ANALYSIS OF CURRENT AND FUTURE LOW IMPACT DEVELOPMENT SITES IN THUNDER BAY, ONTARIO

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ANALYSIS OF CURRENT AND FUTURE LOW IMPACT DEVELOPMENT SITES IN THUNDER BAY, ONTARIO

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ABSTRACT

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The rapid spread of urbanization in Thunder Bay has caused the increase of impermeable surfaces and the increase in flood incidents within the city. Another contributing factor to increased flood incidents is due to the lack of tree canopy cover within the city. Because of increased frequency of intense storm events, stormwater management measures have been taken in the form of Low Impact Development (LID) sites to increase infiltration and filtration rates of city precipitation. The number of current LID sites around town is relatively small and three of these sites have been herein analysed. The three sites are the Beverley Street LID, D&R Sporting Goods LID and the McVicar Creek LID. Future LID sites have also been analysed and their effects hypothesized.

CONTENTS

TABLES

FIGURES

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INTRODUCTION

STORMWATER MANAGEMENT PRIOR TO LOW IMPACT DEVELOPMENTS

The traditional prescription for cities dealing with flooding issues prior to the development of Low Impact Developments (LID's), was bioretention cells (Dietz 2007). Bioretention cells are used to retain and treat urban stormwater. "A bioretention area is initially an excavated basin, at the bottom of which undrains are laid and covered with a gravel envelope" (Hunt *et al.* 2006). Although there are instances when bioretention cells have been proven to be successful in consistently reducing certain pollutants and their deleterious effects, there are a few contaminants that are not accounted for, primarily nitrate-nitrogen and phosphorus contaminants, which can also cause damage in the urban environment (Dietz 2007). Bioretention cells are a simple method for collecting contaminants in a centralized area so they can be dealt with at a later time, while LID's focus on returning the site to the pre-development hydrologic functions by treating runoff on site (Dietz 2007).

Bioretention cells were the epitome of past stormwater management plans because the objectives were solely focused on the quantity and quality of runoff, without a strong focus on the possibility of contaminants entering aquatic systems (Dietz 2007, Zimmer *et al.* 2007). These objectives have evolved to ensure that stormwater management now includes more advanced issues such as: ecosystem restoration, combined sewer overflow reduction, fisheries protection, potable surface/ground water resources protection, and wetland, riparian buffer and stream protection (Liaw *et al.* 2000). Urban stormwater best management practices (BMPs) have also been implemented in order to reduce the potential for aquatic contamination (Zimmer *et al.* 2007). There has also been a drive for intelligent and smart planning of urban growth, specifically water sensitivity planning and methods to prevent floods entirely (Ahiablame *et al.* 2012, Dhalla and Zimmer 2010).

A large portion of the problems that arose from neglecting these issues had previously been mitigated through conservation of natural resources, zoning restrictions, increasing open spaces, structural controls and non-structural controls (pollution prevention etc.) (Liaw *et al.* 2000). Additionally, conventional stormwater management practices were solely interested in controlling peak discharge levels without focusing on the actual cause of the increased discharge rates, such as the proliferation of impervious surfaces within the urban centre (Hewes *et al.* 2013).

IMPORTANCE OF STORMWATER MANAGEMENT

Urbanization increases the risk of flooding through several different ways and requires that flood mitigation efforts be taken into serious consideration (Hollis 1975, Rasid 1988). One factor that increases the risk of urban flooding is that most cities are constructed on floodplains due to the convenience of flat land and the accessibility offered by waterways (Nirupama and Simonovic 2007, Rasid 1998). The issue with building on floodplains is that rivers are prone to flooding during spring runoff or significant storm events and impervious surfaces reduce the rate of infiltration that is normally present in the wetland (Ahiablame *et al.* 2012, Nirupuma and Simonovic 2007, Rasid 1988).

Impervious surfaces reduce infiltration rates; depression and interception storage declines (Hollis 1975). A city can attempt to mitigate these negative effects through the construction of drainage channels, proper design of sewer systems and well-maintained sewer lines (Hollis 1975). If these measures are properly executed, there could be a potential increase in drainage density and a decrease in overland flow time (Hollis 1975). The problem of floods can either be addressed through structural and non-structural measures (Rasid 1988). Canada primarily uses structural measures in the form of engineering structures such as dams, reservoirs, levees, floodwalls, floodways and channelization projects to direct the flood in hopes to reduce damage (Nirupama and Simonovic 2007, Rasid 1988). These measures require a significant amount of money and time to construct, and yet they have been consistently proven to be ineffective in completely controlling floods and reducing the damages (Rasid 1988). Non-structural measures attempt to reduce floodplain occupancy through land use regulations in the hope to reduce the persistence of impervious surfaces (Rasid 1988). The City of Thunder Bay was built on the floodplains of the Kaministiquia, the Neebing and the McIntyre Rivers and as such is prone to flooding, particularly from the Neebing and McIntyre Rivers (Rasid 1988). Development in the intercity portion of the city has increased the risk of flooding from the Neebing and McIntyre, and has prompted the adoption of structural flood control measures (Rasid 1988).

In addition, urbanization decreases plant biodiversity and is replaced with monoculture grasses full of fertilizers and pesticides (Davis 2005). The addition of these contaminants along with those found on the road from vehicle emissions (oils etc.) or road maintenance (tars, salts etc.) can easily make their way into waterways destroying wildlife habitat and aquatic life (Davis 2005). Additional sources of contaminants that increase organic and pathogen loading are in the form of urban animal waste that would otherwise be absorbed into the ground, but instead are washed away into water systems (Davis 2005).

A study done in the Upper Thames River watershed in south-western Ontario found that urbanization increased from 10.07% of the watershed in 1974 to 22.25% of the watershed in 2000 (Nirupama and Simonovic 2007). The rapid increase in impervious surfaces quickly reduced the time to peak and produced higher peakflows in the drainage channels (Nirupama and Simonovic 2007). This gives further proof to the fact that through affecting the hydrologic cycle and reducing infiltration rates, the risk of urban flooding increases. G.E Hollis summed up the effects of urbanization on the hydrological with his statement in 1975 when he said:

> *When large areas of land are rendered impervious by roads, footpaths, roofs, and parking areas, the area in which rainfall can infiltrate into the soil is reduced, depression and interception storage of precipitation may be reduced, and overland flow can take place readily on the relatively smooth impermeable surfaces.*

LOW IMPACT DEVELOPMENT SITES

Low Impact Development sites (LID) were initially developed in Maryland, USA in 1999 and were designed with the purpose to counteract the negative effects of surface runoff and offset the issues of flooding within the urban centre caused by impervious surfaces (Dietz 2007). The goals of LID's are to manage stormwater through decentralized micro-scale control measures (Ahiablame *et al.* 2012). Additional goals include promoting environmentally sensitive designs, prevention of floods rather than mitigation, reductions in costs for stormwater infrastructure and empower the community for environmental protection (Ahiablame *et al.* 2012).

The planning process for the construction of LID's begins at the watershed level and analyzes the following factors as they effect water quantity and quality as it leaves the watershed: development densities, the placement and mixing of developed and undeveloped lands, residential, commercial and other land uses combined (Davis 2005). The next stage is site preparation and attempts to follow the goal of LID's, which is to return the site to predevelopment conditions (Davis 2005). The specific site preparation is highly dependant on the individual sites and can incorporate the natural vegetation of the site into the development (Davis 2005). This contradicts the normal procedure of clearcutting and levelling the site to make room for the LID, and satisfies the natural component of LID's (Davis 2005).

The flexibility of LID's allows them to be constructed in an individual and site-specific manner. However the issue of no designated prescription for LID development arises and can cause difficulties in determining the proper steps to take when developing a LID site (Davis 2005). Another issue in implementing LID's is the land restrictions that either deal with current zoning statutes or regulatory statutes (Davis 2005). A practice that LID's often incorporate into their design is the concept of reducing the width of streets and sidewalks, in order to reduce the amount of impervious surfaces (Davis 2005). However this causes an issue when access to streets by school buses, garbage trucks, and emergency vehicles are taken into account (Davis 2005).

Cost can also become a limiting factor when considering the construction of an LID because it is more costly to build an LID than it is to level the land or create a retention pond. The benefits of LID's are often neglected by the public and can lead to a lack of public support (Davis 2005). A low cost example of an LID is the principle of green roofs (Davis 2005). Green roofs are classified as bio-filtration systems where the rain water is collected, filtered and the subsequent runoff is treated (Davis 2005). Green roofs have the benefit of not requiring land set aside for an LID, but are incorporated onto the roof of buildings (Davis 2005). Although this is cost effective and reduces land requirements it is often executed on a small scale and does not carry the same amount of potential as a large scale LID. LID's are simply one form of urban planning that act as a balance to the detrimental effects of urbanization (Ahiablame *et al.* 2012).

