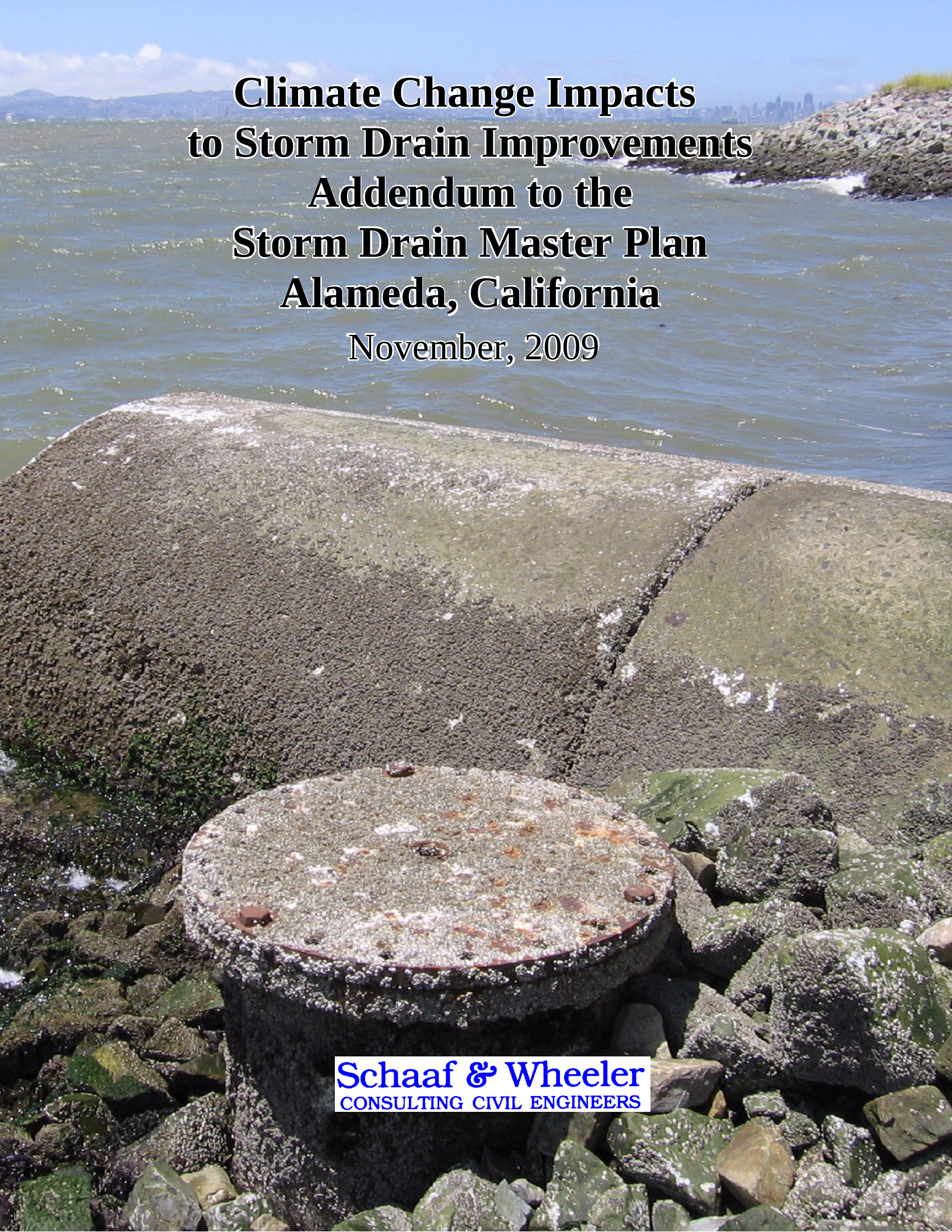

Climate Change Impacts to Storm Drain Improvements Addendum to the Storm Drain Master Plan Alameda, California

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Introduction

Schaaf & Wheeler completed the City of Alameda (City) Storm Drain Master Plan (SDMP) in August, 2008. That report included a brief analysis and discussion of the impacts of sea level rise to City stormwater facilities. In that analysis, a 50-year planning horizon and corresponding 0.5 foot of sea level rise was used. The conclusion was that a half foot of sea level rise applied to the tidal cycle had no significant impacts to the operation of the existing storm drain system.

A more in-depth analysis of sea level rise scenarios was desired by the City. Specifically, the City wished to understand the impacts of a more severe sea level rise scenario on the 10-year improved storm drain system as well as potential inundation of rising sea levels within City limits. This addendum to the City of Alameda SDMP presents the results of these analyses. First, a general background on climate change and sea level rise projections is provided. The current understanding of other potential climate change impacts relevant to the City's flood risks and water resources is also summarized. Next, the impacts of sea level rise assuming an 18 inch rise relative to the City's coastline are presented, including both the risk of inundation within City limits by surrounding water and impacts to the storm drain capacity and operation under this specific sea level rise scenario. Additional improvements to the 10-year improved system are recommended to mitigate these impacts, and cost estimates for the improvements provided. Finally, current regulations, policies, and actions related to climate change from state and local organizations are summarized.

It should be noted that this report does not attempt to detail the specific causes of climate change, nor the distribution between anthropogenic (i.e. human induced) versus natural sources of carbon dioxide in the atmosphere. The purpose of this report is to detail the potential impacts of a specific climate change scenario to Alameda flooding risks, both in magnitude and uncertainty, and discuss conceptual and master planning level mitigation activities. Mitigation activities discussed herein focus on mitigating the impacts of global warming to flood risk within the City rather than mitigating carbon emissions.

Current Status of Climate Change Understanding and Research

It is well understood that carbon dioxide and other anthropogenic green house emissions act as heat trapping greenhouse gasses, which increase troposphere temperatures. Throughout the 1980s, scientists began to note increases in these emissions and postulated that the increases in atmospheric carbon dioxide may cause a range of impacts, some of which may be adverse. Climate change refers to an identifiable change in the state of the climate that persists for an extended period of time. The use of the phrase

‘climate change’ does not necessarily distinguish whether changes are due to natural processes versus human activity. Climate variability, however, refers to natural climate cycles or changes that are not caused by human activities. Many of the impacts of climate change occur quite slowly. Thus, even if carbon emissions are stabilized or greatly reduced in coming years, some impacts such as sea level rise will continue to occur, albeit potentially at a slower pace than predicted by most global climate change models.

As awareness of climate change spreads, an increasing number of analyses are conducted and reports published every year. Tasked with gathering, reviewing, and synthesizing the multitude of published studies is the Intergovenmental Panel on Climate Change. In addition to this international organization, this report summarizes the current understanding reflected in reports produced by the United States Army Corps of Engineers and by departments within the state of California.

Intergovernmental Panel on Climate Change

The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 to provide an objective source of information about climate change. The IPCC does not independently conduct research or gather data. Instead it acts as a comprehensive assessor of the latest scientific, technical, and socio-economic literature produced worldwide relevant to the understanding of human-induced climate change, its impacts, and mitigation strategies. The IPCC was set up by the World Meteorological Organization and by the United Nations Environment Programme.

The First Assessment Report was released by the IPCC in 1990, the Second in 1995, the Third in 2001, and the Fourth in 2007. The conclusion that human induced climate change is occurring has been progressively more certain in each Assessment Report, with the 2007 Assessment Report stating that there is *very high confidence* (at least 9 out of 10 chance of being correct) that the global average net effect of human activities since 1750 has been one of warming, and that human induced warming over the last three decades has *likely* (greater than 66% probability) had a discernible influence at the global scale. Global warming refers to the general warming of the climate system, and the fact that global warming is occurring is unequivocal, based on IPCC findings. The next IPCC Assessment Report is scheduled for publication in 2012.

Uncertainty and Scale

IPCC uses a system of self-explanatory terms to convey qualitative and quantitative uncertainty. Three approaches are used to describe uncertainty. Where uncertainty is

assessed qualitatively, a relative sense of the amount and quality of evidence to support a statement is provided through use of terms such as: high agreement, much evidence; high agreement, medium evidence; medium agreement, medium evidence; etc. Where uncertainty is assessed quantitatively using expert judgment of the correctness of underlying data or analyses, a scale of confidence levels is used to express the assessed change of a finding being correct: very high confidence (at least 9 out of 10); high confidence (about 8 out of 10); medium confidence (about 5 out of 10); low confidence (about 2 out of 10); and very low confidence (less than 1 out of 10). Finally, where uncertainty in specific quantitative outcomes is assessed using expert judgment and statistical analysis, then likelihood ranges are used to express the probability of occurrence: virtually certain (>99%); extremely likely (>95%); very likely (>90%); likely (>66%); more likely than not (>50%); about as likely as not (33%-66%); unlikely (<33%); very unlikely (<10%); extremely unlikely (<5%); and exceptionally unlikely (<1%) (IPCC, 2007). Throughout this report, when these phrases are used based on IPCC findings they have been italicized as a visual reminder of this paragraph.

There are several global climate models that have been developed to estimate future impacts of climate change and global warming. Within each model there are various future condition scenarios representing the range of potential future carbon dioxide and other greenhouse gas emission levels. The more conservative approach is to assume that these emissions increase at a rate equal to or greater than recent trends. Generally the emissions and global warming predictions and impacts are directly proportional – the greater the emissions, the more severe the warming trend.

The vast majority of climate models are global in scale, and although general trends and impact estimates may be concluded from these models, there are multiple issues encountered when trying to downscale either results or models to determine trends or impacts in a localized area. The IPCC has produced a Special Report on the Regional Impacts of Climate Change which analyzes impacts at a continental or sub-continental scale; however this report focuses on impacts due to regional vulnerabilities as opposed to regional differences in physical impacts. Efforts to downscale from the global climate model to the catchment scale for hydrologic analyses and to utilize regional climate models to drive hydrologic models have shown that different ways of creating regional scenarios from the same source can lead to substantial differences in the estimated regional effect of climate change and that errors in the modeling procedure or differences in climate models are greater than hydrologic model uncertainty (Kundzewicz, 2007).

There is no single agreed upon methodology for downscaling climate change results for use in regional hydrology, and results may differ substantially depending on the source model and method used. The process of downscaling does not resolve any of the

uncertainty inherent in global climate models, and introduces new sources of uncertainty such that overall trends are less well defined compared to global models. For example, depending on the global climate model and scaling methodology used the estimated range of impact to mean annual precipitation in California varies in both magnitude and sign by at least 10% (Dettinger, 2004). What this means is that while global climate change trends are relatively well known and documented, regional and local trends, particularly hydrologic parameters such as rainfall and runoff, are less well known.

California Climate Action Team

The California Climate Action Team (CAT) was established by Governor Schwarzenegger under an Executive Order on June 1, 2005. The purpose of the CAT is to coordinate state-level actions relating to Climate Change. The Team is led by the Secretary of the California Environmental Protection Agency and includes the Secretary of the Business, Transportation and Housing Agency, Secretary of the Department of Food and Agriculture, Secretary of the Resources Agency, Chairperson of the Air Resources Board, Chairperson of the Energy Commission and President of the Public Utilities Commission. The Climate Action Team is charged with implementing global warming emission reduction programs and reporting on the progress made toward meeting the statewide greenhouse gas targets that were established in the Assembly Bill 32 (described in more detail later in this report). The first report was sent to the Governor and the Legislature in 2006, and should be updated bi-annually thereafter.

California Climate Change Center

The California Energy Commission's Public Interest Energy Research (PIER) Program conducts public interest research, development, and demonstration projects to benefit California's electricity and natural gas ratepayers. In 2003, the California Energy Commission's PIER Program established the California Climate Change Center (CCCC) to document climate chance research relevant to the states. The CCCC Report Series details ongoing center-sponsored research on climate change predictions and impact analyses. All of the final CCCC reports include a preface which clarifies that the findings presented are interim project results, and information contained within the reports is subject to change.

Global Warming Impacts

The IPCC range of best estimate *likely* temperature increases by the year 2099 is 0.6 – 4.0 degrees Celsius (1 – 7 degrees Fahrenheit), depending on the global climate model utilized (IPCC, 2007). Regionally, scaled down climate models for northern California

estimate global temperature increases up to 4.5 degrees Celsius (9 degrees Fahrenheit) by 2100 (Cayan, 2007). An increase in global temperatures in the IPCC range may have multiple impacts on the water resources of the City of Alameda, even if the changes in local and regional temperature are not yet known.

Sea Level Rise

One of the most publicized impacts of global warming, and the impact with the most direct consequences to the City of Alameda, is sea level rise. Sea level rise can be defined as global or relative. Global sea level rise is defined as the increase of global average sea level. Throughout the world, land may be uplifting or subsiding. This will impact the relative change in depth of water at any given location, depending on the rate of movement compared to the rate of global sea level rise. In addition, coastal bays such as the San Francisco Bay may not experience sea level rise at the same rate as the global average. Relative sea level rise refers to the rise of sea levels accounting for local hydraulics, land uplifting or subsidence.

An example of the importance of global vs. relative sea level rise can be seen when examining the historic sea level trends in San Francisco Bay at the National Ocean and Atmospheric Administration (NOAA) gages for San Francisco (at the Presidio) and Alameda (Pier 3 at the Naval Air Station). The Alameda gage shows a long term average mean sea level rise of 0.82 millimeters per year (NOAA, Alameda Mean Sea Level Trend), while the San Francisco gage long term average mean sea level rise is 2.01 millimeters per year (NOAA, San Francisco Mean Sea Level Trend). Although the San Francisco gage period of record is longer, essentially the same rate of sea level rise is found if it is truncated to match the Alameda gage period of record. The reasons for this difference are unknown, and likely due to a combination of factors, but it serves to exemplify the complexity between local trends, global predictions, and site specific hydraulics.

IPCC Sea Level Rise Estimates

Depending on the emission scenario used, the predicted *likely* global sea level rise ranges from 0.18 – 0.59 meters (IPCC 4th Assessment Report), or 0.6 – 1.9 feet by the year 2099. IPCC reports do not provide mid-range estimates; e.g. sea level rise by 2050. The upper limit of this range is lower than the upper range stated in previous IPCC reports. The two primary factors affecting global sea level rise are thermal expansion of ocean waters due to increased atmospheric temperature, and melting ice. The IPCC estimates that of the global sea level rise that has occurred since 1993, thermal expansion of the ocean has contributed 57% of the total rise, decreases in the extent of glaciers and ice caps have

contributed 28%, and the remaining 15% is due to losses from the polar ice sheets. It must be noted that this range does not include uncertainties in climate-carbon cycle feedbacks or the full effect of changes to ice sheet flow, because a basis in published literature is lacking. Thus these values do not represent an upper bound to projected sea level rise. Long term projections show that global warming sufficient to eliminate the Greenland Ice Sheet (one millennium exposed to an average temperature rise in excess of 1.9 – 4.6 degrees Celsius) results in an additional seven meters (23 feet) of global sea level rise. The IPCC does not offer any uncertainty scale for this possibility.

United States Army Corps of Engineers Sea Level Rise Estimates

The United States Army Corps of Engineers (USACE) published an engineering circular (USACE, 2009) to direct the consideration of sea level rise estimates in project planning and design. While this methodology is required only for USACE civil work activities, it offers a valuable guidance for any planning effort. In summary, the USACE report recommends that the planning, engineering and designing for projects within the tidal zone or with downstream tidal boundary conditions consider how sensitive and adaptable the project is to a range of sea level rise estimates (low, intermediate and high). Specifically, the USACE directs determination of "how sensitive alternative plans and designs are to these rates for future local mean sea-level change, how this sensitivity affects calculated risk, and what design of operations and maintenance measures should be implemented to minimize adverse consequences while maximizing beneficial effects".

The "low" sea level rise estimate recommended by the USACE report is based on local historic tide gauges. In San Francisco, the Presidio tide gauge has the longest period of record and is consistently used for historic sea level trends in San Francisco Bay. For consistency with regional documents the Presidio gauge is used for calculations herein, although the Alameda gauge records described above may be more appropriate for the City. The long term average sea level rise at the Presidio gauge is 2.01 millimeters per year (mm/yr), with a 95% confidence limit of plus or minus 0.21 mm/yr (NOAA, Station 9414290). "Intermediate" and "high" sea level rise estimates are based on the National Resource Council (NRC) curves and equations developed for a 1987 Report (*Responding to Changes in Sea Level: Engineering Implications*), modified to account for the updated annual estimate of sea level rise made in the 2007 IPCC report, and manipulated to include consideration of the date of the equation development. The "intermediate" sea level rise projection is based on the modified NRC Curve I, and the "high" sea level rise projection on the modified NRC Curve III. This equation is:

$$E(t_2) - E(t_1) = 0.0017(t_2 - t_1) + b(t_2^2 - t_1^2)$$

where:

t_1 = time between construction date and 1986;

t_2 = time between date at which sea level rise projection is desired and 1986;

$E(t)$ = eustatic sea-level rise, in meters, as a function of (t);

b = Variable, 2.36E-5 for modified NRC Curve I, 1.005E-4 for modified NRC Curve III.

Table 1 presents the range of sea level rise projects for the City of Alameda using this methodology, assuming adoption of the Presidio gauge for the local historic sea level trend, and construction of any given project in 2010.

Table 1: Range of Sea Level Rise Projections Using USACE Methodology with Presidio Gage and 2010 Construction Year

USACE Methodology Sea Level Rise Projection Range (feet)			
Year	**Low**	**Intermediate**	**High**
2025	0.1	0.2	0.4
2050	0.3	0.5	1.4
2075	0.4	0.9	2.8
2100	0.6	1.5	4.6

California Climate Change Center Sea Level Rise Estimates

A draft version of the *Impacts of Sea-Level Rise on the California Coast*, developed by The Pacific Institute for the CCCC was released in March, 2009, with much publicity of the new 2100 sea level rise estimate of "5 feet" (Chronicle article, March 12, 2009). The development of this sea level rise estimate is presented in somewhat more detail, however, in the *Climate Change Scenarios and Sea Level Rise Estimates for the California 2009 Climate Change Scenarios Assessment* Report (Cayan, 2009), also produced for the CCCC. In short, the sea level rise estimates adopted by the CCCC are based on an empirical formula developed by Rahmstorf (2007) which relates global mean sea level rise to global mean surface air temperature. The report states (and shows graphically) that the Rahmstorf predicted values are then manipulated to include the impact of reservoirs and dams, but exactly what this manipulation entails, and its justification, is unclear. The supporting article cited as the basis of this manipulation, *Impact of Artificial Reservoir Water Impoundment on Global Sea Level* (Chao, 2008),

appears to focus on the impact of reservoir and dam storage to historic sea level trends, and Schaaf & Wheeler was unable to locate any published article which details a modified Rahmstorf method.

