Water St. S, Cambridge, ON – Grand River Embankment Project Proposal

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July 4th, 2025

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Jamie Croft

Manager of Infrastructure Engineering

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Hello Mr. Croft,

Please find attached below the updated report on the embankment located on Water Street, designed to withstand the 20 year flood. This updated report also contains information on the proposed soil that will make up the embankment. This report contains the soil hydraulic conductivity, the bulk density in both saturated and dry conditions, and a finalized angle of repose. With this information a new material price of $960,459.5 was calculated, offering a 4.6% saving from the original cost.

Great foundations looks forward to continuing this process with you to ensure that utmost quality is met, and to continue to keep Cambridge safe. If you have any concerns please reach out at your earliest convenience.

Respectfully submitted.

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Summary

Flooding issues continue to plague the city of Cambridge, causing destruction to important pieces of infrastructure, such as Water Street.

As a solution to this, Great Foundations is proposing an embankment of 5.75 m height, 32.75 m width, and of 350 m length, with a drainage piping system that consists of a main pipe that connects to 2.0 m long horizontal drains spaced 2.0 m apart.

The construction of the embankment will take 33 working days and cost $1341194.7. The construction will require the usage of a CAT D1 dozer, a CAT CS44B compactor and a 14-yard Ledwell dump truck. These machines and the material will all be sourced from local providers.

In this updated report, specifics regarding the soil were calculated. The soil being used to construct the embankment is a fine grained silt. It was experimented on using a hydrometer test. From the test it was found that the angle of repose is 30°. The hydraulic conductivity, and water-saturated and drained bulk density information is also found below. With this information, the cost can be updated, saving 4.6% of the originally proposed cost.

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1.0 Introduction

The Grand River region plays a crucial role in fostering the various municipalities in southern Ontario. Stretching 280 km from its source of Wareham, Ontario to the northern shore of Lake Erie, the river is essential for sustaining the growth in the city of Cambridge [**1**]. However, due to natural and man-made interventions, the river is prone to flooding, which greatly impacts local industries and surrounding ecosystems. Namely, last year was the 50th anniversary of the flooding of Cambridge, where havoc and devastation wreaked throughout the area by which water levels rose 4.0 m [**1**]. The result was $33 million in property damages and the establishment of the "200 year flood" standard for building codes [**1**]. While the Grand River Conservation Authority (GRCA) has set up extensive local flood management programs, the area is still flood prone due to the region being located in a floodplain [**1**]. Thus, it is of utmost importance to address the watershed's historical flooding status to mitigate the repercussions that affect the environment.

One notable example that undergoes the Grand River impacts is Water Street (See **Appendix A** for a detailed map). See also **Figure 1.0.1** on the next page for the topographical view of the land. As shown, the road is within close vicinity to the river, which makes it a high flood risk area [**1**]. Considerably, it is necessary to prepare for shorter-term floods. For these reasons, Great Foundations provide a cost-effective solution that fulfills the criteria of a 25 year flood while adhering to site conditions and other building codes. Therefore, we, Great Foundations Inc., propose an embankment of 5.75 m height, 32.75 m width, and of 350 m length, with a drainage piping system that consists of a 348 m long main pipe spanning across the embankment length that stems 2.0 m long horizontal drains spaced 2.0 m apart. See **Appendix B** for the embankment design.

Namely, the embankment design was engineered by consulting with various documents that provide the necessary calculations and considerations for constructing a safe and sustainable embankment. The team consulted various sources, including and not limited to the NCRS: Conservation Practice Standard code, the New York State DEC Guidelines for dam designs, the WCDE-00335-01 Flooding in the Grand River file, and the WCDE-00335-02 Case Assignment document. The following report details the embankment's design process and provides our cost analysis.

Figure 1.0.1 Water Street Topographical View

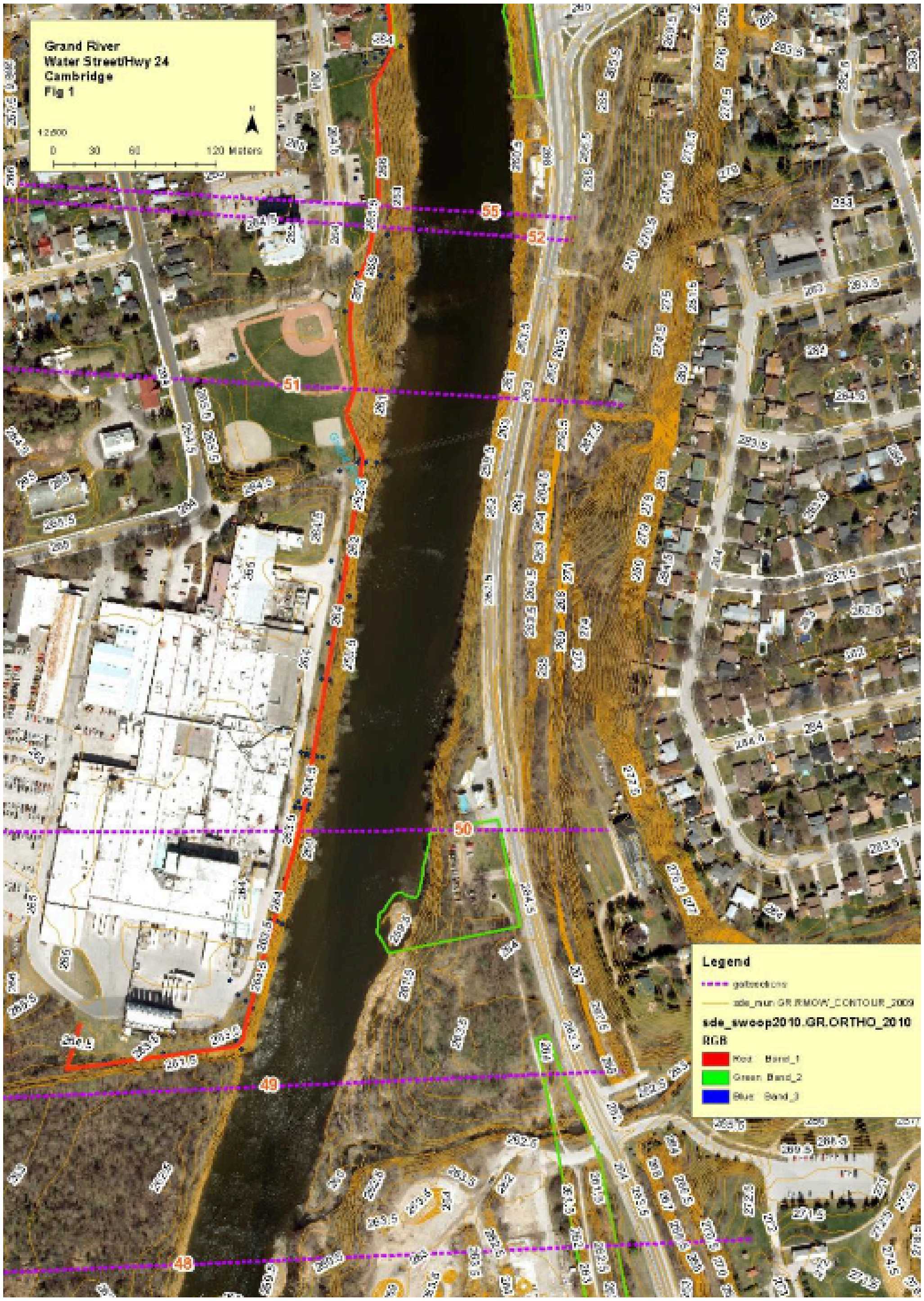


Figure 1.0.1 *displays the elevations and general layout of locations within the Water Street Region* (Retrieved from [**1**]).

2.0 Methodology

2.1 Design Guidelines

To account for peak flood magnitudes, river station 51 was selected for reference and the foundation elevation of 259.5 m was assumed for the ground level. See **Figure 1.0.1** from page 2 of the document for the topographical map of Water Street.

To satisfy the criteria of a 25 year flood and the established reference river station, data from the Grand River Data Table (See **Appendix C**) was reviewed and incorporated. In doing so, the water surface elevation is determined to be 263.3 m for a 25 year flood. Thus, according to **Equation 1**, the maximum water height from the base of the embankment is 3.8 m.

Maximum Water Height = Maximum Water Elevation - Ground Elevation [**Eq 1**]

= 263.3 - 259.5 [**Eq 1**]

= 3.8 m

According to the NRCS: Conservation Practice Standard Code for dikes, the embankment can then be classified as a Class I Earth dike, as 3.8 m falls in the range of 12 feet - 25 feet [**2**].

Finally, to account for standardized codes, the water-side of the embankment is to have a slope of 1:3, while the dry-side is to have a slope of 1:2 to optimize material usage. In short, the embankment will be a Class I Earthen Embankment with a water elevation of 3.8.

2.2 Design Dimensions

2.2.1 Embankment Top Width

According to the New York DEC Guidelines for Dam Design, the minimum allowed top width is the greater dimension of either 3.05 m or W, as calculated through **Equation 2** [**3**].

W = 0.2 (Maximum Water Height) + 7ft [**Eq 2**]

= 0.2 (~12.5) + 7 [**Eq 2**]

= *9.5 Feet* [**Eq 2**]

= ~ 3 m

Thus, the embankment's minimum top width is 3.05 m. To account for tolerances, the proposed top width is 4 m.

2.2.2 Embankment Height

According to the NRCS: Conservation Practice Standard Code, the minimum settlement allowance for the dike is 15% [**2**]. Furthermore, as seen in **Appendix D**, a Class I Earthen dike should have a minimum freeboard height of 1.0 m. Thus, when tolerances are accounted for, the total embankment height is obtained through **Equation 3.**

Embankment Height = (1+0.15)(Height of Water + Freeboard) + Tolerance [**Eq 3**]

= 1.15(3.8+1) +0.23 [**Eq 3**]

= 5.75 m

2.2.3 Width of Embankment

To determine the full width of the design, the widths of the upstream and downstream slopes of the embankment and the top width were summed, as done so in **Equation 4**.

Width of Embankment = Embankment Height/Upstream Slope + Embankment Height/Downstream Slope + Top Width [**Eq 4**]

= 5.75/(⅓)+5.75/(½) + 4 [**Eq 4**]

= 32.75 m

2.2.4 Pipe Length

To determine the length of the horizontal pipes that stem from the main perforated drainage pipe spanning the length of the embankment, **Equation 5** was used, as suggested by Lyndia Stacey, Filzah Nasir, and Professor Andre Unger from the University of Waterloo in the Case Assignment Document [**4**].

Pipe Length = Dike Height / 3 [**Eq 5**]

= 5.75/3 [**Eq 5**]

= 2.0 m

Thus, to ensure that water is safely and efficiently directed out of the embankment, 2.0 m long horizontal pipes are placed every 2.0 m in connection to the main drainage pipe. Finally, the portion of Water Street for the proposed site is 350 m long, so after including 1 m of tolerance on both sides of the embankment, the length of the main pipe was concluded to be 348 m. See **Appendix B** for more details.

2.3 Design Summary

As shown in **Figure 2.3.1** below, the embankment is to be 32.75 m long and 5.75 m tall, with a top width of 4.0 m and a freeboard height of 1.0 m.

Figure 2.3.1 Embankment Elevation View

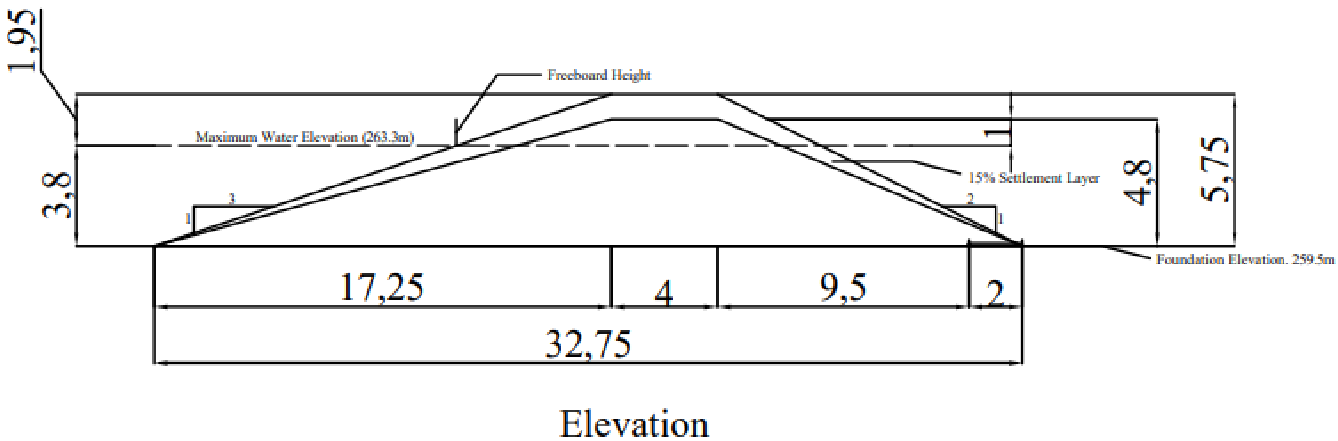
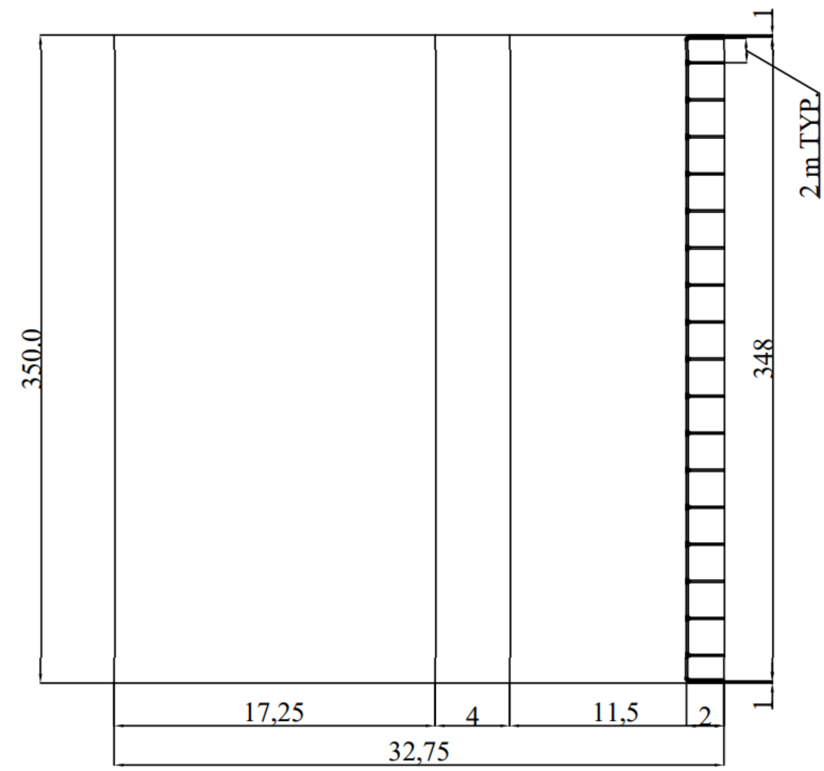


