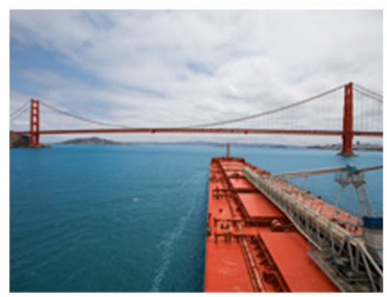
PROJECT REPORT COMPILATION

Sea Level Rise and Adaptation Study



Prepared for

Port of San Francisco
Pier 1
San Francisco, CA

June 2012

URS — Joint Venture — AGS, Inc.

SEA LEVEL RISE AND ADAPTATION STUDY

PROJECT REPORT COMPILATION

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Prepared for

Port of San Francisco
Pier 1, The Embarcadero
San Francisco, CA

June 29, 2012

URS/AGS Joint Venture

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TECHNICAL MEMORANDUM

SEA LEVEL RISE ANALYSIS

Prepared for

Port of San Francisco
Pier 1
San Francisco, CA

March 2011

URS/AGS Joint Venture

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The Port of San Francisco (Port) is responsible for the care and maintenance of 7.5 miles of San Francisco Bay shoreline under the California Tideland Trust. The shoreline is highly urbanized and developed into tourist, commercial and marine services. Numerous studies indicate that sea level rise (SLR) over the next 50 to 100 years could be sufficient to adversely impact activities on the waterfront and possibly result in the inundation and or damage to existing and planned infrastructure. A U.C. Berkeley study on climate change estimates that several hundred billion dollars of real assets associated with California's statewide port infrastructure will become vulnerable to significant damage from sea water flooding and increased wave action (Roland-Holst et al, 2008). To prevent this damage, the Port and/or its lessees may need to implement measures to adapt to these effects.

The goal of this project is to provide a range of possible future SLR scenarios that could be realized along the 7.5 miles of San Francisco Bay shoreline managed by the Port. The results of the study will provide guidance to the Port, Port tenants and potential developers that can be used for project-specific and long term planning of port development. This assessment relies primarily on the global SLR scenario projections developed by Vermeer and Rahmstorf (2009) as shown in the Table below, since these represent the latest scientific developments and are also the ones being adopted as SLR guidance by the State of California.

Range of Model SLR Outputs
(Vermeer and Rahmstorf, 2009)

Year	cm	in
2050	26 - 43	10 - 17
2100	78 - 176	31 - 69

These SLR scenarios represent global averages, which are assumed to apply to the Pacific Ocean and in turn to the San Francisco Bay and Port. The SLR results of this study will also be used in a subsequent URS report to evaluate shoreline inundation impacts at the Port in 2050 and 2100. The SLR results of this study will also be used in a subsequent URS report identifying adaptation options and associated costs for measures that can be implemented along the shoreline to protect shore-side assets.

By studying the latest and best available projections for California and identifying potential adaptation measures, the Port is taking steps to build a basis for making long term decisions that take climate change, and more specifically SLR into account.

For this Technical Memorandum, URS reviewed available historical data and the research literature regarding possible future SLR scenarios for two periods: 2000 - 2050; and 2000 - 2100. The selection of a base year is arbitrary, with most studies assuming 1990 or 2000. 2000 was selected as a base year in this report to align with newly adopted State of California sea level rise guidance.

Global climate warming projections, and by extension SLR, are derived from computer modeling that is based mainly upon selection of alternative future global carbon dioxide emission levels and other factors driving changes in global climate (IPCC, 2007). A detailed description of the scientific basis for projected SLR is provided in Section 2 and Appendix A (see Figures 1 and 2). URS selected several of the available SLR projections, including those corresponding to the A1Fi, A2, and B1 emissions scenarios.

For the San Francisco Bay, key results from this study are the following:

1. Between 2000 and 2050, SLR is expected to rise between 10-17 inches (26-43 cm).
2. Between 2000 and 2100, SLR is expected to rise between 31-69 inches (78-176 cm).

This technical memorandum is not intended to be an independent, in-depth scientific analysis of all aspects of SLR. Significant additional time and resources would be required for such a level of analysis. URS did, however, review and include a synthesis of existing sources of scientific information and policy, and significant new studies and analyses in progress.

The Port of San Francisco (Port) is responsible for the care and maintenance of 7.5 miles of San Francisco Bay shoreline under the California Tideland Trust. The shoreline is highly urbanized and developed into tourist, commercial and marine services operated by lessees and the Port. Numerous studies have indicated that sea level rise (SLR) over the next 50 to 100 years could be sufficient to adversely impact activities on the waterfront and possibly result in the inundation and or damage to existing infrastructure. For example, a UC Berkeley study on climate change estimates that several hundred billion dollars of real assets associated with California's state-wide port infrastructure will become vulnerable to significant damage from sea water flooding and increased wave action during this century (Roland-Holst et al, 2008). To prevent the loss of use, the Port and/or its lessees may need to implement measures to adapt to or if possible reduce the impacts from these effects.

1.1 PURPOSE AND SCOPE

The goal of this study is to provide the Port with an estimate of SLR as it relates to the 7.5 miles of San Francisco Bay shoreline. SLR estimates are provided for two periods:

1. From 2000 through 2050 and
2. From 2000 through 2100.

URS reviewed available historical and research data, literature, policies and studies and provides this technical memorandum discussing our SLR findings and parameters that will become the basis for the coastal inundation study that URS is conducting for the Port.

1.2 REPORT ORGANIZATION

This section presents the Introduction. Section 2 describes the scientific basis that influence SLR in the San Francisco Bay. URS reviewed the most relevant, peer reviewed literature on climate change models, scenarios, effects, and potential impacts applicable to the San Francisco Bay Area in general and the Port in particular. Section 3 describes the SLR policies that either apply to the Port or that may influence future requirements applicable to the Port. Section 4 summarizes the key results of the study and presents URS' recommendations. References for the study are listed in Section 5, followed by the appendices, which contain a description of key SLR policies that may affect the Port and selected documents from the policy and scientific literature.

1.3 APPROACH

In conducting this study, the following approach was used:

- Review scientific literature to compare and contrast different SLR projections, including methods used to project future levels.
- Review SLR policy documents to identify current policies compare and contrast different SLR projections and to understand the scientific basis underlying each policy.
- Summarize the results that appear to have the strongest support within the scientific and policy documents for SLR through the years 2050 and 2100.

URS reviewed historical data and synthesized SLR results from relevant technical and policy literature and studies of the San Francisco Bay region. Numerous studies were performed to project SLR on the global scale and more specifically in North America. The State of California has invested substantially in conducting research into potential SLR effects along the California Coast. In this project, existing studies that project SLR were selected and reviewed based upon their citation in prior adaptation studies and their use of accepted scenarios for predicting future greenhouse gas (GHG) emissions. These studies were authored by multiple agencies of the State of California, the U.S. government, and the Intergovernmental Panel on Climate Change (IPCC). The studies relied upon for this Technical Memorandum draw upon the hundreds of individual scientific studies cited in peer reviewed technical literature.

1.4 LIMITATIONS

Near term SLR projections in 2050 are in a relatively tight cluster of results. However, substantial uncertainty exists in SLR projections for 2100.

This section provides a detailed overview of the science that affects SLR in the San Francisco Bay. Historical trends in SLR at the global and local levels are summarized. This section also reviews, compares and contrasts different SLR projections found in the scientific literature.

2.1 OVERVIEW

Mean sea level has varied considerably over glacial time scales as the extent of ice caps and glaciers have fluctuated with global temperatures. Sea levels rose around 130 m since the last glacial maximum 20,000-25,000 years ago and reached a level close to present at least 6000 years ago (Lambeck et al., 2010). Woodworth et al. (2011) use tide gauge records dating back to the eighteenth century, and saltwater marsh data, to show that SLR has accelerated over this time frame.

This section presents general information related to SLR globally and locally. First, it covers the relationships between atmospheric concentrations of carbon dioxide, temperature trends and SLR along with observed/measured trends over the past 60 to 150 years. Section 2.2 explains why SLR can vary temporally and spatially. An overview of SLR projection methods and results is provided in Section 2.3 and observed/historical SLR is summarized in Section 2.5. This section concludes with a summary of potential modeling improvements.

Atmospheric Concentrations of Carbon Dioxide

Global climate is expected to continue warming due to emissions of greenhouse gases (GHG, chiefly carbon dioxide CO_2) that alter the radiation balance of the earth's atmosphere. Atmospheric GHG absorb heat from the sun and re-radiate that heat into the atmosphere at shorter wavelengths. This creates a natural "greenhouse effect". Figure 2-1 shows the monthly atmospheric CO_2 concentrations from Mauna Loa, HI (Keeling, 1960; Keeling and Whorf, 2005) beginning in 1958. This is the longest, most precise, and reliable record of CO_2 in existence and roughly represents average conditions in the northern hemisphere. The graph has become known as the "Keeling Curve." As of late-2010, atmospheric CO_2 concentrations stand at about 390 parts per million (ppm), which represents an increase of about 45% over the mid-nineteenth century, pre-industrial revolution values of 260-280 ppm. The annual cycle of about 5 ppm superimposed on the upward trend evident in Figure 2.1 is due to the seasonal plant growth and decay cycle that alternately removes and returns CO_2 from and to the air.

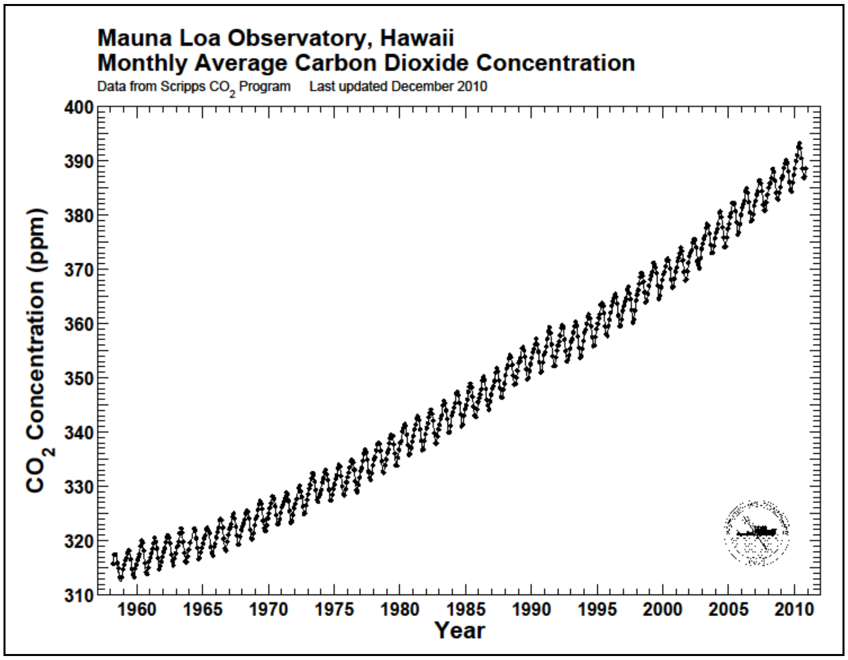

Figure 2-1 Atmospheric CO_2 concentration from 1958-2010 (Source: Scripps Institution of Oceanography, 2011).

Temperature Trends

These anthropogenic GHG contributions have intensified the greenhouse effect and have led to a gradual global warming of about 0.8°C during the twentieth century, as shown in Figure 2-2. The rapid rate of increase in CO_2 concentration is unprecedented in the past 55 million years (Cohen *et al*., 2007). As the earth's surface warms, land-bound ice in glaciers and the northern and southern ice caps (mainly Greenland and Antarctica) melts and the water flows into the ocean raising sea level. Warming also tends to cause the ocean volume to expand, which also raises sea level.

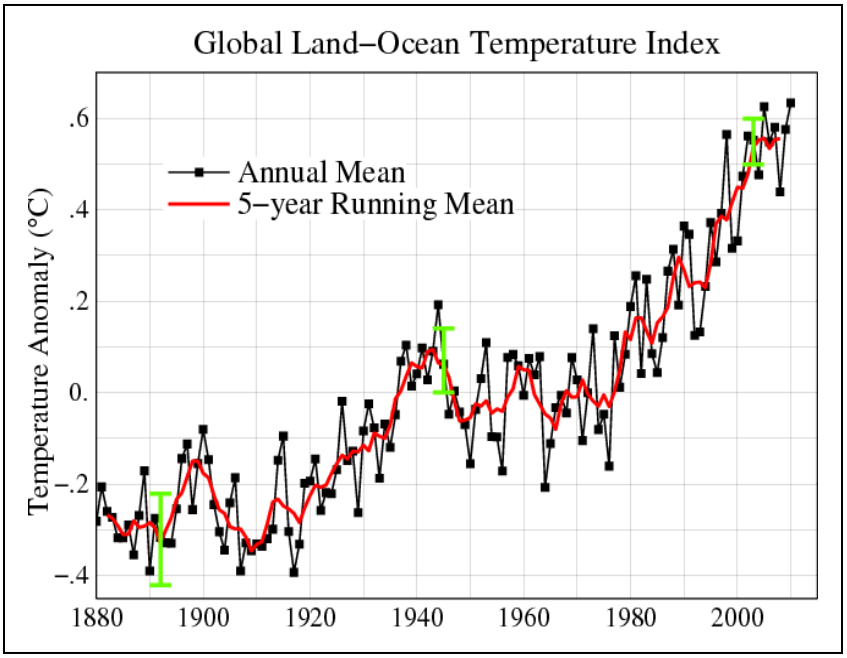

Figure 2-2 Global mean surface temperature from 1880-2010 relative to 1951-1980 base period indicates a warming of about 0.8°C (Source: NASA Goddard Institute for Space Studies, 2011).

Sea Level Measurements

A consensus report by the International Panel on Climate Change (IPCC AR4, 2007) reported there was *high confidence* that the rate of observed SLR increased from the nineteenth to the twentieth century (Bindoff et al., 2007). It also reported that the global mean sea level rose at an average rate of 0.17 [0.12 to 0.22] mm per year over the twentieth century, 1.8 [1.3 to 2.3] mm per year over 1961 to 2003 and at a rate of 3.1 [2.4 to 3.8] mm per year over 1993 to 2003. Whether the faster rate of increase during the latter period reflected decadal variability or an increase in the longer term trend is not known.

However, there is increasing evidence that the contribution to sea level due to mass loss from Greenland and Antarctica is accelerating (Velicogna, 2009). Over the twentieth century, melting and thermal expansion contributed about equally to the 15-20 cm observed rise in global sea level (IPCC AR4, 2007, Chapter 5). Variations in the rate of SLR will occur as a result of variations in heat content in the ocean, which lead to different rates of thermal expansion (e.g., Bindoff et al., 2007; Church et al., 2010; Timmermann et al., 2010).

For the area of concern in this project, Figure 2-3 shows the annual sea level measurements from 1855-2010 for San Francisco Bay, which is the longest continuous tide gauge record in North America. The record clearly shows a SLR of about 20 cm over the twentieth century, in line with global estimates. Other important features of the San Francisco Bay record are discussed in subsequent sections.

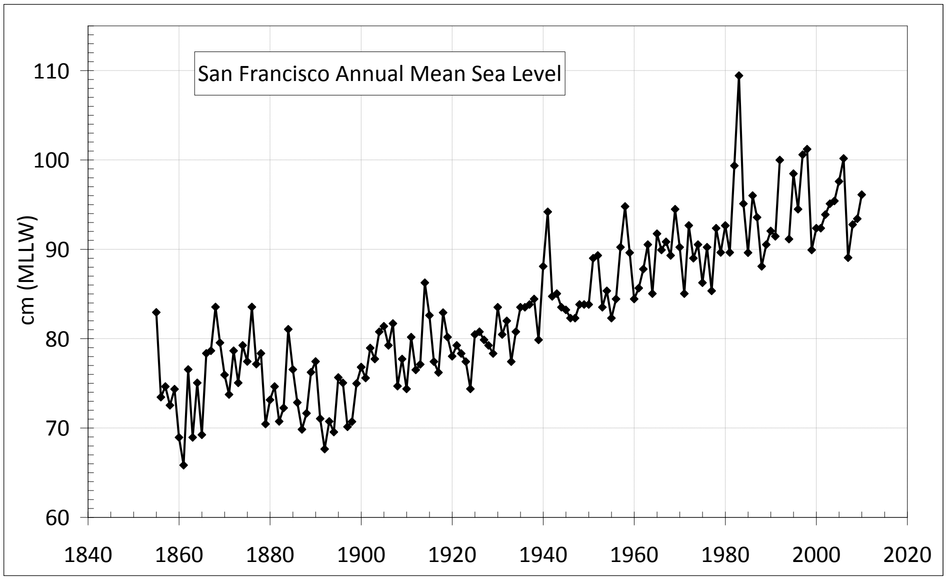

Figure 2-3 Annual average sea levels measured at the San Francisco tide gauge station at Fort Point (1856-2010). (Data from NOAA/NOS compiled by URS, 2011).

2.2 SEA LEVEL FLUCTUATIONS

This section briefly explains the effect of periodic ice ages has on global sea levels over long periods of time. Based upon ice core samples and other paleoclimate data, alternate warming and cooling of the earth by about 4-8°C over at least the past 2.6 million years has been paced by subtle changes in the amount of sunlight that reaches the northern latitudes due to slow variations in the earth's orbit around the sun (Milankovitch, 1920). The "Milankovitch" cycles have characteristic periods of about 21,000, 41,000, and 100,000 years. Once a natural Milankovitch cycle of warming begins, ice starts to melt and the oceans begin to warm. This triggers strong positive-feedback processes including lower albedo, since blue water and brown earth reflect less sunlight back to space than white snow and ice, and release of stored GHG including methane and carbon dioxide from the tundra, upper-ocean, and continental shelves. In addition, more water vapor, another powerful GHG, moves into the atmosphere from increased ocean evaporation. The lower albedo and higher GHG thus reinforce the warming, which continues until a cooling phase is triggered by the Milankovitch cycle and positive feedbacks are activated in the other direction (towards cooling).

These processes explain the earth's periodic warming and cooling and the associated glacial advances and retreats, and ups and downs in sea level. For example, during the last inter-glacial period over the past 20-25,000 years, the polar regions warmed about 8°C as the ice caps melted and retreated, CO_2 concentration rose from 180 to 270 ppm, and global sea level rose about 130 m (425 ft.). A few inter-glacial periods in the past several hundred thousand years have been a few degrees C warmer than current conditions. One of these, about 120,000 years ago, also produced sea level that was up to about 8 m (26 ft.) higher than it is today.

The Milankovitch cycles are important because they demonstrate that even without human influence, sea level fluctuations can be (and have been) much higher than they are today. This is one of the main reasons for concern about future climate change, especially a human-induced "super-interglacial" warming: That the unprecedented recent increase in atmospheric GHG concentrations will trigger a warming of 1-6°C and the associated ice cap melting and SLR that goes with it. We are close to the peak in the Milankovitch cycle. A major element of the work by the Intergovernmental Panel on Climate Change (IPCC) and hundreds of independent studies by scientists and engineers all over the world is to determine what future increases in global temperature and related sea levels may be expected as a result of both past and various future increases in atmospheric CO_2 concentrations. Past emissions matter both because CO_2 is long-lived in the atmosphere (unlike many other GHG), and there is inertia in the response of the climate system due to the large thermal mass of the ocean.

Thus, the Milankovitch cycles have clearly influenced the paleoclimate record. Paleoclimate studies are increasingly producing coupled temperature and sea level rise data over shorter periods of time (i.e., centuries). However, paleoclimate data have not significantly influenced consensus sea level rise projections at the national and international levels. Paleoclimate data did not substantially influence the scientific review involved in developing this memo. The results of further paleoclimate studies may begin to cast more influence on SLR modeling design and results.

2.3 PROJECTED MEAN SEA LEVEL RISE

Because projections of climate change depend heavily upon future human activity, climate models are run against scenarios that are defined in the Special Report on Emissions Scenarios developed by the Intergovernmental Panel on Climate Change (IPCC). The IPCC scenarios are used widely as a basis for medium and long term projections. The most recent IPCC (2007) Fourth Assessment Report (AR4) considered six scenarios with varying ranges of projected increases of CO_2 levels and the resulting increase in global atmospheric temperatures as predicted by a suite of global circulation (computer) models (GCMs). The GCMs use projected CO_2 concentration time series "scenarios" and calculate a set of atmospheric and oceanic responses, including warming and sea level. However, based upon model runs in "hindcast" mode, that is, output from runs using past conditions that are then compared with the known results, GCMs do a robust job of predicting temperature changes, but are not as reliable for predicting SLR. The AR4 range of global temperature increase is 1.1-6.4°C (2.0-11.5°F) by 2100, with an average increase of 2.8°C (5.1°F).

The AR4 projections of future SLR range from 7-23 inches (18-59 cm) by 2100. However, the AR4 authors could not come to a "consensus" position on the range of possible SLR contributions from ice melting owing to the lack at that time of sufficient reliable peer-reviewed literature on the subject. For this reason, the AR4 "excludes future rapid dynamical changes in ice flow," which according to one recent study (Rahmstorf, 2010) makes the upper SLR limit of 59 cm by 2100 almost certainly too low, resulting in an underestimate of projected SLR. Most studies produced since AR4 have similarly found that 59 cm (23") is too low as an upper limit for SLR in 2100

Several studies since the AR4 have developed statistical models that relate twentieth century (e.g., Rahmstorf, 2007; Horton et al., 2008) or longer (e.g., Grinsted et al., 2009; Vermeer and Rahmstorf, 2009) temperature and SLR to extrapolate future global mean sea level. These alternative approaches yield projections of SLR by 2100 of 37-213 cm (Rahmstorf, 2007, Horton et al., 2008, Grinsted et al., 2009, Vermeer and Rahmstorf, 2009). However, as noted by Cazenave et al. (2010) future rates of SLR may be less closely associated with global mean temperature if ice sheet dynamics play a larger role in the future. Using glacier models, Pfeffer et al. (2008) found that SLR of more than 2 m by 2100 is physically implausible.

Results from these studies are depicted in Figure 2-4.

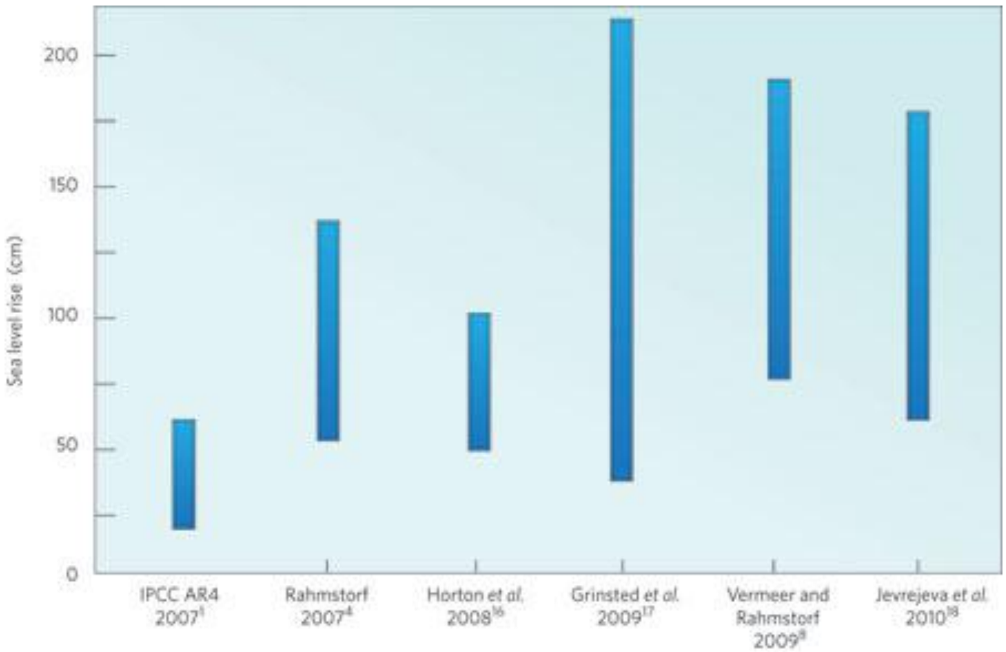

Figure 2-4. Results of IPCC and Post IPCC Sea Level Rise Projection Studies (Rahmstorf, 2010)

The range of projected SLR values found in the scientific literature has grown significantly larger since the IPCC AR4 report was released in 2007. In general, the low end of recent long term projections is near the high end of IPCC AR4 projections while the upper end of the range of recent long term projections has increased substantially.

Due to the wide range in projected future SLR, it is difficult to conclude which approach is best for projecting future SLR. However, senior level staff from 16 California state agencies worked collaboratively from July through October 2010 to develop and then issue an interim SLR guidance document. The agencies reached consensus on the scientific basis for the guidance document's SLR recommendations. The Guidance document is based on methods pioneered by Rahmstorf (2007) and states that its recommendations were "informed by the best available science." Further information on this guidance document is provided below in Section 3.

The Rahmstorf method uses the warming predicted by GCMs and calculates the associated future SLR based upon the observed historical relationship between warming and the rate of SLR. This method was used by Cayan *et al.* (2008, 2009), which helped initiate the recent State of California guidance on SLR, as well as by Vermeer and Rahmstorf (2009), upon which the state guidance document is now based. Additional work using the same approach has been done by Grinsted *et al.* (2009).

Using the Rahmstorf method in conjunction with three of the six IPCC scenarios that span the lowest to the highest future CO_2 emission levels (i.e., A1Fi, A2, and B1), the State of California now projects the sea level along California to rise from 2000 heights by 26-43 cm by 2050 and 78-176 cm by 2100 (Ocean Protection Council et al, 2010). These estimates of possible future

SLR are currently the best available for the planning purposes of the Port of San Francisco, since these estimates are cited in recent State of California agency climate impact assessments and policy documents. It is crucial to recognize that there are large uncertainties in these estimates, which are discussed in subsequent sections. Equally important is the fact that the probability of occurrence of any given future SLR scenario is not known and, even worse, probably not knowable. Notwithstanding the large uncertainties about future emissions of GHG and how and when the earth's climate will respond to increased atmospheric CO_2 concentrations, credible studies report that detectable changes are already underway.

There are two main sources of uncertainty about future climate: First, no one knows what humans will do in the future. Will humans continue with "business as usual" and consume ever greater amounts of fossil fuels for energy, or will we reduce our energy demand, increase efficiency, and turn to more sustainable and less carbon-intensive fuels? The answer is crucial to the trajectory of longer term atmospheric GHG concentrations, and therefore to the degree of future warming. Second, we do not precisely know the "climate sensitivity," which is the atmospheric temperature response to a given change in the radiative forcing associated with a change in GHG concentrations. This is because the physics and chemistry of the atmosphere and ocean are not understood well enough to develop completely reliable GCMs. Estimates range from 1.5° to 4°C warming with a "best-guess" of about 3°C for a doubling of CO_2 concentration in the atmosphere to about 540 ppm. This is the crux of the "climate debate" over global warming: What is the climate sensitivity? How rapidly and to what degree will the earth's systems respond to rising GHG emissions and atmospheric concentrations?

Other research estimates global mean sea levels as high as 2 m by 2100 (Grinsted, 2009; Pfeffer, 2009). Since the probability of a given future SLR cannot be quantified, and because there are so many scenarios for how the future may unfold, rigorous risk assessments also cannot be performed. However, the physics of global warming are beginning to be understood well enough and the dynamics of the ice caps are being studied at a furious pace, so that general statements can now be made, for example, about which outcomes are "more likely" or "highly unlikely" (Rahmstorf, 2010).

Currently, the consensus of scientific judgment suggests that the range of SLR projections across the A2, B1 and A1Fi scenarios is: 26-43 cm by 2050 and about 78-176 cm by 2100, relative to 2000 (e.g., Nicholls et al, 2011; Rahmstorf, 2010). This is consistent with the findings of Church and White (2006), which show an acceleration of SLR since the mid-1800s.

Beyond the consensus, a maximum SLR of about 60 cm by 2050 and 200 cm by 2100 has also been suggested (Pfeffer et al. 2008). In a draft paper by Hansen and Sato (2011), paleoclimate data is used to conclude that multi-meter sea level rise (i.e., 2 m or more) by 2100 is a certainty. Hansen and Sato assert with good evidence that polar ice melt rates doubled over a six year period since 2000 and that ongoing acceleration in melt rates would lead to sea level rise of 5 m in 2100. However, these values are at the upper-end of the published projections and can realistically only come to pass if the Greenland and/or the West Antarctic Ice Sheet begin a rapid collapse. This is possible, but not predicted to be likely in the next several centuries, at least for the West Antarctic Ice Sheet (Bamber, *et al*., 2009).

The Hansen and Sato paper is still a draft and undergoing peer review and therefore did not substantially influence the scientific review involved in developing this technical memo. However, this study is referenced, since first, it represents the upper limit of credible SLR projections over the next century, and second, it illustrates the uncertainty associated with how much and how fast ice cap melting can contribute to SLR. Finally, if such an extreme scenario were to come to pass, it would have catastrophic effects on the Port and almost all other coastal environments.

Figure 2-5 shows the ranges for 2050 and 2100 for the B1, A2, and A1FI global emission scenarios developed by the IPCC (AR4, 2007). This figure demonstrates that:

- The ranges before and including 2050 are more or less independent of the global emission scenarios.
- Even for the B1 scenario, which will require substantial decreases in greenhouse gas emissions at the global level, the sea level projections are higher than what the IPCC reported in 2007 in the Fourth Assessment Report (AR4).

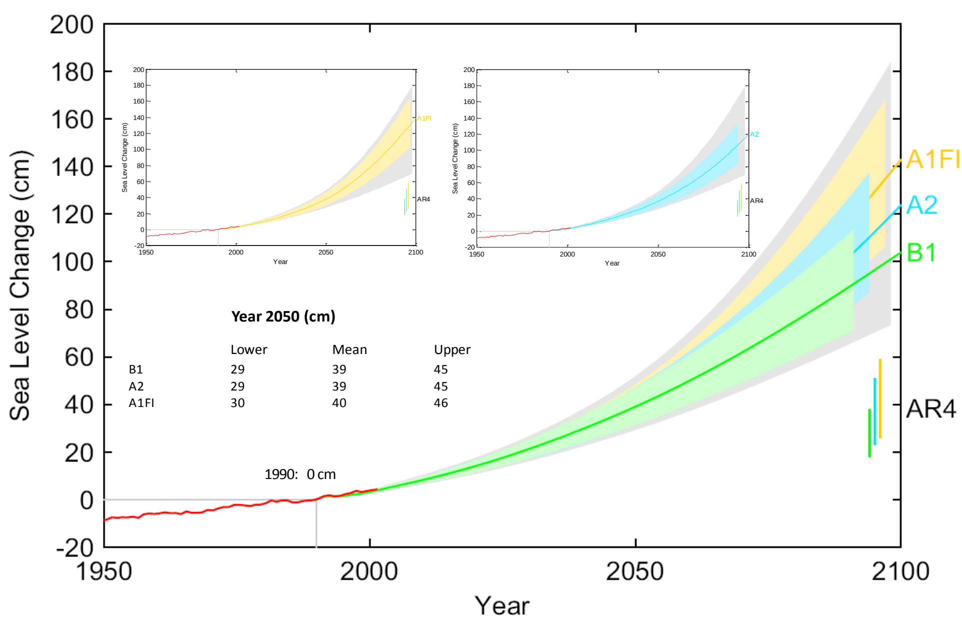

Figure 2-5 Projections of Sea Level Rise from 1990 to 2100
Using Rahmstorf Methods (California Ocean Protection Council, 2011)

Uncertainty ranges are expressed as one standard deviation (68 percent probability) shown as color bands above and below each respective mean curve in Figure 2-5. By comparison, the IPCC in AR4 projects a linear rise in sea level throughout the twenty-first century but many new studies now assume acceleration in SLR, consistent with observed SLR rates in the twentieth century.

Mean sea level is only part of the total sea level picture that will have to be considered for planning by the Port. In fact, over the next several decades SLR is not likely to be the most important factor in flooding and related damages. The same processes that cause flooding and damage in San Francisco Bay now will continue to do so in the future. These processes include:

- Waves from one of three sources – Entering from the ocean through the Golden Gate, generated in the bay by wind, or from ship and boat wakes;
- Peak high tides;
- Storm or wind-driven surges that temporarily raise water levels in the bay;
- Elevated sea levels in the local ocean that persist for months up to several years, such as those related to El Niño events;
- Changes in sea level related to large-scale conditions in the North Pacific that persist for up to several decades and that can suppress or enhance regional SLR rates.

Although much of the California coast south of Cape Mendocino is slowly being uplifted, the rates are too low to significantly mitigate the effects from SLR (Griggs et al, 2010).

The discussion of waves is beyond the scope of this technical memo, which is focused on processes related to the increase to mean sea level. Nevertheless, waves and wakes, especially when they occur during high tides and periods of enhanced sea levels, play an important part in coastal and facilities management in San Francisco Bay and should be considered by the Port. The tide characteristics in San Francisco Bay are considered below, with special emphasis on the conditions that lead to peak high tides. The tides cause the largest fluctuations in sea level besides those associated with the aforementioned glacial advances and retreat, and they have the additional advantage of being predictable for all practical purposes. Storm and wind surges are discussed briefly below, as are longer-term fluctuations in sea level associated with conditions in the Pacific Ocean.

2.4 OBSERVED SLR TRENDS BASED ON SATELLITE MEASUREMENTS

Satellite–based sensors have been making global sea level measurements since about 1992. AVISO Satellite radar altimetry sea level elevation data became available in August 1992 when truly global sea level measurements were made possible with the Topex satellite, which flew from 1992-2005 (Leuliette *et al*., 2004). Additional measurements were made through 2008 with the Jason satellite and analyzed by AVISO (2010) and others. The satellite sensors provide a complete pass of the earth every 10 days measuring sea level with a precision of 3-4 mm. Satellite-based measurements are geocentric, while tide gauge measurements are relative to the surface of the earth where they are located. In principle, the difference in the sea level signals from the two methods should be the local crustal movement at the gauge location. The two methods are considered complementary and are now used to help determine crustal movements by subtracting one from the other (*e.g.* Ray *et al*., 2010).

As shown in Figure 2-6, these satellite data suggest that global sea level has risen at a rate of about 3 mm per year since the early 1990s, which is at least 50% higher than the average for the twentieth century (AVISO, 2010 and others). Inspection of Figure 2-6 suggests, however, that the global SLR rate has decreased to around 2 mm/yr. since about 2006.

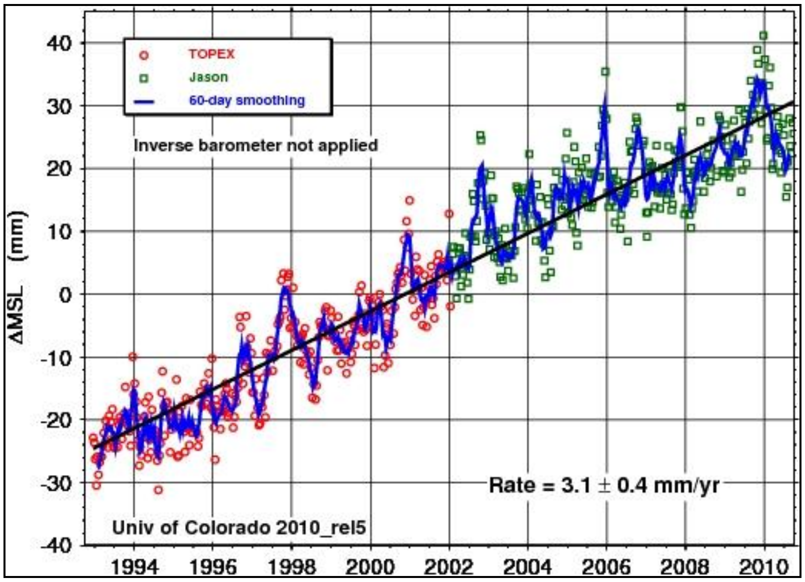

Figure 2-6. Time series of monthly global sea level from 1992-2010 showing SLR at a rate of about 3.1 mm/yr. (University of Colorado, 2010).

SLR is not uniform in space or time. This has been recognized for some time (*e.g.* Barnett, 1983). In addition, rapid melting of ice sheets are projected to lead to non-uniform rates of SLR across the globe due to adjustments in the Earth's gravitational field - i.e., changing mutual gravitational attraction between the ice sheet and the nearby ocean as well as the elastic deformation of the solid Earth to the load redistribution (e.g., Mitrovica et al., 2010).

The satellite coverage has provided a much clearer picture of the spatial variation, which is illustrated in Figure 2-7. Rates of SLR in the western Pacific, especially in the tropics, from 1992-2010 are in the range of up to 10 mm/yr., about three times the global average. In the western equatorial Pacific, sea levels can fluctuate up to half a meter between ENSO phases (Church et al., 2006a). In contrast, the SLR rate along the west coast of North and South America cannot be distinguished from zero (Figure 2-8), consistent with the tide gauge observations.

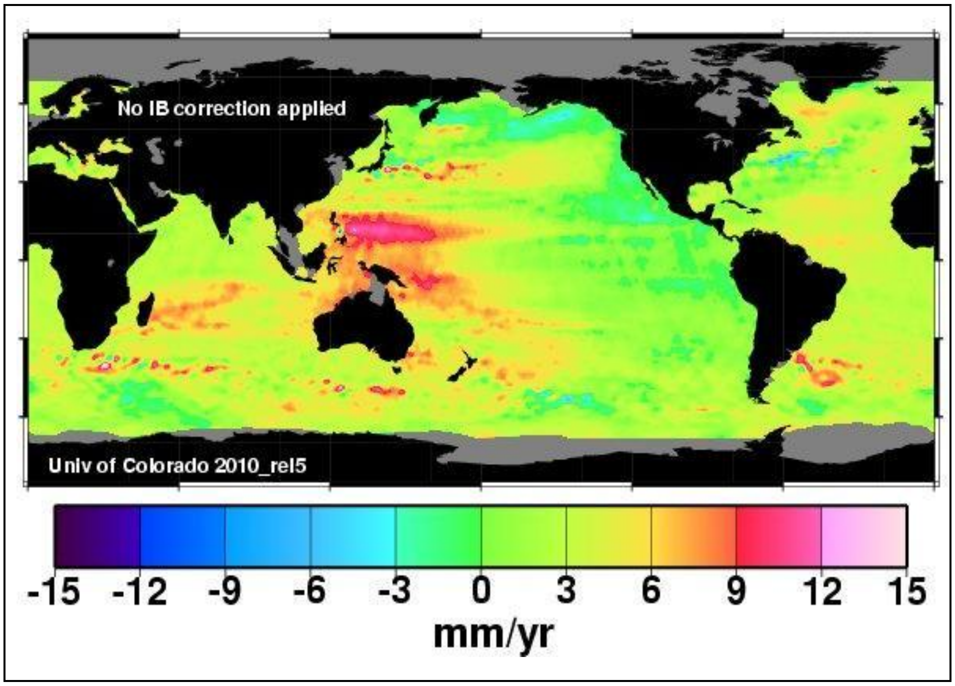

Figure 2-7. Spatial distribution of global SLR from 1992-2010 showing that rates of rise in the western Pacific are much higher than in the eastern Pacific off the coast of the Americas (University of Colorado, 2010).

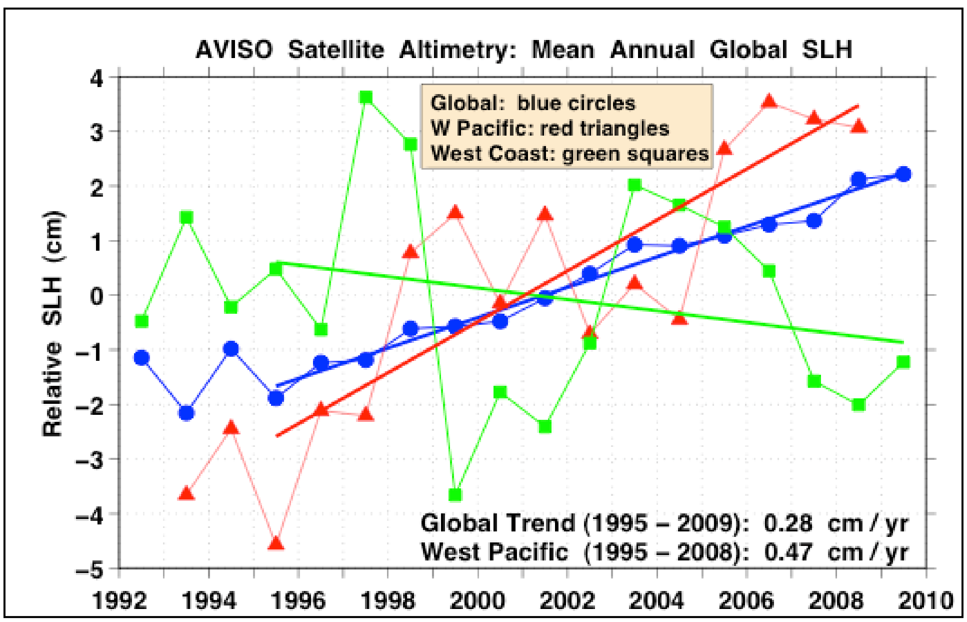

Figure 2-8. Relative sea level from satellite altimetry for different regions (AVISO, 2010). Note the trend for the west coast (eastern Pacific) is not significantly different from zero.

Large-scale winds over each of the world's ocean basins produce circular current patterns called gyres. Changes in wind stress over the clock-wise circulating North Pacific gyre cause changes in the rotation rate that also affect sea level at the continental margins along the coasts. Mean sea level along the west coasts of North and South America, including the San Francisco Bay region is affected by these North Pacific Ocean gyre-scale circulation patterns, which have resulted in suppression of local SLR below the global average value (Figures 2-7 and 2-8). This suppression of MSL rise is almost certainly related to the response of the northern Pacific Ocean to a combination of surface warming and changes in wind stress patterns.

The ocean's response to wind forcing produces what is commonly referred to as the Pacific Decadal Oscillation pattern in sea surface temperature and sea level height across the basin. If and when the component of the ocean dynamics that is responsible for the suppressed rate of SLR along the Pacific coast of North America ever relaxes or reverses, the San Francisco region could see rates above the increasing global average rate (Bromirski *et al.*, in review). Studies suggest that such a reversal, or "regime change," may occur in the next few decades. Currently, gyre processes seem to have suppressed SLR within San Francisco Bay by about 3 mm per year for a total SLR of up to 9 cm since 1980, which is about equal to the global rate of SLR.

2.5 ANTICIPATED FUTURE IMPROVEMENTS TO CLIMATE MODELING

Beyond 2013, there are a number of modeling trends and enhancements that allow for significant improvements in projected SLR (Meehl, NCAR, 2010). Some of these enhancements include:

- Higher resolution Earth System Models (25 km atmosphere, 0.1 degree ocean; coupled carbon cycle, chemistry, aerosols, dynamic vegetation);
- Integrated Assessment Models routinely merged with Earth System Models;
- Initialized decadal predictions with 10 km Atmosphere-Ocean General Circulation Models;
- Time slice experiments with 5 km resolution atmospheric models and even higher resolution possible; and
- Fully coupled Greenland and Antarctic ice sheet models in Earth System Models.

In the longer term, climate change research will increasingly focus on predicting the impact of anthropogenic climate change on coupled human and natural systems, including the magnitude and speed of change in specific regions and sectors. Vast improvements are still required in climate modeling and observation in order to identify our options and limits.

2.6 RESULTS

Due to the increasingly wide range of projected future SLR results found throughout the scientific literature produced since AR4, it is difficult to select an approach that is best for projecting future SLR. However, as noted above, the recently adopted state interim sea level rise guidance document concludes that the state's review of the best available science produces the SLR results shown in Figure 2-9. State SLR policies are discussed in more detail below in Section 3 and Appendix A.

Year		Average of Models	Range of Models
2030		7 in (18 cm)	5-8 in (13-21 cm)
2050		14 in (36 cm)	10-17 in (26-43 cm)
2070	Low	23 in (59 cm)	17-27 in (43-70 cm)
	Medium	24 in (62 cm)	18-29 in (46-74 cm)
	High	27 in (69 cm)	20-32 in (51-81 cm)
2100	Low	40 in (101 cm)	31-50 in (78-128 cm)
	Medium	47 in (121 cm)	37-60 in (95-152 cm)
	High	55 in (140 cm)	43-69 in (110-176 cm)

Note: These projections do not account for catastrophic ice melting, so they may underestimate actual SLR. The SLR projections included in this table do not include a safety factor to ensure against underestimating future SLR. For dates after 2050, three different values for SLR are shown - based on low, medium, and high future greenhouse gas emission scenarios. These values are based on the Intergovernmental Panel on Climate Change emission scenarios as follows: B1 for the low projections, A2 for the medium projections and A1FI for the high projections.

Figure 2-9. Sea-Level Rise Projections Adopted by the State of California – from Base Year 2000 (OPC, CO-CAT, 2010)

The observed acceleration in SLR is perhaps the best evidence that older IPCC projections of SLR in AR4 should be viewed as minimums, and that for projecting long term SLR, it is presently best to use models that produce projections based on accelerated SLR rates.

This section reviews and summarizes existing and proposed SLR and climate change policies established by governmental agencies, with an emphasis upon the State of California. SLR projections and methods (scenarios, models, etc.) adopted by each agency are compared, contrasted and assessed for consistency.

3.1 SUMMARY

Almost all peer reviewed literature and policy guidance documents describe a range of potential SLR effects reflecting a cascading series of uncertainties related to emissions scenarios, climate sensitivity, and modeling uncertainties. One of the more widely cited peer reviewed studies, Vermeer and Rahmstorf (2009), projects a range of SLR above 1990 levels of 32-70 inches (81-179 cm), with model averages for 6 Special Report on Emissions Scenarios from 41-56 inches (104-143 cm).

Table 3-1 shows a summary of SLR policies adopted by a variety of different governmental agencies in California. The table shows that a large degree of consistency across California state agencies with regard to projections in 2050 and 2100. The interim SLR guidance document, which resulted through the coordinated efforts of 16 California state agencies, commissions and departments further encourages consistency in SLR projections. It is important to recognize that most of these new policies have been established in a relatively short period of time, since the beginning of 2009 and by California state agencies having direct jurisdiction over areas subject to SLR. Other less affected or unaffected California state agencies have not adopted a policy or guidance yet.

Table 3-1 also shows that a SLR figure of 55 inches in 2100 is consistently used for vulnerability assessments. However, the interim SLR guidance document encourages risk based approaches which allow for a wide range of projected SLR values to be used for planning purposes. Therefore, future vulnerability studies, especially those that are site-specific, may use a wider variety of SLR values.

The data used for Table 3-1 along with further discussion of each policy are contained in Appendix A.

Table 3-1. Climate Change Studies and Sponsoring Agencies: San Francisco Bay

Study	Agency/Author	Date	Sea Level Rise Projection for SF Bay	Key Assumptions
Executive Order S-13-08	Governor Schwarzenegger	11/2008	2100: 7-23 inches	References IPCC AR4
A Report on Sea Level Rise Preparedness	State Lands Commission	12/2009	2100: 55 inches 2050: 16 inches (Vulnerability assessed using these figures)	A2, B1, A1Fi
California Climate Adaptation Strategy	Governor Schwarzenegger	12/2009	2100: 21-55 inches 2050: 12-18 inches	A2, B1, A1Fi

Table 3-1. Climate Change Studies and Sponsoring Agencies: San Francisco Bay

Study	Agency/Author	Date	Sea Level Rise Projection for SF Bay	Key Assumptions
Statewide Vulnerability Assessment	California Energy Commission et al	2012	2100: TBD 2050: TBD	A2, B1, A1Fi
State of California Sea Level Rise Interim Guidance Document	CO-CAT, Ocean Protection Council with input from 15 other California state entities	10/2010	2100: 31-69 inches 2050: 10-17 inches	A2, B1, A1Fi
Draft Sea-Level Rise Resolution	Ocean Protection Council	11/2010	2100: 31-69 inches 2050: 10-17 inches	A2, B1, A1Fi
California Sea Level Rise Study	National Research Council, National Academies of Sciences	March 2012	TBD	TBD
"Living with a Rising Bay: Vulnerability and Adaptation in San Francisco Bay and on the Shoreline	Bay Conservation and Development Commission	4/2009	2100: 55 inches 2050: 16 inches (Vulnerability assessed using these figures)	A2
Draft Bay Plan Amendments	Bay Conservation and Development Commission	TBD	2100: 23-55 inches 2050: 11-18 inches	TBD
The Impacts of Sea-level Rise on the California Coast	The Pacific Institute Sponsors: California Energy Commission, Caltrans, the Metropolitan Transportation Commission, California EPA	3/2009	2100: 55 inches (Vulnerability assessed using this figure)	A2, B1, A1Fi

3.2 OTHER POLICIES

Most coastal states are taking steps to address the potential impacts of SLR. A recent survey by the California State Lands Commission found that governors of several states, including Florida, Louisiana, Maryland, New Jersey, New York, South Carolina, Virginia, and Washington, have issued executive orders establishing various climate change commissions and advisory committees to consider the potential effects of global climate change, including SLR. States with adaptation plans in place or under development include: Alaska, Arizona, California, Colorado, Connecticut, Florida, Iowa, Kansas, Maine, Maryland, Massachusetts, Michigan, New Hampshire, New York, North Carolina, Oregon, Pennsylvania, South Carolina, Utah, Vermont, Virginia and Washington.

Just as many states and regions are moving forward with GHG mitigation strategies, cities and counties in the U.S. are initiating adaptation planning and adaptive measures in lieu of state or federal policy or planning efforts.

Following California's lead, several states, including New York, have recently issued SLR projections in 2050 and 2100. Despite the large inherent uncertainties in long term projections, alignment exists and is growing between various government agencies with regard to longer term SLR projections.

For example, New York City and New York State recently reached milestones in their coordinated efforts to plan for SLR. In January 2011, the New York State Sea-Level Rise Task Force submitted a SLR report to the state legislature. As shown in the Figure 3-1, under a "Rapid Ice-Melt Scenario," the Task Force projected SLR of 55 inches in 2080.

Lower Hudson Valley & Long Island	2020s	2050s	2080s
Sea level rise[2]	2 to 5 in	7 to 12 in	12 to 23 in
Sea level rise with rapid ice-melt scenario[3]	5 to 10 in	19 to 29 in	41 to 55 in
Mid-Hudson Valley & Capital Region	**2020s**	**2050s**	**2080s**
Sea level rise[2]	1 to 4 in	5 to 9 in	8 to 18 in
Sea level rise with rapid ice-melt scenario[3]	4 to 9 in	17 to 26 in	37 to 50 in

[1] NYSERDA ClimAID Team. 2010. Integrated Assessment for Effective Climate-change Adaptation Strategies in New York State. C. Rosenzweig, W. Solecki, A. DeGaetano, M. O'Grady, S. Hassol, P. Grabhorn, Eds. New York State Energy Research and Development Authority, 17 Columbia Circle, Albany, NY 12203.

[2] Shown is the central range (middle 67%) of values from model-based probabilities (16 global climate models by 3 GHG emissions scenarios) rounded to the nearest inch.

[3] The rapid ice-melt scenario is based on acceleration of recent rates of ice melt in the Greenland and west Antarctic ice sheets and paleoclimate studies.

Figure 3-1. New York State Sea level Rise Projections

On February 17, 2009, the New York City Panel on Climate Change released its "Climate Risk Information" report. Figure 3-2 is an excerpt from the Panel's report and shows an upper limit SLR of 55 inches under a rapid ice-melt scenario. According to the report, rapid ice melt is already occurring. The SLR projections contained in the New York City Panel on Climate Change were adopted by the New York State report to the legislature. Interestingly, the melt rate used by the New York City panel was based on paleoclimate records rather than GCM and/or semi-empirical modeled projections. It is also important to note that the high of 55 inches is projected to occur as early as 2080. Thus, New York City and New York State have each effectively proposed a higher SLR projection (at the high end of the range) in 2100 than is now established in California. Further details regarding the New York City and State efforts are contained in Appendix A.

	Baseline 1971-2000	2020s	2050s	2080s
Air temperature Central range[2]	55°F	+ 1.5 to 3°F	+ 3 to 5°F	+ 4 to 7.5°F
Precipitation Central range[2]	46.5 in	+ 0 to 5 %	+ 0 to 10 %	+ 5 to 10 %
Sea level rise[3] Central range[2]	NA	+ 2 to 5 in	+ 7 to 12 in	+ 12 to 23 in
Rapid Ice-Melt Sea Level Rise[4]	NA	~ 5 to 10 in	~ 19 to 29 in	~ 41 to 55 in

1 Based on 16 GCMs (7 GCMs for Sea Level Rise) and 3 emissions scenarios. Baseline is 1971-2000 for temperature and precipitation and 2000-2004 for sea level rise. Data from National Weather Service (NWS) and National Oceanic and Atmospheric Administration (NOAA). Temperature data are from Central Park; precipitation data are the mean of the Central Park and La Guardia Airport values; and sea level data is from the Battery at the southern tip of Manhattan (the only location in NYC for which comprehensive historic sea level rise data are available).

2 Central range = middle 67% of values from model-based probabilities; temperatures ranges are rounded to the nearest half-degree, precipitation to the nearest 5%, and sea level rise to the nearest inch.

3 The model-based sea level rise projections may represent the range of possible outcomes less completely than the temperature and precipitation projections. See page 18 for more information.

4 "Rapid ice-melt scenario" is based on acceleration of recent rates of ice melt in the Greenland and West Antarctic Ice sheets and paleoclimate studies. See Appendix C for further description.

Figure 3-2. New York City Sea level Rise Projections

This technical memorandum represents an initial examination of potential SLR. The work represents a first step toward defining the issues applicable to the Port of San Francisco in developing a climate change adaptation strategy. A time period of interest for the study was defined as the years between a base period of 2000 and two benchmark future years: 2050 and 2100.

A review of credible technical literature provided data on major projected climate effects grouped into four general categories: temperature, precipitation, severe storms, and SLR. The San Francisco Bay is particularly at risk due to SLR because of some low lying and heavily developed areas.

4.1 STUDY RESULTS

High level results of this study include the following:

- SLR in 2050 and 2100, compared to 2000 are projected as follows:
  - 2050: 26-43 cm (10-17 inches)
  - 2100: 78-176 cm (31-69 inches)
- SLR projections in the near term using various models and scenarios show close agreement compared to SLR projections beyond 2050.
- Uncertainty in post-2050 projections results from uncertainty associated with the level of anthropogenic emissions and model uncertainties.
- 16 State of California agencies, including 12 that have direct jurisdiction over areas subject to SLR, have jointly developed state level guidance on SLR projections.
- State level interagency coordination is likely to result in consistency in longer-term projections across all California state agencies that adopt SLR policies and/or guidance.
- Long-term projections of SLR have fluctuated substantially in the past and may continue to fluctuate in the future as scientific models used to produce the projections mature.

4.2 RECOMMENDATIONS

Key URS recommendations for consideration by the project sponsors include the following:

- Monitor the activities of other ports around the globe regarding scientific methods used to assess and project SLR, and associated strategies and business practices.
- Recognize that near-term SLR projections (through 2050) are within a narrow band whereas there is substantial uncertainty in longer term SLR projections and that this uncertainty may persist or increase even as further scientific research is conducted.
- Monitor long term climate modeling efforts. For the longer term period, (particular, beyond 2050), we recommend that the sponsors provide support (direct or indirect) to groups performing climate modeling (e.g., California Energy Commission PIER program contractors, Scripps Institute, etc.) to address the issues of regional and sub-regional interest.
- Periodically update the SLR projections used for Port projects as the science improves.

- Monitor the range of upper and lower end projections. When the ranges narrow, then SLR policies and strategies may need to be revisited.
- Become involved in the refinement of scenarios used to model SLR in the San Francisco Bay Area on an ongoing basis as new climate models and downscaled products become more available.
- Monitor rapidly emerging studies focused on earth systems that may be subject to nonlinearities or tipping points.
- Monitor paleoclimate studies and how results are being used by local, state, federal and international agencies to project sea levels in 2100.
- Monitor state and federal studies, including the state-wide vulnerability assessment, the National Academies of Science SLR Assessment study, that focus on California-specific and perhaps San Francisco Bay-specific impacts.
- In developing a framework for considering what sea-level rise projections should be applied on a project-by-project basis, review the concepts of risk tolerance and adaptive capacity contained in the Interim Sea Level Rise Guidance Document.
- Engage in federal, state and/or federal/state SLR scientific and policy initiatives.
- Track the development and availability of new modeling tools such as those referenced by the United States Interagency Climate Change Adaptation Progress Report and new models developed for use in conjunction with the IPCC’s fifth Assessment Report.

The effectiveness of the existing policies and Port strategy should be evaluated against actual impacts monitored over time, and projections of the effects and impacts of future climate change. This analysis should be updated periodically (e.g., at least as frequently as the state SLR guidance is updated) with new data and information.

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Appendix A

Summary of Selected Sea Level Rise Policy Documents Reviewed

This appendix contains short summaries of recent government documents that contain either new sea level rise-related obligations or an indication of the scientific methods that are being used or should be used to project sea level rise in the medium and long term range. Since the medium term projections are already fairly closely aligned regardless of which projection methods are used, the following is more focus on longer term projections and methods. Thirteen documents addressing the impacts of climate change upon the State of California are reviewed here along with one document for the State of New York and New York City. In addition, future documents are noted.

1. Executive Order S-13-08 by the Governor Schwarzenegger [1]

On November 24, 2008, Governor Arnold Schwarzenegger issued Executive Order (EO) S-13-08[2] "to enhance the state's management of climate impacts from sea level rise . . ." The EO directs the California Resources Agency, through the Climate Action Team, to develop a State Climate Adaptation Strategy (see below). The EO also requires the development of a "Sea Level Rise Assessment Report" (expected mid-2012, see below). The EO also requires all California state agencies that are planning construction projects in areas vulnerable to future sea level rise 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. The EO references the IPCC projections of sea level rise in 2100 (i.e., 7 – 23 inches). Many of the sea level rise policies summarized below for California stemmed from Executive Order S-13-08 signed by State of California Governor Schwarzenegger in 2008. A few notable policies preceded this Executive Order.

2. State Lands Commission, Policies on Sea Level Rise

In December 2009, following the release of the Pacific Institute Report, the State Lands Commission (SLC) issued a staff report entitled "A Report on Sea Level Rise Preparedness" (Report).[3] The Report included the results of a survey all of major public trust land grantees and lessees of major facilities on state lands along the coast and San Francisco Bay. A resurvey has been issued[4] and will be followed by a new report highlighting progress of grantees towards addressing sea level rise.[5] The SLC Report found that "the majority of respondents have not yet begun to comprehensively consider the impacts of sea level rise." Following issuance of this Staff Report, the State Controller sponsored AB 2598 at the request of the SLC.[6]

On December 10, 2010, the SLC met to hear an update on implementation of sea level rise recommendations previously approved in December 2009.[7] The recommendations include a number of new requirements. For example, new language for the Commission's Application

[1] http://www.climatechange.ca.gov/publications/EXECUTIVE_ORDER_S-13-08.pdf
[2] Available at: http://www.climatechange.ca.gov/publications/EXECUTIVE_ORDER_S-13-08.pdf.
[3] Available at: http://www.slc.ca.gov/Reports/SEA_LEVEL_Report.pdf
[4] Available at: http://www.slc.ca.gov/home_page_docs/SLR_Resurvey.pdf
[5] Conversation between Greg San Martin and Amber Mace (SLC)
[6] Available at: http://www.slc.ca.gov/Reports/SEA_LEVEL_Report.pdf
[7] See: http://archives.slc.ca.gov/Meeting_Summaries/2010_Documents/12-10-10/Items_and_Exhibits/49.pdf
and: http://archives.slc.ca.gov/Meeting_Summaries/2010_Documents/12-10-10/Items_and_Exhibits/49ExhB.pdf

Package[8] requires project proponents in areas subject to tidal action to "provide risk analysis, implications of failure, and adaptation strategies for, addressing

projected sea level rise of 16 inches by year 2050 and 55 inches by year 2100, relative to the projected life expectancy of the project." This language preceded development of the Interim Guidance document and may therefore be revised by the SLC to align with the risk-based approach contained in the Interim Guidance document.

The Commission also directed staff upon finalization of the National Academies of Sciences Sea Level Rise Assessment Report "to make recommendations as to appropriate sea level rise estimates that should be accommodated by new development on sovereign lands." The Commission also directed staff to "evaluate structures (wharves, docks, levees, breakwaters, piers, seawalls, flood control structures, etc.) subject to the ocean environmental (sic) for structural integrity and potential hazards as sea levels rise." SLC Staff indicated they have undertaken an inventory of existing leases to prioritize those having critical improvements/infrastructure vulnerable to projected sea level rises of 16" and 55." The sea level rise figures specified by the SLC do not appear to specify a base year, scenario or modeling approach.

3. California Climate Adaptation Strategy [9]

On December 2, 2009, Governor Arnold Schwarzenegger issued California's Climate Adaptation Strategy (CAS) final report. The Strategy was developed pursuant to the Governor's Executive Order (see above). The Strategy summarizes the best known science on climate change impacts and provides recommendations on how to manage against those threats. The most relevant sector for this Technical Memorandum is the Ocean and Coastal Resources sector. The Strategy articulates guiding principles for adaptation in the Ocean and Coastal Resource Sector and establishes a state policy to avoid future hazards due to climate change and protect critical habitat. Specifically, the Strategy recommends that California state agencies "consider project alternatives that avoid significant new development in areas that cannot be adequately protected from flooding due to climate change," and "generally no plan, develop, or build any new significant structure in a place where that structure will require significant protection from sea level rise, storm surges, or coastal erosion during the expected life of the structure."

The Strategy also recognizes that some vulnerable shoreline areas have or are proposed to have development of "regionally significant economic, cultural, or social value" that may need to be protected, and that "in-fill development in these areas should be accommodated." Although the Strategy itself does not impose new requirements on state or local governments, these Ocean and Coastal Resource Sector adaptation strategies, as well as the overall Preliminary Recommendations of the report may be indicative of policies that the state might adopt in the future.

The development of the Ocean and Coastal Resources Section of the CAS was led by Ocean Protection Council (OPC), and reflects the collective input of other member agencies of the Coastal and Oceans Working Group: California Coastal Conservancy, California Coastal Commission, State Lands Commission, Department of Fish and Game, State Parks, and the Bay

[8] Part II, Section B: Project Description, Subsection 1.e
[9] Available at: http://www.climatechange.ca.gov/adaptation/

Conservation and Development Commission (BCDC). The Strategy is also intended to be instructive for local governments that are developing climate adaptation strategies.

Much of the literature referenced in the CAS was funded by the State of California via the California Climate Change Research Center.[10] This literature provides a strong technical basis for the sea level rise projections specified in the CAS. The primary scientific approach relied upon the use of 6 global climate models and 3 scenarios (A2, B1, A1Fi).

The CAS specifies a range of sea level rise projections in 2050 and 2100. The CAS states, "This report uses the 20-55 inch projection, as it was the best available science at the time of the 2009 impacts assessment (emphasis added)."

4. Statewide Vulnerability Assessment [11]

The State Adaptation Strategy calls on OPC to coordinate with other California state agencies to produce a coastal and ocean vulnerability assessment every five years that consolidates and builds upon existing efforts by the California Energy Commission and other agencies. The result will be a statewide synthesis report and individual reports and maps for related studies including wave run-up projections and a case study on planning for sea-level rise. CEC is the lead agency, with OPC serving on the steering committee and BCDC providing guidance on the San Francisco Bay Area case study. Draft reports for the synthesis document and the individual reports are expected summer 2011, with final reports expected in 2012. According to the CEC, PIER funding is being used to meet these requirements. Funding is being provided to Scripps (Cayan and Bromirsky) for several of these studies.[12] Due to the CEC's role in reviewing the scientific basis for the Interim Guidance, it seems likely that the Vulnerability Assessment that the CEC produces will use sea level rise projections that are consistent with the Sea Level Rise Interim Guidance document. OPC confirms that the Vulnerability Assessment will be informed by the interim guidance document.

5. California Climate Action Team, Sea Level Rise Task Force

Pursuant to an Executive Order[13], the Secretary of the California Environmental Protection Agency (CalEPA) established in the California Climate Action Team (CAT) in 2006. The CAT is made up of representatives from numerous California state agencies, boards and departments. The CAT members work to coordinate statewide efforts to implement the state's Climate Adaptation Strategy (in addition to greenhouse gas emission reduction efforts).

The California Climate Action Team (CAT) and its working groups identified 15 near-term adaptation strategies that will be underway or completed in 2010.[14] More detailed descriptions of each strategy (steps to be taken in implementation, the agency/department responsible, and the timeline for completion) can be found in the individual CAT working group Implementation

[10] A complete set of literature is listed at: http://www.climatechange.ca.gov/research/index.html
[11] Available at: http://www.climatechange.ca.gov/climate_action_team/meetings/2010-06-23_meeting/presentations/04-Amber_Mace_Ocean_and_Coastal_Chapter_Strategy_5.pdf
[12] Call between Greg San Martin (URS) and Guide Franco (CEC), September 23, 2010
[13] See: Governor Arnold Schwarzenegger Executive Order S-3-05, June 6, 2005
[14] See: "*Mitigation Measures and Adaptation Strategies for the CAT Implementation Plan*" http://www.climatechange.ca.gov/climate_action_team/reports/catnip/Mitigation_Measures_and_Adaptation_Strategies_List.pdf

Plans.[15] The CAT Coastal & Ocean Committee established a Sea Level Rise Task Force comprised of representatives from the following California state agencies whose mission may be impacted by SLR.

- Business, Transportation and Housing Agency,
- Coastal Commission,
- Department of Fish and Game,
- Department of Parks and Recreation,
- Department of Public Health,
- Department of Toxic Substances Control,
- Department of Transportation,
- Department of Water Resources,
- Environmental Protection Agency,
- Governor's Office of Planning and Research,
- Natural Resources Agency,
- Ocean Protection Council,
- San Francisco Bay Conservation and Development Commission,
- State Coastal Conservancy,
- State Lands Commission and
- State Water Resources Control Board.

This group was tasked with clarifying how agencies are currently integrating SLR projections into their management and planning processes, and establishing a set of shared principles that will facilitate a unified and synergistic approach to addressing SLR throughout State government. The State of California Sea Level Rise Interim Guidance Document (described below) was first developed and approved by the CO-CAT before it was released by the OPC.

6. State of California, Sea Level Rise Interim Guidance Document[16]

On October 29, the OPC released the State of California Sea Level Rise Interim Guidance Document. The document was developed by the CO-CAT Sea–Level Rise Task Force, with science support provided by the OPC's Science Advisory Team and the California Ocean Science Trust. The document provides guidance for incorporating sea–level rise (SLR) projections into planning and decision making for projects in California. The guidance document outlines the concepts of risk tolerance and adaptive capacity, providing a framework for agencies to consider what sea-level rise scenarios should be modeled on a case-by-case basis. The

[15] Available at: http://www.climatechange.ca.gov/climate_action_team/reports/#catnip

[16] Available at: http://opc.ca.gov/webmaster/ftp/pdf/agenda_items/20110311/12.SLR_Resolution/SLR-Guidance-Document.pdf

Guidance states, "Although the estimates of future SLR provided in this document are intended to enhance consistency across California state agencies, the document is not intended to prescribe that all California state agencies use specific or identical estimates of SLR as part of their assessments or decisions."[17]

Using IPCC scenarios A1Fi, A2 and B1, the Guidance projects an average high sea level rise of 55 inches in 2100 and 14 inches in 2050 with a wide range of model results in 2050 and an even wider range of model results in 2100. The Guidance also states that "these projections do not account for catastrophic ice melting, so they may underestimate actual SLR. The SLR projections included in this table do not include a safety factor to ensure against underestimating future SLR." The Guidance will be regularly revised to incorporate the latest scientific understanding of climate change and sea level rise. For example, shortly following the release of the National Academies of Sciences' Sea Level Rise Assessment Report next year, the Interim Guidance is likely to be updated.

Appendix A to the Interim Guidance Document contains responses from a subcommittee of the OPC's Science Advisory Team (OPC-SAT) to questions posed by the Sea Level rise Task Force of the Ocean and Coastal Working Group of the California Climate Action Team (September 1, 2010). The OPC-SAT subcommittee consisted of the following experts:

- Dr. Dan Cayan, Research Meteorologist, UC San Diego Scripps Institution of Oceanography & U.S. Geological Survey
- Dr. Gary Griggs, Director of the UC Santa Cruz Institute of Marine Sciences
- Dr. Sam Johnson, Research Geologist, USGS Pacific Science Center
- Dr. Tony Haymet, Director of the UC San Diego Scripps Institution of Oceanography

The responses form an important basis for the sea level rise projections in the Interim Guidance. In response to the question asking which approach to use to estimate sea level rise, the subcommittee stated, that it "important to acknowledge that many (if not most) of the current approaches (except the one used by IPCC which ignores any contribution from ice melt) are giving similar results (~75 to 150+ cm of SLR by 2100)." Furthermore, the subcommittee states that "beyond two decades or so, the present state of the art from empirical techniques such as Vermeer and Rahmstorf provide useful guidance, presumably accounting for the contribution from ground–based ice melt from Greenland and Antarctica."

Table A-1 contains a summary of the technical references used to support development of the state's sea level rise Interim Guidance document.

[17] November 19, 2010 Agenda Item #10

Table A-1. Summary of Key Scientific References Supporting the State of California Sea Level Rise Interim Guidance Document

Author(s)	Date	Title	Key Points	SLR Relationship
Vermeer & Rahmstorf	Dec-09	Global sea level linked to global temperature	1. Presents an improvement to the semiempirical method (air temp compared to sea level) of SLR projections proposed by Rahmstorf in 2007. 1. Improved by including rapid ocean surface heating in approach. 2. Ice melt contributions to SLR are unclear based on this semi-empirical model.	SLR estimates are greater than IPCC and Rahmstorf 2007. Projects SLR ranging from 0.75m to 1.9m by 2100.
Rahmstorf	Apr-10	A new view on sea level rise (Commentary)	1. Commentary presents limitations to physical and semi-empirical models re: SLR, but overall, debases the IPCC AR4 SLR estimates. 2. Discusses melting of glaciers and ice sheets and some commentary raised by others.	No independent results/ranges. Refers to other references.
Pfeffer, et al.	Sep-08	Kinematic Constraints on Glacier Contributions to 21st-Century Sea-Level Rise	1. Glacier melt contributions of more than 2 meters to SLR by 2100 are physically indefensible. 2 Provides a "most likely" starting point for SLR forecasts that include ice-flow dynamics.	Up to 2 meters (78.7 inches) of SLR could occur by 2100 from glacier contributions, but more plausibly only about 0.8 meters (31.5 inches).
Wu, et al.	Aug/Sept 2010	Simultaneous estimation of global present-day water transport and glacial isostatic adjustment	1 Estimates mass losses between 2002 and 2008 in Greenland, Alaska/Yukon, and West Antarctica in the tens of Gigatons each (Gt, billions of tons), a reduction compared to other models' estimates.	Estimates non-steric sea level rises (SLR due to glacial mass losses) at approximately ¾ mm/yr.
Jevrejeva, et al.	Apr-10	How will sea level respond to changes in natural and anthropogenic forcings by 2100?	1. Projects SLR as an integrated response of the entire climate system (independent of global mean temperature). Twenty-first century SLR will be clearly dominated by the changes in CO_2 and other GHGs. 2. Reductions in SLR due to severe frequent volcanic eruptions will only delay SLR by 12-20 years. 3. Low solar irradiance has a negligible effect on SLR.	Using an inverse statistical model, and six IPCC radiative forcing scenarios, authors estimate SLR (confidence limits) of 0.59m to 1.8m by 2100.

Table A-1. Summary of Key Scientific References Supporting the State of California Sea Level Rise Interim Guidance Document

Author(s)	Date	Title	Key Points	SLR Relationship
Grinsted, et al.	Jan-09	Reconstructing sea level from paleo and projected temperatures 200 to 2100 AD.	1. Uses a linear response equation to relate 2,000 years of global temperatures and sea level, and likelihood distributions are provided for past and future sea level scenarios. 2. Model links temperature and SLR, finding IPCC projections of SLR are underestimated by factor of 3. The rates of rise far exceed that of anything seen in the last 2,000 years.	From 2090 - 2099, within 5-95 percentiles, SLR is projected to be between 1.45 m and 2.15 m (based on the Jones and Mann 2004 data reconstruction), for IPCC scenario A1FI, the highest SLR of the six temperature scenarios considered.
Bahr, et al.	Feb-09	Sea-level rise from glaciers and ice caps: A lower bound	1. When compared to recent estimates of SLR from all other sources, melt water glaciers must be considered as a particularly important fraction of the total sea-level rise this century. These estimates are substantially larger than previous estimates. 2. At least 0.18m ±0.03m of sea-level rise is expected due to mass loss of mountain glaciers and ice caps over the next 100 years even if the climate does not continue to warm. 3. If the climate continues to warm along current trends, a minimum of 0.37m ± 0.02m of sea-level rise is expected over the next 100 years.	Glacier and ice cap melt may contribute between 0.18m and 0.37m to overall sea-level rise over the next 100 years.
USACE	Jul-09	Water Resource Policies and Authorities Incorporating Sea-Level Change Considerations in Civil Works Programs	1. Presents SLR estimates based on NRC curves (yet modified) originally presented in 1987. Allows user to make risk-informed selection of SLR estimate to best accommodate a range of SLR. 2. Provides step by step guidance to implement.	Estimates 0.5m to 1.5m SLR by 2100 using modified NRC curves.

7. California Ocean Protection Council, Draft Sea-Level Rise Resolution

On November 29, 2010, in support of the Interim Sea Level Rise Guidance document, the OPC released a draft resolution on sea level rise.[18] The Public Comment period closed on January 11, 2011. Public comments (primarily from environmental groups) are currently being incorporated into a revised draft.[19]

The Resolution advises that:

1. California state agencies use the SLR values presented in the December 2009 Proceedings of National Academies of Science publication by Vermeer and Rahmstorf as a starting place;
2. California state agencies select SLR values based on agency and context-specific considerations of risk tolerance and adaptive capacity (as defined);
3. projects with a lifespan that extends beyond 2050, it is especially important to consider risk tolerance and adaptive capacity to guide decisions of whether to use low, medium, or high SLR projections;
4. projects that involve high consequences (high impacts and low adaptive capacity), it is advisable to avoid selecting SLR values that would result in high risk; for most situations this means it is advisable to avoid using low SLR values for high consequence projects;
5. linear extrapolation of SLR, based on historic observations, is inadequate and would likely underestimate SLR estimates beyond two decades;
6. the OPC will "continue to . . . support the development of common modeling assumptions so that planning actions in different agencies are based on shared information and current scientific understanding to the greatest extent possible."

The resolution specifies a range of sea level rise in 2050 and 2100 as well as in 2030 and 2070. It references 6 global climate models and 3 scenarios (A2, B1, A1Fi), consistent with the California Sea-Level Rise Interim Guidance document and with the conclusions in this Memorandum.

On March 11, 2011, the Ocean Protection Council adopted a modified version of the Resolution.[20] SLC committed at the adoption meeting to send copies of this Resolution to all ports and other entities operating on state lands.

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[18] See: http://www.opc.ca.gov/webmaster/ftp/project_pages/Climate/1011_COPC_SLR_Draft%20Resolution.pdf

[19] Telephone conversation between Greg San Martin, URS, and Abe Doherty, OPC, February 3, 2010.

[20] See the OPC Memo on the Revised Resolution of the OPC on Sea-Level Rise, March 11, 2011: http://opc.ca.gov/webmaster/ftp/pdf/agenda_items/20110311/12.SLR_Resolution/20110311OPC-SLR-Resolution-Memo.pdf
Also see the Proposed Resolution of the OPC on Sea-Level Rise, approved at the March 11, 2011 OPC Meeting: http://opc.ca.gov/webmaster/ftp/pdf/agenda_items/20110311/12.SLR_Resolution/20110311OPC-SLR-Resolution.pdf (As noted at the meeting, a copy of the approved Resolution will be sent to all ports and other entities using state lands),

8. National Academies of Sciences, Sea Level Rise Assessment Report [21]

Executive Order S-13-08 called for preparation of a National Research Council study to estimate future sea level rise in California, to assist in state climate change adaptation planning California state agencies[22] joined with the states of Oregon and Washington and three federal agencies[23] to engage the National Academies of Sciences' National Research Council (NRC) in April 2010 in a contract for science review of sea level rise for the West Coast. The Report is expected to be released by mid-2012. Through this contract, a panel of experts will be assembled who will assess sea level rise along the coasts of California, Oregon and Washington for planning purposes for the years 2030, 2050 and 2100.

The scope of work for the study is to:

1. Evaluate each of the major contributors to global sea level rise (e.g., ocean thermal expansion, melting of glaciers and ice sheets); combine the contributions to provide values or a range of values of global sea level rise for the years 2030, 2050, and 2100; and evaluate the uncertainties associated with these values for each timeframe.
2. Characterize and, where possible, provide specific values for the regional and local contributions to sea level rise (e.g., atmospheric changes influencing ocean winds, El Nino-Southern Oscillation effects on ocean surface height, coastal upwelling and currents, storminess, coastal land motion caused by tectonics, sediment loading, or aquifer withdrawal) for the years 2030, 2050 and 2100.

California's intentions with regard to use of the Study results (once they become available) are perhaps best stated by the California Energy Commission[24]:

> The National Research Council study will provide best-available science on expected amounts of sea level rise along the California coast, allowing California state agencies that build and maintain coastal infrastructure or enforce permitting programs to use the information in their programs. The information will facilitate coordinated response to adaptation planning across all agencies of state government, by providing authoritative guidance common to all agencies. The study will likewise be useful for California local agencies carrying out their own land use and infrastructure planning programs.

In June 2010, the California state agencies sponsoring this study held 3 public meetings to accept public comments electronically and to solicit reference information that could be considered by NRC in its science study.[25]

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[21] Available at: http://www.climatechange.ca.gov/climate_action_team/meetings/2010-06-23_meeting/presentations/04-Amber_Mace_Ocean_and_Coastal_Chapter_Strategy_5.pdf

[22] State agencies involved in this work include Department of Water Resources (lead agency coordinating funding), with Ocean Protection Council, Caltrans, State Water Resources Control Board and California Energy Commission serving as a California State Agency Steering Committee.

[23] The Washington Department of Ecology and the Oregon Water Enhancement Board are providing financial support, as are the US Geological Survey, National Oceanic and Atmospheric Administration, and US Army Corps of Engineers.

[24] See http://www.energy.ca.gov/2010publications/CAT-1000-2010-005/Research_Collaboration_Case_Studies/Sea_Level_Rise_Study.pdf

[25] Available at: http://www.swrcb.ca.gov/water_issues/hot_topics/sea_level/docs/notice2010may.pdf

Based on interviews with state agency staff[26], the literature provided to the National Academies of Sciences by the State of California supports the sea level rise projections in the California Interim Sea Level Rise Guidance document. The NRC is under no obligation to produce findings that are consistent with California's existing sea level rise policies. Hansen's draft paleoclimate paper may also be serving as a basis for the NRC's assessment.

9. BCDC San Francisco Bay Plan Amendments [27]

In April 2009, BCDC released a staff report entitled, "Living with a Rising Bay: Vulnerability and Adaptation in San Francisco Bay and on its Shoreline." [28] The analysis was based on sea level rise projections of 16 inches within a 50-year time frame and 55 inches within a 100-year time frame.[29] This report provided the basis for a proposed amendment to the San Francisco Bay Plan[30] that delineates guidance and sea level rise adaptation strategies for areas within BCDC's jurisdiction. As of January 31, 2011, there is no timeline to finalize and adopt the proposed amendment. BCDC was involved in the development of the state interim SLR Guidance document and appears likely to align sea level rise projections in any policies it adopts to the SLR values specified in the state guidance document.

10. Caltrans, California Transportation Hot Spot Map [31]

The purpose of this initiative is to identify specific areas of the state's highway system, railroad system and key local streets that are susceptible to sea-level rise. The deliverables will be a map identifying susceptible transportation infrastructure. Caltrans is the lead agency. The project is anticipated to start in June 2011 and be completed by June 2012.

11. California Environmental Quality Act (CEQA)

The California Attorney General's Office instructs local governments to refer to the California Climate Adaptation Strategy in order to develop "reasonable and rational risk reduction strategies." California Attorney General's Office document entitled, "Straightforward Answers to Some Frequently Asked Questions", specifies that communities with General Plans and Local Coastal Plans should begin when possible to amend their Plans to assess climate change impacts, identify areas most vulnerable to these impacts, and to develop reasonable and rational risk reduction strategies using the California Adaptation Strategy as guidance.).[32] As previously

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[26] Email exchange between Greg San Martin (URS) and Jeanine Jones (CDWR's Interstate Resources Manager)
[27] http://www.bcdc.ca.gov/proposed_bay_plan/bp_amend_1-08.shtml
[28] San Francisco Bay Conservation and Development Commission, Living with a Rising Bay: Vulnerability and Adaptation in San Francisco Bay and on its Shoreline (2009) (Living With a Rising Bay), available at http://www.bcdc.ca.gov/proposed_bay_plan/bp_1-08_cc_draft.pdf.
[29] Pacific Institute, 2008. For more information, see http://www.bcdc.ca.gov/proposed_bay_plan/bp_1-08_cc_draft.pdf
[30] San Francisco Bay Conservation and Development Commission, San Francisco Bay Plan (2008 Reprint), available at http://www.bcdc.ca.gov/pdf/planning/plans/bayplan/bayplan.pdf.
[31] See: http://www.climatechange.ca.gov/climate_action_team/meetings/2010-06-23_meeting/presentations/04-Amber_Mace_Ocean_and_Coastal_Chapter_Strategy_5.pdf
[32] See also Bay Area Conservation and Development Commission, "Update on Guidance for Addressing Climate Change Impacts in California Environmental Quality Act Review," available at: http://www.bcdc.ca.gov/planning/climate_change/adaptation/CEQA_climate_impacts.pdf

noted, the California Adaptation Strategy provides sea level rise projections in 2100 of up to 55 inches.

12. State Coastal Conservancy Project Selection Criteria [33]

On June 4th, 2009, prior to the Executive Order, the Coastal Conservancy adopted criteria for project selection to address climate change. Project applicants are now required to consider a range of sea level rise scenarios for the years 2050 and 2100 in order to assess project vulnerability and, reduce expected risks and increase resiliency to sea level rise. Another, optional project criterion addresses vulnerability from climate change impacts other than sea level rise. The Conservancy will "look favorably" upon projects for which the project objectives, design and siting consider and address these other climate change vulnerabilities.

Like the State Lands Commission, the State Coastal Conservancy adopted SLR projection values of 55 in and 16 in (in 2100 and 2050, respectively). Neither agency appears to have referenced a base year in their SLR policies or scenarios and modeling methods used to arrive at these SLR values. SCC may revise their policy to align with the more recently issued Interim SLR Guidance document.

The Project Selection Criteria includes three new proposed criteria to address greenhouse gas emissions and vulnerability to sea level rise and other climate change impacts.

13. Delta Vision Blue Ribbon Task Force Independent Science Board

In July 2007, prior to the Governor's Executive Order on sea level rise, the CALFED Bay Delta Program asked that the Independent Science Board (ISB) examine the scientific literature relating to sea level rise projections. On September 2007, the ISB responded with a memo containing several important findings. [34] The ISB stated that the most recent empirical models project a rise this century of 20-55 inches. The ISB did not specifically reference a base year in its SLR recommendation nor did it reference models or modeling methods. The ISB also stated that empirical models "likely underestimate long term sea level rise" and that sea level rise could reach ~200 cm (79 inches) this century "if ice cap melting accelerates."

14. New York State and New York City

Executive Order 24 signed by Governor Patterson in August 2009 created the New York Climate Action Council and charged it with creating a Climate Action Plan by September 2010. The Plan is to cover both mitigation and adaptation for all economic sectors in the state. An Integrated Assessment for Effective Climate Change Adaptation Strategies in New York State project began, identifying vulnerabilities, climate risks, and adaptation strategies for sectors including coastal zones and infrastructure.

In 2007, the state legislature created the New York State Sea-Level Rise Task Force to assess the impacts of sea level rise and make recommendations to mitigate such impacts. The Task Force began its efforts in June 2008 and submitted its report to the Legislature in January 2011. The Task Force Report advises their Legislature to "require (New York) state agencies responsible

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[33] See: http://www.scc.ca.gov/index.php?cat=26
Also see: http://scc.ca.gov/2009/01/21/coastal-conservancy-climate-change-policy-and-project-selection-criteria/
[34] See: http://deltavision.ca.gov/BlueRibbonTaskForce/Sept2007/Handouts/Item_9.pdf

for the management and regulation of resources, infrastructure, and populations at risk from sea level rise to factor the current and anticipated impacts into all relevant aspects of decision making." The report states that "agencies should consider storm and sea level rise impacts over the lifespan of proposed projects or actions and the time horizon of any associated impacts to the proposed projects or actions in all state operational, permitting and/or funding decisions. Relevant agencies should regularly update, modify, and refine guidance documents and plans based on the most current information on sea level rise.[35]

Lower Hudson Valley & Long Island	**2020s**	**2050s**	**2080s**
Sea level rise[2]	2 to 5 in	7 to 12 in	12 to 23 in
Sea level rise with rapid ice-melt scenario[3]	5 to 10 in	19 to 29 in	41 to 55 in
Mid-Hudson Valley & Capital Region	**2020s**	**2050s**	**2080s**
Sea level rise[2]	1 to 4 in	5 to 9 in	8 to 18 in
Sea level rise with rapid ice-melt scenario[3]	4 to 9 in	17 to 26 in	37 to 50 in

[1] NYSERDA ClimAID Team. 2010. Integrated Assessment for Effective Climate-change Adaptation Strategies in New York State. C. Rosenzweig, W. Solecki, A. DeGaetano, M. O'Grady, S. Hassol, P. Grabhorn, Eds. New York State Energy Research and Development Authority, 17 Columbia Circle, Albany, NY 12203.

[2] Shown is the central range (middle 67%) of values from model-based probabilities (16 global climate models by 3 GHG emissions scenarios) rounded to the nearest inch.

[3] The rapid ice-melt scenario is based on acceleration of recent rates of ice melt in the Greenland and west Antarctic ice sheets and paleoclimate studies.

Figure A-1. New York State Sea level Rise Projections

Prior to action by New York State, New York City's Climate Change Panel played a key role in developing the sea level rise projections used in New York State's report to the Legislature.[36] On February 17, 2009, the Panel released its "Climate Risk Information" report. Figure A-2 is an excerpt from the Panel's report and shows a maximum of 55 inches of sea level rise before 2100 using a rapid melt scenario. According to the report, rapid ice melt is already occurring. Interestingly, the melt rate used by the Panel was based on paleoclimate records rather than modeled projections. It is also important to note that the high of 55 inches is projected to potentially occur in 2080. Thus, New York State and New York City <u>proposed</u> a more conservative (i.e., higher sea level rise projection in 2100) than is now established in California.

[35] New York State Sea Level Rise Task Force, Report to the Legislature, (December 31, 2010) at p.60, available at: http://www.dec.ny.gov/docs/administration_pdf/slrtffinalrep.pdf.
[36] For example, Table 1 of the New York state report references and adopts the SLR findings published in the New York City study.

	Baseline 1971-2000	2020s	2050s	2080s
Air temperature Central range[2]	55°F	+ 1.5 to 3°F	+ 3 to 5°F	+ 4 to 7.5°F
Precipitation Central range[2]	46.5 in	+ 0 to 5 %	+ 0 to 10 %	+ 5 to 10 %
Sea level rise[3] Central range[2]	NA	+ 2 to 5 in	+ 7 to 12 in	+ 12 to 23 in
Rapid Ice-Melt Sea Level Rise[4]	NA	~ 5 to 10 in	~ 19 to 29 in	~ 41 to 55 in

1 Based on 16 GCMs (7 GCMs for Sea Level Rise) and 3 emissions scenarios. Baseline is 1971-2000 for temperature and precipitation and 2000-2004 for sea level rise. Data from National Weather Service (NWS) and National Oceanic and Atmospheric Administration (NOAA). Temperature data are from Central Park; precipitation data are the mean of the Central Park and La Guardia Airport values; and sea level data is from the Battery at the southern tip of Manhattan (the only location in NYC for which comprehensive historic sea level rise data are available).

2 Central range = middle 67% of values from model-based probabilities; temperatures ranges are rounded to the nearest half-degree, precipitation to the nearest 5%, and sea level rise to the nearest inch.

3 The model-based sea level rise projections may represent the range of possible outcomes less completely than the temperature and precipitation projections. See page 18 for more information.

4 "Rapid ice-melt scenario" is based on acceleration of recent rates of ice melt in the Greenland and West Antarctic Ice sheets and paleoclimate studies. See Appendix C for further description.

Figure A-2. New York City Sea level Rise Projections[37]

Following California's lead, several states, including New York, have recently issued sea level rise projections in 2050 and 2100. Despite the large inherent uncertainties in long term projections, alignment exists and is growing between various government agencies with regard to longer term sea level rise projections.

15. Summary and Future Reports

There are a number of documents that will either establish or inform sea level rise policy. A full listing and description of these initiatives is beyond the scope of this Technical Memorandum. A few examples of future reports include:

- The IPCC's 5th Assessment Report, which will be finalized in 2014.
- California Energy Commission SLR Research
- US Global Climate Change Research Program
- Federal Interagency Climate Change Adaptation Task Force [38]

On October 14, 2010, the Federal Interagency Climate Change Task Force (the Task Force), co-chaired by the White House Council on Environmental Quality (CEQ), the Office of Science and Technology Policy (OSTP), and the National Oceanic and Atmospheric Administration (NOAA), released its interagency report outlining recommendations to President Obama for how

[37] Climate Risk Information – New York City Panel on Climate Change , available at: http://www.nyc.gov/html/om/pdf/2009/NPCC_CRI.pdf

[38] The White House Council on Environmental Quality, Progress Report of the Interagency Climate Change Adaptation Task Force: Recommended Actions in Support of a National Climate Change Adaptation Strategy, October 5, 2010.

federal agency policies and programs can better prepare the United States to respond to the impacts of climate change.

In Spring 2011, the Task Force will establish a partnership committee composed of local, state, and Tribal representatives to consult with the federal government as it begins to implement the recommended actions. The report states that “the federal government must work in partnership with local, state, tribal, and regional authorities as it develops and implements adaptation strategies, since most adaptive actions will occur at the local level.”

By Mid-February 2011, the Office of the Federal Environmental Executive, with the advice of the Task Force’s Agency Adaptation Workgroup, will develop implementing instructions for how agencies should undertake adaptation planning. Through this planning process, agencies will develop and implement strategic plans that identify how and where adaptation should be incorporated into their programs, policies, and regulations.

The Task Force’s report indicates that improving accessibility and precision of sea level rise projections at the municipal level is a priority.[39] The Task Force will issue another progress report in October 2011 containing an amended set of recommendations.

[39] Available at: http://www.whitehouse.gov/sites/default/files/microsites/ceq/Interagency-Climate-Change-Adaptation-Progress-Report.pdf

SEA LEVEL RISE AND ADAPTATION STUDY

COASTAL INUNDATION REPORT

Prepared for

Port of San Francisco
Pier 1, The Embarcadero
San Francisco, CA

June 15, 2011

URS/AGS Joint Venture

URS Corporation
1333 Broadway, Suite 800
Oakland, CA 94612

AGS, Inc.
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San Francisco, CA 9410

26817945

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Plates and Maps

Abbreviations and Acronyms

CSUMB	California State University Monterey Bay
°	degrees
DEM	Digital elevation model
DHI	Danish Hydraulic Institute (Former)
GHG	Greenhouse gas
MIKE21-NSW	MIKE-21 Near-Shore Wave model
MLLW	mean lower low water
m	meters
mm	millimeter
mph	miles per hour
m/sec	meters per second
m/sec^2	meters per second squared
MWD	mean wind direction
n.d.	no date
NAVD88	North American Vertical Datum of 1988
NCDC	National Climatic Data Center
NGVD29	National Geodetic Vertical Datum of 1929
NOAA	National Oceanic and Atmospheric Administration
OAK	Oakland International Airport
SFO	San Francisco Airport
SLR	sea level rise

SWL	still water level
SWAN	simulating waves nearshore
TBC	to be considered
TBD	to be determined
TI	Treasure Island
TWL	total water level
URS	URS Corporation
USACE	U.S. Army Corps of Engineers

GLOSSARY

Bathymetry: Underwater topography of the seabed.

