Weirs Beach Phase II Report

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February 2015

Photos courtesy of www.weirsbeach.com

PHASE II: ALTERNATIVE ANALYSIS FOR THE WEIRS BEACH SAND MIGRATION STUDY
LACONIA, NEW HAMPSHIRE

FINAL REPORT

February 2015

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1.0 INTRODUCTION

This report presents the results for Phase II of the Weirs Beach Sand Migration Study, which consists of a pre-engineering alternative analysis and recommendations geared towards restoration of the Weirs Beach area. Woods Hole Group, Inc. performed the Phase II analysis on behalf of the City of Laconia, New Hampshire and follows a Phase I study that evaluated the physical processes acting on Weirs Beach. Specifically, Phase I was a planning level study that provided a detailed assessment of coastal processes, data observations, wave transformation modeling, and sediment transport modeling in order to develop preliminary alternatives for mitigating erosion at Weirs Beach (Woods Hole Group, 2013). The Phase II scope of work follows up on the results and recommendations from the Phase I scope of work and evaluates the Phase I recommendations in order to assess their potential performance for mitigation of the ongoing erosion at Weirs Beach. Specifically, Phase II consists of an alternative analysis, recommendation of preferred alternative(s) or approach, and final documentation for the overall project. Phase II also represents the first step in the design process by providing a recommended conceptual engineering approach that could be used for more detailed engineering design and permitting.

The primary purpose of this pre-engineering alternative assessment is to evaluate solutions that:

- Maintain or improve current beach usage for a range of valuable recreational activities (beach goers, swimmers, walkers, etc.)
- Maximize beach lifetime
- Minimize potential adverse impacts to neighboring shorelines, marine navigation, and the environment
- Protect existing upland infrastructure from a return period storm
- Be cost effective
- Minimize shoaling in the Weirs Channel and areas to the south

Engineering alternatives were evaluated by using the existing site-specific coastal processes (i.e. winds, waves, sediment transport) from Phase I, and then determining the impact of the alternatives based on the coastal processes. The feasibility evaluation consisted of an alternative analysis that provides recommendations for a conceptual design based on the physical processes at Weirs Beach.

2.0 PHASE I SUMMARY

This section provides a brief review of the Phase I study results (Woods Hole Group, 2013) relevant for Phase II alternatives evaluation, including:

- Data Collection
  - Water Levels
  - Wind data
  - Bathymetry
  - Sediment Grain size
  - Beach Surveys
- Coastal Processes Modeling
  - Wave transformation
  - Sediment transport modeling

A more complete discussion of all the coastal processes impacting Weirs Beach, as well as the erosion causes, can be found in Woods Hole Group (2013).

Water Levels - Woods Hole Group utilized all the lake level data between 2006 and 2012 to determine the variations in water level that occur within Lake Winnipesaukee. These data were used to determine the average annual lake level for use in simulation of an average annual year in the wave model. The lake level data were also used to determine the extreme lake levels that may occur over time (i.e., the maximum lake levels).

Sediment Grain Size - A grain size analysis was performed on eight samples extracted from Weirs Beach. The analysis determined that the majority of the material was relatively homogenous, containing approximately 94% medium to coarse sand. The mean grain size was determined to be approximately 0.3 mm, which is classified as medium sand based on the Wentworth scale.

Wind data - In an enclosed water body such as Lake Winnipesaukee, the primary wave generation mechanism is the wind. In addition, Aeolian sediment transport (wind-blown sand) is also an important aspect of the sand movement at Weirs Beach. Long-term wind data (27 years) were acquired from the Weirs Beach Weather Station, KNHWEIRS3. The most dominant wind was from the west, important from an Aeolian transport perspective, while winds from the northeast, north, and northwest were important from a wave generation standpoint.

Bathymetry - A depth contour chart from February of 1966 which was prepared by the New Hampshire Fish & Game Department (Figure 3-4) was digitized and used to define the offshore bathymetry. These data were also supplemented with more recent bathymetric data and beach profile data collected by the City of Laconia.

Beach Surveys - To provide an improved understanding of the dynamic nature of Weirs Beach, the City of Laconia surveyed the beach using cross-shore beach profiles three times during 2011 and 2012. The surveys were conducted on July 20, 2011, November 9, 2011 and June 7, 2012. These data were invaluable to provide not only the conditions of the beach for use in the coastal modeling, but also to provide an estimate of the annual sediment loss. The survey data were used to identify the observed beach profile evolution, which was useful in validating and understanding model results and other predictions of sediment transport.

Wave Transformation and Sediment Transport Results - Figure 2-1 provides a summary of the sediment transport processes that shape and move sediment at Weirs Beach. This figure was developed from modeling of the wave climate and sediment transport patterns impacting Weirs Beach. The red arrow represents the alongshore, wave-driven sediment transport, which over an average annual year is approximately 500 cubic yards per year to the east. It is likely that a portion of this material is transported around the seaward end of the Weirs channel jetty and is deposited in the channel or transported to the south into Paugus Bay and eventually deposits in the various marinas and boating dock areas to the south. The black arrow represents the Aeolian (wind-blown) sediment transport, which over an average annual year is approximately 600 cubic yards per year. It is likely that a portion of this material is blown over the low profile jetty and into Weirs channel to the same fate as the along-shore driven sediment (deposited to the south in Weirs channel). The blue arrow represents the cross-shore wave-driven sediment transport due to storms and boat wakes, which over an average annual year is highly variable, but generally is around 100 cubic yards per year. The combined annual modeled erosion on the beach was calculated to be approximately 1,200 cubic yards per year, which matched reasonably well with the observed annual erosion (1,275 cyd/yr) measured from profile data (Woods Hole Group, 2013).

These data and models, developed in the Phase I study of existing conditions, were used in the evaluation of alternatives to quantify the performance of various alternative solutions.

Figure 2-1. Combined sediment transport processes and sediment budget at Weirs Beach.

3.0 ALTERNATIVE DEVELOPMENT AND SCREENING

The Woods Hole Group Phase I Report (Woods Hole Group, 2013) identified over ten alternatives in the initial evaluation of potential solutions to the erosion occurring at Weirs Beach. This list was refined to six (6) alternatives through better understating of the existing conditions at the site, which eliminated some the alternatives considered, as presented in Phase I,. For example, seawalls and revetments were ruled out due to the relatively low littoral transport rate and recreational beach usage. The final set of recommended alternatives that were considered in the detailed alternatives analysis presented herein included:

- No action
- Targeted sand fencing
- Weirs Channel jetty enhancements
- Manual backpassing
- Beach nourishment
- Beach nourishment with adjustable groins

3.1 NO ACTION

The no action alternative implies there would be no change to the present conditions at Weirs Beach. Although this is not the preferred alternative for the City, nor recommended by Woods Hole Group, this alternative will be required to be evaluated as part of the regulatory process. Under this action the beach will continue to erode at a rate of approximately 1,200 cy/yr. This is an undesirable outcome for the City of Laconia and eventually Weirs Beach may become relatively unusable. Therefore, the “no action” alternative is not recommended for further consideration.

