MEMORANDUM

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To: Morgan Creek Harbor Association,
c/o Ms. Laurie Schueler, Property Management Services

From: Heath Hansell, PE

CC: ATM File

Date: May 15, 2020

Re: **Morgan Creek Bulkhead Project Alternatives Review**

This memo is a summary of the desktop review conducted by ATM for the Morgan Creek Harbor Association's (MCHA) proposed repair/replacement project alternatives for the existing bulkhead along Morgan Creek, Isle of Palms, SC. Due to the critical nature of the bulkhead structure and high cost of any meaningful project alternative, MCHA contracted ATM to provide a third-party review of the project alternatives to inform the decision-making process of MCHA leaders moving forward.

Background and Methodology

The existing steel sheetpile bulkhead was originally constructed in 1997 and has undergone various modifications and repairs during its lifetime. MCHA has contracted with Jon Guerry Taylor & Associates, Inc. (JGT), Terracon, and several other waterfront, geotechnical, and similar technical groups and contractors to perform annual bulkhead inspections, repair and maintenance activities, and evaluate major rehabilitation and/or replacement options since as early as 2005. In recent years, MCHA has been considering a major rehabilitation or replacement of the bulkhead structure due to the severe corrosion and concern of limited remaining useful life if the corrosion continues. As the project engineer for MCHA, JGT has evaluated several alternatives and developed a recommended project approach to address the severe corrosion issues of the existing bulkhead.

ATM's assessment evaluated the proposed repair/replacement alternatives currently being considered by MCHA, as well as other potential alternatives. Alternatives are compared using important metrics such as potential costs, construction impacts, design life, and other considerations. ATM's methods included:

- Review of Client provided reports, data, and other pertinent documentation.
- Discussions with key technical groups associated with the project and review of any additional documentation provided.
- Review of ATM projects of similar nature to assess cost, constructability, design, and similar considerations.
- Discussions with local and industry representatives in marine construction, cathodic protection, and product manufacturers.

- Development of key metrics for practical and objective comparison of alternatives (i.e. the alternatives matrix).
- Development of planning level comparative data for each metric based on available information and ATM technical experience/expertise (e.g. costs provided by contractors/comparable bids, comparable construction project impacts, pro/con assessments, discussion with industry representatives, etc.).

Existing Conditions and Reported Issues

It is not the intent of this memorandum to describe the history of the bulkhead structure as it stands to date. Various existing reports by others provide this information in great detail. Based on ATM's review of inspection and monitoring reports and discussions with key technical groups associated with the project, several key findings related to existing conditions and issues are noted below.

- The existing bulkhead is a steel sheetpile bulkhead originally constructed in ~1997 and modified in 1999 to install helical tieback anchors to help straighten and support the newly constructed wall that was experiencing deflection issues. The steel bulkhead was built in front of an existing, aging timber bulkhead. A vinyl bulkhead installation was attempted but experienced failures during construction.

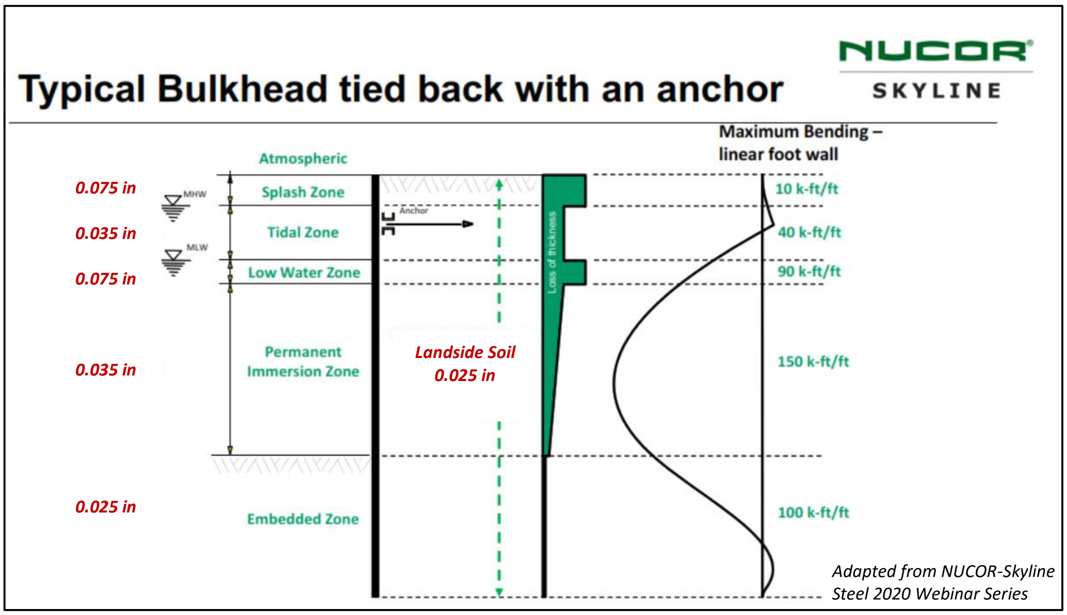
- Exposure heights (i.e. how tall the bulkhead is from the underwater mudline to the top of the wall) of the bulkhead are estimated to be on the order of ~12 ft. These heights can vary along the length of the wall, depending on dredging activities, and may be considered higher for structural design due to poor soil conditions. For example, in the 1998/1999 bulkhead repair construction drawings, exposure heights up to 15+ ft are shown. **Exposure heights are one of the primary factors that impact bulkhead requirements (e.g. bulkhead type, design/materials, ultimate cost, etc.). Especially when combined with poor soil conditions, larger exposure heights (e.g. >10ft) can limit the feasibility of certain bulkhead designs.**

- Bulkhead deflection/rotation (i.e. leaning toward or away from the water) has been monitored since 2005. Deflections are indications of distress in the bulkhead sheet piles and/or tiebacks, or soils. **As indicated in Terracon's 2019 Bulkhead Monitoring Report, most observed deflections are within acceptable ranges and accuracy of measuring devices. A limited number of observations were slightly outside these tolerances, but no apparent distress or movement was observed.**

- Corrosion
    - Design of marine steel structures typically considers corrosion in the design process in one (or combination) of several ways:
        - Sacrificial steel – design the steel sheet pile thicker than it needs to be so corrosion and loss of steel section thickness is still within design limits over the life of the structure. Optionally, additional steel plating (cover plates) can be welded on to known critical corrosion zones of the sheetpile during manufacturing to increase strength and compensate for anticipated section loss.
        - Coating – coat the steel to prevent direct exposure to corrosive environments.

- Cathodic protection – use sacrificial anodes or impressed current systems to slow/minimize corrosion of steel structures.
- Marine Grade Steel (A690) – the use of specific steel alloys such as marine grade steel (A690) has been shown to have lower corrosion rates than other, typical steel grades.

- Corrosion rates of steel structures can vary, but in general, the figure below shows typical expected areas and rates of corrosion on a steel bulkhead. Numbers in red indicate typical anticipated loss of steel thickness during a 25-year period. The figure also shows where typical higher and lower bending forces are experienced along the height of the wall in relation to these corrosion zones.



- Reported corrosion of the existing bulkhead includes corrosion of steel sheet piles on the exposed (i.e. waterside) faces, exposed tieback hardware and connections, and other exposed steel elements of the bulkhead. Corrosion has been noted in multiple inspection reports as an ongoing issue. The landside (below grade) face of the steel sheets has been reported as having severe corrosion (this has been observed/confirmed from limited, localized excavations behind the wall). Pinhole corrosion deterioration of steel sheet piles is regularly observed and repaired from the water side of the bulkhead. This indicates significant section loss, but the extent/coverage of this is unknown as the pinholes appear to originate from corrosion degradation on the landside of the bulkhead.

- Reports indicate that the bulkhead along the southern shoreline of Morgan Creek visually appears to have more severe corrosion than the northern side.

- *Coating*
  - The original steel bulkhead was installed using an industry typical steel grade (A572) and marine coating (coal tar epoxy). The coating was reported to be

applied to only the waterside face of the steel sheets. Design documents were not available and there is no indication of if or how much sacrificial steel thickness was included in the original design.

