Stormwater Infiltration Through Green Infrastructure

BREE 495 - Engineering Design 3
Department of Bioresource Engineering
Engineering Design Report
McGill University

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ABSTRACT

Urbanization is continuously increasing and as a result landscapes are now mainly covered by impervious materials. As a consequence, many issues arise including increased runoff, spreading of pollution, groundwater contamination and the urban heat island effect. A need for improved stormwater management through green infrastructure is therefore highly relevant in urban areas. The Plaza Pointe-Claire parking lot was selected as a representative site to study different possible methods of implementing green infrastructure. Upon analyzing already existing infiltration systems and the barriers involved in their implementation, it was determined that a bioswale would be the most effective green infiltration system to implement at this specific site. Three potential layouts of bioswales in the parking lot were evaluated, with the most appropriate solution involving the placement of four parking two stall sized and one linear bioswales on already existing parking spots that contain storm drains. Material choice, cost, and dimensions have been outlined. Recommendations regarding maintenance are also addressed.

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1. <u>INTRODUCTION</u>

Rapidly increasing urbanization has created a shift in the type of landscapes that surround us. On what was once a pristine natural ecosystem, urban areas now dominate and are primarily covered in concrete and other impervious materials, thus disrupting the natural hydrological cycle. Issues with the imperviousness of such areas are many, including stormwater runoff induced erosion and spreading of pollutants. These issues are predicted to worsen in the coming years with the increasing threat of climate change. Projected increases in intensity of rainfall events may cause significant stress on existing municipal sewer infrastructure. Therefore, there is a need to shift towards restoring the natural hydrological cycle in urban areas and improving the management of stormwater.

The goal of this report is to find a way to better prepare urban environments for climate change through the use of green infrastructure, which would increase the infiltration of stormwater and reduce excess runoff, thus mitigating some of the environmental issues we are faced with. The aim is to design a system that could achieve this goal within the context of a specific site. The site that has been chosen to be studied and used to plan the implementation of green infrastructure is the Plaza Pointe-Claire parking lot, which is a representative example of a large urban impervious area and is typical of suburban land planning.

This report serves to expand upon the concepts originally developed during the previous semester. Firstly, this report aims to provide a better understanding of the issues associated with the wide use of impervious pavements in urban areas. Next, a brief review of existing green infrastructure systems will be provided in order to later evaluate the most appropriate option for the studied site. An overview of the site itself will be undertaken in order to take its specific context into consideration for the design of the green infrastructure. Design alternatives will be discussed and evaluated, and the most viable option will be highlighted and further discussed. Novel items to this report includes an in depth description of the design process, including material selections, functionality calculations and considerations. The final design will then be discussed, along with its social, economic and environmental consequences, safety and maintenance requirements and a cost analysis. This analysis can hopefully provide a basis for such infiltration systems to be successfully implemented in the future.

2. <u>DESIGN OF URBAN PAVEMENTS AND THEIR ENVIRONMENTAL IMPACTS</u>

In densely populated cities, pavements are required to provide “a smooth, safe and stable platform for the movement of vehicles and pedestrians” (Sivakumar Babu et al., 2020). Pavement engineering has allowed for improved mobility, that otherwise would be greatly difficult as natural soils deform heavily under large loads (Sivakumar Babu et al., 2020). In order to assure that a pavement remains functional, durable, and strong over the long-term, it is imperative that hydrological factors, including surface and subsurface waters, be considered in their design and that precipitation be properly drained away (Mallick and El-Korchi, 2018). The different sources of water in pavements, summarized in figure 1, and their effects on the integrity of pavements are outlined below. Water penetrates a pavement's pores either from the surface, through precipitation as either snow or rain, or from the subsurface groundwater through capillary action and consequently compromises the structural integrity of its materials and mixtures (Mallick and El-Korchi, 2018). Furthermore, high moisture content or saturation of subsurface soils and aggregates can lead to large deformations in these layers and a consequent loss of support and shear strength (Mallick and El-Korchi, 2018). Repeated freeze-thaw events also largely contribute to the generation of stress within the pavement and soil layers, leading to cracking or heaving of the paving material (Mallick and El-Korchi, 2018). However, pavement drainage structures, which combine surface and subsurface drainage systems, displace incoming water through their collection, conveyance and discharge and help prevent a pavement's premature failure or degradation (Mallick and El-Korchi, 2018).

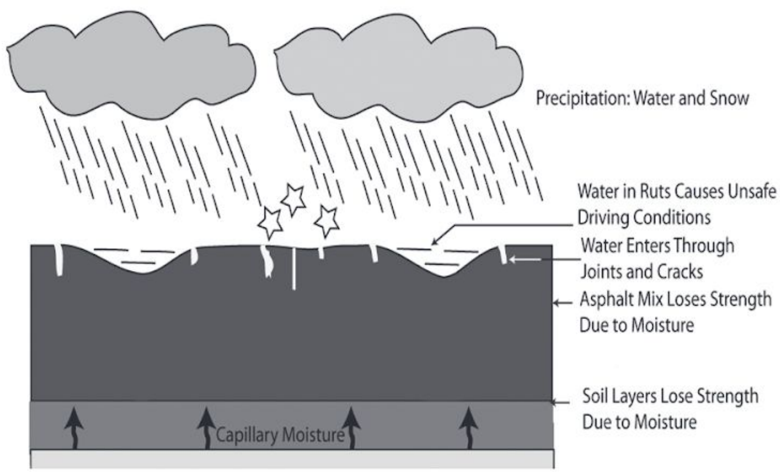

Figure 1. Sources of water in pavements. Source: Sivakumar Babu et al., 2020.

A surface drainage system involves adding a slope to the pavement, to efficiently convey water runoff to side drains or inlets, which then lead it to a closed or open storm drainage system (Sivakumar Babu et al., 2020). A storm drainage system, as seen in figure 2, must be properly sized to accommodate all inflows and can either directly transmit the captured water to a larger body of water or can undergo an intermediate treatment stage to avoid direct contamination of the larger water body (Sivakumar Babu et al., 2020). A subsurface drainage system consists of a series of perforated pipes underneath the surface layer of the pavement, surrounded by stones or wrapped in geotextiles that guide the water away from the pavement (Sivakumar Babu et al., 2020).

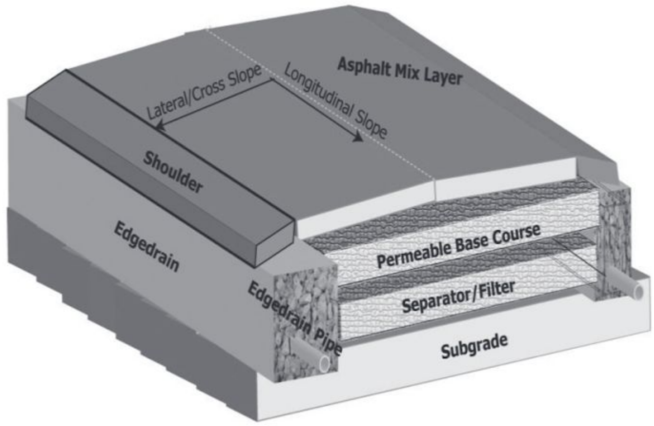

Figure 2. Surface slope and subsurface drainage layers. Source: Sivakumar Babu et al., 2020.

Typical pavements, including asphalt concrete and cement concrete, are "relatively impermeable, allowing precipitation to runoff much faster than it does from vegetated or undeveloped surfaces" (US DOT, 2017). Impervious pavements have a variety of environmental impacts and are largely responsible for the production of excess runoff in urban landscapes, the overflowing of storm and combined sewer systems, pollutant accumulation and pollution in freshwaters, the modification of normal groundwater recharge, and temperature increases through urban "heat islands" caused by a lack of shade quality and solar reflection, normally provided by natural vegetation (Ferguson, 2005). Furthermore, construction works equally disturb natural environmental cycles, as they lead to "compaction and dewatering of the infiltration pathways" (Seiler and Gat, 2007). Urbanization and development within a given watershed, characterized by important increases in hard surfaces, including pavement and rooftops, and large-scale construction projects alters the natural balance of the hydrological cycle, as seen in figure 3 (Donaldson, 2004).

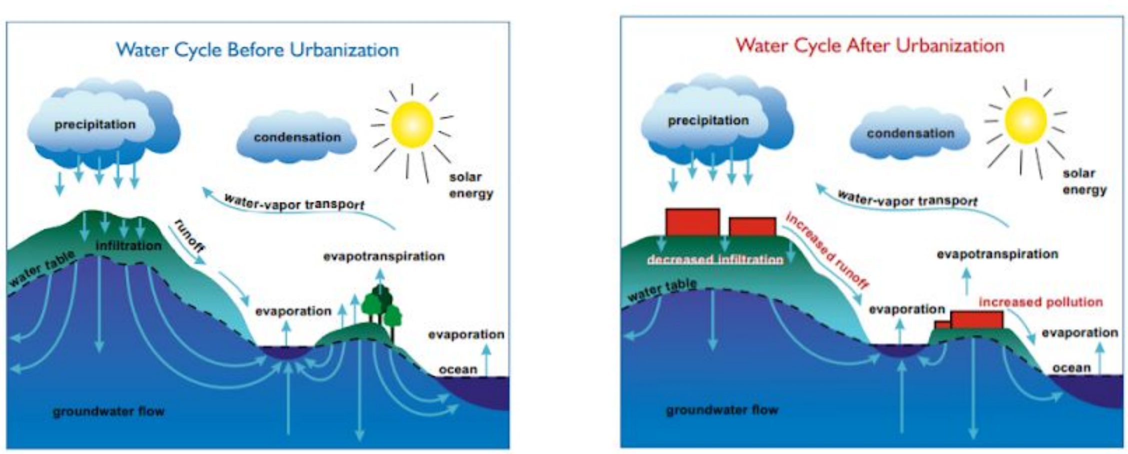

Figure 3. The water cycle before and after urbanization. Source: Donaldson, 2004.

2.1 INCREASED URBAN RUNOFF AND ITS EFFECTS

Developed and impermeable urban landscapes, unlike natural, vegetated and untouched landscapes, are not able to capture precipitation, and thus prevent stormwater from naturally infiltrating into and percolating through the soil system (US EPA, 1996). Infiltration is the process through which precipitation or surface water enters the soil, while percolation describes any movement of water through the soil, following infiltration (Seiler and Gat, 2007). A decrease in the ability of stormwater to infiltrate into the soil will directly translate to an increase in the amount of surface runoff (Donaldson, 2004). Consequently, as the water isn't allowed to infiltrate into the soil slowly and instead runs-off quickly, this leads to far greater peak flow rates that arrive sooner than normal and cause large magnitude urban flood events (US EPA, 1996, Donaldson, 2004).

2.2 POLLUTANT LOAD IN URBAN RUNOFF

Urban sources of pollution are classified into two distinct, broad categories: point or discrete sources and nonpoint or diffuse sources (National Research Council, 2000). Point sources of pollution are known, easily detectable pollutant sources, typically allowed by discharge permits (National Research Council, 2000). Nonpoint sources of pollution are those that are "widely dispersed in the environment" and include agricultural, residential and commercial developments and atmospheric depositions in rainfall and snowmelt (National Research Council, 2000, Donaldson, 2004). Urban stormwater is a critical nonpoint source of pollution, whose primary pollutant is organic carbon compounds, typically hydrocarbons (National Research Council, 2000, Ferguson, 2005). Petroleum products, including oil, grease and chemicals released into the environment from road vehicles, contain toxic hydrocarbons that are transported to larger catchment basins by urban runoff over impermeable pavements (US EPA, 1996). Another nonpoint source of pollution are paved, road surfaces and construction projects, which pollute receiving water bodies by increasing turbidity and total suspended solids (National Research Council, 2000).

Fertilizers and nutrients, applied to gardens and lawns within the urban area, can bring about nutrient enrichment in receiving water bodies, promoting the growth of undesirable algal communities and damage water quality (Torno et al., 1986, US EPA, 1996). Salt, applied to roadways and parking lots to control ice in winter, leads to the contamination of receiving water bodies with sodium and chloride ions (Torno et al., 1986). Furthermore, newly introduced salt ions in freshwater ecosystems can equally lead to abnormal increases in pH, unanticipated shifts in ecological communities, growth of blue-green algae and reduce water quality for industrial applications and human consumption (Torno et al., 1986).

2.3 GROUNDWATER RECHARGE AND CONTAMINATION

In general, the net effects of urbanization on groundwater recharge are difficult to determine, as they largely vary depending on the specific hydrological conditions in a given urban watershed (Barrett, 2004).The increased amounts of polluted runoff, generated due to extensive impervious, paved surfaces and reduced direct infiltration rates, drastically increase the volume of stormwater captured by drainage systems and either directed to treatment plants or directly into receiving waterways (France, 2002, Barrett, 2004). Their overall net impact could range anywhere from major reductions in local groundwater levels to perhaps even modest increases (Barrett, 2004). In order to achieve a good understanding of how urban development affects groundwater recharge in a localized area, it is critical to accurately quantify each component of aquifer recharge (Barrett, 2004). “This process is, however, extremely complex” (Barrett, 2004). Three important sources of groundwater recharge, common to most urbanized watersheds, are water main leaks, storm and sanitary sewer leaks and over-irrigation of parks and gardens, as seen in figure 4 (Lerner, 1990). In fact, hardly any water authorities are able “to reduce leakage [of water supply networks] below 10% of supply, and rates of 50% have been reported” (Lerner, 1990).

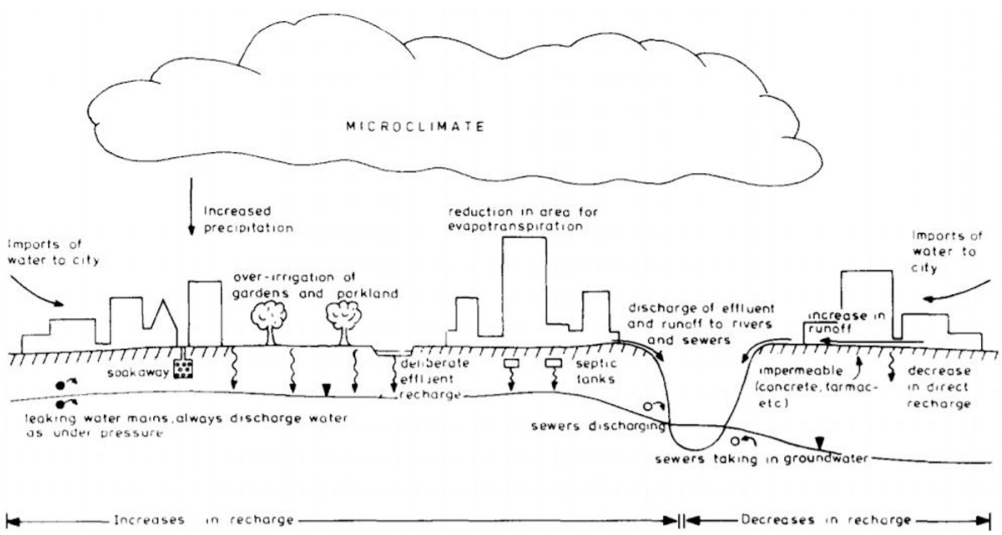

Figure 4. Urban effects on groundwater recharge. Source: Lerner, 1990.

The pollutant loads present in urban runoff, including inorganic salt and metal ions and synthetic and volatile organic chemicals from petroleum products, equally threaten groundwater quality in urban developments and consequently the health of its inhabitants (Zhang et al., 2004). It has been found that the sandstone aquifer below the urban center in Birmingham, England and the alluvial aquifer in Milan, Italy are largely contaminated with chlorinated hydrocarbon solvents, while the groundwater below Milwaukee, Wisconsin is largely polluted with Cl^-, a salt ion introduced into the environment in winter (Lerner, 1990).

2.4 THE URBAN HEAT ISLAND EFFECT

Heat islands, as defined by the United States Environmental Protection Agency, emerge in largely developed, urban areas and are characterized by air and surface temperatures that are considerably higher than other undeveloped, rural, natural areas, as seen in figure 5 (2003a). The exponential loss of vegatative cover, ever-increasing application of paving materials and constant flux of human activity in largely developed areas has given rise to larger, more intense urban heat islands, driving significant changes in urban climate and intensifying urban environmental degradation and ecological footprint (Akbari and Kolokotsa, 2016). Unshaded, dry pavement and roof surfaces with low solar reflectance, characteristic of urban areas, will absorb large amounts of solar radiation incident upon them, and transfer nearly 50% of that heat energy convectively to the ambient air, leading to generally higher air temperatures and upsetting the thermal balance in cities (Akbari and Kolokotsa, 2016). Furthermore, the heat island effect leads to the formation of urban microclimates, characterized by uncharacteristically intense precipitation events (Seiler and Gat, 2007). During the summer months, to combat the extreme, intensified heat in urban centers, energy consumption for cooling and electricity demand spike (Akbari and Kolokotsa, 2016). In turn, this leads to widespread discomfort, as health conditions worsen and mortality rates increase, while also contributing to the emission of high concentrations of ozone, carbon dioxide and volatile organic carbons into the air (Akbari and Kolokotsa, 2016). However, it is now recognized that efforts to reduce the urban heat island effect could effectively result in a "peak utility savings of 5 to 10%" (Swanson and Hobbs, 2014). To counteract the effects of urban heat islands, the use of construction materials with higher solar reflectance and greater thermal emittance, termed "cool materials" and efforts to revegetate urban spaces to increase evapotranspiration rates are currently the most popular mitigation techniques (Akbari and Kolokotsa, 2016). Increased urban vegetation not only has beneficial psychological effects on people, but through the process of evapotranspiration, wherein plants draw "heat from the air to convert water in the leaf structure to water vapor" combat undesirable microclimates in large urban developments (Hoyano, 1988, US EPA, 2003b).

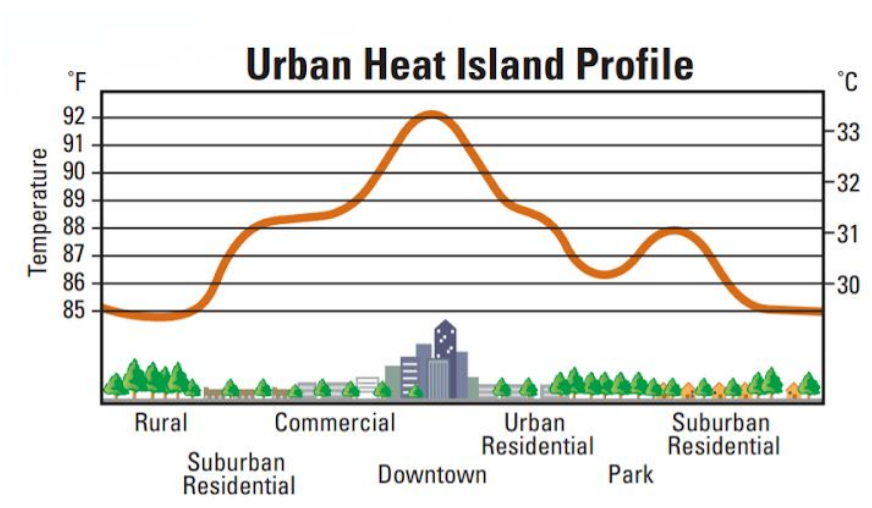

Figure 5. Urban heat island profile. Source: US EPA, 2003a.

