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Climate Adaptation Strategies to Protect Natural Resources for the Saugus Iron Works National Historic Site

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PREFACE

Through generous funding from the Massachusetts Environmental Trust (the Trust), the Saugus River Watershed Council has been working in partnership with the National Park Service and Geosyntec Consultants to identify climate adaptation and mitigation strategies for the Saugus Iron Works National Historic Site. In order to provide a 'value-added' approach, this project is targeted toward climate adaptation strategies that would have the most significant benefit to protecting natural resources in the Saugus River. At the same time, the National Park Service is moving forward with concurrent efforts to develop a suite of landside climate adaptation and mitigation plans and strategies to promote resiliency of buildings and upland features elsewhere on the site.

The focus of this report is to provide a summary of possible impacts to portions of the Saugus Iron Works National Historic Site, specifically, the slag pile and protective berm (i.e., cobble berm) from projected climate change and present recommended engineering solutions to mitigate the impacts. Mitigation and adaptation strategies for the slag pile are needed to consider two potentially complementary objectives: (1) protecting the integrity of the slag pile, which is a contributing feature to the Saugus Iron Works National Historic Landmark and is the only *in situ* historic resource from the 17th century iron works operation, and (2) protecting habitat and wildlife from potential negative impacts associated with historic pollutants that are at risk of migrating into the river system from combined impacts of sea level rise, increased precipitation and upstream river flows during future rainstorms. Similarly, maintaining the integrity of the protective cobble berm between the Saugus River and the turning basin is crucial to preserving the adjacent riffle areas that provide valuable smelt spawning habitat.

The recommendations included in this report seek to address concerns and priorities identified by the National Park Service Saugus Iron Works National Historic Site and the Saugus River Watershed Council. The following individuals provided support for this project by participating in site visits, helping to develop recommendations, or providing review of this report:

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EXECUTIVE SUMMARY

Thirteen government agencies (U.S. Global Change Research Program 2015) have forecasted that projected climate change can pose serious threats to coastal areas in the Northeast region of the United States. By year 2100, the sea level is expected to rise by 4 feet. Total precipitation is expected to increase by 20% in the Northeast region, and the frequency of extreme precipitation events in the future could increase by a factor of four (Melillo et al. 2014).

The Saugus Iron Works National Historic Site (the site) is located on a tidally influenced section of the Saugus River and is susceptible to projected climate change. Geosyntec evaluated the possible impacts from climate change to two areas of the site: 1) the slag pile and 2) the berm protecting fish spawning habitat referred to as the protective berm (see Figure 1 site map). Based on this evaluation, Geosyntec developed recommendations for engineered solutions to mitigate the impacts.

The slag pile currently shows evidence of erosion and slumping at the toe of slope along the waterline, but appears to be generally stable. However, sea level rise and intensified precipitation could result in additional slumping of the pile and erosion of the sloped surfaces. Geosyntec developed the following recommended engineering alternatives to mitigate the impact of climate change on the slag pile:

1. Slope regrading;

2. Remove and replicate the slag pile;

3. Cover critical portions of the slag pile with erosion-resistant material; and/or

4. Construct buttress around the perimeter of the slag pile.

Geosyntec recommends incorporating a combination of Alternatives 1 and 3 for the slag pile. Additional engineering analysis would be required to specify the fill material and side slope geometry and erosion-resistant material.

The protective berm was installed to protect valuable smelt habitat in the Saugus River. The protective berm, constructed of cobble, was installed during restoration of the Turning Basin and surrounding wetlands and was partially eroded during large precipitation events and subsequently enhanced since it was constructed in 2008 (National Park Service 2008).

Geosyntec recommends reinforcing the existing protective berm with large diameter boulder and cobble rock to help reduce potential erosion, dissipate the velocity in flood flows in the river, and direct these flows toward the river channel and not through the protective berm. Geosyntec also recommends evaluating a hydraulic model of the bridge, river and protective berm area to verify that this recommendation would not cause degradation of the smelt spawning habitat.

1. BACKGROUND

The Saugus Iron Works National Historic Site (the site) is the location of the first successful iron works in the New World, in operation between 1646 and 1670. Archaeological excavations at the site started in the 1940s and the site was integrated into the National Park System in 1968. Figure 1 provides a schematic map of major locations at the site.