3.2 TARGETED SAND FENCING

Aeolian transport is a significant contributor to the sediment movement at Weirs Beach. This alternative evaluates the installation of targeted sand fencing and/or drift fencing along the east end of Weirs Beach to limit the amount of sediment that is being lost from the beach by Aeolian transport. Sand fencing has been used successfully in the mitigation of the Aeolian transport of sand along beaches by acting as a sand trap and, as a result, building the beach and/or foredune. Field tests of dune building with sand fences under a variety of conditions have been conducted at Cape Cod, Massachusetts, Core Banks, North Carolina, and Padre Island, Texas. Sand fences are relatively inexpensive, can be installed during any season, and can be immediately effective. They can also be easily adjusted or removed as necessary. Therefore, sand fencing system at Weirs Beach may include seasonal placement and removal. Chapter 4 further evaluates the potential impacts and performance of sand fencing at Weirs Beach.

3.3 WEIRS CHANNEL JETTY ENHANCEMENTS

Currently, it is likely that a significant amount of the wave driven sediment is transported around the end of the existing jetty, as well as over the top of the jetty from the dry beach. This alternative evaluates extending the length and/or raising the elevation of the jetty to reduce the amount of sediment transported around the end or over the top of the

jetty into Weirs channel. The technical evaluation of potential jetty enhancement is presented in Chapter 4.

3.4 MANUAL BACKPASSING

Manual backpassing consists of recycling existing sediment on the beach. This manual backpassing approach consists of mechanically moving sand from an area of accretion (downdrift) back to an area of erosion (updrift) within a littoral cell or beach on an incremental basis. The physical transport would likely consist of minimal construction equipment (e.g., excavator, haul truck, bulldozer) to move the material. The interval of re-occurrence would be dependent on the amount of material moved each episode. This approach has been successfully implemented at other beaches (e.g., New Jersey coastline). This alternative is a supplemental maintenance approach that would need to be coupled with another initial mitigation alternative. The evaluation of manual backpassing is further evaluated in Chapter 4.

3.5 BEACH NOURISHMENT

One of the primary causes of coastal erosion is a deficit of sediment within the coastal littoral cell, which is a key factor in the erosion of the Weirs Beach. While there is sediment leaving the Weirs Beach system (primarily to the east), there is not a significant source of sediment arriving at the beach (i.e., no source of sand to the west). To offset this deficit, nourishing the beach with compatible sediment placement is a logical means for improving the longevity of the shoreline, where such a project is economically feasible. Beach nourishment does not stop erosion. Rather, the damage to landward properties or loss of a recreational beach, is postponed by extending the shoreline toward the ocean. At a site like Weirs Beach, the beach can provide both a damage protection and a recreational benefit.

Beach nourishment is typically the most non-intrusive technique for coastal protection and involves placing sand, from an offshore or upland source, in a designed template on an eroding beach. Figures 3-1 and 3-2 present examples of beach nourishment projects under construction. Beach nourishment is intended to widen the beach, as well as provide added storm protection, increased recreational area, and in some cases, add habitat area. Although nourished sand is eventually displaced alongshore or transported offshore, the nourished sand that is eroded takes the place of the upland area that would normally have been lost or eroded during a storm event. Therefore, beach nourishment serves a significant role in storm protection. In addition, beach nourishment is the only alternative that introduces additional sand into the system. For coastlines with a dwindling sediment supply, such as Weirs Beach, this is critical for long-term success. Solutions that do not involve beach nourishment typically involve rearranging the existing sand in a manner that will only benefit a portion of the beach.

Figure 3-1. Beach nourishment project under construction.

Figure 3-2. Beach nourishment project under construction in Virginia Beach, VA (photo courtesy of Virginia Beach).

Environmental concerns with beach nourishment projects include the potential for decreased water quality when sediments are dredged and deposited, and disturbing

natural habitat when removing or depositing the dredged material. Grain size compatibility between the borrowed and native beach sediments should be maximized in order to increase the lifespan of the nourished beach. For example, large differences in grain size between the native and borrow material may lead to changes in beach slope through natural adjustment of the new grain size introduced to the beach.

The many benefits of beach nourishment, and the ability to control potential negative environmental impacts with careful design and planning, make beach nourishment a viable alternative for Weirs Beach. A beach fill project for this area would mitigate the on-going erosion, improve storm damage prevention and flood protection to infrastructure, and improve the recreational resource of the beach.

A successful beach nourishment project consists of more than simply placing sediment on a beach. Beach nourishment projects are engineered. A beach nourishment template, which consists of numerous design parameters, is based on the characteristics of the site and the needs of a project and needs to be optimized. Every beach nourishment design is unique, since different beaches in different areas have different physical, geologic, environmental, and economic characteristics, as well as different levels of required protection. The design must consider climatology, the shape of the beach, type of native sand, volume and rates of sediment transport, erosion patterns and causes, waves and water levels, historical data and previous storms, probability of certain beach behaviors at the site, existing structures and infrastructure, and past engineering activities in the area. As such, beach nourishment design must identify the coastal processes at the site. Typically, computer models are used to help design the nourishment template.

The structure of a nourishment template is designed to yield a protective barrier that also provides material to the beach. A higher and wider beach berm is designed to absorb wave energy. In some cases dunes can also be constructed, or existing dunes improved, to reduce damage, including potential upland flooding, from storms (although for smaller lake setting such as Weirs Beach, dunes are not necessary). Figure 3-3 depicts a beach berm and dune on a typical beach profile. Nourishment length, berm height and width, dune height, and offshore slope are critical elements of a beach nourishment design, depending on the site-specific nature of a beach. Periodic renourishment intervals are also usually a part of the nourishment design. As a rule of thumb on an ocean coastline, if renourishment is required in less than 5 years, then the nourishment is probably not cost-effective. If renourishment is required between 7-10 years, then a nourishment project is likely cost-effective. The renourishment interval will vary based on the initial design, wave climate, sand used, number and types of storms, and project age. In addition, beach nourishment is not an exact science; variables and uncertainties exist. Actual periodic renourishment intervals may differ from planned intervals based on conditions at the nourished beach and the frequency and intensity of storms from year to year.

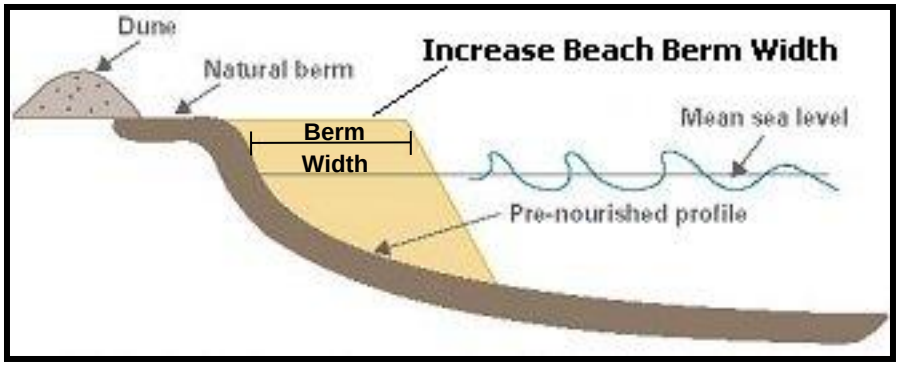


Figure 3-3. Example of increasing the berm width on a beach through beach nourishment (not to scale – vertical scale is exaggerated).

For Weirs Beach, beach nourishment is a recommended component that should be included in any considered alternative approach. Weirs Beach currently is suffering from a lack of available sediment, and the only way to increase the existing sediment volume on the beach is to add material. For example, while adding sand fencing or extending the Weirs Channel jetty may slow the loss of existing sediment from Weirs Beach, these solutions cannot add sediment to the beach. A beach nourishment project would enhance the conditions at Weirs Beach by expanding beach width, length, and protective capacity. The nourishment project would also likely improve the recreational draw of the beach. While beach nourishment alone is a viable alternative, a beach nourishment project could also be coupled with any of the other mitigation alternatives considered (e.g., sand fencing, manual backpassing) to extend the performance and engineering service life of the beach system. Chapter 4 evaluates the performance of a potential beach nourishment project.