3. <u>GREEN INFRASTRUCTURE</u>

As described in Sections 2.1.1 to 2.1.4, the issues associated with widely used impermeable pavements in urban environments are numerous. The following sections highlight and exemplify some existing systems and practices that aid to mitigate some of these issues.

This is primarily done through the implementation of what is commonly referred to as “green infrastructure”, which is infrastructure designed specifically to minimize negative environmental impacts by managing water in a manner that mimics natural water cycles. The following sections will focus on systems that aim to increase and improve infiltration in an urban setting.

3.1 PASSIVE STORMWATER CATCHMENT TECHNIQUES

Kinkade-Levario describes several techniques in her review of passive stormwater catchment methods that aim to mitigate these issues associated with commonly impervious pavements. This includes methods that serve to catch the excess stormwater accumulation and have it infiltrate into the natural landscape rather than simply runoff and be sent to the municipal stormwater collection system. Such techniques include the implementation of “micro basins, swales, French drains, rain gardens, permeable pavements, and curb and road grading design” (Kinkade-Levario, 2007).

Micro basins are typically small green areas dedicated to the catchment of water, such as tree wells or planter islands, which serve to slow stormwater runoff and increase infiltration (Kinkade-Levario, 2007). Rain gardens behave similarly but are typically found over larger areas of vegetation where there is a naturally forming depression. Layers of compost and mulch act as a sponge to absorb runoff from roofs or paved surfaces. Microbial activity in the layers also serves to break down hydrocarbons and the plants can uptake other contaminants which ultimately serves to purify the water.

Similarly, swales also serve to slow runoff and increase infiltration. Generally, they can be described as sloping trenches of varying sizes, often placed next to sidewalks and driveways (Kinkade-Levario, 2007). French drains however are designed to infiltrate water quickly and are filled with gravel in order for water to easily percolate through (Kinkade-Levario, 2007).

Bioswales, or bioretention swales, follow a similar design than that of a typical swale however tend to slow the flow of runoff better due to a higher concentration of vegetation (Pazwash, 2016). A layer of sand may be included at the bottom layer of the bioswale to increase infiltration (Pazwash, 2016). The dense vegetation also serves to remove pollutants from the infiltrating water (Pazwash, 2016). Common applications of bioswales include parking lot islands, which allows for infiltration to occur where there may typically be none (Pazwash, 2016).

Site grading and curb design is also an important factor to take into consideration when designing green infiltration systems. The slope of the land is key in guiding the stormwater runoff to such locations to be infiltrated as opposed to a storm drain. For designing curbs, cuts can be included in order to allow the stormwater to enter the particular system (Kinkade-Levario, 2007).

3.2 PORTLAND'S GREEN STREETS PROGRAM

One notable example of green infrastructure implementation includes the case study highlighting the City of Portland's method for managing stormwater (Kinkade-Levario, 2007). In their Green Streets program, Portland has implemented a series of planters that are specifically designed to take in received stormwater runoff from the city's streets. The goal of these planters is to slow down the inflow of runoff and ultimately have it infiltrate through the vegetation and soil (Kinkade-Levario, 2007). Excess stormwater travels down slope from one planter to the next to infiltrate slowly along the way. Any remaining excess stormwater enters a storm drain at the end of the series of planters in a much cleaner state and in much lower quantities (Kinkade-Levario, 2007). This reduces the amount of water and pollutants leaving the site (Kinkade-Levario, 2007) and improves the overall efficiency of the city's existing pipe infrastructure by reducing sewer backups and overflows (City of Portland, 2019). This project also highlights the importance of integrating the management of stormwater in the design of new buildings, landscapes and site developments (Kinkade-Levario, 2007).

3.3 POROUS PAVEMENTS

An alternative method of stormwater infiltration is through the use of porous pavements. Porous pavements, which have "built-in networks of void spaces" allow water, air and heat to enter the subsurface soil layers, as opposed to traditionally impervious pavements (Ferguson, 2005). There are a variety of different kinds of porous pavements including open cell paving grids, porous asphalt and pervious concrete (Pazwash, 2016). A reduction of finer aggregates which are typically used in pavements recipes is what generally increases the permeability of porous pavements (Pazwash, 2016). Parking lots are one of the well suited applications of porous asphalt and pervious concrete since it allows for infiltration to occur over an otherwise completely impervious material.

Contrary to common belief, the functionality of porous asphalt and pervious concrete is not reduced in colder climate conditions such as in Canada (Pazwash, 2016). By allowing runoff to infiltrate there is a lower chance of the formation of ice (Pazwash, 2016). Additionally, during freezing conditions, the pavement does not tend to freeze completely solid which continues to allow for water to percolate (Pazwash, 2016). The need for salt application is also significantly reduced with the use of porous pavements which can help lower the rate of water pollution due to salt application and reduce overall maintenance costs (Pazwash, 2016). Evidently, the use of porous pavements can be very beneficial when used in parking lots.

3.4 FILTERRA BIORETENTION SYSTEM

Another system commonly used in parking lots and curb sides are bioretention cells, which serve to remove pollutants from stormwater runoff (Pazwash, 2016). The Filterra® Bioretention System, as seen in figure B-2 in the appendix B, is an example of such a system. The system involves a concrete box filled with soil media containing plants or a tree and a layer of mulch at the surface (Stormwater360, 2019). Through a series of chemical and biological processes, this system effectively removes a variety of pollutants “such as total suspended solids, phosphorus, nitrogen, metals, oil and grease” (Stormwater360, 2019). The filtered water then flows to an underdrain and flows through pipes to a discharge point (Stormwater360, 2019).

4. DESCRIPTION OF SITE

The City of Pointe-Claire, a suburb of Greater Montreal, is highly residentially developed, but also the site of important economic activities (Pointe-Claire, 2019a). Its ideal location, with access to Highway 20 and 40, Pierre-Elliott Trudeau International Airport and along the Canadian National and Canadian Pacific railway lines, make it especially well-suited for both commercial and industrial business in the West Island (Pointe-Claire, 2017). It features three commercial strips and a variety of different shopping centers, including Fairview Mall, Complexe Pointe-Claire, Centre Terrarium, Plaza Pointe-Claire, Mégacentre des Sources and Promenades Pointe-Claire (Pointe-Claire, 2017). It has a total population of 31,380 people with a population density of 1,660 people per square kilometer (Statistics Canada, 2016). A map of the region can be found in appendix A of this report.

The City of Pointe-Claire has developed a Policy on Sustainable Development, along with a Climate Change Action Plan, to better guide the actions of municipal, community and external stakeholders (Pointe-Claire, 2019c). An important and recurring action in their Climate Change Action Plan, with the goal of reducing heat islands, retaining and recapturing rainwater, reducing presence of impervious surfaces and increasing plant cover, is to “regulate sustainable design of parking spaces” through the reanalysis of by-laws (Pointe-Claire, 2015). Furthermore, the City of Pointe-Claire encourages that all stormwater retention systems in new constructions be designed according to maximum runoff flow rate criteria to better retain and capture rainwaters (Pointe-Claire, 2015). Pointe-Claire equally prioritizes the use of novel, permeable surfacing materials and the replanting of trees, perennial plants and shrubs (Pointe-Claire, 2015).

Plaza Pointe-Claire, located in the district of Lakeside Heights, is a large shopping complex with 88 stores. It is an important center featuring a variety of stores that customers come to everyday. The component of the Plaza being studied is its main parking lot (a top view photograph of which can be found in figure A-2 in the appendices section). Most notably, the lot is primarily covered with impervious pavement, allowing for very little infiltration of stormwater. The main lot has 8 sewer drains which serve to manage stormwater, as highlighted in figure A-2 (see appendix A). There are very few areas of vegetation present, making it a typical example of an urbanized landscape. By carefully observing the condition of the current site, it became possible to develop a plan for the installation of a green infiltration system.

4.1 STANDARDS AND BY-LAWS

When incorporating a new infiltration system into an already existing site, such as the Pointe-Claire Plaza parking lot, it is important to be familiar with any relevant zoning regulations related to the site as well as any applicable standards. This ensures that the engineers will be able to produce a structurally and legally sound design.

4.1.1 STANDARDS

The standard entitled S413-14 Parking structures (R2019) from the Canadian Standards Association (CSA group) provides an in depth guide for the creation of new parking structures as well as surrounding pedestrian areas. Details include minimum design requirements, maintenance requirements and prevention methods for the corrosion of concrete and metal elements as well as flooding (CSA, 2019).

Many standards are also available for the design of barrier curbs, a useful element to be included in a parking lot, such as the Pointe-Claire Plaza's. For instance, an Ontario Provincial Standard Drawing entitled OPSD 600.110 Concrete Barrier Curb demonstrates that the thickness of the standard curb should fall between 150 and 250 mm (OPSD, 2012). This is useful information which can be applied for the design of green infrastructure in a parking lot. However, a set-size curb material is being considered for this project as an alternative to concrete. If cost prohibitive, the use of concrete can greatly decrease the cost of materials at the cost of increasing the environmental impact of construction.

4.1.2 ZONING BY-LAWS

The City of Pointe-Claire enforces a set of zoning by-laws that are available to read on the city's website. This section summarizes the zoning by-laws of notable relevance particularly to the design of an infiltration system for a parking lot. The complete articles being referenced can be found in appendix C.

Firstly, article 7.4 describes the minimum parking space dimension requirements for spaces perpendicular to the circulation of traffic (as is the case of the existing layout of the Plaza's parking lot), stating that they must be at least 2.7 m wide and 5.5 m long. In addition, the circulation aisles must be at least 6 m for one way circulation and 6.6 m for two way circulation. Article 7.5 states that concrete curbs must be present at a distance of at least 60 cm from the adjacent lot lines and be 15 cm in height. Curb openings can be present to allow for the proper drainage of water (City of Pointe-Claire, 2019).

Article 7.5 also lists the materials that can be used to cover parking areas. While asphalt, concrete or brick is commonly used, porous pavements and materials with high solar reflectance index may also be used. The lot must also include a cover of at least 10% vegetation (or 5% vegetation if the lot is made of porous pavements or has a high solar reflectance index). There must also be a sufficient rainwater drainage system implemented for the lot (City of Pointe-Claire, 2019).

Any lot must also contain a border or median strip which is either a grassy or otherwise landscaped area that contains trees planted at every 8 meters. It should be noted however that there are several prohibited species of trees that are listed in article 9.6.2. (City of Pointe-Claire, 2019).

The number of parking spots required is outlined in article 7.6. In the case of a shopping centre, there must be at least one space for every 20 square meters of rental floor area of the centre (City of Pointe-Claire, 2019).

4.2 CONSTRAINTS OF LOCATION

The Pointe-Claire Plaza has grown a certain familiarity and history amongst its visitors since opening in 1956, which inherently creates an additional design constraint when it comes to making changes to its existing landscape. Any new construction should receive positive feedback from existing customers in order to keep the existing clientele of the plaza satisfied with the redesign. This constraint is not only in regards to aesthetics and history but safety as well, since any change in traffic signalization results in a greater risk for automobile accidents by those accustomed to the current layout. The proposed design must not deviate from the existing traffic design, and must provide even clearer directions for traffic than the original design of the lot, which has remained essentially the same since the Plaza's opening. The mall has a variety of stores including a grocery store, all of which are dependent on customers being able to easily park and shop. In figure A-2 (see appendix A), some of the following can be observed: west of the mall there are single detached dwellings as well as a cemetary, south of the mall there is the railroad and highway 20, east of the mall there are a number of retirement residences (which provide a large customer base) and the Pointe-Claire public works, and finally to the north there is the police and fire station, the townhall and the library. Based on the crowded surroundings of the location, there is no convenient location for shoppers to park and easily access the Plaza other than on-site. This causes a constraint for the reconstruction of the parking lot since it cannot be temporarily closed, especially the north section closest to the popular grocery store due to the predicted client dissatisfaction of having to transport purchases a considerable distance to their vehicles. These seemingly small issues play a big role in determining the best design for this particular problem.

5. DESIGN TYPE AND PLACEMENT SELECTION

Despite the wide variety of options in green infrastructure, most of which can be used in combination to cover a large area like the Pointe-Claire Plaza parking lot, the constraints that are posed by the nature of the project's location render many of these options impractical or not feasible.

5.1 SELECTION OF INFRASTRUCTURE TYPE

To begin, porous pavement, as described in section 3.3 provides a surface for both infiltration and car mobility. However, in the case of the Pointe-Claire Plaza parking lot, this option interferes with the constraint discussed in section 5.2, since it would require the closure of a large portion of the parking lot in order to prevent a lengthy construction time. Due to this construction time and the nature of the construction (excavation followed by repaving), porous pavement is not economically ideal for the location, nor socially since it creates inconvenience during construction and little visible benefit to clientele.

Another solution that has been surveyed is that of rain gardens (section 3.1), which are commonly used in small scale systems. Rain gardens offer a visually pleasing and natural solution for water infiltration. Due to the natural aspect of the rain garden, their effectiveness per unit of area is reduced compared to more engineered systems, making them too large to fit into the parking lot. As mentioned, one of the constraints of the location is the minimum allowable number of parking spots, meaning that rain gardens would likely be impossible or very challenging to implement effectively.

Finally, bioswales propose an important alternative to the rain garden, since it is a similar system but allows for greater infiltration via the use of engineered soil layers. Unlike rain gardens, this improved efficiency allows them to be quite small while still allowing useful infiltration rates for a large drainage area as is seen in the Pointe-Claire Plaza parking lot. This system also allows for the flexibility of shape and location that is not present with porous pavements, and allows for more localized construction.

5.2 PLACEMENT OF INFRASTRUCTURE

When it comes to the positioning of the green infrastructure, which has been determined to be a bioswale, an extremely wide variety of options are available due to the flexible size and shape of the system. All proposed placements are placed atop of existing sewer drains because this limits the need for excessive construction. Since the current paving of the parking lot slopes towards these sewers, the proposed positioning prevents the need to repave and reslope the current lot, which makes this solution economically, socially, and environmentally positive. Nonetheless, the placement of the bioswales atop the current sewer drains can be done in multiple ways, three of which are presented below. It is important to note that the auxiliary parking lot which is seen at the bottom right of figure A-2 (see appendix A) will be disregarded in this project, however the unitary design of bioswales will allow for further expansion when and where appropriate.

Option 1 consists of using swales the size of one to two parking spaces and placing the swales on every rainwater sewer drain in the main lot. identified here with green arrows. This option will allow for the current sloping of the parking lot to be used, working around the location’s constraints. Due to three of the sewer drains being within the thoroughfare, these paths will have to be converted to one-way traffic to accommodate the blocking of a section of the road as shown in the figure below. One exception to the typical bioswale size is to be noted in the north of the parking lot, or right side of figure 6, where the swale would be elongated along the single row of parking spots.

Figure 6. Parking layout of design option 1, the green arrows indicating existing sewer drain and green rectangles indicating the proposed size and position of bioswales. Source: Google Earth

Option 2 is essentially the same as the previous option with the addition of disregard for the sewer drains which are not atop of parking spots. This option prevents any change of traffic signalization within the parking lot and still covers most of the parking lot's drainage area. A rough estimate shows 12 000 square meters of paved surface draining into the 5 bioswales which would be installed in parking spots which include a sewer drain within them.

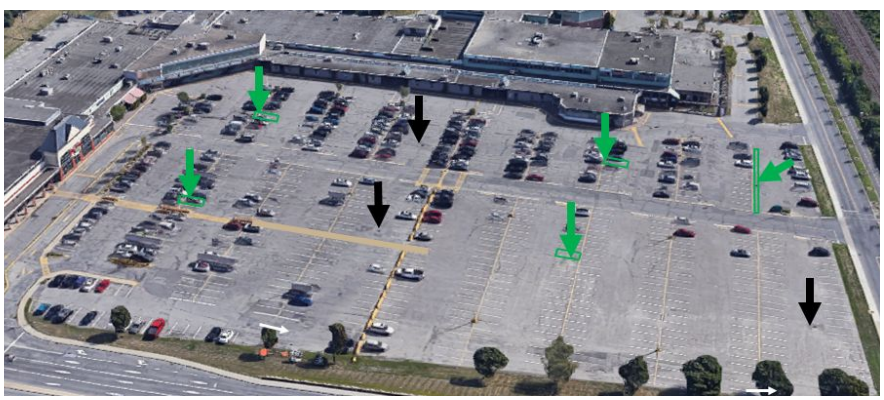

Figure 7. Parking layout of design option 2, the green arrows indicate the location of sewer drains which are proposed to have a bioswale built around them while the black arrows are the drains which are proposed to be left as is. The size of the bioswales are outlined by green rectangles. Source: Google Earth

Option 3 entails placing long swales along the north to south direction, between parking rows. This requires the complete remake of the current parking lot layout, but greatly increased the amount of greenery which would be incorporated into the parking lot. It would potentially create a more cohesive parking lot for customers as well. Two of the sewer drains, highlighted in yellow in figure 8, will not fit into the design shown, meaning they will either be left outside of the green infrastructure or will require the resloping of the existing pavement.

Figure 8. Parking layout of design option 3, the green arrows indicate the location of sewer drains which are proposed to be built into linear bioswales, the yellow arrows point at sewers which do not fall within these swales. Source: Google Earth

To evaluate the three placement options identified, a Pugh chart was created. This chart allowed us to weigh the options based on the same criteria and choose the best one for the criteria of our project.