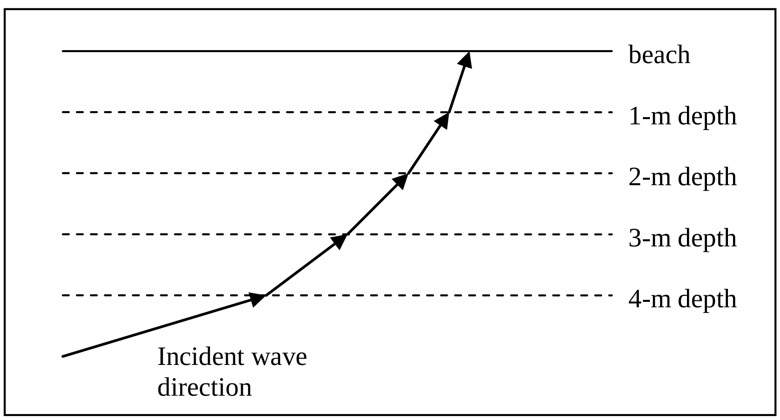
Fetch: Length of open water that wind blows over to generate wind waves.

Mean Lower Low Water: A tidal datum that is the average of the lower low water height of each tidal day observed over the National Tidal Datum Epoch. For stations with shorter series, comparison of simultaneous observations with a control tide station is made in order to derive the equivalent datum of the National Tidal Datum Epoch.

National Tidal Datum Epoch: The specific 19-year period adopted by the National Oceanic and Atmospheric Administration National Ocean Service as the official time segment over which tide observations are taken and reduced to obtain mean values (e.g., mean lower low water, etc.) for tidal datums. It is necessary for standardization because of periodic and apparent secular trends in sea level. The current National Tidal Datum Epoch is 1983 through 2001. It is reviewed annually for possible revision and must be actively considered for revision every 25 years.

Recurrence interval*:* The recurrence interval is based on the probability that the given event will be equaled or exceeded in any given year. For example an event with a recurrence interval of 100 years has a 1% chance of being equaled or exceeded in any given year (1/100 = 0.01 or 1%). It is determined by conducting a frequency analysis.

Refraction: The change in propagation direction of a wave when it enters shallower water. The wave turns toward the shallower water, as illustrated in the following exhibit.



Runup*:* see wave runup

Significant wave height: The average height of the largest one-third of the waves present.

Still water level: The water level of the sea surface in the absence of wind waves. It is about equal to the midpoint of the waves in deep water. It can be thought of as the undisturbed water level also. It includes storm surge.

Tidal prism**:** The volume of water that enters and/or leaves a bay or estuary between mean low water and high water.

Total water level: The water level of the sea surface including wind waves; it is the sum of the SWL and wave runup.

Wave runup: The maximum elevation of wave uprush above still water level.

1.1 INTRODUCTION

This report presents the results of a numerical modeling study of the San Francisco Bay in the vicinity of the Port of San Francisco and whose results form the basis for possible inundation (flooding) along its shoreline. The modeling was used to determine the still water level (SWL) and total water level (TWL) along the San Francisco shoreline for different recurrence intervals. Both existing conditions and future conditions incorporating estimates of sea level rise for the years 2050 and 2100 were analyzed. The SWL incorporates the effect of the tides and storm surge, and the TWL also includes the runup from waves.

The results of the SWL and TWL elevations were used to determine the extent of inundation for the study years 2010, 2050, and 2100, and are shown on the inundation maps attached to this report.

2.1 INTRODUCTION

This report section describes the analysis methods and data used to estimate the SWL along the Port of San Francisco shoreline. Section 2.2 describes the model used for the analysis. Section 2.3 provides a description of the data used.

2.2 ANALYSIS METHOD

The SWL along the San Francisco shoreline was determined with the MIKE 21 modeling software developed by DHI (formerly the Danish Hydraulic Institute). MIKE 21 is a two-dimensional, free-surface flow modeling system that simulates hydraulics and hydraulics-related phenomena in estuaries, coastal waters, and seas where stratification can be neglected. This modeling system simulates the changes in water levels and velocities in response to tides, ocean swell, wind, and freshwater inflows; and solves the time-dependent, vertically integrated equations of continuity and conservation of momentum in two horizontal dimensions. The equations are solved by a finite difference method. Water levels and flows are resolved on a rectangular grid covering the area of interest.

2.3 MODEL INPUTS

Model inputs consist of boundary conditions, physical information on the model extents, and any water sources (such as creeks or rivers) that exist in the interior of the model domain. Boundary conditions are the ocean tides and freshwater inflows at the most up-estuary portion of the model domain. Physical information includes the model grid, bathymetry, friction due to bed resistance and wind shear on the surface. Although not important to this study of the Port of San Francisco shoreline, source inputs include the major rivers that discharge to the Bay such as Alameda Creek, Guadalupe River, Napa River, and Petaluma River, plus numerous smaller creeks.

2.3.1 Boundary Conditions

Boundary conditions consist of the tides at the ocean boundary, and freshwater inflows from the Delta (Delta Outflows). For the ocean boundary condition two different scenarios were simulated, existing conditions and future conditions with sea level rise (SLR).

2.3.1.1 Ocean Boundary Condition

The ocean boundary consists of tides at the Pacific Ocean boundary. The tidal data applied at the Pacific Ocean model boundary were based on measured data from the National Oceanic and Atmospheric Administration (NOAA) tide station at the Presidio (Station 9414290). To capture the natural variability of the tides, a 110-year period of record was analyzed. All water surface elevations in this report are referenced to the NAVD88 vertical datum.

Existing Conditions

Hourly water levels recorded at the Presidio from 1901-2010 (110 years in total) were used to develop the model's open boundary condition. During this period there was an average increase in sea level of about 2 millimeters per year (mm/year). These data were adjusted to a mean sea level of the year 2010 by removing the approximately 2-millimeter-per-year (mm/year) increase in sea level. For example, measured water surface elevations from 1901 were increased by approximately 220 mm (2 mm/year times 110 years), while data from 2000 were only increased by 20 mm (2 mm/year times 10 years). This created a 110-year-long water level time series oscillating around the mean sea level of the year 2010.

During times when the Presidio tide gauge was inoperable or otherwise did not contain observed water level data, the NOAA-predicated water level was used instead. This predicted water level is based on the astronomical tide only, so it does not account for storm surge. However, missing measured data were rare, comprising only 1.6 percent of the hourly records.

Sea Level Rise Scenarios

For purposes of this report, 15 inches was selected from the Sea Level Rise Analysis Technical Memorandum (SLR Analysis) dated March 2011 as the approximate SLR from January 1, 2000 to January 1, 2050; and 55 inches was selected as the approximate SLR from January 1, 2000 to January 1, 2100. As noted in the SLR Analysis (Section 3-1), a SLR of 55 inches in 2100 is consistently used for vulnerability assessments. These SLR values were added directly to the 110-year time-series of tides developed for existing conditions (year 2010) to create two new data series: applicable to either year 2050 or 2100.

In addition to SLR, other aspects of climate change (e.g., increased intensity of storms) could potentially affect sea levels along the San Francisco shoreline. Coastal inundation at specific locations along the San Francisco shoreline at a given point in time is due to four factors: local sea level (tides plus storm surge), ocean swell, wind (due to local wind speed and direction), and freshwater inflows to San Francisco Bay.

For the analyses presented in this report, the above factors were taken from the historic record for existing and future conditions except for tidal elevations, which were increased by the amount described in the SLR Analysis. The future conditions for ocean swell, wind waves, and freshwater inflow are all a function of weather. Climate is the spatial and temporal average of weather. Climate change provides information on how this average may change, but does not describe how individual events will change. Because this analysis depends on the simultaneous occurrence of individual events such as tides and storm surge, ocean swell, wind waves, and fresh water inflow, information is needed on the future values and timing of these inputs. Climate change modeling is not yet capable of predicting these relationships at the temporal and geographic scale used in water-level modeling. However, unless climate change results in major changes in the types of weather that occur in the San Francisco Bay Area (e.g., hurricanes), SLR is the dominant factor affecting future inundation along the San Francisco shoreline; therefore, neglecting these climate change factors should not have a significant impact on future flood inundation estimates.

2.3.1.2 Freshwater Boundary

The freshwater boundary at the most up-estuary portion of the model was specified using the Sacramento-San Joaquin River Delta average daily flow rate estimated by the California Department of Water Resources using the DAYFLOW program (http://www.iep.water.ca.gov/dayflow). This computer program estimates the net Delta outflow by performing a water balance around the boundary of the Delta, taking Chipps Island as the western limit. The net Delta outflow is the sum of the total Delta inflow (including surface water inflows, streamflows, etc.) and runoff from precipitation over the watersheds making up the Delta, minus the Delta-wide consumptive use (e.g., channel depletion) and total Delta exports and diversions.

DAYFLOW output was available for years 1956-2008. For the remainder of the 110-year tide record (1901-1955 and 2009-2010), each year of Delta outflow was selected from the existing data based on a relationship between peak Delta outflow and storm surge in the Bay. This relationship was developed by finding the highest 25-hour-averaged (tidally averaged) water level at the Presidio during each year for which DAYFLOW data exist, and comparing this surge height against the Delta outflow for the day on which that surge was observed. The resulting relationship is shown in Figure 2-1. Although there is considerable variability, the figure indicates a clear correlation between storm surge at the Presidio and Delta outflow. This correlation is likely because the sub-tidal water level surges in the Bay typically correspond to large storm events, which also result in large volumes of freshwater entering the Bay.

To develop flow records for the years 1901-1955 and 2009-2010, the highest sub-tidal surge during each of those years was found from the Presidio tide gauge record. This surge elevation was compared to the surge elevations during years with DAYFLOW data. The year with DAYFLOW data with the surge at the Presidio closest to this value was chosen as representative of the flow during the year without DAYFLOW data. For example, the highest surge in 1901 (a no-flow-data year) is closer to the surge in 1962 than in any of the other with-flow-data years. Therefore, the flow during year 1901 is assumed to be identical to the flow in 1962. This helped preserve the correlation between high Delta outflows and storm surges that are known to occur.

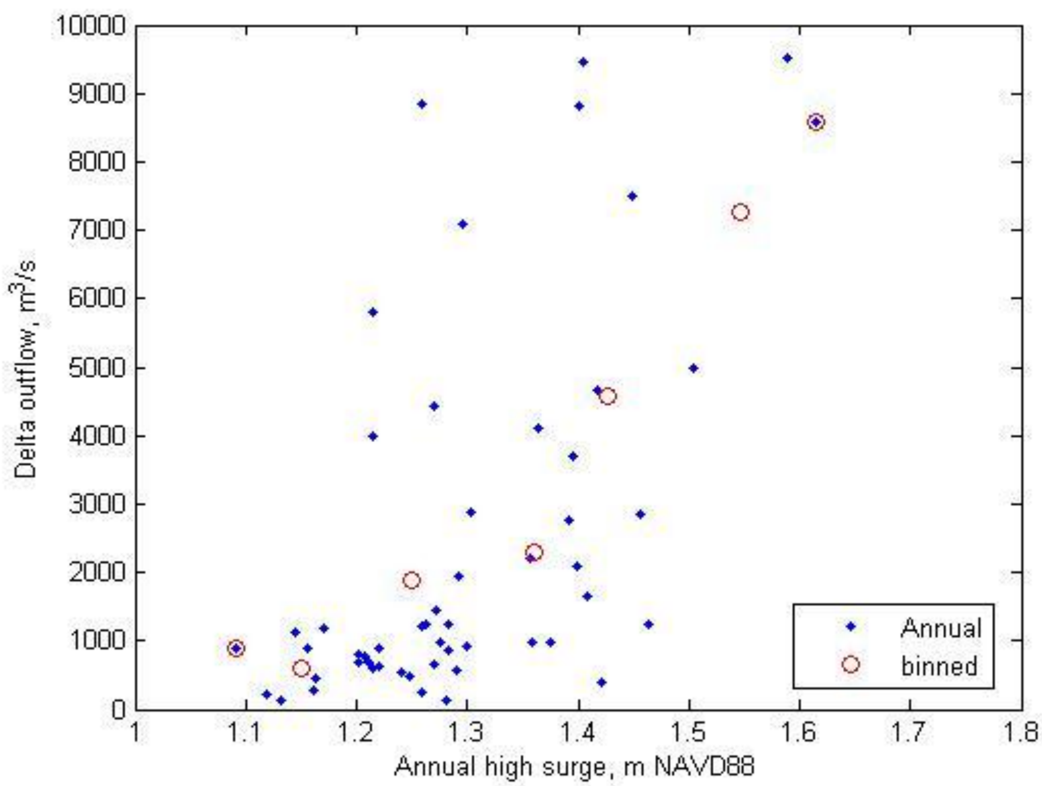


Figure 2-1. Comparison between peak annual tidally averaged water level at the Presidio and Delta outflow on the same day. Annual values represent measured values. Binned values represent average values for elevation and outflow for values within specified bins.

2.3.1.3 Physical Information

Physical information describes the physical attributes of the model such as model domain, bathymetry and grid size, and frictional components such as bed resistance and wind speed and direction.

2.3.1.4 Model Domain, Bathymetry, and Grid Size

For the two-dimensional hydrodynamic model, a trade-off exists between model run time and model resolution. That is, to gain greater resolution (i.e., smaller grid size) model run times need to be increased. For example, doubling the resolution increases model run time by more than a factor of four. Since the model will be run for a long (110-year) simulation period, a larger grid is required to keep model run times to a reasonable value (e.g. ~1 day). A 990-meter resolution grid was selected to represent the bathymetry of the entire San Francisco Bay—from the mouth of the Delta to the Golden Gate—as a compromise between the accuracy of the estimated still-water elevations and the model computation time. The model domain is shown in Figure 2-2.

The 990-meter grid was created using grid aggregation with mean values from a 30-meter grid covering the entire model domain, which is also shown in Figure 2-2 for comparison. The 30-meter grid was compiled from the following datasets:

- A 2-meter resolution grid of the mouth of San Francisco Bay at the Golden Gate from 2004, and 2005 multibeam survey data (Barnard, et al. 2006, CSUMB 2007a).
- A 4-meter resolution grid generated from three multibeam surveys of the central Bay between the Golden Gate and east of Angel Island, performed in 1996 and 1997 (USGS 2007).
- Grids created by URS from NOAA soundings (NOAA, NGDC 2007).
- A 1-meter resolution grid of the south Bay mudflats from LiDAR survey data (Foxgrover and Jaffe 2005, SFEI 2007);
- A 1-meter resolution grid in San Pablo Bay (CSUMB 2007b);
- A 30-meter resolution NOAA digital elevation model (DEM) for San Francisco Bay (NOAA 1998);
- A 25-meter resolution grid for South San Francisco Bay below the Dumbarton Bridge (Smith and Cheng 1994).

The above data were converted from the dataset's vertical datum (mean lower low water [MLLW], National Geodetic Vertical Datum of 1929 [NGVD29], or North American Vertical Datum of 1988 [NAVD88]) to NAVD88. Elevations were converted from MLLW based on a grid of values interpolated from the corrections available at tidal stations located throughout the Bay. Elevations were converted from NGVD to NAVD using a grid made from datum translation values derived from the NOAA/National Geodetic Survey program VERTCON 2.0.

In order to have the correct volume of water enter and leave the Bay during a tidal cycle, the tidal prism of the Delta was represented by adding a region with constant depth to approximately account for the volume of the Delta to preserve the tidal prism in the Bay.

2.3.1.5 Frictional Components

Wind Data

Wind blowing across the water's surface tends to drag the surface of the water in the direction of the wind. This has an effect on the speed and direction of currents in the Bay. It can also result in wind setup, i.e., the tendency for water levels to increase in the downwind direction. The wind speed and direction data collected by the National Climatic Data Center (NCDC) at San Francisco International Airport (SFO) at hourly intervals was selected for model input owing to its relative proximity to the Port of San Francisco, and its long period of record. Although wind speed and direction vary over different parts of the Bay depending on the origin of the wind and the local terrain, the same wind data were applied to the entire Bay.

The applicability of this assumption was tested during a previous study by comparing simulations using SFO wind for the entire Bay to a simulation using a wind field composed of SFO and San Pablo Bay wind data for the South Bay and the North Bay, respectively (URS, 2003). Results from a 1-month simulation from November 1, 1993 to December 1, 1993 showed that the sediment flux at the Bay Bridge was the same for the two simulations, indicating similar hydrodynamics. Therefore, it was concluded that, although the winds observed in the South Bay and the North Bay differ, using the SFO wind data for hydrodynamic modeling of the entire Bay provides approximately the same result as using the respective winds in the different embayments (URS, 2003).

Wind data at SFO were available for years 1932-2007, with measurements at hourly or even more frequent intervals. For years 1901-1931 and 2008-2010, wind data were synthesized by the same method used for Delta outflow. The relation between direction and surge is a nearly constant line because most storm winds at SFO are southerly (wind direction 180 degrees), but the relation between wind speed and surge is not as clear as the relation between Delta outflow and surge, as shown in Figure 2-1. Figure 2-3 shows the relation between wind speed/direction and high surge.

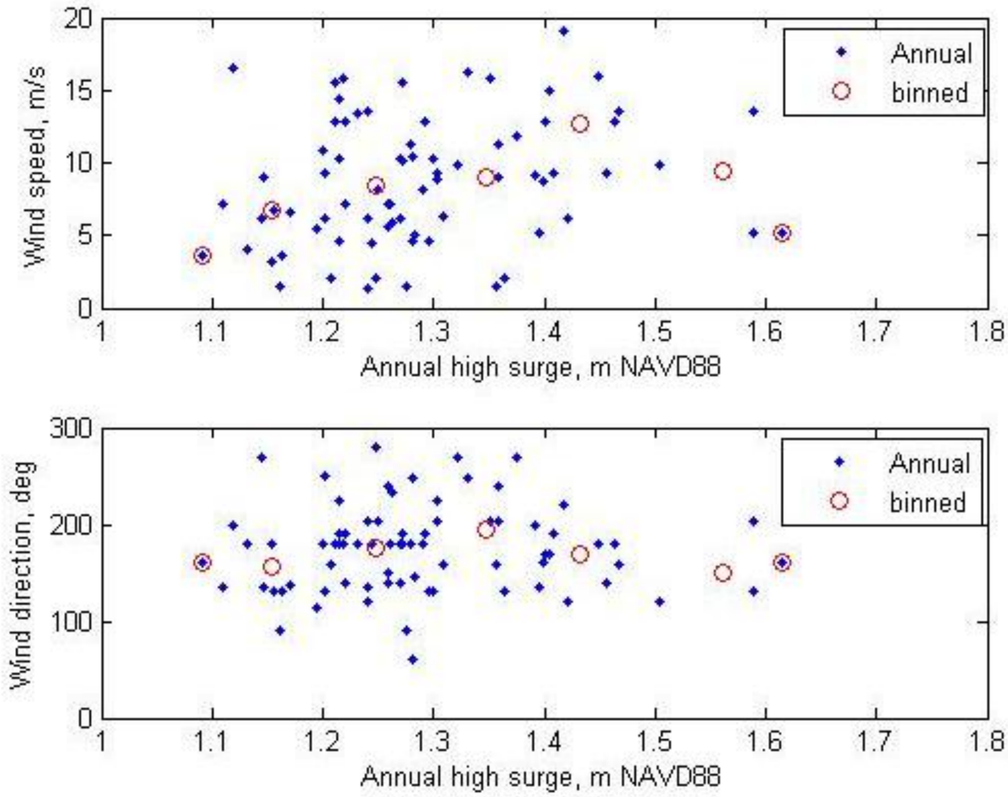


Figure 2-3. Comparison between peak annual tidally averaged water level (high surge) at the Presidio tide gauge and the wind speed and direction on the same day. Annual values represent measured values. Binned values represent the average value for elevation and speed and direction for values within specified surge bins.

Nonetheless, this method of wind data synthesis preserves seasonal and daily wind variations, and any correlations that may exist between high surge, Delta outflow, and wind events (i.e., if a storm produces high water levels at the same time as high Delta outflows and high wind speeds).

Bed Resistance and Turbulence

The bed resistance was represented using Manning's n. These values were determined from a previous calibration of a MIKE 21 model using a 200-meter resolution grid for the San Francisco Bay (URS 2003), and generally ranged from 0.015 in deeper water to 0.033 in shallow water.

Horizontal mixing due to turbulent mixing and other sub-grid-scale mixing processes is represented in the MIKE 21 model by an eddy viscosity formulation. The Smagorinsky formulation calculates the eddy viscosity as a time-varying function of the local velocity gradients multiplied by the Smagorinsky factor (DHI 2009). The Smagorinsky factors were determined from the previous calibration (URS 2003) and were generally used to damp out numerical oscillations that can occur in areas with lower grid resolution.

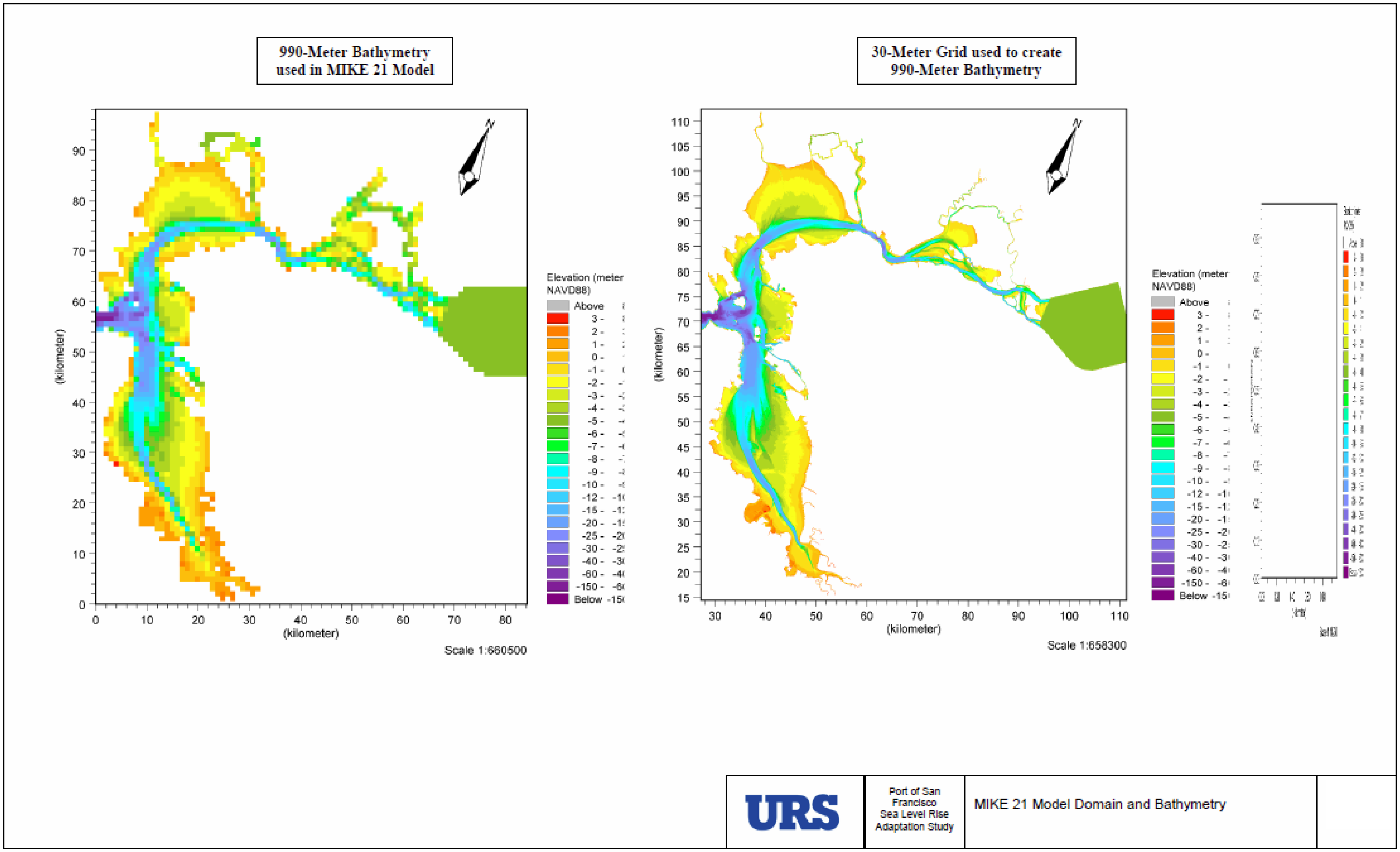


Figure 2-2. MIKE 21 model domain and bathymetry

3.1 INTRODUCTION

This report section describes the methods and data used to calculate the total water level (TWL) in San Francisco Bay along the Port of San Francisco Shoreline. Section 3.2 provides a description of the method used to estimate TWL. Section 3.3 describes the data used in the analysis.

3.2 ANALYSIS METHODS

TWL is the sum of still water level (SWL) and wave runup. Its value depends on all the factors that affect SWL plus ocean swell and wind waves. To calculate the frequency distribution for TWL, it's necessary to estimate any recurrence interval, e.g., 100-year, for all the combinations of the factors affecting TWL need to be included in the analysis. One method of calculating all the combinations of factors is to calculate swell, wave height and runup for all values for which still water level was calculated. However, this would take excess computational time and most values would consist of small waves and runup that do not contribute to the calculation of TWL recurrence intervals. A method for ranking the information so that only those data combinations that may contribute to the TWL recurrence intervals is described that greatly reduces the required computational resources. The method for calculating wind wave and swell runup is also described below.

3.2.1 Waves

Waves incident on the Port's shoreline are a superposition of ocean swell and wind waves. At any given location on the shore, each of these types of waves causes runup independently. Because ocean swell has a longer period than wind waves do, swell can cause a higher runup than a larger wind wave will cause. The total runup height at a given location is the sum of the runup caused by the swell and wind waves individually. Therefore, ocean swell propagation into the Bay, and wind wave generation within the Bay, can be modeled independently. The resulting runup due to each must be calculated at each location of interest along the shoreline, and the runup from each must be added to determine total runup height at that point. The total runup height at a given time is added to the SWL at that time, to determine the TWL at that time.

The most direct method to determine the maximum annual TWL is to model the entire time series of ocean swell and wind waves, calculate the runup caused by each, add these to find the total runup at each location, add the runup to the SWL at that same time obtained from the SWL modeling described in Section 2, and then extract the highest TWL for each year of data. However, modeling 61 years of hourly data would take many days of simulation, and generate enormous data files (~100 gigabytes). The vast majority of the results would be small waves. Therefore, an event ranking system was developed so that only the largest events each year would be simulated, but such that the largest total water level each year was included in the simulations.

3.2.1.1 Ocean Swell Simulation

The ranking system described in Section 3.2.1.2 requires that the time series of ocean swell be transported into the model domain and to the shore of San Francisco. This was accomplished using the MIKE-21 NSW model. MIKE-21 NSW is a wind-wave model that describes the propagation, growth, and decay of short-period and short-crested waves in near-shore areas. The model takes into account the effects of refraction and shoaling due to varying depth, local wind generation, and energy dissipation due to bottom friction and wave breaking. The hourly swell data were evaluated using MIKE-21 NSW, with the grid shown in Figure 3-1. The time series of ocean swell was applied at the western open boundary (as ocean swell propagates in from approximately the west), while the other open boundaries allowed energy to leave the domain. Hourly water levels at the Presidio were used as the water level throughout the model domain. Wave directional spreading was assumed to be 30°. Dissipation of wave energy was allowed to occur via bottom friction and breaking. Figure 3-2 shows an example of the model result for wave height at one particular time. Figures 3-3 and 3-4 show the result for peak wave period and mean wave direction, respectively, at this time. The white circle in Figure 3-2 shows the location of the breakwater at Aquatic Park. For the purpose of ranking wave events described in Section 3.2.1.2, the time series of hourly ocean swell height, period, and direction was extracted from the simulation results at this location.

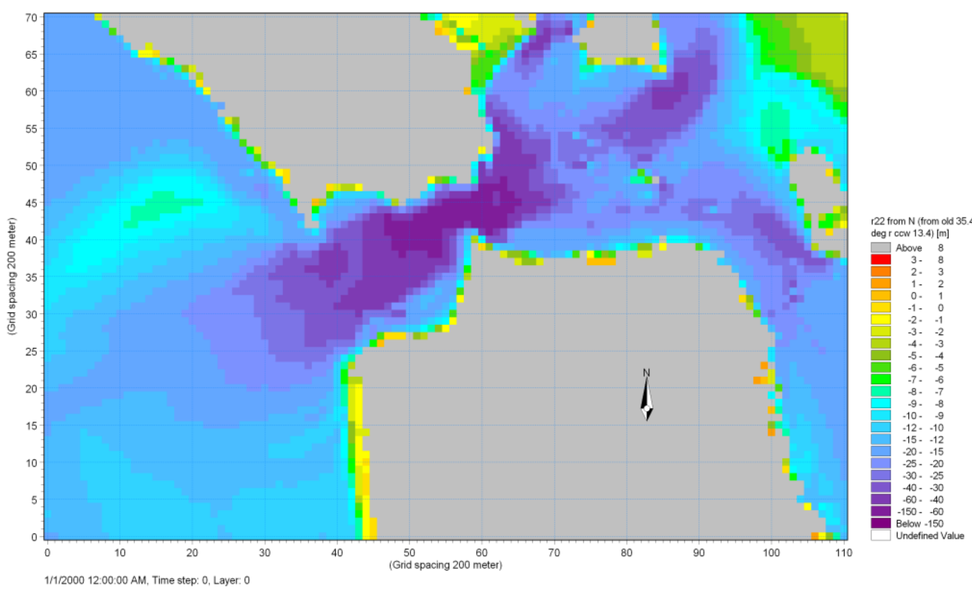


Figure 3-1. MIKE-21 NSW grid used for ocean swell propagation model simulations

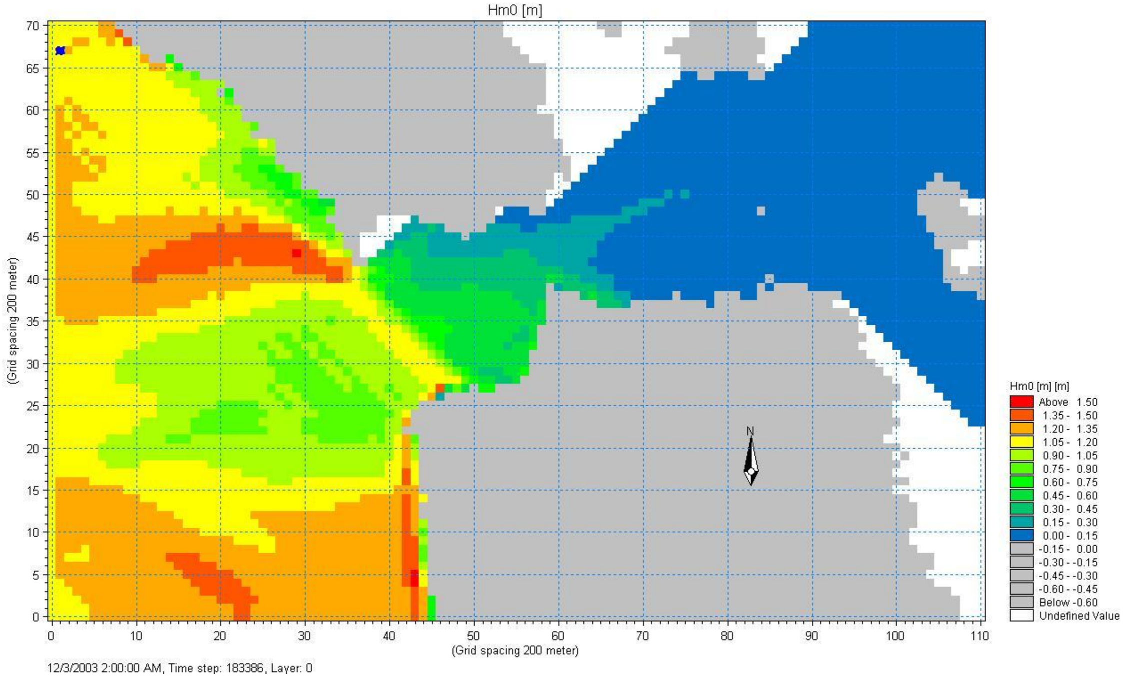


Figure 3-2. MIKE-21 NSW swell height result on December 3, 2003 at 2:00 am. Incident swell height is 1.33 m, period is 12.12 sec, and direction is 269.5 degrees. Still water level is 0.456 m NAVD88. The white circle indicates the location of the Aquatic Park breakwater. White areas indicate the leeward sides of land masses, where ocean swell does not propagate.

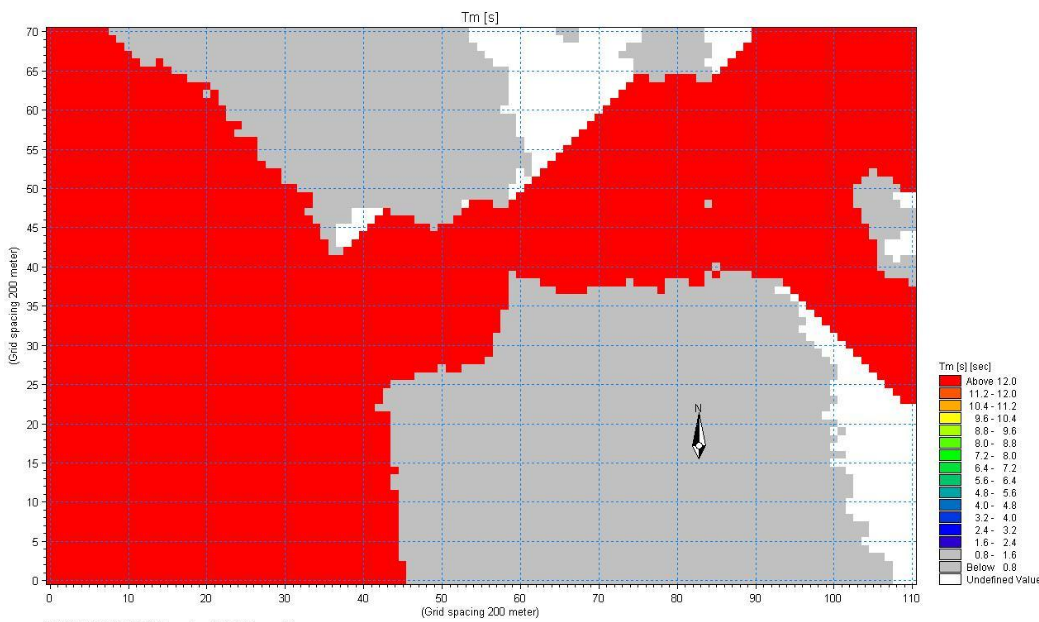


Figure 3-3. MIKE-21 NSW swell period result on December 3, 2003 at 2:00 am

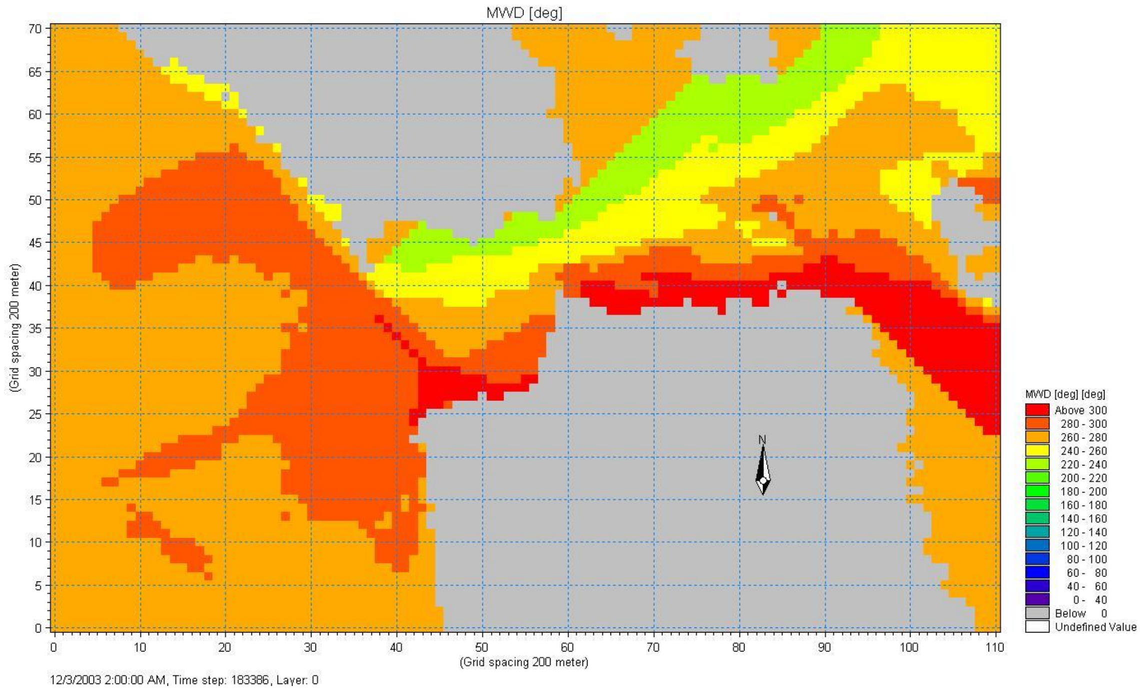


Figure 3-4. MIKE-21 NSW mean swell direction result on December 3, 2003 at 2:00 am

3.2.1.2 Event Ranking

To rank events, the time series of ocean swell at Aquatic Park, still water level at the Presidio, and winds at OAK were all interpolated onto the same hourly time base See Section 3.3.2 for description of wind data). Also, a San Francisco Bay bathymetric grid was generated for each of the 8 octants of the compass rose. MIKE-21 NSW simulates waves that propagate within approximately 22.5° direction of the -x axis.

For example, the grid of Figure 3-2 can only simulate waves propagating from within 22.5° of due west. For ocean swell, this grid was sufficient because all ocean swell entering the Bay enters from the west. Grids for the other 7 quadrants were required for modeling wind waves, and were created by rotating this grid at 45° intervals, for a total of 8 grids. This results in grids oriented in each direction of the compass rose.

For each grid, a representative fetch was determined for the purpose of calculating wind wave heights and periods. The fetches assigned are shown in Table 3-1. The wave heights for winds coming from each octant were then evaluated using the method of U.S. Army Corps of Engineers (USACE 2006) which is repeated below.

$$\frac{gH_{m_0}}{u_*^2} = 4.13 \times 10^{-2} * \left(\frac{gX}{u_*^2}\right)^{\frac{1}{2}}$$

and

$$\frac{gT_p}{u_*} = 0.751 \left(\frac{gX}{u_*^2}\right)^{\frac{1}{3}}$$

$$C_D = \frac{u_*^2}{U_{10}^2}$$

$$C_D = 0.001(1.1 + 0.035\, U_{10}) \qquad (3\text{-}1)$$

$$\frac{gH_{m_*}}{u_*^2} = 2.115 \ x \ 10^2$$

and

$$\frac{gT_p}{u_*} = 2.398 \ x \ 10^2 \qquad (3\text{-}2)$$

Where,

X = straight line fetch distance over which the wind blows (units of m)
H_{m0} = energy-based significant wave height (m)
C_D = drag coefficient
U_{10} = wind speed at 10 m elevation (m/sec)
g= acceleration due to gravity (m/sec^2)
T_p = peak wave period (sec)
u_* = friction velocity (m/sec)

A representative wind wave height H_{m0} near the shoreline is given by the minimum of H_{m0} as determined from equation (3-1), which shows how wave height grows with fetch, and equation (3-2), which shows fully-developed wave height for a given wind speed.

For each hour during the 61-year span of wind data, a representative TWL was determined as the sum of the SWL at the Presidio, the swell height at the Aquatic Park breakwater, and the representative wind wave height determined above. For each octant, the 20 largest events each water year were chosen for further analysis, leading to a total of 160 events per year of the wind data record. However, this ranking assumes that both swell and wind waves are important processes in the ranking, and that the height of the swell is close to its value at the Aquatic Park breakwater. This assumption is valid along the Port’s northern shoreline; however, swell does not extend to the Port’s eastern shoreline, so only wind waves should be included in the ranking along the eastern shore. Therefore, winds from the five quadrants with fetch affecting the Port’s eastern shoreline (for winds coming from within 22.5° of directions 0°, 45°, 90°, 135°, and 180°) were re-ranked without ocean swell as well, so that the TWL was considered as the SWL plus the representative wind wave height. For each of these five octants, the 20 largest events ranked by TWL in this manner for each water year were also selected for further analysis, for an additional 100 events per year of the wind data record. Combining events ranked with and without swell, 260 events per year (minus the number of overlapping events) were selected for further analysis.

Table 3-1. Representative fetch for each grid rotation octant, used in event ranking

Wind incidence direction and Grid direction (azimuth of –x axis)	Fetch, km
0	14
45	12
90	8
135	28
180	2
225	2
270	2
315	8

3.2.1.3 Wind Wave Simulation

All of the events chosen via the ranking process above were further evaluated, using the DHI MIKE-21 NSW model to simulate the wind-induced generation of waves inside the Bay during those events. The water level used to simulate each event was the SLR-adjusted water level at the Presidio. Open boundaries were specified to have no incoming wave energy, and to allow wave energy to flow out without hindrance. Wave directional spreading was assumed to be 30°. Dissipation of wave energy was allowed to occur via bottom friction and breaking. Figures 3-5, 3-6, and 3-7 show example wind wave height, period, and direction fields for the case of a westerly wind.

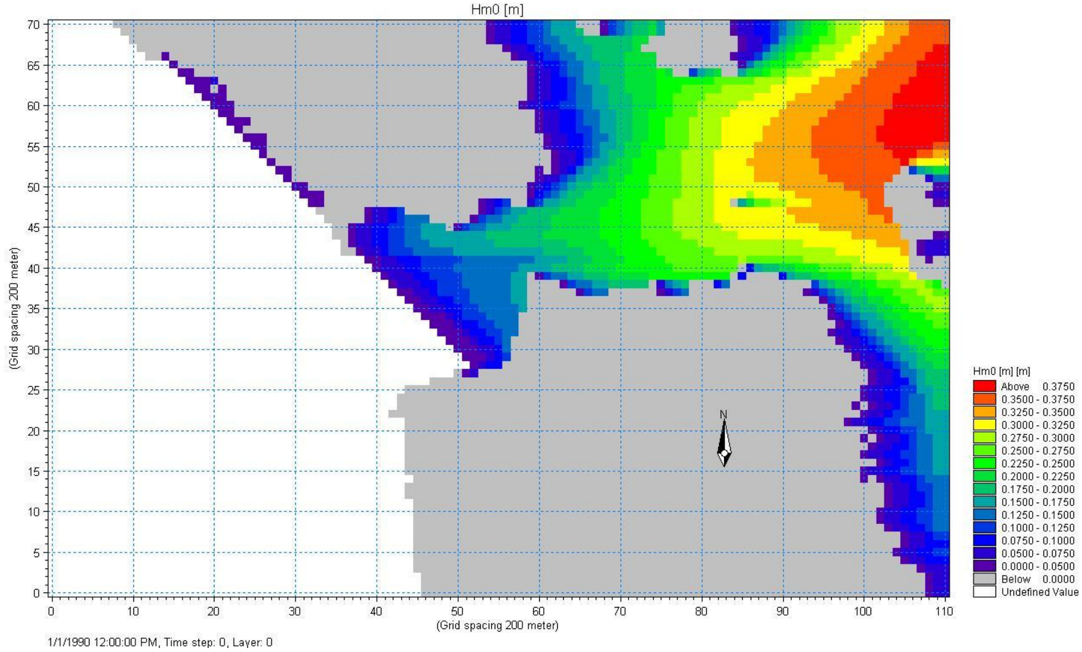


Figure 3-5. Example wind wave height field during a westerly wind

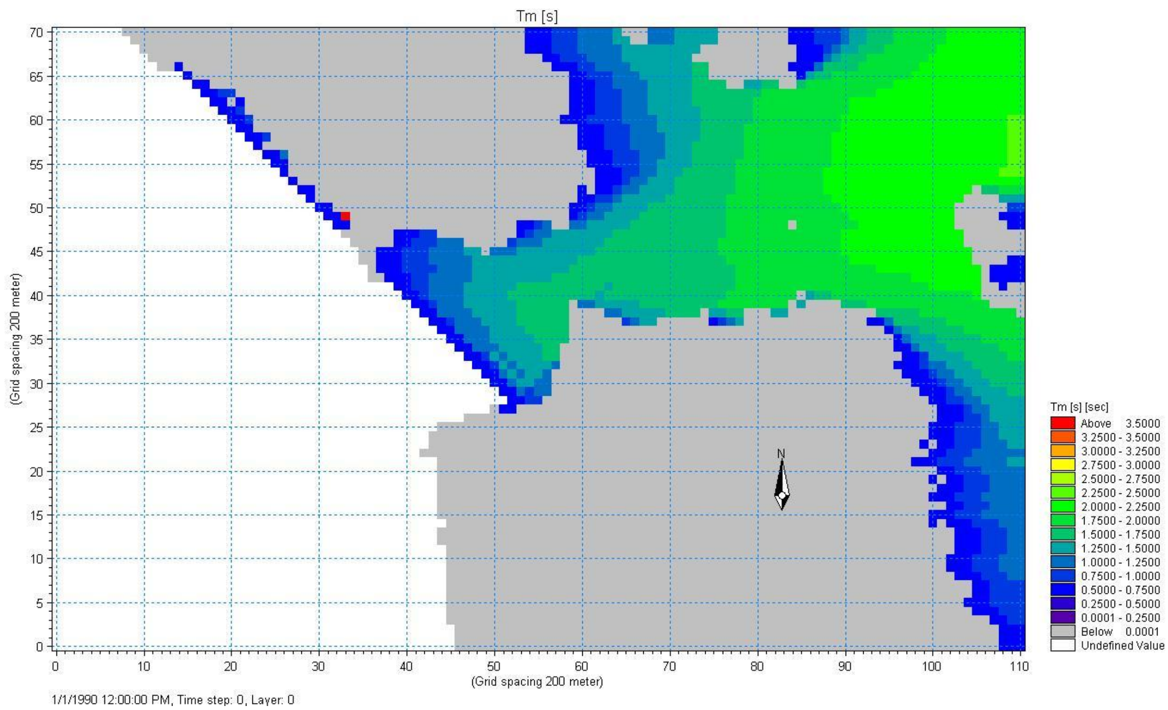


Figure 3-6. Example wind wave period field during a westerly wind

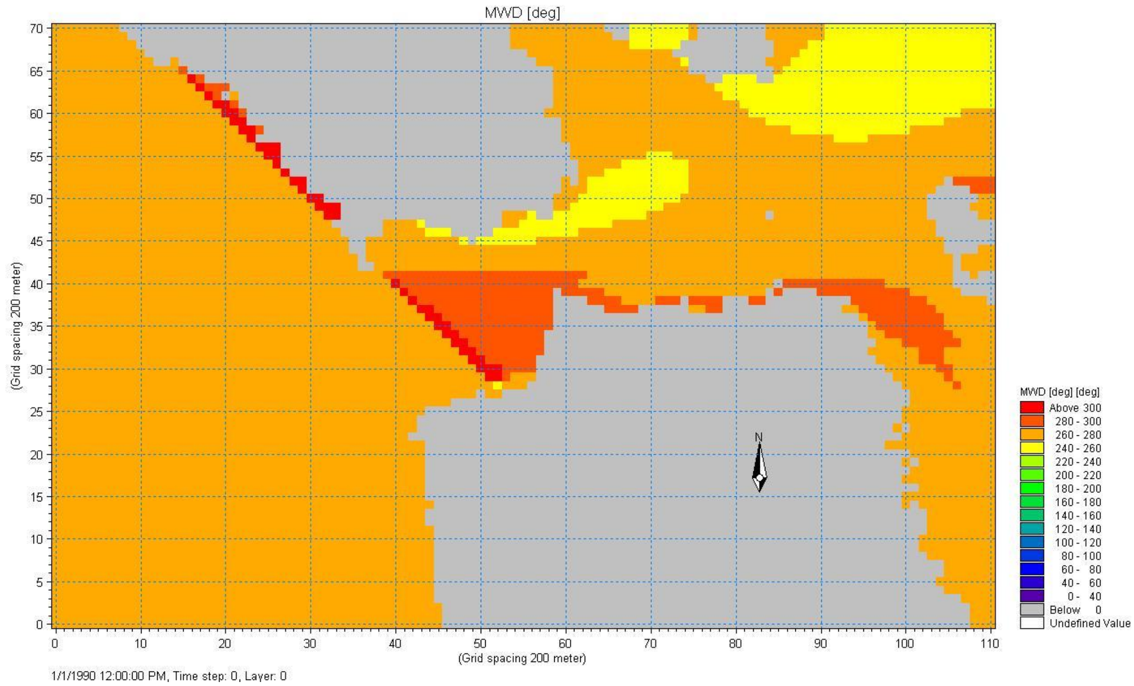


Figure 3-7. Example wind wave direction field during a westerly wind

3.2.1.4 Runup and Total Water Level Calculation

Wave height, period, and direction for both wind waves and ocean swell were extracted from the MIKE-21 NSW result fields for 20 locations along the Port waterfront. These points are listed in Table 3-2. Because individual piers and breakwaters were not resolved in the simulation, each of these points is considered to be located at the seaward extent of any structure near that point.

For each simulated event, runup was calculated independently for the wind wave and for the swell result during that event. For locations with breakwaters, the total water level will be reduced due to the waves being damped by the breakwater. However, the SWL is unaffected.

The wave height inside the breakwaters were analyzed separately by implementing a finer-scale wave model with a 30-meter spatial resolution. The SWAN model [Simulating Waves Nearshore] (Delft, 2009) was used for wave simulations incorporating the breakwater. The reason for choosing SWAN instead of the MIKE-21 NSW wave model is that SWAN is able to resolve the wave field in the lee of obstacles (including the effects of wave diffraction) much better than the MIKE-21 NSW model. To achieve high resolution, only the immediate region around the breakwater was simulated. Therefore, it was necessary to specify the height, period, and direction of waves that could potentially enter through openings in the breakwater.

To avoid analyzing all possible combinations of SWL, wave height, period, and direction that could potentially enter the breakwater, only the wave height and period that when combined with the 100-year SWL produced the 100-year TWL (outside the breakwater) were analyzed since SWL is the dominant component for TWL within the breakwater. The wave direction was chosen to be perpendicular to the opening in the breakwater. This results in a conservative estimate of the 100-year TWL within the breakwater..

Table 3-2. Points where total water level is evaluated along the Port shoreline

(Note: See Figure 4-4 for point # locations)

Point #	Latitude	Longitude	Description
1	37.810811	-122.426412	Aquatic Park breakwater
2	37.810065	-122.421863	Hyde St. Pier
3	37.811591	-122.418301	Pier 45
4	37.810031	-122.413881	Pier 41
5	37.809252	-122.408431	Between Piers 35 and 39
6	37.809421	-122.404096	Pier 33
7	37.807963	-122.400534	Pier 29
8	37.804573	-122.400148	Pier 23
9	37.803114	-122.396672	Pier 15
10	37.800436	-122.393968	Pier 7
11	37.796299	-122.391393	Ferry Building
12	37.792975	-122.390277	Howard St.
13	37.790533	-122.386501	Bay Bridge
14	37.789516	-122.384613	Spear St.
15	37.785853	-122.383797	Beale St.
16	37.782495	-122.384441	Pier 38
17	37.77812	-122.387273	Giants Stadium
18	37.774049	-122.381437	Mission Rock St.
19	37.770928	-122.383668	Pier 52
20	37.768181	-122.383668	Bay Front Park.

At each location, runup calculation assumed the shoreline took the shape of a gently sloping bed ending at a vertical seawall, with the water depth at the seawall at least three times the wave height. Mean runup due to normally incident waves was then obtained from Figure 3-8. Here, H_0' is the wave height incident on the seawall, T is the wave period, g is gravity, d_s is still water depth in front of the seawall, and R is mean runup. The curve for $d_s/H=3$ was used in the calculation, because it is conservative, and because the highest Total Water Levels are expected to occur at a high SWL, when d_s/H will be large.

Actual runup will be smaller than this, however, due to oblique wave incidence (Figure 3-8 assumes normal wave incidence). The method of USACE (2006) was used to reduce runup height due to oblique wave incidence per equations (3-3) and (3-4).

$$R_{oblique} = \gamma_\beta R_{normal} \tag{3-3}$$

Swell	$\gamma_\beta = 1.0$	for $0° \le b \le 10°$	(3-4)
	$\gamma_\beta = \cos(\beta - 10°)$	for $10° \le b \le 63°$	
	$\gamma_\beta = 0.6$	for $b > 63°$	
Wind waves	$\gamma_\beta = 1 - 0.0022b$		

Here, β is the angle between the wave crest and the seawall (the angle of wave incidence), R_{normal} is mean wave runup calculated by Figure 3-8, and $R_{oblique}$ is actual mean wave runup.

At each location, each event's SWL, swell runup, and wind-wave runup were added to find the TWL for that event. The maximum TWL each year was selected from all the events modeled for each year. The result was a 61-year time series of maximum annual TWL at each location. Figure 3-9 shows the maximum annual TWL superimposed above the hourly SWL at the Aquatic Park Breakwater. This figure shows that high TWL usually corresponds with high SWL. Wave runup typically adds between 0.5 meter and 1 meter to the SWL during the largest annual events.

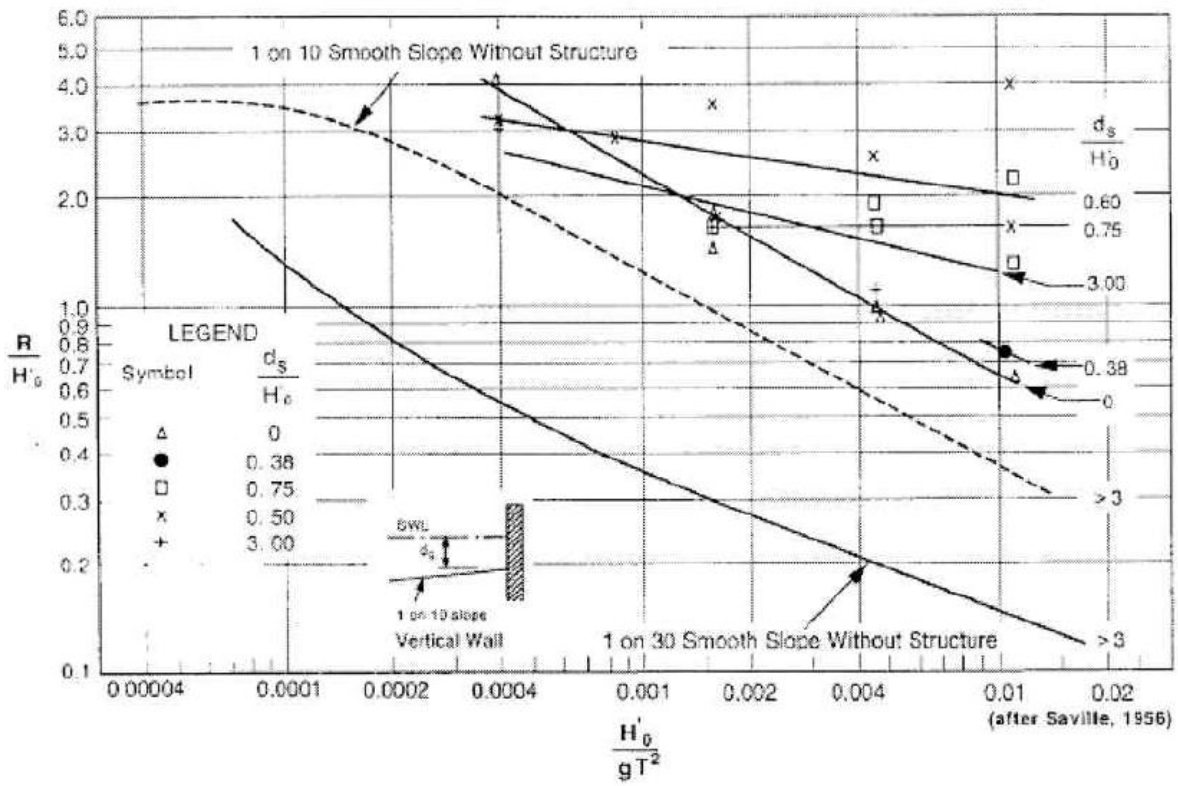


Figure 3-8. Wave runup guidance for a vertical wall
From FEMA (2007) and USACE (1984).

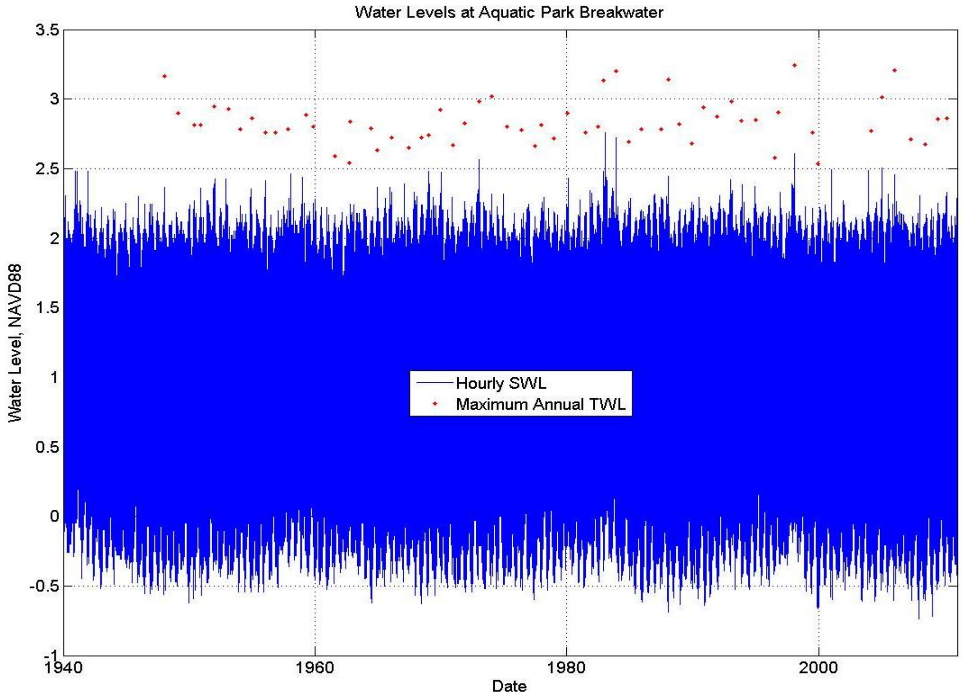


Figure 3-9. Time series of hourly still water level (SWL) and maximum annual total water level (TWL) at the Aquatic Park breakwater.

3.3 MODEL INPUTS

Model inputs required for the MIKE NWS model for the ocean swell and wind waves consist primarily of wind speed and direction and measured ocean swell offshore of San Francisco.

3.3.1 Ocean Swell

Ocean swell was taken from NOAA buoy 46026, located 18 nautical miles west of San Francisco in water with a mean depth of 179 feet (54.6 meters). Hourly data for significant wave height H_s and period T_p were available from July 8, 1982 until December 31, 2010. In addition, data for mean wave direction (MWD) were available from January 17, 2007 until December 31, 2010. To apply swell data along with wind data (for which a 60-year record exists) for wave modeling, the swell data needed to be expanded into a longer time series, just as Delta outflow and wind data were expanded to match the length of the tide record.

Figure 3-10 presents the swell data by month. The figure shows how wave height, period, and direction vary by season. To preserve the seasonal variability, the extension of the time series was done by repeating the swell record over the years before swell data measurement began. For height and period, the time period—January 1, 1983 through December 31, 2010—was repeated between January 1, 1901 and July 7, 1982. For wave direction, the time period January 1, 2008 through December 31, 2010 was repeated between January 1, 1901 and January 16, 2007. The final extrapolated data set for ocean swell is shown in Figure 3-11.

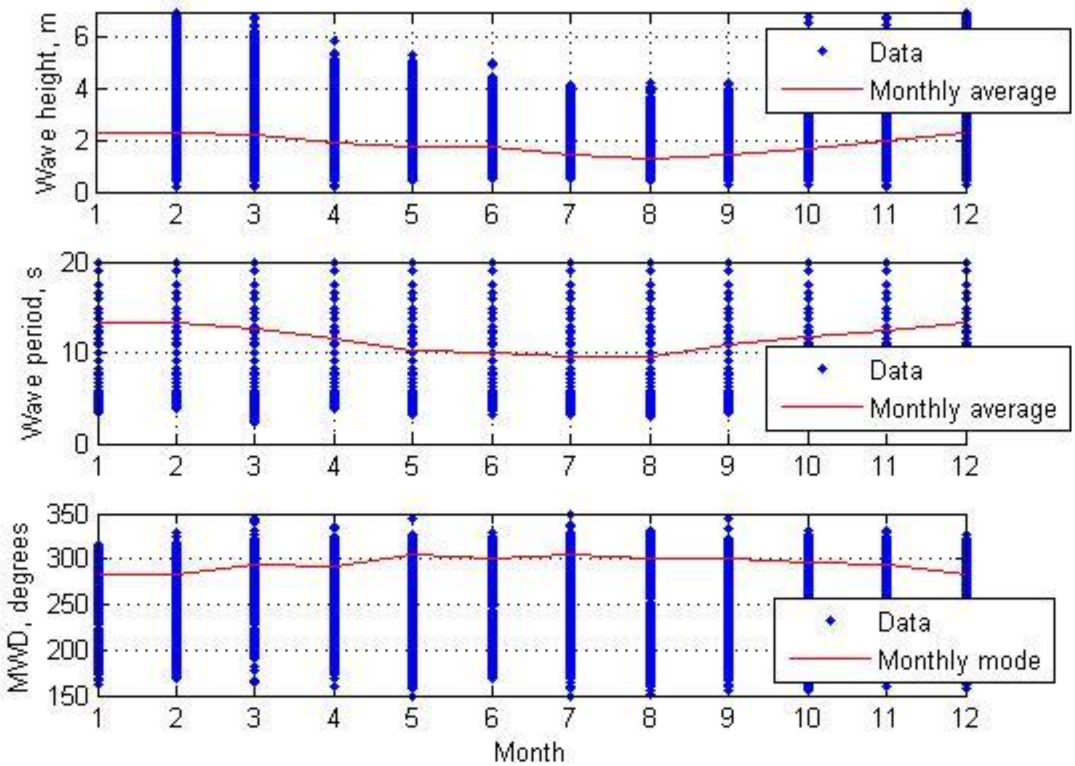


Figure 3-10. Monthly variation in significant wave height and period and direction for ocean swell offshore of San Francisco

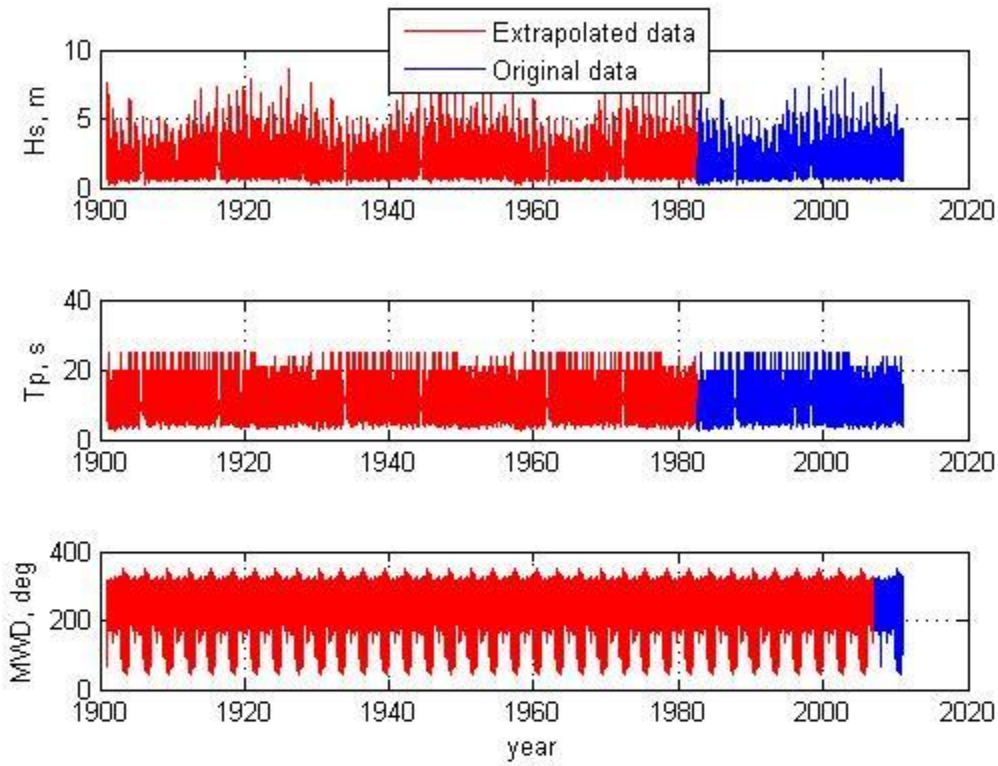


Figure 3-11. Extrapolated ocean swell data set for significant wave height (H_s), peak wave period (T_p), and mean wave direction (MWD)

3.3.2 Wind Waves

Within San Francisco Bay, long time series of hourly wind data are available only from San Francisco and Oakland airports (Table 3-3). Shorter time series of less consistent measurements are available at other locations, including the Presidio (called the San Francisco station), Angel Island (Pt. Blunt), Treasure Island, and Alameda. SFO wind data were not considered appropriate to use in the generation of wind waves near San Francisco's shoreline, because winds at SFO are controlled by the topography of San Bruno Gap, which is not representative of other areas of south and central San Francisco Bay. Winds at Oakland Airport , on the other hand, are not as constrained by topography, and are more representative of winds over the entirety of central and south bays than SFO winds are. Therefore, to estimate the size of wind wave incidents on San Francisco's shoreline, wind data at Oakland Airport were used.

Note that these are different data than were used in the SWL calculation. In the SWL modeling, the wind data mainly drive current speed and direction, and these are influenced by regional wind speed and direction. Previous studies had shown that flows and currents in the Bay are not generally influenced by small regional differences in the wind field. In the TWL modeling, winds are used to generate a local wave field, which is highly dependent on the local wind speed and direction. The wind roses for all winds at Oakland Airport and Treasure Island, which is the closest gauge to the Port's shoreline, are shown in Figures 3-12 and 3-13, respectively, indicating that most winds blow from the west. Figures 3-14 and 3-15, however, show only winds with a speed greater than 15 miles per second (m/s), and show that the strongest storm winds blow from the east, south, and north at both locations. This comparison shows that OAK winds behave similarly to those at Treasure Island.

Table 3-3. Inventory of wind data available from NOAA's National Climatic Data Center

Site	Period of data	Total span of data	Frequency
SFO	1932-2010	79 years	Hourly
OAK	1943, 1948-2000, 2004-2010	61 years	Hourly
Treasure Island	1982-1987, 1992-1996	11 years	Sporadic
Pt. Blunt	1975-1987, 1992-1996	18 years	Sporadic
Presidio	2005-2010	6 years	Hourly
Alameda	2005-2010	6 years	Hourly

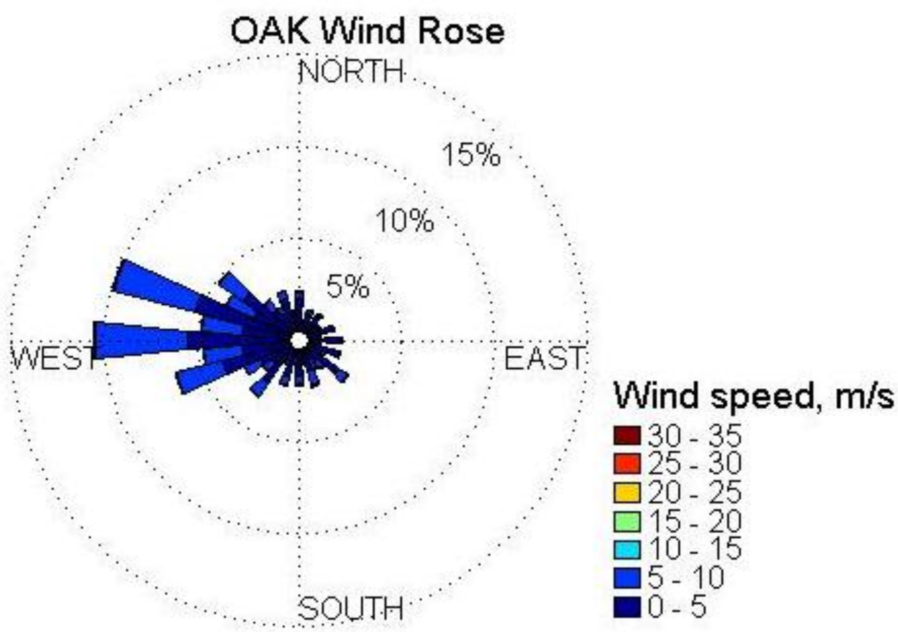


Figure 3-12. Wind rose at Oakland Airport for all observed winds.

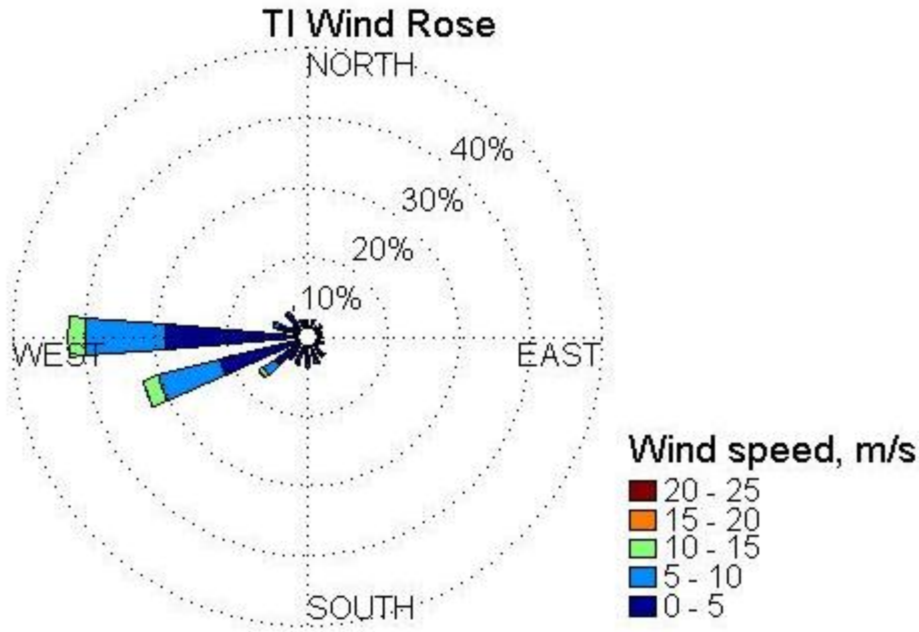


Figure 3-13. Wind rose at Treasure Island (TI) for all observed winds.

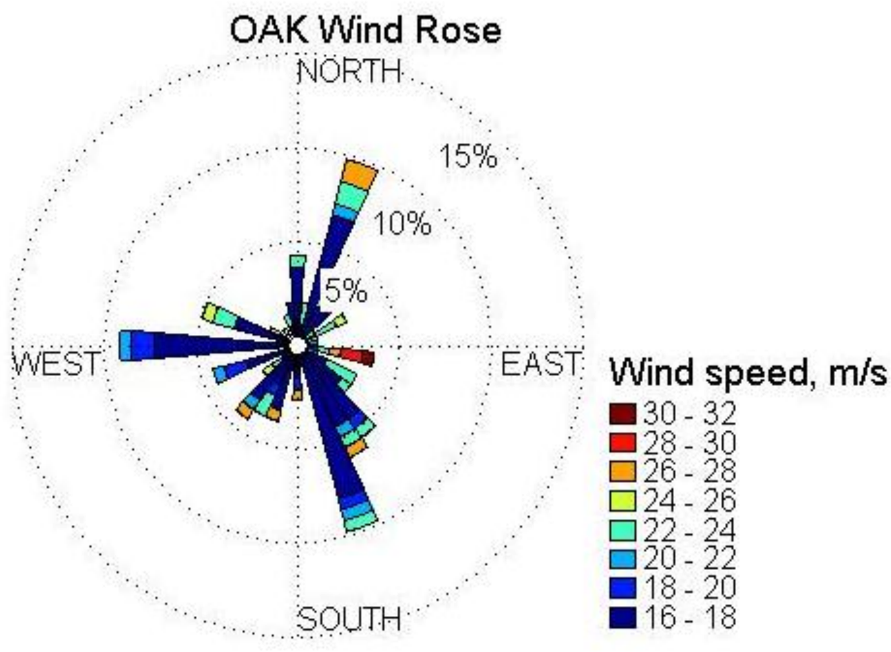


Figure 3-14. Wind rose at Oakland Airport for winds with speed greater than 15 m/s

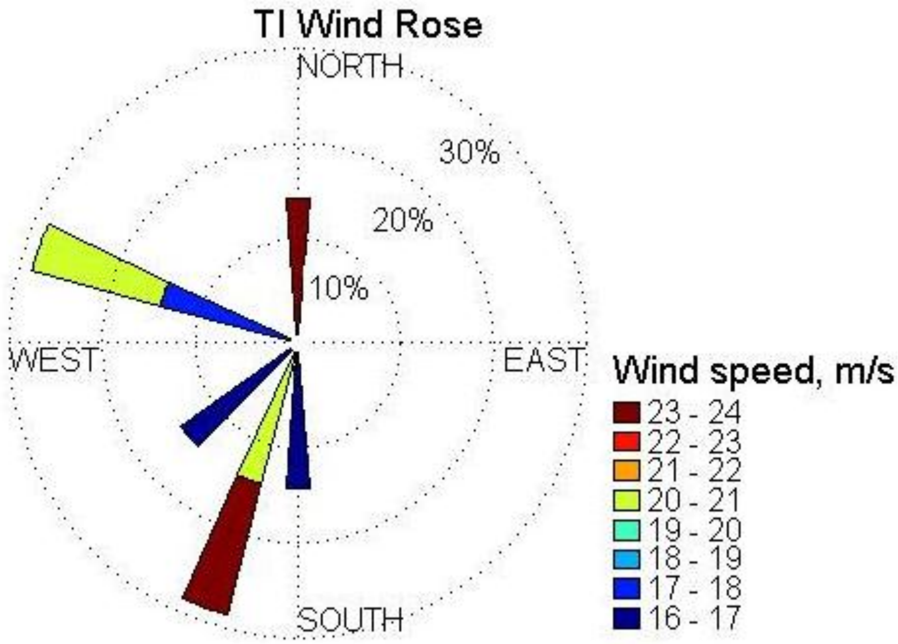


Figure 3-15. Wind rose at Treasure Island for winds with speed greater than 15 m/s

4.1 TOTAL WATER LEVEL RETURN FREQUENCY ANALYSIS

The results of the above analysis were used to determine the return frequency of SWL and TWL. The return frequency was determined by fitting the maximum annual SWLs and TWLs for selected locations to a statistical distribution. The Weibull distribution is a commonly used statistical distribution for analysis of water levels. Based on the 3-parameter Weibull distribution, the probability of exceedance of a given water level is shown in equation (4-1).

$$\text{Prob} = e^{([-((x-\mu)/\lambda)]\wedge k)} \qquad (4\text{-}1)$$

Where, x is the water level, and λ, k, and μ are the Weibull parameters and Prob is the probability of exceedance. The distribution parameters were determined by least-squares fitting of the data points and an estimate of the probability. The probability of exceedance of each maximum annual water level was estimated using the Weibull plotting position, shown in Equation (4-2).

$$\text{Probability of exceedance} = (\text{event rank}) / (\#\text{ of events} + 1) \qquad (4\text{-}2)$$

After fitting the Weibull parameters, the water level corresponding to any return period can be determined. However, the data resulting from the model runs indicated the presence of more than one statistical population. Because of this, Equation (4-1) had to be fit separately to each population. The two populations likely represent events dominated by different phenomenon, such as large ocean swell, large wind waves, or wind waves incident from different directions.

Figure 4-1 shows an example of the fit for the TWL near AT&T Park. In this figure, the events with probability of exceedance less than 0.1 (equivalent to a 10-year return period) fit the red dashed line (Low Weibull fit), while the events with probability of exceedance greater than 0.1 fit the solid blue line (High Weibull fit). Therefore, estimation of an event with probability of exceedance greater than 0.1 (a return period of less than 10 years) requires choosing the appropriate water level from the Low Weibull fit, while an event with probability of exceedance less than 0.1 (a return period of more than 10 years) requires choosing the appropriate water level from the High Weibull fit. In the case of Figure 4-1, the event with probability of exceedance 0.2 (the 5-year event) has a water level of 2.94 meters NAVD88 (from the low Weibull fit), while the event with a probability of exceedance of 0.01 (the 100-year event) has a water level of 3.30 meters NAVD88 (from the High Weibull fit).

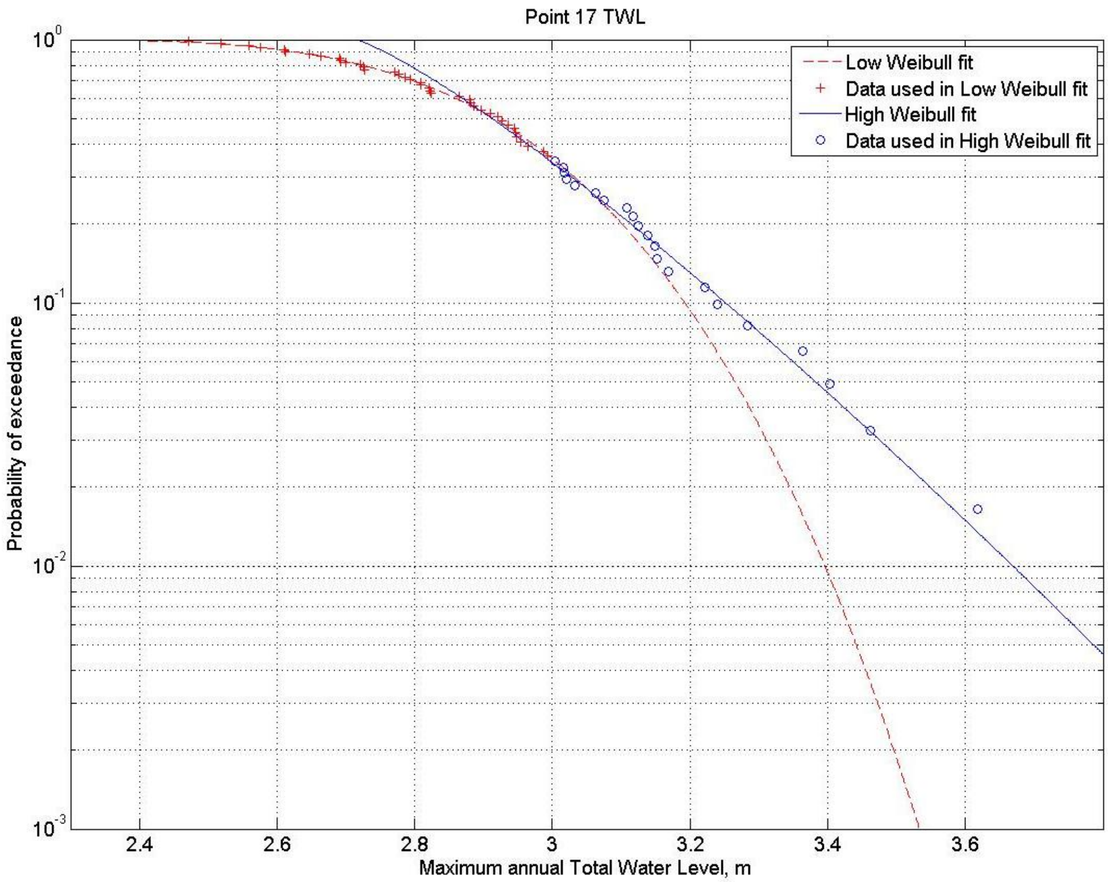


Figure 4-1. Probability of exceedance of TWL near AT&T Park

4.1.1 100-Year Water Surface Elevations

To evaluate the water levels for each of the cases with future sea level rise, the entire procedures described in Sections 2 and 3 were rerun. This allowed for the reduced dissipation that ocean swell and wind waves will experience in deeper water. Therefore, at each location the difference between the SWL and TWL under existing conditions (year 2010), and the SWL and TWL with SLR could be different than simply the amount of SLR. Figures 4-2 and 4-3 show examples of the TWL probabilities of exceedance for the cases of 15 inches and 55 inches of SLR, respectively. Table 4-1 shows the 100-year TWL resulting from each plot, and the increase in the TWL over the existing conditions case.

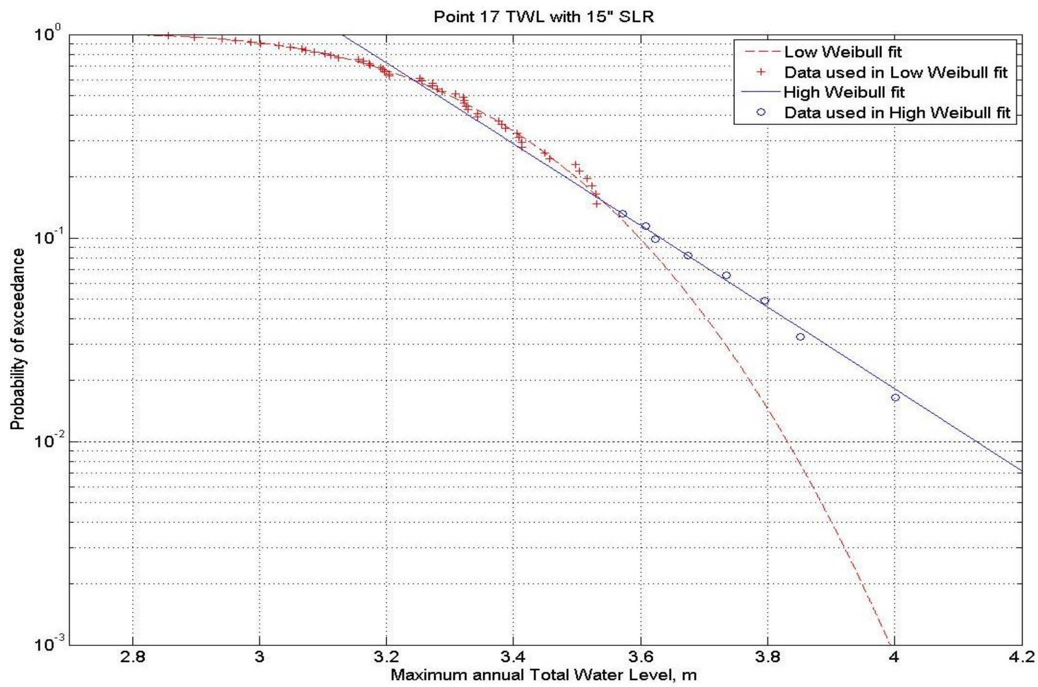


Figure 4-2. Probability of exceedance of TWL near AT&T Park with 15” of sea level rise.

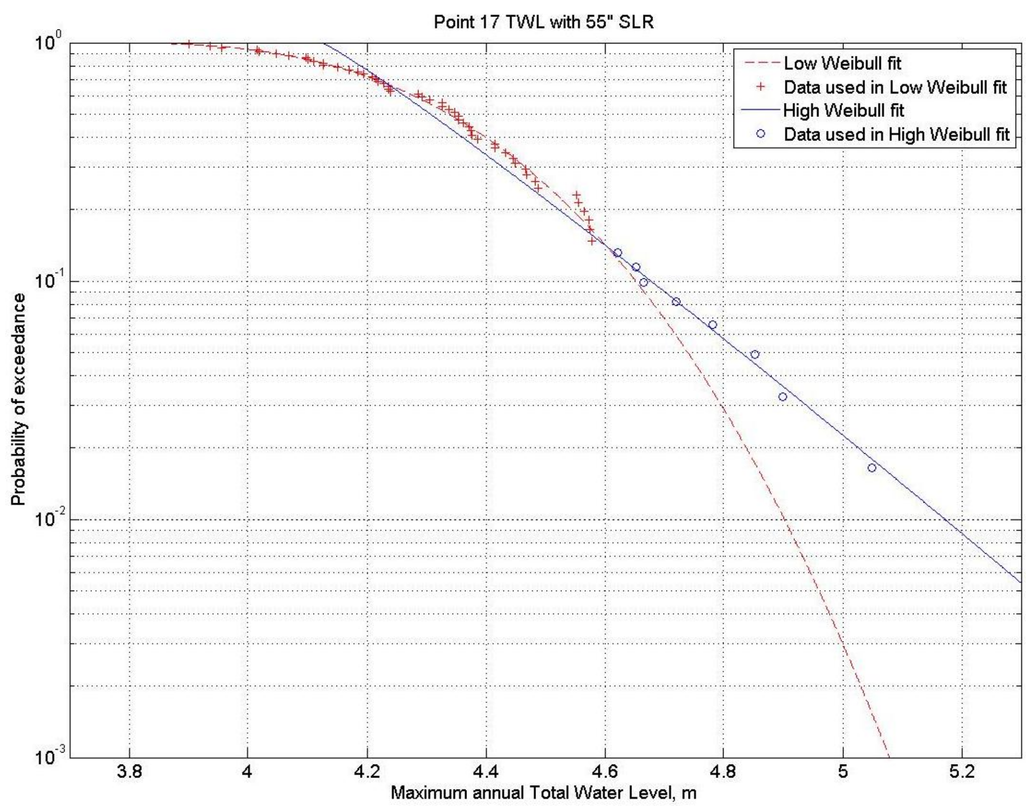


Figure 4-3. Probability of exceedance of TWL near AT&T Park with 55” of sea level rise.

Table 4-1. Example results for TWL near AT&T Park under existing conditions and with 15 inches and 55 inches of SLR

Case	TWL, meters NAVD88	Change in TWL from Existing Conditions case, meters NAVD88
Existing Conditions	3.67	n/a
SLR = 15 inches (0.38 meter)	4.13	0.46 meter
SLR = 55 inches (1.40 meter)	5.17	1.5 meter

Results for the SWL 100-year event at five locations along the San Francisco Shoreline are shown in Table 4-2. There is only a 0.10-foot (0.03-meter) variability in the 100-year water level along the shoreline. A map of the SWLs for 2010, 2050, and 2100 is shown on Plate 1. Detailed views are provided in Maps 1 through 7.

Results for the TWL 100-year event at locations along the San Francisco Shoreline identified in Table 3-2 are shown in Table 4-3. About a 3-foot variability occurs in the 100-year water level along the shoreline. Figure 4-4 shows the locations of the points in Table 4-3. Appendix A provides the SWL and TWL frequency plots for the locations shown on Figure 4-4. Maps 8, 9, and 10 show the TWL for years 2010, 2050, and 2100, respectively. Note that the TWL for point 8 (Pier 23) represents TWL between piers, not at the end of the piers, so it was not used in generating results shown in Maps 7, 8, and 9. Also, for the areas protected by breakwaters the TWL can vary within the breakwater; however, the maximum TWL within the breakwater is shown on the maps. For Pier 14 the breakwater only protects the area behind the breakwater from winds from the southeast. Since most of the largest wind events came from other directions, this breakwater only had a minor effect on the 100-year TWL.

4.2 APPLICATION OF WATER-LEVEL PROJECTIONS

Table 4-4 shows the elevations of the pier decks operated by the Port. Comparing these elevations to the results shown in Figure 4-5 provides a rough order of magnitude estimate of when a particular pier deck will be inundated. Projections of changes in sea level are contingent upon a number of assumptions. One assumption relates to the rate of greenhouse gas (GHG) emission. Results for two cases are shown on Figure 4-5, a low–GHG-emission scenario and a high-GHG-emission scenario. The SLR Analysis prepared for Task 1 (Figure 2-9 in URS, 2011) provides details on these scenarios. In any scenario there is a range of estimates of sea level rise, at least partially due to different models and estimation methods. The range for each scenario provides a measure of the variability in estimates due to estimation methods.

4.3 LIMITATIONS

These studies were conducted to address the inundation of Port facilities under projected SLR conditions. The assumption of SLR values substantially affects the conclusions and opinions presented in this report. These assumptions, although thought to be reasonable and appropriate, may not prove to be true or correct. The conclusions and opinions presented in this report are conditioned upon these assumptions. URS shall not be held responsible for any other use of the results and analysis presented herein.

The opinions presented in this report were developed with the standard of care commonly used as state-of-the-practice in the profession. No other warranties are included, either express or implied, as to the professional advice presented in this report.