Using the above methodology, the 2009 Assessment Report gives a range of sea level rise of 30-45 cm (12 – 18 inches) by 2050 (relative to 2000 levels). Although other CCCC reports, as well as the San Francisco Bay Conservation and Development District, have adopted a 2100 sea level rise projection of 1.4 meters (4.6 feet), this projection is not explicitly stated in the text of the 2009 Assessment Report (it can only be deduced from included graphs). It should be noted that the range of sea level rise estimates produced from this methodology is about 0.6 m – 1.45 m (2.0 – 4.8 feet). The 4.6 feet of rise by 2100 predicted at the upper end of this range is similar to the USACE methodology high range for 2100 for San Francisco Bay, as shown in Table 1.

Sea Level Rise Estimates Summary

In summary, significant uncertainties remain in sea level rise projections, particularly as one forecast's farther into the future. <u>The most current available estimates for sea level rise by 2050 range from 0.3 foot to 1.5 feet, and by 2100 from 0.6 foot – 4.8 feet.</u> Confidence in any sea level rise prediction decreases the further into the future that analysis is projected, due to unknowns about future emission scenarios, potential climate feedback loops and the severity of melting ice. It is important to note that emphasis should not be placed on a particular specific value for sea level rise. Not only is a consensus on a particular value unlikely, but the selection of the year 2100 as a reporting point for sea level rise projections is arbitrary. Even with drastic reductions in carbon emissions sea levels are expected to continue to rise beyond 2100 due at least to continued thermal expansion of ocean waters. Thus, any planning for sea level rise impacts should recognize the inherent uncertainty and long term ongoing nature of these projections.

Rising sea levels have two potential impacts to the City: inundation of Bay water onto City lands and impacts to the operation and performance of City storm drain facilities. Each of these impacts is discussed in more detail below.

<u>Other Climate Change Impacts</u>

Climate change has many predicted impacts in addition to sea level rise. Below, other climate change impacts which may adversely affect flooding risk of the City of Alameda are described. These impacts are: storm surge, wave runup, and precipitation.

Storm Surge

During storm events, ocean water increases in elevation due to low barometric surface pressure. This phenomenon is called storm surge. The FEMA 1% storm surge for San Francisco Bay at Alameda is 7 feet NGVD, compared to a mean high-high tide of 3.7 feet NGVD (NOAA, Alameda Datums). This represents a 1% surge of 3.3 feet. It is *likely* that the incidence of extreme high sea level has increased at a broad range of sites wordwide since 1975. Extreme high sea level is defined as the highest 1% of hourly values of observed sea level at a station for a given reference period (IPCC, 2007).

Pronounced multi-year fluctuations of San Francisco non-tidal residuals (NTR; total water elevations above tidal elevations – for San Francisco Bay NTRs are primarily storm surge and wind driven waves) are evidenced in historical records and no significant changes in the mean monthly positive NTRs exist between 1858 and 2000. However when considering only the highest 2% of extreme winter NTRs there has been a significant increasing trend since about 1950 (Bromirski, 2003). This increased 'storminess' may be part of a larger cycle, but it suggests a relationship between global climate warming and overall storminess on the west coast.

The occurrence of hourly observed high sea levels (above the 99.99th percentile thresholds) in San Francisco Bay has increased sharply since 1969. The maximum observed sea level has also increased since that time, although the period of 1987-2004 had a slightly lower peak sea level than 1969-1987. Recent studies have concluded that if sea level rise is on the lower end of the current predicted ranges, the occurrence of extremely high sea level events will increase, but the increase in extremes would be not so different from the increasing trend that has been seen in California for the past several decades. If, however, sea level increases reach the higher end of the range, extreme events would increase not only in their frequency but also their duration, substantially beyond the historic trend seen in the 19th and 20th centuries (Cayan, 2007).

In short, it is expected that as sea levels rise, not only will the occurrence of high sea level, or surge, events increase, but so may the amount of surge itself (currently about 3.3 feet above mean high high water in Alameda). This increased storm surge elevation may impact flood risk, backwater conditions and storm water pump station operation; however quantitative estimates for the increased storm surge have not been made, and are unlikely to be determined in the near future.

Wave Runup

Wave runup is the elevation wind-driven waves will reach as waves break on land and may be affected by global warming. However, these impacts are not particularly well understood at this time. A review of recently published literature finds that different published studies come to different, and at times directly opposing, conclusions regarding likely climate change impacts to wave energy. Wave heights are greatly influenced by local conditions, likely a major cause for the differing results found in the available literature. Some general trends are well understood, such as that extreme wave heights and surge fluctuations tend to increase from the south to the north along California Coast, as a result of increasing storm intensities along the northern coast (Cayan, 2007).

Wave runup is a function of water depth, wind speed and direction, and the features of the land on which the wave is breaking (slope, roughness, etc.). In some parts of San Francisco Bay, rising sea levels will inundate low lying marshes, creating broad, but shallow, flooded areas. In this scenario, wave runup will likely decrease, as the shallow water will dampen wave heights. In Alameda however, which is generally protected by high land, rising sea levels will create deeper water surrounding the City, potentially resulting in increased wave heights and runup.

Published literature has found that when short term sea level is highest (i.e. during storm surge events), wave energy has an increased likelihood of reaching very high levels. The peak likely significant wave height (the average height of the one third highest waves) increases by 2.5 meters in one scenario where the surge value increased from 4 centimeters (cm) to 30 cm (Cayan, 2007). Thus in that particular scenario, as the storm surge increases, so does wave energy and height, which in turn may increase wave runup. That said, recent downscaled models have also indicated that the incidence of large coastal storms will lessen as part of the overall drying trend (discussed in more detail in the precipitation section below), resulting in a marginal decrease in the wind wave energy reaching California's coast as well as a decreasing trend for significant wave heights (Cayan, 2009). In short, although climate change is expected to impact storm surge and wave runup, these impacts (or even the trend of impacts) is not well understood at this time, and in any event, these impacts are expected to be dwarfed by the impact of increasing mean sea level.

The Bay floor near Alameda is largely composed of Bay mud, a thick deposit of soft, unconsolidated silty clay, which is saturated with water. One potential mitigation action against increased wave height due to deepening water would be to fill to maintain existing water depths. In addition to the multitude of permitting and environment issues with this activity, however, Bay Mud has a very high compressibility. In other words,

Bay Mud will continue to compress even when large volumes or weights are set on it. Thus filling on top of Bay Mud is ineffectual, and when additional environmental impacts are considered with the uncertainty of wave height and runup impacts, not a feasible mitigation alternative for Alameda to offset increased wave heights and runup.

Precipitation

It is *likely* that the frequency of heavy precipitation events (or proportion of total rainfall from heavy storms) has increased over most areas (IPCC, 2007). Global analyses of precipitation from 1901-2005 do not show statistically significant trends due to many discrepancies between data sets and the variability of precipitation in both space and time (Bates, 2008). Likewise, there is no consensus among regional climate models as to how mean annual precipitation totals might change in the United States (Dettinger, 2004), although most recent global and regional models predict that total mean precipitation will modestly decrease (5-20%) in the latter half of the next century (Hayhoe, 2004; Cayan, 2007, Draft 2009). Long term historic analyses of precipitation in the state of California show that there is no statistically significant change in total annual mean precipitation from 1890 through 2000, although the variability of total rainfall in any given year appears to have an increasing trend (DWR, 2006).

While the total mean annual precipitation is not predicted to change significantly, the timing and intensity of storm events is expected to change, with a tendency in California for a modest increase in the number and magnitude of large precipitation events, with longer dry periods between events Climate models predict (and historic records reflect) that proportionally less rainfall will fall during spring and summer months (April – July) and more in winter months (November – March) in northern California due to global climate change (Dettinger, 2004; Cayan 2007; DWR 2006). These shifts in precipitation timing and intensity may have impacts on flooding and water supply.

The most updated *Climate Change Scenarios* report (Cayan, 2009) states that the occurrence of significant storms declines at least marginally and that the occurrence of high daily precipitation events generally remains about the same through 2100 as it does in the historical projections. It should be noted that this conclusion is markedly different from previous conclusions by the same authors, which predicted a tendency in California for a modest increase in the number and magnitude of large precipitation events, with longer dry periods between events (Bates, 2008; Cayan 2007). Several CCCC reports reviewed for this analysis repeat the earlier, and presumably outdated, conclusion.

In summary, while a small decrease in annual precipitation is forecast, the trend in number and magnitude of large precipitation events is unknown. The most current

studies reviewed for this analysis both conflict previous conclusions and other updated studies, further exemplifying that there is no consensus regarding the potential impacts of climate change on the frequency or magnitude of large storm events.

Sea Level Rise Impacts to the City of Alameda

The effects of climate change described above have potential impacts to virtually all water resources within the City of Alameda, including not only local flood control and risk but also regional impacts to sectors such as agricultural and water supply. This report focuses on how rising sea levels may impact the risk of flood inundation of the City from its surrounding waters, and the impact of rising sea levels to the 10-year improvements previously made in the City SDMP. For this analysis, 18 inches (1.5 foot) of sea level rise was assumed. This represents the upper bound of the range of the most recently published sea level rise projections by year 2050 (Cayan, 2009).

When discussing projects to mitigate the impacts of sea level rise, there are several important points to keep in mind. As described above, there is not currently and unlikely to ever be a true consensus in the prediction of sea level rise, particularly a consensus on a projection 100 years into the future. A planning horizon of 100 years is not only far beyond most planning timelines typical to public agencies, but it is also beyond the typical useful life of structural flood protection elements. In other words, even if it were financially feasible to construct a project today to protect for a sea level rise scenario in 2100, it may not be advisable to do so, since that project could be structurally unsound by the time it was needed. Finally, it should be noted that although currently the year 2100 is the most common projection date, sea levels are expected to continue to rise beyond the year 2100.

<u>Inundation due to Rising Waters</u>

As an island community, Alameda is uniquely vulnerable to rising water levels in San Francisco Bay. Currently, Alameda is protected from inundation from its surrounding waters primarily by high ground, as opposed to floodwalls or levees. Interior lagoons are hydraulically connected to the surrounding waters via weir inlets, pumps, or gated outlets.

Figures 1 through 6 reflect City-wide recent topographic data adjusted to show three elevations of interest: existing mean sea level, mean sea level with 18” increase, and the highest tide elevation for various storm events with 18” of sea level rise added. The storm specific tide cycles were developed for the SDMP and the methodology and results of that process are described in detail in that report. It should be noted that these figures

do not take into account potential flood protection of naturally occurring high ground or existing flood control facilities. In other words, a shaded area represents an elevation range only, and does not necessarily mean that surrounding water will be able to reach and pond in all of those locations. One good example of this is shown in Figure 2, which reflects the fact that much of the golf course is below mean sea level. This does not mean, however that the golf course is always inundated with surrounding waters, due to existing high ground and storm drain facilities. That said, the lack of flap gates on many storm drain outlets may allow for backwater due to high tides to reach interior locations of the City. Figures 7 and 8 translate the water surface elevation into depth of water for the most severe (100-year event) scenario. Again, these figures represent potential risk areas without consideration of existing natural or man made protection measures.

Table 2 summarizes the existing and sea level rise scenario mean and high tide levels reflected in Figures 1 through 8. Storm specific tide cycles were developed for the SDMP, and a more complete description of the methodology for that process can be found in the SDMP, Chapter 3.

Table 2: Mean and High Tide Elevations for Existing and Sea Level Rise Scenario

	Existing (NGVD)	Sea Level Rise (18”) Scenario (NGVD)
Mean Sea Level	0.5’	2.0’
10-Year High Tide	5.1’	6.6’
25-Year High Tide	5.4’	6.9’
100-Year High Tide	6.2’	7.7’

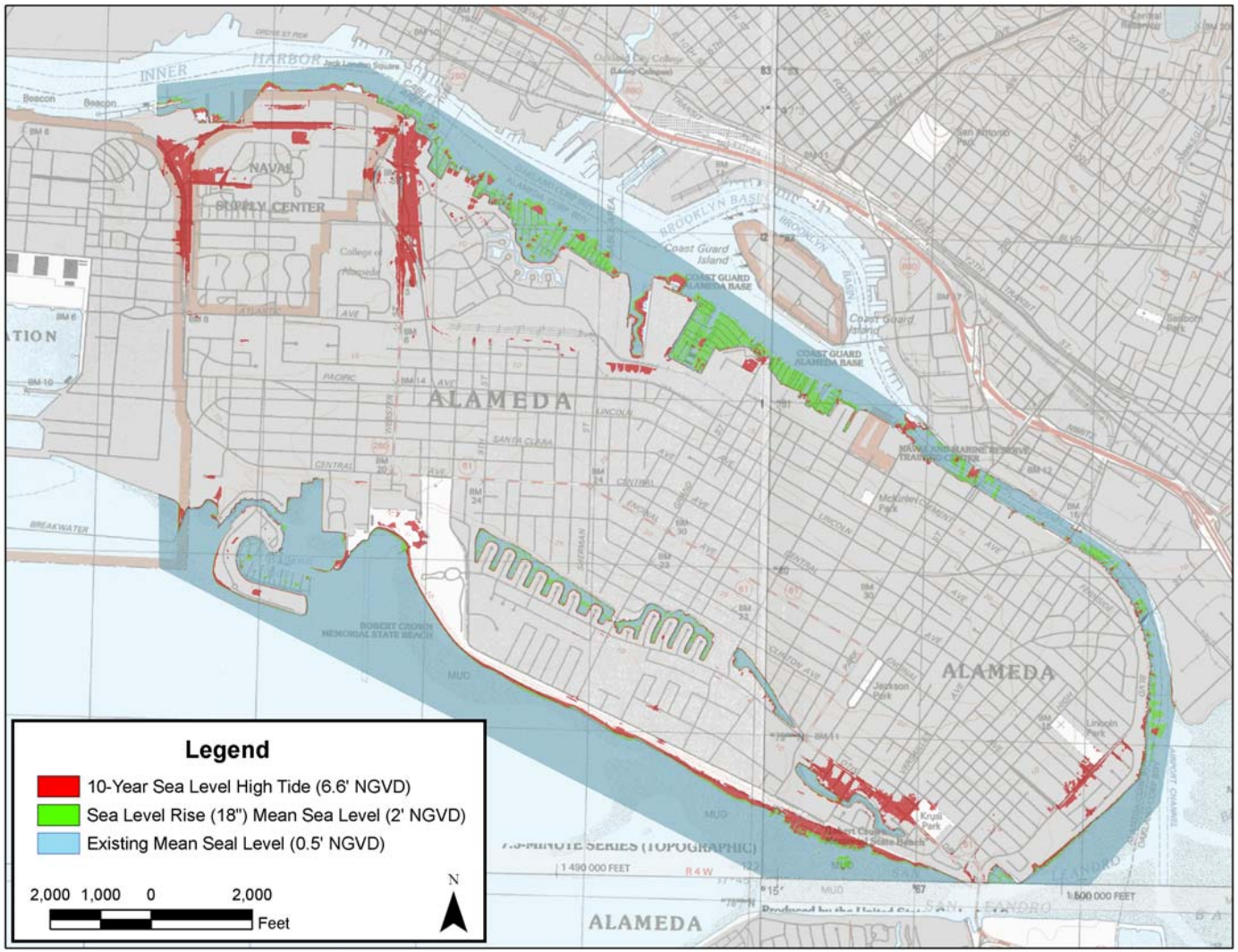

Figure 1: Areas below the 10-year High Tide with 18" of Sea Level Rise, Main Island

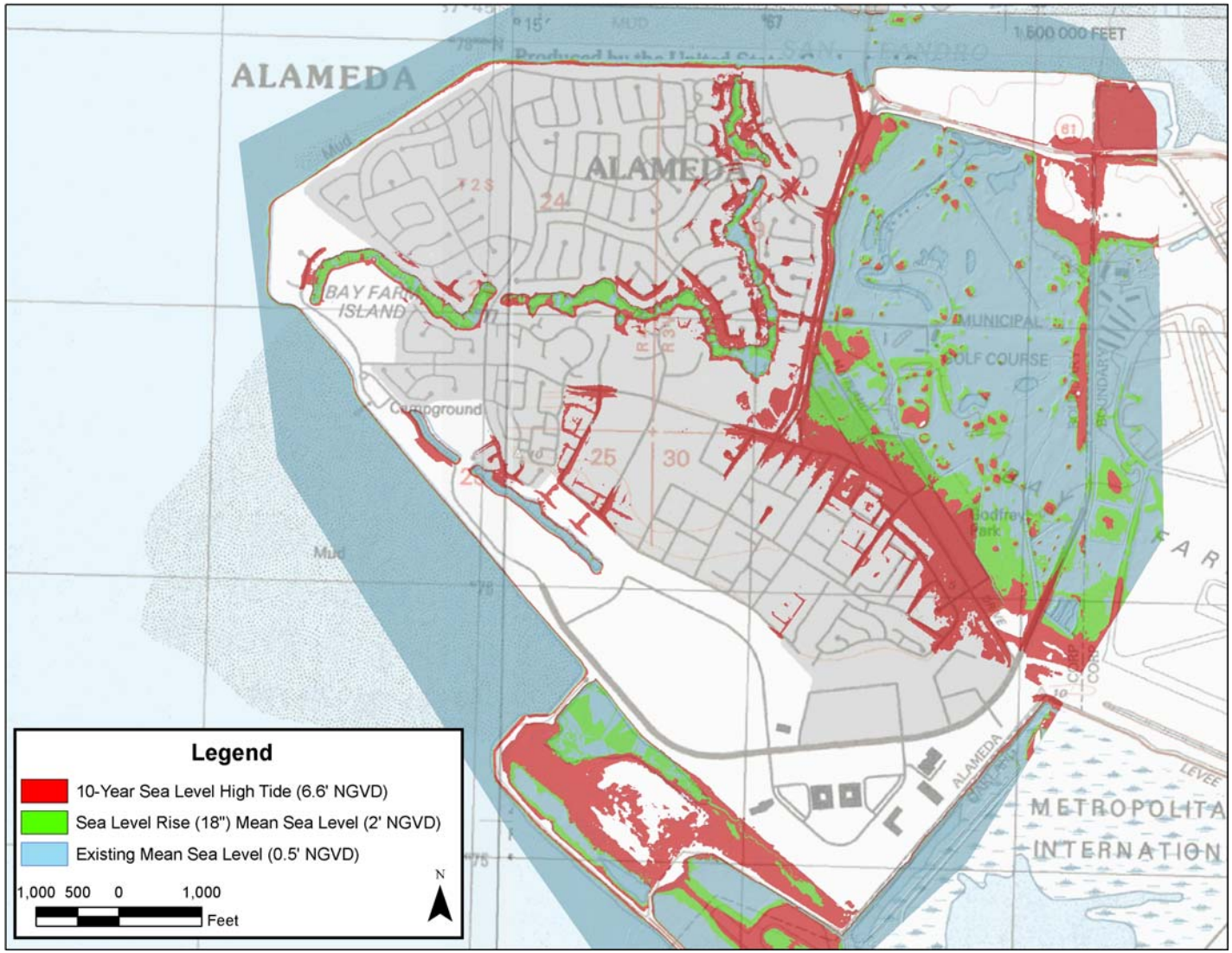

Figure 2: Areas below the 10-year High Tide with 18" of Sea Level Rise, Bay Farm Island