Figure 2.3.1 *displays the elevation view of the designed embankment and corresponding dimensions.*

As shown in **Figure 2.3.2** on the next page, the embankment is to further extend 350.0 m, with a main pipe drain that spans 348 m. Horizontal pipes with 2.0 m lengths further stem from the main pipe every 2.0 m. To further optimize water seepage control, 4” PVC pipes and pipe fittings were used to maximize drainage regulation. See **Figure 2.3.3** on the following page for a detailed parts list for the pipings. Note that 6 PVC elbows and 180 Tees are proposed for the project for overage allowance. In the same manner, there are also approximately 300 m of additional piping lengths proposed to account for efficient ordering. Further note that ordered piping will have to be further modified to desired lengths.

To consolidate, this embankment will cost-effectively reduce the stress put on the soil when water accumulates, as the minimum values provided by the consulted codes were used with only necessary tolerances. Ultimately, flooding occurrences can be reduced and respective consequences can be mitigated. For more detailed views of the design, see **Appendix B**. Note that the road will also have to be shifted 25 m more from the river due to the embankment’s width of 32.75 m being much greater than the narrowest distance between the road and the river of 20 m [**1**].

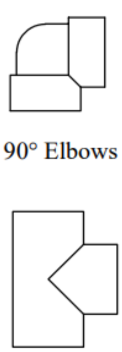
Figure 2.3.2 Embankment Plan View



Plan View

Figure 2.3.2 *displays the plan view of the designed embankment and corresponding dimensions.*

Figure 2.3.3 PVC Piping Parts List



1) 4" PVC 90° Elbows -- 2 Req'd

2) 4" PVC Socket Tees -- 175 Req'd

3) 4" PVC Piping - 1,000 m Req'd

Piping Detailed List

Figure 2.3.3 *displays the minimum quantity of required PVC Piping Parts.*

3.0 Cost Analysis

With consideration of the proposed embankment's design, labor and equipment costs are calculated and presented below. Notably, costs were optimized through engineering a resource-efficient dike, streamlining construction strategies, and obtaining economical quotations. For reference, all pricings are given in CAD.

3.1 Material Cost

3.1.1 Embankment Fill Sourcing

To begin, a quarry to source soil was selected. To do so, the Ontario Pits and Quarries Online database was consulted with. As shown in **Figure 3.1.1.1**, there are two boxed quarries within closest proximity to the labelled construction site.

Figure 3.1.1.1 Location of Nearby Fill Quarries

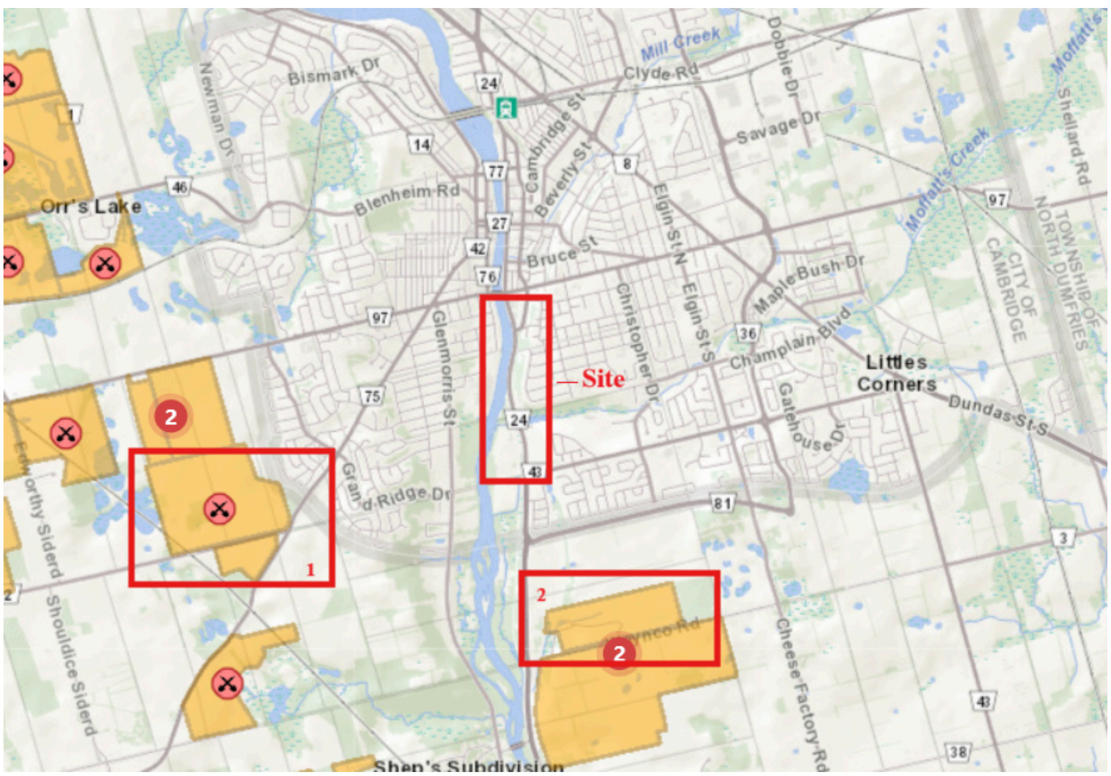


Figure 3.1.1.1 *displays locations of nearby quarries with respect to the site* (Retrieved from [**5**])

Further consider the **Figure 3.1.1.2** on the next page for evaluating the proposed quarry.

Figure 3.1.1.2 Quarry Location Comparison

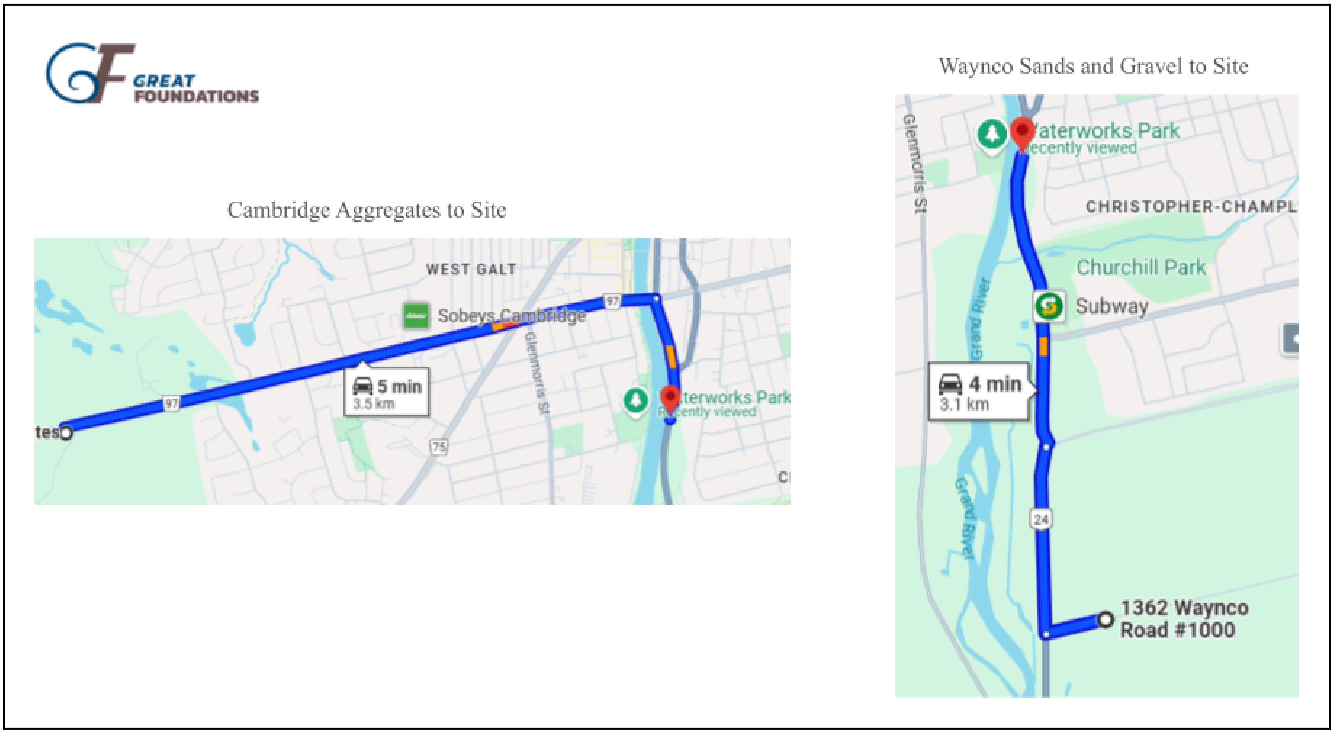


Figure 3.1.1.2 *compares the locations of the two quarries using Google Maps.*

Evidently, the two quarries do not differ significantly in distance from the site for a drastic difference in transportation costs to occur. However, it is apparent in **Figure 3.1.1.1** that Cambridge Aggregates is larger and thus fosters more efficient maneuverability, a significant factor for cost reduction. Through consulting each location's webpage, Cambridge Aggregates has a greater variety of common borrow soil filling in stock as opposed to Waynco Sands and Gravel ([**6**] and [**7**]). Thus, the proposed quarry for sourcing soil is Cambridge Aggregates, owned by Heidelberg Materials, located approximately 5 km from the site, where the soil costs \$13.50 USD/yard^3 as of 2021[**8**]. With inflation, the soil unit cost is \$15.11 USD/yard^3 and thus \$27.07 CAD/m^3 [**9**].

3.1.2 Embankment Fill Sourcing

To find the total filling cost, the total volume of the embankment and its 15% settlement was determined. To do so, the product of the surface area of the embankment end and the length of embankment was obtained. Further consider **Figure 2.3.1**. As the settlement is a component of the dike's total volume, the larger outside trapezoid was used for calculations. Notably, the surface area was calculated through dividing the composite shape into simpler shapes and summing all the individual areas. See **Figure 3.1.2.1** on the next page for details.