Table 4-2. Predicted 100-year still water level (SWL) at selected locations along the Port of San Francisco for existing conditions and with projected SLR at years 2050 and 2100

Point Designation	Distance from Aquatic Park (meters)	Distance from Aquatic Park (feet)	Location	100-year Still Water Level (meters, NAVD88)			100-year Still Water Level (feet, NAVD88)		
				Existing	2050	2100	Existing	2050	2100
A	-700	-2297	Marina Green	2.80	3.18	4.20	9.19	10.43	13.78
B	1181	3875	Pier 41	2.80	3.18	4.21	9.19	10.43	13.81
C	2642	8668	Pier 19	2.82	3.20	4.22	9.25	10.50	13.85
D	4791	15720	Pier 30	2.82	3.20	4.23	9.25	10.50	13.88
E	6662	21858	Pier 54	2.83	3.22	4.23	9.28	10.56	13.88

Table 4-3. Predicted 100-year total water level (TWL) at selected locations along the Port of San Francisco for existing conditions and with projected SLR at Years 2050 and 2100

Point Designation	100-year Total Water Level (meters, NAVD88)			100-year Total Water Level (feet, NAVD88)		
	Existing	2050	2100	Existing	2050	2100
1	3.30	3.69	4.71	10.82	12.10	15.44
2	3.29	3.68	4.759	10.80	12.06	15.61
3	3.27	3.66	4.705	10.72	11.99	15.44
4	3.28	3.66	4.699	10.75	11.99	15.42
5	3.22	3.60	4.620	10.58	11.82	15.16
6	3.78	4.17	5.234	12.40	13.68	17.17
7	4.02	4.37	5.390	13.17	14.33	17.68
8	3.16	3.52	4.604	10.36	11.55	15.11
9	3.57	3.98	5.008	11.73	13.06	16.43
10	3.60	3.96	4.929	11.79	12.99	16.17
11	3.52	3.96	5.017	11.56	13.01	16.46
12	3.16	3.57	4.587	10.36	11.73	15.05

Table 4-3. Predicted 100-year total water level (TWL) at selected locations along the Port of San Francisco for existing conditions and with projected SLR at Years 2050 and 2100

Point Designation	100-year Total Water Level (meters, NAVD88)			100-year Total Water Level (feet, NAVD88)		
	Existing	2050	2100	Existing	2050	2100
13	3.10	3.46	4.500	10.18	11.35	14.76
14	3.85	4.32	5.295	12.62	14.17	17.37
15	3.81	4.23	5.279	12.49	13.87	17.32
16	3.91	4.22	5.281	12.84	13.86	17.33
17	3.67	4.13	5.172	12.04	13.54	16.97
18	3.84	4.21	5.243	12.59	13.82	17.20
19	3.76	4.15	5.269	12.33	13.61	17.29
20	3.76	4.16	5.268	12.33	13.66	17.28

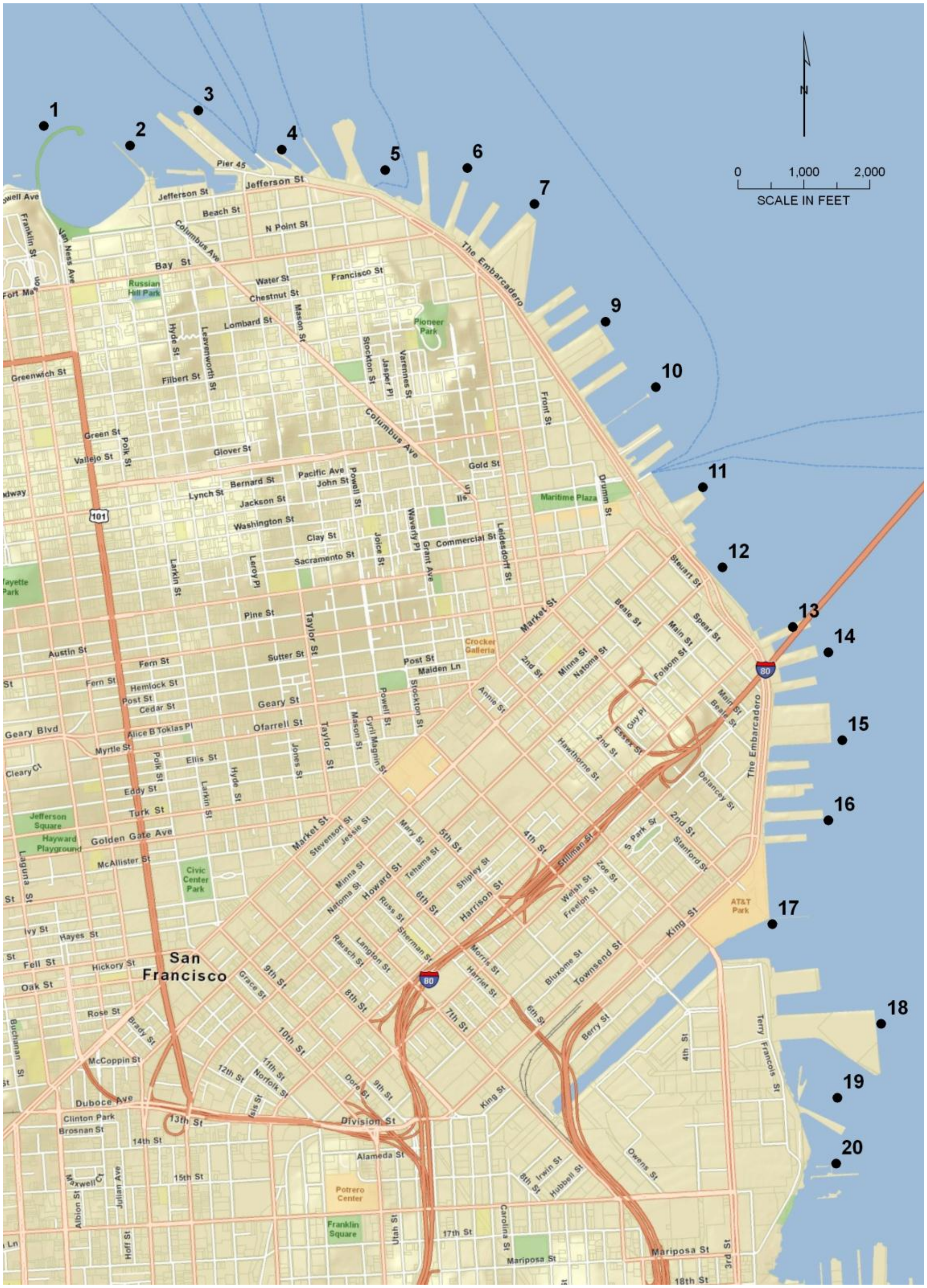


Figure 4-4. Locations where total water level was calculated

Table 4-4. Elevation of piers along San Francisco waterfront on Port property

Pier	Deck Elevation (feet, NAVD 88)
Hyde St. Pier	11.75
47	10.5
45	13.1
45 outer	12.9
45 inner	11.5
43.5	10.6
43	10.8
41	11.1
39	11.6
35	12.6
33	12.2
31	12.5
29	11.9
27	11.9
23	12.1
19	12.4
17	12.2
15	12.4
9	12.0
7	11.3
5	10.1
3	11.8
1.5	10.1
1	11.7
0.5	11.4
FPz	11.3
AgBI/Sinbad	10.8
14	14.8
Rincon Park	13.5
22.5	11.8
26	12.6
28	12.2
30/32	12.7
38	12.6
40	12.7
46	12.9
48	11.8
50	11.8
54	12.3
Low T.C. S/o P54	11.4

Table 4-4. Elevation of piers along San Francisco waterfront on Port property

Pier	Deck Elevation (feet, NAVD 88)
Low A.C. @ P64	11.1
70	11.4
80	12.2
92	11.3
94 (N end)	11.3
94 (S end)	13.6
96	12.8

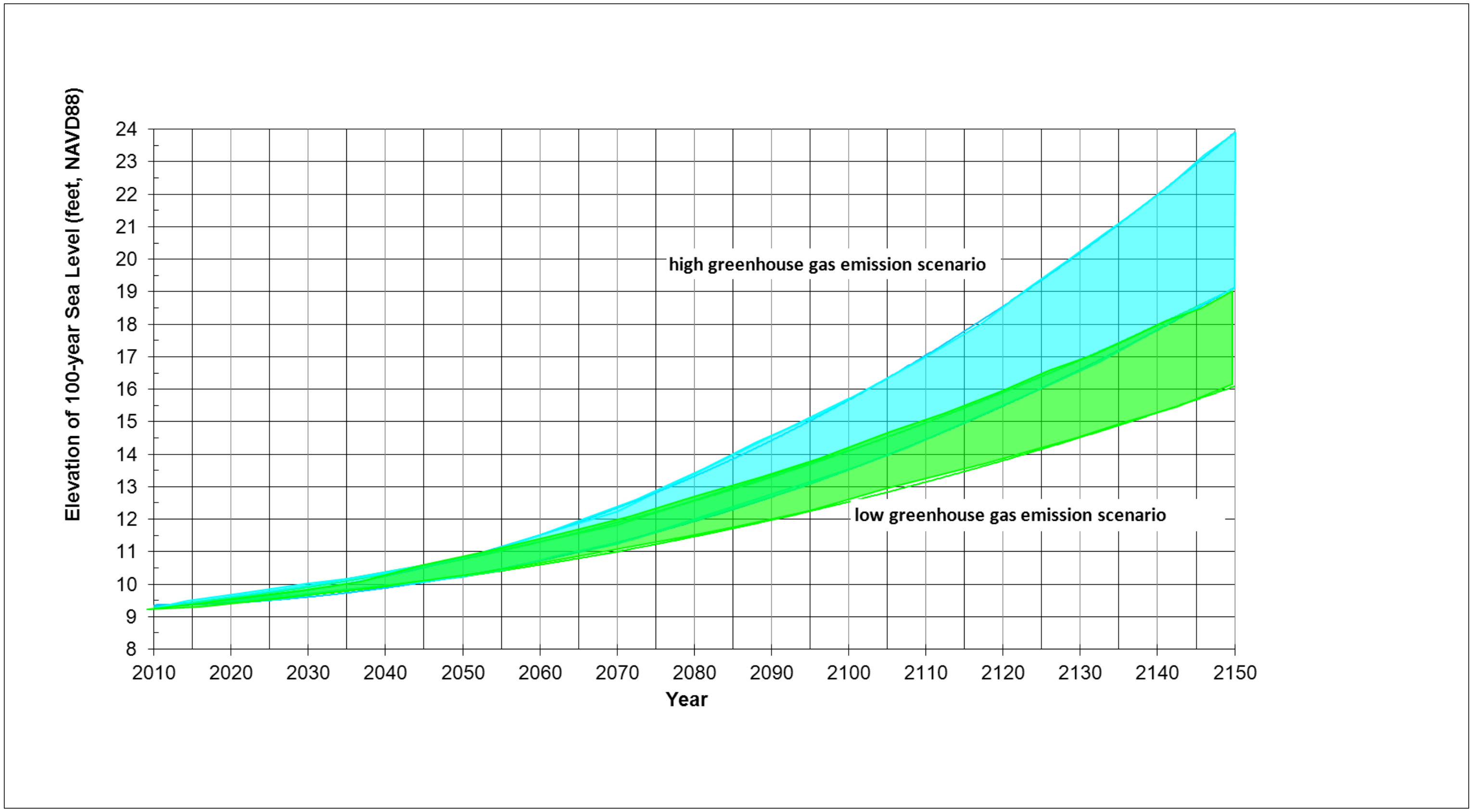


Figure 4-5. Projected Water Surface Elevations at the Port of San Francisco

Note: please see Table 2-9 in URS, 2011 for details of data. Greenhouse gas emission scenarios correspond to scenario B1 and A1F1 in the Intergovernmental Panel on climate change.

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	Deck elevation (in feet)	
Pier	NAVD88	City Datum
Hyde St.	11.8	0.4
47	10.5	-0.8
45	13.1	1.8
45, outer	12.9	1.5
45, inner	11.5	0.2
43.5	10.6	-0.8
43	10.8	-0.6
41	11.1	-0.3
39	11.6	0.3
35	12.6	1.2
33	12.2	0.9
31	12.5	1.2
29	11.9	0.6
27	11.9	0.6
23	12.1	0.7
19	12.4	1.0
17	12.2	0.9
15	12.4	1.1
9	12.0	0.7
7	11.3	0.0
5	10.1	-1.2
3	11.8	0.5
1.5	10.1	-1.2
1	11.7	0.3
0.5	11.4	0.1
Ferry Plaza	11.3	0.0
Ag Building	10.8	-0.5
14	14.8	3.5
Rincon Park	13.5	2.2
22.5	11.8	0.4
26	12.6	1.3
28	12.2	0.9
30/32	12.7	1.4
38	12.6	1.3
40	12.7	1.4
46	12.9	1.5
48	11.8	0.5
50	11.8	0.4
54	12.3	1.0

LEGEND

100-year still water levels (SWL) and inundation area

Year 2010 (existing conditions)
Elevation (ft) = 9.2 (NAVD88), -2.1 (City Datum)

Year 2050
Based on sea level rise scenario of 15 inches
Elevation (ft) = 10.5 (NAVD88), -0.8 (City Datum)

Year 2100
Based on sea level rise scenario of 55 inches
Elevation (ft) = 13.8 (NAVD88), 2.5 (City Datum)

Port of San Francisco jurisdictional boundary

Sea wall lot

0 1,000 2,000
SCALE IN FEET

1 INCH = 600 FEET
AT ANSI D (34x22-INCH) PAGE SIZE

NOTES

1. For an explanation of the analysis presented here, see "Sea Level Rise and Adaptation Study - Coastal Inundation Report" (June 2011).

2. The 100-year still water level (SWL) is the flood level that has a 1% chance of being equaled or exceeded in any given year. FEMA designates areas subject to inundation at the 100-year water level as Special Flood Hazard Areas.

3. Each shading color indicates the modeled extent of inundation for each year. Inundation for each year includes the previous year's inundation (i.e. 2050 includes 2010; 2100 includes 2010 and 2050).

4. Where the deck elevation of a pier/bridge is higher than a given inundation level (i.e. the deck is above water), the perimeter of the pier/bridge is shown.

5. SWL inundation contour lines were derived from LiDAR data provided by the Department of Homeland Security (DHS) for official City of San Francisco use under license from DHS. Survey date: May 16-19, 2007.

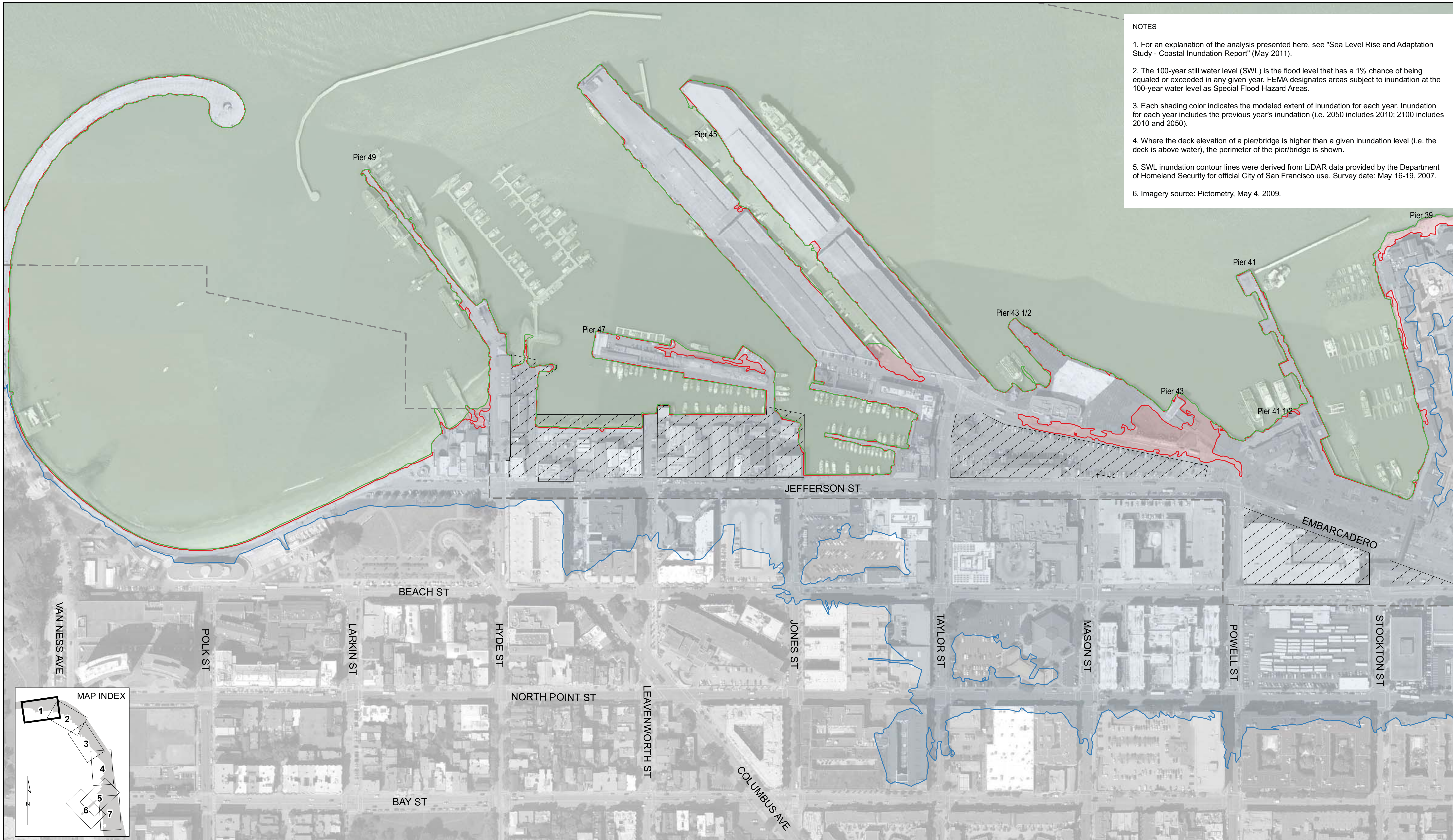
6. Imagery source: USDA National Agriculture Imagery Program (NAIP), 2005.

Plate 1

Inundation based on modeled 100-year still water levels for years 2010, 2050, and 2100

Port of San Francisco
Sea Level Rise and Adaptation Study
June 2011

URS Corp - Oakland CA - C.Raumann L:\Projects\Port_of_SF_Sea_Level\Maps\POSF_Plate1_SWL.mxd - 6/14/2011 @ 1:03:21 PM



100-year still water levels (SWL) and inundation area

- Year 2010 (existing conditions)
  Elevation = 9.2 ft (NAVD88), -2.1 ft (City Datum)
- Year 2050
  Based on sea level rise scenario of 15 inches
  Elevation = 10.5 ft (NAVD88), -0.8 ft (City Datum)
- Year 2100
  Based on sea level rise scenario of 55 inches
  Elevation = 13.8 ft (NAVD88), 2.5 ft (City Datum)
- Port of San Francisco jurisdictional boundary
- Sea wall lot

0 300 600
SCALE IN FEET

1 INCH = 300 FEET AT 11x17-INCH PAGE SIZE

Port of San Francisco
Sea Level Rise and Adaptation Study
June 2011

PORT of SAN FRANCISCO URS

Map 1

Detail of inundation based on modeled 100-year still water levels

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NOTES

1. For an explanation of the analysis presented here, see "Sea Level Rise and Adaptation Study - Coastal Inundation Report" (May 2011).

2. The 100-year still water level (SWL) is the flood level that has a 1% chance of being equaled or exceeded in any given year. FEMA designates areas subject to inundation at the 100-year water level as Special Flood Hazard Areas.

3. Each shading color indicates the modeled extent of inundation for each year. Inundation for each year includes the previous year's inundation (i.e. 2050 includes 2010; 2100 includes 2010 and 2050).

4. Where the deck elevation of a pier/bridge is higher than a given inundation level (i.e. the deck is above water), the perimeter of the pier/bridge is shown.

5. SWL inundation contour lines were derived from LiDAR data provided by the Department of Homeland Security for official City of San Francisco use. Survey date: May 16-19, 2007.

6. Imagery source: Pictometry, May 4, 2009.

100-year still water levels (SWL) and inundation area

Year 2010 (existing conditions)
Elevation = 9.2 ft (NAVD88), -2.1 ft (City Datum)

Year 2050
Based on sea level rise scenario of 15 inches
Elevation = 10.5 ft (NAVD88), -0.8 ft (City Datum)

Year 2100
Based on sea level rise scenario of 55 inches
Elevation = 13.8 ft (NAVD88), 2.5 ft (City Datum)

Port of San Francisco jurisdictional boundary

Sea wall lot

0 300 600
SCALE IN FEET

1 INCH = 300 FEET AT 11x17-INCH PAGE SIZE

Port of San Francisco
Sea Level Rise and Adaptation Study
June 2011

PORT of SAN FRANCISCO URS

Map 2

Detail of inundation based on modeled 100-year still water levels

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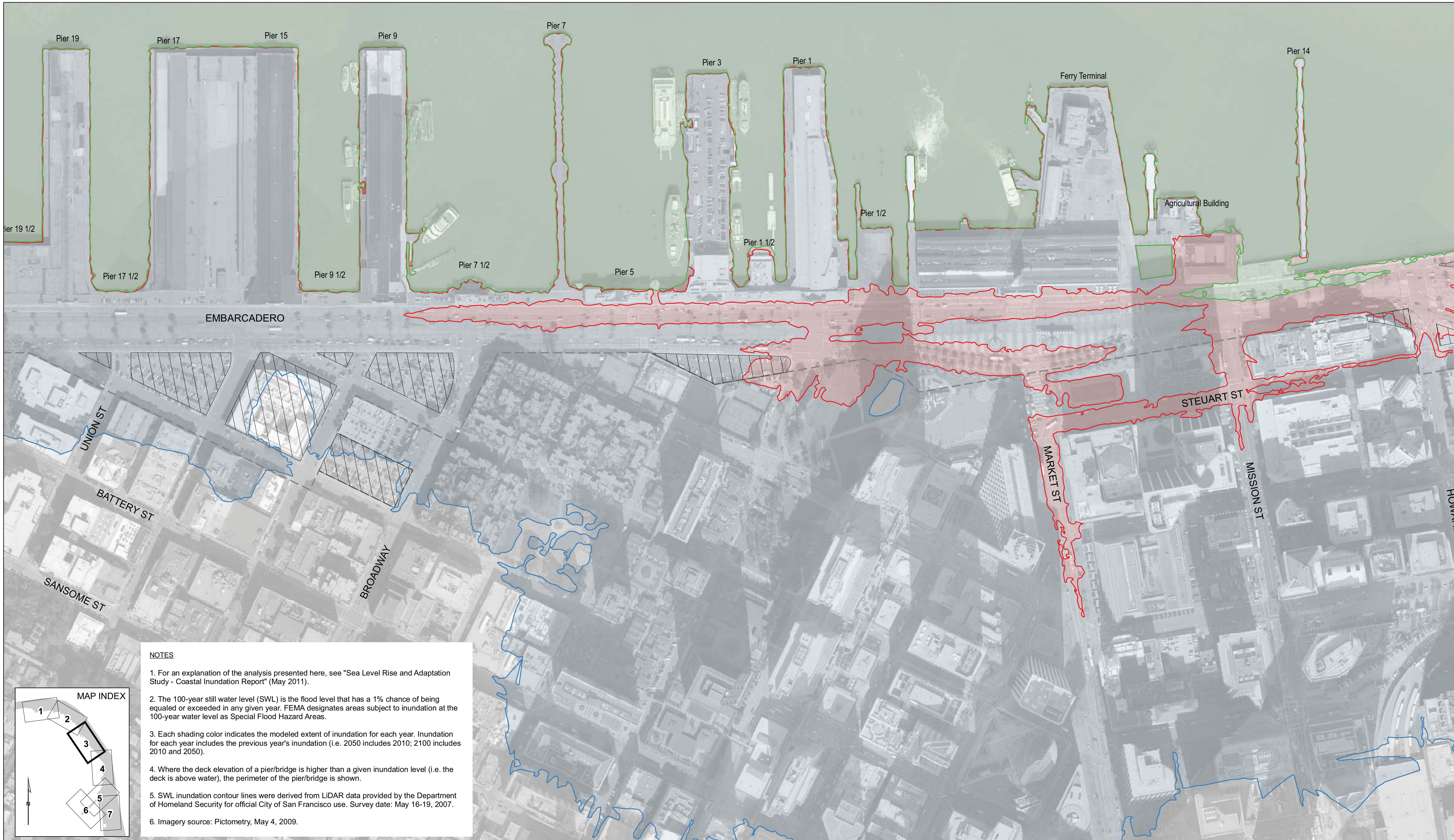


NOTES

1. For an explanation of the analysis presented here, see "Sea Level Rise and Adaptation Study - Coastal Inundation Report" (May 2011).

2. The 100-year still water level (SWL) is the flood level that has a 1% chance of being equaled or exceeded in any given year. FEMA designates areas subject to inundation at the 100-year water level as Special Flood Hazard Areas.

3. Each shading color indicates the modeled extent of inundation for each year. Inundation for each year includes the previous year's inundation (i.e. 2050 includes 2010; 2100 includes 2010 and 2050).

4. Where the deck elevation of a pier/bridge is higher than a given inundation level (i.e. the deck is above water), the perimeter of the pier/bridge is shown.

5. SWL inundation contour lines were derived from LiDAR data provided by the Department of Homeland Security for official City of San Francisco use. Survey date: May 16-19, 2007.

6. Imagery source: Pictometry, May 4, 2009.

100-year still water levels (SWL) and inundation area

- Year 2010 (existing conditions)
  Elevation = 9.2 ft (NAVD88), -2.1 ft (City Datum)
- Year 2050
  Based on sea level rise scenario of 15 inches
  Elevation = 10.5 ft (NAVD88), -0.8 ft (City Datum)
- Year 2100
  Based on sea level rise scenario of 55 inches
  Elevation = 13.8 ft (NAVD88), 2.5 ft (City Datum)
- Port of San Francisco jurisdictional boundary
- Sea wall lot

0 300 600
SCALE IN FEET

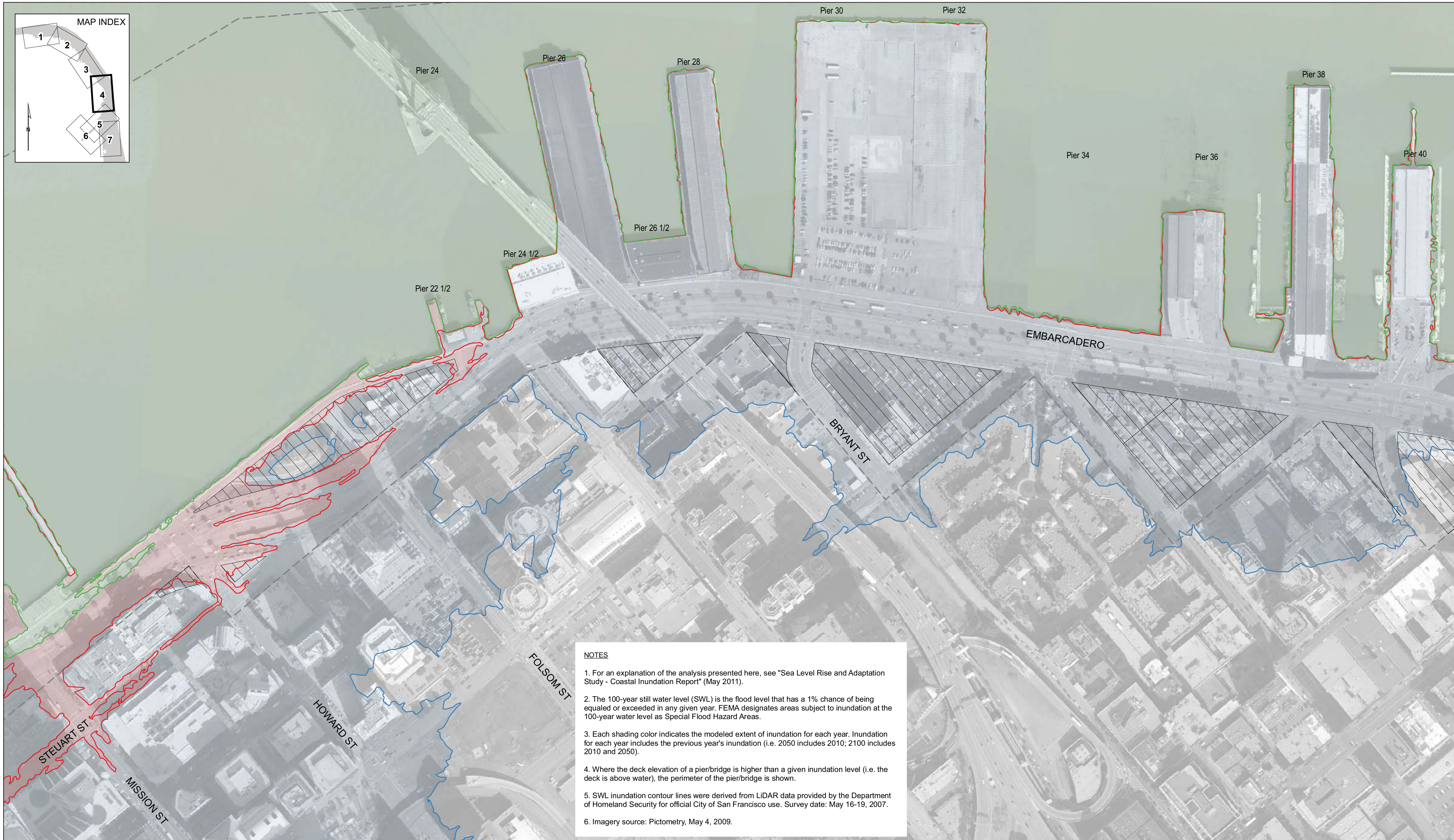
1 INCH = 300 FEET AT 11x17-INCH PAGE SIZE

Port of San Francisco
Sea Level Rise and Adaptation Study
June 2011

PORT OF SAN FRANCISCO URS

Map 3

Detail of inundation based on modeled 100-year still water levels



NOTES

1. For an explanation of the analysis presented here, see "Sea Level Rise and Adaptation Study - Coastal Inundation Report" (May 2011).

2. The 100-year still water level (SWL) is the flood level that has a 1% chance of being equaled or exceeded in any given year. FEMA designates areas subject to inundation at the 100-year water level as Special Flood Hazard Areas.

3. Each shading color indicates the modeled extent of inundation for each year. Inundation for each year includes the previous year's inundation (i.e. 2050 includes 2010; 2100 includes 2010 and 2050).

4. Where the deck elevation of a pier/bridge is higher than a given inundation level (i.e. the deck is above water), the perimeter of the pier/bridge is shown.

5. SWL inundation contour lines were derived from LiDAR data provided by the Department of Homeland Security for official City of San Francisco use. Survey date: May 16-19, 2007.

6. Imagery source: Pictometry, May 4, 2009.

100-year still water levels (SWL) and inundation area

Year 2010 (existing conditions)
Elevation = 9.2 ft (NAVD88), -2.1 ft (City Datum)

Year 2050
Based on sea level rise scenario of 15 inches
Elevation = 10.5 ft (NAVD88), -0.8 ft (City Datum)

Year 2100
Based on sea level rise scenario of 55 inches
Elevation = 13.8 ft (NAVD88), 2.5 ft (City Datum)

Port of San Francisco jurisdictional boundary

Sea wall lot

N

0 300 600
SCALE IN FEET

1 INCH = 300 FEET AT 11x17-INCH PAGE SIZE

Port of San Francisco
Sea Level Rise and Adaptation Study
June 2011

PORT OF SAN FRANCISCO
URS

Map 4

Detail of inundation based on modeled 100-year still water levels

NOTES

1. For an explanation of the analysis presented here, see "Sea Level Rise and Adaptation Study - Coastal Inundation Report" (May 2011).

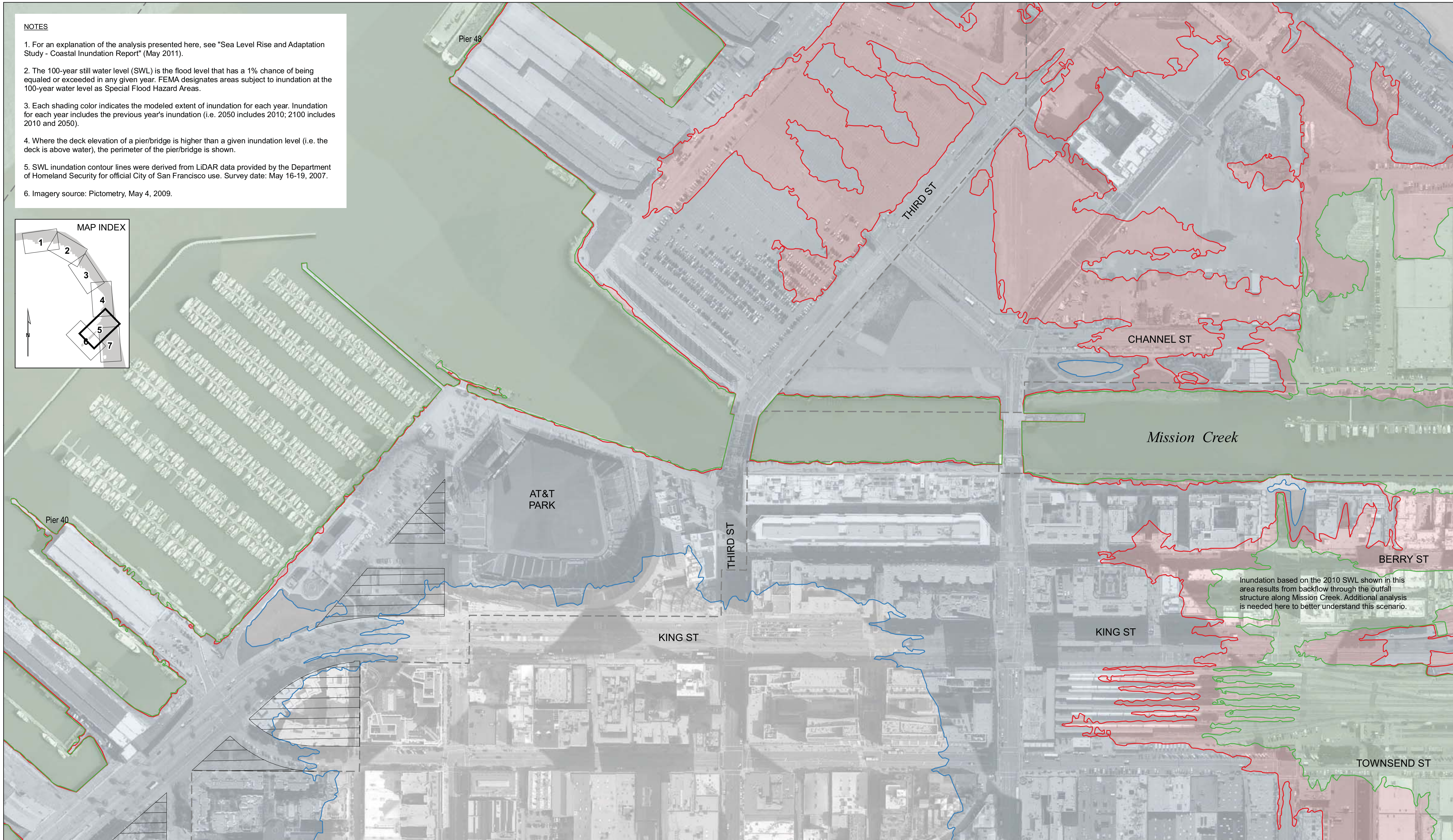
2. The 100-year still water level (SWL) is the flood level that has a 1% chance of being equaled or exceeded in any given year. FEMA designates areas subject to inundation at the 100-year water level as Special Flood Hazard Areas.

3. Each shading color indicates the modeled extent of inundation for each year. Inundation for each year includes the previous year's inundation (i.e. 2050 includes 2010; 2100 includes 2010 and 2050).

4. Where the deck elevation of a pier/bridge is higher than a given inundation level (i.e. the deck is above water), the perimeter of the pier/bridge is shown.

5. SWL inundation contour lines were derived from LiDAR data provided by the Department of Homeland Security for official City of San Francisco use. Survey date: May 16-19, 2007.

6. Imagery source: Pictometry, May 4, 2009.



100-year still water levels (SWL) and inundation area

Year 2010 (existing conditions)
Elevation = 9.2 ft (NAVD88), -2.1 ft (City Datum)

Year 2050
Based on sea level rise scenario of 15 inches
Elevation = 10.5 ft (NAVD88), -0.8 ft (City Datum)

Year 2100
Based on sea level rise scenario of 55 inches
Elevation = 13.8 ft (NAVD88), 2.5 ft (City Datum)

Port of San Francisco jurisdictional boundary

Sea wall lot

0 300 600

SCALE IN FEET

1 INCH = 300 FEET AT 11x17-INCH PAGE SIZE

Port of San Francisco
Sea Level Rise and Adaptation Study
June 2011

PORT OF SAN FRANCISCO URS

Map 5

Detail of inundation based on modeled 100-year still water levels

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NOTES

1. For an explanation of the analysis presented here, see "Sea Level Rise and Adaptation Study - Coastal Inundation Report" (May 2011).

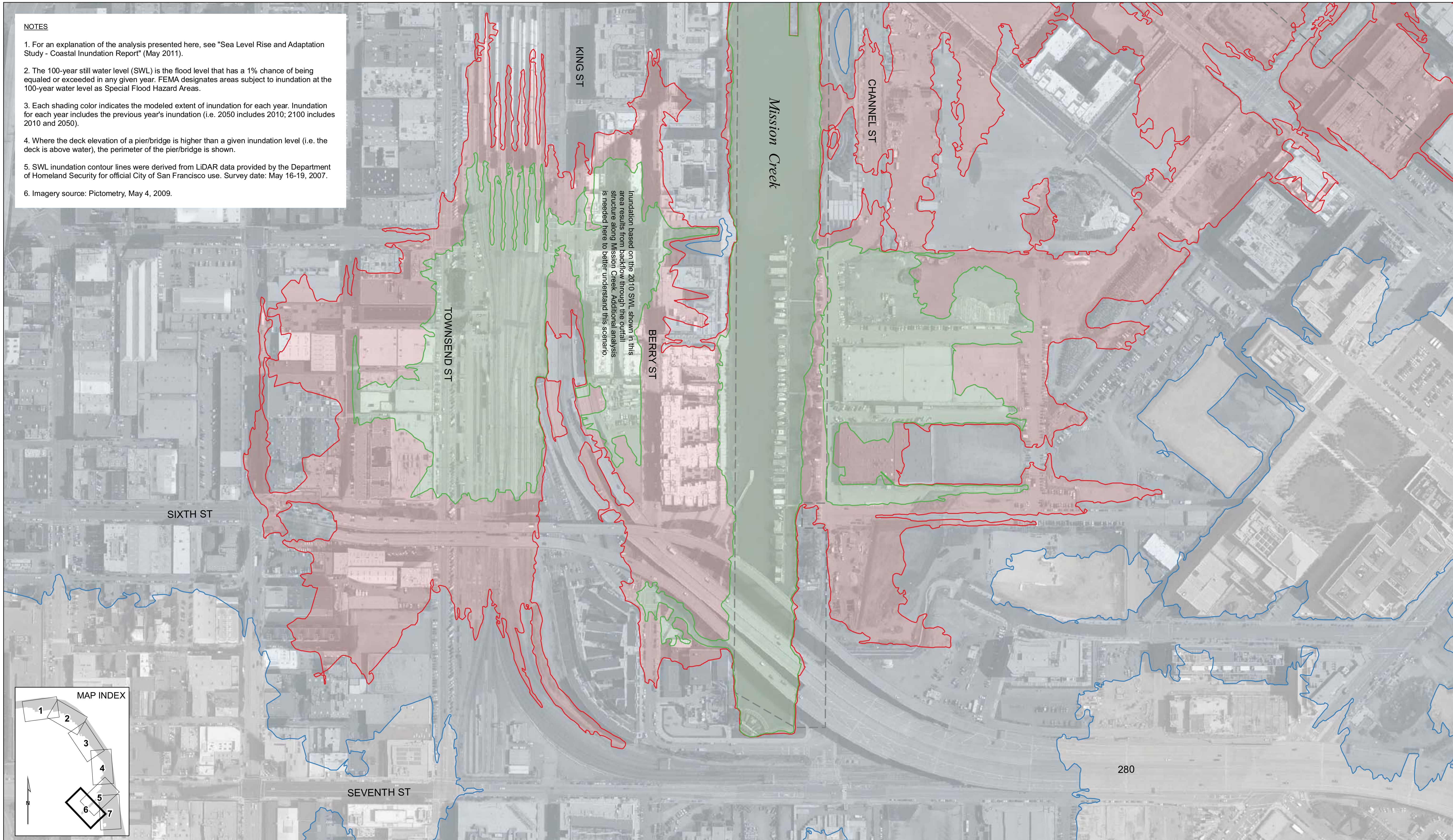
2. The 100-year still water level (SWL) is the flood level that has a 1% chance of being equaled or exceeded in any given year. FEMA designates areas subject to inundation at the 100-year water level as Special Flood Hazard Areas.

3. Each shading color indicates the modeled extent of inundation for each year. Inundation for each year includes the previous year's inundation (i.e. 2050 includes 2010; 2100 includes 2010 and 2050).

4. Where the deck elevation of a pier/bridge is higher than a given inundation level (i.e. the deck is above water), the perimeter of the pier/bridge is shown.

5. SWL inundation contour lines were derived from LiDAR data provided by the Department of Homeland Security for official City of San Francisco use. Survey date: May 16-19, 2007.

6. Imagery source: Pictometry, May 4, 2009.



100-year still water levels (SWL) and inundation area

Year 2010 (existing conditions)
Elevation = 9.2 ft (NAVD88), -2.1 ft (City Datum)

Year 2050
Based on sea level rise scenario of 15 inches
Elevation = 10.5 ft (NAVD88), -0.8 ft (City Datum)

Year 2100
Based on sea level rise scenario of 55 inches
Elevation = 13.8 ft (NAVD88), 2.5 ft (City Datum)

Port of San Francisco jurisdictional boundary

Sea wall lot

0 300 600
SCALE IN FEET

1 INCH = 300 FEET AT 11x17-INCH PAGE SIZE

Port of San Francisco
Sea Level Rise and Adaptation Study
June 2011

Map 6

Detail of inundation based on modeled 100-year still water levels

NOTES

1. For an explanation of the analysis presented here, see "Sea Level Rise and Adaptation Study - Coastal Inundation Report" (May 2011).

2. The 100-year still water level (SWL) is the flood level that has a 1% chance of being equaled or exceeded in any given year. FEMA designates areas subject to inundation at the 100-year water level as Special Flood Hazard Areas.

3. Each shading color indicates the modeled extent of inundation for each year. Inundation for each year includes the previous year's inundation (i.e. 2050 includes 2010; 2100 includes 2010 and 2050).

4. Where the deck elevation of a pier/bridge is higher than a given inundation level (i.e. the deck is above water), the perimeter of the pier/bridge is shown.

5. SWL inundation contour lines were derived from LiDAR data provided by the Department of Homeland Security for official City of San Francisco use. Survey date: May 16-19, 2007.

6. Imagery source: Pictometry, May 4, 2009.

100-year still water levels (SWL) and inundation area

Year 2010 (existing conditions)
Elevation = 9.2 ft (NAVD88), -2.1 ft (City Datum)

Year 2050
Based on sea level rise scenario of 15 inches
Elevation = 10.5 ft (NAVD88), -0.8 ft (City Datum)

Year 2100
Based on sea level rise scenario of 55 inches
Elevation = 13.8 ft (NAVD88), 2.5 ft (City Datum)

Port of San Francisco jurisdictional boundary

Sea wall lot

N

0 300 600
SCALE IN FEET

1 INCH = 300 FEET AT 11x17-INCH PAGE SIZE

Port of San Francisco
Sea Level Rise and Adaptation Study
June 2011

PORT of SAN FRANCISCO URS

Map 7

Detail of inundation based on modeled 100-year still water levels

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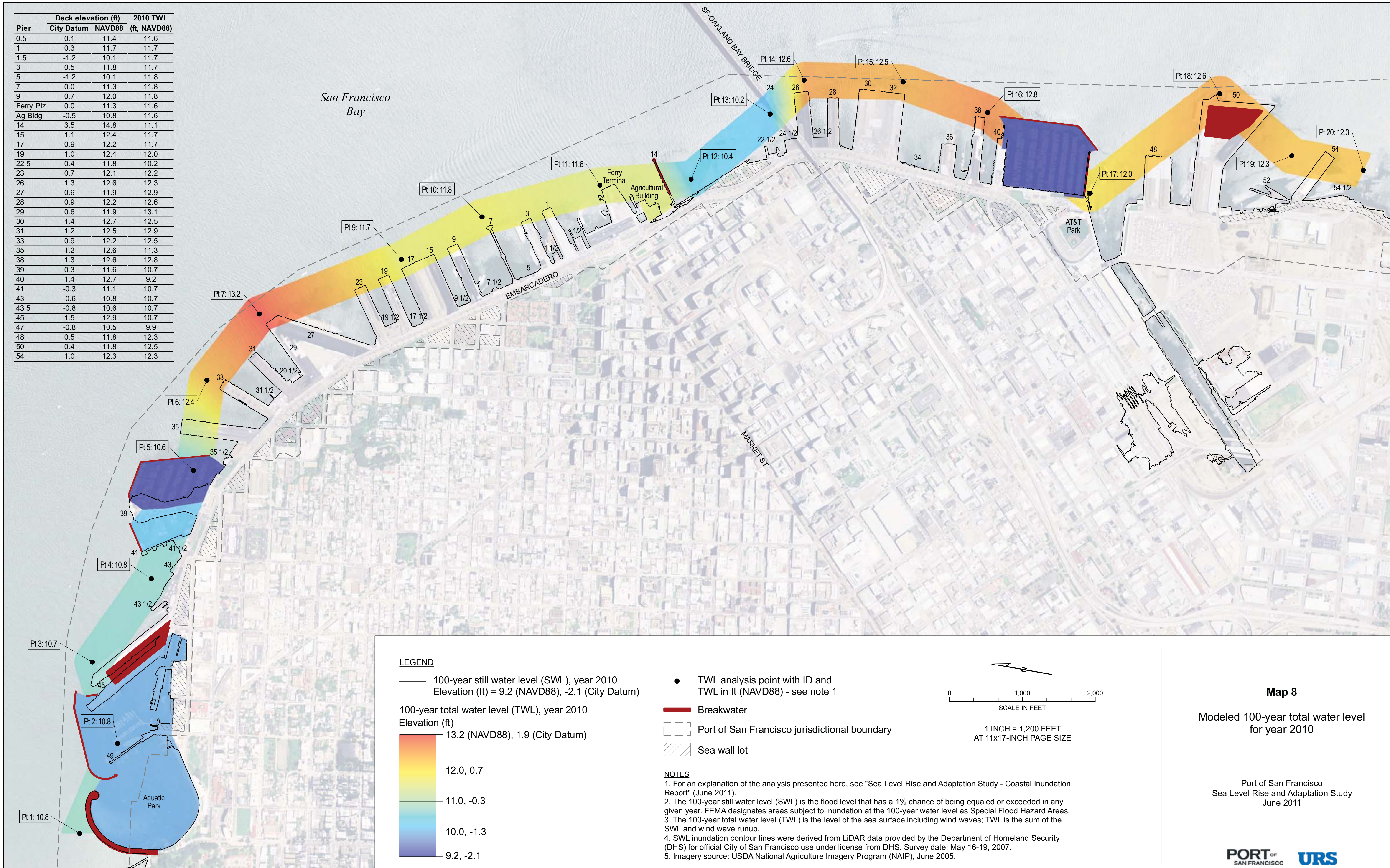
Pier	Deck elevation (ft) City Datum	Deck elevation (ft) NAVD88	2010 TWL (ft, NAVD88)
0.5	0.1	11.4	11.6
1	0.3	11.7	11.7
1.5	-1.2	10.1	11.7
3	0.5	11.8	11.7
5	-1.2	10.1	11.8
7	0.0	11.3	11.8
9	0.7	12.0	11.8
Ferry Plz	0.0	11.3	11.6
Ag Bldg	-0.5	10.8	11.6
14	3.5	14.8	11.1
15	1.1	12.4	11.7
17	0.9	12.2	11.7
19	1.0	12.4	12.0
22.5	0.4	11.8	10.2
23	0.7	12.1	12.2
26	1.3	12.6	12.3
27	0.6	11.9	12.9
28	0.9	12.2	12.6
29	0.6	11.9	13.1
30	1.4	12.7	12.5
31	1.2	12.5	12.9
33	0.9	12.2	12.5
35	1.2	12.6	11.3
38	1.3	12.6	12.8
39	0.3	11.6	10.7
40	1.4	12.7	9.2
41	-0.3	11.1	10.7
43	-0.6	10.8	10.7
43.5	-0.8	10.6	10.7
45	1.5	12.9	10.7
47	-0.8	10.5	9.9
48	0.5	11.8	12.3
50	0.4	11.8	12.5
54	1.0	12.3	12.3



LEGEND

100-year still water level (SWL), year 2010
Elevation (ft) = 9.2 (NAVD88), -2.1 (City Datum)

100-year total water level (TWL), year 2010
Elevation (ft)

13.2 (NAVD88), 1.9 (City Datum)
12.0, 0.7
11.0, -0.3
10.0, -1.3
9.2, -2.1

TWL analysis point with ID and TWL in ft (NAVD88) - see note 1

Breakwater

Port of San Francisco jurisdictional boundary

Sea wall lot

0 1,000 2,000
SCALE IN FEET

1 INCH = 1,200 FEET
AT 11x17-INCH PAGE SIZE

NOTES
1. For an explanation of the analysis presented here, see "Sea Level Rise and Adaptation Study - Coastal Inundation Report" (June 2011).
2. The 100-year still water level (SWL) is the flood level that has a 1% chance of being equaled or exceeded in any given year. FEMA designates areas subject to inundation at the 100-year water level as Special Flood Hazard Areas.
3. The 100-year total water level (TWL) is the level of the sea surface including wind waves; TWL is the sum of the SWL and wind wave runup.
4. SWL inundation contour lines were derived from LiDAR data provided by the Department of Homeland Security (DHS) for official City of San Francisco use under license from DHS. Survey date: May 16-19, 2007.
5. Imagery source: USDA National Agriculture Imagery Program (NAIP), June 2005.

Map 8

Modeled 100-year total water level for year 2010

Port of San Francisco
Sea Level Rise and Adaptation Study
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PORT of SAN FRANCISCO URS

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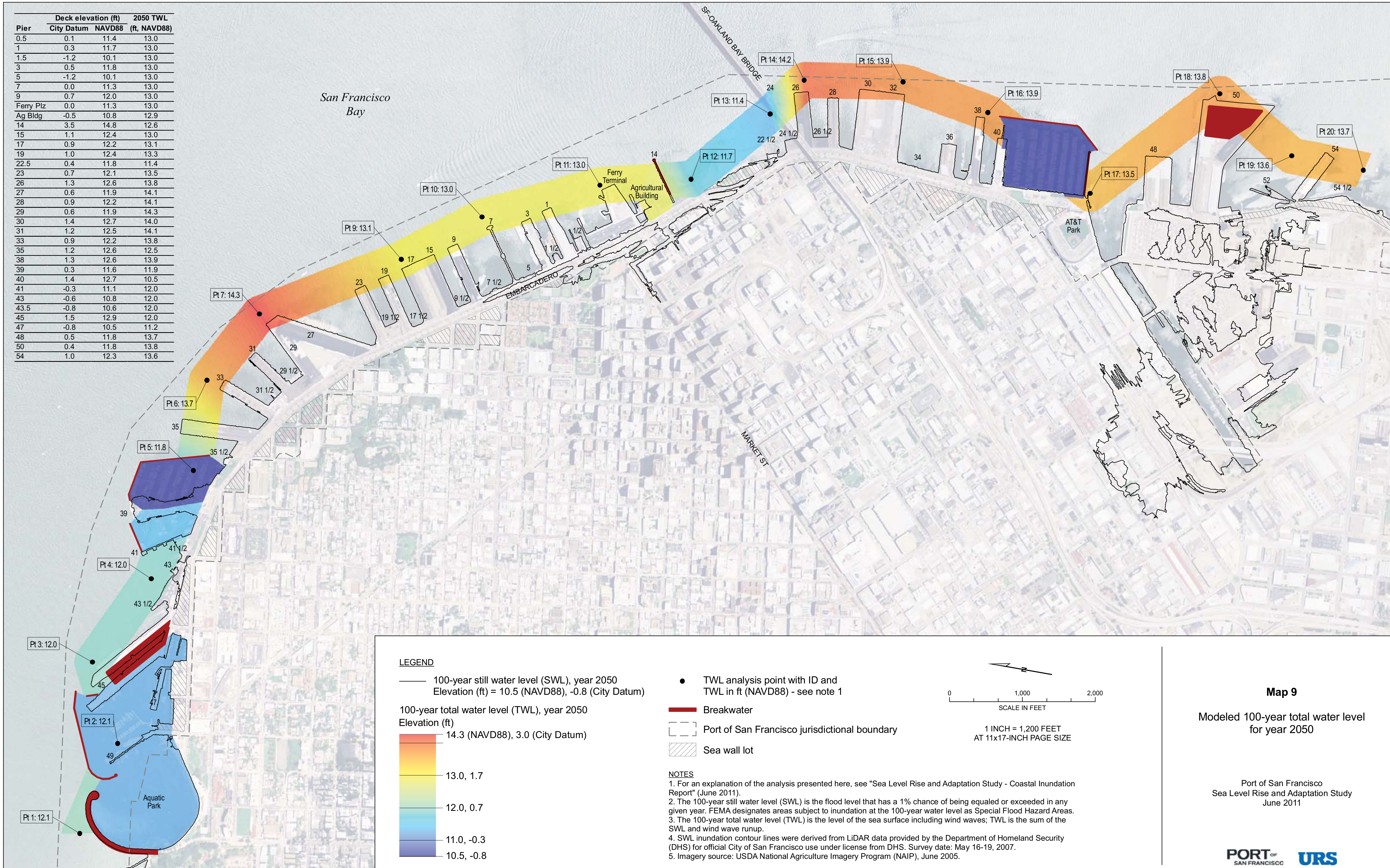
Pier	Deck elevation (ft) City Datum	Deck elevation (ft) NAVD88	2050 TWL (ft, NAVD88)
0.5	0.1	11.4	13.0
1	0.3	11.7	13.0
1.5	-1.2	10.1	13.0
3	0.5	11.8	13.0
5	-1.2	10.1	13.0
7	0.0	11.3	13.0
9	0.7	12.0	13.0
Ferry Plz	0.0	11.3	13.0
Ag Bldg	-0.5	10.8	12.9
14	3.5	14.8	12.6
15	1.1	12.4	13.0
17	0.9	12.2	13.1
19	1.0	12.4	13.3
22.5	0.4	11.8	11.4
23	0.7	12.1	13.5
26	1.3	12.6	13.8
27	0.6	11.9	14.1
28	0.9	12.2	14.1
29	0.6	11.9	14.3
30	1.4	12.7	14.0
31	1.2	12.5	14.1
33	0.9	12.2	13.8
35	1.2	12.6	12.5
38	1.3	12.6	13.9
39	0.3	11.6	11.9
40	1.4	12.7	10.5
41	-0.3	11.1	12.0
43	-0.6	10.8	12.0
43.5	-0.8	10.6	12.0
45	1.5	12.9	12.0
47	-0.8	10.5	11.2
48	0.5	11.8	13.7
50	0.4	11.8	13.8
54	1.0	12.3	13.6



LEGEND

100-year still water level (SWL), year 2050
Elevation (ft) = 10.5 (NAVD88), -0.8 (City Datum)

100-year total water level (TWL), year 2050
Elevation (ft)

14.3 (NAVD88), 3.0 (City Datum)
13.0, 1.7
12.0, 0.7
11.0, -0.3
10.5, -0.8

TWL analysis point with ID and TWL in ft (NAVD88) - see note 1

Breakwater

Port of San Francisco jurisdictional boundary

Sea wall lot

0 1,000 2,000
SCALE IN FEET

1 INCH = 1,200 FEET
AT 11x17-INCH PAGE SIZE

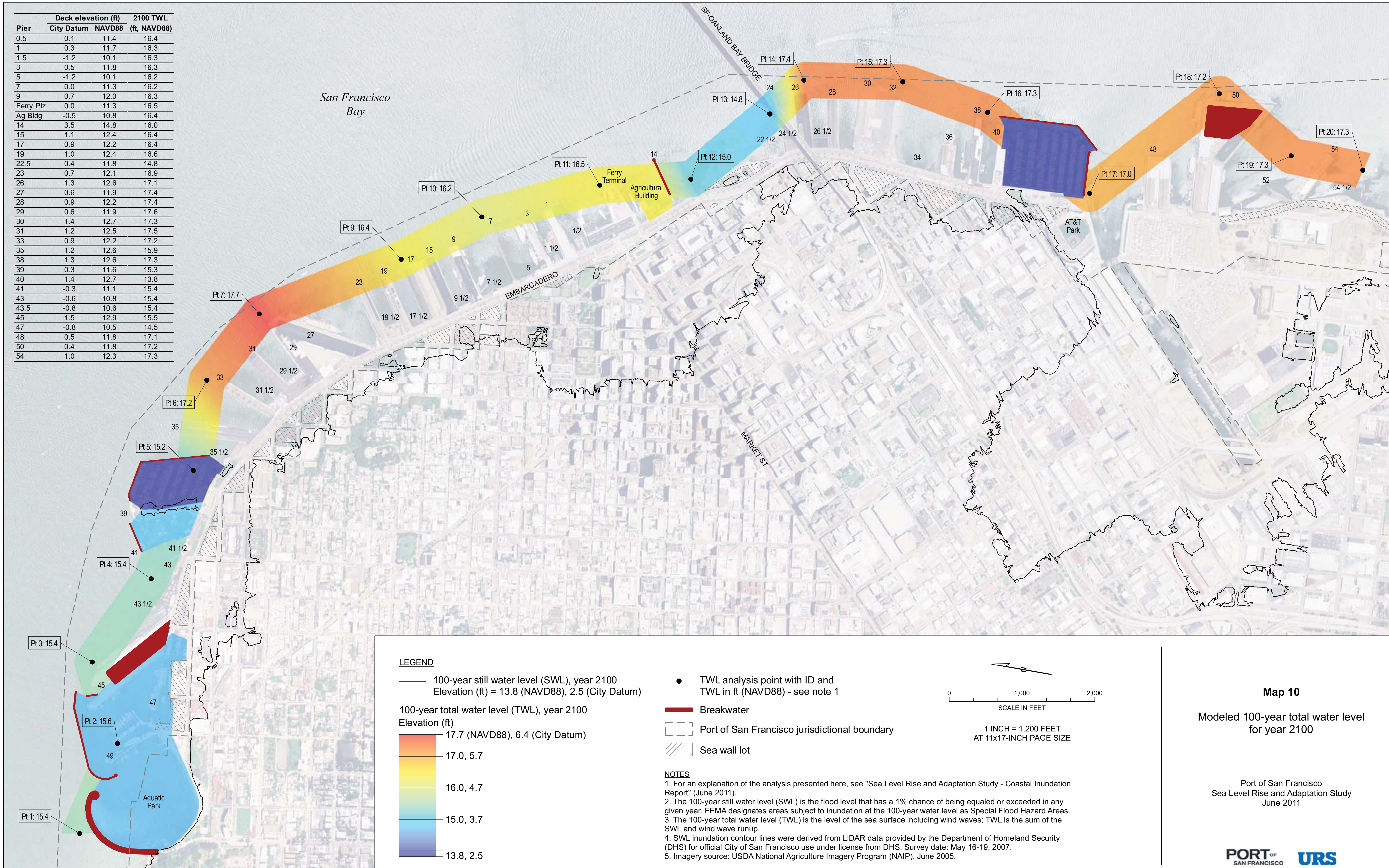
NOTES
1. For an explanation of the analysis presented here, see "Sea Level Rise and Adaptation Study - Coastal Inundation Report" (June 2011).
2. The 100-year still water level (SWL) is the flood level that has a 1% chance of being equaled or exceeded in any given year. FEMA designates areas subject to inundation at the 100-year water level as Special Flood Hazard Areas.
3. The 100-year total water level (TWL) is the level of the sea surface including wind waves; TWL is the sum of the SWL and wind wave runup.
4. SWL inundation contour lines were derived from LiDAR data provided by the Department of Homeland Security (DHS) for official City of San Francisco use under license from DHS. Survey date: May 16-19, 2007.
5. Imagery source: USDA National Agriculture Imagery Program (NAIP), June 2005.

Map 9

Modeled 100-year total water level for year 2050

Port of San Francisco
Sea Level Rise and Adaptation Study
June 2011

URS Corp - Oakland CA - C.Raumann L:\Projects\Port_of_SF_Sea_Level\Maps\POSF_Map8to10_TWL.mxd - 6/14/2011 @ 1:49:43 PM



Pier	Deck elevation (ft) City Datum	Deck elevation (ft) NAVD88	2100 TWL (ft, NAVD88)
0.5	0.1	11.4	16.4
1	0.3	11.7	16.3
1.5	-1.2	10.1	16.3
3	0.5	11.8	16.3
5	-1.2	10.1	16.2
7	0.0	11.3	16.2
9	0.7	12.0	16.3
Ferry Plz	0.0	11.3	16.5
Ag Bldg	-0.5	10.8	16.4
14	3.5	14.8	16.0
15	1.1	12.4	16.4
17	0.9	12.2	16.4
19	1.0	12.4	16.6
22.5	0.4	11.8	14.8
23	0.7	12.1	16.9
26	1.3	12.6	17.1
27	0.6	11.9	17.4
28	0.9	12.2	17.4
29	0.6	11.9	17.6
30	1.4	12.7	17.3
31	1.2	12.5	17.5
33	0.9	12.2	17.2
35	1.2	12.6	15.9
38	1.3	12.6	17.3
39	0.3	11.6	15.3
40	1.4	12.7	13.8
41	-0.3	11.1	15.4
43	-0.6	10.8	15.4
43.5	-0.8	10.6	15.4
45	1.5	12.9	15.5
47	-0.8	10.5	14.5
48	0.5	11.8	17.1
50	0.4	11.8	17.2
54	1.0	12.3	17.3

LEGEND

100-year still water level (SWL), year 2100
Elevation (ft) = 13.8 (NAVD88), 2.5 (City Datum)

100-year total water level (TWL), year 2100
Elevation (ft)

17.7 (NAVD88), 6.4 (City Datum)
17.0, 5.7
16.0, 4.7
15.0, 3.7
13.8, 2.5

TWL analysis point with ID and TWL in ft (NAVD88) - see note 1

Breakwater

Port of San Francisco jurisdictional boundary

Sea wall lot

0 1,000 2,000
SCALE IN FEET

1 INCH = 1,200 FEET
AT 11x17-INCH PAGE SIZE

NOTES
1. For an explanation of the analysis presented here, see "Sea Level Rise and Adaptation Study - Coastal Inundation Report" (June 2011).
2. The 100-year still water level (SWL) is the flood level that has a 1% chance of being equaled or exceeded in any given year. FEMA designates areas subject to inundation at the 100-year water level as Special Flood Hazard Areas.
3. The 100-year total water level (TWL) is the level of the sea surface including wind waves; TWL is the sum of the SWL and wind wave runup.
4. SWL inundation contour lines were derived from LiDAR data provided by the Department of Homeland Security (DHS) for official City of San Francisco use under license from DHS. Survey date: May 16-19, 2007.
5. Imagery source: USDA National Agriculture Imagery Program (NAIP), June 2005.

Map 10

Modeled 100-year total water level for year 2100

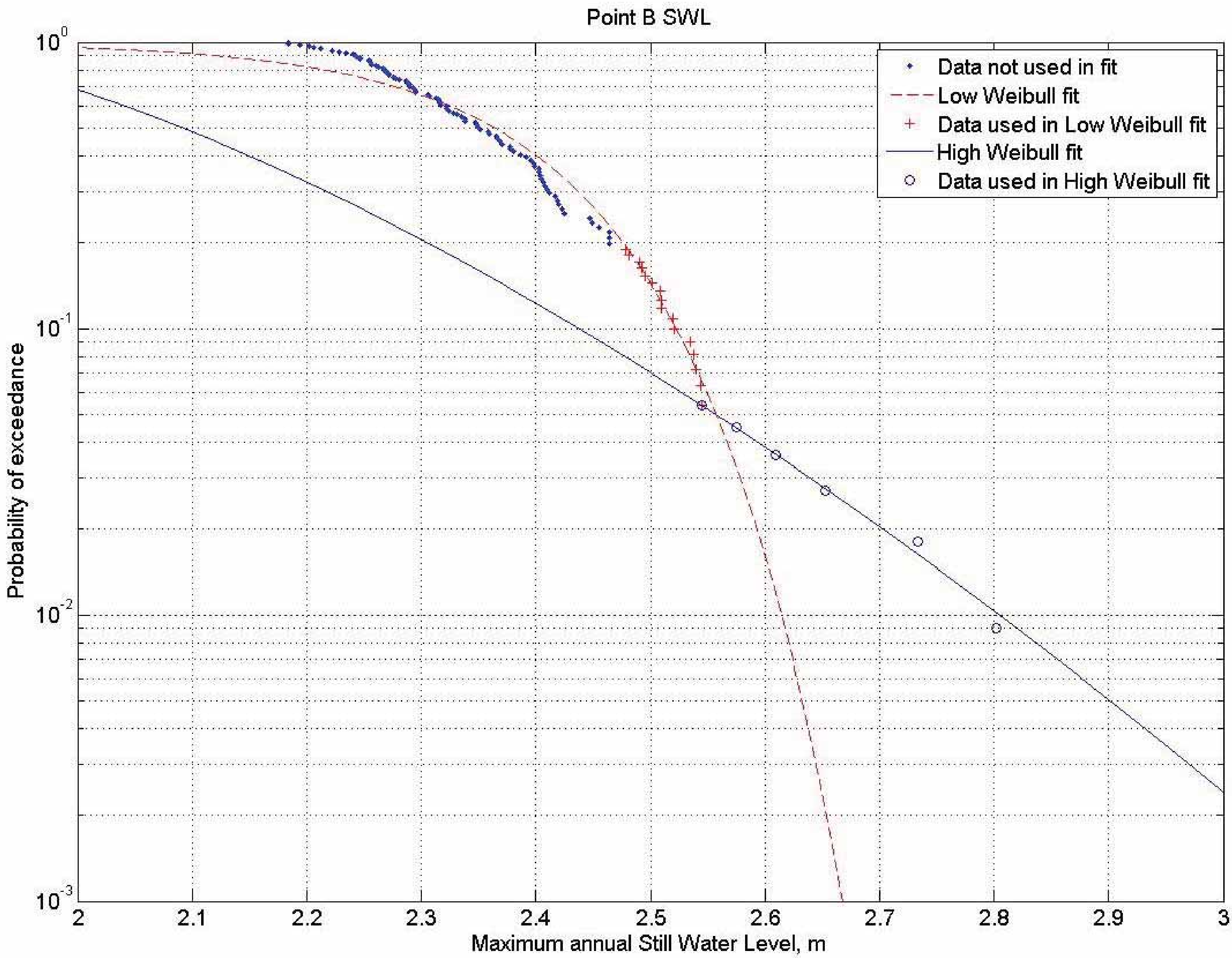
Port of San Francisco
Sea Level Rise and Adaptation Study
June 2011

URS Corp - Oakland CA - C.Raumann L:\Projects\Port_of_SF_Sea_Level\Maps\POSF_Map8to10_TWL.mxd - 6/14/2011 @ 1:49:43 PM

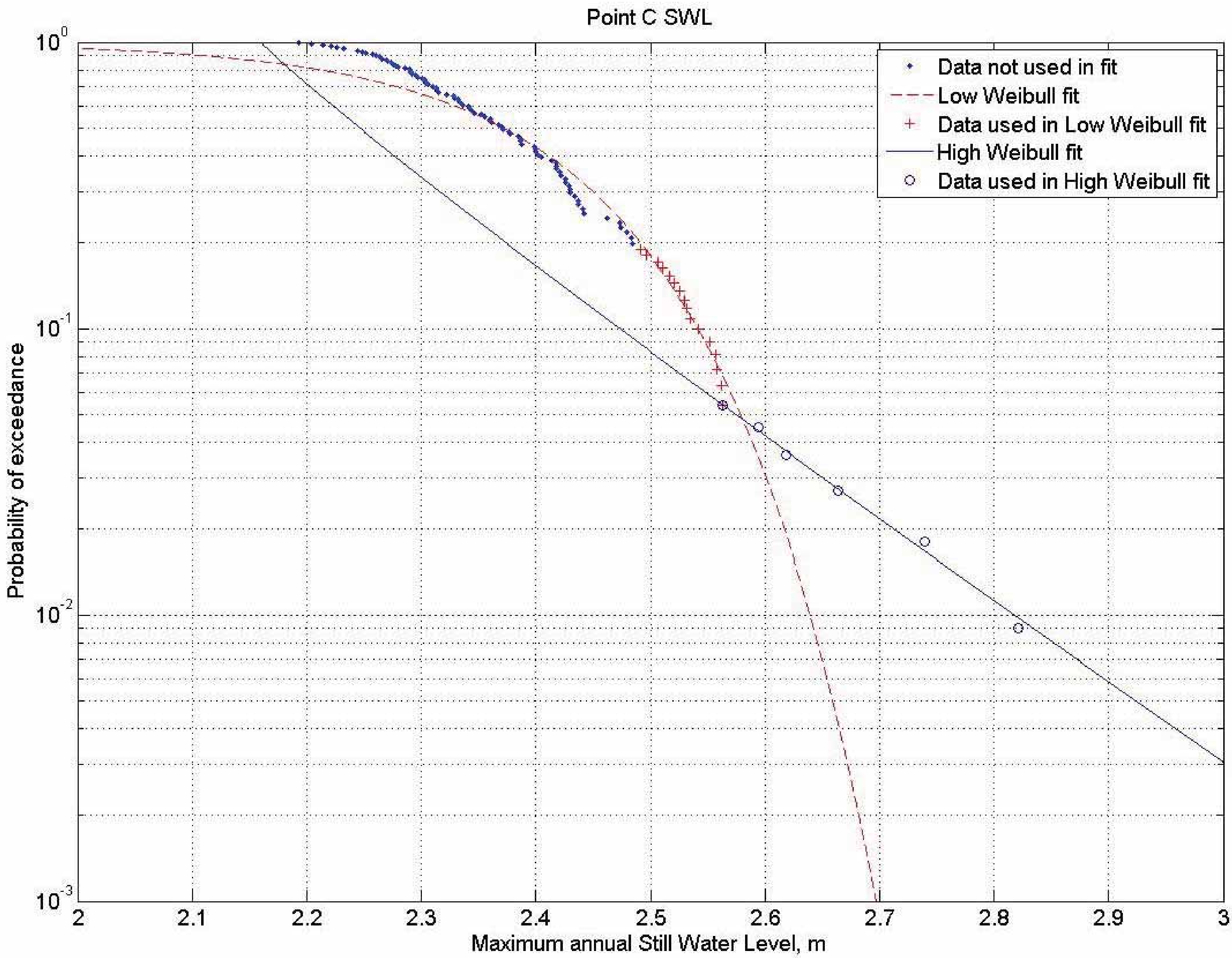
Appendix A

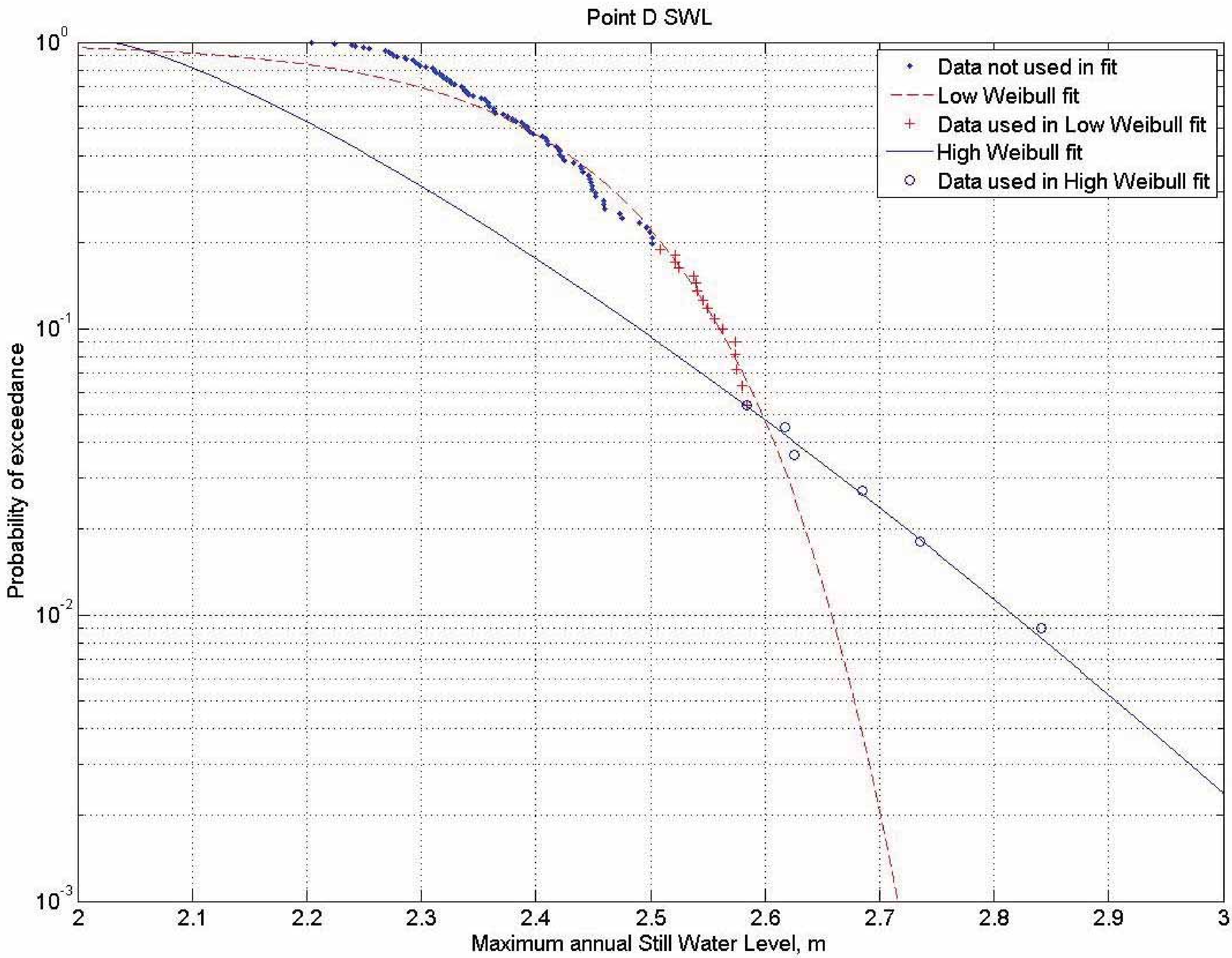
Still Water and Total Water Level Frequency Plots for Selected Locations along the Port of San Francisco Shoreline (see Figure 4-4 for locations)

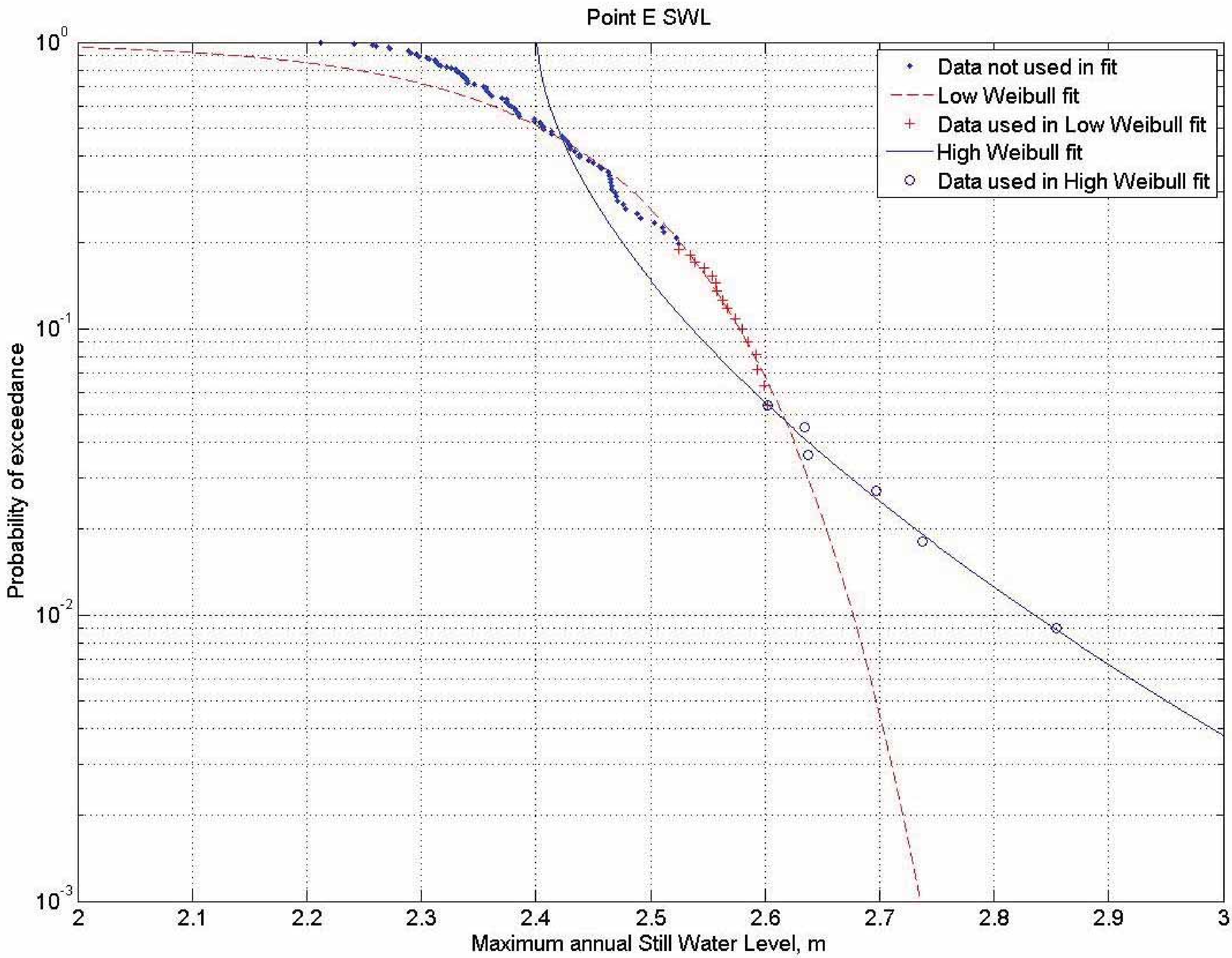
Existing Conditions



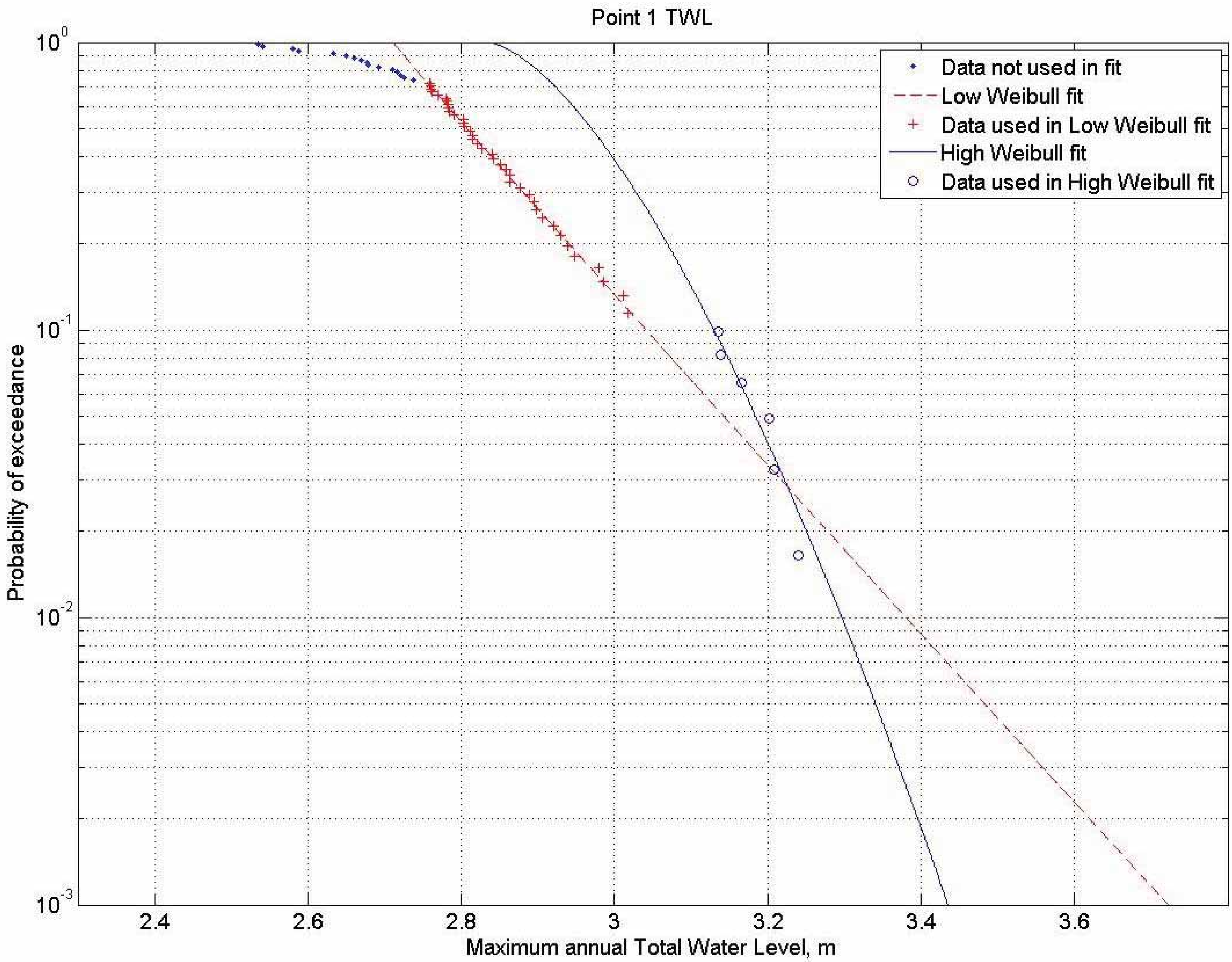
Point B SWL
Data not used in fit
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^{0}
10^{-1}
10^{-2}
10^{-3}
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3
Maximum annual Still Water Level, m

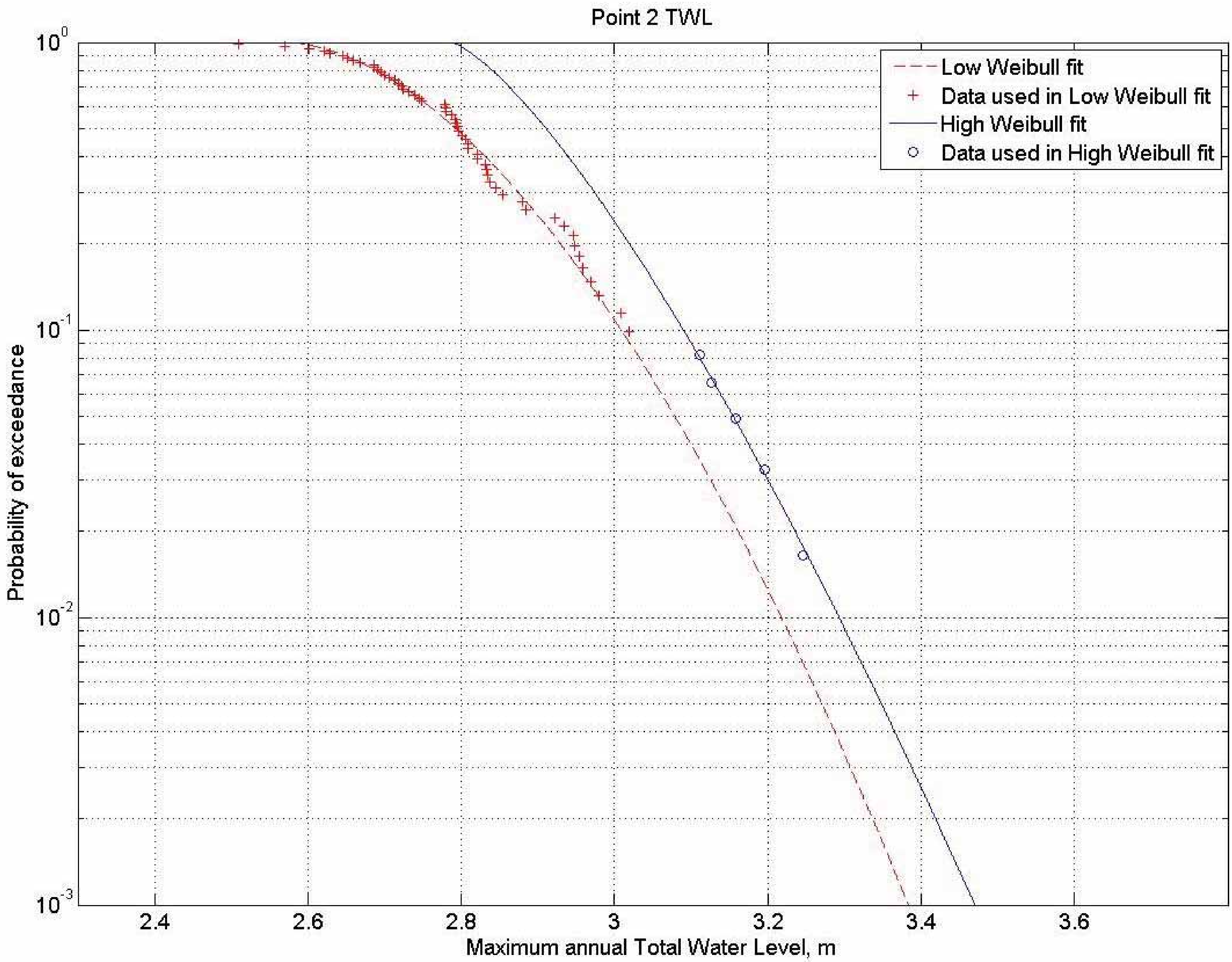

Point C SWL
Probability of exceedance
10^0
10^-1
10^-2
10^-3
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3
Maximum annual Still Water Level, m
Data not used in fit
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit

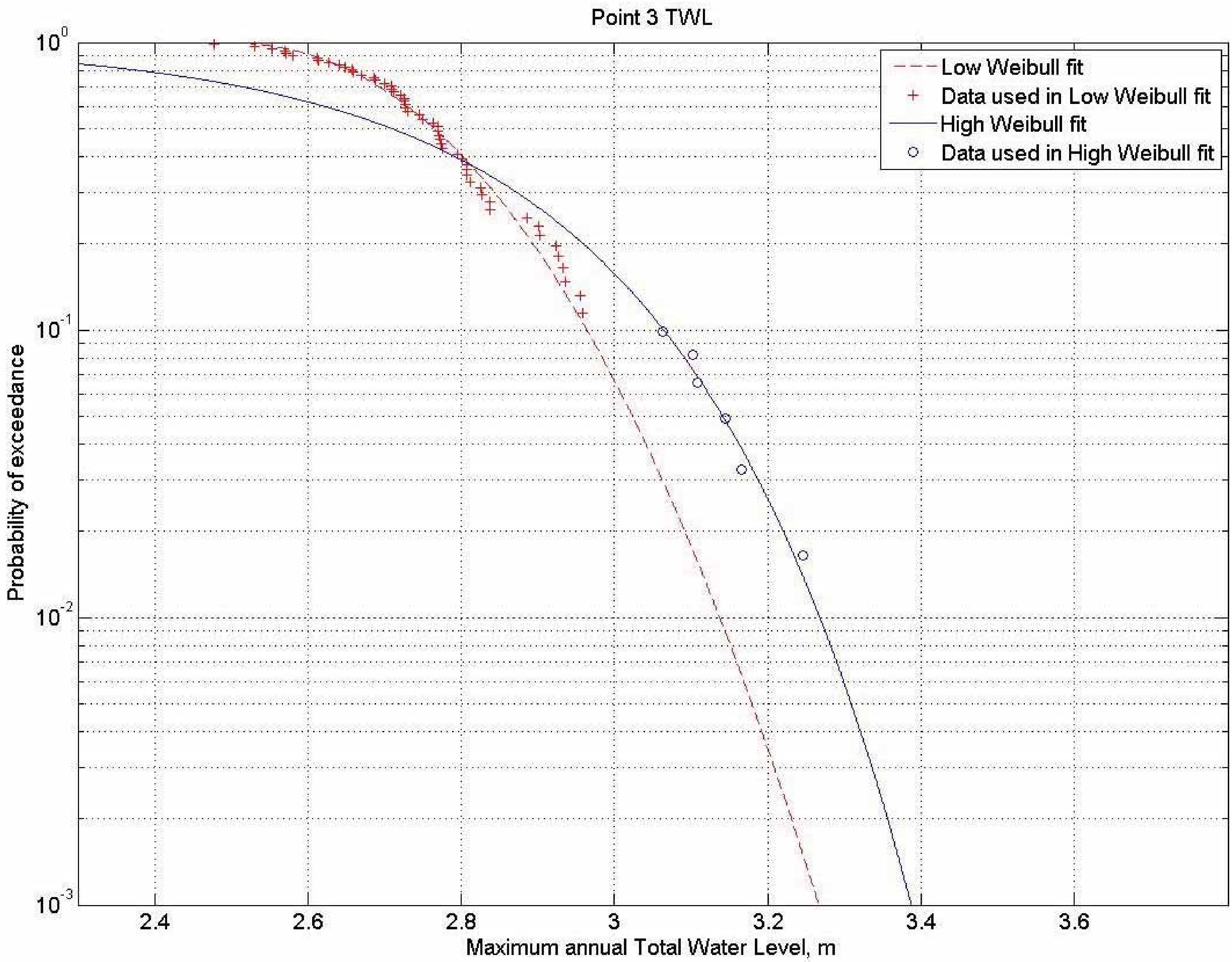

Point D SWL
Probability of exceedance
10^0
10^-1
10^-2
10^-3
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3
Maximum annual Still Water Level, m
Data not used in fit
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit



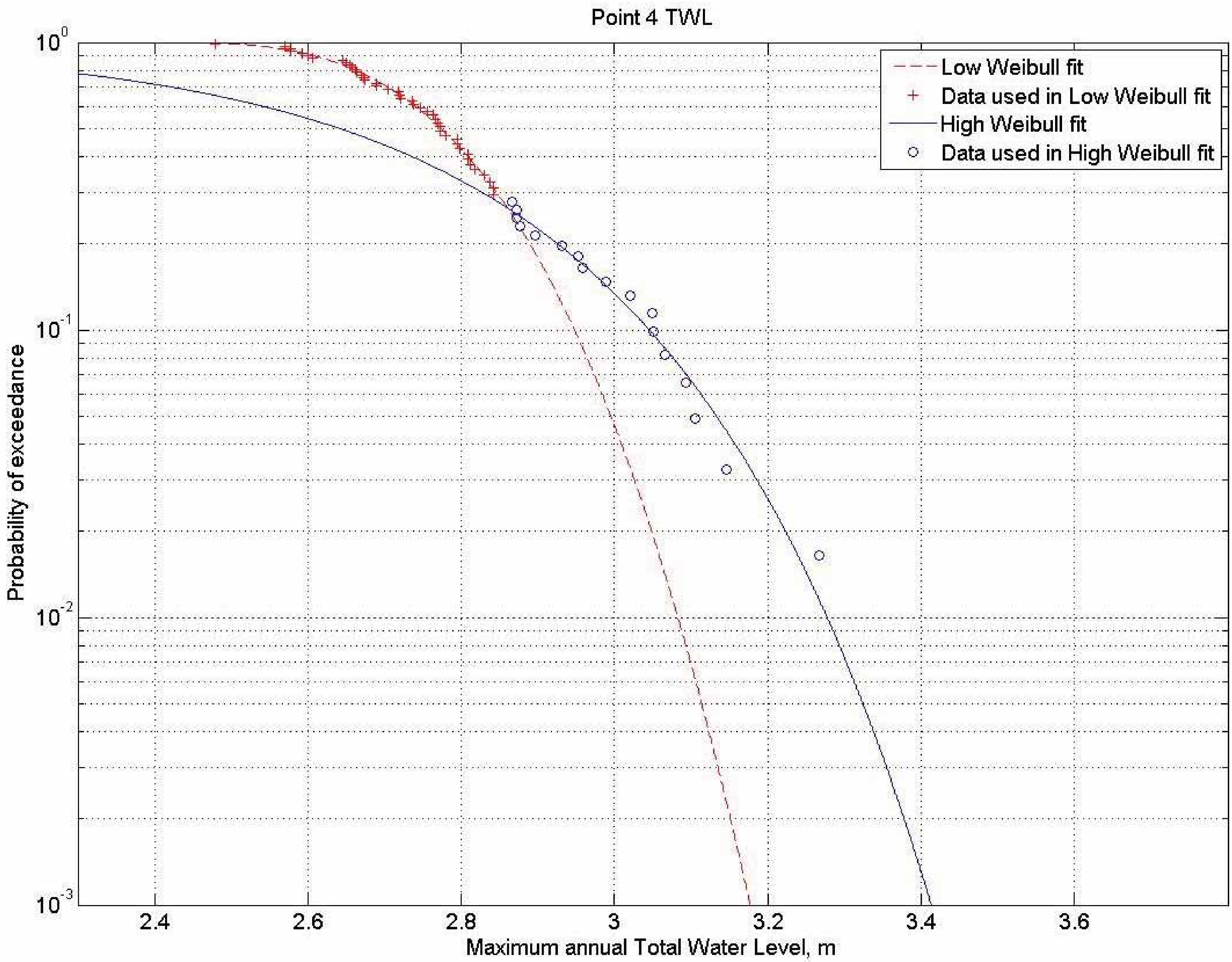
Point E SWL
Probability of exceedance
10^0
10^-1
10^-2
10^-3
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3
Maximum annual Still Water Level, m
Data not used in fit
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit

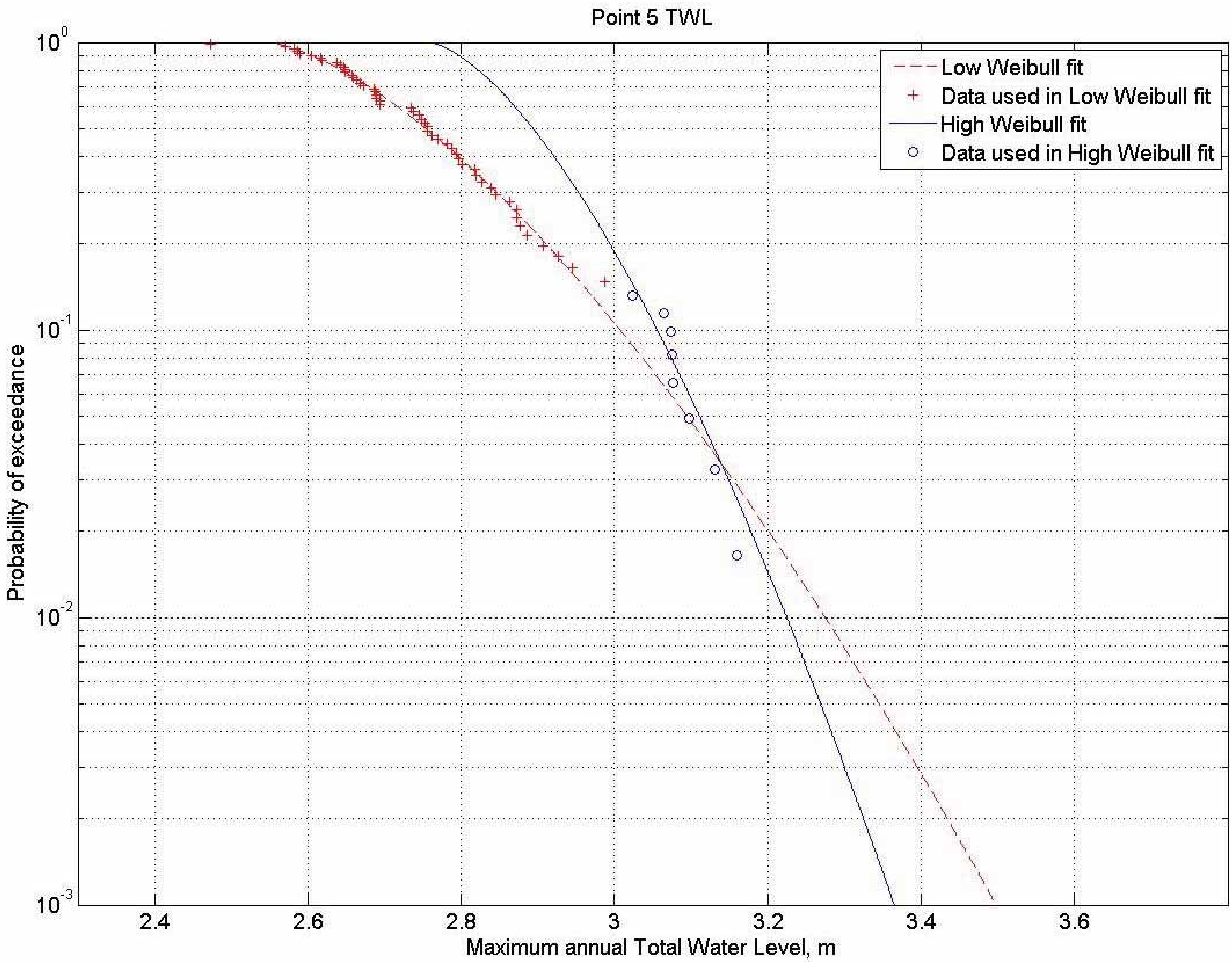

Point 1 TWL
Data not used in fit
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^{-1}
10^{-2}
10^{-3}
2.4
2.6
2.8
3
3.2
3.4
3.6
Maximum annual Total Water Level, m


Point 2 TWL
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^-1
10^-2
10^-3
2.4
2.6
2.8
3
3.2
3.4
3.6
Maximum annual Total Water Level, m

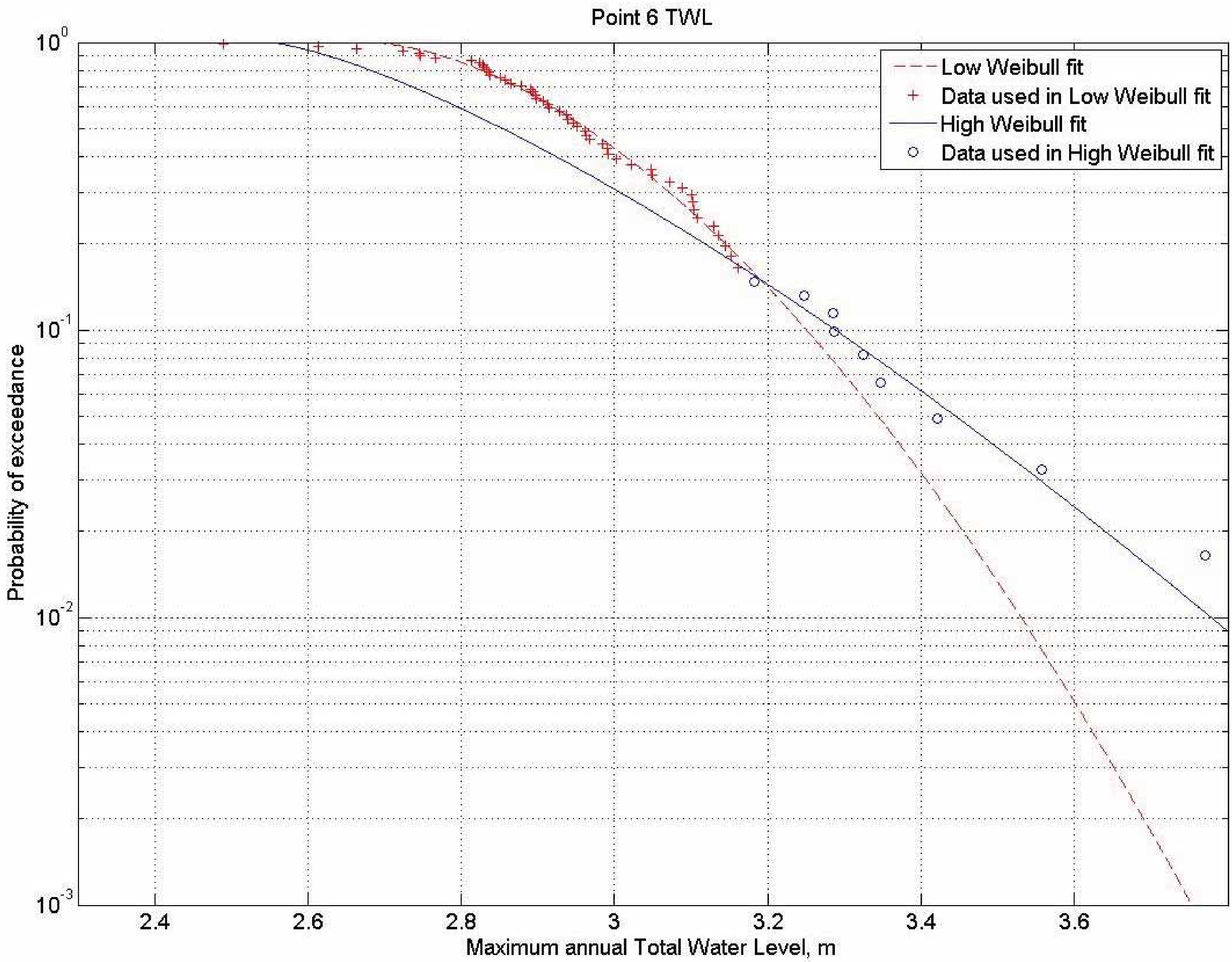


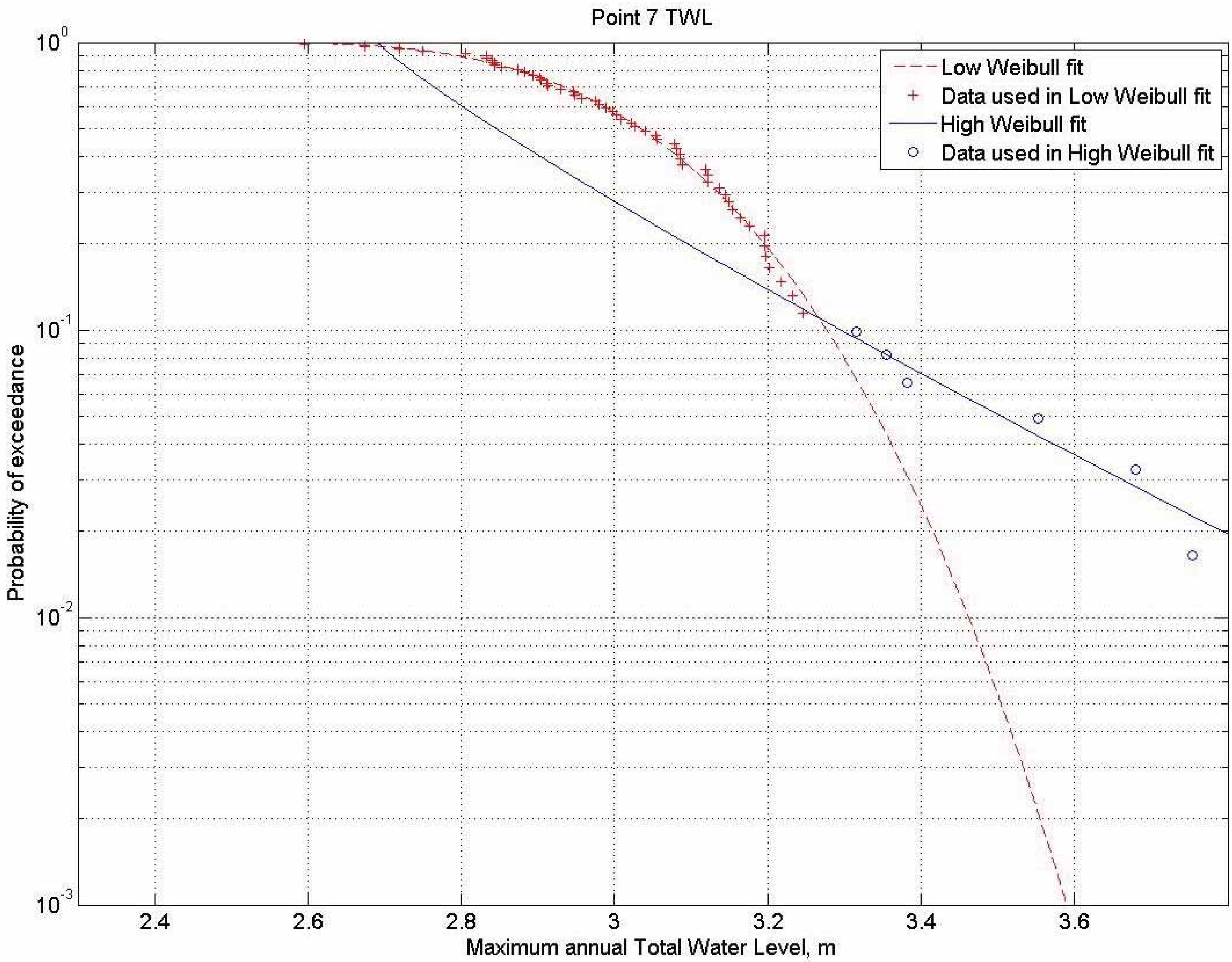
Point 3 TWL
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^-1
10^-2
10^-3
2.4
2.6
2.8
3
3.2
3.4
3.6
Maximum annual Total Water Level, m


Point 4 TWL
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^-1
10^-2
10^-3
2.4
2.6
2.8
3
3.2
3.4
3.6
Maximum annual Total Water Level, m

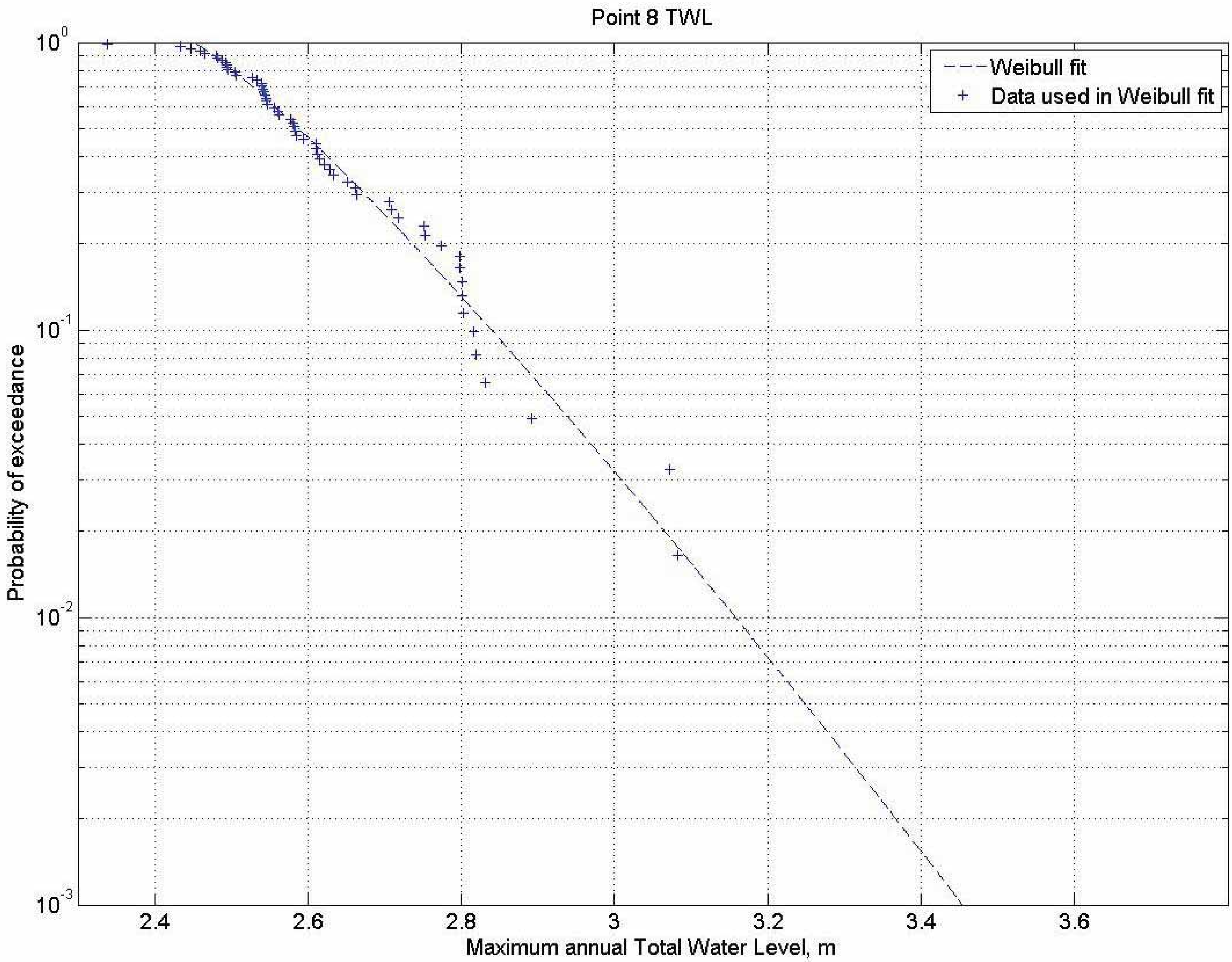


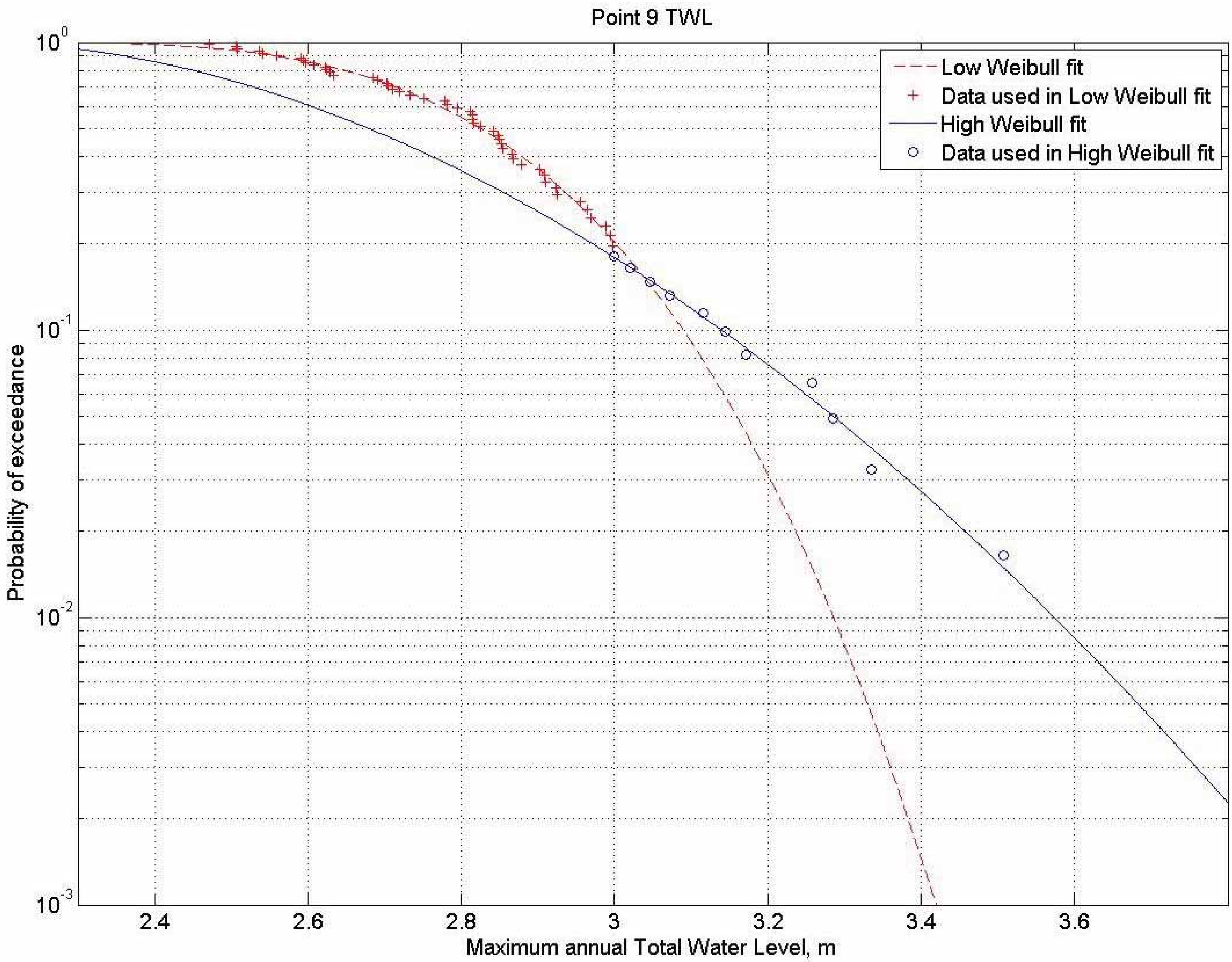
Point 5 TWL
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^{-1}
10^{-2}
10^{-3}
2.4
2.6
2.8
3
3.2
3.4
3.6
Maximum annual Total Water Level, m

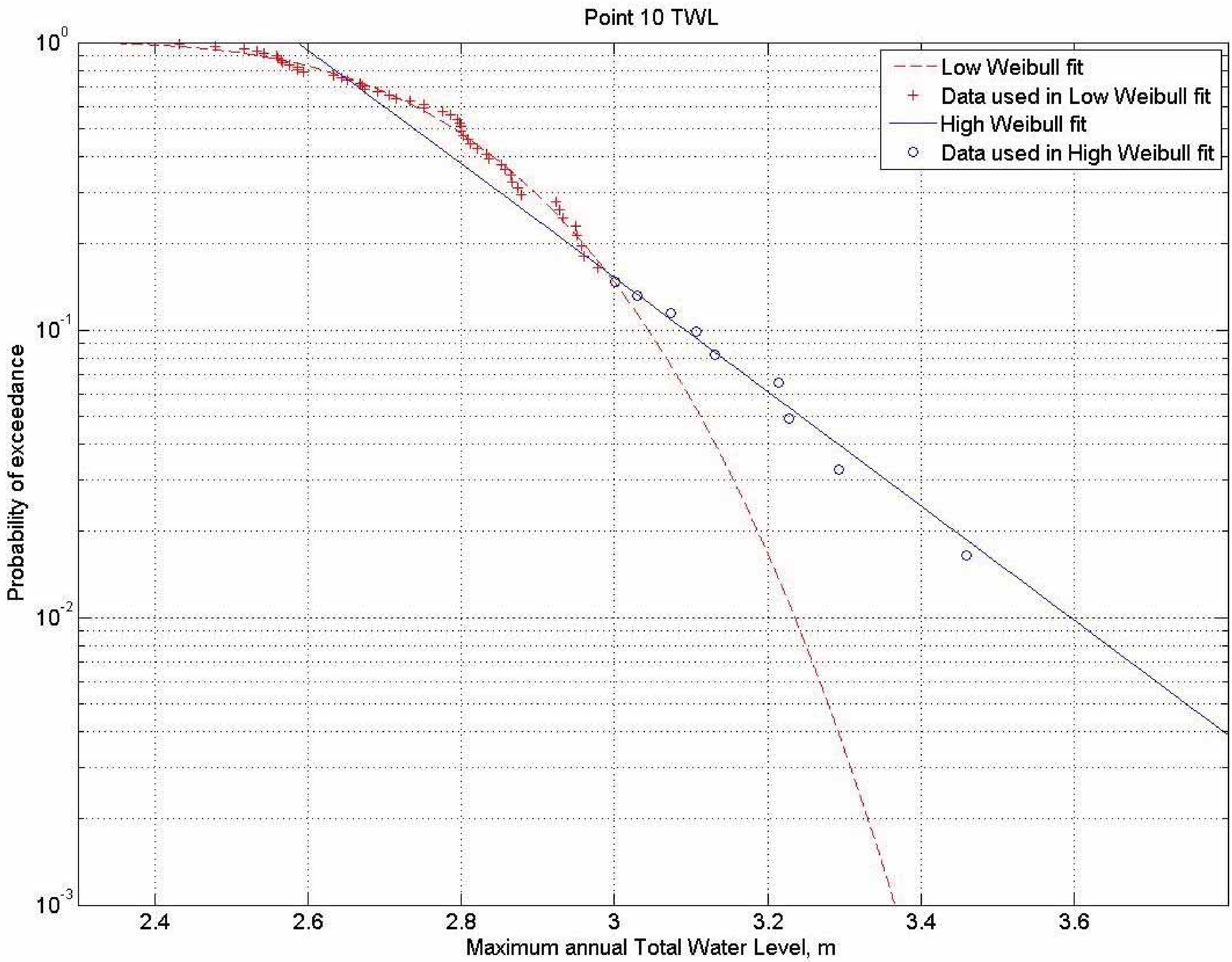

Point 6 TWL
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^-1
10^-2
10^-3
2.4
2.6
2.8
3
3.2
3.4
3.6
Maximum annual Total Water Level, m



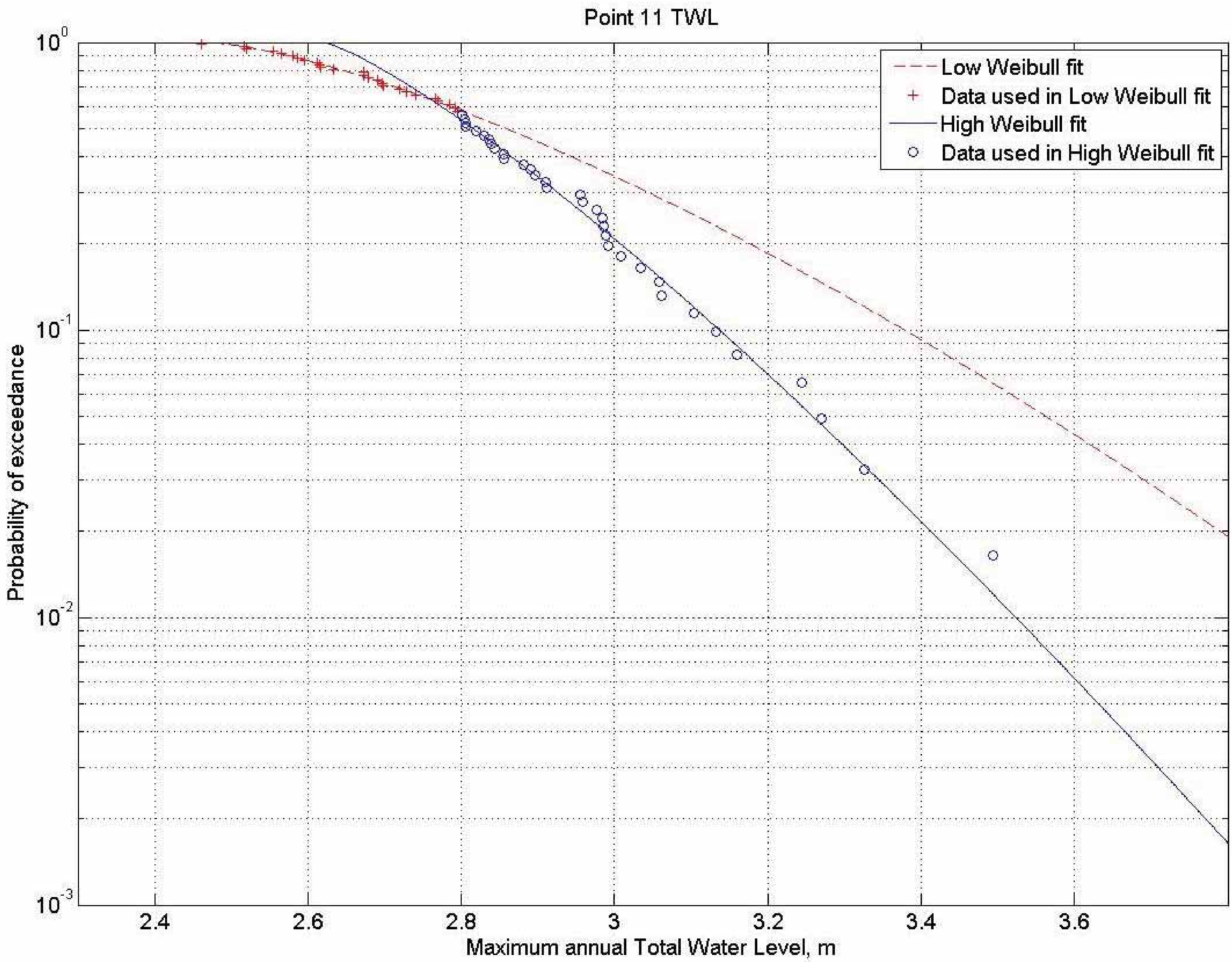
Point 7 TWL
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^{-1}
10^{-2}
10^{-3}
2.4
2.6
2.8
3
3.2
3.4
3.6
Maximum annual Total Water Level, m


Point 8 TWL
Weibull fit
Data used in Weibull fit
Probability of exceedance
10^0
10^-1
10^-2
10^-3
2.4
2.6
2.8
3
3.2
3.4
3.6
Maximum annual Total Water Level, m

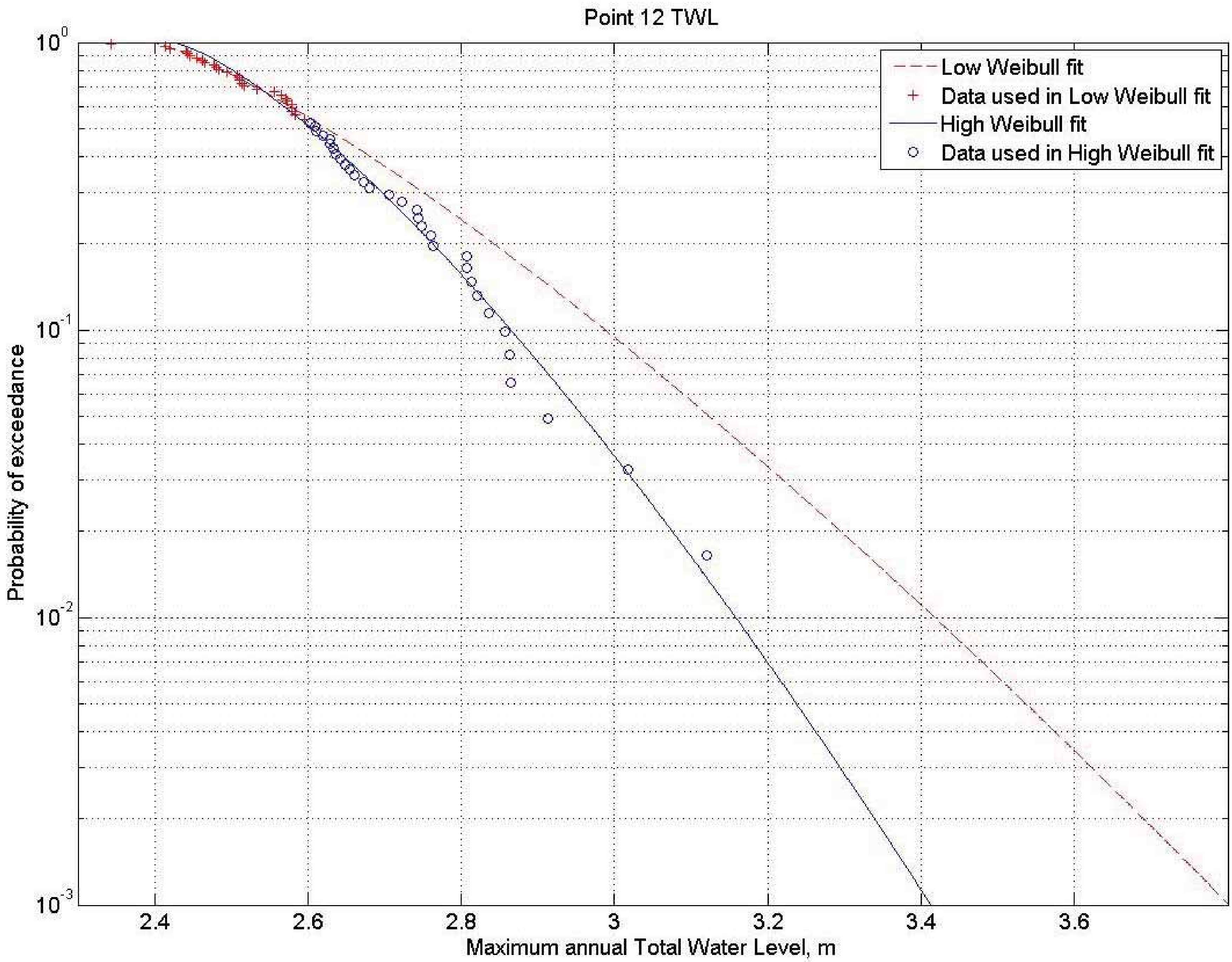

Point 9 TWL
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
10^0
10^{-1}
10^{-2}
10^{-3}
Probability of exceedance
2.4
2.6
2.8
3
3.2
3.4
3.6
Maximum annual Total Water Level, m



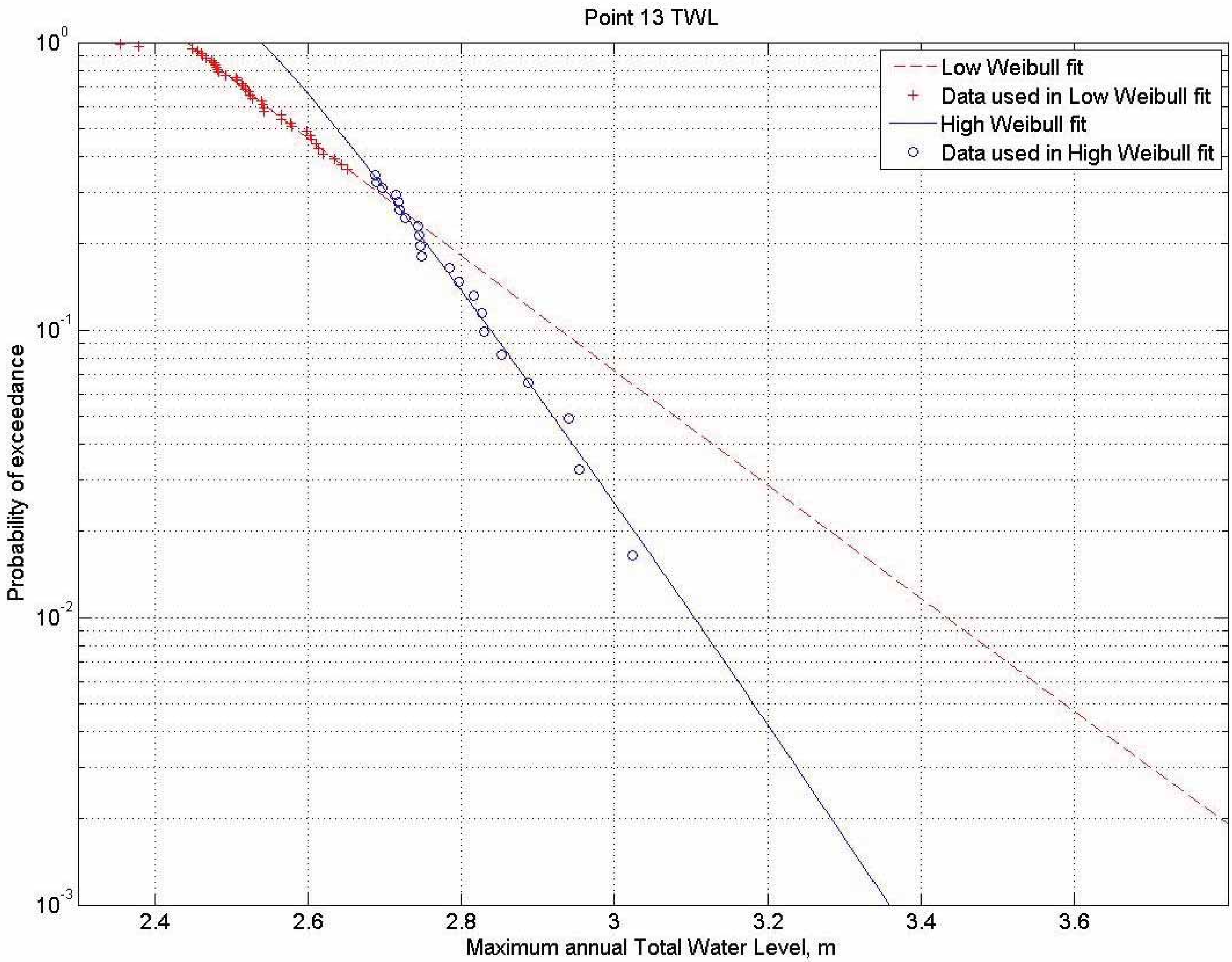
Point 10 TWL
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^-1
10^-2
10^-3
2.4
2.6
2.8
3
3.2
3.4
3.6
Maximum annual Total Water Level, m

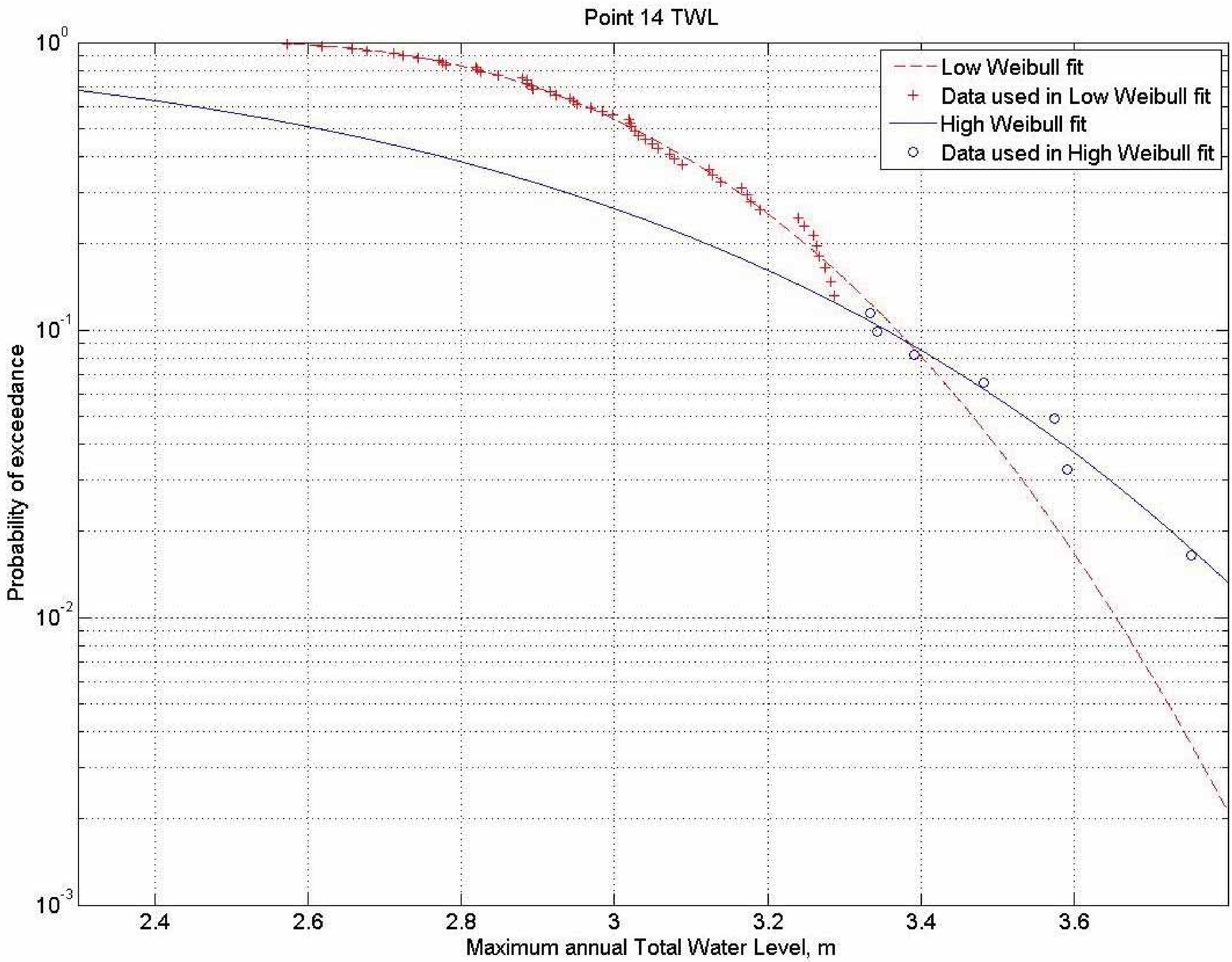


Point 11 TWL
Probability of exceedance
10^{0}
10^{-1}
10^{-2}
10^{-3}
2.4
2.6
2.8
3
3.2
3.4
3.6
Maximum annual Total Water Level, m
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit

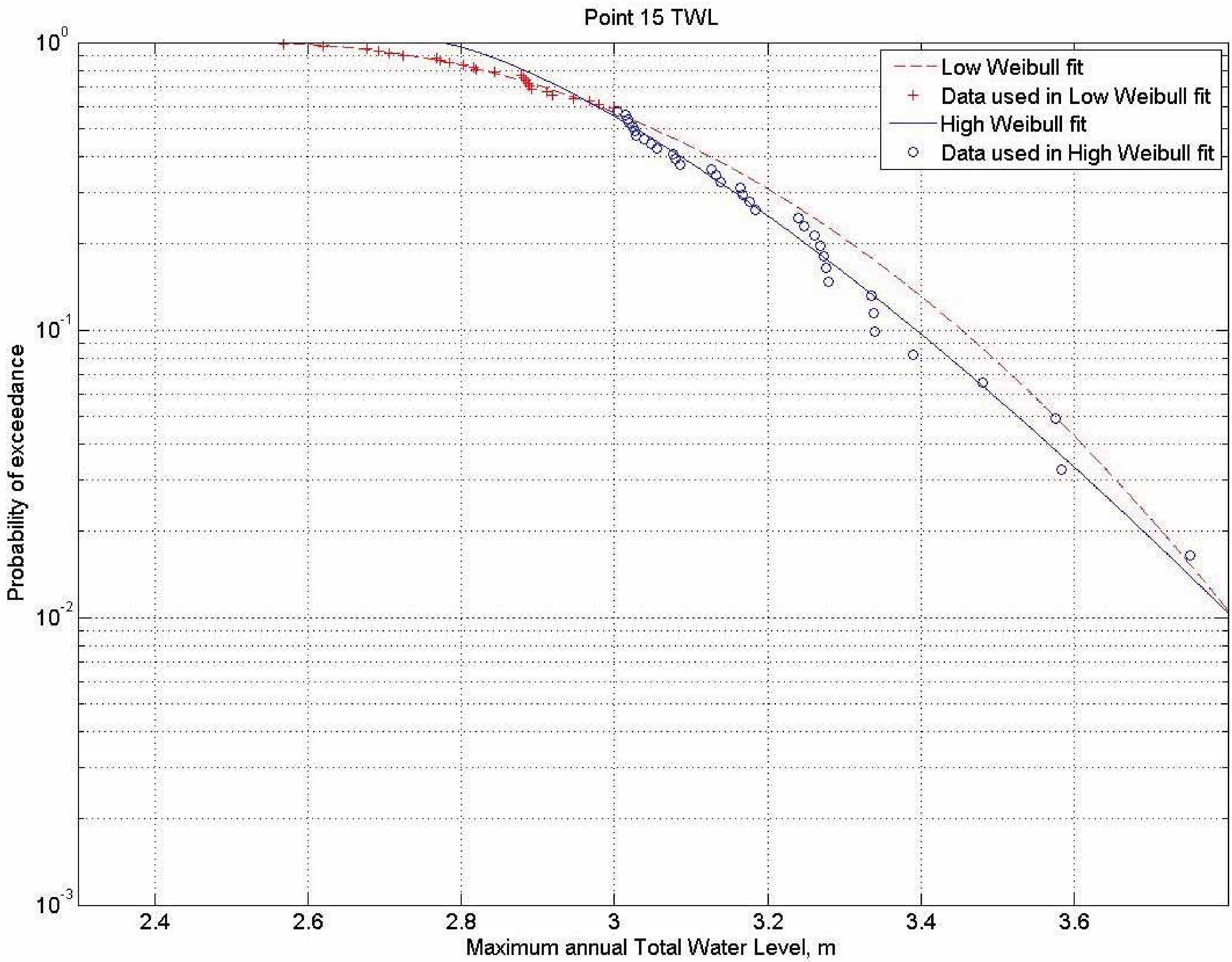


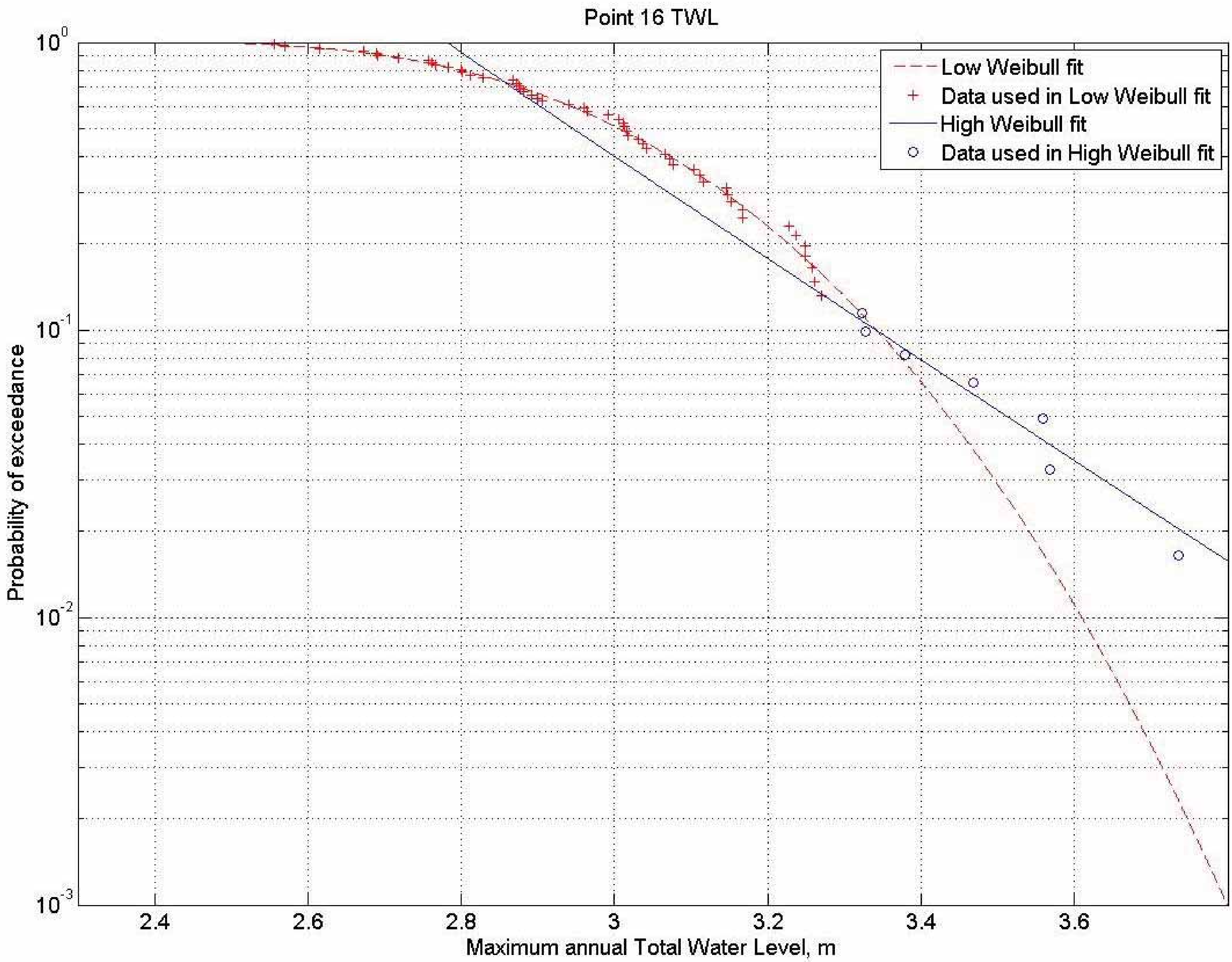
Point 12 TWL
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^-1
10^-2
10^-3
2.4
2.6
2.8
3
3.2
3.4
3.6
Maximum annual Total Water Level, m


Point 13 TWL
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^-1
10^-2
10^-3
2.4
2.6
2.8
3
3.2
3.4
3.6
Maximum annual Total Water Level, m

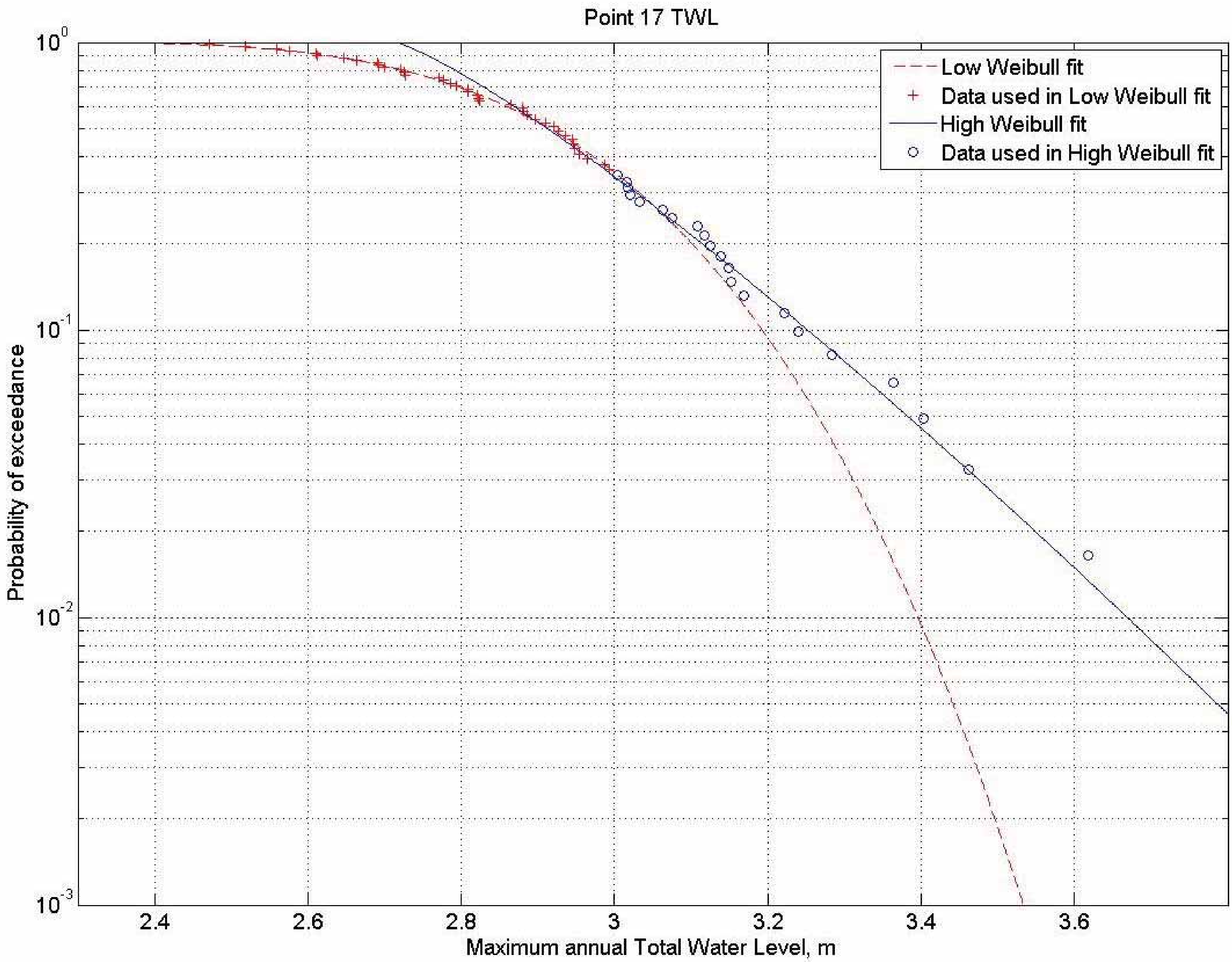


Point 14 TWL
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^{-1}
10^{-2}
10^{-3}
2.4
2.6
2.8
3
3.2
3.4
3.6
Maximum annual Total Water Level, m

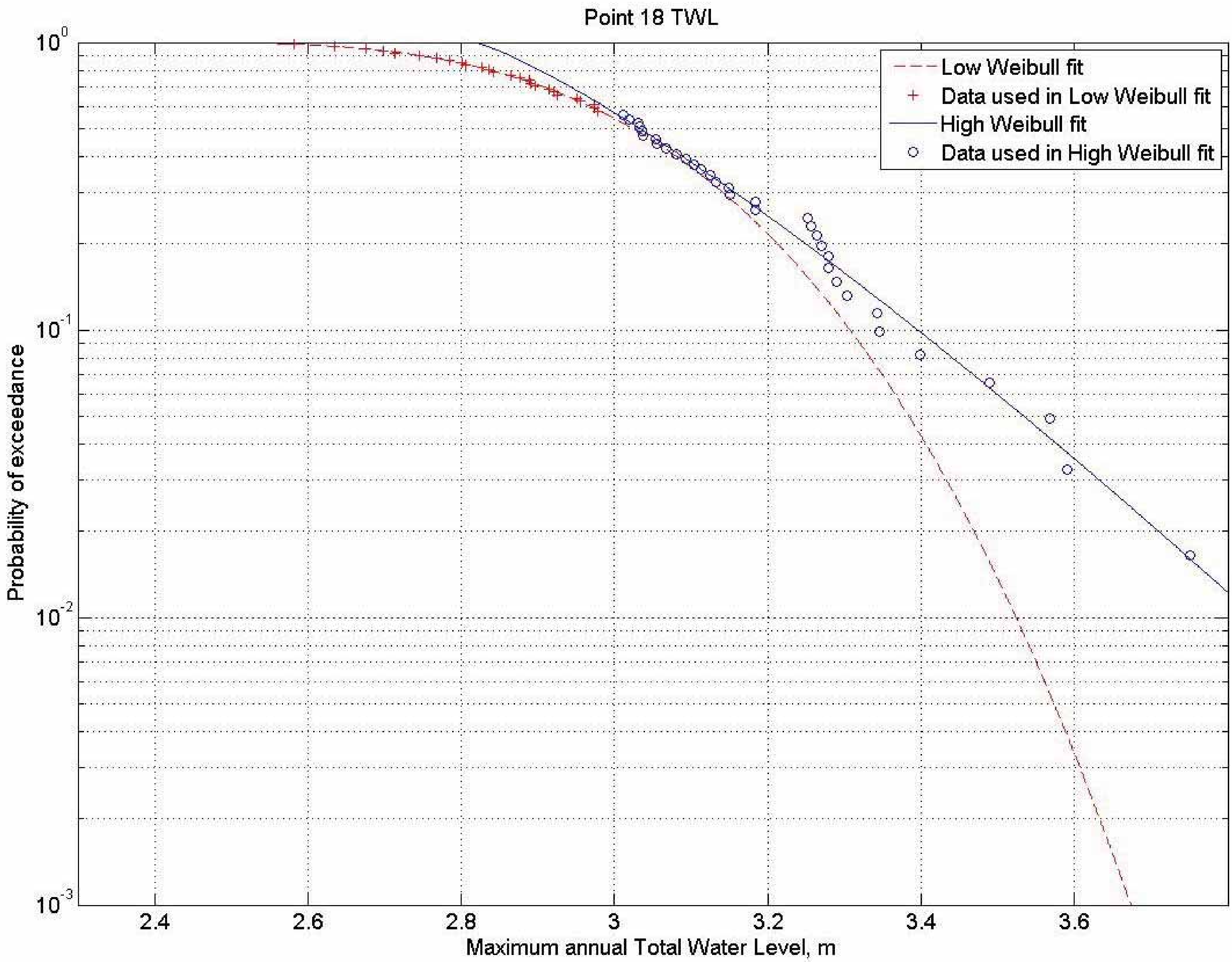

Point 15 TWL
Probability of exceedance
10^0
10^-1
10^-2
10^-3
2.4
2.6
2.8
3
3.2
3.4
3.6
Maximum annual Total Water Level, m
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit

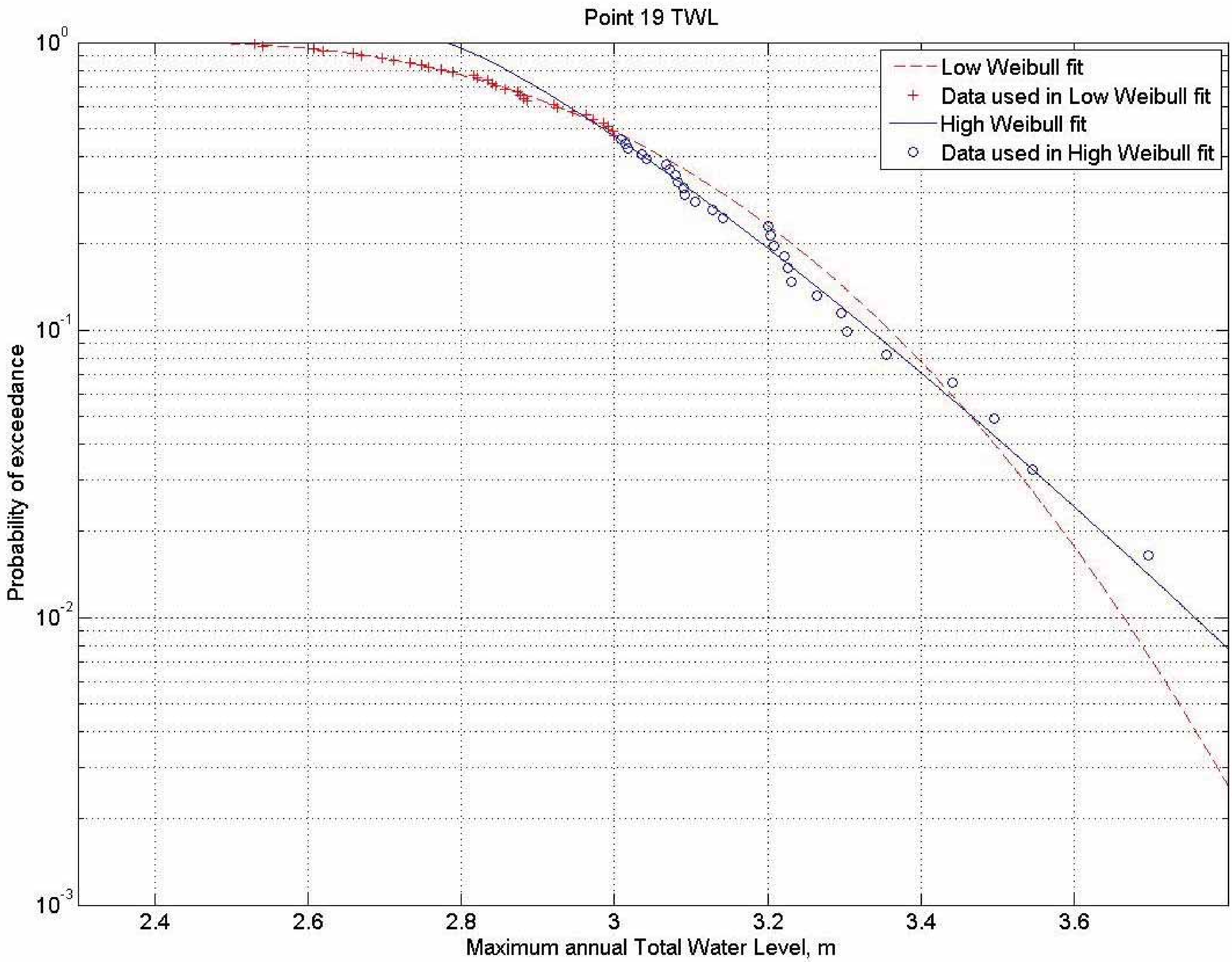


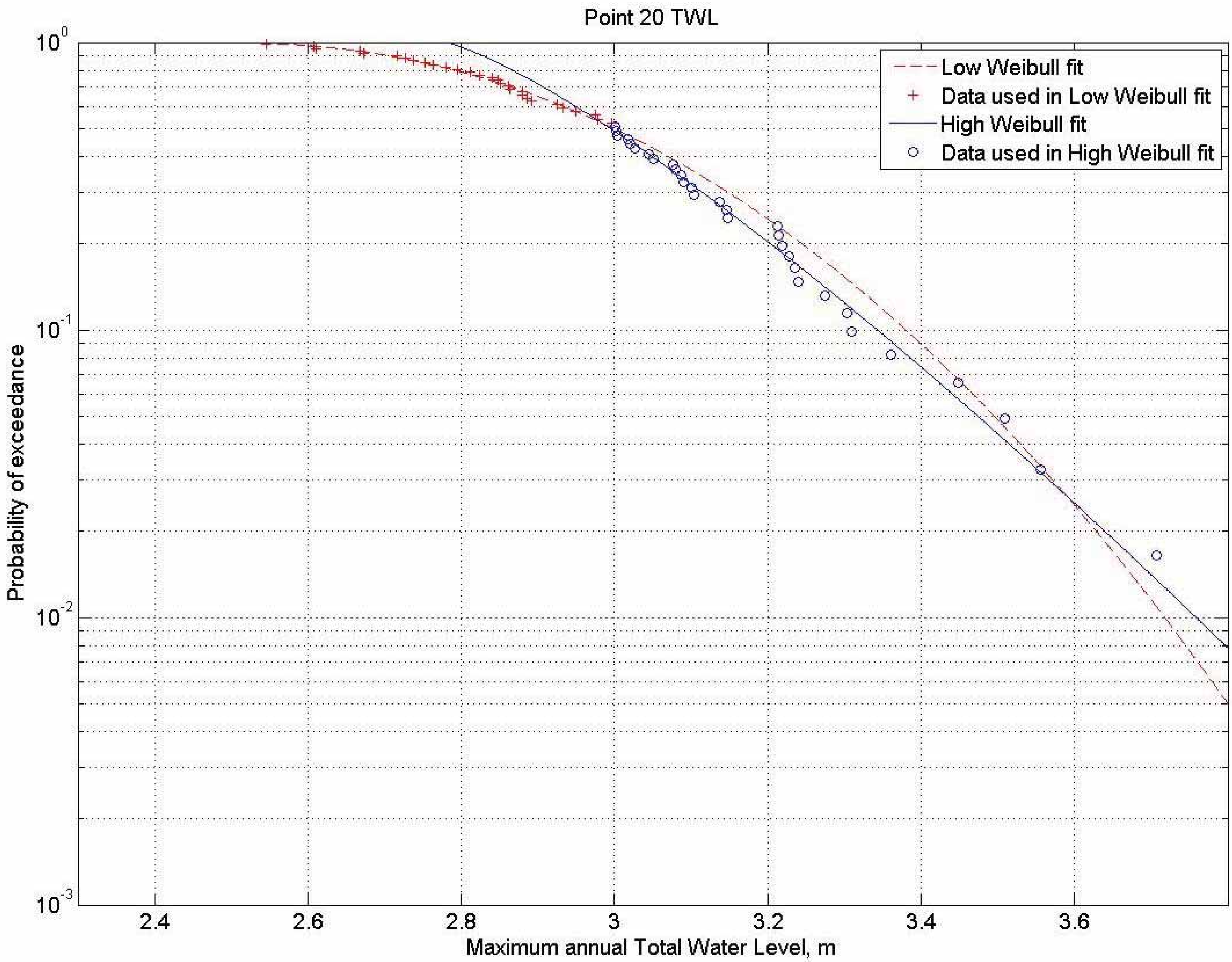
Point 16 TWL
Probability of exceedance
Maximum annual Total Water Level, m
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
10^{0}
10^{-1}
10^{-2}
10^{-3}
2.4
2.6
2.8
3
3.2
3.4
3.6



Point 17 TWL
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^{-1}
10^{-2}
10^{-3}
2.4
2.6
2.8
3
3.2
3.4
3.6
Maximum annual Total Water Level, m

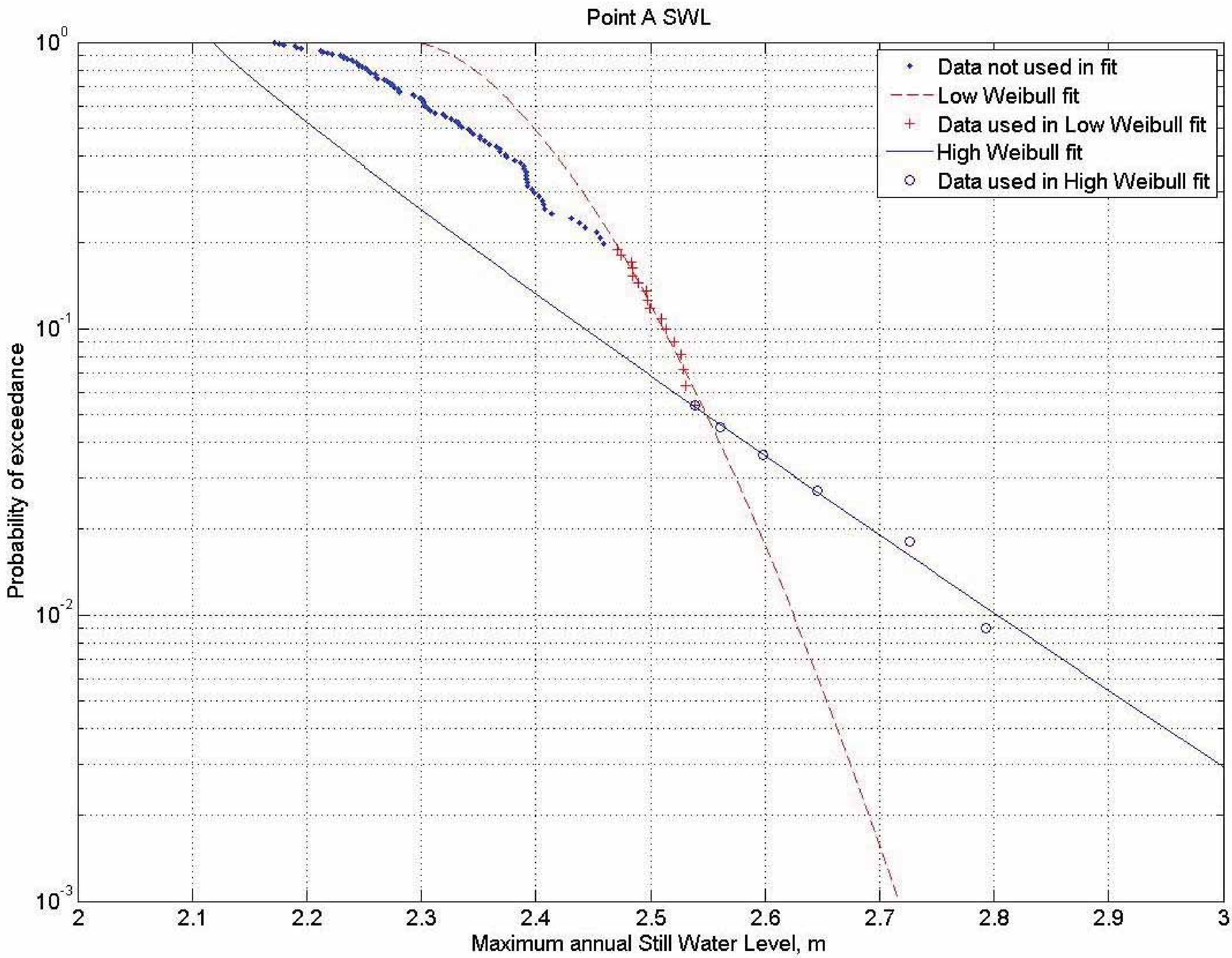

Point 18 TWL
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
Maximum annual Total Water Level, m
10^0
10^{-1}
10^{-2}
10^{-3}
2.4
2.6
2.8
3
3.2
3.4
3.6

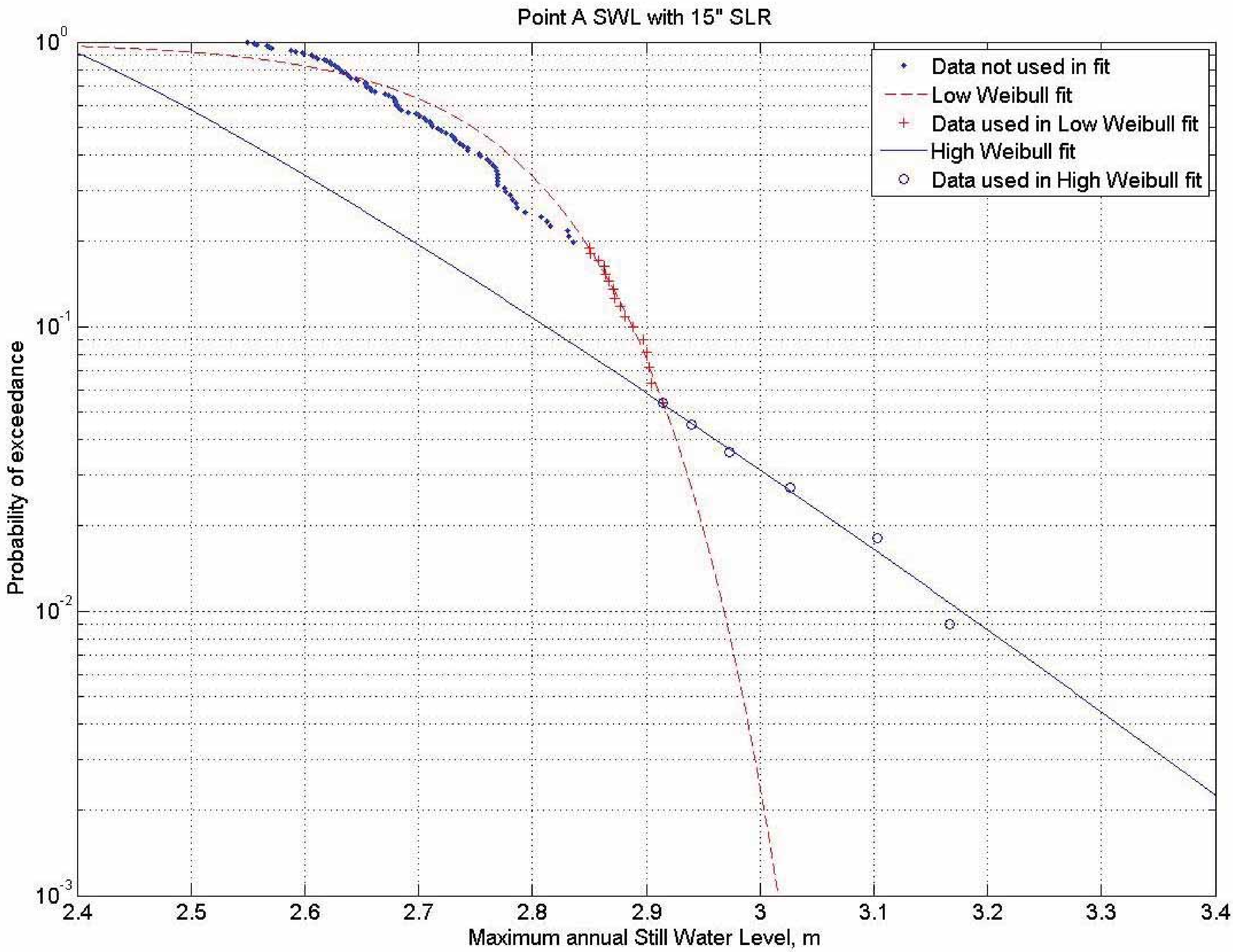

Point 19 TWL
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^{0}
10^{-1}
10^{-2}
10^{-3}
2.4
2.6
2.8
3
3.2
3.4
3.6
Maximum annual Total Water Level, m

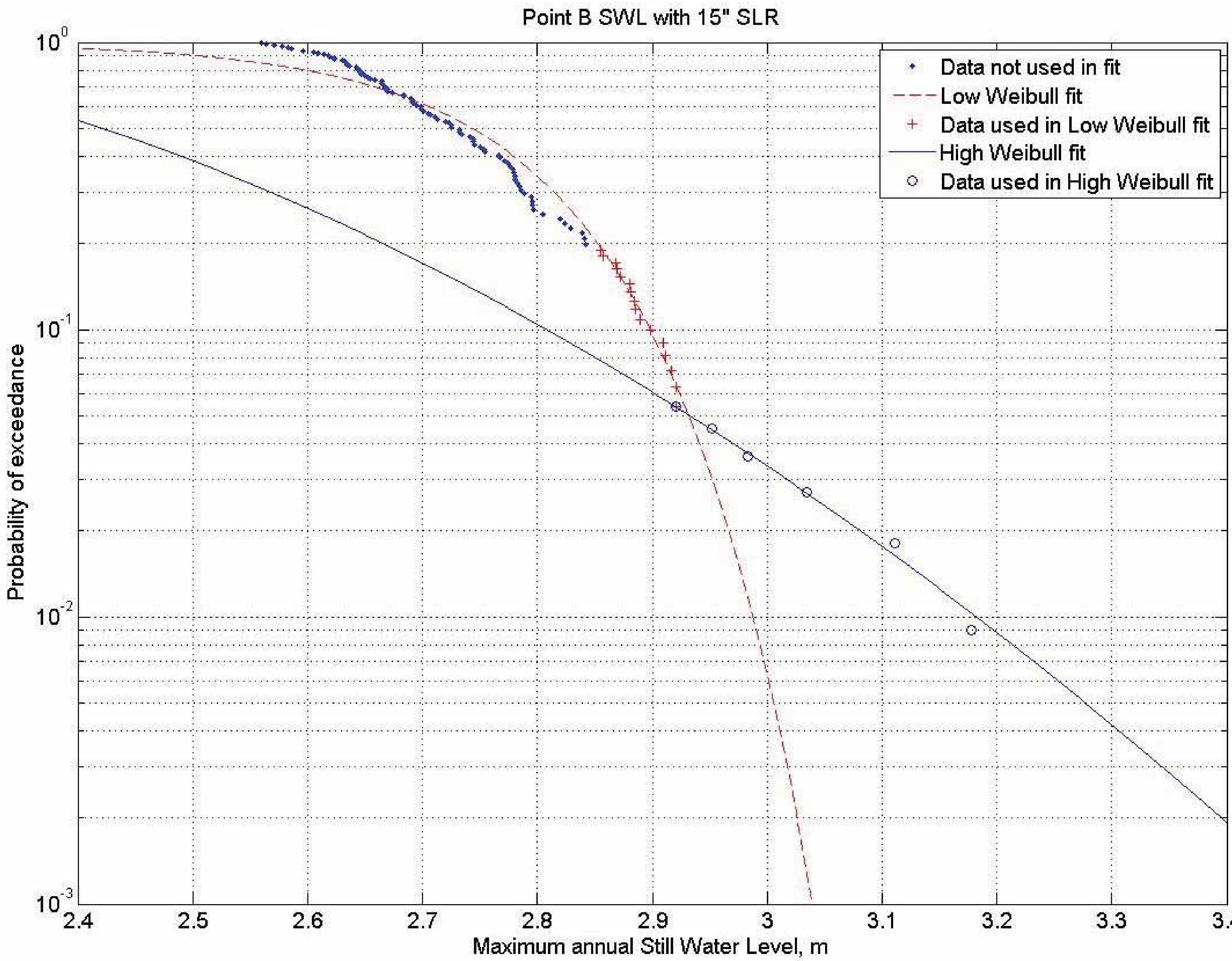


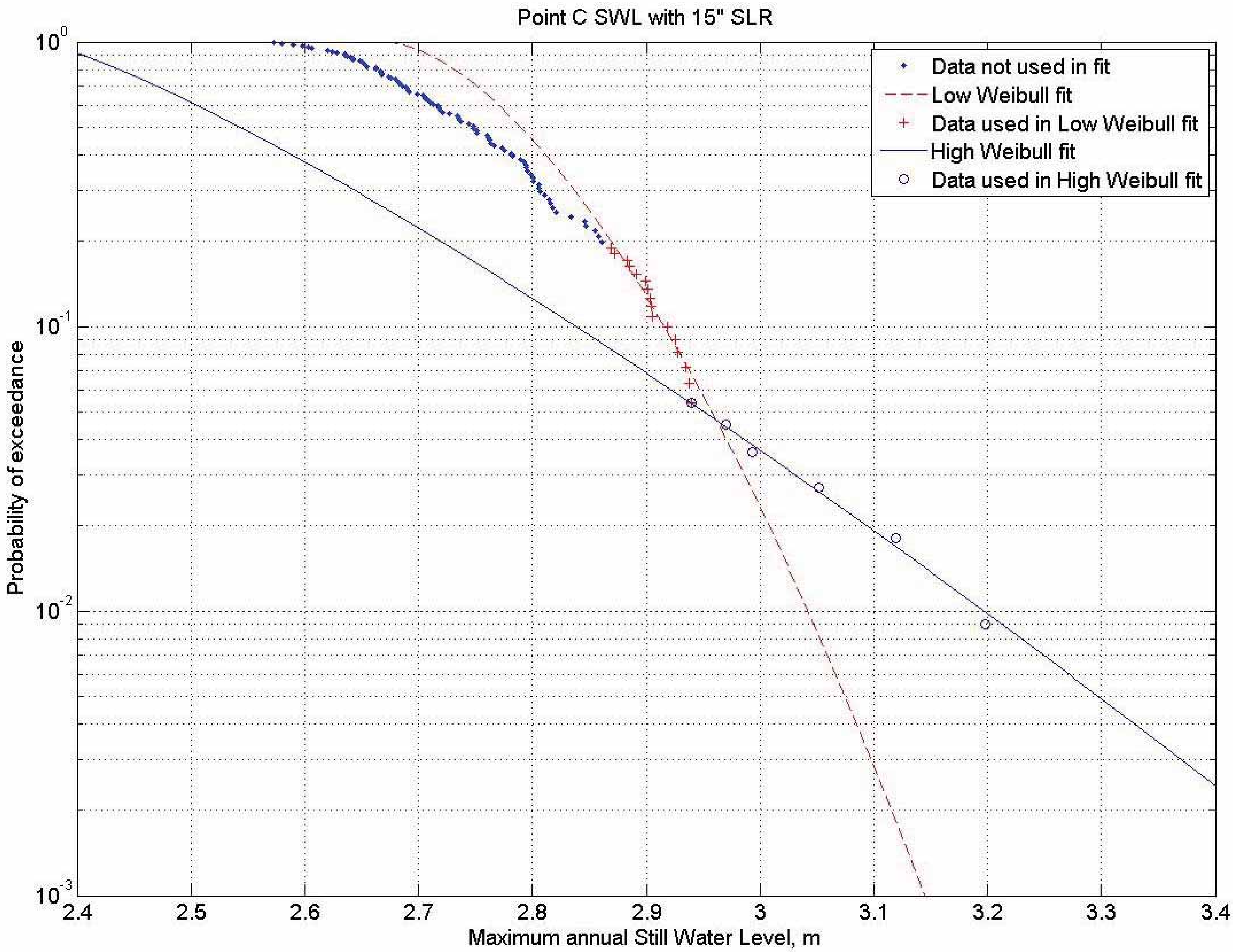
Point 20 TWL
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
Maximum annual Total Water Level, m

Year 2050 Conditions

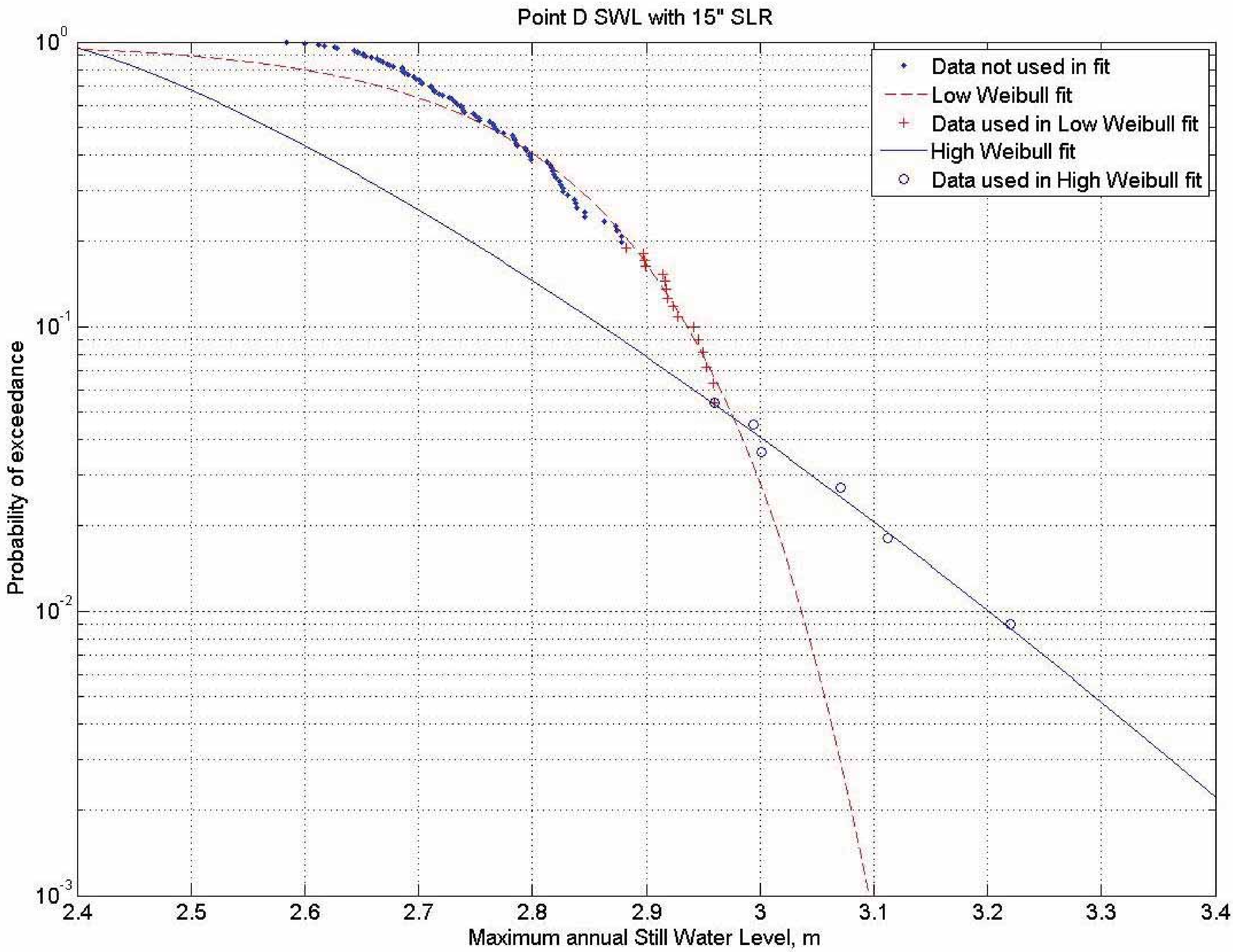

Point A SWL
Probability of exceedance
10^0
10^-1
10^-2
10^-3
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3
Maximum annual Still Water Level, m
Data not used in fit
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit

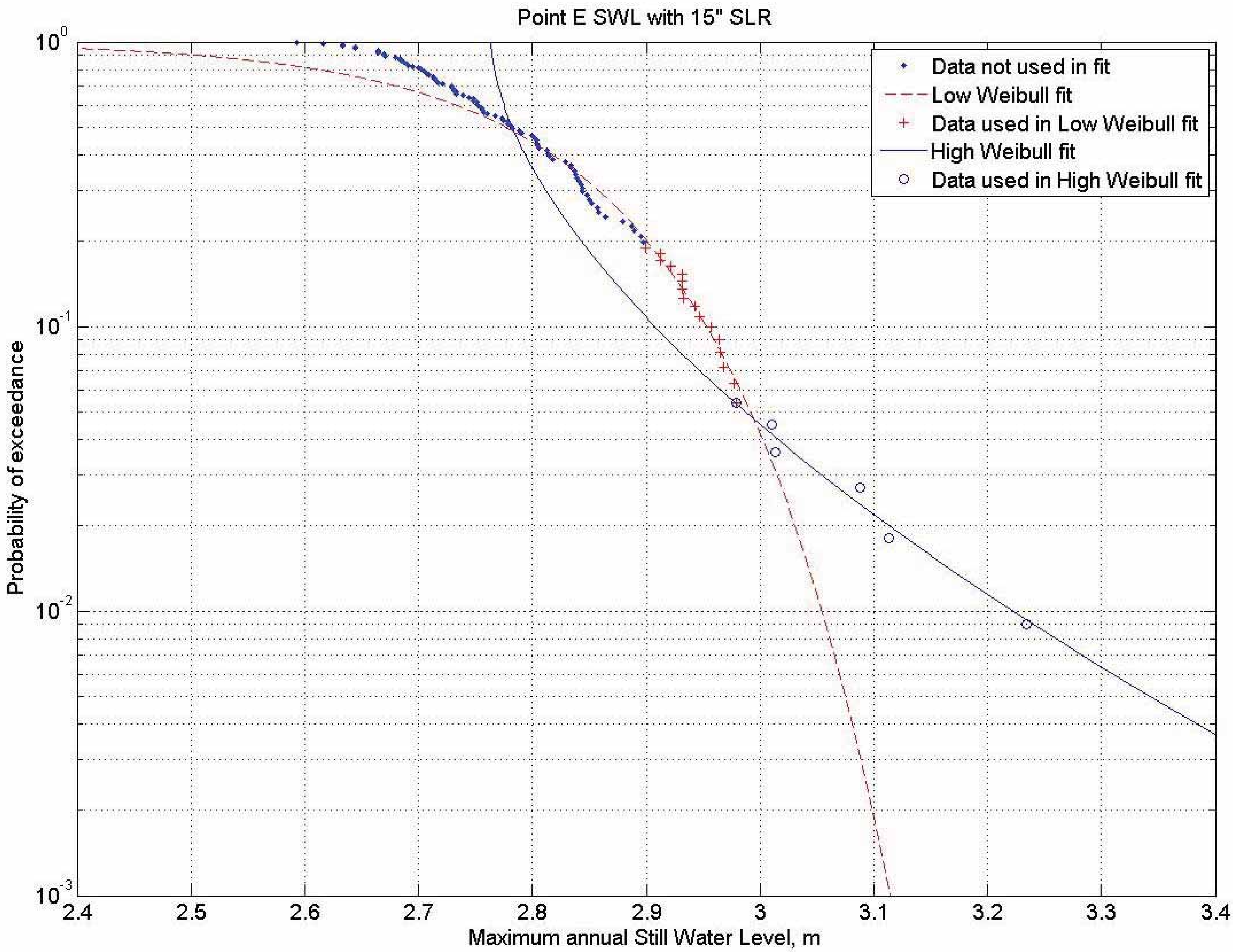

Point A SWL with 15" SLR
Data not used in fit
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^-1
10^-2
10^-3
2.4
2.5
2.6
2.7
2.8
2.9
3
3.1
3.2
3.3
3.4
Maximum annual Still Water Level, m


Point B SWL with 15" SLR
Data not used in fit
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^-1
10^-2
10^-3
2.4
2.5
2.6
2.7
2.8
2.9
3
3.1
3.2
3.3
3.4
Maximum annual Still Water Level, m

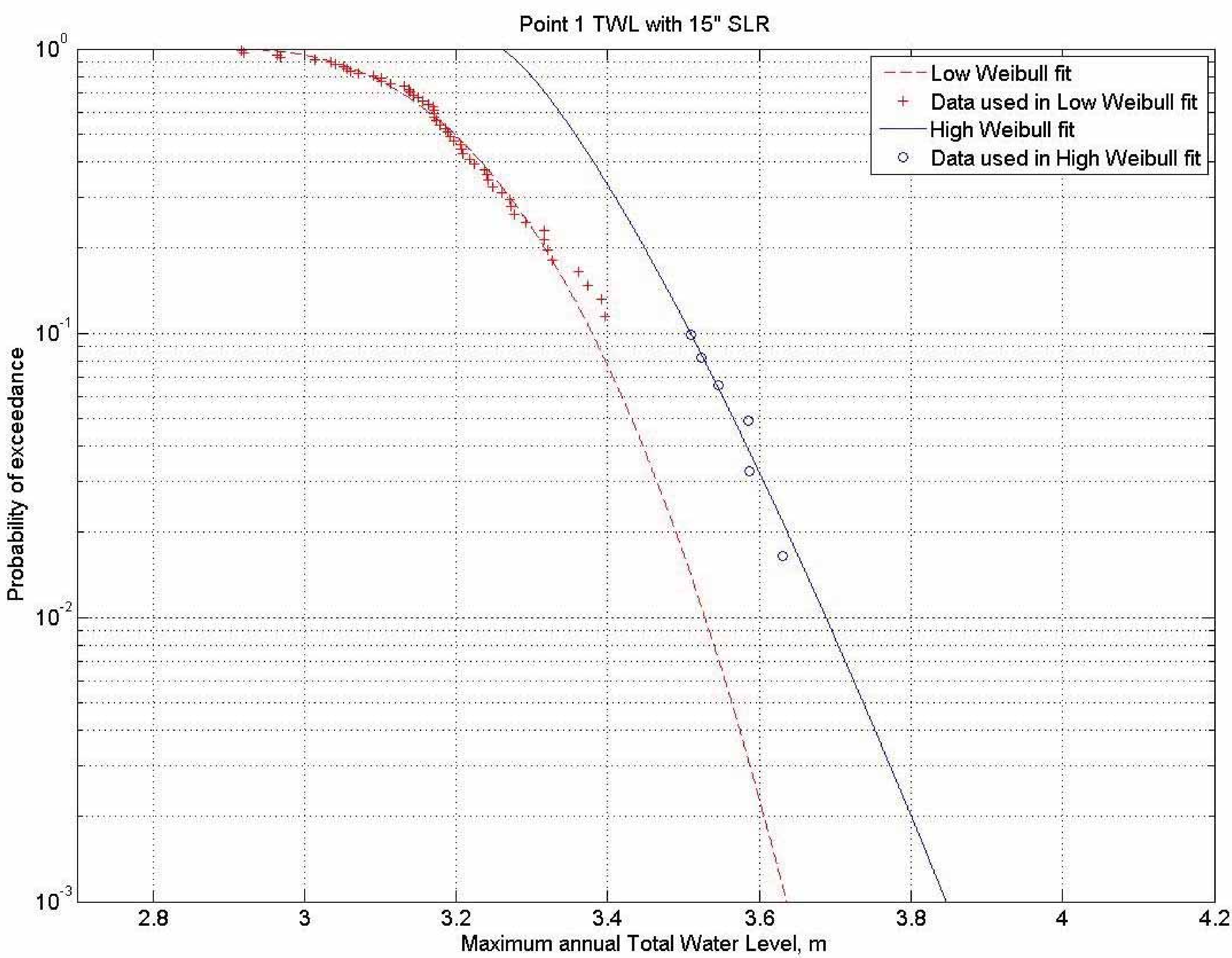


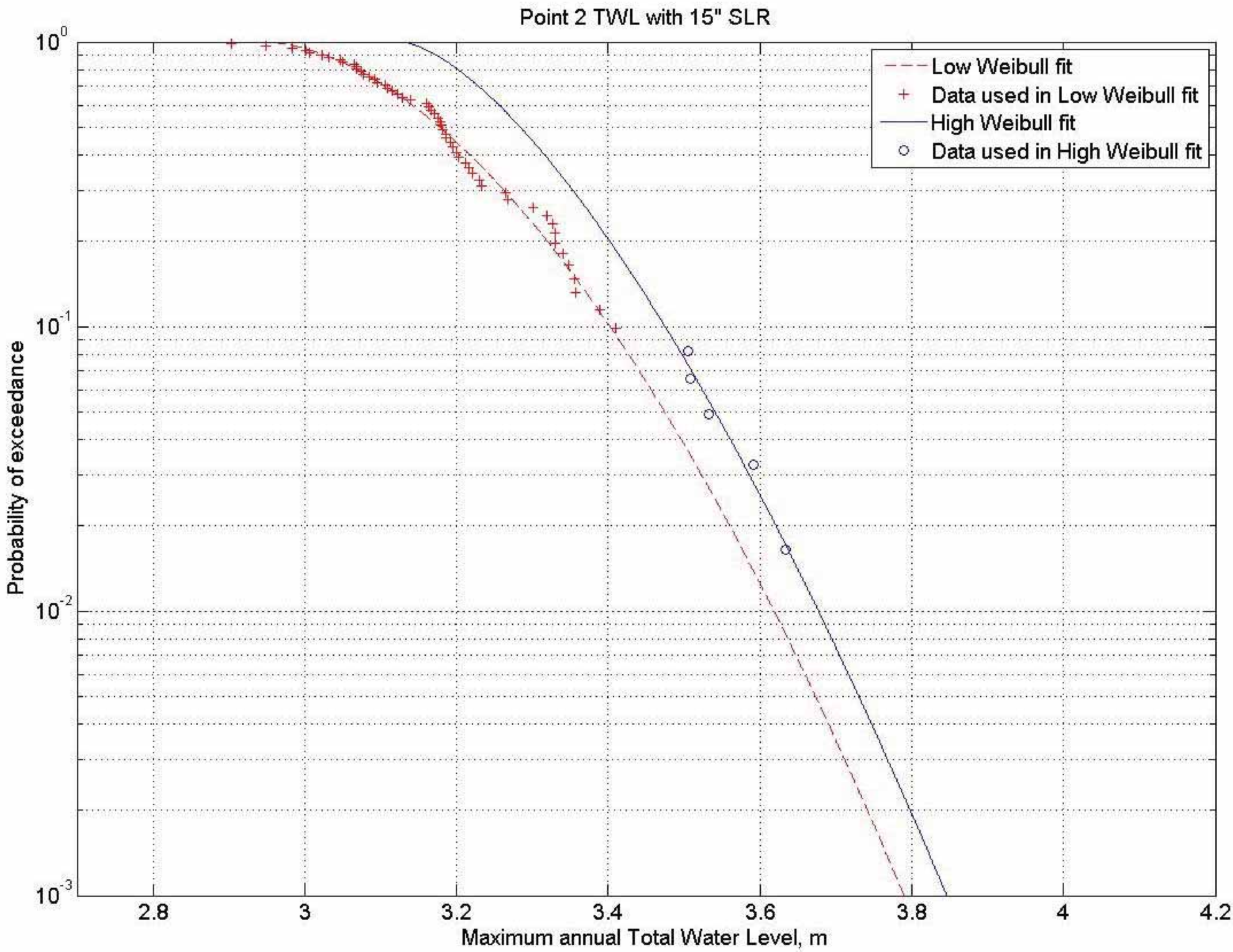
Point C SWL with 15" SLR
Data not used in fit
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^-1
10^-2
10^-3
2.4
2.5
2.6
2.7
2.8
2.9
3
3.1
3.2
3.3
3.4
Maximum annual Still Water Level, m


Point D SWL with 15" SLR
Data not used in fit
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^{0}
10^{-1}
10^{-2}
10^{-3}
2.4
2.5
2.6
2.7
2.8
2.9
3
3.1
3.2
3.3
3.4
Maximum annual Still Water Level, m