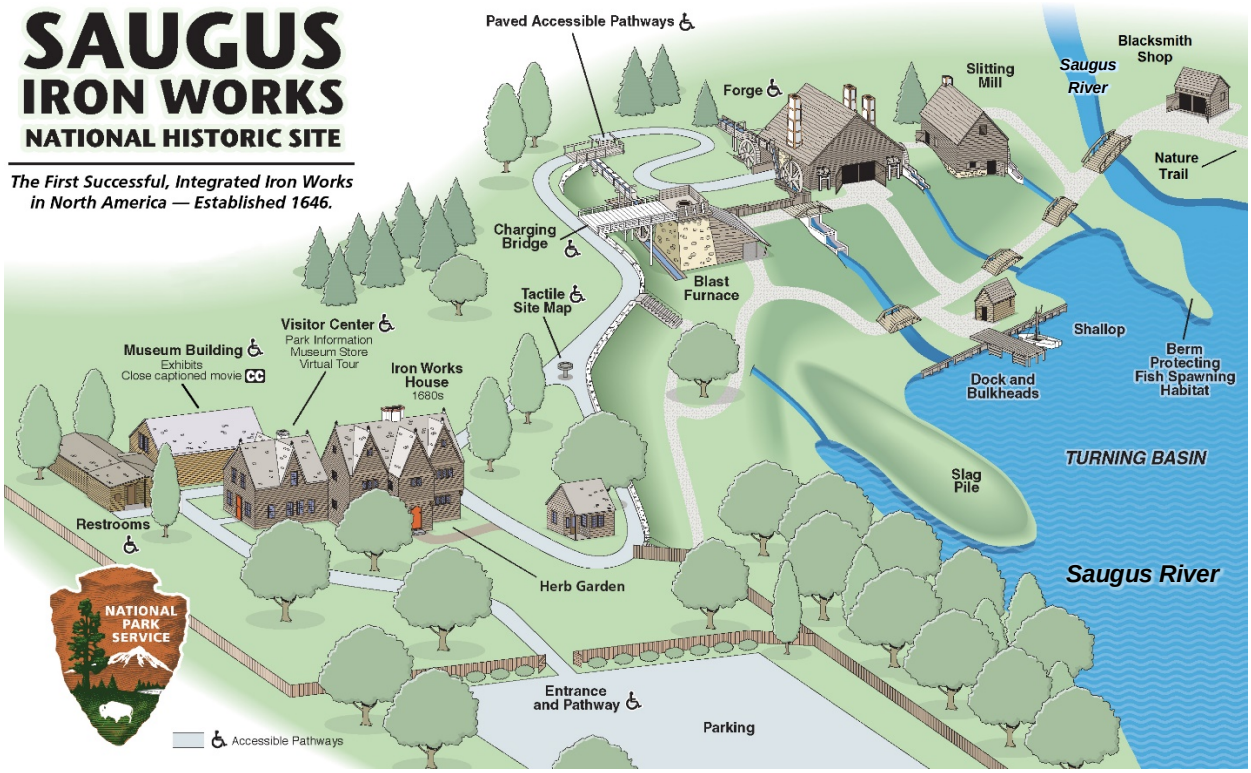

Figure 1. Site schematic map of Saugus Iron Works National Historic Site (National Park Service, 2015).

The Saugus River was key to the operation of the site. Water from the Saugus River emerged from canals and a reservoir not shown in Figure 1 and turned water wheels which powered various machinery in the Iron Works. The site is located at the upstream limit of the tidally-influenced portion of the Saugus River. When the tide was high, workers could ship in raw materials and ship out products using shallow-bottomed sailboats that accessed the site through the Turning Basin.

Geosyntec evaluated possible impacts to the "slag pile" and the "berm protecting fish spawning habitat" (protective berm) from projected climate change and developed recommendations for engineering solutions to mitigate these impacts. The slag pile was created by deposition of waste material generated from the site's blast furnace that operated in the 1600s. The protective berm does not have historic significance, but it provides protection to valuable smelt spawning habitat that exists in the main stream of the Saugus River (located northeast of the berm). This section of the river provides the range of water velocity, bottom particle size, and riffles that are ideal for smelt spawning near the tidal interface (Chase 2009).

The water level in the Turning Basin of the Saugus Iron Works is influenced by the tide of the Atlantic Ocean, approximately 3 miles to the southeast. Thirteen major government agencies (U.S. Global Change Research Program 2015) project that by year 2100, the sea level in the Northeast United States will rise by 1-4 feet. The increased tidal level will result in submerging more of the slag pile, which could reduce its structural stability, expose underlying slag material, leach contaminants, and directly suspend particles containing heavy metals and other pollutants. Another possible outcome of climate change is the intensification of precipitation and a change in rainfall patterns. This could result in increased flow rates through the Saugus River as well as increased direct runoff from the slag pile slopes. The National Park Service (Babson 2014) recommended the development of options for addressing erosion of the slag pile in response to climate change.

The current condition (as of May 2015) of the protective berm is shown in Figure 2, which shows that part of the berm (within the black circle) has been eroded by the flood flows in the Saugus River. From a previous study conducted during 2008 to 2012, CH2MHill (2013) reported that the berm had a general trend of losing gravel particles. Future erosion of the protective berm could be exacerbated by extreme precipitation events, resulting in damage to the smelt spawning habitat.

The Saugus River Watershed Council (LeBlanc 2012), in partnership with the National Park Service, the Massachusetts Division of Marine Fisheries, and the Massachusetts Bays Program, documented the extent of smelt spawning habitat located adjacent to the Saugus Iron Works and identified opportunities to enhance riffle habitat and improve vegetation along the protective berm.

Figure 2. Current condition (as of May 2015) of the protection berm

2. CLIMATE CHANGE

Sea level rise and the change in precipitation patterns are the two major climate change concerns for the site. The climate change projections summarized below are provided to define conceptual design parameters used in Geosyntec's site evaluation and the basis for recommended engineering measures for the slag pile and protective berm. The climate change analysis is not intended to be exhaustive and references existing climate change studies.

2.1 Sea Level Rise

Oceans absorb over 90% of the heat in the atmosphere. Sea level rise is happening as a result of thermal expansion and melting of glaciers and ice sheets and is projected to increase as global temperature continues to increase. Figure 3 shows projected temperature change (represented as the temperature of 2081-2100 compared to that of 1981-2000) for the coldest and hottest days for two possible scenarios from the CMIP5 model (U.S. Global Change Research Program 2015). In Figure 3, Representative Concentration Pathway (RCP) 2.6 scenario assumes a 70% reduction in heat-trapping gas emission by 2050, and RCP 8.5 assumes an unregulated continued increase in emissions.