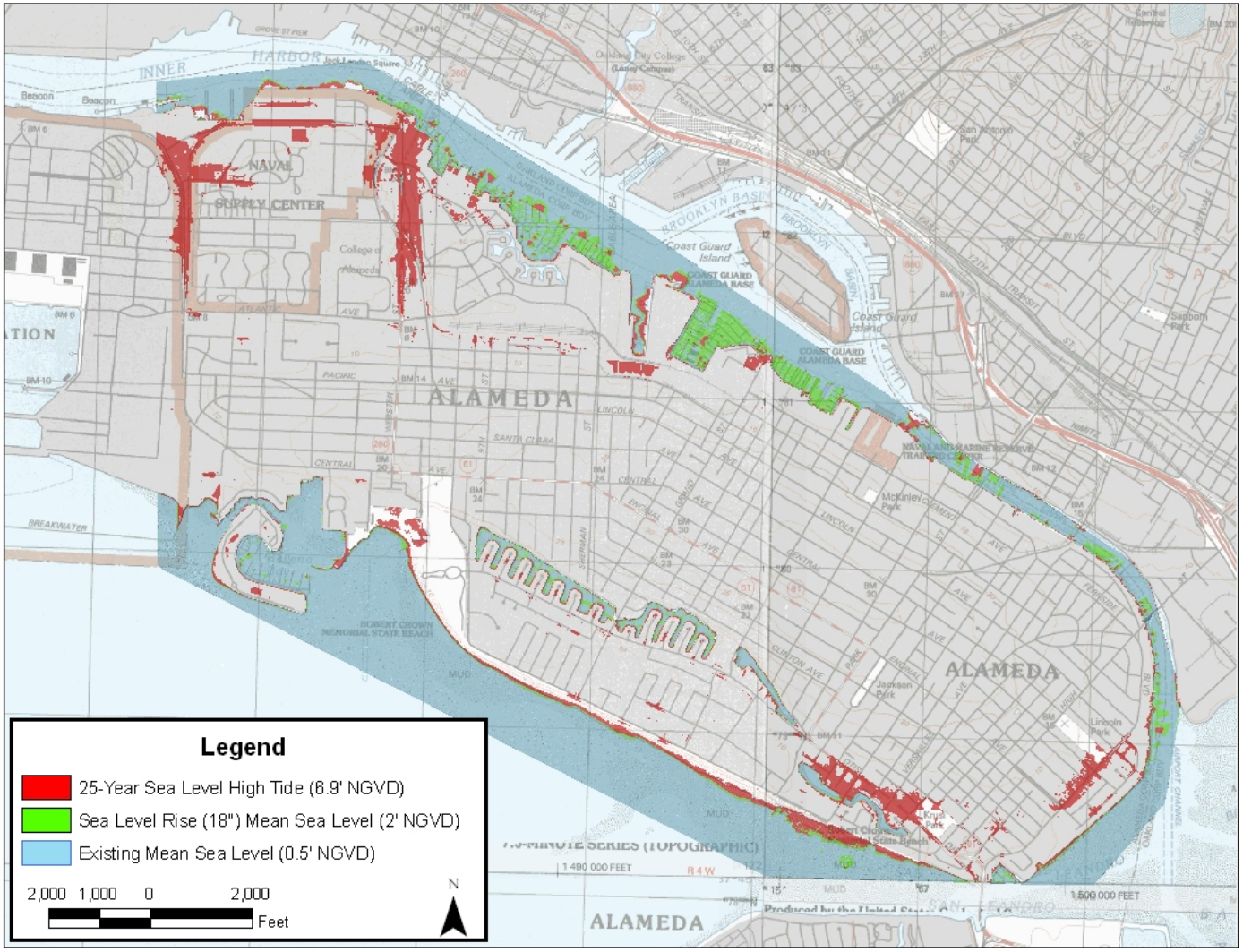

Figure 3: Areas below the 25-year High Tide with 18" of Sea Level Rise, Main Island

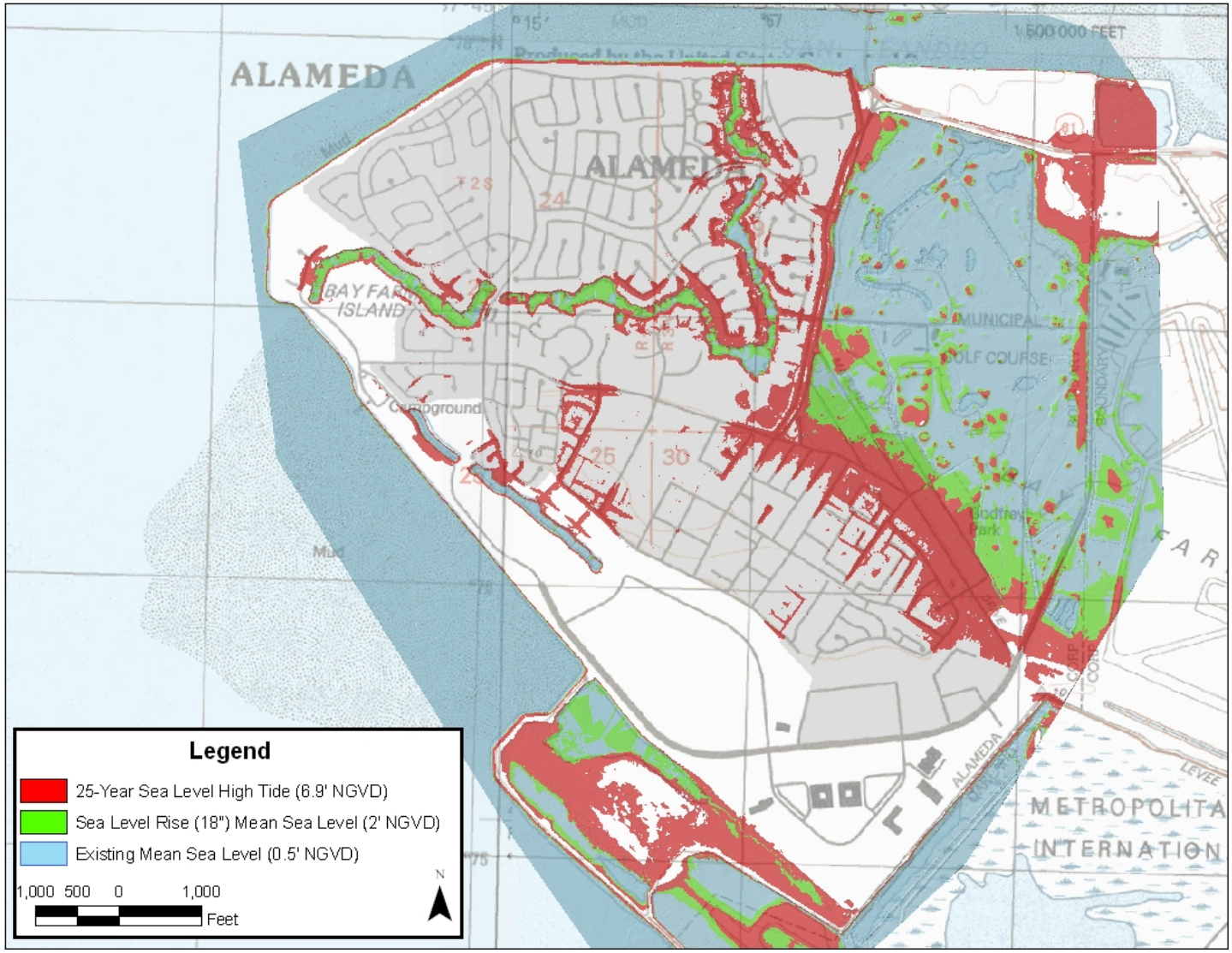

Figure 4: Areas below the 25-year High Tide with 18" of Sea Level Rise, Bay Farm Island

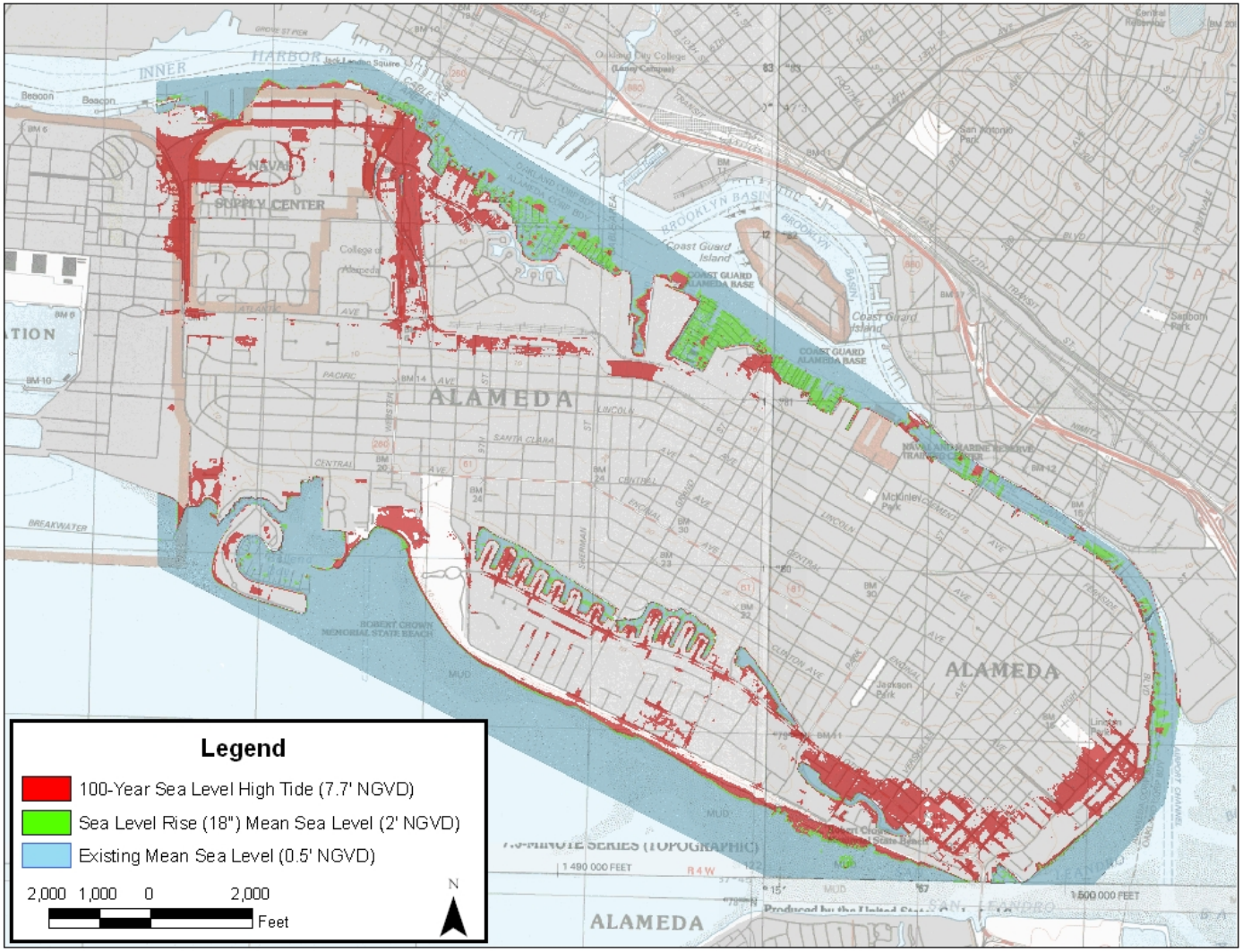

Figure 5: Areas below the 100-year High Tide with 18" of Sea Level Rise, Main Island

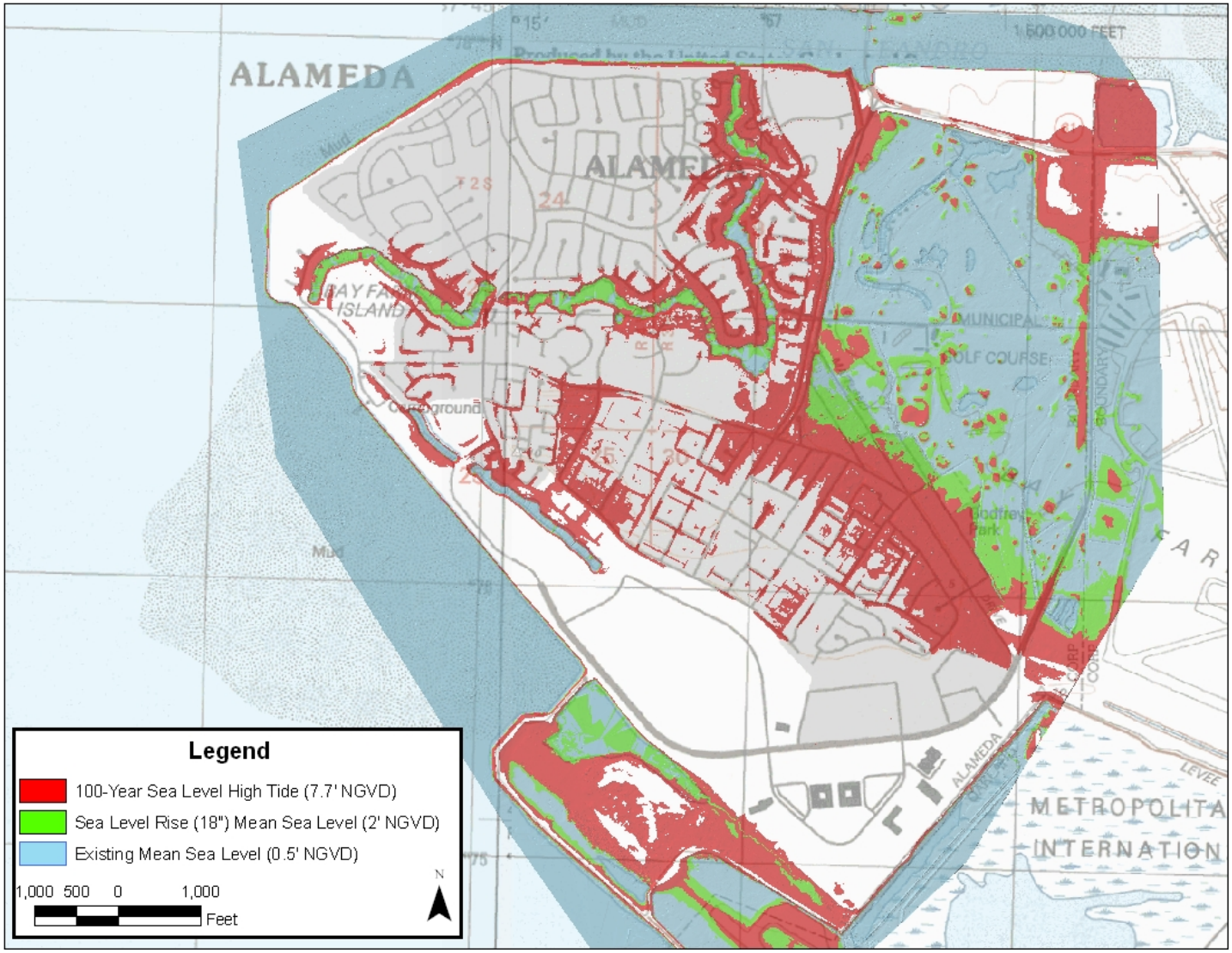

Figure 6: Areas below the 100-year High Tide with 18" of Sea Level Rise, Bay Farm Island