Table 1. Pugh chart evaluation 3 placement options of bioswales throughout parking lot

			Option 1 All Single Bioswales		**Option 2** Most Single Bioswales		**Option 3** Linear Bioswales	
Criteria	**Weight Factor**	**Baseline**	Rating	Weight	Rating	Weight	Rating	Weight
Social								
Construction	2	0	-1	-2	-1	-2	-2	-4
Aesthetics	1	0	+1	1	+1	1	+1	1
Safety & Accustomation	3	0	0	0	+1	3	-1	-3
Environmental								
Construction emissions	1	0	-1	-1	-1	-1	-2	-2
Carbon sequestration	2	0	+1	2	+1	2	+2	4
Infiltration capacity	3	0	+1	3	+1	3	+2	6
Economic								
Upfront cost	2	0	+1	2	+1	2	-1	-2
Maintenance cost	2	0	-1	-2	0	0	-1	-2
SCORE		0		**3**		**8**		**-2**

5.3 PROPOSED SOLUTION / RECOMMENDATIONS

After a thorough analysis and evaluation of the proposed placements of the bioswale, it was determined that the most appropriate solution would be option 2, which consists of a single unit bioswale placed above existing parking spaces that already have sewers on them. It received the highest positive rating when analysed using the Pugh chart method. It held up well compared to the other options as it posed the least amount of safety concern due to none of the existing thoroughfares being blocked. Additionally, little redesign of the lot would be needed seeing as the single unit bioswales would only occupy existing parking spaces, thus minimizing capital cost. With appropriate placement design, the infiltration capacity can still be significant and have positive environmental impacts, which would fulfill the initial requirements of this project.

6. <u>DESIGN PROCESS</u>

6.1 IDENTIFYING THE PRIMARY DESIGN CONSTRAINTS AND CONSIDERATIONS

Following a thorough analysis of a variety of different green stormwater infiltration systems, a number of important design constraints, specific to the Pointe-Claire Plaza location were identified. The design constraints, carefully outlined and briefly explained in figure 9, represent the principal functional requirements expected in the final engineering design submitted. The more technical design constraints, that if not carefully addressed in the design could represent significant barriers to the successful implementation of the system, are further developed in the section below.

Figure 9. Identified primary design constraints and functional requirements, specific to the Pointe-Claire Plaza design location.

6.1.1 STRESSFUL PLANT CONDITIONS

A critical component in the proper functioning of green infrastructure is the composition of its plant communities; however, very little emphasis is placed on this design component as historically it has primarily been based solely on aesthetics (Cameron and Blanuša, 2016). Selecting appropriate plant communities, based on more than just aesthetics, is absolutely essential in providing the optimum, locally relevant and functional ecosystem services (Cameron and Blanuša, 2016). These functional plant ecosystem services broadly include supporting soils, nutrient and water cycling, provisioning food, fiber and fuel, regulating air quality, water quality and climate. The ideal plant community design must incorporate plants that are multifunctional and that complement each other well, while minimizing plant disservices (Cameron and

Blanuša, 2016). Typically, plants chosen for green infrastructure must require “little fertilizer, irrigation, pesticides and pruning” (Dyke, 2011).

Previously, it was recommended to solely use native plant species in urban green infrastructure, as risks of non-native, invasive species driving out native flora and fauna were and remain relevant (Cameron and Blanuša, 2016). Furthermore, it is also suggested that native plants are “better adapted to local climatic conditions than non-native plants” (Dyke, 2011). However, it has been readily shown that certain beneficial inter-relationships can exist between specific native and non-native plant species (Cameron and Blanuša, 2016). The benefits to native plants may include, but are not limited to, the provision of nectar and pollen to their pollinators or strengthening the establishment of perennial native crops, acting as annual, nurse crops (Cameron and Blanuša, 2016). Perennial plants are often used in green infrastructure as opposed to annual plants, however the higher evapotranspiration rates and low maintenance requirements of trees and shrubs perhaps make them a better option (Dyke, 2011).

Furthermore, urban vegetation, if advantageously placed in hydrological flow pathways, can help manage stormwater flooding (Cameron and Blanuša, 2016). Older, larger, heavily branched trees with rough, grooved bark and either fine-textured, needle-like canopies or broad leaf size are better suited to retaining and storing water, as is observed in figure 10 (Cameron and Blanuša, 2016). Structural differences in smaller plant species greatly affect their ability to retain water within their tissues; it has been found that grasses and forbs are better suited than succulents (Cameron and Blanuša, 2016). A plant’s evapotranspiration rate, which dictates a plant’s ability to get rid of stored water, must be high to quickly dry the plant tissues and reestablish adequate storage capacity (Cameron and Blanuša, 2016).

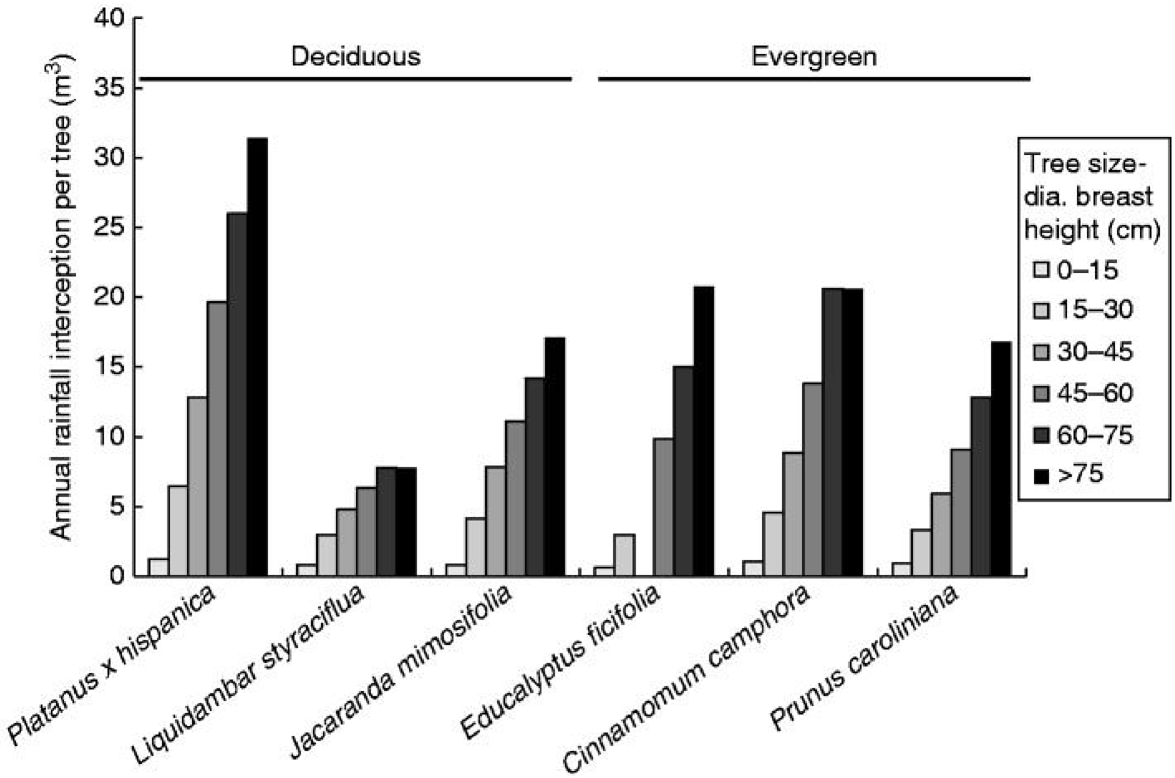

Figure 10. Tree size and character (leaf/branch habit and duration of leaf retention) affect rainfall interception. Larger trees (increasing diameter at breast height) capture more rainfall, but also note differences between deciduous species. Source: Cameron and Blanuša, 2016.

Certain plant species are equally recognized for their ability to phytoremediate highly-contaminated soils, filter out aerial particulates and pollutants in stormwater runoff (Cameron and Blanuša, 2016). Leaf structure was identified as an important factor to consider when assessing a plant's ability to filter out aerial particulates emitted by motor vehicles along roadways (Cameron and Blanuša, 2016). In a study of typical green roof vegetation, grasses with their "complex canopy structures which reduce near-surface air flow and increase deposition rates" and their parallel leaf venation that effectively traps particles were better suited at filtering the air than broad-leaved plants or succulents (Cameron and Blanuša, 2016).

In summary, the characteristics that make certain plant species better suited to green infrastructure projects are the ability to assimilate toxins and pollutants in their tissues, continued productivity and seed germination under conditions of heavy sediment deposition, fertilizer and nutrient retention, non-invasiveness, salt-tolerance, and the ability to survive periods of successive droughts and floods (Shaw et al., 2003). A plant species that has been identified as a good candidate for use in urban green infrastructure, due to its tolerance for high salinity, is *Solidago sempervirens*, commonly known as seaside goldenrod (Vizachero, 2013). *Solidago sempervirens* is a perennial, salt-tolerant, drought tolerant plant that can tolerate standing water, grow moderately fast and flourish in medium to infertile soils (DNR, 2019; USDA, 2019c). *Solidago sempervirens* is also native to southern Quebec and "its bright yellow flowers provide an attractive contrast to its lush, thick, green vegetation" (USDA, 2019c). Furthermore, utilizing urban trees in a green stormwater infiltration unit has been proven to help better manage large water inflows, as their roots and leaf area absorb important quantities of water (Delta Institute, 2017).

6.1.2 SOIL DRAINAGE AND STABILITY

To minimize the risk of flooding, the excess runoff generated from large expanses of impervious surfaces must infiltrate into the soil quickly (DWER WA, 2005). However, in order for urban contaminants to be properly filtered and adsorbed by the soil, the water must not infiltrate into the soil too quickly (SSSA, 2019). Furthermore, in order for the smaller plants and urban trees to survive and perform their important ecosystem services in green infiltration systems, there must be a sufficient amount of quality planting soil to support advantageous and prolific root expansion (Delta Institute, 2017).

Different soil profiles can be utilized based on specific site conditions, but a well-engineered soil mix must universally perform three essential tasks, namely infiltrate water quickly but not too quickly, resist compaction, and retain a sufficient amount of water and nutrients to support plant life (SSSA, 2019). Soil profiles for green infiltration systems typically rely on a combination of principal materials, namely gravel, sand, compost and topsoil, and some other small additives (Delta Institute, 2017). Sand and gravel, the primary components of most soil mixes, are not as well-equipped to remove contaminants, like metals and nutrients, from infiltrated surface waters or to store those waters, due to their characteristically low cation exchange capacity and large pore space, respectively (SSSA, 2019). Sand and gravel's primary function in any green infiltration system is to help in the quick drainage of the engineered soil, and typically coarser sands with larger grains are favored as they do not readily clog pores and have better control over drainage speed (SSSA, 2019). Compost, the second primary component of a good mix, is characterized by large, chemically and biologically active molecules, that are especially well-suited to the removal of metals, nutrients and organic chemicals from the infiltrated surface waters (SSSA, 2019). Topsoils with low clay content serve as an important media for the growth of plants, with their larger particles that can retain nutrients, metals and water for use by plants (SSSA, 2019). Wood chips are normally only used as soil amendments, as they are acidic and if overapplied, could lower soil pH and consequently reduce the soil's ability to hold contaminants (SSSA, 2019). However, in appropriate quantities, wood chips can adjust the carbon-to-nitrogen ratio to help minimize nutrient leaching into groundwater resources, can protect the exposed soil layer from erosion, all the while helping to retain water in the soil during periods of drought (SSSA, 2019). It has equally been suggested that recycling active treatment residuals from wastewater treatment plants, including aluminum and iron oxides, could also serve to absorb contaminants, including metals, nitrates and phosphates (SSSA, 2019). Any engineered soil profile "should be verified by materials testing prior to its placement" to ensure it will perform adequately and to prove due-diligence (Delta Institute, 2017).

6.1.3 SEASONAL CONDITIONS

The application of green infrastructure for stormwater infiltration in northern, cold climates with harsh winters is a point of contention, as the ability of such systems to function in winter due to the inactivity of bacteria and plants is regularly called into question (Shaw et al., 2003). These concerns are valid, as cold, winter weather has been shown, through a variety of different studies, to lead to functional changes in green infrastructure, primarily due to "decreased evapotranspiration at lower temperatures, reduced plant water uptake, and reduced infiltration into frozen soil" (Driscoll et al., 2015). That being said, it is important to note that across each of these studies there was a considerable amount of variability in the actual reduction of performance and that our ability to predict how effectively a piece of green infrastructure will perform in diverse seasonal conditions is poor (Driscoll et al., 2015). In bioretention cells installed in parking lots, it has been observed that "snow removal from parking areas has the potential to markedly improve winter performance" (Driscoll et al., 2015). Furthermore, in order to improve infiltration in the system during winter, no snow should be piled onto it and any large deposits of snow or ice that accumulate in the infiltration basin or on the manhole cover should be cleared (US EPA, 2013). It is equally advised to educate those responsible for maintenance of the parking lot about "proper application techniques to reduce over-application" of road salt and sand in winter (Mackenbach, 2017). Furthermore, the use of other substances to manage ice formation in the parking lot can be examined, for example a liquid de-icer mix of magnesium chloride (US EPA, 2013). As a whole, in order to minimize issues related to the poor functioning of green infrastructure in winter, it is critical to fully understand the climatic and soil conditions in the specific design location and to develop a realistic operation and maintenance plan (Mackenbach, 2017).

6.1.4 PERFORMANCE, MAINTENANCE AND OPERATION

Green infiltration systems in parking lots not only require targeted maintenance in the winter to ensure they remain operational, but they equally require regular maintenance in the warmer months to ensure they maintain optimal performance efficiencies (Delta Institute, 2017). These maintenance operations may include the removal of collected debris, litter and large sediment from the pretreatment zone, weeding, trimming and occasional watering to allow for plant establishment or to prevent plant desiccation during periods of extreme drought (Delta Institute, 2017). In the Quebec's government manual for the management of stormwater, the importance of including a pretreatment component in an infiltration system is highlighted (MDDEFP and MAMROT, 2019). These pretreatment systems reduce peak runoff velocities, thus allowing the settling and filtration of large particles, litter and debris and acting to minimize clogging of the soil pores and ultimately the maintenance costs associated with the system (PWD, 2018). Finally, seeing as the infiltration system equally acts to filter out urban pollutants through bioaccumulation in the plant tissues, harvesting and safe disposal of the contaminated plant tissues will be required at set intervals.

6.1.5 CONSTRUCTION

The successful construction of a green stormwater infiltration system involves effective communication between and coordination of many different key players, namely between the design engineer and contractor (Delta Institute, 2017). To ensure the success of the infiltration unit, mitigation efforts must be undertaken to minimize the effects of sediment transport and compaction during installation operations, as these actions could potentially lead to clogging of the soil's pores and a consequent poor infiltration rate (Delta Institute, 2017). As such, it is strongly recommended that after the contractor removes the desired section of impermeable surfacing from the lot and digs out the hole for the engineered soil, that they take the opportunity to thoroughly rake or rototill the first six inches of native soil that will remain below the engineered soil to counteract the effects of compaction and clogging (Delta Institute, 2017). Also, the use of construction machinery can lead to heavy compaction, and therefore the operators must take care not to drive over the infiltration area.

6.2 PRELIMINARY DESIGN

A preliminary design of the single unit bioswale was then formed. Using the concepts reviewed in Section 3, an infiltration unit with distinct functional layers was designed within the context of the study site. In this preliminary and rough design, it was estimated that the bioswale would occupy one parking space, placed strategically in the parking lot to take advantage of the existing stormwater sewer drains. No exact dimensions had been decided on for the preliminary bioswale design depicted below in Figure 11, as these precise components were to be discussed in more depth after a site visit and after performing in-depth calculations. However, as a start, it was decided that the swale would be surrounded by a border, which would ensure a distinct boundary between the paved surface and the infiltration bed. The addition of this border would ultimately prevent potential harm to the vegetation within the swale from people, cars or plows. The border would have indentations that would allow runoff from the surrounding pavement to make its way into the infiltration bed. The border, due to cost considerations, would likely be made of Portland cement concrete. However, other more eco-friendly alternatives were equally being looked into. Upon entry into the swale, the water would enter a pretreatment zone, which was one of the set functional requirements, seen earlier in section 4.4. The most natural version of this pretreatment was found to be a heap of stones, called a filter strip, that acts to filter out any large components from the water and slow its speed as it enters the bioswale.

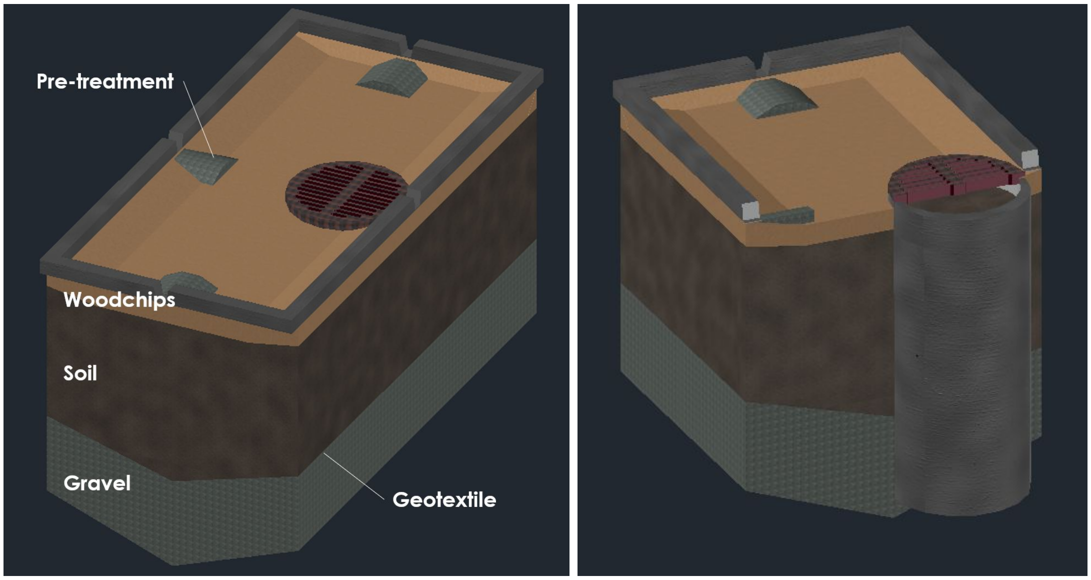

Figure 11. Preliminary design of one parking stall sized bioswale unit.

As seen in the Figure 11 above, the bioswale's top layer was originally designed using a surface cover of wood chips. This is the material most commonly employed in Pointe-Claire to cover garden beds. However, the optimal material for this top layer was later reexamined, as wood chips were at risk of floating up and into the sewer drain during intense storm events. Thus, different types of decorative stones were looked into as a potential alternative. The roots of plants aid in the infiltration of water into the soil. The water would then percolate through the soil until it reaches a geotextile layer, which acts to prevent soil from filling the pores of the gravel sub layer. Once this water reaches the gravel, it travels through the pores quickly, and further percolates into the soil below and laterally, leaving more room for the incoming water to drain into the soil of the infiltration bed. In case of intense precipitation, it was assumed that the water would accumulate on the infiltration bed, until its level reached that of the sewer, which is slightly lower than the surrounding pavement, therefore preventing the backup of water and flooding of the region outside of the swale.

