trench drains (i.e., an excavated trench that allows groundwater to seep in and collect) could be used to collect and convey groundwater to a more central location for pumping. This would reduce the number of pumps required and may also reduce the potential subsidence

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[36] Cut-off walls (and grout curtains and sheet pile walls) are vertical subsurface barriers composed of impervious or low permeability natural or engineered materials, such as cement, bentonite clay, or steel (in the case of sheet pile walls). These structures prevent subsurface flow in both directions. Although effective at reducing groundwater intrusion into the city, the structures can also prevent the natural flow of groundwater from Alameda to the Bay after large rainfall events.

[37] Deep soil mixing is an in-situ soil treatment in which native soils are blended with cementitious and/or other materials, typically referred to as binders. Compared to native soils or fills, the soil-binder composite material that is created has enhanced engineering properties such as increased strength, lower permeability, and reduced compressibility. Deep soil mixing has been used all over the world, and locally for the Oakland International Airport and Port of Oakland shoreline projects (Yang et al. 2004) and Treasure Island (CMG 2015).

risks that often come with excessive groundwater pumping. Regardless of the solution, the pumped groundwater is likely to be brackish (i.e., a mix of fresh water and saltwater) and may be contaminated by surface pollutants and soil and groundwater contaminants (see Sections 2.3 and 2.6). If contaminants are present, direct discharge of the collected groundwater to the Bay is not likely to be permitted by the RWQCB or the California EPA. The collected groundwater would require retreatment before discharge. The City would need to coordinate with EBMUD to assess if the groundwater can be discharged to the sanitary sewer system, or if an alternate onsite treatment solution would be required.

5.5 Groundwater Pumping

Groundwater pumping for dewatering or lowering groundwater levels is a commonly used approach, particularly during construction when groundwater levels must be depressed to construct below-grade supporting infrastructure and foundations. This strategy is usually deployed for a small geographic area, such as a construction site. In general, groundwater pumps have a localized effect. The groundwater in the vicinity of the well is lowered, and the groundwater table gradually slopes up towards the original groundwater table height forming a “cone of depression” around the well. The size of the cone of depression is based on many factors, including the pumping rate and the hydraulic conductivity of the surrounding soils. To lower the groundwater level across a large geographic area, a distributed network of wells may be required, in combination with monitoring wells, to monitor and adjust pumping rates as needed. If pumping rates are not closely coordinated, the water table could be lowered in an uneven or unpredictable manner and result in land subsidence and potential structural damage.

Placing groundwater extraction wells along the shoreline, in combination with shoreline protection structures as noted in Section 5.4, or in the absence of structures, could provide a means of disrupting the inland rise of the groundwater table. As sea levels rise, the groundwater pumping rates would increase, and the inland areas could, theoretically, maintain their existing groundwater fluctuations and elevations. More sophisticated modeling would be required to determine well placement and pumping rates, and to assess over what range of sea level rise amounts this solution can remain valid. It is possible that additional wells, or alternate well placement strategies, could be required with higher amounts of sea level rise.

As noted in Section 5.4, the pumped groundwater is likely to be brackish, and will likely require treatment before it can be discharged to the Bay or a suitable alternate location. The most significant challenge could involve finding a place for the pumped groundwater to go (Environment Agency 2011, 2014). If the groundwater is pumped directly to San Francisco and San Leandro Bay’s, a continuous loop of water from the Bay – to the ground – and back to the Bay could be created. Although pumping is likely to be essential in the in the short term, in the longer-term, solutions other than (or in addition to) pumping will be required. Appendix C provides additional information and examples on groundwater pumping.

5.6 Governance Strategies

Physical strategies alone are generally not enough to increase resilience to flood hazards, including coastal flooding, urban stormwater flooding, and emergent groundwater flooding. The city can update existing plans, policies, ordinances, and building codes to help increase the resilience of new, remodeled, and rehabilitated infrastructure and new developments. Examples of documents that can be updated include:

- **General Plan:** The City of Alameda's General Plan outlines goals and policies to guide the city's future conservation and development efforts. The Governor's Office of Planning and Research released updated General Plan guidelines in 2017 that include climate change considerations. Alameda's Climate Action and Resilience Plan is related to the General Plan; however, climate change considerations and risks can be explicitly included to support resilient, equitable, and economically vibrant long-range planning.
- **Local Hazard Mitigation Plan:** The City of Alameda's Local Hazard Mitigation Plan was updated in 2016 (City of Alameda 2016). The plan includes climate change considerations, including increases in temperature, sea level rise, and its impacts on landslides, earthquakes, and flooding. The next update should consider the latest climate change science and include the potential for the shallow groundwater layer to rise above the ground level and create new flooding hazards.
- **Capital Improvement Plan:** For many cities, the Capital Improvement Plan guides investments in infrastructure and facilities throughout the city. The City of San Francisco developed capital planning guidance related to sea level rise to increase the resilience of investments within the "sea level rise vulnerability zone" (CPC 2015). San Francisco's guidance was updated in 2019 to consider the latest climate change science. The City of Alameda could adopt similar guidance that considers both sea level rise and the rising groundwater table.
- **Storm Drain Master Plan:** Alameda released their Storm Drain Master Plan in 2008, with updates released in 2011 and 2017 (Schaaf & Wheeler 2017). Rising groundwater levels are intricately linked with the City's storm drain system and lagoon operations. Future updates to this plan could consider the potential for a rising groundwater table, with increased investments on identifying areas with groundwater infiltration.
- **Building Codes:** The City of Alameda could update the Building Code to include requirements related to flood resilient building materials, flood proofing, floodable designs, drainage for below-grade living- and workspaces, etc. The codes could require consideration of a higher groundwater table in structural designs, and to plan for groundwater tables that can vary by five feet or more seasonally. New below-grade basements and living spaces should not be allowed.
- **Floodplain Management Ordinance:** The ordinance includes provisions for residential and commercial construction in flood prone areas. The flood prone areas are generally defined by the FEMA Flood Insurance Rate Maps and base flood elevations. These provisions can be extended to include areas projected to be exposed by sea level rise and/or emergent groundwater.

Additional governance strategies that have been used by other jurisdictions throughout the nation are included in Appendix C, and updates to the CARP's recommended strategies are included in Appendix D.

6 Next Steps

This study represents a first step at better understanding the shallow groundwater layer in the City of Alameda, the response of this layer to sea level rise, and the potential for emergent groundwater, surface flooding, and contaminant risks. Additional steps can be taken to refine and improve this analysis.

6.1 Incorporate within the Climate Action and Resiliency Plan

This study fills a data gap identified in the CARP. As the CARP is updated over time, information about the rising groundwater surface and the potential for contaminant mobilization should be incorporated. The CARP also identified eleven priority areas for adaptation, based on sea level rise, storm surge, the potential for shoreline overtopping, and precipitation-based flooding associated with a 25-year rainfall event. When emergent groundwater is considered, additional areas or assets could become high-priority areas for adaptation. The vulnerability assessment presented in the CARP should therefore be expanded to consider emergent groundwater. The preliminary review identified that half of the high priority adaptation sites could be vulnerable to emergent groundwater at an earlier time than the sea level rise scenarios suggest.

The CARP also included an estimate for the cost of inaction. This cost analysis should be revisited and updated with the groundwater information provided in this assessment.

6.2 Update the Digital Elevation Model

The groundwater mapping, as well as the ART sea level rise and storm surge mapping, relies on a DEM based on LiDAR data collected in 2010 and 2011. Development that has occurred since this timeframe is thus not represented in the LiDAR data or the groundwater mapping. For example, fill material was imported to raise the grades for the Corica Golf Course on Bay Farm Island. The groundwater mapping shows that the golf course could have emergent groundwater with 12 inches of sea level rise. However, due to the raised grades, the golf course is unlikely to be vulnerable under this early scenario. Grade changes have also occurred since 2010 in the vicinity of Alameda Landing and Alameda Point. There are two potential options for updating the groundwater mapping (and the sea level rise mapping) to better reflect current conditions:

- New LiDAR data can be collected. A new LiDAR baseline will create a more current snapshot in time for ground elevations in Alameda. (Post-processing of the LiDAR data to create a bare earth digital elevation model would also be required).
- Survey data can be collected in areas with known grade changes, and the DEM can be modified to reflect the new elevations. If digital as-built drawings are available for the developed areas, these drawings can be used to support DEM updates. (In many cases, grading plans created for re-development projects do not reflect actual built conditions, and they are unsuitable for updating the DEM unless they have been verified post-construction as the as-built condition).

6.3 Increase Spatial Distribution of Groundwater Monitoring Wells

Additional groundwater monitoring wells, particularly in residential areas where they are limited, would benefit future updates to the groundwater mapping and provide insight into the response of the shallow groundwater layer to sea level rise. Additional groundwater monitoring wells would also decrease the reliance on reviewing and tabulating information from geotechnical soil borings for future updates.

Figure 6.1 presents locations that could benefit from additional monitoring well locations, with the numbers reflected a potential order of priority.

1. **Bay Farm Island:** Currently, no monitoring wells are located within the residential or commercial areas on Bay Farm Island. Additional monitoring wells near the lagoon system, the shoreline, the Bay Farm Bridge touchdown, on Maitland Drive, and in the commercial district along Harbor Bay Parkway would provide information to better characterize the existing groundwater surface. Monitoring wells can also help better characterize the relationship between lagoon water levels and the groundwater table elevation. This area is also built on Bay Fill (see Section 2.4); therefore, sampling contaminant concentrations could be beneficial depending on the quality of the fill material used.
2. **Fernside Neighborhood:** Several monitoring wells are located near the intersection of High Street, Fernside Boulevard, and Gibbons Drive. This area appears to have high contamination concentrations and could exhibit emergent groundwater with 12 inches of sea level rise. However, the extent of the contamination within the residential areas is unclear. Monitoring wells placed near the intersections of Gibbons Drive, Northwood Drive, and Southwood Drive could help better characterize the existing groundwater surface and the extent of contamination.
3. **Jean Sweeney Open Space Park:** Monitoring wells are planned within the park. These wells will be beneficial for characterizing the extent of residual contamination in soils, as well as the potential for re-mobilization of the lead contamination capped beneath the bike trail. Emergent groundwater is projected to occur along Buena Vista Avenue with 12 inches of sea level rise. Wells in the park and along Buena Vista Avenue in this vicinity will be beneficial for characterizing the existing groundwater surface.
4. **Woodstock / Old Alameda Point:** No monitoring wells are in this area. This area includes residential housing, Encinal Junior and Senior High School, and other light industrial and commercial uses, including former military land use. Emergent groundwater is projected to occur along Central Avenue and Main Street with 36 inches of sea level rise. Monitoring wells in this area would help inform both residual contaminant concentrations and the existing groundwater surface.
5. **Main Island Alameda Lagoons:** No monitoring wells are found on either side of the Main Island lagoon system. In the absence of modified lagoon operations, emergent groundwater is projected to occur with 12 inches of sea level rise. However, managing lagoon water levels can likely mitigate the rise in the groundwater table in this area. Monitoring wells can help better characterize the relationship between lagoon water levels and the groundwater table elevation.
6. **Webster and Posey Tube / Target Parcel:** Monitoring wells may be present within the Target Parcel (see Section 2.6.4); however, the observations are not available within the GAMA GeoTracker database. The area surrounding Webster Street and Mariner Square Drive is projected to exhibit emergent groundwater with 12 inches of sea level rise. Emergent groundwater in this area could impact egress and ingress through the tubes. Monitoring wells in this area could help better characterize the existing groundwater table and confirm if emergent groundwater is a likely concern at this early sea level rise scenario.