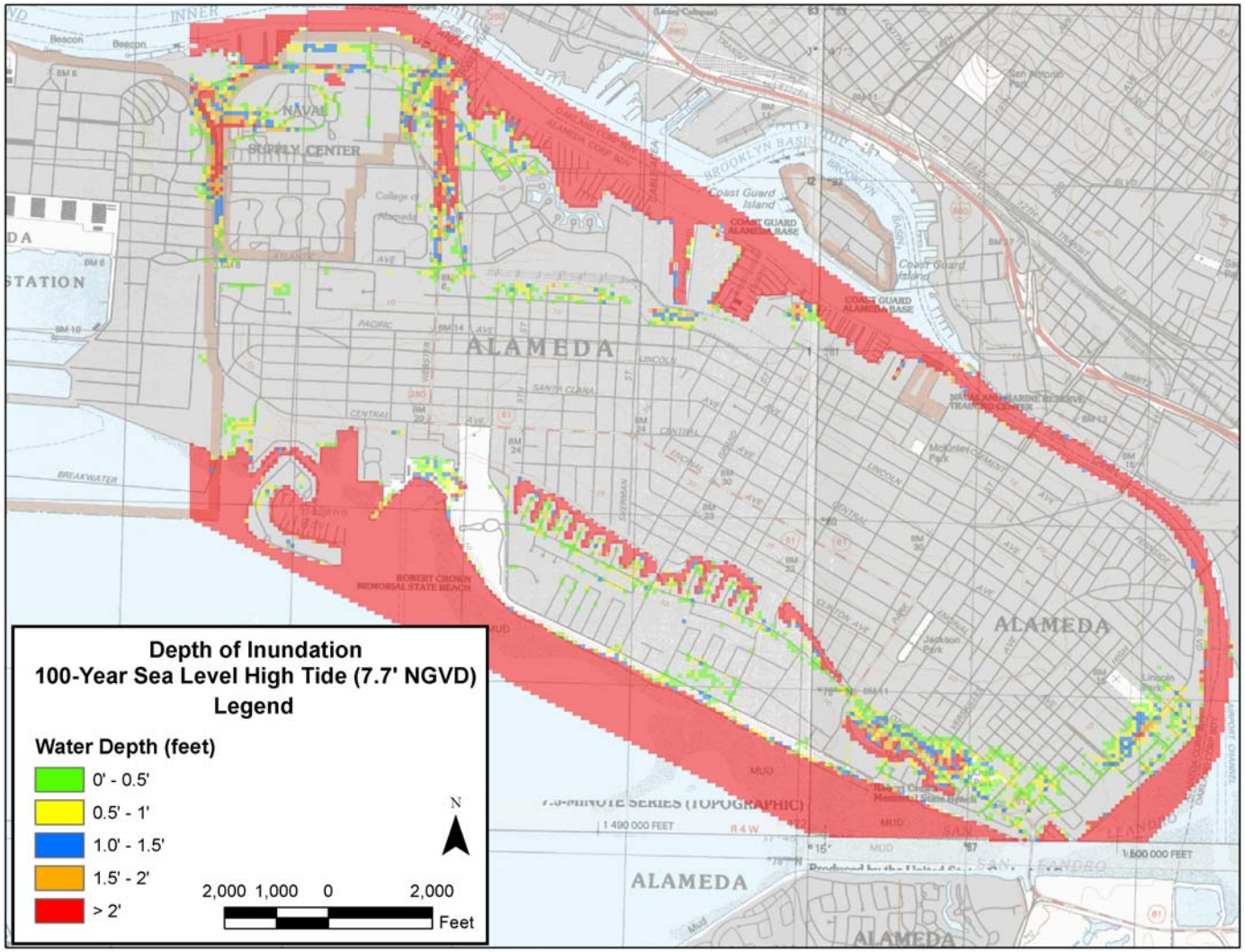

Figure 7: Depth of Water below the 100-year High Tide with 18" of Sea Level Rise, Main Island

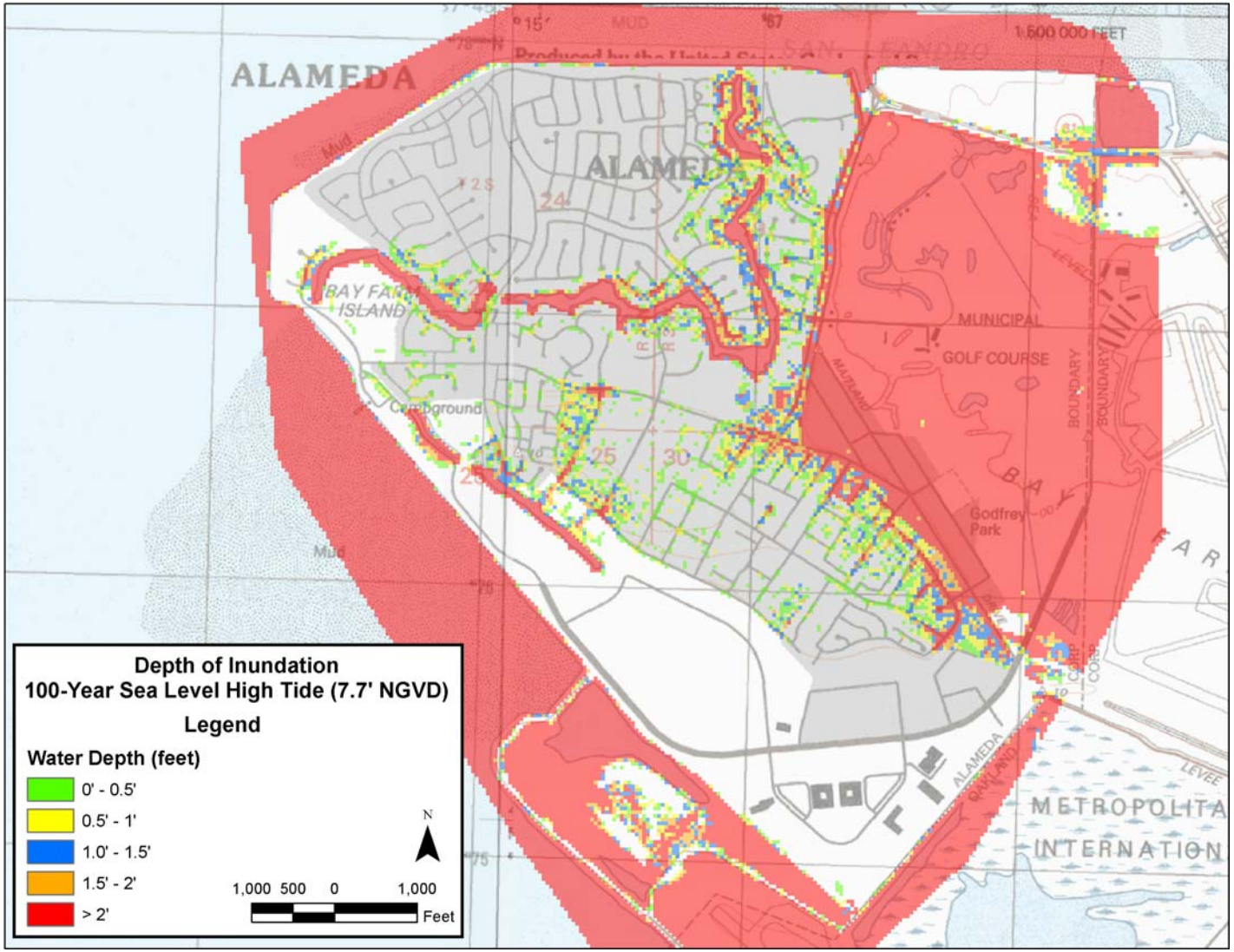

Figure 8: Depth of Water below the 100-year High Tide with 18" of Sea Level Rise, Bay Farm Island

As shown in the figures above, the primary inundation area on the Main Island is the low lying ground in the south eastern portion of the island, as well as the area immediately south of the tunnel (Webster / Posey Tube) between the Cities of Alameda and Oakland. This second area is largely included in the Federal Emergency Management Agency (FEMA) Flood Insurance Rate Map (FIRM) 100-year floodplain delineation. On Bay Farm Island, the primary areas of inundation are those areas adjacent to interior lagoons or the low-lying areas of the golf course.

On both Alameda Island and Bay Farm Island, the most significant impact is seen during the peak storm conditions. That is, the increase in mean sea level from 0.5 feet NGVD to 2.0 feet NGVD is relatively small, whereas the area in shaded red, representing the elevation of the peak storm tide with an additional 18 inches of sea level rise, is much larger. The water surface elevation represented by the red area is a peak elevation and is not sustained over long periods of time even during a storm event.

Projects to Mitigate Sea Level Rise Inundation

There are several projects which may partially mitigate the inundation areas shown in Figures 1 through 8 above. As mentioned previously, however, it should be noted that structural improvements are not necessarily a recommended long term strategy to mitigate sea level rise impacts, particularly inundation. Any projects undertaken should include flexibility to adjust or adapt the project for continued sea level rise beyond the 18 inches used for this analysis.

Bay Farm Island lagoon water levels are controlled via pump station outlets, and an intake weir. The operation of the pump stations is currently manual. The operation of the pump stations and the configuration of the intake weirs may need to be adjusted to maintain existing lagoon water surface elevations in the event of sea level rise. While inundation via the golf course appears more significant on the above figures, the peak tide condition is not expected to be maintained long enough to cause the widespread inundation shown. If inundation does occur, a floodwall along Island and Doolittle Drives is one potential mitigation project, however at that stage, the Oakland Airport would also be experiencing flooding due to higher sea levels and coordination with the Airport on flood protection measures is advisable. Alternative mitigation options may include increased pumping capacity at the golf course pump station, or raising the streets bordering the Golf Course to act as flood barriers.

The Main Island inundation map shows the low lying areas of land in south eastern as well as north central Alameda below extreme water surface elevations in the sea level rise scenario. In this case, although only a slim strip of bayfront land is below the high tide

with sea level rise elevation, water may also reach many of these areas via storm drain pipes which are currently without flap gates. Projections of sea level rise predict that not only will extreme sea levels occur more often, they may also occur for longer durations (Cayan, 2009). Thus, interior ponding due to backwater from long periods of extreme tides is a possibility. The installation of flap gates at storm drain outfalls would protect City streets from this backwater condition. Due to the relatively short duration of high waters expected, an adaptive management approach which prioritizes projects based on actual backwater experienced is recommended for outfall flap gate installation. As such, flap gates have not been included in this analysis of sea level rise impacts to the CIP.

Storm Drain Capacity

In the 2008 Storm Drain Master Plan, Schaaf & Wheeler presented a Capitol Improvement Program (CIP) to achieve a 10-year level of service for the storm drain network throughout the City of Alameda. The CIP included upsizing existing pipes, additional capacity at several storm drain pump stations, new pipes to provide storm drain capacity to areas currently underserved by the existing system, and several non-capacity related improvements such as trash racks at pump stations. The City directed Schaaf & Wheeler to determine how sea level rise would affect the proposed CIP. In other words, if all CIP projects were completed to meet a 10-year level of service, what additional projects would be necessary to achieve this same level of service assuming that 18" of sea level rise occurs.

For this analysis, Schaaf & Wheeler assumed that sea level rise affects the tide cycle uniformly, that is, both peak and ebb tides are increased by 18 inches. Global warming may in fact impact the tide cycle itself during storm events, particularly storm surge as described above; however numerical projections of these impacts do not currently exist. Figures 9 through 15 show the impact of this sea level rise scenario on the 10-year improved storm drain network.

In addition to the impact scenario described above, Schaaf & Wheeler analyzed the improved 10-year storm drain system operation during a 2-year storm event, but with a 100-year sea level rise scenario tide. This serves to exemplify how the improved system will operate under a relatively minor storm but severe tide. The result of this analysis is essentially identical to the areas shows in Figures 1-6. In this scenario the rainfall is inconsequential, and backwater from the tide cycle determines peak water surface elevation. As described previously, the time period when water surface elevations exceed rim (i.e. ground) elevations is relatively short, generally on the order of 15 minutes or less, although the duration of flooding increases closer to the outfalls due to lower ground elevations at the boundaries of the City.

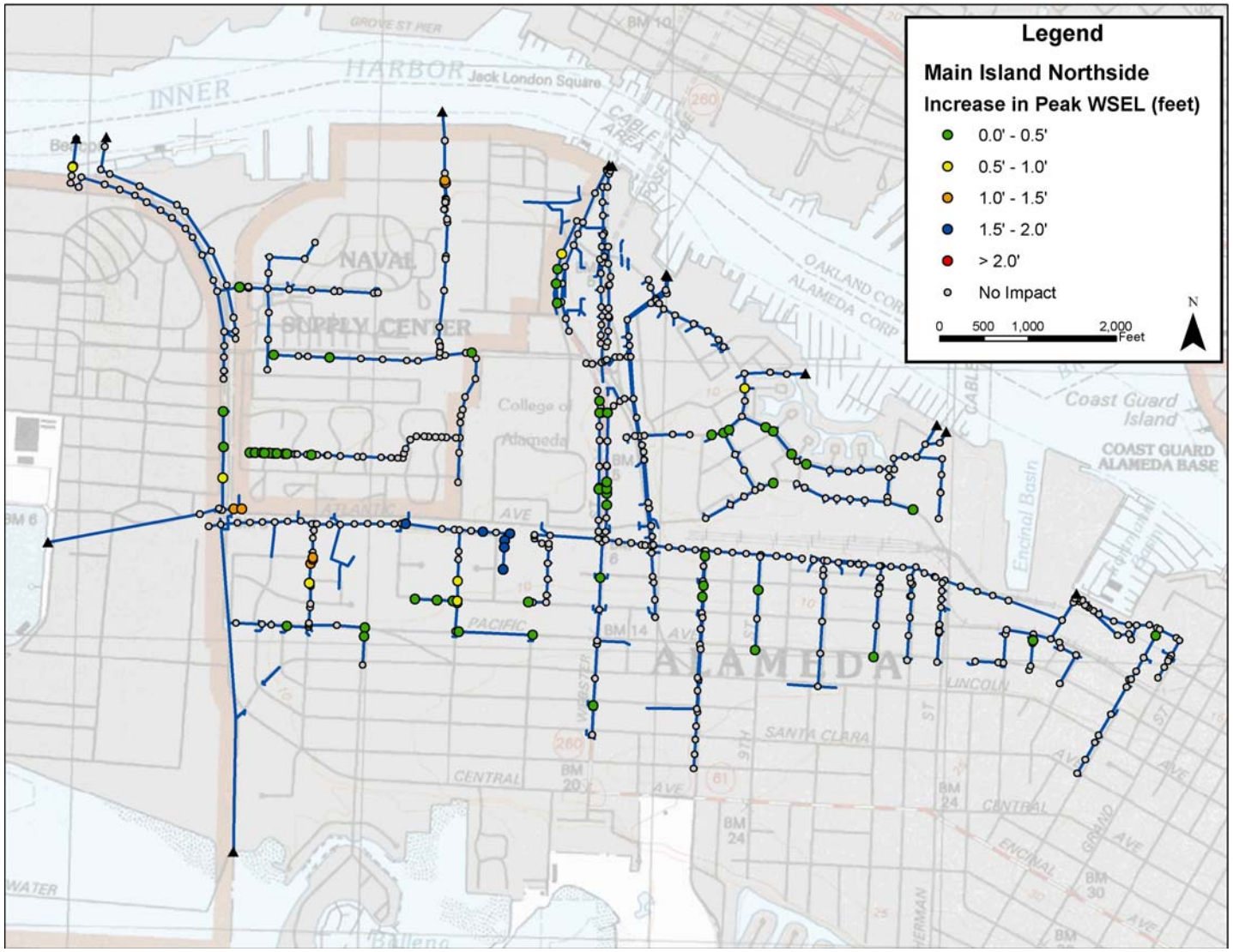

Figure 9: Impact of 18" Sea Level Rise on 10-Year Improved System, 10-Year Storm, Main Island Northside

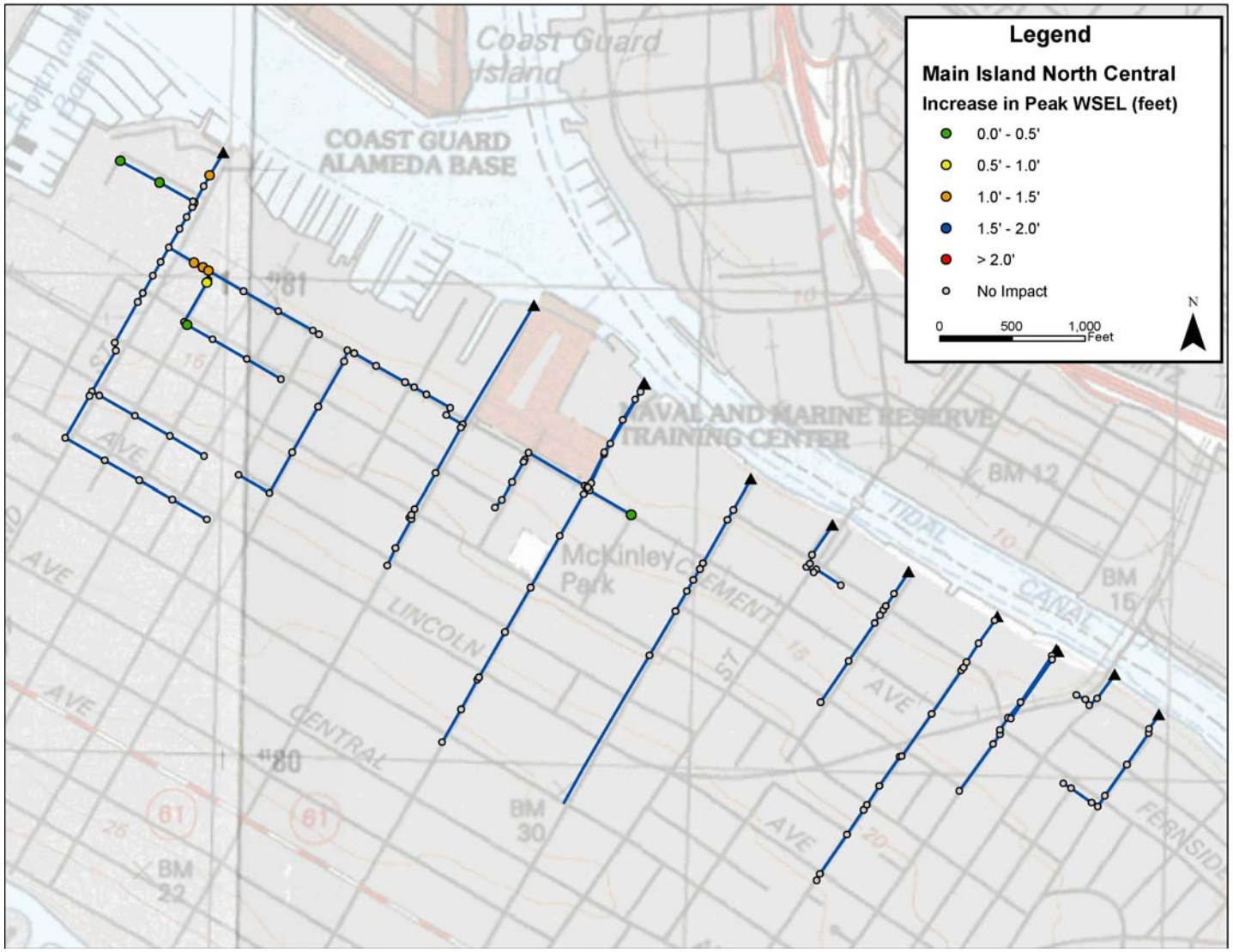

Figure 10: Impact of 18" Sea Level Rise on 10-Year Improved System, 10-Year Storm, Main Island North Central