Figure 3.1.2.1 Embankment Side View for Surface Area Calculations

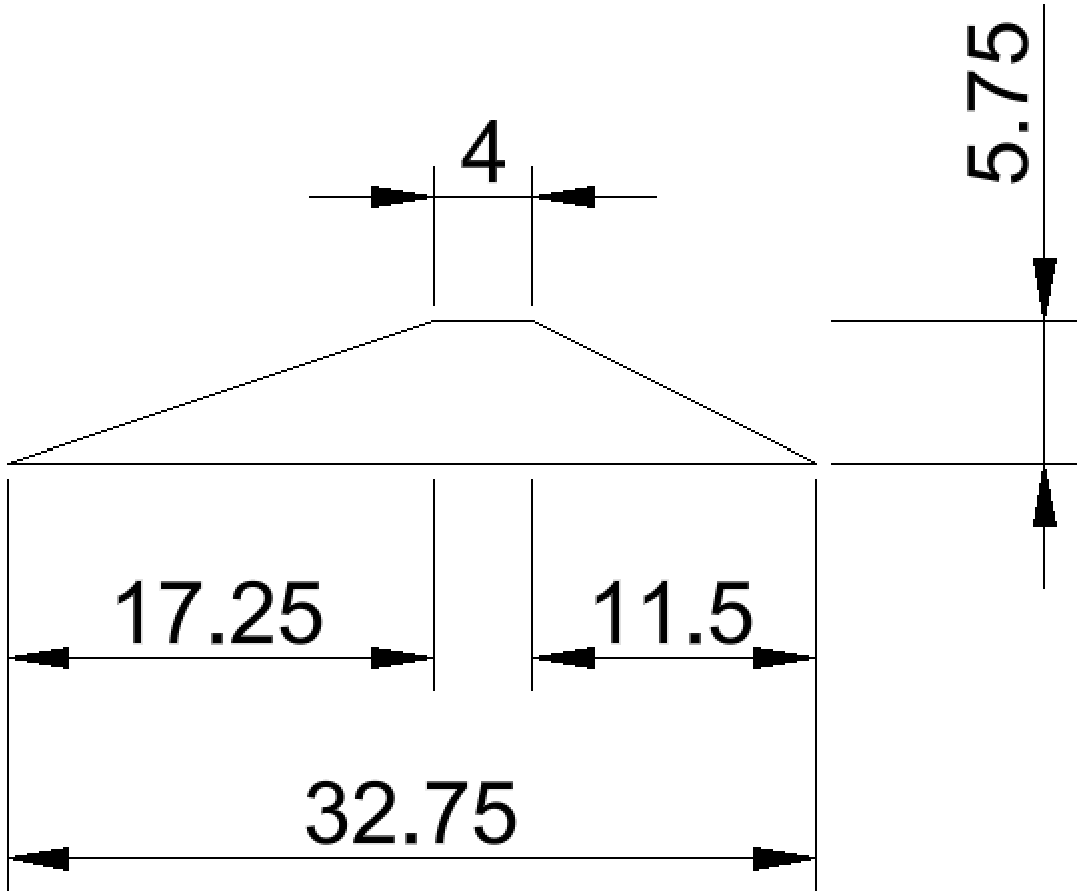


Figure 3.1.2.1 *displays the areas the composite shape was divided into.*

The area of region 1 was calculated with the equation for the area of a triangle, as shown in **Equation 6**.

$$\textit{Area of Region 1} = \frac{Base \times Height}{2} \text{ [Eq 6]}$$

$$= \frac{17.25\ m \times 5.75\ m}{2} \text{ [Eq 6]}$$

$$= 49.59\ m^2$$

The area of region 2 was calculated with the equation for the area of a rectangle, as shown in **Equation 7** on the next page.

$$\textit{Area of Region 2} = \textit{Height x Width} \text{ [}\textbf{Eq 7}\text{]}$$

$$= 5.75\ m \times 4\ m \text{ [}\textbf{Eq 7}\text{]}$$

$$= 23\ \text{m}^2$$

The area of region 3 was also calculated with the equation for the area of a triangle, as shown in **Equation 8** below.

$$\textit{Area of Region 3} = \frac{Base \times Height}{2} \text{ [}\textbf{Eq 8}\text{]}$$

$$= \frac{11.50\ m \times 5.75\ m}{2} \text{ [}\textbf{Eq 8}\text{]}$$

$$= 33.06\ \text{m}^2$$

Thus, the cross sectional area of the embankment end is obtained through **Equation 9**.

$$\textit{Total Area} = \textit{Area of Region 1} + \textit{Area of Region 2} + \textit{Area of Region 3} \text{ [}\textbf{Eq 9}\text{]}$$

$$= 49.59\ m^2 + 23\ m^2 + 33.06\ m^2 \text{ [}\textbf{Eq 9}\text{]}$$

$$= 105.65\ \text{m}^2$$

This value is supported by examining the properties of the polygon in the AutoCAD drawing for the embankment's design in **Figure 3.1.2.2**.

Figure 3.1.2.2 Cross Sectional Area Validation

Figure 3.1.2.2 *displays the confirmation of the value for the surface area using AutoCAD.*

Collectively, the total volume of soil for the embankment was found using **Equation 10** on the next page.

$$\textit{Total Volume} = \textit{Cross Sectional Area x Length of Embankment} \ [\textbf{Eq 10}]$$

$$= 105.65\ m^2 \ x\ 350\ m \ [\textbf{Eq 10}]$$

$$= 36,977.5\ m^3$$

Thus, the total cost for the soil filling for an embankment with a volume of 36, 977.5 m^3 when the material cost is \$27.17/m^3 is found using **Equation 11** below.

$$\textit{Total price} = \textit{Total Volume}\ \ x\ \textit{Price} \ [\textbf{Eq 11}]$$

$$= 36,997.5\ m^3\ x\ \$27.17/m^3 \ [\textbf{Eq 11}]$$

$$= \$1,004,678.88$$

Thus, the total cost for the soil filling is $1,004,678.88 CAD.

3.1.3 Cost of Drainage

In addition to the cost of soil for filling the embankment, the material to construct the drainage system must further be accounted for. Consider further **Figure 2.3.3** on page 6 of the document for the required PVC piping and fittings. To construct the drainage system, 2 4" PVC 90° elbows, 175 4" socket tees, and 700 m of 4" piping is required. However, to account for overage allowance, **6** 4" PVC 90° elbows, **180** 4" PVC socket tees, and **1,000 m** of perforated piping is proposed for construction, where **350 m** is required for the internal connecting pipe parallel to to the length of the embankment, **350 m** is required to construct the 175 **2 m** smaller drains stemming from main pipe, and **300 m** is proposed for leeway. See **Table 3.1.3.1** for the piping quotation, where prices were obtained from the Site Work & Landscape Costs Handbook [**10**]. Note that prices have already factored in inflation and have already been converted from USD to CAD.

Table 3.1.3.1 Piping Quotation

Part Number	Part Description	Unit Price	Quantity	Cost
2100	4" Perforated PVC Pipe	3.25$/m	1,000 m	$3,250
0240	4" PVC Piping Elbows (90°)	5.40$/Each	6	$32.40
0340	4" PVC Piping Socket Tees	5.55$/Each	180	$999.00
				Total: $4,281.40

Thus, the total material cost for constructing the drainage is $4,281.40 CAD. Note that this is only the raw cost and doesn't include tax, delivery fees, and labor costs for pipe length modification, which are discussed later in the document.

3.1.4 Total Raw Material Cost Summary

The total raw material cost was then determined through the sum of the filling cost and the drainage cost (See **Equation 12** on the next page).

$$Total\ Raw\ Material\ Cost = Filling\ Soil\ Material\ Cost + Drainage\ Material\ Cost \text{ [\textbf{Eq 12}]}$$

$$= \ 1{,}004{,}678.88 + 4{,}281.40 \text{ [\textbf{Eq 12}]}$$

$$= \$1{,}008{,}960.28$$

The total raw material cost is thus $1,008,960.28.

3.2 Equipment Cost

After all materials have been purchased, it is crucial to determine how the products can arrive on site in a time and cost efficient manner. The respective construction strategies are aided by a variety of construction equipment. The pricings for these areas are presented below.

3.2.1 Dozer Selection

As Caterpillar Inc. (CAT) is one of the largest suppliers for construction vehicles, their products will have more reliable quality and costs. Therefore, CAT dozers will be examined for the embankment construction. Recall that the total volume of soil for the embankment is 36,977.5 m^3. Further, assume a soil density on the higher end of 2,000 kg/m^3 [**11**]. Therefore, to overshoot the mass, the soil weighs approximately 74,000,000 kg by **Equation 13**.

$$Mass = Density\ x\ Volume \text{ [\textbf{Eq 13}]}$$

$$= 36{,}977.5\ x\ 2{,}000 \text{ [\textbf{Eq 13}]}$$

$$= 73{,}955{,}000 \text{ kg}$$

While the mass seems significantly high, the soil can be moved to the site in various cycles. Recall further from **Figure 2.3.3** that the embankment is only 350 m long and 32.75 m wide. In view of the relatively small area to be traveled, a smaller dozer is more efficient and ideal. For these reasons, the CAT D1 dozer was proposed. For future reference, according to the Caterpillar specifications sheet, this model of dozers can move 1.65 m^3 of soil per cycle [**12**].

Aside from the model of dozer selected, the dozer(s) will be sourced from Tri-City Equipment in Guelph, roughly 25 km from the site. The proposed supplier was selected as they are one of the closer suppliers, and rental prices are lower in view of the company's relatively smaller size.

According to the supplier, the cost of mobilizing and demobilizing the dozer is estimated to be $625 [**13**] in consideration of factors including and not limited to fuel costs and loading/unloading times. In consideration that the width of the embankment is 32.75 m, the total length of the embankment is 350 m, and that the quarry is 10 m from the proposed embankment site, as transportation will be a round trip, the following calculations were made to calculate the production cost of the dozer.

3.2.2 Dozer Production Rates

To begin, production costs are heavily dependent on cycle times and can be calculated using **Equation 14** below**.** Note that the cycle distance is the sum of the distance from the drop-off location for the soil to onsite and the width of the embankment. Also consider that the dozer's role is to move soil around the site. This means the dozer will be transporting soil from the point of the embankment that's closest to the quarry, which thus increases time and cost efficiency. Namely, the location will be 10 m from the embankment to provide optimal space for maneuverability. However, this location only brings the dozer to the toe of the embankment. Thus, the width of the embankment is factored to bring the distance the dozer travels to 42.75 m. Note further that the top speed is the sum of the forward speed and reverse pass for both dozers and compactors.

$$Cycle\ Time\ =\ Cycle\ Distance\ (km/cycle)\ \div\ Top\ Speed\ (km/h)\ \textbf{[Eq 14]}$$

$$=\ (0.03275\ km/cycle\ +\ 0.010\ km/cycle)\ \div\ 10\ km/h\ \textbf{[Eq 14]}$$

$$=\ 0.004275\ hours/cycle$$

It is further necessary to determine the number of cycles that can be completed per hour, so time can become a dependent variable. See **Equation 15** below for the calculations.

$$Cycle\ Per\ Hours\ =\ 1\ \div\ Cycle\ Time\ (hours/cycle)\ \textbf{[Eq 15]}$$

$$=\ 1\ \div\ 0.004275\ hours/cycle\ \textbf{[Eq 15]}$$

$$=\ 233.918\ cycles\ per\ hour\ \textbf{[Eq 15]}$$

$$\simeq\ 233\ cycles\ per\ hour$$

Finally, to determine the production rate, **Equation 16** can be followed below.

$$Production\ Rate\ =\ Cycles\ per\ hour\ \times\ Capcity$$ **[Eq 16]**

$$=\ 233\ cycles\ per\ hour\ \times\ 1.65\ m^3/cycle$$ **[Eq 16]**

$$=\ 384.45\ m^3\ of\ soil/hour$$

Note that this production rate is per dozer. In view of fluctuations due to onsite conditions, each CAT D1 dozer can thus move on average $384.45\ m^3$ each hour. This value can further be used to determine the time it takes to move all the soil, while considering drainage trenching. Recall that there are 2 m long subdrains every 2 m that span across a 348 m long main drain that spans the length of the whole embankment. See **Equation 17** for the trenching time calculations on the next page. Note that the lengths travelled will be 2 as the dozer has to move into the subdrainage trench and back out.

Trenching Time = (Subdrain Length x Lengths Travelled)/Top Speed [**Eq 17**]
= (2 m x 2)/10 [**Eq 17**]
= 0.4 h

The time it takes to move the soil can be calculated using **Equation 18** below.

Material Location Time = Volume of Material / Production Rate [**Eq 18**]
= 36,977.5 m^3 / $384.45\ m^3$/h [**Eq 18**]
= 96.2 h

The total time it takes to supply the soil is thus the sum of the trenching and location time. See **Equation 19** below for the total time.

Total Time = Trenching Time + Material Location Time [**Eq 19**]
= 0.4 h + 96.2 h [**Eq 19**]
= 96.6 h

To further reduce the total time of soil transportation, more dozers can be used. However, the total time required for relocating soil from the quarry to the site is approximately 100 h for one CAT D1 dozer.

3.2.3 Dozer Utilization Costs

According to Ontario.ca's database on motor fuel prices, a CAT D1 dozer consumes 1.71 gallons of ULSD fuel per hour [**14**]. Given the current price of ULSD fuel ($2.73/gallon), a D1 dozer will cost $4.67 an hour to operate. A dozer operator will also have to be hired to drive the dozer. They will be paid $28 an hour, which is standard for that position [**15**].

In light that the minimum time for transporting all the soil from the quarry to onsite is 96.6 hours and that there are on average 5 8-hour working days per week per worker, 13 working days are required for completion (See **Equation 20**).

$$\#of\ Working\ Days = \frac{96.6\ hours}{8\ hours/days}\ \textbf{[Eq 20]}$$
$$= 12.075\ days\ \textbf{[Eq 20]}$$
$$\simeq 13\ days$$

The total cost for one worker can be obtained through **Equation 21** below.

$$Total\ Cost_{Worker} = \#of\ days\ x\ \ 8\ hours/day\ x\ \$28/hour\ \textbf{[Eq 21]}$$
$$= 13\ days\ x\ 7\ hours/day\ x\ \$28/hour\ \textbf{[Eq 21]}$$
$$= \$2,548$$

The total cost for gas can be further obtained through **Equation 22**.

$$Total\ Cost_{Gas} = 96.6\ hours\ x\ \$4.67/hour\ \textbf{[Eq 22]}$$
$$= \$451.12$$

Collectively, the total cost for dozer production and operations is obtained through **Equation 23** below.

Total Cost = Total Cost$_{Worker}$ *+ Total Cost*$_{Gas}$ *+ Mobilization Cost + (Rental Cost x 3 of Working Days)* **[Eq 23]**
*= $2,548 + $451.12 + $1,250 + 725*13* [**Eq 23**]
= $13,674.12

The data was consolidated into **Table 3.2.3.1** on the next page. Note that in view that dozers have to mobilize and demobilize, the cost of mobilization is doubled. Costs for dozer rentals are also retrieved from [**13**].