Although there are many highlights to the implementation of LID's, there are still many that are sceptical as to the cost effectiveness and how accurately it achieves its goals (Ahiablame *et al.* 2012). The main reason for this scepticism arises from the fact that LID's are still a relatively new field of study and as such there are knowledge gaps that cannot be accounted for (Ahiablame *et al.* 2012). As previously mentioned the goals of LID's are; "To offset these [urbanization] impacts, an increased emphasis on maintaining natural water balance and replicating the predevelopment hydrologic cycle is required" (Ahiablame *et al.* 2012). LID's were designed to provide measures to restore hydrologic health to the watersheds through conservation site design strategies, infiltration practices, rainwater harvesting, runoff storage and evapotranspiration, runoff conveyance, filtration practices and landscaping (Dhalla and Zimmer 2010). With the goal of site-by-site treatment it can be assumed that it could be potentially more efficient to employ greater numbers of smaller LID's rather than fewer larger LID's to ensure water is being dealt with at the source (Damodaram *et al.* 2010). LID's are also designed in such a way to be as natural as possible and recreate predevelopment conditions (Damodaram *et al*. 2010). Some of the planning and design principles that are taken into account when designing a LID are: 1) minimize impacts to the extent practicable by reducing imperviousness, conserving natural resources/ecosystems, maintaining natural drainage courses, reducing use of curbs, gutters and pipes, and minimizing clearing and grading; 2) provide runoff storage measures dispersed uniformly throughout the landscape with the use of a variety of small-decentralized detention, retention, and runoff practices; 3) maintain predevelopment time of concentration by strategically routing flows to maintain travel time and control discharge; and 4) implement effective public education programs to encourage property owners to use pollution prevention measures and maintain a lot of management practices (Liaw *et al.* 2000).

EXAMPLES OF LOW IMPACT DEVELOPMENTS

LID's are highly diverse and are designed based on the particular site that the LID will be treating and as such there are many different examples of how LID's have been implemented. A study conducted in Waterford, Connecticut monitored the effects of storm events on a traditional (17 lots) subdivision and a LID (12 lots) subdivision and found that runoff and pollutant exports were much higher on the traditional sites than on the LID sites (Dietz 2007). LID's are able to produce this result by mimicking the natural hydrologic process of a natural forest in the form of vegetation interception, small depression storage, channel storage, infiltration and evaporation (Liaw *et al.* 2000).

Permeable pavements are another type of LID and allow water to infiltrate through the pavement to the soil underneath through the presence of void spaces (Hewes *et al.* 2013). There are 2 main types of permeable pavement that are used to decrease runoff and increase infiltration (Hewes *et al.* 2013). The first method uses very fine particles in traditional asphalt or concrete to increase infiltration and the second uses block pavers (either made from plastic or concrete), which creates small pathways for the water to infiltrate into the soil (Hewes *et al.* 2013).

A key component to combating flooding and the negative effects of storm water in the urban environment is the presence of vegetation (Donovan *et al.* 2016). LID's attempt to recreate the natural landscape by incorporating vegetation into the planning process. This leads to the importance of understanding the relationship between trees and stormwater runoff (Donovan *et al.* 2016). The three ways that vegetation effect stormwater runoff is through interception, transpiration and infiltration (Donovan *et al.* 2016). Interception is the process of rainwater being caught in the canopy and evaporated off the tree, transpiration is the water the tree uses for natural processes and infiltration is increased by the presence of roots in the soil (Donovan *et al.* 2016). Canopy structure and shape has been found to be a strong leader in reducing stormwater through the increase of rainfall interception (Donovan *et al.* 2016, Xiao and McPherson 2003). Therefore trees with large full canopies are better suited to reduce stormwater in the urban centre (Donovan *et al.* 2016). The study conducted by Donovan *et al.* 2016 discovered that although trees reduce rainfall reaching the ground, it is the grass and shrubs on the ground that reduce overland flow more effectively than tree cover (Donovan *et al.* 2016). The main difference when considering the placement of trees or shrubs is the fact that planting trees does not necessarily remove large amount of impervious surfaces, while grasses and shrubs require the reduction of such surfaces (Donovan *et al.* 2016).

An area in cities that has both the potential to increase runoff and decrease runoff are parking lots (Rushton 2001). There was a study conducted on the introduction of LID sites into several parking lots and it was found that even the small swales and garden areas used reduced the runoff significantly (Rushton 2001). Reducing the size of the parking lots was also used as a way to reduce impervious surfaces. The next step of the study was to analyze the pollutant loads in the runoff and see if the LID's did in fact reduce pollutants (Rushton 2001). It was found that the parking lots with LID's had a much lower percentage of pollutants than the runoff from the unprocessed sites (Rushton 2001).

CLIMATE CHANGE

Fossil fuels have been accumulating in the atmosphere at a steady rate such that there has been a global temperature increase of 0.74°C (OCCIAR 2010). The increase in temperature has lead to the decreased availability of water, increase damage from flooding and storms and it is projected to get worse as time goes on (OCCIAR 2010). Northwest Ontario has experienced an increase of mean annual temperature by 1.4°C since 1948 and models have shown this value will increase by 2.5 to 3.7°C in the next 30 years (OCCIAR 2010). Flooding has been an issue for many communities and as the temperature increases, the frequency and intensity of these events is estimated to also increase (OCCIAR 2010). Data collected at the Kapuskasing weather station have shown that over the past 73 years the greatest increase in temperature is found in the spring. This correlates well with the time for the spring melt and could increase the speed of snow melt and thus flooding (OCCIAR 2010).

THUNDER BAY FLOODING

On May 28th 2012, Thunder Bay experienced a record rainfall event that caused thousands of dollars in property damage (Saunders 2012). According to the Environment Canada forecast at 4 pm on May 27th, they predicted showers with a slight risk of a thunderstorm and an estimated precipitation of 10 to 15 millimeters (Saunders 2012). The rain event began at 12 am that night and during the first hour of recording there was a total of 50 mm of rainfall, followed by 70 mm after two hours and 100 mm in the first 24 hours (Saunders 2012). The average precipitation in the month of May averages around 65 mm, and for 2012 the total precipitation was 201 mm (Saunders 2012). A flash flood occurred as a result, reaching the 100-year return level (Hobbs 2012). The rapid increase in precipitation and the reduction of permeable surfaces allowed the sewage system to be flooded which lead to the flooding of many houses with contaminated sewage water (CBC 2012). Although this was the 7th declared emergency in Thunder Bay in the previous seven years, it was the largest in terms of scope, scale and duration (Hobbs 2012). There were approximately 4,000 to 5,000 homes that were affected and led to many people having to find temporary accommodation at Lakehead University (Hobbs 2012). After the flood, the City developed strategies to be implemented so as to reduce the risk of future flooding (Hobbs 2012). One strategy was the Neighbourhood Master Stormwater Drainage Study, with the purpose to study the areas most affected by the flooding and the second strategy was to create two LID's (Hobbs 2012).

CITY OF THUNDER BAY RESPONSE

In response to the flood in 2012 the City of Thunder Bay has developed two LID sites in town. The larger one is on Beverley Street and the second is across Memorial Avenue in front of the D&R Sporting Good Store. Both sites maintain the same general objective of being used for storm water retention and water purification (Gail Willis pers.comm.). However there are several differences between the two, due to the varying soil conditions at both sites. The Beverley Street LID has the benefit of having a much deeper water table and as such can retain and infiltrate the water into the soil, while the D&R LID has a much higher water table and can only filter the water (Gail Willis pers.comm.). Due to the fact that the Beverley LID was the first one implemented in Thunder Bay it was not placed in the most efficient location to achieve the desired objective, but instead was designed to be an experimental site and a method to raise public awareness to the idea of LID's (Gail Willis pers.comm.). While there are only a few LID's in Thunder Bay currently, there are plans for the next year to develop three to five more LID's across town to further reduce the risk of the deleterious effects of flooding events (Gail Willis pers.comm.).

RATIONALE FOR PRESENT STUDY

Due to the fact that Thunder Bay has only recently implemented the use of LID's for storm-water retention there are a wide variety of unknowns that should be analyzed. The variables that will be analyzed through the course of this study include the efficiency and effectiveness of the present LID's as well as the future effects of the planned LID's. Both the present and future LID's will be analyzed in terms of different components of construction used in the purification process, the exact placement and their size. It is hypothesized that climate change will only increase the incidents of flooding events in Thunder Bay and that the importance of LID's will grow exponentially in the urban sector.