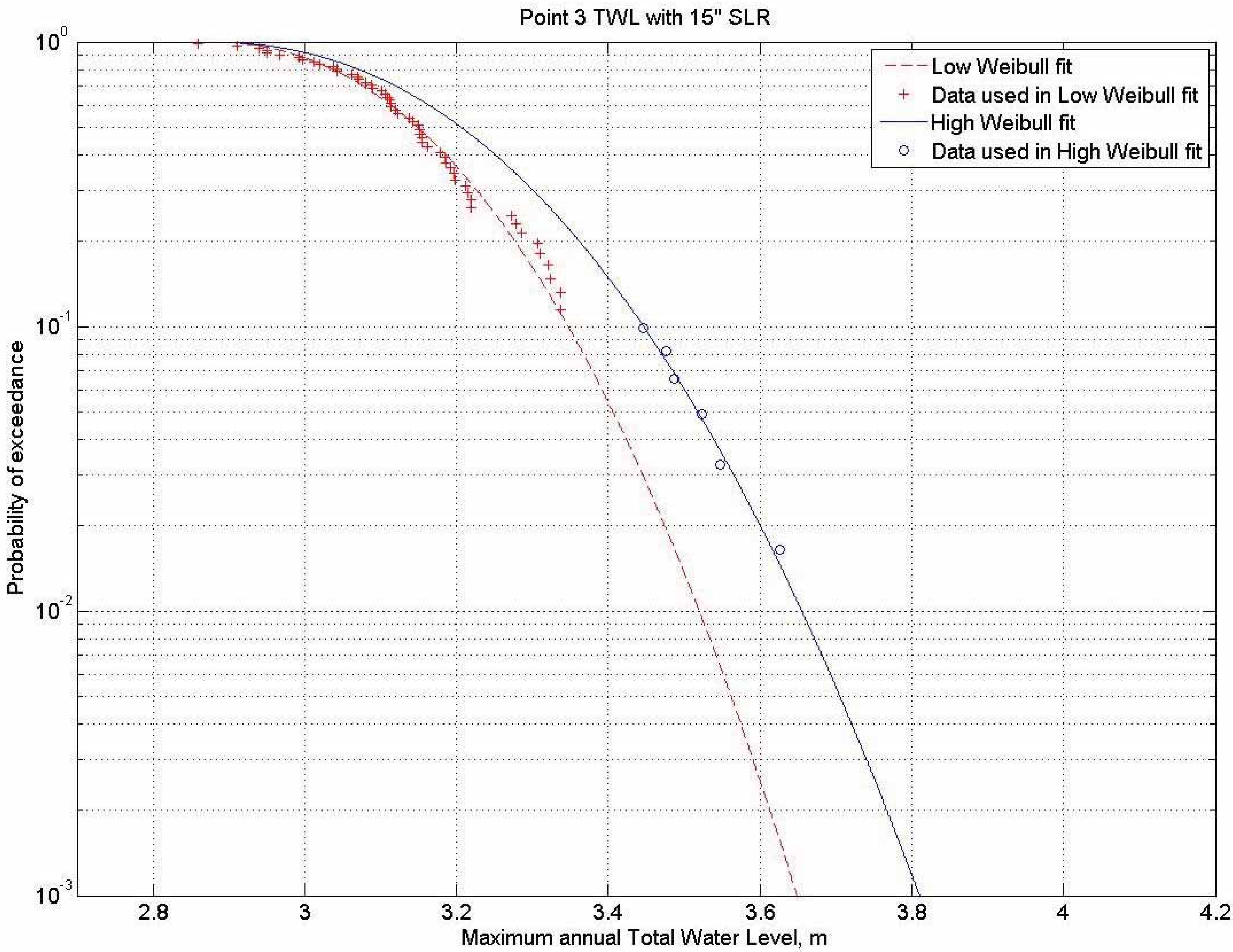


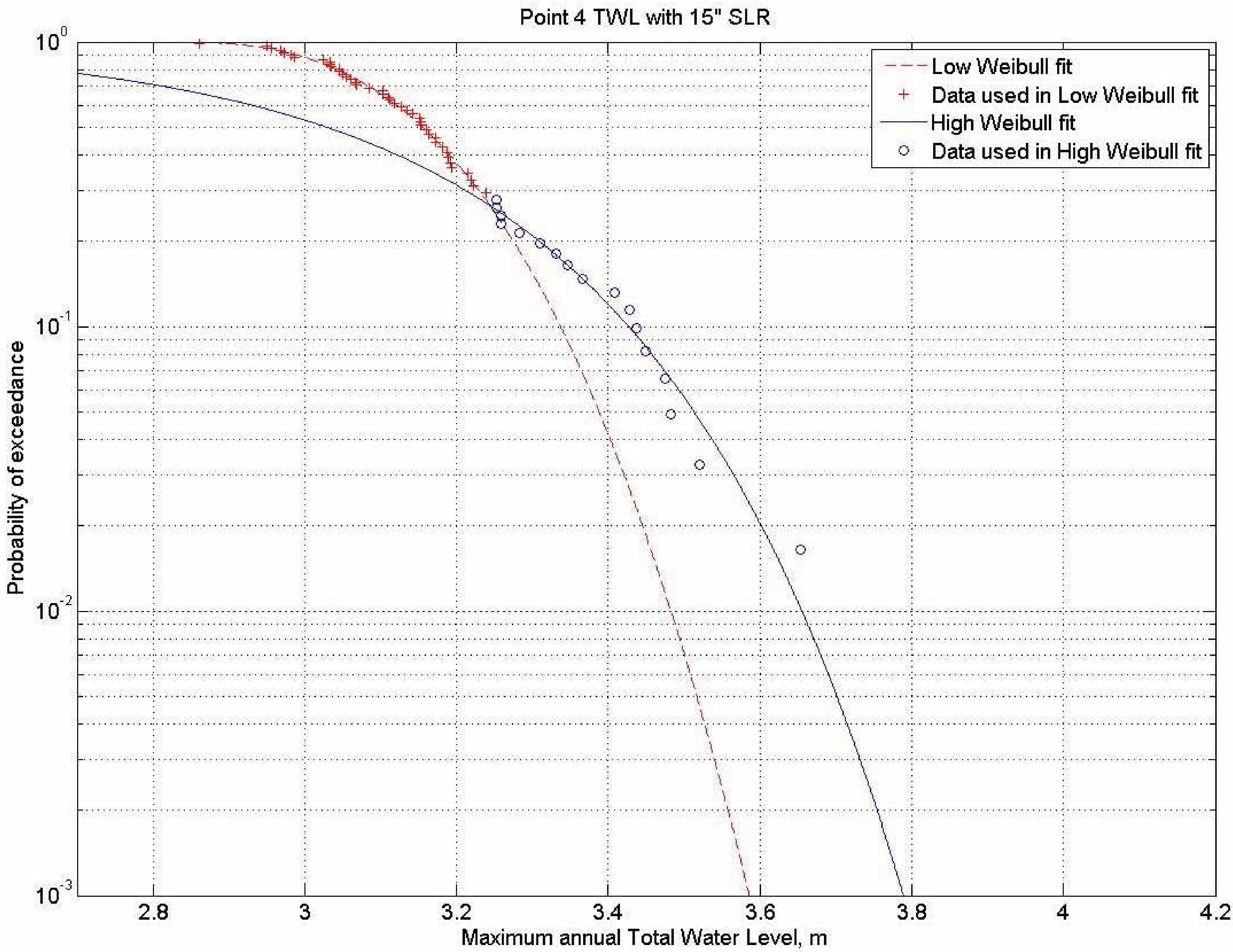
Point E SWL with 15" SLR
Data not used in fit
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^-1
10^-2
10^-3
2.4
2.5
2.6
2.7
2.8
2.9
3
3.1
3.2
3.3
3.4
Maximum annual Still Water Level, m

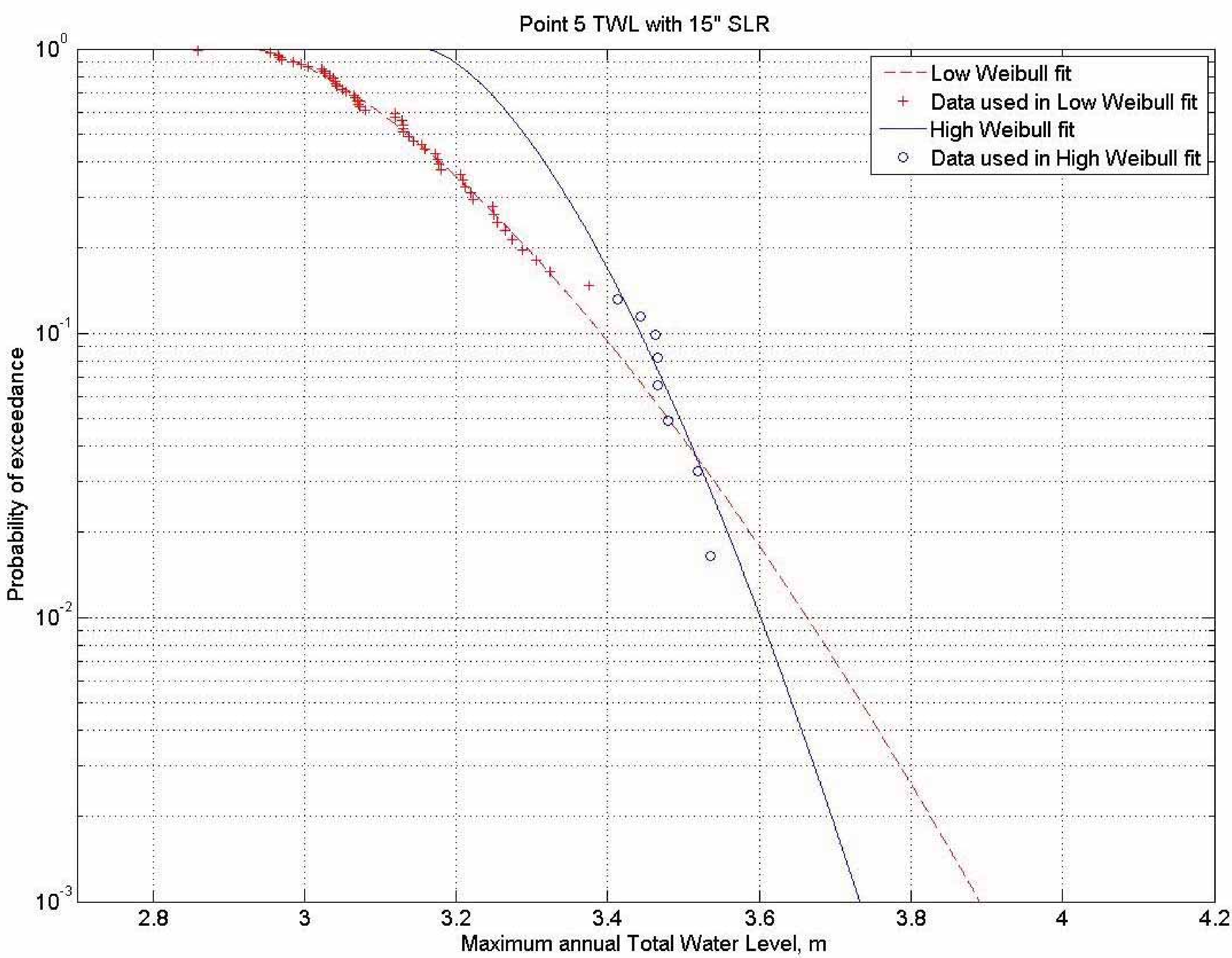

Point 1 TWL with 15" SLR
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^-1
10^-2
10^-3
2.8
3
3.2
3.4
3.6
3.8
4
4.2
Maximum annual Total Water Level, m

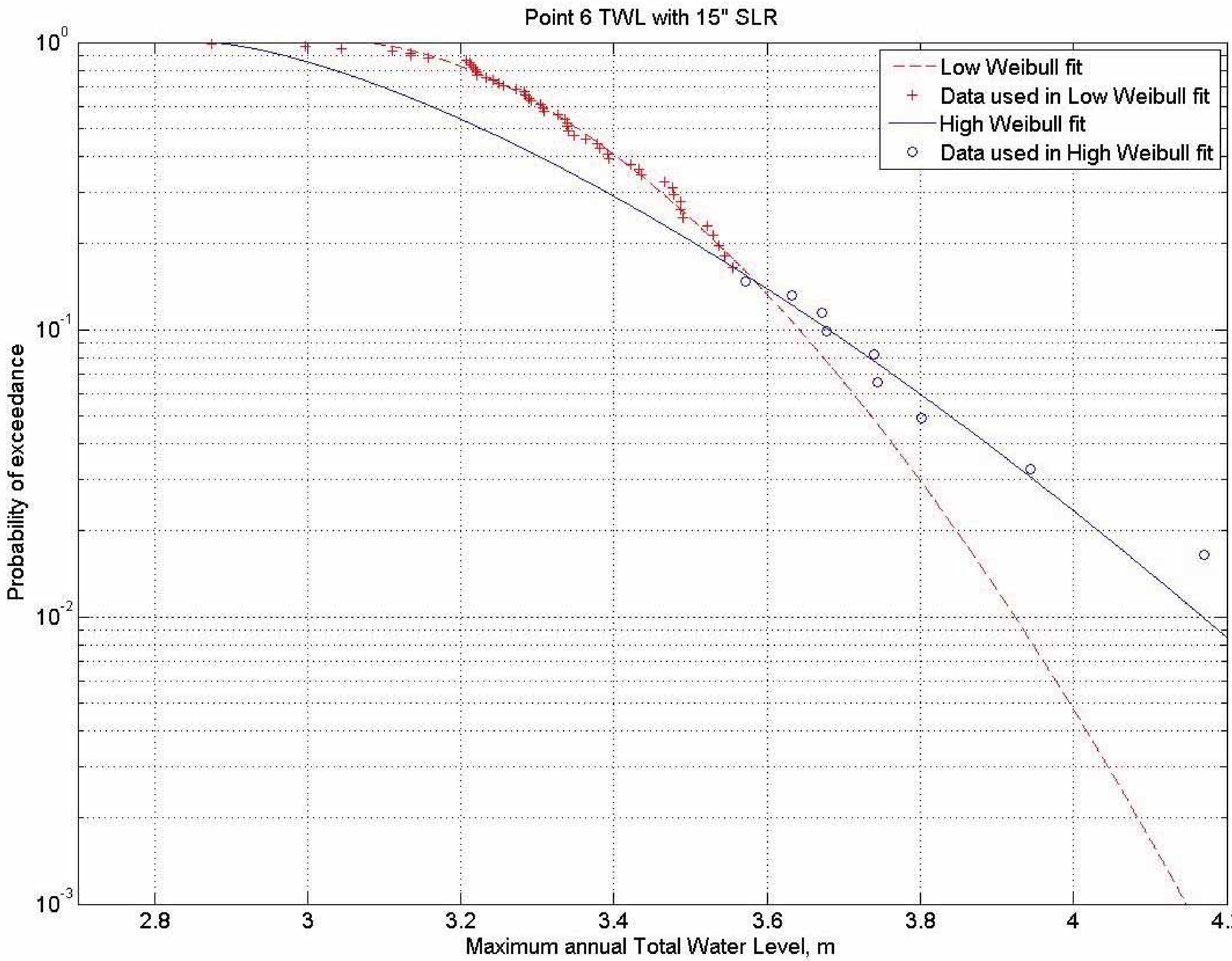


Point 2 TWL with 15" SLR
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^-1
10^-2
10^-3
2.8
3
3.2
3.4
3.6
3.8
4
4.2
Maximum annual Total Water Level, m

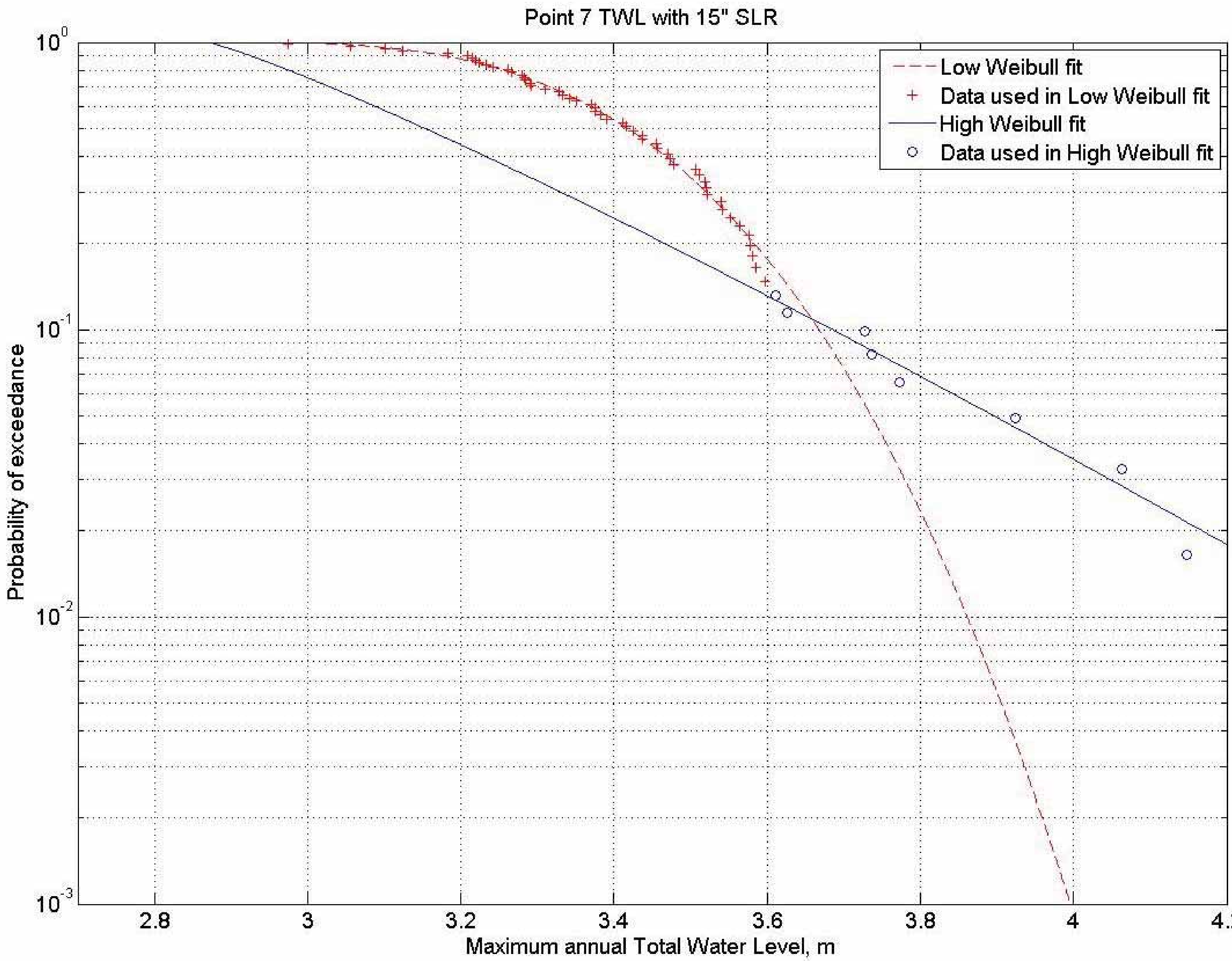

Point 3 TWL with 15" SLR
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^{-1}
10^{-2}
10^{-3}
2.8
3
3.2
3.4
3.6
3.8
4
4.2
Maximum annual Total Water Level, m

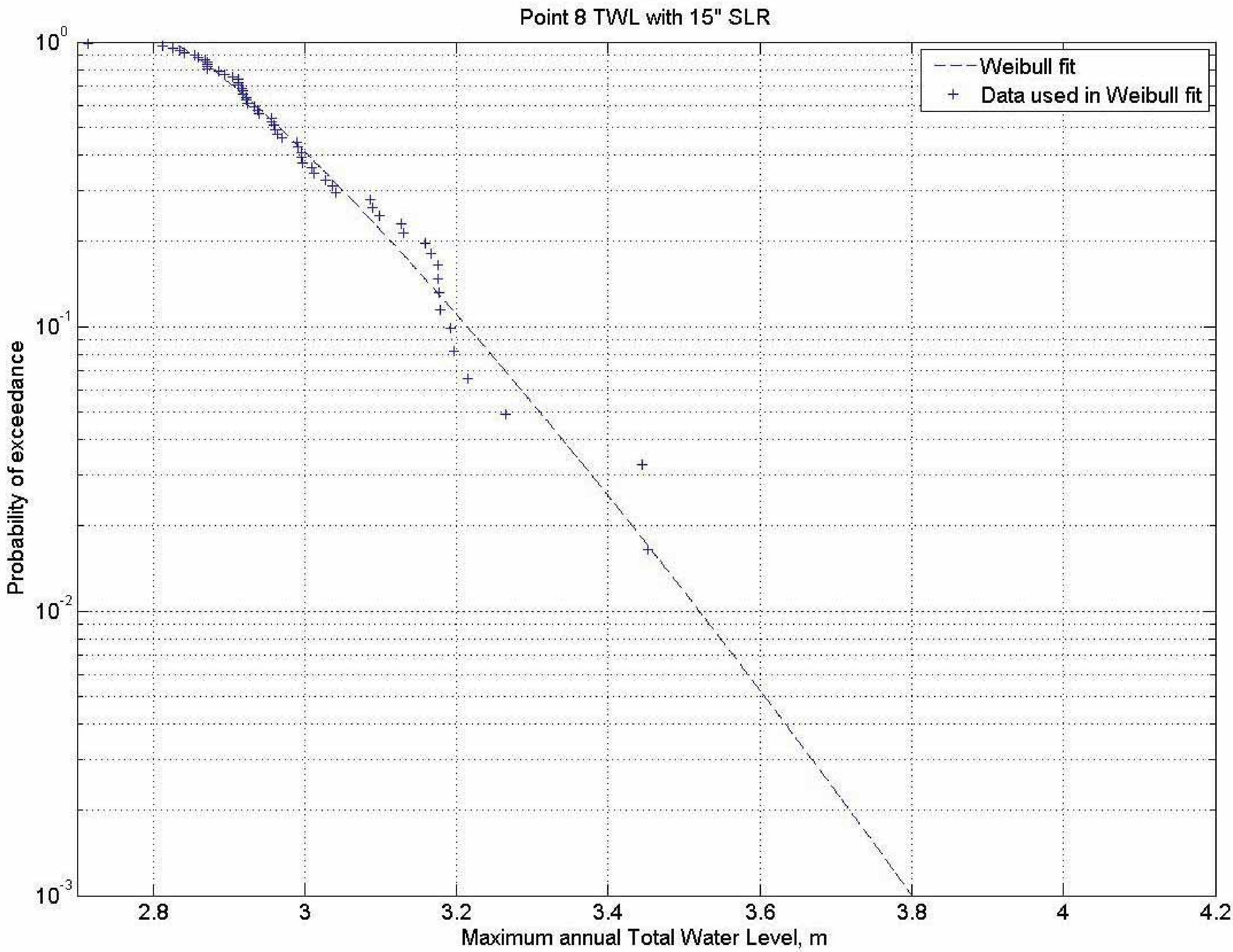

Point 4 TWL with 15" SLR
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^-1
10^-2
10^-3
2.8
3
3.2
3.4
3.6
3.8
4
4.2
Maximum annual Total Water Level, m

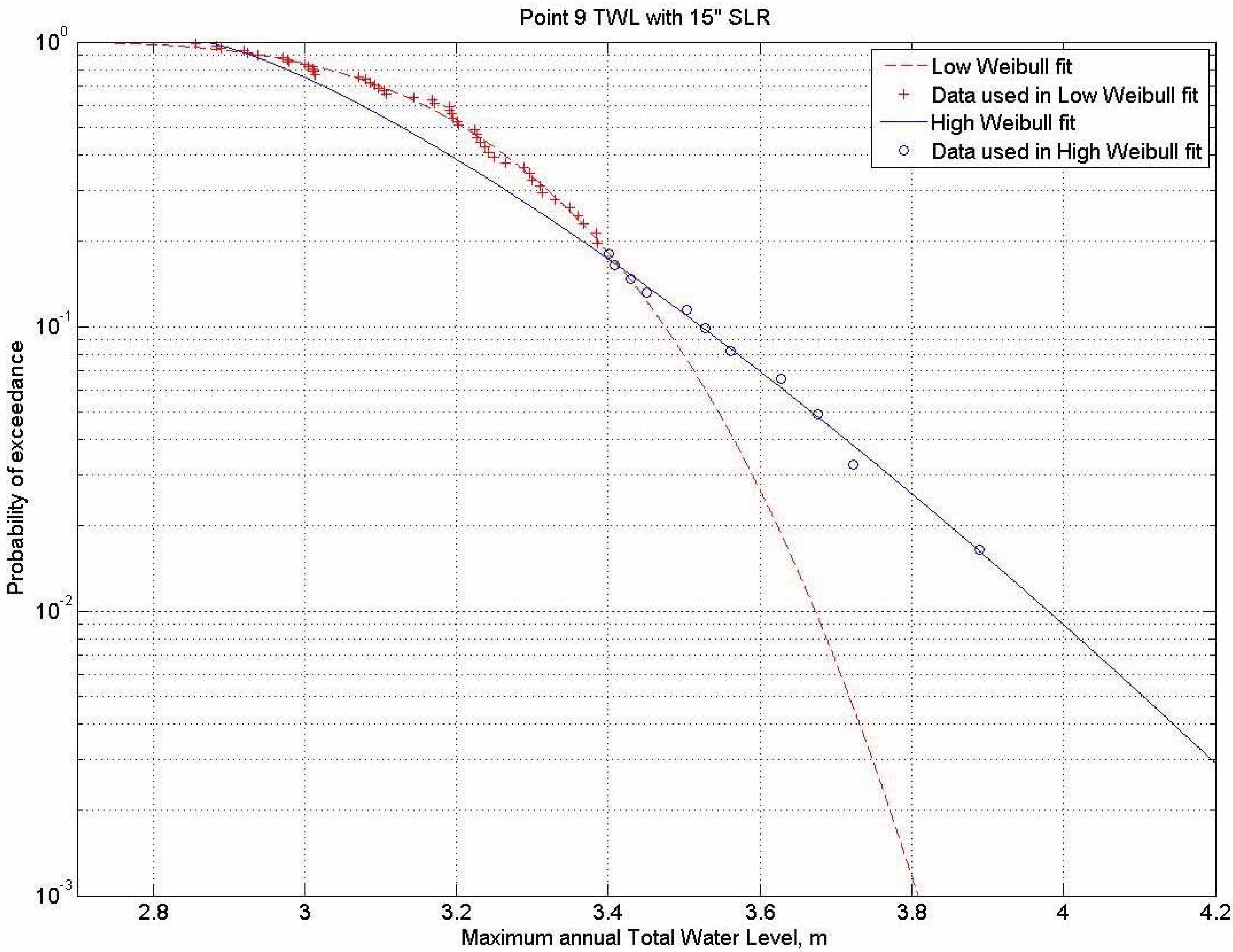

Point 5 TWL with 15" SLR
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^{0}
10^{-1}
10^{-2}
10^{-3}
2.8
3
3.2
3.4
3.6
3.8
4
4.2
Maximum annual Total Water Level, m



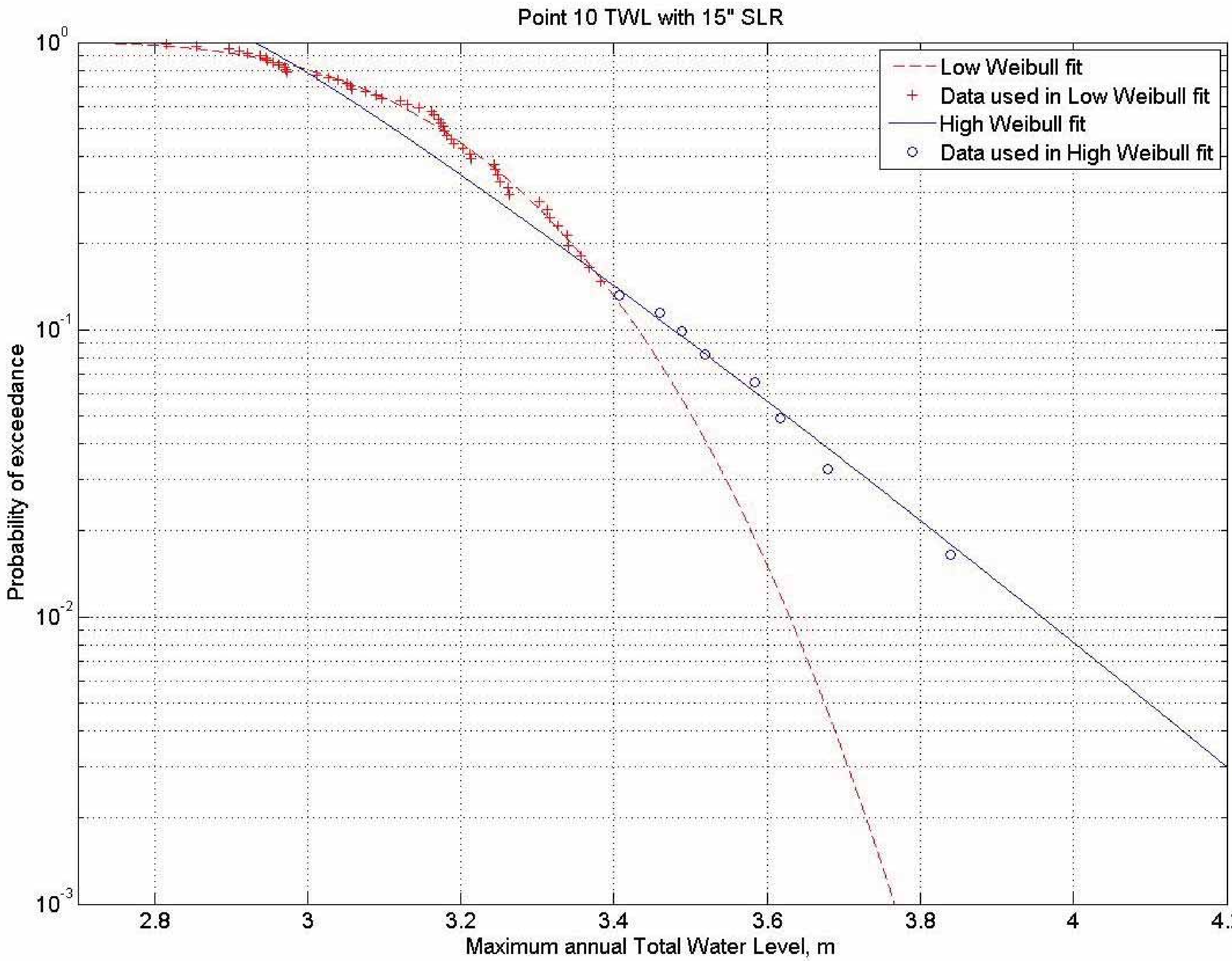
Point 6 TWL with 15" SLR
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^-1
10^-2
10^-3
2.8
3
3.2
3.4
3.6
3.8
4
4.2
Maximum annual Total Water Level, m

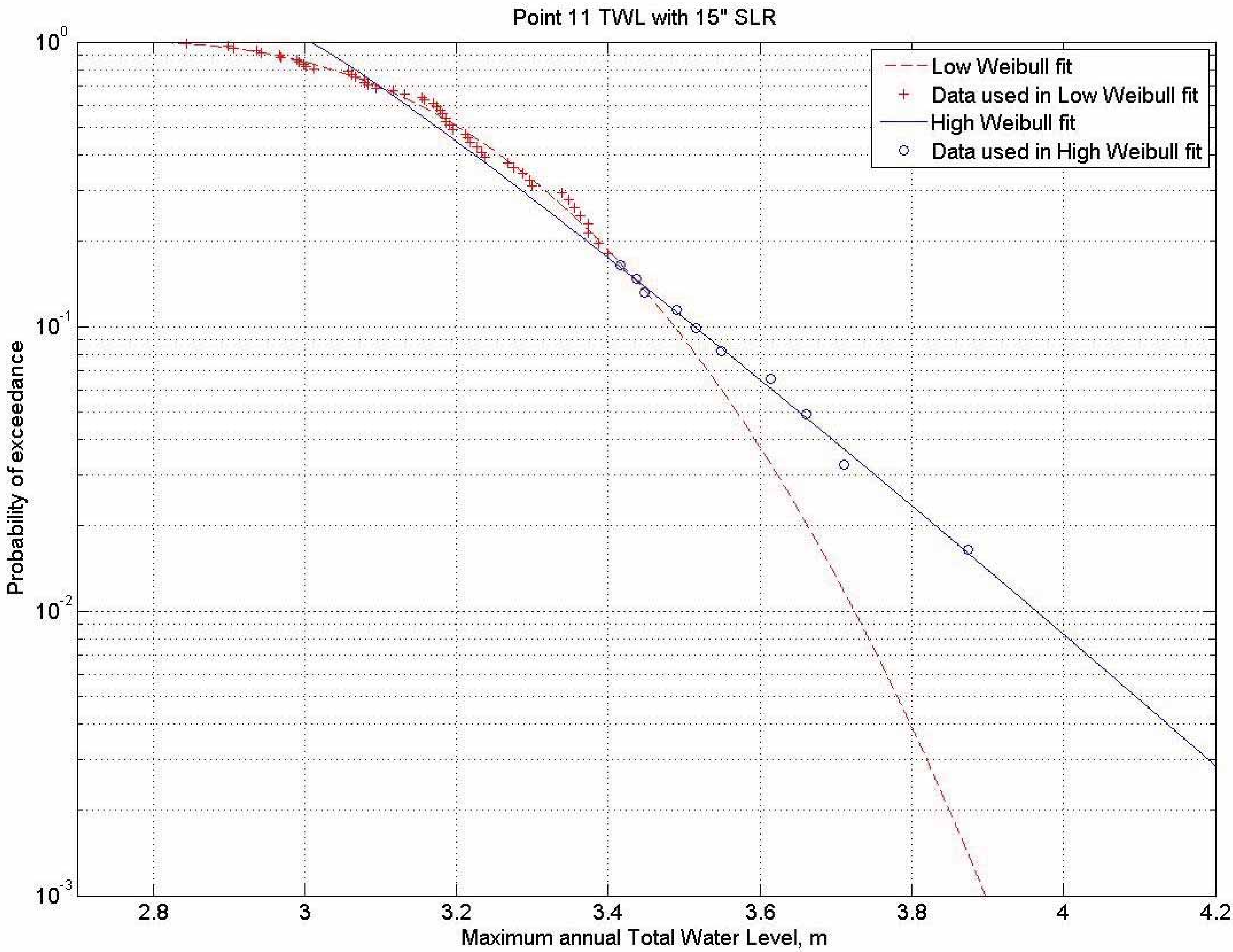

Point 7 TWL with 15" SLR
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^-1
10^-2
10^-3
2.8
3
3.2
3.4
3.6
3.8
4
4.2
Maximum annual Total Water Level, m

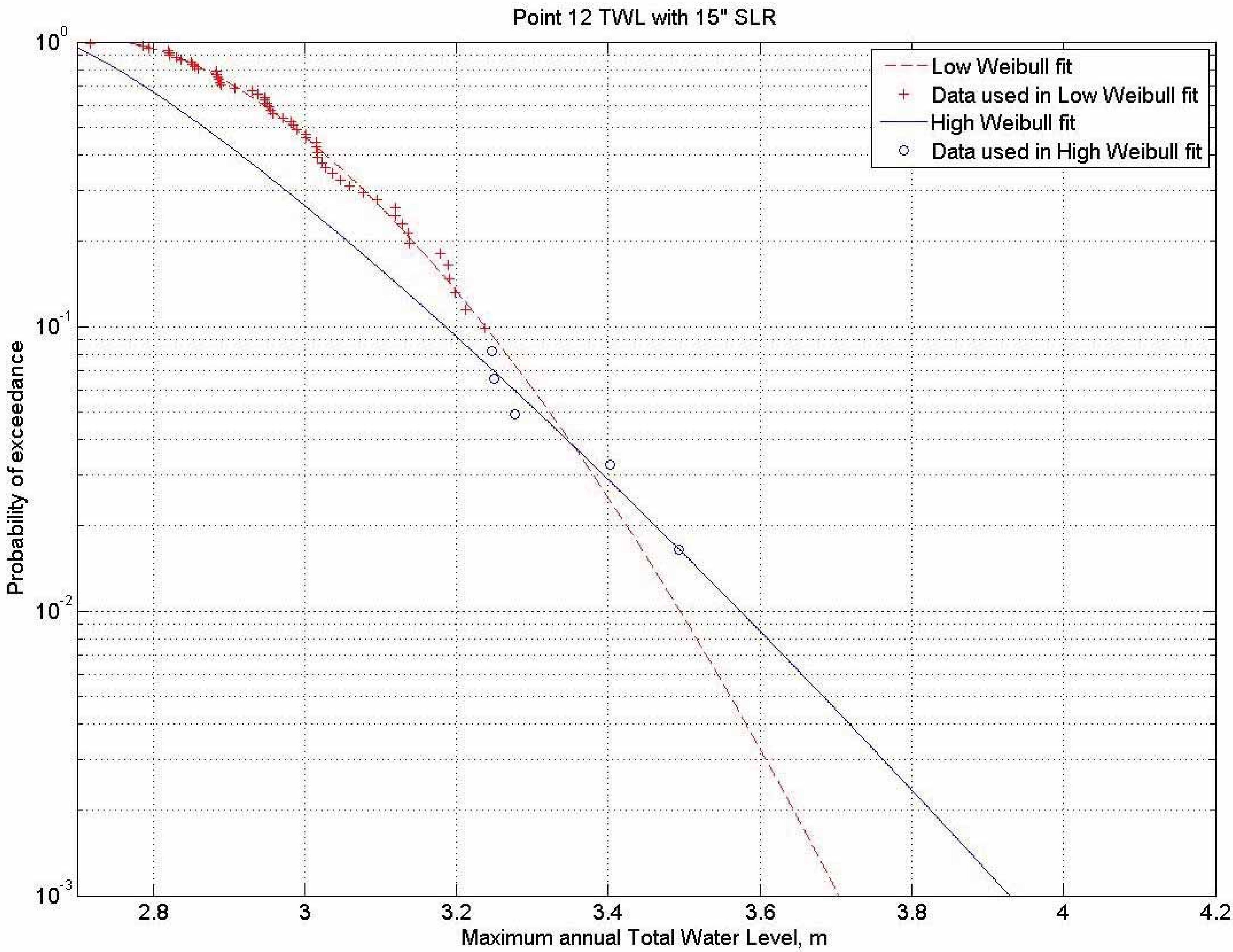

Point 8 TWL with 15" SLR
Weibull fit
Data used in Weibull fit
Probability of exceedance
10^0
10^-1
10^-2
10^-3
2.8
3
3.2
3.4
3.6
3.8
4
4.2
Maximum annual Total Water Level, m



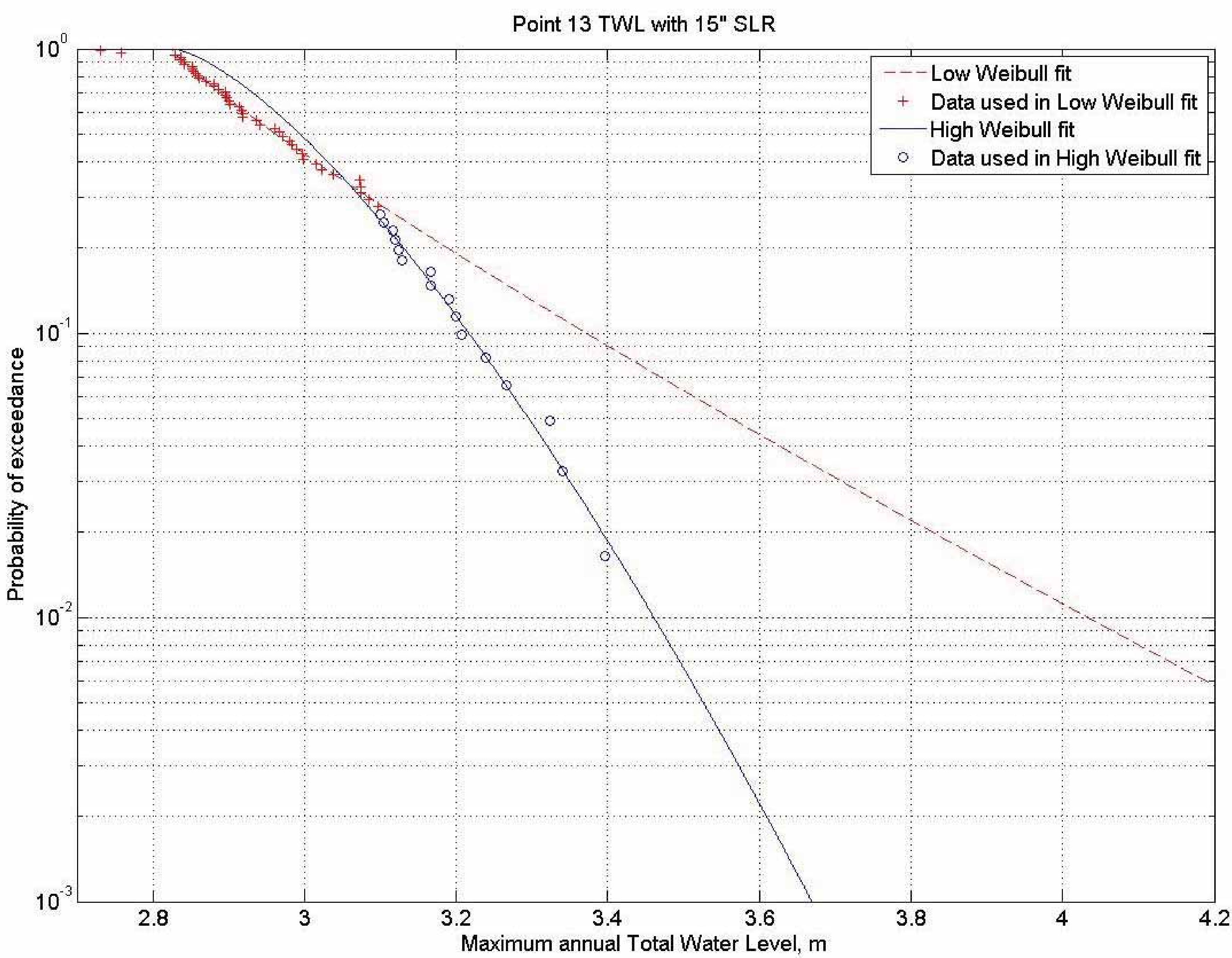
Point 9 TWL with 15" SLR
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^-1
10^-2
10^-3
2.8
3
3.2
3.4
3.6
3.8
4
4.2
Maximum annual Total Water Level, m

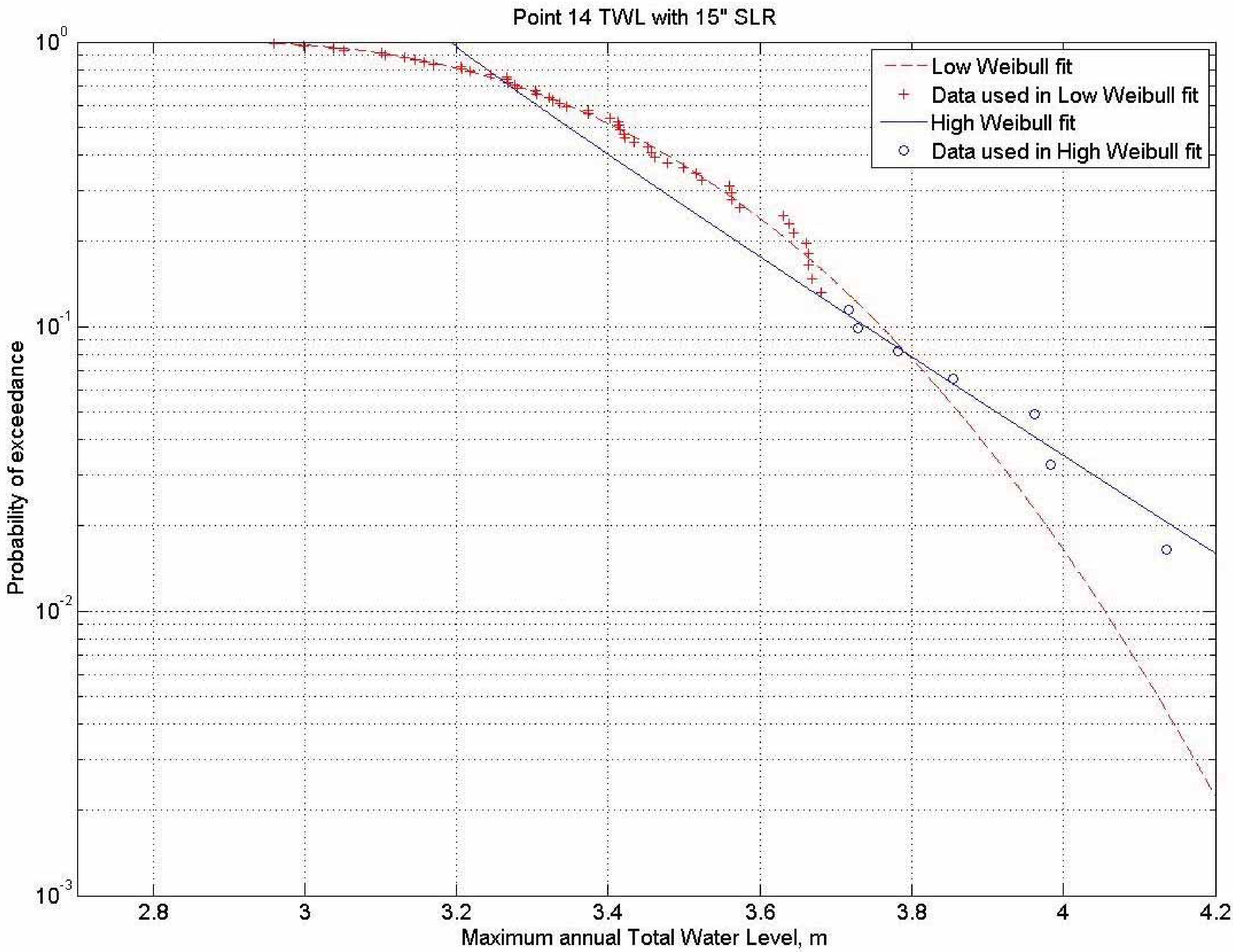

Point 10 TWL with 15" SLR
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^-1
10^-2
10^-3
2.8
3
3.2
3.4
3.6
3.8
4
4.2
Maximum annual Total Water Level, m

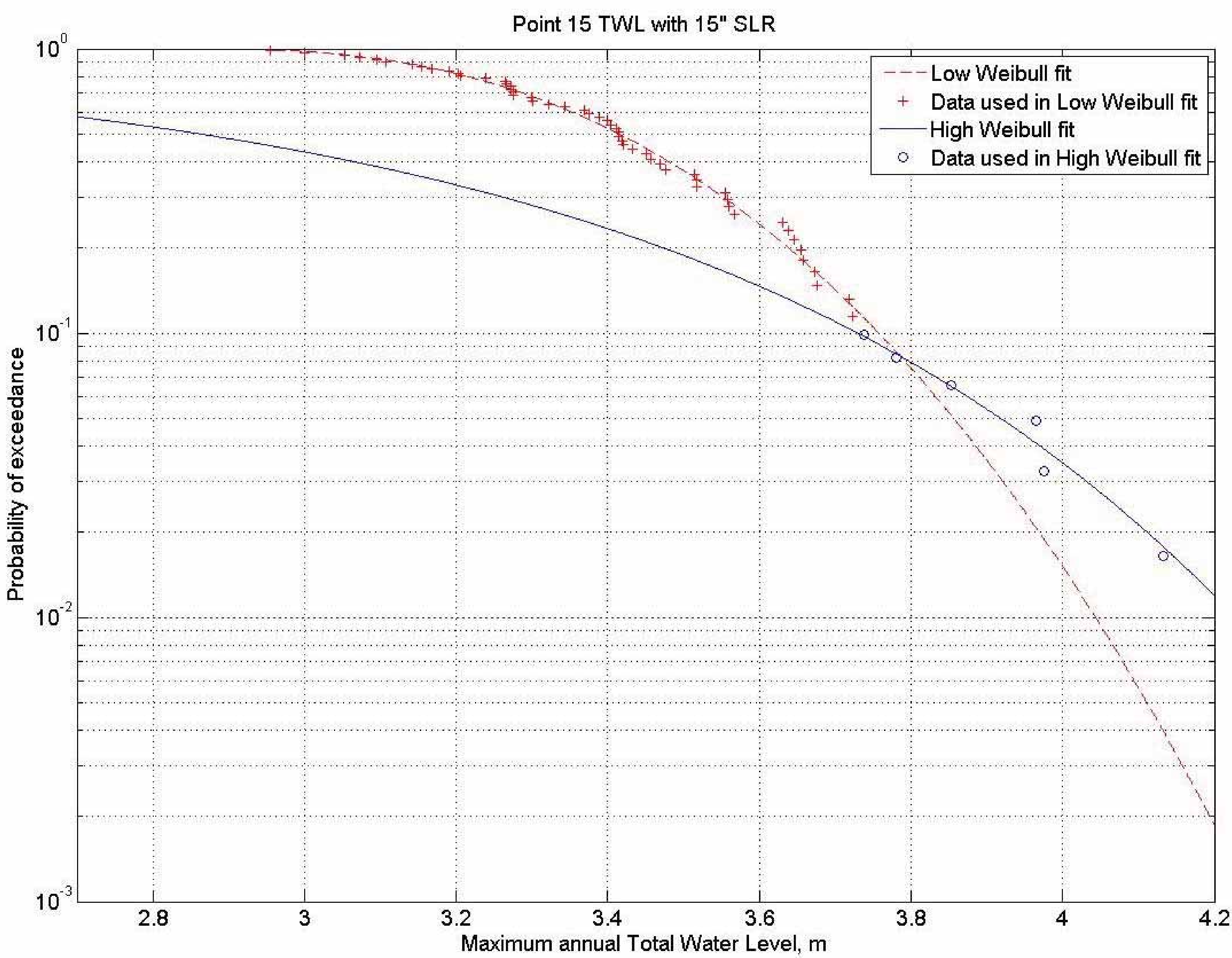

Point 11 TWL with 15" SLR
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^-1
10^-2
10^-3
2.8
3
3.2
3.4
3.6
3.8
4
4.2
Maximum annual Total Water Level, m

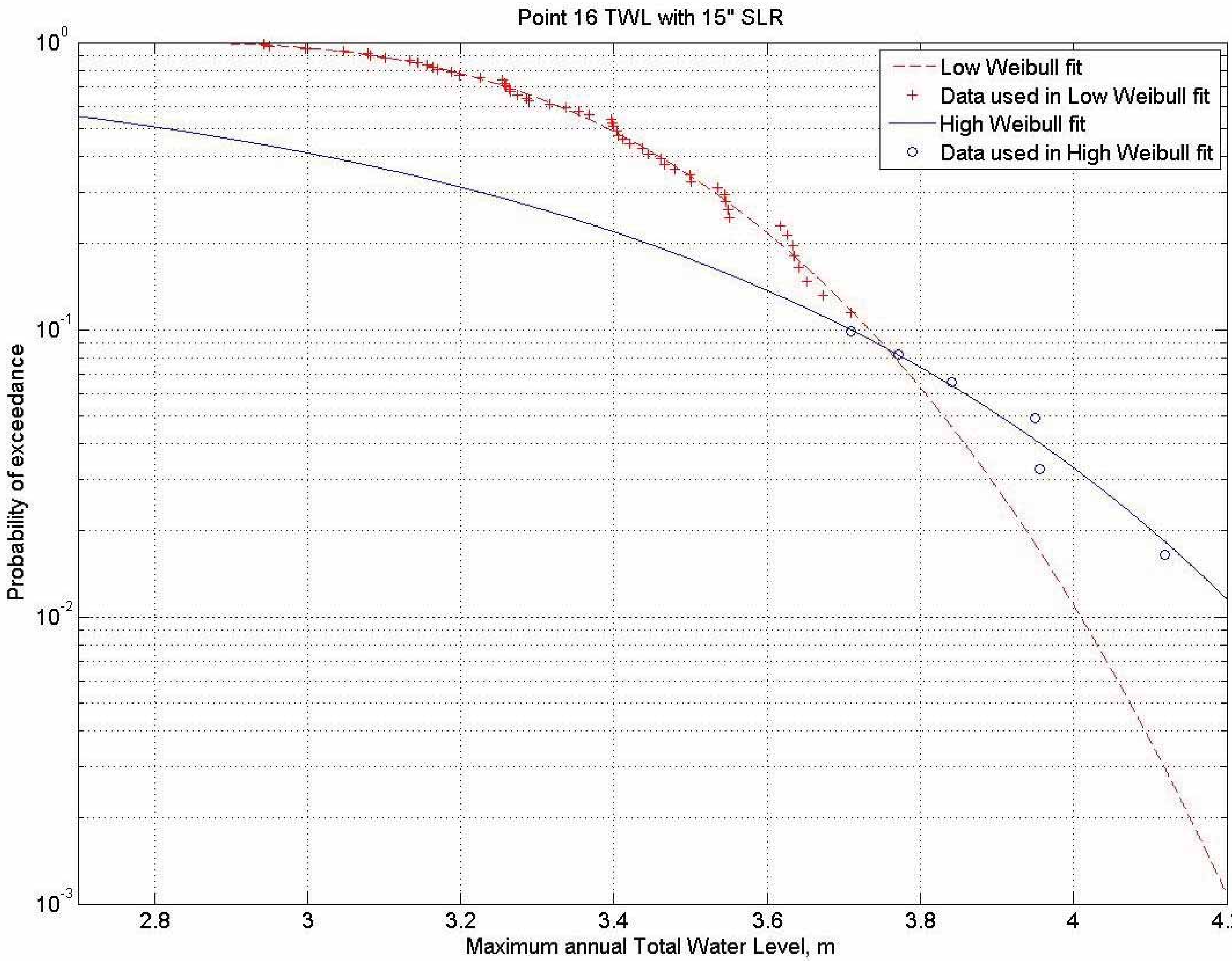


Point 12 TWL with 15" SLR
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^-1
10^-2
10^-3
2.8
3
3.2
3.4
3.6
3.8
4
4.2
Maximum annual Total Water Level, m

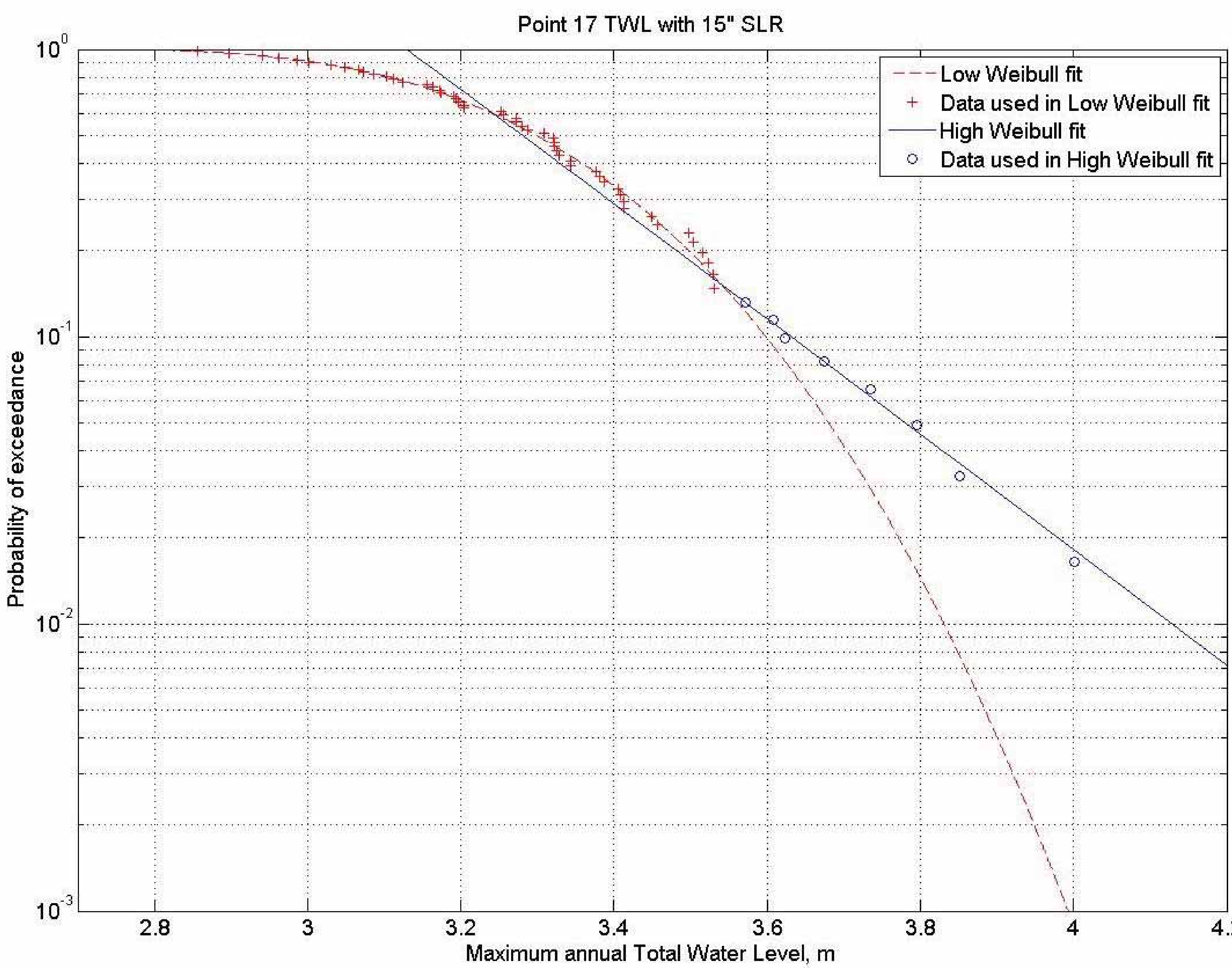

Point 13 TWL with 15" SLR
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^-1
10^-2
10^-3
2.8
3
3.2
3.4
3.6
3.8
4
4.2
Maximum annual Total Water Level, m

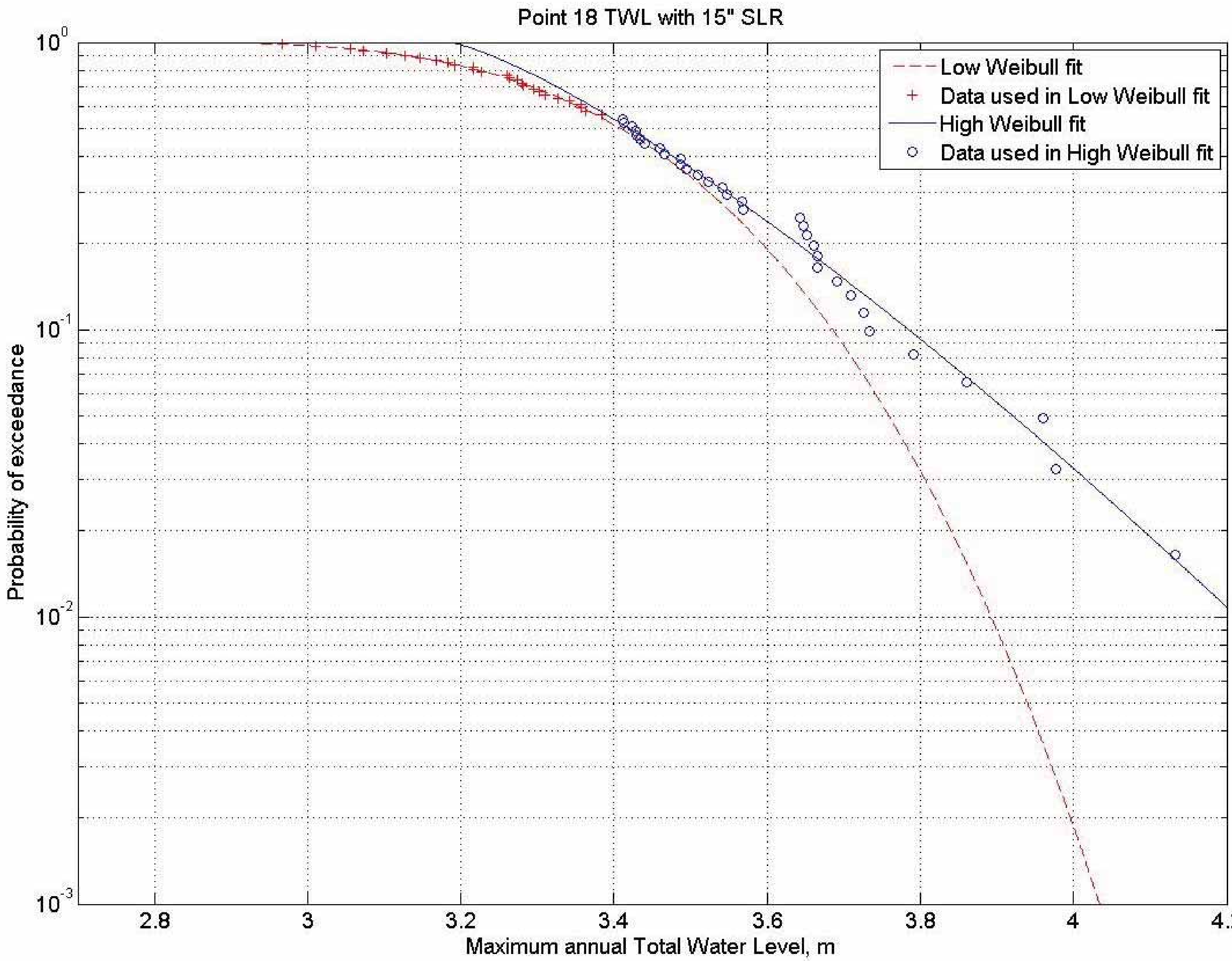

Point 14 TWL with 15" SLR
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^{0}
10^{-1}
10^{-2}
10^{-3}
2.8
3
3.2
3.4
3.6
3.8
4
4.2
Maximum annual Total Water Level, m


Point 15 TWL with 15" SLR
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^{-1}
10^{-2}
10^{-3}
2.8
3
3.2
3.4
3.6
3.8
4
4.2
Maximum annual Total Water Level, m

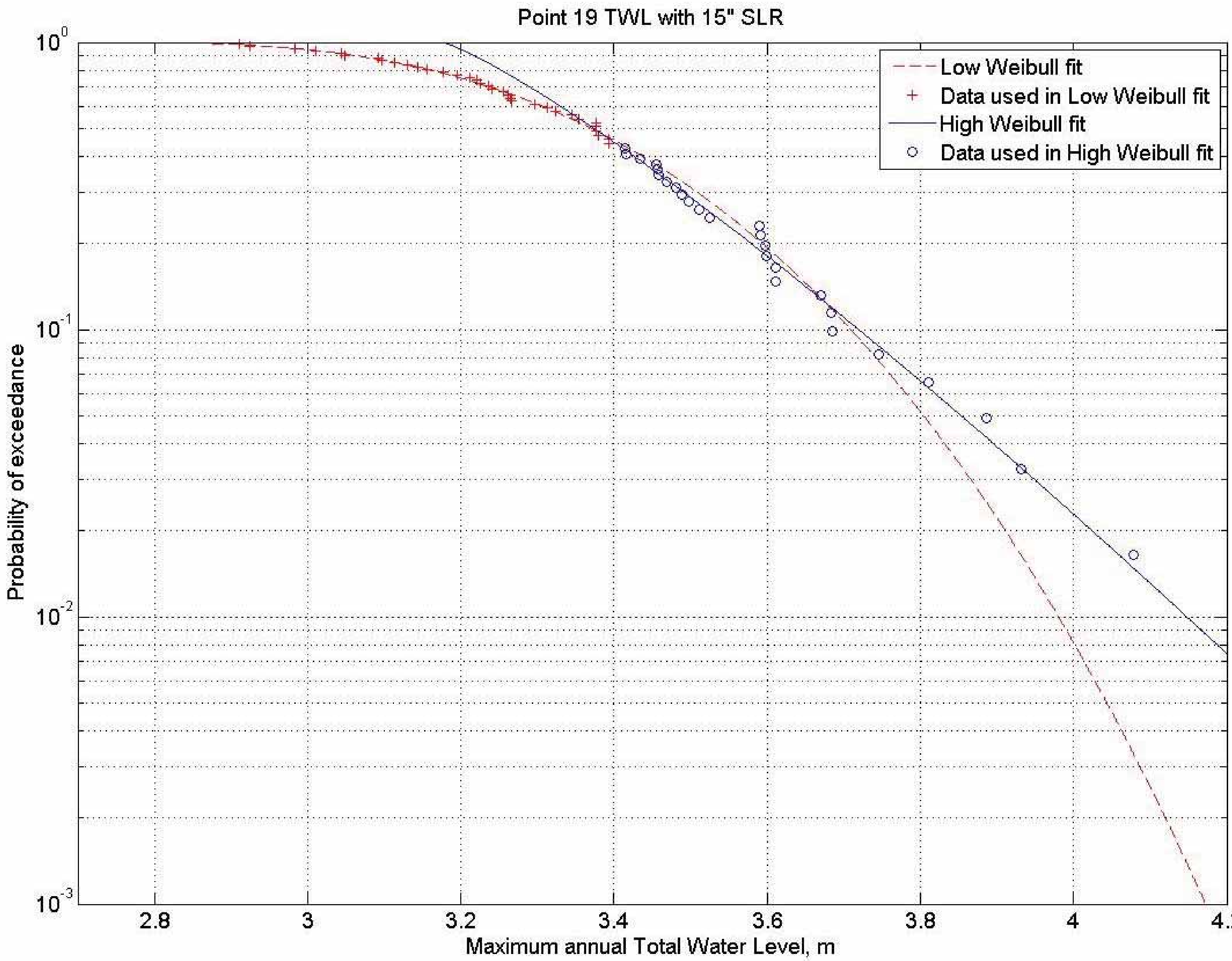


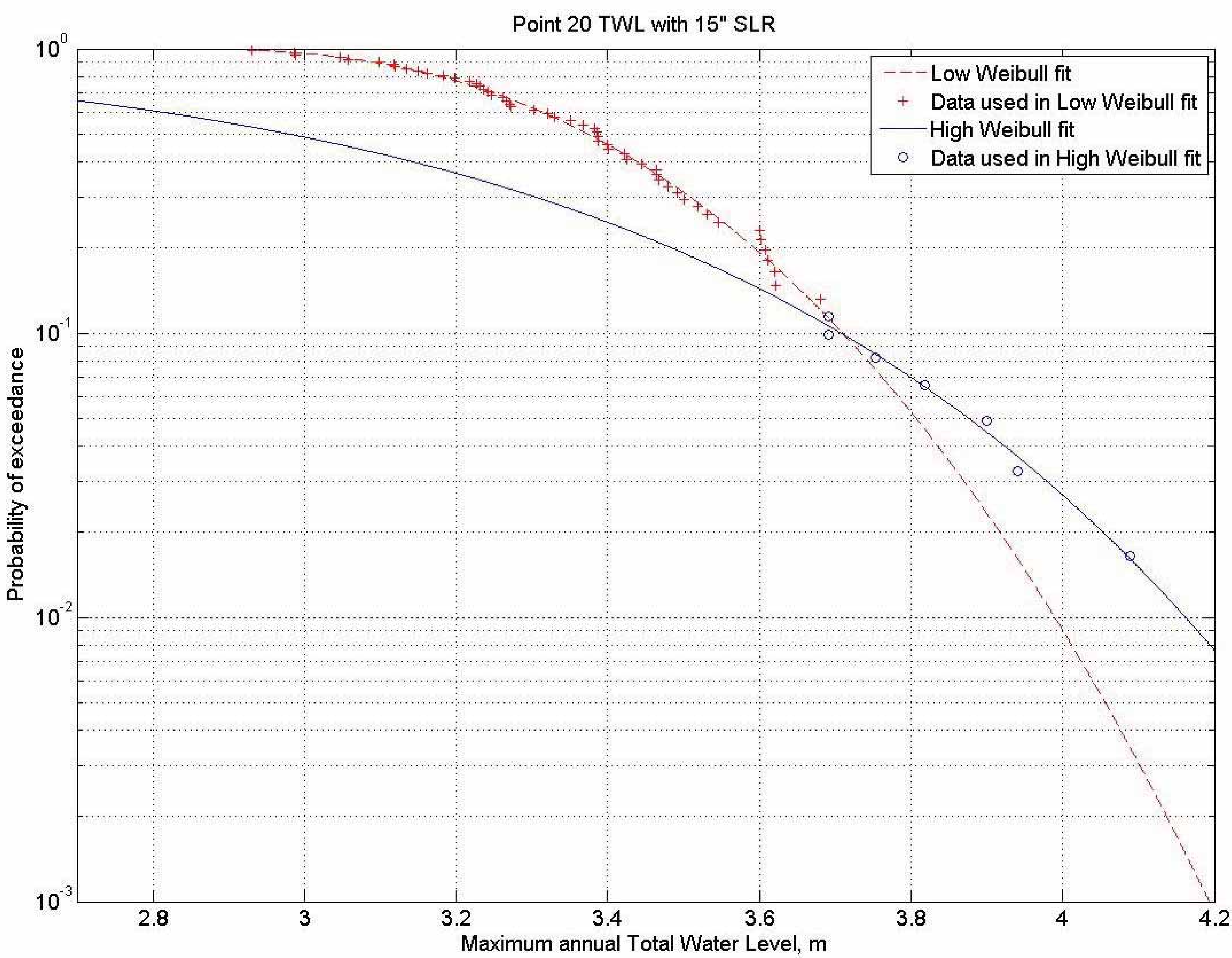
Point 16 TWL with 15" SLR
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^-1
10^-2
10^-3
2.8
3
3.2
3.4
3.6
3.8
4
4.2
Maximum annual Total Water Level, m


Point 17 TWL with 15" SLR
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^-1
10^-2
10^-3
2.8
3
3.2
3.4
3.6
3.8
4
4.2
Maximum annual Total Water Level, m

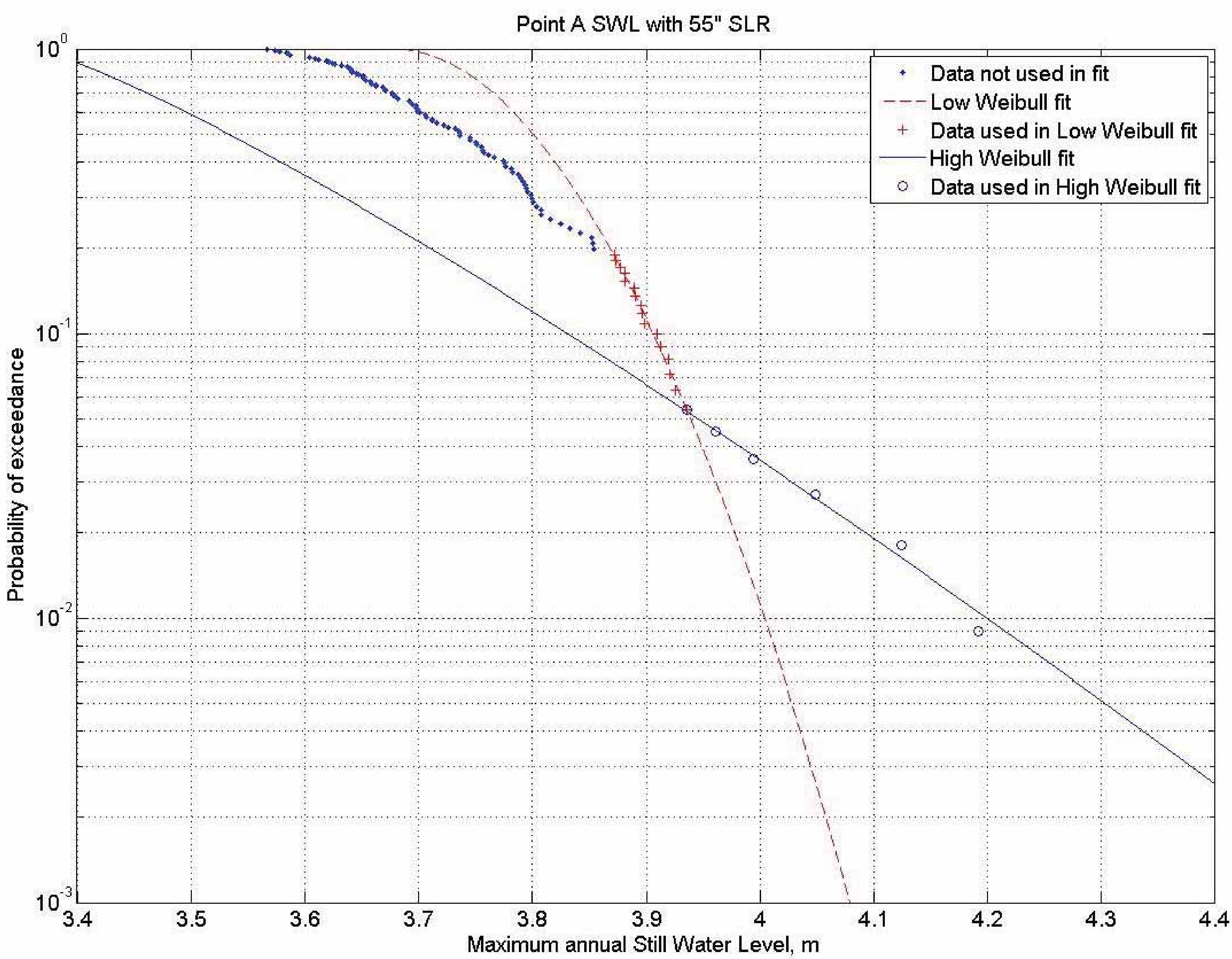


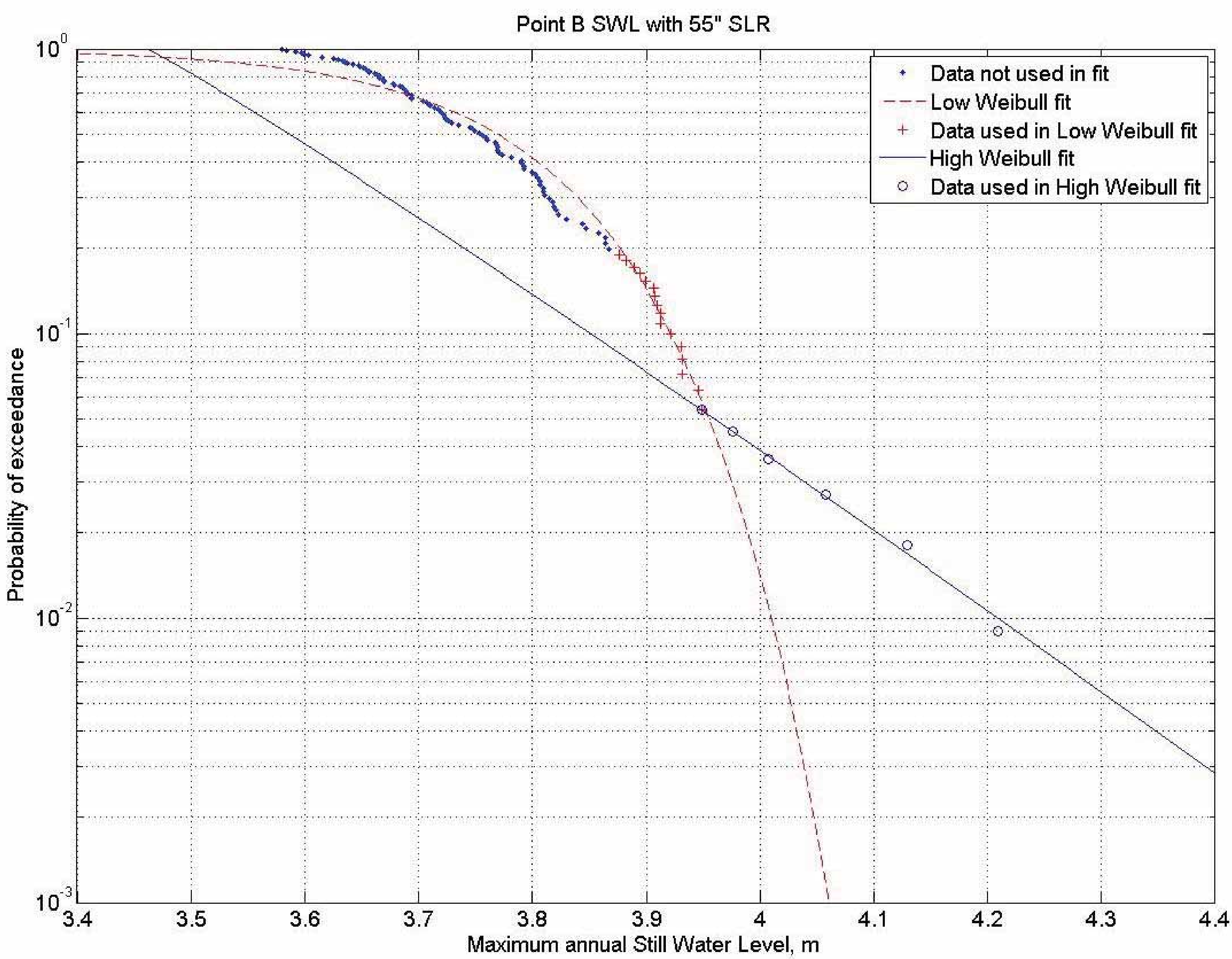
Point 18 TWL with 15" SLR
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^{0}
10^{-1}
10^{-2}
10^{-3}
2.8
3
3.2
3.4
3.6
3.8
4
4.2
Maximum annual Total Water Level, m

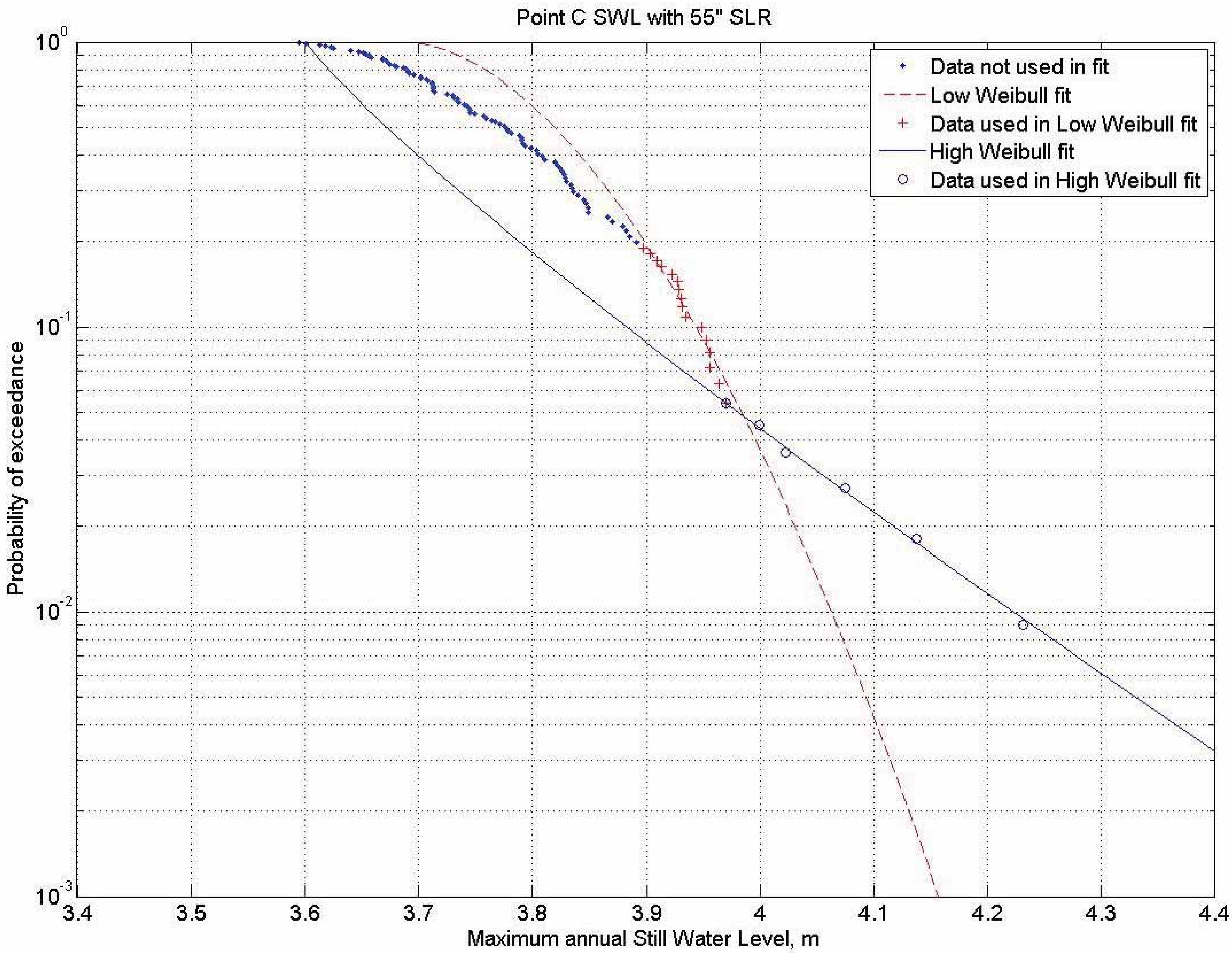

Point 19 TWL with 15" SLR
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^-1
10^-2
10^-3
2.8
3
3.2
3.4
3.6
3.8
4
4.2
Maximum annual Total Water Level, m


Point 20 TWL with 15" SLR
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^-1
10^-2
10^-3
2.8
3
3.2
3.4
3.6
3.8
4
4.2
Maximum annual Total Water Level, m

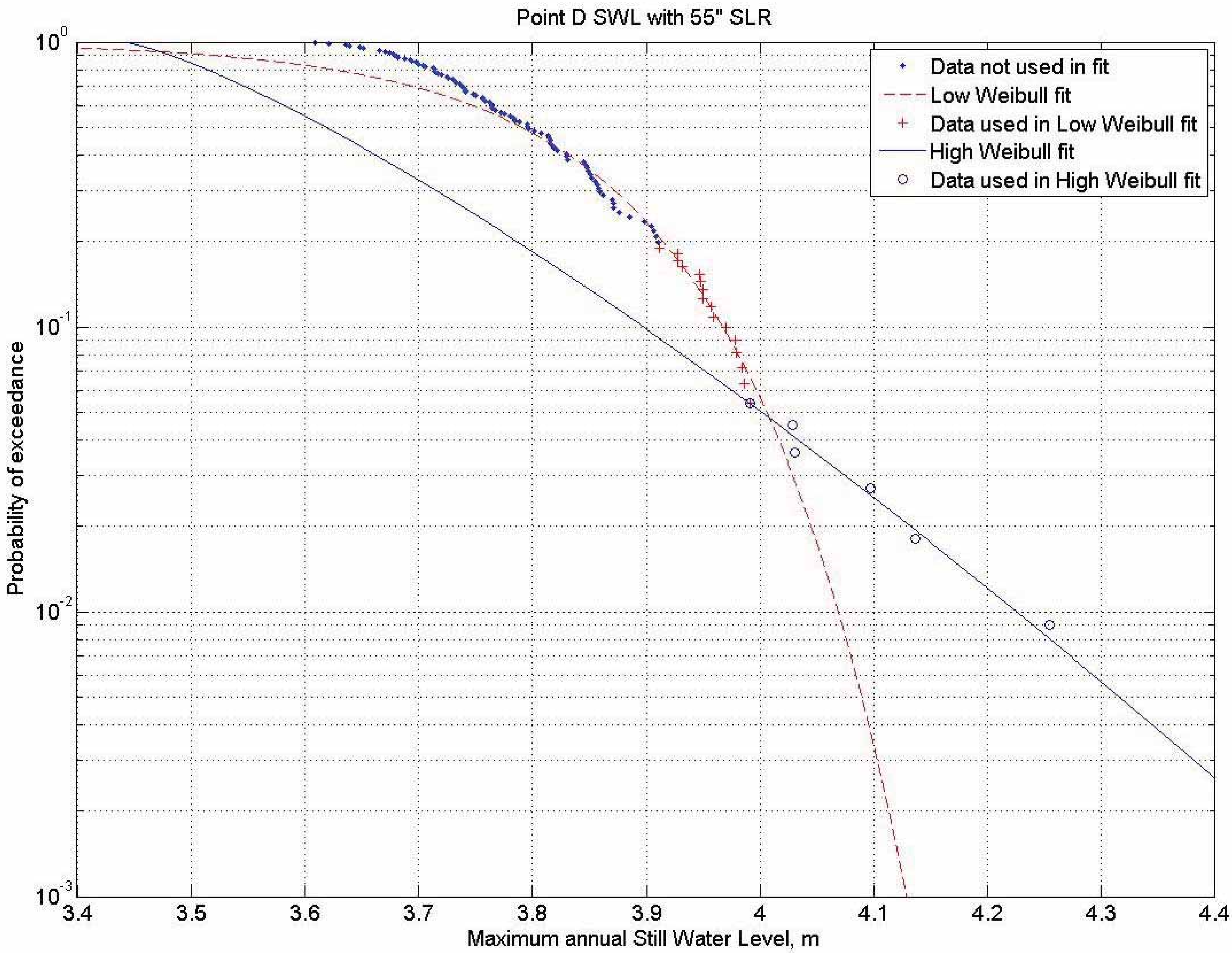
Year 2100 Conditions


Point A SWL with 55" SLR
Data not used in fit
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
Maximum annual Still Water Level, m
10^0
10^{-1}
10^{-2}
10^{-3}
3.4
3.5
3.6
3.7
3.8
3.9
4
4.1
4.2
4.3
4.4

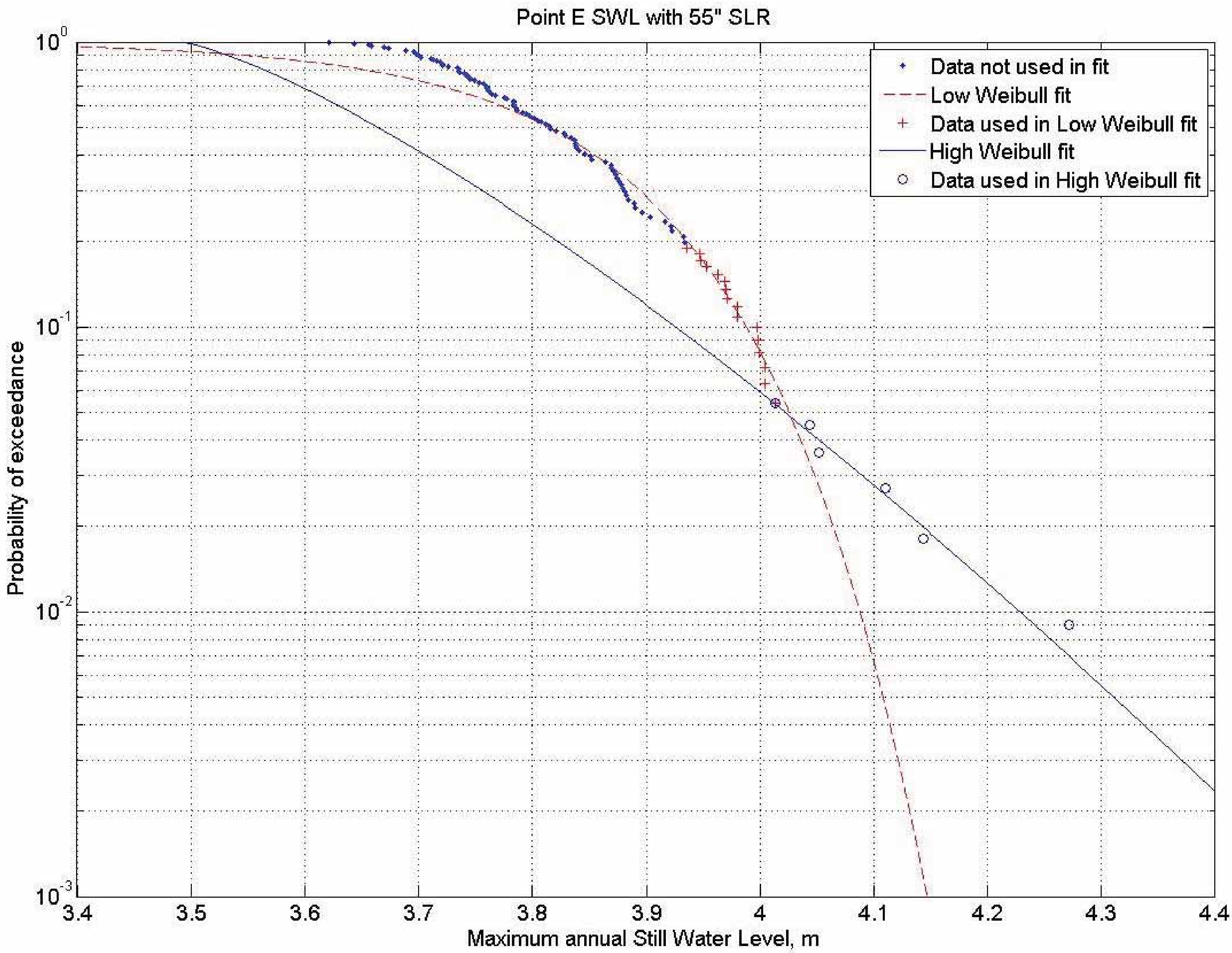

Point B SWL with 55" SLR
Probability of exceedance
Maximum annual Still Water Level, m
Data not used in fit
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
10^0
10^-1
10^-2
10^-3
3.4
3.5
3.6
3.7
3.8
3.9
4
4.1
4.2
4.3
4.4

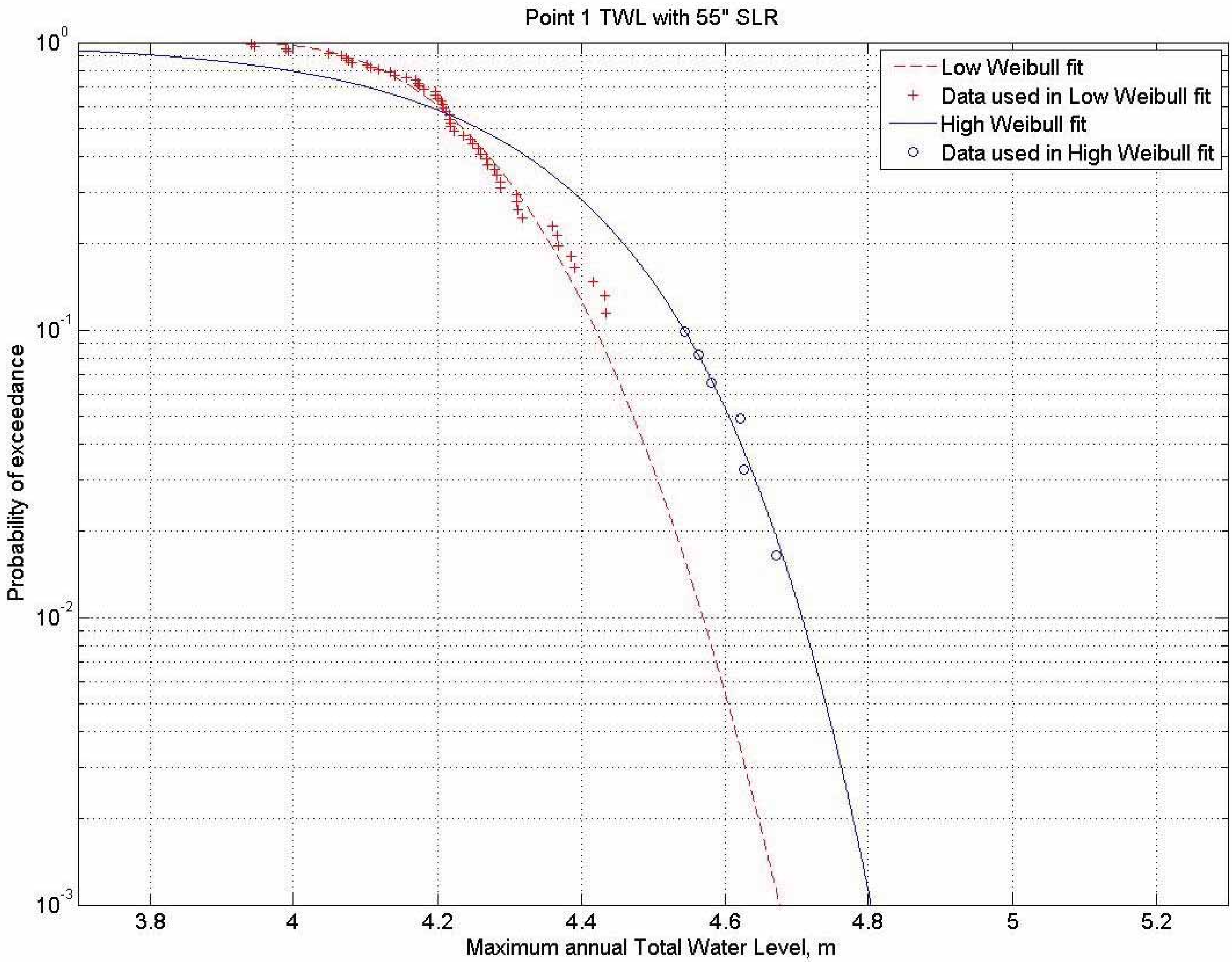


Point C SWL with 55" SLR
Data not used in fit
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^-1
10^-2
10^-3
3.4
3.5
3.6
3.7
3.8
3.9
4
4.1
4.2
4.3
4.4
Maximum annual Still Water Level, m

