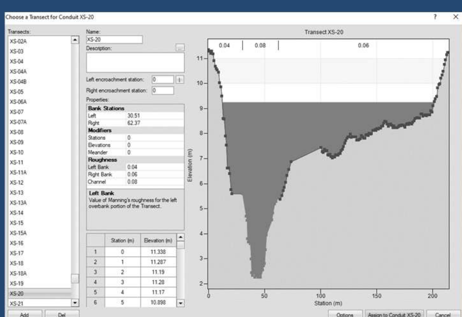

DRAFT REPORT

March 4, 2020

Sackville Rivers Mitigation Planning Study

Project No.: 19-174

SUBMITTED BY:

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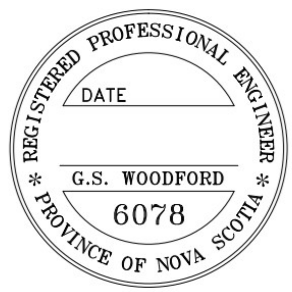

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This report was prepared by DesignPoint Engineering & Surveying Ltd. for the Halifax Regional Municipality using the care and skill ordinarily exercised by members of the engineering profession currently practicing under similar circumstances on similar projects in Nova Scotia.

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EXECUTIVE SUMMARY

Overland flooding is a serious issue facing towns and municipalities across the world. In an effort to address flooding along the Sackville River and Little Sackville River, the Halifax Regional Municipality (HRM) has retained DesignPoint to assess the effectiveness of several flood mitigation measures in the area. Building on previous phases of the floodplain study and expanding on the PCSWMM model completed by CBCL in Phase 2 of the floodplain study, this report details the evaluation of these measures.

Through a review of previous flood studies and discussion with HRM and Halifax Water staff, several flood-prone areas have been identified. For each of these areas, mitigation measures were assessed to reduce flooding based on the design flood lines prepared in the Phase 2 project. The identified areas are:

1. Lower Sackville River, Bedford Highway Bridge to Highway 102 (NDMP Site 25);
    - Union Street from Bedford Highway to Bridge Street is within this portion of the floodplain as well.
2. Rankin Drive at Glendale Drive (NDMP Site 20);
3. Sunnyvale Crescent at Beaver Bank Road (NDMP Site 21); and
4. Sackville Drive at Cobequid Road / Highway 101 (NDMP Site 26).
5. Beaver Bank Cross Road / Brook Street Extension;
6. Millwood Drive at Jackladder Drive;
7. Millwood Drive near Sackville Drive;
8. Seawood Avenue at Sackville Cross Road;
9. Hallmark Avenue;
10. Memory Lane at Bedford Bypass; and
11. Range Park.

To evaluate these specific areas, the PCSWM model was updated to provide more detail. This revised model was then calibrated to approximate the results of the Phase 2 work for consistency with planning strategies.

In evaluating the identified areas, several mitigation measures were reviewed including both policy based and construction based measures. The majority of the mitigation measures discussed are specific to the problem areas however, some strategies, particularly the policy based strategies, are applicable to the entirety of the watershed.

Evaluation of the mitigation measures consisted of tailoring the measure for each of three design flood events. The effectiveness of the measure was analyzed based on the reduction in flood area along with the feasibility of application, effects on other portions of the watershed, and the cost to complete. The three design flood events are:

1. Historical Maximum Storm (March 2003): 106 m^3/s
2. 1 in 5-Year Rainfall (Phase 2 Design Storm): 266 m^3/s
3. 1 in 100-Year Rainfall (Phase 2 Design Storm): 619 m^3/s

Having completed the evaluation of the mitigation measures, the following conclusions and recommendations are presented.

Conclusions

1. Both public and private infrastructure in close proximity to the Sackville Rivers is at risk of damage due to flooding;
2. Portions of local drainage infrastructure cause stormwater to back up, adding to flooding from the rivers;
3. There is currently significant development potential within the watershed which will have a negative effect on drainage patterns and runoff volumes;
4. Unmitigated stormwater flow from unserviced developments will increase runoff within the watershed;
5. Balanced stormwater discharge (as per current regulations) from serviced developments can result in increased flow within the rivers due to extended peak flows;
6. When selecting mitigation options, the magnitude of the flow to be mitigated significantly impacts the cost to complete the mitigation measures;
7. Model results indicate design flows which far exceed historical peak flows;
8. Including Low Impact Development principles in future development within the watershed will reduce peak flows in the rivers while adding to operations and maintenance requirements;
9. The downstream flow of the rivers is sensitive to changes in the level of McCabe Lake;
10. The existing bridge structures at Beaver Bank Road, Sackville Drive, and Bedford Highway are hydraulic restrictions and increase upstream flood levels;
11. Restricting development within the floodplain of the rivers will reduce future flooding damage; and
12. Flooding in Areas 2, 3, 4, 6, 7, and 10 is not directly caused by water levels in the Sackville Rivers.

Recommendations

1. Place restrictions on future development within the floodplain identified in Phase 2 and include elevation restrictions based on the water surface profiles associated with Map 9 in the Phase 2 study, allowing adjustments to be made with topographic survey information from a licensed surveyor;
2. Implement a watershed specific stormwater management strategy which relates development to downstream flow in the rivers which includes Low Impact Development principles;
3. Require stormwater management for unserviced developments within the watershed;
4. Consider design flows and flood plain width when reconstructing any structure which crosses the Sackville or Little Sackville Rivers;
5. Construct a control structure at the outlet of McCabe Lake based on the 1 in 100-Year design storm and the typical range in lake level;
6. Area 1 - Construct an overflow diversion to keep the historical maximum flow within the riverbanks from Range Park to the Sackville River outlet;
7. Area 1 – Purchase properties in close proximity to the river as identified in this report;
8. Area 2 – Investigate the storm and sanitary sewers in this area and consider increasing capacity where needed;
9. Area 3 – Investigate local storm drainage infrastructure and consider upgrades as required to provide adequate drainage;
10. Area 4 – Evaluate local culverts in the area and consider upgrading the culverts as needed (this could be done in conjunction with Area 10);
11. Area 5 – Purchase properties within the 1 in 100-Year flood lines;
12. Area 6 – Evaluate the culvert under Millwood Drive and consider upgrading as necessary;

13. Area 7 – Evaluate local drainage routes and consider upgrading as needed;
14. Area 8 – Purchase properties within the 1 in 100-Year flood lines;
15. Area 9 – Construct a protective berm at the rear of homes within the flood lines;
16. Area 10 – Evaluate local culverts in the area and consider upgrading the culverts as needed (this could be done in conjunction with Area 4); and
17. Area 11 – Accept flooding conditions.

Table 1: Cost of Non-Policy Mitigation Measures

Area	Mitigation Measure	Cost ($)
Sackville River	Construct control outlet on McCabe Lake	12.0 M
Area 1 – Lower Sackville River	Construct emergency overflow based on historical maximum storm	53.0 M
Area 1 – Lower Sackville River	Purchase properties near Bedford Highway Bridge	1.3 M
Area 5 – Beaver Bank Cross Road and Brook Street	Purchase properties within 1 in 100-Year flood extents	5.2 M
Area 8 – Seawood Avenue	Purchase properties within 1 in 100-Year flood extents	5.1 M
Area 9 – Hallmark Avenue	Construct protective berm	0.2 M
Area 11 – Range Park	Accept flooding conditions	0 M
	Total	**76.8 M**
Property purchases are based on assessed value only, additional purchase and demolition costs will apply		
Local drainage improvements not related to the Sackville Rivers have not been included		
Estimated construction costs include 25% contingency		

1.0 INTRODUCTION

Throughout Canada, overland flooding is at the forefront of challenges facing municipalities. Flooding costs the economy more than any other hazard and is the single largest draw on the Disaster Financial Assistance Arrangements (DFAA). In Canada from 2003 to 2012, flooding resulted in over $20 billion in damages. The intensity and amount of rainfall is expected to increase over time due to climate change, which along with rising sea levels will exacerbate current flooding problems.

In response to the increasing risk of natural disasters and associated costs, the federal government created the National Disaster Mitigation Program (NDMP) and budgeted to spend $200 million from 2015-2020 to help municipalities identify and plan for projects which could reduce or eliminate the risks of flooding events in their communities. Municipal governments throughout the province can apply for funding to assist with one of the following four phases:

Phase 1: Risk Assessments;
Phase 2: Flood Mapping;
Phase 3: Mitigation Planning; and
Phase 4: Investments in Non-Structural and Small-Scale Structural Mitigation Projects.

Previously, the municipality completed the Sackville Rivers Floodplain Study Phase 1 (completed by GHD in 2015) and Phase 2 (competed by CBCL in 2017) on the watershed under this program. Following those studies, HRM hired DesignPoint to review the mitigation strategies proposed as part of the previous studies with the intention of completing a cost benefit analysis of the pertinent mitigation strategies. Recommendations on which strategies to implement and in what order were also to be included as part of this study.

The Sackville Rivers watershed extends north-south from Mount Uniacke to the Bedford Basin and west-east from Pockwock to Lower Sackville. The watershed includes approximately 18 lakes with various interconnected waterways. The two major rivers are the Sackville River and the Little Sackville River. The figure below illustrates the general layout of the lakes within the watershed.

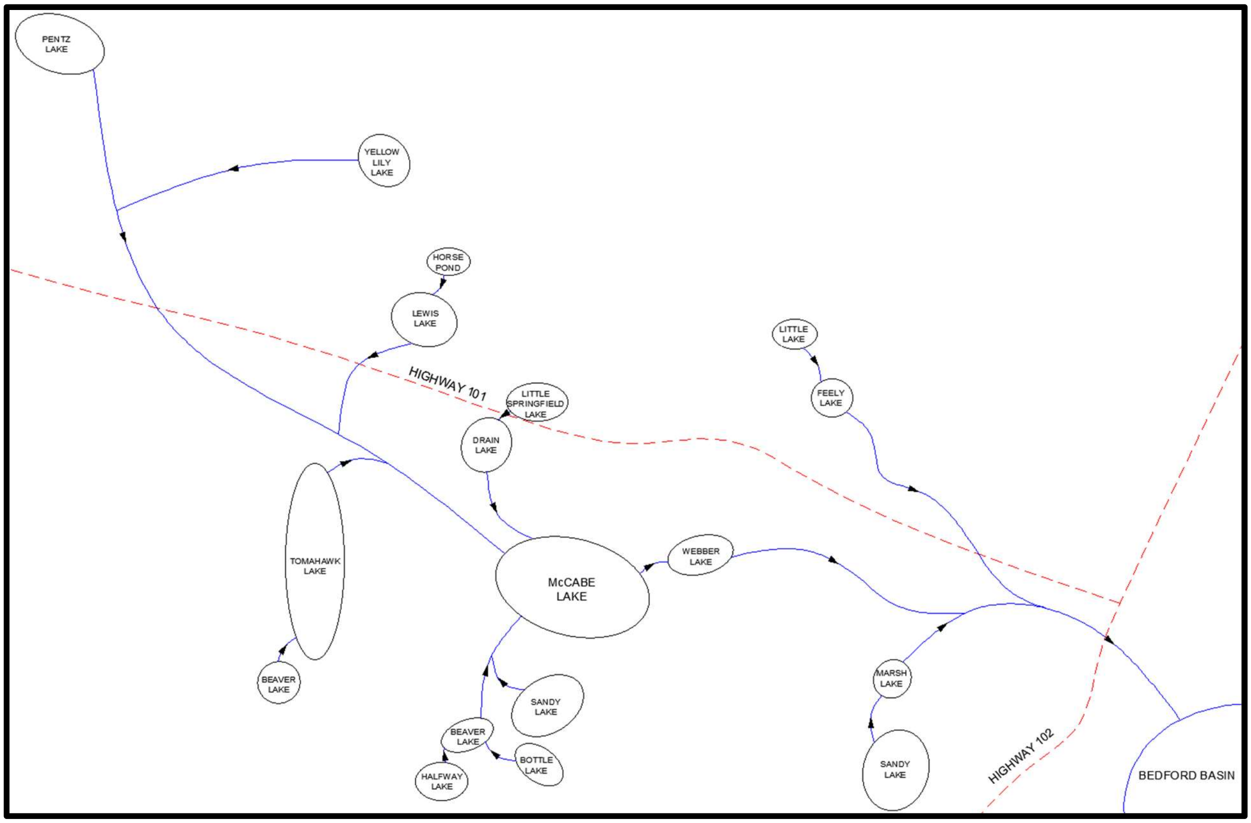


Figure 1-1: Connectivity Schematic of Sackville Rivers Watershed

Figure 1-2: Flooding of Sackville River – *flitelab 2014*

Flooding along the Sackville and Little Sackville Rivers is well known and a relatively frequent occurrence. Studies on both river systems date back to 1981. After a significant rain event, it is common to experience high water levels in Bedford from Range Park down to the Bedford Basin. The ball fields in Range Park, located behind the commercial development on the Bedford Highway, are often under water after a large rain event. The parking areas at the Bedford Place Mall and the adjacent residential development along Union Street have also been subject to flooding on occasion. Flooding has affected downstream portions of the river as well, with flooding at Fish Hatchery Park shown in the following figure. Fish Hatchery Park is located directly adjacent to the Sackville River just downstream of the Bedford Highway river crossing.

Figure 1-3: Fish Hatchery Park Flooding

2.0 SACKVILLE RIVERS WATERSHED

The Sackville River begins with the confluence of several tributaries in an undeveloped area in Mount Uniacke, east of NS Highway 1. The river crosses Highway 101 upstream of McCabe Lake. The river passes through McCabe Lake and Webber Lake, through an unserviced development. Downstream of the lakes, the river flows through a forested area before crossing Highway 102 and entering an urbanized portion of the watershed parallel to Bedford Highway. Just downstream of Bedford Highway, the river discharges to the Bedford Basin. Several tributaries, including the Little Sackville River, drain into the Sackville River. Several lakes are located within the watershed, most notably Tomahawk, McCabe, Webber, and Sandy.

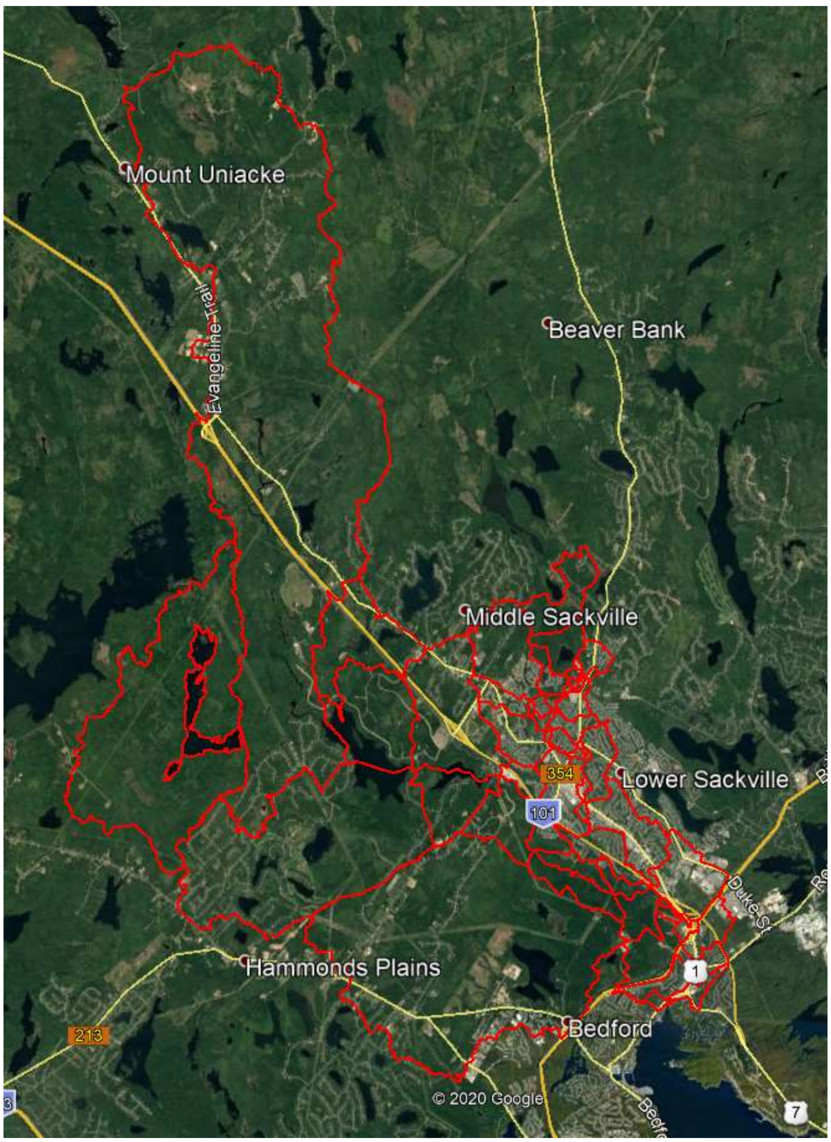


Figure 2-1: Sackville Rivers Subwatersheds

In general, the Sackville River watershed is approximately 24.5 km long and 8 km wide, covering an area of approximately 150 km^2. Elevations within the watershed range from 205 m in the northern portion of the watershed to 0 m (sea level) at the outlet to Bedford Basin. The geometry of the Sackville River varies substantially along its approximately 33 km length. The watercourse slope ranges from over 3% to 0%, has both straight and meandering sections, and passes through both undeveloped and developed areas of the watershed. The average slope of Sackville River along its length is 0.4%, while the average slope of Little Sackville River is 0.9 %. Portions of the rivers, such as the area downstream of Range Park and Highway 102, have development in close proximity to the riverbanks.

Much of the watershed is still naturally forested, however significant portions of the watershed have been developed. Figure 2-2 and Figure 2-3 below show the changes in the watershed between 1984 and 2020, with significant developments being completed between Highway 101 and Hammonds Plains Road. As the area has developed, the runoff rates within the watershed have increased.

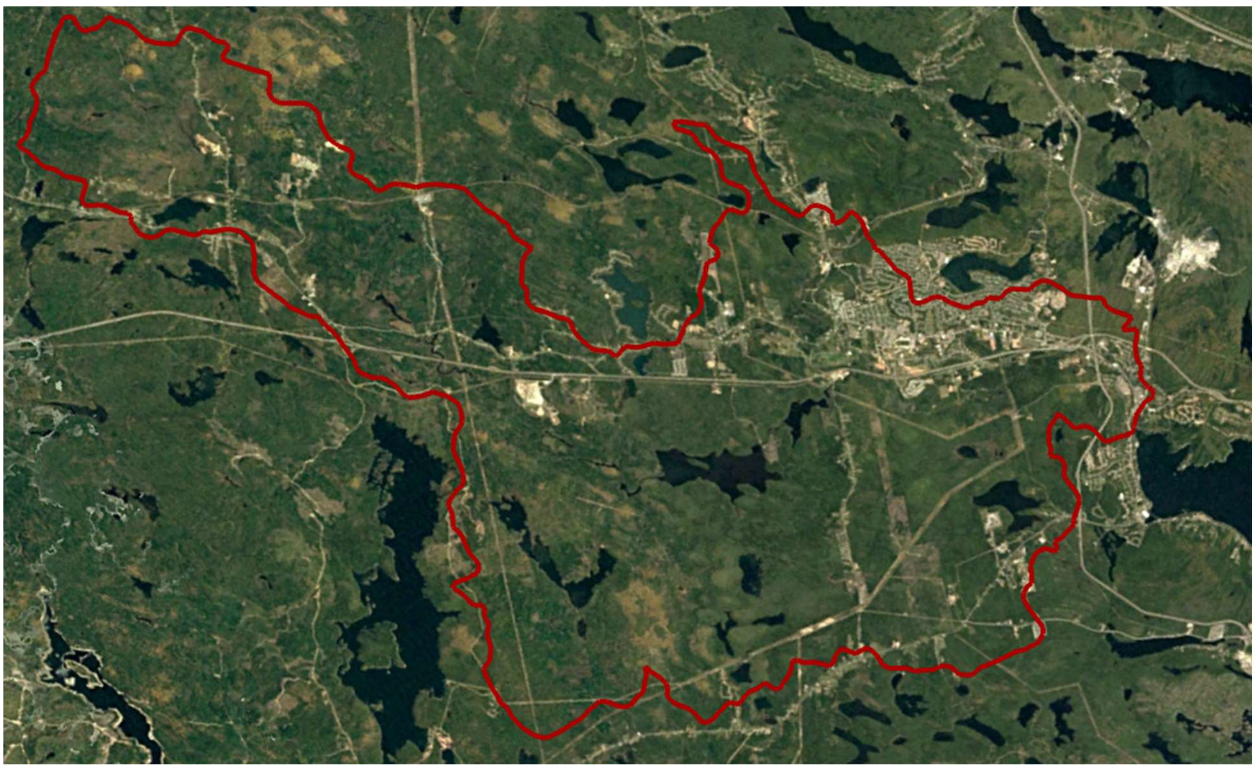


Figure 2-2: Sackville Rivers Watershed 1984 - ***Google Earth***

Figure 2-3: Sackville Rivers Watershed 2020 - *Google Earth*

3.0 PCSWMM MODEL

Phase 1 and Phase 2 of the Sackville Rivers Floodplain Study have been completed in 2015 and 2017 by GHD and CBCL, respectively. These reports culminated in the creation of a watershed model using a software called PCSWMM, the selection of design flood events, and the generation of flood extents.

During the Phase 2 project, CBCL created a model of the Sackville Rivers watershed using PCSWMM software. The model is made up of various catchments, storage areas (lakes), nodes, and reaches which represent the geometry of the rivers and the surrounding watershed.

The PCSWMM model was created and calibrated to measured flows during historical seasonal rainfall events. For design purposes, winter conditions were selected for the Sackville River sub-watershed while Fall conditions were selected for the Little Sackville River sub-watershed. In addition, a 48-hour Chicago storm was assigned to catchments draining to the Sackville River while a 24-hour rainfall was assigned to those draining to the Little Sackville River. The design storms were applied uniformly over the entirety of the watershed and flows within the rivers were calculated. Several existing gauging stations along Sackville River and Little Sackville River were used as reference locations for calibration of the model. Various inputs of the model were adjusted in an effort to calibrate and validate the model to historical results.

3.1 PHASE 2 MODEL DEVELOPMENT

In the previous phase of the Sackville Rivers project, base flood conditions were selected for planning purposes. The report, prepared by CBCL, noted that the most conservative model results were selected through consultation with HRM. The design flood lines were obtained based on the following:

- Watershed characteristics calibrated to the fall season – Little Sackville River;
- Watershed characteristics calibrated to the winter season – Sackville River;
- 24-hour design storm – Little Sackville River;
- 48-hour design storm – Sackville River;
- Future development watershed conditions based on HRM input;
- Climate change conditions (Western University IDF-CC tool upper bound); and
- 1 in 20-year and 1 in 100-year return periods.

Return periods for severe events are also discussed in the Phase 2 report, such as the 1 in 20-year or 1 in 100-year events listed above. While these are common terms for describing these events, it is better to think of any event as having a certain probability of occurring in a giver year. For instance, a 1 in 20-year event has a 5% chance of occurring in any given year. Even if a 1 in 20-year event happens in 2020, there is still a 5% chance of another 1 in 20-year event occurring in 2021. Referring to events by their expected return period can give the public a false sense of probability.

Flood limits based on the above scenario were shown on Map 9 in the CBCL report. The rainfall and peak flow conditions from this scenario are summarized in the table below along with the 1 in 5-year modelled flow and historical documented maximums.

Table 3-1: Phase 2 Modelled and Historical Flows - Various Return Events

Flood Event	Annual Probability of Exceedance	Flow (m^3/s) Sackville River (01EJ001)	Little Sackville River (01EJ004)
1 in 5-year	20%	241	38
1 in 20-year	5%	393	64
1 in 100-year	1%	593	113
Historical Maximum	-	106 (March 2003)	22 (July 1982)

Gauging station data is available for the Sackville River from 1970 to 2017 and for the Little Sackville River from 1980 to 2016. These stations record the flow and level of the river over time and report both average and peak instantaneous values. A flood frequency analysis can be completed on the historical values to determine various return flows based on the gauging station recorded data. Table 3-2 below summarizes the analysis based on a Log-Pearson III model.