METHODS

This study was primarily an analytical review of the current and future LID sites/measures in Thunder Bay, and as such, the majority of the data collected were obtained through presentations, individual discussions and a workshop that occurred at Confederation College on LID construction. The people that were presenting or consulted, where either directly involved with the LID implementation or were experts in the field of LID design, thus ensuring the accuracy of the data. Among those who participated in discussions was Werner Schwar, Supervisor-Parks and Open Spaces Planning in Thunder Bay and Gail Willis, senior technologist in the Engineering and Operations Division for the City of Thunder Bay. The presentation on LID design and construction was done by Chris Denich, an engineer from Aquafor Beech Ltd. in Southern Ontario with more than ten years experience in LID implementation. The information obtained from the discussions and the workshop is highly relevant to the study because they either deal directly with the different LID sites that were studied, or dealt with pertinent data to future LID developments. The area of study was in the city of Thunder Bay and the majority of the data used were acquired from the office of the Thunder Bay Parks and Open Spaces Section and the different measures taken by the City during the LID developments studied. The LID's that were the main focus of the study were those located: a) on Beverley Street, b) in front of the D&R Sporting Goods

Store and c) the McVicar Creek walkway on Clayte Street. During the course of the study it was discovered that the location of the current LID's was not relevant to the principle purpose of the LID's, but were designed for other societal or experimental purposes. These purposes included public education, test runs, public interest or the availability of funding. Sample handling was conducted through discussions, presentations and workshops. This study was designed to incorporate all aspects of LID design including the following factors: location, engineering, construction, subsequent planting and future planning. The questions asked were directed at the plant vegetation that was used on site to determine the effects of plant life on LID functions. The data used during the analytical component of the study were gathered from online sources, first hand accounts and government issued documents such as the Stormwater Management Plan for Thunder Bay (City of Thunder Bay 2016) and the Low Impact Development Stromwater Management Planning and Design Guide (City of Thunder Bay 2016).

Aerial images of the three different LID sites are presented in Figures 1-3. The Beverley Street (Fig.1) and D&R Sporting Goods LID's (Fig.2) are clearly visible in the figures as they were constructed previous to when the images were taken. The McVicar Creek LID's (Fig.3) however are not visible because they were only recently constructed, but it spans over both sides of the bridge and lies on the north side of the path and bridge.

Figure 1. Beverley Street LID Source: Google earth

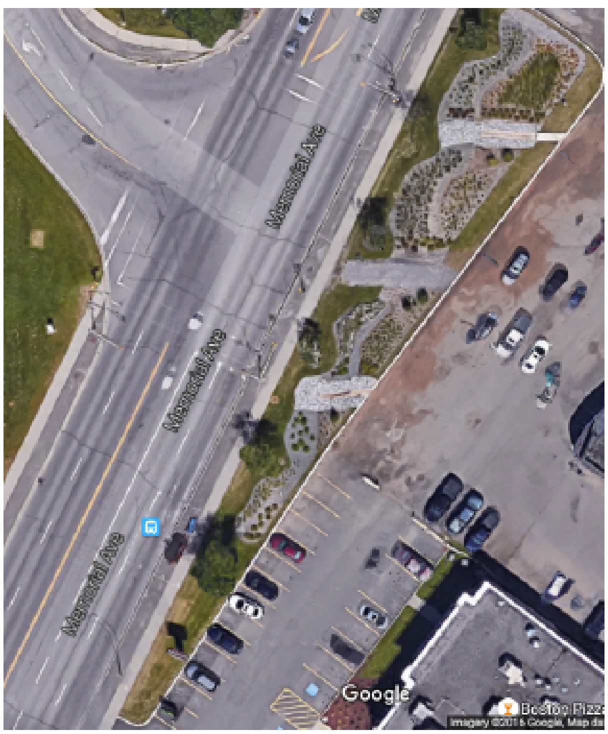

Figure 2. D&R Sporting Goods LID Source: Google earth

Figure 3. McVicar Creek LID Source: Google maps

RESULTS

As a response to the flooding in 2012 the City of Thunder Bay has incorporated LID's into the city's Stormwater Management Plan and began building LID's around the city. Due to the fact that LID's are a recent development, many of the sites were built as experiments to test whether the system would work in Thunder Bay. Three of the larger sites became the focus of this study and were analyzed based on their efficacy, placement and construction. The first LID that was studied is the one on Beverley Street.

BEVERLEY STREET LID

The Beverley Street LID was designed and built with the purpose to act as a societal and financial experiment. Although there were goals to reduce runoff from Beverley and High Street, the main objectives of choosing the location was due to the public nature of the location. The City wanted to ensure that the public would have a chance to see and interact with the LID in order to see if they were interested in further projects. Due to the large size and scale of the LID, there was little information on how the development should proceed in terms of construction design, vegetation planted and overall success of the development. There were external sources of information from North Dakota and Michigan that were used during the planning stage, but the general solution to decision making was based on scientific speculation. The Beverley Street LID was purposed as a bio-retention site and contributes to the reduction of water contaminants through infiltration and contaminant retention.

The specific plant species on the LID were chosen based on the individual species aesthetics and drought tolerance. The main reason for this was because the site was situated on an old roadbed and as such the soil was nutrient poor and was only able to sustain hardy plant species. The majority of the plant species were shipped in from external nurseries in Winnipeg and Toronto to accomplish the designated planting plan. The types of species used were perennial shrubs, trees and a bioretention seed mixture with strong hardiness.

Figure 4 shows the two curbside entrances for the LID site and were purposed to receive runoff from Beverley Street in the west and High Street in the north. The curbside entrance was a cost effective method for facilitating the flow of water off the road and directly into the site.

Figure 4. Road entrances (Beverley Street LID)

Figure 5 shows the pre-treatment area for the LID. The purpose of the pre-treatment area was to remove and reduce the amount of large debris that enters the site and increase the efficiency of site clean up. In this instance large debris accounts for anything that gets washed into the treatment site from the different roads that feed into it. The material used was a basic white stone that allows water to easily pass through while stopping large debris. This was a common trend that was seen with the other two LID sites as well. Although large debris does not hinder the infiltration of water into the soil, it reduces the aesthetics of the site and can cause the public to reject further developments if they are seen as garbage accumulation zones. The pre-treatment zone was a combination of 10-25 cm clean rock weirs for the top layer, followed by concrete pre-treatment runnel, compacted aggregate base and lastly the compacted sub-base beneath the pre-treatment area.

Figure 5. Pre-treatment area (Beverley Street LID)

Figure 6 is a panoramic view of the entire LID site from the east end (front) to the west end (back). The site was designed in such a way that there was a slight decrease in slope from the sides into the facility and from the front to the back end of the facility. This would increase the flow of water into the facility and enable any water that did not infiltrate into the soil, to move into the storm drain underneath the facility. The main portion of the facility consisted of a bio retention mixture of 90% washed sand, 10% compost, shredded hardwood mulch and subgrade. Due to the fact that the main portion of the facility is designed to be submerged under water the only vegetation planted was a variety of different water tolerant grasses.

Figure 6. Complete LID (Beverley Street LID)

Although the purpose of the site is to facilitate infiltration rates, the storm drain ensures that there is not an elongated period of stagnant water. There were three observation stations within the site (Fig.7) and allows for the water levels in the site to be observed. Since the construction of the site there has not been a rain event large enough to cause a water build up within the site and as such all attempts to observe and test the water within the site has yielded no results. The storm drain exits from the west side of the site and goes under the road and into the D&R Sporting Goods facility.

Figure 7. Drain pipe observation stations (Beverley Street LID)

D&R SPORTING GOODS LID

The LID facility in front of the D&R Sporting Goods store along Memorial Street was designed with the purpose to reduce the flooding that was occurring in the parking lot. For the design and construction of this facility, the City outsourced the job to Emmons and Oliver Resources (EOR) from Oakdale Minnesota, which is a company that has had past experience with LID construction. This facility was also used as a test run for EOR to see how effective LIDs could be in such northern a setting as Thunder Bay. EOR was also responsible for choosing the vegetation within the site. The main difference between the Beverley LID across the street and the D&R LID was that the water level was much closer to the surface on the D&R site. For this reason the D&R LID was classified as a filtration system.