Figure 6.1 Potential Locations for Additional Monitoring Wells

6.4 Increase Temporal Distribution on Monitoring Observations

The SWRCB requires limited monitoring of the existing wells. Most well locations are currently monitored twice per year, in the winter and summer, although monitoring requirements may vary based on permit conditions. More frequent monitoring, particularly during and after precipitation events, would provide additional information on the response of the shallow groundwater table to precipitation. More frequent monitoring would also increase the likelihood of capturing peak water table elevations during wet winters.

The University of Berkeley has graduate student researchers that are interested in advancing groundwater science. The City of Alameda could partner with the University and help a graduate student gain access to multiple wells on the Main Island for the installation of remote monitoring equipment that can collect measurements every 15 minutes. This information could help tease out the influence of the tides, rainfall, and longer-term sea level rise on the elevation of the water table. Depending on the number and extent of wells that can be monitored concurrently, this could also help inform the inland extent of the tidal influence on the shallow groundwater layer (i.e., how far inland is the 1:1 relationship between sea level rise and groundwater rise a reasonable approximation).

6.5 Identify Residential Underground Storage Tanks

Alameda is home to numerous turn-of-the-century (late 1800s and early 1900s) homes and buildings, and over ten thousand homes constructed prior to 1930. Many older homes may have used oil-fired boilers and furnaces with oil storage tanks located underground or in the basement. A survey could be conducted to help identify potential legacy underground oil storage tanks that were not removed when heating systems were upgraded over time. As the shallow groundwater table rises, these underground storage tanks could provide an additional source of contamination for the city.

6.6 Analyze Additional Contaminants

This study reviewed and analyzed contaminants that had concentrations above human health benchmarks between 2000 and 2019. However, additional contaminants are monitored and reported to the SWRCB throughout the city. A more thorough assessment could be completed to catalog and map additional contaminants in areas with emergent groundwater risks.

6.7 Analyze Potential Landfill Risks

Over three dozen historic and closed landfills are located along the San Francisco Bay shoreline. The landfills vary from former military landfills, residential dumps, and relics of mining and other waste from the Gold Rush era. Some landfills were operated as official landfills by waste management agencies, while others began as unregulated dump sites. In 1961, the organization Save the Bay mobilized to close these landfills and reduce the risk of polluting the Bay. Many of these former landfills have been turned into public parks, although the legacy trash and waste remain buried beneath the ground surface. As sea levels rise and waves along the shoreline become more erosive, coastal erosion along the shoreline edge of some landfills, including the Doolittle Landfill, could create a pollution risk to the Bay. Rising groundwater levels could also pose a risk and increase the potential for leachate to seep from the landfills into the Bay and surrounding soils. Due to the high number of former landfills along the shoreline, this is an area of study that would benefit from regional attention and coordination.

It has also been noted that the Corica Golf Course was constructed on top of an old landfill site and groundwater monitoring has occurred quarterly since approximately 2013. At the time this groundwater assessment was completed, records of the old landfill and the respective groundwater monitoring data was not obtained. The Corica Golf Course has also changed substantially in recent years as fill has been imported and the site has been raised, re-graded, and improved. Re-evaluation of any old landfill material underlying the golf course is also recommended.

6.8 Analyze and Update Liquefaction Zones

A cross-discipline team at the USGS is currently completing a pilot analysis of the interaction between sea level rise and rising groundwater tables and how that may impact liquefaction hazards. As this science advances, there may be a need to update the liquefaction zone mapping (see Figure 2.11). The City of Alameda should continue to monitor advancements in the science and participate in regional conversations on groundwater issues.

6.9 Coordinate with Regulators

The cleanup efforts for contaminated lands are currently regulated by the SWRCB, the RWQCB, and DTSC. In general, smaller sites with leaking underground storage tanks are regulated by the SWRCB and RWQCB, and larger contaminated lands such as former military areas are regulated by DTSC. Existing remediation efforts consider a stationary climate, i.e., the remediation efforts do not consider the effects of climate change such as sea level rise, rising groundwater levels, or increased storm intensity and frequency. The City of Alameda should coordinate with regulators and encourage consideration of climate change in remediation efforts. Some formerly contaminated lands may require re-investigation if residual or legacy contamination can be remobilized with a rising groundwater table. Ultimately, existing regulations and remediation methods or timelines may need to be revised to address the changing climate. This will require larger coordination efforts and conversations at the regional, state, and federal levels.

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Appendix A: Contaminant Tables

Table A.7.1 Average Benzene Concentrations between 2015 and 2019 (HHB 1 µg/L)

Well	Number of Observations	Historic Max Measurement (µg/L)	Historic Max Date	Historic Monitoring Average (µg/L)	Current Average (2015 - 2019)	GAMA Well ID
Benzene 1	1	0.6	11/18/16	0.6	0.61	T0600100977-MW-2B
Benzene 2	14	1,300	10/14/11	460	0.75	T06019744728-MW-1RA
Benzene 3	3	20	4/18/13	9	0.82	T0600100980-MW-10
Benzene 4	2	3	4/17/13	3	**2**	T0600100980-MW-16
Benzene 5	19	13	7/15/13	6	**3**	T06019744728-MW-6
Benzene 6	16	350	11/28/11	59	**3**	T0600101803-OW-2
Benzene 7	1	4	5/19/16	4	**4**	T0600100424-MW-3
Benzene 8	3	4	8/24/18	4	**4**	T10000009401-MW-2
Benzene 9	1	5	5/19/16	5	**5**	T0600100424-MW-1
Benzene 10	1	6	5/19/16	6	**6**	T0600100424-MW-4
Benzene 11	3	8	4/2/18	6	**6**	T10000009401-MW-3
Benzene 12	23	22	12/5/14	9	**9**	T0600100980-MW-8
Benzene 13	4	72	8/30/18	20	**20**	T10000009940-MW-1
Benzene 14	6	72	8/30/18	22	**22**	T10000005974-MW-1
Benzene 15	15	89	7/23/12	19	**30**	T06019744728-MW-1RB
Benzene 16	17	260	5/23/02	34	**31**	T0600100330-MW-6
Benzene 17	14	220	4/17/13	45	**34**	T0600100980-MW-6R
Benzene 18	40	7,300	8/15/03	1,300	**37**	T0600100330-MW-7
Benzene 19	25	140	1/18/12	85	**85**	T06019744728-MW-5
Benzene 20	36	3,700	10/26/04	1,100	**130**	T0600101803-MW-2
Benzene 21	28	3,300	11/19/13	680	**240**	T0600101803-EW-2
Benzene 22	35	5,800	5/30/07	650	**320**	T0600101803-MW-4
Benzene 23	30	2,400	11/19/13	1,000	**720**	T0600101803-EW-5
Benzene 24	17	1,900	8/16/16	580	**850**	T0600100980-MW-4R
Benzene 25	21	6,800	1/19/18	730	**870**	T0600100980-MW-12
Benzene 26	24	4,400	12/10/15	1,300	**1,490**	T0600101803-EW-4
Benzene 27	19	5,000	9/14/17	1,200	**1,610**	T0600100980-MW-5R
Benzene 28	14	6,200	2/20/15	1,700	**1,700**	T0600100980-MW-14

Well	Number of Observations	Historic Max Measurement (µg/L)	Historic Max Date	Historic Monitoring Average (µg/L)	Current Average (2015 - 2019)	GAMA Well ID
Benzene 29	18	18,000	6/25/14	6,500	**2,300**	T0600100980-MW-7R
Benzene 30	36	8,800	1/4/06	4,100	**3,600**	T0600101803-MW-1
Benzene 31	4	9,400	5/10/12	5,300	**4,000**	T0600100980-MW-2R
Benzene 32	20	13,000	2/6/08	6,900	**4,400**	T0600100330-C-1

32 out of 155 wells in the City of Alameda currently monitor benzene concentrations.

Table A.7.2 Average MTBE Concentrations between 2015 and 2019 (HHB 13 µg/L)

Well	Number of Observations	Historic Max Measurement (µg/L)	Historic Max Date	Historic Monitoring Average (µg/L)	Current Average (2015 - 2019)	GAMA Well ID
MTBE 1	40	50	11/28/11	4	1	T0600101803-OW-2
MTBE 2	17	4	9/13/17	1	1	T0600100980-MW-16
MTBE 3	17	6	8/10/15	1	2	T0600100980-MW-12
MTBE 4	14	8	8/10/15	4	4	T0600100980-MW-13
MTBE 5	15	7	8/17/16	3	4	T0600100980-MW-15
MTBE 6	4	12	8/30/18	5	5	T10000009940-MW-1
MTBE 7	51	6,200	12/12/02	1,200	6	T0600102263-MW-6
MTBE 8	21	930	5/28/09	160	7	T0600102263-MW-1AR
MTBE 9	42	270	11/29/11	63	8	T0600101803-EW-2
MTBE 10	6	51	2/25/16	12	12	T10000005974-MW-1
MTBE 11	48	1,700	10/26/04	96	**23**	T0600101803-MW-2
MTBE 12	46	3,600	5/30/07	310	**25**	T0600101803-MW-4
MTBE 13	42	710	12/10/15	100	**170**	T0600101803-EW-4
MTBE 14	42	480	12/10/15	110	**180**	T0600101803-EW-5
MTBE 15	42	570	2/5/14	18	**180**	T0600102263-MW-5
MTBE 16	47	6,200	9/8/06	1,200	**320**	T0600101803-MW-1
MTBE 17	21	13,000	5/28/09	840	**640**	T0600102263-MW-9
MTBE 18	20	18,000	9/14/09	5,300	**1,800**	T0600102263-MW-11

There are 18 wells where MTBE is currently monitored in the City of Alameda, and there are 247 wells with MTBE monitoring in the historic record.