Table 3-2: Flood Frequency Analysis from Gauging Station Data (Existing Conditions)

Return Period (Years)	Annual Probability of Exceedance	Flood Discharge (m^3/s) Sackville River (01EJ001)	Little Sackville River (01EJ004)
1.25	80%	41	12
2	50%	54	15
5	20%	69	18
10	10%	78	19
25	4%	88	21
50	2%	95	22
100	1%	102	23
500	0.2%	117	
1,000	0.1%	123	
10,000	0.01%	142	

It is evident that the modelled flows in both rivers are significantly higher than what has been measured in the rivers at the gauging stations. The modelled flows are also higher than the more severe flows (including the 1 in 10,000-year flow) based on the flood frequency analysis. The Phase 2 model includes some conservative assumptions:

1. Uniform rainfall distribution over the entire watershed (150 km^2);
2. High impervious percentage in all subcatchments;
3. Chicago storm distribution;
4. Climate change forecast (upper limit);
5. Worst case conditions in the Sackville River and Little Sackville River watersheds (winter and fall conditions, respectively); and
6. Future development conditions.

The combination of the above assumptions resulted in flows much larger than those experienced historically for the Sackville River and those anticipated based on flood frequency analysis. The flood levels developed in the CBCL Phase 2 report and published in Map 9 were accepted by HRM for planning purposes and were used in this study to test mitigation measures.

3.2 MODEL UPDATES

DesignPoint was tasked with adding further detail to the Phase 2 model, while maintaining the flood lines adopted by HRM. While local updates were made to the model to aid in mitigation assessment, the final model was calibrated to generally match the results from the Phase 2 model.

Inclusion of Lakes

Tomahawk Lake, a large water body upstream of McCabe Lake, was added to the model. This lake has been identified as a potential future expansion to water supply for Halifax Water. It is understood that consideration is being given to permanently increasing the available storage in the lake to improve supply. Adding storage to the lake has the potential to provide some reduction in downstream flows, therefore the lake was added to the model.

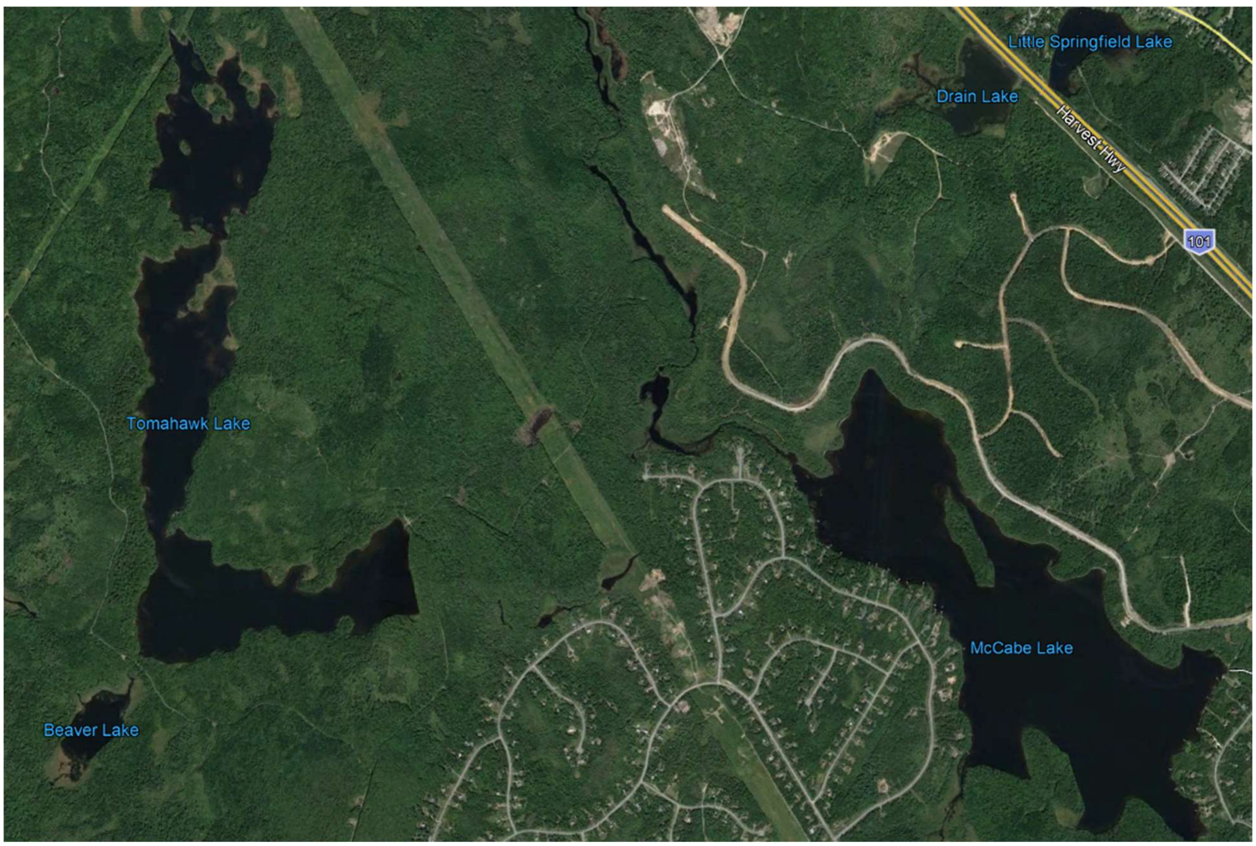


Figure 3-1: Tomahawk Lake

Consideration was given to including Sandy Lake in the model as well. Since the model was to be calibrated to match the results of the Phase 2 model, it was determined that there would be no benefit to including Sandy Lake. Inclusion of this lake would only have improved the model if there were mitigation options proposed for the lake specifically.

Crossing Structures

A desktop review was completed for major structure crossings along the rivers. It was noted that the geometry of the Lucasville Road bridge in the model was out of date and had a significantly smaller bridge opening than the existing structure (9.1 m compared to 20.5 m). The existing bridge is shown in the figure below. The increase in available flow area for Sackville River is significant and provides less of a restriction to the outlet of Webber Lake.

The existing geometry of the bridge was measured by a DesignPoint survey crew. Collected measurements were then imported into the model.

Figure 3-2: Lucasville Road Bridge

Lake Outlets

To improve the accuracy of modelled discharge from three of the major lakes, a survey team collected additional measurements. The outlets of Tomahawk Lake, McCabe Lake, and Webber Lake were measured and incorporated into the model. Having a detailed model of the lake outlets dramatically improves calculation of the capacity of the outlets. Correctly representing the outlets of these lakes improves calculations for the storage within the lakes as well as the flow downstream of each lake.

It should be noted that the outlet from McCabe Lake was previously controlled by a timber dam when forestry work was being done in the area. The remains of this dam are still visible beneath the water's surface during low flow. The natural outlet was modified to act as a river crossing with multiple concrete culverts and large stones covering the access road. In this scenario, the normal low flows would pass through the culverts but, during times of higher flows, water would overtop the access road.

The outlet was again altered by the Sackville Rivers Association with the removal of the culverts and placement of large boulders as shown in the following image to reduce the available flow area and decrease the flow out of the lake. However, several significant streams currently exist which allow high flows to bypass this rock wall at the lake outlet. Regrading portions of the land near the rock wall would reduce the amount of flow which bypasses the main outlet and would allow installation of a more controllable outlet such as a weir or sluice gate. Having control of the outlet conditions of the lake would allow HRM to manage water levels and use the lake storage to minimize flows out of the lake and reduce flooding in the downstream sections of the Sackville River.

Figure 3-3: McCabe Lake Outlet

Initial lake levels were also adjusted in McCabe Lake and Webber Lake. The Phase 2 model started with lake levels relatively low; however, typical peak flow events occur when lakes are high and little storage is available. Accounting for higher starting lake levels allowed the evaluation of lake storage as a mitigation option. Table 3-3 below summarizes the lake levels used in the model.

Table 3-3: Lake Ranges

Lake	Typical Low Lake Level (m)	Typical High Lake Level (m)	Initial Level Used in Updated Model (m)
Tomahawk[1]	96.2	97.9	96.9
McCabe[2]	73.7	75.7	74.9
Webber[2]	70.2	72.6	71.2
Elevations reference CGVD28			
[1]Typical levels assumed based on outlet geometry and visible conditions			
[2]Typical levels based on resident feedback			

Model Calibration

With the inclusion of the above updates to the Phase 2 model, flow profiles along Sackville River were significantly different than in the original model. This difference was expected, as the original model was calibrated to historical data and the model parameters would have indirectly accounted for Tomahawk Lake as well as the actual lake outlets and bridge structures.

Calibration was completed to generate flow profiles in the updated model that are reasonably similar to those presented in the Phase 2 report. The flood lines in the Phase 2 report are intended to be the lines used for planning purposes. Results from the updated model used in this report are for the assessment of individual mitigation options only and are not intended to revise the results of the Phase 2 report.

Due to the inherent complexity of the PCSWMM model, it is not feasible to make significant changes to the modelled lake system and generate identical model results. The model was calibrated to maintain the flow profile from the original report for the 1 in 5-year and 1 in 100-year events as closely as possible. A separate scenario was developed to evaluate the performance of mitigation measures during the historical maximum flow as there were differing initial conditions and seasonal variables compared to the other design events.

Flood Event	Annual Probability of Exceedance	Flood Discharge at XS-08 (m^3/s)	
		Phase 2 Results	Updated Model Results
1 in 5-year	20%	241	266
1 in 100-year	1%	593	619
Historical Maximum	-	106	106
No significant changes were made to Little Sackville River watershed; no changes in flows were observed			

4.0 MITIGATION MEASURES

Mitigation measures along the rivers were evaluated with the updated PCSWMM model. Through discussion with HRM, the following flow events were used identify mitigation measures and assess their effectiveness:

1. Historical Maximum Storm (March 2003 at Sackville River Gauging Station): 106 m^3/s
2. 1 in 5-Year Rainfall (Phase 2 Design Storm at XS-08): 266 m^3/s
3. 1 in 100-Year Rainfall (Phase 2 Design Storm at XS-08): 619 m^3/s

4.1 AREAS OF CONCERN

Several areas within close proximity to the Sackville Rivers have historical flooding issues. While longer return period storms are expected to create significantly larger flooded areas, addressing the more frequent flooding problems is a priority. Throughout the locations with flooding issues, the primary focus for mitigation is protecting public infrastructure.

As part of the National Disaster Mitigation Program (NDMP), HRM hired WSP to report on flooding problems throughout HRM, including areas surrounding the Sackville River system. Four areas were identified in this report as being susceptible to flooding:

1. Lower Sackville River, Bedford Highway Bridge to Highway 102 (NDMP Site 25);
    - Union Street from Bedford Highway to Bridge Street is within this portion of the floodplain as well.
2. Rankin Drive at Glendale Drive (NDMP Site 20);
3. Sunnyvale Crescent at Beaver Bank Road (NDMP Site 21); and
4. Sackville Drive at Cobequid Road / Highway 101 (NDMP Site 26).

Through consultation with HRM and Halifax Water staff, additional areas of concern were identified within the watershed:

5. Beaver Bank Cross Road / Brook Street Extension;
6. Millwood Drive at Jackladder Drive;
7. Millwood Drive near Sackville Drive;
8. Seawood Avenue at Sackville Cross Road;
9. Hallmark Avenue;
10. Memory Lane at Bedford Bypass; and
11. Range Park.

Each of these areas has been reviewed as part of this project and an assessment of potential mitigation strategies has been made. A decision matrix for each of these measures can be found in Appendix A. Sketches (CSKs) depicting several of the mitigation measures can be found in Appendix B.

4.2 POLICY BASED MEASURES

The most effective way to reduce the long-term flood damage from the rivers is to implement stormwater and development policies within the watershed. Guiding the ways in which development progresses within the floodplain and watershed with a focus on flood risk mitigation will assist in maintaining the overall health of the Rivers and protect infrastructure. Policy based measures which have been reviewed in this study include:

- Promotion of Low Impact Development (LID) and Best Management Practices (BMPs);
- Implementation of a watershed-based stormwater management strategy; and
- Enforcement of development restrictions within floodplains.

Low Impact Development – Best Management Practices

Low Impact Development (LID) is a philosophy of minimizing impacts on watersheds due to hydrologic and hydraulic changes. This is completed by incorporating natural processes or constructing infrastructure which mimics natural processes into the design of development. Natural process such as infiltration, evapotranspiration, filtration, and absorption are promoted as small-scale controls located in close proximity to impervious areas. By immediately directing stormwater to these controls, the stormwater runoff can be controlled to more closely resemble natural storm runoff conditions and processes.

Traditional developments based on piped or ditched stormwater systems being controlled by a large downstream detention pond control peak flows but result in an imbalance of water volume distribution when compared to natural processes. A high percentage of stormwater leaves the site as runoff instead of entering the ground, being used by vegetation, or evaporating/transpiring. LID strives to reduce the percentage of stormwater which leaves the development as runoff.

Typical Best Management Practices (BMPs) related to the LID philosophy include rain gardens, bioswales, green roofs, permeable pavement, box planters, minimized impermeable surfaces, and rainwater harvesting. These strategies would be implemented in addition to traditional stormwater management practices including pipes, ditches, and retention ponds, shown in CSK-1. These BMPs promote the natural processes typically lost during development and improve overall stormwater quality in a region.

Promoting LID in the Sackville Rivers watershed requires an understanding of the geologic properties throughout the watershed. For instance, infiltration may not be possible when a development is on bedrock or an impermeable clay. In addition, the effectiveness of some of these methods is significantly reduced by sufficient frost or snow cover.

The operational and maintenance requirements of the constructed BMPs must be considered. Sediment buildup, vegetative overgrowth, and erosion can take place within these naturalized controls which need to be addressed over time. Currently, stormwater management facilities are owned and regulated by the Municipality. Should LID methods be employed and accepted by the Municipality, the operation and maintenance of these methods must be accepted as well.

Watershed-Based Stormwater Management Strategy

Currently, stormwater is managed on a site-specific basis for new developments. Pre-development stormwater discharge is calculated for the project watershed, and any post-development discharge is restricted to pre-development levels. While this is an effective strategy for local drainage systems, there are limitations when the strategy is considered at the major watershed level.

Often, when reducing post-development flows to pre-development levels, peak flows are released over a longer period of time. Under pre-development conditions, a project watershed may release peak flow over a 30-minute period. When the development is complete, the same peak flow is released, but the peak flow may occur over several hours. It is important to consider however, that the project watershed in question is a small portion of a major watershed for a river or stream.

While balancing flows from a project watershed has minimal effect on local infrastructure that has capacity for the released flow, drainage issues occur when multiple sub-watersheds join together. The pre-development peak flow from the new development may pass through a downstream watercourse before peaks from other contributing sub-watersheds. When the development is complete, the peak flow is released over a longer period, and can overlap with other peak flows. As these peaks overlap, flows in the major watershed can increase significantly, as shown in the figures below.

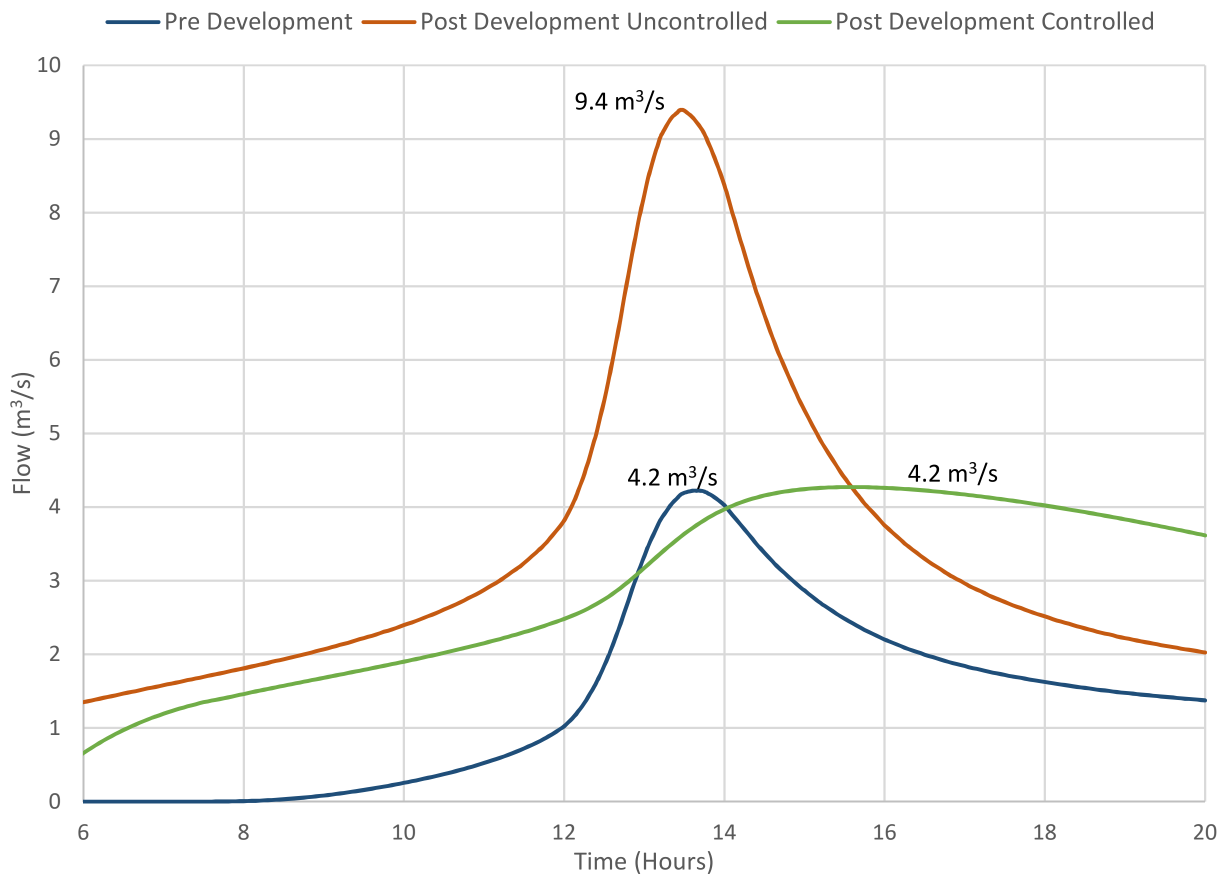


Figure 4-1: Project Watershed Pre- and Post-Development Flows

The above graph shows an example of the flows from a development before and after its completion. The post-development flows match pre-development flows, but the peak is released over a longer duration. The graph below shows the results for the major watershed, which is analogous to the Sackville River. Once the development is completed, the downstream flow in the river within the major watershed is increased by approximately 10%. This is an over-simplified model of a complex process; however, the results are a reality for watersheds across the province. Should many developments occur within a watershed, peak flows from all of the sub-watersheds within the major watershed could potentially overlap, substantially increasing downstream flows in the river.

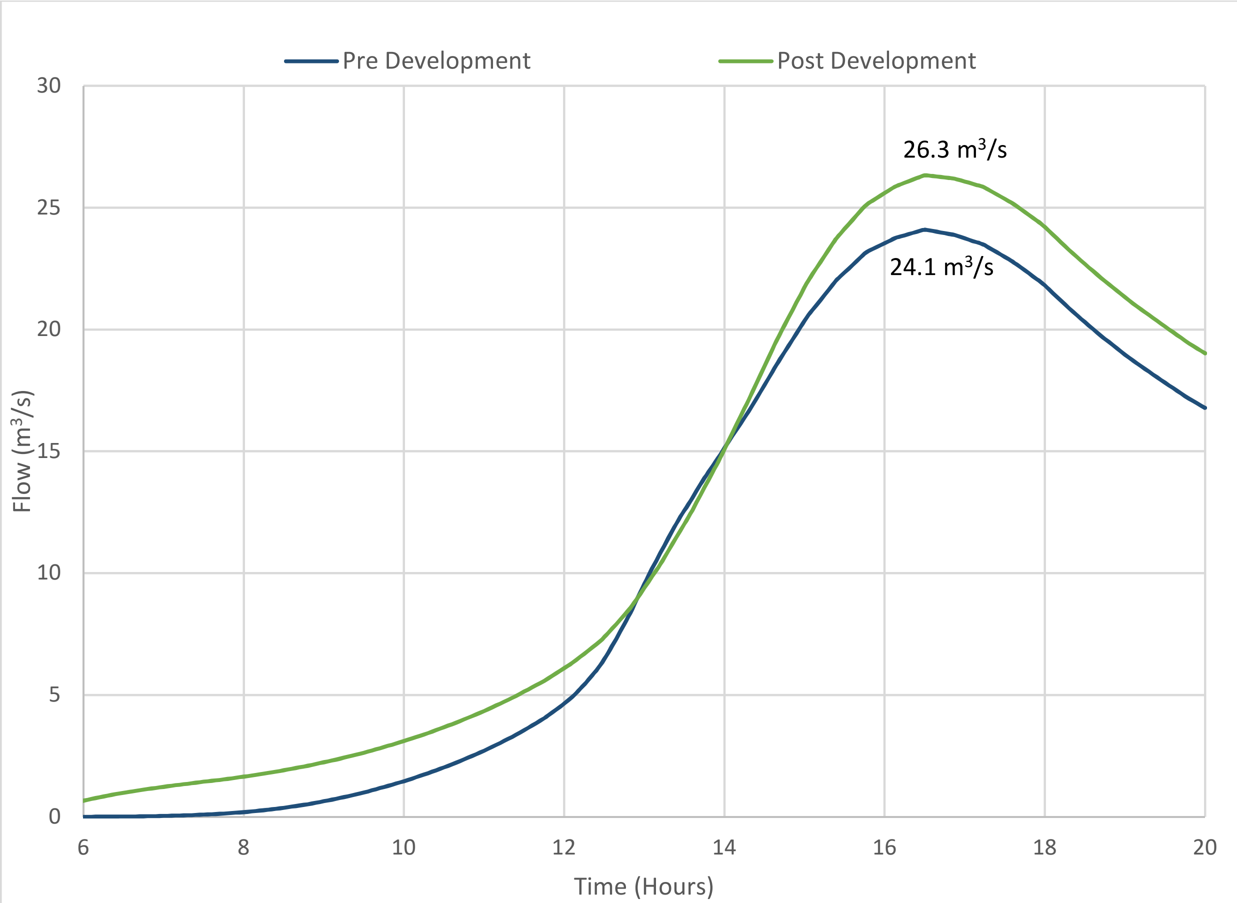


Figure 4-2: Major Watershed Pre- and Post-Development Flows

Stormwater is currently controlled only on developments serviced by storm sewers. Unserviced developments do not currently have a requirement to balance stormwater flows. While unserviced developments result in a lesser increase in runoff when compared to predevelopment conditions, there is still an increase due to removal of vegetation which is replaced with roads, homes, and lawns. Large portions of the developable area within the Sackville Rivers are unserviced, and post-development flows are expected to increase once development is completed.

One method of limiting the potential downstream effects of individual developments is to develop a comprehensive watershed master plan. This plan would dictate targets for stormwater release within the watershed with the goal of maintaining current conditions on a watershed level.

For any watershed management strategy to be effective however, enforceable regulations must be put in place and development must be reviewed and approved with these regulations in mind. Specific runoff targets must be set regarding the rate and volume of allowable runoff within the watershed to achieve this.

For example, the 1 in 100-year flow based on a frequency analysis of historical flows is 106 m^3/s and the total watershed area is 150 km^2 (15,000 Ha). The peak 1 in 100-year flow per hectare is 6.8 L/s/Ha. One possible regulation is to limit the peak flow from any developed site in the Sackville River watershed to a maximum of 6.8 L/s/Ha during the 1 in 100-year storm. In addition, runoff from the 1 in 5-year storm could be limited to 4.5 L/s/Ha (based on 69 m^3/s in the Sackville River from frequency analysis).

For comparison, a hectare of asphalt parking lot with uncontrolled runoff would produce a peak 1 hour, 1 in 100-year flow of 125 L/s.

Reducing flows to match return period flows requires stormwater management over and above the existing regulations. Controlling runoff in this matter however still accounts for the matching of peak flows once development is complete. By pro-rating the allowable discharge based on area, the peak flow in the river would not exceed the design flow, assuming the entire watershed was developed based on this regulation.

Development Restrictions within Floodplains

The single most effective way to reduce the risk of damage due to flooding is to restrict development within the design floodplain. Requiring development to be constructed above design water levels and/or outside of floodplain reduces the risk of a flood impacting the development.

HRM has begun implementing planning strategies based on Map 9 from Phase 2 of the Sackville Rivers Planning Study. Restrictions will be placed on development within the floodplains delineated in this map.