The pre-treatment area for the LID (Fig. 8) is only one, out of the two, areas for water to enter the system. Although the LID used the same clean rock as the Beverley Street LID, there was a slight increase in infrastructure via a cement portion that led further into the facility. There is one pre-treatment area north of the storm drain, and one at the southern end. The main reason it was required that two pre-treatment areas be constructed is because of the length of the facility and increasing the facilitation of runoff into the facility.

Figure 8. D&R Sporting goods LID entrance and pre-treatment

As previously stated the main difference between two LID's (Beverley and D&R) is the water level. This affected how the site would be constructed and planted and these differences can be seen in Figure 9. One significant difference in the planting process was the use of plant associations rather than planting a mix. This resulted in there being a limited amount of ground cover, for example little to no grasses, and the use of non-native plant species. There was also a significant difference in the materials used during construction. The west side of the facility was lined with a portion of a sand filter with rock and mulch, while the east side consisted predominantly of shredded hardwood mulch.


Figure 9. The north (Left) and south (Right) sides of the D&R LID

Figure 10 demonstrates the existing storm drain that the facility straddles. It comes from across Memorial Street and leads into the City's main storm drain. In order to increase the flow of water from both sides of the facility, it required there to be a moderate slope towards the drain. Gravel was applied on top of the drain to allow ease of water percolation.

Figure 10. Storm drain (D&R LID)

To increase the speed of water movement towards the storm drain, PVC pipes were incorporated into both sides of the facility. For observation purposes, stations along the PVC pipes were constructed to monitor water levels and retrieve potential water samples. An example of one of the observation stations can be seen in Figure 11.

Figure 11. Drainpipe observation station (D&R LID)

McVICAR CREEK LID

The LID at McVicar Creek has two components that traverse both sides of the creek. This is one of the most recent LID developments undertaken by the City and was completed in October of 2016. Both the west and east site LID's feed into the creek, but were constructed with slightly different designs. The main reason that the LID development was constructed at McVicar Creek was because of the McVicar Creek restoration plan, rather than for the hydrological significance of the site (City of Thunder Bay 2014). The plan called for the beautification of the site and provided the funds required to finance the development and construction of the LID.

Figure 12 shows the pre-treatment area for the west side of the creek can be seen. The LID accepts water from Clayte Street, Hartviksen Street and Balsam Street. The pipe feeding into the LID from the storm drain is identified within the white circle. As a result from the introduction of the LID to the already functioning storm drain system, there were modifications needed to facilitate water movement. The pre-treatment area followed the same guidelines as the other two LID's and used the white wash rocks as a large debris accumulation zone.

Figure 12. West LID entrance and pre-treatment and feeder pipe (white circle) (McVicar Creek LID)

The main difference between the two sites of the LID lies in the purposed function and subsequently the construction. The west side LID (Fig. 13) consisted of hardwood mulch, soil mixture (90% washed sand, 10% compost), deep pea gravel and a clear stone bottom. One goal that was met by the vegetative mixture of several different woody shrubs such as *Diervilla lonicera* Mill. (dwarf bush honeysuckle) and *Cornus sericea* L. (red osier dogwood), was the goal of aesthetics. Similar in design to the other LID's was the white observation port to analyze water flow and infiltration efficiency. There is a sub-drain that feeds excess water into a splash pad of river stone that leads to the creek.

Figure 13. West LID complete (McVicar Creek LID)

The East LID had a much larger and evident entrance to the system than the west side (Fig. 14). A significant difference that influenced the construction of the entrance and pre-treatment area of the east side LID lies in the fact that there is no storm drain feeding into the site. This would mean that water flow would need to be facilitated and channelled into the facility. Hence the concrete runnel ensures water is entering the facility. The same rock material was used for the pre-treatment process of the LID.

Figure 14. East LID entrance and pre-treatment (McVicar Creek LID)

The main portion of the LID consisted of the same rock material as the entrance and pre-treatment area. Surrounding the outside of the treatment area was a combination of woody species such as bush honeysuckle, red osier dogwood and several saplings of *Sorbus decora* C.K Schneid (showy mountain ash) and *Larix laricina* (Du Roi) K.Koch (tamarack). Similarly to the west side there was a sub-drain and cleanout that led under the path to a splash pad with river stone that would feed excess water into the creek should the system be overloaded. The complete east side LID is shown in Figure 15.

Figure 15. East LID complete (McVicar Creek LID)

The LID at McVicar Creek was constructed with the objective to reduce the amount of contaminants entering the Thunder Bay harbour, which is classified as an Area of Concern (AOC), and was placed on McVicar Creek because of the availability of funds through the McVicar Creek Protection & Rehabilitation plan (MCRP) (City of Thunder Bay 2014). The objectives of the MCRP are to ensure there is “a healthy and sustainable watershed that contributes to the economic, environmental, and social vitality of the city, while serving as a precedent for Thunder Bay and the greater Lakehead community” (City of Thunder Bay 2014). At the time when the plan was written in 2014, the concept of LID’s was still in the experimental stage of development and as such was only considered as being possibly implemented. Figure 16 depicts plans for the portion of McVicar Creek where the LID was eventually developed. Under the MCRP the areas labelled PR 9 and PR 10 were considered to be areas where the treatment type would be bioretention with pre-treatment and is exactly what they turned out to be.

Figure 17 was selected from the Thunder Bay Stormwater Management Plan (SMP) to show the different watersheds that are associated with Thunder Bay. The Beverley Street and D&R LID's are found in the McIntyre watershed and the McVicar Creek LID is in the McVicar watershed.

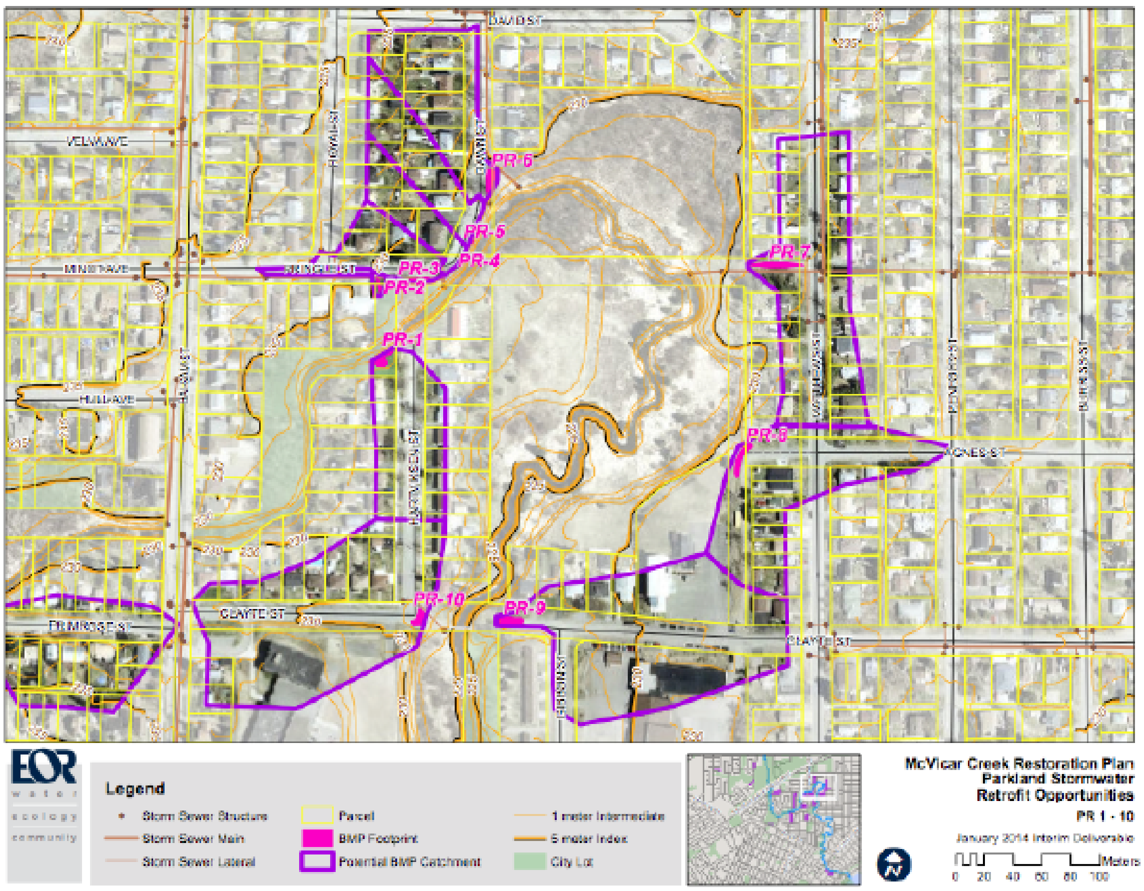

Figure 16. Parkland Retrofits: BMPs and catchments

Figure 17. Lakehead watersheds Source: Thunder Bay SMP

DISCUSSION

After an in-depth review of the three different LID's, an analysis covering different components of LID development in Thunder Bay was undertaken. The analysis examines the current placement of the LID's and attempts to discern whether they were placed in the most efficient location to achieve the goals of stormwater management or alternative locations that might have more efficiently reached those goals. Different aspects of LID construction will be examined and the policies surrounding LID development will be compared to methods used in the City of Portland, Oregon. The City of Thunder Bay has already planned future locations for potential LID placement and these will be analyzed for efficiency purposes.

