Town of Annapolis Royal

Wharf Rehabilitation Terraced Fill Embankment

CONCEPTUAL DESIGN OPTIONS

CIMA+ project number: Z0027061
January 2026 – Version 0A

Town of Annapolis Royal

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Property and Confidentiality

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1. Introduction

1.1 Project Description

The town wharf is a picturesque waterfront destination in Annapolis Royal, Nova Scotia (Mindtrip, 2026). It also features a gangway, floating dock and four guest moorings in the middle of the Annapolis Basin (Annapolis Royal, 2026). The wharf was originally constructed using timber, and the existing corrugated sheet piles were subsequently installed as part of its rehabilitation. Unfortunately, following a recent structural report issued by Able Engineering on September 22, 2022, the wharf has been found to require rehabilitation or replacement within the next five years. Since the conclusion of this report, the Town of Annapolis Royal is assessing options to address the structural issues at the town wharf.

The Town of Annapolis Royal subsequently prepared a feasibility study (Town of Annapolis Royal, 2024) addressing flood risk assessment and various adaptation concepts, including options related to the wharf's replacement. The study examined the possibility of constructing a new exterior shell around the existing wharf, rather than rebuilding it entirely, to retain the existing fill as the deteriorating sheet piles continue to corrode and perforate. The proposed shell would also integrate a terraced embankment (the "Terrace") on the south side of the wharf as part of the shoreline restoration efforts, thereby reducing the extent of vertical wall construction required for rehabilitation.

In addition to other shoreline rehabilitation and flood mitigation measures, the feasibility study (Town of Annapolis Royal, 2024) also provided a magnitude cost estimate for the Terrace. Additional work is needed to complete designs for the Terrace and provide a more detailed cost estimate that can be put towards applications for capital funding. The Town is looking for support from a climate change roster expert (CIMA+) to develop design options for the Terrace with a more detailed cost estimate for the options than what was completed in the feasibility study.

1.2 Project Objective

The objective of this assignment is to develop design options for the terrace and to prepare detailed cost estimates for each option, incorporating insights from previous engineering assessments as well as traditional ecological knowledge (TEK). The design options will include:

- Conceptual designs and initial renderings, presenting alternatives with varying terrace elevations and configurations, including differing numbers of terrace levels.
- An expanded cost estimate, building upon the preliminary cost information provided in the flood risk assessment and adaptation concepts report.

1.3 Location of Scope of Work

The Town of Annapolis Royal is located on the banks of the Annapolis River on the northwest coast of Nova Scotia (Figure 1.1).

Figure 1.1: Location of Annapolis Royal wharf

The rehabilitation concept under study consists of a terraced slope on the south side of the wharf. The sheet pile portion of the wharf is excluded from the scope of this report (Figure 1.2).

Source: Town of Annapolis Royal, 2024

Figure 1.2: Initial plan view of the terrace concept (taken from the 2024 feasibility study)

Surrounding the wharf, the existing waterfront has been impacted by over two hundred years of development, which has altered the riverbanks and salt marshes that originally thrived in the intertidal zone. The area between the wharf and King's Theatre has been protected from erosion with a mix of large stones and driven sheet pile walls (Figure 1.3).

Source: Town of Annapolis Royal, 2024

Figure 1.3: Existing conditions at the town wharf (taken from the 2024 feasibility study)

2. Desktop Review and Synthesis of Existing Data and Resources of the Wharf Replacement

Throughout the design process, the Town of Annapolis Royal has made available several reference documents to support the work of CIMA+. The following section summarizes the key documents that provided guidance for this process.

2.1 Climate Change Plan

A climate change survey was conducted at the beginning of June 2022 focusing on getting better insight into how community members in Annapolis Royal understand climate change and the effects of climate change relating to Annapolis Royal. The survey highlighted that the Town has recognized the threats of climate change for decades and continues to seek solutions to protect and safeguard the Town's environmental, economic and social integrity (Town of Annapolis Royal, 2022).

While reducing the production of GHG emissions in the community and corporate sector is a way to mitigate climate change and support alternative solutions to address threats such as global warming, the impacts of climate change are inevitable for the inhabitants of Annapolis Royal:

- Intense heat waves
- Shorter or longer seasons
- Severe weather
- Sea-level rise
- Drought

These impacts will gradually intensify, and future effects must be considered while designing the terrace concept.

The 2022 climate change plan of the Town of Annapolis Royal illustrates four guiding principles, which are:

1. Protect and strengthen natural habitats and biodiversity.
2. Foster stronger collaboration among neighbouring communities to identify shared priorities and opportunities for responding to climate change.
3. Encourage meaningful community involvement by connecting local governments, stakeholders, and residents.
4. Enhance long-term sustainability and multiple benefits of adaptation and mitigation initiatives by aligning them with local economic, social, and environmental goals.

The first guiding principle was an integral part of the thinking and designing behind the terrace's concept decision-making process.

2.1.1 Sea-level rise and Flooding

Climate change, sea-level rise and flooding have accelerated the erosion rate around coastal areas, such as the Town of Annapolis Royal, resulting in faster deterioration of flood protection structures. Sea-level rise will continue to threaten Annapolis Royal in the coming decades, especially in the downtown core (Town of Annapolis Royal, 2022).

Living shorelines were identified as a potential adaptation method to tackle erosion and help the coastline reach a more stable state (Town of Annapolis Royal, 2022). Also known as ecosystem services, living shorelines improve water quality and diversify coastal habitats. In addition, living shoreline approaches, such as coastal forests, salt marshes, as well as vegetated slopes and dunes, protect shores from erosion and provide flood protection. Erosion is a natural process that transpires over time as the water hits the coastline (Town of Annapolis Royal, 2022).

With these preferred approaches, living coastlines and salt marshes were the fundamental elements considered in the conception of the terrace as coastal protection.

2.1.2 Land Acknowledgment and Traditional Ecological Knowledge (TEK)

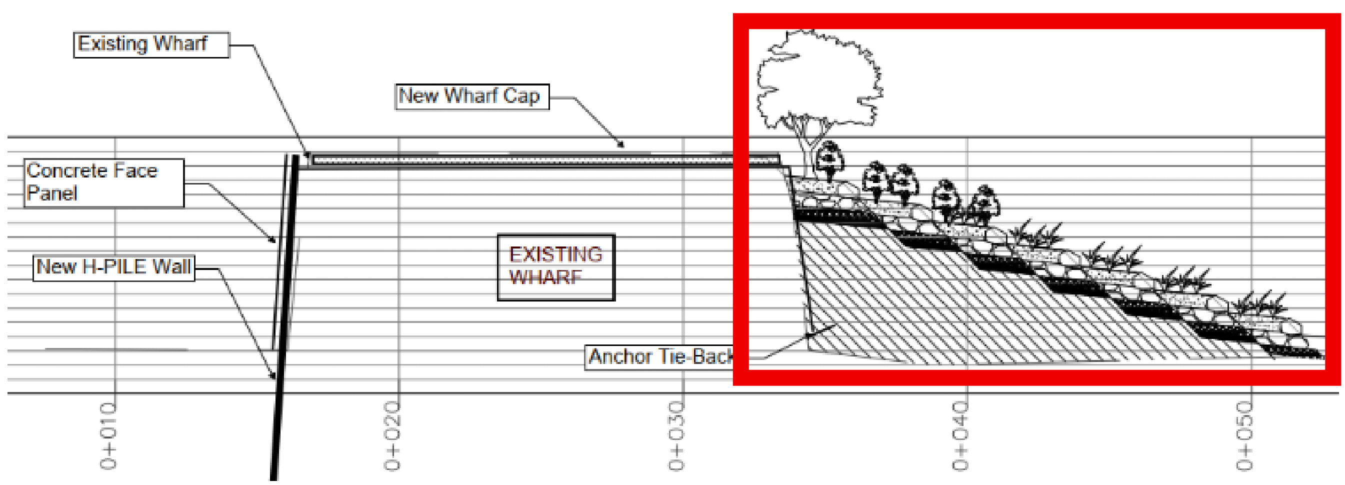
All land in Nova Scotia is considered unceded Mi'kmaq territory. Living in a world affected by climate change, elders, scholars and other Indigenous knowledge holders carry valuable knowledge to help governments and decision-makers address climate change (Town of Annapolis Royal, 2022). In this regard, the terrace concept has great potential for not only consultation, but collaboration on aspects of the project, such as restoring native species' habitat, historical markers, informative signage, or any storytelling through art (Town of Annapolis Royal, 2024).