There are typically two methods to identifying floodplains and restricting development within them. The first method is to place restrictions within horizontal flooding extents. The second method is similar; however, it also assigns an elevation to the flooding extents in select locations such as lakes and flat sections of rivers. Assigning a flood elevation at specific locations along the rivers and lakes is a much more robust method of protecting the public from flood waters.

The lines produced on a flood map are based on the existing ground contours as they exist at the time of the study. In the case of the Sackville Rivers flood lines, these contours are based on LiDAR information, which is generally accurate, but not perfect. LiDAR in this area has an average error of 15 cm, but errors in certain locations can be as much as 100 cm. In addition, these contours are not fixed, as elevations within or adjacent to the flood lines could change if the watershed is developed, rendering the flood lines invalid. Assigning an elevation to the flood scenario for critical locations limits the uncertainty. It is also an easy metric to regulate. Instead of considering: "Does the development occur inside the lines?", the question becomes "Is the development above the flood elevation?".

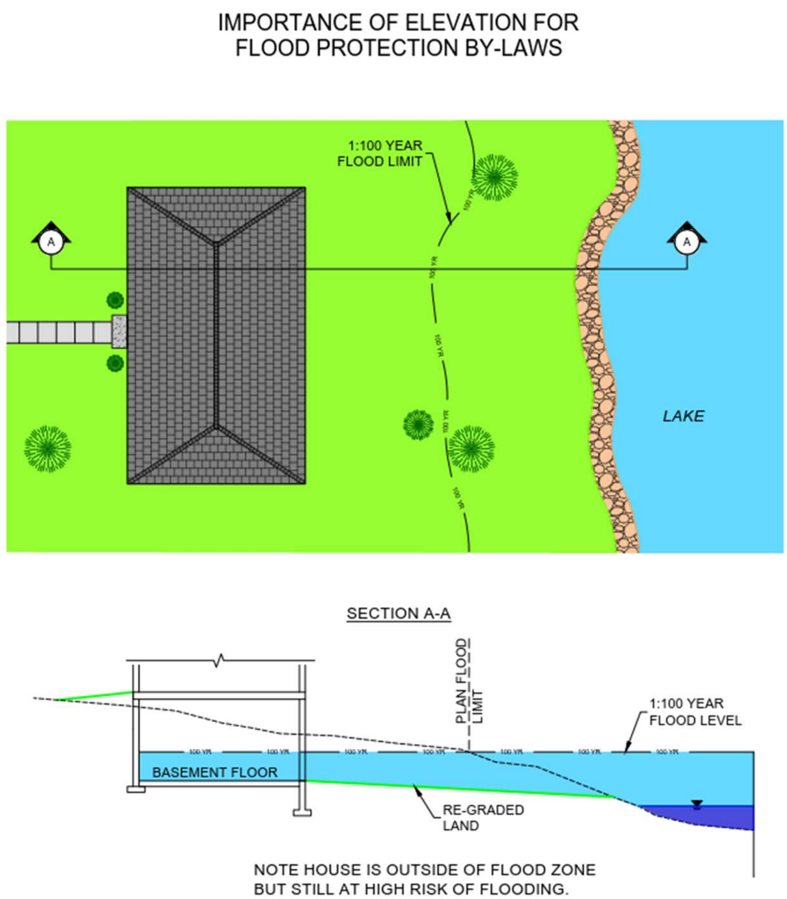


Figure 4-3: Incorporation of Elevation in Flood Mapping

An example scenario to which this would apply is a resident building a home outside of the mapped flood extents who regrades their lot lower than the maximum flood elevation. This will result in a home that appears to be outside of the flooding zone but will still experience flooding during high water levels as shown in Figure 4-3.

It could also be the case that a property is shown within the design flood boundary but, due to inaccurate or outdated LiDAR data, the property is actually above the flood elevation. A property owner could prove that the property is out of the flood zone by providing a topographic survey. Regulations should include the ability for flood lines to change when additional survey information is provided, showing an area to be higher in elevation than the design flood. Table 4-1 below summarizes peak water elevations for several areas of interest within the study area fir the three design events.

Table 4-1: Maximum Water Levels – Areas with Flat Hydraulic Slope

Location	Max HGL – Historical Maximum Flow (m)	Max HGL – 1 in 5-Year (m)	Max HGL – 1 in 100-Year (m)
Tomahawk Lake	97.1	98.7	98.4
McCabe Lake	75.5	76.6	77.7
Little Lake	75.5	75.7	76.0
Webber Lake	71.9	73.4	75.5
Feely Lake	69.0	69.2	69.4
Barrett Lake	62.5	62.8	62.9
Millwood Drive (Upstream)	54.0	54.6	55.6
Beaver Bank Cross Road (Upstream)	51.7	52.9	53.6
Gantry Road (Upstream)	51.1	51.5	52.4
Sackville Drive (Upstream)	38.4	39.5	40.9
Highway 101 (Upstream)	13.3	14.0	14.9
Bedford Rifle Range	8.1	9.1	10.5
Highway 102 (Upstream)	8.0	9.0	10.4
Range Park	7.9	8.8	10.1
Bedford Mall	7.6	8.4	9.6
Bedford Highway Bridge (Upstream)	4.1	5.9	8.0
Elevations reference CGVD28			

4.3 CONSTRUCTION MEASURES

To protect existing public infrastructure against flooding resulting from design events, construction-based mitigation measures have been evaluated. When referencing the measured or calculated flows from these events, it is important to reference a similar location for consistency. The flow at the Sackville River Gauging

Station (Government of Canada Station 01EJ001) has been used for measured flows during historical events. For modelled results, the model element which corresponds to the gauging station location, XS-08, has been referenced. The magnitude of each mitigation measure has been considered for three design conditions:

- Historical Maximum Storm (March 2003, 106 m^3/s measured at Sackville River Gauging Station);
- 1 in 5-year Future Design Storm (266 m^3/s modelled at XS-08); and
- 1 in 100-year Future Design Storm (619 m^3/s modelled at XS-08).

Evaluation of each measure had to be considered for each return period due to the variations in magnitude of the three events. The scale of construction required to manage a flow of 619 m^3/s is considerably larger than that required for the historical maximum storm.

Lake Storage

Two large lakes are located along the upper reaches of the Sackville River; Tomahawk Lake and McCabe Lake. McCabe Lake receives runoff from an area of 91.3 km^2, including Tomahawk Lake and its drainage area of 16.9 km^2.

When a large storm such as the March 2003 event occurs, often the lakes in the watershed are at relatively high levels. Often, when similar rainfall events occur with lakes at lower levels, downstream flows in rivers are considerably lower. For example, the March 2003 event involved 80 mm of rainfall in 10 hours along with snowmelt. This rainfall event is between a 1 in 5-year and a 1 in 10-year rainfall event over 12 hours, however it resulted in the maximum flow ever recorded at the Sackville River Gauging Station. Water levels in the lakes prior to the March event were noted by residents to be reasonably high due to snow melt.

Based on anecdotal evidence from residents living on McCabe Lake along with survey measurements, there is a typical range of 2 m between high lake level and low lake level. Based on the Phase 2 model, lake levels are calculated to exceed the typical range of the lake. The volume between the typical low water elevation of the lake and the calculated peak water level lake can be utilized as storage to mitigate downstream flows in Sackville River. A drawing of a potential flow control on the lake is shown in Figure 4-4. The typical range of Tomahawk Lake is unknown; however storage can still be provided. Webber Lake was initially considered for storage as well, however the storage volume was deemed to be insufficient for mitigation purposes.

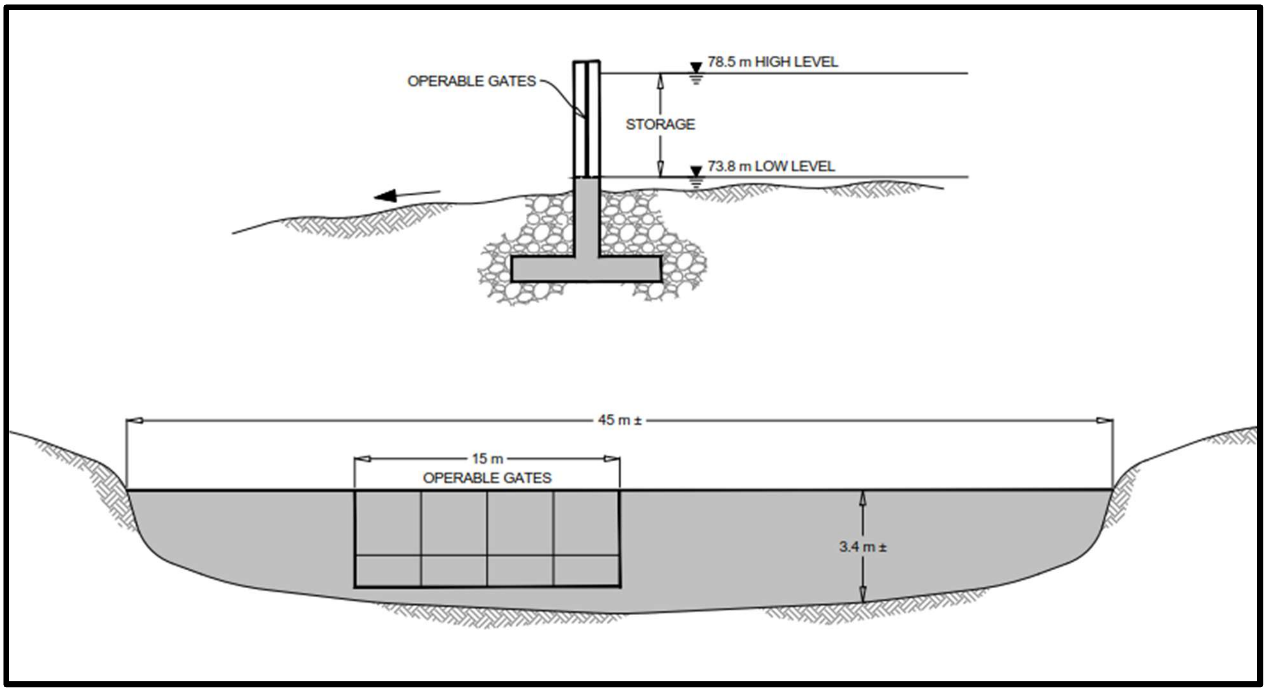


Figure 4-4: McCabe Lake Control Structure Concept

The addition of storage in Tomahawk Lake and McCabe Lake was included in the model, shown in CSK-2, by incorporating a restriction at each lake outlet with an adjustable opening. Table 4-2 summarizes the results of the modelling including lake storage.

Table 4-2: Model Results Including Lake Storage

Flow Event	Lake with Added Storage	Tomahawk Lake Max Level (m)	McCabe Lake Max Level (m)	Flow at XS-08 (m^3/s)
Historical Maximum	None	97.1	75.5	106
	Tomahawk	96.9	75.4	104
	McCabe	97.1	75.2	88
	Tomahawk + McCabe	96.9	75.1	88
1 in 5-year	None	97.7	76.6	266
	Tomahawk	97.8	76.5	259
	McCabe	97.7	76.8	237
	Tomahawk + McCabe	97.8	76.7	231
1 in 100-year	None	98.4	77.7	619
	Tomahawk	98.5	77.6	609
	McCabe	98.4	78.1	572
	Tomahawk + McCabe	98.5	78.1	562
Elevations reference CGVD28				

Based on the model results, adding storage to McCabe Lake is feasible to reduce peak flows in Sackville River while storage at Tomahawk Lake has little effect. It is estimated that the cost to add storage to McCabe Lake is $12M plus the cost of any necessary land acquisition.

Bridge Widening

Any structure crossing a river within projected flood lines results in some degree of flow restriction, shown in CSK-3. In many cases, the restriction is not sufficient to raise flood levels upstream of the crossing. There are locations however where crossing structures do increase flood levels. In some cases, flood waters overtop the bridges as well, risking the infrastructure.

No structures were identified which required urgent widening. There are structures however that, if widened, would reduce flooding extents upstream of the bridge. Reducing the flow restriction by widening the bridge can negatively impact downstream water levels as more flow passes through the opening. The flood elevations and design flows at these crossing locations should be considered at the time of detailed design of replacement structures as well as the downstream water levels. The tables below summarize the bridges and culverts which have been identified for upsizing when prudent.

Table 4-3: Crossing Structures Considered for Upgrade

Location	River Crossing	Existing Infrastructure*
Beaver Bank Road	Little Sackville River	1.9 x 1.6 m Box and 1.7 x 1.6 m Box (Timber)
Sackville Drive	Little Sackville River	3.3 x 3 m Arch and 3.4 x 2.04 m Arch (CSP)
Bedford Highway	Sackville River	14 x 4.5 m Bridge
Highway 102	Sackville River	37.7 x 7.1 m (3-Span Bridge)
*Existing sizing from Phase 2 report		

Table 4-4: Water Surface Elevations with Crossing Upgrades

Location	Road Elevation @ Crossing* (m)	Historical Max		1 in 5-year		1 in 100-year	
		Existing HGL (m)	Revised HGL** (m)	Existing HGL (m)	Revised HGL** (m)	Existing HGL (m)	Revised HGL** (m)
Beaver Bank Road	50.7	50.3	49.3	51.0	49.7	51.4	50.7
Sackville Drive	40.1	38.4	37.3	39.5	37.6	40.9	38.5
Bedford Highway	7.0	4.1	3.5	5.9	4.8	8.0	6.4
Elevations reference CGVD28							
*Road elevations from Phase 2 report							
**Structure widened to not negatively impact upstream flood levels							

The crossing of the Little Sackville River and Highway 101 as well as the crossing of Sackville River and Highway 102 were also assessed to determine if upsizing the existing infrastructure would effectively reduce peak water levels. By replacing the existing crossings with a bridge spanning a distance large enough to not impede design flows, peak water levels were reduced by approximately 0.15 m for the future 1 in 100-year event. The levels were reduced even less for the more frequent storm events. Due to the minimal change in water level, it was determined that the upsizing of the infrastructure is not warranted.

Channel Reconstruction

One method of reducing flooding along a river is to increase the capacity of the river itself. In narrow locations of a river, the channel can be excavated and widened, allowing more flow to pass within the widened banks such as in CSK-4. Another option is to remove constructed restrictions, such as retaining walls, along the riverbanks as shown in CSK-5. Construction within the riverbanks is regulated through Nova Scotia Environment and would require extensive studies and consultation to gain approval.

A review of construction within the Sackville River channel was completed as part of this study. The only location along the river in which flood waters back up due to a lack of channel capacity is along the Bedford Highway, between the Highway 102 and Bedford Highway bridges. Due to the flatness of the channel in this location, the river would have to be widened much more than is feasible due to nearby development, including Bedford Highway itself, in order to substantially reduce flows. Based on the amount of widening required, the property impacts, and the regulatory hurdles related to this option, reconstruction of the channel is not recommended.

In 2019, CBCL provided additional analysis of the Sackville River between Highway 102 and Bedford Highway, specifically relating to channel widening. Based on the analysis, limited improvement in water levels was gained by increasing the channel width.

Overflow Construction

Construction of an overflow channel or conduit along a river (shown in CSK-6) provides a route for high flows while maintaining the natural flow of a river. Generally, a flow restriction such as a berm would be constructed to direct high flows to a control structure. The normal flow range would pass through the river while high flows would pass through the control structure and flow along the overflow before rejoining the river at a downstream location with capacity for the flow. While costly, this method is highly effective in locations with limited hydraulic capacity such as downstream of Range Park.

Protective Berms

It is possible to protect property outside of riverbanks by constructing protective berms as shown in CSK-7. While these berms protect properties behind them, the berms reduce the available floodplain width, and raise flood levels to account for the lost flow area. Care must be taken when constructing berms on one side of the river to not worsen flooding on the other side of the river. As this mitigation measure primarily protects private property, detailed analysis was not completed. Berms are a viable method should private property protection be required in the future.

Property Raising

Individual structures and/or properties within the floodplain can be raised above flood levels for protection as shown in CSK-8. This process relies heavily on the condition of existing structures as moving a structure which has deteriorated could potentially lead to failure. Completing property raising can be costly and requires a great deal of public consultation. The change in the floodplain must also be considered by modelling the effects on surrounding areas. Raising a property or properties restricts flow which leads to increased flow velocities and flow depth, potentially negatively impacting nearby locations along the river. This mitigation measure would generally be used for private property, and as such has not been considered in great detail as part of this project.

Structural Flood Protection

Refitting existing structures within the floodplain to improve flood protection (CSK-9) can be an effective method of limiting flood damage. Work would often include waterproofing, the addition of local drainage, and options for removal of high waters. This mitigation measure is focused on protection of existing private properties and does not affect water levels along the rivers.

Relocation of Flood Prone Properties

Some properties are so prone to flooding that the only viable method of reducing flood damage is to remove or relocate the structure. This can be completed by purchasing flood prone property (CSK-10) or retreating/displacing structures (CSK-11). While this method is highly disruptive to property owners, it eliminates frequent flooding along with the associated costs. Properties purchased by public entities could be used as passive parkland, with the understanding that the land will be susceptible to flooding at times. All public infrastructure along the Sackville Rivers is located on publicly owned land and therefore this mitigation measure is only applicable to private property.

4.4 AREA SPECIFIC MITIGATION OPTIONS

Area 1 - Lower Sackville River, Bedford Highway Bridge to Highway 102

This area floods to the elevations as follows:

Table 4-5: Lower Sackville River Water Elevations

Event	Flow (m^3/s)	Water Elevation (m)
Historical March 2003 Storm	106	6.8
Future 1 in 5-year Storm	266	8.1
Future 1 in 100-year Storm	619	9.4
Flow and level measured upstream of XS-08 (Sackville River Gauging Station)		
Elevations reference CGVD28		

Flooding in this area has been well documented and affects the large sports field (Range Park), single family homes, the Bedford Place Mall area, other businesses along the Bedford Highway, and public roads which become impassible.

The following mitigation measures were considered:

1. **Property Purchase:** The homes along Union Street could be purchased and removed as the cost of these properties is less than the probable ongoing damage due to flooding. The assessed value of these homes is estimated at $7.1M. Costs for the purchase of properties are expected to be higher than the assessed value.

   The lower end of this area, immediately upstream of Bedford Highway, is developed very closely to the Sackville River as outlined in Figure 4-5. Regardless of the other mitigation measures put in place, purchase of certain properties may be necessary to reduce risk. The assessed value of these properties is approximately $1.5M, however this includes properties with an assessed value of $0. It is understood that the assessed value is not necessarily an applicable sales price, an additional percentage of the assessed value may be required for purchase. Should the properties be purchased, there would be additional costs to demolish and remove the homes. Once the structures are removed, this area could be converted into a passive park.

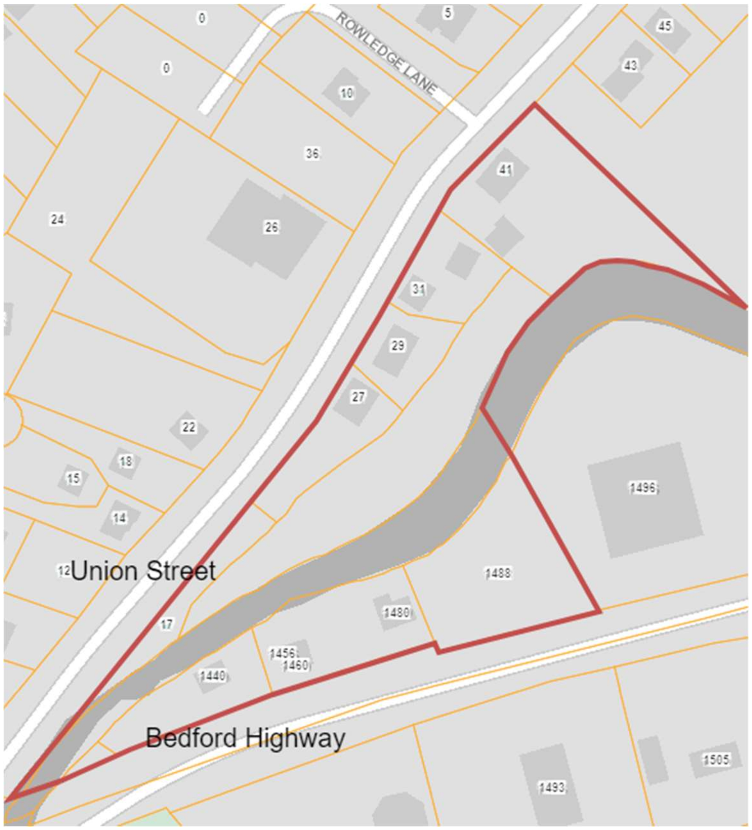


Figure 4-5: Bedford Highway / Union Street Properties for Purchase

2. **Property Raising:** This option would work for many of the smaller buildings including the residential properties along Union Street, however, the street itself would need to be raised.

   If the larger buildings such as the Bedford Place Mall were to be raised up, this would provide protection to the buildings, however, the parking areas will need to remain at a similar elevation to continue to act as the floodway for the river. Any new building permits in this area should require:
   a. The buildings are above the 1 in 100-year flood level; and
   b. The floodplain width/depth is not reduced.

3. **Emergency Overflow:** An emergency overflow (1.4 km, shown in Figure 4-6) could be constructed from the lower end of Range Park to the mouth of the Sackville River near Fish Hatchery Park. We have modelled various storms to test the effectiveness of such a mitigation measure. The following sizing was completed for the various scenarios:
   a. Historical Peak Flow (March 2003) – a twin 2.4 m x 3.0 m overflow box culvert (or equivalent end area) would have prevented the flood waters from exceeding the riverbanks. We have estimated the cost of this option to be approximately $53M.
   b. Future 1 in 5-Year Flow – a 8.5 m diameter overflow tunnel would prevent the design flood waters from exceeding the riverbanks. We have estimated the cost of this option to be in excess of $200M.
   c. Future 1 in 100-Year Flow – a 13 m diameter overflow tunnel would prevent the design flood waters from exceeding the riverbanks. We have estimated the cost of this option to be in excess of $240M.

4. **Bridge / Culvert Upgrade:** As noted in Section 4.3, increasing the span of the Bedford Highway bridge can lower water levels in this area by 1.1 m in the 1 in 5-Year event. When this structure is to be replaced, consideration of the design flows should be given in order to reduce flood levels.

5. **Channel Widening:** Widening of the channel to increase capacity was considered in this area by CBCL in a memo dated January 16, 2019 to HRM. It was determined that channel widening would be expected to reduce water levels along a portion of this area by 10-270 mm, while slightly increasing water levels in discrete locations. Due to the level of future design, modelling, and coordination with approval agencies required to acquire approval for channel widening, the moderate decrease in water elevation was not determined to be worth the expense.

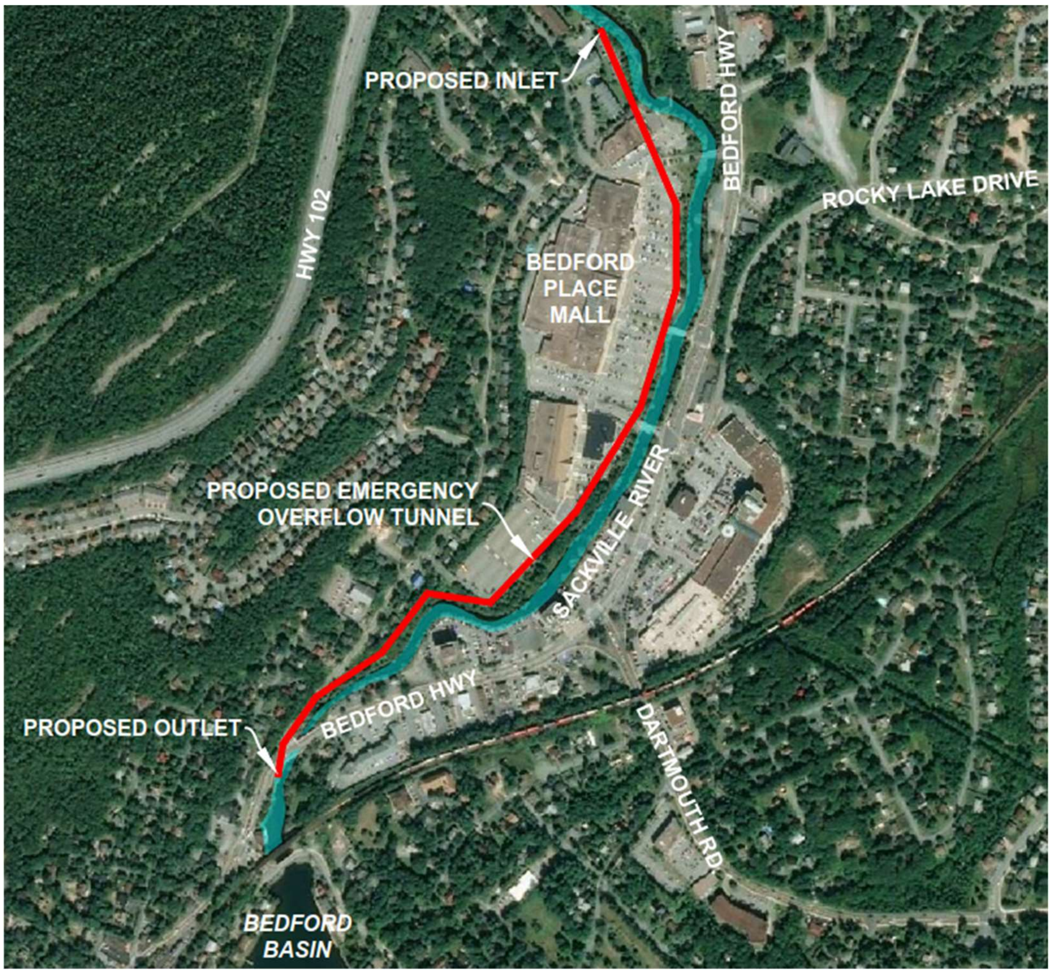


Figure 4-6: Emergency Overflow - Lower Sackville River

Area 2 – Rankin Drive at Glendale Drive

The area between Matador Court and Glendale Drive experiences flooding. The basements of the properties along Matador Court have experienced significant flooding on numerous occasions. The likely cause of the flooding based on resident reports is surcharging of the nearby sewers. This area is low lying and at the bottom of a steep hill, a configuration which commonly results in sewer surcharge as the hydraulic grade line in the sewer on the hill can be significantly higher than the sewer in the low area.