Table 3.2.3.1 Dozer Summary

Category	Selection
Type	CAT D1 Dozer
Production	$384.45m^3\ of\ soil/hour/dozer$
Fuel Costs	$4.67 per hour

Operation Costs	\$28 per hour
Mobilization/ Demobilization Costs	\$1250
Rental Cost	\$725 daily or \$8,938 weekly
Hours	96.6 hours or 13 working days
Total Cost	\$13,674.12

3.2.4 Dump Truck Selection

With dozers being ready for soil transportation within the site, Recall from **Figure 3.1.1.2** that the quarry is approximately 5 m from the site. This means that the distance to be travelled is minimal, so a dump truck of higher duty is considerable. Furthermore, the fill material was agreed upon with the client to be sourced to the site ahead of time, in order to ensure maximum efficiency.

Thus, the dump truck proposed for sourcing soil from the quarry to onsite is the 14-yard Ledwell dump truck, as its size is just enough for efficiency in time and costs. According to the vehicle's specification page, one truck has a capacity of towing 10.7 m^3 [**16**]. Namely, the vehicle will be rented from Herc Rentals, as the supplier is one of the nearest locations from the site by being 4 km away from Water Street. According to the requested quotation, the cost for renting one truck is \$830/day [**17**]. The namesake trucks further utilize diesel fuel, which costs \$15.62/hour [**14**]. Note further that the cost for a dump truck driver is \$25/h [**15**].

3.2.5 Dump Truck Cost Calculations

To optimize costs and construction efficiency, 15 dump trucks will be used for transporting embankment fillings.

Firstly, the number of trips taken per dump truck were determined through **Equation 24** below**.**

$$Trips\ =\ Volume\ of\ Soil \div (Volume\ per\ dump\ truck\ \times 15\ dump\ trucks)\quad \textbf{[Eq 24]}$$

$$=\ 36,977.5m^3 \div (10.7m^3 \times 15\ dump\ trucks)\ \textbf{[Eq 24]}$$

$$= 231\ \text{Trips}$$

The total time spent transporting the soil is further calculated through **Equation 25** below. Note that the time is determined from **Figure 3.1.12** previously and doubled accordingly to account for the round trip. Further note that the loading and unloading times are retrieved from [**16**].

$$Time = (Time_{Forward} + Time_{Back} + Time_{Loading} + Time_{Unloading})\ x\ 231\ trips\ \textbf{[Eq 25]}$$
$$= (10\ minutes + 10\ minutes + 10\ minutes + 10\ minutes)\ x\ 231\ trips\ \textbf{[Eq 25]}$$
$$= 9{,}240\ minutes$$
$$= 154\ hours$$

To further determine the number of working days, where a working day is 8 hours long excluding lunch breaks, see **Equation 26**.

$$Days\ =\ Time\ \div\ 8\ hours/day\ \textbf{[Eq 26]}$$
$$=\ 154\ hours\ \div\ 8\ hours/day\ \textbf{[Eq 26]}$$
$$= 20\ days$$

To further determine the total cost of renting and operating 15 dump trucks, see **Equation 27** below.

$$Total\ Cost\ =\ (Time\ \times\ Fuel\ cost\ \times\ 15\ trucks)\ +$$
$$(Days\ \times\ 8\ hours\ \times\ Cost\ for\ 15\ Drivers) +\ (Rental\ Cost\ \times\ 20\ days\ \times\ 15\ )\ \textbf{[Eq 27]}$$
$$=\ (154\ hours\ \times\ 15\ \times\ \$15.62\ per\ hour)\ +\ (20\ days\ \times\ 8\ hours\ \times\ 15\ \times\ 25\ per\ hour)$$
$$+\ \$830\ \times\ 20\ days\ \times\ 15\ \textbf{[Eq 27]}$$
$$= \$345{,}082.20$$

All specifications and calculations regarding the dump truck are summarized in **Table 3.2.4.1** on the next page.

Table 3.2.4.1 Dump Truck Summary

Category	**Selection**
Type	14-yard Ledwell
Quantity	15
Capacity	10.7 m^3
Fuel Costs	$15.62 per hour
Operation Costs	$25 per hour
Rental Costs	$830 daily or $3,300 weekly
Hours	154 hours or 20 working days
Total Costs	$345,082.20

3.2.6 Compactor Selection

After soil has been brought to the site and the dozer has moved the soil around to their respective locations, the compactor will be used to compact every layer of soil. For similar specifications used previously, the compactor selected will be the CAT S44B, as its size permits the most cost and resource efficient solution [**18**]. Essentially, the compactor is instructed to make one cycle after each dozer cycle, and as such, two compactors are proposed for construction. Other notable specifications are that the model of compactor runs on diesel and thus costs $10.98 per hour to run [**14**].

3.2.7 Compactor Costs and Calculations

Cycle time rates and compacting durations are first calculated through **Equation 28** below and **Equation 29** on the following page. Further note that the cycle distance is just the width of the embankment as discussed before. The top speed is, as mentioned previously, the sum of the forward speed and reverse pass, as obtained through [**18**]. Note further that the number of compactor cycles is essentially the number of dozer cycles from section 3.2.2 in 96.6 hours, which is the total time for the dozer. However, as the compactor must operate quicker than the dozer, this number is overshot to 25,772 cycles.

$$Cycle\ Time\ =\ Cycle\ Distance\ \div Top\ Speed \quad \textbf{[Eq 28]}$$

$$=\ 0.03275km\ \div\ 7\ km/h \quad \textbf{[Eq 28]}$$

$$=\ 0.00467\ \text{hours/cycle}$$

$$\#of\ Cycle\ Hours\ =\ (\#\ of\ Cycles\ \times\ Cycle\ Time)\ \div\ \#\ of\ Compactors \quad \textbf{[Eq 29]}$$

$$=\ (25,\ 772\ cycles\ \times\ 0.00467 hours/cycle)\ \div\ 2 \quad \textbf{[Eq 29]}$$

$$=\ 60.5\ \text{hours}$$

Evidently, the number of hours is less than the 96.6 hours the dozer is on site for, as originally planned. Finally, the hours of compactor operations will be used to find the respective cost below in **Equation 30**.

$$Total\ Cost\ =\ (Hours\ \times\ Fuel\ Costs\ \times\ \#\ of\ Compactors)$$

$$+\ (Hours\ \times\ Driver\ Cost\ \times\ \#\ of\ Compactors)\ +$$

$$(Days\ \times\ RentalCost\ \times\ \#\ of\ Compactors) \quad \textbf{[Eq 30]}$$

$$=\ (96.6\ hours\ \times\ \$15.62\ \times\ 2)\ +\ (96.6\ hours\ \times\ \$25/hour\ \times\ 2)$$

$$+\ (8\ days\ \times\ \$242/day\ \times\ 2\ ) \quad \textbf{[Eq 30]}$$

$$=\ \$11,719.48$$

All findings are presented in **Table 3.2.7.1** below.

Table 3.2.7.1 Compactor Summary

Category	Selection
Type	CAT CS44B
Quantity	2
Fuel Costs	$10.98 per hour
Operator Costs	$22 per hour
Rental Costs	$1688/Week or $242 Daily
Hours	96.6 hours or 13 working days
Total Cost	$11,719.78

This construction is scheduled to take 13 working days, as that is the time it takes the dozer to operate. Note that the compactor duration was not factored as its working schedule overlaps with the dozer's. On the other hand, the dump truck's working duration isn't included as the soil is intended to reach the site before the construction of the embankment. While the project should only take 13 days, an extra day has been booked to account for delays.

3.2.8 Other Labour Costs

Table 3.2.8.1 Labor Cost Estimate

Worker	Hourly Wage	Total Hours Worked	Projected Wages
Site Foreman	$ 41/hour	7h/day x 14 days = 98 hours	$4,018
Extra Labour (4 Recommended)	$20/hour	7h/day x 14 days =	$1,960
Total			$5,978

3.2.9 Miscellaneous Costs

While these costs are not included in the overall quotation, they are notable for the client. These costs include the costs to modify the piping lengths to create drains as well as any required equipment for doing so like band saws or other labor expenditures. Costs including taxes and any discounts that the client may have with suppliers are also not factored. More importantly, and certainly not finally, the embankment width surpasses the width of the road in areas along Water Street. As such, the road is recommended to be offset 25 meters more from the river. Such a procedure can also be costly and should be anticipated for.

3.3 Cost Summary

Collectively, the following table presents the summary of the overall cost estimate for the construction of the proposed embankment.

Table 3.3.1 Labor Cost Estimate

Item	Cost
Dozer	\$13,674.12
Dump Truck	\$345,082.20
Compactor	\$11,719.48
Support Staff	\$5,978
Soil	\$1,004,678.88
Equipment (Piping & Fittings)	\$4,281.40
Total Cost	**\$1,385,414.08**

3.4 Damages and Avoided Cost Estimation

To prove the validity of Great Foundation's proposed cost for the embankment, an analysis of damages and avoided costs estimation is provided below. To begin, **Figure 3.4.1** on the following page is provided for the client. This graph essentially estimated the cost of flooding over estimated damage costs based on flooding events of 2 to 200 year floods.

The following equation models the trendline for a cost function of time.

$$C(t) = 0.8 \cdot t^{3.5} \quad \textbf{[Eq 31]}$$

In short, overall damage cost is represented by C(t) and the return period over years is represented by t. **[Eq 31]** was determined through data provided in **Table 3.4.2,** which displays expenses the City of Cambridge can expect for different flood return periods throughout the embankment's lifetime.

Figure 3.4.1 Estimated Costs of Flooding

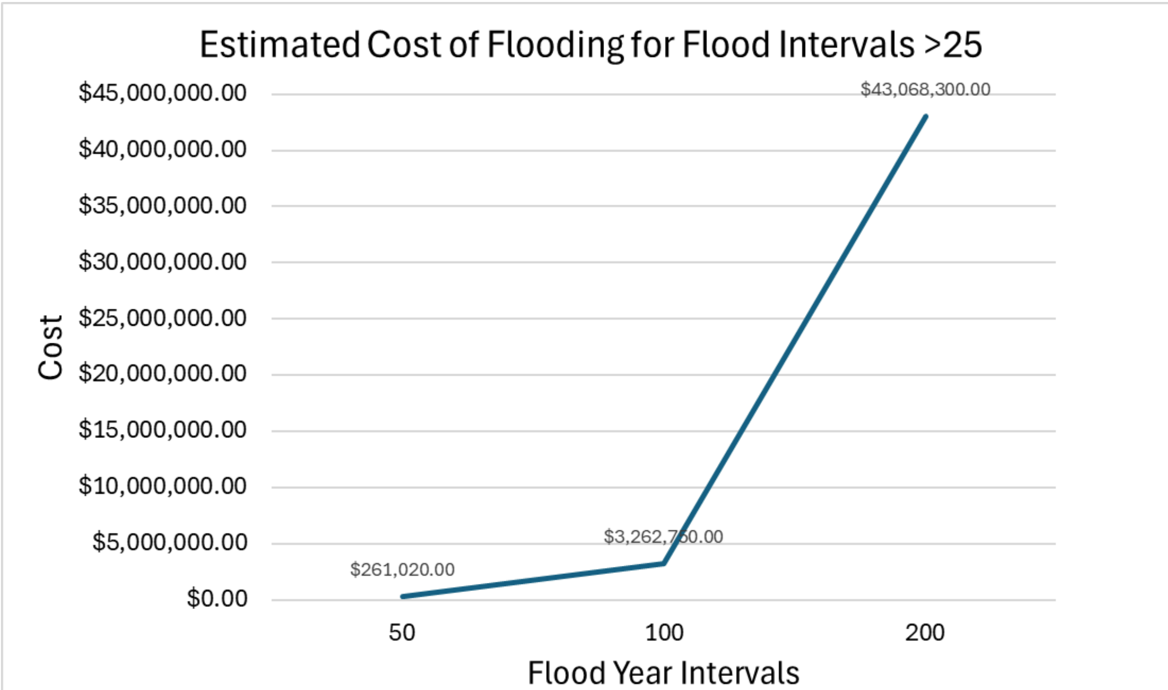


Figure 3.4.1 *models of the cost of flooding for notable flood year intervals.*

Other consulting companies have investigated a design for an embankment on this site previously, as flooding problems on Water St. have long been a problem to the people of Cambridge. The team at Great Foundations consulted with those groups to obtain estimates in 2014 for the cost of building embankments for different flood-year intervals. Great Foundations has taken those estimates and updated them by accounting for inflation since those estimates were given. The calculation for that can be found below in **Equation 32.**

$$Previous\ Cost\ (P)\ *\ (1\ +\ \%\ Inflation/100)\ =\ Current\ Cost\ (C)$$ **[Eq 32]**

$$\$5\ *\ (1\ +\ 30.51/100)\ =\ \$6.53$$ **[Eq 32]**

Through referencing **Equation 32**, the table on the following page was created based on the estimates from other consulting companies. See **Table 3.4.2** on the next page for the flood cost chart.