- A maintenance wall cleaning and recoating project was conducted in ~2012 with some success using a marine grade coating.
- **Maintenance coating of marine structures is extremely difficult.** Very specific chemical (e.g. no salts or oil residues) and physical properties (e.g. perfectly clean, bare metal with specific surface roughness) are recommended/required for the new coating to properly adhere and perform long-term. Working around tidal fluctuations, marine growth, rust, and existing coatings, nearby vessels and structures, increases project costs and risk of coating issues. Additionally, it is very difficult to extend the new coating to and below lower water levels. This leaves critical corrosion areas unprotected unless other protection systems are used in conjunction with the new coating.
- While coating of steel sheet piles on both the waterside and landside is preferred for additional protection, based on ATM's experience, it is not uncommon to leave the landside face of steel sheet pile bulkheads uncoated unless there are known abnormal upland soil/site conditions that necessitate it or the cost/benefit ratio of additional coating and protection is acceptable to the project Owner.

- *Corrosion Investigations*
  - In addition to the visual observations from routine maintenance and monitoring events, limited investigations have been conducted and documented in an attempt to measure various factors that could contribute to the observed corrosion and the actual extent/severity of the corrosion of the existing bulkhead. Terracon's Bulkhead Monitoring Report (June 6, 2014) detailed recommended investigations:
    - *"A complete site investigation, including backfill soil sampling, corrosion product sampling, corrosion characteristic testing, metallurgical testing of samples, electrochemical testing and electrical continuity evaluation among others would be required to evaluate the corrosion damage and to provide repair/prevention recommendations."*
  - Conducted tests with available documentation includes:
    - Soil Testing
      - Five shallow borings were tested, and **results indicated that soil properties are not likely causing any increase in corrosion rates.**
      - It should be noted that results are limited to areas of borings. Other soil properties may exist elsewhere along the bulkhead. Original bulkhead drawings indicate "backfill material to be sand dredged from harbor". If this was, in fact, the material and method used for backfilling, this material may have contained higher corrosive elements than normal and the disturbed nature of this backfill may have introduced extra oxygen into the soil matrix, which would also increase corrosion. Limited shallow borings may not have reached these original backfill materials.

- Steel Thickness Measurements
  - Steel thickness measurements using an ultrasonic thickness (UT) measuring device were conducted along the length of the bulkhead. Details are limited as to exact locations and elevations of measurements.
  - Over 500 thickness measurements were conducted along the length of the wall. Results indicated:
    - Minimum Steel Thickness = 0.15”
    - Average Steel Thickness = 0.36”
    - Maximum Steel Thickness = 0.45”
  - At the time of the testing (2015) it was reported that the design thickness of the steel bulkhead was unknown and thus assumed to be 0.5”.
    - Using this assumed design steel thickness, an average section loss (corrosion) of ~0.14” (~20% to 30%) of the original design steel thickness was reported.
  - Based on drawings and documentation made available to ATM, the existing steel bulkhead utilized AZ 18 steel sheet piles.
    - AZ 18 is a standardized steel sheet pile section with a thickness ~ 0.34”
    - Average reported thickness measurements (0.36”) would indicate an increase in steel thickness which is not possible. It is noted that corrosion deformations (rust/scaling of steel on the buried landside) can skew thickness measurements.
  - **Due to the measurement discrepancies with designed sections, steel thickness measurements are considered inconclusive. Therefore, corrosion rates and precise structural thicknesses of the existing steel sheet piles is unknown. Verifying the original design conditions (including any sacrificial steel thicknesses) and accurate existing steel structure thicknesses, corrosion rates, and structural capacity is considered a critical step before undertaking any major repair or rehabilitation efforts. During this effort, it may be determined that some sections of the bulkhead are in much better shape than other sections and repair or rehabilitation efforts can be tailored to shoreline sections by actual need.**
- Coating Adhesion and Dry Film Thickness (DFT) Testing
  - No major abnormalities were found during these testings.

- Information regarding other tests performed or their results was unavailable at the time of this report. Communication with several individuals indicated some additional testing may have taken place but were not documented or made available.
  - Discussions with a cathodic protection specialist from Southern Cathodic Protection (SCP) indicated that various current and corrosion tests were conducted and indicated no significant abnormalities (e.g. stray currents

or structural deficiencies) that would be the cause of increased corrosion rates in the marine environment at the site.

- Communication with a representative from Electric Supply Co., Inc. indicated routine current leakage testing is conducted for wetslips and leakage is typically attributed to improper wiring on berthed vessels.

- Stray currents (e.g. from marina waterside or upland facilities/soil conditions) and related structural deficiencies (e.g. bonding/grounding) are known to increase corrosion rates for marine steel structures. Based on ATM's discussions with the SCP corrosion specialist familiar with the site, no such conditions are known to exist at the site or contribute to increased corrosion rates. **Determining (or ruling out), with high confidence levels, the exact cause of any suspected abnormally high corrosion rates experienced by the existing bulkhead is considered a critical step before undertaking any major repair or rehabilitation efforts. For example, if an unknown stray current exists and a new steel wall alternative is constructed, the new structure could likely experience higher than normal corrosion rates if the stray current issue is not corrected. It may also negatively impact the performance of cathodic protection systems if not properly accounted for.**
- Around the time of the original bulkhead construction, it was not uncommon for structural steel produced and imported into the US for construction projects to be of substandard quality. This could be a possible explanation for suspected high corrosion rates. It is likely that detailed metallurgical testing (previously recommended by Terracon) of a sample cut from the existing steel structure would be required to determine this.

- <u>Tieback Anchors</u>
  - Tieback anchors were not in the original bulkhead design but added several years after wall construction to address deflection issues and provide adequate support for the structure.
  - In 2019, four tieback anchors were evaluated for corrosion and load testing. Results indicate that the buried steel tie rods suffered minimal loss from corrosion and could likely provide adequate resistance to the 20-ton proof load applied for testing.
  - Corrosion of exposed tieback hardware (where is penetrates the bulkhead and is on the waterside face) was noted in several reports. This is typical in a marine environment and these elements commonly require more routine maintenance (e.g. regular scraping and re-coating).
  - Re-use of the tieback anchors for any new construction appears feasible but alternatives for re-use or installation of new anchors should be bid for final cost comparison. The engineer of record (EOR) for the project must take ultimate responsibility for re-use of anchors and final design.

- <u>Weep Holes and Groundwater</u>
  - Proper drainage of groundwater levels from the landside to the waterside helps even out hydrostatic loads and decreases bending stresses on any bulkhead structure. The inclusion of drainage and weep holes is standard good practice for design.

- There is an existing french drain and flapper gate system that releases groundwater through the bulkhead. There are ~111 flapper gates along the entire ~6,100 ft long wall (indicating an average spacing of ~55 ft). They are reported to be functioning adequately but their elevations between +2.5 ft to +3 ft above mean sea level indicates they only alleviate groundwater pressure from the upper section of the wall and remaining hydrostatic pressures between these elevations and lower tide levels increases stresses on the bulkhead. With any aging and corroding structure, the release of groundwater and hydrostatic pressure via weep holes or drains should be implemented to reduce stress.

Regardless of the exact cause or precise severity of corrosion, it is visually apparent the structure is experiencing ongoing corrosion issues and some form of maintenance, repair, or replacement is warranted. Steel bulkheads are typically designed for 50-year service life. The fact that the existing wall is experiencing the reported severe corrosion issues at only ~22-years of age indicates some inherent problem. However, before any major repair or rehabilitation efforts, it would be prudent to confidently determine the cause and severity of existing corrosion, estimate the current strength of the bulkhead (compared to existing/design requirements), and predict remaining service life based on measured corrosion rates. The cost of this testing and analysis program should be weighed against repair or rehabilitation costs.

Just as critical is the schedule and timing of any additional testing, analyses, deliberations, design, permitting, bidding, and eventual construction of any repair or rehabilitation. If the visually observed corrosion has severely impacted steel section thickness and is continuing at a high rate, the existing strength of the wall and remaining service life may necessitate short term repairs be conducted immediately or the project phased to address critical areas first while time consuming deliberations and major project planning/design/permitting/bidding is underway.

Project Synthesis

In order to evaluate and compare project alternatives, and based upon our above review, ATM identified overarching project goals, desired ancillary benefits, and potential project related concerns. These items may not all be the same for all lengths of shoreline or for all user groups, but they provide important metrics for comparison of project alternatives.