The flooding in this area is not caused or affected by the Sackville Rivers. We recommend that the storm and sanitary sewers in this area be studied to determine the cause of the surcharging and identify mitigation options.

Area 3 – Sunnyvale Crescent at Beaver Bank Road

This area has local flooding issues related to street drainage, culverts, and storm sewers. The flooding at this location is not related to the flooding of the Sackville Rivers. At this location, the local storm drainage infrastructure should be investigated and upgraded to provide adequate drainage from this localized low area.

Area 4 – Sackville Drive at Highway 101

This area is flooding due to the overflow of a pond and watercourse north of Memory Lane. The pond and watercourse receive runoff from a large urban area in Sackville. The pond is drained through a series of culverts to the Sackville River under Highway 101 and these culverts do not have the capacity to handle the peak flows and are prone to clogging as shown in Figure 4-7.

Figure 4-7: Culverts Downstream of Memory Lane

Area 5 – Beaver Bank Cross Road / Brook Street Extension

This area is low lying and within the flood limits of the Little Sackville River and experiences occasional flooding of roads and homes. The houses in this area are pre-manufactured homes built in a factory and moved onto leased lots set on blocks, with no foundation. There are approximately 60 pre-manufactured homes in this area within the flood limits.

The following mitigation measures have been considered:

1. **<u>Bridge / Culvert Upgrade:</u>** The culvert on Gantry Road is undersized, leading to increased water levels during typical flow. There is currently an 1,800 mm diameter CSP culvert in place to handle the flow in the Little Sackville River. If this culvert were upsized, Gantry Road would need to be raised, and the flood limits in this area would not change. Upsizing this culvert would be a good thing to do to bring

this river crossing into regulatory compliance but will not significantly reduce flooding in the area under design flood events.

2. **Retreating / Displacing Properties:** It is possible to raise most of these homes and add fill to adjust the surrounding grade to match the homes. These homes are on wooden or concrete blocks and can be raised with minimal costs. For this to be effective, the roads would also need to be raised. Most of these roads are private roads. It is recommended that a minimum house elevation of 52.7 m be set. This elevation is 0.3 m above the 100-Year flood elevation.

3. **Property Purchase:** These homes are relatively inexpensive, approximately $35,000 is assessed value each. Also, the homes could be moved or may have some value if able to be relocated. The owner of the land lease community would then own lots which could not have homes and no rent would be collected. The land lease lots may also need to be purchased to account for the loss in land value. We estimate the cost per lot to be approximately $30k. Based on assessed values and approximate lot costs, we estimate property purchase in this area to cost $5.2M. It is understood that the assessed value is not necessarily an applicable sales price, an additional percentage of the assessed value may be required for purchase. Should the properties be purchased, there would be additional costs to demolish and remove the homes. Once the structures are removed, this area could be converted into a passive park.

Area 6 – Millwood Drive at Jackladder Drive

This area has experienced localized flooding in the back yards of properties where a brook passes under Millwood Drive through a culvert. This flooding is not related to the Sackville Rivers.

It is recommended that the hydrology and hydraulics of this culvert crossing Millwood Drive be reviewed. It is likely the case that there is a capacity constraint at this crossing, which consists of 4 culverts of 1,200 mm diameter.

Area 7 - Millwood Drive near Sackville Drive

This area has local flooding in back yards and surrounding the low area on Millwood Drive. The low area receives drainage from a large urban area and a watercourse crosses under Sackville Drive which adds considerable flow to the area. The area which experiences flooding is located approximately 10 to 15 m above the flood waters of the Little Sackville River and flooding in this area is not caused by flooding from the Sackville Rivers.

It is recommended that the local storm drainage sewers and culverts under Millwood Drive and Sackville Drive be reviewed in this area.

Area 8 – Seawood Avenue at Sackville Cross Road

This area is very low and flat compared to the flood levels in the Little Sackville River. Many of the basements are below even modest water levels in the river. Additionally, there are local back yard drainage features which get blocked and back up, adding to the flooding problems.

The following mitigation measures have been considered:

1. **Property Raising:** There are approximately 31 homes and 475 m of public road which would require raising to be above the flood levels. Raising the road and these homes would cost more than purchasing the homes.

2. **Property Purchase:** This area is a natural floodplain and the Municipality could consider property purchases in the area. There are approximately 31 homes in this area with a total assessed value of $5.1M. It is understood that the assessed value is not necessarily an applicable sales price, an additional percentage of the assessed value may be required for purchase. Should the properties be purchased, there would be additional costs to demolish and remove the homes. Once the structures are removed, this area could be converted into a passive park.

3. **Retreating / Displacing Properties:** There is no space available for this option on the lots and there is no higher ground to move the homes to. Due to these constraints, this measure is not feasible.

4. **Local Drainage Improvements:** It is possible to install local deep storm sewers that provide drainage to this area. The Little Sackville River becomes steep downstream of this area and the outlet of a deep storm sewer system would need to chase the river to get sufficient grade for an outfall. This measure would provide drainage relief for the homes and streets for most storms, but not for the larger storms. In the modelled 1 in 100-Year storm, this area would be severely flooded with or without a deep storm sewer.

Area 9 – Hallmark Avenue

Hallmark Avenue is a street with residential, single-family homes located between the street and the Little Sackville River. The street generally runs parallel to the river with approximately 60 m between the street and the river. Many of the homes and rear yards are within the flood lines. There is public land at the rear of these lots, between the rear lot lines and the river with an HRM owned trail.

The following mitigation measures have been considered:

1. **Berm Construction:** The walking trail at the rear of the properties could be raised to act as a protective berm to prevent high water levels from entering the properties along the river as shown in Figure 4-8 below. Based on model results, this solution appears to be effective. Construction of the berm is estimated to cost $0.2M.

2. **Structural Flood Protection:** The houses along Hallmark Avenue could install specific flood protection measures such as water proofing and sump pumps. This strategy would need to be assessed and customized for each house. In addition, this measure would not protect the trail or the rear yards from flooding.

3. **Retreating / Displacing Properties:** This option would be very expensive as there are approximately 30 homes affected in this area. Additionally, there is limited space to move the homes, meaning that the homes would have to be removed or raised. Due to the costs of this option and the constraints of the existing properties, this option has not been deemed feasible.

Figure 4-8: Proposed Berm - Hallmark Avenue

Area 10 - Memory Lane at Bedford Bypass

This area experiences occasional flooding, the river modelling shows the area being affected by high water levels in the river however, during historical storms, the river flooding has not caused flooding in this area. This area floods due to the same infrastructure limitations described in Area 4, namely the series of culverts under Highway 101.

The following mitigation measures were considered:

1. **Property Purchase:** There are only 3 homes on Memory Lane and these properties could be purchased. The roads in this area would continue to flood and the property purchase would not completely eliminate the flooding here.

2. **Upsize Culverts Under Highway 101:** The existing culverts are not of sufficient size to drain this large urban area. The culverts can be replaced to provide flood relief for this area. We recommend that these culverts be upsized.

3. **Retreating / Displacing Properties:** While the homes could be relocated, the road is needed to access the properties. Only one of these homes is within the flood lines and, even if this house was moved to higher ground, the road would not be passable during high water events.

Area 11 - Range Park (Upper End of the Bedford Place Mall to Highway 102 Bridge)

This area floods approximately two (2) times per year to various degrees. This site is mainly a Municipality owned park with ball fields, a sports track, a soccer field, and a walking trail along the river. There are some multi-unit residential buildings on the south side of the river and a few commercial buildings on the Bedford Highway that are all within the 1 in 100-Year flood limits.

The following mitigation measures were considered:

1. **Structural Flood Protection:** Additional drainage could be placed throughout the park area to allow for quicker drainage after a flood recedes (this would only marginally assist in making the sports fields more available for use). It may be possible to install all weather turf, but the area is prone to long term settlement due to the alluvial soils and substantial geotechnical reinforcing would be required.

2. **Property Raising:** This would prevent the fields from flooding but would increase flooding elsewhere as this area is part of the floodway. It may be practical to raise Bedford Highway in the small lower area that is within the 1 in 100-year flood limits.

3. **Emergency Overflow:** If the emergency overflow in the Lower Sackville River is constructed then it could be extended to the Highway 102 bridge. The bridge opening could be reconfigured to only allow approximately 65 m^3/s down the river with the remaining flow spilling into the emergency overflow. This would prevent the fields, roads, and buildings from flooding. The additional length of the overflow pipe/conduit to get to the Highway 102 bridge is approximately 300 m. Extending the overflow past Highway 102 is estimated to have the following costs in addition to those noted for the Lower Sackville River Overflow (Area 1):
    a. Historical Peak Flow March 2003 – extension of twin 2.4 m x 3.0 m overflow box culvert (or equivalent end area). Cost of extension: $11M.
    b. Future 1 in 5-Year Flow – extension of 8.5 m diameter overflow tunnel. Cost of extension: $35M.
    c. Future 1 in 100-Year Flow – extension of 13 m diameter overflow tunnel. Cost of extension: $41M.

4. **Accept Flooding Conditions:** The flood-prone area in Range Park is used for recreation and is owned by HRM. It is understood that occasional flooding is generally acceptable in this location as recreational activities do not occur during large flood events. Should it be desired to reduce the amount of time the park is encumbered by flood waters, local drainage improvements could be installed to relieve the area when necessary.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Flooding along Sackville River and Little Sackville River continues to be a concern with respect to both private and public infrastructure. The evaluation of mitigation measures to reduce the impacts of flooding in the area has been completed based on modelling and conclusions completed in the Phase 2 Sackville Rivers Floodplain study. The Phase 2 model was updated to include additional detail and mitigation strategies along the watershed were considered with a focus on the protection of public infrastructure. The following conclusions have been made with respect to the watershed:

1. Both public and private infrastructure in close proximity to the Sackville Rivers is at risk of damage due to flooding;
2. Portions of local drainage infrastructure cause stormwater to back up, adding to flooding from the rivers;
3. There is currently significant development potential within the watershed which will have a negative effect on drainage patterns and runoff volumes;
4. Unmitigated stormwater flow from unserviced developments will increase runoff within the watershed;
5. Balanced stormwater discharge (as per current regulations) from serviced developments can result in increased flow within the rivers due to extended peak flows;
6. When selecting mitigation options, the magnitude of the flow to be mitigated significantly impacts the cost to complete the mitigation measures;
7. Model results indicate design flows which far exceed historical peak flows;
8. Including Low Impact Development principles in future development within the watershed will reduce peak flows in the rivers while adding to operations and maintenance requirements;
9. The downstream flow of the rivers is sensitive to changes in the level of McCabe Lake;
10. The existing bridge structures at Beaver Bank Road, Sackville Drive, and Bedford Highway are hydraulic restrictions and increase upstream flood levels;
11. Restricting development within the floodplain of the rivers will reduce future flooding damage; and
12. Flooding in Areas 2, 3, 4, 6, 7, and 10 is not directly caused by water levels in the Sackville Rivers.

Based on a comparison of model results both with and without the inclusion of mitigation options, the following is a list of recommendations in order of implementation along with a cost estimate in Table 5-1:

1. Place restrictions on future development within the floodplain identified in Phase 2 and include elevation restrictions based on the water surface profiles associated with Map 9 in the Phase 2 study, allowing adjustments to be made with topographic survey information from a licensed surveyor;
2. Implement a watershed specific stormwater management strategy which relates development to downstream flow in the rivers which includes Low Impact Development principles;
3. Require stormwater management for unserviced developments within the watershed;
4. Consider design flows and flood plain width when reconstructing any structure which crosses the Sackville or Little Sackville Rivers;
5. Construct a control structure at the outlet of McCabe Lake based on the 1 in 100-Year design storm and the typical range in lake level;
6. Area 1 - Construct an overflow diversion to keep the historical maximum flow within the riverbanks from Range Park to the Sackville River outlet;

7. Area 1 – Purchase properties in close proximity to the river as identified in this report;
8. Area 2 – Investigate the storm and sanitary sewers in this area and consider increasing capacity where needed;
9. Area 3 – Investigate local storm drainage infrastructure and consider upgrades as required to provide adequate drainage;
10. Area 4 – Evaluate local culverts in the area and consider upgrading the culverts as needed (this could be done in conjunction with Area 10);
11. Area 5 – Purchase properties within the 1 in 100-Year flood lines;
12. Area 6 – Evaluate the culvert under Millwood Drive and consider upgrading as necessary;
13. Area 7 – Evaluate local drainage routes and consider upgrading as needed;
14. Area 8 – Purchase properties within the 1 in 100-Year flood lines;
15. Area 9 – Construct a protective berm at the rear of homes within the flood lines;
16. Area 10 – Evaluate local culverts in the area and consider upgrading the culverts as needed (this could be done in conjunction with Area 4); and
17. Area 11 – Accept flooding conditions.

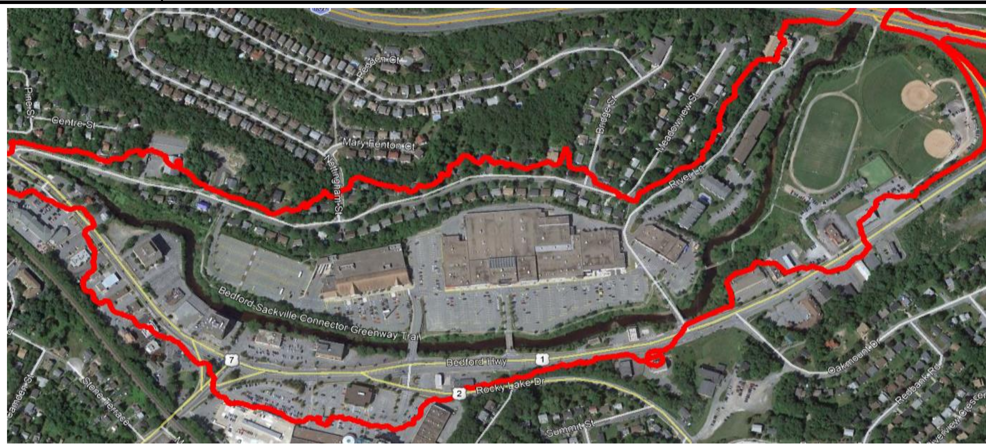
Table 5-1: Cost of Non-Policy Mitigation Measures

Area	Mitigation Measure	Cost ($)
Sackville River	Construct control outlet on McCabe Lake	12.0 M
Area 1 – Lower Sackville River	Construct emergency overflow based on historical maximum storm	53.0 M
Area 1 – Lower Sackville River	Purchase properties near Bedford Highway Bridge	1.3 M
Area 5 – Beaver Bank Cross Road and Brook Street	Purchase properties within 1 in 100-Year flood extents	5.2 M
Area 8 – Seawood Avenue	Purchase properties within 1 in 100-Year flood extents	5.1 M
Area 9 – Hallmark Avenue	Construct protective berm	0.2 M
Area 11 – Range Park	Accept flooding conditions	0.0 M
	Total	**76.8 M**
Property purchases are based on assessed value only, additional purchase and demolition costs will apply		
Local drainage improvements not related to the Sackville Rivers have not been included		
Estimated construction costs include 25% contingency		

APPENDIX A – MITIGATION DECISION MATRICES

Project Name: Sackville Rivers Mitigation Planning Strategy
Project Number: 19-174
Mitigation Strategy Decision Matrix

Location:	Area 1 - Lower Sackville River, Bedford Highway Bridge to Highway 102 (NDMP Site 25)
Typical Flooding Frequency:	1 in 5-Year or more frequent
Extents of Flooding:	Many residential properties on Union Street, Bedford Place Mall lands, and HRM sports field. Mostly sports fields, parking lots, and some residential properties flood on a regular basis. There is a much larger number of properties at risk with the occurance of a 1 in 100-Year storm.



Mitigation Measure	Estimated Effectiveness	Feasibility	Rank	Rationale
Channel Widening	10	2	5	Property ownership, limited space, highway, roads
Berm Construction	3	3		Limited space, need place to drain land behind berm
Bridge/Culvert Upgrade	5	2	4	Bedford Highway bridge should be upsized when replacement is necessary
River Restoration	5	2		Not enough land available
Structural Flood Protection	4	4		Flooding is too extensive
Retreating/Displacing Properties	10	2		Not enough land available to move buildings
Flow Reduction through Infiltration	1	1		Too long term / will not help this area in the near future
Property Purchase	10	7	1	Yes, good for homes of low cost but less feasible for high value commercial/retail
Property Raising	9	8	2	May work for smaller homes or new development
Emergency Overflow	6	7	3	May provide flood relief but expensive
Addition of Storage	2	3		May work at sports field / rifle range

Effectiveness 1-10 (10 most effective, 1 not effective)
Rank top 4 based on most effective

Feasibility 1-10 (10 most feasible, 1 not feasible)
Rank top 3 based on most effective/feasible

Project Name: Sackville Rivers Mitigation Planning Strategy
Project Number: 19-174
Mitigation Strategy Decision Matrix

Location:	Area 2 - Rankin Drive at Glendale Drive (NDMP Site 20)
Typical Flooding Frequency:	1 in 5-Year
Extents of Flooding:	Roadway, ditches and some homes, Little Sackville River backs up into this area

Mitigation Strategy	Estimated Effectiveness	Feasibility	Rank	Rationale
Channel Widening	9	4		This area is not near channel
Berm Construction	1	1		No place to drain area behind berm
Bridge/Culvert Upgrade	7	9	1	Should upsize culvert
River Restoration	1	1		River is in natural condition here
Structural Flood Protection	1	1		Road floods
Retreating/Displacing Properties	9	4	2	May work to raise road
Flow Reduction through Infiltration	1	1		Too little and would not help in the near future
Property Purchase	9	2		May work for a few low lying homes
Property Raising	9	6	3	Yes, for roads or house lots
Emergency Overflow	1	1		Channel not near this location
Addition of Storage	3	2		May reduce flood level

Effectiveness 1-10 (10 most effective, 1 not effective)
Rank top 4 based on most effective

Feasibility 1-10 (10 most feasible, 1 not feasible)
Rank top 3 based on most effective/feasible

Project Name: Sackville Rivers Mitigation Planning Strategy
Project Number: 19-174
Mitigation Strategy Decision Matrix

Location:	Area 3 - Sunnyvale Crescent at Beaver Bank Road (NDMP Site 21)
Typical Flooding Frequency:	1 in 2-Year
Extents of Flooding:	Streets, ditches, homes, local flooding issue not caused by Little Sackville River flooding

Mitigation Strategy	Estimated Effectiveness	Feasibility	Rank	Rationale
Channel Widening	1	1		Local drainage issue, not Little Sackville River
Berm Construction	1	1		Local drainage issue
Bridge/Culvert Upgrade	9	9	1	Culvert upsizing
River Restoration	1	1		Local drainage issue
Structural Flood Protection	1	1		Local drainage issue
Retreating/Displacing Properties	9	4	3	Expensive
Flow Reduction through Infiltration	1	1		Too long term
Property Purchase	9	2	4	Expensive
Property Raising	9	5	2	May work for a few properties
Emergency Overflow	1	1		Local flooding issue
Addition of Storage	1	1		Local flooding issue

Feasibility 1-10 (10 most feasible, 1 not feasible)
Rank top 3 based on most feasible

Feasibility 1-10 (10 most feasible, 1 not feasible)
Rank top 3 based on most effective/feasible

Project Name: Sackville Rivers Mitigation Planning Strategy
Project Number: 19-174
Mitigation Strategy Decision Matrix

Location:	Area 4 - Sackville Drive at Cobequid Road / Highway 101 (NDMP Site 26)
Typical Flooding Frequency:	1 in 10-Year to 1 in 100-Year
Extents of Flooding:	Sackville Drive and Highway 101

Mitigation Strategy	Estimated Effectiveness	Feasibility	Rank	Rationale
Channel Widening	1	1		Next to highway
Berm Construction	8	2	3	Would cause flood levels to rise elsewhere
Bridge/Culvert Upgrade	9	8	1	Upsize culvert from pond near Memory Lane to Sackville Drive
River Restoration	1	1		Environmental regualtions
Structural Flood Protection	2	3		Mostly roads flooding
Retreating/Displacing Properties	1	1		Highways / roads are critical infrastructure, need to be in this location
Flow Reduction through Infiltration	1	1		Not practical
Property Purchase	1	1		Public roads
Property Raising	9	9	2	Roads should be built higher here
Emergency Overflow	1	1		No place for overflow
Addition of Storage	2	1		Storage may marginally reduce flood level

Feasibility 1-10 (10 most feasible, 1 not feasible)
Rank top 3 based on most feasible

Feasibility 1-10 (10 most feasible, 1 not feasible)
Rank top 3 based on most effective/feasible

Project Name: Sackville Rivers Mitigation Planning Strategy
Project Number: 19-174
Mitigation Strategy Decision Matrix

Location:	Area 5 - Beaver Bank Cross Road / Brook Street Extension
Typical Flooding Frequency:	1 in 2-Year/ Risk to entire homes being sewpt away in large flood
Extents of Flooding:	Significant risk to life / safety

Mitigation Strategy	Estimated Effectiveness	Feasibility	Rank	Rationale
Channel Widening	1	1		No land available, road next to channel
Berm Construction	1	1		No place to drain upstream side
Bridge/Culvert Upgrade	6	10	1	Upsize culvert on Gantry Rd.
River Restoration	1	1		Would not help, no land
Structural Flood Protection	1	1		Mobile homes, structural protection ineffective
Retreating/Displacing Properties	8	6	2	Homes could be moved away from channel
Flow Reduction through Infiltration	1	1		Will not help in the short term
Property Purchase	7	7	3	Could purchase properties (inexpensive)
Property Raising	9	6		Could raise homes, they are moveable
Emergency Overflow	1	1		No place to overflow to
Addition of Storage	4	2		May help some, but will not completely solve the problem

Feasibility 1-10 (10 most feasible, 1 not feasible)
Rank top 3 based on most feasible

Feasibility 1-10 (10 most feasible, 1 not feasible)
Rank top 3 based on most effective/feasible

Project Name: Sackville Rivers Mitigation Planning Strategy
Project Number: 19-174
Mitigation Strategy Decision Matrix

Location:	Area 6 - Millwood Drive at Jackladder Drive
Typical Flooding Frequency:	1 in 2-Year to 1 in 5-Year
Extents of Flooding:	Road and backyards flood / local drainage issue not related to Little Sackville River

Mitigation Strategy	Estimated Effectiveness	Feasibility	Rank	Rationale
Channel Widening	1	1		
Berm Construction	1	1		
Bridge/Culvert Upgrade	10	10	1	Need to upsize culvert under Millwood Drive
River Restoration	1	1		
Structural Flood Protection	1	1		
Retreating/Displacing Properties	1	1		
Flow Reduction through Infiltration	1	1		
Property Purchase	1	1		
Property Raising	1	1		
Emergency Overflow	1	1		
Addition of Storage	1	1		