Table 3.4.2 Flood Costs and Damages adjusted to Inflation

Interval Years	2014 (Damages)	2025 (Damages)	2014 (Costs)	2025 (Costs)
2	$33,000,000.00	$43,068,300.00	$925,000.00	$1,207,217.50
5	$2,500,000.00	$3,262,750.00	$725,000.00	$946,197.50
10	$200,000.00	$261,020.00	$600,000.00	$783,060.00
20	$15,000.00	$19,576.50	$500,000.00	$652,550.00
25	$6,000.00	$7,830.60	$425,000.00	$554,667.50
50	$500.00	$652.55	$250,000.00	$326,275.00
100	$50.00	$65.26	$100,000.00	$130,510.00
200	$5.00	$6.53	$50,000.00	$65,255.00

As this proposal is for a 25 year flood, costs greater for 25+ years are necessary to be used for calculating damages. For avoided costs, all flooding years from 2 to 25 need to be considered, as the embankment is built to withstand these years. The calculation for damage costs estimation is found by summing the ratio of all flooding events that exceed 25 year flood, and then multiplying it by 200-year design life [**1**].

$$D = 200\left(\frac{C(50)}{50} + \frac{C(100)}{100} + \frac{C(200)}{200}\right) \quad \textbf{[Eq 32]}$$

$$A = 200\left(\frac{C(2)}{2} + \frac{C(5)}{5} + \frac{C(10)}{10} + \frac{C(20)}{20} + \frac{C(25)}{25}\right) \quad \textbf{[Eq 33]}$$

These equations were used in conjunction with the numbers found in **Table 3.4.2** to construct **Table 3.4.3** below.

Table 3.4.3 Flood Damage Cost Estimates

Interval Years	Construction Cost($)	Damage Cost($)	Avoided Cost($)
2	$65,255.00	$43,068,300.00	$6.53
5	$130,510.00	$3,262,750.00	$65.26
10	$326,275.00	$261,020.00	$652.55
20	$554,667.50	$19,576.50	$7,830.60
25	$1,385,414.08	$7,830.60	$19,576.50
50	$783,060.00	$652.55	$261,020.00
100	$946,197.50	$65.26	$3,262,750.00
200	$1,207,217.50	$6.53	$43,068,300.00

Table 3.4.4 was further included below to display the flood damage cost estimations with the corresponding logarithmic values for graphing.

Table 3.4.4 Flood Damage Cost Estimates with Logarithmic Values

Interval Years	Construction Cost($)	Log Construction Cost ($)	Damage Cost($)	Log Damage Cost($)	Avoided Cost($)	Log Avoided Cost($)
2	$65,255.00	4.81	$43,068,300.00	7.63	$6.53	0.81
5	$130,510.00	5.12	$3,262,750.00	6.51	$65.26	1.81
10	$326,275.00	5.51	$261,020.00	5.42	$652.55	2.81
20	$554,667.50	5.74	$19,576.50	4.29	$7,830.60	3.89
25	$1,385,414.08	6.14	$7,830.60	3.89	$19,576.50	4.29
50	$783,060.00	5.89	$652.55	2.81	$261,020.00	5.42
100	$946,197.50	5.98	$65.26	1.81	$3,262,750.00	6.51
200	$1,207,217.50	6.08	$6.53	0.81	$43,068,300.00	7.63

3.5 Optimal Design

The data from **Table 3.4.4** was used to create the graph to display the trends of analyzing avoided costs and damage costs. It can be observed that the breakeven point is at about the 50 year flood recurrence interval. Therefore, while Great Foundations provides the most economical price for the 25-year flood, the City of Cambridge is welcome to consider the 50-year flood.

Figure 3.4.4 Recurrence vs Optimal Design

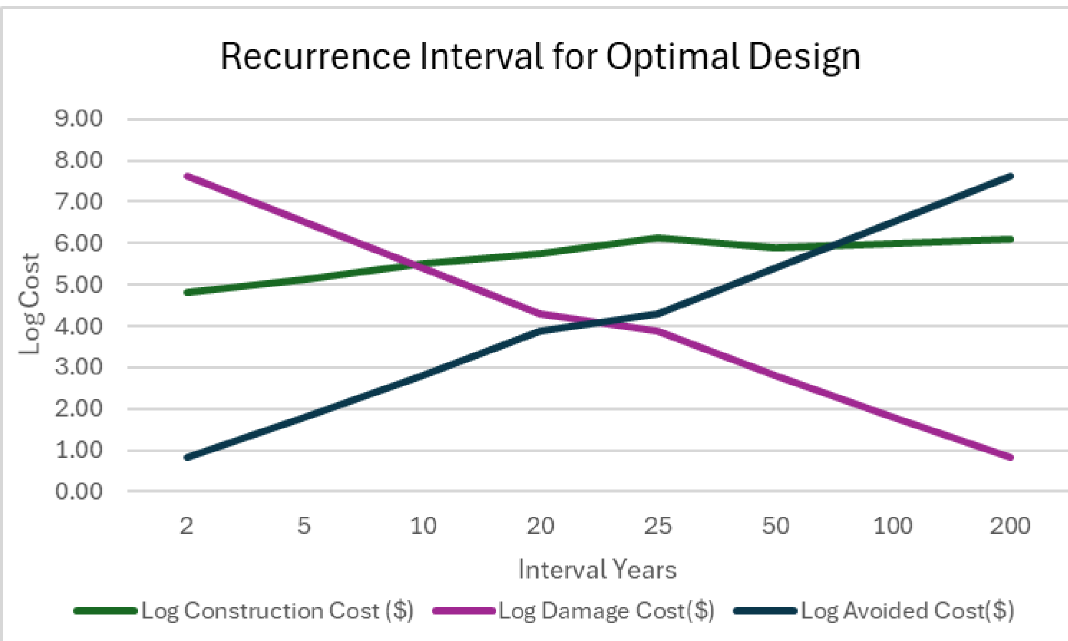


Figure 3.4.4 models the recurrence interval for the optimal design.

4.0 Material Selection

The following section outlines the materials that will be utilized in the construction of the embankment. Essentially, the sample chosen was one that optimized safety through consulting the FAO Homogenous Dam Material Envelope to follow standardized guidelines. Ultimately, the angle of repose is maximized to provide cost efficient purchasing solutions for the embankment fill, the hydraulic conductivity is minimized to reduce seepage through the embankment, and the bulk density is determined to prepare for fully-water-saturated and drained conditions.

After completing a series of soil tests, the hydrometer test was chosen in view that the sample best conforms to the FAO percent passing curve. Essentially the angle of repose was calculated to ensure the most cost effective design while maintaining the structure's safety. The hydraulic conductivity was further minimized and bulk densities were determined to guarantee the embankment's structural integrity. In truth, less material will be used to make a safe structure to reduce the cost of the project. The calculations performed to determine the optimal soil sample are detailed below.

4.1 Percent Passing

Figure 4.1.1 Hydrometer Analysis Curve Fitting

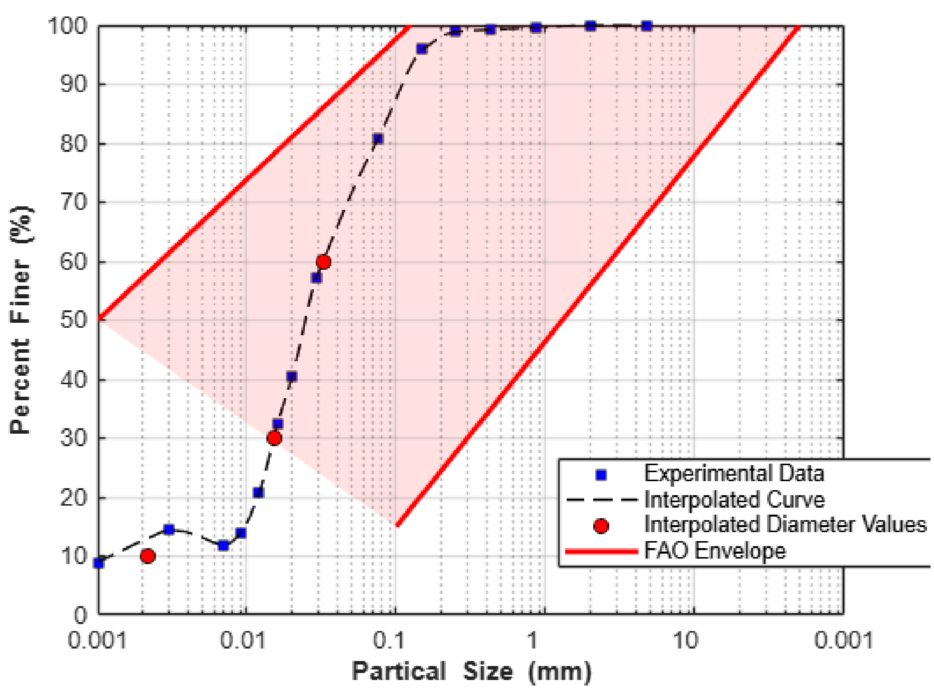


Figure 4.1.1 models the graph of the hydrometer test sample, vs the FAO Envelope

As the graph modeling the results of the hydrometer test displays, the soil sample chosen for the embankment is optimal as it fits well within the highlighted FAO Homogenous Dam Material Envelope area. Further consider particles of size 0.016 mm. Evidently, the sample particles near the FAO envelope boundaries. However, the percent passing curve reaches an asymptote and the increasing rate decreases. As such, the percent passing curve for the sample fits well within the FAO boundaries for all elements within the sample.

In further consideration of the results of the hydrometer test regarding the soil information in **Appendix E** and the United Soil Classification System (USCS) in **Appendix F**, the liquid limit and plastic index of the chosen simples reveals that the soil type was ML. Thus, the dry soil sample chosen was classified as inorganic silt to optimize the determinations of the angle of repose, the hydraulic conductivity, and the bulk densities.

4.2 Angle of Repose

Given the classification of soil and the shear box test, the angle of repose was updated to 30°, as supported by the information provided by Lyndia Stacey, Filzah Nasir and Andre Unger **[19]**. Note the information was retrieved from the following table. In view that the range for the angle of repose was 26-35 degrees, to balance between cost efficiency (larger angle) and structural integrity smaller angle), the truncated mean angle was selected to ensure the embankment's stability. See **Table 4.2.1** below for the angle of repose classifications. Further note that the angle of friction is the angle of repose for this development project.

Table 4.2.1 Angle of Friction for Sands and Silts

Typical Values of Drained Angle of Friction for Sands and Silts [3]	
Soil Type	**ϕ' (deg)**
Sand: Rounded grains	
Loose	**27 – 30**
Medium	**30 – 35**
Dense	**35 – 38**
Sand: Angular grains	
Loose	**30 – 35**
Medium	**35 – 40**
Dense	**40 – 45**
Gravel with some sand	**34 – 48**
Silts	**26 – 35**

Consider the corresponding updated designs for the embankment to incorporate the angle of repose in the following section.

4.2.1 Updated Drawings

Figure 4.2.1.1 Updated Embankment Elevation View

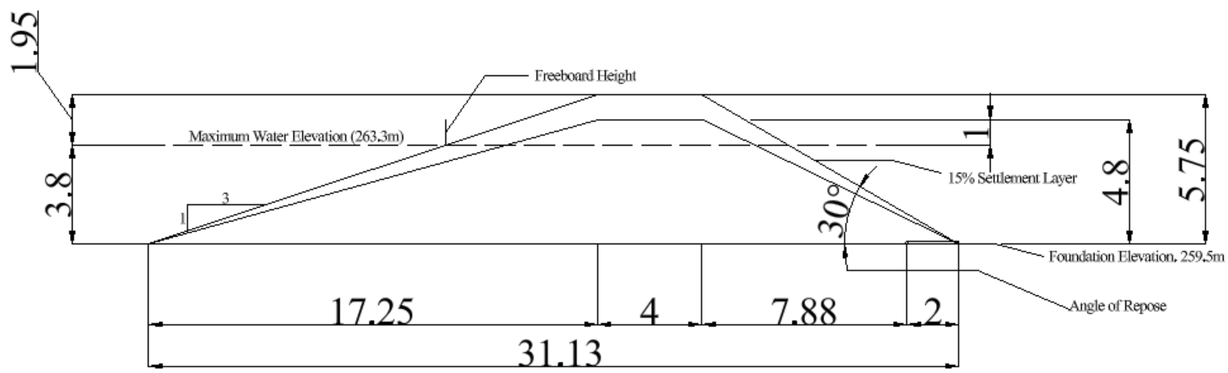


Figure 4.1.1.1 *displays the updated elevation view of the designed embankment and corresponding dimensions.*

Figure 4.2.1.2 Updated Embankment Plan View

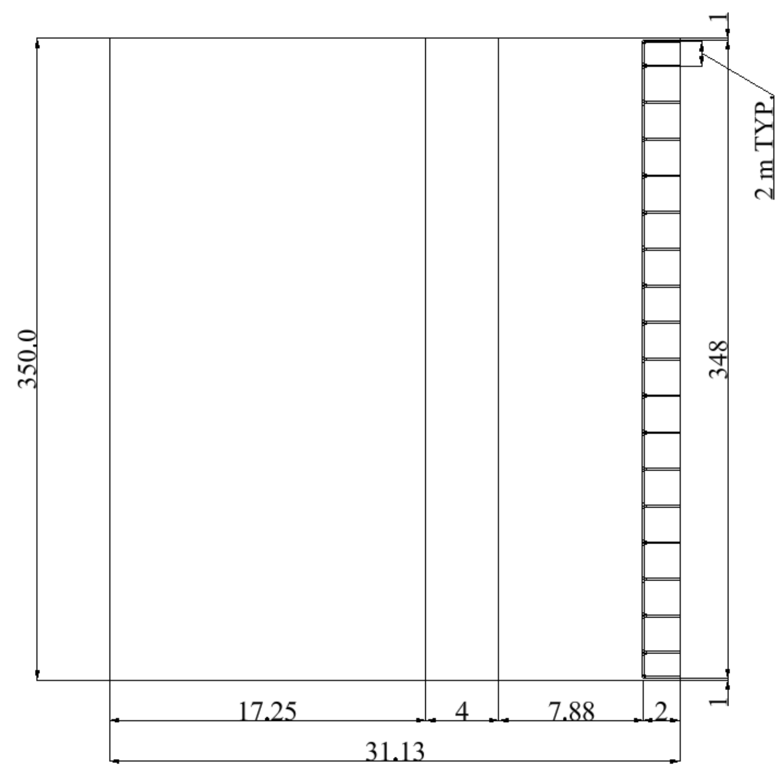


Figure 4.1.1.2 *displays the updated plan view of the designed embankment and corresponding dimensions.*

4.2.2 Cost savings

Evidently, the dry side of the embankment was steeper compared to the preliminary design presented in section 3. Subsequently, the cross-sectional area is reduced so that less soil is required to construct the embankment. The following series of calculations prove the cost reduction as a result of the angle of repose.