3.6 Beach Nourishment with Adjustable Groins

Woods Hole Group also recommends that any beach nourishment may want to consider potential installation of adjustable groin(s) to help stabilize the beach. An example of an adjustable groin is shown in Figure 3-4. In some cases, groins are included in a nourishment project to reduce the forces that cause rapid sediment losses and extend the time between renourishment events. In order for this alternative to be effective at Weirs Beach, it is likely that a groin field consisting of more than a single groin may need to be constructed. These groins would be significantly different than the historic groins that were along Weirs Beach and are intended to be easily adjusted such the sediment allowed to bypass or retained by each structure can be controlled. This would allow the City to adaptively manage the beach to help try to extend the beach nourishment service life and performance and thus reduce the potential maintenance requirements of the beach nourishment. The adjustable groin alternative would need to be coupled with a beach nourishment project to reasonably fill the beach structures. Simply placing groins on the beach without supplemental sediment would not provide functional performance and may result in negative impacts to the beach caused by the interruption of the littoral drift. The evaluation of adjustable groins, in concert with a beach nourishment project, is presented in Chapter 4.

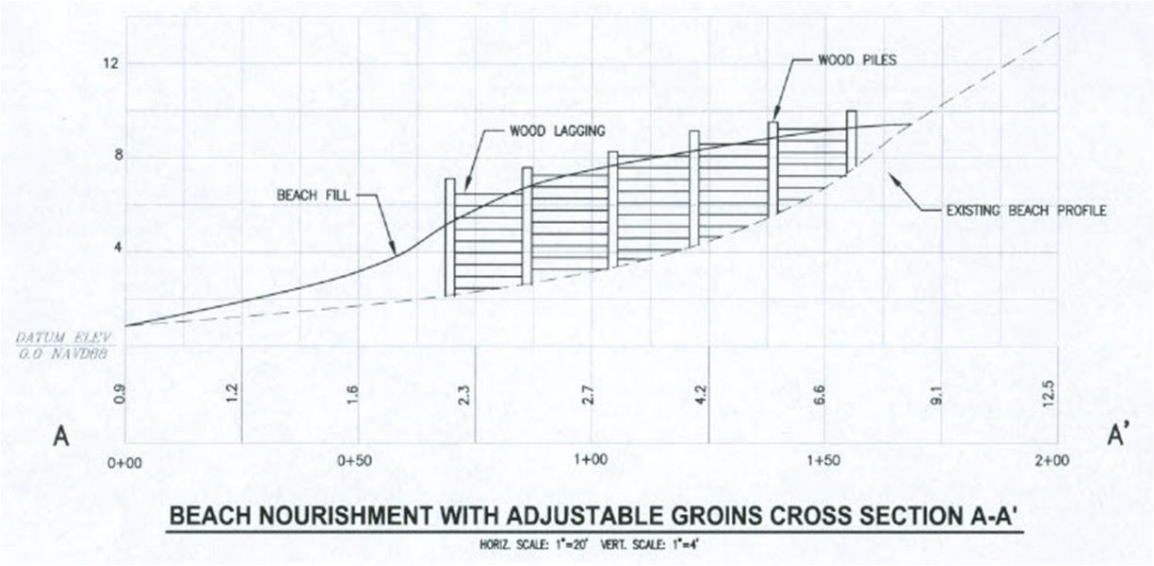


Figure 3-4. Beach nourishment with adjustable groins cross section.

4.0 ALTERNATIVE ANALYSIS

The primary purpose of this engineering alternative analysis is to assess options for reducing erosion and improving Weirs Beach. An alternatives analysis is the basis for determining the optimal solution and assessing potential impacts, both physical and environmental. A variety of factors are considered when evaluating the various alternatives (e.g., cost, feasibility, performance, environmental impacts, constructability, etc.), with the overall objective focused on selecting the optimal solution. As such, the goal of the assessment is to evaluate reasonable, practicable, and feasible alternatives that will achieve the goals and objectives of the project, while minimizing the short and long-term adverse effects, if any. In some cases, there are numerous potential alternatives that may be technically feasible, or a combination of alternatives that may supplement each other.

Decisions regarding management of Weirs Beach can only be made after a thorough evaluation of both the coastal processes and available erosion mitigation alternatives. The following chapter presents and evaluates a variety of alternatives identified in Section 3.

4.1 TARGETED SAND FENCING

The Shore Protection Manual (SPM, 1984) provides some basic guidelines for the construction of sand fencing. The basic specification includes a fence that is 4 ft high with 1.5 inch wide slats (pickets) with similar width spacing to provide approximately 50 percent porosity. Snow fencing constructed of individual wooden slats bound with wire is most commonly used due to cost, availability, effectiveness, and ease of installation; however, geosynthetic fabrics have also been successfully employed. Placement of the fence must be far enough back from the waters edge in order to limit wave attack; however, in this case the sand fencing should be placed far enough away from the Weirs channel to allow sediment to be captured on the beach and prior to entering the channel. Sand fencing requires periodic inspection of the installation, replacement of damaged or vandalized fencing, and installation of new fencing to continue the stabilization process. Sediment trapping by sand fences is not a constant process and can vary by location, season, and year to year. Fences can be more effective during short periods of high winds than prevailing winds. A rendition of sand fencing installed at Weirs Beach is provided in Figure 4-1. The recommended sand fencing in this case would capture wind-blown sediment before it is transported and deposited in the water of Weirs channel. Public works could determine if they want the sand fencing to be deployed seasonally (e.g., removed during peak summer times) or remain in place for the majority of the year. Sediment captured by the sand fencing could either be left in place to build a mound of sediment or could be redistributed back to the west along the beach in a manual backpassing (maintenance) based approach.

Figure 4-1. Rendering of potential sand fencing installed on Weirs Beach parallel to the jetty.

Past studies along typical ocean beaches have shown that the trapping capacity of a single 4-foot-high sand fence averages between 4 to 6 cubic yards per linear foot and will fill to maximum capacity within 1 year. It is estimated that approximately 150-200 linear feet of sand fencing would be required along the beach facing the channel between the jetty and parking lot. Therefore, theoretically, appropriately installed sand fencing along the eastern edge of Weirs Beach could potentially trap up to 600 cubic yards of sand per year, essentially equivalent to the annual Aeolian transport rate. However, at Weirs Beach, it is unlikely that the trapping efficiency of the sand fencing will be enough to fill to capacity within one year due to small scale of the beach and relatively light prevailing winds. The amount of time, T, for the sand fencing to fill to capacity can be estimated by Equation 4-1

$$T = [\rho\, H \cot(\alpha)]/Q \qquad (4\text{-}1)$$

where ρ is the apparent density, H is the height of the sand fencing, and α is the angle of repose of the sand (Hotta et al., 2010). The calculation suggests that it could take as much as 7.7 years for the sand fence to fill to capacity.