Goal:
- To have a durable, functional shoreline edge treatment that serves the water access needs of its users for a reasonable project life.

Ancillary Benefits (of existing shoreline edge treatment – steel sheetpile bulkhead):
- Provides convenient attachment point for gangways and access to floating docks and marina.
- Provides usable upland green space to water's edge.
- Provides usable water footprint to land's edge.

Primary Concerns:
- Cost and Return on Investment
    - Initial Project Construction Cost

- Maintenance and Operating Costs
- Durability/Service Life
- Potential Construction Impacts
  - Upland construction corridor (landside disturbance and restoration)
  - Marine footprint of construction operations - required temporary closings of wet slips/docks
  - Length of construction related impacts (e.g. noise, traffic, vibrations, etc.)
  - Timing of construction related impacts (e.g. boating season vs wetslip closings)
- Project Impacts
  - Loss of usable water footprint
    - Loss of or encroachment on some wet slips adjacent to shoreline
    - Relocation/reconfiguration of floating docks/pilings
  - Loss of usable upland green/open space.
    - Usable upland green/open space is highly valued by various user groups and some potential project alternatives may encroach on this area and limit its utility as open/green space.
  - Dredging implications.
    - The ability to dredge and maintain navigable depths for all wetslips is important. Some project alternatives may place some restrictions on dredging near the shoreline.
  - Other (e.g. aesthetics/environmental impact)

Project Alternatives

Alternatives for repair or rehabilitation of the MCHA bulkhead are presented below with a review of general descriptions, costs, advantages, disadvantages, and related issues for feasible alternatives. MCHA indicated to ATM that several primary project alternatives have previously been considered for approval. Many are also discussed in the JGT report entitled "Morgan Creek Bulkhead Cathodic Protection and Re-Coating Project" (herein referred to as the JGT Report). Nine alternatives were evaluated, including:

1. No Action
2. Cathodic Protection and Recoating (Including Weep Drains)
3. New Steel Sheet Pile Bulkhead with Tiebacks
4. New Composite Sheet Pile Bulkhead with Tiebacks
5. New 'Truline' Vinyl-Concrete Hybrid Bulkhead with Tiebacks
6. Bulkhead Encapsulation
7. Combination Wall – Cantilever Steel Pile and Steel Sheet Pile
8. Concrete Soldier Pile Bulkhead
9. Shoreline Reconfiguration

Potential alternatives are described in the following sections:

Alternative 1. No Action

This alternative assumes no work is performed. It was included in the JGT Report and was not recommended therein.

The existing bulkhead is corroded but the actual steel section loss (and corrosion rates) are unknown. Without these values, the existing strength of the bulkhead and estimated remaining service life cannot be determined. Reported observations and discussions with technical representatives monitoring the bulkhead indicate significant corrosion. Under this alternative, corrosion, coating deterioration, and backfill material loss will likely continue and worsen. A limited remaining service life of 5 years is assumed as a placeholder value in lieu of structural analysis using valid steel thickness measurements and corrosion rates. Maintenance would be on an as-needed basis of critical items such as infilling sinkholes, welding plates

The construction cost of this alternative is $0. Maintenance costs would include annual inspections and as-needed repairs and touch-up coating similar to ongoing efforts.

A summary of advantages and disadvantages of the alternative are as follows:

Advantages	*Disadvantages*
• Zero initial construction cost • Allows time to confidently determine cause of corrosion, specific corrosion rates, and remaining bulkhead service life to inform repair or rehabilitation decision • No construction or project impacts	• Limited service life (assumed 5 years) • Continued and increased corrosion, backfill, and similar issues and required regular maintenance • Higher potential for premature structure failure due to unknowns

Alternative 2. Cathodic Protection and Re-Coating (Including Weep Drains)

This is the recommended alternative in the JGT Report. It includes:

- Design and installation of impressed current cathodic protection (ICCP) system. The JGT Report provides a detailed description, but in general, this includes:
  - Installation of ~30 subsurface anodes along the length of the wall. These would be installed ~10' landward of the wall. Electrical control equipment, and power/wiring would be required at each location and is proposed to be hidden in special screening and landscaping. Three to four new electrical meters will also need to be installed throughout the project area.
  - The reported life expectancy of a properly designed, operated, and maintained ICCP system is 40 years. There is a one-year warranty on the cathodic protection system that covers parts and labor.
  - The system will require routine monitoring, inspections, and limited maintenance.

- Extensive bulkhead cleaning, surface preparation, and re-coating of the waterside face of the steel bulkhead from just above lower water levels to the top of the structure.

  - Cleaning and surface preparation will require extensive blasting, material recovery, and protective measures.
  - A coal tar epoxy coating is proposed to be applied with low pressure spray techniques. This coating type is considered the industry standard for steel coatings in the marine environment.
  - The coating will require regular touch-up maintenance of damaged or deteriorated coating.
  - The reported life expectancy of a properly applied and maintained coating is 20 years. There is a five-year warranty on the cathodic protection system that covers materials and labor.

- Installation of ~750 Jet Filter brand weep hole drains just above the low water level.
  - The proposed weep holes would have an average spacing of ~8 ft between drains (compared to the existing ~50' spacing between flapper gates).
  - The installation of these weep hole drains would require the use of a diver and could be installed prior to the recoating.
  - Regular maintenance to avoid clogging of the drains would be required. The Jet Filter drains are specifically designed to allow regular maintenance of the filter mechanism. They are also constructed of durable materials for marine exposure.

- Restoration of disturbed upland and landscaping
  - This project alternative would require extensive temporary construction impacts landward of the wall for land-based ICCP system installation as well as permanent impacts from rectifier installations, screening, and landscaping.

This alternative would significantly slow the corrosion of the bulkhead structure. The new coating would provide protection where the ICCP is ineffective and weep holes would decrease the stresses on the existing corroded structure. It is important to note that this alternative will not strengthen the existing bulkhead. It will basically maintain its existing condition. If there are sections of the existing bulkhead that are at or near failure, this system may not prevent all bulkhead degradation issues. As noted previously, without knowing the extent of steel section loss and remaining useful life of the existing, unprotected structure, it is difficult to estimate a service life expectancy of a bulkhead with the alternative 1 protection system in place. A moderate service life of 15 years is assumed as a placeholder value for this alternative.

From a USACE and SC-DHEC/OCRM regulatory point of view, the ICCP system is technically out of their jurisdiction (upland) and the coating and installation of weep holes would likely be considered maintenance and require minimal effort for regulatory approval.

The estimated cost to construct this alternative is estimated at $7.7 million. This is based on the detailed cost estimate in the JGT Report and includes construction, additional wall repairs, and "soft costs" related to engineering/permitting and a contingency of $600,000 (~9% of total cost). This total cost allocated along the ~6,100 ft bulkhead provides a unit cost of $1,262/linear foot (LF) of bulkhead shoreline.

Estimated total construction time is ~1.5 years. Coating efforts would be halted during summer months.

A summary of advantages and disadvantages of the alternative are as follows:

Advantages	*Disadvantages*
• Moderate cost • No heavy barge/equipment anticipated on water side and only temporary construction impacts to water side/boating (during winter months) • Already investigated in greater detail (e.g. preliminary design) • Minimal regulatory approval efforts	• Moderate service life • Does not strengthen existing structure • Significant upland temporary construction and permanent project impacts • Annual maintenance/utility/ monitoring costs • Maintenance recoating very difficult

<u>Alternative 3.</u> **<u>New Steel Sheet Pile Bulkhead with Tiebacks</u>**

This alternative would construct a new, properly designed steel sheetpile bulkhead with adequate corrosion protection just waterward of the existing structure. New steel sheet piles would be driven as close as possible to the existing wall. New helical tieback anchor and waler system, bulkhead cap, and weep holes would be installed. Utilities, drainage, and gangway attachments would require modification/extension through the new bulkhead. The void space between the new and old wall would be filled with gravel material. Work would be conducted primarily from heavy water-based barge/equipment and, based on the provided Cape Romain construction methodology, involve the removal and reinstallation of floating docks and anchor piles in 500 ft long sections while work was conducted along those sections. Fill between the existing and new wall may be required to utilize land-based installation with associated impacts and restoration. Estimated service life for a properly designed new steel bulkhead is 50 years.