Table A.7.3 Average Manganese Concentrations between 2015 and 2019 (HHB 50 µg/L)

Well	Number of Observations	Historic Max Measurement (µg/L)	Historic Max Date	Historic Monitoring Average (µg/L)	Current Average (2015 - 2019)	GAMA Well ID
Manganese 1	10	560	5/17/16	270	**310**	T0600100980-MW-16
Manganese 2	10	820	6/11/15	400	**460**	T0600100980-MW-10
Manganese 3	1	550	9/7/17	550	**550**	T0600100977-MW-6
Manganese 4	10	980	5/17/16	610	**680**	T0600100980-MW-15
Manganese 5	1	820	9/7/17	820	**820**	T0600100977-MW-3A
Manganese 6	1	990	9/7/17	990	**990**	T0600100977-MW-5
Manganese 7	9	2,700	12/4/14	1,000	**1,000**	T0600100980-MW-13
Manganese 8	1	1,200	9/7/17	1,200	**1,200**	T0600100977-MW-4
Manganese 9	10	7,800	12/4/14	2,000	**1,300**	T0600100980-MW-4R
Manganese 10	10	1,800	11/10/15	1,200	**1,300**	T0600100980-MW-8
Manganese 11	10	4,800	12/30/14	1,800	**1,300**	T0600100980-MW-5R
Manganese 12	10	2,100	2/19/15	1,400	**1,400**	T0600100980-MW-12
Manganese 13	9	1,900	2/20/15	1,400	**1,500**	T0600100980-MW-14
Manganese 14	10	3,100	12/4/14	1,600	**1,500**	T0600100980-MW-6R
Manganese 15	10	3,900	1/22/15	2,800	**2,700**	T0600100980-MW-7R
Manganese 16	10	10,000	6/26/14	4,300	**3,200**	T0600100980-MW-9
Manganese 11	10	560	5/17/16	270	**310**	T0600100980-MW-16
Manganese 12	10	820	6/11/15	400	**460**	T0600100980-MW-10
Manganese 13	1	550	9/7/17	550	**550**	T0600100977-MW-6
Manganese 14	10	980	5/17/16	610	**680**	T0600100980-MW-15
Manganese 15	1	820	9/7/17	820	**820**	T0600100977-MW-3A
Manganese 16	1	990	9/7/17	990	**990**	T0600100977-MW-5

There are 16 wells where manganese is currently monitored in the City of Alameda, and there are 48 wells with manganese monitoring in the historic record.

Table A.7.4 Average Toluene Concentrations between 2015 and 2019 (HHB 150 µg/L)

Well	Number of Observations	Historic Max Measurement (µg/L)	Historic Max Date	Historic Monitoring Average (µg/L)	Current Average (2015 - 2019)	GAMA Well ID
Toluene 1	32	110	4/18/13	7	0	T0600100980-MW-10
Toluene 2	20	2	9/13/17	0	0	T0600100980-MW-16
Toluene 3	34	1	3/7/17	0	0	T0600100330-MW-5

Well	Number of Observations	Historic Max Measurement (µg/L)	Historic Max Date	Historic Monitoring Average (µg/L)	Current Average (2015 - 2019)	GAMA Well ID
Toluene 4	26	170	11/28/11	17	0.3	T0600101803-OW-2
Toluene 5	3	0.6	8/24/18	0.3	0.3	T10000009401-MW-3
Toluene 6	48	480	5/14/04	34	0.3	T0600100330-MW-7
Toluene 7	49	5	3/27/18	0.3	0.7	T0600100330-MW-6
Toluene 8	4	1	8/30/18	0.7	0.7	T10000009940-MW-1
Toluene 9	6	3	2/25/16	0.9	0.9	T10000005974-MW-1
Toluene 10	30	19	11/19/13	5	2	T0600101803-EW-2
Toluene 11	3	4	4/2/18	3	3	T10000009401-MW-2
Toluene 12	37	77	5/28/08	22	4	T0600101803-MW-2
Toluene 13	1	5	5/19/16	5	5	T0600100424-MW-1
Toluene 14	30	79	11/19/13	14	7	T0600101803-EW-4
Toluene 15	32	52	12/5/14	6	8	T0600100980-MW-8
Toluene 16	25	9	1/9/14	6	8	T06019744728-MW-5
Toluene 17	35	3,700	5/30/07	240	13	T0600101803-MW-4
Toluene 18	21	150	05/10/2012	18	15	T0600100980-MW-12
Toluene 19	21	150	12/4/14	18	15	T0600100980-MW-12
Toluene 20	1	16	5/19/16	16	16	T0600100424-MW-3
Toluene 21	30	3,400	11/28/11	700	18	T0600101803-EW-5
Toluene 22	36	8,200	09/12/05	1,400	28	T0600101803-MW-1
Toluene 23	21	140	11/10/2015	38	44	T0600100980-MW-6R
Toluene 24	20	5,300	11/27/2001	630	**160**	T0600100330-C-1
Toluene 25	20	3,800	8/16/2016	620	**870**	T0600100980-MW-4R
Toluene 26	19	7,000	05/17/2016	870	**1,100**	T0600100980-MW-14
Toluene 27	21	14,000	08/16/2016	5,500	**6,700**	T0600100980-MW-5R
Toluene 28	4	24,000	08/09/2018	14,000	**16,000**	T0600100980-MW-2R
Toluene 29	20	45,000	04/17/2013	21,000	**14,000**	T0600100980-MW-7R

There are 29 wells where toluene is currently monitored in the City of Alameda, and there are 180 wells with toluene monitoring in the historic record.

Table A.7.5 Average Iron Concentrations between 2015 and 2019 (HHB 300 µg/L)

Well	Number of Observations	Historic Max Measurement (µg/L)	Historic Max Date	Historic Monitoring Average (µg/L)	Current Average (2015 - 2019)	GAMA Well ID
Iron 1	8	2,900	6/25/14	480	**130**	T0600100980-MW-6R
Iron 2	12	7,700	10/3/14	3,000	**650**	T0600101803-EW-2
Iron 3	10	28,000	10/3/14	14,000	**1,000**	T0600101803-EW-4
Iron 4	7	15,000	6/26/14	3,300	**1,300**	T0600100980-MW-12
Iron 5	4	2,800	6/19/14	1,800	**1,300**	T0600101803-MW-3
Iron 6	7	7,200	8/17/16	1,500	**1,700**	T0600100980-MW-16
Iron 7	7	3,800	8/11/15	1,900	**2,200**	T0600100980-MW-5R
Iron 8	3	15,000	6/19/14	8,500	**5,200**	T0600101803-MW-4
Iron 9	8	9,900	6/18/15	4,000	**6,200**	T0600101803-OW-2
Iron 10	8	35,000	6/25/14	11,000	**7,200**	T0600100980-MW-7R
Iron 11	12	27,000	10/3/14	20,000	**9,600**	T0600101803-EW-5
Iron 12	6	23,000	6/19/14	11,080	**11,000**	T0600101803-MW-2
Iron 13	5	370,000	6/19/14	87,000	**12,000**	T0600101803-MW-1
Iron 14	7	50,000	11/10/15	12,000	**12,000**	T0600100980-MW-4R
Iron 15	7	28,000	6/26/14	18,000	**16,000**	T0600100980-MW-14
Iron 16	7	78,000	8/17/16	20,000	**22,000**	T0600100980-MW-13
Iron 17	8	43,000	11/10/15	29,000	**25,000**	T0600100980-MW-10
Iron 18	8	66,000	8/16/16	29,000	**26,000**	T0600100980-MW-9
Iron 19	8	81,000	11/10/15	30,000	**35,000**	T0600100980-MW-8
Iron 20	7	160,000	3/2/17	53,000	**53,000**	T0600100980-MW-15

There are 20 wells where iron is currently monitored in the City of Alameda, and there were 52 wells with iron monitoring in the historic record.

Table A.7.6. Average TBA Concentrations between 2015 and 2019 (HHB 12 µg/L)

Well	Number of Observations	Historic Max Measurement (µg/L)	Historic Max Date	Historic Monitoring Average (µg/L)	Current Average (2015 - 2019)	GAMA Well ID
TBA 1	5	3	12/5/11	0.7	2	T06019716048-MW3
TBA 2	25	14	12/6/11	2	4	T0600100766-MW-4
TBA 3	6	35	2/25/16	6	6	T10000005974-MW-1
TBA 4	41	1,600	1/17/05	280	6	T0600137103-TBW-N
TBA 5	26	8,800	3/24/05	1,700	8	T0600100555-MW4

Well	Number of Observations	Historic Max Measurement (µg/L)	Historic Max Date	Historic Monitoring Average (µg/L)	Current Average (2015 - 2019)	GAMA Well ID
TBA 6	18	680	11/22/06	110	11	T0600137103-S-4B
TBA 7	27	220	5/14/12	33	**28**	T0600102263-MW-1
TBA 8	26	22,000	6/14/05	4,700	**40**	T0600100555-MW6
TBA 9	24	150	9/18/03	72	**41**	T0600102128-MW-3
TBA 10	26	1,300	11/29/07	190	**48**	T0600100555-MW2
TBA 11	18	690	11/18/10	140	**49**	T0600101803-MW-4
TBA 12	26	350	5/26/11	54	**73**	T0600101803-OW-2
TBA 13	28	290	5/26/11	79	**80**	T0600101803-EW-2
TBA 14	20	2,300	2/10/05	350	**90**	T0600101651-MW-1
TBA 15	13	100	1/20/11	23	**100**	T0600102128-MW-5
TBA 16	28	760	12/10/15	150	**120**	T0600101803-EW-4
TBA 17	21	960	2/5/10	220	**120**	T0600102263-MW-8
TBA 18	26	16,000	9/12/05	4,000	**140**	T0600100555-MW3
TBA 19	20	480	5/26/11	130	**140**	T0600101803-MW-2
TBA 20	19	7,000	9/19/07	1,600	**150**	T0600100766-MW-8
TBA 21	26	26,000	6/12/06	8,200	**190**	T0600100555-MW1
TBA 22	20	1,600	2/5/10	370	**210**	T0600102263-MW-11
TBA 23	28	760	6/18/15	310	**350**	T0600101803-EW-5
TBA 24	19	17,000	2/25/09	3,100	**800**	T0600101803-MW-1
TBA 25	20	2,800	2/2/12	1,100	**1,200**	T0600102263-MW-7

There are 75 wells where TBA was historically monitored in City of Alameda, and there are 25 wells in the current period record.