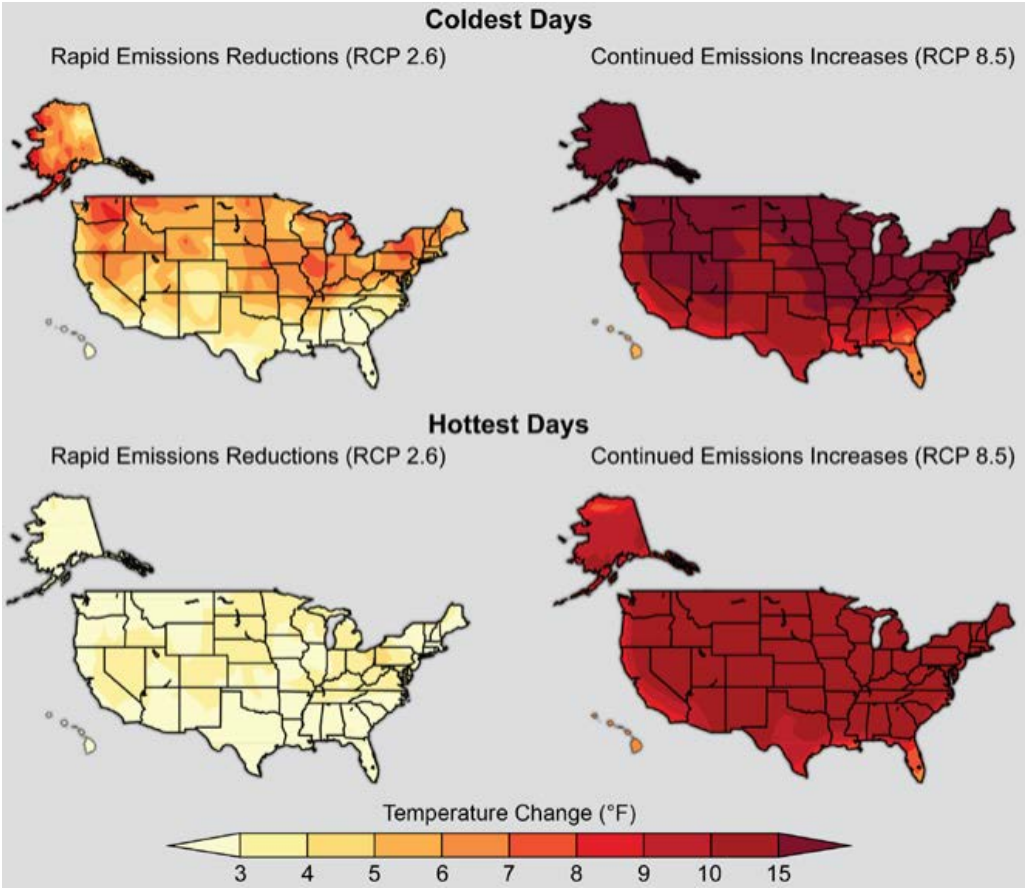

Figure 3. Projected temperature change from the CMIP5 models for two possible emission scenarios (U.S. Global Change Research Program 2015)

Depending on the success of future emission control efforts, the projected sea level rise is highly variable. Figure 4 shows the observed past sea level elevation and projected future sea level elevation. In Figure 4, "proxy records" refers to indirect data such as sediment records. The most likely range of global sea level rise to occur by the year 2100 is 1 to 4 feet, which is the range being considered in this project when evaluating climate adaptation strategies for the Saugus Iron Works site. The historical rate of sea level rise observed at the Boston NOAA tide gauge (0.86 ft./century) has exceeded the global rate shown in Figure 4, which indicates that future sea level rise for the Northeast may be on the higher end of the predicted global rise of 1 to 4 feet.