From a USACE and SC-DHEC/OCRM regulatory point of view, the alternative would require regulatory approvals, but projects of this nature are not uncommon, and a typical moderate level of permitting effort would be anticipated to acquire a joint individual permit.

The estimated cost to construct this alternative is $25.5 million. This is based on the construction cost estimate provided by Cape Romain marine contractors ($20.6M) and includes additional allowance for upland landscape restoration, soft costs at 3% of construction costs, and 15% contingency on construction costs. This total cost allocated along the ~6,100 ft bulkhead provides a unit cost of $4,180/linear foot (LF) of bulkhead shoreline.

Contractor estimated construction time is approximately 2 years.

A summary of advantages and disadvantages of the alternative are as follows:

Advantages	*Disadvantages*
• Long Service Life • Well known and understood project from design, regulatory, and construction standpoint • Maintain existing usable upland open/green space • Preliminary planning level section design has been	• High Cost • Significant temporary construction impacts to waterside/boating. Requires removal and reinstallation of existing docks. • Heavy barge/equipment anticipated • May have significant temporary construction impacts to upland if fill material required to be trucked from upland rather than barged. • Project may permanently encroach up to ~3' into adjacent wetslips. • Installing new steel structure in area with unknown, potentially abnormal corrosion issues is risky. • Require continued inspections and maintenance efforts • May require cathodic protection system

Alternative 4. New Composite Sheet Pile Bulkhead with Tiebacks

This alternative would construct a new fiber reinforced polymer (FRP) composite material sheetpile bulkhead just waterward of the existing structure. New composite sheet piles would be driven as close as possible to the existing wall. Utilities, drainage, and gangway attachments would require modification/extension through the new bulkhead. The void space between the new and old wall would be filled with granular or flowable fill material. Flowable fill may help encapsulate the existing steel bulkhead and help strengthen the shorelines treatments and slow deterioration.

Two options were proposed for tiebacks of the new composite bulkhead. The first was confirming the capacity of existing tieback anchors of the steel bulkhead, and if, acceptable, tie the new composite bulkhead back to the steel bulkhead sheets. This is not recommended unless detailed engineering and methods confirm capacity since the steel bulkhead will continue to corrode and weaken. Since the new composite bulkhead would be tied back to the steel sheets instead of the anchors, this could jeopardize the strength and service life of the new bulkhead. It is assumed new helical tieback anchor and waler system, bulkhead cap, and weep holes would be installed.

Work would be conducted primarily from medium water-based barge/equipment and removal and reinstallation of floating docks and anchor piles would be required. Fill between the existing and new wall may be required to utilize land-based installation with associated impacts and restoration.

FRP composite material offers benefits over other materials (e.g. steel or concrete) in the marine environment. It is lightweight and virtually maintenance free. Due to the relatively uncommon use of the material in construction (e.g. compared to steel), contractors often consider additional risk for unknowns associated with special handling and installation requirements. One common concern is splitting of the material, especially at the joints, during installation. This typically occurs below the mudline and is undetectable which can weaken the structure. Softer soils such as those found at the site are more manageable for driving without too much risk of splitting. Design of composite is generally governed by bending since it is much more flexible than steel. Designs must carefully consider worst case loading scenarios and bending limits. It should be assumed that the existing, buried bulkhead would offer no additional support as it will eventually corrode. Failures of composite materials are typically considered more "catastrophic" than steel. Steel can bend and deform when overloaded, but composites will generally reach a "breaking point" where the material completely fails, usually by splitting at the seams. Similar to steel various companies manufacture, engineer, and sell FRP composite sheet pile products for use as marine bulkhead structures. Reputable manufacturers and engineers have conducted extensive research and testing of design properties of FRP composite sheets are well understood and similar to, though somewhat less standardized, than steel properties. One such manufacturer is Everlast Synthetic Products (ESP), who designs and manufactures vinyl and composite sheet piles and accessories for bulkhead installations. They have conducted preliminary assessment and design concepts for the MCHA project and have successfully designed and overseen installation of numerous composite bulkhead structures similar to this alternative. Estimated service life for properly designed FRP composite structures is reportedly up to 80-yrs.

Impact damage is a major concern for composite materials. This can be from vessel impacts, maintenance activities, or maintenance dredging of the creek and wetlsip berths adjacent to a composite bulkhead. Composite is more susceptible to major damage from impacts compared to steel or concrete and maintenance dredging may be restricted near the bulkhead or require special low intensity techniques.

From a USACE and SC-DHEC/OCRM regulatory point of view, the alternative would require regulatory approvals, but projects of this nature are not uncommon (albeit material type is unusual for this area), and a typical moderate level of permitting effort would be anticipated to acquire a joint individual permit.

The estimated cost to construct this alternative is $26.6 million. This is based on the base construction cost estimate provided by Cape Romain marine contractors ($20.7M) and includes additional allowance for upland landscape restoration, soft costs at 3% of construction costs, and 20% contingency on construction costs. The increased contingency (20% instead of 15%) is to account for additional uncertainty due to the unique material. This total cost allocated along the ~6,100 ft bulkhead provides a unit cost of $4,370/linear foot (LF) of bulkhead shoreline.

It should be noted that some contractors are more hesitant to use atypical materials and construction techniques, as these carry some inherent risk to the contractor. Depending on the size, experience, material familiarity, backlog, and other variables of potential contractors, (including timing of the project), costs and construction methods/impacts can vary drastically. Based on discussion with a representative of ESP familiar with the MGHA bulkhead project, they

believe the construction of this alternative can be completed for ~$14.2M without removing existing floating docks. Including additional allowances and contingencies similar to above, the planning level cost would come to $18.7M

Estimated construction time is approximately 2 years.

A summary of advantages and disadvantages of the alternative are as follows:

Advantages	*Disadvantages*
• Reported Very long service life • Very low maintenance • High corrosion resistance • Long-term aesthetics (i.e. no rusting) • Typical level of permitting effort	• Potential high cost (depending on contractor/method) • Potential significant temporary construction impacts to waterside/ boating. Requires removal and reinstallation of existing docks (depending on contractor/method) • Medium barge/equipment anticipated • May have significant temporary construction impacts to upland if fill material required to be trucked from upland rather than barged. • Project may permanently encroach up to ~3' into adjacent wetslips. • Larger contractors used to working with steel are hesitant to perform composite projects. • Susceptible to impact damage • Maintenance dredging may be restricted

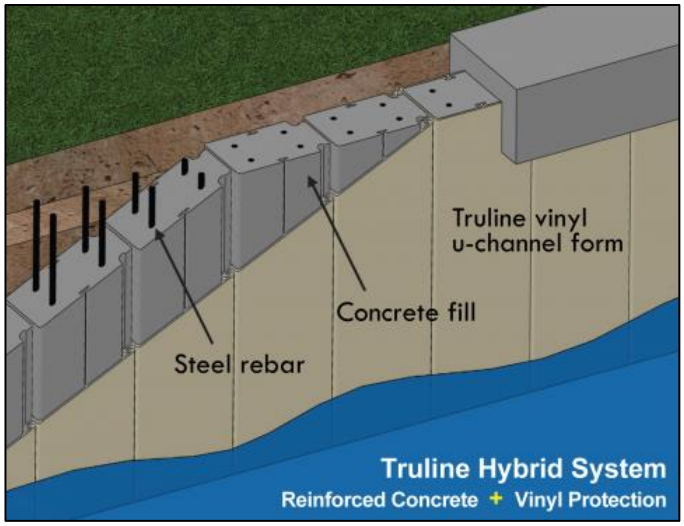
Additional preliminary alternatives were discussed in the JGT Report, but the report indicated they were impractical or not feasible and not ultimately recommended. ATM concurs with the assessment of feasibility and decision to not recommend these alternatives based on the details and commentary included in the JGT Report. These include:

- New Sloped Rip Rap Revetment in front of Bulkhead
- New Concrete Sheet Pile Bulkhead
- New Aluminum Bulkhead
- New Vinyl Bulkhead
- New Timber Bulkhead

After ATM review of the above alternatives (proposed for evaluation by MCHA and/or included in the JGT Report), additional project alternatives were conceived and assessed. They include:

Alternative 5. **New 'Truline' Vinyl-Concrete Hybrid Bulkhead with Tiebacks**

This alternative would construct a new proprietary bulkhead system manufactured by Truline LLC. This alternative was not included in the JGT Report and proposed for evaluation by MCHA. The Truline system can generally be described as a modular, double walled vinyl sheetpile form filled with reinforced concrete. It is visualized in the below figure from the Truline website.