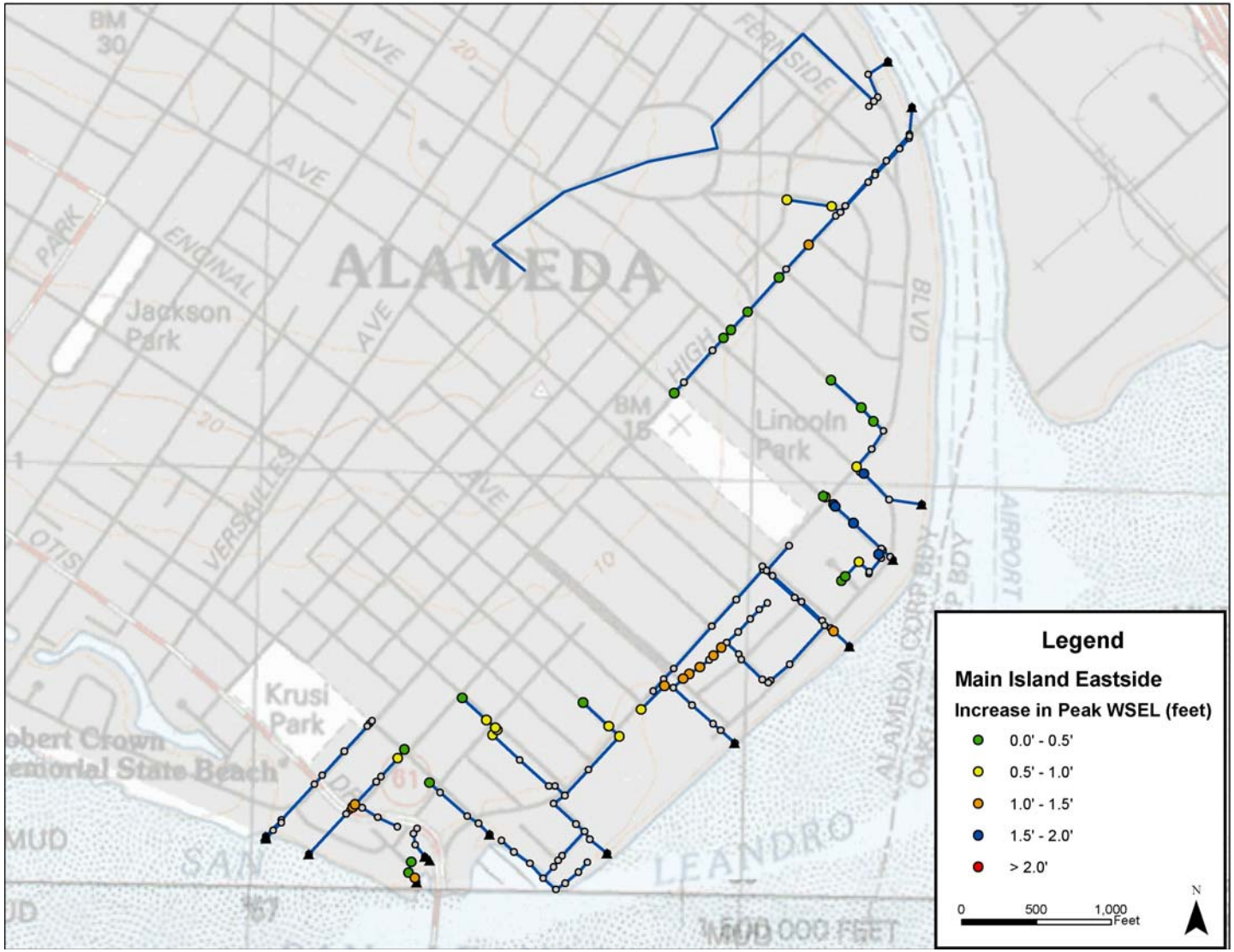

Figure 11: Impact of 18" Sea Level Rise on 10-Year Improved System, 10-Year Storm, Main Island Eastside

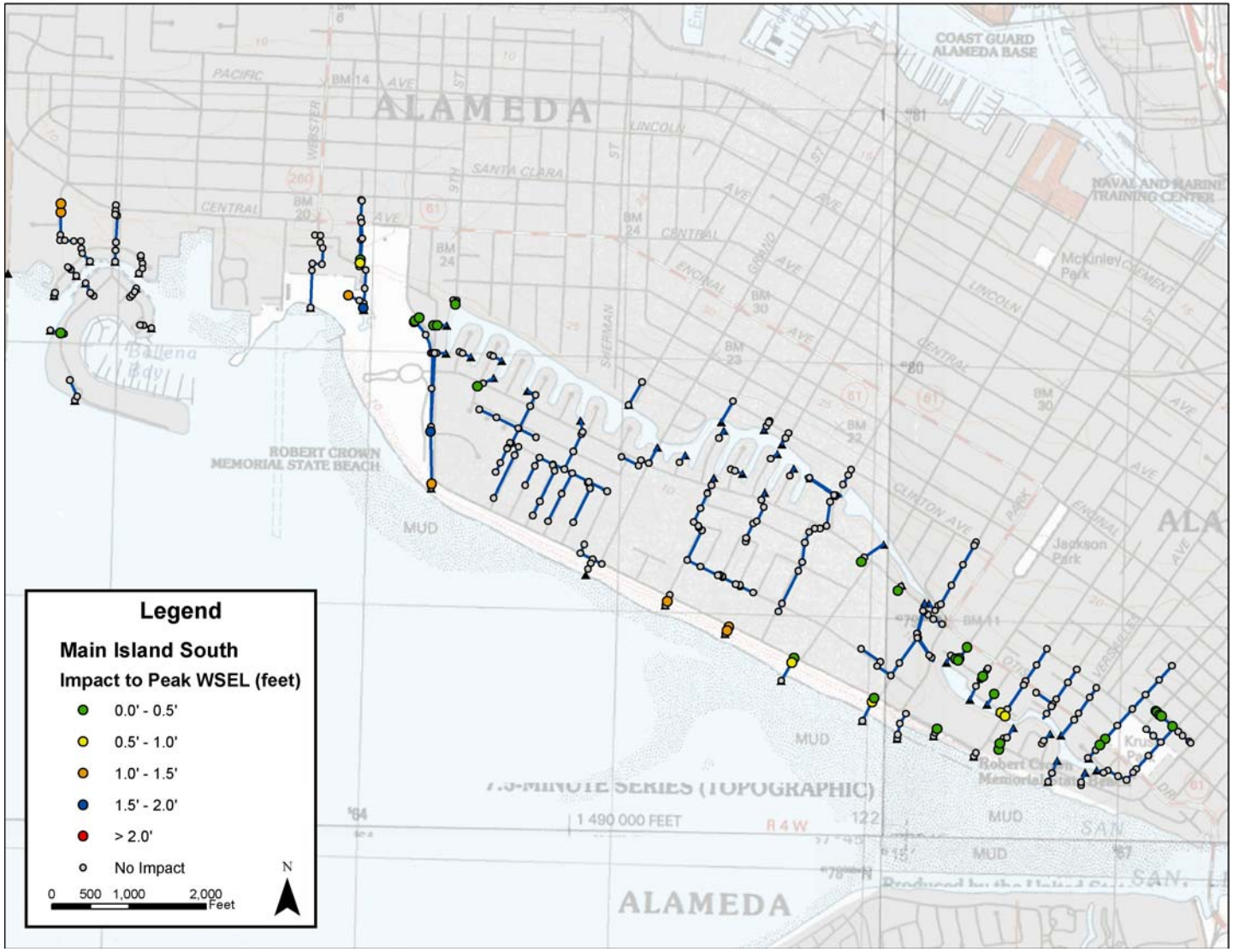

Figure 12: Impact of 18" Sea Level Rise on 10-Year Improved System, 10-Year Storm, Main Island South

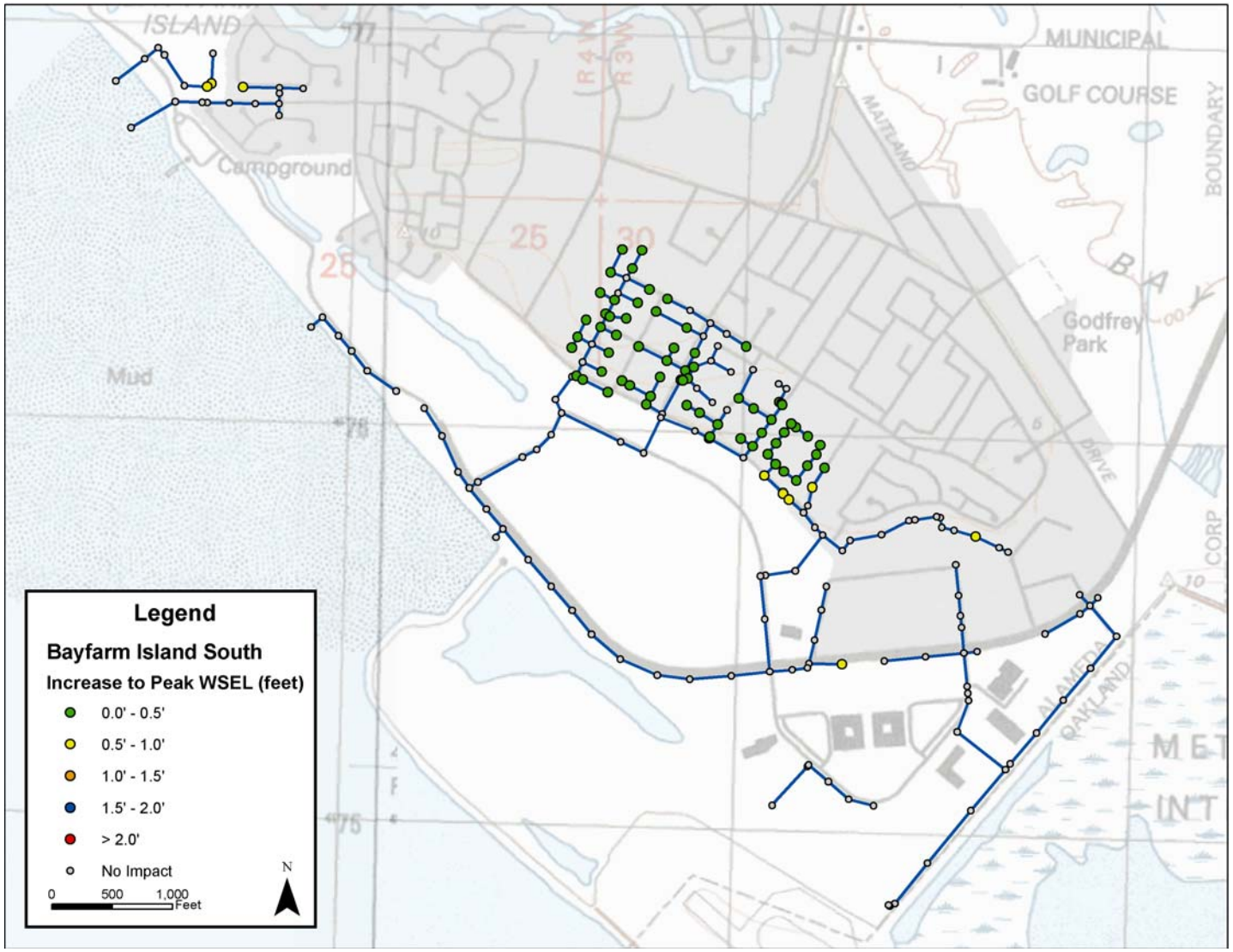

Figure 13: Impact of 18" Sea Level Rise on 10-Year Improved System, 10-Year Storm, Bay Farm Island South

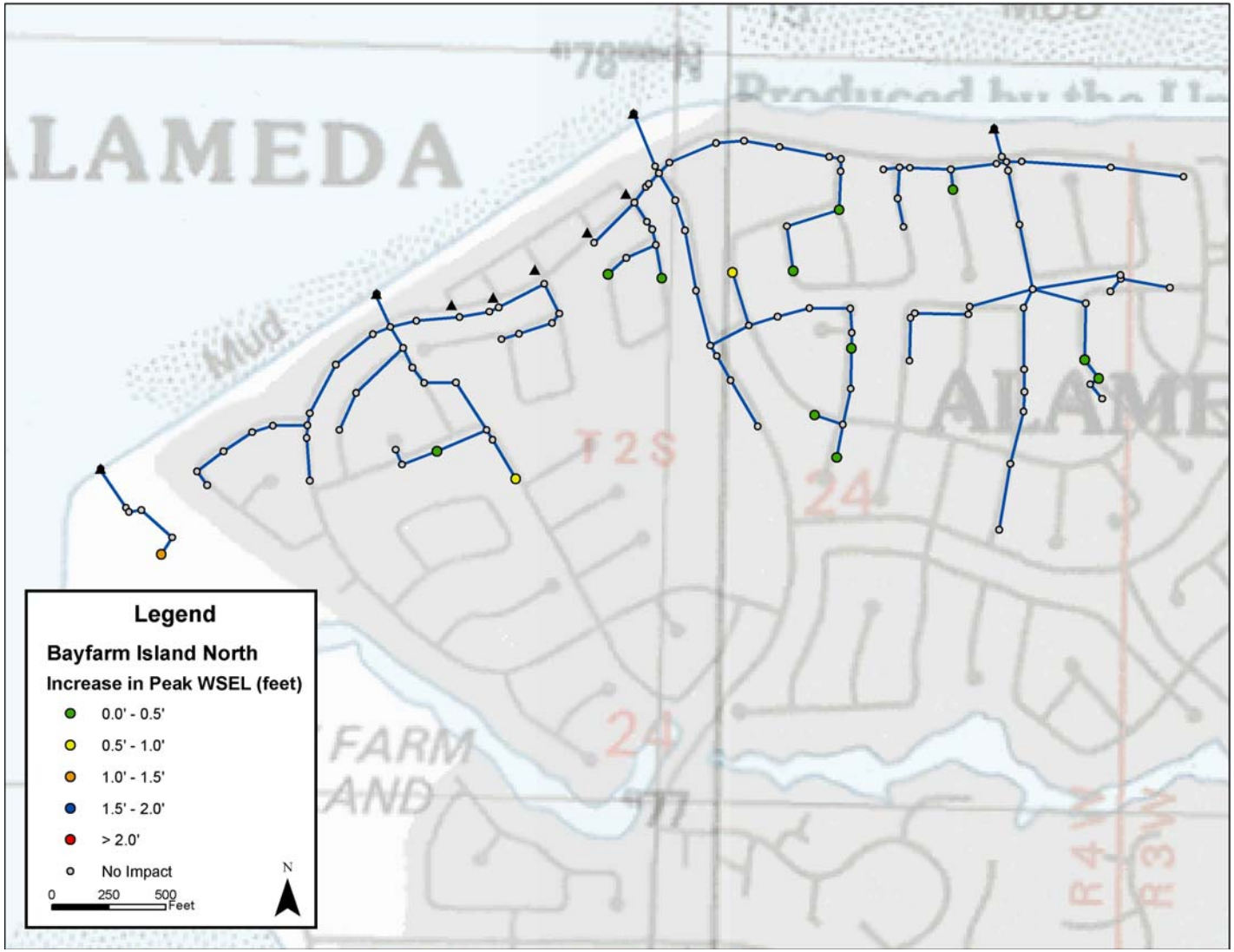

Figure 14: Impact of 18" Sea Level Rise on 10-Year Improved System, 10-Year Storm, Bay Farm Island North

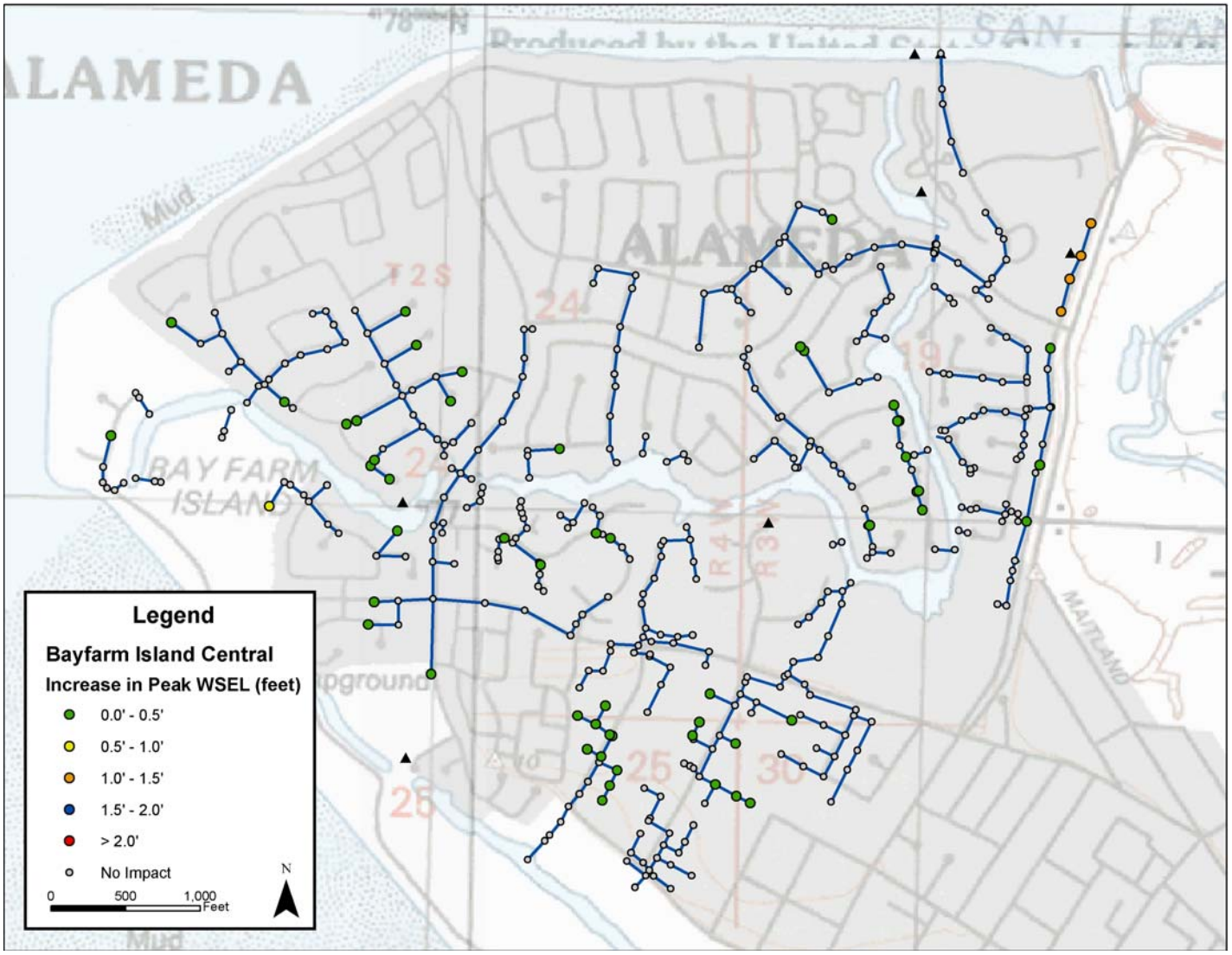

Figure 15: Impact of 18" Sea Level Rise on 10-Year Improved System, 10-Year Storm, Bay Farm Island Central

No figure is included for Bay Farm Island East because there are no impacts in that area. As shown above, in general these impacts are relatively small (most commonly less than a half foot) as expected given the existing conditions 10-year level of service of the system in this scenario.