Once the sand fence has filled to capacity it will not trap any additional sand. Sand fencing would likely limit the amount of material transported by the wind from the beach to the navigational channel; however, it would do little to improve beach width or berm height outside of the immediate vicinity of the sand fence. As such, a manual

backpassing program, which would move the captured sand back to the western part of the beach, could be implemented to help enhance the performance of the sand fencing and reduce the sediment entering Weirs Channel. The SPM (1984) estimated that an average of 6 man-hours are required to erect 200 feet of wooden, picket-type fence by a six-man crew using a posthole digger and materials onsite. The cost to installed sand fencing is estimated to be $36 per linear foot (Khalil, 2008). Sand fencing is an alternative that is generally inexpensive and straight forward to construct, but it alone would do little to mitigate the overall erosion of the beach. It is an alternative that could be employed in conjunction with other alternatives such as beach nourishment or jetty enhancements and certainly should be considered to reduce the wind-blown loss of material at Weirs Beach.

4.2 MANUAL BACKPASSING

Manual backpassing consists of the physical transport of sand from the end of the littoral cell to the beginning of a littoral cell in order to recycle sediment. Sand would be moved from the end of the littoral cell at the eastern portion of the beach adjacent to the jetty, to the western portion of the beach. This alternative would likely consist of minimal construction equipment (e.g., excavator, loader, bulldozer) to move the material. The interval of re-occurrence would be dependent on the amount of material moved each episode and the conditions occurring any individual year; however, it is likely that this would need to be conducted every 2 to 3 years. All of the material naturally transported from the western beach is not directly obtainable by simple mechanical excavation. Although this method can provide some additional material to the eroding western portion of the beach, the existing sediment supply on the beach will not supply enough material to fully stem the background erosion rate of 1,200 cyd/yr. Therefore, manual backpassing would require additional sediment supplements as well. Manual backpassing is recommended for further evaluation as a potential cost saving approach performed in concert with other alternatives, and as a supplemental source to recycle sediment as needed. For example, manual backpassing of the wind-blown material capture by the sand fencing may be a reasonable maintenance program to consider.

4.3 JETTY ENHANCEMENTS

The existing jetty at the eastern end of Weirs Beach could be enhanced (extended seaward, elevation increase) in order to reduce the amount of material lost from the beach into Weirs channel. The existing jetty starts approximately 150 feet from the furthest landward end of the beach and extends for approximately 100 feet into the lake. The enhancements would include lengthening the jetty to reduce sediment transported around the seaward end and/or raising the jetty height in order to mitigate the loss of material transported over the jetty (primarily by Aeolian transport). Raising the jetty would have a similar effect as sand fencing in that it would trap windblown sand. Theoretically, the maximum amount of sand that could be trapped by the jetty would be a triangular shaped wedge on the windward side of the jetty with the slope at the angle of repose of the sand (approximately 34°). The potential benefits of incrementally raising the jetty height 1, 2, and 3 feet was analyzed for two cases including 1) the existing jetty footprint and 2) extending the jetty landward to the back of the beach (approximately 150 feet). The results shown in Table 4-1 indicate that increasing the jetty height and jetty footprint will

increase the amount of windblown material sediment trapped by the jetty; however, these volumes are generally small and less than the sediment volume trapping estimates for sand fencing. Therefore, there is little justification for increasing the elevation of the existing structure, specifically the beach and landward section of the jetty. The same benefit is likely to be attained from a much less costly sand fencing approach. Increasing the elevation of the existing jetty, or extending it further landward, would be costly and have limited benefit. As such, increasing the jetty elevation is not recommended.

Table 4-1. Volume of material trapped on dry portion of beach due to jetty enhancements.

Incremental Jetty Height Increase (ft)	Volume of material (cyd) trapped by raising jetty height	Volume of material (cyd) trapped by raising jetty height and extending footprint landward 150 ft
1	8	20
2	33	83
3	74	185

While increasing the elevation of the existing jetty was evaluated and determined to have limited benefit, lengthening the existing jetty further seaward to intercept a larger portion of the alongshore transport was also evaluated (Figure 4-2). The impacts of lengthening the jetty seaward can be quantified by calculating the cross-shore distribution of the alongshore sediment transport using relationships proposed by Longuet-Higgins (1970, 1970a). Using the cross-shore distribution, the effect of a shore-perpendicular structure (e.g., jetty, groin) on the alongshore sediment transport can be estimated. In other words, increasing the length of the jetty will reduce the amount of material transported into Weirs channel and retain more material on the beach.

The cross-shore distribution of longshore transport can be determined using a theoretical radiation stress approach (Longuet-Higgins and Stewart, 1962). This momentum based theory describes the energy imparted on the bottom of a nearshore breaking zone by shallow water waves. When shallow water waves break at an angle that is not perpendicular to the coastline, the result is a net force that pushes a parcel of water in the direction of the oblique angle, and in turn moves sediment. In the case of a series of multiple waves breaking at a similar angle; a net current results that continually forces water along the shore (or alongshore). The total volume flow rate, Q, is given as a function of velocity, v_o, as

$$Q = \frac{1}{3s} {h_B}^2 v_0 = \frac{1}{3} h_B |x_B| v_0 \qquad (4\text{-}2)$$

where h_B is the depth of water at the breaker line, s is the slope of bottom, and x_B is the normalized distance to the breaker line.

Figure 4-2. Rendering of lengthening the existing jetty.

Horizontal mixing is the result of waves breaking at different locations and wave-induced eddies varying the profile of the cross-shore velocity distribution. To account for this variability due to mixing, a quadratic equation is used to create a typical cross-shore flow profile. This distribution is calculated based on site-specific physical processes data and modeling results for Weirs Beach, and is presented in Figure 4-3. The vertical axis presents the water flux in cubic feet per second (used as a proxy for the sediment flux distribution), while the horizontal axis presents the cross-shore distance. The distribution can then be applied to assess the impact of the lengthening the jetty by determining the amount of littoral transport that may be intercepted by the extension. The distribution shows that the majority of the longshore sediment transport (95%) is occurring within 20 feet of the beach assuming that the jetty is non-permeable. Therefore, extending the jetty length 20 feet would only allow 5% of the existing littoral transport (approximately 25 cubic yards per year) to bypass the jetty. Therefore, a minor jetty extension and sand tightening, coupled with a potential beach nourishment project is a viable alternative to consider at Weirs Beach. The jetty extension would serve two purposes. First, the extension would reduce the amount of material that migrates into Weirs channel, and eventually shoals in navigation channels or docking areas. Second, the jetty extension would serve to maintain Weirs Beach, and improve the performance of any beach nourishment project conducted.

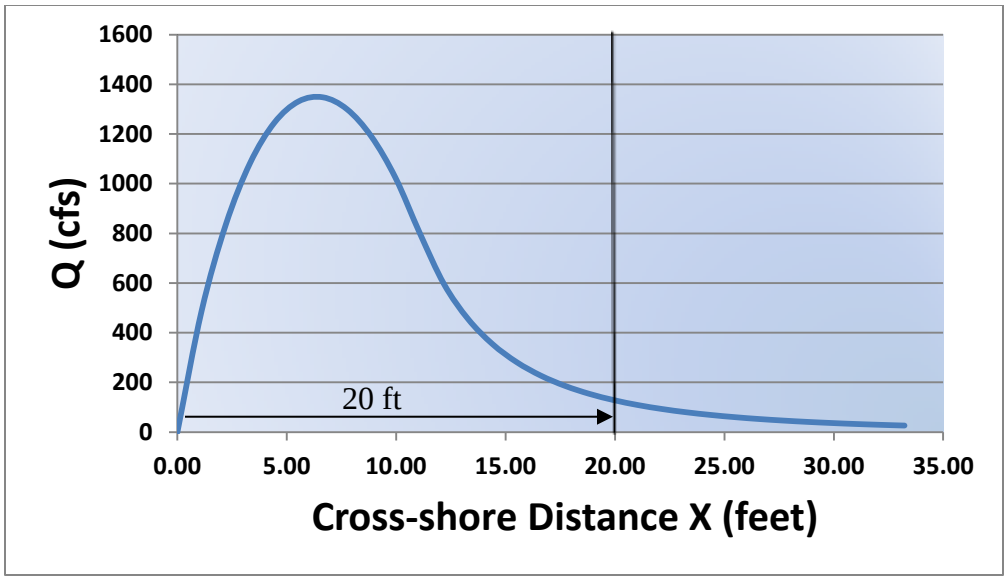


Figure 4-3. Cross-shore distribution of along shore flux for Weirs Beach.