New Truline vinyl sheet forms would be driven as close as possible to the existing wall. The installation would require soil removal from inside the forms, placement of reinforcing steel inside the cell, and tremie filling with concrete. Utilities, drainage, and gangway attachments would require modification/extension through the new bulkhead. The void space between the new and old wall would be filled with granular or flowable fill material. Flowable fill may help encapsulate the existing steel bulkhead and help strengthen the shorelines treatments and slow deterioration.

Similar to other alternatives, tiebacks would be required. Discussions with a Truline engineering representative indicate that maximum exposure heights within the MCHA project (up to ~15+') are beyond the typical maximum exposure height for Truline systems. Additional engineering and multiple levels of tiebacks and walers would likely be required. Truline systems have not been installed for exposure heights of this magnitude before. Service life for this system is estimated at up to 40 years, but there are no existing long-term projects to compare this to.

Work could be conducted from land or water-based operations with small/medium sized equipment. The modular lightweight vinyl units are typically easily transported with small equipment or by hand if required. Due to poor soil conditions and exposure heights at the project area, the vinyl sheets would likely be required in longer than typical lengths. Longer vinyl sheet lengths are more difficult to transport, handle, and install due to their extreme flexibility. Removal of soil material via jetting would have to ensure turbid effluent was contained or regulatory/environmental issues could arise. Steel reinforcing would come into contact with saltwater prior to filling with concrete which raises corrosion concerns. Flowable concrete could be pumped from trucks to fill the Truline system. Fill between the existing and new wall may be required to utilize land-based installation with associated impacts and restoration.

From a USACE and SC-DHEC/OCRM regulatory point of view, this option would likely undergo additional scrutiny and a more prolonged permitting process due to the uncommon nature of the construction for the local area. A higher level of permitting effort would be anticipated to acquire a joint individual permit.

The estimated cost to construct this alternative is $18.2 million. This is based on preliminary order of magnitude unit costs of ~$2000/LF provided by Truline representatives and includes additional allowance for upland landscape restoration, soft costs at 10% of construction costs (to account for additional engineering/permitting likely required for the unique alternative), and 30% contingency on construction costs. The increased contingency (30% instead of 20% or 15%) is to account for additional uncertainty due to the unique proprietary system and some of the largest exposure heights attempted by this system. This total cost allocated along the ~6,100 ft bulkhead provides a unit cost of $3,030/linear foot (LF) of bulkhead shoreline.

Truline estimated installation rates were ~15LF/day but due to the more complex nature of the project, estimated construction time is 1.5 to 2 yrs.

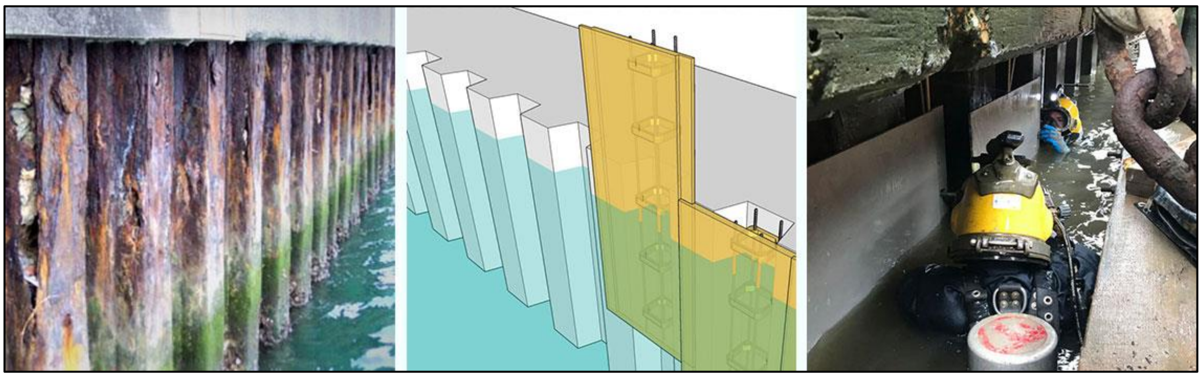
A summary of advantages and disadvantages of the alternative are as follows:

Advantages	*Disadvantages*
• Longer service life • Higher corrosion resistance • Very low maintenance • Long-term aesthetics (i.e. no rusting) • Use of smaller/medium duty construction equipement. Anticipated lower level of construction impacts. • Potentially no or limited construction impacts to waterside/boating if conducted using land-based methods. Potentially no removal and reinstallation of docks.	• Moderate Cost • Significant temporary construction impacts to upland if assumed land-based construction. • Project may permanently encroach up to ~2' into adjacent wetslips. • Atypical material carries some uncertainty for contractors • Very large exposure heights and poor soils are likely beyond the practical working and constructability limits of this system. • Maintenance dredging may be restricted to limit damage to vinyl forms

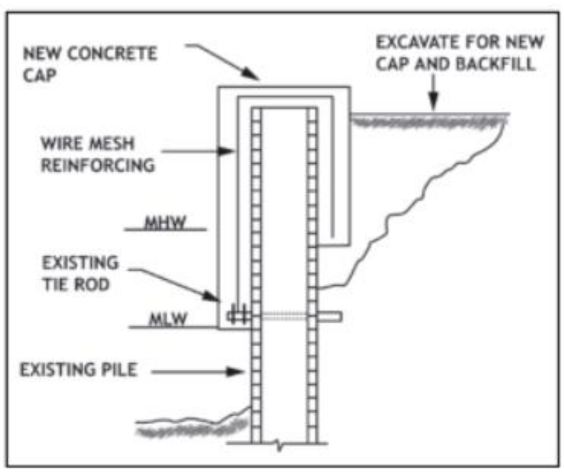
<u>Alternative 6.</u> **<u>Bulkhead Encapsulation</u>**

This alternative would rehabilitate the existing steel sheetpile bulkhead by encapsulating it in reinforced concrete. This alternative would effectively seal off the encapsulated portion of the steel from corrosive environments and strengthen the structure by bonding reinforced concrete directly to the existing steel sheet piles. Encapsulation is generally accomplished using temporary (e.g. timber) or permanent (e.g. composite panels/forms or even vinyl or composite sheet pile) formwork secured to the face of the existing steel bulkhead (or temporarily supported) and filling the void with reinforced concrete. Concrete encasement of the waterside and landside of the structure would be required due to the reported unusually high rate of landside corrosion. Encapsulation would likely extend all the way to the mudline on the waterside and require excavation of upland behind the existing bulkhead for landside encapsulation.

Exposed tieback anchors would be encapsulated within the structure. The installation would require placement of reinforcing and tremie filling with concrete. Utilities, drainage, and gangway attachments would require modification/extension through the encapsulated bulkhead. Several manufacturers produce specific products for encapsulation. The figure below shows the SPiRe system by QuakeWrap, Inc.



The SPiRE product and application (above) is generally intended for encapsulation and strengthening of the water side face of corroding steel sheetpile bulkheads. Landside encapsulation would also be required similar to what is shown in the following figure from the Federal Highway Administrations reference manual on bridge repair.



It is common to use shorter length composite or vinyl sheet piles driven partially into the mudline in front of the existing bulkhead to be used as permanent forms for the pouring of encapsulating concrete. While these sheet piles offer a protective surface layer and some limited strengthening of the rehabilitated system, they are not intended to support the shoreline in the event of failure of the existing wall like other alternatives (e.g. Alternative 4) unless existing tiebacks are extended to the outer form sheets. These vinyl or composite sheet pile forms can be installed as large sections to speed construction as shown in the below photo below provided by Creative Pultrusion (another composite sheet pile and component manufacturer).