Projects to Mitigate Impacts of Sea Level Rise on Storm Drain Capacity

Additional projects are required to maintain a 10-year level of service if 18" of sea level rise is applied to the tide cycle. Figures 16 through 22 show additional projects necessary to reach a 10-year level of service under the assumed sea level rise scenario. Pipes which have a white highlighted background are pipes that have been improved from the existing condition to meet existing 10-year service levels. In other words, these pipes are already recommended for improvement in the SDMP CIP, but their recommended size must be adjusted to meet the sea level rise scenario. Pipes which are not highlighted represent new projects where no previous work was recommended to meet 10-year service levels under existing sea levels.

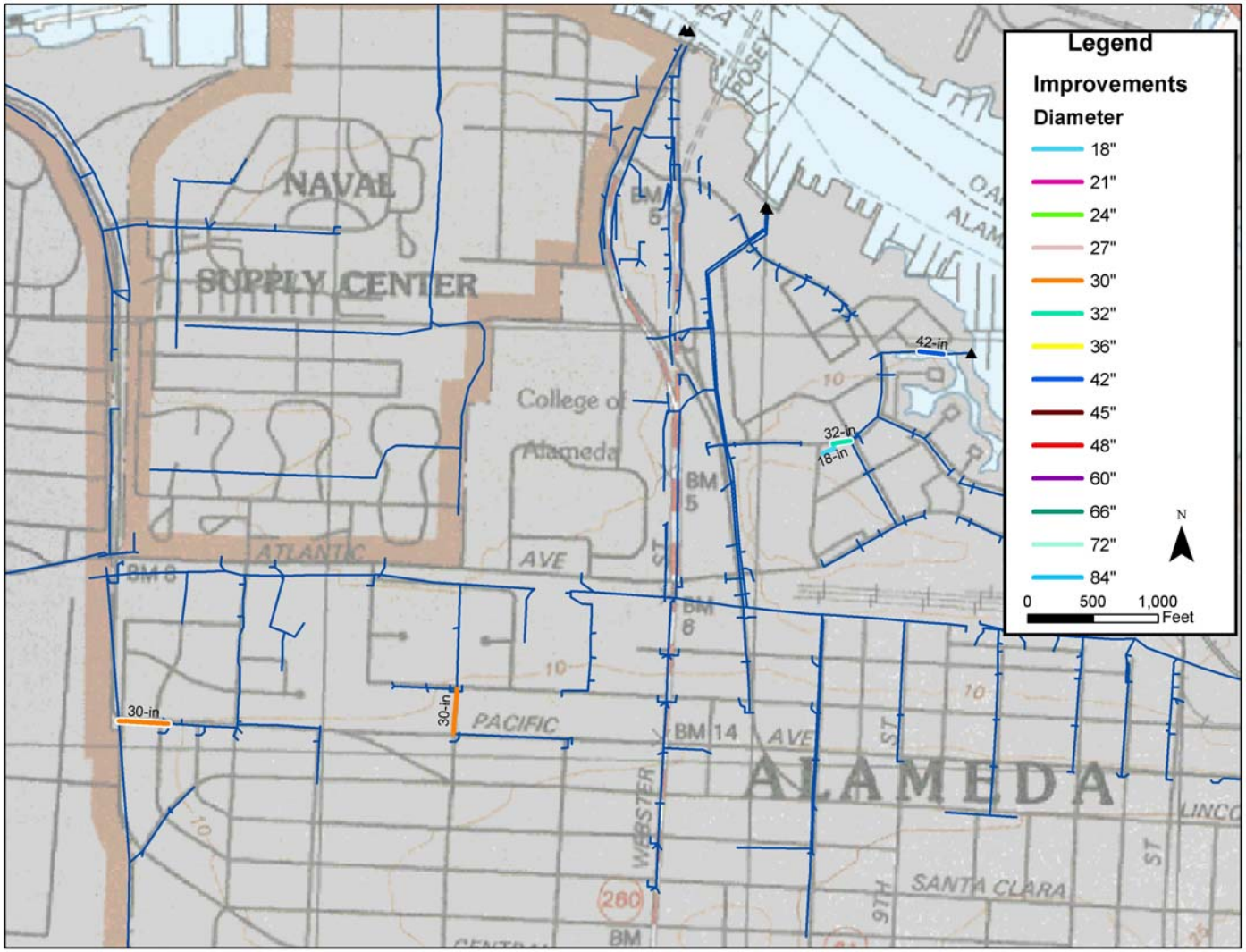

Figure 16: Improvements to Maintain 10-Year Level of Service with 18" of Sea Level Rise, Main Island Northside

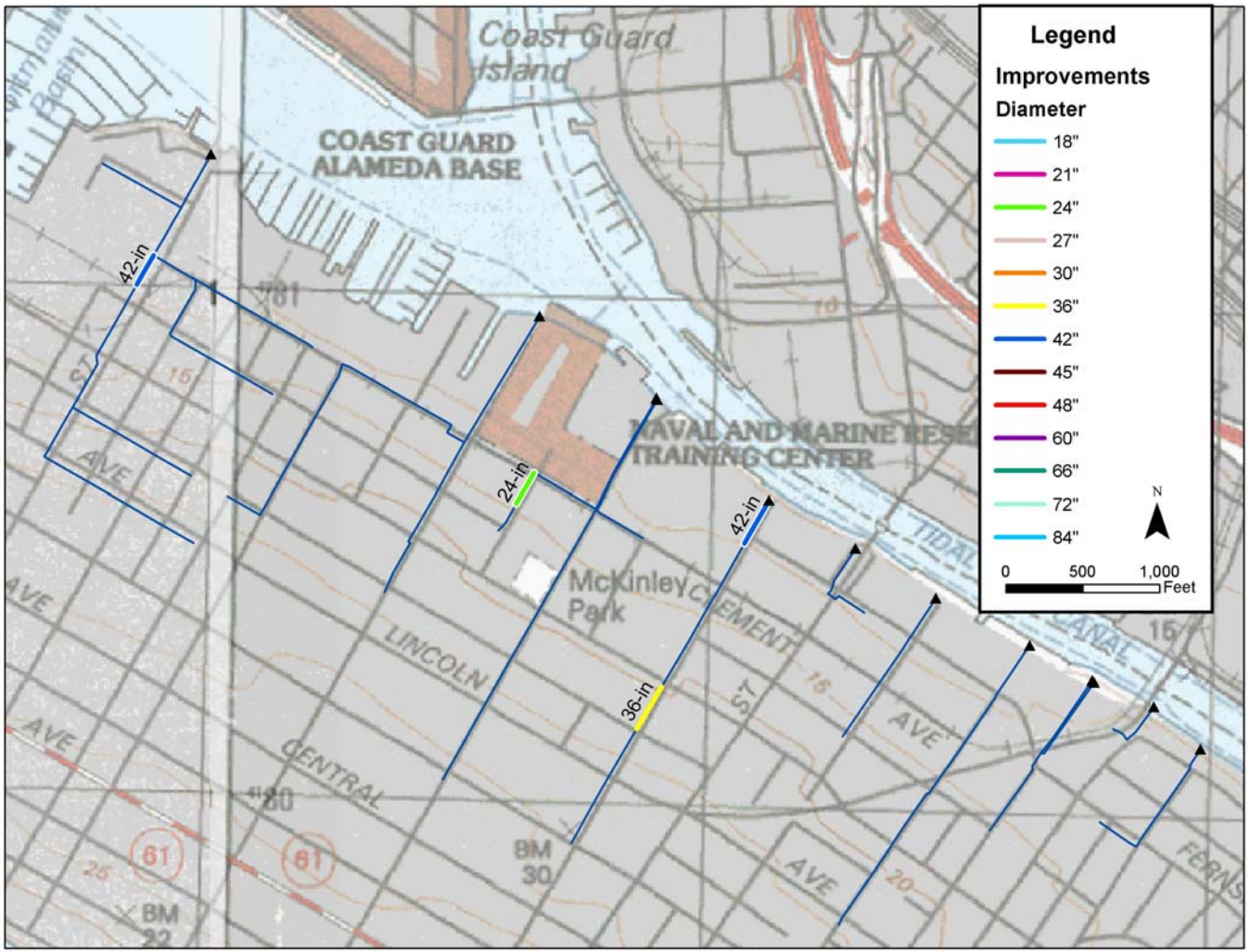

Figure 17: Improvements to Maintain 10-Year Level of Service with 18" of Sea Level Rise, Main Island North Central

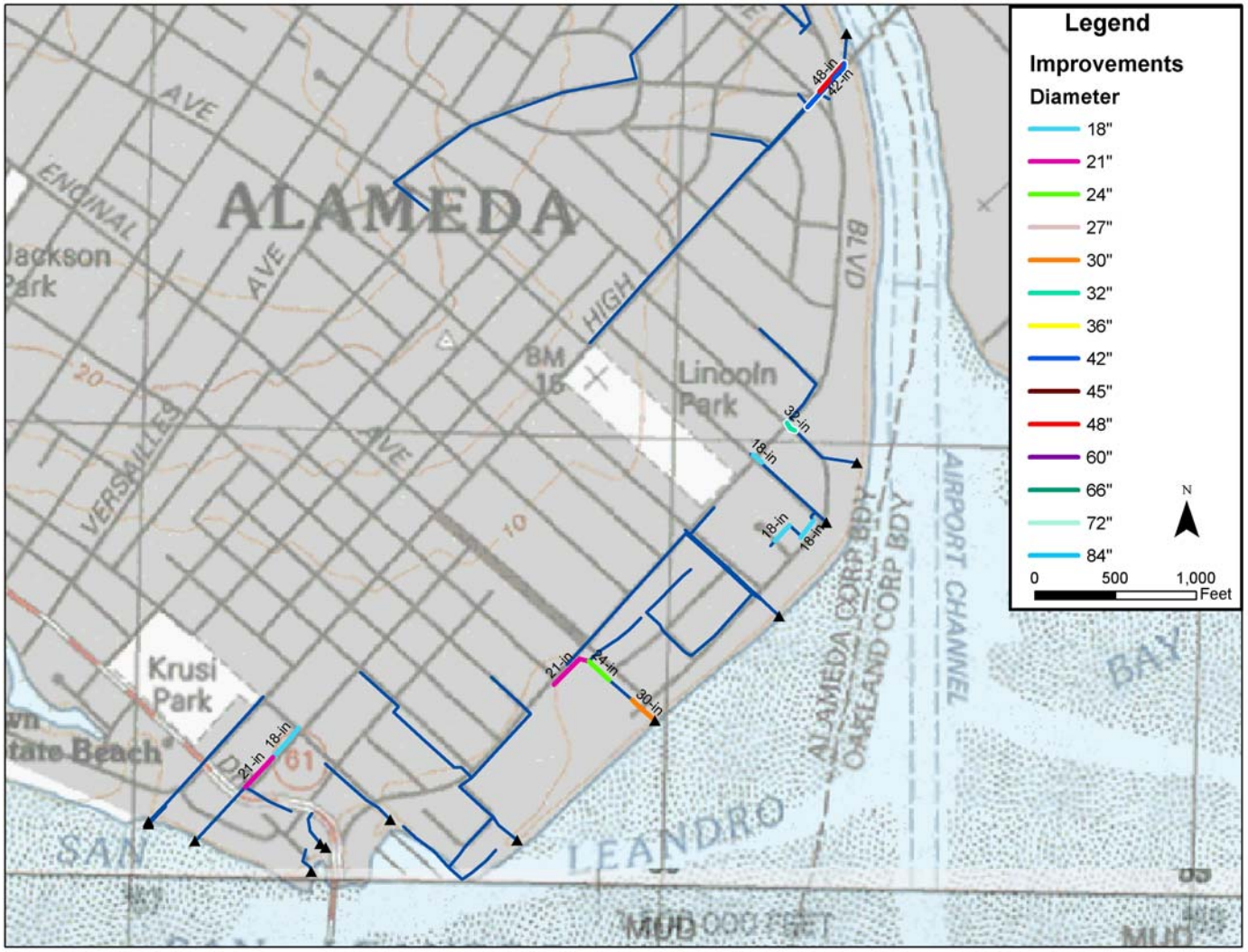

Figure 18: Improvements to Maintain 10-Year Level of Service with 18" of Sea Level Rise, Main Island Eastside

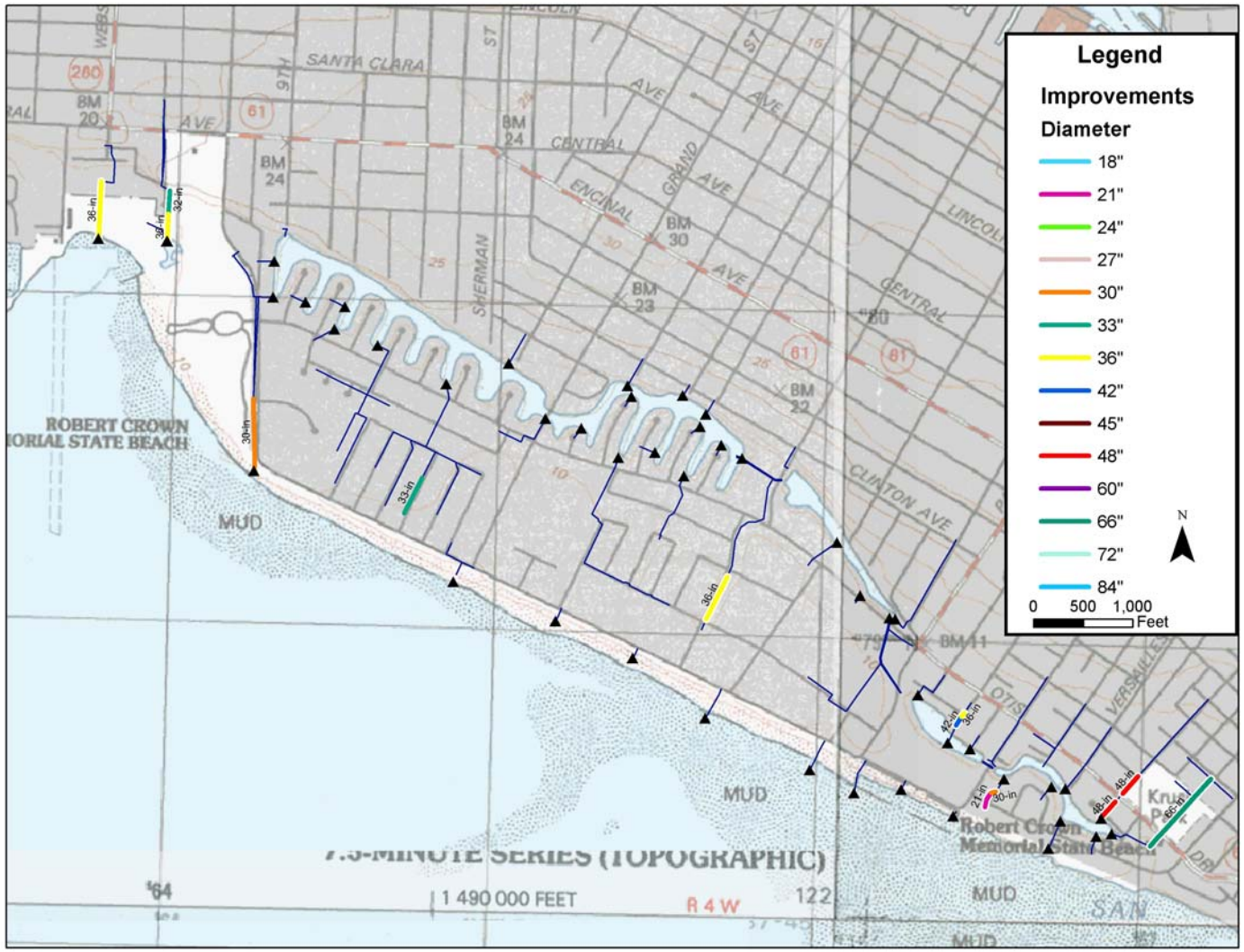

Figure 19: Improvements to Maintain 10-Year Level of Service with 18" of Sea Level Rise, Main Island South