Feasibility 1-10 (10 most feasible, 1 not feasible)
Rank top 3 based on most feasible

Feasibility 1-10 (10 most feasible, 1 not feasible)
Rank top 3 based on most effective/feasible

Project Name: Sackville Rivers Mitigation Planning Strategy
Project Number: 19-174
Mitigation Strategy Decision Matrix

Location:	Area 7 - Millwood Drive near Sackville Drive
Typical Flooding Frequency:	1 in 5-Year
Extents of Flooding:	Backyards and road, local flooding not related to Little Sackville River

Mitigation Strategy	Estimated Effectiveness	Feasibility	Rank	Rationale
Channel Widening	1	1		
Berm Construction	1	1		
Bridge/Culvert Upgrade	10	10	1	Upsize culvert under Millwood Drive
River Restoration	1	1		
Structural Flood Protection	1	1		
Retreating/Displacing Properties	1	1		
Flow Reduction through Infiltration	1	1		
Property Purchase	1	1		
Property Raising	8	4	2	Could help to raise backyards of properties upstream of Millwood Drive
Emergency Overflow	1	1		
Addition of Storage	1	1		

Feasibility 1-10 (10 most feasible, 1 not feasible)
Rank top 3 based on most feasible

Feasibility 1-10 (10 most feasible, 1 not feasible)
Rank top 3 based on most effective/feasible

Project Name: Sackville Rivers Mitigation Planning Strategy
Project Number: 19-174
Mitigation Strategy Decision Matrix

Location:	Area 8 - Seawood Avenue at Sackville Cross Road
Typical Flooding Frequency:	1 in 5-Year, street flooding , some basements, larger risk in 1 in 100-Year flood event
Extents of Flooding:	Basements, streets and homes

Mitigation Strategy	Estimated Effectiveness	Feasibility	Rank	Rationale
Channel Widening	3	2		Not much space / environmental regulations
Berm Construction	5	4		May work for some homes
Bridge/Culvert Upgrade	1	4		Flooding upstream and downstream of culvert - structure has been replaced
River Restoration	1	1		Mostly in natural state now
Structural Flood Protection	1	1		Too many homes plus streets
Retreating/Displacing Properties	7	5	3	Expensive
Flow Reduction through Infiltration	1	1		Not practical
Property Purchase	7	5	2	Expensive
Property Raising	8	6	1	Could raise grades of homes and road
Emergency Overflow	1	1		No room
Addition of Storage	3	4		May help slightly

Feasibility 1-10 (10 most feasible, 1 not feasible)
Rank top 3 based on most feasible

Feasibility 1-10 (10 most feasible, 1 not feasible)
Rank top 3 based on most effective/feasible

Project Name: Sackville Rivers Mitigation Planning Strategy
Project Number: 19-174
Mitigation Strategy Decision Matrix

Location:	Area 9 - Hallmark Avenue
Typical Flooding Frequency:	1 in 5-Year
Extents of Flooding:	Backyards / homes / commercial parking lot

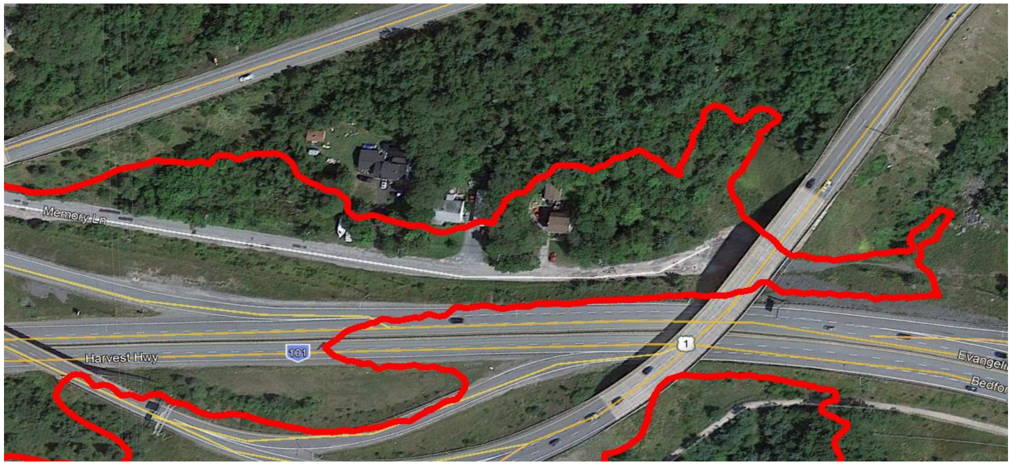
Mitigation Strategy	Estimated Effectiveness	Feasibility	Rank	Rationale
Channel Widening	8	4		Environmental regualtions
Berm Construction	9	6	1	Build berm on walking trail, have raised walking trail
Bridge/Culvert Upgrade	1	1		No, culverts or bridges nearby
River Restoration	2	2		Channel is in natural state
Structural Flood Protection	6	5	2	Select houses may be able to utilize specific flood proof measures
Retreating/Displacing Properties	9	2	3	Expensive
Flow Reduction through Infiltration	1	1		Not practical
Property Purchase	10	1		Expensive
Property Raising	8	3		Expensive
Emergency Overflow	1	1		No place to overflow to
Addition of Storage	3	2		May help minimally

Feasibility 1-10 (10 most feasible, 1 not feasible)
Rank top 3 based on most feasible

Feasibility 1-10 (10 most feasible, 1 not feasible)
Rank top 3 based on most effective/feasible

Project Name: Sackville Rivers Mitigation Planning Strategy
Project Number: 19-174
Mitigation Strategy Decision Matrix

Location:	Area 10 - Memory Lane at Bedford Bypass
Typical Flooding Frequency:	1 in 10-Year
Extents of Flooding:	Road / front yards / basements



Mitigation Strategy	Estimated Effectiveness	Feasibility	Rank	Rationale
Channel Widening	1	1		No space here / environmental regualtions
Berm Construction	1	1		No place to drain land behind berm
Bridge/Culvert Upgrade	9	9	2	Install upsized culvert from north side of 101 to Sackville River
River Restoration	1	1		Environmental regulations
Structural Flood Protection	4	7		May help individual homes
Retreating/Displacing Properties	8	6	3	Only three homes to move, roads would still flood
Flow Reduction through Infiltration	1	1		
Property Purchase	8	6	1	Only three homes to purchase, roads would still flood
Property Raising	7	5		Expensive
Emergency Overflow	1	1		No place for overflow
Addition of Storage	2	1		May help minimally

Feasibility 1-10 (10 most feasible, 1 not feasible)
Rank top 3 based on most feasible

Feasibility 1-10 (10 most feasible, 1 not feasible)
Rank top 3 based on most effective/feasible

Project Name: Sackville Rivers Mitigation Planning Strategy
Project Number: 19-174
Mitigation Strategy Decision Matrix

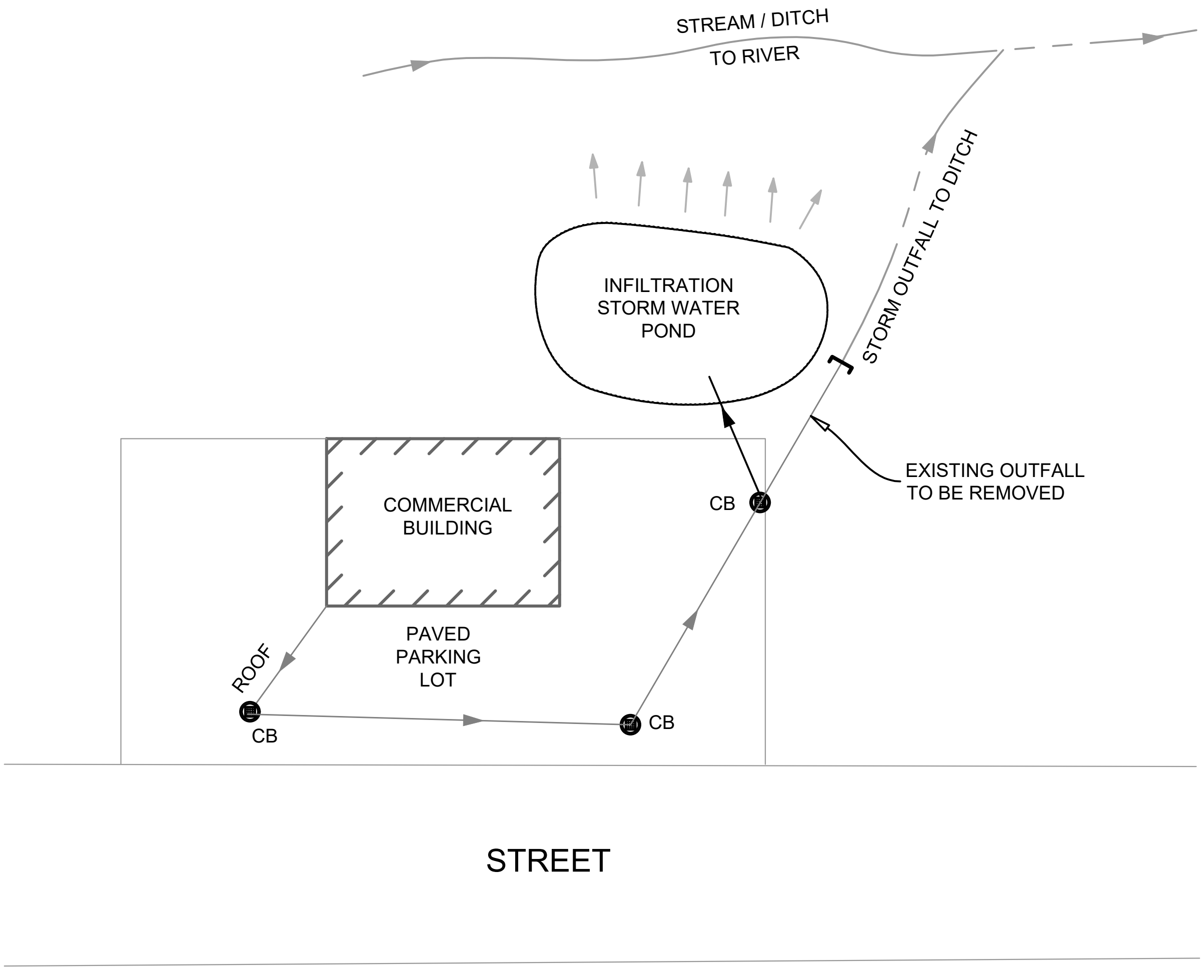
Location:	Area 11 - Range Park
Typical Flooding Frequency:	2 times per year
Extents of Flooding:	Entire fields once every 5 years

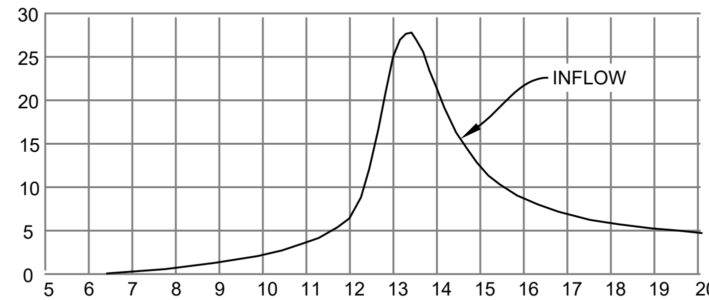
Mitigation Strategy	Estimated Effectiveness	Feasibility	Rank	Rationale
Channel Widening	6	1		Environmental regulations
Berm Construction	2	2		No place to drain back side of berm
Bridge/Culvert Upgrade	1	1		Will not change things, flooding high on downstream side of bridges
River Restoration	3	1		Environmental regulations
Structural Flood Protection	6	6	1	May use artificial turf / move drainage infrastructure to drain fields quickly after flooding
Retreating/Displacing Properties	10	1		Fields are popular and often in use
Flow Reduction through Infiltration	1	1		Not practical
Property Purchase	1	1		Public land
Property Raising	7	2	2	Would increase flooding elsewhere
Emergency Overflow	5	4	3	Would help some
Addition of Storage	3	4		May reduce flood levels slightly

Feasibility 1-10 (10 most feasible, 1 not feasible)
Rank top 3 based on most feasible

Feasibility 1-10 (10 most feasible, 1 not feasible)
Rank top 3 based on most effective/feasible

APPENDIX B – MITIGATION OPTION SKETCHES





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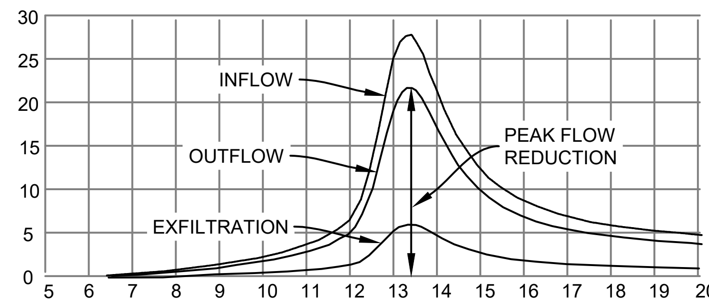

POST-INFILTRATION

PREPARED FOR

HALIFAX

PREPARED BY

DESIGN POINT
ENGINEERING & SURVEYING

PHONE: 902.832.5597

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PROJECT

SACKVILLE RIVER MITIGATION PLANNING

SACKVILLE , NOVA SCOTIA

DESCRIPTION

REDUCE PEAK FLOWS THROUGH BEST MANAGEMENT PRACTICES

Engineer
G.S.W.

Drawn
E.E.H.

Scale
N.T.S

Date
MAR. 3, 2020

Project No.
19-174

Drawing No.
CSK-1

Filename
19-174_CSK.dwg

1 OF 11

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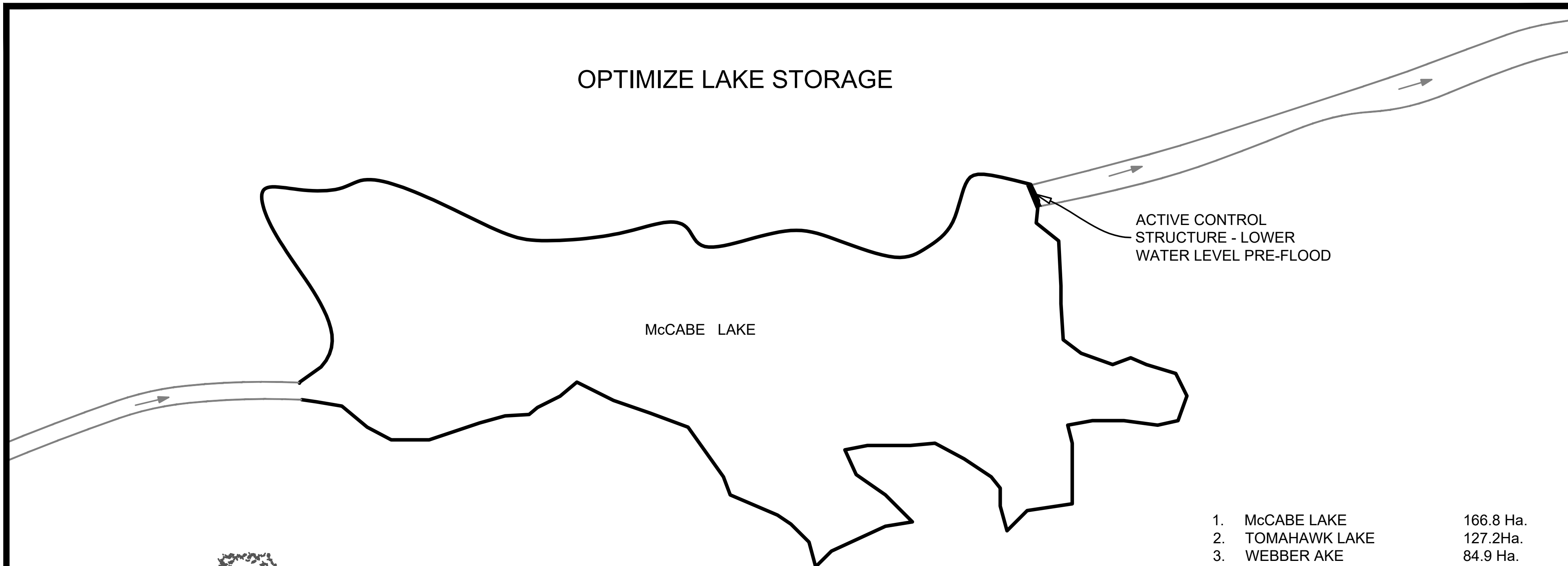
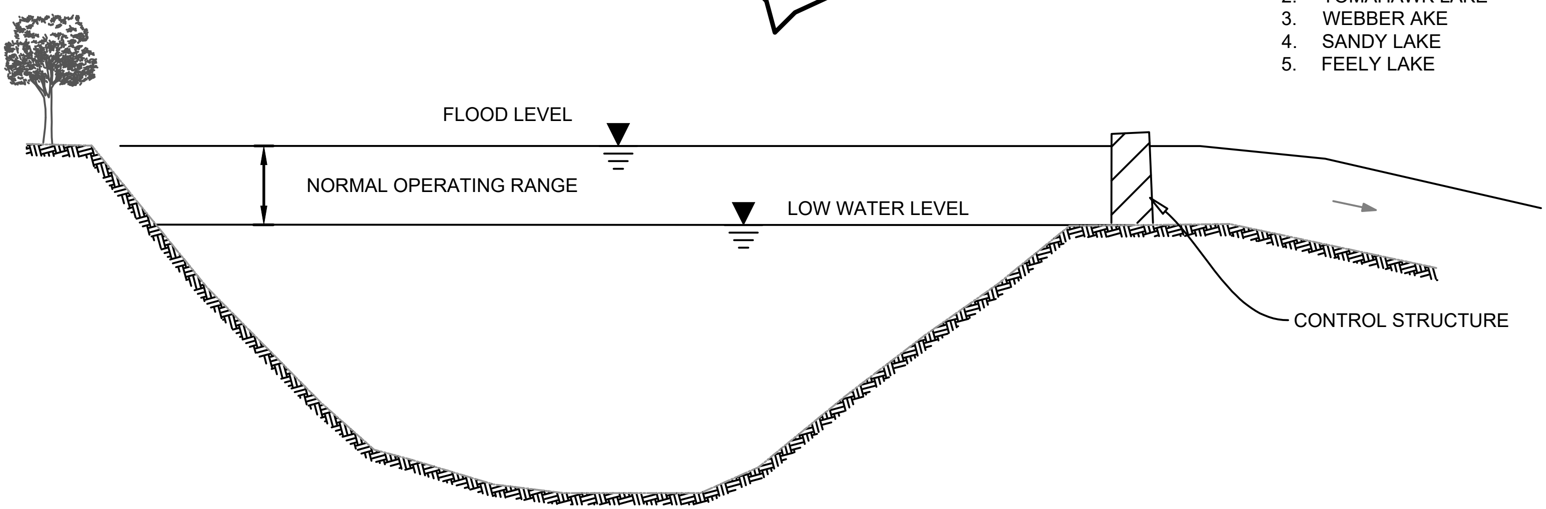
OPTIMIZE LAKE STORAGE



1.	McCABE LAKE	166.8 Ha.
2.	TOMAHAWK LAKE	127.2Ha.
3.	WEBBER AKE	84.9 Ha.
4.	SANDY LAKE	77.9 Ha.
5.	FEELY LAKE	10.7 Ha.



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HALIFAX	DESIGN POINT ENGINEERING & SURVEYING	SACKVILLE RIVER MITIGATION PLANNING SACKVILLE , NOVA SCOTIA	G.S.W.	E.E.H.
			Scale: N.T.S	Date: MAR. 3, 2020
		DESCRIPTION	Project No.: 19-174	Drawing No.
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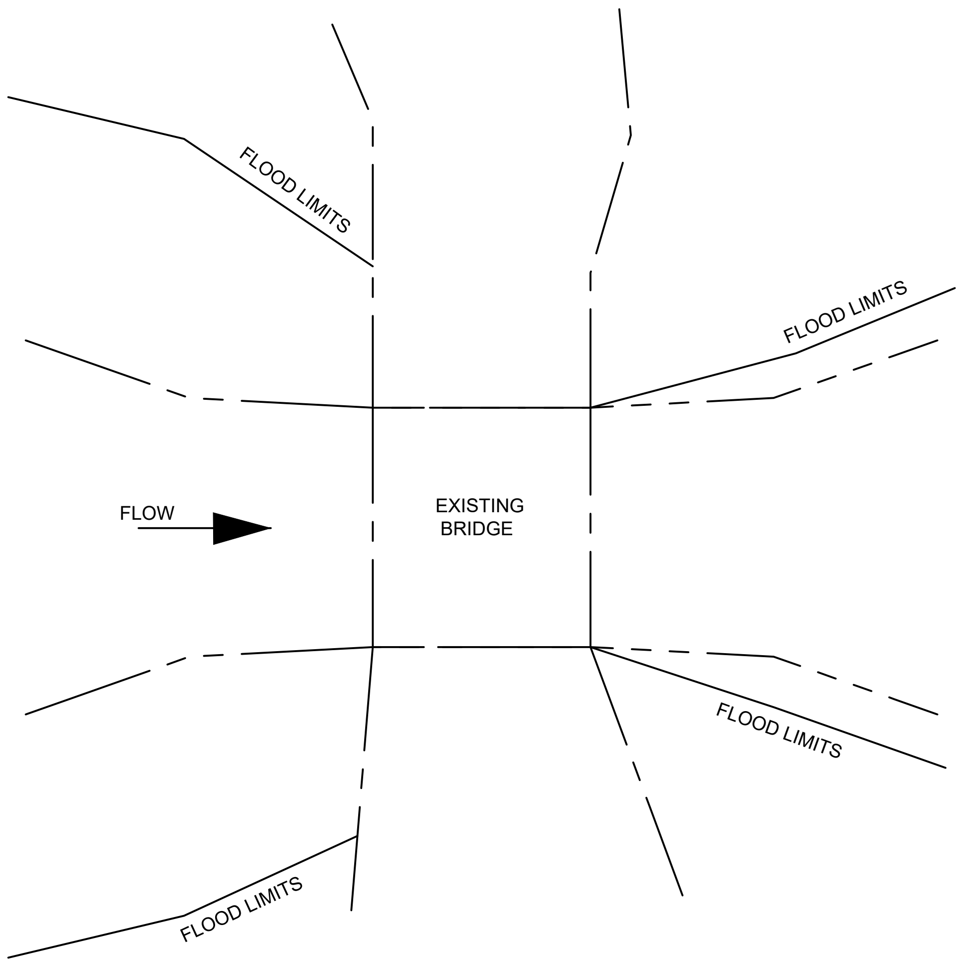
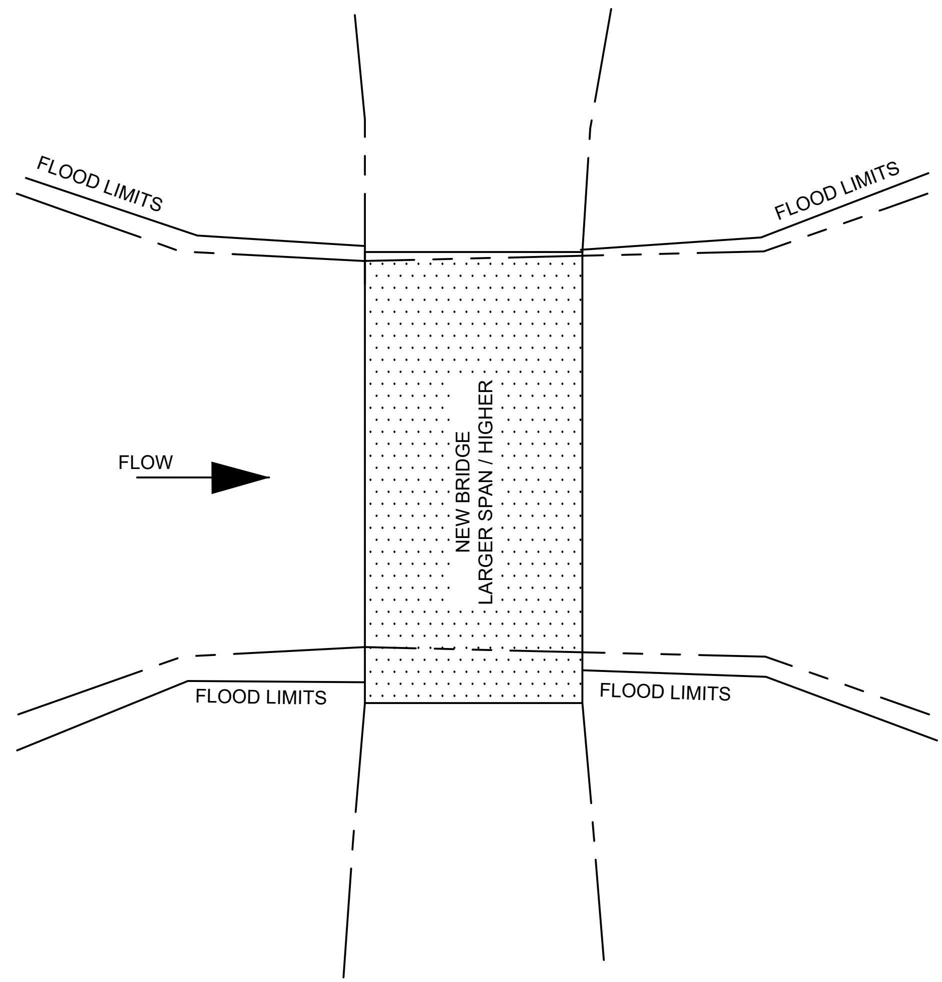