The new cross sectional area is calculated below:

$$\text{Area of Region 1} = \frac{Base \times Height}{2} \quad \textbf{[34]}$$

$$= \frac{17.25\ m \times 5.75\ m}{2} \quad \textbf{[34]}$$

$$= 49.59\ \mathrm{m}^2$$

$$\text{Area of Region 2} = \text{Height x Width} \quad \textbf{[35]}$$

$$= 5.75\ m\ x\ 4\ m \quad \textbf{[35]}$$

$$= 23\ \mathrm{m}^2$$

$$\text{Area of Region 3} = \frac{Base \times Height}{2} \quad \textbf{[36]}$$

$$= \frac{9.88m \times 5.75\ m}{2} \quad \textbf{[36]}$$

$$= 28.41\ \mathrm{m}^2$$

$$\text{Total Area} = \text{Area of Region 1} + \text{Area of Region 2} + \text{Area of Region 3} \quad \textbf{[37]}$$

$$= 49.59\ m^2 + 23\ m^2 + 28.41\ m^2 \quad \textbf{[37]}$$

$$= 101\ \mathrm{m}^2$$

The area is further supported by the provided properties of the cross-sectional area polygon in AutoCAD on the next page in **Figure 4.2.2.2**.

Figure 4.2.2.2 Cross Sectional Area Confirmation

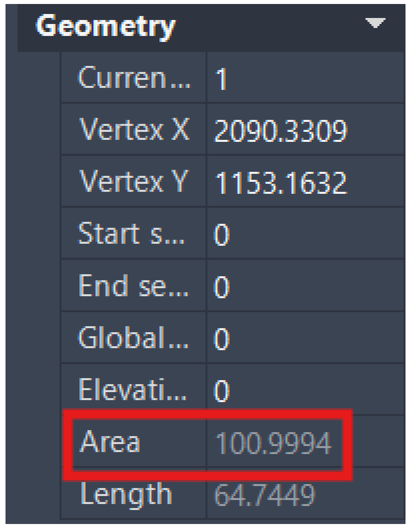


Figure 4.2.2.2 *displays the area of the cross-sectional polygon's area from AutoCAD.*

The following calculations determine the updated cost for the embankment filling.

Total Volume = Cross Sectional Area x Length of Embankment **[38]**

$= 101\ m^2 \times 350\ m$ **[38]**

$= 35{,}350\ m^3$

Total Price = Total Volume x Price **[39]**

$= 35350\ m^3 \times \$27.17/m^3$ **[39]**

$= \$960{,}459.50$

Cost Reduction = (1 -Updated Cost/Initial Cost) x 100 **[40]**

$= (1 - 960{,}495.50/1{,}004{,}678.88) \times 100$ **[40]**

$= 4.4\%$

Therefore, the adjusted cost of soil is $960,459.5, representing a 4.4% reduction from the original material cost.

4.3 Hydraulic Conductivity

Hydraulic Conductivity is a property of porous material that quantifies its ability to transmit water. Different values are able to be determined through the Beyer, USBR, and Kruger equations [**19**]. When considering these three equations, it's important to consider the maximum conductivity estimate, as this will provide the greatest hydraulic conductivity value. This is essential as the greatest hydraulic conductivity value provides the greatest amount of seepage through the embankment, which reveals the worst possible scenario for the design. Consider the following table for the provided information for guidance in determining the hydraulic conductivity.

Table 4.3.1 Soil Properties used to Determine the Hydraulic Conductivity

Soil Property	Measured Value with Units
Total Mass (M_T)	5.5E-02 (kg)
Oven Dried Mass (M_s)	4.94E-02 (kg)
Total Volume (V_T)	3.32E-05 (m^2)
Specific Gravity (G_s)	2.613
Bulk Density (ρ_b)	1666.67kg/m^3
Volume of Water in Voids (V_w)	5.6E-06 (m^3)
Water Density (ρ_w)	1000 (kg/m^3)
Molecular Weight of Water (M_w)	1.23E-02 (Kg)
Porosity (n)	0.29

Furthermore, extrapolated data points from **Figure 4.1.1** above are displayed in **Table 4.3.2**, highlighting the grain sizes at 10%, 20%, and 60% passing to calculate the hydraulic conductivity.

Table 4.3.2: Grain Size Extrapolated Values

Diameter	Size [mm]
D10	0.0021
D20	0.0151
D60	0.0323

Notably, the hydraulic conductivity was calculated through the Beyer equation below.

$$K = C \times (d_{10})^2 \quad \textbf{[Eq 41]}$$

However, to do so, the uniformly coefficient, U was first determined through **Equation 42,** to be 15.38.

$$U = \frac{D60}{D10} \text{ [Eq 42]}$$

$$= \frac{0.0323}{0.0021} \text{ [Eq 42]}$$

$$= 15.38$$

Coefficient C in the Beyer Equation was further calculated in **Equation 43,** using the coefficient of uniformity that was found in **Equation 42.** C was thus calculated to be 0.00680.

$$C = 4.5 \times 10^{-3} \times log(\frac{500}{U}) \quad \text{[Eq 43]}$$

$$= 4.5 \times 10^{-3} \times log(\frac{500}{15.38}) \text{[Eq 43]}$$

$$= 0.00680$$

Therefore, the hydraulic conductivity from the Beyer equation from **Equation 41** was determined to be $3.0\ x\ 10^{-8}\ m/s$.

$$K = 0.00680 \times (0.0021)^2 \text{ [Eq 41]}$$

$$= 3.0 \times 10^{-8}\ m/s \text{ [Eq 41]}$$

The hydraulic conductivity was further determined using the USBR equation. This equation is displayed below in **Equation 44** and the hydraulic conductivity was determined to be $8.21\ x\ 10^{-8}\ m/s$.

$$K = 0.36 \times (d20)^2 \text{ [Eq 44]}$$

$$= 0.36 \times (0.0151)^2 \text{ [Eq 44]}$$

$$= 8.21 \times 10^{-5}\ cm/s$$

$$= 8.21 \times 10^{-8}\ m/s$$

Finally, the hydraulic conductivity was also calculated using the Kruger equation, which is displayed in **Equation 45** below. However, before the hydraulic conductivity was calculated for, the Effective Diffusivity (d_e) was determined first The equation for d_e was displayed below in **Equation 46** on the next page.

$$K = 240 \times n \times \frac{de^2}{(1-n)^2} \text{ [Eq 45]}$$

$$\frac{1}{de} = \sum \frac{gi}{di} \textbf{ [Eq 46]}$$

To calculate for $\frac{1}{de}$, the $\frac{gi}{di}$ values must be determined. These values were obtained through the sieve analysis lab data found in **Table 4.3.3**, where the percentage retained, in decimal form, was divided by its respective sieve size. The values of $\frac{gi}{di}$ were then summed up to be 25.181.

Table 4.3.3 Sieve Size Analysis Data for Determining $\frac{gi}{di}$

Sieve Size (mm) (di)	**%Retained (gi)**	g_i/d_i
63.00	0.0000	0.00000
37.50	0.1950	0.00520
26.50	0.3640	0.01374
22.40	0.3810	0.01701
19.00	0.3810	0.02005
16.00	0.3960	0.02475
13.20	0.4150	0.03144
9.50	0.5710	0.06011
6.70	0.6970	0.10403
4.75	0.7530	0.15853
2.36	0.8170	0.34619
1.18	0.8380	0.71017
0.60	0.8680	1.44667
0.30	0.9090	3.03000
0.15	0.9520	6.34667
0.08	0.9650	12.86667

After summing values of $\frac{gi}{di}$, the value of d_e was determined to be 3.9×10^{-2} below.

$$de = \frac{1}{25.181} \textbf{ [Eq 46]}$$

$$= 3.9 \times 10^{-2}$$

Considering the value of d_e, the hydraulic conductivity was calculated using **Equation 47** on the next page, where it was found to be 2.52×10^{-6} m/s.

$$K = 240 \times n \times \frac{de^2}{(1-n)^2} \textbf{ [Eq 47]}$$

$$= 240 \times 0.29 \times \frac{(3.9 \times 10^{-2})^2}{(1-0.29)^2} \textbf{ [Eq 47]}$$

$$= 2.52 \times 10^{-6} \frac{m}{s}$$

The three hydraulic conductivity values were summarized below in **Table 4.3.4.** Notably, the largest hydraulic conductivity was calculated to be 2.52×10^{-6} $[\frac{m}{s}]$. As this value represents the "worst case" scenario, the value is to be used for future calculations to account for the greatest possible amount of seepage into the dyke. Therefore, the proposed hydraulic conductivity value will ensure a conservative design.

Table 4.3.4 Calculated Hydraulic Conductivity Values

Equations	**Hydraulic Conductivity** $[\frac{m}{s}]$
Beyer	3.0×10^{-8}
USBR	8.21×10^{-8}
Kruger	2.52×10^{-6}

4.4 Water-Saturated and Drained Bulk Density

In this section, the bulk density was calculated to account for two extreme conditions. The first is an extremely low water content value, to account for when the soil is drained. The second is an extremely high water content value to account for when the soil is fully saturated. Extremely dry soil can cause the foundation to weaken due to shrinkage, whereas extremely saturated soils can cause erosion. $S_W = 0.1$ and $S_W=1.0$ will be used respectively.

To calculate the bulk density of the soil in those extreme conditions, the overall bulk density, moisture content, void ratio, volume of voids, volume of water, and mass of water in the soil sample must be calculated first. Firstly, the overall bulk density was calculated using **Equation 48** on the following page.

$$P_b = \frac{M_T}{V_T} g \textbf{ [Eq 48]}$$

$$= \frac{0.055kg}{0.000033m^3} \times 9.81 \textbf{ [Eq 48]}$$

$$= 1666.67 \text{ kg/m}^3$$

The moisture content was calculated using **Equation 49.**

$$\theta_w = \frac{M_T - M_S}{M_S} \times 100\% \textbf{ [Eq 49]}$$

$$= \frac{0.055 - 0.0494}{0.0494} \times 100\% \textbf{ [Eq 49]}$$

$$= 11.3\%$$

The void ratio was calculated using **Equation 50**

$$e = G_s(1 + \theta_w)(\frac{\rho_w}{\rho_b}) - 1 \textbf{ [Eq 50]}$$

$$= 2.613(1 + 0.113)\frac{1000}{1666.67} - 1 \quad \textbf{[Eq 50]}$$

$$= 0.7449$$

The percent porosity was calculated using the void ratio using the equation below in **Equation 51.**

$$n = \frac{e}{e+1} \times 100\% \textbf{ [Eq 51]}$$

$$= \frac{e}{e+1} \times 100\% \textbf{ [Eq 51]}$$

$$= \frac{0.7449}{1.7449} \times 100\% \textbf{ [Eq 51]}$$

$$= 42.69\%$$

The volume of voids was calculated using **Equation 52** on the following page.

$$V_V = n\, x\, V_T \textbf{ [Eq 52]}$$

$$= 0.426901\, x\, 0.000033[\mathrm{m}^3] \textbf{ [Eq 52]}$$

$$= 1.41 \times 10^{-5}\ \mathrm{m}^3$$

The volume of water in the drought condition was calculated using **Equation 53.**

$$V_w = S_w\, x\, V_V \textbf{ [Eq 53]}$$

$$= 0.1 \bullet 1.41\, x\, 10^{-5} \textbf{ [Eq 53]}$$

$$= 1.41 \times 10^{-6}\ \mathrm{m}^3$$

The volume of water in the saturated condition was calculated using **Equation 54.**

$$V_w = S_w\, x\, V_V \textbf{ [Eq 54]}$$

$$= 1\, x\, 1.41 \times 10^{-5} \textbf{ [Eq 54]}$$

$$= 1.41 \times 10^{-5}\ \mathrm{m}^3$$

The mass of water in the drought condition is calculated using **Equation 55.**

$$M_w = V_w\, x\, \rho_w \textbf{ [Eq 55]}$$

$$= 1.41 \times 10^{-6} \bullet 1000 \textbf{ [Eq 55]}$$

$$= 1.41 \times 10^{-3}\ \mathrm{kg}$$

The mass of water in the drought condition is calculated using **Equation 56.**

$$M_w = V_w\, x\, \rho_w \textbf{ [Eq 56]}$$

$$= 1.41 \times 10^{-5} \bullet 1000 \textbf{ [Eq 56]}$$

$$= 1.41 \times 10^{-2}\ \mathrm{kg}$$

Finally, the bulk density in the drought and saturated conditions was calculated using the values from all previous calculations. To calculate the bulk density in the drought condition, the following **Equation 57** was used. Note that the M_S was obtained from **Table 4.3.1**.

$$\rho_b = \frac{M_s + M_w}{V_T} \quad \textbf{[Eq 57]}$$

$$= \frac{4.94\times10^{-2} + 1.41\times10^{-3}}{3.23\times10^{-5}} \quad \textbf{[Eq 57]}$$

$$= 1573.065 \text{ kg/m}^3$$

Likewise, the bulk density in saturated conditions was calculated using the following equation of **Equation 58**.

$$\rho_b = \frac{4.94\times10^{-2} + 1.41\times10^{-2}}{3.23\times10^{-5}} \quad \textbf{[Eq 58]}$$

$$= 1965.944 \text{ kg/m}^3$$

All calculated bulk densities were further summarized in **Table 4.4.1** below.