6.3 MATERIALS SELECTION

After identifying certain problematic aspects of this preliminary design, updated primary material choices were made and the particular requirements of each substrate layer refined. First, the surface cover of wood chips, which were at risk of floating and entering the sewer drain if water ponding was ever to occur in the bed, were replaced with denser, heavier decorative river stones. These inert river stones, as explained in Section 6.1.2, do not have the same ability as wood chips to adjust the carbon-to-nitrogen ratio in the soil, to prevent nutrient leaching. However, similarly to wood chips, they are capable of minimizing soil erosion and helping to retain water in the soil during periods of drought. By minimizing the excess fertilizers introduced into the system to support the plants, by strictly managing application quantities and times, the effects of nutrient leaching can be mitigated elsewhere.

Furthermore, the profiled soil layers of the preliminary system were further developed to ensure that the system met infiltration requirements, had adequate treatment ability, and limited the damaging effects of pore clogging. Outlined in table 2, the specific requirements of each of the materials selected were designated, based on material class guidelines for infiltration systems, clearly laid out in the Minnesota Stormwater Manual, a useful reference guide developed to help orient stormwater managers worldwide (MPCA, 2017). Transitions between adjacent layers were refined to ensure that smaller materials in the layers above would not fill the pores of the layers below, seeing as the sustained porosity of the coarse sand, crushed stone and gravel layers is critical to proper infiltration. Furthermore, the materials used were often specifically identified as “cleaned” or “washed” to limit the amount of dust and fine particles introduced into the system. Furthermore, given the high clay content of the native soils at the study site and their consequent unsuitability for infiltration applications, it was decided that the native topsoil would not be repurposed into the system, but that sandy topsoil of hydrologic soil group A would be brought in to support the infiltration capacity of the bed.

Finally, selecting an appropriate material for the curb was challenging, as it had to be strong and durable, resistant to weathering, and not be damaged by water and should withstand any potential collisions from automobiles. Of course, given the flexibility in this particular material choice decision, selecting a material based on environmental considerations is most desirable. As opposed to a regular concrete Portland cement curb, that contributes to greenhouse gas emissions through its production, a recycled composite plastic material would be well-suited, because of its resistance to water, its durability and valorization of recycled materials. However, in order for this construction project to remain feasible and realistic, the cost of this superficial replacement must first be weighed and considered.

Table 2. Materials selected for surface cover and subsurface infiltration system substrate.

Surface cover and subsurface infiltration system substrate layers	
Layer	**Description**
1	RIVER STONES (surface cover)
2	SANDY TOPSOIL (with perlite additive)
3	CLASS 1 MATURE COMPOST (filter berm)
4	ASTM C-33 COARSE, CLEAN SAND (less than 1-2% fines)
5	POLYPROPYLENE, NON-WOVEN GEOTEXTILE
6	1” CRUSHED, CLEAN-WASHED STONE
7	2" UNIFORM, DOUBLE-WASHED GRAVEL (less than 0.5% wash loss)

6.4 PLANT SELECTIONS

In the preliminary design, due to the limited vegetated area available within the single parking stall design, the only plant species targeted for use in the infiltration bed was seaside goldenrod, *Solidago sempervirens*. Seaside goldenrod is an ideal choice, as it is a perennial, herbaceous native plant, with good salt-tolerance, drought tolerance and an ability to tolerate standing water, grow moderately fast and flourish in medium to infertile soils. These optimal characteristics, that make seaside goldenrod well-suited for implementation in an infiltration bed located in a parking lot, are explained in greater detail, in the preceding section, Section 6.1.1. However, as the potential need for larger infiltration beds, occupying up to four parking stalls was weighed, a need for a larger diversity of plant species, namely other herbaceous, resilient plants and shrubs, was determined. In order to minimize the required depth of sandy topsoil, which must be transported over to the study site due to the poor condition of the native soils for infiltration, large coniferous trees with larger rooting depth requirements were no longer considered appropriate for this design.

Therefore, another species of herbaceous, perennial grass to be implemented alongside the seaside goldenrod, is *Elymus canadensis*, otherwise known as Canadian wild rye. Similarly, Canadian wild rye also tolerates frequently saturated soil conditions well and has an adequate salt tolerance (MPCA, 2020b). Furthermore, the dense, evergreen shrub *Hypericum kalmianum*, native to northeastern Canada, otherwise known as Kalm's St. John's wort is also to be implemented in this design system. The Kalm's St. John's wort is a very low maintenance shrub, as it does not drop all of its leaves, like other, more common, deciduous shrubs do. It is tolerant of salt-spray, of drought and flooding and of soils with a high pH (Cornell University, 2014). Another semi-evergreen shrub, *Myrica pensylvanica*, commonly known as Northern Bayberry, also a native plant to northeastern North America, could equally be implemented. It is also low maintenance, extremely tolerant of sandy soils, salt spray, flooding, drought and high pH soils (Cornell University, 2014). However, most interestingly, it is a plant that is capable of fixing nitrogen from the air, which could supplement the growth of plants within the infiltration bed without the need for the application of solid or liquid fertilizers (Cornell University, 2014).

6.5 CALCULATIONS

Please note that this section of the design report is a condensed and brief overview of the calculations performed and the results obtained in this larger engineering study. For the in-depth, raw mathematical calculations, please refer to the accompanying Microsoft Excel document named “Calculations-Stormwater Infiltration Through Green Infrastructure”.

6.5.1 DEFINING COVERAGE AREAS

In order to perform appropriate sizing calculations, the parking lot at the study site was first divided into eight set areas, based on its current sloping design. Within each of these identified areas, the slope of the pavement directs the runoff generated during and after a precipitation event to an ideally located stormwater sewer drain, positioned at the lowest point of the area. As was determined in Section 5.2, certain stormwater sewer drains in the Plaza Pointe-Claire parking lot were considered unsuitable for the placement of an infiltration bed, as they would obstruct the normal foot and vehicle pathways of the parking lot. Therefore, these runoff areas of the parking lot are considered “uncovered” by the infiltration system. The runoff areas, where the placement of the current stormwater sewer drain could accommodate an infiltration bed with ease, are considered “covered” by the infiltration system. The total area of the parking lot is approximately 21,757 m^2, measured using aerial photographs and the Google Maps Area Calculator Tool. The areas of the parking lot draining stormwater into an infiltration bed, called “covered” areas, and the areas of the parking lot draining directly into the sewer, called “uncovered” areas are summarized below in table 3 and depicted in figure 12.

Table 3. Covered and uncovered areas of the Plaza Pointe-Claire parking lot.

Runoff Area Reference Number	Area (m^2)	Covered (Suitable for Infiltration Bed) OR Uncovered (Unsuitable for Infiltration Bed)
1	2 772	Covered
2	2 809	Covered
3	3 112	Covered
4	2 319	Covered
5	1 719	Covered
6	4 016	Uncovered
7	2 794	Uncovered
8	2 216	Uncovered
TOTAL / COVERAGE PERCENTAGE	27 757	**Covered** = 58.515% **Uncovered** = 41.485%

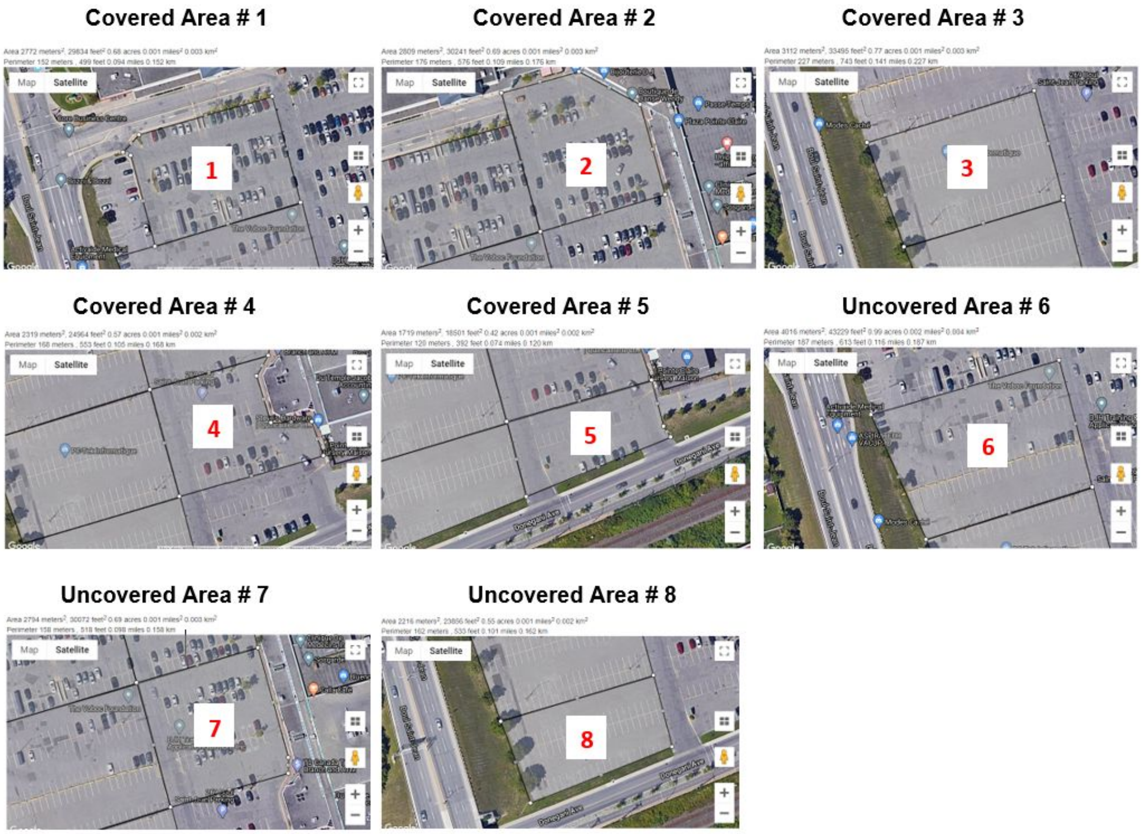

Figure 12. Aerial images and calculated areas of the covered and uncovered areas of the Plaza Pointe-Claire parking lot.

6.5.2 RUNOFF VOLUME

To properly size the infiltration beds within each of the covered areas to meet both the set functional requirements and the site specific constraints, the total runoff volume shed from the portion of the covered area that remains paved the following installation of an infiltration bed must be calculated by applying the SCS Runoff Curve Number method. This is an empirical equation, based on experiments and observed data (USDA, 1986). The SCS Runoff Curve Number method is governed by the following equation, Equation 1.

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad (1)$$

where
Q = excess rainfall, also known as runoff depth (mm)
P = rainfall depth (mm)
I_a = initial abstractions (mm)
S = potential maximum retention (mm)

The initial abstractions I_a, which may include precipitation lost through surface storage, interception, evaporation and infiltration, are approximated by Equation 2.

$$I_a = 0.2S \tag{2}$$

While, the potential maximum retention S is calculated using Equation 3, defined below.

$$S = \frac{25400}{CN} - 254 \tag{3}$$

where
CN = curve number

The curve number depends on five main factors, namely “the hydrologic soil group, cover type, treatment, hydrologic condition, and antecedent runoff condition” (USDA, 1986). Two different curve numbers are required in this study, namely the curve number of the paved asphalt surface and the curve number of the vegetated infiltration bed. These runoff curve numbers were determined using table D-2 and table D-3, respectively (see appendix D). In order to determine the appropriate curve numbers, the hydrologic soil group and the cover type for each of the two applications had to first be determined.

To identify the hydrological soil group of the native soil underlying the paved asphalt surface in the parking lot, the soil map for Montréal and Laval, seen in Figure D-1, developed by the Research and Development Institute For The Agri-Environment (IRDA), a non-profit research corporation, was used. Based on this soil map, it could be precisely determined that the native soil below the pavement is primarily Châteauguay clay loam, with small portions better described as Saint-Urbain clay. Therefore, given these descriptions, it can be said that the native soil below the paved surface is generally a clay-loam. As such, based on the qualities provided in table 1, the hydrologic soil group of the native clay-loam soil was determined to be group C. However, determining the cover type was not as straightforward for the paved asphalt surface, seeing as the actual state of the parking lot’s surface no longer qualifies as a truly impervious area. Given the amount of cracking, surface defects and potholes observed in the parking lot, assuming 100% impervious cover, as is implied by the incredibly high curve number for an “impervious area, paved parking lot” listed in Table D-3 (see appendix D), is not realistic in this location. To develop a more realistic model of the location, the curve number for the paved surface with hydrologic soil group C was decidedly not modelled using the curve number of 98, assigned to impervious paved parking lot areas. Instead, it was modelled as an industrial urban area, with an average percent impervious area of 72%. This way, the important cracks, surface defects and potholes observed throughout the parking lot could be taken into account. As such, the CN for the paved parking surface in the Pointe-Claire Plaza, modelled as an industrial lot, with an underlying soil hydrologic group C was found to be 91.

The built soil complex, below the vegetated infiltration bed and thin layer of decorative river stones, is engineered to support plant growth and allow stormwater to infiltrate quickly, while filtering out important urban contaminants. An appreciable layer of sandy topsoil will be used, meeting the requirements of a soil of hydrologic soil group A. The vegetative cover type implemented, which primarily includes dense woody, low-to-the-ground herbaceous plants and bushes, was modelled as a brush-weed-grass mixture, with brush the major element. From table D-2 (see Appendix D), the curve number for brush, under hydrologic soil group A, with fair ground cover, meaning 50% to 75% ground cover is equal to 35.

The rainfall depth P, also required to execute Equation 1, can be determined using the Rainfall Intensity-Duration-Frequency (IDF) data for the Montreal Pierre Elliott Trudeau International Airport, seen in Figure D-2 (see appendix D). The Pierre Elliott Trudeau International Airport is in close proximity to the study location and at a similar elevation, which therefore makes it a good representation of this specific design site. Using this short-duration IDF curve data, the approximate rainfall depths obtained over a 24 duration, during storms of varying return period, could be obtained with an adequate degree of confidence, and are displayed in table 4 below. These values were obtained by multiplying the intensity, obtained directly from the IDF curve in Figure D-2, by the chosen 24 hour duration. The 24 hour duration was not chosen arbitrarily, but was based on the widely-accepted design standards for similar infiltration systems (EPA, 2014).

Table 4. 24-hour rainfall data for storms of varying return period at Pierre-Elliott Trudeau Airport.

Return Period (years)	Intensity (mm/h)	24-hour Rainfall Depth, P (m)
2	2.000	0.048
5	2.625	0.063
10	2.875	0.069
25	3.333	0.079992
50	3.666	0.087984
100	3.950	0.0948

In order to develop a better understanding of which size infiltration bed is most practical and best suited for this application, three different design sizes were evaluated throughout the calculations. Three iterations of the calculations were completed, using infiltration bed areas, occupying one parking space, two parking spaces or four parking spaces within any one given covered area. These three design sizes were the ones chosen to be evaluated, as they represented the lower, middle and upper limits of the parking spaces available for potential repurposing. For example, given that five targeted covered areas were identified for the placement of infiltration beds, if the four parking space infiltration bed design size was chosen, twenty parking spaces would be repurposed and no longer usable at the Pointe Claire Plaza. As outlined in Section 4.1.2, the number of parking spaces in the center is regulated, and there must be at least one parking space for every twenty square meters of building floor area (City of

Pointe-Claire, 2019). Given the rather large and expanding floor area of the Pointe Claire Plaza shopping center, removing more than twenty parking spaces to replace them with infiltration beds occupying more than four parking spaces each, would be imprudent or infringe on certain municipal by-laws. Therefore, for practicality and to ensure that all municipal by-laws are fully respected, these three conservative sizes of infiltration bed were set and thoroughly investigated.

Following a site visit, the exact dimensions of the targeted parking spaces in the Plaza Pointe Claire parking lot and the placement of the targeted stormwater sewer drains were determined, as seen in figure E-1 to figure E-4 (see appendix E). Using these dimensions and by only taking into account the vegetated infiltration areas of each infiltration bed design size, the areas over which improved infiltration could take place in the parking lot were determined, and are presented in table 5 below. Please note that the area of the infiltration bed's border, subtracted from the area of the parking space, was rounded up to account for inconsistencies in the construction materials.

Table 5. Usable infiltration areas of three chosen infiltration bed designs evaluated.

Evaluated infiltration bed design size	**Vegetated infiltration bed design size** (m^2) (not including the area of the retained parking lines, the protective bordering curb and the sewer drain)
1 parking space	11.7066
2 parking space	26.3388
4 parking space	55.4640

Applying the equations of the SCS Runoff Curve Number Method and inputting the values obtained for normal rainfall depth, as well as the curve number of the paved asphalt surface, the excess rainfall, or rather total runoff depth, generated by the paved asphalt surfaces around the installed infiltration beds could be found, and are seen below in table 6.

Table 6. Excess rainfall (m) generated by the paved asphalt surface at the study site.

Return Period (years)	**24-hour Rainfall Depth, P (m)**	**Excess Rainfall, Q (m)**
2	0.048	0.027122
5	0.063	0.040449
10	0.069	0.045938
25	0.079992	0.056152
50	0.087984	0.063678
100	0.0948	0.070147

By multiplying the values obtained for excess rainfall, seen above in table 6, by the covered areas identified less the area of the vegetated infiltration bed, the volume of runoff directed into each infiltration bed within each of the designated covered areas from the surrounding paved area could be confidently determined. The runoff volumes generated, reported in m^3 and obtained for each of the covered areas and design sizes are summarized below in table 7.

Table 7. Runoff volumes (m^3) generated in each covered area by the paved asphalt surfaces surrounding the different sized infiltration bed designs (*PS = parking space*).

	Covered Area #1 (2772 m^2 - Usable Infiltration Surface Area)			**Covered Area #2 (2809 m^2 - Usable Infiltration Surface Area)**			**Covered Area #3 (3112 m^2 - Usable Infiltration Surface Area)**			**Covered Area #4 (2319 m^2 - Usable Infiltration Surface Area)**			**Covered Area #5 (1719 m^2 - Usable Infiltration Surface Area)**		
Infiltration Bed Design	1 PS	2 PS	4 PS	1 PS	2 PS	4 PS	1 PS	2 PS	4 PS	1 PS	2 PS	4 PS	1 PS	2 PS	4 PS
Return Period (years)	**Runoff volumes (m^3) generated by the paved asphalt surfaces surrounding usable infiltration bed areas**														
2	74.86	74.47	73.68	75.87	75.47	74.68	84.09	83.69	82.90	62.58	62.18	61.39	46.31	45.91	45.12
5	111.65	111.06	109.88	113.15	112.56	111.38	125.40	124.81	123.63	93.33	92.74	91.56	69.06	68.47	67.29
10	126.80	126.13	124.79	128.50	127.83	126.49	142.42	141.75	140.41	105.99	105.32	103.98	78.43	77.76	76.42
25	155.00	154.17	152.54	157.07	156.25	154.62	174.09	173.27	171.63	129.56	128.74	127.10	95.87	95.05	93.41
50	175.77	174.84	172.98	178.12	177.19	175.34	197.42	196.49	194.63	146.92	145.99	144.14	108.72	107.78	105.93
100	193.63	192.60	190.56	196.22	195.20	193.15	217.48	216.45	214.41	161.85	160.82	158.78	119.76	118.74	116.69

6.5.3 INFILTRATION

To calculate the volume of stormwater infiltrated through the vegetated area of each infiltration bed, the same SCS Runoff Curve Number Method is applied, but the rainfall depth P is adjusted to account for the large volume of runoff being directed into the infiltration bed from the surrounding paved asphalt surface of its covered area. The runoff volumes, presented above in table 7, were transformed into equivalent rainfall depths, through a single division with the area of the vegetated infiltration bed upon which they are incident. The equivalent rainfall depth obtained for the runoff volume was then added to the normal rainfall depths typically incident upon the vegetated infiltration bed area, seen in table 4. This ultimately provided values for a new, adjusted total rainfall depth, of which the final results are summarized in table 8 below.