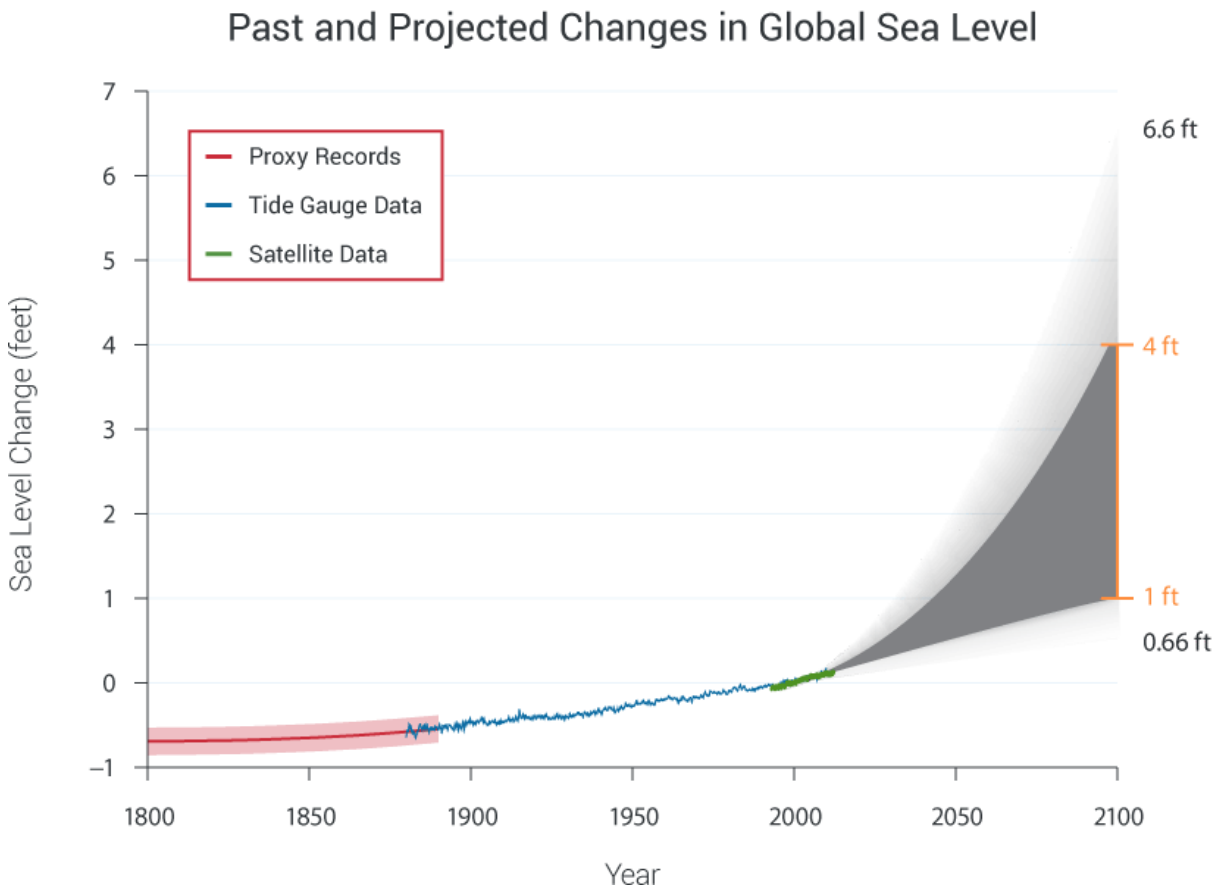

Figure 4. Past and projected sea level rise between 1800 and 2100 relative to year 2000 (U.S. Global Change Research Program 2015).

2.2 Change in Precipitation

Generally, the United States has had increased annual precipitation since 1990 (U.S. Global Change Research Program 2015) and this trend is expected to continue. Figure 5 and Figure 6 show the projected change (seasonal precipitation for 2071-2099 compared to that of 1970-1999) in precipitation from the rapid emission reduction scenario (RCP 2.6) and the continued emission scenario (RCP 8.5), respectively. In the figures, hatched areas indicate that projected changes

are significant and consistent among models (other than CMIP5), and white areas indicate that the changes are not projected to be larger than what could be expected from natural variability. Figure 5 and Figure 6 show that the Northeast will likely experience an increase of 10%-20% in precipitation.

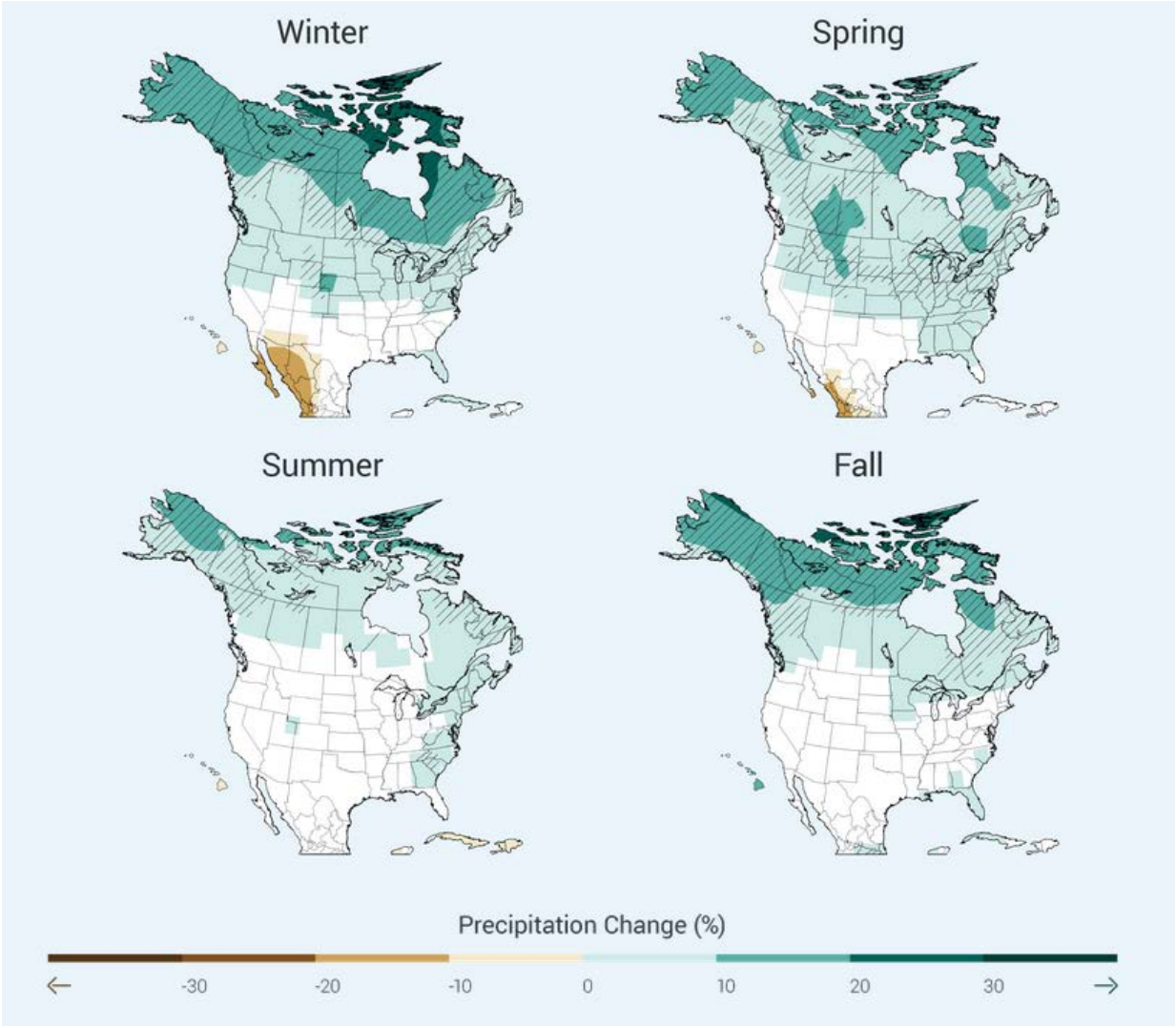

Figure 5. Change in seasonal precipitation for the rapid reduction scenario (RCP 2.6) from the CMIP5 model (U.S. Global Change Research Program 2015)