The impacts of jetty enhancements including raising and/or lengthening the jetty were evaluated. Raising the jetty height and extending it landward would trap only a small volume of sand along the dry portion of the beach and is not recommended due to the significant cost and limited benefit. Lengthening the jetty seaward would result in a significant reduction in amount of material transported out of the beach system and into Weirs channel. Overall, the jetty lengthening alone would not provide adequate restoration to Weirs Beach, but this alternative could be considered as a component of an overall restoration program (e.g., coupled with beach nourishment).

4.4 BEACH NOURISHMENT

The purpose of the beach nourishment alternative is to evaluate replenishing sediment that has been eroded and lost from the littoral cell by introducing new sediment into the Weirs Beach system. In an effort to provide an improved understanding of the dynamic nature of Weirs Beach, the City of Laconia surveyed cross-shore beach profiles on July 20, 2011, November 9, 2011 and June 7, 2012. The location of the beach profiles are shown in Figure 4-4. The figure shows the exact location of the survey points made on each of the three surveys. The blue x markers show the points observed on July 20, 2011, the red circles show the points observed on November 9, 2011, and the green stars show the survey points observed on June 7, 2012. The individual transects (or profiles) are labeled with a nomenclature A through I (from west to east), with a far eastern transect labeled Z. This survey information was then used to provide valuable information for the wave and sediment transport modeling, and also served to provide the basis for beach nourishment template design.

A variety of beach nourishment designs were tested to determine the optimal, yet reasonable size and cost, design template. Distribution of fill material over the beach face is most effective when the fill forms a profile slightly steeper than the expected

equilibrium profile, (Dean and Dalrymple, 2002). Initial erosion of the exposed recreational beach occurs as the equilibrium cross-shore profile develops. Some material is moved offshore, but is not lost, as it serves to dissipate wave energy naturally during winter months. Figure 4-5 presents the approximate extension of the Weirs Beach shoreline where the orange line in the right hand panel shows the total proposed increased beach width. The cross-sections for the surveyed transects used to develop the proposed nourishment template are shown for select profiles in Figure 4-6. The nourishment template (red line) was constructed over the existing profile (black line). Woods Hole Group does not recommend expanding the beach width much further than presented in the proposed cross-sections. Further expansion of the beach width may result in undesired shoaling in the vicinity of public docks (inhibiting vessel draft and access), and/or increased sedimentation into Weirs channel jetty and Paugus Bay.

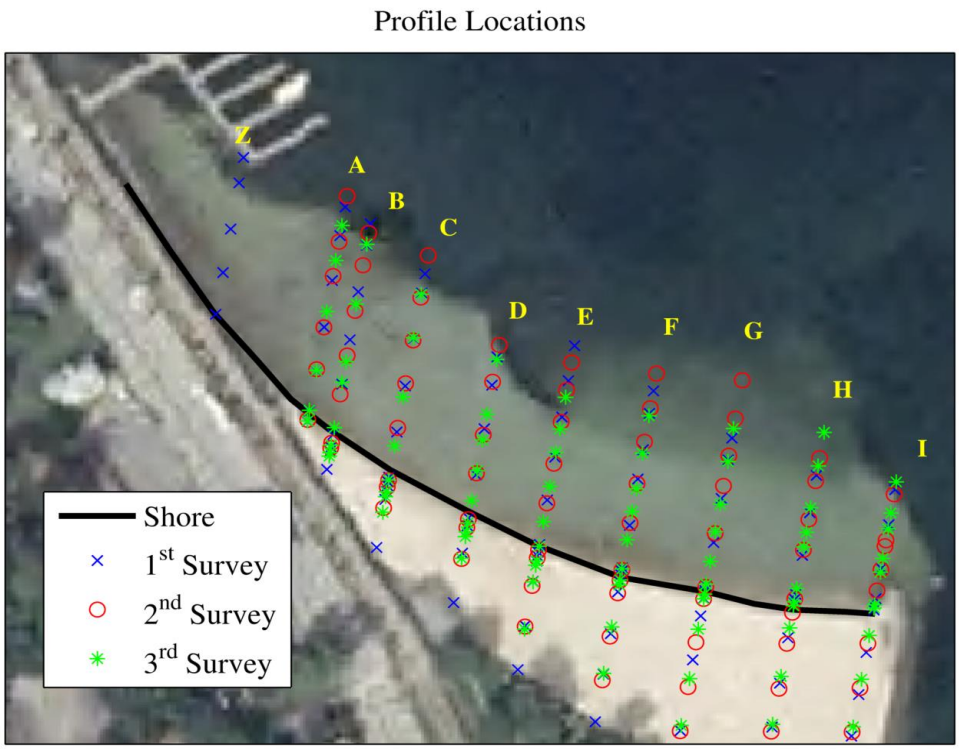


Figure 4-4. Location and nomenclature of transects observed at Weirs Beach. The survey points are also shown as individual markers.

Figure 4-5. Existing conditions (left panel) and approximate extension of proposed nourishment (orange line in right panel). This represents approximate expansion of width only.

The design was engineered based on the following parameters:

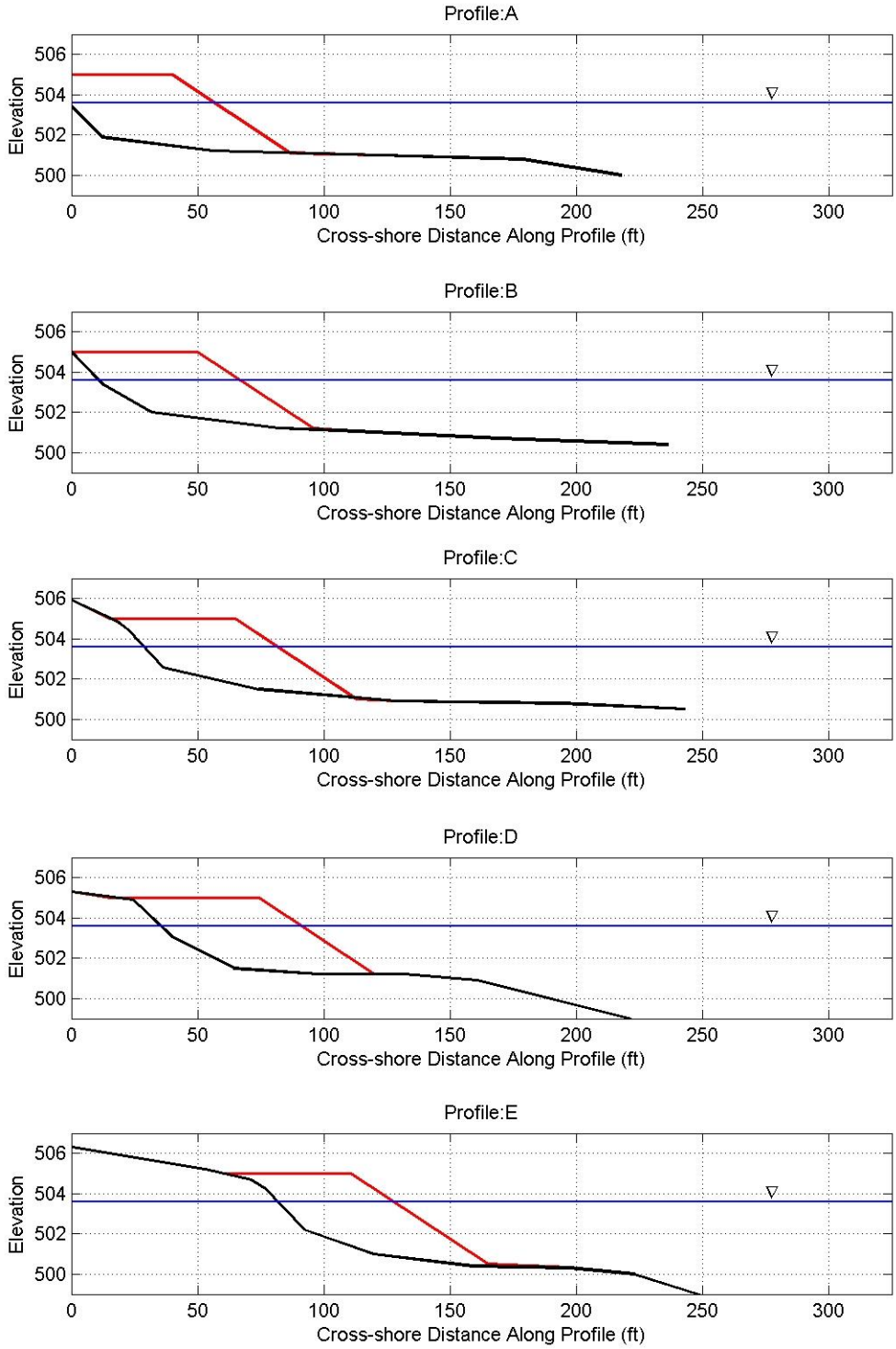
- Nourishment Length – A total nourishment length of approximately 900 feet that spans from the terminal jetty at the east end of the beach to Lakeside Dr. in the vicinity of the Mt Washington Cruises dock to the west, as shown in Figure 4-5. The planform limits of the fill are tapered. This nourishment length will extend the length of the current beach approximately 300 feet in the alongshore direction.

- Berm Width and Berm Height - Increasing the beach berm is defined by extending the natural berm seaward at a constant elevation. In reality, the beach width will typically be wider than the berm width due to the sloping nature of the beach profile and nourishment template design. The template consists of raising the berm to uniform elevation of 505 feet and extending the berm an additional 50 feet offshore of its current location. This increases the beach width approximately 60-75 feet compared to the existing beach width.

- Offshore Slope – At the terminus of the 50 foot berm extension, the berm transitions into a 1V:12H foreshore slope down to the existing grade of 499-501 feet. This offshore slope is approximately the same as the foreshore slope of the existing beach. A 1V:12H slope allows for the intersection of the existing profile at a reasonable distance offshore, provides a mild beach slope for wave dissipation, and can be reasonably constructed.

- Grain Size – A similar grain size to the native material of 0.3 mm was assumed for the fill material. Ultimately, the sediment size, color, and distribution will be a function of the borrow site sediment (e.g., upland quarry sediment).

- Nourishment Volume – A total nourishment volume was estimated based on the profiles and surveys performed at Weirs Beach. A total volume of approximately 7,300 cubic yards is required to fill the recommended beach nourishment template.



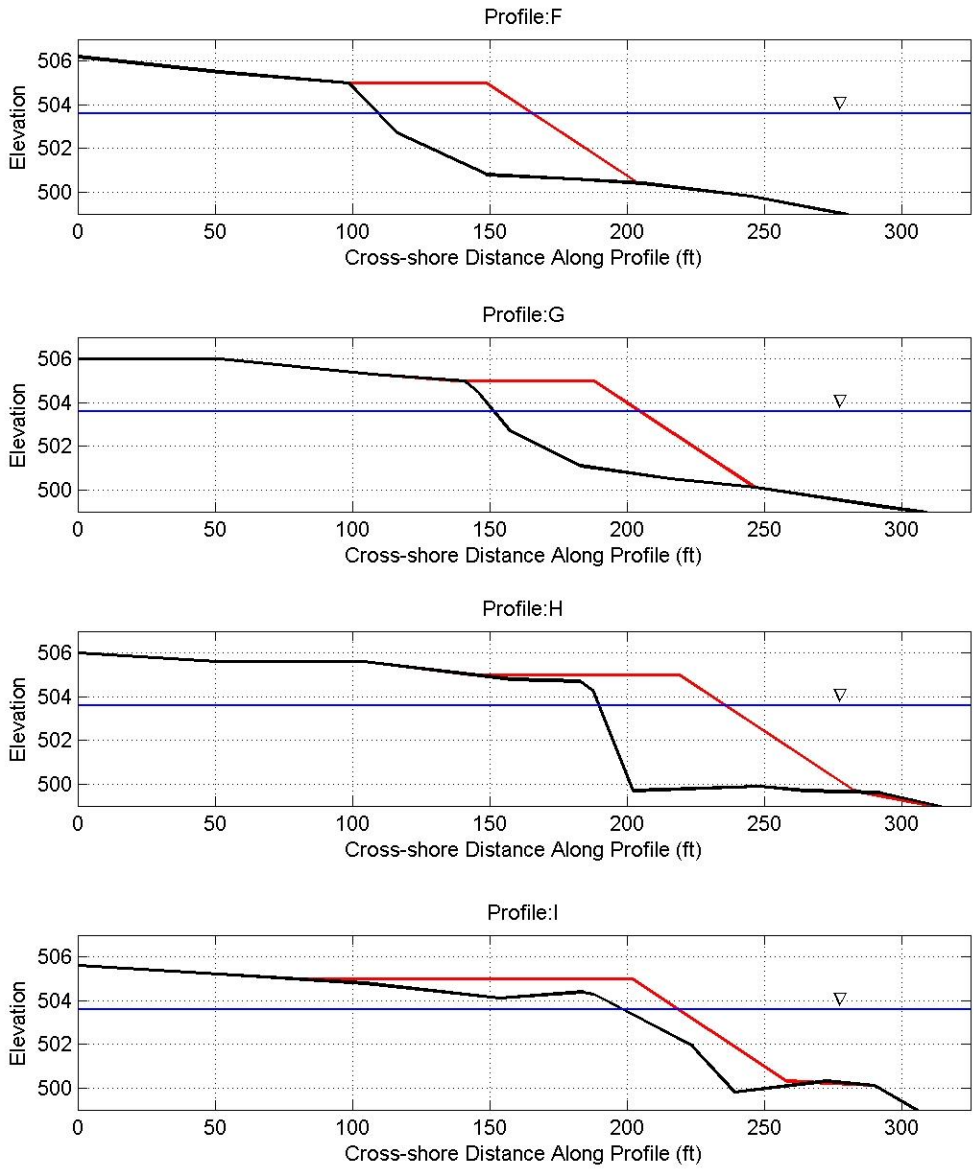


Figure 4-6. Existing June 2012 (black line) profile and proposed (red line) nourished cross-shore profile at Weirs Beach for selected cross shore transects.