Construction of this alternative could likely be completed using land-based or a combination of land and water-based methods. Small/medium duty equipment would be needed to install forms, likely with the assistance of divers. Flowable concrete would need to be pumped and placed using the tremie technique for the waterside. Additional excavation would be required on the landside but would be within typical construction footprints of other alternatives. Depending on the materials and construction method used, there would be limited waterside/boating impacts and minimal dock relocation requirements. Estimated service life of the rehabilitation is 30 to 40 years depending on the condition of the existing bulkhead. Maintenance efforts would be limited to repair of any exposed concrete degradation. This would likely be limited to the exposed upper bulkhead cap.

From a USACE and SC-DHEC/OCRM regulatory point of view, this option may undergo minimal additional scrutiny during the permitting process due to the uncommon nature of the construction for the local area. A moderate level of permitting effort would be anticipated to acquire a joint individual permit.

The estimated cost to construct this alternative is $24.9 million. This is based on construction costs and similar project estimates for typical waterside only encapsulation with an adjustment factor for landside work and encapsulation. It includes additional allowance for upland landscape restoration, soft costs at 3% of construction costs, and 15% contingency on construction costs. This total cost allocated along the ~6,100 ft bulkhead provides a unit cost of $4,090/linear foot (LF) of bulkhead shoreline.

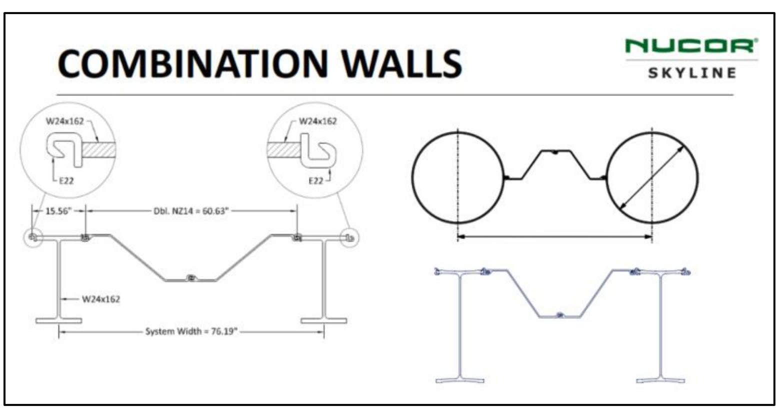
Estimated construction time is approximately 1 to 1.5 years.

A summary of advantages and disadvantages of the alternative are as follows:

Advantages	*Disadvantages*
• Longer service life • Higher corrosion resistance maintenance • Long-term aesthetics (i.e. no rusting) • Use of smaller/medium duty construction equipment. Anticipated lower level of construction impacts. • Potentially no or limited construction impacts to waterside/boating if conducted using land-based methods. Potentially no removal and reinstallation of docks. • Smaller land-based equipment /methods are more easily phased to address critical sections first.	• High Cost • May have significant temporary construction impacts to upland if fill material required to be trucked from upland rather than barged. • Project may permanently encroach up to ~2' into adjacent wetslips. • Diver work likely required • Atypical materials/methods carry some uncertainty for contractors • Some cleaning of the existing wall may be required prior to encapsulation to prevent future spalling. • Verification that additional concrete weight is acceptable on sheet pile structure.

<u>Alternative 7.</u> **<u>Combination Wall – Cantilever Steel Pile and Steel Sheet Pile</u>**

This alternative would construct a new, properly designed cantilever steel "combination wall" consisting of alternating steel piles and steel sheet piles. Steel piles would be pipe or H-pile shapes. The construction would be similar to the new steel sheet pile wall (Alterative 2) but would eliminate the need for tiebacks because combination walls can provide more lateral capacity than typical tied back sheet pile walls. This configuration would protrude slightly further beyond the existing wall than Alternative 2 because the piles are larger than sheet piles. The figure below shows common combination wall configurations.



Service life, regulatory permitting, and other variables are similar to Alternative 2. Combination walls can be economical over steel sheetpile under high load or poor soil situations. The advantages and disadvantages are similar to Alternative 3. An added benefit would be the elimination of tiebacks and disturbance to the existing wall with this cantilever wall.

Alternative 8. Concrete Soldier Pile Bulkhead

This alternative would construct a new concrete solder pile and panel bulkhead just waterward of the existing structure. New concrete piles would be driven as close as possible to the existing wall. If required, new helical tiebacks would be installed at each soldier pile. Between the piles, pre-cast reinforced concrete panels would be installed to span the distances between each solder pile. Utilities, drainage, and gangway attachments would require modification/extension through the new bulkhead. The void space between the new and old wall would be filled with gravel material. Work would be conducted primarily from heavy water-based barge/equipment and removal and reinstallation of floating docks and anchor piles would be required. Fill between the existing and new wall may be required to utilize land-based installation with associated impacts and restoration. Estimated service life for a properly designed new concrete soldier pile bulkhead is 50 years. A photo of a soldier pile bulkhead (with steel soldier piles instead of concrete) is shown below.

From a USACE and SC-DHEC/OCRM regulatory point of view, the alternative would require regulatory approvals. While not concrete bulkheads are not very common in the local area, projects of this nature are, and a typical moderate level of permitting effort would be anticipated to acquire a joint individual permit.

The estimated cost to construct this alternative is $22.3 million. This is based on material cost estimates for similar project and a labor multiplier of two. Cost includes additional allowance for upland landscape restoration, soft costs at 3% of construction costs, and 20% contingency on construction costs. This total cost allocated along the ~6,100 ft bulkhead provides a unit cost of $3,645/linear foot (LF) of bulkhead shoreline

Estimated construction time is 1 to 1.5 years.

A summary of advantages and disadvantages of the alternative are as follows:

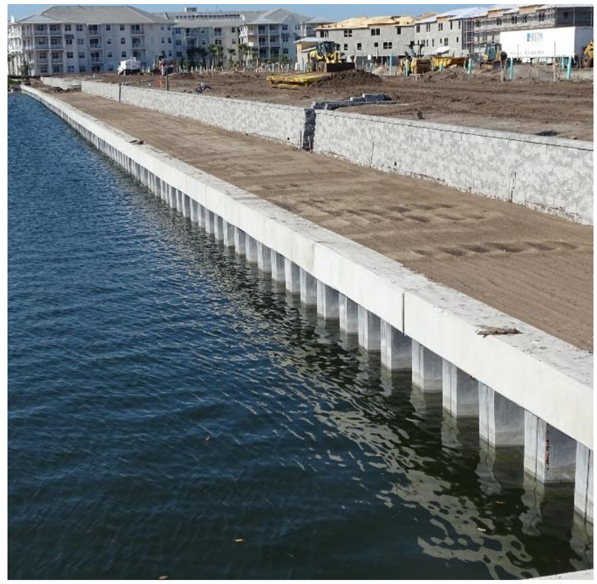
Advantages	*Disadvantages*
• Long Service Life • Higher corrosion resistance • Maintain existing usable upland open/green space • Lower maintenance • Pre-cast systems readily available and commonly used in marine construction	• High Cost • Significant temporary construction impacts to waterside/boating. Requires removal and reinstallation of existing docks. • Heavy barge/equipment anticipated • May have significant temporary construction impacts to upland if fill material required to be trucked from upland rather than barged. • Project may permanently encroach up to ~3' into adjacent wetslips. • Require continued inspections and maintenance efforts

Alternative 9. Shoreline Reconfiguration

This conceptual alternative includes the reconfiguration of the existing vertical wall bulkhead into a sloped or terraced edge treatment. In general, it would include:

- Cutting and removing the upper corroded sections of the existing steel bulkhead just above the mudline or low water elevation.
- Excavation of upland behind the existing wall, including demolition and removal of tiebacks and the buried historic timber bulkhead
- Construction of a sloped or terraced shoreline treatment landward of the cutoff bulkhead using a variety of possible materials and methods.

This option would require substantial upland excavation, demolition and debris removal. The sloped or terraced shoreline could be created using typical rip rap rock, modular block units, mechanically stabilized earth (MSE) methods, smaller terraced bulkheads/retaining walls, or similar methods. Structurally, the benefit of this terraced configuration is that it reduces the exposure heights of the individual bulkhead which requires less robust structures and gives more flexibility in design/materials. Assuming an idealized cutoff of the existing bulkhead at the mudline and typical installed revetment slope landward (1V:1.5H), this final configuration could encroach into the upland up to approximately 25ft landward of the existing bulkhead location. The photos below show examples of terraced shorelines. One shows where two levels of bulkheads were used to create a high tide living shoreline.