EXISTING BRIDGE



NEW BRIDGE

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			Scale: N.T.S	Date: MAR. 3, 2020
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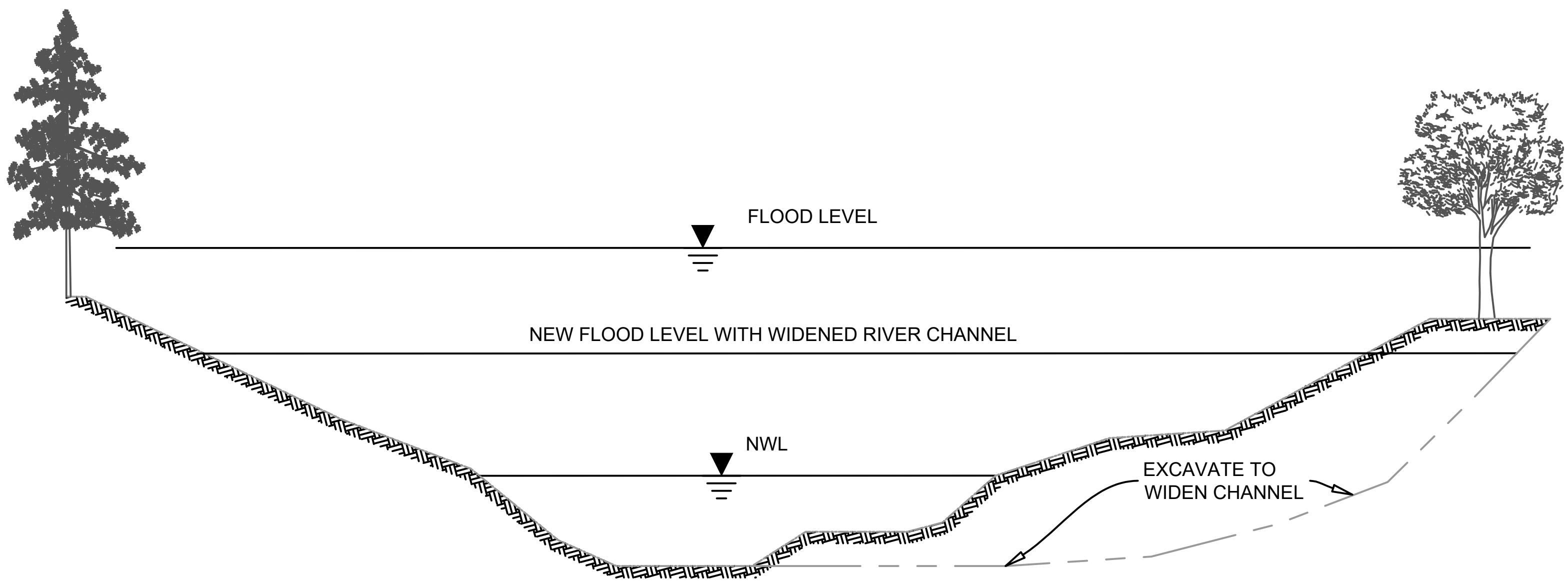

PREPARED FOR	PREPARED BY	PROJECT	Engineer	Drawn
HALIFAX	DESIGN POINT ENGINEERING & SURVEYING	SACKVILLE RIVER MITIGATION PLANNING SACKVILLE , NOVA SCOTIA	G.S.W.	E.E.H.
			Scale N.T.S	Date MAR. 3, 2020
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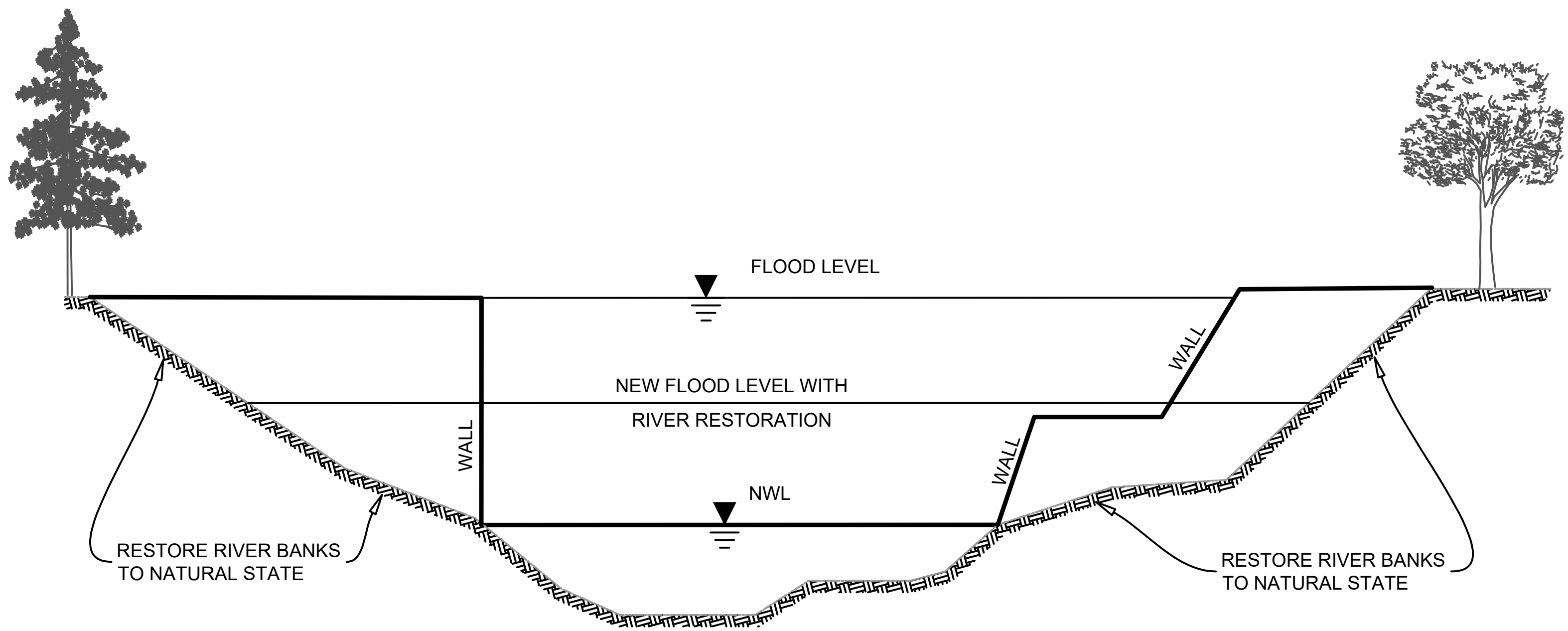

PREPARED FOR	PREPARED BY	PROJECT	Engineer G.S.W.	Drawn E.E.H.
HALIFAX	DESIGN POINT ENGINEERING & SURVEYING	SACKVILLE RIVER MITIGATION PLANNING SACKVILLE , NOVA SCOTIA	Scale N.T.S	Date MAR. 3, 2020
	PHONE: 902.832.5597 www.designpoint.ca	DESCRIPTION	Project No. 19-174	Drawing No.
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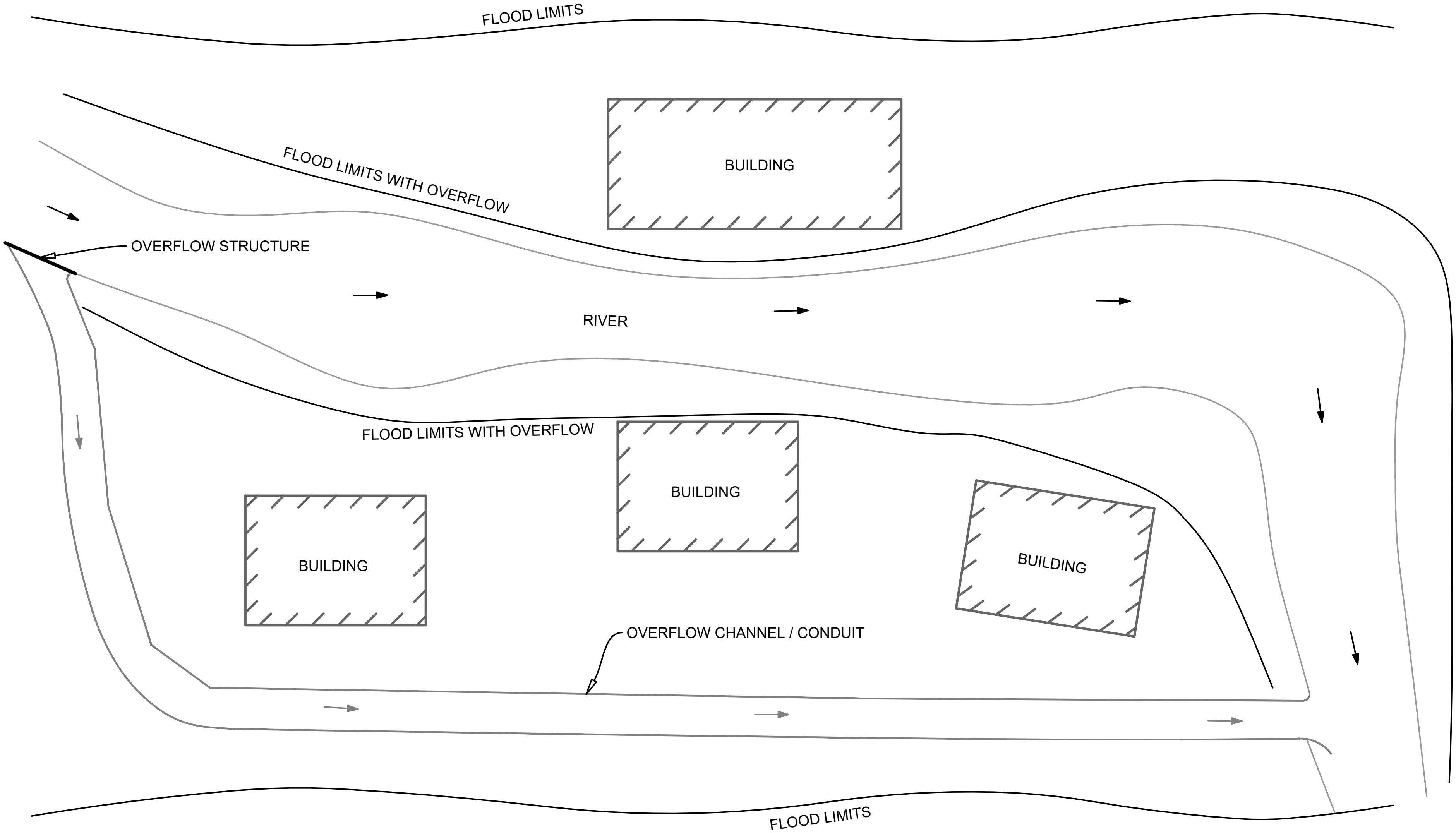

EMERGENCY OVERFLOW

PREPARED FOR	PREPARED BY	PROJECT		
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			Scale N.T.S	Date MAR. 3, 2020
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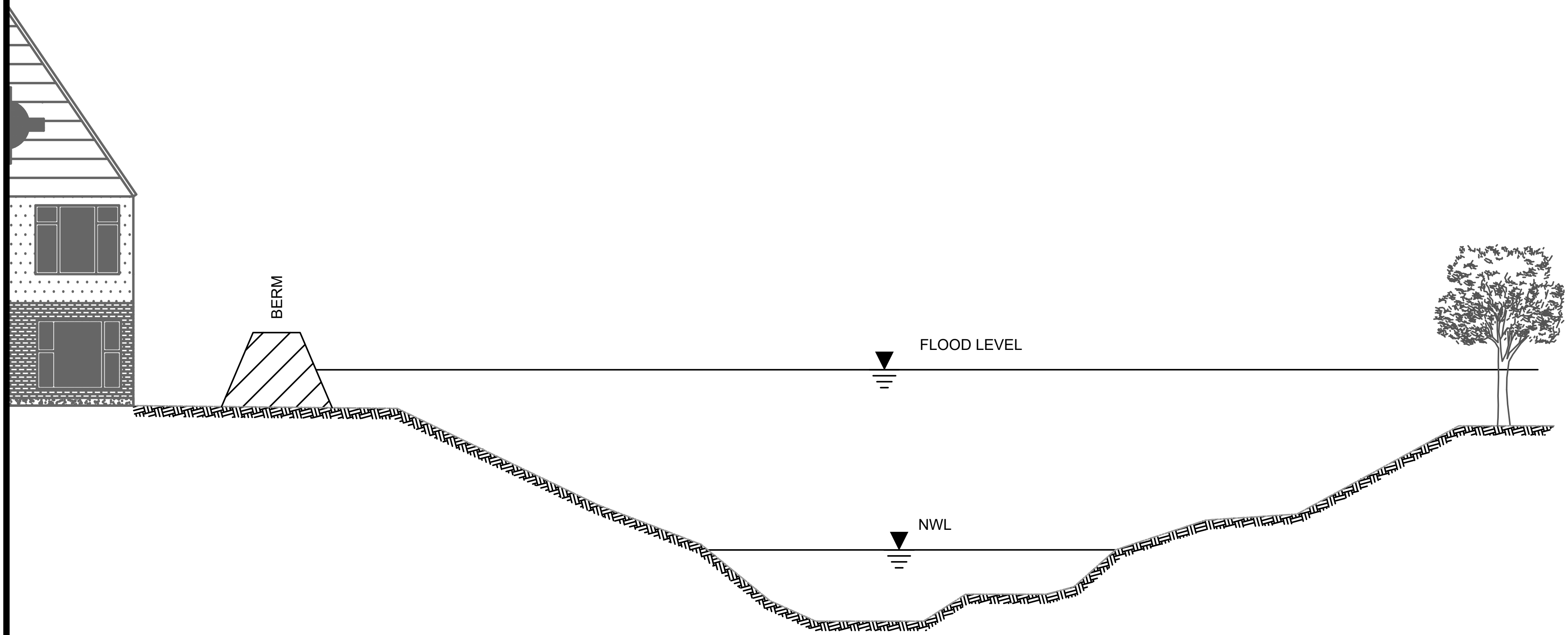

PREPARED FOR	PREPARED BY	PROJECT	Engineer G.S.W.	Drawn E.E.H.
HALIFAX	DESIGN POINT ENGINEERING & SURVEYING	SACKVILLE RIVER MITIGATION PLANNING SACKVILLE , NOVA SCOTIA	Scale N.T.S	Date MAR. 3, 2020
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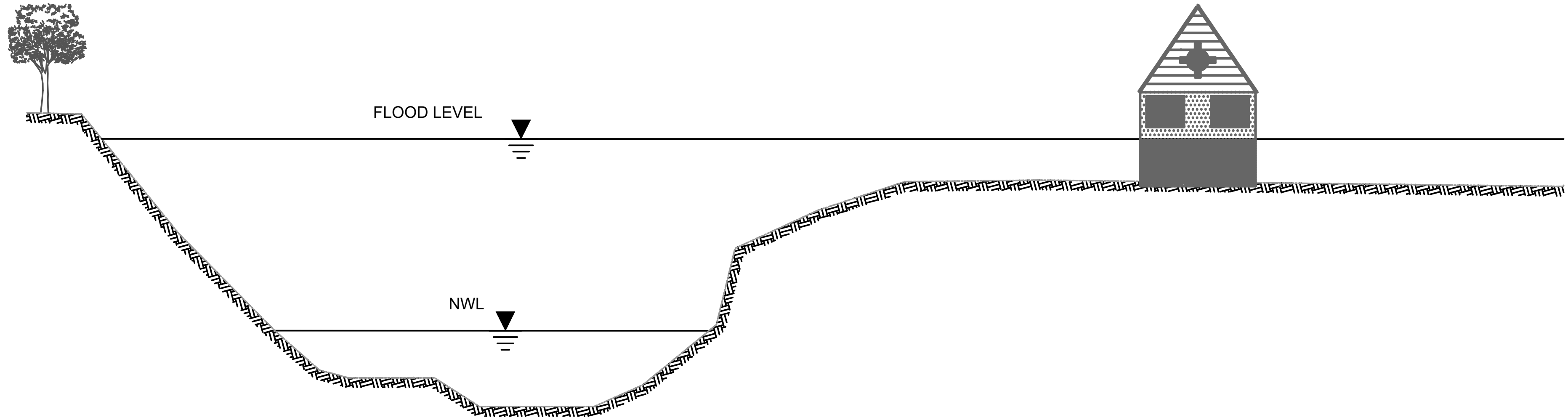
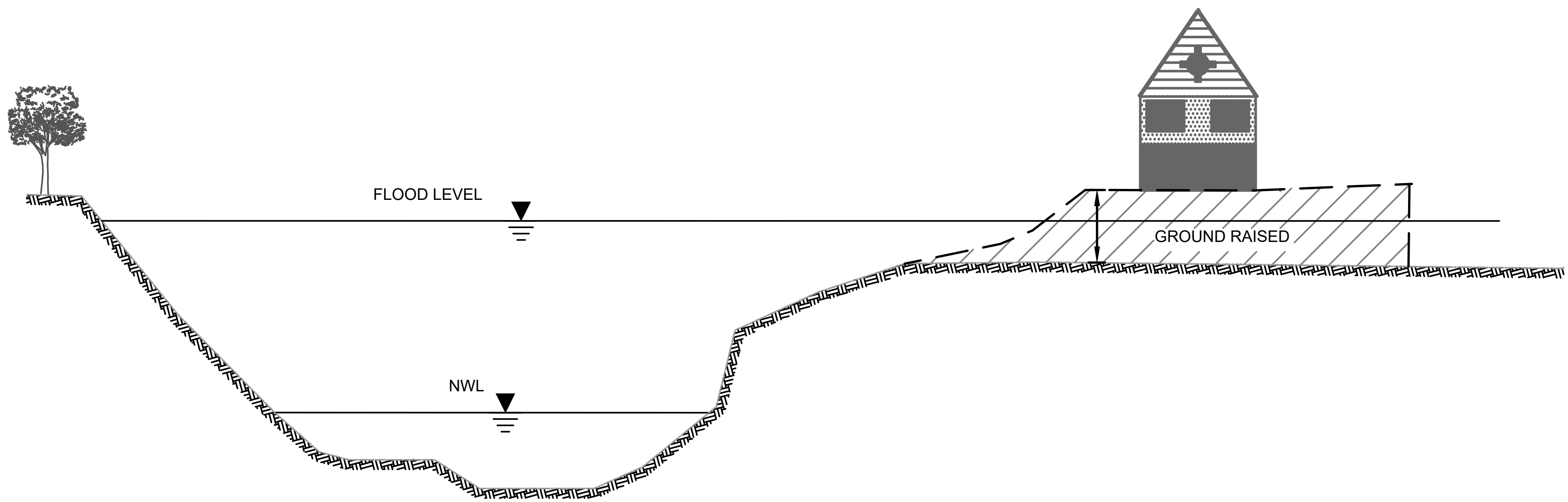
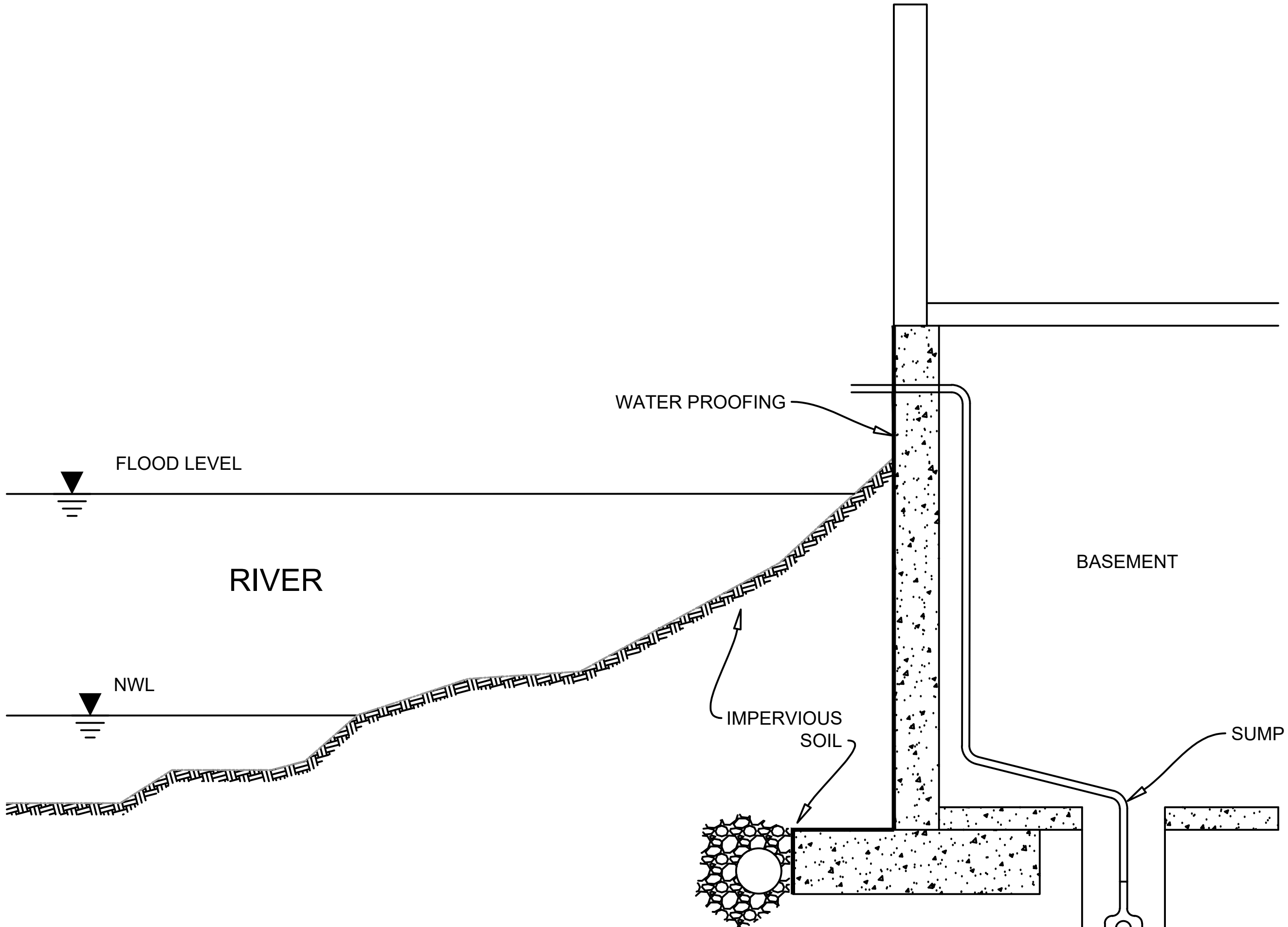