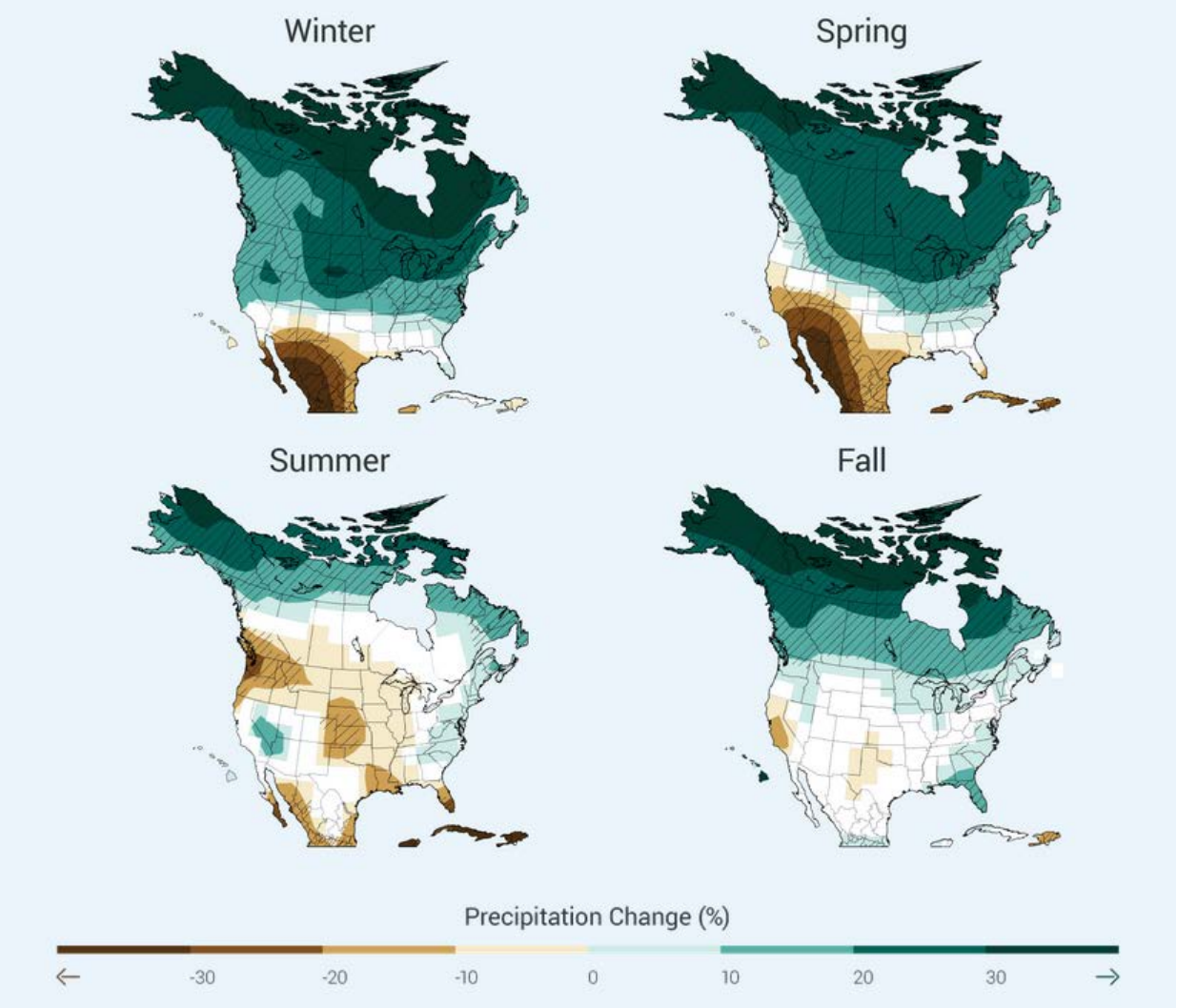

Figure 6. Change in seasonal precipitation for continued emission scenario (RCP 8.5) from the CMIP5 model (U.S. Global Change Research Program 2015)

In addition to long-term precipitation, the frequency of large precipitation events (defined as the heaviest 1% of all daily events) has also increased, particularly in the Northeast. Figure 7 shows the change in the amount of annual precipitation from large precipitation events in this region.

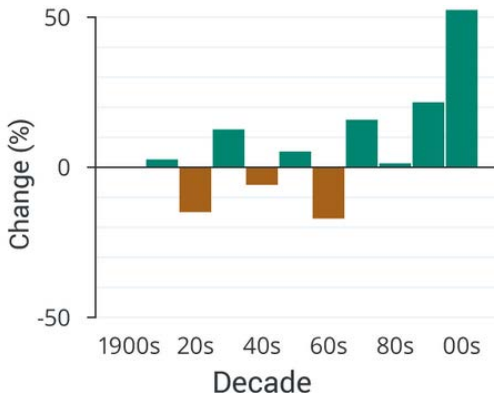

Figure 7. Change in annual precipitation from extreme events in the Northeast region (U.S. Global Change Research Program 2015).

From the simulation results of the CMIP5 climate model, the projected change in frequency (represented as the frequency of 2081-2100 compared to that of 1981-2000) of extreme precipitation events is shown in Figure 8. The projected increase in frequency of extreme events in the Northeast is two times more often in the rapid emission reduction scenario (RCP 2.6), and three to four times more often under the continued emission scenario (RCP 8.5).