Table 8. Adjusted total rainfall depth (m) incident upon the usable, vegetated area of the different infiltration bed designs within each of the designated covered areas (*PS = parking space*).

	Covered Area #1			**Covered Area #2**			**Covered Area #3**			**Covered Area #4**			**Covered Area #5**		
Infiltration Bed Design	1 PS	2 PS	4 PS	1 PS	2 PS	4 PS	1 PS	2 PS	4 PS	1 PS	2 PS	4 PS	1 PS	2 PS	4 PS
Return Period (years)	**Adjusted total rainfall depth (m) incident upon the usable, vegetated area of the infiltration bed (within the designated covered areas).**														
2	6.443	2.875	1.376	6.529	2.913	1.394	7.231	3.225	1.543	5.394	2.409	1.155	4.003	1.791	0.861
5	9.600	4.280	2.044	9.728	4.336	2.071	10.775	4.802	2.292	8.035	3.584	1.714	5.962	2.662	1.276
10	10.901	4.858	2.319	11.046	4.922	2.350	12.235	5.451	2.601	9.123	4.068	1.944	6.769	3.021	1.447
25	13.320	5.933	2.830	13.498	6.012	2.868	14.951	6.658	3.174	11.147	4.968	2.372	8.269	3.689	1.764
50	15.103	6.726	3.207	15.304	6.815	3.249	16.952	7.548	3.597	12.638	5.631	2.687	9.375	4.180	1.998
100	16.635	7.407	3.531	16.857	7.506	3.577	18.672	8.313	3.961	13.920	6.201	2.958	10.325	4.603	2.199

This new, adjusted total rainfall depth was then re-introduced into the governing equations of the SCS Runoff Curve Number Method, along with the curve number for the vegetated infiltration bed, to get the total runoff depth, or rather excess rainfall, generated from each size infiltration bed design in each of the designated covered areas. The results are summarized in table 9 below.

Table 9. Excess rainfall (m) generated in the usable, vegetated area of the different infiltration bed designs within each of the designated covered areas (*PS = parking space*).

	Covered Area #1			Covered Area #2			Covered Area #3			Covered Area #4			Covered Area #5		
Infiltration Bed Design	1 PS	2 PS	4 PS	1 PS	2 PS	4 PS	1 PS	2 PS	4 PS	1 PS	2 PS	4 PS	1 PS	2 PS	4 PS
Return Period (years)	**Excess rainfall (m) generated in the usable, vegetated area within designated covered areas**														
2	5.910	2.378	0.937	5.995	2.415	0.954	6.694	2.721	1.092	4.866	1.923	0.734	3.488	1.328	0.475
5	9.057	3.761	1.570	9.184	3.818	1.596	10.229	4.279	1.809	7.496	3.074	1.254	5.431	2.170	0.845
10	10.354	4.334	1.835	10.499	4.398	1.865	11.686	4.923	2.109	8.580	3.552	1.474	6.234	2.521	1.003
25	12.770	5.403	2.334	12.947	5.481	2.370	14.399	6.124	2.671	10.600	4.443	1.886	7.729	3.177	1.302
50	14.551	6.191	2.703	14.752	6.280	2.745	16.399	7.010	3.087	12.089	5.102	2.193	8.832	3.663	1.525
100	16.082	6.870	3.021	16.303	6.968	3.068	18.118	7.772	3.446	13.370	5.669	2.458	9.780	4.081	1.719

To later determine the volume of stormwater that would infiltrate into the vegetated area of the infiltration beds in each of the covered areas, the depth of water infiltrated had to first be obtained. This was accomplished by subtracting the excess rainfall values, summarized above in table 9 and obtained from the SCS equations, from the adjusted total rainfall depth values, summarized in table 8, inputted into the SCS equations. This yields a depth of water infiltrated into the different sizes of infiltration bed, which can then be converted into a infiltration water volume by multiplying the obtained depth by the surface area of the infiltration bed design size under study. Following this procedure for all five of the targeted covered areas and then adding the infiltration volumes obtained together, the total volume of stormwater infiltrated into the ground, through the implementation of this five unit system could be determined. The total volume of stormwater infiltrated by all five infiltration beds was determined for the different infiltration bed size designs and storm return periods. These preliminary results are summarized in table 10, below.

Table 10. Total volume of water infiltrated (m^3) into the five infiltration beds installed, depending on chosen infiltration bed size design and storm return period.

Return Period (years)	Volume Infiltrated (m^3) for Five Infiltration Beds (covering 1 parking space each)	Volume Infiltrated (m^3) for Five Infiltration Beds (covering 2 parking space each)	Volume Infiltrated (m^3) for Five Infiltration Beds (covering 4 parking space each)
2	30.986	64.530	118.532
5	31.660	67.505	128.853
10	31.829	68.272	131.649
25	32.058	69.330	135.601
50	32.181	69.906	137.804
100	32.266	70.308	139.364

However, given that in all three infiltration bed designs, a ponding depth of 0.1524 m was specified. The associated volume of excess stormwater captured through ponding in each of the three infiltration bed designs, before overflow into the stormwater sewer drain began, had to be taken into consideration, and added to the stormwater infiltration values obtained in table 9. Infiltration volumes, adjusted to take into account ponding depths of 0.1524 m within the infiltration bed design size, are summarized in table 11 below. This excess volume of ponded stormwater would be later infiltrated into the soil complex over the system's set drawdown time, which is designed to be less than 24 hours. It is calculated by multiplying the ponding depth by the area of the chosen infiltration bed design size.

This precise allowable ponding depth for the system was determined, based on common drawdown times associated with soils of hydrologic soil group A, which is present at this system's interface between the surface and subsurface systems. It is known that 0.4572 m of ponding depth in hydrologic soil group A, is associated with a drawdown time of 48 hours (MPCA CGP, 2020). While ponding depths of 0.2286 m in hydrologic soil group A are associated with a drawdown time of 24 hours (MPCA CGP, 2020). Given that the allowable ponding depth for this particular system is set at 0.1524 m, which is well-below this standard value, the drawdown time for the system is expected to be somewhere below 24 hours. Of course, this is a rough estimation. Ideally, given access to more resources, in-depth infiltration testing on the built soil complex and native soils at the study site would be conducted before the implementation of this project. These infiltration and soil tests would include visual inspections, capacity testing, synthetic runoff testing and monitoring experiments, allowing us to determine more accurate drawdown times and infiltration rates (MPCA, 2020a).

Table 11. Total volume of water infiltrated (m^3) including excess volume allowed to pond and infiltrate later over the set drawdown time, into the five infiltration beds installed, depending on chosen infiltration bed size design and storm return period.

Return Period (years)	Volume Infiltrated (m^3) for Five Infiltration Beds (covering 1 parking space each)	Volume Infiltrated (m^3) for Five Infiltration Beds (covering 2 parking space each)	Volume Infiltrated (m^3) for Five Infiltration Beds (covering 4 parking space each)
2	32.77	68.54	126.98
5	33.44	71.52	137.31
10	33.61	72.29	140.10
25	33.84	73.34	144.05
50	33.96	73.92	146.26
100	34.05	74.32	147.81

In order to determine how much of the total runoff volume directed into the infiltration bed is infiltrated over the storm duration and drawdown time through the implementation of this system, the percentage of the total runoff produced captured through infiltration into the five beds was resolved. These percentages allow for the determination of the intrinsic value of implementing such a system, and are summarized below in table 12 for the different design sizes and storm return periods.

Table 12. Percentage of total runoff volume generated from the five infiltration beds' surrounding paved asphalt surface infiltrated into the ground below the parking lot, depending on chosen bed size design and storm return period.

Return Period (years)	Percentage of Volume Infiltrated (m^3) from Five Infiltration Beds (covering 1 parking space each)	Percentage of Volume Infiltrated (m^3) for Five Infiltration Beds (covering 2 parking space each)	Percentage of Volume Infiltrated (m^3) for Five Infiltration Beds (covering 4 parking space each)
2	9.53%	20.06%	37.60%
5	6.52%	14.03%	27.26%
10	5.77%	12.49%	24.49%
25	4.76%	10.37%	20.60%
50	4.21%	9.21%	18.44%
100	3.83%	8.41%	16.92%

6.5.4 MATERIAL DEPTHS

As was previously mentioned, given the financial and regulatory constraints on this project, it was not feasible to perform in-depth soil and infiltration testing at the privately-owned study site, and therefore material depths could not be determined using traditional methods. Therefore, to determine the approximate material depths used to construct the surface cover and subsurface systems of this design, water storage capacity was used to determine the depth required for the principal substrate layer, 2” uniform, double-washed gravel while the depth of the other layers was based off standard depths used in other similar, successful system designs or determined based on broader system requirements, namely plant and pollutant holding capacity.

The following relation, Equation 4, was used to determine the depth of the principal substrate layer, the 2” uniform, double-washed gravel.

$$d = \frac{V}{A\,(V_S)} \tag{4}$$

where
d = depth of gravel layer (m)
V = volume of water infiltrated (m^3)
A = area of infiltration bed (m^2)
V_S = void space of gravel layer

The void space of the particular chosen gravel material, applied in this design, is 40% (Barr Engineering Co., 2001). Plugging in the previously calculated volumes of water infiltrated, not taking into account ponding, for each coverage area, infiltration bed design and return period, as well as the appropriate infiltration bed area, the depth of gravel required for the infiltration bed within each covered area could be determined. The values obtained, for the depth of the gravel layer, from this basic calculation are summarized in table 13.

Table 13. Depth of 2” uniform, double-washed gravel layer (m) for the different infiltration bed designs within each of the designated covered areas (*PS = parking space*).

	Covered Area #1			Covered Area #2			Covered Area #3			Covered Area #4			Covered Area #5		
Infiltration Bed Design	1 PS	2 PS	4 PS	1 PS	2 PS	4 PS	1 PS	2 PS	4 PS	1 PS	2 PS	4 PS	1 PS	2 PS	4 PS
Return Period (years)	**Depth of 2” uniform, double-washed gravel layer (m) for the different infiltration bed designs within each of the designated covered areas**														
2	1.33	1.24	1.10	1.33	1.25	1.10	1.34	1.26	1.13	1.32	1.22	1.05	1.29	1.16	0.97
5	1.36	1.30	1.19	1.36	1.30	1.19	1.37	1.31	1.21	1.35	1.27	1.15	1.33	1.23	1.08
10	1.37	1.31	1.21	1.37	1.31	1.21	1.37	1.32	1.23	1.36	1.29	1.18	1.34	1.25	1.11
25	1.37	1.33	1.24	1.38	1.33	1.24	1.38	1.34	1.26	1.37	1.31	1.21	1.35	1.28	1.16
50	1.38	1.34	1.26	1.38	1.34	1.26	1.38	1.34	1.28	1.37	1.32	1.23	1.36	1.29	1.18
100	1.38	1.34	1.27	1.38	1.34	1.27	1.39	1.35	1.29	1.38	1.33	1.25	1.36	1.30	1.20

The other five layers of the system, requiring a design depth and described in table 2 in Section 6.3 “Materials Selection” above, were designed based on the standard technical requirements laid out in the Minnesota Stormwater Manual, often used as a model in a wide variety of locations to guide the best management and design practices of stormwater managers (MPCA, 2017). If ever a range of depths was provided in the guide for a substrate layer, the largest design depth was chosen to incorporate an informal factor of safety into the design. The summary of the design depths are outlined in table 14, below. The depth of sandy topsoil was primarily based on the rooting depth requirements of the plants it supports, chosen in Section 6.4 above.

Table 14. Design depths (m) of other substrate materials, based on guidelines laid out in the Minnesota Stormwater Manual.

Surface cover and subsurface infiltration system substrate layers		
Layer	**Description**	**Depth of layer (m)**
1	RIVER STONES	0.0508
2	SANDY TOPSOIL	0.4572
3	CLASS 1 MATURE COMPOST	0.0762
4	ASTM C-33 COARSE, CLEAN SAND	0.2032
5	POLYPROPYLENE, NON-WOVEN GEOTEXTILE	Negligible
6	1” CRUSHED, CLEAN-WASHED STONE	0.3048
7	2" UNIFORM, DOUBLE-WASHED GRAVEL	Calculated based on water holding capacity

These standard depths were added to the calculated depth of the principal gravel layer, to determine the final overall depths of the required infiltration systems, including the decorative surface cover layer. These final results are outlined in table 15, below.

Table 15. Depths required (m) for the total combination of surface cover and subsurface layers of the infiltration bed designs within each of the designated covered areas (*PS = parking space*).

	Covered Area #1			**Covered Area #2**			**Covered Area #3**			**Covered Area #4**			**Covered Area #5**		
Infiltration Bed Design	1 PS	2 PS	4 PS	1 PS	2 PS	4 PS	1 PS	2 PS	4 PS	1 PS	2 PS	4 PS	1 PS	2 PS	4 PS
Return Period (years)	**Depths required (m) for the total combination of all surface cover and subsurface layers of the infiltration bed designs within each of the designated covered areas**														
2	2.43	2.34	2.19	2.43	2.34	2.19	2.43	2.35	2.22	2.41	2.31	2.14	2.38	2.25	2.06
5	2.45	2.39	2.28	2.45	2.39	2.28	2.46	2.40	2.30	2.44	2.37	2.24	2.42	2.32	2.17
10	2.46	2.40	2.30	2.46	2.40	2.30	2.46	2.41	2.32	2.45	2.38	2.27	2.43	2.34	2.20
25	2.47	2.42	2.33	2.47	2.42	2.34	2.47	2.43	2.35	2.46	2.40	2.30	2.44	2.37	2.25
50	2.47	2.43	2.35	2.47	2.43	2.35	2.48	2.44	2.37	2.46	2.41	2.33	2.45	2.39	2.27
100	2.47	2.44	2.36	2.48	2.44	2.37	2.48	2.44	2.38	2.47	2.42	2.34	2.46	2.40	2.29

These final depths were reevaluated following the completion of the material depth calculations to ensure that the setback distances from the bottom of the infiltration system to the underlying bedrock and high seasonal water table were suitable. It is required that the bottom of the infiltration system be within 1 meter of bedrock and the high seasonal water table (CVC, 2012). The depth to the bedrock at the study site was determined using a gradient map, seen in figure 13 below, provided by the Civil Engineering and Applied Mechanics Department of McGill University, and was found to be between 5-10 m below the soil surface. After much effort, the high seasonal water table for the study site could not be located. Therefore, for the purposes of this experiment, it was assumed that given the large elevation difference between the adjacent, large water reservoir, Lac Saint-Louis, and the study site, the seasonal high water is within a suitable setback distance from the bottom of the infiltration bed. As such, the current design system would meet the required setback distances from bedrock and groundwater levels.

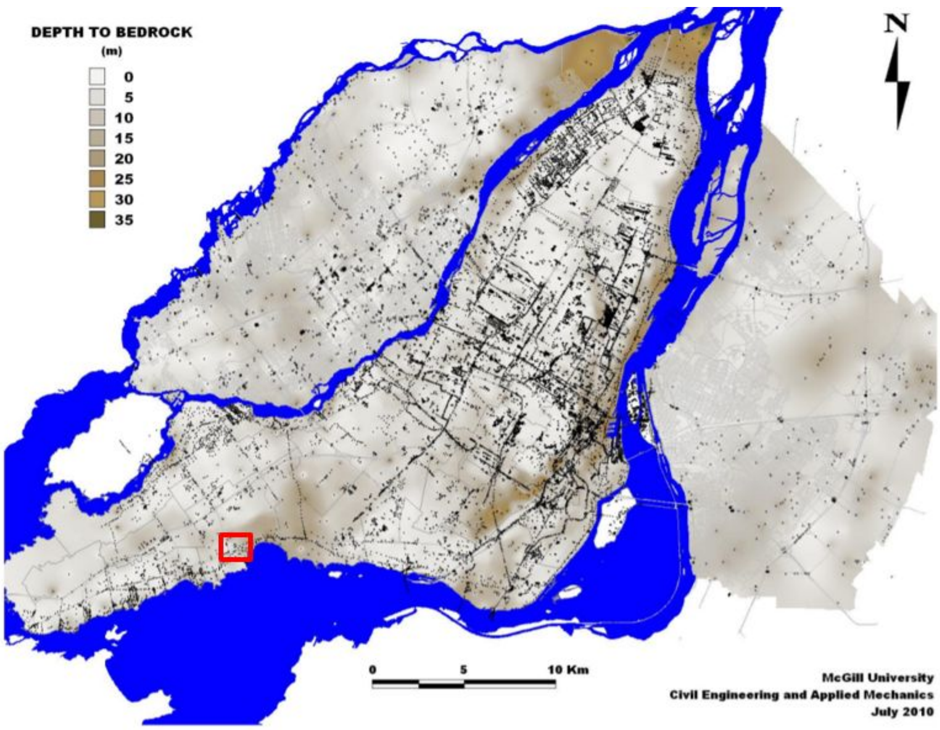

Figure 13. Depth to bedrock gradient map of Montréal and Laval, with the study site highlighted in a red rectangle. Source: McGill University, 2016.

7. <u>PROPOSED DESIGN</u>

7.1 DESIGN SPECIFICATIONS

After a thorough analysis of the in-depth calculations performed, the new, proposed design was amended and now covers 4 parking stalls to maximize the percentage of water infiltrating into the soil, as well as to be a more substantial structure within the very large lot. The linear garden bed placed at the South entrance of the lot covers a larger area than 4 parking stalls, while the other 4-stall units create a symmetry within the parking lot and break up the monotonous stalls with greenery.

Figure 14. Map of infiltration infrastructure within the parking lot marked in green

The design of the bed nicely complements the existing infrastructure in the City of Pointe-Claire since the recent reconstruction project of the Donegani bicycle path included goldenrod and the plastic lumber border reminds of the benches in many of Pointe-Claire's parks which are made of the same material.