Table A.7.7 Average TCE Concentrations between 2015 and 2019 (HHB 5 µg/L)

Well	Number of Observations	Historic High Measurement (µg/L)	Historic High Date	Historic Monitoring Average (µg/L)	Current Average (2015 - 2019)	GAMA Well ID
TCE **1**	1	0	6/20/07	0	N/A	SF-43
TCE **2**	1	0	12/13/05	0	N/A	T0600140375-MW-6
TCE 3	2	0.2	10/10/05	0	N/A	T0608592037-C3S032B039
TCE 4	2	0.2	12/13/05	0.2	N/A	T0600140375-MW-5

Well	Number of Observations	Historic High Measurement (µg/L)	Historic High Date	Historic Monitoring Average (µg/L)	Current Average (2015 - 2019)	GAMA Well ID
TCE 5	1	0.7	10/24/13	0.7	N/A	T0600100655-DPE-8
TCE 6	3	0.7	10/5/05	0.5	N/A	T0608592037-C3S032B041
TCE 7	2	1	10/6/05	1	N/A	T0608592037-C3S032B021
TCE 8	1	2	10/24/13	2	N/A	T0600100655-DPE-4
TCE 9	1	3	10/24/13	3	N/A	T0600100655-DPE-6
TCE 10	2	3	10/12/05	2	N/A	T0608592037-C3S032B038
TCE 11	1	6	10/24/13	6	N/A	T0600100655-MW-2
TCE 12	2	6	2/15/06	5	N/A	T0608592037-IR32-MW-03
TCE 13	1	6	10/24/13	**6**	N/A	T0600100655-DPE-11
TCE 14	4	6	10/6/05	**3**	N/A	T0608592037-C3S032B024
TCE 15	2	16	10/24/13	16	N/A	T0600100655-MW-5
TCE 16	2	19	1/21/14	19	N/A	T0600100655-MW-4
TCE 17	1	29	10/24/13	29	N/A	T0600100655-DPE-10
TCE 18	1	31	10/24/13	31	N/A	T0600100655-DPE-9
TCE 19	1	64	10/24/13	64	N/A	T0600100655-MW-3
TCE 20	41	81	3/3/05	16	N/A	SL0600177511-MW-2
TCE 21	37	100	3/12/14	32	N/A	SL0600177511-MW-1
TCE 22	3	0.2	7/19/19	0.1	0.1	T10000009401-MW-1
TCE 23	5	0.2	6/6/16	0	0	T10000005974-MW-2A
TCE 24	3	0.4	2/15/19	0.3	0.3	T10000009401-MW-3
TCE 25	1	2	5/19/16	2	**16**	T0600100424-MW-1
TCE 26	14	54	7/27/17	20	**23**	T0600101803-EW-4
TCE 27	14	570	10/3/14	380	**150**	T0600101803-EW-2

There are 27 wells where TCE was historically monitored in City of Alameda, and there are 6 wells in the current period record.

Table A.7.8 Average PERC/PCE Concentrations between 2015 and 2019 (HHB 5 µg/L)

Well	Number of Observations	Historic High Measurement (µg/L)	Historic High Date	Historic Monitoring Average (µg/L)	Current Average (2015 - 2019)	GAMA Well ID
PERC/PCE 1	1	0	6/20/07	0	N/A	SF-43
PERC/PCE 2	1	0.3	7/2/04	0.3	N/A	T0600140375-C3B012
PERC/PCE 3	3	1	12/3/18	0.9	N/A	T10000009401-MW-3
PERC/PCE 4	36	1	12/6/05	0.4	N/A	SL0600177511-MW-4
PERC/PCE 5	37	1	12/4/08	0	N/A	SL0600177511-MW-3
PERC/PCE 6	17	1	11/14/12	0	N/A	T0600100980-MW-12
PERC/PCE 7	1	1	10/24/13	1	N/A	T0600100655-DPE-6
PERC/PCE 8	2	7	10/24/13	7	N/A	T0600100655-MW-5
PERC/PCE 9	2	13	10/24/13	13	N/A	T0600100655-MW-4
PERC/PCE 10	37	850	9/23/11	230	N/A	SL0600177511-MW-1
PERC/PCE 11	6	0.6	8/31/17	0.3	0.3	T10000009940-MW-2A
PERC/PCE 12	5	0.6	6/6/16	0.4	0.4	T10000005974-MW-2A
PERC/PCE 13	1	2	5/19/16	2	2	T0600100424-MW-1
PERC/PCE 14	1	2	5/19/16	2	2	T0600100424-MW-3
PERC/PCE 15	1	3	5/19/16	2	3	T0600100424-MW-4
PERC/PCE 16	3	4	12/3/18	3	3	T10000009401-MW-1
PERC/PCE 17	14	120	6/27/16	63	**73**	T0600101803-EW-4
PERC/PCE 18	41	7,700	3/3/05	1,500	**210**	SL0600177511-MW-2
PERC/PCE 19	14	1,000	6/18/15	510	**540**	T0600101803-EW-2

There are 19 wells where PERC/PCE was historically monitored in City of Alameda, and there are 9 wells in the current period record.

Table A.7.9 Average Legacy Lead Concentrations between 2005 and 2010 (HHB 15 µg/L)

Well	Number of Observations	Historic Max Measurement (µg/L)	Historic Max Date	Historic Monitoring Average (µg/L)	Current Average (2015 - 2019)	GAMA Well ID
Lead 1	5	2	5/4/10	0.4	N/A	T06019716048-MW1
Lead 2	2	2	6/21/04	1	N/A	T0600140375-MW-4
Lead 3	1	1	2/15/06	1	N/A	T0608592037-IR32-MW-02
Lead 4	5	4	5/4/10	1	N/A	T06019716048-MW2
Lead 5	4	7	6/30/09	2	N/A	T0600100207-MW-2

Well	Number of Observations	Historic Max Measurement (µg/L)	Historic Max Date	Historic Monitoring Average (µg/L)	Current Average (2015 - 2019)	GAMA Well ID
Lead 6	1	2	2/16/06	2	N/A	T0608592037-IR32-MW-05
Lead 7	1	3	2/15/06	3	N/A	T0608592037-IR32-MW-01
Lead 8	3	10	6/30/09	3	N/A	T0600100207-MW-6
Lead 9	5	14	5/4/10	5	N/A	T06019716048-MW3
Lead 10	2	6	6/30/09	5	N/A	T0600100207-RW-1
Lead 11	4	36	6/30/09	9	N/A	T0600100207-MW-4
Lead 12	2	19	12/13/05	10	N/A	T0600140375-MW-1
Lead 13	3	54	6/30/09	**26**	N/A	T0600100207-MW-1
Lead 14	4	310	12/13/05	**78**	N/A	T0600140375-MW-5
Lead 15	3	280	12/13/05	**94**	N/A	T0600140375-MW-6
Lead 16	2	380	12/13/05	**200**	N/A	T0600140375-MW-3

There are 16 wells where lead was historically monitored in City of Alameda, however there are no wells in the current period record.

Table A.7.10 Average Legacy Arsenic Concentrations between 2003 and 2013 (HHB 10 mg/L)

Well	Number of Observations	Historic Max Measurement (µg/L)	Historic Max Date	Historic Monitoring Average (µg/L)	Current Average (2015 - 2019)	GAMA Well ID
Arsenic 1	5	0.8	10/26/11	0.2	N/A	T0600100766-MW-3
Arsenic 2	5	1	4/19/11	0.4	N/A	T0600100766-MW-6
Arsenic 3	5	1	10/26/11	0.5	N/A	T0600100766-MW-4
Arsenic 4	5	2	4/19/11	0.7	N/A	T0600100766-MW-9
Arsenic 5	5	2	10/26/11	1	N/A	T0600100766-MW-7
Arsenic 6	5	6	12/5/11	3	N/A	T06019716048-MW3
Arsenic 7	5	8	12/5/11	6	N/A	T06019716048-MW2
Arsenic 8	2	6	2/15/06	6	N/A	T0608592037-IR32-MW-03
Arsenic 9	5	27	7/11/13	7	N/A	T0600100766-MW-2
Arsenic 10	5	11	7/11/13	7	N/A	T0600100766-MW-8
Arsenic 11	1	7	2/16/06	7	N/A	T0608592037-IR32-MW-05
Arsenic 12	1	9	2/16/06	9	N/A	T0608592037-IR32-MW-04
Arsenic 13	1	11	2/15/06	**11**	N/A	T0608592037-IR32-MW-02
Arsenic 14	5	19	12/5/11	**16**	N/A	T06019716048-MW1

Well	Number of Observations	Historic Max Measurement (µg/L)	Historic Max Date	Historic Monitoring Average (µg/L)	Current Average (2015 - 2019)	GAMA Well ID
Arsenic 15	3	43	12/13/05	**24**	N/A	T0600140375-MW-6
Arsenic 16	1	33	7/3/09	**33**	N/A	T06019744728-MW-5
Arsenic 17	2	43	8/25/03	**36**	N/A	T0600140375-MW-1
Arsenic 18	4	53	8/27/03	**39**	N/A	T0600140375-MW-5
Arsenic 19	1	42	2/15/06	**42**	N/A	T0608592037-IR32-MW-01
Arsenic 20	2	57	8/26/03	**47**	N/A	T0600140375-MW-4
Arsenic 21	2	120	8/25/03	**100**	N/A	T0600140375-MW-3

There are 21 wells where arsenic was historically monitored in City of Alameda; however, there are no wells in the current period record.