A research project aiming to recommend climate equity actions to build a partnership with Annapolis Valley First Nation and Bear River First Nation on the project is still in process and no available outcome of municipal engagement with First Nations is currently available. Nevertheless, ecological benefits and native habitats were carefully considered and integrated into the design of the terrace concept options.

It is recommended that the concept developed and presented in this report be shared with the First Nations in order to discuss the proposed approach, explore opportunities for planting native species, establish resilient coastal ecosystems, potentially incorporate historical and informational markers, and ensure that the design option aligns with climate resilience and partnership principles established between the Town of Annapolis Royal, Annapolis Royal First Nation, and Bear River First Nation.

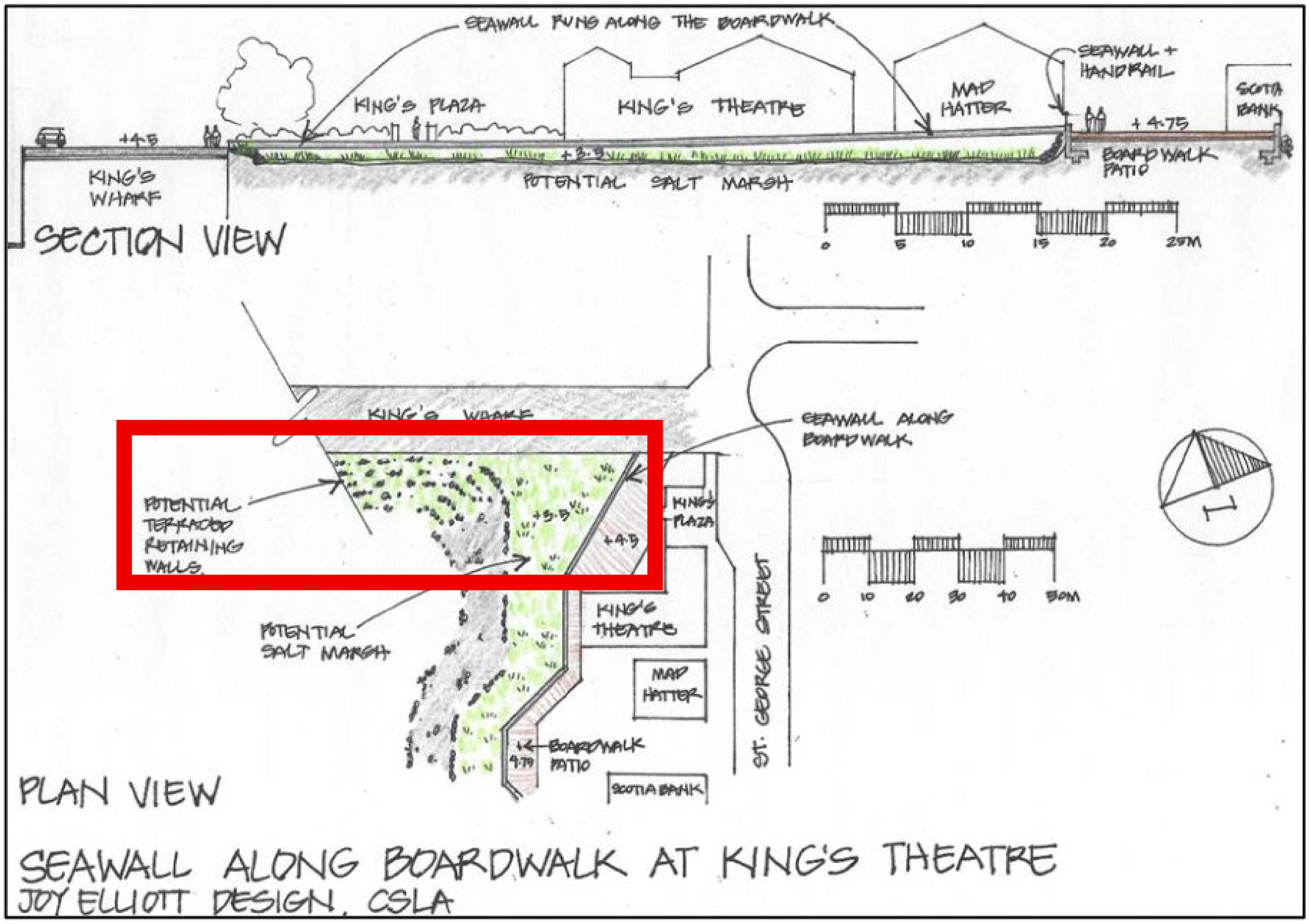
2.2 Shoreline Restoration

The wharf rehabilitation embankment fill constitutes one of the proposed measures to retain and protect the town's wharf but also takes place in a shoreline restoration project as presented in the feasibility study. This restoration project presents an opportunity to reinstate aquatic habitats and biodiversity, such as a rich salt marsh within the intertidal zone. Within the broader shoreline restoration initiative, the Terrace concept entails infilling the area in successive tiers to reflect aquatic environments that support ecological functions and enhance biodiversity. Figure 2.1 and Figure 2.2 show the initial terracing and shoreline restoration concept at King's Theatre.



Source: Town of Annapolis Royal, 2024

Figure 2.1: Wharf rehabilitation concept section A-A (taken from the 2024 feasibility study)



Source: Town of Annapolis Royal, 2024

Figure 2.2: Terracing and shoreline restoration at King's Theatre (taken from the 2024 feasibility study)

3. Designing Criteria

Following the desktop review, it became clear that the design concept needed to prioritize environmental considerations, with a strong emphasis on maximizing ecological function and biodiversity through the integration of living shoreline elements and salt marsh restoration. The design process aimed to incorporate insights and input from First Nations and local communities, but no insights were available from the ongoing engagement project. However, to ensure the development of a resilient and enduring concept, hydraulic preliminary calculations were required to inform and validate the proposed design criteria.

3.1 Armour Stone Sizing

Even with the idea of making a well-vegetated riprap to be able to design a sustainable wharf rehabilitation concept, the appropriate size of the armour stones must be established. No site-specific hydraulic and ice studies, including a hydraulic model of the bay are available. Information was provided on the projected water levels under climate change (including sea-level rise and storm surge).

In the absence of detailed hydraulic and ice data, supplementary calculations were undertaken to estimate wave generation and ice thickness for the design of the stone armour protection. A technical note was prepared to establish the armour stone sizing and to identify the required crest width (appendix A)[1]. Additional details about designing criteria are provided in the technical note.

The recommended stone size for wave stability is 600-800 mm.

The recommended crest elevation is 4.9 m CGVD2013 and the recommended crest width is 2.4 m.

3.2 Tide Characteristics

According to the Digby station (#00325), the tidal range between the Higher High Water Mean Tide (HHWMT) and the Mean Water Level (MWL) is 3.4 m (Table 3.1).

Table 3.1 : Tide characteristics at Digby Station (#00325)

Tide Characteristics	Water Elevation (CD datum)	Water Elevation (CGVD28)	Water Elevation (CGVD2013)
Highest Astronomical Tide	9.38	4.95	4.31
Higher High Water Large Tide	9.17	4.74	4.10
Mean Higher High Water (Higher High Water Mean Tide)	**7.94**	**3.51**	**2.87**
Mean High Water (High Water Mean Tide)	7.8	3.37	2.73
Mean Water Level	**4.54**	**0.11**	**-0.53**
Mean Low Water (Low Water Mean Tide)	1.25	-3.18	-3.82
Mean Lower Low Water (Lower Low Water Mean Tide)	1.12	-3.31	-3.94
Lower Low Water Large Tide	-0.16	-4.59	-5.23
Lowest Astronomical Tide	-0.35	-4.78	-5.42

Source: Government of Canada, 2025

[1] Refer to technical note (appendix A) for more details about flow velocity, ice thickness and wave action criteria.