CURRENT LID PLACEMENT/CONSTRUCTION

Due to the fact that LID's have only been implemented in Thunder Bay since the 2012 flood, there are still many variables left unknown with regards to how to increase the effectiveness of LID placement. The three LID's that were studied all had different reasons for why they were placed in the locations they can be found.

The Beverley Street LID, which is one of the largest of the LID's, was placed purely because of the publicity of the area. The City planners wanted to increase the public's knowledge of LID's in an attempt to gain public approval of the new system to be implemented in Thunder Bay. A key benefit to LID's is the fact that they do not appear to be water treatment facilities and can look similar to other vegetated areas to the naked eye. It was on this benefit that the City planners were attempting to capitalize on when they chose the location for the first large LID development in Thunder Bay.

Upon examining the location of the LID it is in a highly trafficked area between the roads of Beverley, High and Memorial, all of which experience peak amounts of vehicle traffic. It is also close to the Thunder Bay Community Auditorium, the Port Arthur Stadium and the Canada Games Complex. These three facilities experience heavy amounts of traffic as well and ensures that the LID is highly visible to the patrons visiting the three different facilities.

The secondary purpose for the positioning of the LID was due to the need of a venue for Arbor Day. This benefited toward the publicity of the LID by allowing people to see how aesthetically pleasing a water treatment facility could be. The only issue with this approach was that this meant a slight reduction in the functionality of the LID to increase its aesthetical appeal to the public.

In terms of the water treatment capacity for the facility, its location allows for accumulated runoff from High Street and Beverley Street to enter the facility. The placement and slope of these streets means that runoff from the area between Beverley St, Oliver Rd, and High St. could potentially feed into the facility and be treated before entering the stormdrain and going back into the lake. Figure 18 can be used to understand the potential area feeding into the facility in the bottom right corner.

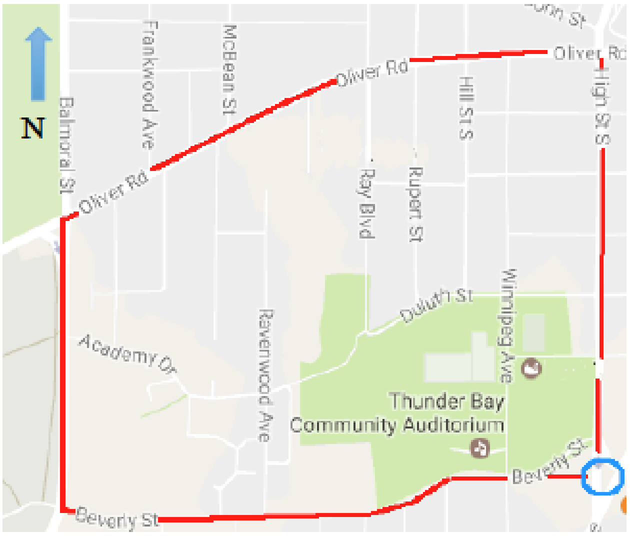

Figure 18. Facility source area (blue circle is the facility) Source: Google maps

The second LID that was analyzed was directly across the street in front of the D&R Sporting Goods Store. One difference between the two LID's is that the Beverley LID was placed for the objective of increasing publicity towards LID facilities; the D&R LID was placed for functional purposes. The store had been experiencing issues with the flooding of the parking lot and wanted a solution to the problem of it freezing during the winter. For this reason the LID was constructed with a very small target area in mind, whereas the Beverley LID had a large target area. Although the LID was constructed only to remove water from the parking lot, it could have been designed in such a way as to facilitate the movement of runoff from Memorial Avenue into the facility through curb cuts or a pipe system. This would increase the target area and efficiency of the facility.

Another component that was different between the two LID's was due to the fact that the water table was much higher on the D&R site, meaning that the company constructing the LID was limited to only creating a filtration facility and not an infiltration facility. Although the primary goal of the facility was its function, the placement of the facility along Memorial Street meant that it also had to have an aesthetic appeal to it. The limiting factor of a high water table meant that there was a smaller percentage of vegetated species that would be able to survive in the moister conditions. As a result, the two LID's varied in combinations of different vegetation, this is shown in the aesthetical differences of the two sites. The Beverley Street site was able to accomodate more tree species and a combination of different grasses, where the D&R LID only had a few tamarack trees and a robust selection of different sedges. This proves that the aesthetical component of LID's is highly dependent on the location of the facility and the particular soil structure.

Regarding the McVicar Creek LID, the benefit to placing the LID in such a residential setting is that it helps to gain the public support of those living in the vicinity. The MCRP discusses in detail the different methods for stormwater management that the public can undertake on their own properties. The Public Cost Share Program was created in an attempt to assist landowners with the implementation of stormwater management practices on private residential properties (City of Thunder Bay 2014). The program also aims to engage the public and foster stewardship towards their surrounding water resources, for example McVicar Creek. Another program to enhance the use of LID's in residential settings outlined in the MCRP is the Neighbourhood Pilot Raingarden Program (City of Thunder Bay). The LID generates a prime example of the functionality and appearance of LID's, and will potentially encourage people to look into the aforementioned programs for themselves.

Functionally the McVicar Creek LID is placed such that it has the ability to remove large amounts of runoff from the surrounding area. A benefit that increases the source water feeding into the facility is the fact that the storm drain feeds into the facility. This means that not only surface runoff from the surrounding streets (Clayte St, Hartviksen St, Balmoral St) will potential feed into the facility, but also any water in the storm drains accumulated from other streets that lead into Balmoral St.

FUTURE LID PLACEMENT

With the public acceptance and effectiveness of the current LID's, the City has incorporated the construction of LID's in their Stormwater Management Plan. The City has already established 552 sites for potential LID sites and it was revealed that for the year 2017 five new sites are being considered for construction (Werner Schwar.pers.comm). Mr. Schwar continued by saying that the development of future LID's in Thunder Bay are highly dependant on the availability of grants and hopes that the community realizes the full potential of LID's and help with the financing. The potential LID's by watershed can be seen in Table 1. It is interesting to note that the largest number of potential sites for LID's are in the Neebing watershed with a total of 161 identified locations. Considering that the flood that occurred in Thunder Bay in 2012 was most damaging to the southern portion of the city, it makes financial and hydrological sense to have the largest portion of the city's LID's in the area with the highest risk of flooding (City of Thunder Bay 2016).

Table 1. Identified LID's per watershed and potential costs Source: City of Thunder Bay 2016.

Watershed	Total # of BMPs	Benefits: Total TP Removal (kg/yr)	Benefits: Total TSS Removal (kg/yr)	Benefits: Total Volume Reduction (m^3/yr)	Costs: Total Present Cost (CAD)	Costs: Total Feasibility Cost (CAD)
Current	83	233	81,780	260,100	$ 8,693,000	$ 556,600
Kaministiquia	62	716	803,700	691,700	$ 21,601,000	$ 2,120,000
McIntyre	136	968	647,400	656,000	$ 38,140,000	$ 2,754,000
McVicar	27	17	4,922	19,350	$ 1,560,000	$ 0
Mosquito	17	5	1,359	12,590	$ 649,200	$ 0
Neebing	161	513	338,400	779,000	$ 30,460,000	$ 1,355,000
Pennock	9	3	1,273	8,347	$ 1,365,000	$ 131,300
Waterfront	57	311	169,200	355,800	$ 13,760,000	$ 1,043,000
Total	552	2,765	2,048,034	2,782,887	$ 116,228,200	$ 7,959,900

The potential for future LID use in Thunder Bay is also highly dependent on the road designing protocols that the City has been predominantly implementing. The goal of LID's is to reduce the amount of impervious surfaces within a city and increase infiltration rates. In an attempt to meet these goals in terms of road construction, the City has begun implementing LID's into new road construction and will potentially look into updating existing roads for implementation possibilities.