Table A.7.11 Average Legacy Chromium Concentrations between 2005 and 2010 (HHB 50 µg/L)

Well	Number of Observations	Historic Max Measurement (µg/L)	Historic Max Date	Historic Monitoring Average (µg/L)	Current Average (2015 - 2019)	GAMA Well ID
Chromium 1	5	2	10/26/11	0.8	N/A	T0600100766-MW-7
Chromium 2	5	8	11/5/10	2	N/A	T06019716048-MW3
Chromium 3	2	2	2/15/06	2	N/A	T0608592037-IR32-MW-03
Chromium 4	1	2	2/16/06	2	N/A	T0608592037-IR32-MW-04
Chromium 5	5	10	7/11/13	2	N/A	T0600100766-MW-9
Chromium 6	1	2	2/15/06	2	N/A	T0608592037-IR32-MW-02
Chromium 7	1	3	2/16/06	3	N/A	T0608592037-IR32-MW-05
Chromium 8	5	17	7/11/13	4	N/A	T0600100766-MW-6
Chromium 9	3	12	12/13/05	4	N/A	T0600140375-MW-6
Chromium 10	19	23	10/25/12	4	N/A	T0600102263-MW-11
Chromium 11	5	13	7/11/13	5	N/A	T0600100766-MW-4
Chromium 12	1	9	7/3/09	9	N/A	T06019744728-MW-3
Chromium 13	4	31	12/13/05	9	N/A	T0600140375-MW-5
Chromium 14	1	10	7/3/09	10	N/A	T06019744728-MW-4
Chromium 15	27	24	9/14/09	10	N/A	T0600102263-MW-10
Chromium 16	1	13	2/15/06	13	N/A	T0608592037-IR32-MW-01
Chromium 17	24	170	9/14/09	14	N/A	T0600102263-MW-1AR
Chromium 18	1	15	7/3/09	15	N/A	T06019744728-MW-2

Well	Number of Observations	Historic Max Measurement (µg/L)	Historic Max Date	Historic Monitoring Average (µg/L)	Current Average (2015 - 2019)	GAMA Well ID
Chromium 19	2	27	12/13/05	16	N/A	T0600140375-MW-3
Chromium 20	26	79	8/3/10	17	N/A	T0600102263-MW-7
Chromium 21	23	250	9/14/09	19	N/A	T0600102263-MW-1BR
Chromium 22	26	140	5/28/09	20	N/A	T0600102263-MW-8
Chromium 23	2	52	12/13/05	26	N/A	T0600140375-MW-1
Chromium 24	19	98	4/26/11	26	N/A	T0600102263-MW-6
Chromium 25	5	170	7/11/13	35	N/A	T0600100766-MW-2
Chromium 26	5	170	7/11/13	36	N/A	T0600100766-MW-3
Chromium 27	19	160	11/21/11	40	N/A	T0600102263-MW-5
Chromium 28	26	520	9/14/09	41	N/A	T0600102263-MW-9
Chromium 29	1	51	9/21/07	**51**	N/A	T0600100980-MW-8
Chromium 30	25	220	9/14/09	**52**	N/A	T0600102263-MW-1
Chromium 31	1	68	9/21/07	**68**	N/A	T0600100980-MW-9
Chromium 32	1	100	9/21/07	**100**	N/A	T0600100980-MW-10
Chromium 33	1	120	9/22/07	**120**	N/A	T0600100980-BL
Chromium 34	1	130	9/22/07	**130**	N/A	T0600100980-BG
Chromium 35	1	350	9/22/07	**350**	N/A	T0600100980-BH
Chromium 36	1	430	9/22/07	**430**	N/A	T0600100980-BK
Chromium 37	1	1,100	9/22/07	**1,100**	N/A	T0600100980-BM

There are 37 wells where chromium contamination was historically monitored in City of Alameda, however there are no wells in the current period record.

Appendix B: DTSC Contaminated Lands

Table B.7.12 DTSC Investigation Locations

Status	Site Name (Envirostor ID)
Not analyzed for this study:	
Duplicate Entry	GEN ENGRG & DRYDOCK CO. (J09CA0060)
Investigated, no activity required	ISLAND CITY GUN CLUB (01790001)
	MILLER ELEMENTARY SCHOOL (60000087)
	WOODSTOCK ELEMENTARY SCHOOL (01880005)
	ENCINAL SCHOOL SITE (01420130)
Needs Evaluation	TODD SHIPYARD (J09CA0038) (80000024)
	TRIDENT MANAGEMENT, INC. (71003347)
Referred to another Agency	U.S. COAST GUARD, SUPPORT CENTER ALAMEDA (71003610),
	UNITED STATES COAST GUARD (01970014)
Expired Permit	PROCESS TECHNOLOGY COMPANY/MOBILE UNIT (CAD066568429)
Analyzed for this study:	
Related to Navy	ALAMEDA NAS (01970005)
	ALAMEDA AIR DEPOT (80000007)
	ALAMEDA NAVAL AIR STATION EAST HOUSING (01970013)
	ALAMEDA NAVY SUPPLY CENTER (NSC) ANNEX (01970007)
	ALAMEDA NAVAL AND MARINE RESERVE CENTER (71000003)
	NAS ALAMEDA (J09CA0066) (80000046)
	NAVY BRAC PMO-W (ALAMEDA PT) (CA2170023236)
	NAVY BRAC PMO-W (ALAMEDA PT) (CA2170023236)
	NIRS ALAMEDA FORGE (J09CA0069) (80000048)
	U.S. NAVY, NAVAL AIR STATION, ALAMEDA/DEPOT (71003595)
	UWS NAVY/FLEET & INDUST SUPL CTR-ALAMEDA (CA1170090012)
	UWS NAVY/FLEET & INDUST SUPL CTR-ALAMEDA (80001236)
Active, Undergoing investigation	2100 CLEMENT AVENUE (60002415)
	CADENCE AND LINEAR AT ALAMEDA LANDING (60002675)
	COLLINS PROPERTY (01390007)
	FORMER J. H. BAXTER FACILITY, ALAMEDA (01240036) • Extra Space Storage

	• Fox-Collins Property • Dutra-Velodyne Property
	JEAN SWEENEY OPEN SPACE PARK (60001930)
	LINCOLN AVENUE AFFORDABLE HOUSING PROJECT (60001386)
	RETAIL CENTER (60002671)
	SHINSEI GARDENS (80001226)
	STARGELL COMMONS (60002676)
	SYMMETRY AT ALAMEDA LANDING (60002672)
	TARGET PARCEL (60002299)
Historical, low priority	KEM MIL CO, DIVISION OF GRAPHIC SERVICES (01350100)
	PENNZOIL COMPANY (01290012)

Appendix C: National Groundwater Adaptation Strategy Examples

Summary of Potential Groundwater Adaptation Strategies for City of Alameda: National Examples

Introduction

This document describes potential physical, governance, and informational adaptation strategies to address rising groundwater levels as a result of sea level rise. This summary is a companion document to an Alameda-specific set of groundwater adaptation strategies being developed by Silvestrum Climate Associates. These strategies are drawn from a review of groundwater management techniques applied throughout the country. The groundwater management strategies identified in this review have not historically been applied specifically to address sea level rise related groundwater hazards; however, they are presented here to provide an initial list of potential strategies that could be adapted and applied in Alameda upon further review and evaluation. The purpose of this document is to present an initial list of potentially applicable sea level rise related groundwater management strategies for the City based on typical groundwater strategies that have been applied successfully elsewhere.

In coastal areas, groundwater levels in the surficial aquifer are strongly influenced by the water level in the adjacent surface water body. When the surface water body is tidal (such as in San Francisco Bay), groundwater in the coastal area fluctuates daily with the tides and seasonally/annually in response to precipitation patterns and rates of pumping and recharge. At the shoreline, groundwater is generally equal to mean sea level, on average, and it is anticipated that coastal groundwater levels will rise in response to future sea level rise. The effect of sea level rise in raising groundwater levels tapers moving inland to a point where groundwater levels are insensitive to the Bay's influence. In general, the width of the coastal zone where groundwater is affected by Bay water levels varies and depends on a variety of factors, including the amount of sea level rise, rates of precipitation and recharge, underlying geology and hydraulic conductivity, presence of artificial fill, and existing pumping and groundwater lowering activities. There is little information available about the landward extent of Bay influence on groundwater levels within San Francisco Bay. An ongoing groundwater modeling study by the U.S. Geological Survey and University of Wyoming may help provide further information on these factors (results will be available in 2020).

Several means of addressing rising groundwater levels and associated impacts are summarized in the sections below. The different adaptation approaches identified in this document have historically been applied to address several causes of elevated groundwater levels, including:

- Water supply or wastewater collection system leakage
- Excessive irrigation using potable or reclaimed water
- Natural groundwater flow impediment due to underground structures
- Curtailment of groundwater extraction

- Increased upstream groundwater recharge
- Increase in impervious surfaces as a result of paving and building construction that reduced evaporation at the ground surface

The national examples discussed in this document were compiled based on a review of typical groundwater lowering and/or management strategies used to address elevated groundwater levels elsewhere. The strategies were not necessarily developed specifically for groundwater rise due to sea level rise; however, they show potential applicability for the City of Alameda. The applicability of different adaptation measures to address the specific challenges associated with sea level rise and groundwater will need to be further assessed in future studies and evaluations prior to implementation.

Physical Strategies

The physical strategies identified to address rising groundwater generally fall into three categories: lower, divert, or adapt. Groundwater hazards can be managed at a regional, site, or asset level by either managing the groundwater hazard itself (i.e., lowering or diverting groundwater) or adapting infrastructure to be less sensitive to groundwater rise (i.e., harden, raise, or relocate). Hardening strategies may be applied to existing infrastructure (i.e., retrofitting) or new construction.

Strategies for Lowering or Diverting Groundwater

As sea levels rise in the Bay, discharging excess groundwater from low-lying inland areas will likely require pumping, especially in locations where existing or new shoreline protection features such as levees, seawalls, and tide gates prevent natural drainage of surface and ground water to the Bay. Pumping for dewatering or lowering groundwater levels is a commonly used approach and sea level rise will likely necessitate increased rates of pumping in areas where groundwater lowering already occurs and may require pumping in new areas where elevated groundwater levels become a problem. Due to Alameda's proximity to the Bay, high pumping rates may be required to maintain a satisfactory drawdown of the groundwater surface – especially during wet winters or times of heavy precipitation. In some cases, subsurface groundwater barriers such as grout curtains, cut-off walls, or sheet pile walls[1] anchored to impervious or less pervious soil layers may need to be used in conjunction with pumping to control groundwater levels at a site level and prevent recharge by subsurface Bay waters as pumping occurs.