This conceptual alternative would require extensive commercial diving activities to cut and remove the existing steel sheetpile. It would also require relatively extensive upland construction activities, including, excavation, debris and earth removal, and material installation.

Access to existing floating docks would most likely be accomplished via construction of fixed access piers from the undisturbed upland grade, across the sloped or terraced shoreline to the existing location of gangway accesses. Alternatively, access location shorelines could be addressed differently, for example, with a new steel bulkhead surrounding the existing bulkhead at the access locations, and slope or terraced shorelines where no access is required. Pile supported boardwalks could also be constructed along the shoreline over any sloped or terraced treatment to recapture usable upland space, but this would add substantially to costs.

Cost, regulatory requirements, construction timelines, and service life could vary greatly depending on the materials and methods used. Any project of this nature would be specifically designed to provide a maximum service life. In general, sloped or terraced shorelines experience less stress (and require less maintenance) and require less maintenance than a vertical bulkhead shoreline with larger exposure heights. Failures in sloped or terraced shorelines are also typically less catastrophic than a vertical bulkhead failure (e.g. a small sloughing of a sloped shoreline versus a failure of a wall and collapse).

A summary of advantages and disadvantages (which may vary by concept/design) of the concept alternative are as follows:

Advantages	*Disadvantages*
• Long Service Life • Limited encroachment on existing water footprint/slips (if any) • Lower maintenance • Less risk of catastrophic failure compared to vertical shoreline • Could integrate environmental benefits (vegetation)	• Existing bulkhead demolition and removal would require commercial divers for cutoff. Demolition and removal of existing and buried bulkheads and tiebacks could be expensive. • Significant temporary construction impacts to waterside/boating. • Permanent loss of useable upland • Required construction of access piers and likely utility reconfigurations.

<u>Project Alternative Comparison – Alternative Matrix</u>

In general, the alternatives presented above, including those in the JGT Report and considered by MCHA reflect the range of potential resolutions to the current situation at MCHA's corroding steel sheetpile bulkhead. The alternatives were assessed further using key project metrics identified in the "Project Synthesis" section (i.e. primary project concerns), among others.

Attached as Exhibit A is the "Alternatives Matrix". The Alternatives Matrix provides a succinct method to visually rank and compare project alternatives based on key metrics. Each alternative/metric was given a relative ranking from 1 to 5, 5 being the most preferred and 1 being the least preferred. For example, an alternative with a very long useful service life would be given a 5 ranking and one with a short service life would be given a 1. Similarly, an alternative with a much lower relative cost would be given a 5 ranking compared to a lower ranking for more costly alternatives.

<u>Summary and Recommended Approach</u>

Based on ATM's review of available information on existing conditions and reported issues, key findings and considerations are reiterated in the following text. These are generally in bold text throughout the report.

- **Exposure heights are one of the primary factors that impact bulkhead requirements (e.g. bulkhead type, design/materials, ultimate cost, etc.). Especially when combined with poor soil conditions, larger exposure heights (e.g. >10ft) can limit the feasibility of certain bulkhead designs.**
- **As indicated in Terracon's 2019 Bulkhead Monitoring Report, most observed deflections are within acceptable ranges. A limited number of observations were slightly outside these tolerances, but no apparent distress or movement was observed.**

- **Maintenance and post construction coating of marine structures is extremely difficult.**
- **Limited soil testing results indicated that soil properties are not likely causing any increase in corrosion rates.**
- **Steel thickness measurements are considered inconclusive. Therefore, corrosion rates and precise structural thicknesses of the existing steel sheet piles is unknown. Verifying the original design conditions (including any sacrificial steel thicknesses) and accurate existing steel structure thicknesses, corrosion rates, and structural capacity is considered a critical step before undertaking any major repair or rehabilitation efforts. During this effort, it may be determined that some sections of the bulkhead are in much better shape than other sections and repair or rehabilitation efforts can be tailored to shoreline sections by actual need.**
- **Determining (or ruling out), with high confidence levels, the exact cause of any suspected abnormally high corrosion rates experienced by the existing bulkhead is considered a critical step before undertaking any major repair or rehabilitation efforts. For example, if an unknown stray current exists and a new steel wall alternative is constructed, the new structure could likely experience higher than normal corrosion rates if the stray current issue is not corrected. It may also negatively impact the performance of cathodic protection systems if not properly accounted for.**
- **Regardless of the exact cause or precise severity of corrosion, it is visually apparent the structure is experiencing ongoing corrosion issues and some form of maintenance, repair, or replacement is warranted. Steel bulkheads are typically designed for a 50-year service life. The fact that the existing wall is experiencing the reported issues at only ~22-years of age indicates some inherent problem. However, before any major repair or rehabilitation efforts, it would be prudent to confidently determine the cause and severity of existing corrosion, estimate the current strength of the bulkhead (compared to existing/design requirements), and predict remaining service life based on measured corrosion rates. The cost of this testing and analysis program should be weighed against repair or rehabilitation costs.**
- **Just as critical is the schedule and timing of any additional testing, analyses, deliberations, design, permitting, bidding, and eventual construction of any repair or rehabilitation. If the visually observed corrosion has severely impacted steel section thickness and is continuing at a high rate, the existing strength of the wall and remaining service life may necessitate short term repairs be conducted immediately or the project phased to address critical areas first while time consuming deliberations and major project planning/design/permitting/bidding is underway. Similarly, the longer any major construction project is delayed, the more costly it can become due to inflation.**

It is unusual for smaller property owner groups and similar stakeholder entities such as MCHA to have the ability to immediately finance major construction projects such as bulkhead replacement. Normally, in addition to financing availability, other factors that are unique to each project and owner group must be considered. In light of the this, various project alternatives were considered for comparison and the following table summarizes the combined results of the Alternatives Matrix rankings and key metrics.

		Summary Ranking			
Alternative	Name	Total Life-Cycle Cost Rank (Normalized)	Total Construction Impact Rank (Normalized)	Total Project Impact Rank (Normalized)	*Final Rank (Normalized)*
1	No Action	3.0	5.0	3.3	*3.8*
2	Cathodic Protection and Recoating (Including Weep Drains)	3.3	4.0	3.7	*3.6*
3	New Steel Sheet Pile Bulkhead with Tiebacks	3.3	3.3	3.8	*3.5*
4	New FRP Composite Sheet Pile Bulkhead with Tiebacks	4.0	3.3	4.0	*3.8*
5	New Truline Vinyl-Concrete Hybrid Bulkhead with Tiebacks	3.3	3.3	4.2	*3.6*
6	Bulkhead Encapsulation	2.8	3.3	3.8	*3.3*
7	New Combination Wall - Cantilever Steel Pile and Sheet Pile	3.3	3.3	3.7	*3.4*
8	New Concrete Soldier Pile Bulkhead	3.5	3.7	4.0	*3.7*
9	Shoreline Reconfiguration (Slope/Terrace)	3.3	2.7	3.7	*3.2*

Items to note regarding costs and construction impacts:

- *Detailed cost estimates have been acquired for Alternatives 2 and planning level estimates have been acquired for Alternatives 3 and 4. Additional cost estimates herein are based on historic similar local and regional/national project costs, material quotes, labor multipliers, information provided by manufacturers, and general discussions with contractors and engineering judgment at the time of this report.*
- *Due to the inherent volatility in material and fuel prices; unique project challenges specific the MCHA bulkhead; and variations in contractor size, experience, familiarity with unique materials/methods, and backlog, the anticipated costs and construction impacts for alternatives may vary.*

<u>Recommendations:</u>

- Addressing specific sections of shoreline that present critical life/safety concerns (if any) should be given priority for immediate localized repairs/rehabilitation (if required).

- MCHA should discuss with their technical consultants to determine if there are any sections of shoreline that are more critical than others. If needed, accurate steel thickness testing or other investigations and remaining service life calculations should be conducted <u>on a section by section basis.</u> It may be determined that project experience and visual observations overrule the need for these steps and immediate repair replacement of the entire bulkhead is the recommended approach.