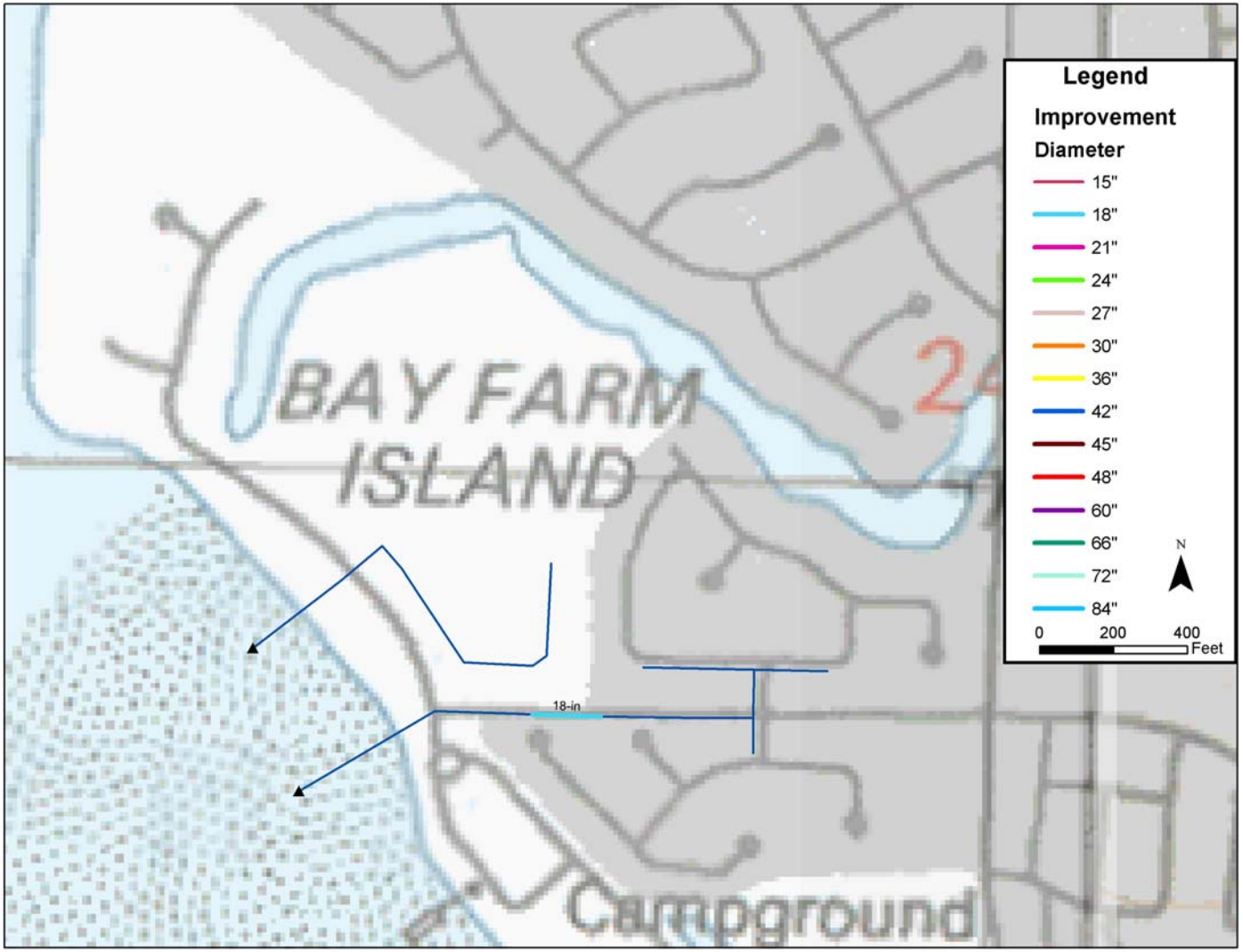

Figure 20: Improvements to Maintain 10-Year Level of Service with 18" of Sea Level Rise, Bay Farm Island South

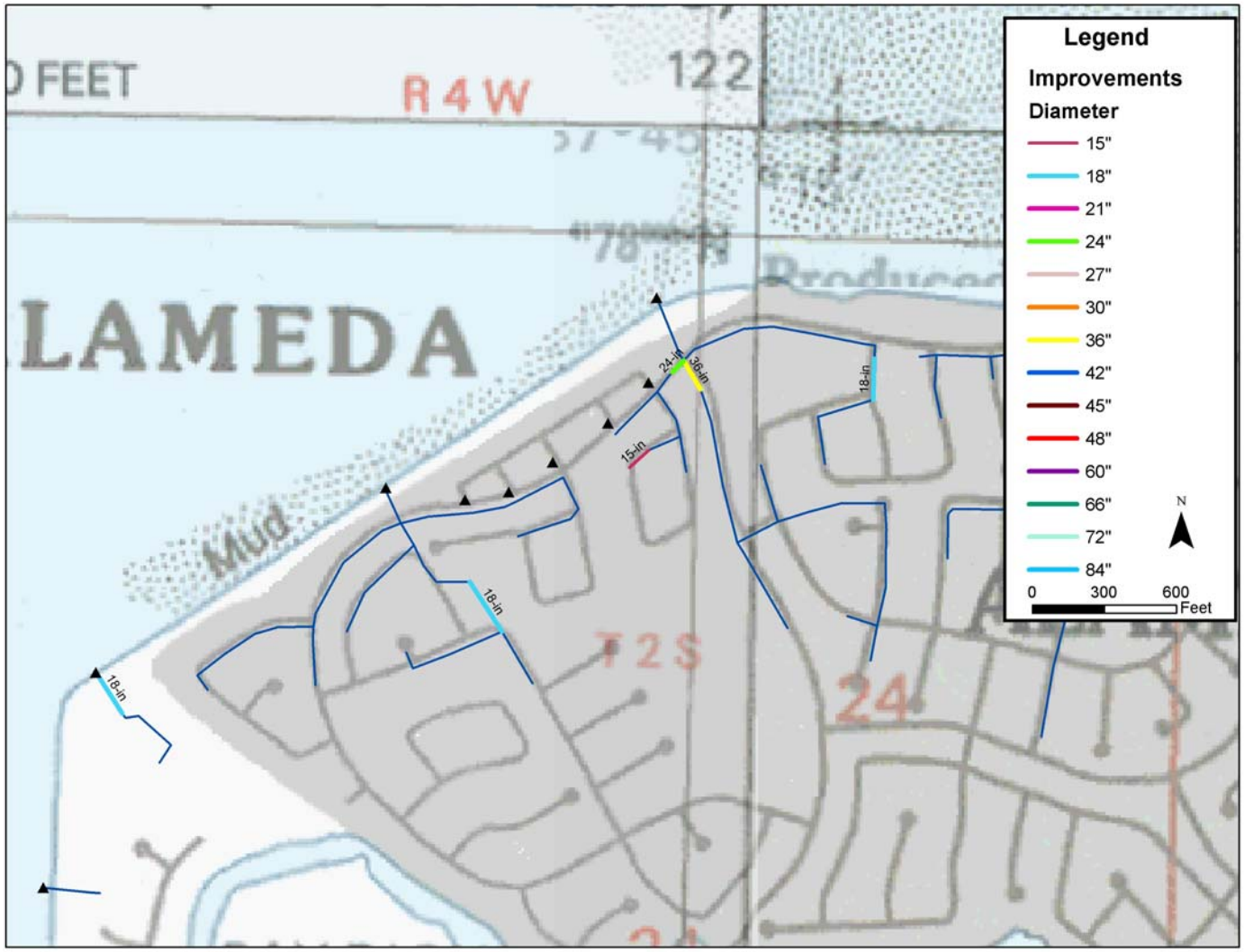

Figure 21: Improvements to Maintain 10-Year Level of Service with 18" of Sea Level Rise, Bay Farm Island North

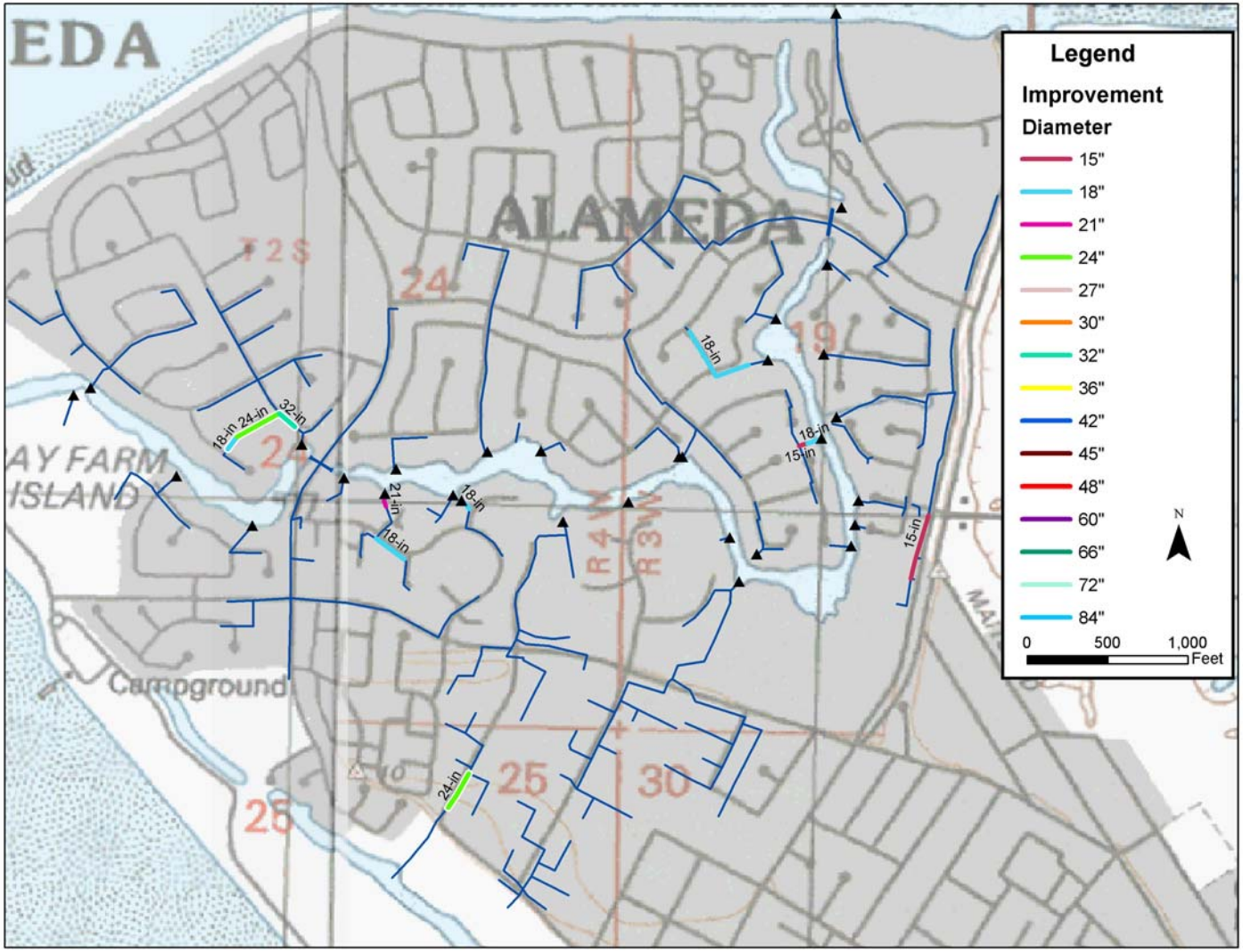

Figure 22: Improvements to Maintain 10-Year Level of Service with 18" of Sea Level Rise, Bay Farm Island Central

Impact of Sea Level Rise Improvements to Storm Drain Master Plan CIP

As shown in Figures 16 through 22 above, new pipe replacement projects, or increased pipe diameters compared to the SDMP CIP are required to maintain a 10-year level of service to the system in the event of 18" of sea level rise. Costs have been estimated using information from other projects, cost estimating guides (2009 Current Construction Costs, Saylor Publications, Inc.), and engineering judgment. These costs are summarized in Table 3.

Table 3: Storm Drain Cost Per Linear Foot

Diameter (inches)	Dollar per Linear foot of Pipe	Dollar per Connection
15	$116	$9,089
18	$128	$9,504
21	$150	$9,668
24	$172	$9,830
27	$194	$9,993
30	$216	$10,157
33	$241	$10,332
36	$267	$10,508
42	$300	$10,870
48	$335	$11,245
54	$369	$11,632
60	$413	$12,051
72	$502	$12,890
96	$679	$14,567

Table 4 summarizes the cost impact of these additional improvements. For pipes which are recommended for improvements in the SDMP (i.e. the highlighted pipes in Figures 14 through 20), the cost included in this table is the difference in costs between the SDMP recommended improvement and the size needed to provide the same level of protection for this sea level rise scenario. Note that costs presented in Table 3 do not include the 40% increase for design, administration, and contingency included in Table 4.

Table 4: Increase in Storm Drain Master Plan Capitol Improvement Program to Maintain 10-Year Level of Service with 18" of Sea Level Rise

City of Alameda Areas	Additional Costs to SDMP CIP
Main Island Eastside	$711,000
Main Island North Central	$190,000
Main Island South	$652,000
Main Island Northside	$234,000
MAIN ISLAND TOTAL	**$1,800,000**
Bay Farm Island North	$325,000
Bay Farm Island Central	$542,000
Bay Farm Island South	$70,000
BAY FARM ISLAND TOTAL	**$937,000**
CITY OF ALAMEDA TOTAL	**$2,700,000**

More detailed cost summary tables are included in Appendix A.

In addition to the costs of structural improvements (i.e. increased storm drain capacity requirements), there are also indirect costs to the City due to the sea level rise scenario. Due to the change in boundary conditions, storm drain pumps may run for longer periods of time, resulting in increased energy usage, maintenance and replacement costs. If the golf course is more often rendered unusable by flood waters, this could also indirectly impact City economics. While these costs are expected to be small compared to the improvement costs, they will be experienced regardless of projects undertaken to mitigate storm drain performance.

Current Status of Regulations Pertaining to Climate Change

The current status of potential regulations pertaining to climate change is explored below. Research and regulations regarding climate change are regularly, and sometimes rapidly, updated and modified; thus this section should be considered representative, and may not represent a complete list of current or pending regulations.

Federal

At a Federal level there are currently very few recommendations or guidelines for incorporating the risks of sea level rise into project planning, and virtually no required measures. It should be noted, however, that with the administration change of 2009, based on President Obama's statements that global warming is a priority of the new administration, relatively rapid changes in the Federal government's involvement in

global warming analyses and impacts may be forthcoming. Thus far it appears that those changes will be focused on emission standards as opposed to impact mitigation.

Flood Programs - Federal Emergency Management Agency

Although the Federal Emergency Management Agency (FEMA) has issued several statements in the last decade pertaining to climate change and the risks of global warming, at this time FEMA policy has not changed to reflect these risks or impacts. Sea level rise is not directly considered in the National Flood Insurance Program (NFIP). In 2001 FEMA published a report on the projected impact of relative sea level rise on the NFIP, which concluded that the NFIP would not be significantly impacted by sea level rises under one foot by the year 2100, and the gradual timeframe of sea level rise provides ample opportunity for the NFIP to consider alternatives and implement them. The report recommended that FEMA should continue to monitor analyses and predictions of sea level rise and strengthen the Community Rating System (CRS) by encouraging measures that would mitigate the impacts of sea level rise (FEMA, 1991).

In March 2007 the United States Government Accountability Office published a report on the financial risks to federal and private insurers as a result of climate change, and recommended that the NFIP analyze the potential long-term fiscal implications of climate change and report these findings to Congress (GAO-07-285, March 2007). It is foreseeable that when this analysis takes place, changes to the NFIP will be made to lessen the financial risk to the insurers. Potential policy changes may include increased freeboard requirements for Bay or Riverfront levees and/or some consideration or discussion of sea level change in floodplain analyses, but when or if any policy changes will occur is unknown.

On March 17, 2009, the National Association of Insurance Commissioners (NAIC) adopted a mandatory requirement that insurance companies disclose to regulators the financial risks they face from climate change, and actions that the companies are taking to respond to those risks. This requirement impacts all insurance companies with annual premiums of $500 million or more. Those companies must complete an “Insurer Climate Risk Disclosure Survey” every year, with the first report due on May 1, 2010.

Research on Climate Change - National Oceanic and Atmospheric Administration

The National Oceanic and Atmospheric Administration (NOAA) is the federal agency that appears to have taken the lead in analyses of the impacts of global warming to the United States of America. NOAA is primarily a scientific research and reporting agency, with little regulatory power. From the NOAA webpage:

> "NOAA is charged with helping society understand, plan for, and respond to climate variability and change. This is achieved through the development and delivery of climate information services, the implementation of a global observing system, and focused research and modeling to understand key climate processes. The NOAA climate mission is an end-to-end endeavor focused on providing a predictive understanding of the global climate system so the public can incorporate the information and products into their decisions."

Recent budget proposals from President Obama suggest that this responsibility may shift from NOAA to NASA in the future.

State

California has been on the leading edge of creating legislation to mitigate both greenhouse gas emissions and the impacts of climate change. At this time, several concrete steps have been taken to reduce greenhouse gas emissions in the state, while specific impact mitigation strategies have been recommended but not fully developed. The California Climate Action Team, described in detail earlier in this report, is responsible for coordinating state-level actions relating to climate change.

Assembly Bill 32

The California Global Warming Solution Act, also known at Assembly Bill 32 (AB32), was signed into law by Governor Schwarzenegger in 2006. AB32 requires the California Air Resources Board (CARB) to:

- Establish a statewide greenhouse gas emissions cap for 2020, based on 1990 emissions by January 1, 2008.
- Adopt mandatory reporting rules for significant sources of greenhouse gases by January 1, 2009.
- Adopt a plan by January 1, 2009 indicating how emission reductions will be achieved from significant greenhouse gas sources via regulations, market mechanisms and other actions.
- Adopt regulations by January 1, 2011 to achieve the maximum technologically feasible and cost-effective reductions in greenhouse gas, including provisions for using both market mechanisms and alternative compliance mechanisms.
- Convene an Environmental Justice Advisory Committee and an Economic and Technology Advancement Advisory Committee to advise CARB.
- Ensure public notice and opportunity for comment for all CARB actions.

- Prior to imposing any mandates or authorizing market mechanisms, CARB must evaluate several factors, including but not limited to impacts on California's economy, the environment and public health; equity between regulated entities; electricity reliability, conformance with other environmental laws and ensure that the rules do not disproportionately impact low-income communities.