3.3 Local Plant Biodiversity

The scope of the project did not include a site visit from CIMA+ team. However, Clean Foundation conducted a survey of the shoreline during the summer of 2025 regarding the plant community elevations (Table 3.2). As a result, *Sporobolus alterniflorus* dominate the low marsh, while *Sporobolus pumilis* and *Juncus gerardii* prevail the high marsh. In addition to these species, most often the high marsh, a range of other halophytes typical of the region were also observed in the salt marsh, indicating good biodiversity and the presence of viable seed banks should the project move forward (L. Horrocks, Clean Foundation, personal communication, October 24, 2025):

- *Limonium Carolinum*
- *Suadea spp.*
- *Triglochlin martima*
- *Plantago maritima*
- *Solidago sempervirens*
- *Glaux maritim*
- *Atriplex spp.*
- *Sporobolus michauxiana*
- *Salicornia europea*
- *Carex palacea*

Table 3.2 : Elevation results on the Annapolis Royal survey site

Group	Minimum Elevation (m)	Mean Elevation (m)	Maximum Elevation (m)
Brackish marsh	3.40	3.66	3.88
High marsh	2.70	3.03	3.50
High/low marsh	2.44	2.70	2.99
Low marsh	1.39	2.18	2.91

Source: Clean Foundation, 2025

3.4 Land Registry

Without the land registry, CIMA+ approximated that the initial plan view of the terrace concept had a width of 27 to 28 m as shown on Figure 1.2 in Section 1.3.

The Town of Annapolis Royal confirmed the project must remain within the lot adjacent to the Wharf, as permission to extend beyond the property line is not granted. Figure 3.1 shows the lot boundaries. The measured distance on the drawing is approximately 25 m, which limits the final integrated design option for the terraced embankment fill riprap to this length. For further plan development, accurate surveying is recommended to ensure that no encroachment occurs onto the adjacent property.

Figure 3.1: Land registry drawing (Town of Annapolis Royal, 2025)

4. Design Options

Considering all designing criteria, two options were developed[2]. The implementation of vegetated terraces was constrained by the stone size of the riprap recommended in hydraulics. A benefit of using such large stone size riprap is that slope stability is less of an issue. To minimize encroachment and optimize planting space, the riprap slope was set to 1.5:1. The crest width of the upper terrace was maintained at 2.4 m in accordance with hydraulic recommendations, although only 1.4 m (equivalent to two stones of 700 mm) was considered for the lower terraces. This allowed for optimized planting space as well. In each option, no matter the elevation, stone paving was added on top of planting soil to keep the material in place under hydraulic stress.

The lower portion of the riprap was not considered even for a lower salt marsh implementation for the following reason: based on field survey results, the lowest elevation of the low marsh is 1.39 m, with an average of 2.18 m. Vegetation integration below this elevation would not survive.

4.1 Option 1

The first option aims to increase the number of salt marsh terraces. A vertical spacing of 1.55 m was maintained between each terrace. This configuration provides three vegetated levels, totalling 11.2 m of salt marsh terrace, with the following widths (Figure 4.1):

- Terrace 1: 5.2 m.
- Terrace 2: 3.0 m.
- Terrace 3: 3.0 m.

However, this option offers limited planting space, and the elevation of the lower terrace remains below the average elevation of the low marsh recorded during the field survey. As a result, the chances of lower salt marsh plants surviving are less likely when considering the existing environmental conditions.

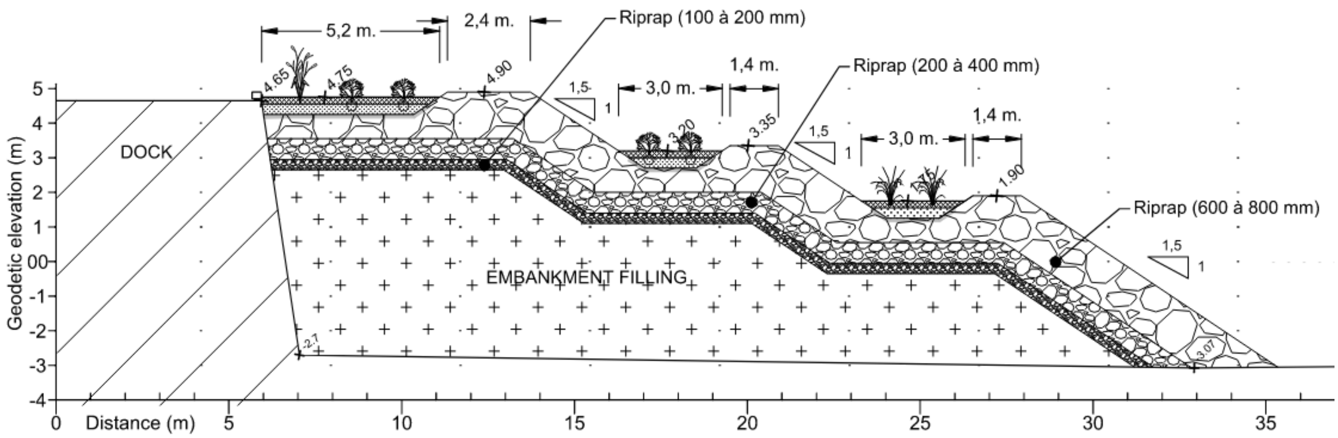


Figure 4.1: Option 1 – terrace concept

[2] The projected width of the Wharf is 28 m, as described in Section 3.4.

4.2 Option 2

The second option aims to increase the salt marsh area instead of the number of terraces. A vertical spacing of 1.9 m was considered between each terrace. This configuration provides two vegetated levels, totalling 13 m of salt marsh terrace, with the following widths (Figure 4.2):

- Terrace 1: 7.0 m.
- Terrace 2: 6.0 m.

This option offers more planting space, and the elevation of the lower terrace is over the average elevation of the high/low marsh recorded during the field survey. As a result, the chances of high and lower marsh plants surviving are more likely when considering the existing environmental conditions.

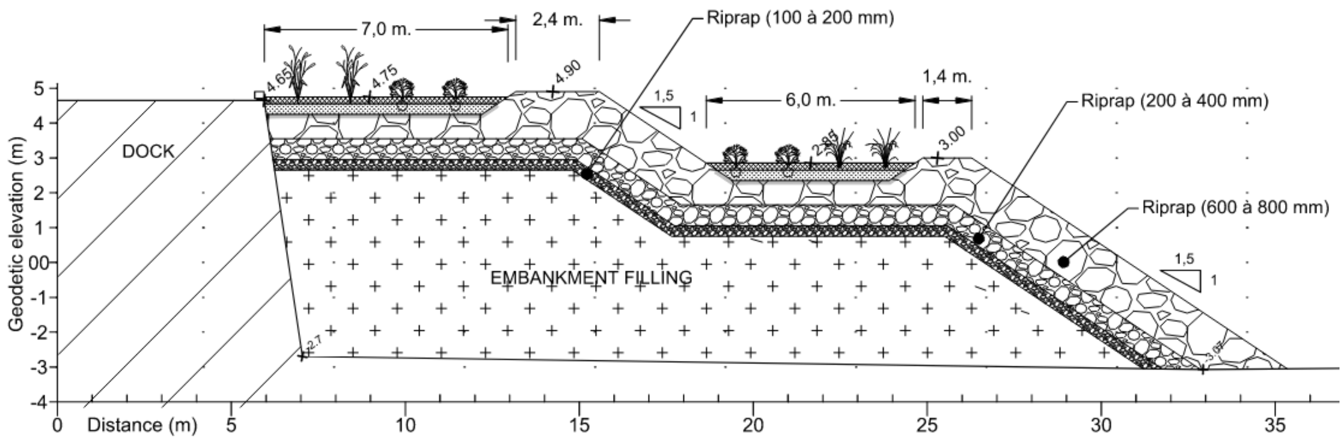


Figure 4.2: Option 2 – terrace concept

5. Integrated Design Option Selected

During a discussion with the Town of Annapolis Royal, the advantages of each design option were evaluated. Following this discussion, option 2 was selected and refined based on the feedback from the Town (Figure 5.1), which emphasized the importance of making the terrace accessible to enhance social acceptability and minimize vegetation trampling. Consequently, the chosen concept was adjusted to integrate natural stone paving along the upper riprap crest (Figure 5.2).

This refined option provides a greater planting space, 10 m[3], and the elevation of the lower terrace exceeds the average high and low marsh elevations recorded during the field survey by the Clean foundation in 2025. Consequently, the likelihood of successful establishment and long-term survival of marsh vegetation is significantly improved based on the existing environmental conditions. Overall, this option could offer superior ecological benefits compared to the alternative, as it maximizes habitat potential and supports the resilience of the restored marsh ecosystem. The geotextile and planting soil used shall comply with applicable standards.