The performance (service life) of the proposed nourishment was assessed using an analysis that combines the conservation of sediment equation with the linearized transport equation. This formulation, called the Pelnard-Considére (1956) equation (Equation 4-3), is used to obtain theoretical results to establish design and performance standards for the nourishments. This analysis essentially determines how long the nourishment is expected to provide adequate value to the beach. A more detailed description of the derivation of the equations and their applications can be found in Dean (2002).

$$M(t) = \frac{2\sqrt{Gt}}{l\sqrt{\pi}}\left(e^{-\left(\frac{l}{2\sqrt{Gt}}\right)^2 - 1}\right) + erf\left(\frac{l}{2\sqrt{Gt}}\right) \tag{4-3}$$

where *M(t)* is the proportion of sand remaining in the placed location, *G* is the alongshore diffusivity parameter, *t* is time, and *l* is the project (nourishment) length. The alongshore diffusivity (Equation 4-4) is presented by *Pelnard-Considére* (1956).

$$G = \frac{KH_b^{5/2}\sqrt{g/\kappa}}{8(s-1)(1-p)(h_* + B)} \tag{4-4}$$

where *K* is the sediment transport coefficient, which is a function of sediment size, *B* is the berm elevation, H_b is the breaking wave height, h_* is the depth of closure, *p* is the *in-situ* sediment porosity (approximately 0.35 to 0.40), *s* is the sediment specific gravity (approximately 2.65), and κ is the ratio of wave height to water depth within the surf zone (approximately 0.78).

Since the material spreads over time, it is possible to evaluate the longevity of the nourishment by looking at the amount of material left in the project area. Subsequently, nourishment alternatives can be compared to one another based on their longevity. The service life of the beach nourishment can be based upon the percent of the initial beach nourishment left within the boundary of the initial fill. The percentage remaining will decrease with time, but that material is not necessarily lost from the system, it has just spread to regions outside of the original nourishment template. For example, sediment may have been transported offshore or along the beach. Therefore, although the sediment no longer falls within the initial nourishment template, it has not completely disappeared from the system.

Two beach nourishment scenarios were analyzed including 1) beach nourishment and 2) beach nourishment with an adjustable groin field consisting of two adjustable groins. The purpose of the later scenario is to evaluate the effectiveness of a groin field in extending the beach nourishment service life and performance over nourishment alone. The groin field accomplishes this by locking the nourishment in place by interrupting the longshore sediment transport processes and dispersion of the nourishment. In the analysis, two groins are proposed with a length of 100 feet and spacing of 150 feet between each other and the terminal jetty (as illustrated in Figure 4-7).. The adjustable nature of the groins would allow for the design length to be optimized and adapted to changing site conditions.

Figure 4-7. Beach nourishment combined with an adjustable groin field (approximate expansion shown by beach nourishment, not fully representative of beach width increase).

Figure 4-8 presents the performance of the proposed nourishment at Weirs Beach both with and without groins. The performance is expressed in terms of amount of material remaining in the initial template region, as a function of time. Results for the nourishment alone are shown as a red line, while results for the nourishment coupled with adjustable groins are shown as a blue line. The percent of initial material remaining is presented along the left hand axis, while the time in years is presented along the bottom axis. For example, after 5 years, approximately 50% of the initial fill volume is remaining for the nourishment only scenario, while approximately 75% of the initial fill volume is remaining for the scenario of nourishment with an adjustable groin field. After 25 years, approximately 27% is remaining for the nourishment only scenario while 48% is remaining for the nourishment with an adjustable groin field. The curves represent the service life of the proposed nourishment. Both the nourishment alone, as well as the nourishment coupled with the adjustable groins, provide reasonable service life and last for over 25 years before a periodic nourishment needs to be considered (typically renourishment should be considered when the percent of the fill remaining reaches 30%).. The adjustable groins do provide a relatively significant improvement in service life, but also come at an increased cost.

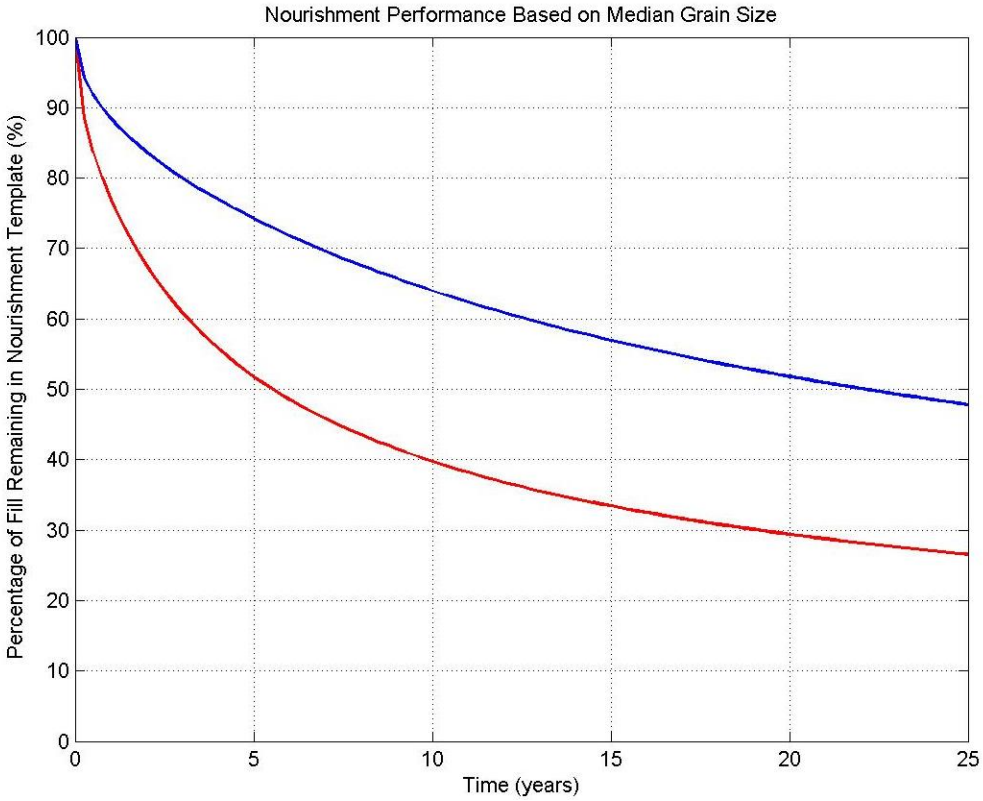


Figure 4-8. Estimated beach nourishment performance for the proposed nourishment at Weirs Beach.

5.0 ALTERNATIVES COMPARISON AND SELECTION

Ultimately, the goal of this evaluation is to identify the potential alternative or combination of alternatives that can create an improved beach system at Weirs Beach, while minimizing environmental impacts. Table 5-1 presents a summary of all the alternatives considered for Weirs Beach. The table presents the alternatives relative to a number of criteria, including impacts to beach, permit requirements, approximate cost, service life, maintenance, safety, and modular (or adaptive) design. Alternatives were evaluated using a number of factors (Table 5-1); however, it was most critical to maximize the following overarching goals:

- Mitigate erosion of the beach.
- Minimize shoaling of the navigational channel.
- Provide a technically sound, robust solution that can contend with dynamic coastal processes
- A cost effective solution that minimized ongoing maintenance requirements.