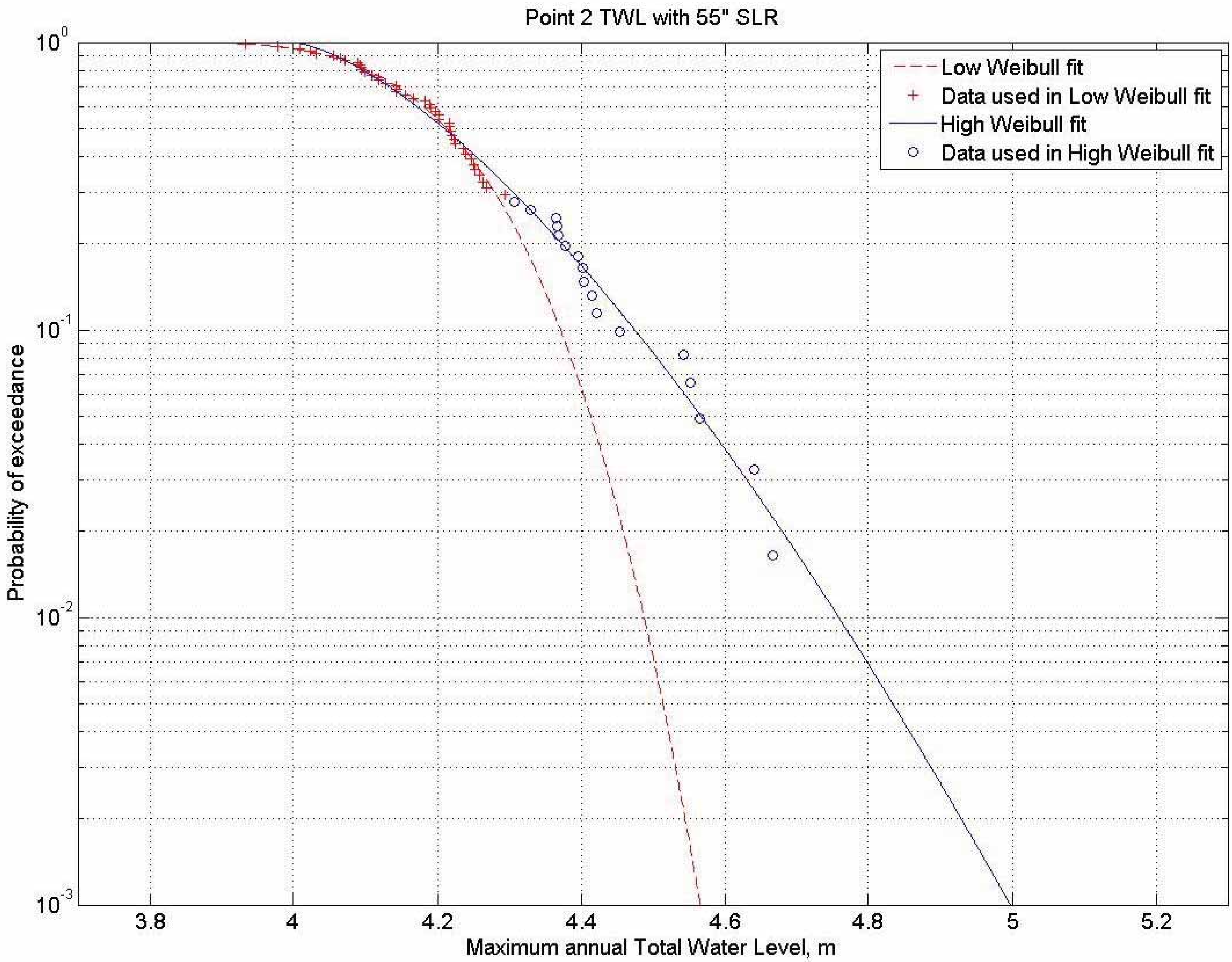


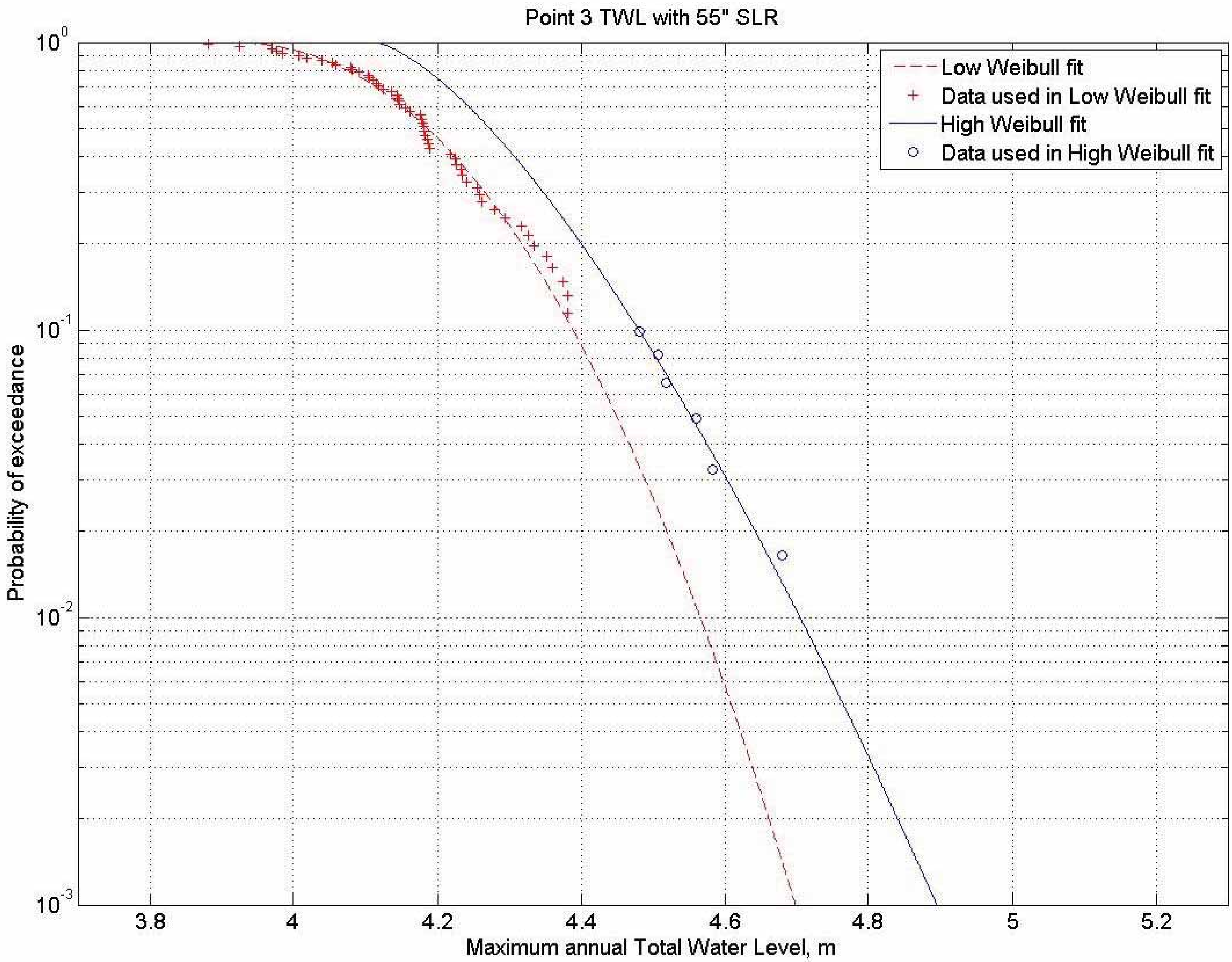
Point D SWL with 55" SLR
Data not used in fit
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^-1
10^-2
10^-3
3.4
3.5
3.6
3.7
3.8
3.9
4
4.1
4.2
4.3
4.4
Maximum annual Still Water Level, m


Point E SWL with 55" SLR
Probability of exceedance
Maximum annual Still Water Level, m
Data not used in fit
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
10^0
10^-1
10^-2
10^-3
3.4
3.5
3.6
3.7
3.8
3.9
4
4.1
4.2
4.3
4.4

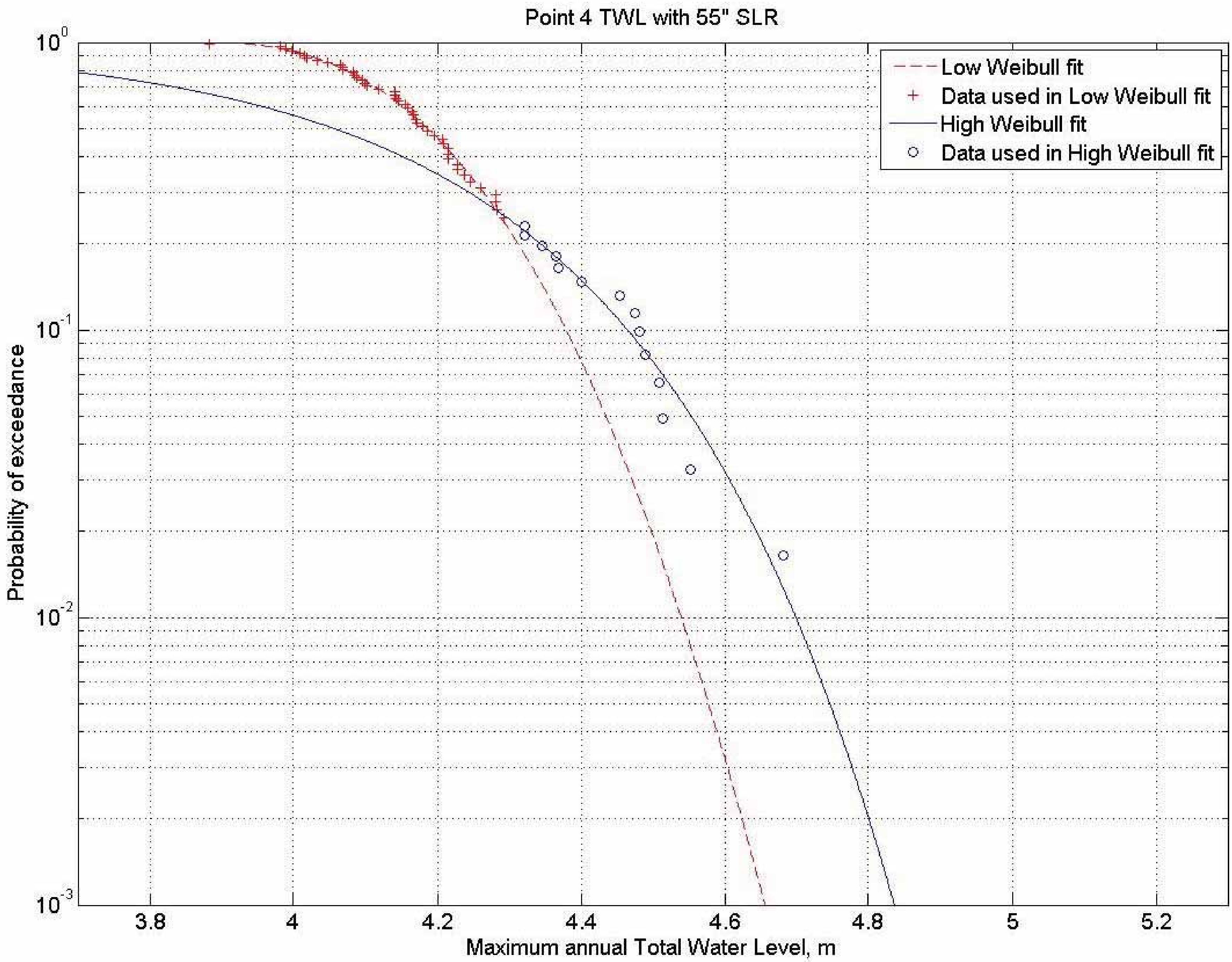


Point 1 TWL with 55" SLR
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^{-1}
10^{-2}
10^{-3}
3.8
4
4.2
4.4
4.6
4.8
5
5.2
Maximum annual Total Water Level, m

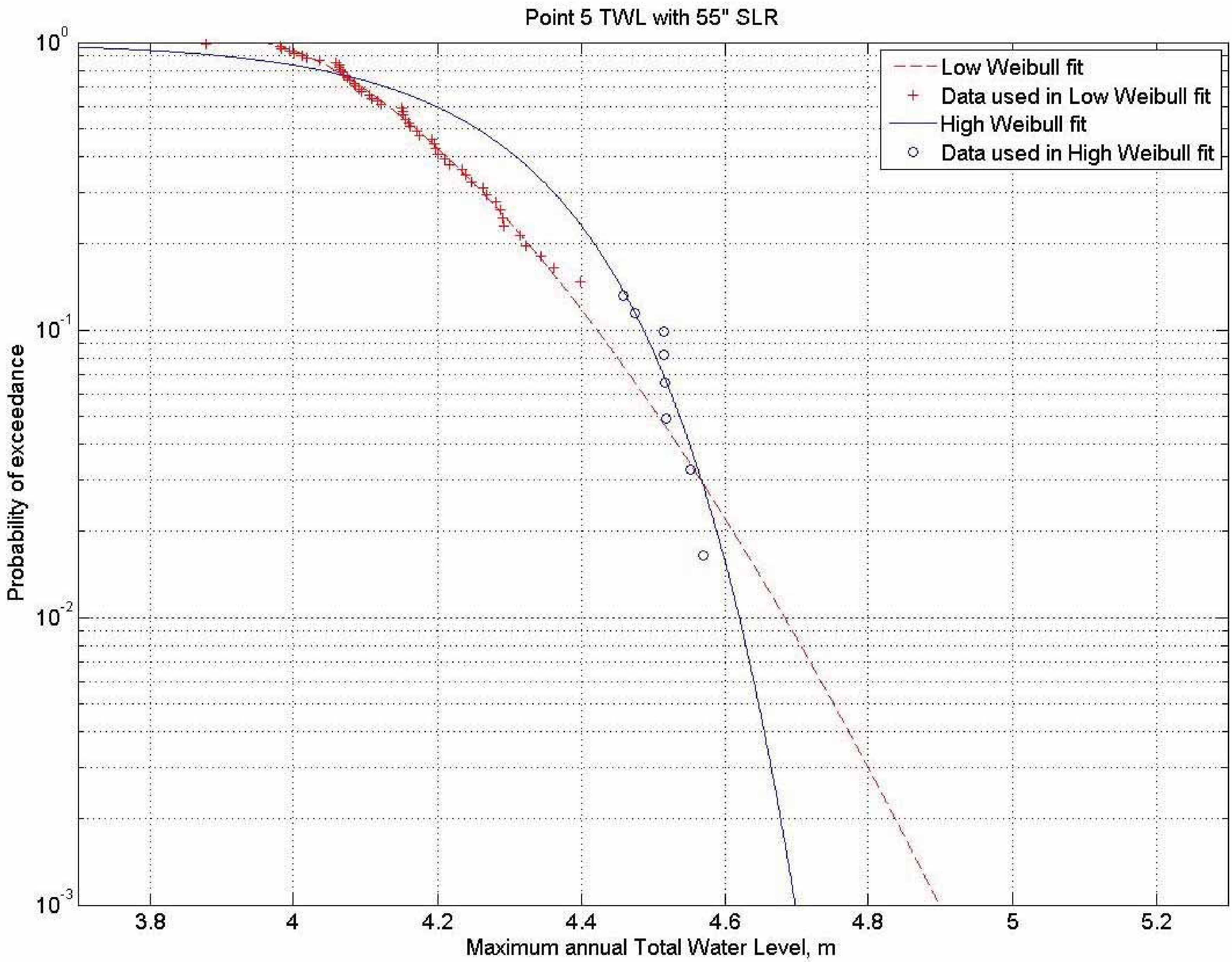

Point 2 TWL with 55" SLR
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^-1
10^-2
10^-3
3.8
4
4.2
4.4
4.6
4.8
5
5.2
Maximum annual Total Water Level, m



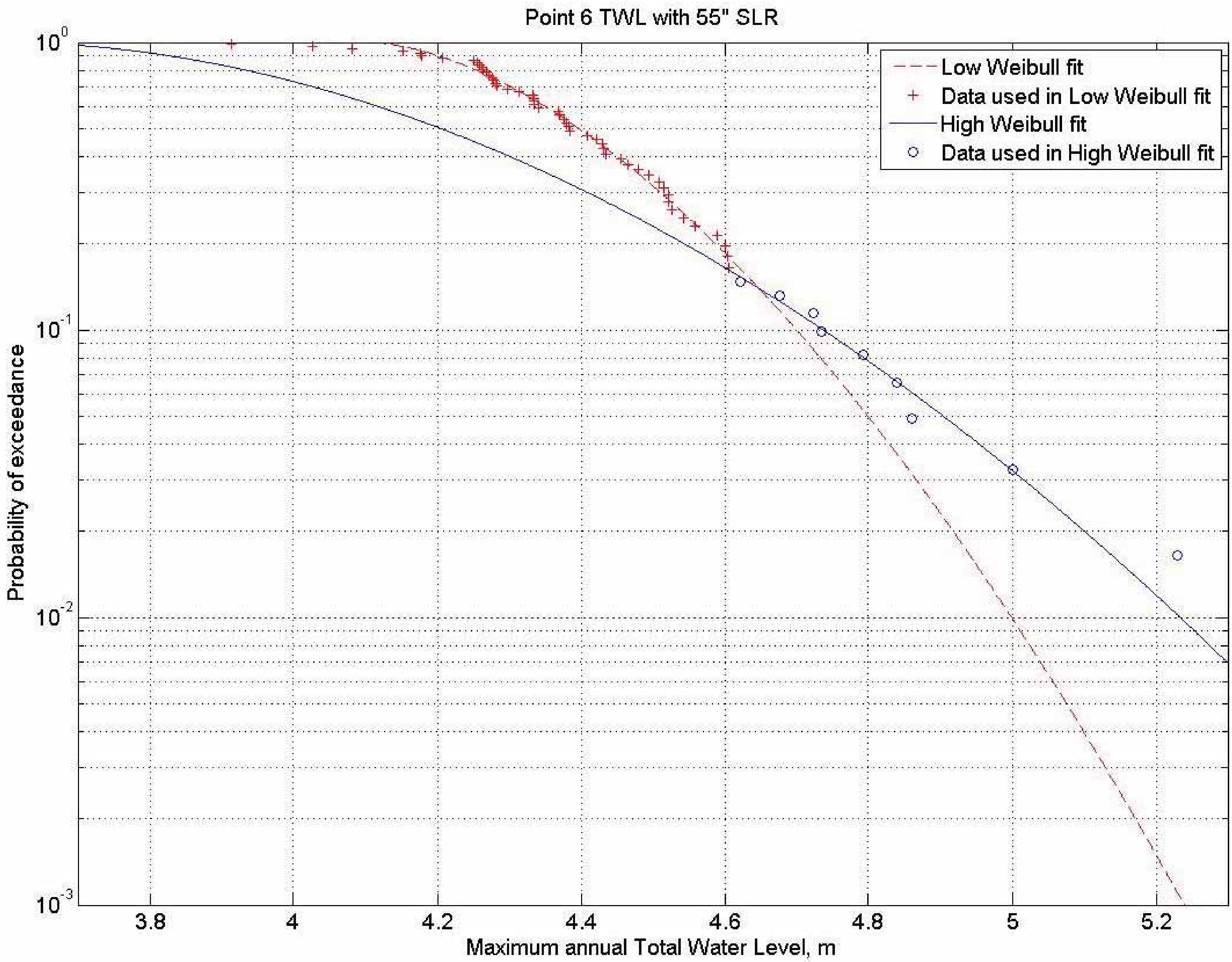
Point 3 TWL with 55" SLR
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
Maximum annual Total Water Level, m

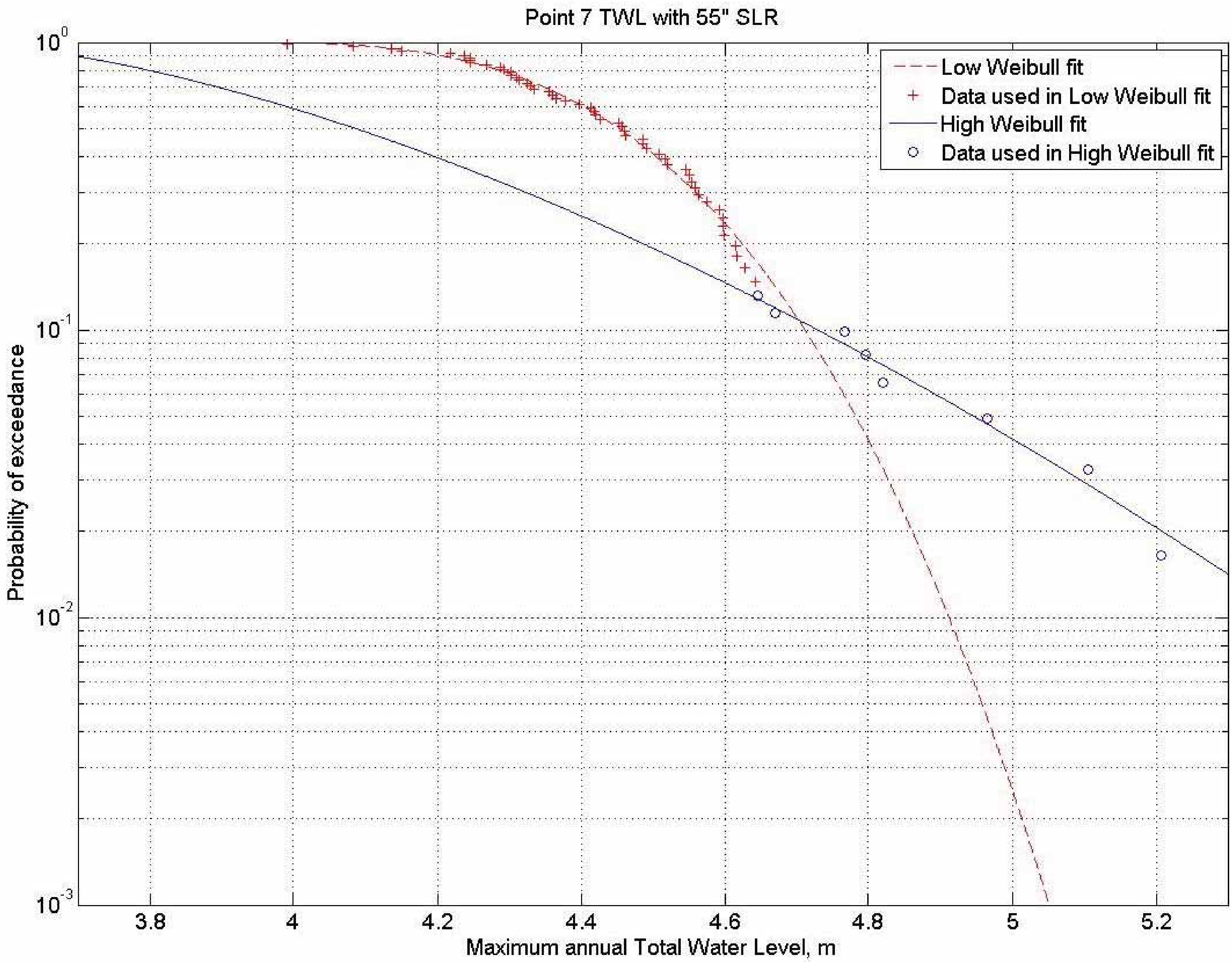


Point 4 TWL with 55" SLR
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^{-1}
10^{-2}
10^{-3}
3.8
4
4.2
4.4
4.6
4.8
5
5.2
Maximum annual Total Water Level, m

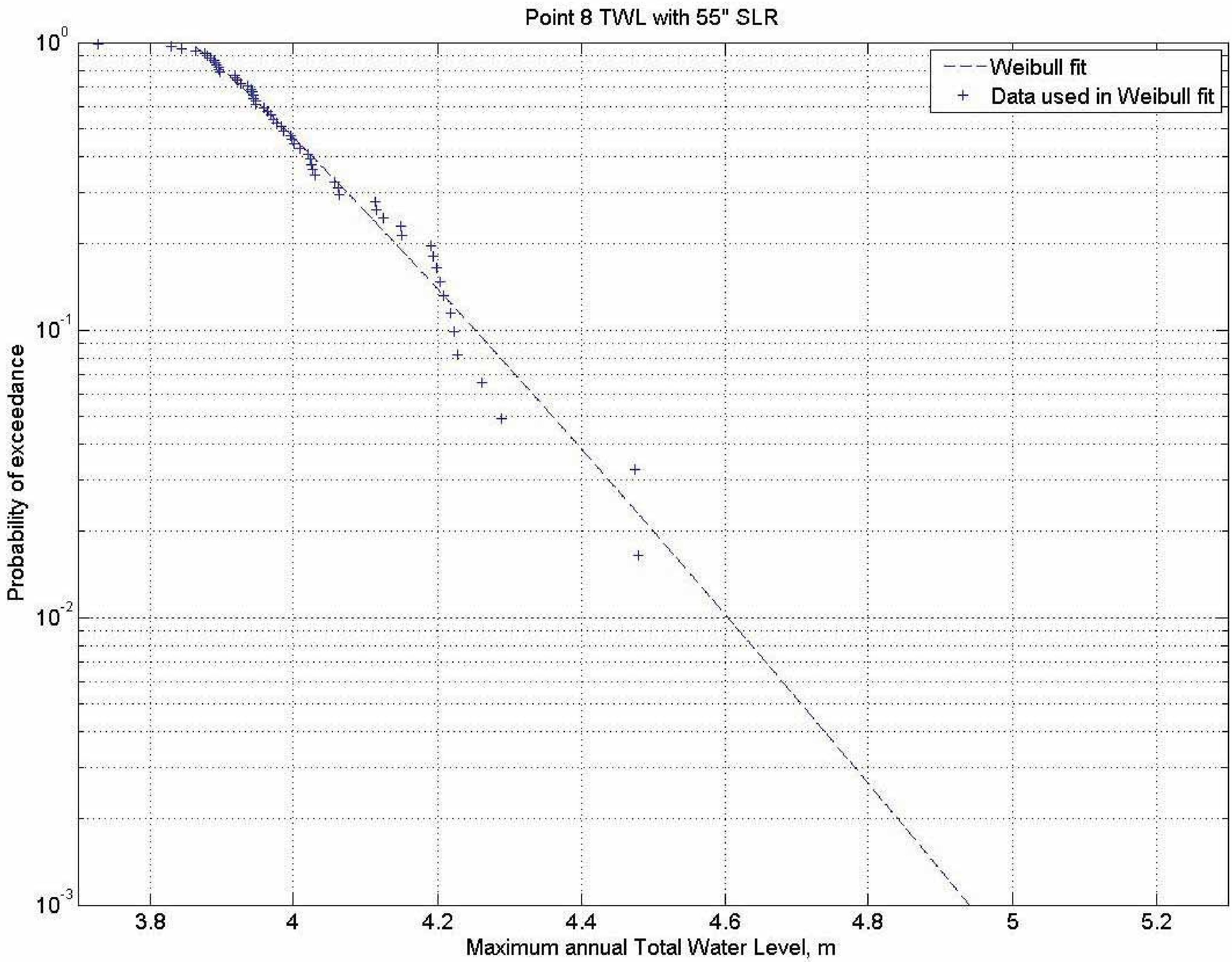


Point 5 TWL with 55" SLR
Probability of exceedance
10^0
10^{-1}
10^{-2}
10^{-3}
3.8
4
4.2
4.4
4.6
4.8
5
5.2
Maximum annual Total Water Level, m
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit

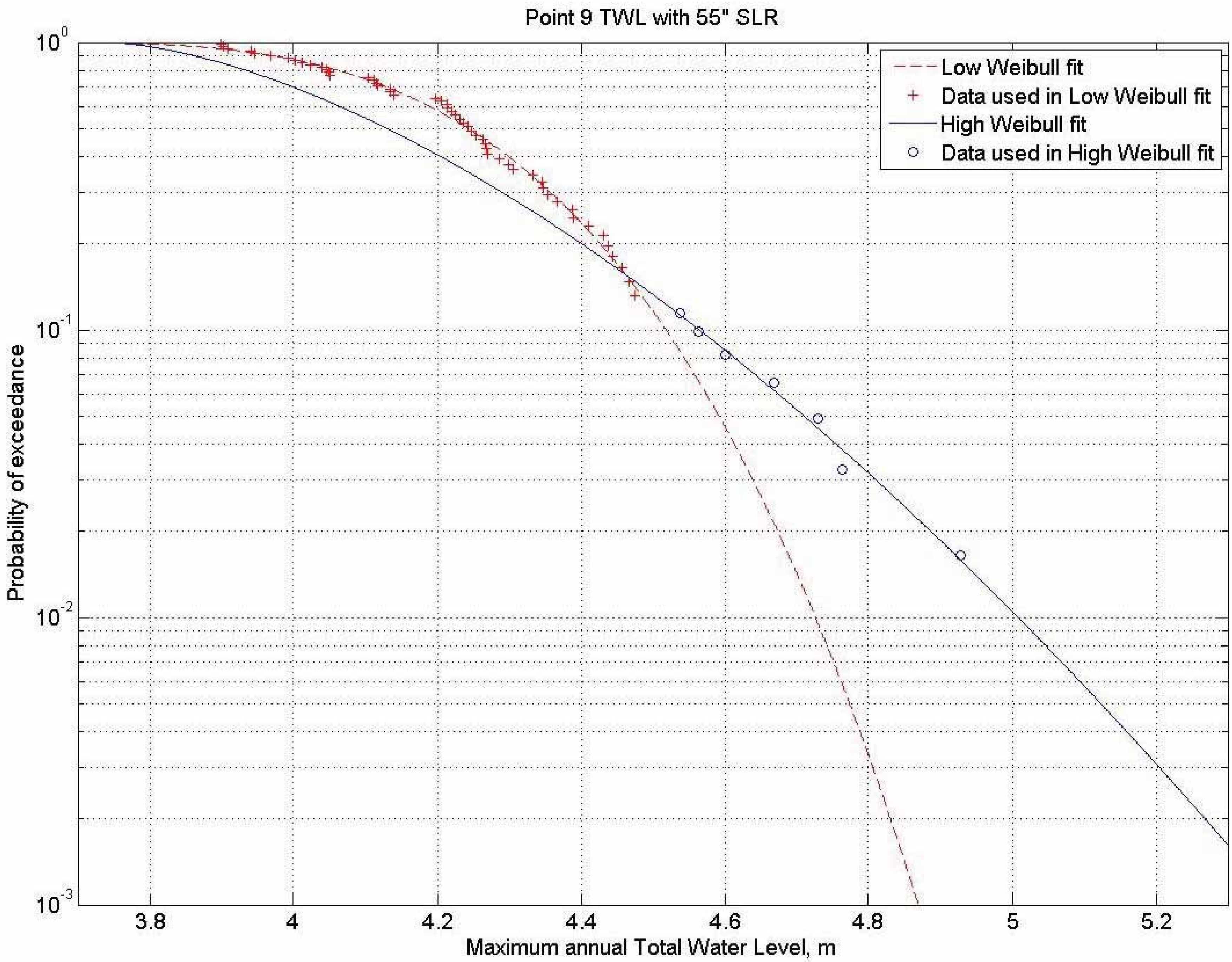

Point 6 TWL with 55" SLR
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^-1
10^-2
10^-3
3.8
4
4.2
4.4
4.6
4.8
5
5.2
Maximum annual Total Water Level, m

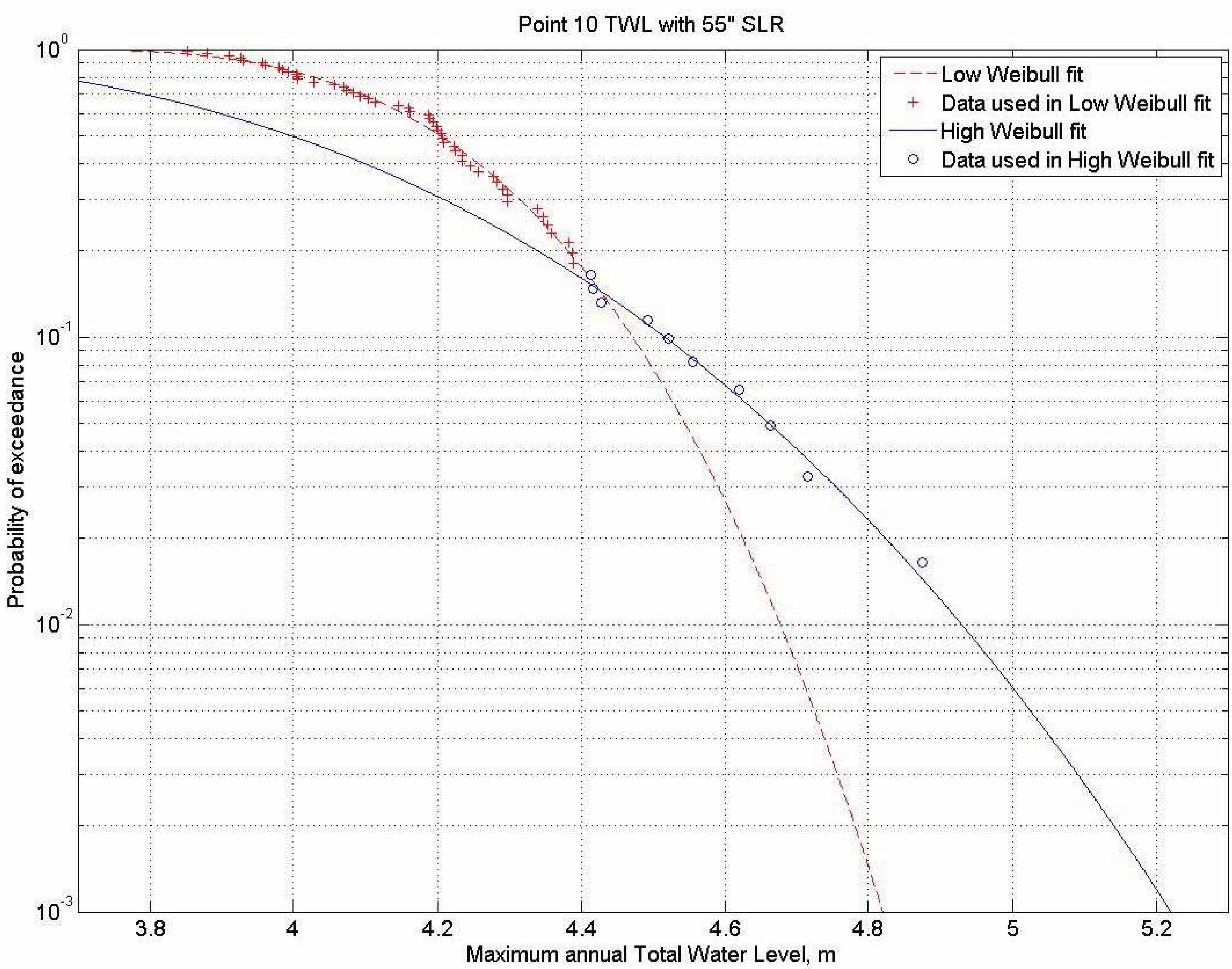


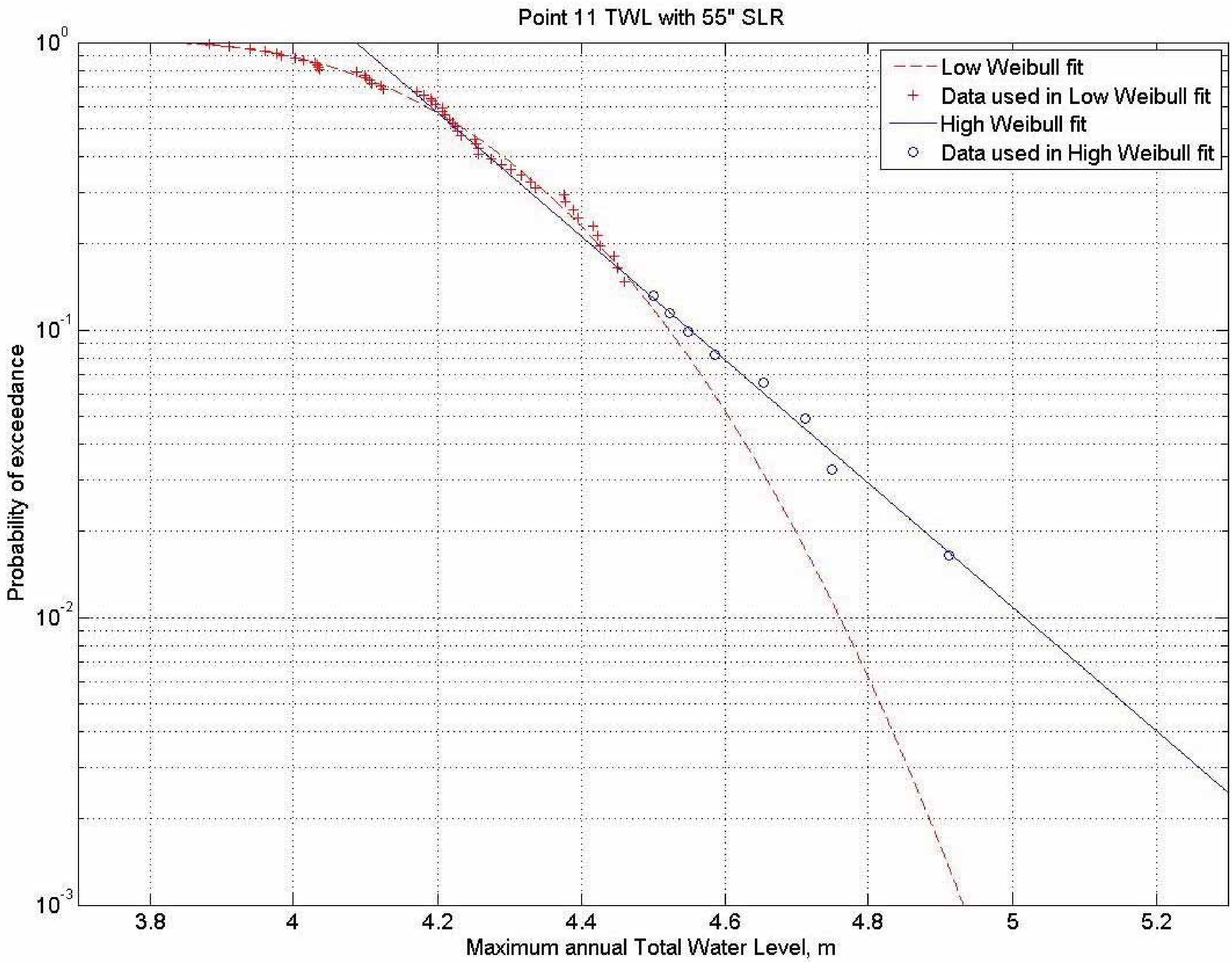
Point 7 TWL with 55" SLR
Probability of exceedance
10^0
10^-1
10^-2
10^-3
3.8
4
4.2
4.4
4.6
4.8
5
5.2
Maximum annual Total Water Level, m
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit

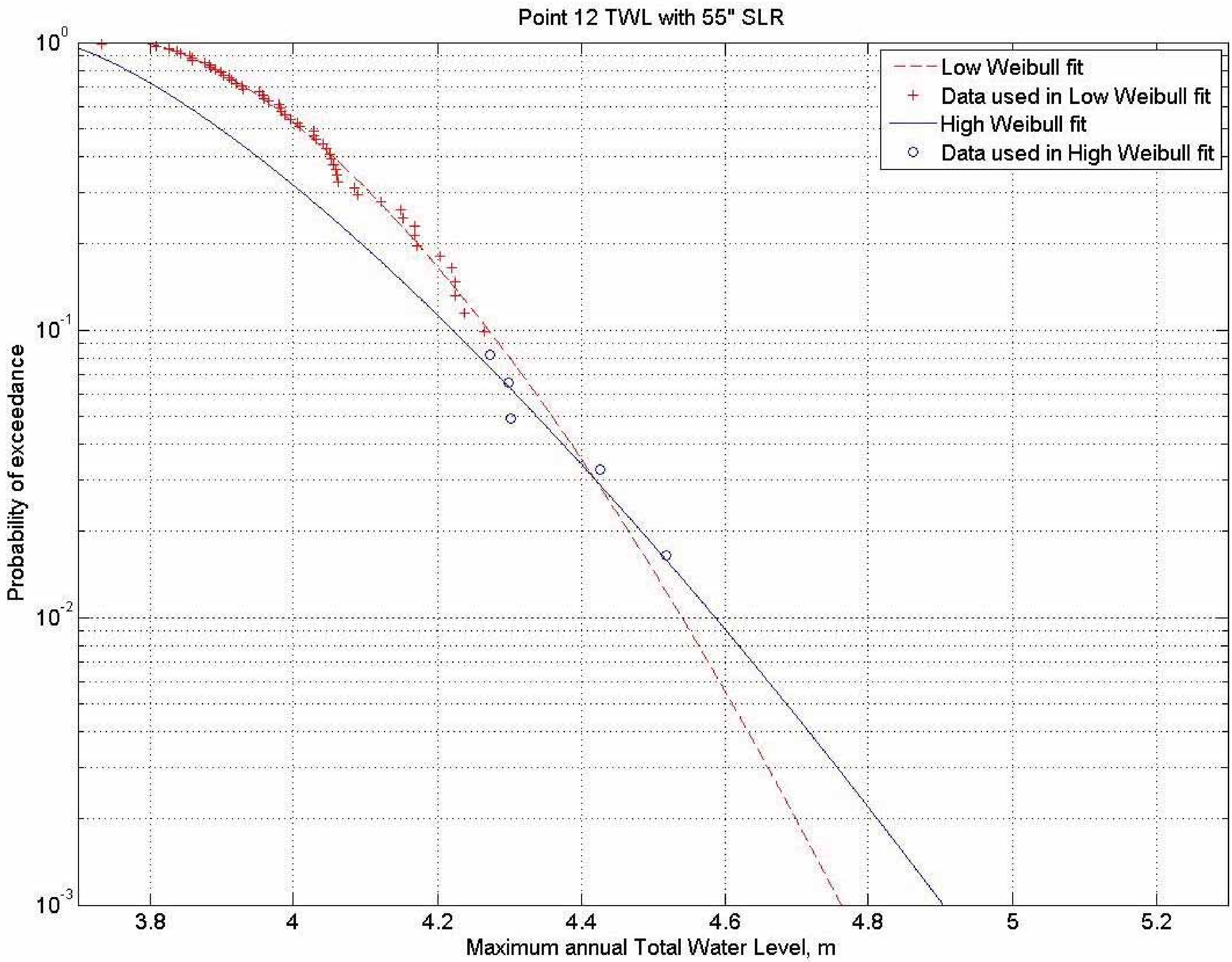


Point 8 TWL with 55" SLR
Weibull fit
Data used in Weibull fit
Probability of exceedance
10^0
10^{-1}
10^{-2}
10^{-3}
3.8
4
4.2
4.4
4.6
4.8
5
5.2
Maximum annual Total Water Level, m

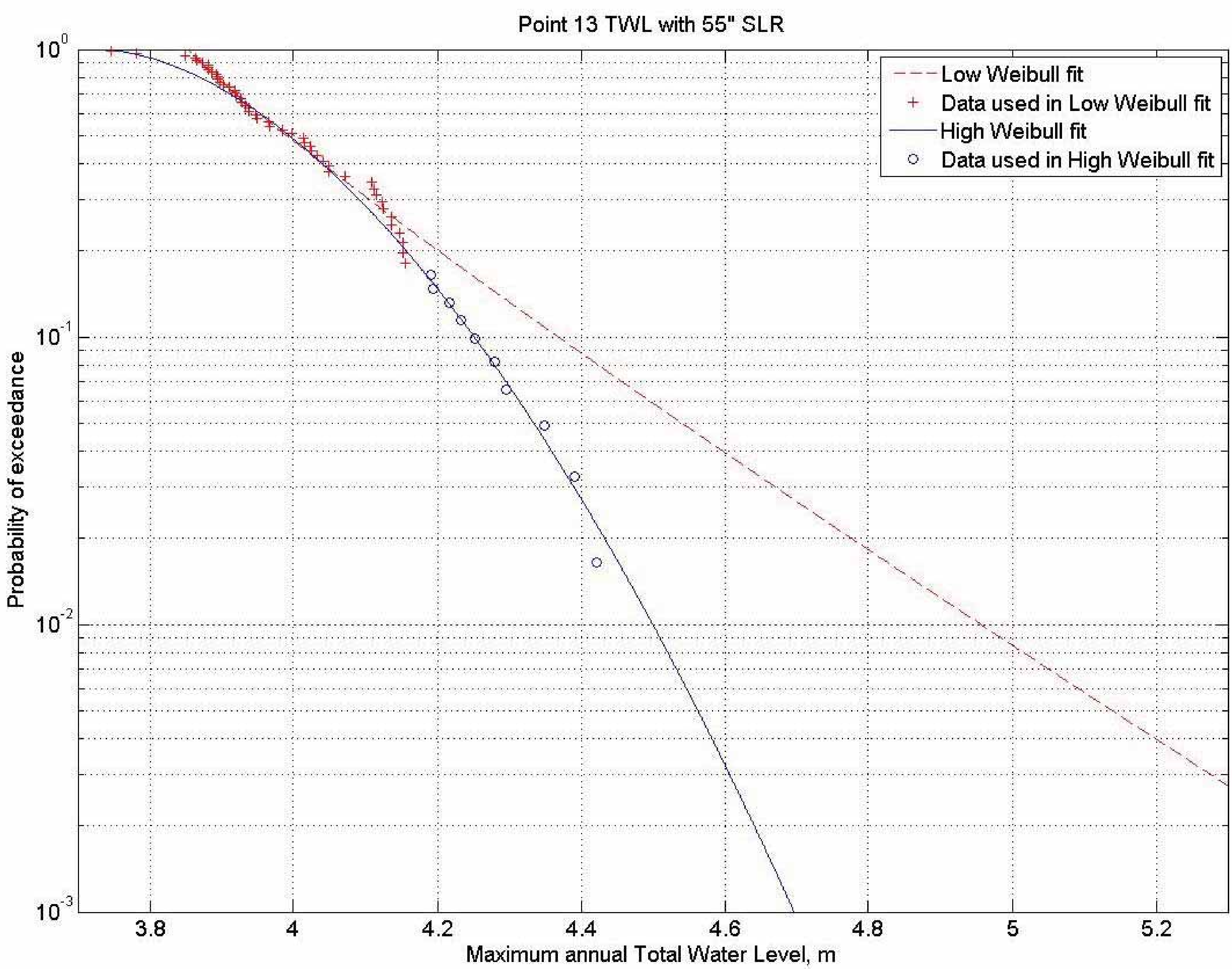

Point 9 TWL with 55" SLR
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^{0}
10^{-1}
10^{-2}
10^{-3}
3.8
4
4.2
4.4
4.6
4.8
5
5.2
Maximum annual Total Water Level, m


Point 10 TWL with 55" SLR
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^{-1}
10^{-2}
10^{-3}
3.8
4
4.2
4.4
4.6
4.8
5
5.2
Maximum annual Total Water Level, m

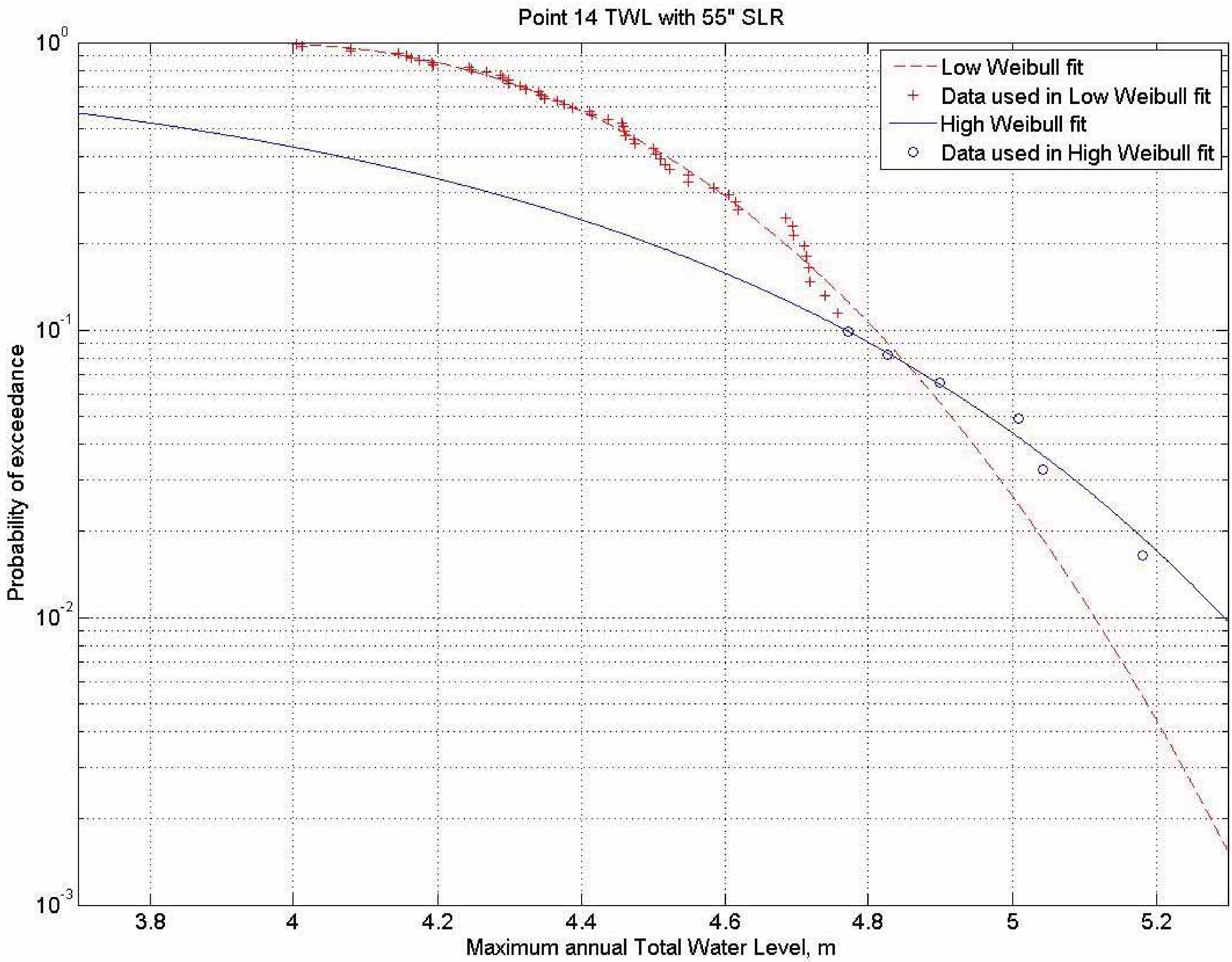

Point 11 TWL with 55" SLR
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^{-1}
10^{-2}
10^{-3}
3.8
4
4.2
4.4
4.6
4.8
5
5.2
Maximum annual Total Water Level, m



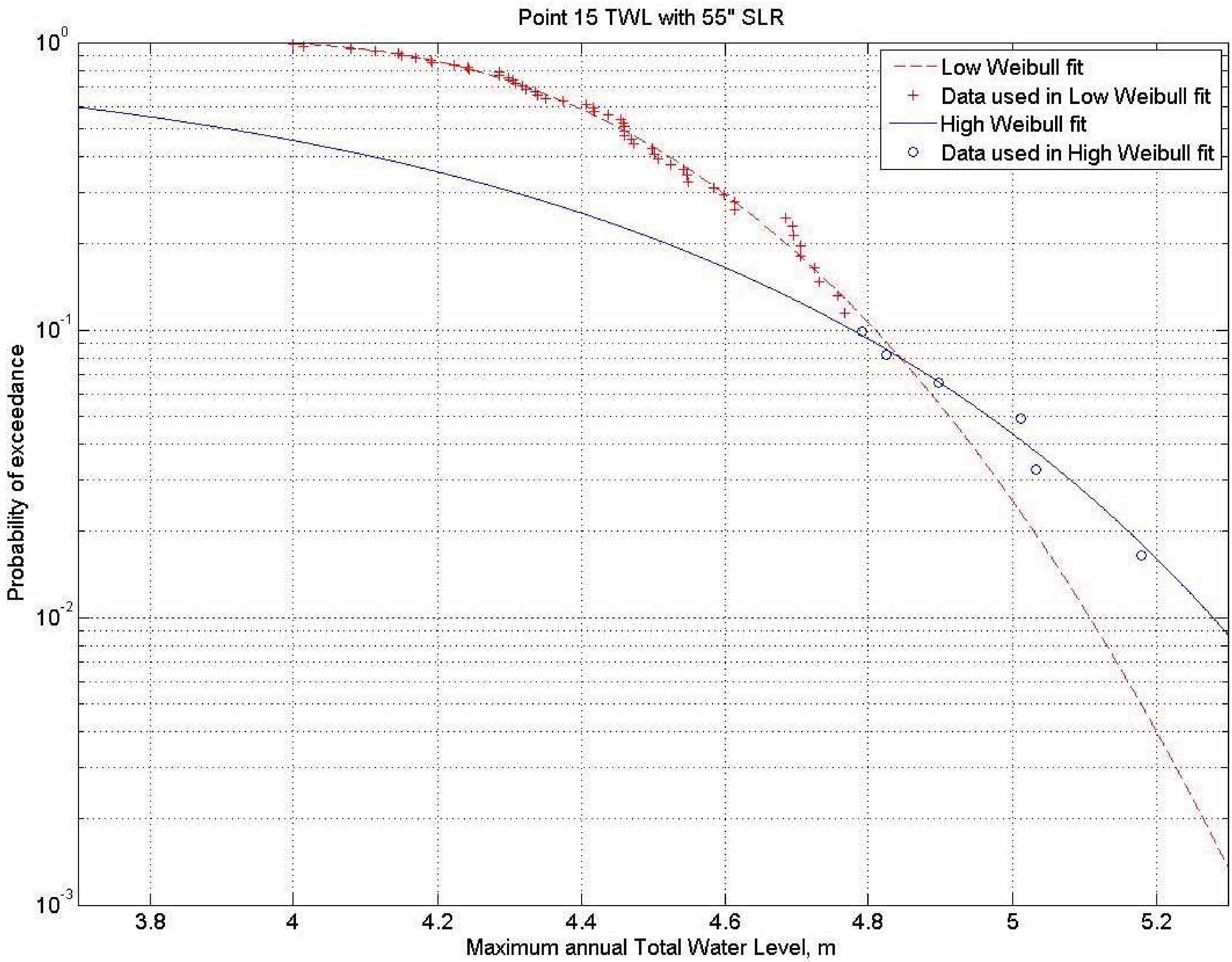
Point 12 TWL with 55" SLR
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^-1
10^-2
10^-3
3.8
4
4.2
4.4
4.6
4.8
5
5.2
Maximum annual Total Water Level, m

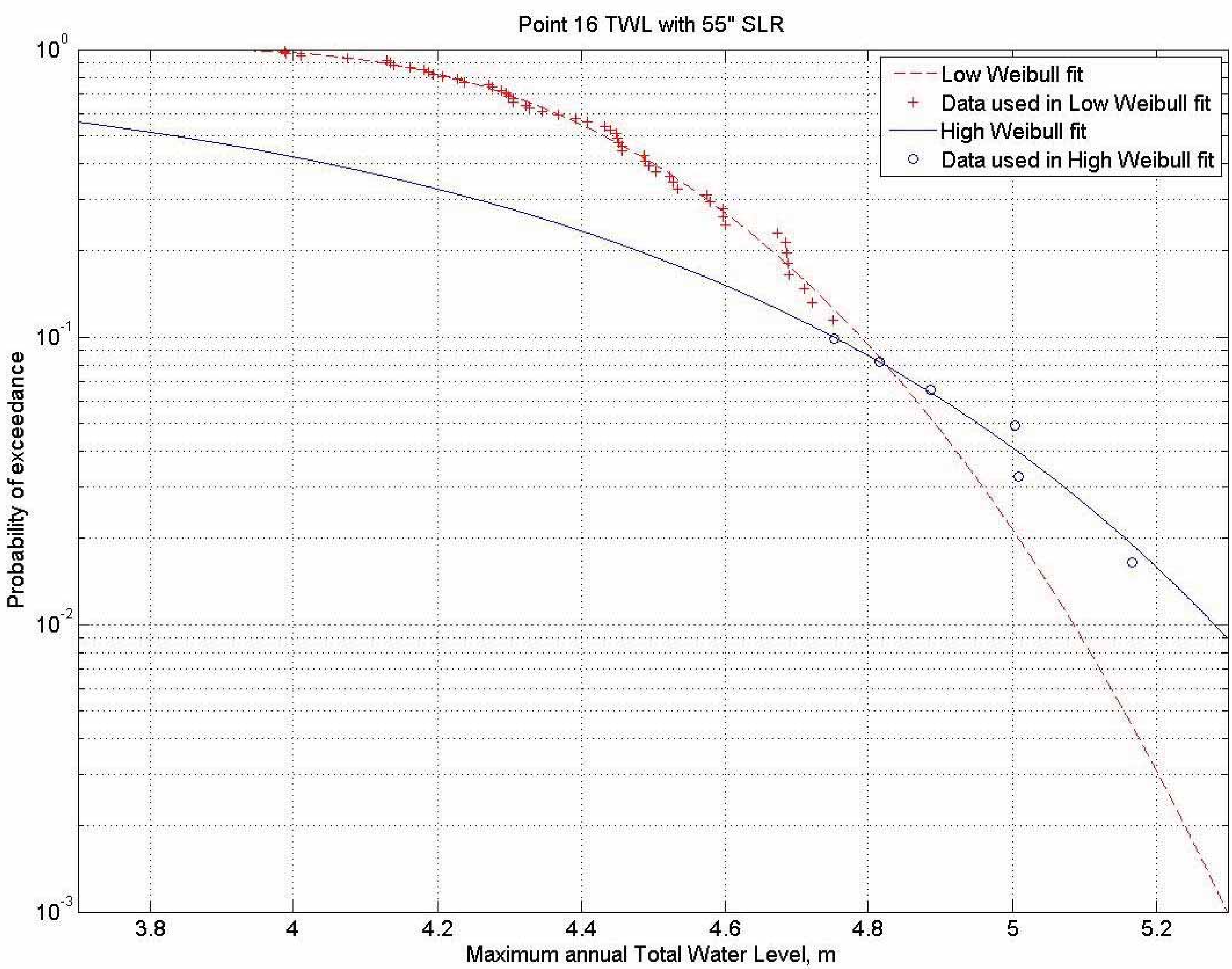


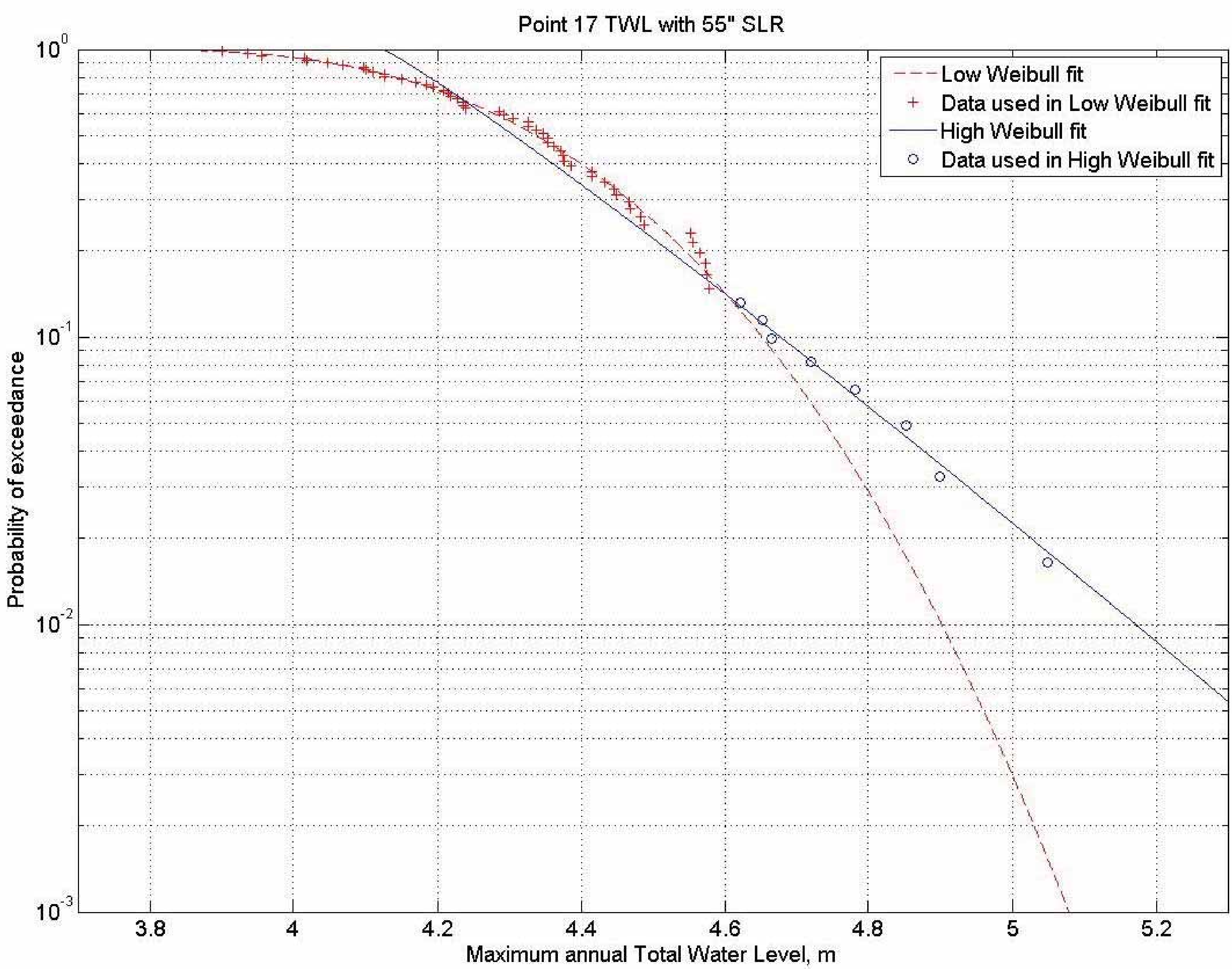
Point 13 TWL with 55" SLR
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^-1
10^-2
10^-3
3.8
4
4.2
4.4
4.6
4.8
5
5.2
Maximum annual Total Water Level, m



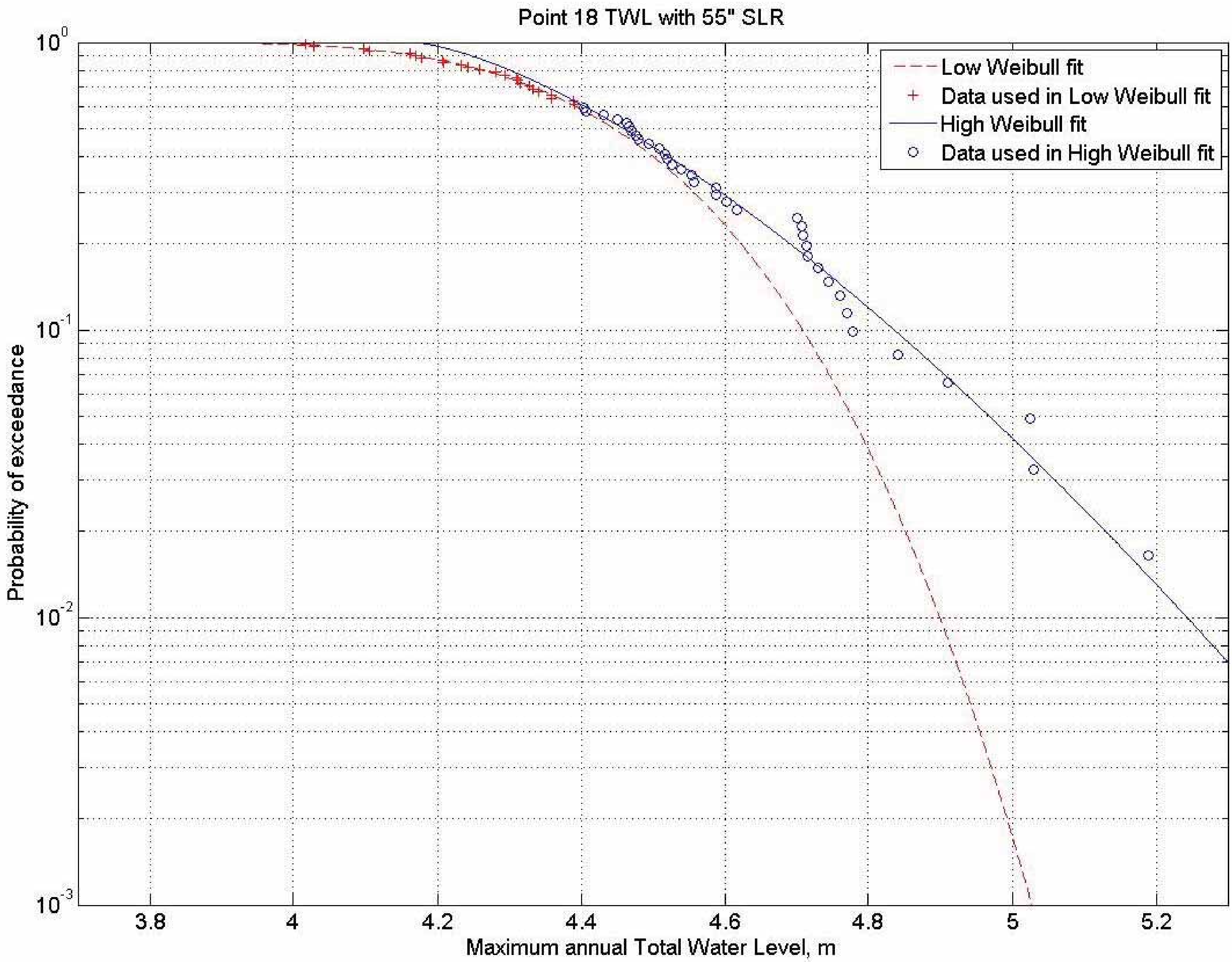
Point 14 TWL with 55" SLR
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^{0}
10^{-1}
10^{-2}
10^{-3}
3.8
4
4.2
4.4
4.6
4.8
5
5.2
Maximum annual Total Water Level, m


Point 15 TWL with 55" SLR
Probability of exceedance
Maximum annual Total Water Level, m
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
10^0
10^-1
10^-2
10^-3
3.8
4
4.2
4.4
4.6
4.8
5
5.2

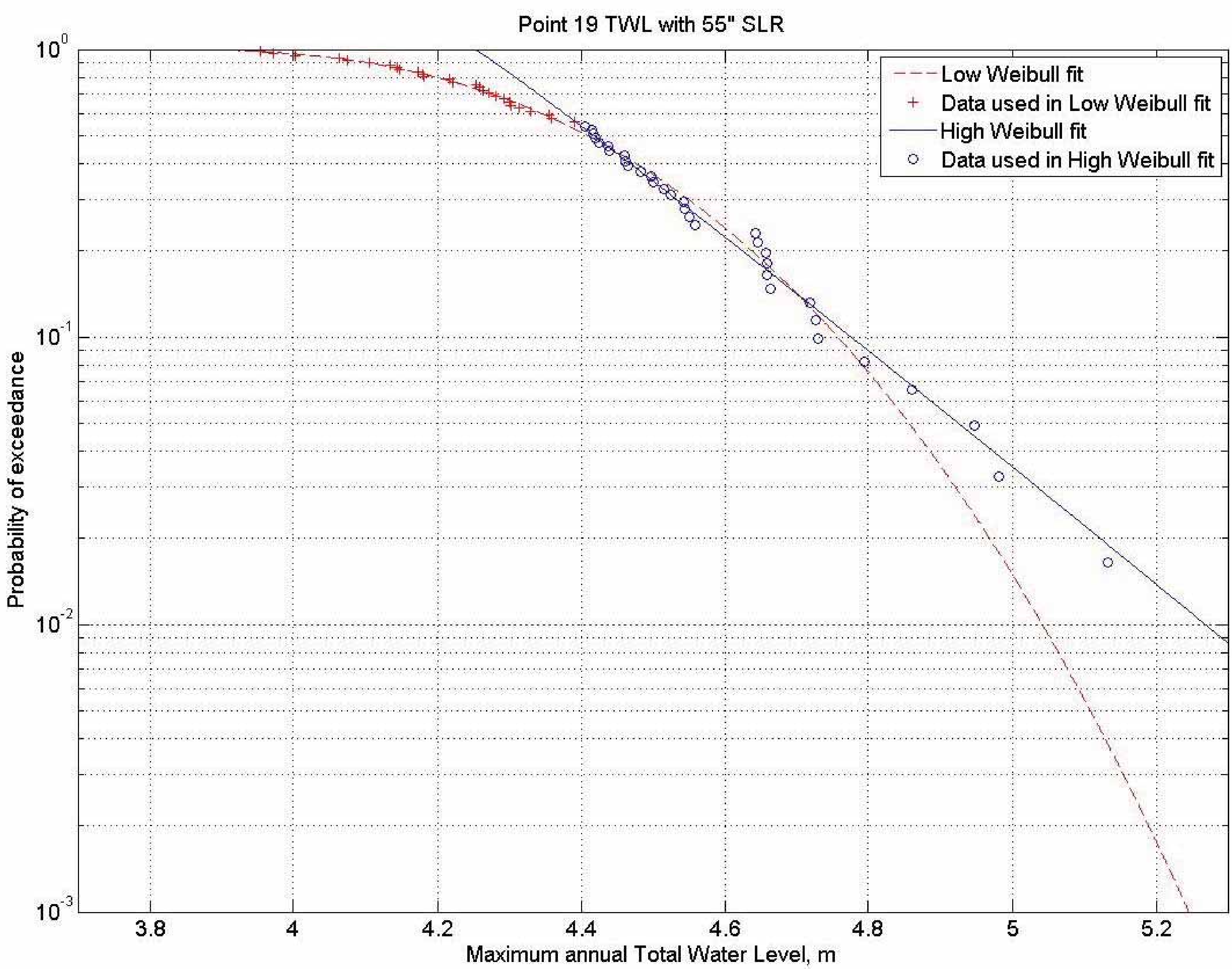

Point 16 TWL with 55" SLR
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^{0}
10^{-1}
10^{-2}
10^{-3}
3.8
4
4.2
4.4
4.6
4.8
5
5.2
Maximum annual Total Water Level, m

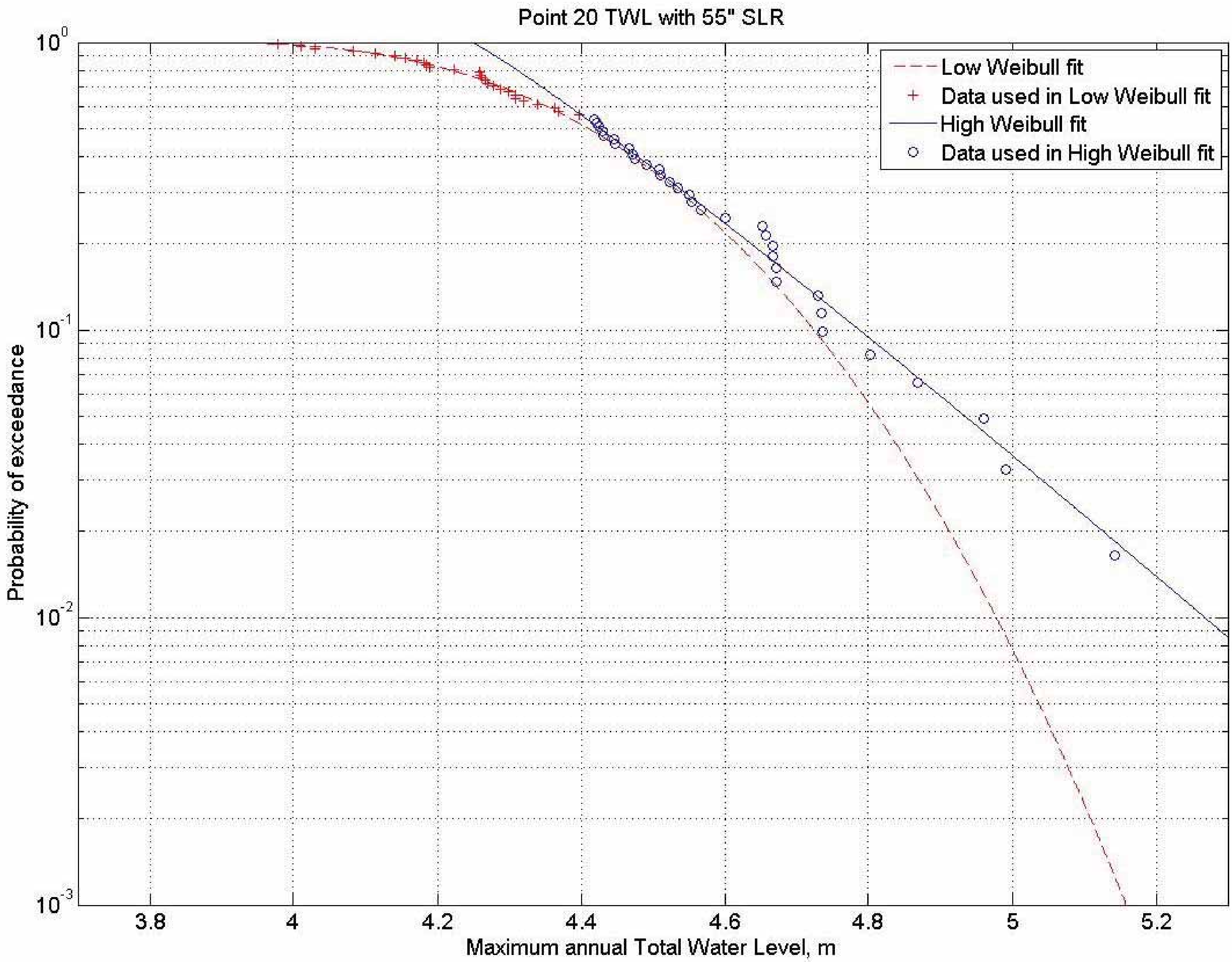


Point 17 TWL with 55" SLR
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^{-1}
10^{-2}
10^{-3}
3.8
4
4.2
4.4
4.6
4.8
5
5.2
Maximum annual Total Water Level, m



Point 18 TWL with 55" SLR
Probability of exceedance
10^0
10^-1
10^-2
10^-3
3.8
4
4.2
4.4
4.6
4.8
5
5.2
Maximum annual Total Water Level, m
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit


Point 19 TWL with 55" SLR
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^{0}
10^{-1}
10^{-2}
10^{-3}
3.8
4
4.2
4.4
4.6
4.8
5
5.2
Maximum annual Total Water Level, m


Point 20 TWL with 55" SLR
Low Weibull fit
Data used in Low Weibull fit
High Weibull fit
Data used in High Weibull fit
Probability of exceedance
10^0
10^-1
10^-2
10^-3
3.8
4
4.2
4.4
4.6
4.8
5
5.2
Maximum annual Total Water Level, m

SEA LEVEL RISE AND ADAPTATION STUDY

ADAPTATION ALTERNATIVES REPORT

Prepared for

Port of San Francisco
Pier 1, The Embarcadero
San Francisco, CA

June 29, 2012

URS/AGS Joint Venture

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Acronyms

AOC	area of concern
City	City of San Francisco
GIS	geographic information system
LiDAR	light detection and ranging
NAVD88	North American Vertical Datum of 1988
Port	Port of San Francisco
SFDPW	San Francisco Department of Public Works
SFPUC	San Francisco Public Utilities Commission
SWL	still water level
TWL	total water level

GLOSSARY

***Recurrence interval**:* The recurrence interval is based on the probability that the given event will be equaled or exceeded in any given year. For example an event with a recurrence interval of 100 years has a 1% chance of being equaled or exceeded in any given year (1/100 = 0.01 or 1%). It is determined by conducting a frequency analysis.

***Runup**:* see wave runup

Still water level: The water level of the sea surface in the absence of wind waves. It is about equal to the midpoint of the waves in deep water. It can be thought of as the undisturbed water level also. It includes storm surge.

Total water level: The water level of the sea surface including wind waves; it is the sum of the SWL and wave runup.

Wave runup: The maximum elevation of wave uprush above still water level.

The goals of this section are (1) to determine the areas of concern within Port of San Francisco (Port) jurisdiction based on the sea-level rise modeling and mapping results that the URS/AGS Team completed (Section 2) and (2) to research and identify potential adaptation options appropriate for the areas of concern (AOCs). The AOCs discussed in this report are vulnerable to heightened sea levels, as shown in modeled 100-year-return (i.e., recurrence interval) still water levels (SWL) and total water levels (TWL) for the years 2010, 2050, and 2100. For the complete discussion of the sea-level rise modeling and mapping referenced in this report, see the *Sea Level Rise and Adaptation Study: Coastal Inundation Report* (June 2011).

A glossary is provided in the table of contents of this report which provides an explanation of the following hydrology terms used frequently in this report: *recurrence interval*, *wave runup*, *SWL*, and *TWL*.

1.1 Determining the areas of concern

This section presents the methodology for determining the AOCs.

1.1.1 Process of determination

The URS/AGS Team, using input from Port engineering staff, determined the AOCs through review of previous task results from this project and current knowledge about the Port, including existing areas of concern under current climatic conditions. On completion and review of the *Sea Level Rise and Adaptation Study: Coastal Inundation Report*, the URS/AGS Team met with Port staff on June 24, 2011, to discuss the approach to this study. During the meeting, the participants reviewed the SWL and TWL maps and identified potential AOCs as shown by inundation or high water for years 2010, 2050, and/or 2100. The URS/AGS Team used the resulting list of potential AOCs as a starting point for determining the AOCs presented below.

1.1.2 Criteria for determination

The URS/AGS Team considered several variables in addition to expert knowledge of the study area in determining the AOCs. We used three primary criteria to group the AOCs:

- Inundation due to modeled year 2010 and year 2050 SWL
- Inundation due to modeled year 2100 SWL
- Effects of modeled year 2050 TWL

Effects of modeled year 2100 TWL were not assessed beyond a cursory review due to the significant water-level elevation of modeled year 2050.

Some of the AOCs that were identified based on these criteria (e.g., Pier 27) are already undergoing improvements to mitigate flooding according to Port staff; however, these areas were still identified as AOCs based on the evaluated milestone years shown above. Also, for TWL, most of the Port piers are lower than the TWL at year 2050, so we identified the areas of greatest concern relative to the rest of the Port. Finally, some of the identified AOCs are affected by multiple water-level scenarios; however, we group and discuss each AOC in the context of its primary water-level scenario of concern.

1.2 Descriptions of areas of concern

The following descriptions of the AOCs consider the primary water-level scenario that is a concern for each area. The alphanumeric naming convention for the IDs is based on the term “area of concern” (AOC) and a unique numerical value for each site. Figures 1-3 through 1-10 are selected photos taken earlier during this study that show all or a portion of each AOC except for the AOCs along Mission Creek (no photos were taken in this area).

1.2.1 Areas inundated based on modeled year 2010 and year 2050 SWL

Figure 1-1 illustrates each of the following AOCs as they overlie the modeled SWL inundation.

- **AOC01** – **Pier 45.** The 100-year SWL modeling shows that the area between the sheds on Pier 45 is inundated at years 2010 and 2050. The inundated area at year 2010 is approximately 3.1 acres, with a slight increase at year 2050. The end of Pier 45 (Figure 1-3) shows that the area between the two sheds is the water-entry point.
- **AOC02** – **Pier 5.** The 100-year SWL modeling shows that the low point at Pier 5 between the two buildings that extends to the water’s edge (Figure 1-4) is inundated at year 2050. The width of this area between the two buildings is approximately 40 feet. This point is the water-entry point for significant flooding along the Embarcadero, and floodwaters also flow from this point to AOC03. The total area of inundation that AOC02 has continuity with along the Embarcadero and along other streets is approximately 18 acres.
- **AOC03 – Embarcadero.** AOC03 extends approximately 2,400 feet along the waterfront from the Agricultural Building to the north (Figure 1-5), along the Embarcadero and Rincon Park, and ends to the south at Pier 22½ (Figure 1-6). A portion of the Embarcadero floods intermittently during large storms under current conditions; this flooding is also verified by the year 2010 SWL modeling. At year 2050, all of AOC03 is inundated at the SWL, which results in significant flooding along the Embarcadero and other streets, including the Muni tunnel on Embarcadero between Howard and Folsom. The total area of inundation for this area is approximately 18 acres; the floodwaters from AOC03 have hydrologic connectivity with the floodwaters flowing from AOC02.
- **AOC04** – **Mission Creek Outfall Structure.** Backflow through the overland flow outfall structure along the north bank of Mission Creek may be a water-entry point at the modeled 100-year SWL for both years 2010 and 2050. Additional analysis that is beyond the scope of this study is needed to better understand this scenario.
- **AOC05** – **Mission Creek, North Bank.** AOC05 extends approximately 1,300 feet along the north bank of Mission Creek from the edge of the Channel Pump Station upstream to the Park Terrace building downstream. AOC05 allows significant flooding (approximately 43 acres) along Berry Street and adjacent areas, including the Caltrain station, at the modeled year 2050 SWL.
- **AOC06** – **Mission Creek, South Bank.** AOC06 extends approximately 1,800 feet along the south band of Mission Creek along Channel Street. The low area here is a water-entry point for moderate inundation of the Mission Bay area at the year 2010 SWL and extensive inundation at the year 2050 SWL. The approximately 61 acres of inundation in the Mission Bay area at year 2050 has hydrologic connectivity with floodwaters from AOC07.

- **AOC07 – Pier 52 Boat Launch.** AOC07 extends approximately 650 feet along Terry A. Francois Blvd. from the northern boat launch (Figure 1-7) past a second boat launch to the south (Figure 8). This entire stretch of shoreline is a water-entry point for inundation of the Mission Bay area (approximately 61 acres). Year 2050 floodwaters from AOC07 have hydrologic connectivity with floodwaters flowing from AOC06.

1.2.2 Areas inundated based on modeled year 2100 SWL

Figure 1-1 illustrates the following AOC that overlies the SWL inundation:

- **AOC08 – Entire Waterfront.** Almost the entire Port waterfront and extensive inland areas are shown to be inundated at the modeled 100-year SWL for year 2100. All of the piers along the Port waterfront are inundated at this SWL except for a portion of Pier 39. Total area inundated in 2100 (not including 2010 and 2050 inundation) is 727 acres, with 289 acres within Port jurisdiction and 438 acres outside of Port jurisdiction.

1.2.3 Areas affected based on modeled year 2050 TWL

Figure 1-2 illustrates each of the following AOCs that overlie TWL values.

- **AOC09 – Pier 27/29.** AOC09 comprises Pier 27 and Pier 29 (Figure 1-9). The year 2050 modeling shows that this is an area of relatively high TWL, and the difference between the TWL and the deck elevations (TWL is higher) in this area is very high relative to the rest of the waterfront. The deck elevation of these two piers is also lower than the modeled year 2010 TWL, which adds to the level of concern for this area. Furthermore, based on guidance from the Port, Pier 27 is of special concern due to the impending Pier 27 Cruise Terminal Project.
- **AOC10 – Pier 30 Vicinity.** The northern extent of AOC10 is Pier 26 and the southern extent is Pier 38, with Pier 30 at the approximate midpoint (Figure 1-10). The year 2050 modeling shows that the difference between the 100-year TWL and the deck elevations (TWL is higher) in this area is high relative to the rest of the waterfront.

1.3 Potential adaptation options for areas of concern

Adaptation measures will be needed to address AOCs in 2050 and 2100. This section summarizes potential adaptation measures that may be needed to address the AOCs in 2050 and 2100. This section also summarizes the importance of adaptive management as a tool for deciding how to phase adaptation over a multi-decadal time frame.

Effective, innovative adaptation approaches can

- Minimize public safety risks and impacts to critical infrastructure
- Maximize compatibility with and integration of natural processes and public access
- Provide topographic resilience over a range of sea levels, potential flooding impacts, and storm intensities
- Provide adaptive management techniques as historical data are collected over the ensuing decades (approaching 2050 and 2100)

AOCs in 2050 are relatively easy to envision and are based on more certain projections of sea-level rise than projections for 2100. Current determinations of AOCs in 2100 are much more uncertain than those for 2050 because they are more dependent on other assumptions (e.g., the effectiveness of future emission control policies). Selection of the best mix of adaptation measures for the Port and how construction of the proposed measures can be phased in over time will be discussed in Sections 3 and 4 of this report.

1.3.1 Adaptation to address AOCs in 2050

Adaptation measures that may be needed at the Port to address AOCs in 2050 include:

- Increase sea-wall heights to minimize the effects of SWL.
- Increase the heights of other structures (e.g., boat launch ramps) over which bay water may enter the Port jurisdiction to minimize the effects of SWL.
- Install breakwaters to minimize the effects of TWL.
- Install other wave attenuation devices (e.g., submerged shoreline baffles) to reduce the effects of TWL.

1.3.2 Adaptation to address AOCs beyond 2050 to 2100

Adaptation measures that may be needed at the Port to address AOCs from 2050 through 2100 include:

- Increase sea-wall heights across the entire Port to minimize the inland impacts of SWL.
- Install a shoreline berm (e.g., like shoreline berms in Japan) to reduce the effects of SWL and TWL.
- Install a storm-surge gate at the mouth of San Francisco Bay or the mouth of Mission Creek to minimize the effects tidal high-water extremes.
- Install breakwaters or submerged baffles to minimize the effects of TWL.

1.3.3 Adaptation concepts for consideration

An example from Mississippi shows that rather than abandoning or retreating, the state port (Gulfport) plans to expand its port upward by 25 feet and laterally outward to capture more of the international shipping market anticipated to result from the enlargement of the Panama Canal. Also, the Port of Rotterdam in the Netherlands has a long history of expansion upward and outward.

1.3.4 Adaptive management and the use of phased approaches

Adaptive management is a cyclic, learning-oriented approach that is especially useful for complex environmental systems characterized by high levels of uncertainty about system processes and the potential for different ecological, social, and economic impacts from alternative management options.

Effective adaptive management requires setting clear and measurable objectives, collecting data, reviewing current scientific observations, monitoring the results of policy implementation or management actions, and integrating this information into future actions.

The Port's adaptive management strategy must recognize that the science of climate change remains uncertain and that this uncertainty increases for longer-term projections. Adaptively managing (i.e., preventing) impacts to the Port means tying major financial decisions to the certainty of the science.

The goals of this section are (1) to make a preliminary selection of the adaptation options for each of the AOCs within the Port's jurisdiction, as identified by the URS/AGS Team in Section 2, and (2) to provide detailed maps that show the approximate locations of the proposed adaptation options and their corresponding elevations.

2.1 Adaptation selection

The URS/AGS Team made a preliminary selection of the adaptation options for each of the AOCs based on previous work done for this study and the individual characteristics of each of the AOCs. In some cases, more than one type of adaptation is proposed for an AOC to address the variability of the AOC itself. Also, in some cases, the proposed adaptations are described in general terms (e.g., "raised structure") to allow for the more-detailed description based on Port input of site characteristics selected in Section 4. We recommend that the Port reevaluate the suitability of these proposed adaptation alternatives and/or begin more detailed planning around the year 2030. This timing will allow the Port to benefit from observing the effects of actual, rather than modeled, sea-level fluctuations as well as utilizing other innovative adaptation strategies that may be available at that time.

Determination of the elevations for the adaptations was based primarily on either the modeled SWL or the TWL that contributed to these sites being identified as AOCs. Actual elevations for the proposed adaptations are based in part on the amount of freeboard required. Review of and subsequent feedback on these selections from the Port engineering staff was critical in refining the selection and elevations of appropriate adaptations.

To avoid confusion, dikes and levees are both referred to as *dikes*.

2.2 Proposed adaptation options

Figures 2-1 through 2-5, 2-7, and 2-8 are maps that illustrate the proposed adaptation option(s) for each AOC for the year 2050; Figures 2-6a and 2-6b illustrate adaptation options for the year 2100. The adaptations as shown on the maps are generalized in both location and extent and should only be used as a guide for more detailed engineering design.

2.2.1 AOC01 – Pier 45

Two adaptation options are proposed for the AOC01 – Pier 45 (Figure 2-1):

1. An approximately 117-foot-long raised structure to be constructed near the end of the deck. This feature would act as a dike to prevent water from flowing through and inundating the deck area behind it. The material for this structure would be determined based on more-detailed engineering design, but concrete appears to be suitable. Both ends of this structure should be designed so that vehicles can pass over or through it to access the apron of the pier. Drainage on the deck should also be evaluated and improved as needed.

2. An approximately 609-foot-long solid wall to be constructed along the perimeter of the apron and end of the deck. This feature would prevent water from flowing through and inundating the deck and apron behind it. The material for this structure would be determined based on more detailed engineering design. The design should include a

method for allowing loading and unloading of vessels docked along the apron. Drainage on the deck should also be evaluated and improved as needed.

For both options, the top elevation of the structure should be at least elevation 11.0 feet (North American Vertical Datum of 1988 [NAVD88]), -0.4 feet (City Datum), which is 0.5 feet higher than the modeled year 2050 SWL. The current average elevation near the end of the deck and most of the deck area between the two sheds is approximately 9.0 feet (NAVD88), -2.3 feet (City Datum).

2.2.2 AOC02 – Pier 5

The proposed adaptation for the AOC02 – Pier 5 is a 496-foot solid wall that follows the edge of the pier in front of the two buildings and walkways (Figure 2-2). This feature would prevent inundation from flooding the two buildings and would prevent water from flowing through the walkway and subsequently along the Embarcadero. The design of this wall should include either a top railing that extends above the wall or is integrated into the wall itself. Also, special attention needs to be paid to overland flow drainage and backflow prevention during design. The top elevation of this solid wall should be at least 11.0 feet (NAVD88), -0.4 feet (City Datum), which is 0.5 feet higher than the modeled year 2050 SWL. The current average deck elevation along AOC02 is approximately 8.5 feet (NAVD88), -2.8 feet (City Datum).

2.2.3 AOC03 – Embarcadero

AOC03 – Embarcadero is divided into two proposed adaptations due to the variability of the site (Figure 2-3). The proposed northern adaptation is to construct a new solid wall along the edge of the piers from Pier 14 to along the Agricultural Building. This wall would prevent floodwaters from inundating the ground floor of the Agricultural Building and flowing along the Embarcadero and into the Financial District.

The second proposed adaptation, which would extend along the waterfront from near Pier 14 to Pier 22½, is to raise the existing solid wall that would then act as a dike to prevent water from inundating the relatively large area behind it, including the Muni tunnel. The length of this adaptation is approximately 1,649 feet. According to the San Francisco Department of Public Works (SFDPW), the primary purpose of this existing wall is to direct overland flow into the bay. This wall currently has gaps to allow overland flow to pass through it, so the design of this adaptation must include measures to solidify the length of the wall. Accordingly, special attention needs to be paid during design to overland flow drainage and backflow prevention. Furthermore, due to the heavy pedestrian traffic in this area, special attention should be paid to create a design that will allow public access over and/or around the wall on steps, ramps, or other features.