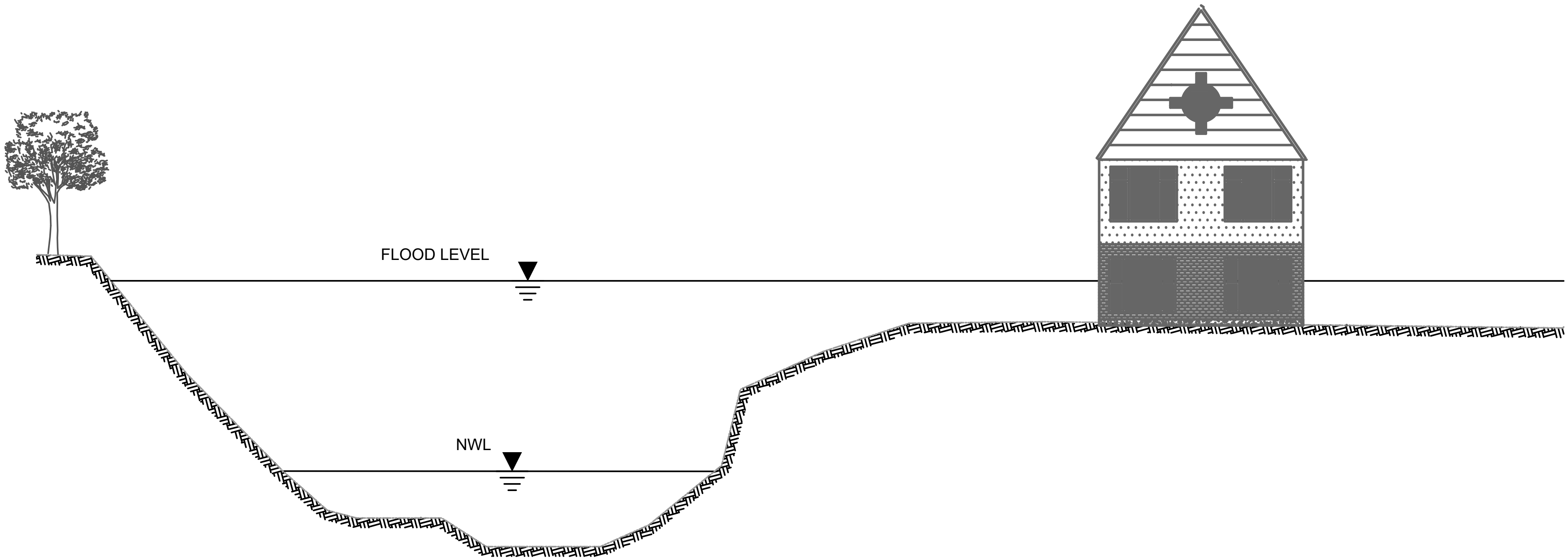
PREPARED FOR	PREPARED BY	PROJECT	Engineer	Drawn
HALIFAX	DESIGN POINT ENGINEERING & SURVEYING	SACKVILLE RIVER MITIGATION PLANNING SACKVILLE , NOVA SCOTIA	G.S.W.	E.E.H.
	PHONE: 902.832.5597 www.designpoint.ca	DESCRIPTION	Scale N.T.S	Date MAR. 3, 2020
		PROPERTY RAISING	Project No. 19-174	Drawing No. CSK-8
			Filename 19-174_CSK.dwg	8 OF 11

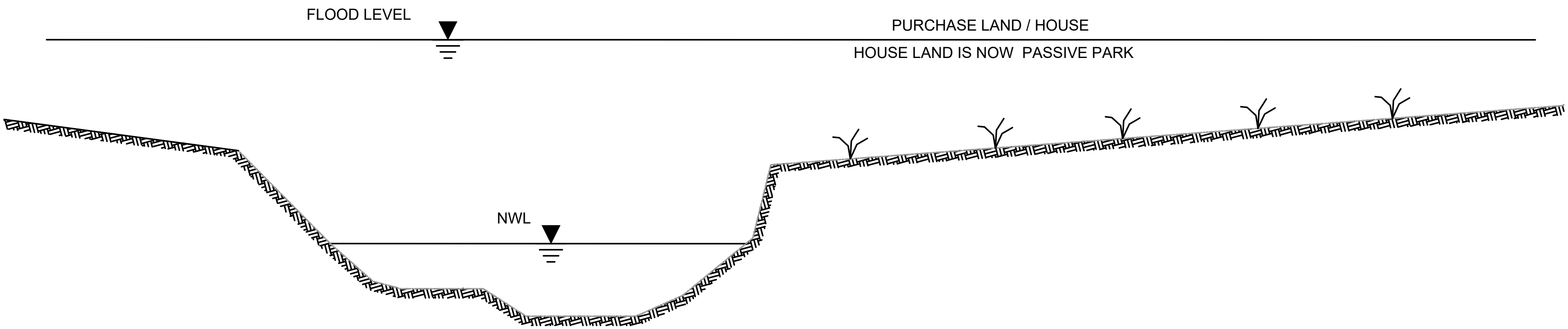
P:\2019\19-174 HRM - Sackville River Mitigation Planning Study\01 - Drawings\Engineering Design\19-174_CSK.dwg, Plot Date: 2020-Mar-2, Plot Size: ANSI FULL BLEED A (8.50 X 11.00 INCHES)



STRUCTURAL FLOOD PROTECTION

PREPARED FOR	PREPARED BY	PROJECT	Engineer G.S.W.	Drawn E.E.H.
HALIFAX	DESIGN POINT ENGINEERING & SURVEYING	SACKVILLE RIVER MITIGATION PLANNING SACKVILLE , NOVA SCOTIA	Scale N.T.S	Date MAR. 3, 2020
	PHONE: 902.832.5597 www.designpoint.ca	DESCRIPTION STRUCTURAL FLOOD PROTECTION	Project No. 19-174 Filename 19-174_CSK.dwg	Drawing No. CSK-9 9 OF 11





PREPARED FOR	PREPARED BY	PROJECT		
HALIFAX	DESIGN POINT ENGINEERING & SURVEYING PHONE: 902.832.5597 www.designpoint.ca	SACKVILLE RIVER MITIGATION PLANNING SACKVILLE , NOVA SCOTIA	Engineer G.S.W.	Drawn E.E.H.
			Scale N.T.S	Date MAR. 3, 2020
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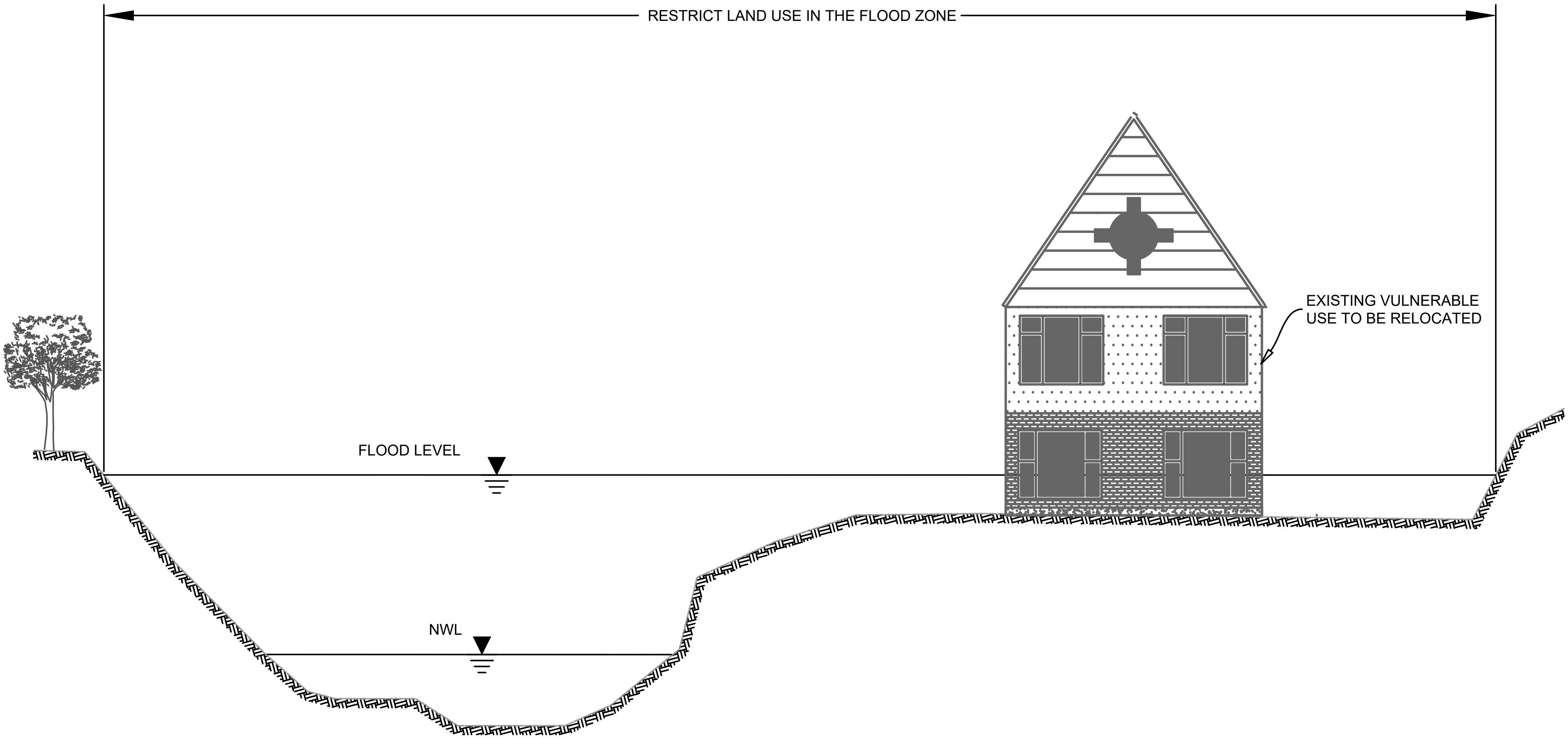
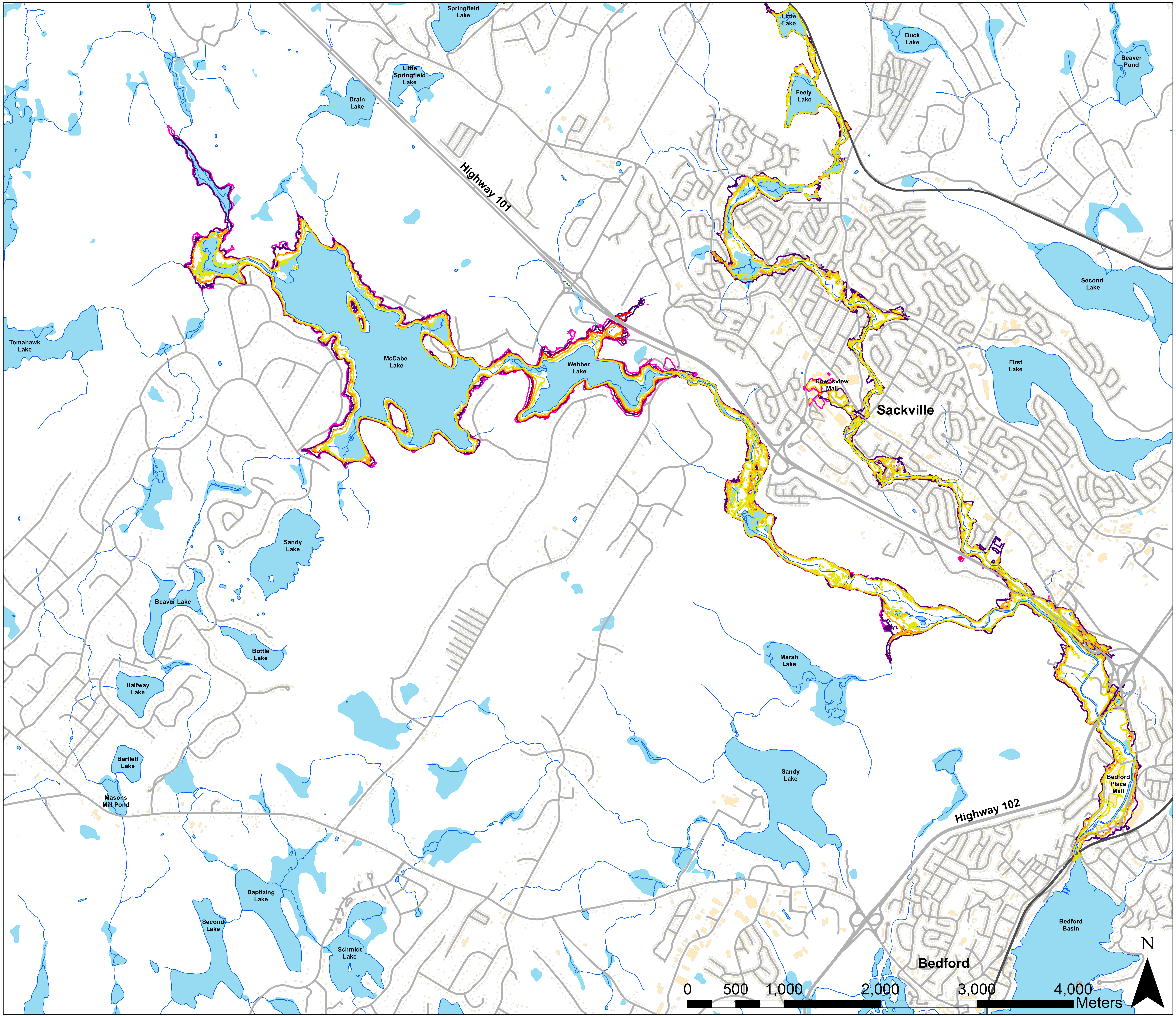
		PURCHASING FLOOD PRONE PROPERTY	Filename 19-174_CSK.dwg	10 OF 11



PREPARED FOR	PREPARED BY	PROJECT	Engineer G.S.W.	Drawn E.E.H.
HALIFAX	DESIGN POINT ENGINEERING & SURVEYING PHONE: 902.832.5597 www.designpoint.ca	SACKVILLE RIVER MITIGATION PLANNING SACKVILLE , NOVA SCOTIA	Scale N.T.S	Date MAR. 3, 2020
		DESCRIPTION RETREATING / DISPLACING	Project No. 19-174 Filename 19-174_CSK.dwg	Drawing No. CSK-11 11 OF 11

APPENDIX C – MODELLED FLOOD LIMITS



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Sackville Rivers Mitigation Planning Study

Flood Line Delineation

Map 1:

Flood Limit Comparison: DesignPoint, CBCL Base 1:5-Year and 1:100-Year Flows (Future IDF & Sea Level) vs Historical Maximum Flow Flood Line

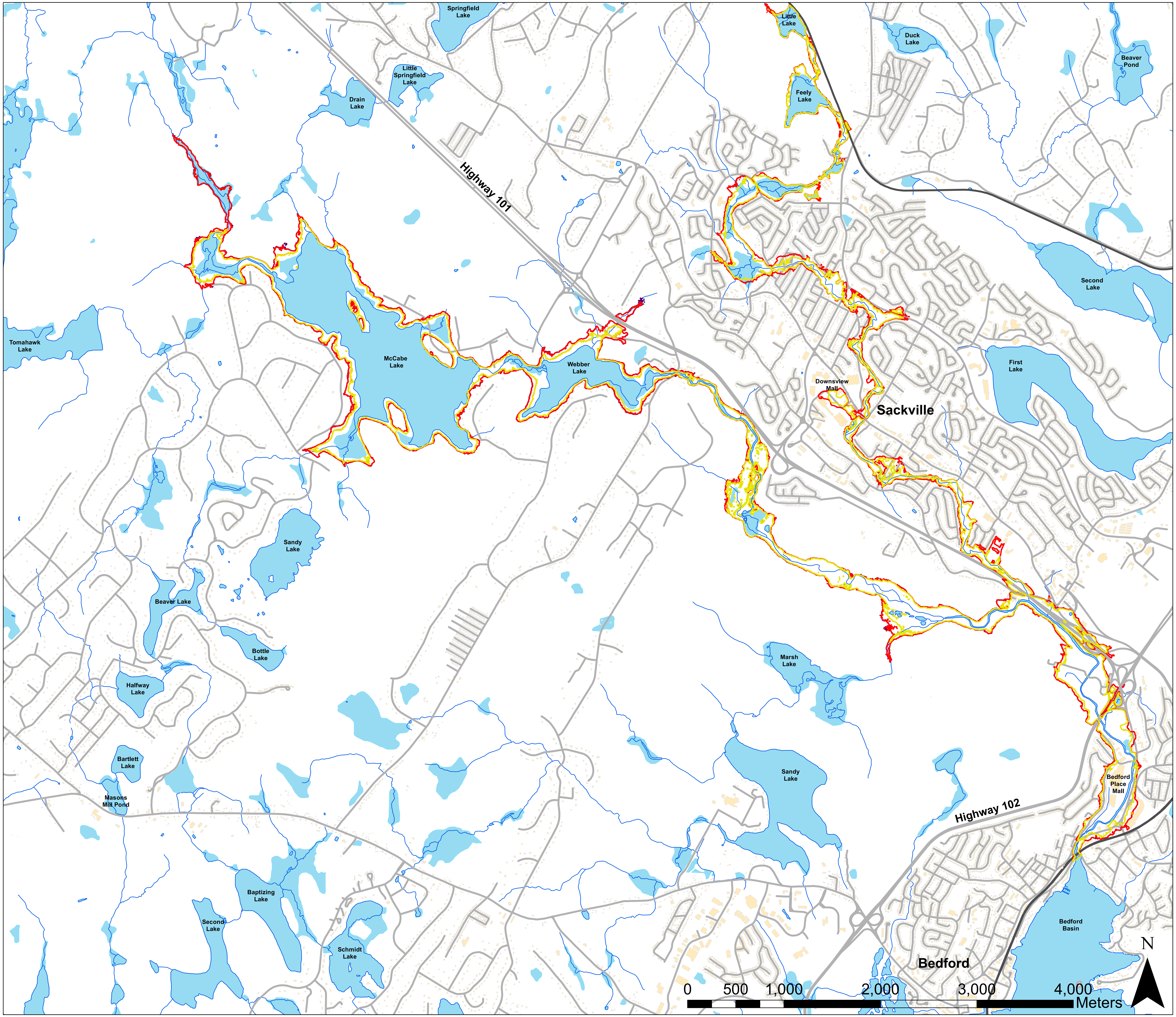
Legend

- Historical Maximum Flow Flood Line
- DesignPoint 1 in 5-Year Flood Line
- CBCL 1 in 5-Year Flood Line
- DesignPoint 1 in 100-Year Flood Line
- CBCL 1 in 100-Year Flood Line
- Buildings
- Railways
- Roads
- Watercourses
- Waterbodies

SCALE: 1:18,000

Date: March 4, 2020
Project #: 19-174

DESIGN POINT
ENGINEERING & SURVEYING



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Flood Line Delineation

Map 2:

Increased Tomahawk Lake Storage

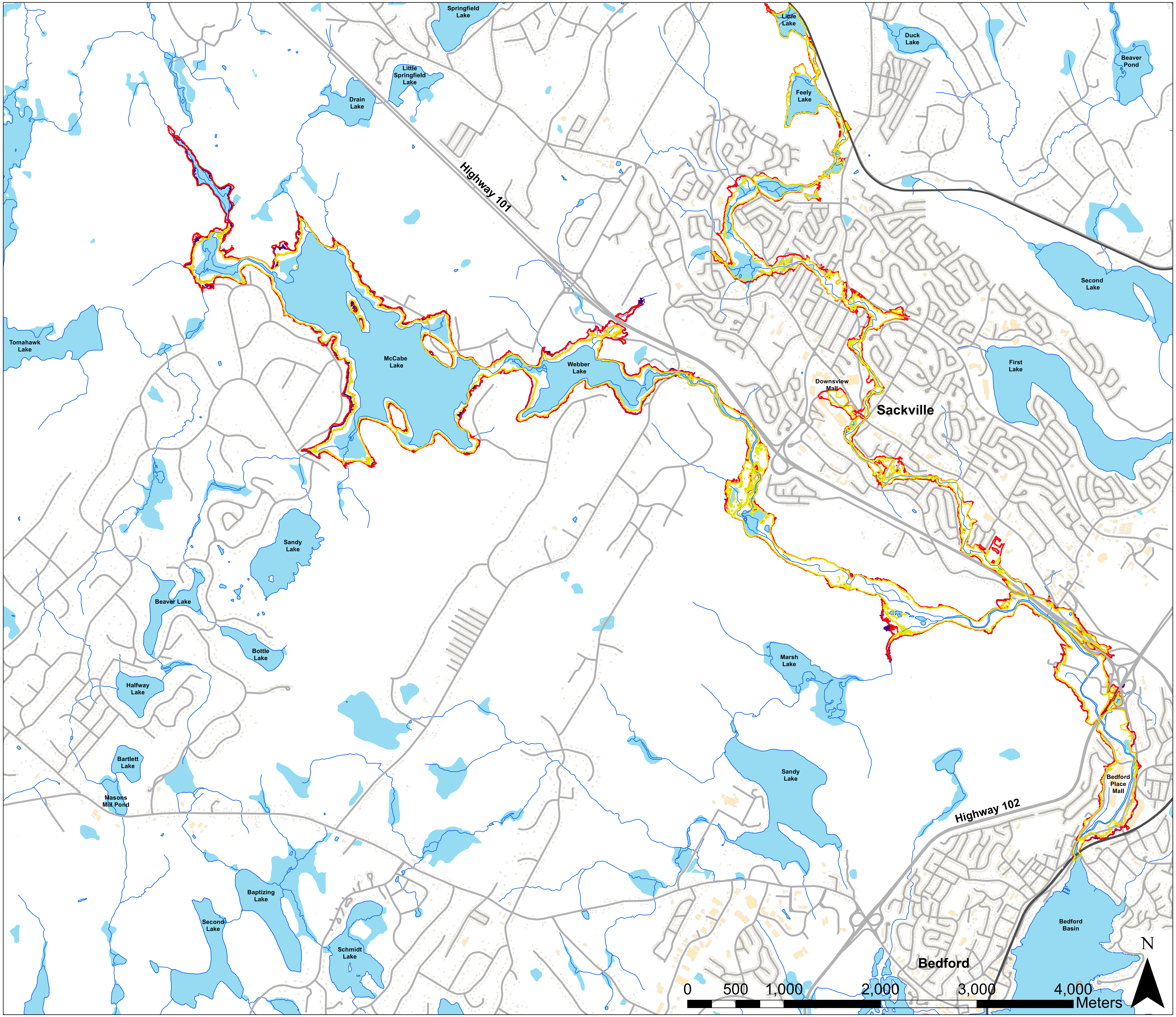
Legend

- Tomahawk Lake Storage 1 in 5-Year Flood Line
- Base 1 in 5-Year Flood Line
- Tomahawk Lake Storage 1 in 100-Year Flood Line
- Base 1 in 100-Year Flood Line
- Buildings
- Railways
- Roads
- Watercourses
- Waterbodies

SCALE: 1:18,000

Date: March 4, 2020
Project #: 19-174

DESIGN POINT ENGINEERING & SURVEYING



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Sackville Rivers Mitigation Planning Study

Flood Line Delineation

Map 3:

Increased McCabe Lake Storage

Legend

- McCabe Lake Storage 1 in 5-Year Flood Line
- Base 1 in 5-Year Flood Line
- McCabe Lake Storage 1 in 100-Year Flood Line
- Base 1 in 100-Year Flood Line
- Buildings
- Railways
- Roads
- Watercourses
- Waterbodies