THUNDER BAY STORMWATER MANAGEMENT PLAN (2016)

The City of Thunder Bay has developed a Stormwater Management Plan (SMP) (City of Thunder Bay 2016) and incorporates many recent and new developments, including LID's. These were added to the plan to act as a management tool used to deal with the issue of stormwater events. The goals and objectives of the SMP are to ensure the proper management of ecosystem health, water quality, water quantity, operations and maintenance, monitoring and data assessment, regulation and enforcement, education and outreach, funding and organization, climate change adaptation (City of

Thunder Bay 2016). The plan is functional within the time frame of 20 years and has a number of implementation activities to aid in achieving the SMP goals (City of Thunder Bay 2016). The SMP aims to incorporate activities that will not only be corrective, for example implementing LID's in a area with severe flooding risk, but also proactive steps such as possibly modifying the City's existing Engineering and Development Standards and the City's By-Laws (City of Thunder Bay 2016). LID's are one way that the City is attempting to reach the new approach of "keeping the raindrop where it falls, thereby mimicking natural hydrology in order to minimize the amount of runoff, prevent pollution from reaching lakes, rivers, streams and wetlands, and maintain recharge of the groundwater system" (City of Thunder Bay 2016).

An important step that the City is taking to increase the implementation of LID's is through increasing the accessibility and frequency of LID training for the Thunder Bay community of designers, contractors, and related agency staff (City of Thunder Bay 2016). One of these training sessions was held at Confederation College in 2016 by a LID specialist from Toronto to provide resources for LID construction. Public education programs are also being made available to increase the importance of LID developments within the community and gain public endorsement (City of Thunder Bay 2016).

The City has an extensive plan for the implementation of LID's for the next 20 years that includes replacing existing storm sewer infrastructure to allow for the placement of LID's (City of Thunder Bay 2016). Through the course of writing the plan the City was able to identify 552 different potential LID locations and is planning to increase the construction year by year to reach their goal of 96 LID's within 18 years (City of Thunder Bay 2016).

The main issue that might hinder the possibility of reaching this goal is the lack of finances directed to LID implementation and will require donations by large corporations or government grants (City of Thunder Bay 2016). Currently the City uses tax levys to finance a significant portion of its stormwater management activities and has also implemented a stormwater utility fee (City of Thunder Bay 2016). The utility fee is charged predominantly to residential, industrial and commercial stormwater customers and aids in funding services directly related to the implementation of stormwater programs (City of Thunder Bay 2016). "A stormwater utility is a stand-alone service unit that generates revenues through user fees for service related to the control and treatment of stormwater, separate from the tax levy" (City of Thunder Bay 2016). There are several grants that the City can attempt to apply for in order to gain the funds needed and the requirement and funding for these programs can have the potential for variation (City of Thunder Bay 2016). The different Federal grants are Climate Change Adaptation Program, Gas Tax Fund, New Building Canada Fund – Provincial-Territorial Infrastructure Component, Recreational Fisheries Conservation Partnerships Program, and Federation of Canadian Municipalities (FCM) – Green Municipal Fund (City of Thunder Bay 2016). There are also a number of Provincial grants to aid in financing the new stormwater management plans such as Ontario Community Infrastructure Fund, Showcasing Water Innovation Program, Ontario Trillium Foundation, Rural Water Quality Program and Ontario Drinking Water Stewardship Program (City of Thunder Bay 2016).

CONCLUSION

Climate change is a prevalent and fast occurring issue that must be incorporated into future planning in order for proper mitigation efforts to be in place. Thunder Bay has already experienced the effects of climate change through the flood of 2012 and has begun to take mitigation steps through the construction of LID's. Precipitation levels are expected to increase in the future and so is the rate of urban growth and infrastructure within Thunder Bay. It is essential that future infrastructure and development are conducted in such a way to reduce the risk of flooding and increase the sustainability of the city.

LID's are an essential tool for stormwater management in the urban centre and have the potential to decrease the risk and damage by flooding, while increasing the rate of infiltration and sustainability in the City. They attempt to return the site to its predevelopment hydrologic conditions through the reduction of impervious surfaces and increased infiltration abilities. The systems remove contaminants from runoff, therefore making the stormwater reaching waterways much cleaner and sustainable to the ecosystem. Due to the highly diverse and flexible nature of LID's, they have the benefit of being able to be constructed in such a way as to be aesthetically appealing and functionally efficient at the same time.

Thunder Bay has begun using LID's to reduce flooding risk and increase the livability of the city through several different LID sites. The three sites that were analyzed, Beverley Street, D&R Sporting Goods Store, and McVicar Creek, were all developed for different specific reasons, although all of them were created to increase infiltration rates within the city. The reasons for the development were respectively to publicize the benefits of LID's as well as experiment to see if they could in fact work in the city.

An important step to ensuring the continued use of LID's in Thunder Bay is to generate legislation, or a plan that incorporates the use of LID's for stormwater management. The Stormwater Management Plan for Thunder Bay that was developed in 2016 does incorporate the use of LID's for the next 20 years of the planning period. Thunder Bay is relatively new to the development of LID's and as such the plan is not as fully comprehensive as other cities plans. Portland, Oregon for example has been using LID's and BMPs to reduce the damage caused by flooding for several years.

Upon examining Portland's stormwater management plan for 2016 it is evident on how much importance they place on these facilities (City of Portland 2016). One way that it is evident is through the fact that Portland has set up rules on the creation of stormwater on private property and how the owner is responsible to either pay for the stormwater generated or create LID's to eliminate the stormwater. Thunder Bay could do well to incorporate some of these principles in its stormwater management plan.

The future development of LID's in Thunder Bay is highly dependent on the funding made available to finance the construction of LID's. The City has established 552 sites that could have potential LID's, and simply requires the grants needed to pay for them. For this reason it is imperative that the public be involved and educated on the benefits of LID's so as to increase their acceptance of the potential costs they might have to endure. Opportunities for LID training has already been increasing within the City and could be the key to ensuring the proper respect and recognition for benefits of LID's and further their development.