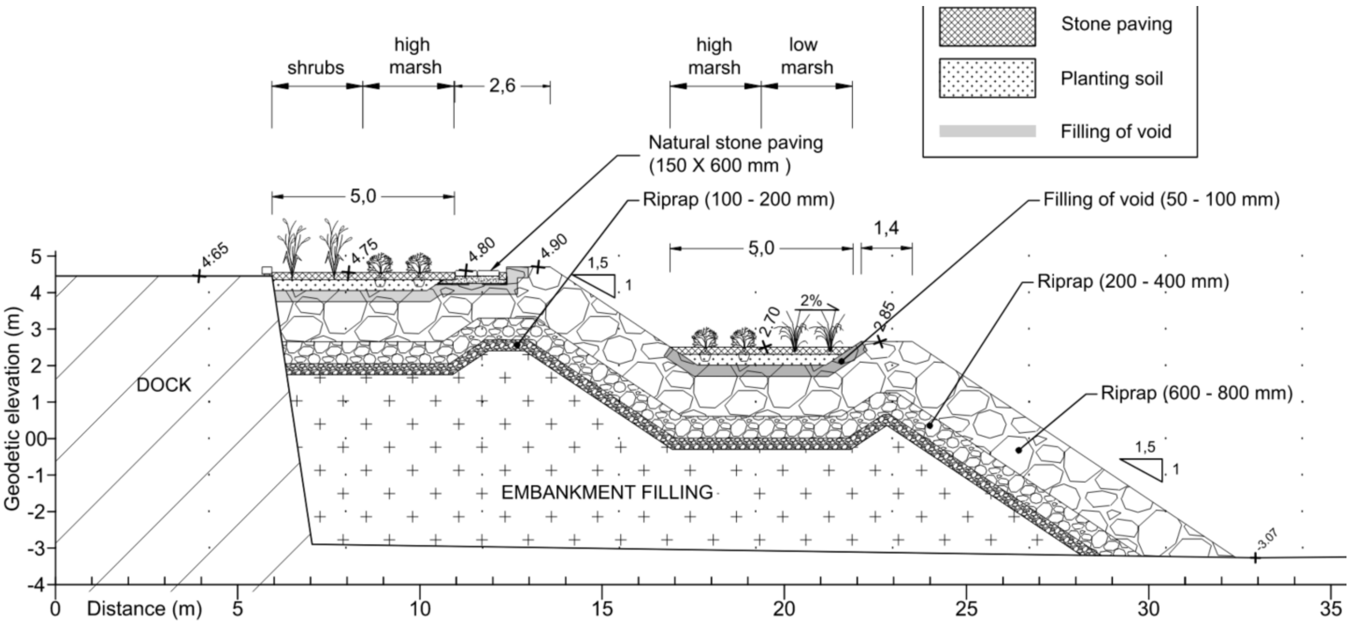


Figure 5.1: Selected terrace concept

[3] The projected width of the Wharf was reduced to 25 m, as described in Section 3.4.

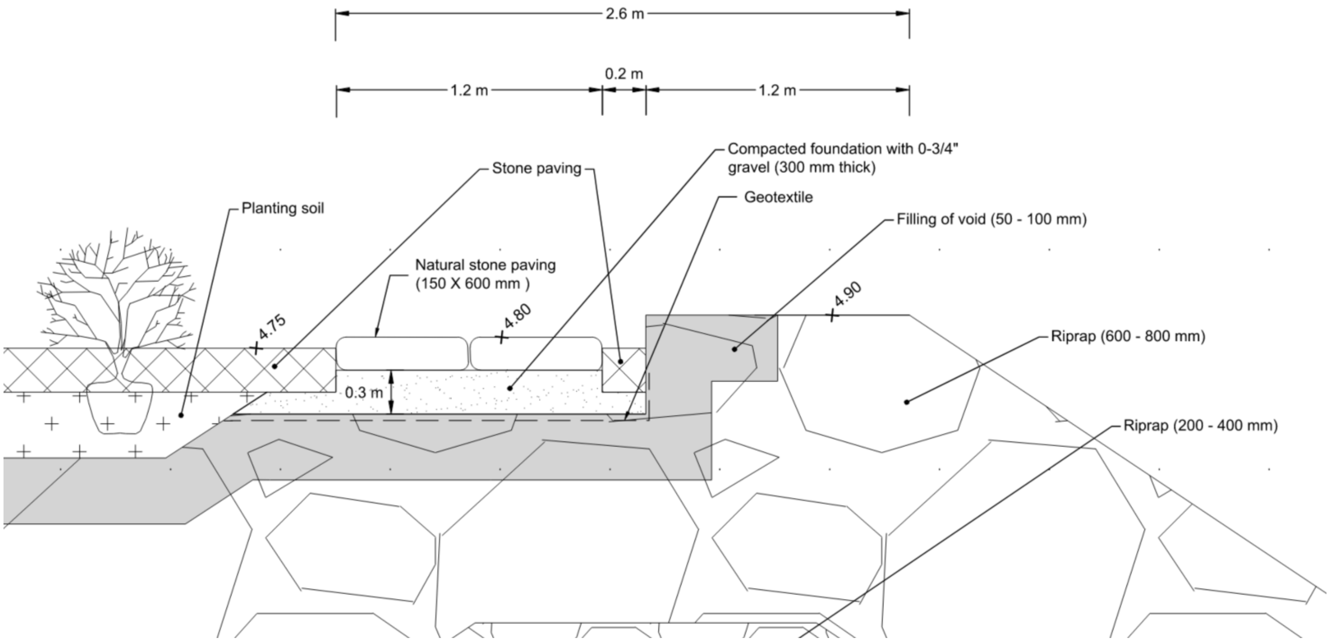


Figure 5.2: Selected terrace concept – enlargement – stone paving footpath

5.1 Terrace Fill Concept Cost Estimate

Upon the preliminary cost information provided, an extended cost estimate was prepared. As shown in Table 3-2 of the flood risk assessment and adaptation concepts report (Table 5.1), the approximate cost of the Embankment fill, rock placement, geotextile, vegetation and planting was $782,200.

Based on the final integrated design option presented in Section 5, an expanded cost estimate was carried out. Additionally, an approximate cost has been added to cover expenses associated with environmental measures, such as performing work at low tide or installing a turbidity curtain.

Considering all the elements presented in Table 5.2, the approximate total amount is estimated at $1,758,347. The main difference explaining the increase compared to the preliminary cost information is the substantial riprap installation required to adapt the embankment fill to the hydraulic constraints. This estimate is based on current assumptions and quantities and should be regarded as preliminary still and subject to change. It is also strongly recommended to verify current prices locally.

Table 5.1: Wharf rehabilitation opinion of probable cost (taken from the 2024 feasibility study)

Element	Approximate Cost (2023$)
Steel Piling and Wall Face	$ 630,000
Structural Steel Work	$ 325,680
Tie-Back System	$ 87,000
Embankment fill, rock placement and geotextile	$ 726,200
Vegetation and Planting	$ 56,000
Concrete capping	$ 140,875
Miscellaneous Staging and Other Elements	$ 38,245
Subtotal	**$ 2,004,000**
Geotechnical Investigation and Detail Design	**$ 162,500**
25% Contingency for unknowns (includes contingency on design)	$ 541,625
Total without architectural panels	**$ 2,708,125**
Architectural Pre-Cast Panels	$ 1,128,000
25% Contingency for unknowns	$ 282,000
Total with architectural panels	**$ 4,118,125**

Source: Town of Annapolis Royal, 2024

Table 5.2: Selected wharf terrace fill concept cost estimate

Art	Code	Designation of Work	Quantity	Unit	Unit price	Product Price
1.0	**Global Measures**					
1.1	01.01.99	Environmental measures	1	Flat Rate	$25,000	$25,000
1.0	**Subtotal – Global Measures**					**$25,000**
2.0	**Embankment Fill, rock placement and geotextile**					
2.1	02.01.99	Embankment fill	7,257	m^3	$90	$653,130
2.2	02.02.99	Riprap 100-200 - 300 mm Thickness	719	m^3	$120	$86,280
2.3	02.03.99	Riprap 200-400 - 600 mm Thickness	1,548	m^3	$140	$216,720
2.4	02.04.99	Riprap 600-800 - 1 400 mm Thickness	3,811	m^3	$160	$609,760
2.5	02.05.99	Filling of void[1]	75	m^3	$110	$8,300
2.6	02.06.99	Planting soil[2]	260	m^3	$85	$22,100
2.7	02.07.99	Pebble paving [3]	165	m^3	$110	$18,150

Art	Code	Designation of Work	Quantity	Unit	Unit price	Product Price
2.8	02.08.99	Natural stone paving	136	m^2	$500	$68,000
1.0	**Subtotal – Embankment Fill**					**$1,682,440**
3.0	**Vegetation and planting**					
3.1	03.01.99	Low marsh – Herbaceous[4]	2 180	ea	$15	$32,693
3.2	03.02.99	High marsh – Herbaceous[5]	759	ea	$15	$11,384
3.3	03.03.99	High marsh – Shrubs[6]	228	ea	$30	$6,830
3.0	**Subtotal - Vegetation**					**$50,907**
Total Cost Estimate for the Wharf Terrace Fill Concept						**$1,758,347**

[1] 25% of the surface area of the salt marshes
[2] 90% of the surface area of the salt marshes
[3] 90% of the surface area of the salt marshes
[4] Density considered of 5 plants/m^2 over the low marsh
[5] Covers 40% of the surface area of the high marsh
[6] Covers 60% of the surface area of the high marsh

6. Conclusions and Recommendations

The report presents an initial draft of an integrated design option for the terraced fill embankment concept, developed as part of a broader shoreline restoration project. By expanding the planted area in the selected design, this would promote healthier marsh vegetation, enhancing soil stability, biodiversity, resilience to sea-level rise, and natural coastal protection for the town wharf. This broader vegetated zone would also help the marsh keep pace with rising sea levels while contributing to the mitigation of storm impacts and flooding affecting the wharf and its surrounding areas.