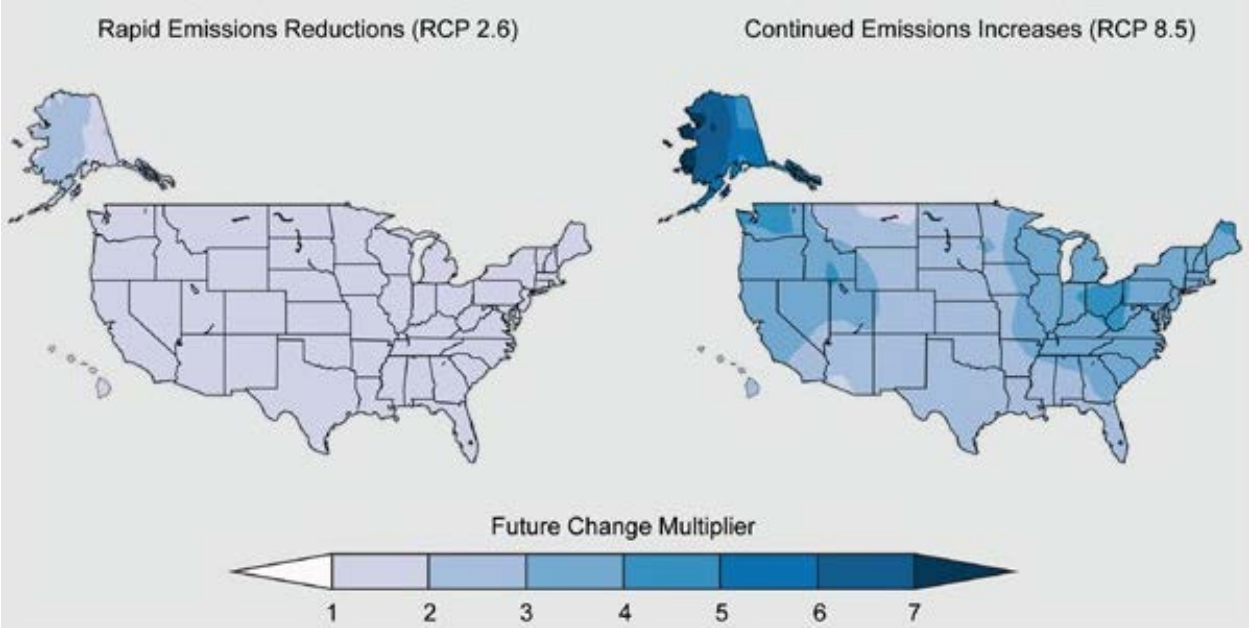

Figure 8. Increase of frequency of extreme events from 1981-2000 to 2081-2100 (U.S. Global Change Research Program 2015).

3. RECOMMENDED ENGINEERING MEASURES

3.1 Slag Pile

The slag pile will be exposed to the combined effects of sea level rise and precipitation changes. These factors could cause slumping of the pile and erosion of the side slopes, resulting in exposed slag and the potential for leaching of contaminants.

Slumping can occur from water seepage into the slag pile and relatively rapid recession of the tide. This repeated motion can create an unstable toe which causes slump. The slag pile is currently covered with riprap and vegetation at the toe of slope, as shown in Figure 9. The riprap and vegetation create good slope protection at the toe of the slag pile for the current water levels.

Figure 9. View of the eastern slope of the slag pile, approximately 2 hours after high tide on May 15, 2015.

As described above, the intensity of extreme events is assumed to increase by a magnitude similar to the change of seasonal precipitation (i.e., 10%-20%). Compounding that with the increased frequency of extreme events (i.e., 2-4 times higher in frequency), the potential of long-

term soil erosion from precipitation is approximately 4.9 times in the worst-case scenario[1]. Geosyntec recommends the following alternatives to reduce these climate change impacts:

1. Regrade the Slope of the Slag Pile

This alternative includes placing a structural, low-permeability soil to regrade the slag pile side slopes. Figure 10 shows a conceptual cross section of this alternative. The side slopes could be contoured to mimic the irregular slopes of the existing pile to preserve the historic accuracy of the pile. From the USLE (Universal Soil Loss Equation) (USDA 1978) calculations, the slope should be regraded from 40° (current) to approximately 20° to cancel the effect of increased storm intensity and frequency. This change will increase the slope length and potentially affect the adjacent dock. A steeper slope (i.e., between 20° and 40°) could be used to accommodate site constraints (e.g., dock area), although this would require additional erosion control. Additional engineering analysis is needed to determine the final slope and soil specifications.

Native, drought tolerant vegetation should be established on the fill slopes to provide long term protection from increased precipitation. The species used for vegetative cover should be carefully selected to meet erosion control needs, aesthetic considerations, and consistency with the historic values of the site.