Both the top of the new solid wall and the raised existing wall should be at least elevation 11.0 feet (NAVD88), -0.4 feet (City Datum), which is 0.5 feet higher than the modeled year 2050 SWL. The proposed adaptations could potentially be constructed in phases, depending on other variables such as observed sea-level rise and the timing of other construction projects in the vicinity.

2.2.4 AOC04 – Mission Creek Outfall Structure

This area is greatly affected by how other San Francisco city and county agencies address the local storm outfall structure, and thus this area is not part of the scope of this study and is not considered further in this analysis.

2.2.5 AOC05 – Mission Creek, North Bank

The proposed adaptation for AOC05 – Mission Creek, North Bank, is a dike along this 1,066-foot bank (Figure 2-4). The top of this dike should be at least elevation 11.0 feet (NAVD88), -0.4 feet (City Datum), which is 0.5 feet higher than the modeled year 2050 SWL. The 610-foot eastern portion of this dike would likely require the construction of an overlying boardwalk similar to the boardwalk currently in place at the site.

2.2.6 AOC06 – Mission Creek, South Bank

The proposed adaptations for AOC06 – Mission Creek, South Bank, are dikes (Figure 2-4). The western dike would run along the 906-foot bank between the existing parking area and the shoreline park. The eastern dike would run along the 188-foot bank between the park and Mission Creek. The tops of both of these dikes should be at least elevation 11.0 feet (NAVD88), -0.4 feet (City Datum), which is 0.5 feet higher than the modeled year 2050 SWL.

2.2.7 AOC07 – Pier 52 Boat Launch

The proposed adaptation for AOC07 – Pier 52 Boat Launch, is a dike or other raised structure along this 529-foot length of San Francisco Bay shoreline along Terry A. Francois Blvd. (Figure 2-5). The proposed dike elevation is relatively low; thus, it is envisioned that minimal modifications will be necessary to maintain future access to the boat launch. The top elevation of this adaptation feature would likely be at minimum 11.0 feet (NAVD88), -0.4 feet (City Datum), which is 0.5 feet higher than the modeled year 2050 SWL.

2.2.8 AOC08 – Entire Waterfront

Adaptation to the year 2100 sea-level rise scenario would likely require a large-scale, phased approach to be implemented throughout San Francisco by multiple agencies and stakeholders. A variety of structural adaptation/mitigation techniques could be implemented, such as a system of dikes, pier improvements wrapped around existing high-value existing piers or a raised marginal wharf (e.g., generally parallel with the Embarcadero), walkways, piers, and sea walls.

Figures 2-6a (Preferred Solution 1) and 2-6b (Preferred Solution 2) show several proposed adaptations to be constructed along the waterfront that were chosen with the goal of protecting inland areas from inundations due to the modeled year 2100 SWL. Specific measures would be needed to address inundation of the piers, and each of the Preferred Solutions includes one or a combination of the following two primary adaptation options:

1. Year 2100 Option #1 "Supplemental Pier" – Take the existing pier structures and "wrap" them with an adjacent new and elevated approximately 20-foot "pier type" structure on three sides including waterproofing the interface between the new and existing structure. This adaptation may be especially suitable for high-value piers (e.g., the Ferry Building, the proposed new Pier 27 Cruise Terminal).
2. Year 2100 Option #2 "Marginal Wharf" – Remove all of the existing piers and the existing 40- to 60-foot marginal wharf to the existing seawall and then replace it with a raised-finish-elevation marginal wharf approximately 400 feet on the waterside of the existing seawall and generally paralleling the existing Embarcadero roadway in a to-be-determined phased construction method. The creation of this marginal wharf barrier also raises the issue of how storm water would be addressed as it is captured behind these civil barriers.

The two Preferred Solutions are as follows:

1. Preferred Solution 1 – For the area between Pier 43½ and Pier 40, Preferred Solution 1 consists of constructing a new 20-foot-wide elevated supplemental pier (Option #1) around each of the existing piers (Figure 2-6a). For the remaining areas, a combination of walls, dikes, and other improvements is proposed.
2. Preferred Solution 2 – As shown on Figure 2-6b, the existing piers from Pier 43½ to Pier 40 would be demolished, except for Pier 27/29 and the Ferry Terminal. A new 20-foot-wide elevated supplemental pier (Option #1) will be constructed around Pier 27/29 and the Ferry Terminal. A 400-foot-wide elevated marginal wharf (Option #2) will be constructed along the remainder of the waterfront in place of the demolished finger piers. For the remaining areas, a combination of walls, dikes, and other improvements is proposed.

The top elevation of all of these year 2100 adaptations should be at least elevation 14.0 feet (NAVD88), 2.8 feet (City Datum), which is 0.2 feet higher than the modeled year 2100 SWL. Because these are large-scale adaptations that would likely affect many current activities, the engineering design will be critical to successful implementation. Also, special attention needs to be paid during design to overland flow drainage and backflow prevention.

2.2.9 AOC09 – Pier 27/29

The adaptation to the modeled TWL for year 2050 for AOC09 – Pier 27/29 is a 12-inch-by-12-inch solid bullrail fastened by 1-inch pins to the entire perimeter of Piers 27 and 29 (Figure 2-7). Since the year 2050 TWL is a measure of SWL plus wind-wave run-up against a solid object (e.g., a sea wall) and not actual wave height, this bullrail should be sufficient for dissipating any wave run-up that might reach the height of the deck, which varies between 12.5 and 13.5 feet (NAVD88).

2.2.10 AOC10 – Pier 30 Vicinity

Adaptation to the modeled TWL for year 2050 for AOC10 – Pier 30 Vicinity is a new breakwater (Figure 2-8). This breakwater would extend approximately 2,854 feet from Pier 26 to Pier 38. The top elevation should be at least 14.3 feet (NAVD88), 3.0 feet (City Datum), which is the height of modeled year 2050 TWL. The breakwater starts at Pier 26 and runs along the Pier and Bulkhead Line until it reaches the southernmost corner of Pier 30/32; from there the breakwater runs just south of Pier 38.

The goal of this section is to analyze the effectiveness of the proposed adaptation options for each AOC presented in Section 2. After analyzing the effectiveness of the adaptation options, the URS/AGS Team maps the effects of the adaptation options on the modeled 100-year SWL and 100-year TWL.

3.1 Adaptation effects: SWL for years 2010 and 2050

All of the adaptation options presented in Section 2 and their corresponding top elevations reduce the amount of inundation due to the modeled 100-year SWL for year 2010 and 2050 and would prevent water from flowing through topographically low areas (i.e., the AOCs) and then inundating the low-lying areas behind the AOCs in the Port and the City. To illustrate the successful implementation of these adaptations, we modified the inundation polygons in a Geographic Information System (GIS) for both years 2010 and 2050 to show the modified extent of inundation. The effects of the following adaptations are shown on Figure 3-1:

- **AOC01 – Pier 45**: A 117-foot-long raised structure near the end of the deck (Option #1)
- **AOC02 – Pier 5**: A 496-foot-long solid wall following the edge of the pier
- **AOC03 – Embarcadero**: A 603-foot-long solid wall along the edge of the piers from Pier 14 to the Agricultural Building (northern adaptation) and a raised 1,649-foot section of the existing wall from near Pier 14 to Pier 22½ (southern adaptation)
- **AOC04 – Mission Creek Outfall Structure**: Not considered in this analysis
- **AOC05 – Mission Creek, North Bank**: A 1,066-foot-long dike along Mission Creek
- **AOC06 – Mission Creek, South Bank**: A 906-foot-long dike along Mission Creek (western adaptation) and a 188-foot-long dike along Mission Creek (eastern adaptation)
- **AOC07 – Pier 52 Boat Launch**: A 529-foot-long dike along Terry A. Francois Blvd.

3.2 Adaptation effects: SWL for year 2100

As indicated in Section 2, the proposed adaptations for year 2100 were chosen with the goal of protecting inland areas from inundations due to the modeled year 2100 SWL. Specific measures would be needed to address inundation of the piers. To illustrate the successful implementation of these adaptations, the URS/AGS Team modified the inundation polygons in a GIS for year 2100 to show the modified extent of inundation based on Preferred Solution 1 (Figure 3-2a) and Preferred Solution 2 (Figure 3-2b).

The impending need is unclear at best; however, it will become clearer with time as the responses to sea-level rise are further explored worldwide. To address potential solutions for an unclear need is currently beyond the scope of this study; however, the unclear need should be adequately addressed in time.

3.3 Adaptation effects: TWL for year 2050

The construction of a breakwater at AOC10 – Pier 30 Vicinity would reduce the wave energy entering the protected area to nearly nil. Thus, the 100-year TWL in the protected area is reduced to be equal to the 100-year SWL. The URS/AGS Team ran the SWAN wave model to evaluate the effect on the protected area of 1-meter height and 3-second-period waves incident from either the north or the southeast. Figure 3-3 illustrates the resulting wave height for waves incident from the north, and Figure 3-4 illustrates the resulting wave height for waves incident from the south. In all cases, wave height incident on the shoreline is nearly zero, except for the basins directly adjacent to the openings in the breakwater.

Figure 3-5 shows the effect of the proposed breakwater for AOC10 on the 100-year TWL for year 2050. The effect of the proposed 12-inch by 12-inch bullrail around the perimeter for Piers 27 and 29 cannot be effectively illustrated on a map and thus only the location of this proposed adaptation is shown on Figure 3-5.

The goals of this task are (1) to prepare conceptual design details for the proposed adaptation options for each of the AOCs identified in Section 2 and (2) to prepare conceptual cost estimates for the proposed adaptation options.

4.1 Conceptual design objectives

The conceptual design objectives are as follows:

- Prevent flooding in waterfront areas due to future sea-level rise
- Attempt to minimize negative impacts to existing waterfront structures and users
- Maintain access to existing facilities
- Maintain the aesthetic value of the waterfront
- Minimize disruptions to bay views from land facilities
- Consider a phased approach to improvements
- Consider the cost of capital improvements, to the extent possible

4.2 Conceptual details for SWL

4.2.1 Year 2050

The conceptual details provided here correspond to the plan figures provided in Section 2 for each AOC. The locations for each detail are shown on the corresponding figures in Section 2. The URS/AGS Team reviewed the existing light detection and ranging (LiDAR) data to determine the approximate elevations of existing features and the approximate heights of the proposed walls, dikes, and raised wharves in each location. The URS/AGS Team has also indicated the minimum elevations for the top of the proposed adaptations. The actual wall or berm heights may vary in some locations to achieve the correct minimum elevations. The following details were prepared for each AOC:

- **AOC01 – Pier 45:** See Figure 4-1, which corresponds to Figure 2-1. Figure 4-1 assumed a minimum 5-inch-thick existing concrete deck.
- **AOC02 – Pier 5:** See Figure 4-1, which corresponds to Figure 2-2.
- **AOC03 – Embarcadero:** See Figure 4-1, which corresponds to Figure 2-3, for the 603-foot-long wall adjacent to the Agricultural Building.

  See Figure 4-2 for the 1,649-foot-long wall along the Embarcadero. An existing seat wall is adjacent to the existing concrete rail along portions of this area. The top of the existing seat wall appears to be near elevation 11.0 (NAVD 88) in some locations. Future surveys of the top of the existing seat wall may indicate that portions of the proposed concrete wall can be eliminated.
- **AOC04 – Mission Creek Outfall Structure:** Not considered in this analysis. Treatment of existing storm drain outfalls and potential future pumping of storm flows will be addressed by others at a future date.

- **AOC05 – Mission Creek, North Bank:** See Figure 4-3, which corresponds to Figure 2-4. The URS/AGS Team originally considered a dike/berm at this location. The width of a 2-foot-high berm is about 12 feet (see Figure 4-4 for the south bank of Mission Creek). On the north bank of Mission Creek, existing condominiums are present with at-grade entrances and a pedestrian promenade. It would not be possible to fit a berm in that area without significantly compromising the width of the promenade or encroaching into Mission Creek. Therefore, the URS/AGS Team is proposing a concrete wall.
- **AOC06 – Mission Creek, South Bank:** See Figure 4-4, which corresponds to Figure 2-4. The earth berm will be hydroseeded in this area because the berm would be situated in landscaped areas.
- **AOC07 – Pier 52 Boat Launch:** See Figure 4-4, which corresponds to Figure 2-5. The earth berm will be covered with a 2-inch asphaltic-concrete surface in this area to match the existing paving. The side slopes of the berm will transition from 2 horizontal to 1 vertical (2H:1V) to 10H:1V at the location of the Pier 52 boat launch to accommodate vehicles with boat trailers. The width of the boat launch area is about 60 feet.

4.2.2 Year 2100

The proposed improvements for the year 2100 adaptations for AOC08 are shown on Figures 2-6a (Preferred Solution 1) and 2-6b (Preferred Solution 2). The following list describes the conceptual details for those adaptations:

- Figure 4-5: Year 2100 mitigation—Proposed reinforced concrete wall from Pier 45 to Aquatic Park
- Figure 4-6: Year 2100 mitigation—Proposed reinforced-concrete wall at AT&T Park

  The URS/AGS Team assumed a minimum existing 10-inch-thick concrete deck for the proposed 5-foot-high concrete wall; the suitability of the existing concrete deck should be evaluated in the future
- Figure 4-7: Year 2100 mitigation—Proposed 400 foot-wide marginal wharf at the Embarcadero (typical of Year 2100 Option #2)
- Figure 4-8: Year 2100 mitigation—Proposed 20 foot-wide surrounding existing piers (typical of Year 2100 Option #1)
- Figure 4-9: Year 2100 mitigation—Proposed plan of Mission Creek tide gate at McCovey Cove

  The URS/AGS Team originally proposed an approximately 5-foot-high dike/berm around Mission Creek on both sides of the creek. That proposal presented a problem at the Third Street and Fourth Street bridges. With the proposed berms, it would be necessary to raise those bridges about 4 or 5 feet each, together with the approaches on either side, or abandon the bridges. The Fourth Street bridge also has the new Muni tracks, which continue south on Third Street to the Bayview District. It might be cost-prohibitive to raise the two bridges, the approaches, and, particularly, the Muni tracks.

  The revised proposal is to put a gate across the creek immediately downstream (east) of the Third Street Bridge. This proposal would leave the bridges alone and delete the dike/berm along both sides of the creek west of Third Street. Not enough room is available for a berm between the creek and the new buildings on the north side of Mission Creek anyway. That would have to be a concrete wall.

If necessary, the gate could then be opened on any given day during low tide. It may be possible to leave the gate open for months at a time, until an anticipated 100-year high tide event occurs. That period would probably depend on how the actual sea-level rise elevations play out.

The San Francisco Public Utilities Commission (SFPUC) would have to close storm drain outfall points into the channel and open new outfall points/pump stations along the Embarcadero that would empty into McCovey Cove, and possibly south of Mission Creek, near Pier 48. SFPUC will have to put in new large pump stations to deal with sea-level rise, so new pump stations along the Embarcadero should not be a large additional cost. As previously noted, the storm drain improvements and pump stations are not a part of the scope of this report and will be addressed by others.

- Figure 4-10: Year 2050 mitigation—Proposed Mission Creek tide gate at McCovey Cove

  The URS/AGS Team researched examples of potential tide gates from Venice, Tokyo, the Netherlands, and New Orleans. An example from Venice and one from Tokyo appeared to be the most appropriate for this sized channel. The example from Tokyo is raised vertically and requires a large structure above the water. It is both obtrusive and ugly. The example from Venice is raised up from the bottom of the channel and would look much better, so that is the example being proposed.

  The proposed gate is a hollow metal gate on a concrete structure supported by piles. When water is pumped into the gate, it lays flat, below the water, on the concrete structure. When air is pumped into the gate it rises and prevents water from moving through the area.

- Figure 4-11: Year 2050 mitigation—Proposed 5 foot high earth berm south of Mission Creek.

  In some locations, it may be necessary to adjust some waterfront streets or encroach into the bay to accommodate the 25-foot-wide berm.

4.3 Conceptual details for TWL

Adaptation measures were identified for two areas of concern in Task 3.2 regarding TWL. The AOCs and their corresponding proposed conceptual details follow:

- **AOC09 – Pier 27/29:** See Figure 4-12, which corresponds to Figure 2-7. A timber bullrail was originally proposed. A concrete bullrail has been substituted because the timber bullrail would not be waterproof.
- **AOC10 – Pier 30 Vicinity:** See Figure 4-13, which corresponds to Figure 2-8.

4.4 Cost estimates

4.4.1 Cost summary for SWL, year 2050

The costs to address SWL at year 2050 include the improvements for AOC01, AOC02, AOC03, AOC06, and AOC07. The plans are shown on Figures 2-1 to 2-5, and the conceptual details are shown on Figures 4-1 to 4-4. Two options have been proposed for the improvements at Pier 45. Option #1 is a 117-foot structure at the end of Pier 45; Option #2 is a 609-foot structure around the aprons at Pier 45.

1. Total cost (including Pier 45 Option #1): $4,041,000
2. Total cost (including Pier 45 Option #2): $4,641,000

4.4.2 Cost summary for SWL, year 2100

The costs to address SWL at year 2100 include the improvements for AOC08. The plans are shown on Figures 2-6a and 2-6b, and the conceptual details are shown on Figures 4-5 to 4-11. Two Preferred Solutions are proposed for adaptation to year 2100 SWL; Preferred Solution 1 and Preferred Solution 2 are previously described in Section 3.2.

1. Total cost for Preferred Solution 1: $646,040,000
2. Total cost for Preferred Solution 2: $2,773,460,000

The Mission Creek tide gate is required for both Preferred Solutions, and the estimated cost of $28,480,000 for the Mission Creek tide gate is included in the costs indicated above.

The Year 2100 cost estimates do not include potential improvements to the existing piers which will remain. Each existing pier must be individually reviewed and inspected in the future for potential improvements to address water pressure on existing pier decks from below.

4.4.3 Cost summary for TWL, year 2050

The costs to address TWL at year 2050 include the improvements for AOC09 and AOC10. The plans are shown on Figures 2-7 and 2-8, respectively, and the conceptual details are shown on Figures 4-12 and 4-13, respectively.

1. Total cost for TWL adaptation, year 2050: $52,553,000

4.4.4 Cost breakdown and assumptions

For a detailed cost breakdown and a list of the assumptions used, see the attached Appendix A “Estimate of Probable Construction Cost, dated March 2012” prepared by M. Lee Corporation. As noted therein, the estimate specifically excludes the following items:

a. Permit and plan check fees

b. Administration costs such as bidding, advertising, and contract award

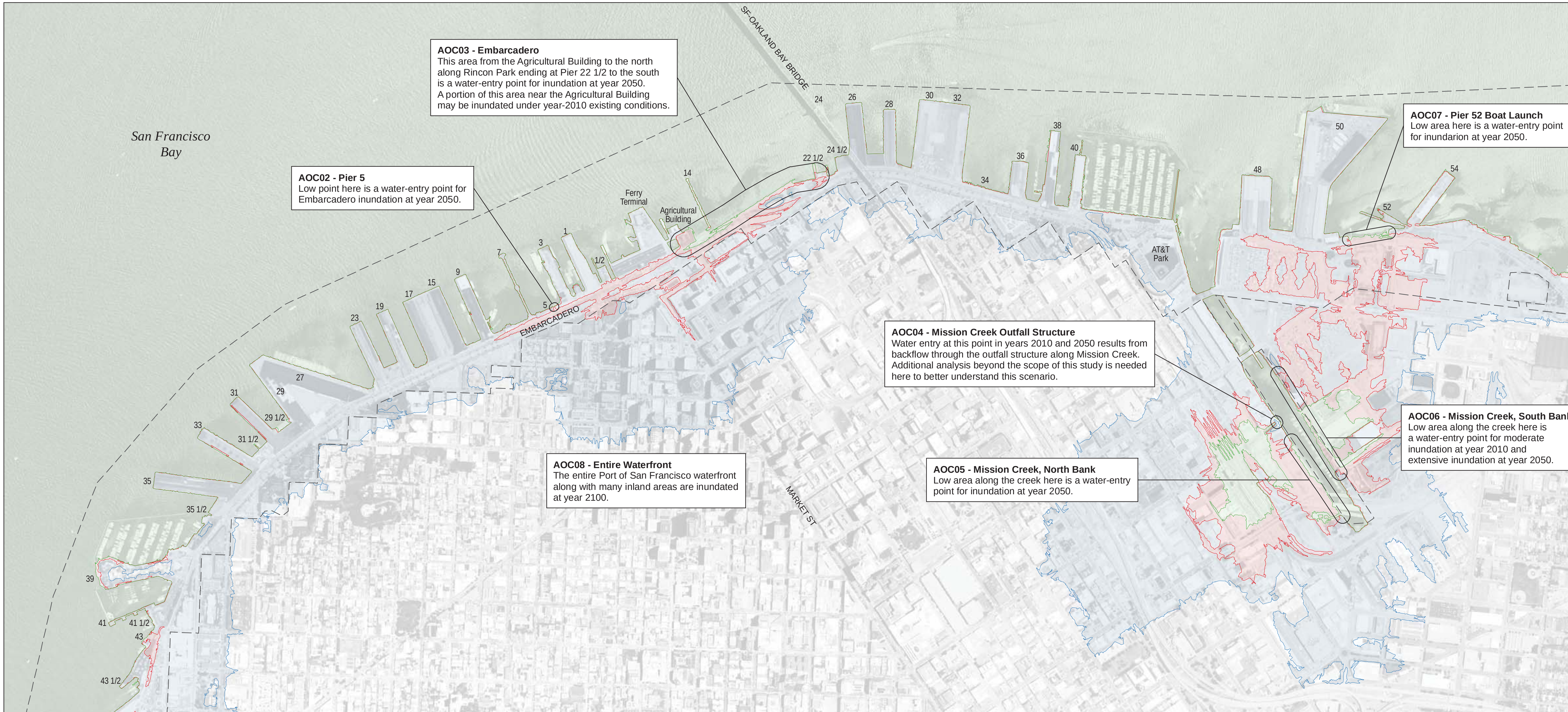
c. Professional fees for architect, engineers, consultants, construction management, and other soft costs

d. Costs for independent testing and inspection

e. Construction change orders

f. Cost escalation beyond the date of this estimate

It is assumed that the above items, if needed, are included elsewhere in the owner's overall project budget.



LEGEND

Area of concern (AOC) with ID and annotation

100-year still water levels (SWL) and inundation area

Year 2010 (existing conditions)
Elevation (ft) = 9.2 (NAVD88), -2.1 (City Datum)

Year 2050
Based on sea level rise scenario of 15 inches
Elevation (ft) = 10.5 (NAVD88), -0.8 (City Datum)

Year 2100
Based on sea level rise scenario of 55 inches
Elevation (ft) = 13.8 (NAVD88), 2.5 (City Datum)

Port of San Francisco jurisdictional boundary

0 1,000 2,000
SCALE IN FEET

1 INCH = 1,200 FEET
AT 11x17-INCH PAGE SIZE

NOTES

1. For an explanation of the analysis presented here, see "Sea Level Rise and Adaptation Study - Coastal Inundation Report" (June 2011).

2. The 100-year still water level (SWL) is the flood level that has a 1% chance of being equaled or exceeded in any given year. FEMA designates areas subject to inundation at the 100-year water level as Special Flood Hazard Areas.

3. Each shading color indicates the modeled extent of inundation for each year. Inundation for each year includes the previous year's inundation (i.e. 2050 includes 2010; 2100 includes 2010 and 2050).

4. Where the deck elevation of a pier/bridge is higher than a given inundation level (i.e. the deck is above water), the perimeter of the pier/bridge is shown.

5. SWL inundation contour lines were derived from LiDAR data provided by the Department of Homeland Security (DHS) for official City of San Francisco use under license from DHS. Survey date: May 16-19, 2007.

6. Imagery source: USDA NAIP, 2005.

Figure 1-1

Areas of concern in relation to inundation based on modeled 100-year still water levels for years 2010, 2050, and 2100

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Sea Level Rise and Adaptation Study

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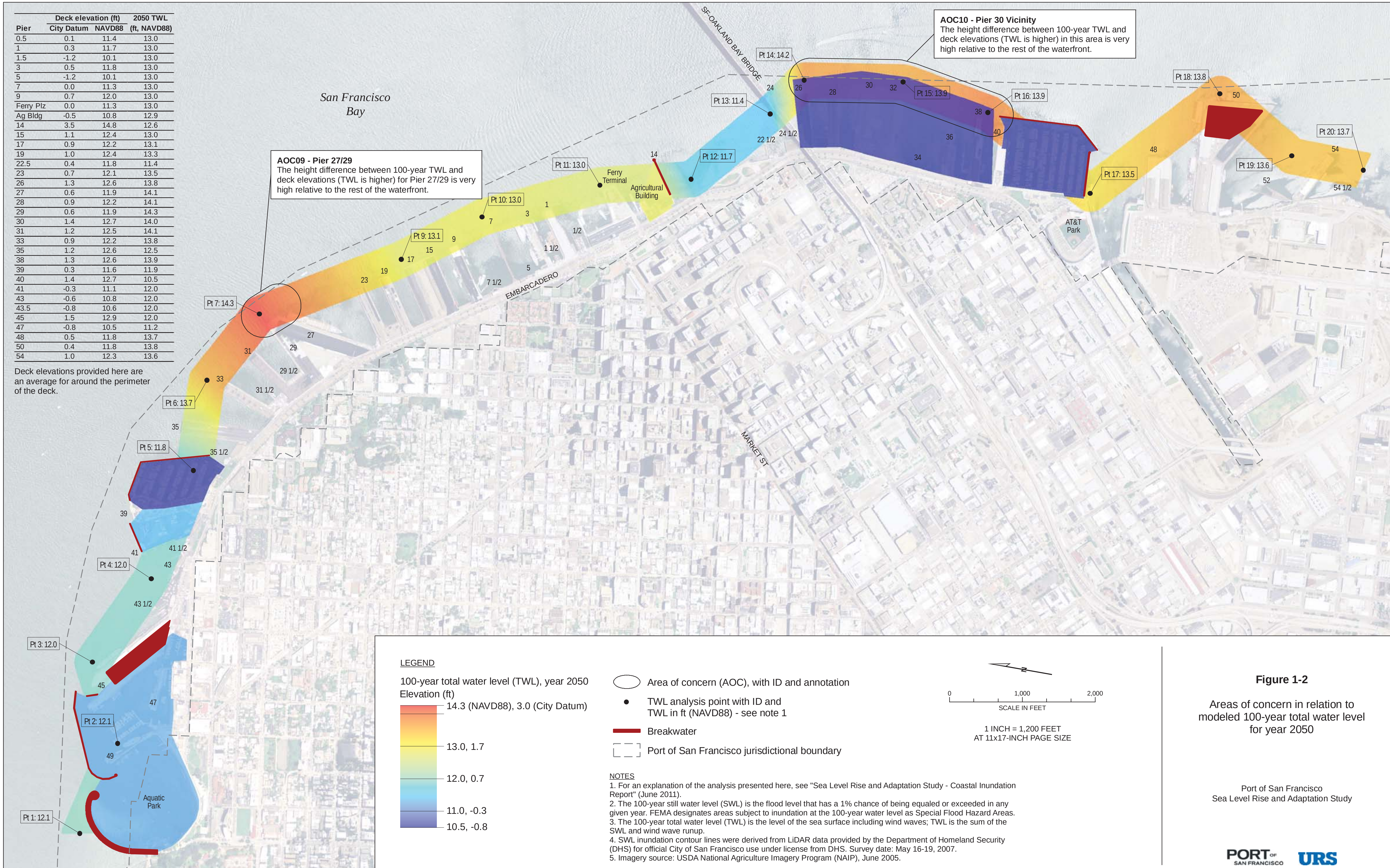
	Deck elevation (ft)		2050 TWL
Pier	City Datum	NAVD88	(ft, NAVD88)
0.5	0.1	11.4	13.0
1	0.3	11.7	13.0
1.5	-1.2	10.1	13.0
3	0.5	11.8	13.0
5	-1.2	10.1	13.0
7	0.0	11.3	13.0
9	0.7	12.0	13.0
Ferry Plz	0.0	11.3	13.0
Ag Bldg	-0.5	10.8	12.9
14	3.5	14.8	12.6
15	1.1	12.4	13.0
17	0.9	12.2	13.1
19	1.0	12.4	13.3
22.5	0.4	11.8	11.4
23	0.7	12.1	13.5
26	1.3	12.6	13.8
27	0.6	11.9	14.1
28	0.9	12.2	14.1
29	0.6	11.9	14.3
30	1.4	12.7	14.0
31	1.2	12.5	14.1
33	0.9	12.2	13.8
35	1.2	12.6	12.5
38	1.3	12.6	13.9
39	0.3	11.6	11.9
40	1.4	12.7	10.5
41	-0.3	11.1	12.0
43	-0.6	10.8	12.0
43.5	-0.8	10.6	12.0
45	1.5	12.9	12.0
47	-0.8	10.5	11.2
48	0.5	11.8	13.7
50	0.4	11.8	13.8
54	1.0	12.3	13.6

Deck elevations provided here are an average for around the perimeter of the deck.



LEGEND

100-year total water level (TWL), year 2050
Elevation (ft)

14.3 (NAVD88), 3.0 (City Datum)
13.0, 1.7
12.0, 0.7
11.0, -0.3
10.5, -0.8

Area of concern (AOC), with ID and annotation

TWL analysis point with ID and TWL in ft (NAVD88) - see note 1

Breakwater

Port of San Francisco jurisdictional boundary

0 1,000 2,000
SCALE IN FEET

1 INCH = 1,200 FEET
AT 11x17-INCH PAGE SIZE

NOTES
1. For an explanation of the analysis presented here, see "Sea Level Rise and Adaptation Study - Coastal Inundation Report" (June 2011).
2. The 100-year still water level (SWL) is the flood level that has a 1% chance of being equaled or exceeded in any given year. FEMA designates areas subject to inundation at the 100-year water level as Special Flood Hazard Areas.
3. The 100-year total water level (TWL) is the level of the sea surface including wind waves; TWL is the sum of the SWL and wind wave runup.
4. SWL inundation contour lines were derived from LiDAR data provided by the Department of Homeland Security (DHS) for official City of San Francisco use under license from DHS. Survey date: May 16-19, 2007.
5. Imagery source: USDA National Agriculture Imagery Program (NAIP), June 2005.

Figure 1-2

Areas of concern in relation to modeled 100-year total water level for year 2050

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Sea Level Rise and Adaptation Study

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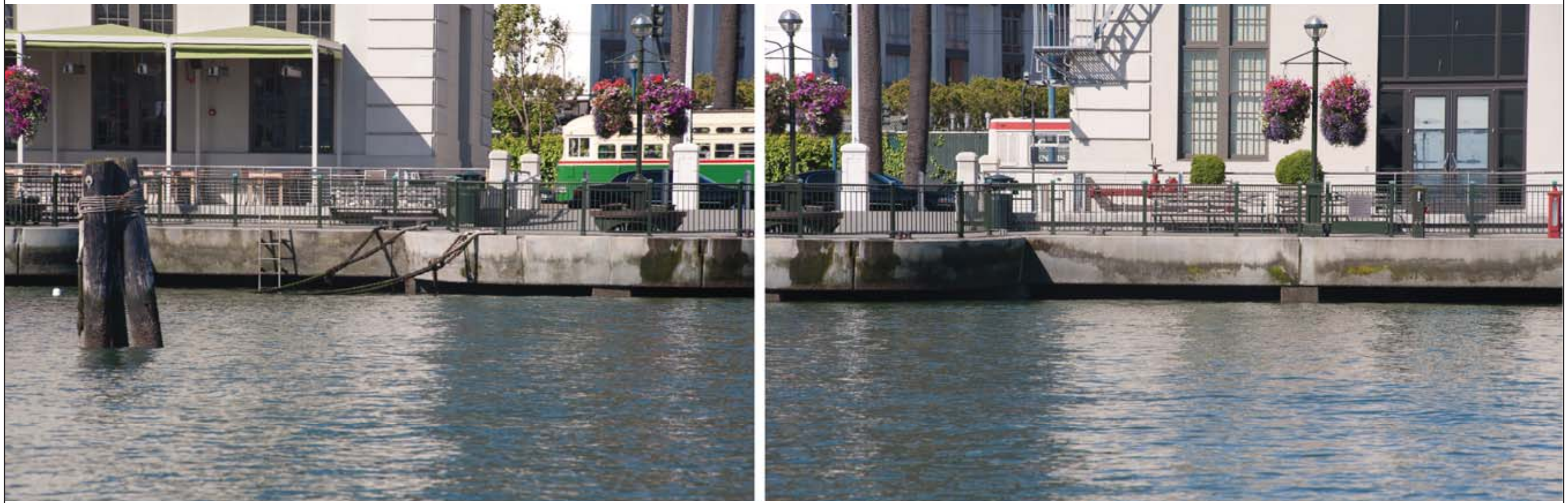
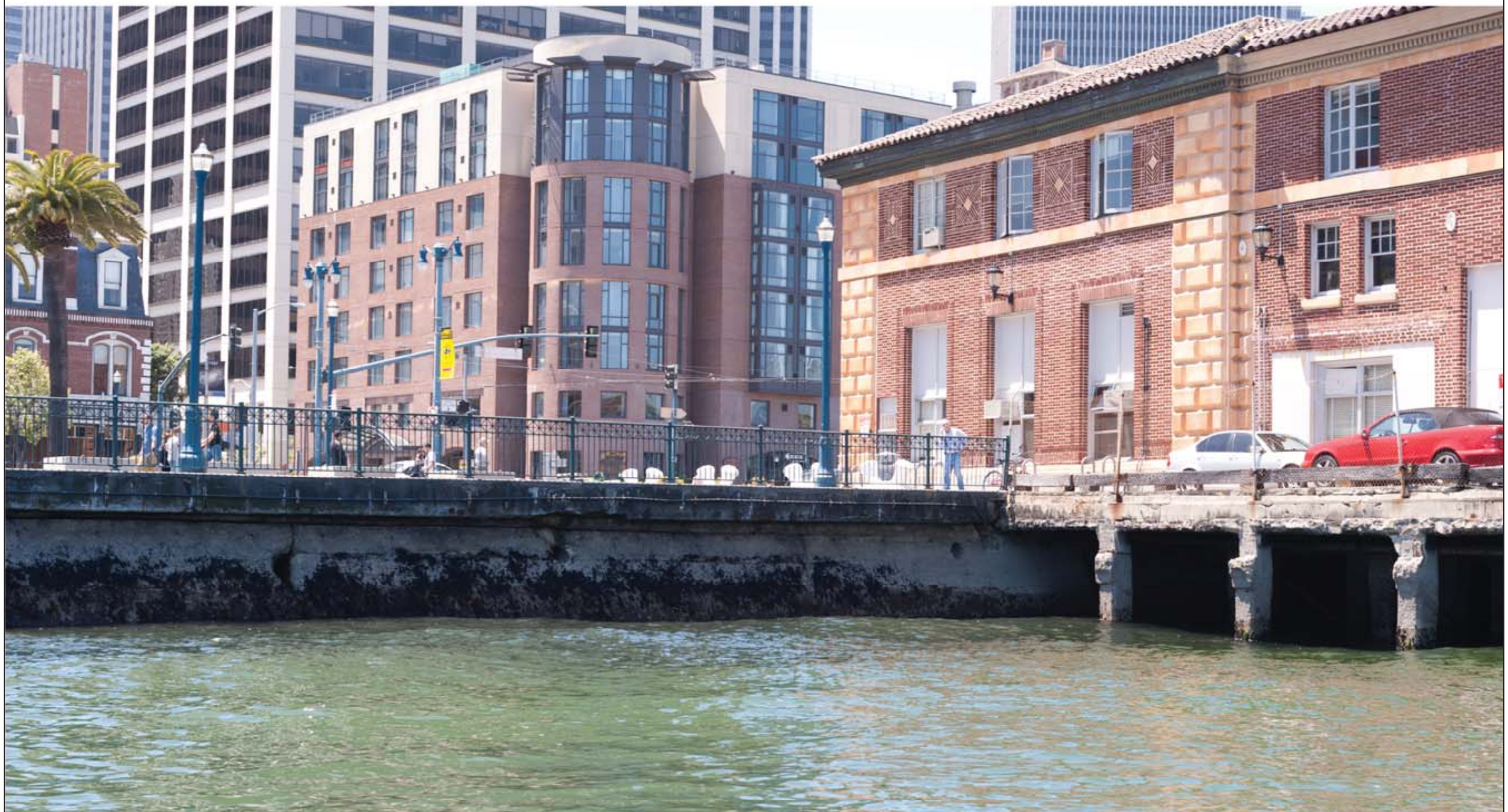
Looking southeast at the end of Pier 45.
Based on 100-year SWL modeling, the area between the sheds (middle of photo) is inundated at years 2010 and 2050.



Looking southwest at Pier 5.
Based on 100-year SWL modeling, the low point between the two buildings is a water-entry point for Embarcadero inundation at year 2050.



Looking west at the Agricultural Building and Embarcadero; this is the approximate northern extent of AOC03.
Based on 100-year SWL modeling, this is a water-entry point for significant inundation at year 2050.

Looking west at Pier 22 ½ and Embarcadero; this is the approximate southern extent of AOC03.
Based on 100-year SWL modeling, this is a water-entry point for significant inundation at year 2050.

Looking west at the boat launch along Terry A. Francois Blvd.; this is the approximate northern extent of AOC07.
Based on 100-year SWL modeling, this is a water-entry point for significant inundation at year 2050.

Figure 1-7
Photo of AOC07 - Pier 52 Boat Launch north

Looking west at the boat launch along Terry A. Francois Blvd.; this is the approximate northern extent of AOC07.
Based on 100-year SWL modeling, this is a water-entry point for significant inundation at year 2050.

Figure 1-8
Photo of AOC07 - Pier 52 Boat Launch south

Looking southwest along the length of Pier 27. Based on modeling, the 100-year TWL at year 2050 is a concern in this area.

Looking west at the northeast corner of Pier 30; this is the approximate center of AOC10.
Based on modeling, the 100-year TWL at year 2050 is a concern in this area.

LEGEND

Area of inundation based on modeled year 2050 still water level (SWL) Elevation = 10.5 ft (NAVD88), -0.8 ft (City Datum)

Approximate location of proposed adaptation

Port of San Francisco jurisdictional boundary

4-1 Proposed adaptation detail; see Section 4 for discussion

N

0 50 100
SCALE IN FEET

1 INCH = 50 FEET AT 11x17-INCH PAGE SIZE

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Sea Level Rise and Adaptation Study

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Figure 2-1
Detail of AOC01 (Pier 45) and approximate location of proposed adaptation to modeled 100-year SWL for year 2050

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NOTES

1. The 100-year still water level (SWL) is the flood level that has a 1% chance of being equaled or exceeded in any given year. FEMA designates areas subject to inundation at the 100-year water level as Special Flood Hazard Areas.

2. Where the deck elevation of a pier/bridge is higher than a given inundation level (i.e. the deck is above water), the perimeter of the pier/bridge is shown.

3. SWL inundation contour lines were derived from LiDAR data provided by the Department of Homeland Security for official City of San Francisco use. Survey date: May 16-19, 2007.

4. Imagery source: Pictometry, May 4, 2009.

LEGEND

Area of inundation based on modeled year 2050 still water level (SWL) Elevation = 10.5 ft (NAVD88), -0.8 ft (City Datum)

Approximate location of proposed adaptation

Port of San Francisco jurisdictional boundary

4-1 Proposed adaptation detail; see Section 4 for discussion

N

0 50 100

SCALE IN FEET

1 INCH = 50 FEET AT 11x17-INCH PAGE SIZE

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Sea Level Rise and Adaptation Study

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Figure 2-2
Detail of AOC02 (Pier 5) and approximate location of proposed adaptation to modeled 100-year SWL for year 2050

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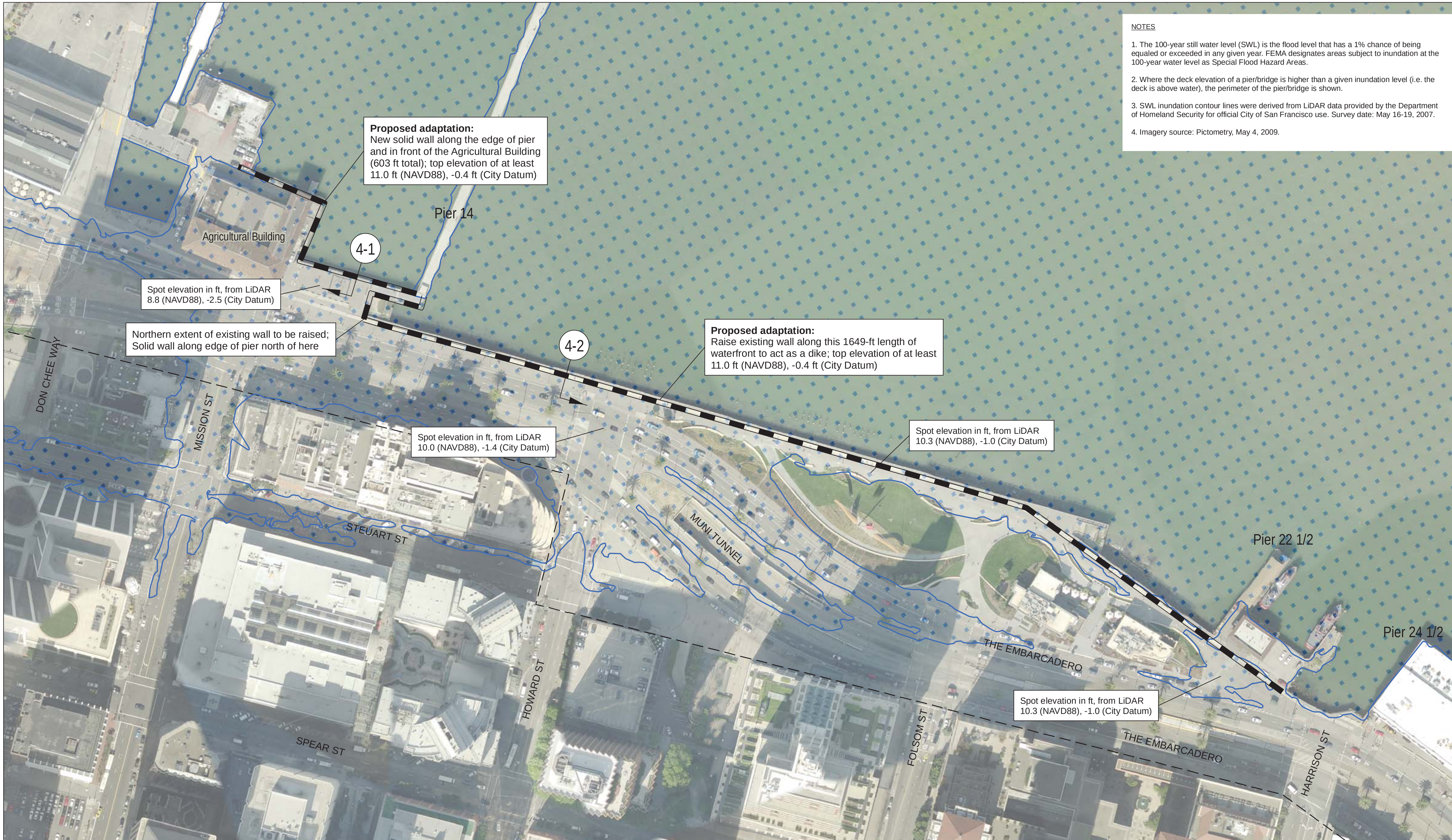

LEGEND

Area of inundation based on modeled year 2050 still water level (SWL)
Elevation = 10.5 ft (NAVD88), -0.8 ft (City Datum)

Approximate location of proposed adaptation

Port of San Francisco jurisdictional boundary

4-1 Proposed adaptation detail; see Section 4 for discussion

0 100 200
SCALE IN FEET

1 INCH = 150 FEET AT 11x17-INCH PAGE SIZE

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Sea Level Rise and Adaptation Study

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Figure 2-3
Detail of AOC03 (Embarcadero) and approximate location of proposed adaptation to modeled 100-year SWL for year 2050

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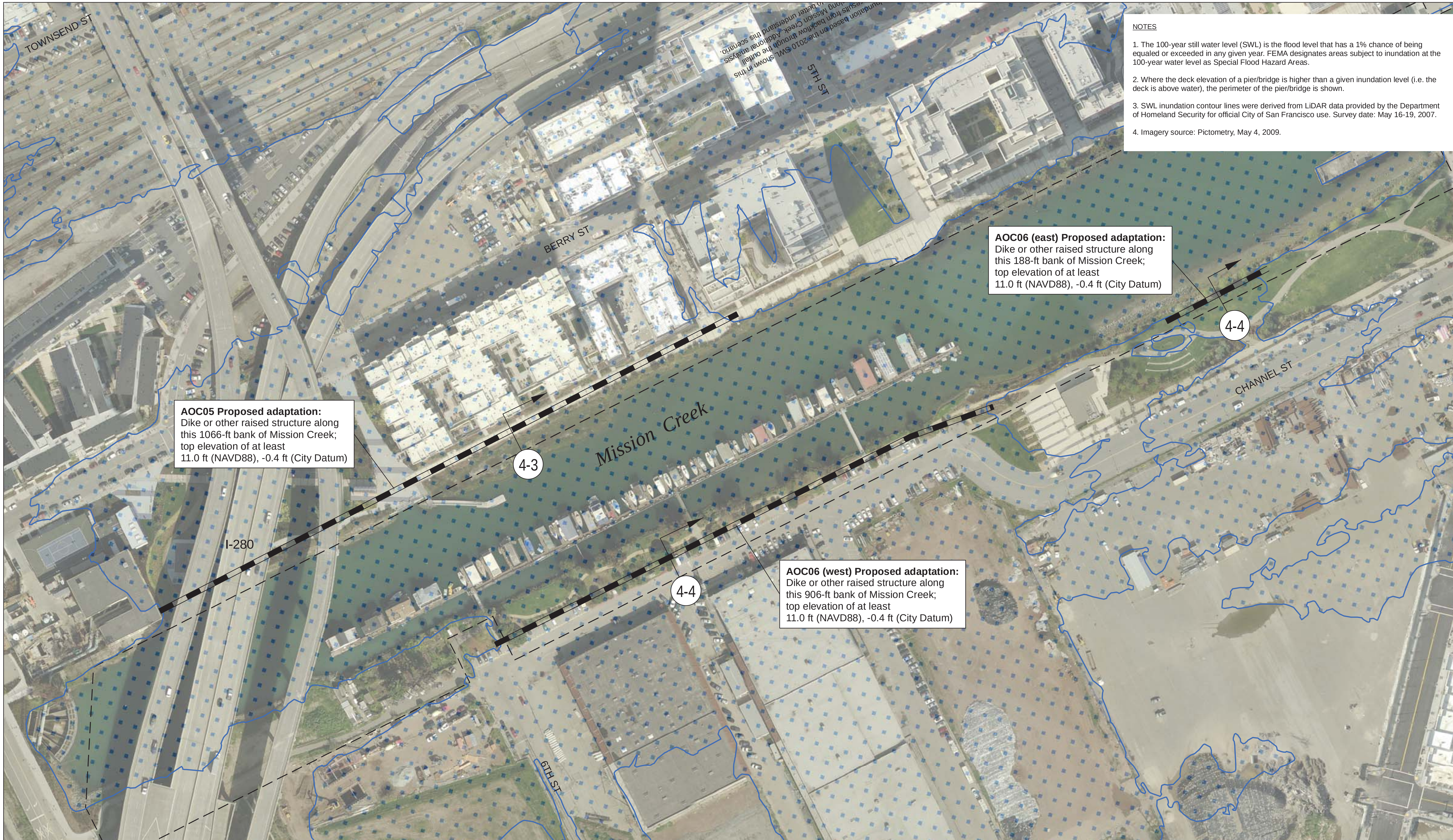

NOTES

1. The 100-year still water level (SWL) is the flood level that has a 1% chance of being equaled or exceeded in any given year. FEMA designates areas subject to inundation at the 100-year water level as Special Flood Hazard Areas.

2. Where the deck elevation of a pier/bridge is higher than a given inundation level (i.e. the deck is above water), the perimeter of the pier/bridge is shown.

3. SWL inundation contour lines were derived from LiDAR data provided by the Department of Homeland Security for official City of San Francisco use. Survey date: May 16-19, 2007.

4. Imagery source: Pictometry, May 4, 2009.

LEGEND

Area of inundation based on modeled year 2050 still water level (SWL) Elevation = 10.5 ft (NAVD88), -0.8 ft (City Datum)

Approximate location of proposed adaptation

Port of San Francisco jurisdictional boundary

4-1 Proposed adaptation detail; see Section 4 for discussion

0 100 200
SCALE IN FEET

1 INCH = 150 FEET AT 11x17-INCH PAGE SIZE

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Sea Level Rise and Adaptation Study

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Figure 2-4
Detail of AOC05 and AOC06 (Mission Creek, North and South Banks) and approximate location of proposed adaptation to modeled 100-year SWL for year 2050

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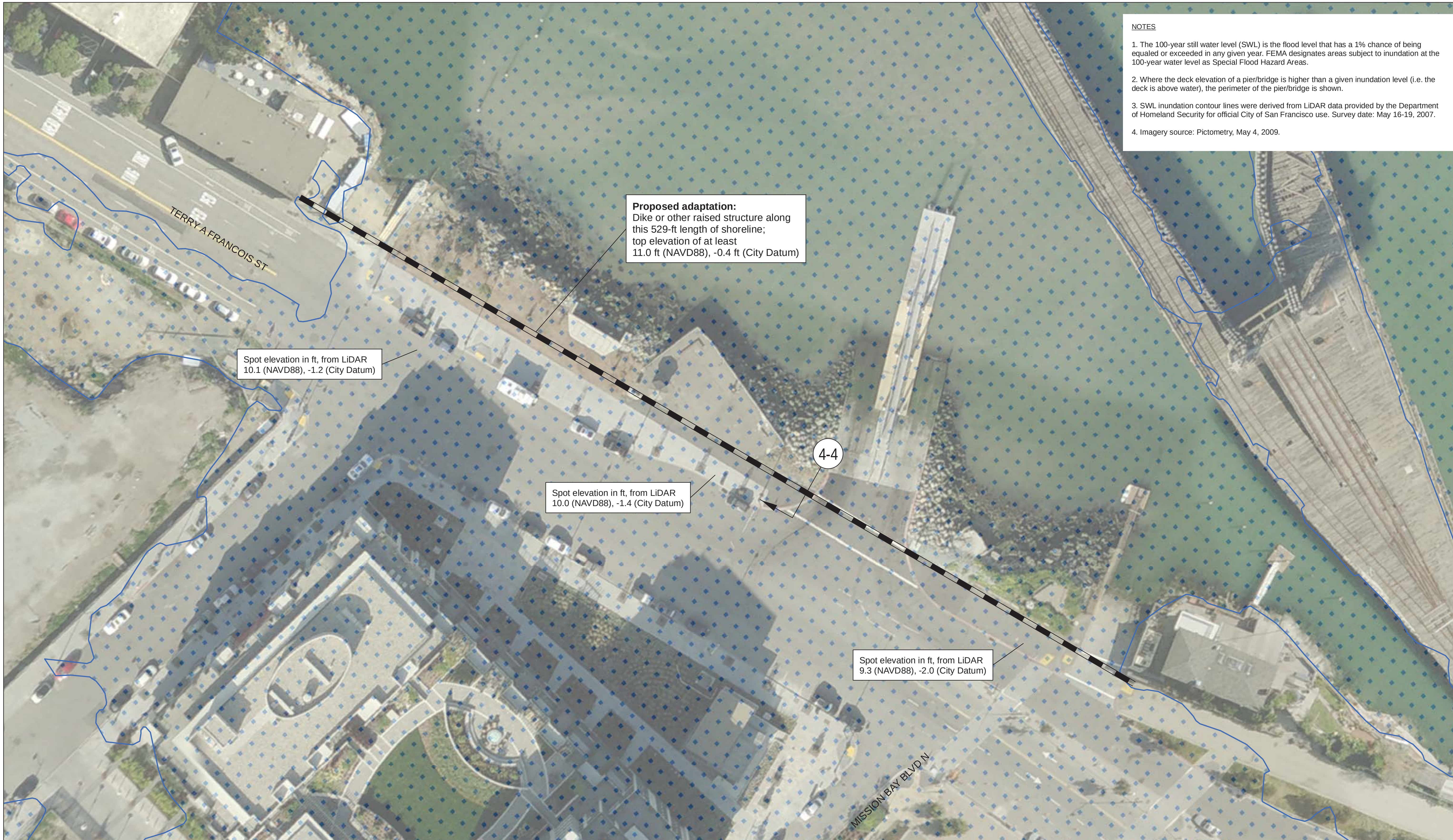

NOTES

1. The 100-year still water level (SWL) is the flood level that has a 1% chance of being equaled or exceeded in any given year. FEMA designates areas subject to inundation at the 100-year water level as Special Flood Hazard Areas.

2. Where the deck elevation of a pier/bridge is higher than a given inundation level (i.e. the deck is above water), the perimeter of the pier/bridge is shown.

3. SWL inundation contour lines were derived from LiDAR data provided by the Department of Homeland Security for official City of San Francisco use. Survey date: May 16-19, 2007.

4. Imagery source: Pictometry, May 4, 2009.

LEGEND

Area of inundation based on modeled year 2050 still water level (SWL)
Elevation = 10.5 ft (NAVD88), -0.8 ft (City Datum)

Approximate location of proposed adaptation

Port of San Francisco jurisdictional boundary

4-1 Proposed adaptation detail; see Section 4 for discussion

0 50 100
SCALE IN FEET

1 INCH = 50 FEET AT 11x17-INCH PAGE SIZE

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Sea Level Rise and Adaptation Study

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Figure 2-5
Detail of AOC07 (Pier 52 Boat Launch) and approximate location of proposed adaptation to modeled 100-year SWL for year 2050

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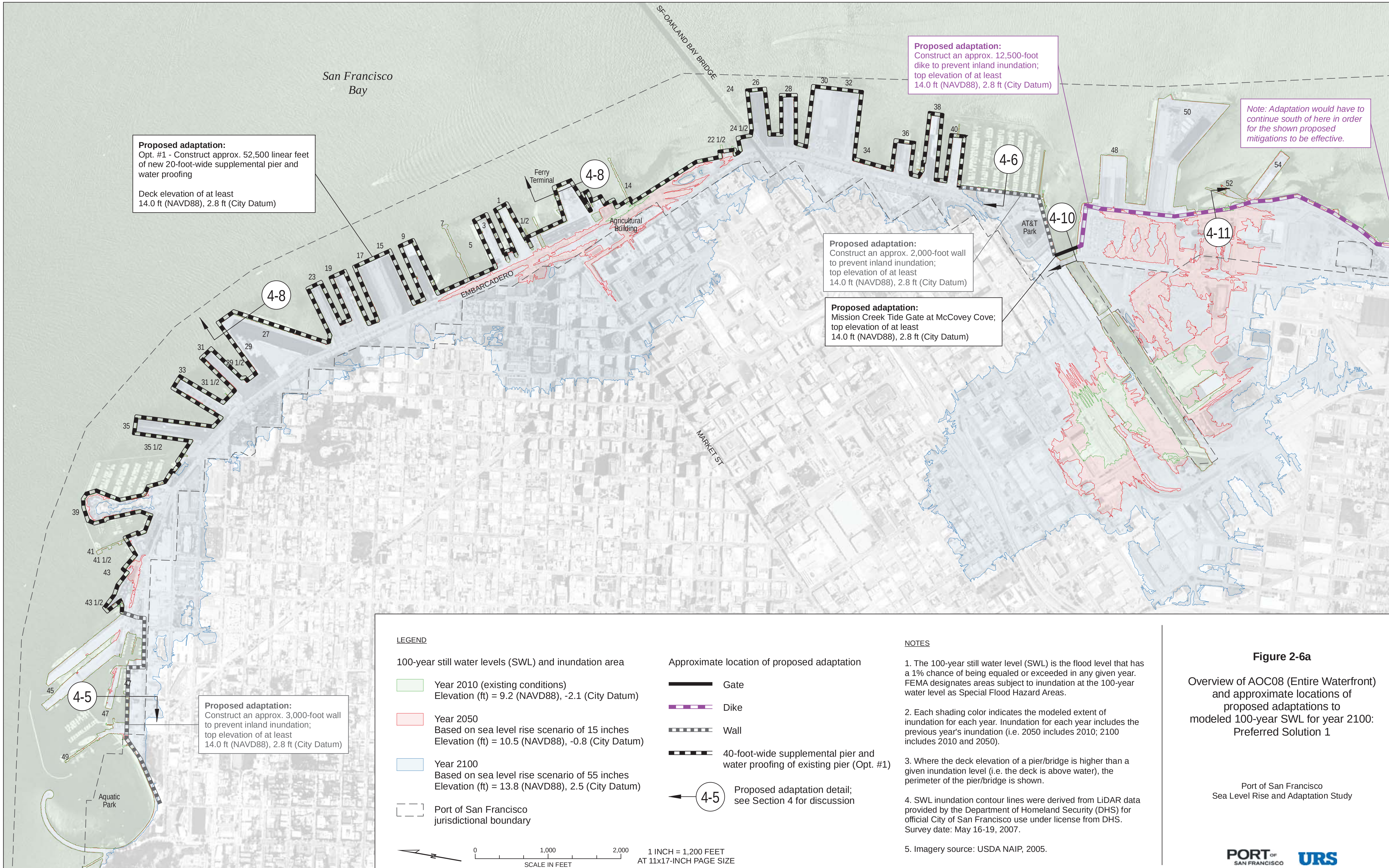

LEGEND

100-year still water levels (SWL) and inundation area

- Year 2010 (existing conditions)
  Elevation (ft) = 9.2 (NAVD88), -2.1 (City Datum)
- Year 2050
  Based on sea level rise scenario of 15 inches
  Elevation (ft) = 10.5 (NAVD88), -0.8 (City Datum)
- Year 2100
  Based on sea level rise scenario of 55 inches
  Elevation (ft) = 13.8 (NAVD88), 2.5 (City Datum)
- Port of San Francisco jurisdictional boundary

Approximate location of proposed adaptation

- Gate
- Dike
- Wall
- 40-foot-wide supplemental pier and water proofing of existing pier (Opt. #1)
- 4-5 Proposed adaptation detail; see Section 4 for discussion

NOTES

1. The 100-year still water level (SWL) is the flood level that has a 1% chance of being equaled or exceeded in any given year. FEMA designates areas subject to inundation at the 100-year water level as Special Flood Hazard Areas.

2. Each shading color indicates the modeled extent of inundation for each year. Inundation for each year includes the previous year's inundation (i.e. 2050 includes 2010; 2100 includes 2010 and 2050).

3. Where the deck elevation of a pier/bridge is higher than a given inundation level (i.e. the deck is above water), the perimeter of the pier/bridge is shown.

4. SWL inundation contour lines were derived from LiDAR data provided by the Department of Homeland Security (DHS) for official City of San Francisco use under license from DHS. Survey date: May 16-19, 2007.

5. Imagery source: USDA NAIP, 2005.

Figure 2-6a

Overview of AOC08 (Entire Waterfront) and approximate locations of proposed adaptations to modeled 100-year SWL for year 2100: Preferred Solution 1

Port of San Francisco
Sea Level Rise and Adaptation Study

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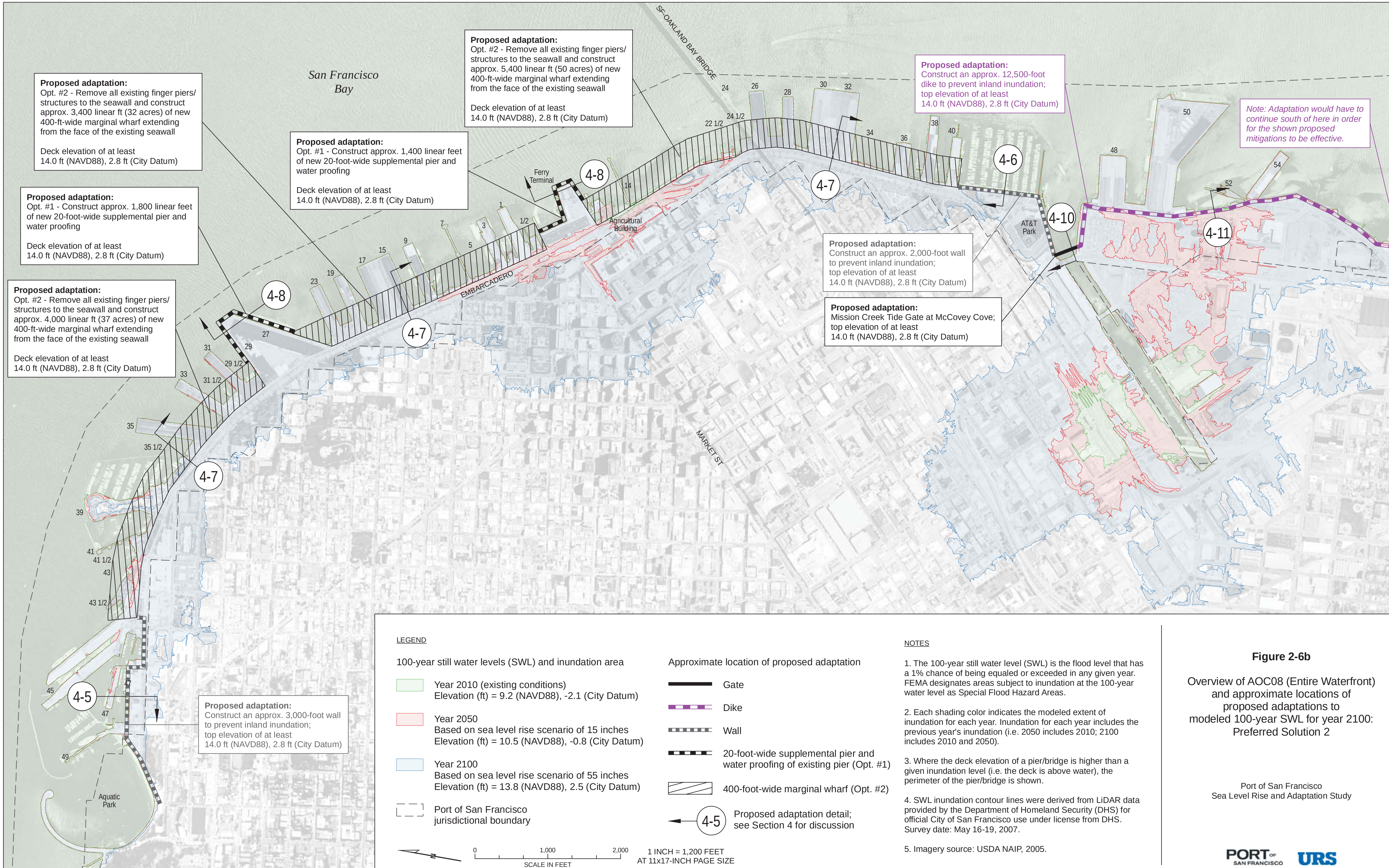

LEGEND

100-year still water levels (SWL) and inundation area

- Year 2010 (existing conditions)
  Elevation (ft) = 9.2 (NAVD88), -2.1 (City Datum)
- Year 2050
  Based on sea level rise scenario of 15 inches
  Elevation (ft) = 10.5 (NAVD88), -0.8 (City Datum)
- Year 2100
  Based on sea level rise scenario of 55 inches
  Elevation (ft) = 13.8 (NAVD88), 2.5 (City Datum)
- Port of San Francisco jurisdictional boundary

Approximate location of proposed adaptation

- Gate
- Dike
- Wall
- 20-foot-wide supplemental pier and water proofing of existing pier (Opt. #1)
- 400-foot-wide marginal wharf (Opt. #2)
- 4-5 Proposed adaptation detail; see Section 4 for discussion

0 1,000 2,000
SCALE IN FEET

1 INCH = 1,200 FEET
AT 11x17-INCH PAGE SIZE

NOTES

1. The 100-year still water level (SWL) is the flood level that has a 1% chance of being equaled or exceeded in any given year. FEMA designates areas subject to inundation at the 100-year water level as Special Flood Hazard Areas.

2. Each shading color indicates the modeled extent of inundation for each year. Inundation for each year includes the previous year's inundation (i.e. 2050 includes 2010; 2100 includes 2010 and 2050).

3. Where the deck elevation of a pier/bridge is higher than a given inundation level (i.e. the deck is above water), the perimeter of the pier/bridge is shown.

4. SWL inundation contour lines were derived from LiDAR data provided by the Department of Homeland Security (DHS) for official City of San Francisco use under license from DHS. Survey date: May 16-19, 2007.

5. Imagery source: USDA NAIP, 2005.

Figure 2-6b

Overview of AOC08 (Entire Waterfront) and approximate locations of proposed adaptations to modeled 100-year SWL for year 2100: Preferred Solution 2

Port of San Francisco
Sea Level Rise and Adaptation Study

PORT OF SAN FRANCISCO URS

URS Corp - Oakland CA - C.Raumann

Port of San Francisco
Sea Level Rise and Adaptation Study

Figure 2-7
Detail of AOC09 (Pier 27/29) and approximate location of proposed adaptation to modeled 100-year TWL for year 2050

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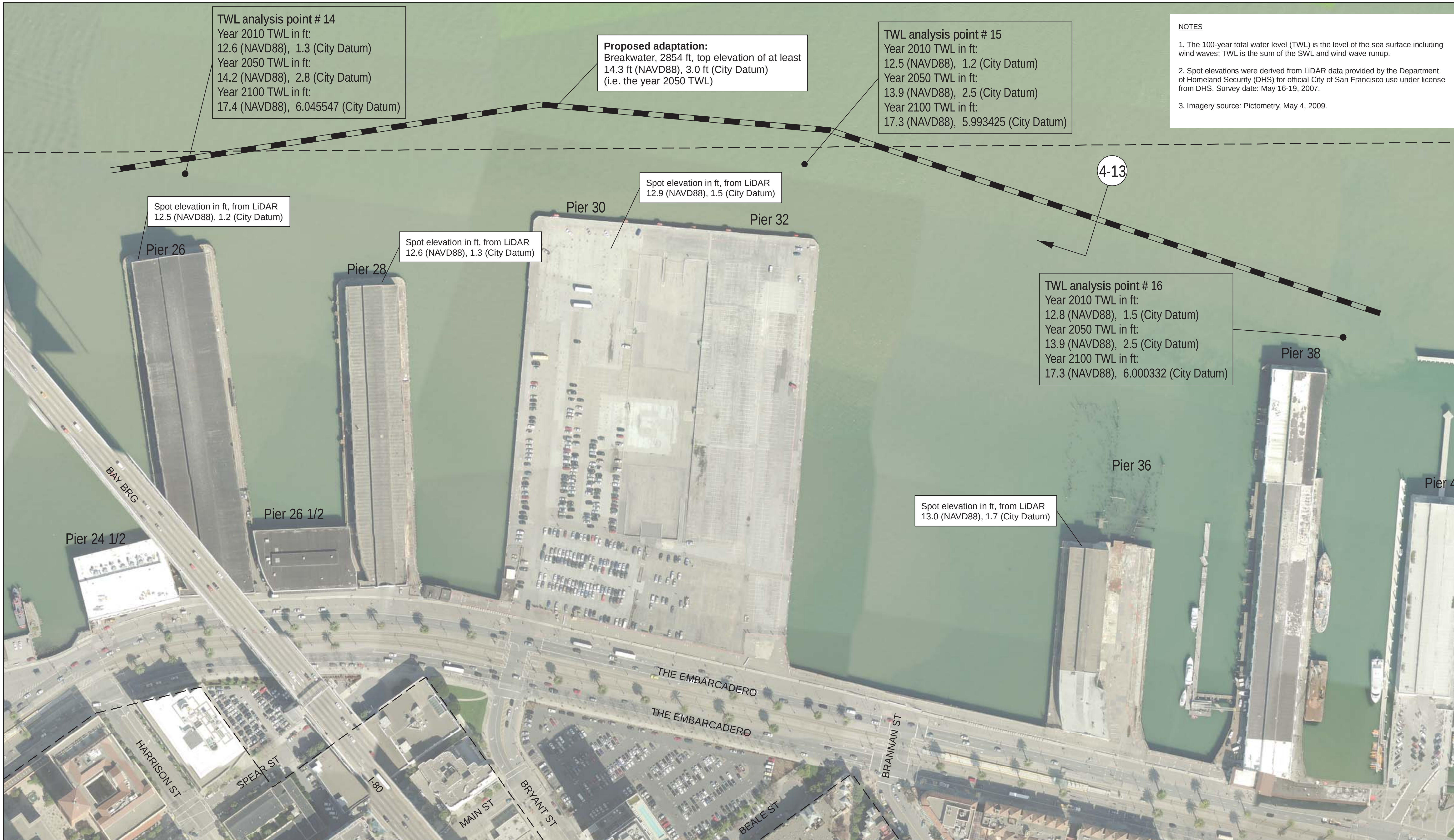

NOTES

1. The 100-year total water level (TWL) is the level of the sea surface including wind waves; TWL is the sum of the SWL and wind wave runup.

2. Spot elevations were derived from LiDAR data provided by the Department of Homeland Security (DHS) for official City of San Francisco use under license from DHS. Survey date: May 16-19, 2007.

3. Imagery source: Pictometry, May 4, 2009.

LEGEND

- Total water level (TWL) analysis point with ID and TWL in ft
- Approximate location of proposed mitigation (linear)
- Port of San Francisco jurisdictional boundary
- 4-13 Proposed adaptation detail; see Section 4 for discussion

0 100 200
SCALE IN FEET

1 INCH = 200 FEET AT 11x17-INCH PAGE SIZE

Port of San Francisco
Sea Level Rise and Adaptation Study

PORT OF SAN FRANCISCO URS

Figure 2-8

Detail of AOC10 (Pier 30 Vicinity) and approximate location of proposed adaptation to modeled 100-year TWL for year 2050

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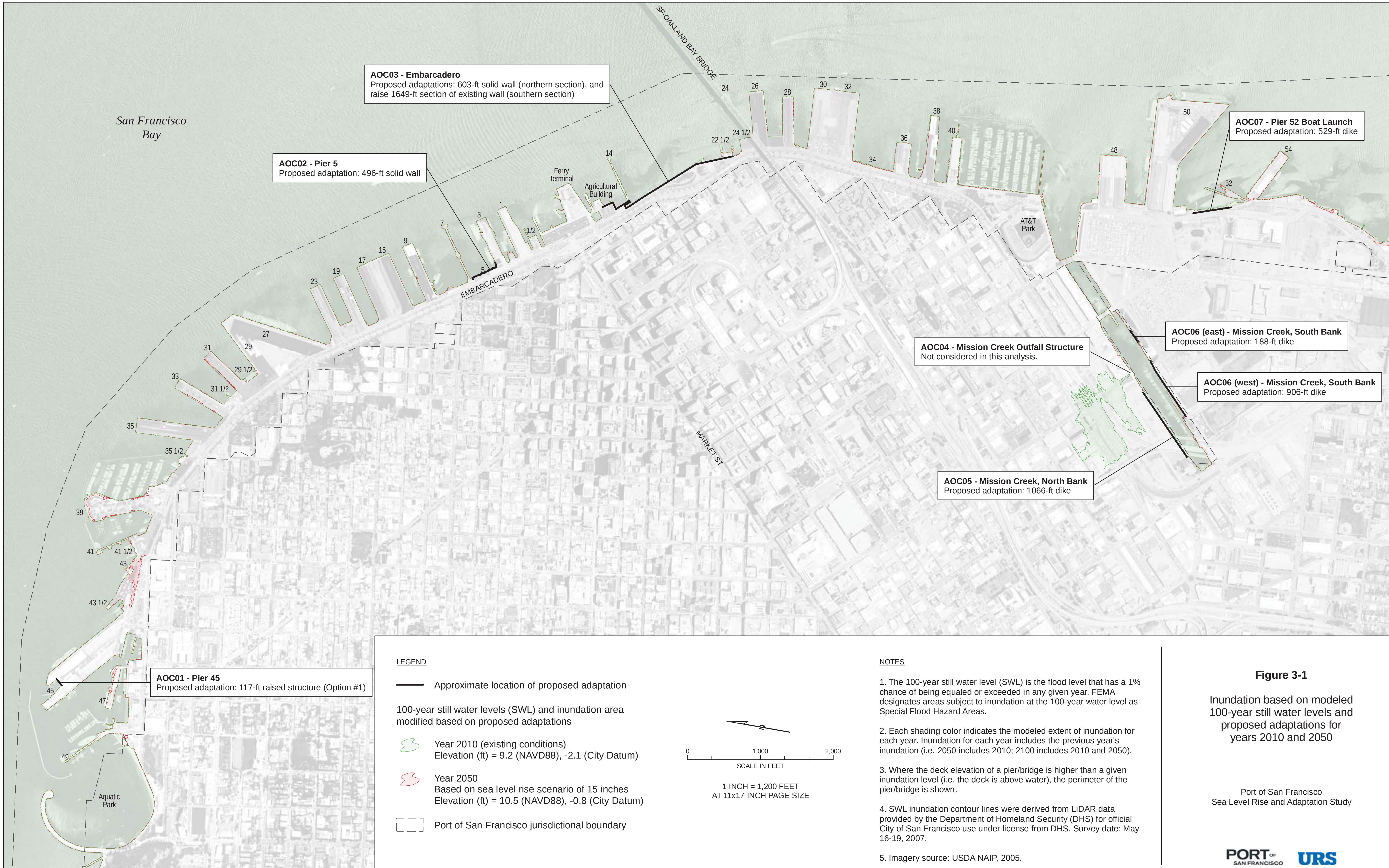


LEGEND

Approximate location of proposed adaptation

100-year still water levels (SWL) and inundation area modified based on proposed adaptations

Year 2010 (existing conditions)
Elevation (ft) = 9.2 (NAVD88), -2.1 (City Datum)

Year 2050
Based on sea level rise scenario of 15 inches
Elevation (ft) = 10.5 (NAVD88), -0.8 (City Datum)

Port of San Francisco jurisdictional boundary

NOTES

1. The 100-year still water level (SWL) is the flood level that has a 1% chance of being equaled or exceeded in any given year. FEMA designates areas subject to inundation at the 100-year water level as Special Flood Hazard Areas.

2. Each shading color indicates the modeled extent of inundation for each year. Inundation for each year includes the previous year's inundation (i.e. 2050 includes 2010; 2100 includes 2010 and 2050).

3. Where the deck elevation of a pier/bridge is higher than a given inundation level (i.e. the deck is above water), the perimeter of the pier/bridge is shown.

4. SWL inundation contour lines were derived from LiDAR data provided by the Department of Homeland Security (DHS) for official City of San Francisco use under license from DHS. Survey date: May 16-19, 2007.

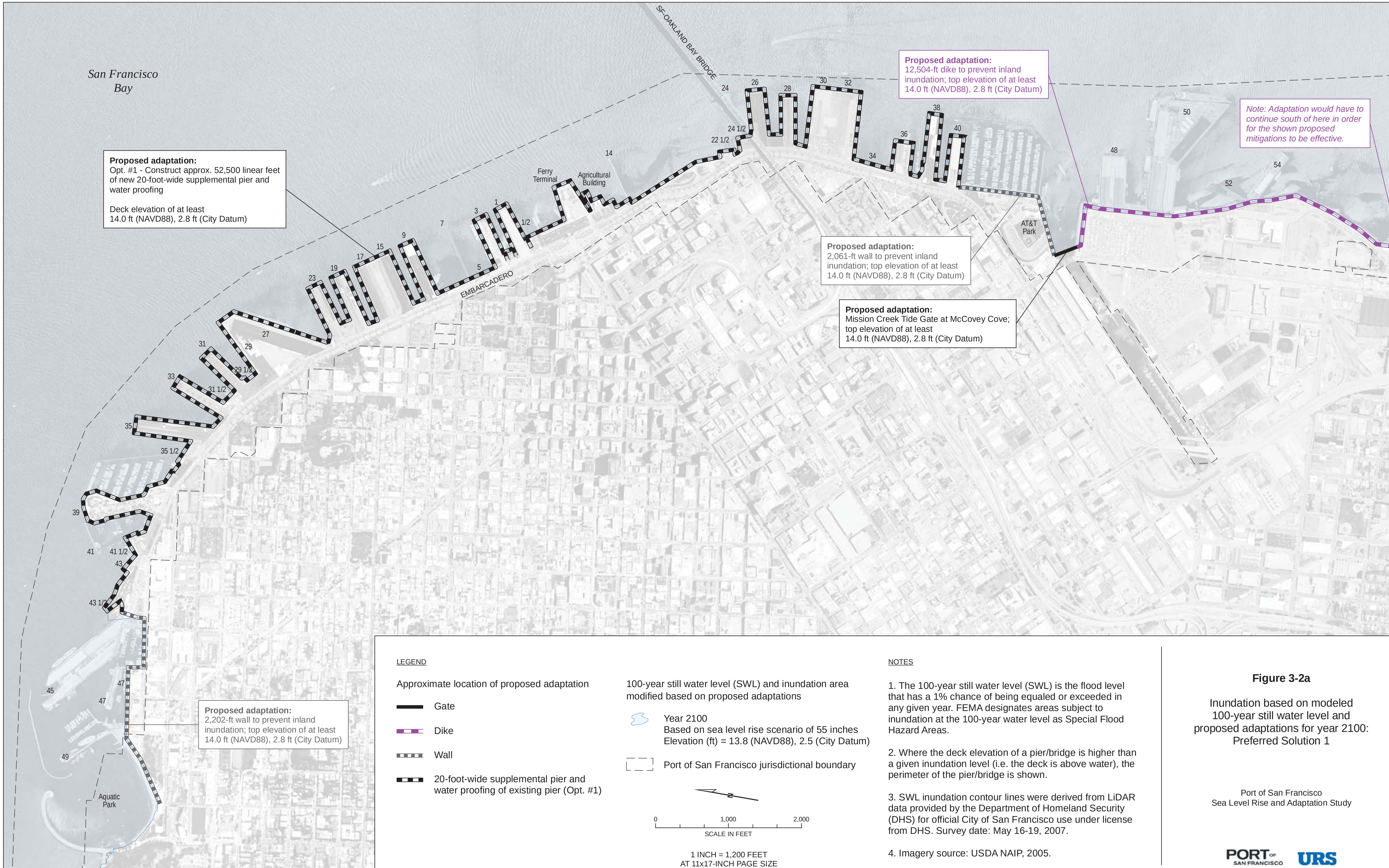
5. Imagery source: USDA NAIP, 2005.

Figure 3-1

Inundation based on modeled 100-year still water levels and proposed adaptations for years 2010 and 2050

Port of San Francisco
Sea Level Rise and Adaptation Study

PORT OF SAN FRANCISCO
URS



NOTES

1. The 100-year still water level (SWL) is the flood level that has a 1% chance of being equaled or exceeded in any given year. FEMA designates areas subject to inundation at the 100-year water level as Special Flood Hazard Areas.

2. Where the deck elevation of a pier/bridge is higher than a given inundation level (i.e. the deck is above water), the perimeter of the pier/bridge is shown.

3. SWL inundation contour lines were derived from LiDAR data provided by the Department of Homeland Security (DHS) for official City of San Francisco use under license from DHS. Survey date: May 16-19, 2007.

4. Imagery source: USDA NAIP, 2005.

Figure 3-2a

Inundation based on modeled 100-year still water level and proposed adaptations for year 2100: Preferred Solution 1

Port of San Francisco
Sea Level Rise and Adaptation Study

PORT OF SAN FRANCISCO URS

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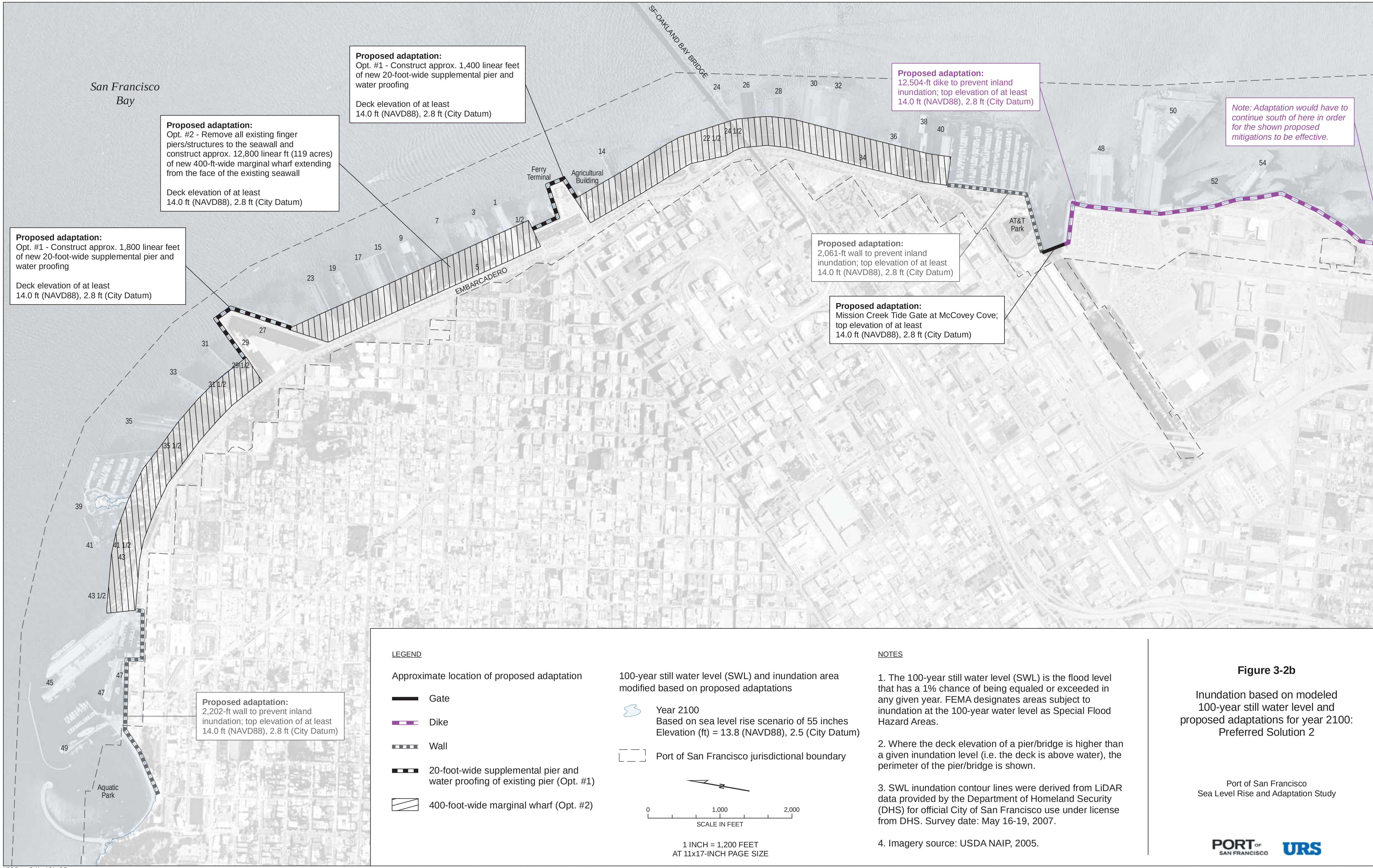


Figure 3-2b

Inundation based on modeled 100-year still water level and proposed adaptations for year 2100: Preferred Solution 2

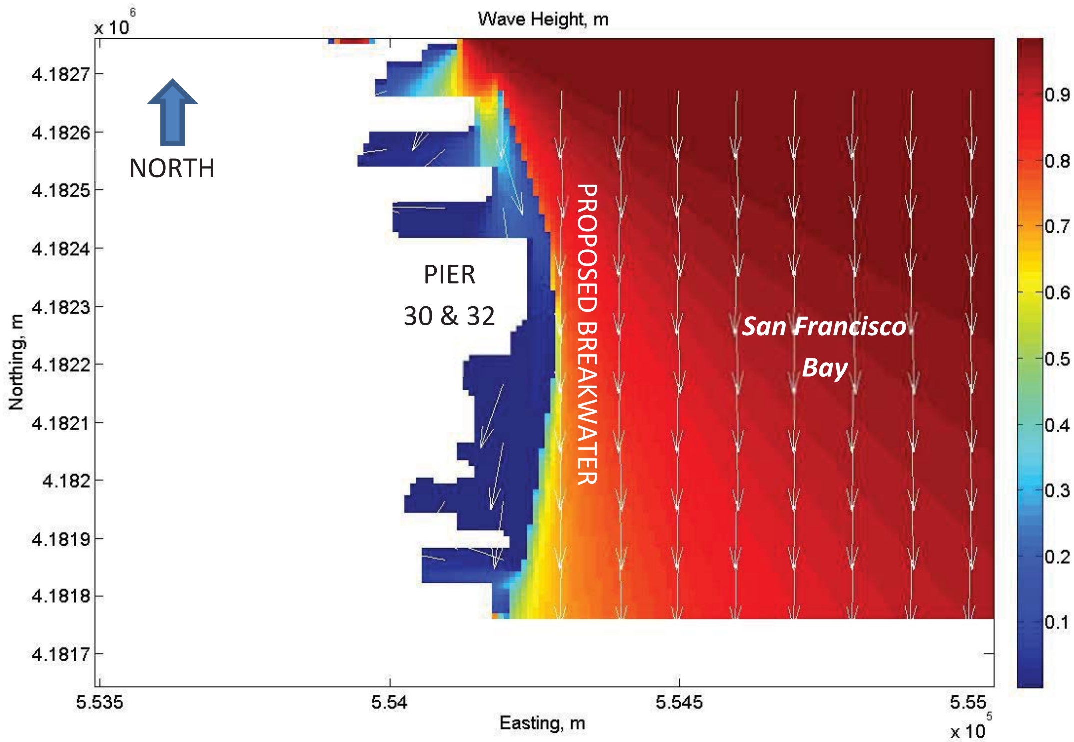


Figure 3-3. Wave height for waves incident from the north at the proposed breakwater at Pier 30.

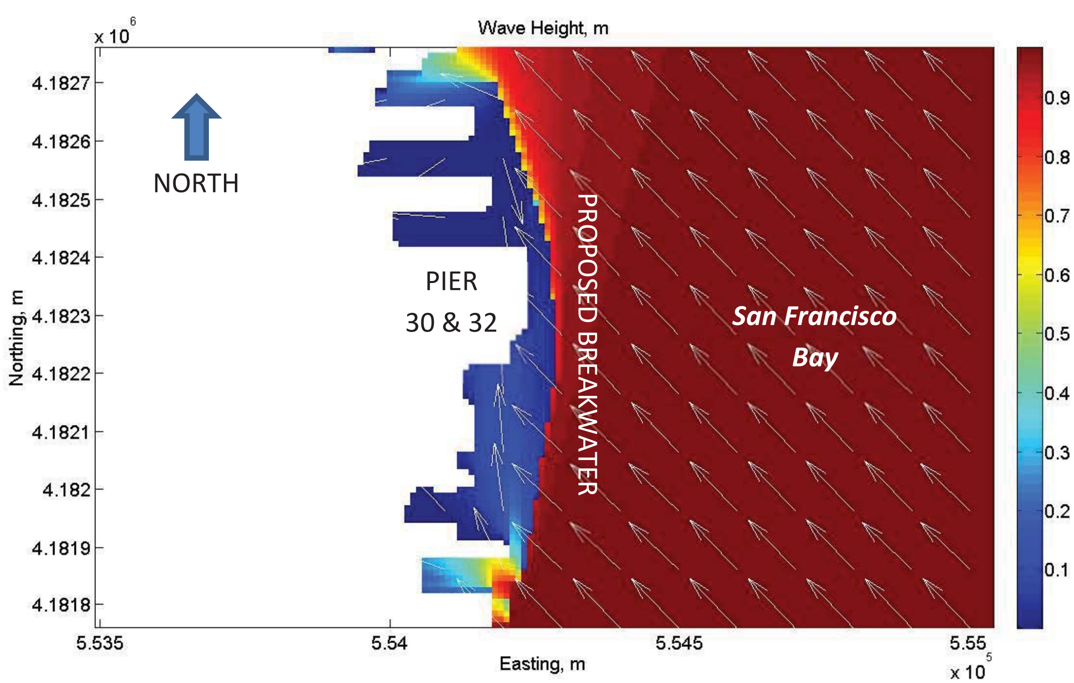
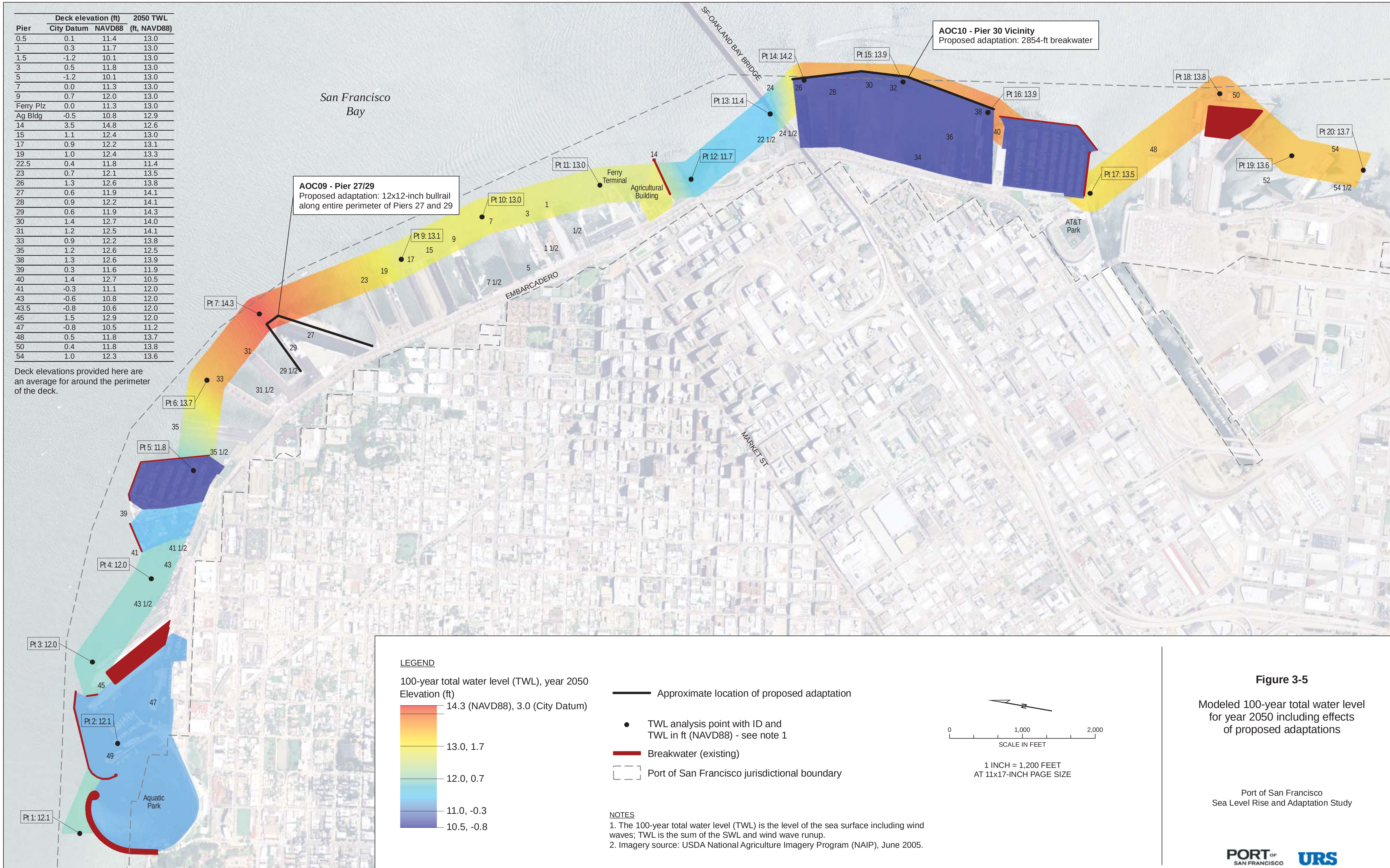


Figure 3-4. Wave height for waves incident from the southeast at the proposed breakwater at Pier 30.