- Pending the results of testing and remaining service life assessment (or visual prioritization) on a section by section basis of the bulkhead, and barring any covenant-type requirements, not all sections of shoreline (and/or adjacent governing user groups) necessarily require the same type of repair/replacement strategy at the same time.

- Different user groups or shoreline sections may be amenable to different project alternatives and costs. For example, the shoreline along the Wild Dunes Marina dock trees has significant upland open space that may be more suited to Alternative 9 (Shoreline Reconfiguration).
- If certain large sections of bulkhead are found to have significantly have less remaining service life than others, phasing of the project may be considered to address these areas sooner and spread out costs. Multiple mobilizations will increase costs overall but may be negligible relative to time between phases and total costs.
- This approach also provides an opportunity for MCHA to observe construction method/impacts of specific shoreline types and by specific contractors, understand detailed costing, and negotiate add-ons or change order if larger sections of shoreline have a need and/or desire to participate.
- It is not recommended this phased or sectioned approach be conducted on a small scale, such as a lot-by-lot basis, but on sections of ~500ft in length or longer to take advantage of economy of scale.

- Based on the project alternatives comparison: (SAY CORROSION RESISTANT IN CONCRETE AND FRP)
  - Alternative 1 – No Action – is not recommended.
  - Alternative 2 – Cathodic Protection, Coating, and Weep Drains – is a practical and feasible alternative only if:
    - Remaining service life assessments show that existing bulkhead is structurally sound enough to merit protecting. It is not advisable to invest in maintaining the current condition of a near-failure structure.
    - Testing or adequate design can confidently ensure there are no site abnormalities or other conditions that would inhibit the proper and long-term effectiveness of the cathodic protection system.
  - Alternative 3 – New Steel Sheet Pile Bulkhead with Tiebacks – is a practical and feasible alternative only if:
    - Testing or adequate design can confidently ensure there are no site abnormalities or other conditions that would prematurely corrode a new steel structure.
  - Alternative 4 - New Composite Sheet Pile Bulkhead with Tiebacks – is a practical and feasible alternative that would be resistant to future corrosion.
    - Maintenance dredging will need to be carefully conducted with low impact methods or restricted at the structure.
    - Construction costs/methods may vary by contractor.
  - Alternative 5 - New 'Truline' Vinyl-Concrete Hybrid Bulkhead with Tiebacks – is not considered a practical or feasible alternative. Although ranking criteria may score it slightly higher, this is considered a more atypical construction method and the required exposure heights at MCHA are beyond the limits of normal installation of existing systems.
  - Alternative 6 – Bulkhead Encapsulation – is a practical and feasible alternative. However, the costs of this alternative will likely approach costs of a new bulkhead construction which would be preferred.
  - Alternative 7 – Cantilever Steel Pile and Steel Sheet Pile Wall – similar to Alternative 3, this is a practical and feasible alternative. If a new steel sheetpile bulkhead is considered

for bidding/construction, this alternative should be included as a bid alternate for comparison.

- Alternative 8 – Concrete Soldier Pile Bulkhead – is a practical and feasible alternative. Soil conditions and typical local construction methods may present design and construction cost hurdles.
- Alternative 9 – Shoreline Reconfiguration – is a feasible alternative. Practically, additional costs and construction impacts may limit its use to only certain shoreline sections.

The ultimate decision on how to proceed lies with MCHA and will depend on financial ability, risk aversion, aesthetic preferences, and user group preferences.

Exhibit A
Alternatives Matrix

Alternative	Name	Relative Cost Ranking				
		Initial		Near - Term	Long-Term	*Total Life-Cycle Cost Rank (Normalized)*
		Typical Shoreline Treatment Construction Costs	Atypical construction requirements (cost increases)	Maintenance/Operating Requirements	Service Life	
1	No Action	5	5	1	1	***3.0***
2	Cathodic Protection and Recoating (Including Weep Drains)	4	5	2	2	***3.3***
3	New Steel Sheet Pile Bulkhead with Tiebacks	2	4	3	4	***3.3***
4	New FRP Composite Sheet Pile Bulkhead with Tiebacks	3	3	5	5	***4.0***
5	New Truline Vinyl-Concrete Hybrid Bulkhead with Tiebacks	3	2	5	3	***3.3***
6	Bulkhead Encapsulation	2	3	3	3	***2.8***
7	New Combination Wall - Cantilever Steel Pile and Sheet Pile	2	4	3	4	***3.3***
8	New Concrete Soldier Pile Bulkhead	3	3	4	4	***3.5***
9	Shoreline Reconfiguration (Slope/Terrace)	2	2	4	5	***3.3***

Alternative	Name	Relative Construction Impact Ranking			
		Construction Duration	Marine Footprint/ Boating Impacts	Upland Construction Corridors/Impacts	*Total Construction Impact Rank (Normalized)*
1	No Action	**5**	**5**	**5**	***5.0***
2	Cathodic Protection and Recoating (Including Weep Drains)	4	5	3	***4.0***
3	New Steel Sheet Pile Bulkhead with Tiebacks	3	3	4	***3.3***
4	New FRP Composite Sheet Pile Bulkhead with Tiebacks	3	4	3	***3.3***
5	New Truline Vinyl-Concrete Hybrid Bulkhead with Tiebacks	3	4	3	***3.3***
6	Bulkhead Encapsulation	3	4	3	***3.3***
7	New Combination Wall - Cantilever Steel Pile and Sheet Pile	3	3	4	***3.3***
8	New Concrete Soldier Pile Bulkhead	4	3	4	***3.7***
9	Shoreline Reconfiguration (Slope/Terrace)	3	3	2	***2.7***

Alternative	Name	Relative Project Impact Ranking						
		Loss of Usable Slip/Potential Dock Relocation	Loss of Upland Green/Open Space	Dredging Implications	Gangway/Water Access Implications	Aesthetics	Environmental	*Total Project Impact Rank (Normalized)*
1	No Action	5	5	3	4	1	2	***3.3***
2	Cathodic Protection and Recoating (Including Weep Drains)	5	3	5	5	3	1	***3.7***
3	New Steel Sheet Pile Bulkhead with Tiebacks	3	5	5	4	4	2	***3.8***
4	New FRP Composite Sheet Pile Bulkhead with Tiebacks	3	5	3	4	5	4	***4.0***
5	New Truline Vinyl-Concrete Hybrid Bulkhead with Tiebacks	4	5	3	4	5	4	***4.2***
6	Bulkhead Encapsulation	4	4	4	4	4	3	***3.8***
7	New Combination Wall - Cantilever Steel Pile and Sheet Pile	2	5	5	4	4	2	***3.7***
8	New Concrete Soldier Pile Bulkhead	2	5	5	4	5	3	***4.0***
9	Shoreline Reconfiguration (Slope/Terrace)	4	2	4	2	5	5	***3.7***

Alternative	Name	Summary Ranking			
		Total Life-Cycle Cost Rank (Normalized)	Total Construction Impact Rank (Normalized)	Total Project Impact Rank (Normalized)	*Final Rank (Normalized)*
1	No Action	**3.0**	**5.0**	**3.3**	***3.8***
2	Cathodic Protection and Recoating (Including Weep Drains)	**3.3**	**4.0**	**3.7**	***3.6***
3	New Steel Sheet Pile Bulkhead with Tiebacks	**3.3**	**3.3**	**3.8**	***3.5***
4	New FRP Composite Sheet Pile Bulkhead with Tiebacks	**4.0**	**3.3**	**4.0**	***3.8***
5	New Truline Vinyl-Concrete Hybrid Bulkhead with Tiebacks	**3.3**	**3.3**	**4.2**	***3.6***
6	Bulkhead Encapsulation	**2.8**	**3.3**	**3.8**	***3.3***
7	New Combination Wall - Cantilever Steel Pile and Sheet Pile	**3.3**	**3.3**	**3.7**	***3.4***
8	New Concrete Soldier Pile Bulkhead	**3.5**	**3.7**	**4.0**	***3.7***
9	Shoreline Reconfiguration (Slope/Terrace)	**3.3**	**2.7**	**3.7**	***3.2***

Rank	Relative Comparison
5	**Great**
4	**Good**
3	**Fair**
2	**Mediocre**
1	**Poor**

ATM DESIGN ENGINEERING CONSULTING