Pumping could occur at distributed wells or from underground tanks to which groundwater would be conveyed by pipes or French drains[2]. Depending on proximity to the Bay and local groundwater dynamics, pumped water may be fresh, brackish (a mix of fresh and saltwater), or saline. The salinity and degree of contamination of pumped groundwater may dictate how it is discharged. Clean freshwater may be reused for other purposes such as irrigation (e.g., in other parts of the City where elevated groundwater levels are not a concern). Clean brackish or saline water may be conveyed to the

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[1] Grout curtains, cut-off walls, and sheet pile walls are vertical subsurface barriers composed of impervious or low permeability natural or engineered materials, such as cement, bentonite clay, or steel (in the case of sheet piles).

[2] A French drain is a trench filled with gravel containing a perforated pipe that collects and redirects surface or groundwater away from an area or away from the foundation of a building.

City’s stormwater system and ultimately discharged to the Bay (either by gravity at low tide or by pumping). For combined stormwater-sewer systems, it would be important to assess any potential impacts of conveying high salinity waters to the wastewater treatment plant to avoid disrupting biological treatment processes. Pumped groundwater that is contaminated may need to undergo further treatment or dilution before conveyance to the stormwater system or discharging directly to the Bay, depending on the types of contaminants, degree of contamination, and discharge permit requirements.

In open space areas (such as parks) or in new developments, site grades could be raised by placing fill to elevate ground elevations above future groundwater hazards and avoid issues with emergent groundwater flooding. Placement of additional soil would provide greater infiltration and storage capacity for runoff and provide an additional benefit of reducing risk of flooding from surface waters. Depending on the City’s green infrastructure goals, raising site elevations to create additional storage and infiltration capacity may be required to successfully implement stormwater-related green infrastructure installations that rely on infiltration in areas of high groundwater.

Table 1 presents a summary of potential physical strategies to address rising groundwater by lowering or diverting. For each strategy, a description of the strategy is provided along with its potential applicability to Alameda and additional considerations for implementation.

Table 1. Potential Physical Strategies to Address Rising Groundwater by Lowering or Diverting

Name of strategy	**Description**	**Applicability to Alameda**	**Considerations**	**Case Study/Example**
Pumping	Distributed pumping wells to lower groundwater levels.	*Applicable.* Primarily applicable in low hydraulic conductivity areas or in conjunction with barriers to prevent recharge by Bay waters.	Requires connection to stormwater system or existing/new Bay discharge point. Excessive pumping could lead to increased rates of subsidence.	Bolton, Ontario. Use of sump pumps to manage groundwater levels and seepage along excavated surface during construction project. https://www.peelregion.ca/pw/water/environ-assess/pdf/bolton/appendix/Appendix_E_-_Hydrogeological_Report.pdf
Groundwater Barriers	Low hydraulic conductivity barriers to reduce groundwater flow or tidal influence from Bay.	*Applicable.* May be applicable to address high groundwater levels immediately adjacent to the shoreline in conjunction with pumping.	While groundwater barriers will reduce influence of subsurface Bay waters in inland areas, they will also prevent natural discharge of groundwater to the Bay, necessitating pumping.	Lake Okeechobee, Florida. Installation of seepage barrier underneath dike. https://www.semanticscholar.org/paper/Changes-in-the-saltwater-interface-corresponding-to-Prinos-Valderrama/842666442ec28ce525655ef1758a5278ef93577b Many other examples of seepage cutoff walls for levees, flood barriers, and construction projects.

Name of strategy	**Description**	**Applicability to Alameda**	**Considerations**	**Case Study/Example**
French Drains	Perforated pipes in trenches collect groundwater and convey to the stormwater system, discharge points, or to underground tanks from which groundwater is pumped.	*Applicable.* Could be applicable in conjunction with pumping stations.	French drains may not perform properly in shallow surficial groundwater coastal aquifers with tidal influence. These systems may cause groundwater flow to be reversed during high tide events.	Miami International Airport, FL. Installation of exfiltration trenches and perforated pipes to manage stormwater and groundwater infiltration from an asphalt parking area. https://www.environment.fhwa.dot.gov/env_topics/water/ultraurban_bmp_rpt/5mcs1.aspx
Green areas for groundwater management	Increase soil storage capacity by elevating green areas (e.g., parks, golf courses) to facilitate implementation of green infrastructure strategies. Retrofit/construct green areas with capacity to absorb excess stormwater and emergent groundwater	*Potentially applicable.* Could be applicable in low-lying areas	Site-specific applicability, depending on elevation, groundwater table, stratigraphy, and green space availability	Bronx, New York, NY. Use of raingarden in urban park to capture runoff and infiltrate or convey excess water to combined sewer. https://ascelibrary.org/doi/10.1061/JSWBAY.0000880 Miami Beach, FL. The City is evaluating raising low-lying shoreline parks to reduce flooding from sea level rise. The City is already raising streets to prevent flooding and better manage stormwater. Raising parks could

Name of strategy	**Description**	**Applicability to Alameda**	**Considerations**	**Case Study/Example**
				provide additional infiltration and stormwater storage and reduce tidal flooding as well.
SeepCat	SeepCat is an experimental groundwater capture system designed by Deltares intended to prevent intrusion of saline groundwater into freshwater aquifers by capturing excess groundwater and returning it to its marine source.	*Potentially applicable.*	Further piloting is needed for case studies on the main land and different geological settings. While the primary purpose of the SeepCat system is to protect freshwater aquifers for drinking water, it has the potential to be a systematic approach for lowering groundwater levels as well.	SeepCat description: https://www.deltares.nl/en/news/seepcat/

Strategies for Asset Adaptation

Elevated groundwater can be problematic for both buried and at grade infrastructure, causing seepage into basements, saturation of roadway subgrades, infiltration into stormwater and sanitary sewer pipes, buoyancy forces on buried pipes and tanks, uplift forces on impermeable surfaces (such as slab foundations, parking lots, or sidewalks), increased risk of liquefaction, and increased soil saturation and salinity. Table 2 lists groundwater impacts on infrastructure and potential hardening strategies that could be further investigated for application in the City of Alameda. For each groundwater impact, potential asset adaptation strategies are discussed for retrofitting existing infrastructure and for new construction. Any strategies identified for new construction may require a corresponding governance strategy to update design guidelines and/or standards to incorporate these resilience measures into new projects at the planning and design stage. Developing and providing future groundwater hazard maps to planners and designers will be a key aspect of successful implementation of these adaptation measures for new construction.

Table 2. Potential Physical Strategies to Address Rising Groundwater through Asset Adaptation

Groundwater Impact on Infrastructure	**Potential Asset Adaptation Strategies (Retrofit or New Construction)**
Seepage into basements	Retrofit existing structures to seal or floodproof basement walls and/or foundations to prevent seepage into basements. Seal or floodproof new basement walls and/or foundations for new construction in areas identified as exposed to elevated groundwater levels due to sea level rise.
Infiltration into stormwater and sanitary sewer pipes (or leakage of pipes)	Seal or retrofit existing pipes experiencing high infiltration (e.g., sliplining, etc.). Construct new pipes using more robust materials to reduce infiltration in areas identified as exposed to elevated groundwater levels due to sea level rise. Monitor pipes in areas of high groundwater to identify and address infiltration issues.
Buoyancy forces on buried pipes and tanks	Retrofit buried pipes and tanks by anchoring pipes to prevent damage by increased buoyancy forces. Anchor new pipe and tank construction in areas identified as exposed to elevated groundwater levels due to sea level rise.
Uplift forces on impervious surfaces	Retrofit existing impervious surfaces or construct new impervious surfaces with vertical drains to provide a controlled pathway for emergent groundwater to flow up instead of uplifting concrete or seeping around and causing erosion.
Increased risk of liquefaction	Retrofit foundations for existing buildings considering potential seismic hazards under conditions with increased liquefaction risk. Perform seismic analysis and design for new buildings considering increased liquefaction risk due to elevated groundwater conditions as a result of sea level rise.
Increased soil saturation and salinity	Monitor soil saturation and salinity condition in existing green areas to identify potential issues with elevated groundwater.

Groundwater Impact on Infrastructure	**Potential Asset Adaptation Strategies (Retrofit or New Construction)**
	Change planting palettes for landscaping in areas identified as exposed to elevated groundwater levels due to sea level rise to plants more adaptable to saturated conditions and/or higher salinities[3].

Data Needs for Physical Strategy Implementation

Based on the above it appears that strategies to address rising groundwater levels due to sea level rise will need to be site or asset specific. However, the planning and design of these facilities will require larger scale evaluations including compilation of existing data on soils (stratigraphy, hydraulic conductivity, storage coefficients), exploratory well drilling, aquifer testing, ground water level monitoring network, and groundwater models. These data are needed because, while the projects will be local, they will interact with large scale groundwater flow patterns including underlying soils, which will control response of local groundwater levels to sea level rise and dictate the efficacy of the various strategies. At a site level, application of groundwater models (such as MODFLOW as being applied by the U.S. Geological Survey) may be required. If the groundwater response is sensitive to density differences between saline Bay waters and fresh groundwater, three-dimensional groundwater models capable of accounting for these variations may be needed.

Governance Strategies

Planning for climate change includes consideration of various components which carry significant uncertainty along with them. These include uncertainty in projections of future physical conditions, such as precipitation, temperatures, and sea level trends as well as planning related uncertainties such as future development, building codes, regulatory environment, and public infrastructure needs. As discussed above for the physical strategies, successful implementation of asset adaptation may require companion governance strategies to update regulations, codes, or design guidelines.