Pier	Deck elevation (ft) City Datum	Deck elevation (ft) NAVD88	2050 TWL (ft, NAVD88)
0.5	0.1	11.4	13.0
1	0.3	11.7	13.0
1.5	-1.2	10.1	13.0
3	0.5	11.8	13.0
5	-1.2	10.1	13.0
7	0.0	11.3	13.0
9	0.7	12.0	13.0
Ferry Plz	0.0	11.3	13.0
Ag Bldg	-0.5	10.8	12.9
14	3.5	14.8	12.6
15	1.1	12.4	13.0
17	0.9	12.2	13.1
19	1.0	12.4	13.3
22.5	0.4	11.8	11.4
23	0.7	12.1	13.5
26	1.3	12.6	13.8
27	0.6	11.9	14.1
28	0.9	12.2	14.1
29	0.6	11.9	14.3
30	1.4	12.7	14.0
31	1.2	12.5	14.1
33	0.9	12.2	13.8
35	1.2	12.6	12.5
38	1.3	12.6	13.9
39	0.3	11.6	11.9
40	1.4	12.7	10.5
41	-0.3	11.1	12.0
43	-0.6	10.8	12.0
43.5	-0.8	10.6	12.0
45	1.5	12.9	12.0
47	-0.8	10.5	11.2
48	0.5	11.8	13.7
50	0.4	11.8	13.8
54	1.0	12.3	13.6

Deck elevations provided here are an average for around the perimeter of the deck.



LEGEND

100-year total water level (TWL), year 2050
Elevation (ft)

14.3 (NAVD88), 3.0 (City Datum)
13.0, 1.7
12.0, 0.7
11.0, -0.3
10.5, -0.8

Approximate location of proposed adaptation

TWL analysis point with ID and TWL in ft (NAVD88) - see note 1

Breakwater (existing)

Port of San Francisco jurisdictional boundary

0 1,000 2,000
SCALE IN FEET

1 INCH = 1,200 FEET
AT 11x17-INCH PAGE SIZE

NOTES
1. The 100-year total water level (TWL) is the level of the sea surface including wind waves; TWL is the sum of the SWL and wind wave runup.
2. Imagery source: USDA National Agriculture Imagery Program (NAIP), June 2005.

Figure 3-5

Modeled 100-year total water level for year 2050 including effects of proposed adaptations

Port of San Francisco
Sea Level Rise and Adaptation Study

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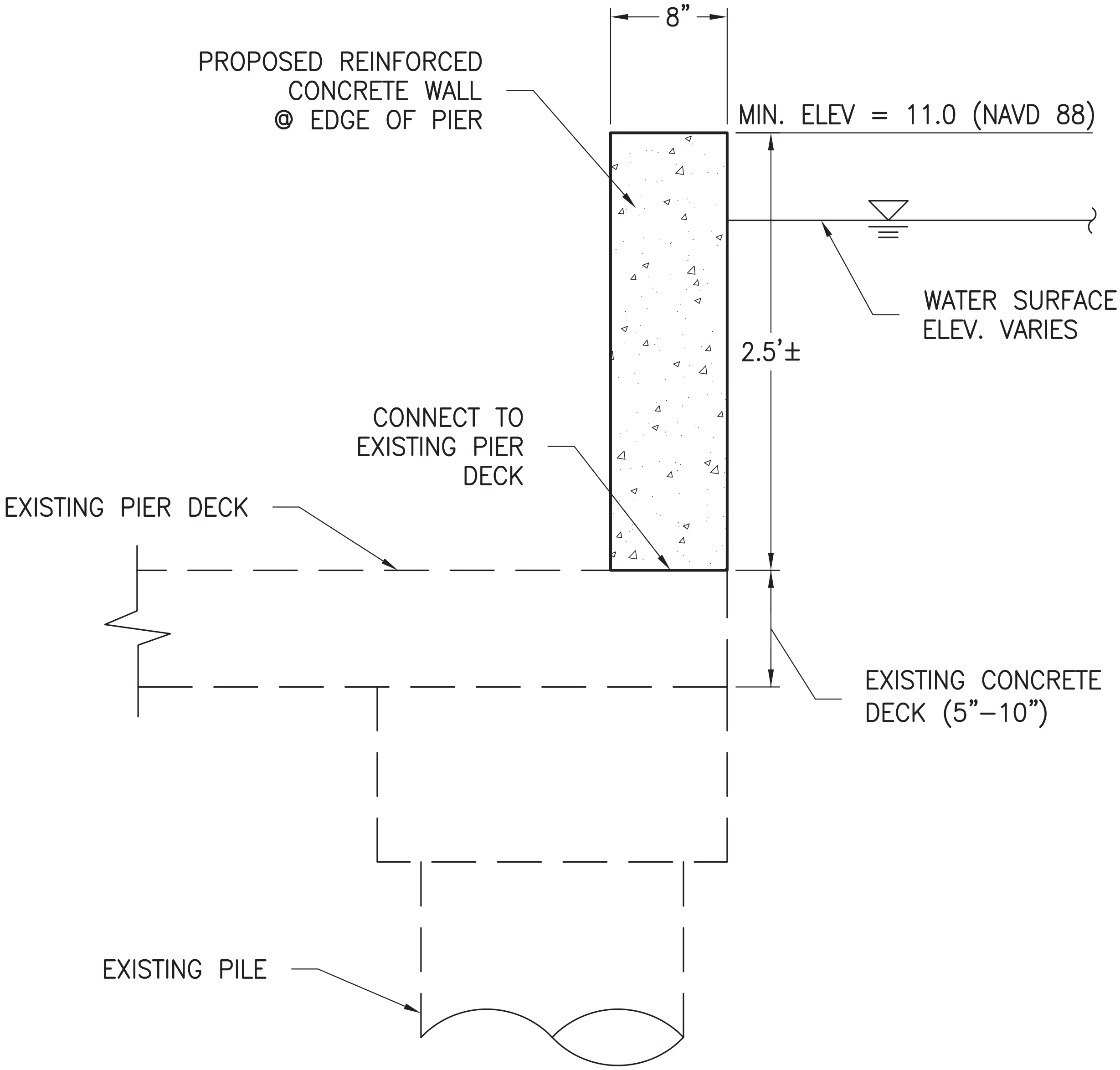
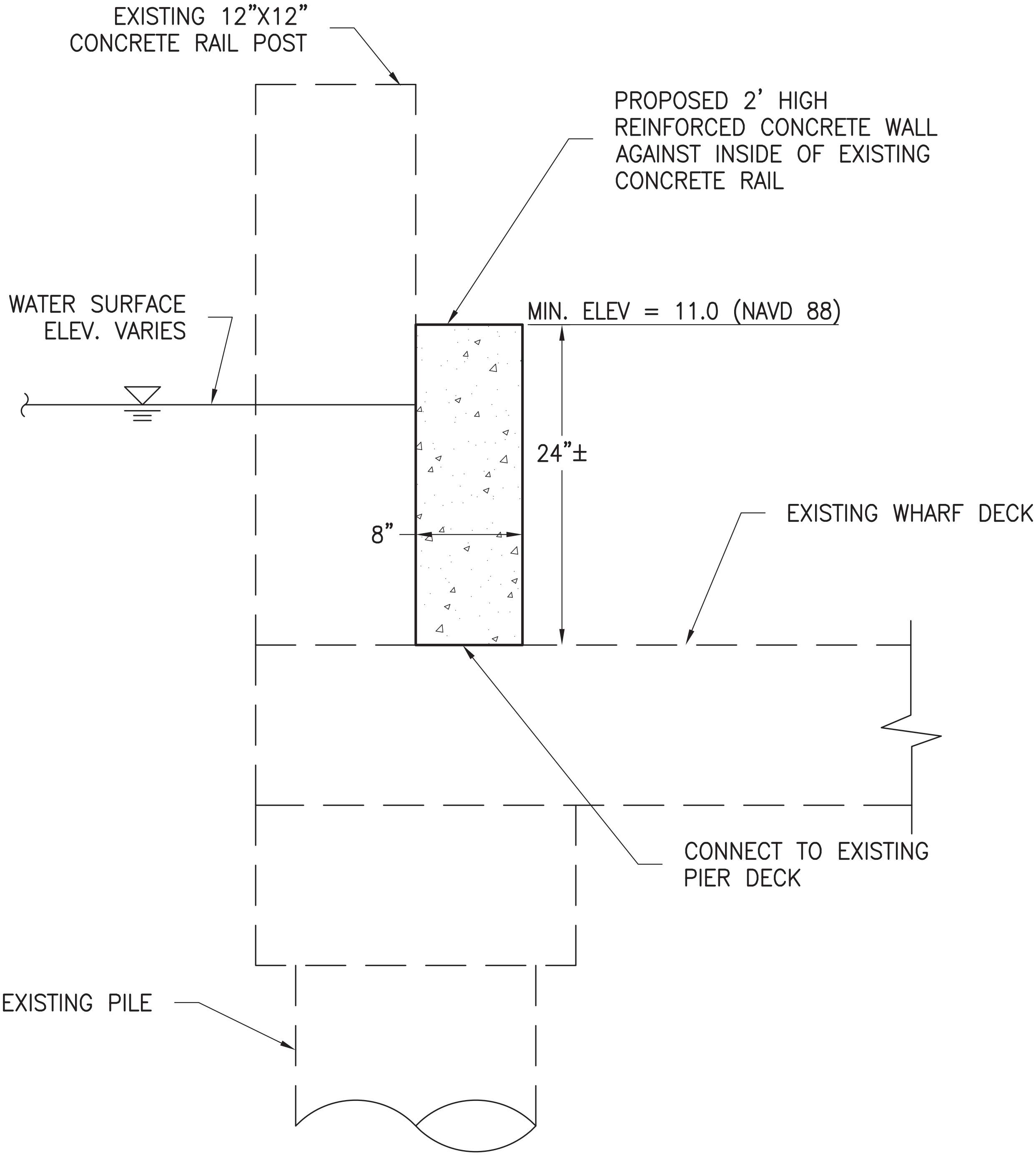


PROPOSED WALL @ PIERS 5, 45, AND AGRICULTURAL BUILDING
SEE FIGURES 2–1 (AOC01), 2–2 (AOC02), & 2–3 (AOC03)

SCALE: 1"=1'

Figure 4-1

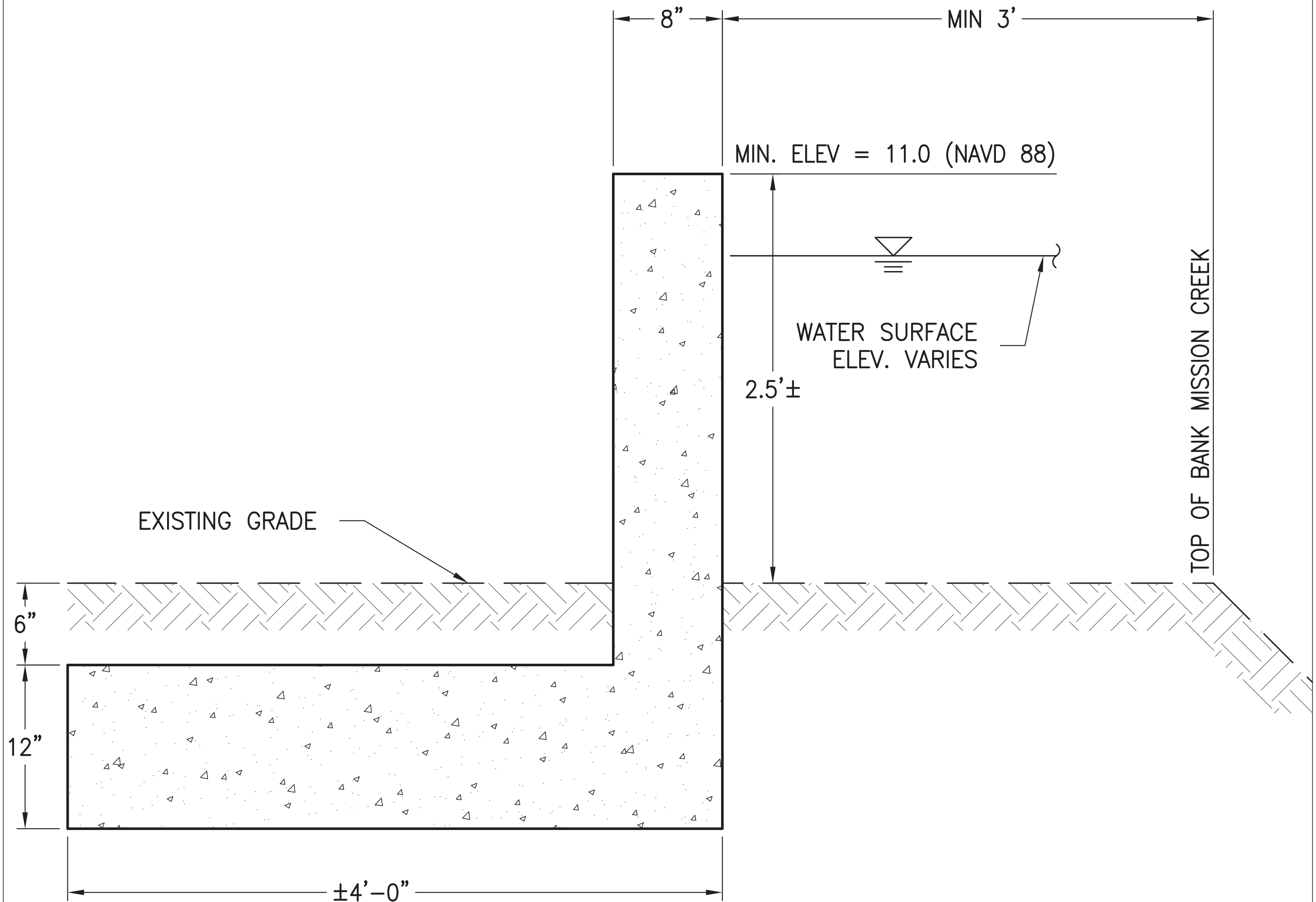
Year 2050 Mitigation



PROPOSED REINFORCED CONCRETE WALL
@ EXISTING CONCRETE RAIL ALONG EMBARCADERO
SEE FIGURE 2–3 (AOC03)
SCALE: 1"=1'

Figure 4-2

Year 2050 Mitigation



PROPOSED REINFORCED CONCRETE WALL
@ NORTH BANK OF MISSION CREEK
SEE FIGURE 2-4 (AOC05)

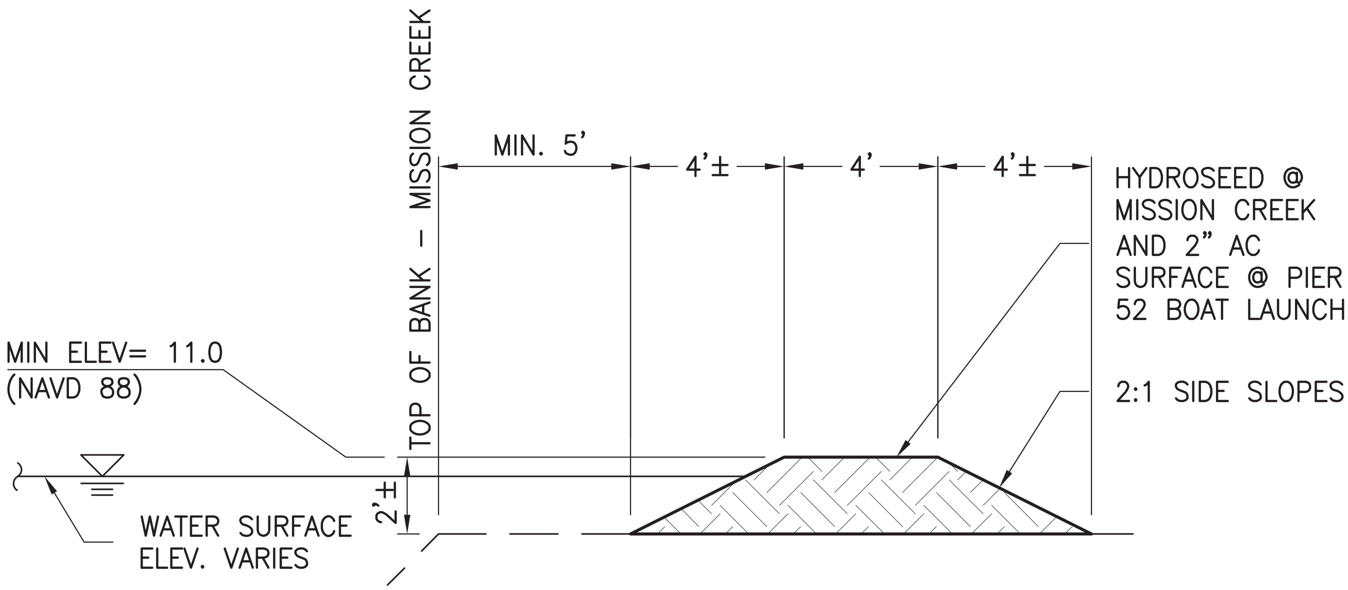
SCALE: 1"=1'

Port of San Francisco
Sea Level Rise and Adaptation Study

PORT OF SAN FRANCISCO AGS

Figure 4-3

Year 2050 Mitigation



NOTE:

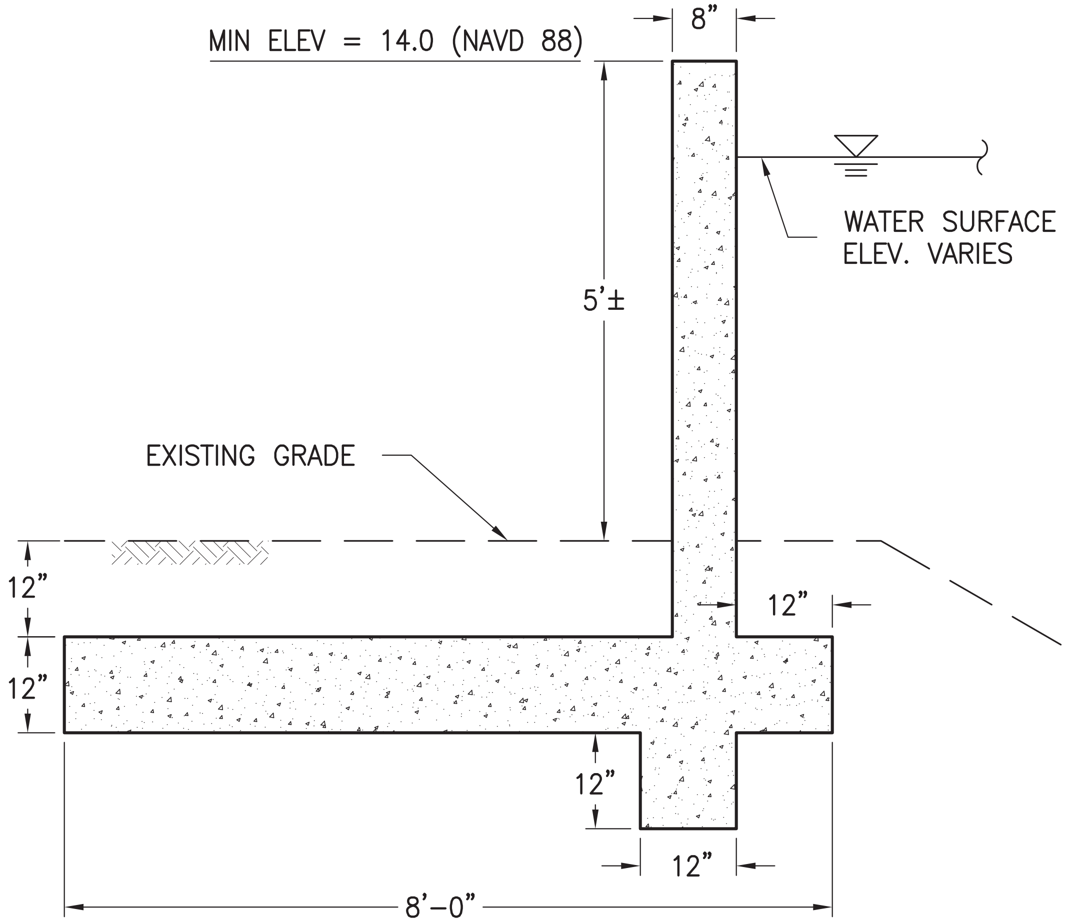
REVISE SIDE SLOPES TO 10:1 FOR 60' LONG SECTION @ PIER 52 BOAT LAUNCH, FOR BOAT ACCESS.

PROPOSED 2 FOOT HIGH EARTH BERM @ SOUTH BANK OF MISSION CREEK AND @ PIER 52 BOAT LAUNCH
SEE FIGURES 2–4 (AOC06) AND 2–5 (AOC07)

SCALE: 1"=5'

Figure 4-4

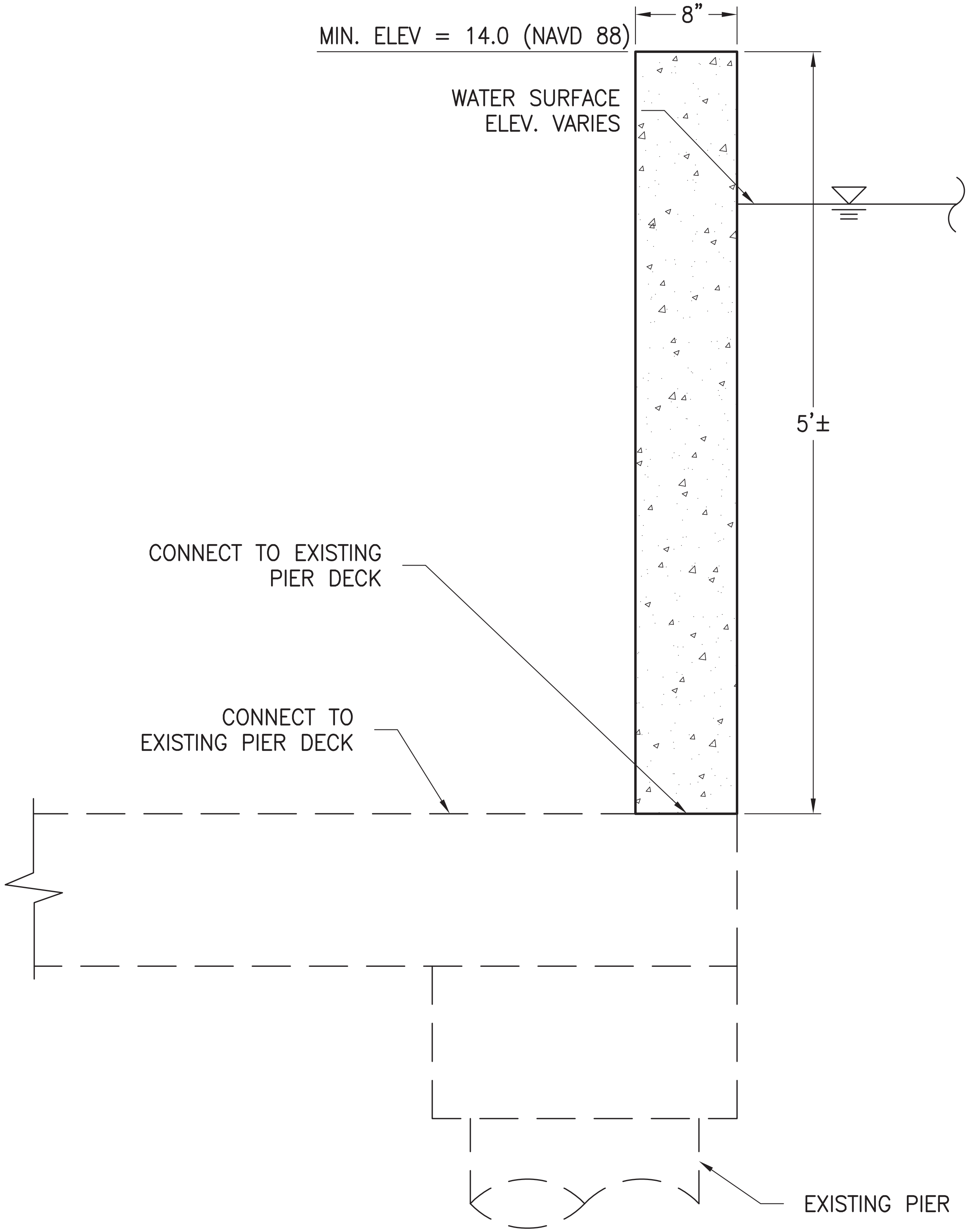
Year 2050 Mitigation



PROPOSED REINFORCED CONCRETE WALL
FROM PIER 45 TO AQUATIC PARK
SEE FIGURE 2–6 (AOC08)
SCALE: 1"=2'

Figure 4-5

Year 2100 Mitigation



PROPOSED REINFORCED CONCRETE WALL @ AT&T PARK
SEE FIGURE 2–6 (AOC08)

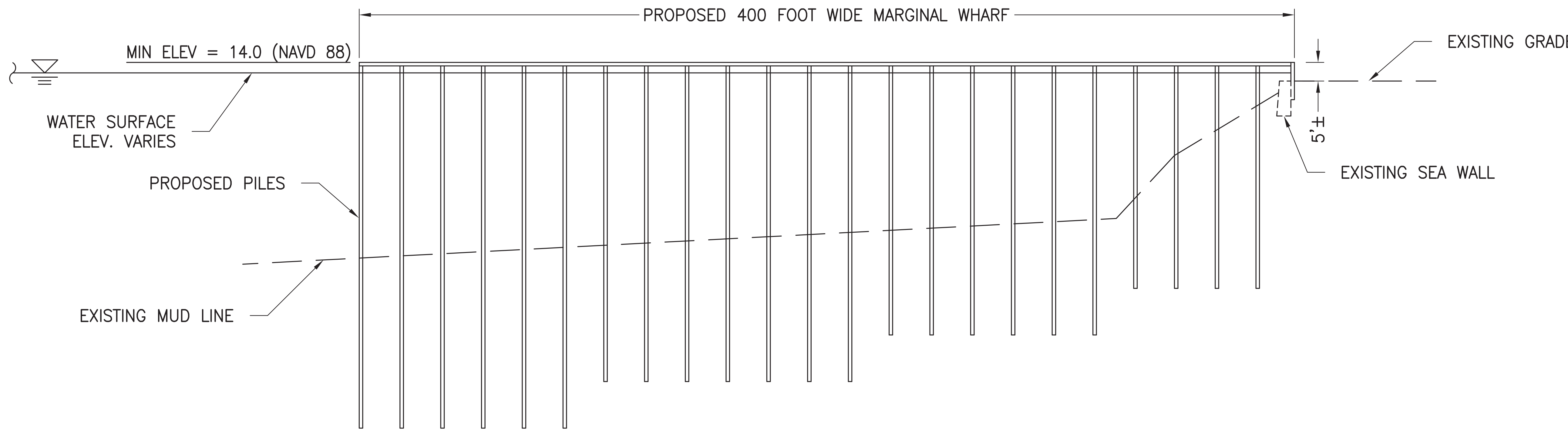
SCALE: 1"=1'

Port of San Francisco
Sea Level Rise and Adaptation Study

PORT OF SAN FRANCISCO AGS

Figure 4-6

Year 2100 Mitigation



PROPOSED 400 FOOT WIDE MARGINAL WHARF @ THE EMBARCADERO
SEE FIGURE 2–6 (AOC08)
SCALE: 1"=50'

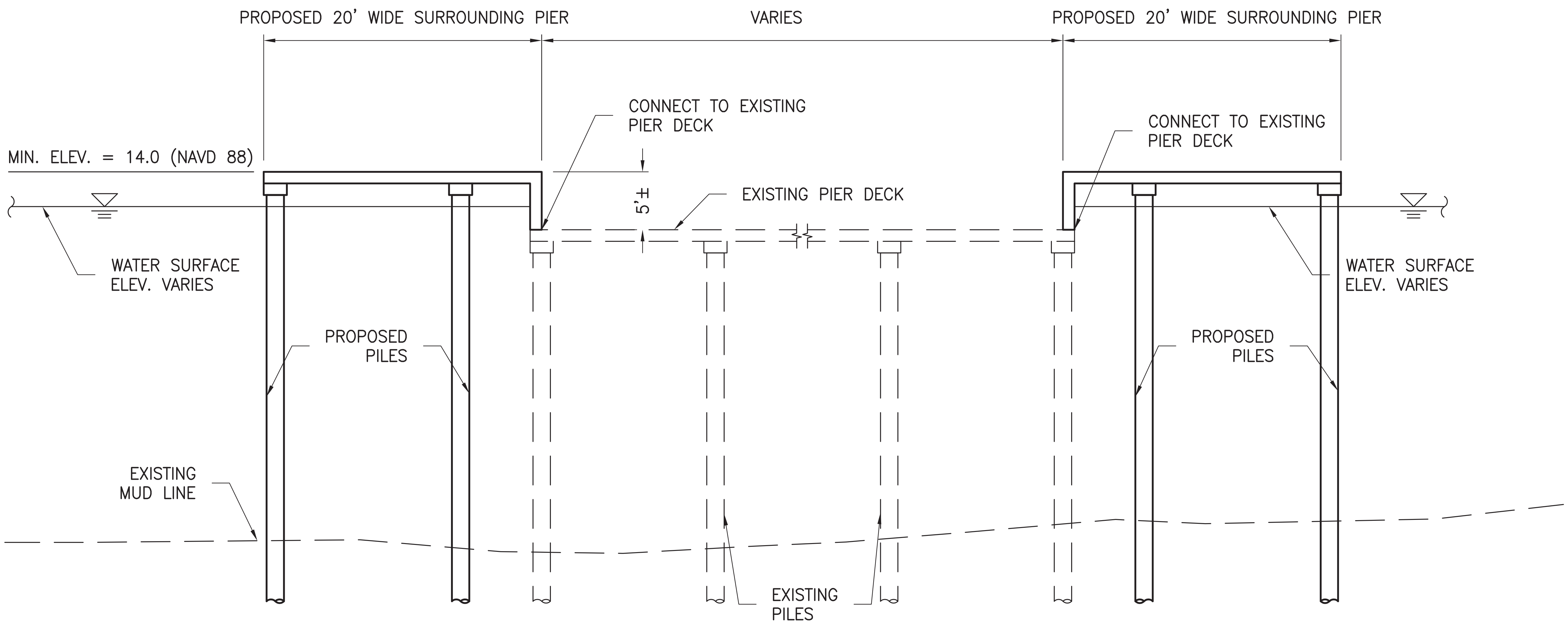
NOTE: THIS IS THE TYPICAL YEAR 2100 OPTION #2 (MARGINAL WHARF) FOR YEAR 2100. SEE FIGURE 2-6 FOR PLAN VIEW.

Port of San Francisco
Sea Level Rise and Adaptation Study

PORT OF SAN FRANCISCO AGS

Figure 4-7

Year 2100 Mitigation



PROPOSED 20 FOOT WIDE SURROUNDING PIER
@ THE FERRY BUILDING AND PIER 27/29
SEE FIGURE 2–6 (AOC08)
SCALE: 1"=10'

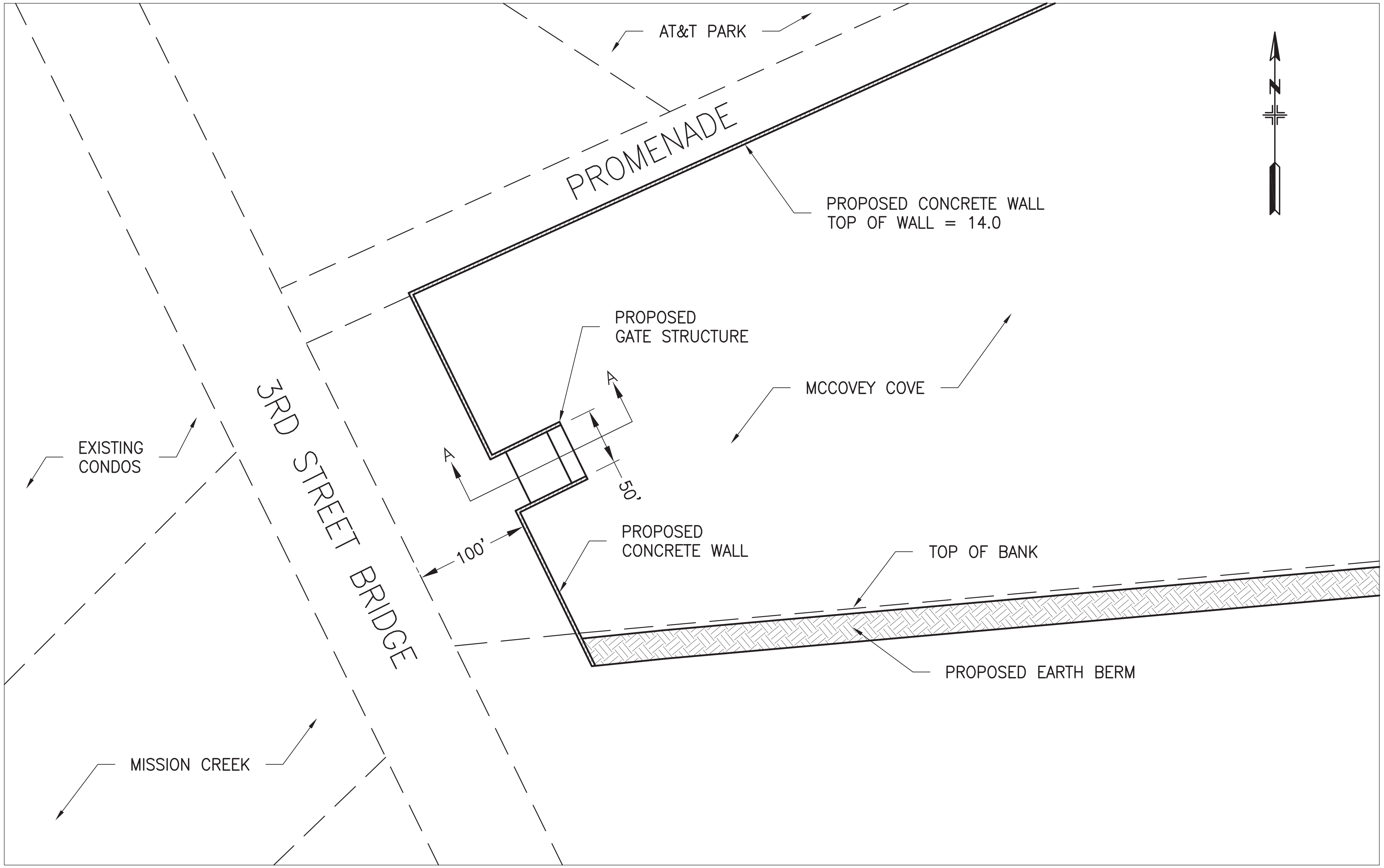
NOTE: THIS IS THE TYPICAL YEAR 2100 OPTION #1 (SUPPLEMENTAL PIER) FOR YEAR 2100. SEE FIGURE 2-6 FOR PLAN VIEW.

Port of San Francisco
Sea Level Rise and Adaptation Study

PORT OF SAN FRANCISCO AGS

Figure 4-8

Year 2100 Mitigation



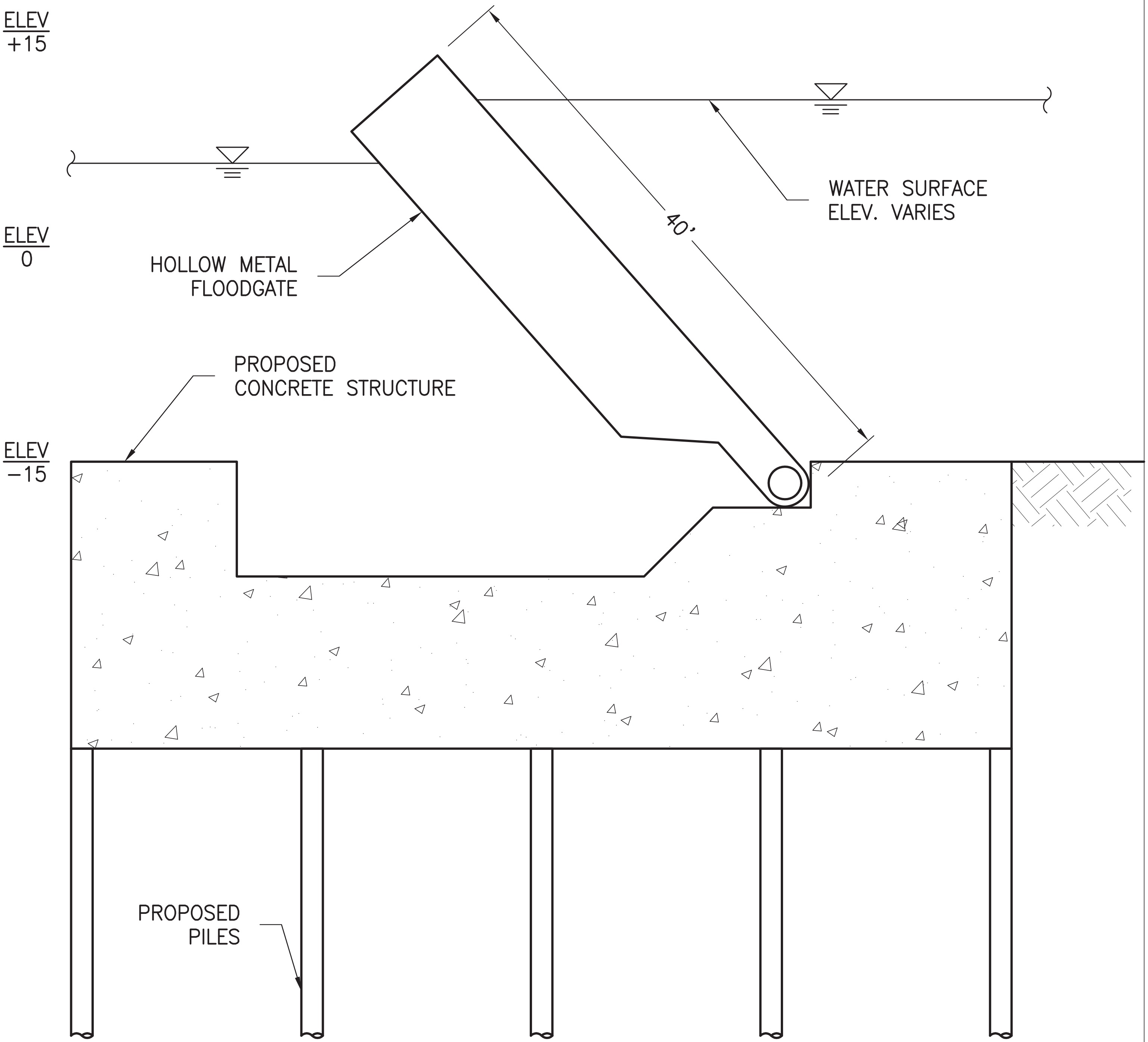
PROPOSED PLAN OF MISSION CREEK TIDE
GATE @ MCCOVEY COVE
SEE FIGURE 2–6 (AOC08) & 4–10 (SECTION A–A)
SCALE: 1"=100'

Port of San Francisco
Sea Level Rise and Adaptation Study

PORT OF SAN FRANCISCO AGS

Figure 4-9

Year 2100 Mitigation



PROPOSED MISSION CREEK TIDE GATE @ MCCOVEY COVE – SECTION A–A

SEE FIGURE 2–6 (AOC08) & 4–9

SCALE: 1"=10'

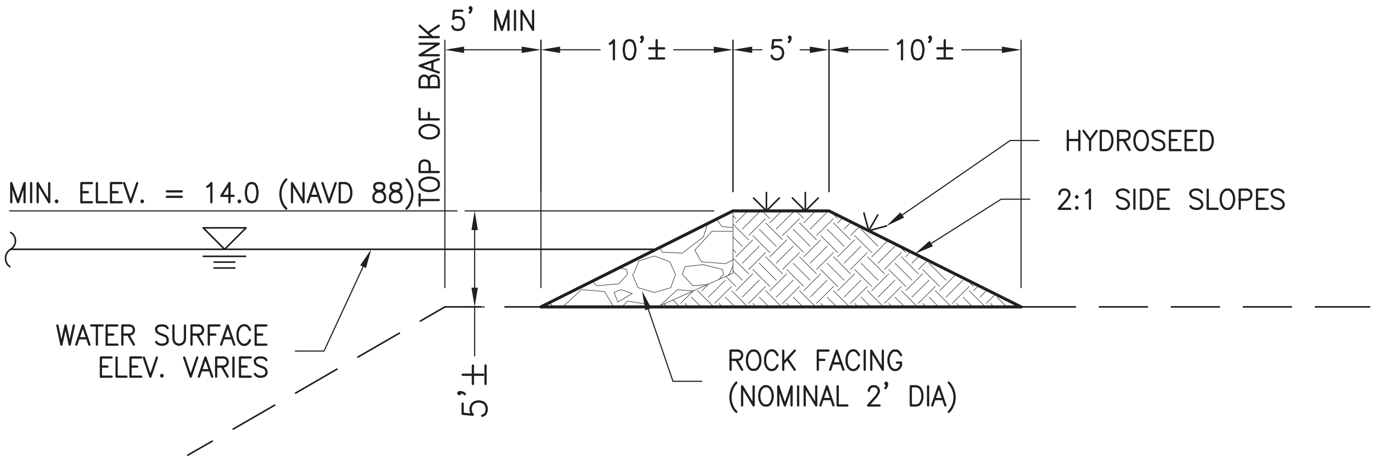
Port of San Francisco
Sea Level Rise and Adaptation Study

PORT OF SAN FRANCISCO

AGS

Figure 4-10

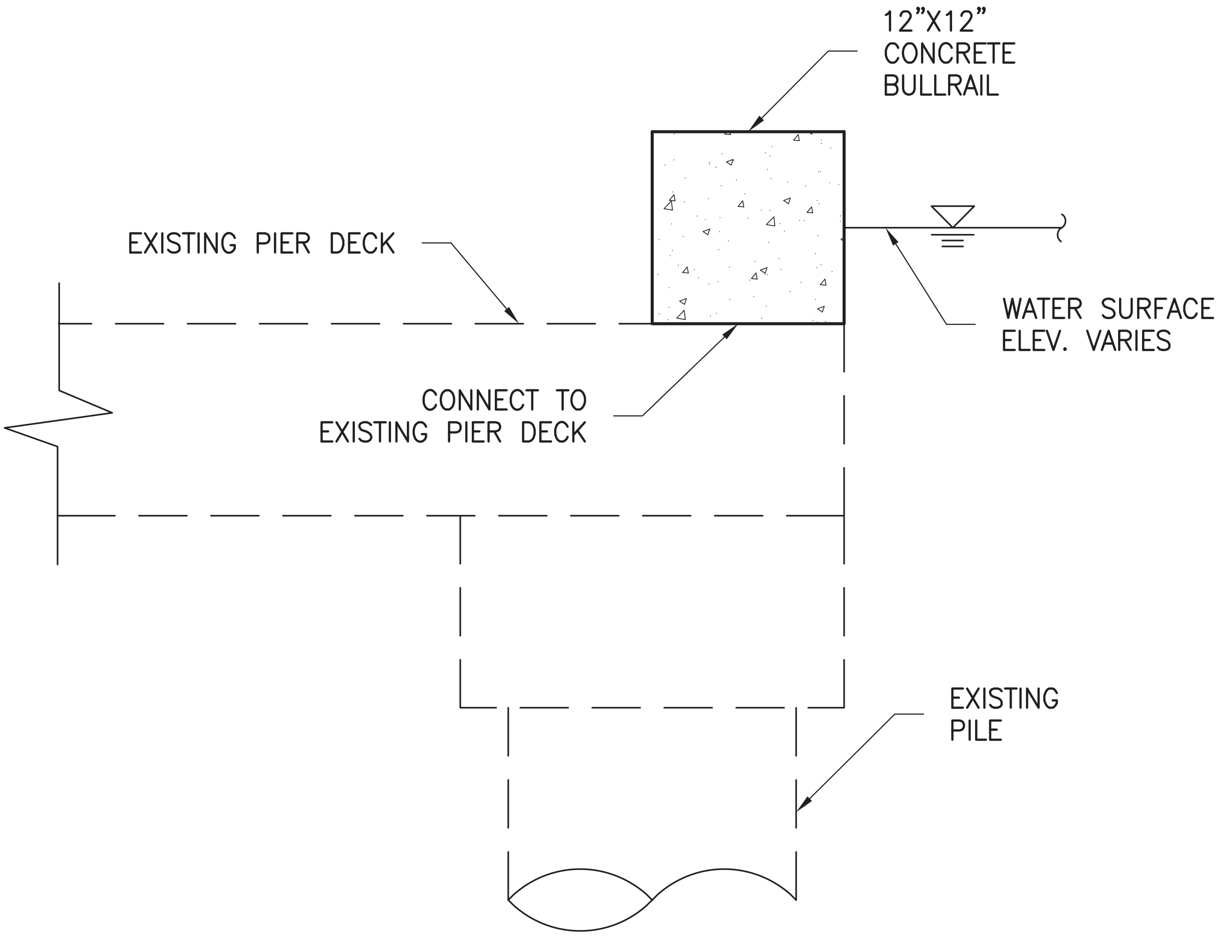
Year 2100 Mitigation



PROPOSED 5 FOOT HIGH EARTH BERM
SOUTH OF MISSION CREEK
SEE FIGURE 2-6 (AOC08)
SCALE: 1"=10'

Figure 4-11

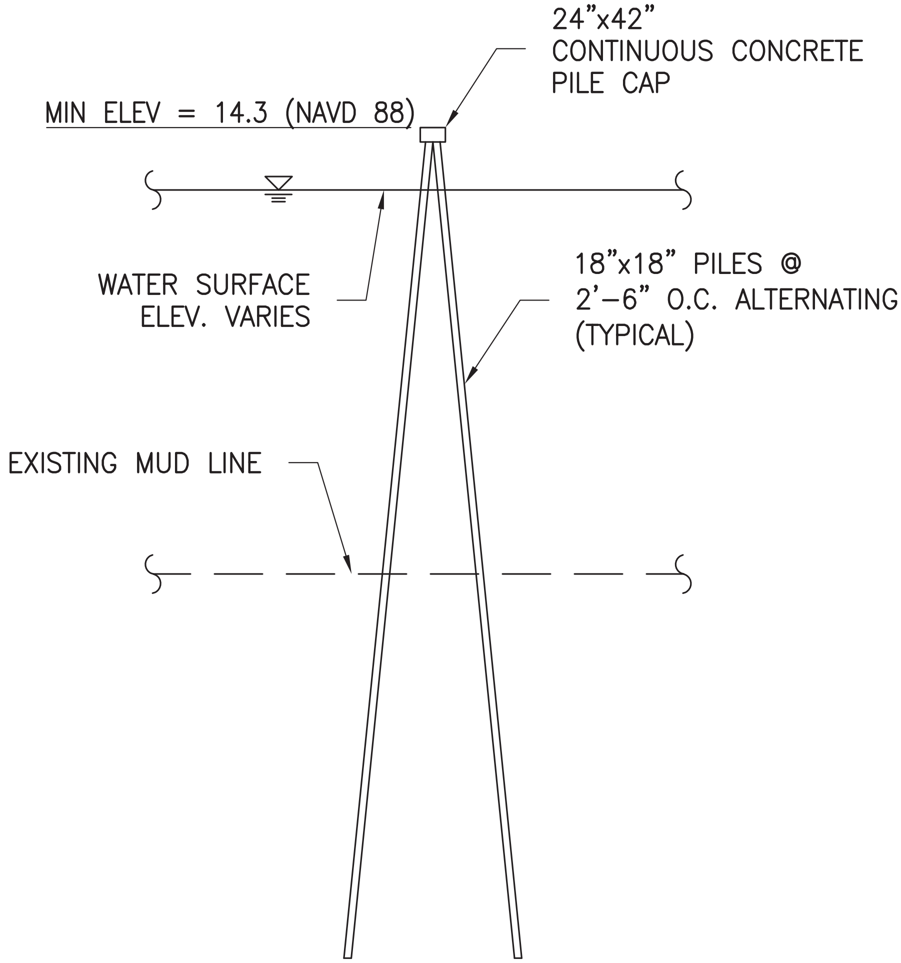
Year 2100 Mitigation



PROPOSED 12 INCH X 12 INCH
CONCRETE BULLRAIL @ PIER 27/29
SEE FIGURE 2–7 (AOC09)
SCALE: 1"=1'

Figure 4-12

TWL Mitigation



PROPOSED BREAKWATER @ PIER 30 VICINITY
SEE FIGURE 2–8 (AOC10)
SCALE: 1"=40'

Port of San Francisco
Sea Level Rise and Adaptation Study

PORT OF SAN FRANCISCO   AGS

Figure 4-13

TWL Mitigation

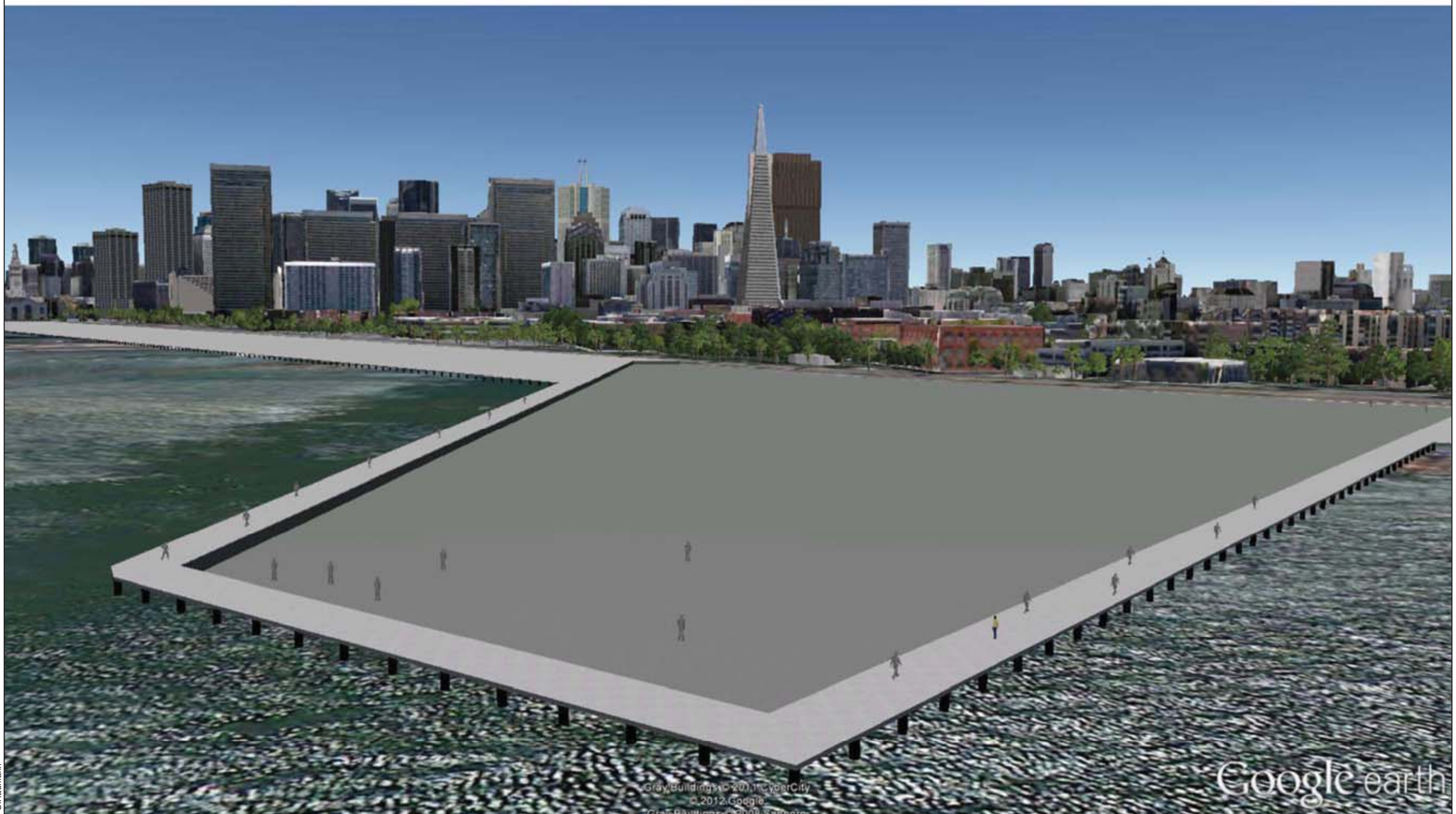
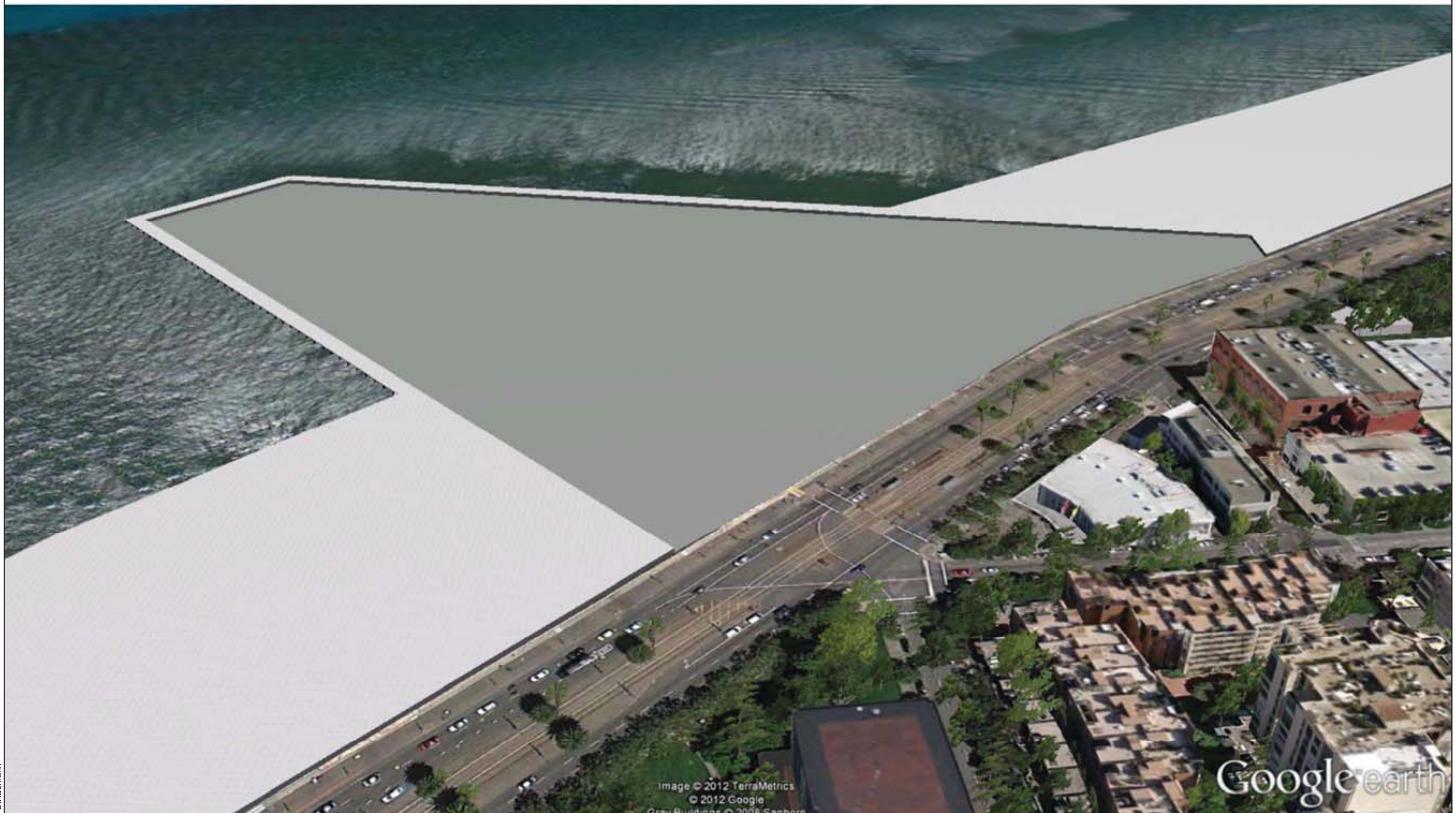


Figure 4-14
Visual simulation of supplemental pier and marginal wharf at Pier 27/29, looking southwest



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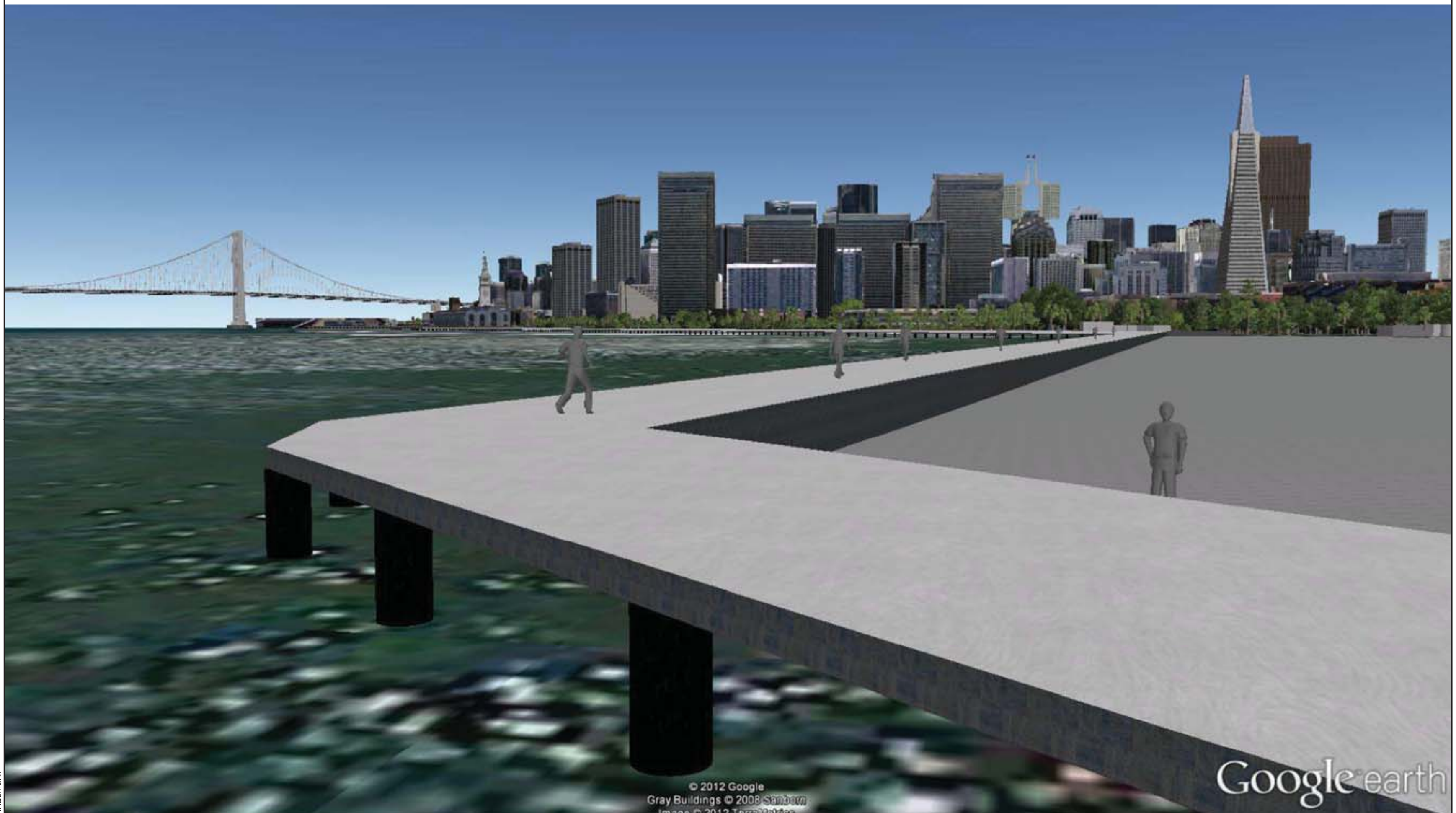
Sea Level Rise and Adaptation Study

Figure 4-15
Visual simulation of supplemental pier and marginal wharf at Pier 27/29, looking east



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Sea Level Rise and Adaptation Study

Figure 4-16
Visual simulation of supplemental pier and marginal wharf at Pier 27/29, detailed view looking southwest

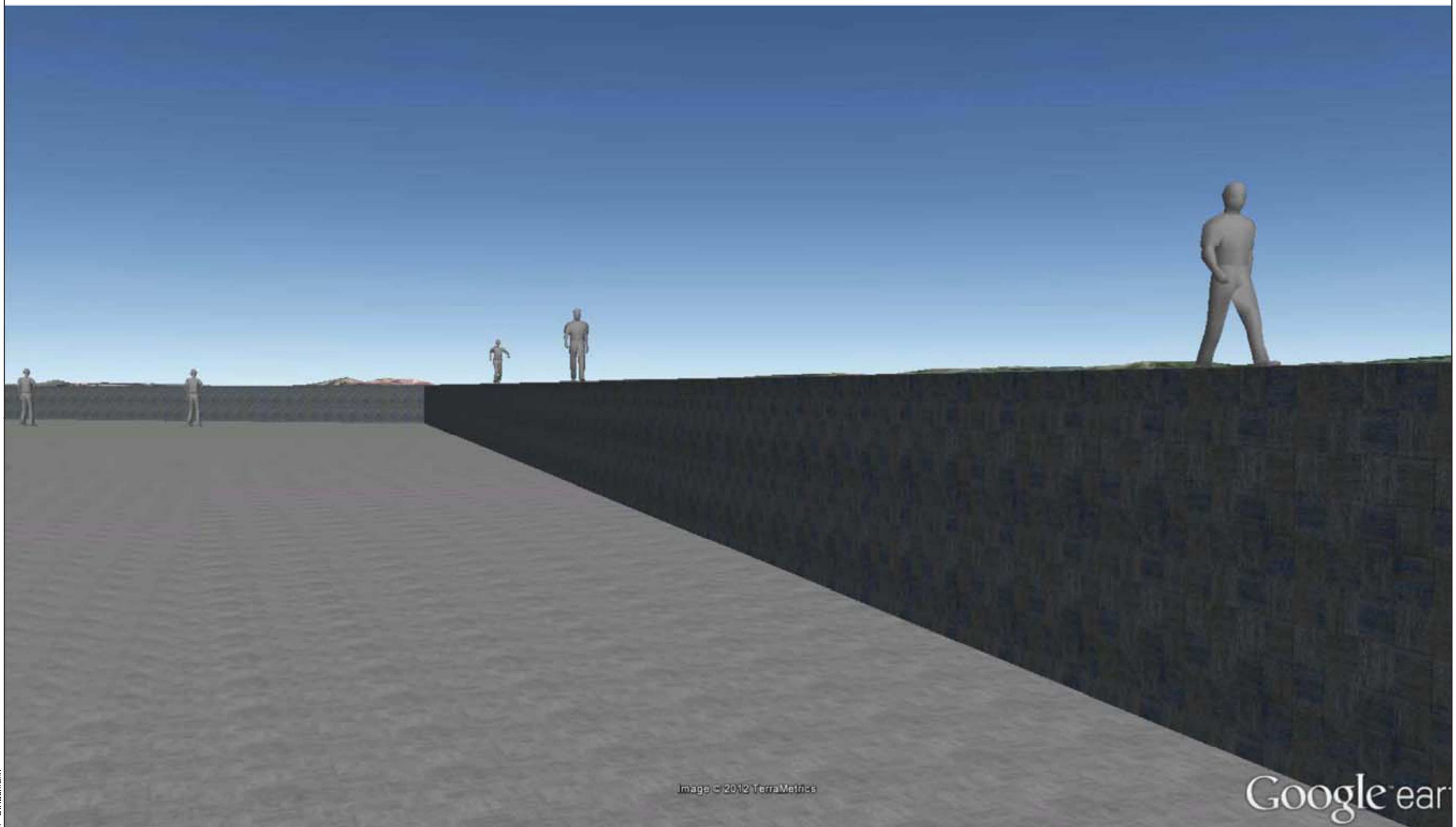

Figure 4-17
Visual simulation of supplemental pier at Pier 27/29, detailed view looking northeast

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Sea Level Rise and Adaptation Study

Figure 4-18
Visual simulation of supplemental pier at Pier 27/29, detailed view looking north

SEA LEVEL RISE AND ADAPTATION STUDY

SAN FRANCISCO, CA

ESTIMATE OF PROBABLE CONSTRUCTION COST
(AN OPINION OF PROBABLE CONSTRUCTION COST)

Owner
SAN FRANCISCO PORT COMMISSION
PORT OF SAN FRANCISCO

Prepared for
URS/AGS, JV
5 Freelon Street
San Francisco, CA 94107
(415) 777-2166; FAX (415) 777-2167

Prepared by
M. LEE CORPORATION
Construction Management & Consulting
Cost Estimating and Project Scheduling
500 Sutter Street, Suite 923
San Francisco, CA 94102
(415) 693-0236; FAX (415) 693-0237
www.mleecorp.com

Date: 6/7/2012 R2

file: 1008 Sea Level Rise

SEA LEVEL RISE AND ADAPTATION STUDY

SAN FRANCISCO, CA

ESTIMATE OF PROBABLE CONSTRUCTION COST
(AN OPINION OF PROBABLE CONSTRUCTION COST)

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Date: 6/7/2012 R2

PORT OF SAN FRANCISCO
SEA LEVEL RISE AND ADAPTATION STUDY
PRELIMINARY ESTIMATE OF PROBABLE CONSTRUCTION COST
PREAMBLE

Date: 6/7/2012 R2

1 The estimate, which represents our opinion of probable construction cost, consists of the following integral sections:
- a Preamble
- b Grand Summary
- c Estimate Details

Please see Table of Contents for details

2 The estimate is based on the following:
- a A set of Conceptual set of drawings, Figures 2-1 through 2-8, prepared by URS, and received by us on Jan 25, 2012
- b A set of Conceptual technical details, Figures 4-1 through 4-8, prepared by AGS, and received by us on Jan 25, 2012
- c A narrative for the Sea Level Rise Study, prepared by URS/AGS, dated Jan 1, 2011 and received by us on Jan 25, 2012
- d Clarifications from designers

3 The estimate includes the following scope of work:
- a Study of proposed mitigation options for seven areas of concern (AOC) along the San Francisco Waterfront (2050 SWL)
- b Study of proposed mitigation options for the entire San Francisco Waterfront (2100 SWL)
- c Study of proposed mitigation options for the Total Water Level (TWL)
- d Associated Piers/Building demolition

4 The impacted area for the 2100 SWL study is approximately 192 acres

5 The estimate specifically excludes the following items:
- a Permit and plan check fees
- b Administration costs such as bidding, advertising and contract award
- c Professional fees for architect, engineers, consultants, construction management and other soft costs
- d Costs for independent testing and inspection
- e Construction change orders
- f Cost escalation beyond the date of this estimate

It is assumed that the above items, if needed, are included elsewhere in the owner's overall project budget.

6 The estimate is based on the following assumptions:
- a The work will be constructed as multiple phases under mutliple general contracts.

- b All work will be done during regular working hours; no overtime work has been allowed.
- c Unit costs are based on prevailing wage rates.
- d Construction period to be determined

7 The estimate is based on estimated prices current as of June 2012, with 4 to 6 responsible and responsive bids under a competitive bidding environment for a fixed price lump sum contract. Experience shows fewer bidders may result in higher bids, and conversely more bidders may result in lower bids.

8 The following is a list of some items that may affect the cost estimate:
- a Modifications to the scope of work or assumptions included in this estimate
- b Special phasing requirements
- c Restrictive technical specifications or excessive contract conditions
- d Any specified item of equipment, material, or product that cannot be obtained from at least three different sources
- e Any other non-competitive bid situations.

9 a The estimate has been prepared using accepted estimating practices and it represents our opinion of probable construction costs based on a fair-market competitive bidding situation. Since we have no control over market conditions and other factors which may affect the bid prices, we cannot and do not warrant or guarantee that the bid or final cost will not deviate from our estimate.

10 Please note that the estimate has been prepared based on very preliminary information and design assumptions which are subject to verifications and changes as the design progresses. An updated estimate should be prepared when more specific and detailed design information is available.

11 Abbreviations used in the estimate:

cy = cubic yard
ea = each
gsf = gross square foot
lb = pound
lf = linear foot
loc=location
ls = lump sum
sf = square foot
sfca = square foot contact area
AOC = Area of Concern

PORT OF SAN FRANCISCO
SEA LEVEL RISE AND ADAPTATION STUDY
PRELIMINARY ESTIMATE OF PROBABLE CONSTRUCTION COST
ESTIMATE SUMMARY

Date: 6/7/2012 R2

AOC	DESCRIPTION	ESTIMATED AMOUNT (All in 2012 Dollars)
	FOR YEAR 2050 SWL	
AOC01	Pier 45	
	Option #1	$477,000
	Option #2	$1,077,000
AOC02	Pier 5	$423,000
AOC03	Embarcadero	
	Mitigation #1	$544,000
	Mitigation #2	$783,000
AOC04	Mission Creek Outfall Structure	N/A
AOC05	Mission Creek, North Bank	$1,016,000
AOC06	Mission Creek, South Bank	$474,000
AOC07	Pier 52, Boat Launch	$324,000

Prices in 2012 dollars
Please read the attached "Preamble", "Estimate Summary", and "Estimate Details"
for assumptions, exclusions, qualifications and scope of work.

PORT OF SAN FRANCISCO
SEA LEVEL RISE AND ADAPTATION STUDY
PRELIMINARY ESTIMATE OF PROBABLE CONSTRUCTION COST
ESTIMATE SUMMARY

Date: 6/7/2012 R2

AOC	DESCRIPTION	ESTIMATED AMOUNT (All in 2012 Dollars)
AOC08	Entire Waterfront	
	Preferred solution #1 (excluded Mission Creek)	$617,560,000
	Preferred solution #2 (excluded Mission Creek)	$2,744,980,000
	Mission Creek	$28,480,000

	FOR TOTAL WATER LEVEL (TWL)	
AOC09	Pier 27/29	$261,000
AOC10	Pier 30 Vicinity	$52,292,000

Prices in 2012 dollars
Please read the attached "Preamble", "Estimate Summary", and "Estimate Details"
for assumptions, exclusions, qualifications and scope of work.

PORT OF SAN FRANCISCO					Date: 6/7/2012 R2
SEA LEVEL RISE AND ADAPTATION STUDY					
PRELIMINARY ESTIMATE OF PROBABLE CONSTRUCTION COST					
YEAR 2050 SWL ESTIMATE DETAILS					
Line	**Description of Work**	**Quantity**	**Unit**	**Unit Cost**	**Estimated Total $**
	AOC01-Pier 45				
1	Per Figure 2-1				
2	**Option #1**				
3	Solid Wall, 117' L x 2.5' H x 8" T	293	SF	60.00	17,550
4	Temporary work platform from edge of pier	117	LF	100.00	11,700
5	Dowels, assumed 12" o.c.	117	EA	45.00	5,265
6	Waterproofing/waterstop	117	LF	30.00	3,510
7	Site demolition (metal rails, metal fences, etc)	1	LS	5,000.00	5,000
8	Vehicles access to aprons	1	LS	50,000.00	50,000
9	Pedestrian access	1	LS	25,000.00	25,000
10	Drainage modification at parking area including regrading	50,000	SF	4.00	200,000
11					
12	---	----------	----------------	-----------------	
13	Subtotal				318,025
14	Add Markup			0.50	159,000
15	Total Estimated Construction Cost				477,025
16				rounded-off	**477,000**
17					
18	**Option #2**				
19	Solid Wall, 609' L x 2.5' H x 8" T	1,523	SF	60.00	91,350
20	Temporary work platform from edge of pier	609	LF	100.00	60,900
21	Dowels, assumed 12" o.c.	609	EA	45.00	27,405
22	Waterproofing/waterstop	609	LF	30.00	18,270
23	Site demolition (metal rails, metal fences, etc)	1	LS	15,000.00	15,000
24	Site improvement (metal rails, metal fences, etc)	1	LS	50,000.00	50,000
25	Disconnect and reinstall (E) finger pier	1	LS	30,000.00	30,000
26	Loading and unloading features for vessels	1	LS	200,000.00	200,000
27	Pedestrian access	1	LS	25,000.00	25,000
28	Drainage modification at parking area including regrading	50,000	SF	4.00	200,000
29					
30	---	----------	----------------	-----------------	
31	Subtotal				717,925
32	Add Markup			0.50	359,000
33	Total Estimated Construction Cost				1,076,925
34				rounded-off	**1,077,000**
35					
36	**AOC02-Pier 5**				
37	Per Figure 2-2				
38	Solid Wall, 496' L x 2.5' H x 8" T	1,240	SF	65.00	80,600

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SEA LEVEL RISE AND ADAPTATION STUDY					
PRELIMINARY ESTIMATE OF PROBABLE CONSTRUCTION COST					
YEAR 2050 SWL ESTIMATE DETAILS					
Line	**Description of Work**	**Quantity**	**Unit**	**Unit Cost**	**Estimated Total $**
39	Temporary work platform from edge of pier	496	LF	100.00	49,600
40	Dowels, assumed 12" o.c.	496	EA	45.00	22,320
41	Waterproofing/waterstop	496	LF	30.00	14,880
42	Site demolition (metal rails, metal fences, etc)	1	LS	25,000.00	25,000
43	Drainage improvement	1	LS	50,000.00	50,000
44	Remove/replace lighting	1	LS	40,000.00	40,000
45					
46	--	----------	----------------	-----------------	
47	Subtotal				282,400
48	Add Markup			0.50	141,000
49	Total Estimated Construction Cost				423,400
50				rounded-off	**423,000**
51					
52	**AOC03-Embarcadero**				
53	Per Figure 2-3				
54	**Mitigation #1**				
55	Solid Wall, 603' L x 2' H x 8" T	1,206	SF	60.00	72,360
56	Temporary work platform from edge of pier	603	LF	100.00	60,300
57	Dowels, assumed 12" o.c.	603	EA	45.00	27,135
58	Waterproofing/waterstop	603	LF	30.00	18,090
59	Site demolition (metal rails, metal fences, etc)	1	LS	15,000.00	15,000
60	Disconnect Pier 14 from wharf	1	EA	10,000.00	10,000
61	Reconnect Pier 14 to wharf	1	EA	50,000.00	50,000
62	Ramp to wharf	1	LS	60,000.00	60,000
63	Drainage improvement	1	LS	50,000.00	50,000
64					
65	--	----------	----------------	-----------------	
66	Subtotal				362,885
67	Add Markup			0.50	181,000
68	Total Estimated Construction Cost				543,885
69				rounded-off	**544,000**
70					
71	**Mitigation #2**				
72	Solid Wall, 1649' L x 2' H x 8" T	3,298	SF	60.00	197,880
73	Dowels, assumed 12" o.c.	1,649	EA	45.00	74,205
74	Waterproofing/waterstop	1,649	LF	30.00	49,470
75	Pedestrian access	1	LS	50,000.00	50,000
76	Drainage improvement	1	LS	150,000.00	150,000
77					
78	--	----------	----------------	-----------------	
79	Subtotal				521,555
80	Add Markup			0.50	261,000
81	Total Estimated Construction Cost				782,555

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SEA LEVEL RISE AND ADAPTATION STUDY					
PRELIMINARY ESTIMATE OF PROBABLE CONSTRUCTION COST					
YEAR 2050 SWL ESTIMATE DETAILS					
Line	**Description of Work**	**Quantity**	**Unit**	**Unit Cost**	**Estimated Total $**
82				rounded-off	**783,000**
83					
84	**AOC05-Mission Creek, North Bank**				
85	Per Figure 2-4				
86	Solid wall, 1066' L x 3' H x 8" T	3,198	SF	60.00	191,880
87	Waterproofing/waterstop	1,066	LF	35.00	37,310
88	Foundation	158	CY	600.00	94,800
89	Excavation	174	CY	50.00	8,690
90	Off-haul/Backfill	174	CY	30.00	5,214
91	Remove (E) boardwalk, assumed 75%	3,205	SF	2.50	8,013
92	Replace boardwalk	3,205	SF	50.00	160,250
93	Replace landscape	1,068	SF	2.50	2,670
94	Remove utilities	1	LS	10,000.00	10,000
95	Replace utilities	1	LS	20,000.00	20,000
96	Remove lighting	1	LS	10,000.00	10,000
97	Replace lighting	1	LS	20,000.00	20,000
98	Remove irrigation	1	LS	1,000.00	1,000
99	Replace irrigation	1	LS	2,500.00	2,500
100	Drainage improvement	1	LS	100,000.00	100,000
101	Miscellaneous demolition	1	LS	5,000.00	5,000
102					
103	--	----------	----------	---------------	-----------------
104	Subtotal				677,327
105	Add Markup			0.50	339,000
106	Total Estimated Construction Cost				1,016,327
107				rounded-off	**1,016,000**
108					
109	**AOC06-Mission Creek, South Bank**				
110	Per Figure 2-4				
111	Earth dike, 1094' L x 2' high	645	CY	80.00	51,600
112	Hydroseed	14,084	SF	0.30	4,225
113	Remove (E) hardscape, assumed 25%	3,265	SF	2.50	8,163
114	Remove (E) landscape, assumed 75%	9,796	SF	0.75	7,347
115	Irrigation	1	LS	15,000.00	15,000
116	Pedestrian access	1	LS	20,000.00	20,000
117	Disconnect and reinstall gangways	1	LS	50,000.00	50,000
118	Remove utilities	1	LS	10,000.00	10,000
119	Replace utilities	1	LS	30,000.00	30,000
120	Remove lighting	1	LS	5,000.00	5,000
121	Replace lighting	1	LS	15,000.00	15,000
122	Drainage improvement	1	LS	100,000.00	100,000
123					
124	--	----------	----------	---------------	-----------------
125	Subtotal				316,335
126	Add Markup			0.50	158,000

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SEA LEVEL RISE AND ADAPTATION STUDY					
PRELIMINARY ESTIMATE OF PROBABLE CONSTRUCTION COST					
YEAR 2050 SWL ESTIMATE DETAILS					
Line	**Description of Work**	**Quantity**	**Unit**	**Unit Cost**	**Estimated**
					Total $
127	Total Estimated Construction Cost				474,335
128				rounded-off	**474,000**
129					
130	**AOC07-Pier 52 Boat Launch**				
131	Per Figure 2-5				
132	Earth dike, 529' L x 2' high	348	CY	80.00	27,840
133	Hydroseed	2,359	SF	0.30	708
134	2" AC	4,471	SF	3.00	13,413
135	Remove (E) hardscape, assumed 75%	4,750	SF	2.50	11,875
136	Remove utilities	1	LS	10,000.00	10,000
137	Replace utilities	1	LS	20,000.00	20,000
138	Irrigation	1	LS	2,500.00	2,500
139	Pedestrian access	1	LS	20,000.00	20,000
140	Drainage improvement	1	LS	100,000.00	100,000
141	Miscellaneous demolition	1	LS	5,000.00	5,000
142	Miscellaneous demolition structures	1	LS	5,000.00	5,000
143					
144	---		----------	----------------	-----------------
145	Subtotal				216,336
146	Add Markup			0.50	108,000
147	Total Estimated Construction Cost				324,336
148				rounded-off	**324,000**
149					

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SEA LEVEL RISE AND ADAPTATION STUDY					
PRELIMINARY ESTIMATE OF PROBABLE CONSTRUCTION COST					
YEAR 2100 SWL ESTIMATE DETAILS					
Line	**Description of Work**	**Quantity**	**Unit**	**Unit Cost**	**Estimated Total $**
	AOC08-Entire Waterfront				
1	Per Figure 2-6				
2	**Preferred solution #1 - Wrapping existing piers with a new and elevated 20-foot pier structure**				
3	From Aquatic Pier to Pier 45				
4	Solid Wall, 2980' L x 6' H x 8" T	17,880	SF	60.00	1,072,800
5	Foundation	890	CY	600.00	534,000
6	Heel	111	CY	600.00	66,600
7	Excavation, foundation & heel	1,891	CY	50.00	94,550
8	Backfill	890	CY	30.00	26,700
9	Off-haul	1,001	CY	30.00	30,030
10	Remove hardscape, assumed 50% of total affected area	12,014	SF	2.50	30,035
11	Replace hardscape	12,014	SF	20.00	240,280
12	Remove utilities	1	LS	50,000.00	50,000
13	Replace utilities	1	LS	100,000.00	100,000
14	Remove lighting	1	LS	30,000.00	30,000
15	Replace lighting	1	LS	150,000.00	150,000
16	Pedestrian access	1	LS	40,000.00	40,000
17	Drainage improvement	1	LS	50,000.00	50,000
18	From Pier 43 1/2 to Pier 40				
19	Supplemental pier, 52500' L x 20' W	1,050,000	SF	95.00	99,750,000
20	Piles, assumed 2 pile per 200 SF, assumed 130' long	10,500	EA	25,000.00	262,500,000
21	5' high concrete wall, waterproofed	262,500	SF	60.00	15,750,000
22	Pedestrian access/ Site improvement	1,050,000	SF	4.00	4,200,000
23	AT&T Park				
24	Solid Wall, 2000' L x 5' H	10,000	SF	60.00	600,000
25	Temporary work platform from edge of pier	2,000	LF	100.00	200,000
26	Waterproofing/waterstop	2,000	LF	35.00	70,000
27	Dowels, assumed 12" o.c.	4,948	EA	45.00	222,660
28	Site demolition (metal rails, metal fences, etc)	1	LS	125,000.00	125,000
29	Disconnect and reconnect gangways	1	LS	100,000.00	100,000
30	Disconnect and reconnect floats	1	LS	100,000.00	100,000
31	Pedestrian access/ Site improvement	1	LS	50,000.00	50,000
32	Drainage improvement	1	LS	100,000.00	100,000
33	From Pier 48 to South				
34	Earth dike, 4500' L x 5' H				
35	Rock facing, nominal 2' dia	5,333	CY	90.00	479,970
36	Engineering soil	11,334	CY	60.00	680,040
37	Hydroseed	96,000	SF	0.25	24,000
38	Remove (E) hardscape, assumed 75%	112,500	SF	2.50	281,250
39	Remove (E) landscape, assumed 25%	37,500	SF	0.75	28,125

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SEA LEVEL RISE AND ADAPTATION STUDY					
PRELIMINARY ESTIMATE OF PROBABLE CONSTRUCTION COST					
YEAR 2100 SWL ESTIMATE DETAILS					
Line	**Description of Work**	**Quantity**	**Unit**	**Unit Cost**	**Estimated Total $**
40	Remove (E) buildings/sheds	522,720	SF	30.00	15,681,600
41	Remove utilities	1	LS	100,000.00	100,000
42	Replace utilities	1	LS	300,000.00	300,000
43	Remove lighting	1	LS	50,000.00	50,000
44	Replace lighting	1	LS	200,000.00	200,000
45	Irrigation	1	LS	100,000.00	100,000
46	Pier demolition for wrapping (E) piers				
47	Temporarily relocate (E) finger piers	1	LS	2,500,000.00	2,500,000
48	Reinstall finger piers	1	LS	5,000,000.00	5,000,000
49					
50	---	----------	--------------------	--------------------	
51	Subtotal				411,707,640
52	Add Markup			0.50	205,854,000
53	Total Estimated Construction Cost				617,561,640
54				rounded-off	**617,560,000**
55					
56	**Preferred solution #2 - Raised marginal wharf**				
57	From Aquatic Pier to Pier 45				
58	Solid Wall, 2980' L x 6' H x 8" T	17,880	SF	60.00	1,072,800
59	Foundation	890	CY	600.00	534,000
60	Heel	111	CY	600.00	66,600
61	Excavation, foundation & heel	1,891	CY	50.00	94,550
62	Backfill	890	CY	30.00	26,700
63	Off-haul	1,001	CY	30.00	30,030
64	Remove hardscape, assumed 50% of total affected area	12,014	SF	2.50	30,035
65	Replace hardscape	12,014	SF	20.00	240,280
66	Remove utilities	1	LS	50,000.00	50,000
67	Replace utilities	1	LS	100,000.00	100,000
68	Remove lighting	1	LS	30,000.00	30,000
69	Replace lighting	1	LS	150,000.00	150,000
70	Pedestrian access	1	LS	40,000.00	40,000
71	Drainage improvement	1	LS	50,000.00	50,000
72	From Pier 43 1/2 to Pier 29 1/2				
73	Marginal wharf, 4000' L x 400' W	1,600,000	SF	95.00	152,000,000
74	Piles, assumed 1 pile per 200 SF, 130' long avg	8,000	EA	25,000.00	200,000,000
75	Pedestrian access/ Site improvement	1,600,000	SF	4.00	6,400,000
76	Drainage improvement	1,600,000	SF	1.00	1,600,000
77	Pier 29-27				
78	Supplemental pier, 1800' L x 20' W	36,000	SF	95.00	3,420,000
79	Piles, assumed 2 pile per 200 SF, assumed 130' long	360	EA	25,000.00	9,000,000
80	5' high concrete wall, waterproofed	13,875	SF	60.00	832,500
81	Pedestrian access/ Site improvement	36,540	SF	4.00	146,160

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SEA LEVEL RISE AND ADAPTATION STUDY					
PRELIMINARY ESTIMATE OF PROBABLE CONSTRUCTION COST					
YEAR 2100 SWL ESTIMATE DETAILS					
Line	**Description of Work**	**Quantity**	**Unit**	**Unit Cost**	**Estimated Total $**
82	From Pier 23 to Pier 1/2				
83	Marginal wharf, 3400' L x 400' wide	1,360,000	SF	95.00	129,200,000
84	Piles, assumed 1 pile per 200 SF, assumed 130' long	6,800	EA	25,000.00	170,000,000
85	Piles, assumed 23 piles every 10 feet, 130' long avg	7,934	EA	25,000.00	198,350,000
86	Pedestrian access/ Site improvement	1,360,000	SF	4.00	5,440,000
87	Drainage improvement	1	LS	450,000.00	450,000
88	Ferry Terminal				
89	Supplemental pier, 1400' L x 20' W	28,000	SF	95.00	2,660,000
90	Piles, assumed 2 pile per 200 SF, assumed 130' long	280	EA	25,000.00	7,000,000
91	5' high concrete wall, waterproofed	10,370	SF	60.00	622,200
92	Pedestrian access/ Site improvement	28,000	SF	4.00	112,000
93	From Agricultural Building to Pier 40				
94	Marginal wharf, 5400' L x 400' W	2,160,000	SF	95.00	205,200,000
95	Piles, assumed 1 pile per 200 SF, 130' long avg	10,800	EA	25,000.00	270,000,000
96	Pedestrian access/ Site improvement	2,160,000	SF	4.00	8,640,000
97	Drainage improvement	1	LS	400,000.00	400,000
98	AT&T Park				
99	Solid Wall, 2000' L x 5' H	10,000	SF	60.00	600,000
100	Temporary work platform from edge of pier	2,000	LF	100.00	200,000
101	Waterproofing/waterstop	2,000	LF	35.00	70,000
102	Dowels, assumed 12" o.c.	4,948	EA	45.00	222,660
103	Site demolition (metal rails, metal fences, etc)	1	LS	125,000.00	125,000
104	Disconnect and reconnect gangways	1	LS	100,000.00	100,000
105	Disconnect and reconnect floats	1	LS	100,000.00	100,000
106	Pedestrian access/ Site improvement	1	LS	50,000.00	50,000
107	Drainage improvement	1	LS	100,000.00	100,000
108	From Pier 48 to South				
109	Earth dike, 4500' L x 5' H				
110	Rock facing, nominal 2' dia	5,333	CY	90.00	479,970
111	Engineering soil	11,334	CY	60.00	680,040
112	Hydroseed	96,000	SF	0.25	24,000
113	Remove (E) hardscape, assumed 75%	112,500	SF	2.50	281,250
114	Remove (E) landscape, assumed 25%	37,500	SF	0.75	28,125
115	Remove (E) buildings/sheds	522,720	SF	30.00	15,681,600
116	Remove utilities	1	LS	100,000.00	100,000
117	Replace utilities	1	LS	300,000.00	300,000
118	Remove lighting	1	LS	50,000.00	50,000
119	Replace lighting	1	LS	200,000.00	200,000
120	Irrigation	1	LS	100,000.00	100,000
121	Pier demolition for marginal wharf				

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SEA LEVEL RISE AND ADAPTATION STUDY					
PRELIMINARY ESTIMATE OF PROBABLE CONSTRUCTION COST					
YEAR 2100 SWL ESTIMATE DETAILS					
Line	**Description of Work**	**Quantity**	**Unit**	**Unit Cost**	**Estimated Total $**
122	Remove (E) Piers deck and piles	4,617,360	SF	70.00	323,215,200
123	Remove (E) Buildings	3,484,800	SF	30.00	104,544,000
124	Temporarily relocate (E) finger piers	1	LS	2,500,000.00	2,500,000
125	Reinstall finger piers	1	LS	5,000,000.00	5,000,000
126	Replace utilities	1	LS	1,000,000.00	1,000,000
127	Replace lighting	1	LS	250,000.00	250,000
128					
129	--		----------	---------------------	--------------------
130	Subtotal				1,829,989,700
131	Add Markup			0.50	914,995,000
132	Total Estimated Construction Cost				2,744,984,700
133				rounded-off	**2,744,980,000**
134					
135	**Mission Creek**				
136	Hollow metal floodgate, 40' wide x 50' long, approx 196 ton	1	EA	2,000,000.00	2,000,000
137	Cover electronics and gate controls	1	EA	200,000.00	200,000
138	Temporary cofferdam	36,000	SF	100.00	3,600,000
139	Dewatering	1	LS	50,000.00	50,000
140	Concrete foundation	1,920	CY	800.00	1,536,000
141	Excavation	2,433	CY	55.00	133,815
142	Off-haul	2,433	CY	25.00	60,825
143	Pile, 24" pipe filled with concrete, 100' long	56	EA	55,000.00	3,080,000
144	Concrete wall, 3' thick	15,414	SF	110.00	1,695,540
145	Pile, 42" pipe filled with concrete, 100' long	78	EA	85,000.00	6,630,000
146					
147	--		----------	---------------------	--------------------
148	Subtotal				18,986,180
149	Add Markup			0.50	9,493,000
150	Total Estimated Construction Cost				28,479,180
151				rounded-off	**28,480,000**

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SEA LEVEL RISE AND ADAPTATION STUDY					
PRELIMINARY ESTIMATE OF PROBABLE CONSTRUCTION COST					
TOTAL WATER LEVEL (TWL) ESTIMATE DETAILS					
Line	**Description of Work**	**Quantity**	**Unit**	**Unit Cost**	**Estimated Total $**
	AOC09-Pier 27/29				
1	Per Figure 2-7				
2	Concrete bullrail, 12"x12"	2,337	LF	30.00	70,110
3	1" pin, assumed 12" o.c.	2,337	EA	35.00	81,795
4	Roughen (E) concrete deck	2,337	SF	4.00	9,348
5	Remove (E) wood bullrail	2,337	LF	5.50	12,852
6					
7	--	----------	---------------	-----------------	
8	Subtotal				174,105
9	Add Markup			0.50	87,000
10	Total Estimated Construction Cost				261,105
11				rounded-off	**261,000**
12					
13	**AOC10-Pier 30 Vicinity**				
14	Per Figure 2-8				
15	Continuous concrete pile cap, 24"x42"	2,857	LF	200.00	571,400
16	18"x18" pile, assumed 170' long	1,143	EA	30,000.00	34,290,000
17					
18	--	----------	---------------	-----------------	
19	Subtotal				34,861,400
20	Add Markup			0.50	17,431,000
21	Total Estimated Construction Cost				52,292,400
22				rounded-off	**52,292,000**
23					

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SEA LEVEL RISE AND ADAPTATION STUDY
PRELIMINARY ESTIMATE OF PROBABLE CONSTRUCTION COST
MARKUPS

Item		Total $	
Direct Cost- Building		100.00	
Design & Estimating Contingencies	25%	25.00	
Subtotal		125.00	
General Conditions & Requirements	12%	15.00	
Payment & Performance Bonds	2%	2.80	
Subtotal		142.80	
General Contractor's Fee (OH&P)	5%	7.14	
TOTAL		149.94	
MARKUP %		50%	MU

Please read the attached "Preamble" and 'Estimate Details" for assumptions, exclusions, qualifications and scope of work