In September, 2008, Governor Schwarzenegger signed Senate Bill 375, which builds on AB32 by requiring the CARB to develop regional greenhouse gas emission reduction targets to be achieved from the automobile and light truck sectors for 2020 and 2035. Both AB32 and Senate Bill 375 focus on reducing greenhouse gas emissions, as opposed to predicting or mitigating climate change impacts in California.

AB 32 Scoping Plan

The AB 32 Scoping Plan contains the main strategies California will use to reduce the greenhouse gases (GHG) that cause climate change. The Scoping Plan has a range of GHG reduction actions which include direct regulations, alternative compliance mechanisms, monetary and non-monetary incentives, voluntary actions, market-based mechanisms such as a cap-and-trade system, and an administrative fee to fund the program. The AB 32 Scoping Plan was approved at the Air Resources Board hearing on December 11, 2008.

Six greenhouse gas emission reduction measures are proposed for the Water sector in the Scoping Plan. They address water use efficiency, water recycling, water system energy efficiency, reuse of urban runoff, increased renewable energy production and public goods charges for funding investments that improve water and energy efficiency (CARB, 2008).

California Environmental Quality Act

The California Governor's Office of Planning and Research is expected to certify and adopt amendments to the CEQA Guidelines which incorporate analyses and mitigation of Greenhouse Gas Emissions (GHG) on or before January 1, 2010 (CA Governor's Office, 2008). In the interim, the Office of Planning and Research has created a technical advisory which includes the recommended approach for incorporating climate change impacts to the CEQA process. The recommended approach includes recommendations for approaches to identifying project GHG emissions, determining significance, and mitigating the impacts.

California Adaptation Strategy

In November, 2008, Governor Schwarzenegger signed Executive Order S-13-08 (EO), which calls for the development of California's first statewide climate change adaptation strategy to assess the state's expected climate change impacts, vulnerabilities, and recommend climate adaptation policies, to be completed by 2009. This is the first legislative action to initiate active planning for the impacts of global warming in the state of California. In addition to the climate change adaptation strategy, the EO also requests that the National Academy of Science establishes an expert panel to report on sea level rise impacts in California, issues interim guidance to state agencies for how to plan for sea level rise in designated coastal and floodplain areas for new projects, and initiates a report on critical infrastructure (planned and existing) vulnerable to sea level rise. In the interim, all state agencies planning construction projects are directed to consider a range of sea level rise scenarios for the years 2050 and 2100 in order to assess project vulnerability and, to the extent feasible, reduce expected risks and increase resiliency to sea level rise (CA Governor Press Release, 2008).

California Water Plan

Following the passage of AB 32 in 2006 which called for a reduction in greenhouse gas emissions, DWR voluntarily joined the California Climate Action Registry. DWR addresses climate change in its California Water Plan, updated every five years, that provides a framework for water managers, legislators, and the public to consider options and make decisions regarding California's water future. In July, 2008, DWR published a technical memorandum report on the progress of incorporating climate change into the management of California's water resources. The focus of this report was the impact of global warming to California's water supply, although increased flood risks were presented in brief. In October 2008, the Department released a climate change white paper that proposes a series of adaptation strategies for state and local water managers to improve their capacity to handle change. On a regional level these strategies include integrated water management and increased water use efficiency.

<u>Local</u>

City of Alameda

The City of Alameda completed a Local Action Plan for Climate Protection in February 2008. This Plan identified initiatives to reduce City-wide greenhouse gas emissions by 25% of the 2005 levels by 2020. Initiatives are divided into four categories: transportation and land use, energy, waste and recycled, and community outreach and

education. Initiatives that are particularly relevant to new or re-development include (City of Alameda, 2008):

- Requirement that all new major developments' short and long-term transportation emissions impacts are reduced by 10%;
- Require that all recommended City Council actions include an analysis or evaluation of whether the action supports or is consisten with Alameda's Local Action Plan Initiatives and futhers progress toward the Greenhouse Gases Reduction Target;
- Ammend the Alameda Municipal Code to include sustainable design and green building standards for all new, substaintially expanded, and remodeled buildings; and
- Develop a wood-burning prohibition ordiancne to reduce air pollution for new residential construction.

East Bay Municipal Utility District

The East Bay Municipal Utility District (EBMUD) provides domestic water to the City of Alameda. EBMUD's primary source of water is the Mokelumne River watershed, which is fed by snowpack in the Sierra Mountains. In addition to the current drought, climate change is expected to decrease snow pack, and thus snow melt and water supply, in coming years. In 2008, EBMUD incorporated climate change into its strategic plan, and is currently pursuing water conservation, water recycling, and seeking out additional water sources for future use (Wallis, 2008). The City of Alameda already has several water conservation programs, but additional reductions may eventually be required by EBMUD to address decreasing water supply as a result of climate change.

San Francisco Bay Conservation and Development District

The San Francisco Bay Conservation and Development District (BCDC) is a state agency created in 1965 to regulate development in the Bay and along its shoreline for the purpose of limiting and controlling the amount of fill placed in the Bay. In October 2007 BCDC released an eight year regional strategy for controlling greenhouse gases and preparing for the impacts of sea level rise of San Francisco Bay. BCDC does not have the authority or responsibility to initiate many of the identified strategies. In September 2008 BCDC released a revised strategy which considers the regulatory limitations of the agency.

In May 2009, BCDC submitted preliminary recommendations for amendments to the Bay Plan to incorporate climate change. This proposal adopts sea level rise estimates of 16

inches (1.3 feet) by 2050 and 55 inches (4.6 feet) by 2100. Proposed changes to the Bay Plan which may be relevant to the City include the following (Travis, 2009):

- "Addressing the impacts of sea level rise and shoreline flooding may require large-scale flood protection projects, including some that extend across jurisdictional or property boundary. Coordination with adjacent property owners or jurisdictions to create contiguous, effective shoreline protection is critical when planning and constructing flood protection projects. Failure to coordinate may result in inadequate shoreline protection (e.g., a protection system with gaps or one that causes accelerated erosion in adjacent areas)"

- "New shoreline protection projects and the maintenance or reconstruction of existing projects should be authorized if: (a) the project is necessary to proect the shoreline from erosion or to protect shoreline development from flooding; (b) the type of the protective structure is appropriate for the project site, the uses to be protected, and the erosion and flooding conditions at the site, (c) the project is properly engineering to provide erosion control and flood protection for the expected life of the project based on a 100-year flood event that takes future sea level rise into account; (d) the project is properly designed and constructed to prevent signiciant impediments to physical and visual public access; and (e) the protection is integraded with adjacent shoreline protection measures."

- "…the Commission should…encourage new projects on the shoreline to be set back from the edge of the shore above a 100-year flood level that takes future sea level rise into account for the expected life of the project, or otherwise be specifically designed to tolerate sea level rise and stroms and to minimize environmental impacts; discourage new projects that will require new structureal shoreline protection during the expected life of the projects, especially where no shoreline protection currently exits [*sic*]; determine whether alternative measures that would involve less fill or impacts to the Bay are feasible; require an assessment of risks from a 100-year flood that takes future sea level rise into account for the expected life of the project; and require that where shoreline protection is necessary, ecosystem impacts are minimized.".

- "The Commission may approve fill that is needed to provide flood protection for existing projects. New projects on fill or near the shoreline should either be set back from the edge of the shore so that the project will not be subject to dynamic wave energy, be built so the bottom floor level of structures will be above a 100-year flood elevation that takes future sea level rise into account for the expected life of the project, be specifically designed to tolerate periodic flooding, or employ other effective means of addressing the impacts of future sea level rise and storm activity. Right-of-way for levees or other structures protecting inland areas from tidal flooding should be sufficiently wide on the upland side to allow for future levee widening to support additional levee height so that no fill for levee widening is placed in the Bay."

- "Design and evaluation (of any ecosystem restoration project) should include an analysis of: (a) how the system's adaptive capacity can be enhanced so that it is resilient to sea level rise an climate change…(h) an appropriate buffer, where feasible, between shoreline development and habitats to protect wildlife and provide space for marsh migration as sea level rises…".

- "Public access should be sited, designed, managed, and maintained to avoid significant adverse impacts from sea level rise and shoreline flooding."

These changes, if approved, may have significant impacts on the City's approach to development, planning, and design of both flood control projects and new or re-development within portions of the City.

Other Storm Drain Master Plan Updates

During the preparation of this report, the Northside (Marina Village) pump station experienced failure during an approximately 10-year storm event. The impact to the City's storm drainage system operation during the storm due to this failure was significant. The Northside (Marina Village) pump station is connected via storm drains to the Arbor pump station. In the SDMP, standby power is identified as high priority improvements for both the Arbor and Northside (Marina Village) pump stations. Capacity improvements are also recommended at the Arbor pump station. In addition, the operation of the Main Island lagoon system has experienced elevation water levels during storm events.

Due to the recent pump station failure and its consequences, the Northside (Marina Village) pump station is currently a high priority storm drain pump station for potential improvement. The pump stations' generators, panels, pumps, motors and layout need to be optimized to provide the highest level of service possible. It may be feasible that increasing the capacity of the Northside (Marina Village) pump station while this work occurs would reduce or remove the need for increased capacity at Arbor pump station. A more detailed analysis of how this connected system operates and whether improvements at Northside (Marina Village) may offset recommended improvements at Arbor pump station is needed. Additional analysis and eventual improvements of the Main Island Lagoon system are also needed.

Summary

As an island community, the City of Alameda is uniquely exposed to climate change impacts to the San Francisco Bay region, particularly rising sea levels. Rising sea levels may impact the City via both inundation of City lands by higher mean sea levels and tide cycles, and also may impact the capacity and operation of its storm drain system. At this

time, structural projects to mitigate inundation from surrounding waters, such as floodwalls, levees, elevating structures, etc. are not recommended due to the inherent uncertainty and long time scale of sea level rise projections. If structural solutions are sought in the long term, coordination with the Oakland Airport adjacent to Bay Farm Island will be essential to protect that portion of the City.

Projects have been identified to maintain a 10-year level of service for the storm drain network in the event of 18" of sea level rise. Many of these storm drain system improvements are increased pipe diameters in areas already identified for capacity improvements in the SDMP. The impact to the SDMP CIP is $2,700,000. The majority of the additional required improvements are on the Main Island, and of those, the majority are located in the South and Eastside areas. Given the relatively low cost to install a slightly larger pipe if a pipe replacement project is already planned, Schaaf & Wheeler recommends using the pipe sizes herein for pipe replacement projects undertaken in the future. Replacing pipes for the sole purpose of meeting the sea level rise scenario 10-year level of service should be considered low priority.

Regulations regarding climate change are currently in a state of rapid development and fluctuation. At this time, the most significant existing regulations potentially affecting the City are those contained in the City Local Action Plan. Based on our findings, Schaaf & Wheeler concludes that it is likely that significant development of the former naval base in the future will be required to study and mitigate for not only greenhouse gas emissions, but also future sea level rise scenarios.

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Appendix A: Detailed Cost Calculations

Model Pipe ID	Recommended Diameter (ft)	Recommended Diameter (in)	Manholes	Length (feet)	SDMP Improvement Diameter (in)	NEW COST	OLD COST	Actual Increased Cost
Main Island Eastside						**$687,000**	**$179,000**	**$508,000**
SL141	1.25	15	1	75		$17,324	-	
SL142	1.50	18	1	166		$30,263	-	
SL146	1.75	21	2	206		$49,165	-	
SL195	1.75	21	1	225		$42,823	-	
SL2_2	1.75	21	1	48		$16,395	-	
SL206	1.75	21	1	60		$18,095	-	
SL207	2.00	24	2	172		$48,181	-	
SL275	1.50	18	2	133		$35,018	-	
SL280	1.50	18	2	134		$35,143	-	
SL300	2.50	30	1	126		$36,996	-	
SL325	2.50	30	1	67		$24,126	-	
SL97	1.50	18	2	72		$27,313	-	
SLIMP_104	2.75	33	1	41	21	$19,797	$15,369	
SLIMP_105	2.75	33	2	31		$27,152	-	
SLIMP10_44	3.50	42	1	237	36	$81,345	$73,267	
SLIMP10_49	4.00	48	2	234	42	$99,696	$90,781	
SLIMP10_50	3.50	42	1	96		$38,957	-	
SLIMP10_51	3.50	42	1	15		$14,794	-	
SLIMP10_52	3.50	42	2	13		$24,565	-	

Note: Above Costs do not include 40% Contingency Applied to Summary Table in Report Text

Model Pipe ID	Recommended Diameter (ft)	Recommended Diameter (in)	Manholes	Length (feet)	SDMP Improvement Diameter (in)	NEW COST	OLD COST	Actual Increased Cost
Main Island North Central						**$407,000**	**$271,000**	**$136,000**
SLimp03l1	3.0	36	2	319		$105,049	-	
SLimp184	2.0	24	2	55	18	$28,064	$25,058	
SLimp230	2.0	24	1	159	18	$36,566	$29,350	
SLimp232	2.0	24	1	18	18	$12,416	$11,322	
SLimp276	3.5	42	1	78	36	$33,828	$30,924	
SLimp279	3.5	42	2	245	36	$93,976	$85,302	
SLimp430	3.5	42	1	108	36	$42,660	$38,794	
SLimp431	3.5	42	2	113	36	$54,634	$50,243	

Note: Above Costs do not include 40% Contingency Applied to Summary Table in Report Text

Model Pipe ID	Recommended Diameter (ft)	Recommended Diameter (in)	Manholes	Length (feet)	SDMP Improvement Diameter (in)	NEW COST	OLD COST	Actual Increased Cost
Main Island South						**$1,586,000**	**$1,165,000**	**$421,000**
SLimp449l1	2.75	33	2	399		$116,008	-	
SLimp178	3.00	36	1	28	30	$17,579	$15,800	
SLimp178_1	3.50	42	2	103	33	$51,582	$44,526	
SLimp178_2	3.00	36	1	21	24	$15,653	$12,978	
SLimp220	1.75	21	2	79	18	$30,218	$28,199	
SLimp223	1.75	21	1	81	18	$21,263	$19,368	
SLimp224	2.50	30	1	47	24	$19,843	$17,423	
SLimp376l1	4.00	48	2	233	42	$99,429	$90,542	
SLimp378l1	4.00	48	2	84	42	$49,583	$45,914	
SLimp379l1	4.00	48	1	142	42	$58,368	$53,018	
SLimp408l3	5.50	66	2	256	60	$128,660	$128,660	
SLimp415l2	5.50	66	1	235	60	$108,573	$108,573	
SLimp425l1	5.50	66	1	236	60	$108,931	$108,931	
SLimp426l1	5.50	66	1	55	60	$34,214	$34,214	
SLimp427l1	5.50	66	1	132	60	$66,129	$66,129	
SLimp99	3.00	36	2	476	24	$147,034	$100,315	
SLimpF06-511l1	3.00	36	1	91	30	$34,333	$29,370	
SLimpF06-512l1	3.00	36	1	487	30	$140,026	$114,976	
SLimpF06-612l1	2.75	33	1	234	30	$66,233	$60,226	
SLimpF06-615l1	3.00	36	1	198	33	$62,813	$57,545	
SLimpF06-619l1	3.00	36	1	84	30	$32,482	$27,870	
SLintake3l1	2.50	30	1	55		$21,494	-	
SLintakel1	2.50	30	1	673		$155,192	-	

Note: Above Costs do not include 40% Contingency Applied to Summary Table in Report Text

Model Pipe ID	Recommended Diameter (ft)	Recommended Diameter (in)	Manholes	Length (feet)	SDMP Improvement Diameter (in)	NEW COST	OLD COST	Actual Increased Cost
Main Island Northside						**$375,000**	**$208,000**	**$167,000**
SLD381EC0A14C702DA	1.50	18	1	39		$14,026	-	
SLD381EC0A14C702F2	1.50	18	1	95		$21,162	-	
SLD381EC0A14C71C52	2.50	30	2	21		$23,817	-	
SLD381EC0A14C71C5B	2.50	30	1	324		$79,735	-	
SLimpD381EC0A14C70200	3.50	42	2	188	36	$76,902	$70,086	
SLimpD381EC0A14C702A3	2.75	32	2	134	27	$48,214	$44,901	
SLimpD381EC0A14C7173B	2.50	30	1	295	24	$73,497	$59,986	
SLimpE05-111l1	2.50	30	2	85	24	$37,712	$33,280	
Bay Farm Island North						**$232,000**	**$0**	**$232,000**
SL176	1.50	18	2	248		$49,866	-	
SL208	1.50	18	1	204		$35,108	-	
SL32	1.25	15	2	108		$29,766	-	
SL48	3.00	36	1	139		$47,043	-	
SL53	2.00	24	2	66		$29,958	-	
SL79	1.50	18	2	171		$39,931	-	

Note: Above Costs do not include 40% Contingency Applied to Summary Table in Report Text

Model Pipe ID	Recommended Diameter (ft)	Recommended Diameter (in)	Manholes	Length (feet)	SDMP Improvement Diameter (in)	NEW COST	OLD COST	Actual Increased Cost
Bay Farm Island Central						**$541,000**	**$154,000**	**$387,000**
SL105	1.50	18	1	94		$21,118	-	
SL166	1.75	21	1	37		$14,674	-	
SL167	1.75	21	2	44		$24,936	-	
SL176	1.50	18	2	72		$27,278	-	
SL241	1.50	18	2	323		$59,394	-	
SL242	1.50	18	1	216		$36,739	-	
SL290	1.25	15	1	56		$15,110	-	
SL291	1.50	18	2	94		$30,059	-	
SL420	1.50	18	2	219		$46,069	-	
SL620	1.25	15	2	275		$49,156	-	
SL621	1.25	15	1	69		$16,697	-	
SL623	1.25	15	1	67		$16,401	-	
SLimp106	2.00	24	1	303	18	$61,315	$47,825	
SLimp93	2.75	33	2	130	30	$50,886	$47,316	
SLimps53	2.00	24	2	151	18	$44,577	$37,384	
SLimps57	2.00	24	1	100	18	$26,463	$21,809	
Bay Farm Island South						**$50,000**	**$0**	**$50,000**
SL25	2.00	24	2	185		$50,424	$0	

Note: Above Costs do not include 40% Contingency Applied to Summary Table in Report Text