Table 4.4.1 Calculated Hydraulic Conductivity Values

Condition	Drought	Saturated
Bulk Density (ρ_b)[kg/m^3]	1573.065	1965.944

To further verify the values for the bulk density, the inequality in **Equation 59** below was used to validate the bulk densities calculated. Note that the density of water was ρ_W = 1000 kg/m^3 and the specific gravity for the sample was G_s = 2.613 as seen in **Table 4.3.1.**

$$1000 \text{ kg/m}^3 < 1573.065 \text{ kg/m}^3 < G_s \times \rho_w \text{ in drought conditions } \textbf{[Eq 59]}$$

$$1000 \text{ kg/m}^3 < 1573.065 \text{ kg/m}^3 < 2.613 \times 1{,}000 \ \textbf{[Eq 59]}$$

$$1000 \text{ kg/m}^3 < 1573.065 \text{ kg/m}^3 < 2.613 \times 2{,}613 \text{ kg/m}^3$$

Likewise, for saturated conditions, the following inequality was created.

$$1000 \text{ kg/m}^3 < 1965.944 \text{ kg/m}^3 < 2.613 \times 2{,}613 \text{ kg/m}^3$$

Considerably, both inequalities were true, which proves that the ML soil sample selected was optimal for ensuring a cost effective structurally integral embankment to withstand a 25-year flood.

5.0 Deliverable Cost

The team at Great Foundations worked diligently to create this deliverable for the client. Thus, on behalf of the whole team, the Project Manager presents the overall billings for completing this deliverable.

Below is the cost of this deliverable, broken down into the billing hours of each group member (**Figure 5.0.1**, **Figure 5.0.2 and Figure 5.03**). The amount of time that everyone billed represents the amount of work that each worker completed. Project timeline charts are further provided for both weeks; they include the breakdown of each task and explains the overall cost of this deliverable being $11,324.

Figure 5.0.1 Billing Hours for Deliverable 1

Great Foundations Time Matrix								
Task #	Role	Project Manager (Alex van Pinxteren) $180	Technical Lead (John Milloy) $140	Engineering Staff (Jason Wang) $90	Engineering Staff (Jacob Raposo) $90	Engineering Staff (Yuheng Situ) $90	Engineering Staff (Leo Chen) $90	Total
Deliverable #1								
1	Indenity Flood Magnitude	$ -	$ 140.00	$ 90.00	$ -	$ -	$ -	$ 230.00
2	Design Top Width And Length	$ -	$ 140.00	$ 90.00	$ -	$ -	$ -	$ 230.00
3	Design Slopes	$ -	$ 140.00	$ 90.00	$ -	$ -	$ -	$ 230.00
4	Design Horizontal Drainage	$ -	$ 140.00	$ 45.00	$ -	$ -	$ 45.00	$ 230.00
5	Write Deliverable 1 Report	$ 990.00	$ 980.00	$ 450.00	$ 45.00	$ 90.00	$ 45.00	$2,600.00
Total (Each Person)		$ 990.00	$ 1,540.00	$ 765.00	$ 45.00	$ 90.00	$ 90.00	
Total								$3,520.00

The cost for the first proposal is thus $3,520.

Figure 5.0.2 Billing Hours for Deliverable 2

Great Foundations Time Matrix								
Task #	Role	Project Manager (John Milloy) $180	Technical Lead (Jason Wang) $140	Engineering Staff (Alexander van Pinxteren) $90	Engineering Staff (Jacob Raposo) $90	Engineering Staff (Yuheng Situ) $90	Engineering Staff (Leo Chen) $90	Total
Deliverable #2								
1	Project Mangement	$ -	$ 210.00	$ -	$ -	$ -	$ -	$ 210.00
2	Cost Estimation	$ 2,160.00	$ 560.00	$ 630.00	$ 90.00	$ -	$ -	$3,440.00
3	Cost of Failure	$ -	$ -	$ -	$ 180.00	$ -	$ -	$ 180.00
4	Damages and Avoided Cost	$ -	$ -	$ 180.00	$ 90.00	$ -	$ -	$ 270.00
5	Opitmal Design	$ -	$ -	$ 360.00	$ -	$ -	$ -	$ 360.00
6	Write Deliverable 2 Report	$ 1,080.00	$ 1,680.00	$ 180.00	$ 90.00	$ -	$ -	$3,030.00
Total (Each Person)		$ 3,240.00	$ 2,450.00	$ 1,350.00	$ 450.00	$ -	$ -	
Total								$7,490.00

The cost for the second proposal is thus $7,490

Figure 5.0.3 Billing Hours for Deliverable 3

Task #	Role	Project Manager (Jason Wang) $180	Technical Lead (Alexander van Pinxteren) $140	Engineering Staff (John Milloy) $90	Engineering Staff (Jacob Raposo) $90	Engineering Staff (Yuheng Situ) $90	Engineering Staff (Leo Chen) $90	Total
		Great Foundations Time Matrix						
Deliverable #3								
1	New Gantt and Labour Charts	$ 90.00	$ 140.00	$ 45.00	$ -	$ -	$ -	$ -
2	Append Cover Letter, Table of Contents/Figs/Tables, Summary, Background / Methodology, and Conclusions	$ 360.00	$ 280.00	$ 270.00	$ 180.00	$ -	$ -	$ -
3	Select Soil and generate Grain Size Curve	$ -	$ -	$ 90.00	$ -	$ -	$ -	$ -
4	Update roadside Slope Redraw Cross Section	$ 900.00	$ -	$ -	$ -	$ -	$ -	$ -
5	Calculate hydraulic conductivity	$ -	$ -	$ 45.00	$ 180.00	$ -	$ -	$ -
6	Calculate saturated and dry bulk density values	$ -	$ 560.00	$ -	$ -	$ -	$ -	$ -
	Total (Each Person)	$ 1,350.00	$ 980.00	$ 450.00	$ 360.00	$ -	$ -	
	Total							$ 3,140.00

The cost for the second proposal is thus $3,340.

Figure 5.0.4 Project Timeline for Deliverable 1

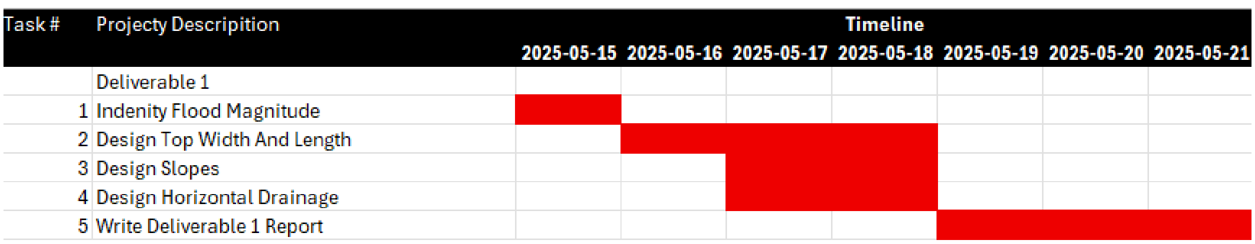


Figure 5.0.5 Project Timeline for Deliverable 2

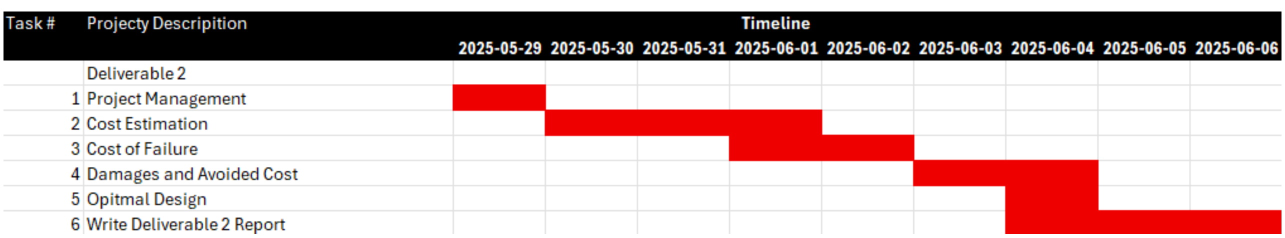
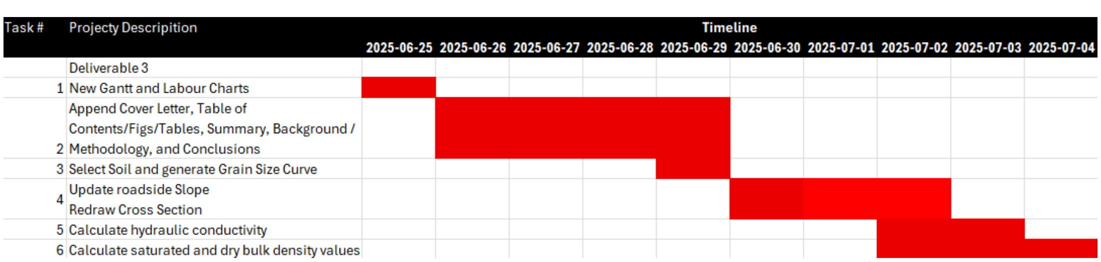


Figure 5.0.5 Project Timeline for Deliverable 3

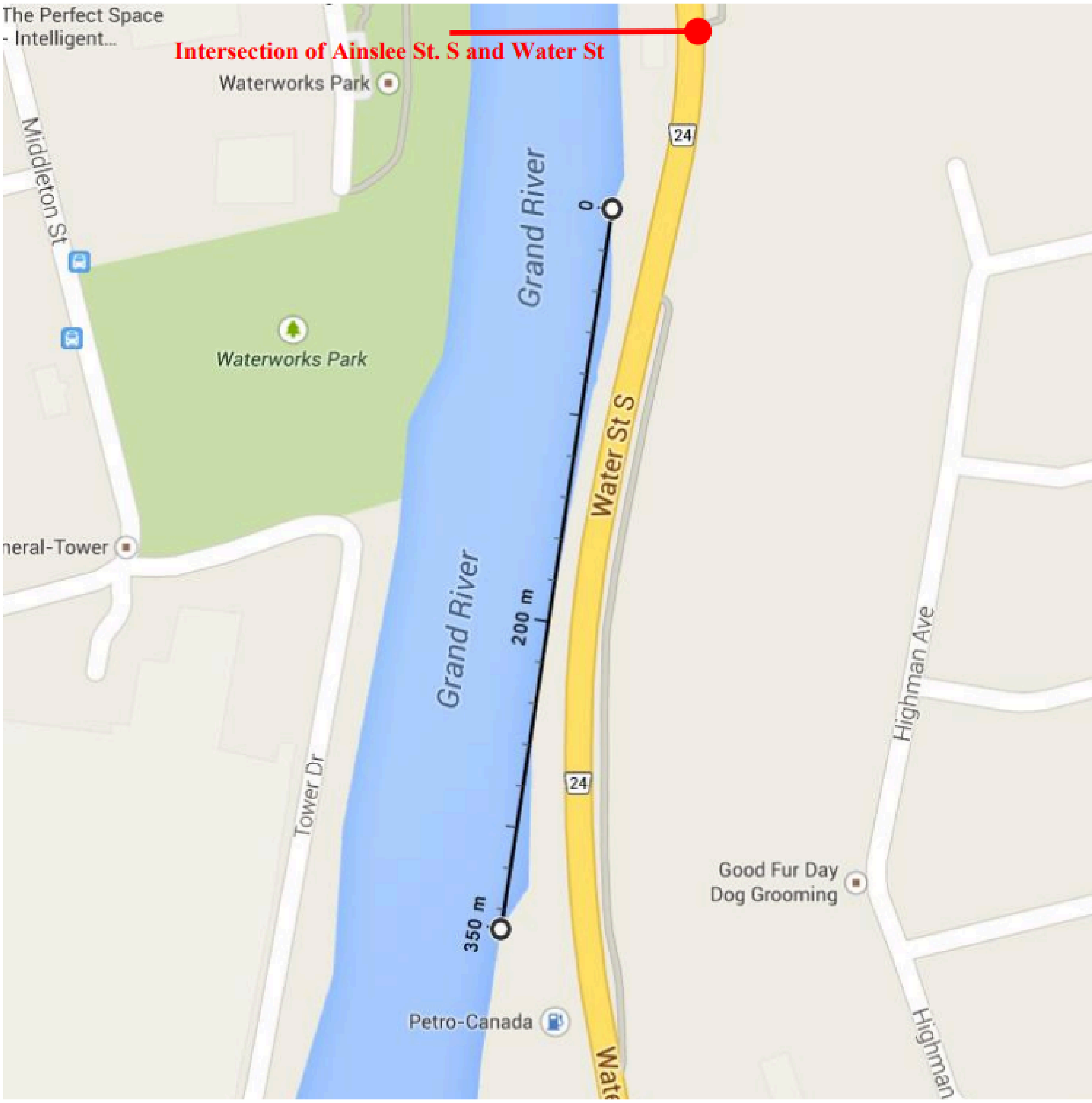


6.0 Conclusion

This embankment presents a cost effective and sustainable way to protect Water Street during a 25-year flood event. Through diligent consulting with various sources, the solution is an embankment of 32.75 m wide, 350 m long, and 5.75 m high, with a comprehensive internal drainage system for directing seepage water in a controlled manner. As shown in the report, despite the initial investment, this embankment will offset its cost of construction over time, ensuring that Cambridge remains safe, no matter the weather conditions. By the end of this report, the current cost sums to $1,385,414.08 (Proposed Construction Cost) + $10,830 (Engineering Costs) = **$1,396,244.08**. This report also outlines the choice of soil, and the properties of the soil, including the angle of repose, the hydraulic conductivity and the water-saturated and drained bulk density.