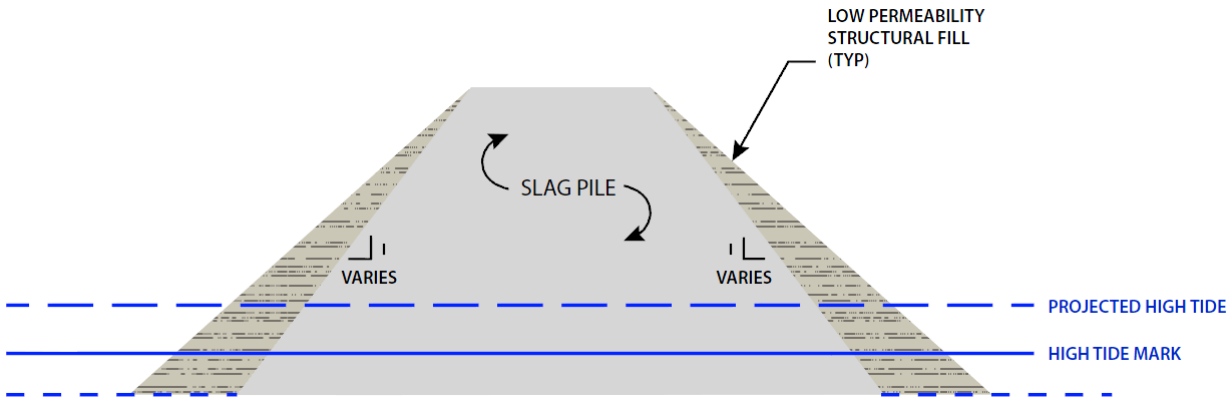

Figure 10. Conceptual cross section of the slag pile before and after slope regrading

2. Remove the Slag Pile and Replicate the Slag Pile with Structural Fill

This alternative includes removing and replicating the slag pile with a structural, low-permeability fill material. The replicated pile could be graded to match the existing slag pile. An engineering analysis would be required to determine the final slope and soil specifications. The intent of this recommendation would be to completely remove the source of potential arsenic contamination from its current location adjacent to the Saugus River, dispose of contaminated

[1] From the USLE (Universal Soil Loss Equation) (USDA 1978), the energy-times-intensity (EI) is calculated by $(916 + 331 \cdot log_{10} I) \cdot I_{30}$ where I is the intensity in inch per hour, and I_{30} is 30-min intensity (USDC 1963). EI is then multiplied by 4 to represent the effect from an increased frequency of extreme events.

materials at an appropriate upland facility, and replace the existing slag pile with an inert interpretive feature. Implementation of this option would require a detailed cost benefit analysis to weigh the environmental impacts associated with disturbing vs. containing contaminants in the slag pile. This option would also require significant environmental permitting and disposal costs, as well as an archeological assessment associated with excavation work.

3. Cover Critical Portions of the Slag Pile with Erosion-Resistant Material

This alternative includes installing erosion-resistant materials to the existing slag pile or fill material (in Alternatives 1, 2 and 4) to protect the underlying material from sea level rise and erosion. Rock armoring could be used as a flexible option to provide slope protection as needed based on observed sea level changes and to stay ahead of future projected changes. Native, drought tolerant vegetation could be established on fill slopes to provide long term protection from increased precipitation. The materials used for rock armoring and vegetative cover should be carefully selected to meet erosion control specifications, aesthetic considerations, and consistency with the historic values of the site.

4. Construct a Buttress around the Perimeter of the Slag Pile Base

This alternative includes constructing a buttress of structural fill around the perimeter of the slag pile. Figure 11 shows a conceptual cross section of this alternative. The buttress will reinforce the toe to increase slope stability and resist slumping, prevent erosion, and provide access to National Park staff for maintenance of vegetation on the slag pile. The height of the bench can also be scalable for future climate scenarios. Armoring described in Alternative 3 could be used to provide additional erosion protection of the toe. Native vegetation could be planted on the top of the bench to provide additional erosion control.

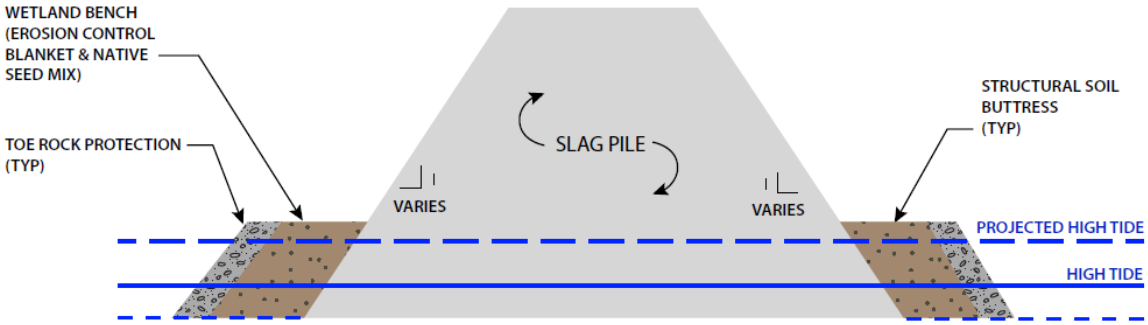

Figure 11. Conceptual cross section for the slag pile with buttress.

5. Final Slag Pile Recommendations

Geosyntec recommends incorporating a combination of Alternatives 1 and 3 for the slag pile. Figure 12 shows a conceptual cross section of the final recommendation. Additional engineering analysis would be required to specify the fill material, side slope geometry, and erosion-resistant material.

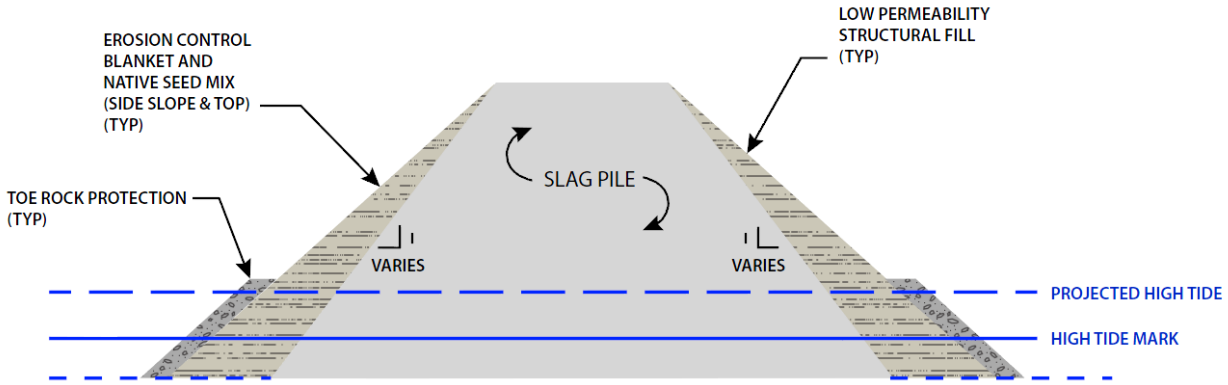

Figure 12. Conceptual cross section of the final recommendation.