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APPENDIX I

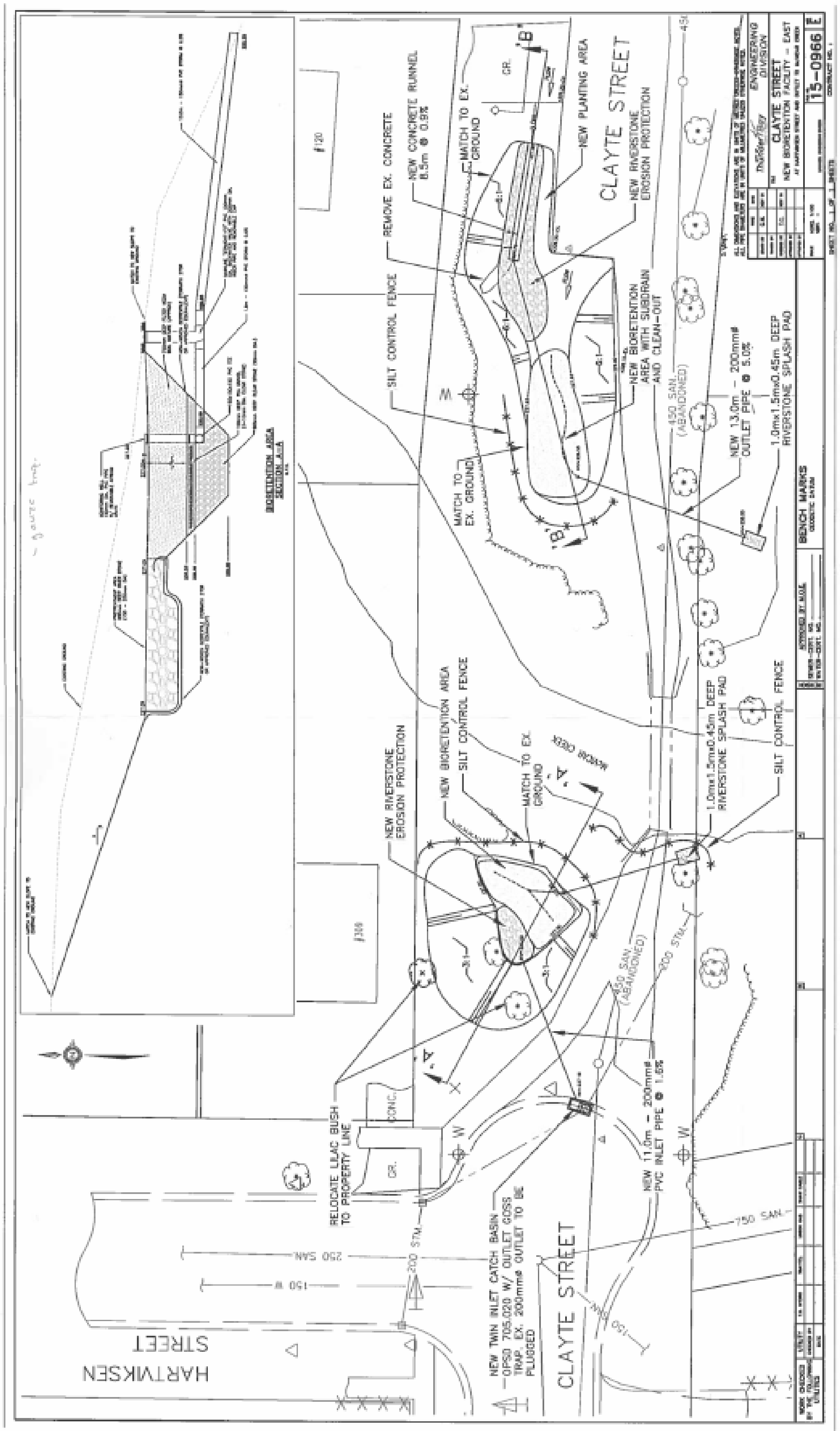

Figure 19. McVicar Creek LID engineering designs

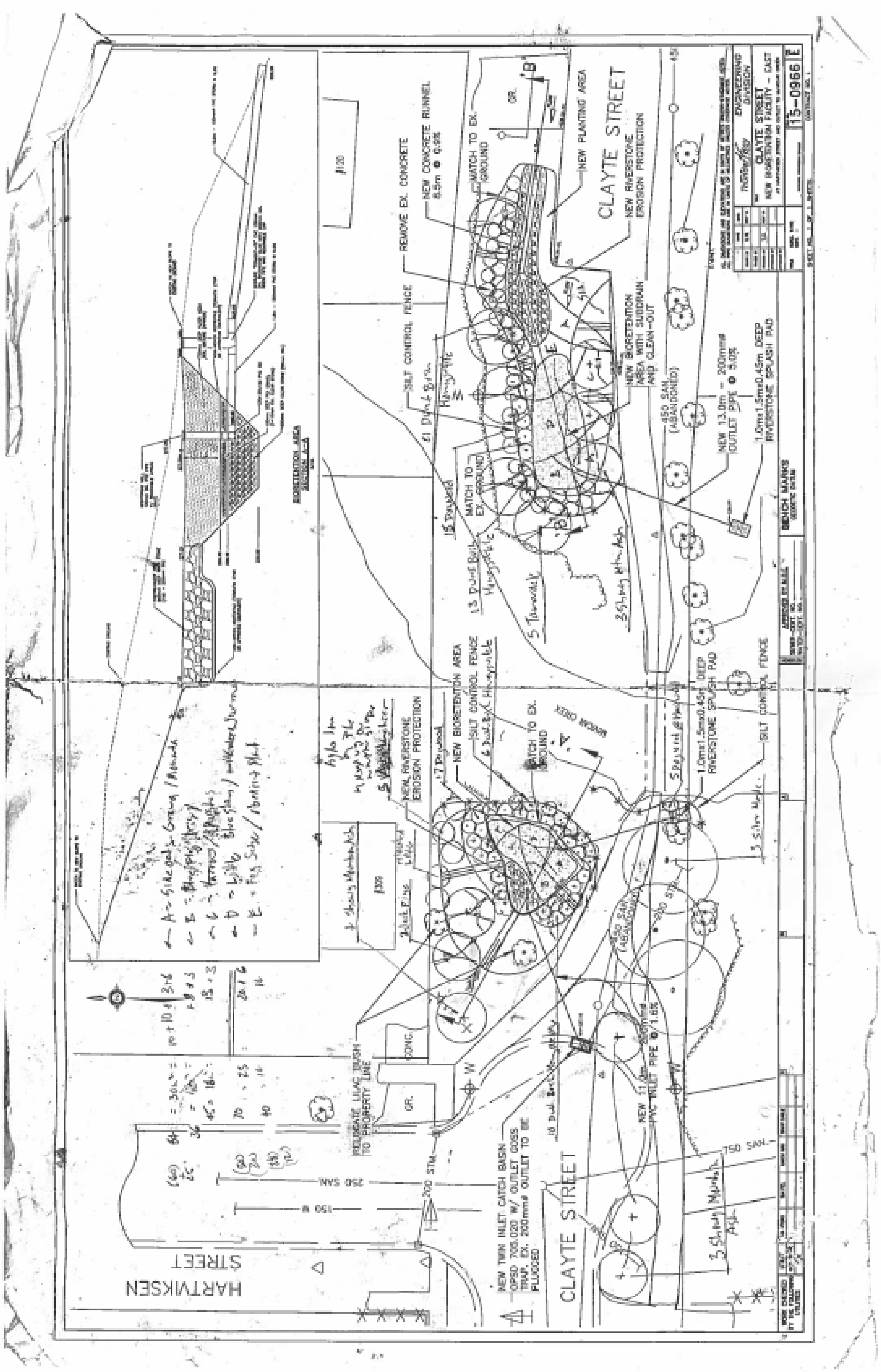

Figure 20. McVicar Creek LID engineering designs (with plant species)