The cost estimate ($1,758,347) differs significantly from the preliminary cost provided ($782,200), primarily due to the quantity of material required and the larger riprap rock sizes recommended to ensure the long-term stability of the structure. In contrast, the integration of vegetation for salt marsh implementation represents only a small portion of the overall cost. One potential solution not considered in the cost estimate is the reuse of existing riprap material. Assessing this option could help reduce overall costs by reusing material already available onsite, while also minimizing expenses associated with material disposal. In addition to the economic benefits, this approach would contribute to reducing the project's environmental footprint by limiting the need for new material extraction and transportation.

Further work recommended:

- Validate prices locally.
- Share the initial draft concept with the First Nations to discuss the proposed approach.
- Identify native species for planting and establishing resilient coastal ecosystems.
- Evaluate the opportunity to integrate historical and informational markers within the project.
- Evaluate overtopping using a numerical model such as XBeach to refine crest elevation.
- Consult residents to confirm winter ice conditions.
- Validate flow conditions through field inquiry or a 2D hydrodynamic model, although velocities are expected to be low due to shelter from the main channel.
- Validate the feasibility of the terrace fill concept by assessing the condition of the wharf and the structural elements that must be deployed on the opposite side to ensure adequate reinforcement.

7. References

Horrocks, Logan. 2025. Clean Foundation. Personal communication. October 24, 2025

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A

Appendix A
Technical note for the design of riprap stone size, crest elevation and crest width

TECHNICAL NOTE

Project:	Wharf Rehabilitation Terraced Fill Embankment
Version:	Rev. B - Preliminary
Date:	2025-09-22
Ref.:	Z0027061
Object:	Technical Note for the Design of Riprap Stone Size, Crest Elevation and Crest Width

1. Context

As part of the rehabilitation of the Annapolis Royal Wharf using a terraced slope, the appropriate size of the armour stones must be established. The 2024 Flood Risk Assessment and Adaptation Concepts report was reviewed for this study. At the outset, it was anticipated that site-specific hydraulic and ice studies, including a hydraulic model of the bay, would be available. In practice, the only information provided concerned projected water levels under climate change (including sea level rise and storm surge).

In the absence of detailed hydraulic and ice data, supplementary calculations were undertaken to estimate wave generation and ice thickness for the design of the stone armour protection. This technical note presents the resulting armour stone sizing together with the determination of the required crest width.

2. Location and Concept

The Town of Annapolis Royal is located in Nova Scotia, on the eastern shore of a tidal inlet of the Bay of Fundy (Figure 2-1).

Figure 2-1: Location of Annapolis Wharf

The rehabilitation concept under study consists of a terraced slope on the south side of the wharf (Figure 2-2). The sheet pile portion of the wharf is excluded from this technical note.

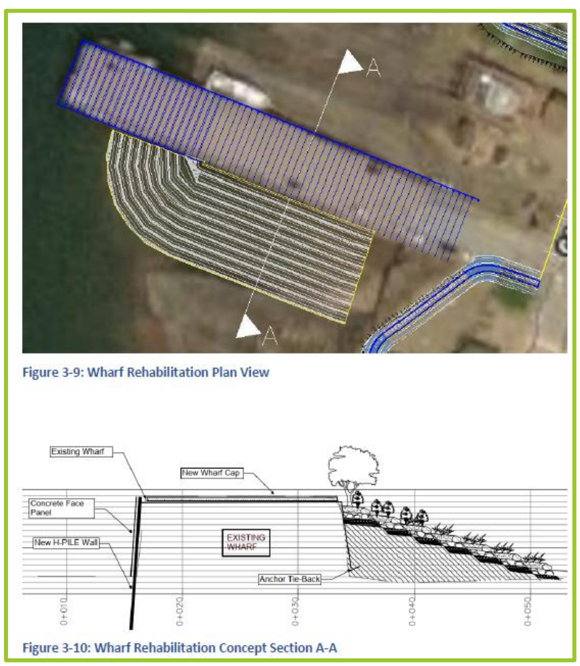

Figure 2-2: Terrace Concept (Taken from the 2024 Flood Risk Assessment)

3. Armour Stone Sizing Criteria

The armour stone size is generally determined based on the most critical of the following three phenomena:

1. Flow velocity;
2. Ice thickness;
3. Wave action.

Flow velocities can be estimated using a hydraulic model. However, no model or hydraulic study was available to CIMA+ for this project. Velocities are therefore neglected in this sizing exercise. However, it is not expected that flow velocities will be the governing factor for stone size in this case.

Ice conditions are discussed in Section 4, and wave conditions in Section 5.

4. Ice Conditions

Based on aerial imagery from the last 10 years (Google Earth and USGS Earth Explorer), ice does not appear to be a significant issue at the wharf site. No ice was observed in the 11 January–February images examined. The upstream dam retains ice and limits the probability of ice runs during thaws.

No information from local residents has yet been obtained to confirm ice conditions.

For reference, ice thickness was simulated using the Stefan equation and freezing degree-days recorded at the Environment Canada Greenwood A station (54 km from the site) for the years 1916 to 2006. Years with missing freeze-up data (1960, 1961, 1987, 1999, 2000, 2002, and 2006) were excluded. Based on site conditions, the Ice Engineering Manual, and previous projects, a regional coefficient of 2.3 was applied. Return periods for ice thickness were then computed using HYFRAN PLUS, with a normal distribution fitted to the data. Results are shown below:

Table 4-1: Ice Thickness Return Periods

Return period (yrs)	Ice thickness (cm)
100	63
50	60
20	57
10	54
2	44

According to Hydro-Québec's Hydroelectric Works Design Guide (2008), the median stone size D_{50} should be equal to or greater than the ice thickness when water levels fluctuate significantly, as is the case in this tidal inlet. The tidal range between the mean high water and the mean low water is 6.55 m, as shown in Table 4-2. No additional safety factor is included for ice runs, since the upstream dam makes large ice blocks unlikely. For a 1:50-year return period, this yields ***D_{50}*≥600 mm** to withstand ice forces.

Table 4-2: Tide Characteristics at Digby station (#00325)

Tide Characteristic	Water Elevation (CD datum)
Highest Astronomical Tide	9.38
Higher High Water Large Tide	9.17
Mean Higher High Water (Higher High Water Mean Tide)	7.94
Mean High Water (High Water Mean Tide)	7.8
Mean Water Level	4.54
Mean Low Water (Low Water Mean Tide)	1.25
Mean Lower Low Water (Lower Low Water Mean Tide)	1.12
Lower Low Water Large Tide	-0.16
Lowest Astronomical Tide	-0.35

5. Wave Conditions

Waves are generated by wind blowing over a distance known as the fetch. Three fetch origins were identified, and radials were drawn every 3° to capture possible wave approach directions from offshore. The analysed fetches are shown in Figure 5-1.