The preferred recommendation reflects the most feasible option from a cost and environmental permitting perspective for mitigating potential negative impacts associated with erosion from the slag pile into the Saugus River as soon as possible. The National Park Service may also want to continue evaluating the feasibility of alternative 2 (removal and replication of the slag pile) as a long term option for eliminating this potential source of arsenic contamination to the resource area while retaining the interpretive historic value of this site feature.

3.2 Protective Berm

The protective berm (i.e., cobble berm) has the potential to further erode and degrade under future climate change conditions. Table 1 shows the particle distribution change from 2008 to 2012 (CH2M Hill 2013).

Table 1. Change in particle distribution at the center section of the berm from 2008 to 2012.

	2008	2012
Sand (< 2mm)	12%	38%
Very fine gravel (2-4 mm)	2%	0
Fine gravel (5-8 mm)	4%	4%
Medium gravel (9-16 mm)	10%	8%
Coarse gravel (17-32 mm)	36%	20%
Very coarse gravel (33-64 mm)	34%	20%
Small cobble (65-90 mm)	2%	8%
Medium cobble (91-128 mm)	0	2%
Large cobble (129-180 mm)	0	0

As shown in Table 1, the particle distribution became increasingly bimodal from 2008 to 2012. This could be because this section of the river is still experiencing geomorphology changes to the bed material placed in 2008. These changes include degradation as the gravel component has been transported, leaving the heavy cobbles behind and exposing the underlying sands. Bunte

and Abt (2001) report that a bimodal sediment distribution could also be a sign of changes in the upstream sediment sources.

Geosyntec recommends reinforcing the existing protective berm with large diameter boulder and cobble rock to reduce erosion and help dissipate stream velocity in flood flows and direct these flows toward the river channel and not through the protective berm. Cobbles of medium (91-128 mm) or larger (129-180 mm) sizes are recommended for this approach. The selected cobble sizes are in the depositing size range according to Table 1, and are within the depositing size range with a 20% increase in peak flow rate under projected extreme precipitation[2]. Geosyntec also recommends evaluating a hydraulic model of the bridge, river, and protective berm area to verify that this recommendation would not cause degradation of the smelt spawning habitat.

Efforts to ensure long-term integrity of the protective berm via installation of boulders and cobble would need to be implemented in close coordination with previously recommended opportunities to enhance smelt spawning habitat (LeBlanc 2012) as outlined in the Saugus River Watershed Council's Final Report on the Saugus River Smelt Spawning Habitat Assessment. In consultation with the Massachusetts Division of Marine Fisheries and the National Park Service, that report recommended improving and enhancing riffle habitat by conducting strategic grooming of the river substrate. Several potential restoration / enhancement sites are located both upstream and downstream of the Saugus Iron Works bridge. River grooming upstream of Bridge Street in the vicinity of the old dam should focus on improving fish passage to enhance upstream spawning opportunities. Grooming adjacent to the Saugus Iron Works should focus on expanding riffle habitat and improving slope at specific locations to aid upstream passage.

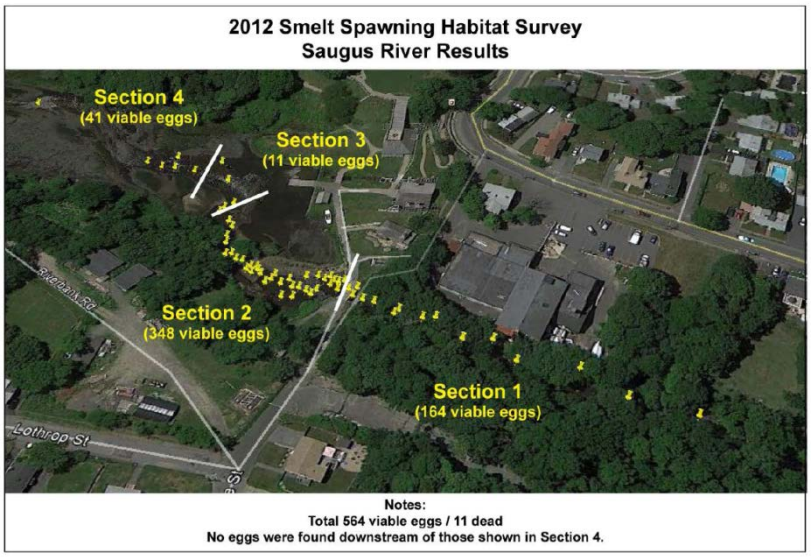

Figure 13. Smelt spawning activity adjacent to the protective berm (Section 2).

[2] From Table 1, the depositing size range starts at small cobble (65-90 mm), which can stand a flow velocity of around 6.5 feet per second (Environmental Protection Division 2015). A 20% increase in flow velocity gives a value of 7.8 feet per second. The mean size of stone to just withstand that flow velocity is around 4.6 inches (117 mm), which is close to that of "medium cobble" in Table 1.

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