Some examples of potential groundwater related governance strategies are listed below:

- Update the City's Floodplain Management Ordinance to include provisions for residential and commercial construction in areas projected to be exposed to elevated groundwater levels due to sea level rise. Provisions could include standards of construction related to anchoring of buried pipes and tanks, use of water-resistant construction materials, floodproofing of basement walls and foundations, elevation of structures (i.e., freeboard) in areas potentially exposed to emergent groundwater flooding, and updated standards for utilities to acknowledge groundwater hazards and minimize or eliminate infiltration due to groundwater.
- Update the City of Alameda Building Code to include guidance/requirements related to:
    - Flood resistant building materials

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[3] For example, Point Blue's Climate Smart Restoration Toolkit (https://www.pointblue.org/climate-smart-restoration-toolkit/)

  - Floodable designs
  - Guidance on groundwater management
- Update the City's Local Hazard Mitigation Plan to include maps and discussion of existing and future groundwater hazards
- Develop capital planning guidance for City projects to include consideration of sea level rise and groundwater hazards in planning and design
- Develop a Citywide groundwater hazard planning map to identify areas potentially exposed to groundwater hazards; tie map to building code and capital planning guidance; include in Local Hazard Mitigation Plan
- Establish green infrastructure planning and design guidance that accounts for higher groundwater levels and potentially reduced effectiveness of infiltration
- Implement land use or deed restrictions for properties in areas projected to be exposed to elevated groundwater levels due to sea level rise to minimize risk of groundwater hazards (for example, restrictions related to basements, irrigation, etc.)
- Establish incentives for drought-resistant plantings to reduce irrigation needs which contribute to higher groundwater levels
- Establish overlay zones or districts for sites or neighborhoods projected to be exposed to elevated groundwater levels due to sea level rise to apply additional regulations based on the unique nature of groundwater hazards
- Investigate options to purchase development rights, land use swap, or land acquisition (i.e., buyouts) of areas projected to be exposed to elevated groundwater levels due to sea level rise
- Update zoning and land use in areas projected to be exposed to elevated groundwater levels due to sea level rise to limit development in those areas
- Review/revise land use regulations to regulate construction on liquefiable soils. Require liquefaction assessments for new construction to consider effects of elevated groundwater levels due to sea level rise in design.
- Establish an ordinance to require local minimum standards for sustainable-green building practices through LEED (e.g., LEED Gold Certification) and/or Living Building Challenge certification for new construction exceeding, for example, 5,000 sq-ft. For existing construction, the standards could apply to ground level additions exceeding, for example, 10,000 sq-ft of added floorplan area.

  The City could also potentially pass an ordinance to require LEED certification credits to include groundwater lowering systems (i.e., continuous dewatering with well-points, etc.). Ordinances could also give priority to LEED credits that incorporate adaptation strategies to flooding from rising sea levels and rainfall, which is a way to address the consequences of emerging groundwater.
- Establish an ordinance to require minimum standards for sustainable and resilient infrastructure through ENVISION Certification (e.g., Gold Certification) for new construction of public infrastructure projects involving stormwater, wastewater, and water infrastructure as well as retrofits. Ordinances could give priority to Envision credits that incorporate adaptation strategies to flooding from rising sea levels and rainfall, which is a way to address the consequences of emerging groundwater.

Informational Strategies

Informational strategies seek to address data gaps and unknowns to better position the City to understand vulnerabilities and make adaptation decisions. The science of sea level rise impacts on groundwater levels in coastal areas is rapidly evolving and only in the last couple years has it received and increased awareness and dedication of resources to study this hazard. Through this work in support of the City's Climate Action and Resiliency Plan, initial steps at developing groundwater hazard maps and identifying potential contaminants that could be mobilized by rising groundwater levels, the City has taken important first steps in improving the understanding of this emerging hazard. Potential information strategies that could be pursued in the City are discussed in the main body of this report.

Some additional examples of potential groundwater related informational strategies are listed below:

- Install monitoring wells near the shoreline at locations representative of various subsurface conditions and distance from the Bay to better define the boundaries of tidal influence on groundwater within Alameda
- Conduct pilot projects to collect and divert excess groundwater, including testing of groundwater quality and potential needs and methods to treat pumped groundwater if it is found to be contaminated
- Research products and methods to floodproof building foundations to prevent seepage of groundwater into residential and commercial buildings
- Collect hydrological and geological data necessary to conduct more detailed groundwater modeling in the future, for example meteorological data and hydrogeological data throughout the City
- Conduct coupled surface-groundwater modeling of existing and future conditions to better understand sea level-groundwater interactions. A model could also be used to investigate the effectiveness of potential groundwater management strategies prior to potentially costly in-the-ground installations.
- Further identify and investigate groundwater management case studies from other national and international examples

Appendix D: Suggested Revisions to the Climate Action and Resilience Plan

The City of Alameda's Climate Action and Resilience Plan (CARP) contains several tables with recommended strategies (City of Alameda 2019). In this Appendix, select tables are re-produced with suggested additions relevant to rising groundwater levels. These recommendations are not intended to represent the full suite of updates that may be required for the next update the CARP.

Suggested modifications to Table 4-18 in the CARP are included below. Deletions are presented as ~~strike outs~~, and additions are presented in red.

Table 4-18 (Modified) Increasing Building Resilience

Strategy	Action(s)	Relative Cost	Responsible Entity	Timeline
Encourage implementation of flood-proofing	The Alameda Building Code currently requires that any new building construction or substantial improvements within the special flood hazard area (100-year floodplain) be elevated and flood-proofed in accordance with FEMA requirements. Alameda should consider re-defining "substantial improvement" to capture more redevelopment projects that currently do not meet the threshold for this requirement. If substantial improvement includes replacing the structures foundation, the installation of drain tile or French drain systems should be required.	$	City of Alameda	Short
Encourage implementation of flood-proofing	Implement programs to encourage flood-proofing retrofits to existing buildings and redevelopment in flood-prone areas and areas where the existing average groundwater table is within 5 feet of the ground surface. Amend local codes and by-laws to mandate flood-proofing techniques in defined flood hazard zones and adjacent areas to protect them from future sea level rise and rising groundwater levels while considering the impact on disadvantaged communities.	$	City of Alameda	Medium
Encourage implementation of flood-proofing	Inventory and prioritize highest at-risk buildings, including those serving vulnerable populations, for resiliency upgrades. Alameda should identify options to help low-income households and other vulnerable residents pay for flood retrofits.	$	City of Alameda	Short
Encourage implementation of flood-proofing	Consider incorporating sea level rise and rising groundwater levels into the flood management section of the Building Code (Appendix H) to encourage, incentivize, or require compliance with base floor elevation and flood-proofing requirements to the upper estimate of mid-century sea levels (or higher) as adopted be the State of California.	$	City of Alameda	Medium

Encourage implementation of flood-proofing	Consider incorporating rising groundwater levels into the flood management section of the Building Code (Appendix H) to encourage, incentivize, or require consideration of a higher groundwater table (a minimum of 5 feet above current average levels, or at the ground surface if the existing water table is within 5 feet of the ground surface) during design and construction.	$	City of Alameda	Medium
Engage the community in climate adaptation efforts and build grassroots support	Launch a consumer education campaign on flood insurance, ~~and~~ flood preparedness, and what to do during and after a flood event occurs (include information on coastal flooding, urban (stormwater) flooding, and groundwater flooding in basements). Develop materials to help residents and businesses identify financial support for flood insurance and flood retrofits. Engage community leaders in reaching out to underserved and vulnerable communities to give them the support they need.	$	City of Alameda and FEMA	Short
Manage costs associated with growing flood risk	Work with FEMA to identify ways to increase Alameda's Community Rating to reduce flood insurance costs.	$	City of Alameda and FEMA	Short
Investigate and adopt requirements for managing runoff from impervious surfaces using green infrastructure	Building Code chapter 15.08, section 458.10 (site design), requires construction projects creating over 2500 ft^2 of impervious surface to incorporate at least one of six stormwater infiltration measures. This provision should be reviewed for effectiveness and strengthened as necessary to add other options (e.g., de-paving, under-drains in high groundwater areas) and include runoff reduction targets. Should site constraints limit meeting targets, the City should consider an in-lieu fee program. Under this program, in lieu of fully meeting targets, funds are deposited into a dedicated account to be used for strategically designing and constructing stormwater management projects citywide to optimize flood mitigation and co-benefits. By systematically targeting optimal stormwater recharge, the City can align this requirement with green street priority projects and provide irrigation for tree planting in heat island areas. Compost can be used as part of this effort to provide healthy soils for healthy tree growth and carbon sequestration. Consider expanding an in-lieu fee program for meeting other resilience measures to support projects that address multiple vulnerabilities.	$	City of Alameda	Short

Implement requirements for managing runoff from impervious surfaces using green infrastructure	Consider design modifications for infiltration-based green infrastructure in areas with ~~shallow groundwater~~ a groundwater table within 5 feet of the existing ground elevation. Designs should consider potential flood pathways to adjacent areas during when the groundwater table is at or near the surface and rainwater cannot infiltrate as designed. Incorporate requirements for stormwater management in new development and redevelopment permits. For example, see concept drawings for “under-drained stormwater treatment” in the Draft Alameda Point Storm Water Plan. Ensure that capacity upgrades to the stormwater system (e.g., pipe and pump upgrades) can accommodate increased flow from non-infiltration stormwater management approaches.	$$	City of Alameda	Short
Implement requirements for managing the control and discharge of water from residential sump pumps	To reduce the risk of flood damage in basements, provide guidance to homeowners related to sump pump requirements. For example, homeowners should use 2 sump pumps unless pump failure would not affect living spaces, electrical equipment or large appliances, or neighboring properties (more than 2 pumps may be required for multi-family or larger structures). The discharge should be directed to a storm drain collection system or curb line upstream of the pump, or to a landscaped or adjacent lawn area where the maximum anticipated flows would not impact the structure or neighboring properties. Discharge velocities should be low so as not to create a potential hazard. Ponding against buildings and retaining walls should not be allowed. Sump pumps must have a fitted cover to prevent accidental access to the sump pump by children or pets. Installation must follow California Plumbing Code. Homeowners should regularly check and maintain the sump pump system and prevent blockage of the discharge pipe. If a homeowner suspects the discharge may contain contaminants, the City should be notified so that suitable testing can be completed.	$$	City of Alameda	Short
Study groundwater to better understand current groundwater conditions and the impact of sea level rise.	Develop a model of groundwater levels across Alameda, either by expanding and adopting regional groundwater models or creating a new model with more locally specific data. Model the impact of sea level rise on groundwater and project groundwater elevations and salinity at mid- and end-of-century levels. Assess building vulnerability (e.g., systems in basements) to future groundwater levels/salinity and integrate building adaptation strategies for future groundwater conditions into the CARP. Install groundwater monitoring wells as needed to collect long-term data on groundwater levels. (This report fulfills this recommendation in the CARP; however, this information should be updated and reviewed in regular intervals (i.e., every five years, in response to regulatory changes, or as significant advancements in climate science occur).	$$	City of Alameda, USGS, and Alameda County	Medium