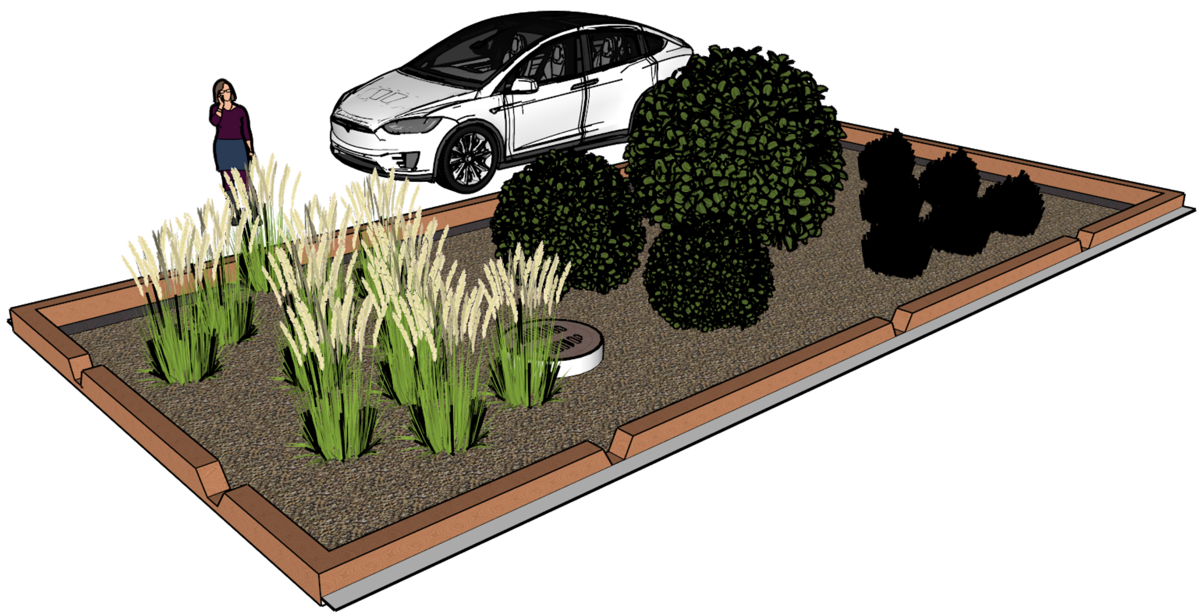

Figure 15. Scale rendering of the infiltration bed and its border.

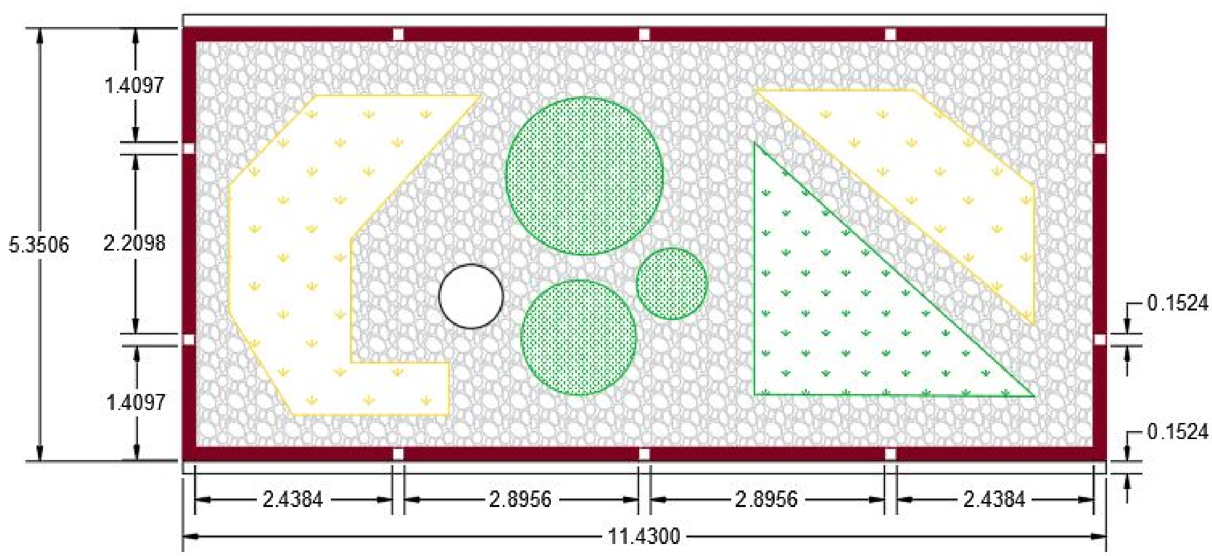

Figure 16. Top view of 4 stall infiltration bed with border measurements in meters (m)

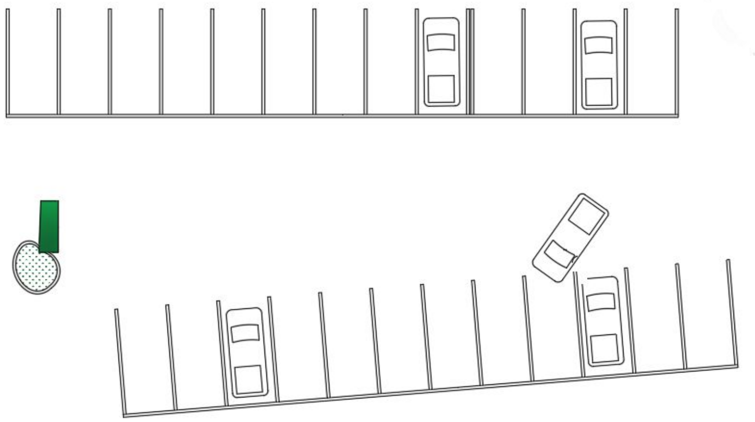

Figure 17. Existing parking design at the South end of the parking lot

Current placement of sign and small garden bed will be displaced to make room for a large infiltration area and welcoming entrance to the Plaza's parking lot. Despite the need to modify the existing positioning of the Pointe-Claire Plaza sign slightly to the north, this design allows for an impressive infiltration area of roughly 73 square meters (excluding the sewer and sign) without needing to remove any parking stalls.

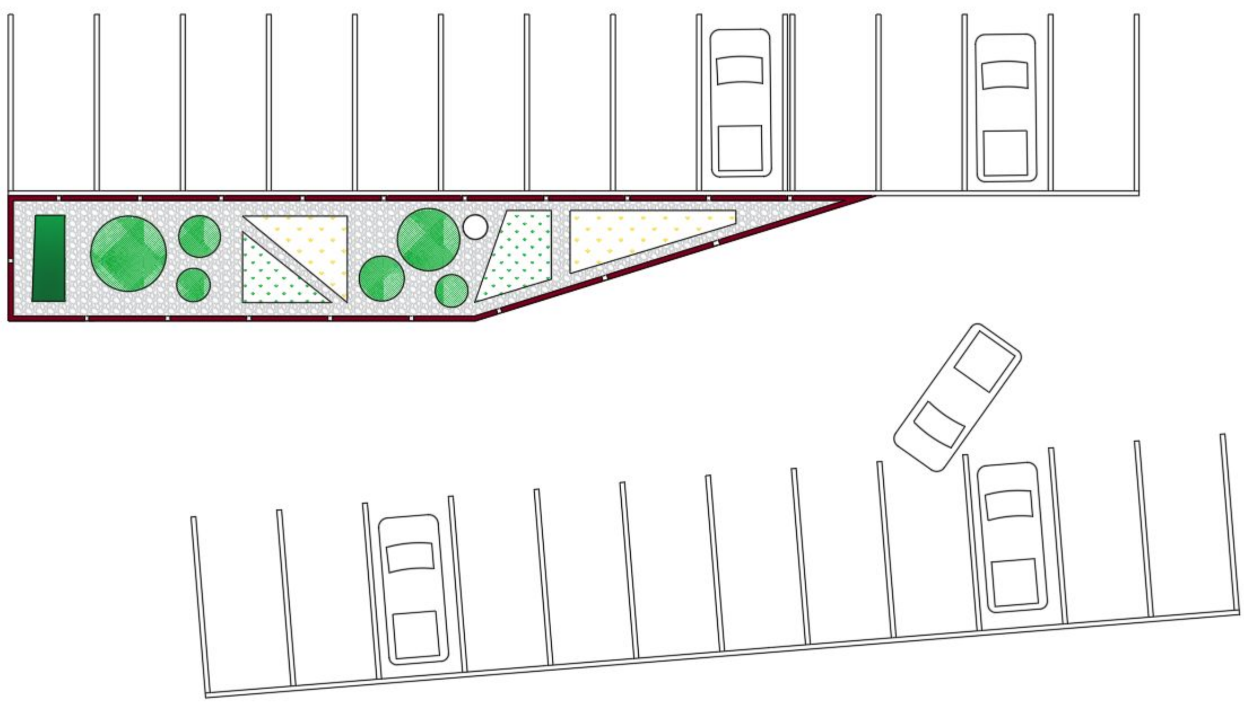

Figure 18. Linear garden bed design at the South side of the parking lot. Total bed area is 76.1758 square meters with a 2.6883m^2 sign and 0.4869m^2 drain.

The border is made of recycled plastic timber which is easy to cut and can be worked with standard woodworking equipment. It does not experience water damage as real lumber would, it does leach out chemicals that can pollute groundwater as treated lumber would, and graffiti and vandalism can easily be removed from it. The design of the border allows for 12.70 centimeters to be visible above the pavement while the bottom of the border rests on a layer of pavement or earth produced by carving away roughly 5 cm of the existing pavement. The border is secured by a galvanized spike, commonly used for railroad ties and landscaping.

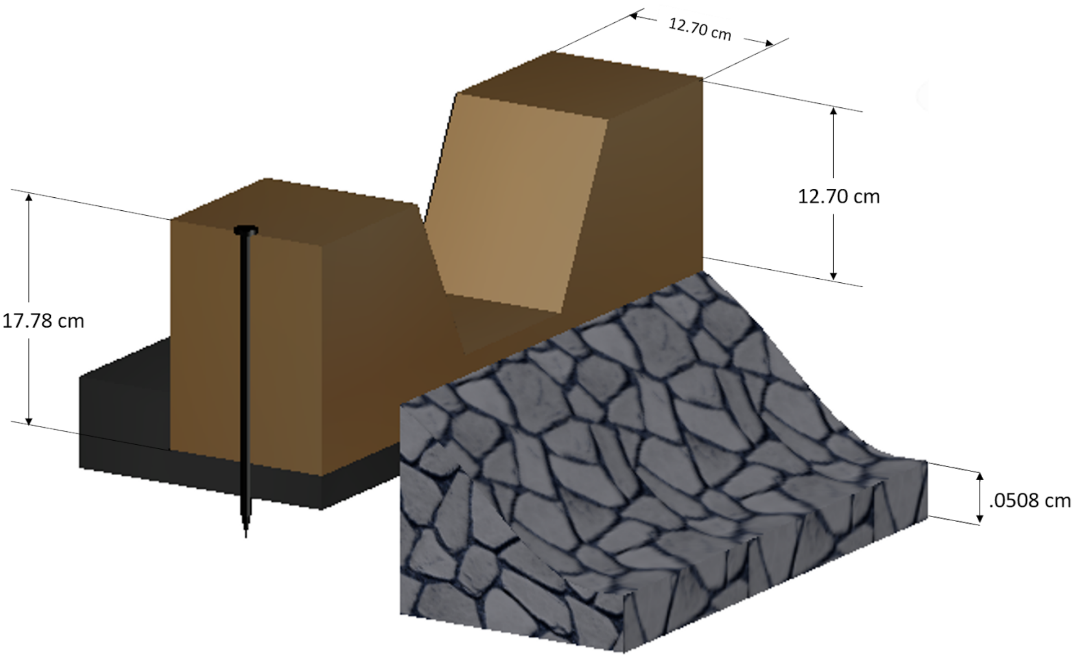

Figure 19. The design of the wood coloured border with respect to the pavement, which is represented by the thin dark layer.

The choice of materials to include in the infiltration system was discussed in section 6.5.4. The depth of the gravel layer alone should be sufficient to hold most of the infiltrated water, and since during the accumulation of water throughout a 24 hour storm the water reaching the gravel will begin infiltrating into the surrounding soil, the system is well equipped to handle heavy precipitation events. Since not all the water will be infiltrated, it should be noted that once the 15.24 cm ponding layer is filled, water will spillover into the sewer instead of backing into the parking lot, which prevents any potential for flooding with regards to the infiltration rate. Although not a structural element, a pre-treatment “pool” in the surface layer riverstone aligned with the inlets allows for the accumulation of leaves for easy retrieval.

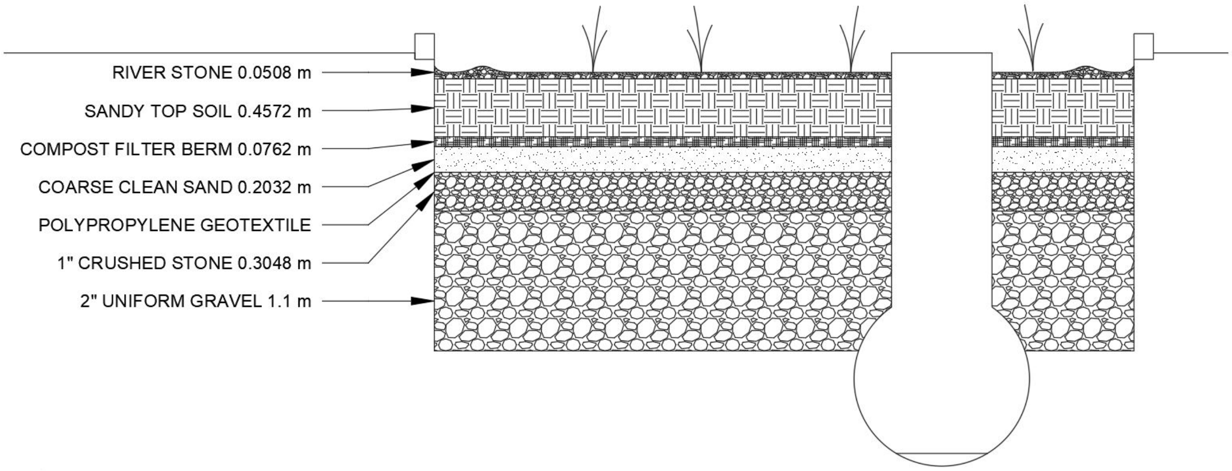

Figure 20. Materials and their depths within the infiltration unit

7.2 MAINTENANCE

A highly important consideration of this design is its maintenance. Proper maintenance is essential to ensure that this engineered infrastructure can have a long life of functional use.

One of the primary maintenance considerations of a vegetated infiltration bed involves the care and upkeep of the plants, a highly important component of the system. Regular maintenance such as pruning and weeding would be needed to improve aesthetics and functionality. Periodically or at the end of growing seasons, the plants and debris from the plants may need to be harvested. Plants are also required to be periodically collected especially if there are high levels of contamination accumulating in the infiltration bed and plant tissue. The collected plants in this scenario would have to ultimately be landfilled or otherwise disposed of.

Similarly, the soil substrate that supports the plants may also require maintenance. After long periods of use, the top layers of the infiltration bed may need to be excavated and replaced with fresh substrate. This would be to ensure that a healthy growing medium is provided to the plants. After long periods, the top layer of substrate may have experienced compaction and large amounts of contamination. To ensure that the infiltration bed maintains functionality and continues to infiltrate and treat stormwater runoff, periodic inspection and maintenance of the substrate is required.

Additionally, a system such as an infiltration bed which requires high volumes of water evidently runs the risk of becoming saturated which can lead to several issues. The water collected should be able to drain through the system and infiltrate into the soil within a relatively short amount of time. However, if this is found to not be the case, there could be an issue with the system such as clogging that will need to be addressed. Standing water can lead to anaerobic conditions which can create additional issues such as odours and plant growth prevention. The infiltration bed must therefore be periodically inspected visually to ensure that it is functioning as it should. Regular maintenance of the system would also be needed to ensure that debris or leaves that are accumulated in the pre-treatment component is regularly removed. This is to maintain functionality by not impeding the flow of runoff from entering the infiltration bed.

The installation of bioswales can potentially complicate the snow clearing for the rest of the lot during the winter. A plowing plan is therefore needed in which snowplow operators are told which paths to follow and where to push the snow (MPCA CGP, 2020). Markers should be added to the borders of the infiltration beds during the fall so that they remain visible during heavy snowfall in the winter. The infiltration beds themselves should not be ploughed over often or used for snow storage to avoid compaction and damage to the system (MPCA CGP, 2020). Furthermore, during the later winter months, as the accumulated snow from the winter begins melting, the stormwater sewer drains within the infiltration beds should be inspected periodically to ensure that an ice film has not developed over them. An ice sheet over the stormwater sewer drain could cause flooding in the parking lot, as the infiltration bed has only limited functionality in the colder months and is not able to assimilate as much water, as it normally would. In the unlikely event that an ice sheet is observed over one of the stormwater sewer drains, the person conducting the regular inspection and maintenance should clear it as soon as possible.

Developing and abiding by a landscaping plan is also essential to the functionality of the infiltration bed (MPCA CGP, 2020). For instance, vegetation should be selected and placed based on their specific hydric tolerances (MPCA CGP, 2020). Woody plants such as shrubs should not be placed near pretreatment zones in order to ensure that they can be properly maintained and that debris can be easily removed (MPCA CGP, 2020). Salt tolerant plants should also be placed in zones that are expected to receive application, such as is the case for most parking lots (MPCA CGP, 2020).

A perpetual easement or deed restriction should also be put in place to ensure the protection of the filter strip from being used for purposes other than sustainable development. Ideally, no future development, disturbance or clearing would occur in that location thus allowing it to maintain its function as a piece of green infrastructure.

7.3 COST ANALYSIS

There are many components within the infiltration system which require to be purchased and installed, they will be over in brief here since costs are very variable depending on the installation and shipping costs. The costs listed do not include tax.

7.3.1 BORDER COST

The material chosen for the border is a recycled plastic lumber which is very easy to work with but is quite costly at $135 for an eight foot or 2.44 meter length (Markstaar, 2020). For the entire project, which would require 78 lumber units, this would total $10 530 of plastic lumber. If this is considered cost prohibitive for the size of the project, an alternative of using concrete as is often used in these systems would cost as low as $2215 or on average $3635 for the borders including installation and cleanup (Homewyse, 2020b). The border also requires the stripping of 5 cm of the existing pavement, for which the cost is very variable depending on equipment and cost of labour at the time of construction. Lastly, the border also needs galvanized spikes, which would total roughly $160 to have 3 spikes per lumber unit (Home Depot, 2020).

