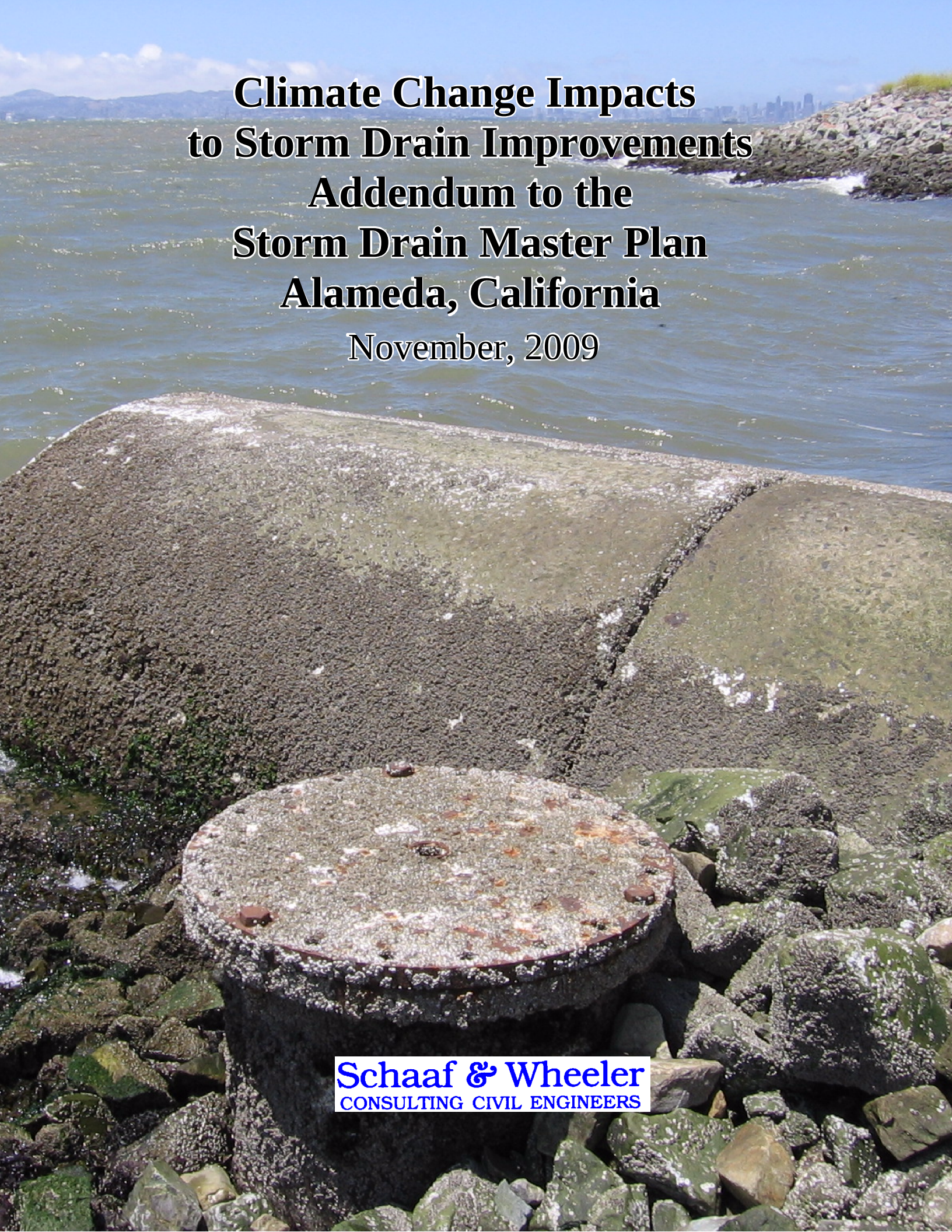

Climate Change Impacts to Storm Drain Improvements Addendum to the Storm Drain Master Plan Alameda, California

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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’