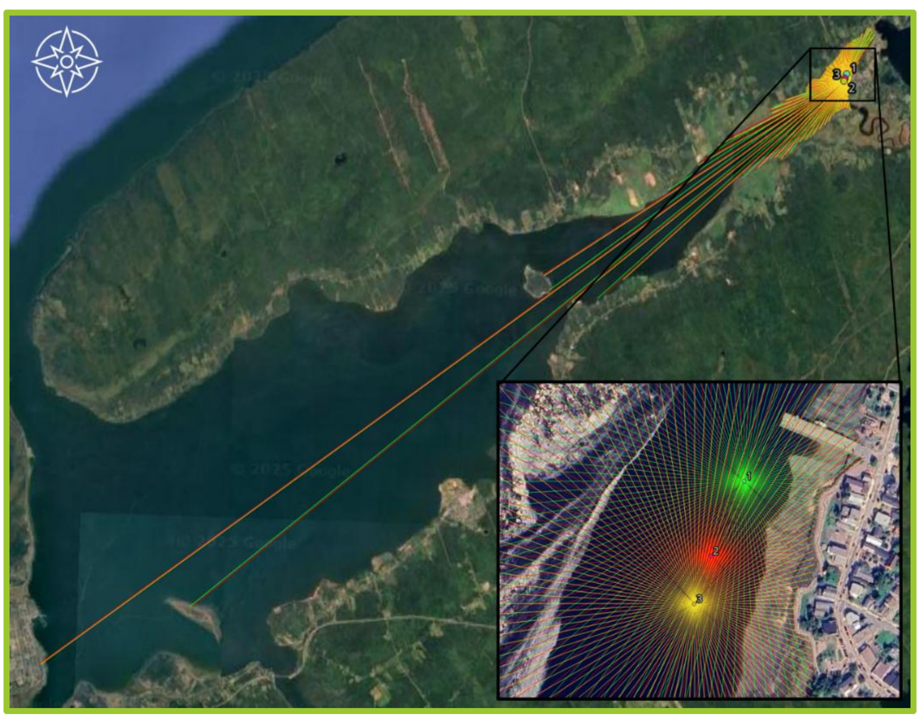

Figure 5-1: Analysed Fetches

Effective fetches were calculated using the mean plus half a standard deviation method. For each of the 16 directions, the maximum effective fetch among the three origins was retained.

Hourly wind speeds from the Environment Canada Greenwood A station (1953–2025) were used. The wind rose for the station is shown in Figure 5-2.

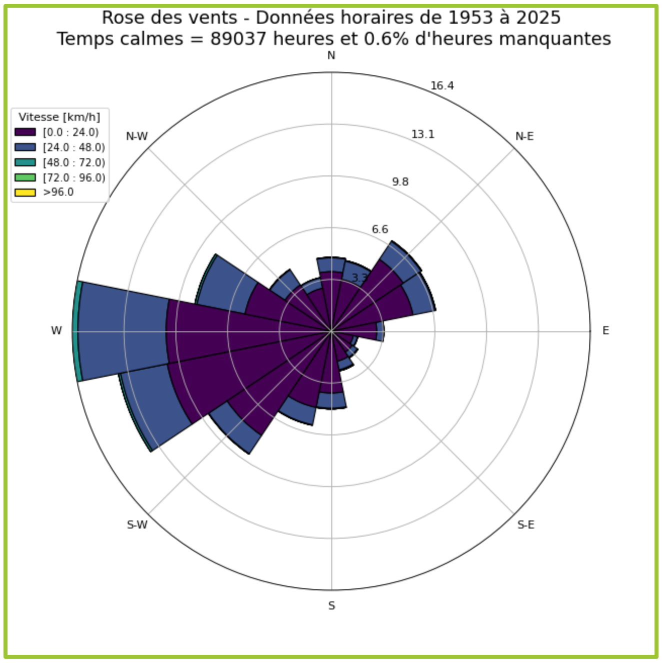

Figure 5-2: Greenwood A Station Wind Rose

A characteristic water depth of 13 m was used for the fetch origins. This corresponds to the future climate 1:100-year water level (4.96 m CGVD2013, feasibility study) minus local bathymetry (~–7 m CGVD2013 from NONNA10 data).

Waves were generated using the GENEREUX model, which applies the equations from the Shore Protection Manual (1977). Annual maximum significant wave heights (H_s) were extracted for each year. A frequency analysis with HYFRAN PLUS was then performed, fitting a Pearson Type III distribution to obtain wave heights for given return periods:

Table 5-1: Characteristic Wave Height Return Periods

Return period (yrs)	H_s (m)
100	1.31
50	1.23
20	1.12
10	1.04
2	0.82

The **Hudson formula** (1974) from the *Coastal Engineering Manual* was applied using the 50-year return period wave height, for a slope of 1V:1.5H.

Table 5-2: Stone Size

Stone type	Size (mm)	Layer Thickness (m)
Armour	600–800	1.2
Filter (1st layer)	200–400	0.7
Filter (2nd layer)	100-200	0.3

The recommended second layer of filter stone can be replaced by a thick nonwoven geotextile underlay (e.g., Texel 7634, 5.8 mm thick) to limit the migration of fine particles found in the embankment.

To prevent scour, a toe berm corresponding to 1xD_{50} of the armour rocks (700 mm) is recommended.

6. Crest Elevation and Width

The Town of Annapolis Royal does not wish to raise the wharf, as this would require a full replacement. However, it is recommended to raise the armour crest relative to the current wharf elevation to provide sufficient freeboard during high tides and storms. This would protect the rip rap integrity itself as well as the wharf infrastructure behind it.

Without detailed water level or overtopping modelling, it is not possible to give a precise crest elevation to limit damage landward of the armour. As a preliminary and conservative measure, an **elevation of 4.9 m CGVD2013** is recommended–slightly below the future climate 1:100-year water level (4.96 m according to the 2024 Flood Risk Assessment). Based on the survey provided by the Town of Annapolis, the current wharf elevation is 4.7 m CGVD2013 (measured at the north-west extremity of the wharf).

The crest width should be **3–4 × D_{50}** of the armour stone. Given that the selected crest elevation allows for some overtopping, a value of 4 × D_{50} is recommended:

$$\boldsymbol{B_{crest}} = 4 \times 0.60\ m = \mathbf{2.4\ m}$$

7. Conclusions and Recommendations

- **Stone size:** For wave stability, armour stone should be 600–800 mm. This size also meets the ice-resistance criterion, although ice is not expected to be a critical issue at this site.
- **Crest elevation:** Preliminary recommendation of 4.9 m CGVD2013.
- **Crest width:** 2.4 m (4 × D_{50}).

Further work recommended:

- Evaluate overtopping using a numerical model such as XBeach to refine crest elevation;
- Consult local residents to confirm winter ice conditions;
- Validate flow conditions through field inquiry or a 2D hydrodynamic model, although velocities are expected to be low due to shelter from the main channel.

Prepared by:

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Verified by:

Pierre-Marc Pelletier, P.Eng, M.A.Sc.