7.3.2 INFILTRATION BED COST

The infiltration bed is the most expensive section of the proposed design since it requires the excavation of a large volume of soil and pavement, and the addition of many layers of materials into the excavated space. The excavation could cost $90 000 including hauling away of the material (Homewyse, 2020a). The cost of the layers of material are presented below, which are overestimated.

Table 16. Cost of materials within the infiltration bed. Cost based on mid-sized projects, meaning it is an overestimate for this project (Greely, 2020).

Layer	Total Volume (m^3)	Cost ($)
Surface cover river stone	16	1720
Sandy topsoil	136	4588
Class 1 mature compost filter berm	23	1083
Coarse, clean sand ASTM C33	61	1722
Polypropylene non-woven geotextile	299 m^2	616
1” Crushed stone, clean-washed	91	4307
2” Uniform gravel, double-washed	328	15433

7.3.3 COST OF PLANT SPECIES CHOSEN

The four targeted plant species, including the two perennial herbaceous species *Solidago sempervirens* and *Elymus canadensis* and the two shrubs *Hypericum kalmianum* and *Myrica pensylvanica*, may incur different costs depending on the local availability at the time of purchase and planting. However, these two herbaceous plant species were specifically chosen for this experiment because of their stress tolerance abilities, but also because of their perennial life cycle, which does not require constant repurchase and replanting every year. Furthermore, these two herbaceous plant species are rhizomatous, and therefore will proliferate within the infiltration bed over time without the need for a dense initial planting. The shrubs are also permanent aspects of the infiltration bed, as they persist through many growth seasons through Québec’s harsh winter. It is important to ensure that the plants establish themselves well in the infiltration bed, to ensure their prolonged survival and the consequent, improved functionality of the infiltration system. If the plants are damaged, do not overwinter properly, or are too heavily burdened by high concentrations of urban contaminants accumulated in their tissues, at some point during the operational life of the system, they may need to be replaced.

Therefore, assuming that the low urban contaminant load in the parking lot remains and that the plants are properly cared for and maintained, the plants should only incur an initial cost. It would equally be important to first consider buying these plants from a local nursery, to avoid potential stresses during transportation, the environmental cost of long-distance transportation, and to support the local, social environment. The cost of each of the targeted plant species was found, but due to a high degree of variability in the pricing, the results of this part of the feasibility study were not included. Seeing as, they were thought to render the costing estimate inaccurate, and consequently irrelevant.

7.4 SAFETY CONSIDERATIONS

As with any new piece of infrastructure, it is of utmost importance to consider the safety of the people interacting with this system. In the case of the infiltration beds being installed in the Pointe-Claire Plaza parking lot, the people to consider and primarily the drivers, pedestrians and construction workers. Safety has already been considered when selecting the appropriate infiltration bed layout in section 5.3. The layout was selected partially since it posed the least amount of safety concern by not obstructing any of the existing thoroughfares. However, other safety concerns remain to be considered.

Firstly, modification to a high traffic and highly frequented area can cause confusion to drivers and shoppers who are accustomed to the original layout of the parking lot. For this reason, it is important to include proper signage to inform the public of this project. Before construction begins, it would be ideal to make information available explaining the construction and purpose of this project. During the construction phase however, it is important to ensure proper distancing of the drivers and the construction workers by blocking off the required area that is needed for construction. Construction of the five units should also occur one at a time and during low traffic periods in order to minimize the amount of parking spaces being occupied by construction equipment and vehicles and minimize the risk of any potential collisions of shoppers' vehicles from occurring. Permanent signage should also be installed for after the construction is complete to maximize the visibility of the system.

Surrounding the infiltration bed with a reflective material can also help reduce the chance of collisions, possibly by drivers who cannot see the borders of the beds during times of low visibility such as at night.

7.5 CONSEQUENCES OF PROPOSED SOLUTION

7.5.1 ECONOMIC

Due to the small footprint of the proposed design, the on-site construction is minimal, which is economically beneficial. Due to the modular and unitary design of the proposed solution, the construction can be done one or several units at a time, allowing the flexibility of having a short construction period with large closures in the parking lot or a longer construction period with periodic closures of small areas of the parking lot. Further analysis can be performed to determine the balance between time of rental of construction equipment and the effect on business within the plaza at different levels of construction closures. The design also offers a compact system which implies lower maintenance and operation costs.

7.5.2 SOCIAL

During construction the social effects are primarily negative, however the parking lot is not very close to residences and thus is unlikely to cause problems with regards to inhabitants. However, the ability to divide the construction times between units allows for minimal construction closures in the parking lot, minimizing the negative effects of construction. The chosen layout also relies on the same layout of the existing parking lot, making it optimal in terms of safety for the returning clientele. To maximize any possible social benefits drawn during the construction phase of this project, it would be important to maximize the use of local small-businesses, whenever economically and environmentally feasible. The aesthetics of greenery within the otherwise fully paved parking lot will increase visitor and worker morale, as well as provide a more welcoming environment for new clients. Lastly, the swale can offer the benefit of acting as an educational location, allowing visitors to learn more about green infrastructure via explanatory panels and potentially encourage other green infrastructure projects in Quebec.

7.5.3 ENVIRONMENTAL

The environmental impacts of the construction will be negative due to the current equipment being mostly petrol powered, despite the unitary design allowing for comparatively minimal construction. The use of recycled plastic timber as an alternative to Portland cement concrete for the curb alleviates some of the impact associated with the production of concrete. Where possible, materials will be locally sourced to minimize transportation emissions. Once constructed, the swale will be beneficial in remediating precipitation water, replenishing groundwater and reducing the direct discharge of water to the lac Saint-Louis. Since the area of the chosen design is smallest, its effect of greenhouse gas sequestration and heat island reduction are minimal compared to the alternative layouts, but this is offset by reduced emissions during construction.

8. CONCLUSION

The need for green infrastructure continues to grow as urbanization expands over more landscape. When observing an already existing urbanized area, the Plaza Pointe-Claire parking lot, a plan for the implementation of a green stormwater infiltration system was successfully commenced. The analysis of the issues associated with commonly used impervious pavements as well a review of existing green infrastructure systems has given a good understanding of the types of methods and materials that can be used, as well as the problems that need to be solved. When observing the site, it was remarked that customer safety, environmental benefit and economic feasibility were among the main priorities that need to be considered for the design of the system. It was determined that the most viable solution would be the implementation of four parking stall size and one linear bioswale infiltration units located on the already existing sewer drains of the parking lot, which minimizes the need to completely redo the layout of the lot. Upon analysing many of the constraints associated with our studied location, a choice of materials and plants was made and a preliminary design was formed for an infiltration bed. Specific calculations were then performed iteratively in order to determine the most appropriate size of the system needed as well its predicted functionality. Future work still remains in order to fully formulate the plan for implementing these bioswales. A cost analysis was performed to evaluate the economic viability of this solution. Finally an evaluation of the safety considerations and economic, social and environmental consequences was performed. While the implementation of green infrastructure may be more convenient during the initial construction of a site, this study goes to show that implementing green infrastructure in existing urbanized spaces is possible and can lead to a better, more sustainable, and greener future.

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APPENDICES

A. MAPS

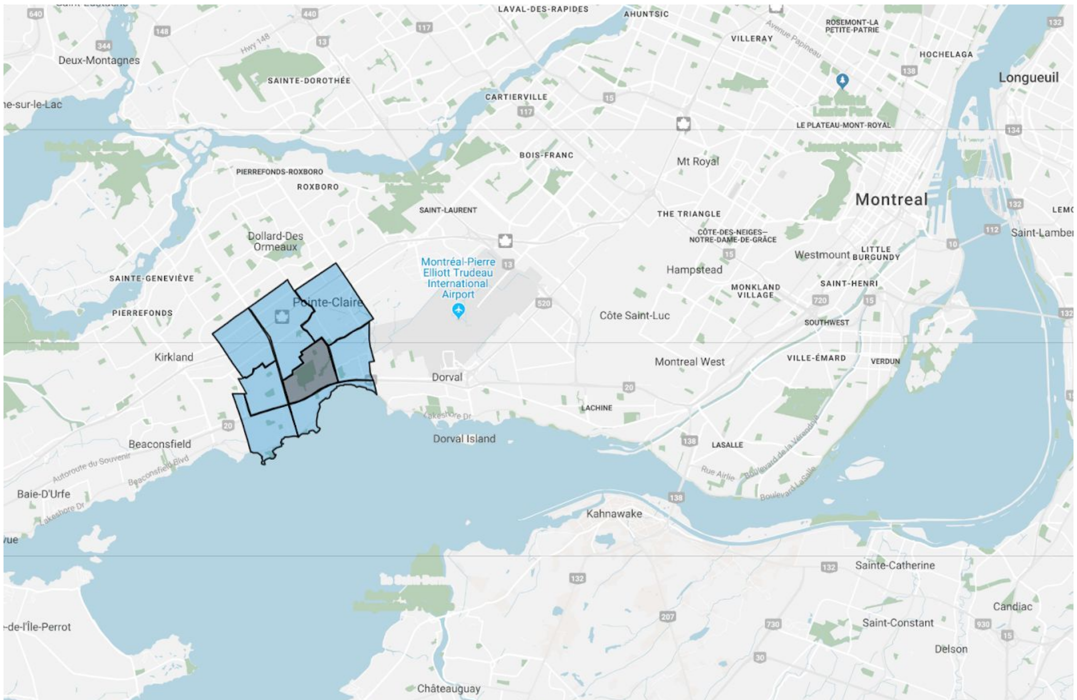

Figure A-1. Map of the City of Pointe-Claire with the district of Lakeside Heights highlighted in grey. Source: Pointe-Claire, 2019b.

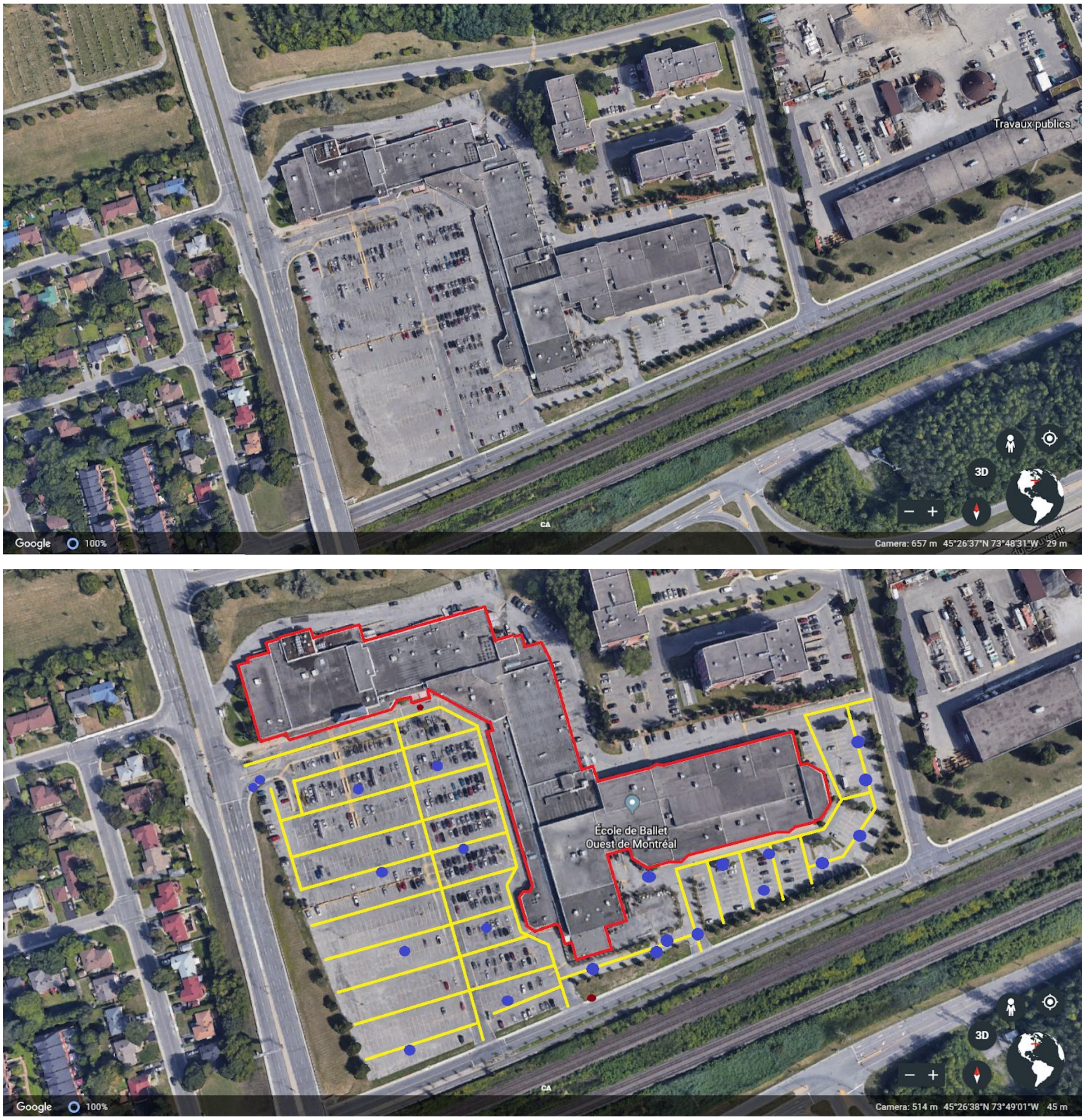

Figure A-2. Satellite view of Plaza Pointe-Claire and marked-up satellite view of Plaza Pointe-Claire where, (a) outlined shopping center (red line); (b) main thoroughfares (yellow lines); (c) water manholes (blue circles); (d) sewer manholes (brown circles). Source: Google Earth.

B. ADDITIONAL FIGURES

Figure B-1. A series of planters designed to infiltrate water as a part of the City of Portland's Green Streets program. Source: City of Portland, 2019.

Figure B-2. The Filterra® Bioretention System with curb openings to allow for water inflow. Source: Stormwater360, 2019.

C. CITY OF POINTE-CLAIRE ZONING BY-LAWS

7.4 Parking layout

Parking Angle (in relation to the direction of the circulation)	Parking Space		Circulation Aisle Minimum Width	
	Minimum Width	Minimum Length	One Way	Two Ways
0 degrees	2.5 metres	7 metres	4.5 metres	6 metres
45 degrees	2.6 metres	5.5 metres per space and 5.73 metres in width perpendicular to the aisle	4.5 metres	6.5 metres
90 degrees	2.7 metres	5.5 metres	6 metres	6.6 metres

7.5 Building of parking areas

a) Outdoor parking areas and access lanes must be covered with one or more of the following materials:
i) Porous concrete, pervious paving, open-grid pavement or grass pavers;
ii) An inert material, other than non-stabilized gravel or pebbles, with a solar reflectance index of at least 29,as certified in accordance with the manufacturer's specifications of the material;
iii) Asphalt, concrete, paving stones or interlocking brick.

c) All ground level parking areas of six (6) spaces or more shall be bordered by a concrete curb at least 15 centimetres (6 inches) high and located at least 60 centimetres (2 feet) from the adjacent lot lines. This curb can be discontinued to allow the rainwater to flow towards the surrounding natural surfaces. It shall be solidly anchored and properly maintained.
Amendment PC-2775-39 (February 2, 2018)

e) The layout of a ground level, non-covered parking area with twenty (20) or more parking spaces must include vegetation landscaping elements covering at least 10% of its surface. However, if the parking area is covered, in whole or in part, with a material identified in subparagraphs i. and ii of the present article, the vegetalized landscaped area may be reduced to 5%, in proportion to the parking area that is covered with a material that is identified under either of sub-paragraphs i. or ii. of paragraph 7.5 a).

Furthermore, the parking lot area must include one or both of the following 2 features:
i) A border at least 2 metres wide;
ii) A median with a minimum width of 2 metres.

In a border or a median, a deciduous tree with a minimum diameter of 5 centimetres and a minimum height of 1 metre above the ground or a coniferous tree with a height of at least 2 metres at the time of planting must be planted every 8 metres within this grassy or otherwise landscaped strip.
Amendment PC-2775-55 (June10, 2019)

f) Any parking area of more than 465 square metres (5,005 square feet) must be equipped with a rainwater drainage and retention system in accordance with the provisions of the Construction By-Law of the City of Pointe-Claire.

<u>7.6 Number of spaces required</u>

c) Businesses and services
ii) Class "B":
Group of Class "B" establishments (shopping centre) totalling more than 1,000 square metres of rental floor area: One (1) space per 20 square metres (215.3 square feet) of rental floor area, even if the shopping centre contains restaurants, bars and movie theatres.
Class "B" establishments outside of a shopping centre: One (1) space per 25 square metres (269.1 square feet) of rental floor area.

<u>9.6.2 Planting</u>

f) Prohibited tree species
Planting of the following tree species is prohibited throughout the territory of the City, except in public parks:
i) Weeping willow (Salix alba);
ii) Laurel willow (Salix laurifolia or Salix pentandra);
iii) Black willow (Salix nigra);
iv) Any other species of high branching willow (Salix spp.);
v) White poplar (Populus alba);
vi) Cottonwood (Populus deltoides);
vii) Lombardy poplar (Populus nigra var. italica);
viii) Any other species of high branching poplar (Populus spp.);
ix) All species of ash trees (Fraxinus);
x) Silver Maple (Acer saccharinum).