Promote retrofit efforts to reduce the impact of earthquakes and liquefaction	Explore incorporation of new requirements for new development and redevelopment permits to increase building resilience to liquefaction. Continue and expand existing efforts like the Soft Stories Building Program to retrofit homes and businesses for earthquakes. In areas with existing buildings that are built on fill and more susceptible to liquefaction (e.g., reuse areas on Alameda Point), liquefaction mitigation measures are restricted to existing structures and utilities (ground improvement techniques are not possible). In areas with no current development, ground improvement techniques are possible to increase the density of the substrate. See Alameda Point MIP for more detailed examples of the engineering techniques available to address liquefaction. These and other relevant techniques should be incorporated as possible into future new development and redevelopment plans across Alameda, especially in areas along the shoreline that are built on fill and more susceptible to liquefaction.	$$$	City of Alameda	Medium
Encourage installation of solar panels and storage	Incentivize installation of solar panels on existing rooftops and solar canopies over parking lots (in conjunction with changing parking surfaces to water-permeable materials to lessen stormwater runoff).	$$	City of Alameda	Medium
Modify building codes to encourage implementation of heat reduction techniques	Review building codes and identify provisions for encouraging/requiring the installation of cool roofs, green roofs, and/or other energy-efficient cool building methods. These methods mitigate heat impacts and reduce runoff (green roofs) for new development and substantial redevelopment that involve roof repair/replacement. Consider prioritizing and incentivizing cool/green roofs in heat island areas.	$$	City of Alameda	Short
Modify building codes to discourage new or expanded below grade living areas.	Review building codes and identify provisions for discouraging new construction and/or substantial improvements that include creating or expanding below grade living areas. New construction and/or substantial improvements should plan for a shallow groundwater table that is at least 5 feet above the existing annual groundwater table, including the installation of appropriate drainage systems under and adjacent to the foundation, to reduce water pressure on the exterior of the structure, and the ability to add or increase sump pump capacity over time.	$$	City of Alameda	Short

Suggested modifications to Table 4-23 in the CARP are included below. Deletions are presented as ~~strike outs~~, and additions are presented in red. However, please note that the first strategy presented in the CARP was modified and split into three separate strategies for clarity in the table below.

Table 4-23 (Modified) Citywide Adaptation Strategies and Actions for Contaminated Lands

Strategy	Action(s)	Relative Cost	Responsible Entity	Timeline
Engage socially vulnerable communities and ensure transparency in management of contaminated lands	Encourage residents and landowners to use hazardous waste disposal and drop-off locations to reduce the amount of potentially hazardous materials released during a flood event. Increase the availability of such sites, especially in areas with high levels of transit dependence where residents are unable to drive to disposal facilities.	$-$$	City of Alameda	Short
~~Address information gaps to support prioritization of contaminated sites~~	~~Review remediation timelines for contaminated sites based on groundwater model with projected sea level rise impacts. Work with applicable agencies to adjust remediation, as applicable.~~	~~$~~	~~City of Alameda~~	~~Short~~
Coordinate with state and regional water board agencies to address closed clean-up cases	The City of Alameda's groundwater assessment evaluated sites with active groundwater monitoring well information. However, it is possible that some closed sites under the jurisdiction of the state and/or regional water board have legacy contamination that remains. An assessment of closed cases should be evaluated. If legacy contamination could become emergent, the cases can be re-opened and evaluated for additional cleanup by the respective water board.	$	City of Alameda	Short
Coordinate with the Department of Toxic Substances Control (DTSC) regarding contamination cleanup methods and timelines	Contaminated lands under the jurisdiction of DTSC that were not fully remediated (where legacy contamination and institutional control remain) have the potential to create a public health hazard in the future. The City should engage the DTSC regarding remediation efforts that consider rising groundwater levels. Current regulations regarding remediation requirements do not consider rising groundwater levels.	$	City of Alameda	Short
Update cost of inaction to consider groundwater information	The CARP provided a cost of inaction estimate that did not include information associated with rising and emergent groundwater. The cost of inaction estimate should be revisited and updated with the groundwater information.	$	City of Alameda	Short

Suggested modifications to Table 4-24 in the CARP are included below. Deletions are presented as ~~strike outs~~, and additions are presented in red. However, please note that the first strategy presented in the CARP was modified and split into three separate strategies for clarity in the table below.

Table 4-24 (Modified) Increasing Utility Resilience

Strategy	Action(s)	Relative Cost	Responsible Entity	Timeline
Ensure resilience and long-term functionality of stormwater and sewer systems	Conduct comprehensive visual and functional test monitoring and asset condition assessment. Consider the impact of rising groundwater levels and increasing salinity on buried utility infrastructure like sewer and stormwater pipes. Prioritize replacement of iron pipes with high-density polyethylene or other non-corrosive materials as appropriate. When pipelines are replaced, utility trenches can be over-excavated and filled with crushed rock below the elevation of the pipelines. This strategy can help maintain the integrity of the utilities as the water level table rises and falls. Consider lining and/or replacing problematic pipelines with high suspected infiltration rates. Grout can be applied using remote controlled equipment to seal cracks or joints and prevent groundwater infiltration.	$$$	City of Alameda	Short–Medium
Ensure resilience and long-term functionality of stormwater and sewer systems	Model potential impacts to utility infrastructure under future sea level rise scenarios, including an assessment of potential increases in inflow and infiltration rates from rising groundwater, and the impact of reduced outflow capacities at the City's 278 outfall locations.	$$	City of Alameda	Short–Medium
Ensure resilience and long-term functionality of stormwater and sewer systems	Conduct regular inspection and maintenance of storm sewer infrastructure to identify infiltration points and maintain the conveyance capacity of the system.	$	City of Alameda	Short–Medium
Ensure resilience and long-term functionality of stormwater and sewer systems	Consider the impact of flooding on electrical infrastructure (AMP), including utility poles and pull boxes. Develop and implement an asset management plan that prioritizes repairing or replacing infrastructure that flooding is likely to impact.	$$	AMP	Short–Medium
Ensure resilience and long-term functionality of stormwater and sewer systems	Improve backup power and reserve fuel capacity at critical utility facilities (note: backup systems are already in place at key sewer pump stations). Implement recommendations from Storm Drain Master Plan to install backup power at pump stations. Purchase and strategically place backup portable pumps in the event of major disruptions to pump stations.	$$$	City of Alameda and AMP	Short

Ensure resilience and long-term functionality of stormwater and sewer systems	Incorporate long-term sea level rise and storm projections into upgrades at critical utility facilities, including capacity upgrades to the stormwater system. Ensure electrical infrastructure is flood-proofed or elevated. Where possible, move assets out of the hazard zone, including elevating utility junction boxes and other electrical infrastructure on scaffolding. Prioritize new construction of utility infrastructure outside of the hazard zone if possible. Use flood-resistant building materials like steel utility poles when repairing or replacing existing infrastructure.	$$$	City of Alameda, AMP, and EBMUD	Medium
Ensure resilience and long-term functionality of stormwater and sewer systems	~~Research the implications of rising groundwater on decisions surrounding infiltration and inflow, specifically whether green infrastructure designed for infiltration may exacerbate flooding due to rising groundwater. In some cases, alternatives like under-drained treatment may be necessary to prevent infiltration in areas with especially high groundwater.~~ The elevation of the existing shallow water table should be considered during the design of all green-infrastructure projects. Large-scale green infrastructure may not be preferred in areas where the existing shallow groundwater table elevation is within 3 feet of the ground surface elevation. All large-scale green infrastructure projects should include underdrain systems to reduce the likelihood of standing water, waterlogged soils, and mosquitos. Smaller-scale green infrastructure projects would not require underdrain systems.	$	City of Alameda	Short
Ensure resilience and long-term functionality of stormwater and sewer systems for new developments	New developments should consider curb and gutter underdrain networks in tandem with the stormwater drainage system to reduce the likelihood of emergent groundwater and nuisance flooding during heavy precipitation events when the groundwater table can reach the ground surface and create waterlogged soils and surface ponding.	$$	City of Alameda	Short to Medium
Ensure resilience and long-term functionality of stormwater and sewer systems	Encourage the adoption of distributed green infrastructure solutions on private property (e.g., rain barrels/rain gardens, pervious pavement). Amend the Alameda Municipal Code to prohibit residents from pouring concrete (or other non-porous material) in planter strips along public roadways.	$	City of Alameda	Medium
Ensure resilience and long-term functionality of stormwater and sewer systems	Collaborate with and participate in EBMUD wastewater system resiliency efforts. Implement wastewater resilience best practices for the City- owned sewer system by incorporating sea level rise projections into the City's next Sewer Management Plan.	$	City of Alameda	Short

Expand green infrastructure	Implement the recommendations, guidance, and strategies of the City's Green Infrastructure Plan where appropriate. Incorporate green infrastructure into new city buildings and within parks. Continue to expand green infrastructure along roadways as part of a "Complete Streets" design.	$$	City of Alameda	Short–Medium
Participate in regional assistance programs	Develop new and maintain existing mutual aid agreements with adjoining jurisdictions for cooperative assistance and response to flooding events. Continue participation in CalWARN Mutual Aid and Assistance Program, and support EBMUD efforts related to drinking water system preparedness.	$	City of Alameda and EBMUD	Short
Ensure resilience and long-term functionality of energy distribution systems	Encourage PG&E to conduct a more localized assessment of gas lines and their risk to sea level rise in Alameda.	$	City of Alameda	Short
Ensure long-term resilience of the areas surrounding the lagoon systems	The water levels in the lagoons are managed in coordination with the tides to maintain adequate water quality. In the wet season, the lagoon water levels are lowered to accommodate additional stormwater runoff from the adjacent neighborhoods. Water levels in the lagoons will likely influence the shallow groundwater table near the lagoons. Maintaining lower water levels in the lagoon could help depress the shallow groundwater table near the lagoons and prevent or reduce the likelihood of emergent groundwater in the early sea level rise scenarios (12 to 36 inches). The effectiveness of this measure in depressing the shallow groundwater table should be modeled or analyzed to ensure it can meet the desired objective.	$$	City of Alameda	Medium