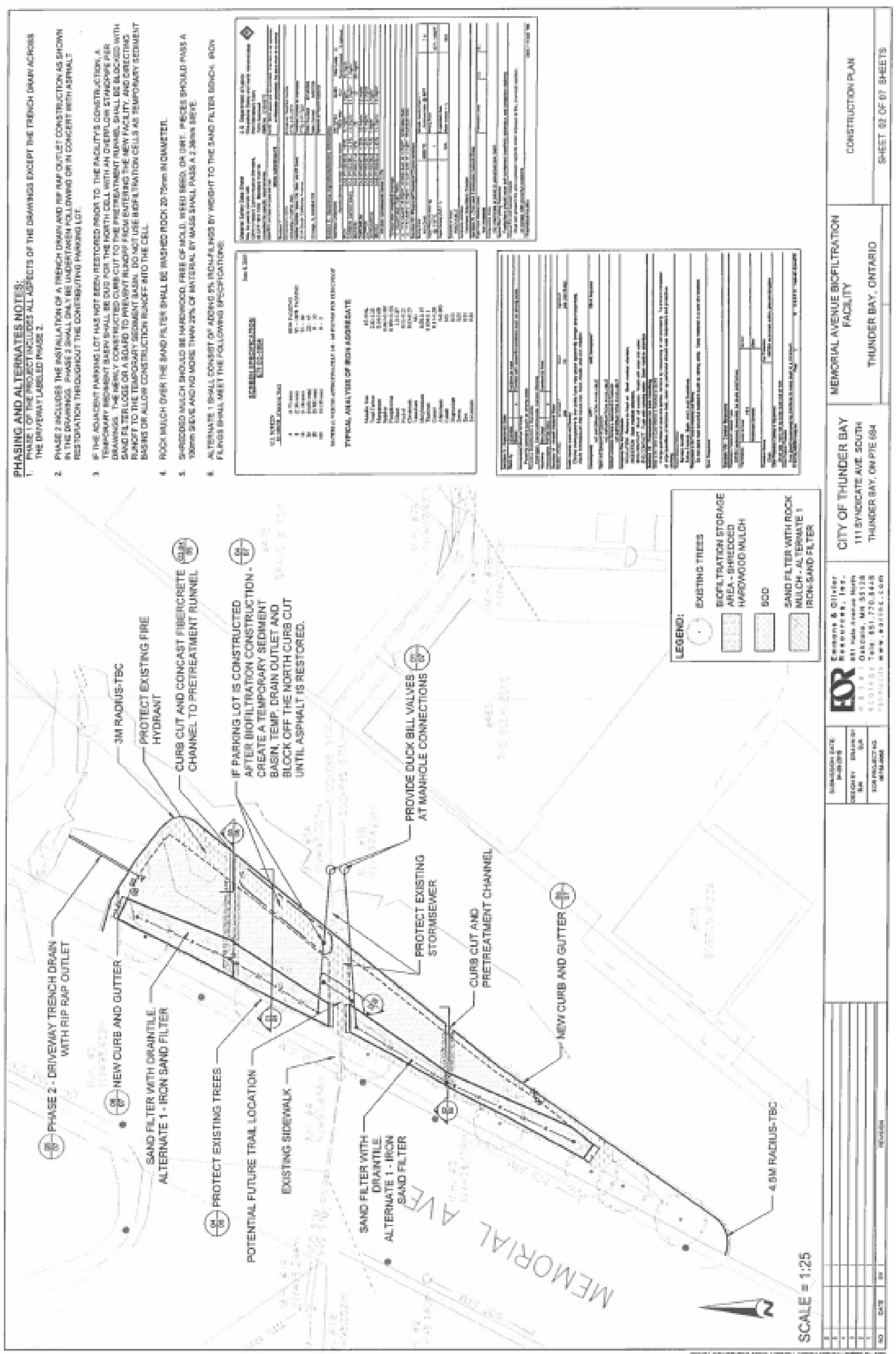

Figure 21. D&R Sporting Goods LID engineering designs

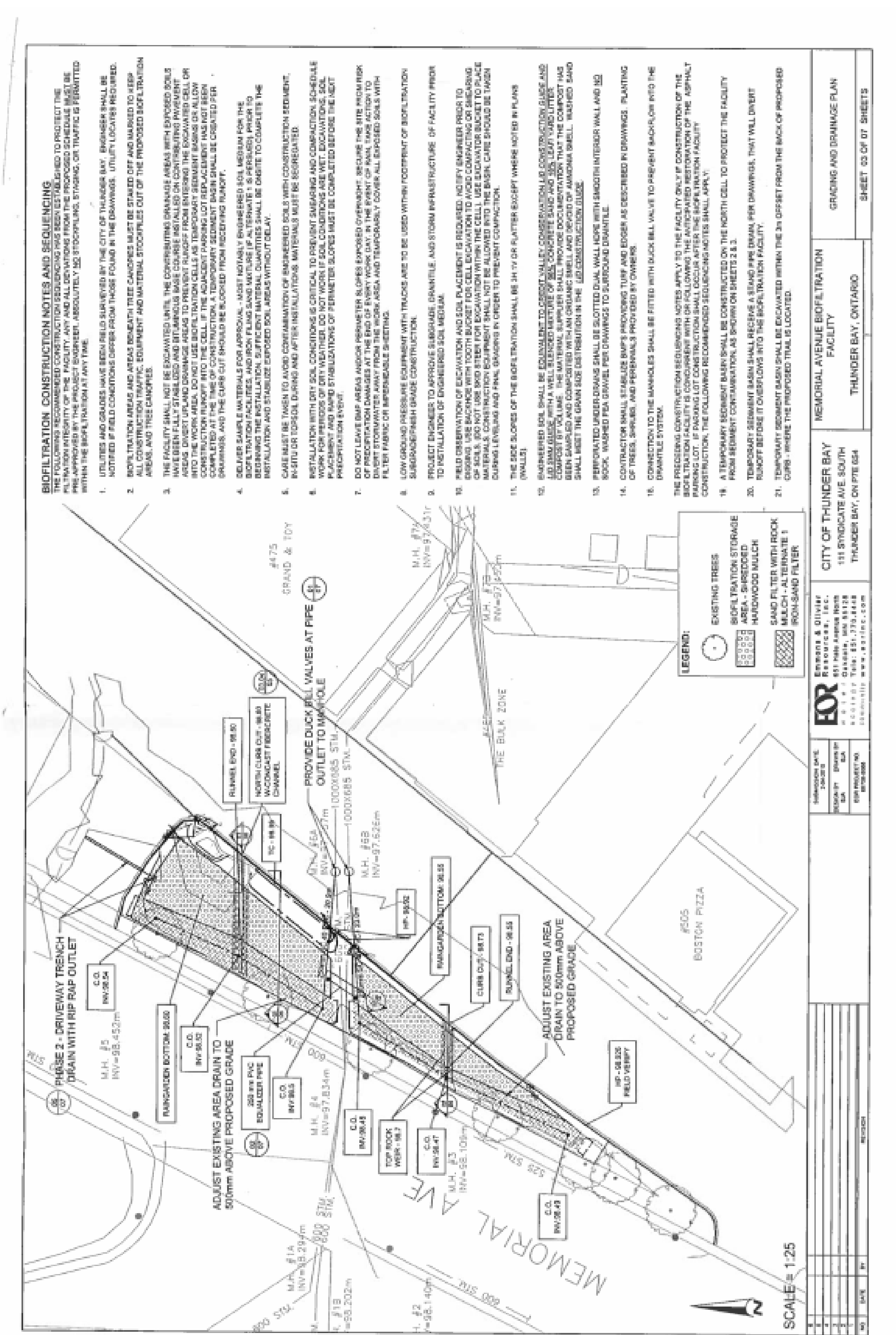

Figure 22. D&R Sporting Goods LID engineering designs continued

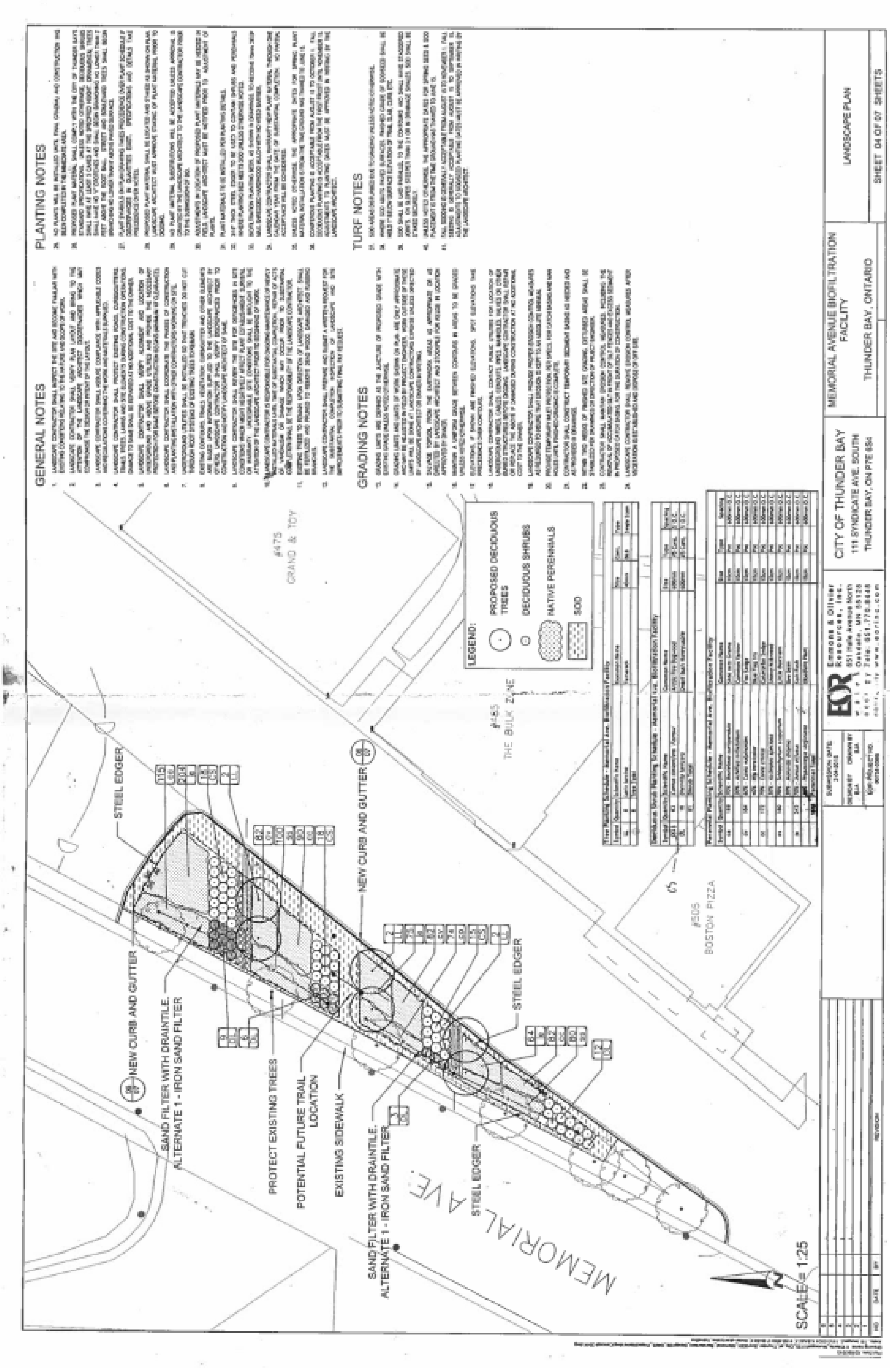

Figure 23. D&R Sporting Goods LID engineering designs (with vegetation)