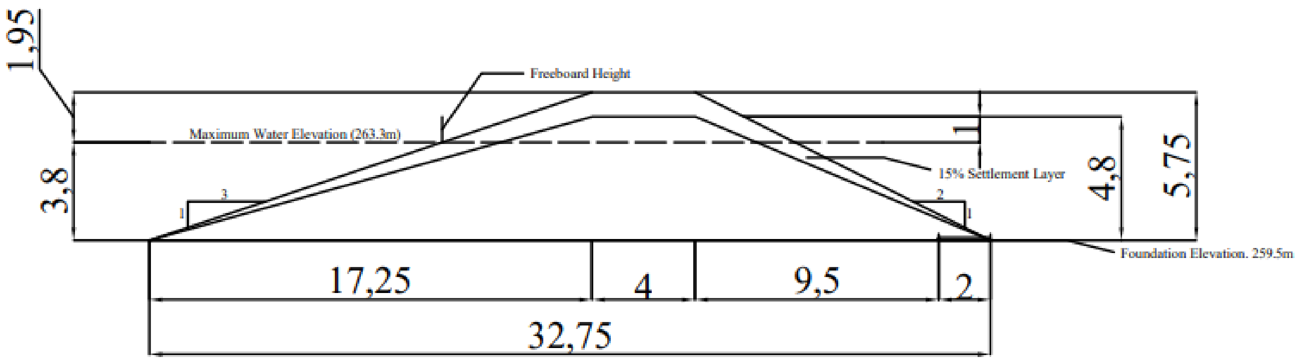
7.0 Appendices

Appendix A: General Layout of Location



Detailed Map of Site [**1**]

Appendix B: Detailed Side View of Design



Design of embankment

Appendix C : Flood Frequency Chart

Table 1 - Water surface elevation data for Grand River based on different storm events [11]

River station	Profile	Total Flow (m^3/s)	Water Surface Elevation (m)
48	2 year	434.0	261.1
48	5 year	647.0	261.5
48	10 year	797.0	261.8
48	20 year	947.0	262.1
48	25 year	996.0	262.2
48	50 year	1150.0	262.5
48	100 year	1310.0	262.7
48	May 1974	1550.0	263.2
49	2 year	434.0	261.4
49	5 year	647.0	261.9
49	10 year	797.0	262.2
49	20 year	947.0	262.5
49	25 year	996.0	262.6
49	50 year	1150.0	262.9
49	100 year	1310.0	263.1
49	May 1974	1550.0	263.5
50	2 year	434.0	261.7
50	5 year	647.0	262.3
50	10 year	797.0	262.6
50	20 year	947.0	262.9
50	25 year	996.0	263.0
50	50 year	1150.0	263.2
50	100 year	1310.0	263.5
51	2 year	434.0	261.9
51	5 year	647.0	262.5
51	10 year	797.0	262.8
51	20 year	947.0	263.2
51	25 year	996.0	263.3
51	50 year	1150.0	263.6
51	100 year	1310.0	263.8
51	May 1974	1550.0	264.2

Chart provided by [**1**] *for water elevation assignment.*

Appendix D: NRCS Chart

Table 1. Minimum Design Criteria for Dikes.

Classification	Material [1/]	Height (H) [2/] (Feet)	Minimum Storm Design Frequency (Years)	Minimum Freeboard (Feet)	Minimum Top Width (Feet)	Minimum Side Slope Ratio [3/] (H:V)	Berm Width (Feet)
Class I	Earth	0 to 6	100	H/3	10	2:1	12
		>6 to 12	100	2	10	Note [4/]	Note [4/]
		>12 to 25	100	3	12	Note [4/]	Note [4/]
		>25	100	3	14	Note [4/]	Note [4/]
	Manufactured	0 to 8	100	H/4	N/A	N/A	Note [4/]
		>8 to 12	100	2	N/A	N/A	Note [4/]
		>12	100	3	N/A	N/A	Note [4/]
Class II	Earth	0 to 6	25	H/3	6	2:1	12
		>6 to 12	25	2	8	2:1	15
	Manufactured	0 to 8	25	H/4	N/A	N/A	Note [4/]
		>8 to 12	25	2	N/A	N/A	Note [4/]
Class III	Mineral Soils	0 to 3	10	H/3	4	2:1	8
		>3 to 6	10	1	6	2:1	8
		>6 to 12	25	2	8	2:1	8
	Organic Soils [5/]	0 to 2	10	H/2	4	2:1	10
		>2 to 4	10	1	6	2:1	10
		>4 to 6	10	2	8	2:1	15

[1/] Earth includes rock. Manufactured materials are erosion resistant materials such as concrete, PVC and steel that provides the structural strength for the dike.

[2/] Height is the difference between normal ground elevation at the dike centerline and the design high water elevation. When determining normal ground elevation, exclude crossings of channels, sloughs, small low areas, small ridges, swales, or gullies.

[3/] Minimum side slope ratios are for compacted earth fill. Dumped earth fill without compaction will be flatter.

[4/] Side slope ratios and berm widths shall be determined by a stability analysis.

[5/] Organic soils are permitted only for Class III dikes 6 feet or less in height. Higher dike heights result in excessive settlement and decomposition.

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NRCS Chart provided by [**1**] for design guidance.

Appendix E: Soil Data

Hydrometer

Date Tested: May 20, 2025

Tested By: Alex van Pinxteren, John Milloy

Date Completed: May 21, 2025

Sample ID: SH13

Table 1: Table of Hygroscopic Data

Description	Value
Mass of Pan	15.33 (g)
Air Dried Weight + Pan	56.31 (g)
Oven Dried Weight + Pan	56.17 (g)
Mass of Air Dried Soil (M_{ad})	40.98 (g)
Mass of Oven Dried Soil (M_{od})	40.84 (g)
Mass of Water (M_w)	0.14 (g)
Hygroscopic Water Content (%) (Θ_{hw})	0.34%
Hygroscopic Correction Factor (H_{cf})	0.9965

Table 2: Sieve Size Analysis Before Hydrometer

Sieve Size Analysis Before Hydrometer				
Sieve Size (mm)	**Non-Cumulative Weight (g)**	**Cumulative Weight (g)**	**%Retained**	**%Passing**
19.0	0.0	1260.89	0.0	100
13.2	0.0	1260.89	0.0	100

9.5	0.0	1260.98	0.0	100
4.75	0.0	1260.98	0.0	100
2.00	0.0	1260.89	0.0	100

Total Sample Weight (g): 1260.89

Table 3: Sieve Size Analysis After Hydrometer

Sieve Size Analysis After Hydrometer				
Sieve Size (µm)	**Non-Cumulative Weight (g)**	**Cumulative Weight (g)**	**%Retained**	**%Passing**
850	0.22	0.22	0.44	99.56
425	0.18	0.40	0.81	99.19
250	0.17	0.57	1.15	98.85
150	0.38	0.55	1.11	98.89
75	0.25	0.80	1.62	98.38

Table 4a: Hydrometer Test Sample Data

Description	Value
Mass of Total Hydrometer Sample (g)	49.49
Specific Gravity of Solids (G_s)	2.613
Hydrometer Type	152H
Hydrometer Number	4327544
Composite Correction	6

Meniscus Correction	+1
Mass of Hydrometer Sample Tested (M)	49.32g

Table 4b: Hydrometer Test Data

Hydrometer Test Data						
Date	**Time**	**Elapsed Time (min)**	**Hydro Reading (mm)**	**Temp (°C)**	**Meniscus Corrected Hydro Reading (R_{actual})**	**L (cm)**
05/20/2025	9:06	0.0	-	-	-	-
05/20/2025	9:08	2.0	45	20.5	46	7.7
05/20/2025	9:11	5.0	33.5	20.5	34.5	10.6
05/20/2025	9:14	8.0	30.0	20.5	31	11.2
05/20/2025	9:21	15.0	25.0	20.8	26	12
05/20/2025	9:36	30.0	21.0	20.8	22	12.7
05/20/2025	10:36	60.0	15.0	20.8	16	15.7
05/20/2025	13:16	250.0	12.0	20.3	13	14.2
05/21/2025	9:06	1440.0	11.0	20.0	12	14.3

Hydrometer Test Data (Continued)						
K (-)	**D (mm)**	**C_T (-)**	**a (-)**	**Corrected Hydrometer Reading (g/L)**	**%Finer (P)**	**%Finer (P_A)**
-	-	-	-	-	-	-

0.01369	0.029	0.07	1.01	40.07	82	80.67
0.01369	0.020	0.07	1.01	128.57	58	57.06
0.01369	0.016	0.07	1.01	25.07	51	50.17
0.01369	0.012	0.18	1.01	20.18	41	40.32
0.01369	0.009	0.18	1.01	16.18	33	32.47
0.01369	0.007	0.18	1.01	10.18	21	20.66
0.01386	0.003	0.04	1.01	7.04	14	13.77
0.01386	0.001	0.04	1.01	6.04	12	11.81

Given Data

Description	**Value**
Total Mass (M_T)	5.5E-02 (kg)
Oven Dried Mass (M_s)	4.94E-02 (kg)
Total Volume (V_T)	3.32E-05 (m^2)
Specific Gravity (G_s)	2.613
Liquid Limit (LL)	0
Plastic Limit (PL)	0
Bulk Density (ρ_b)	1666.67kg/m^3
Unit Weight (γ_b)	16.34kN/m^3
Moisture Content (θ_w)	11.3%
Void Ratio (e)	0.74
Porosity (n)	0.4269
Volume of Void (V_v)	1.41E-05 (m^3)

Volume of Water in Voids (V_w)	5.6E-06 (m^3)
Water Saturation (S_w)	0.38
Water Density (ρ_w)	1000 (kg/m^3)

Description	**Value**
D_{10}	0.0021
D_{30}	0.0151
D_{60}	0.0323
Coefficient of Uniformity (C_u)	15.38
Coefficient of Graduation (C_C)	3.36
%Gravel	0%
%Sand	1.62%
%Fines	98.38%

Appendix F: USCS Classification

Table 3.6 Unified Soil Classification System (Based on Material Passing 75-mm Sieve)

Criteria for Assigning Group Symbols				Group Symbol
Coarse-Grained Soils More than 50% of retained on No. 200 sieve	**Gravels** More than 50% of coarse fraction retained on No. 4 sieve	Clean Gravels Less than 5% fines[a]	$C_u \geq 4$ and $1 \leq C_c \leq 3$[c]	GW
			$C_u < 4$ and/or $1 > C_c > 3$[c]	GP
		Gravels with Fines More than 12% fines[a,d]	$PI < 4$ or plots below "A" line (Figure 3.16)	GM
			$PI > 7$ and plots on or above "A" line (Figure 3.16)	GC
	Sands 50% or more of coarse fraction passes No. 4 sieve	Clean Sands Less than 5% fines[b]	$C_u \geq 6$ and $1 \leq C_c \leq 3$[c]	SW
			$C_u < 6$ and/or $1 > C_c > 3$[c]	SP
		Sands with Fines More than 12% fines[b,d]	$PI < 4$ or plots below "A" line (Figure 3.16)	SM
			$PI > 7$ and plots on or above "A" line (Figure 3.16)	SC
Fine-Grained Soils 50% or more passes No. 200 sieve	**Silts and Clays** Liquid limit less than 50	Inorganic	$PI > 7$ and plots on or above "A" line (Figure 3.16)[e]	CL
			$PI < 4$ or plots below "A" line (Figure 3.16)[e]	ML
		Organic	$\frac{\text{Liquid limit – oven dried}}{\text{Liquid limit – not dried}} < 0.75$; see Figure 3.16; OL zone	OL
	Silts and Clays Liquid limit 50 or more	Inorganic	PI plots on or above "A" line (Figure 3.16)	CH
			PI plots below "A" line (Figure 3.16)	MH
		Organic	$\frac{\text{Liquid limit – oven dried}}{\text{Liquid limit – not dried}} < 0.75$; see Figure 3.16; OH zone	OH
Highly Organic Soils	Primarily organic matter, dark in color, and organic odor			Pt

[a] Gravels with 5 to 12% fine require dual symbols: GW-GM, GW-GC, GP-GM, GP-GC.

[b] Sands with 5 to 12% fines require dual symbols: SW-SM, SW-SC, SP-SM, SP-SC.

[c] $C_u = \frac{D_{60}}{D_{10}}$; $C_c = \frac{(D_{30})^2}{D_{60} \times D_{10}}$

[d] If $4 \leq PI \leq 7$ and plots in the hatched area in Figure 3.16, use dual symbol GC-GM or SC-SM.

[e] If $4 \leq PI \leq 7$ and plots in the hatched area in Figure 3.16, use dual symbol CL-ML.

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