D. SCS RUNOFF CALCULATIONS

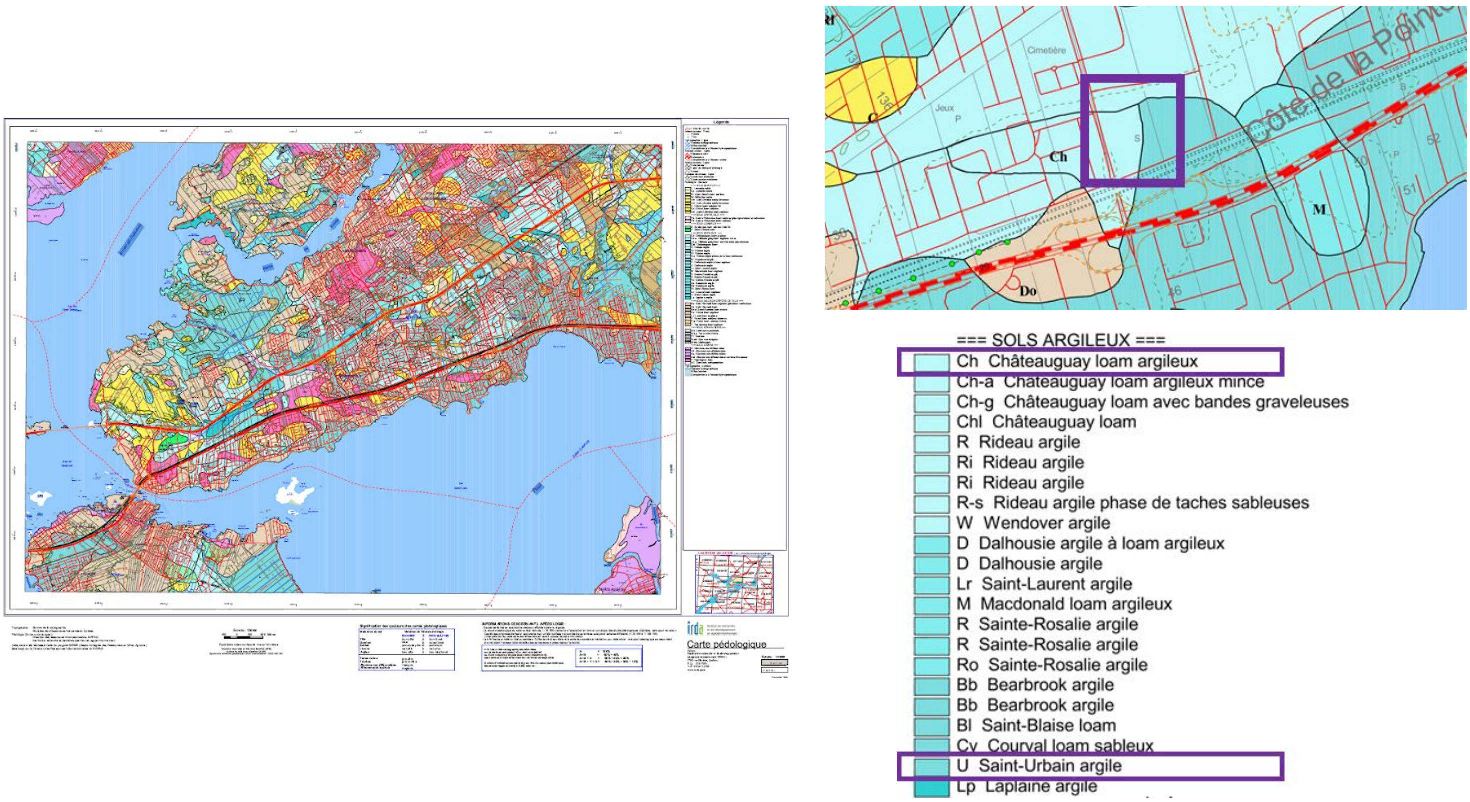

Figure D-1. IRDA Soil Map 31H05201- Montréal/Laval. Source: IRDA, 2020.

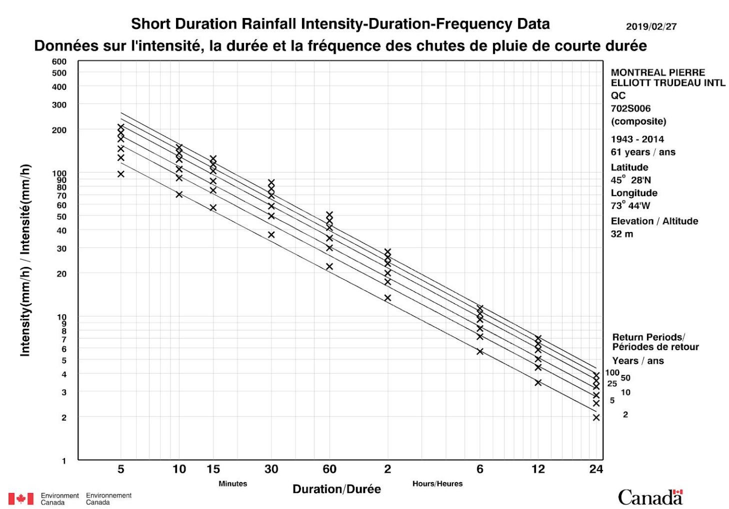

Figure D-2. Short Duration Rainfall Intensity-Duration-Frequency Data. Source: Environment Canada, 2019.

Table D-1. Curve Number Hydrologic Soil Group.

Group A	Group B	Group C	Group D
Low runoff potential	Moderate runoff potential	Moderate runoff potential	High runoff potential
High infiltration (>8 mm/hr)	Moderate infiltration (4 to 8 mm/hr)	Slow infiltration (1 to 4 mm/hr)	Low infiltration (<1 mm/hr)
•deep, well drained sands and gravels	•shallow loess, sandy loam	• soils with an impeding layer • moderately fine to fine textured soils •clay loams, shallow sandy loam, soils low in organic content, soils high in clay	• clay soils with a high swelling potential • permanently high water table • clay pan or a clay layer nest the surface • shallow soils over nearly impermeable materials

Table D-2. Runoff curve numbers for selected agricultural, suburban and rural areas.

Table 4B-3 Runoff curve numbers for selected agricultural, suburban, and rural areas (eastern Washington).

	CNs for hydrologic soil group			
Cover Type and Hydrologic Condition	**A**	**B**	**C**	**D**
Open Space (lawns, parks, golf courses, cemeteries, landscaping, etc.):[1]				
Poor condition (grass cover on <50% of the area)	68	79	86	89
Fair condition (grass cover on 50% to 75% of the area)	49	69	79	84
Good condition (grass cover on >75% of the area)	39	61	74	80
Impervious Areas:				
Open water bodies: lakes, wetlands, ponds, etc.	100	100	100	100
Paved parking lots, roofs, driveways, etc. (excluding right of way)	98	98	98	98
Porous Pavers and Permeable Interlocking Concrete (assumed as 85% impervious and 15% lawn):				
Fair lawn condition (weighted average CNs)	95	96	97	97
Gravel (including right of way)	76	85	89	91
Dirt (including right of way)	72	82	87	89
Pasture, Grassland, or Range – Continuous Forage for Grazing:				
Poor condition (ground cover <50% or heavily grazed with no mulch)	68	79	86	89
Fair condition (ground cover 50% to 75% and not heavily grazed)	49	69	79	84
Good condition (ground cover >75% and lightly or only occasionally grazed)	39	61	74	80
Cultivated Agricultural Lands:				
Row Crops (good), e.g., corn, sugar beets, soy beans	64	75	82	85
Small Grain (good), e.g., wheat, barley, flax	60	72	80	84
Meadow (continuous grass, protected from grazing, and generally mowed for hay):	30	58	71	78
Brush (brush-weed-grass mixture, with brush the major element):				
Poor (<50% ground cover)	48	67	77	83
Fair (50% to 75% ground cover)	35	56	70	77
Good (>75% ground cover)	30[2]	48	65	73
Woods-Grass Combination (orchard or tree farm):[3]				
Poor	57	73	82	86
Fair	43	65	76	82
Good	32	58	72	79
Woods:				
Poor (forest litter, small trees, and brush are destroyed by heavy grazing or regular burning)	45	66	77	83
Fair (woods are grazed but not burned, and some forest litter covers the soil)	36	60	73	79
Good (woods are protected from grazing, and litter and brush adequately cover the soil)	30	55	70	77
Herbaceous (mixture of grass, weeds, and low-growing brush, with brush the minor element):[4]				
Poor (<30% ground cover)		80	87	93
Fair (30% to 70% ground cover)		71	81	89
Good (>70% ground cover)		62	74	85
Sagebrush With Grass Understory:[4]				
Poor (<30% ground cover)		67	80	85
Fair (30% to 70% ground cover)		51	63	70
Good (>70% ground cover)		35	47	55

For a more detailed and complete description of land use curve numbers, refer to Chapter Two (2) of the Soil Conservation Service's Technical Release No. 55 (210-VI-TR-55, Second Ed., June 1986).

[1] Composite CNs may be computed for other combinations of open space cover type.
[2] Actual curve number is less than 30; use CN = 30 for runoff computations.
[3] CNs shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CNs for woods and pasture.
[4] Curve numbers have not been developed for Group A soils.

Table D-3. Runoff curve numbers for urban areas. Source: USDA, 1986.

Table 2-2a Runoff curve numbers for urban areas [1]

Cover description: Cover type and hydrologic condition	Average percent impervious area [2]	Curve numbers for hydrologic soil group: A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.) [3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) [4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation) [5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

1 Average runoff condition, and $I_a = 0.2S$.

2 The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.

3 CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.

4 Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.

5 Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4 based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

E. PARKING STALL AND DRAIN DIMENSIONS

The following dimensioned drawings represent the parking stalls which will be replaced by infiltration infrastructure. **All dimensions are in meters (m).**

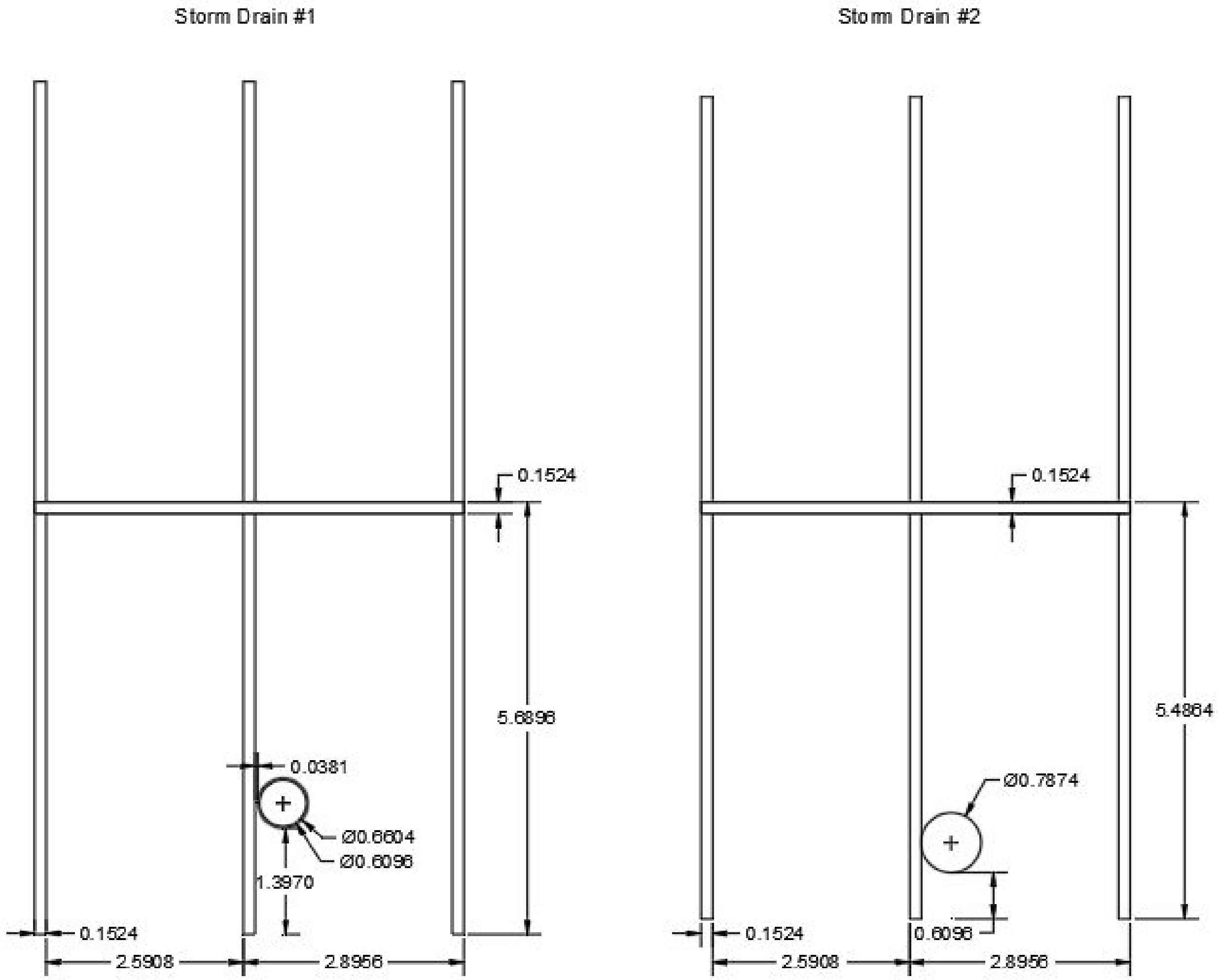

Figure E-1. Actual dimensions of parking spaces and stormwater sewer drain in Covered Area #1 and Covered Area #2.

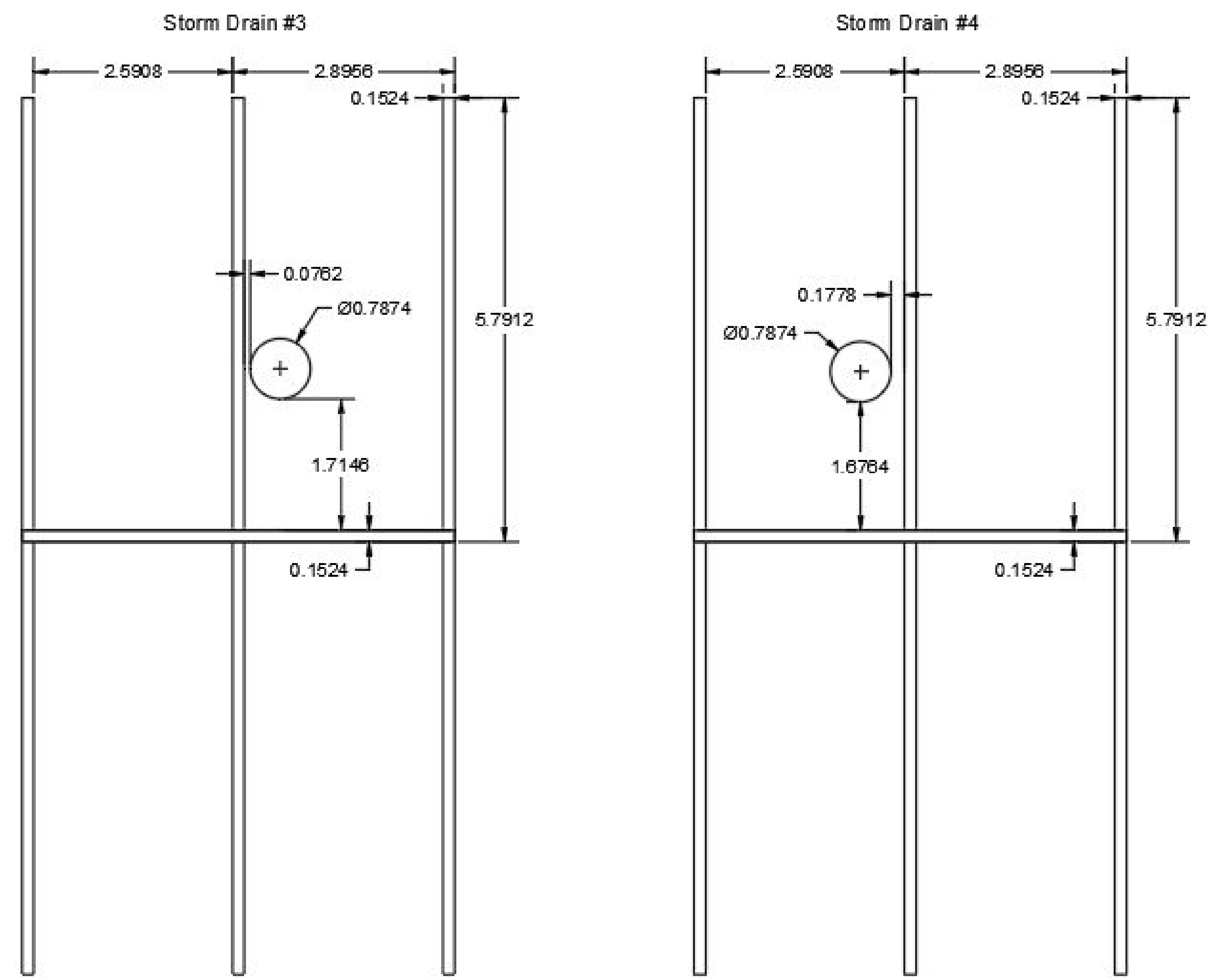

Figure E-2. Actual dimensions of parking spaces and stormwater sewer drain in Covered Area #3 and Covered Area #4.

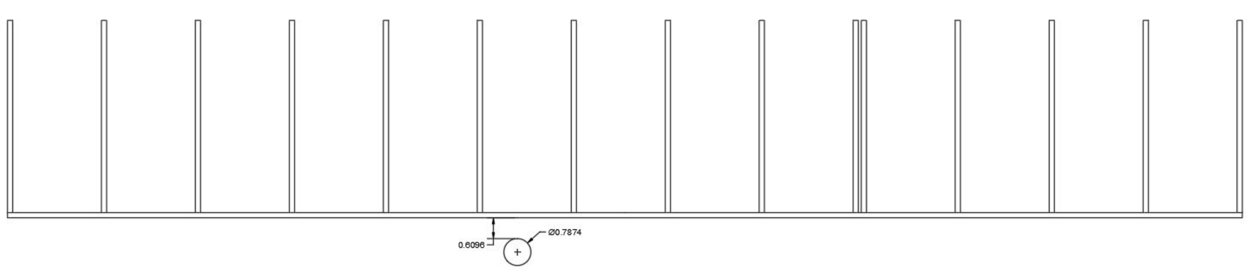

Figure E-3. Placement and dimensions of stormwater sewer drain in Covered Area #5.

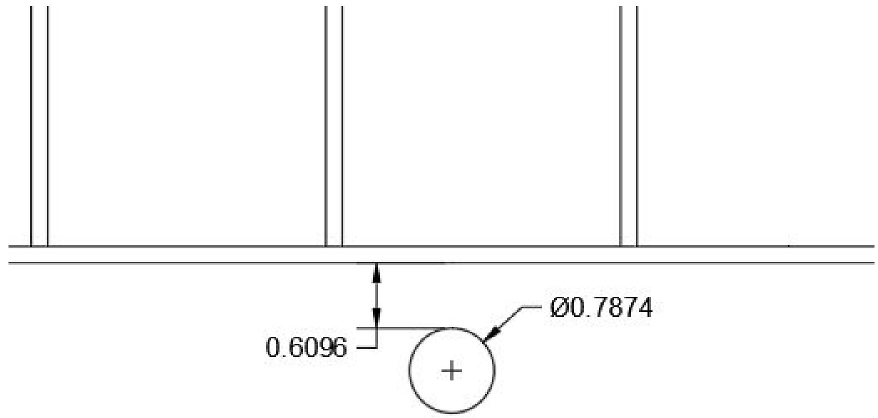

Figure E-4. Up-close view of dimensioned AutoCAD drawing and placement of stormwater sewer drain in Covered Area #5.