A

Appendix A

Winter Aerial Imagery

Figure 1: 2015-02-28

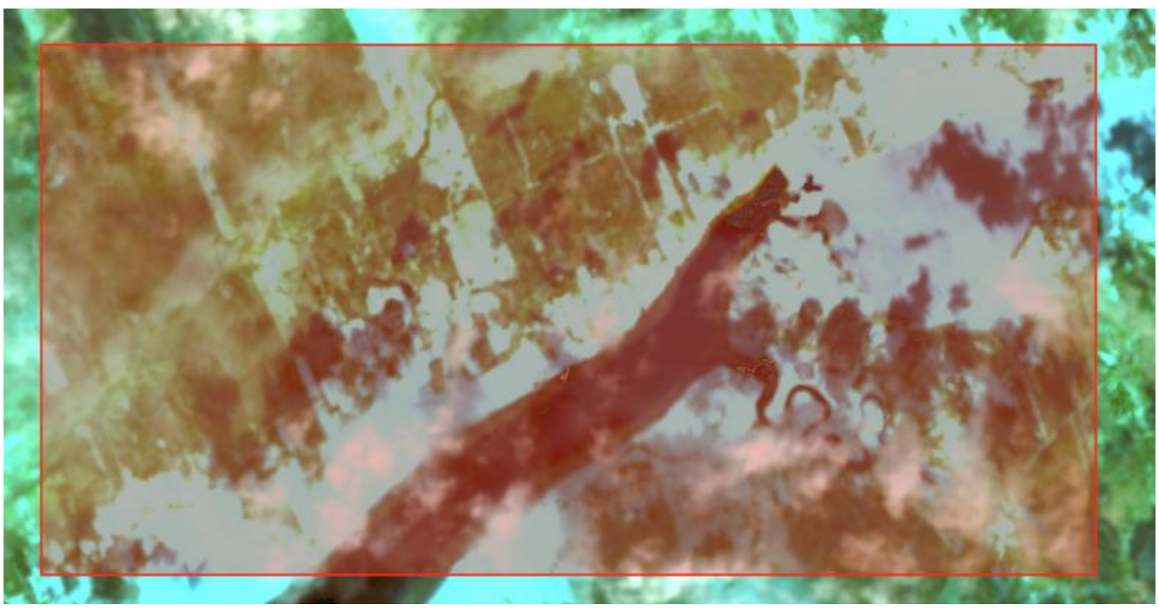


Figure 2: 2016-02-15

Figure 3: 2016-02-23

Figure 4: 2019-02-23

Figure 5: 2020-02-26

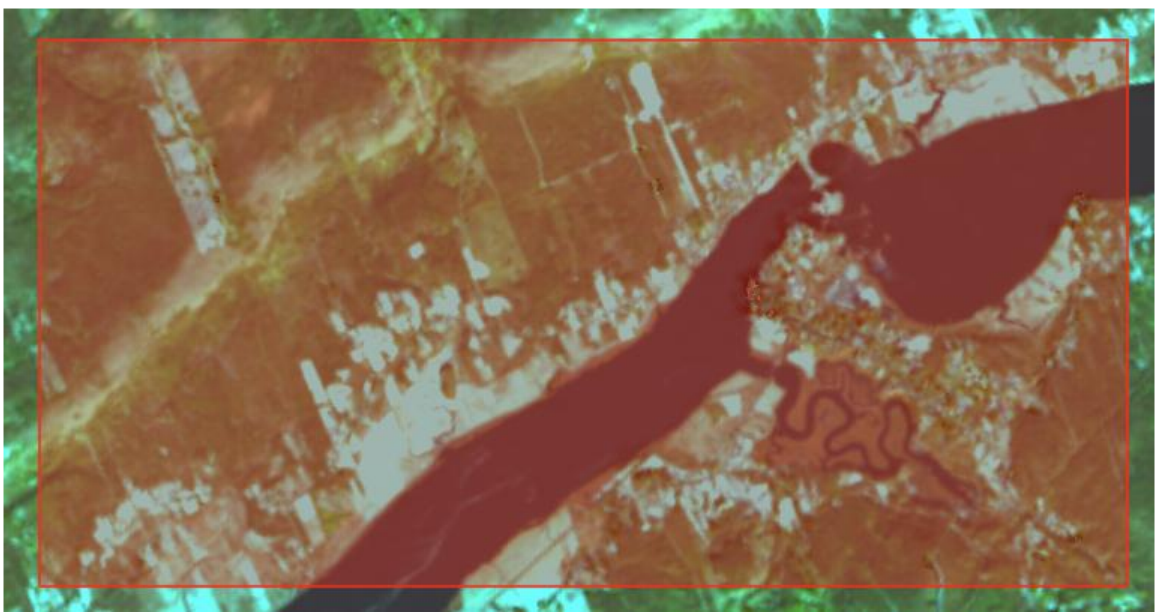


Figure 6: 2021-01-11

Figure 7: 2023-01-25

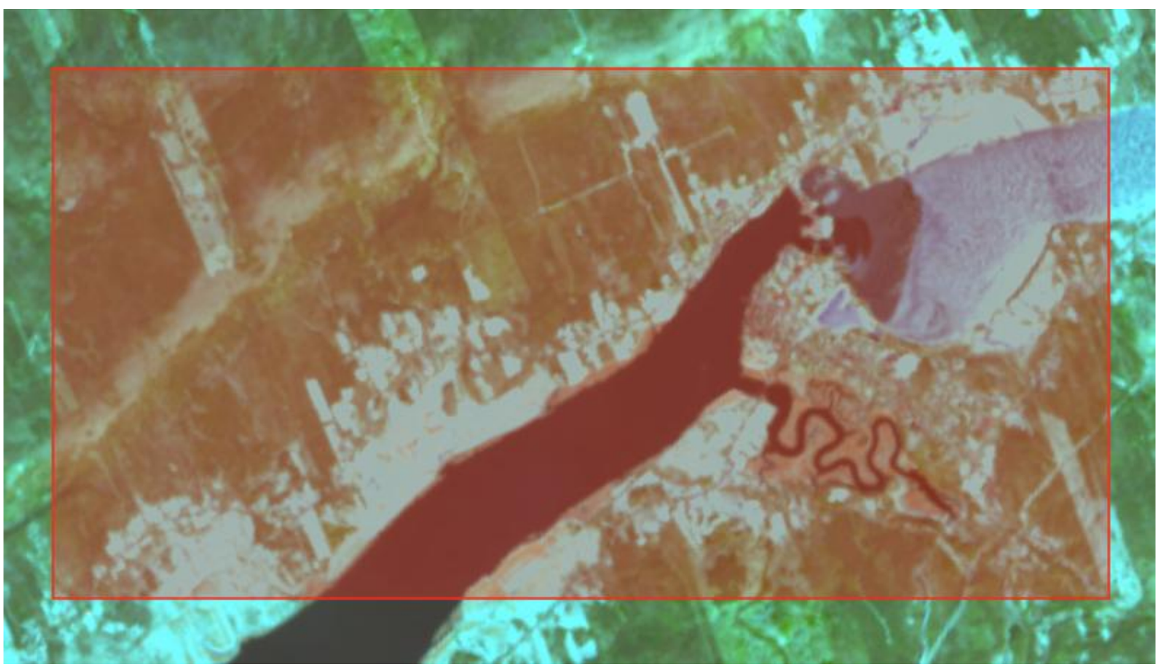


Figure 8: 2023-02-21

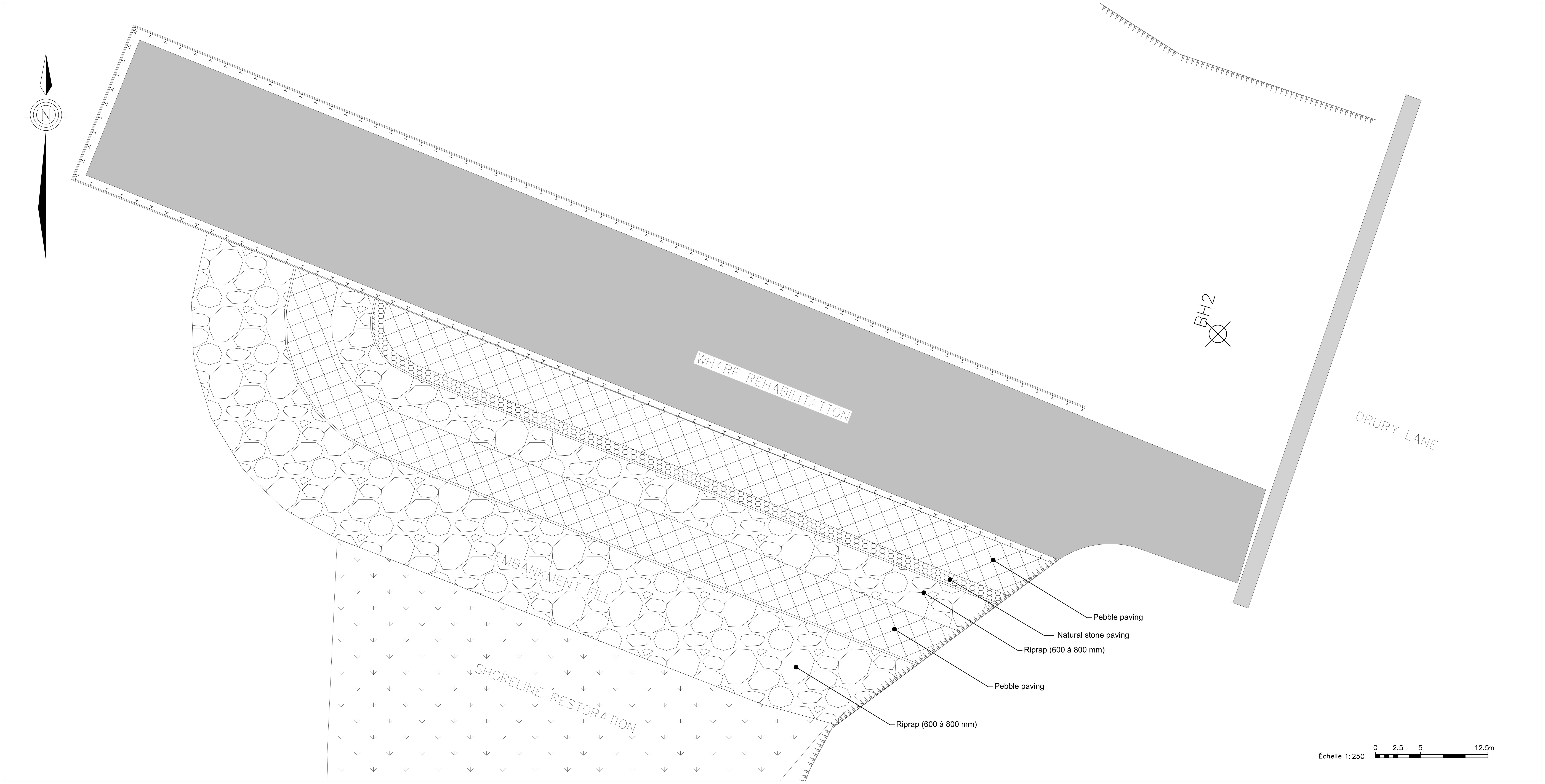
Figure 9: 2025-01-22

Figure 10: 2025-02-15

B

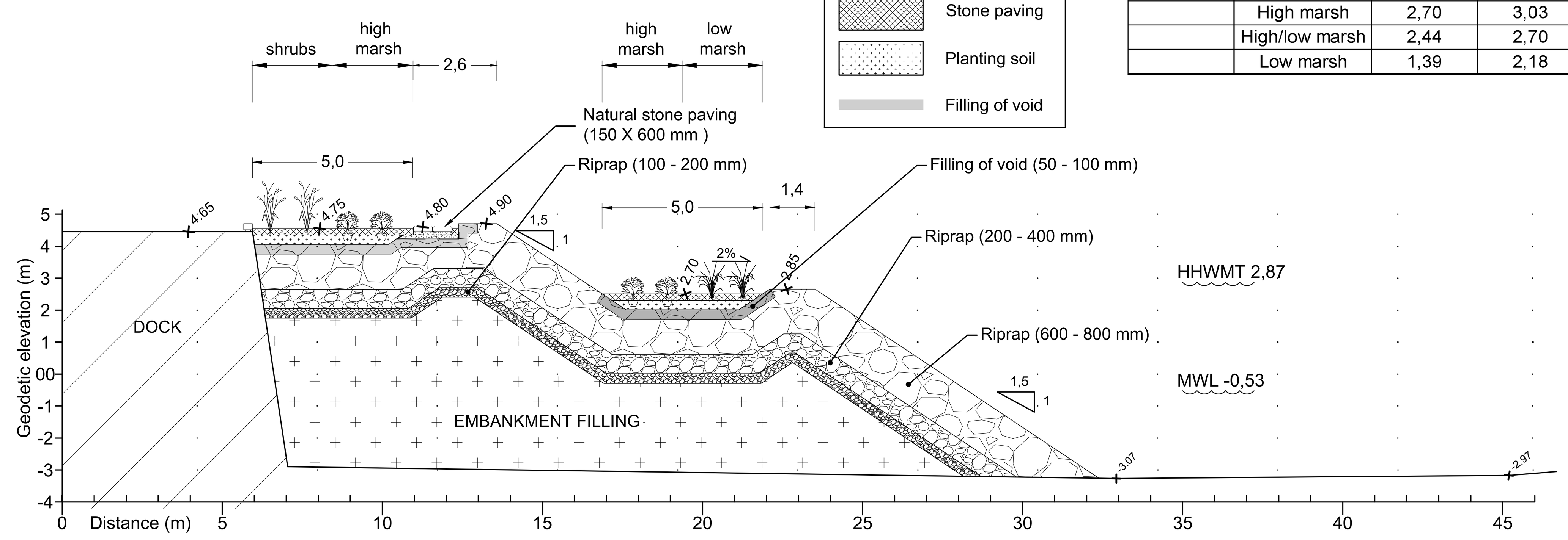
Appendix B
Embankment fill conceptual design

Z0027061–P01

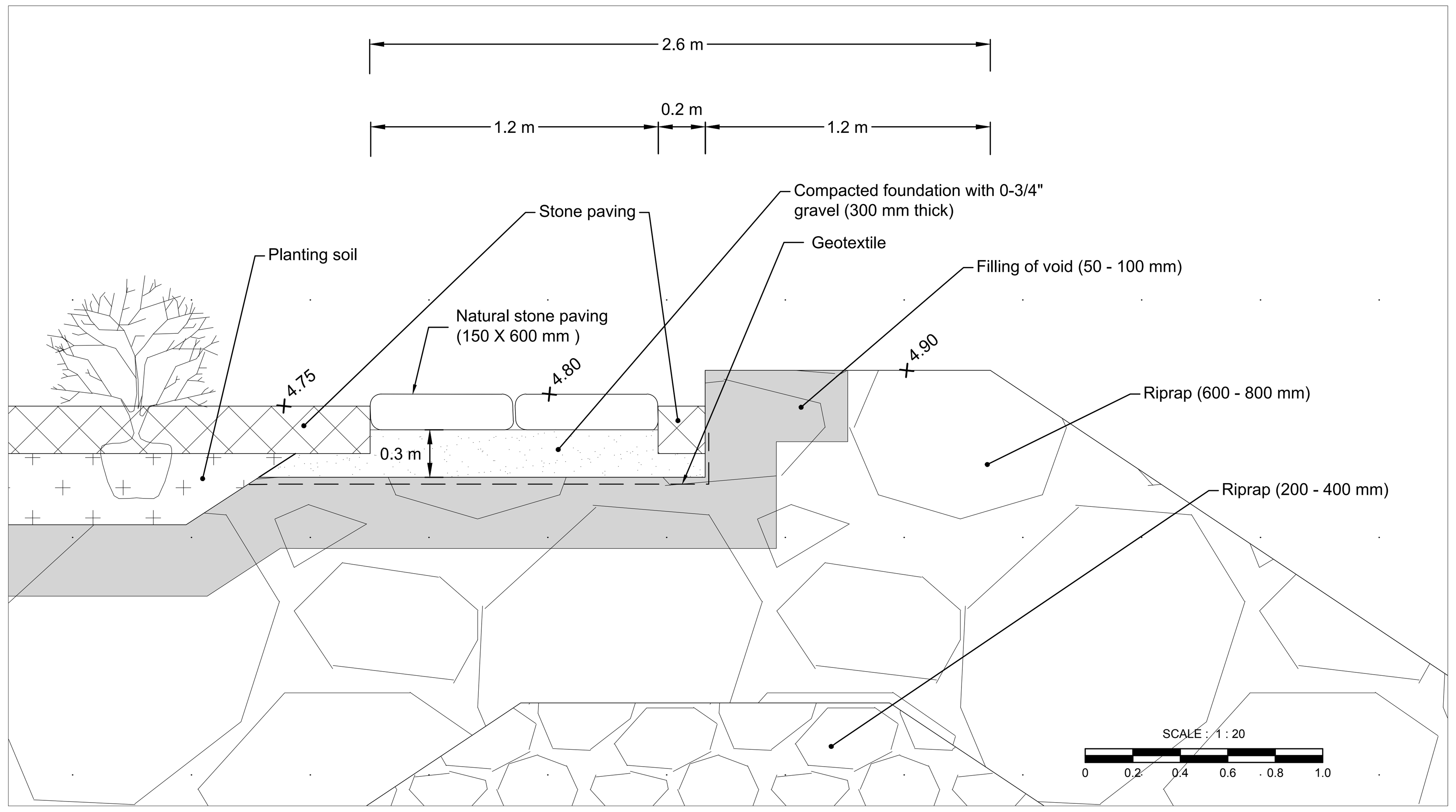


Note:
- the dimensions are meters.

SITE	GROUP	MIN ELV	MEAN ELV	MAX ELV
Annapolis	Brackish marsh	3,40	3,66	3,88
	High marsh	2,70	3,03	3,50
	High/low marsh	2,44	2,70	2,99
	Low marsh	1,39	2,18	2,91



OPTION 2



Enlargement

CLIENT:

Annapolis Royal
Nova Scotia

A	M	J	CONCEPTUAL DESING	RÉV.

SEAL:

CONCEPT PLAN

prepared by: ....

TECHNICAL TEAM:

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PROJECT:

Wharf Rehabilitation
Terraced Fill Embankment

TITLE:

Embankment Fill
Conceptual desing

SCALE:

PREPARED: François Lambert, tech.
Raphaël Pouliot, ing. f., M.Sc.
DRAWN: Gaétan Couture, tech.
VERIFIED: Charles White, biol., M.Sc.

DATE: 2026-01-09 | # PLAN: Z0027061-P01 | 1/1

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