Therefore, from all the alternatives that were evaluated, the following alternatives/components, and potential combinations of alternatives, were considered reasonable, technically feasible, and most environmentally appropriate for the Weirs Beach system and are therefore recommended for consideration.

1. **Beach Nourishment:** The primary cause of beach erosion at Weirs Beach is the deficit of sediment within the littoral cell due to the lack of a natural updrift sediment source, such as an eroding headland, meaning that the sediment supply is not being replenished. Alternatives designed to capture sediment being transported along or over the beach, such as enhancing jetty or installing sand fencing, will only limit the amount of material lost from the littoral but not replenish it. Therefore, Woods Hole Group recommends nourishing the beach with compatible sediment to offset this deficit by introducing sediment into the littoral cell. Beach nourishment can be combined with other alternatives to enhance the performance of the nourishment (e.g., adjustable groins) as well as try to maintain the beach (e.g., sand fencing). One potential drawback associated with this alternative is increased shoaling potential of Weirs channel; however, this can be limited by coupling the nourishment with a Weirs channel jetty extension. Beach nourishment is the preferred alternative for Weirs Beach and can be coupled with additional alternatives to enhance the system.

Other alternatives were evaluated as secondary, optional items that could be performed in concert with the preferred alternative (e.g., beach nourishment) include:

2. **Sand Fencing:** An inexpensive and easy to construct solution that could be implemented with or without nourishment. It would likely be useful in mitigating Aeolian transport of sand from the beach to the channel; however, it cannot improve the overall condition of the beach width and volume. Sand fencing could also be implemented with a manual backpassing program to maximize retainage

of sediment in the system. Due to the limited cost and potential benefit, this alternative is recommended for pilot implementation over a few years to gauge the performance.

3. **Jetty Lengthening:** When coupled with a beach nourishment, this alternative will reduce amount of sediment lost from the beach system as well as reduce the sediment shoaling in Weirs Channel and downstream areas. It is recommended as a component of the beach nourishment but overall will not mitigate erosion from the rest of the beach. This solution is only recommended as a component coupled with the beach nourishment alterative, and is not recommended as a standalone alternative.

4. **Sediment Backpassing:** This solution could be part of an effective maintenance strategy for the nourished beach that would recycle sand within the littoral cell. Coupled with a jetty lengthening and sand fencing, both of which will capture sediment on the eastern side of the beach, a manual backpassing program could be initialized that moves sediment back to the west once the jetty and sand fencing are filled to entrapment. This alternative is not likely to be successful without beach nourishment since the existing sediment supply on the beach will not supply enough material to fully stem the background erosion rate of about 1,200 cyd/yr.

5. **Adjustable Groins:** This alternative could be implemented with a beach nourishment to enhance the service life of the nourishment. It is not considered a required element of the recommended solution, but has been shown to provide increased beach stability for the Weirs Beach system. This alternative is not recommended as a standalone mitigation solution and must be coupled with beach nourishment.

Table 5-1. Weirs Beach Alternative Evaluation Summary Matrix.

Alternatives	Evaluation Criteria								
	Weirs Channel Shoaling	Beach Enhancement	Permit Requirements	Approximate Initial Capital Cost*	Service Life	Maintenance Requirements	Public Benefit	Dependence on Beach Nourishment	Modular Design and Flexibility
No Action	No change from existing conditions	Background erosion of beach continues, beach system eventually absent	N/A	None	Beach has limited service life before recreational usage becomes limited	Eventually erosion may result in required maintenance to infrastructure	Potential storm damage concerns, and loss of recreational beach	N/A	N/A
Sand Fencing	Minor reduction in channel shoaling	Minimal improvement to beach; however limits loss of material from system	Minor	$8,000-9,000	5-6 years before replacement of fence components may be required	Requires frequent inspection and minor repairs.	Aesthetically may be undesirable, not a safety hazard.	Could be installed with or without a beach nourishment	Can be easily removed or reconfigured to optimize trapping efficiency. Also can be removed seasonally. Provides a source area for sand backpassing
Manual Backpassing	Minor reduction in channel shoaling	Minor improvement	Minimal permit requirements	$15,000-$17,000 initial, 6,000/yr maintenance	N/A	Requires ongoing maintenance	Minor improvement.	Requires beach nourishment to be effective. Also could be coupled with sand fencing and jetty extension.	N/A
Jetty Extension	Reduction in shoaling in channel.	Potential to improve beach width and area	Moderate permit requirements	$90,000-$100,000	Structural service life expected to be 50-75 years	Minimal	May provide increased beach width in the vicinity of the jetty, also provides improved navigation and reduced shoaling at Weirs channel.	Only recommended to be implemented with beach nourishment. Also could be coupled with sand backpassing	Structural cannot be adaptively managed, but sand backpassing provides some flexibility
Beach Nourishment+	Potential for increased shoaling of the channel without proper maintenance or implementation of jetty extension and sand fencing.	Replenished beach with increased width of 60-75 feet.	Permits will be required for beach nourishment, not expected to be problematic	$200,000-$300,000	~25 yrs, perhaps more if implemented with sand backpassing	Maintenance of beach (periodic nourishment expected to occur every 25 years.	Provides increased beach width and height for the greatest public benefit. No safety concerns.	N/A	N/A
Adjustable Groins	Minor reduction in channel shoaling.	Improvement to beach service life	Permits may be more difficult to obtain due to installation of coastal structures.	$125-000- $150,000	50-75 years for structure, ~40 years for beach	May require increased maintenance (dredging) of inlet. Potential improved beach stability	Increases longevity of beach nourishment for greatest public benefit. Some safety concerns with new structures on beach.	Requires beach nourishment.	New components could consist of adjustable panels for adaptive management

* = cost include estimates for permitting, engineering, and construction. Detailed construction costs will be developed in the engineering design phase
+ = preferred alternative

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6.0 SUMMARY AND CONCLUSIONS

The purpose of this alternative analysis presented herein was to evaluate the potential alternatives for mitigating erosion at Weirs Beach. All elements of the project were geared towards arriving at a technically feasible, cost-effective, and long-term solution. A variety of alternatives were considered for the beach, and were evaluated against a number of criteria, with the most critical technical performance factors including:

- Mitigate erosion of the beach.
- Minimize shoaling of the navigational channel.
- Provide a technically sound, robust solution that can contend with dynamic coastal processes
- A cost effective solution that minimized ongoing maintenance requirements.

The preferred alternative is beach nourishment consisting of approximately 7,300 – 9,000 cubic yards of beach compatible sediment. This alternative would increase the beach width by 60-75 feet (varies along the beach) at a constant elevation of 505 feet. This is the only alternative that replenishes the sand deficit in the littoral cell and maximizes beach restoration and benefit to the public by increasing the amount of recreational area for the beach.

The preferred beach nourishment alternative can also be supplemented by complimentary other alternatives at Weirs Beach. Woods Hole Group also recommends the installation of targeted, seasonal sand fencing along the eastern edge of the beach to reduce Aeolian transported losses. The jetty extension is also recommended to enhance the performance of the nourishment and reduce shoaling in Weirs channel. A manual backpassing program is also recommended in concert with the nourishment, jetty extension, and sand fencing that could be completed on an as needed basis. Finally, an adjustable groin field, consisting of two groins, could also be considered to improve the service life of the nourishment and allow for adaptive management of the beach system to changing conditions. The adjustable groin field could also be easily removed if necessary. However, the adjustable groin field is not a required component of the mitigation program.

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