SCALE: 1:18,000

Date: March 4, 2020
Project #: 19-174

DESIGN POINT
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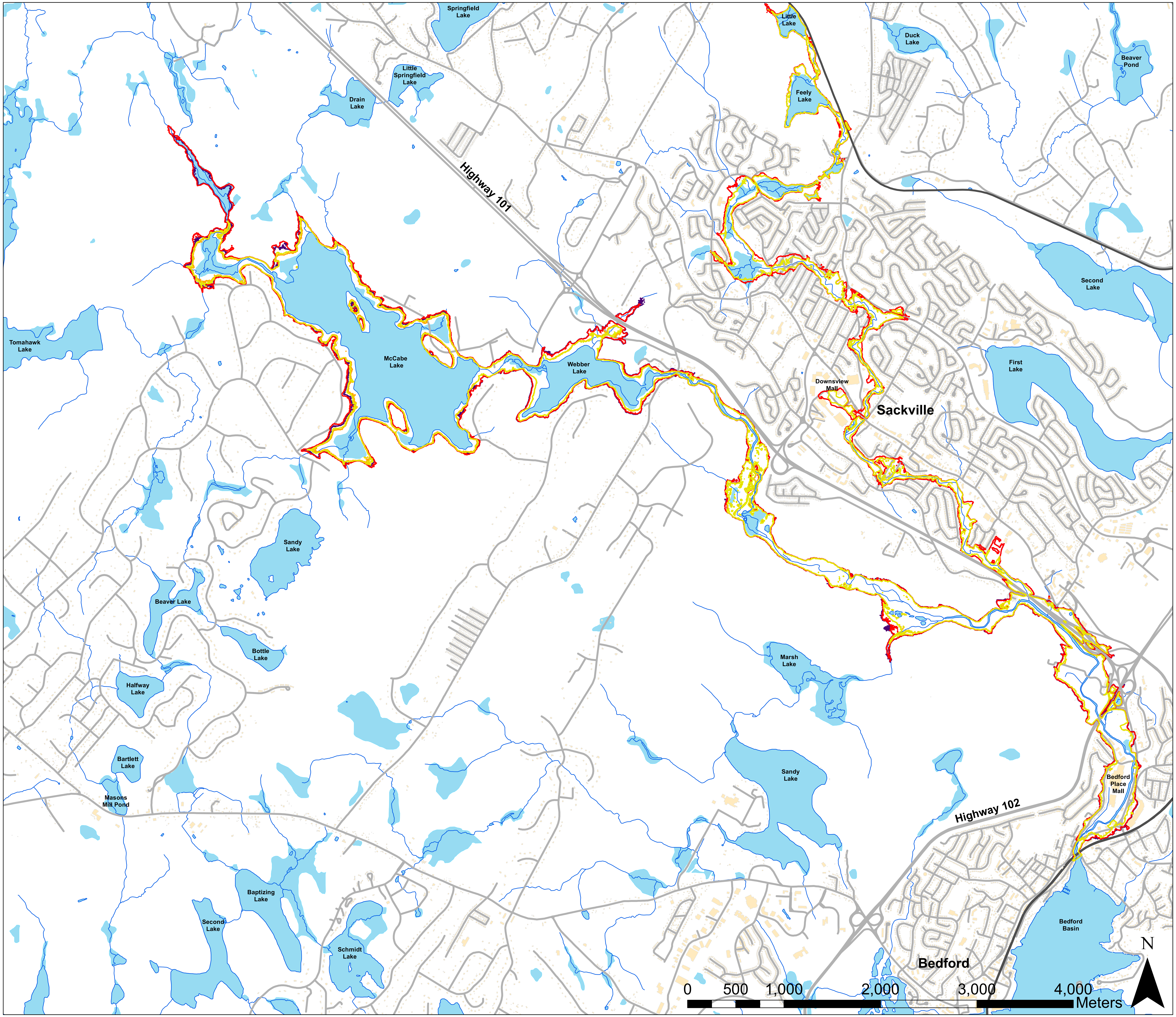

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Sackville Rivers Mitigation Planning Study

Flood Line Delineation

Map 4:

Increased Tomahawk Lake and McCabe Lake Storage

Legend

- Tomahawk Lake and McCabe Lake Storage 1 in 5-Year Flood Line
- Base 1 in 5-Year Flood Line
- Tomahawk Lake and McCabe Lake Storage 1 in 100-Year Flood Line
- Base 1 in 100-Year Flood Line
- Buildings
- Railways
- Roads
- Watercourses
- Waterbodies

SCALE: 1:18,000

Date: March 4, 2020
Project #: 19-174

DESIGN POINT
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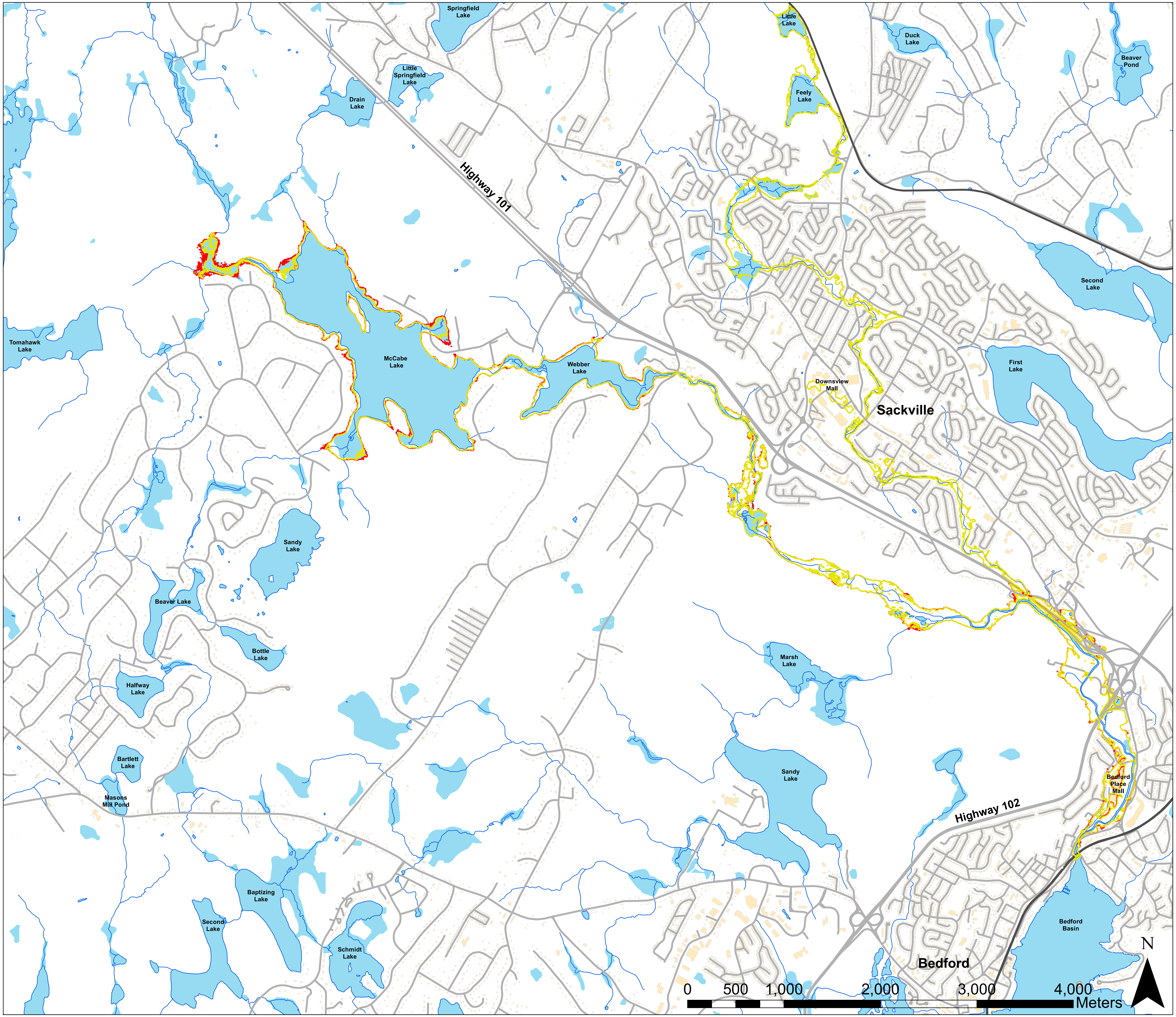

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Flood Line Delineation

Map 5:

Increased McCabe Lake Storage for Historical Maximum Flow Flood Line

Legend

- McCabe Lake Storage Historical Maximum Flow Flood Line
- Historical Maximum Flow Flood Line
- Buildings
- Railways
- Roads
- Watercourses
- Waterbodies

SCALE: 1:18,000

Date: March 4, 2020
Project #: 19-174

DESIGN POINT
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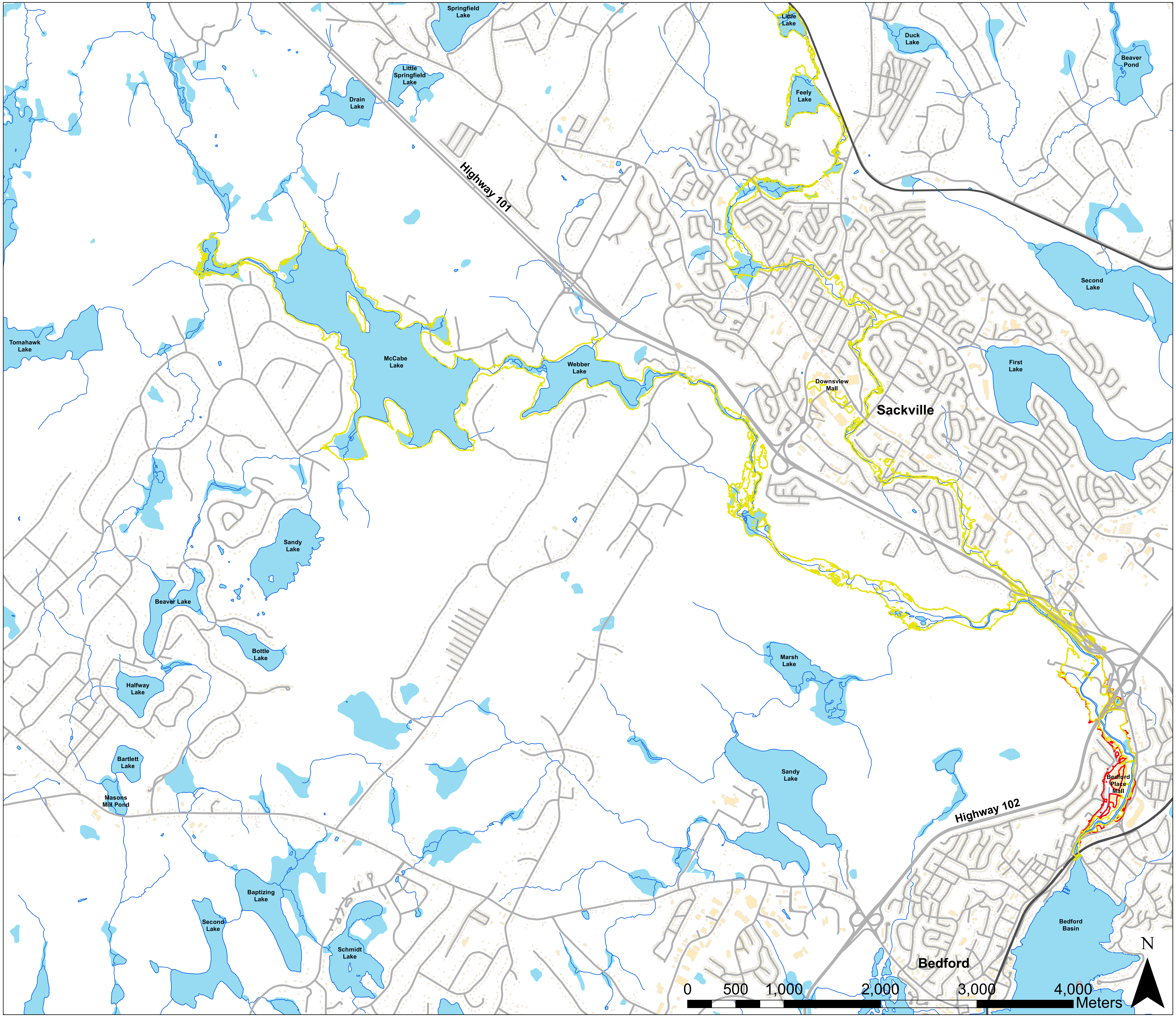

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Flood Line Delineation

Map 6:

Emergency Spillway Tunnel Sized for Historical Maximum Flow (Twin Box Culverts)

Legend

- Historical Maximum Flow Flood Line with Twin Box Culverts
- Historical Maximum Flow Flood Line
- Buildings
- Railways
- Roads
- Watercourses
- Waterbodies

SCALE: 1:18,000

Date: March 4, 2020
Project #: 19-174

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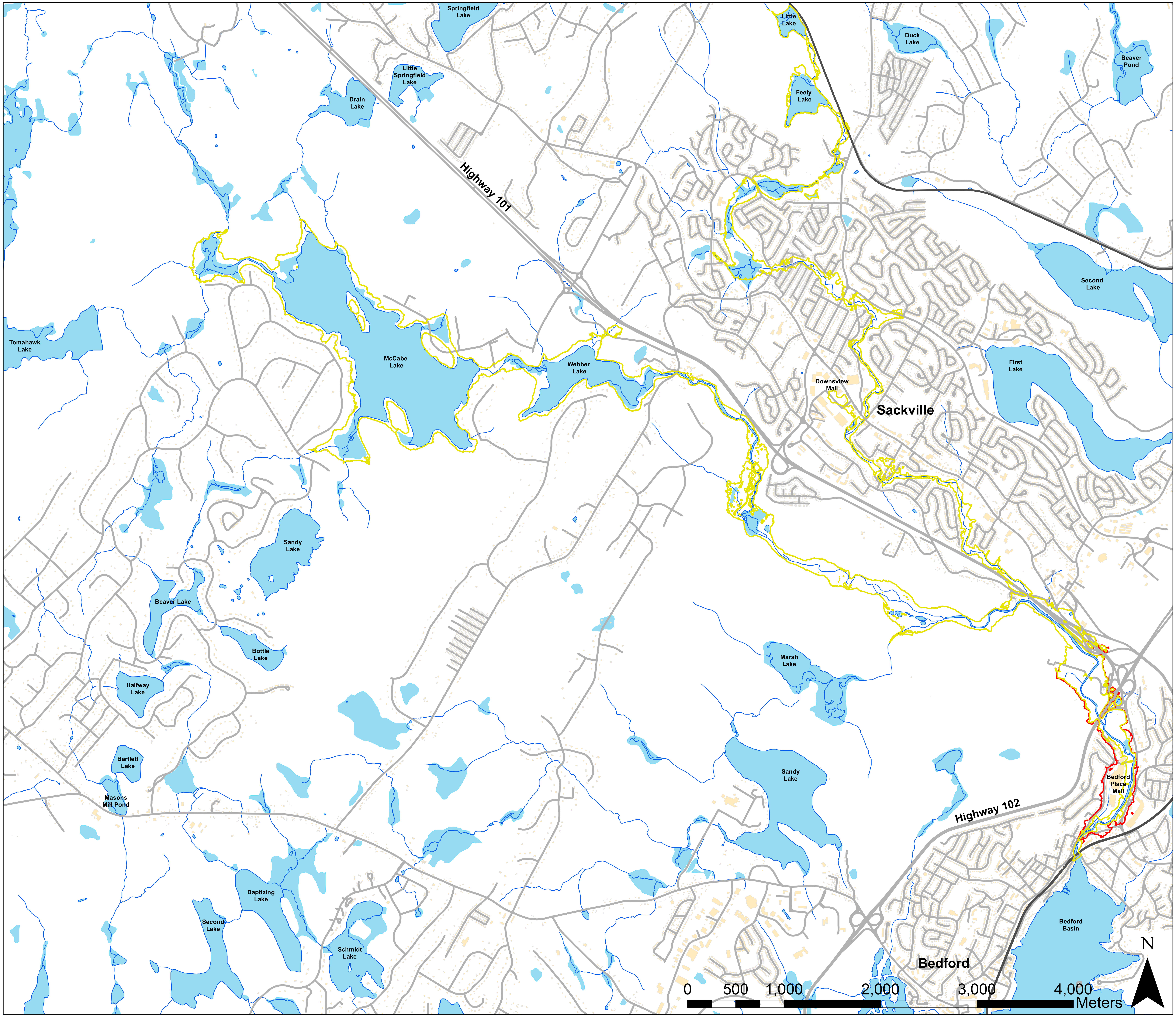

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Flood Line Delineation

Map 7:
Emergency Spillway Tunnel Sized for 1:5-Year Flow (8.5 m diameter)

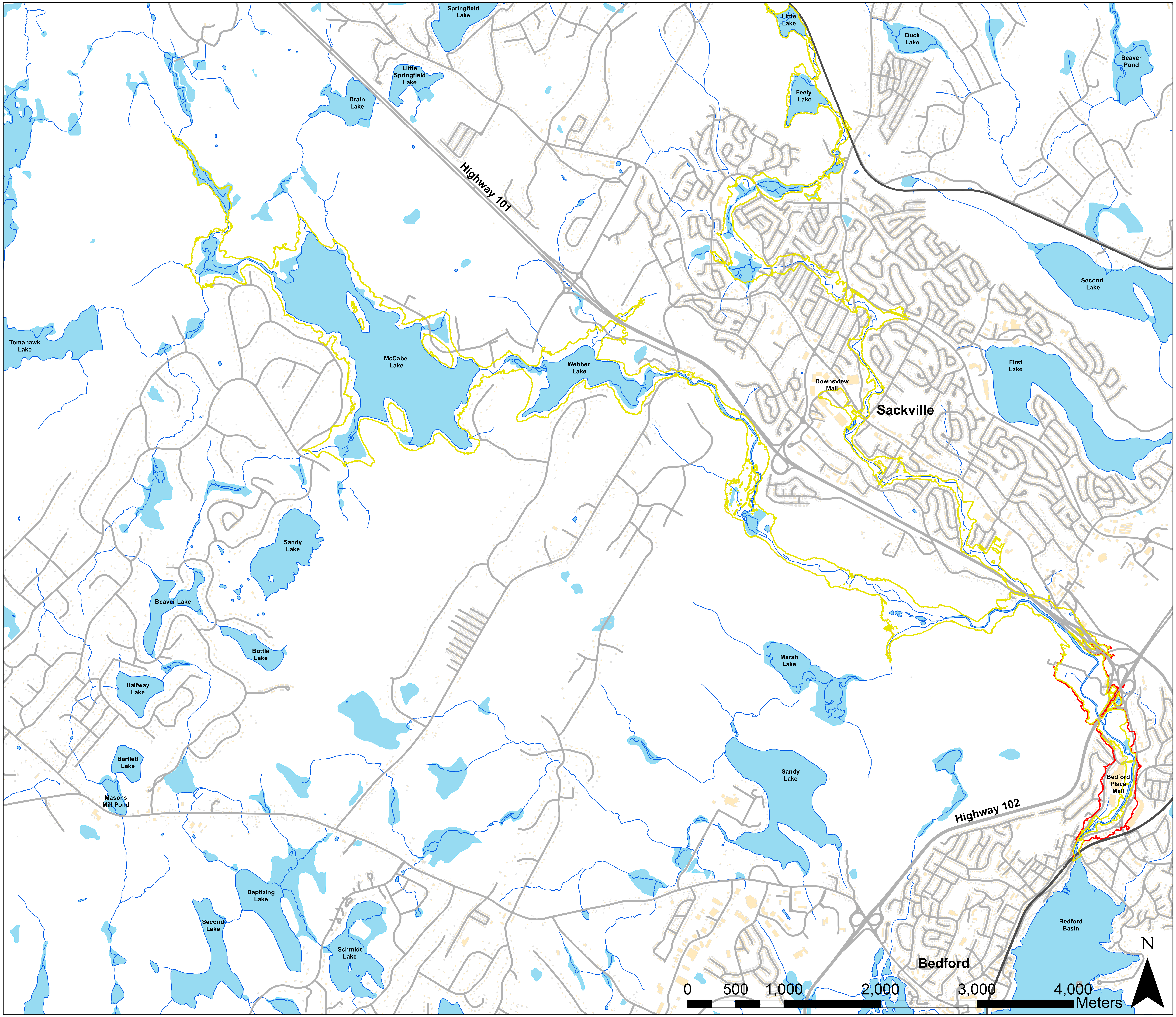
Legend

- 1 in 5-Year Flood Line with Emergency Spillway Tunnel (8.5m diameter)
- Base 1 in 5-Year Flood Line
- Buildings
- Railways
- Roads
- Watercourses
- Waterbodies

SCALE: 1:18,000

Date: March 4, 2020
Project #: 19-174

DESIGN POINT ENGINEERING & SURVEYING



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Flood Line Delineation

Map 8:

Emergency Spillway Tunnel Sized for 1:100-Year Flow (13 m diameter)

Legend

- 1 in 100-Year Flood Line with Emergency Spillway Tunnel (13m diameter)
- Base 1 in 100-Year Flood Line
- Buildings
- Railways
- Roads
- Watercourses
- Waterbodies

SCALE: 1:18,000

Date: March 4, 2020
Project #: 19-174

DESIGN POINT
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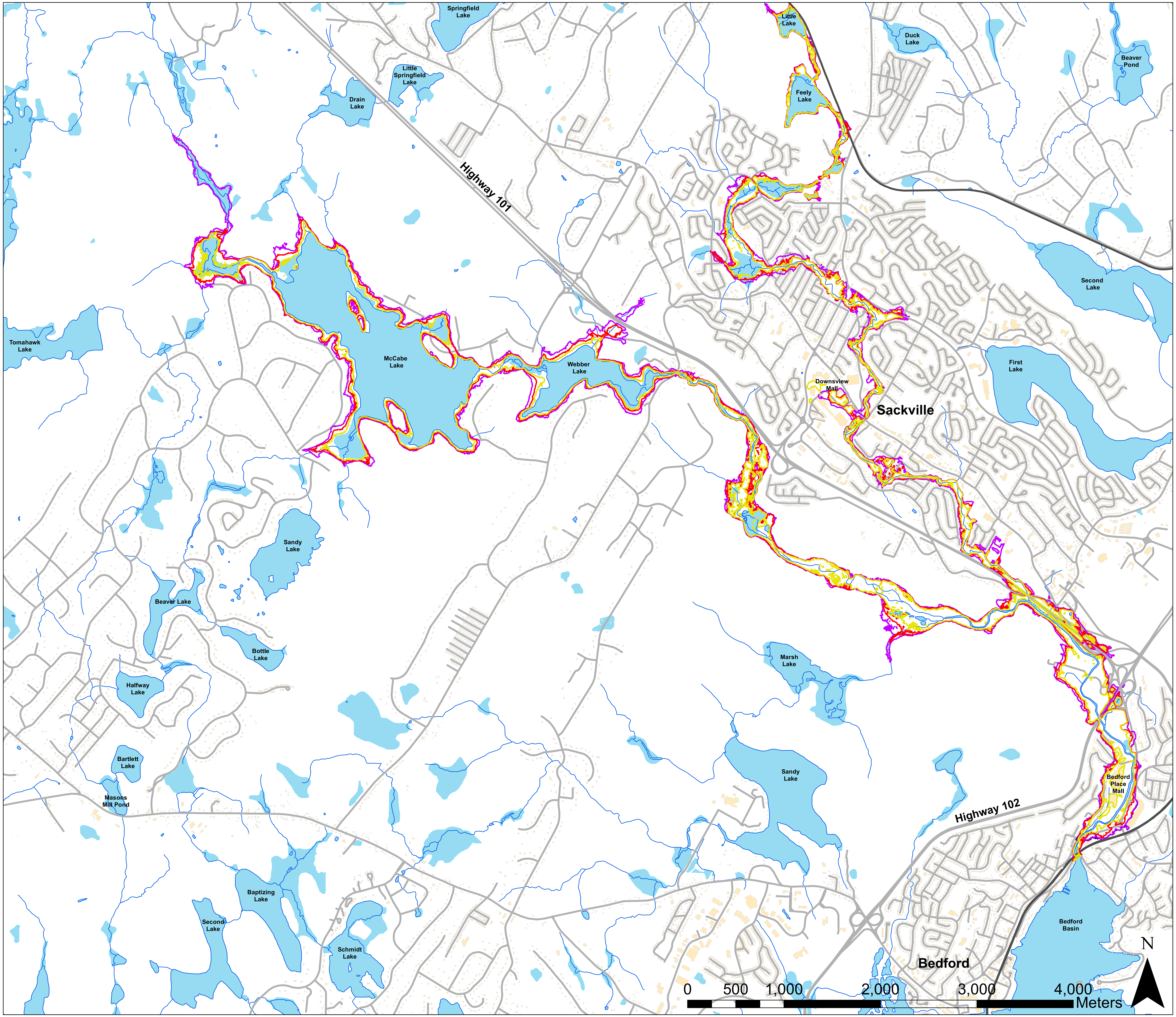

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Sackville Rivers Mitigation Planning Study

Flood Line Delineation

Map 9:

Bedford Highway Bridge Upsizing:

Legend

- Historical Maximum Flow Flood Limit with Bedford Highway Bridge Upsizing
- Historical Maximum Flow Flood Line
- 1 in 5-Year Flood Line with Bedford Highway Bridge Upsizing
- Base 1 in 5-Year Flood Line
- 1 in 100-Year Flood Line with Bedford Highway Bridge Upsizing
- Base 1 in 100-Year Flood Line
- Buildings
- Railways
- Roads
- Watercourses
- Waterbodies

SCALE: 1:18,000

Date: March 4, 2020
Project #: 19-174

DESIGN POINT
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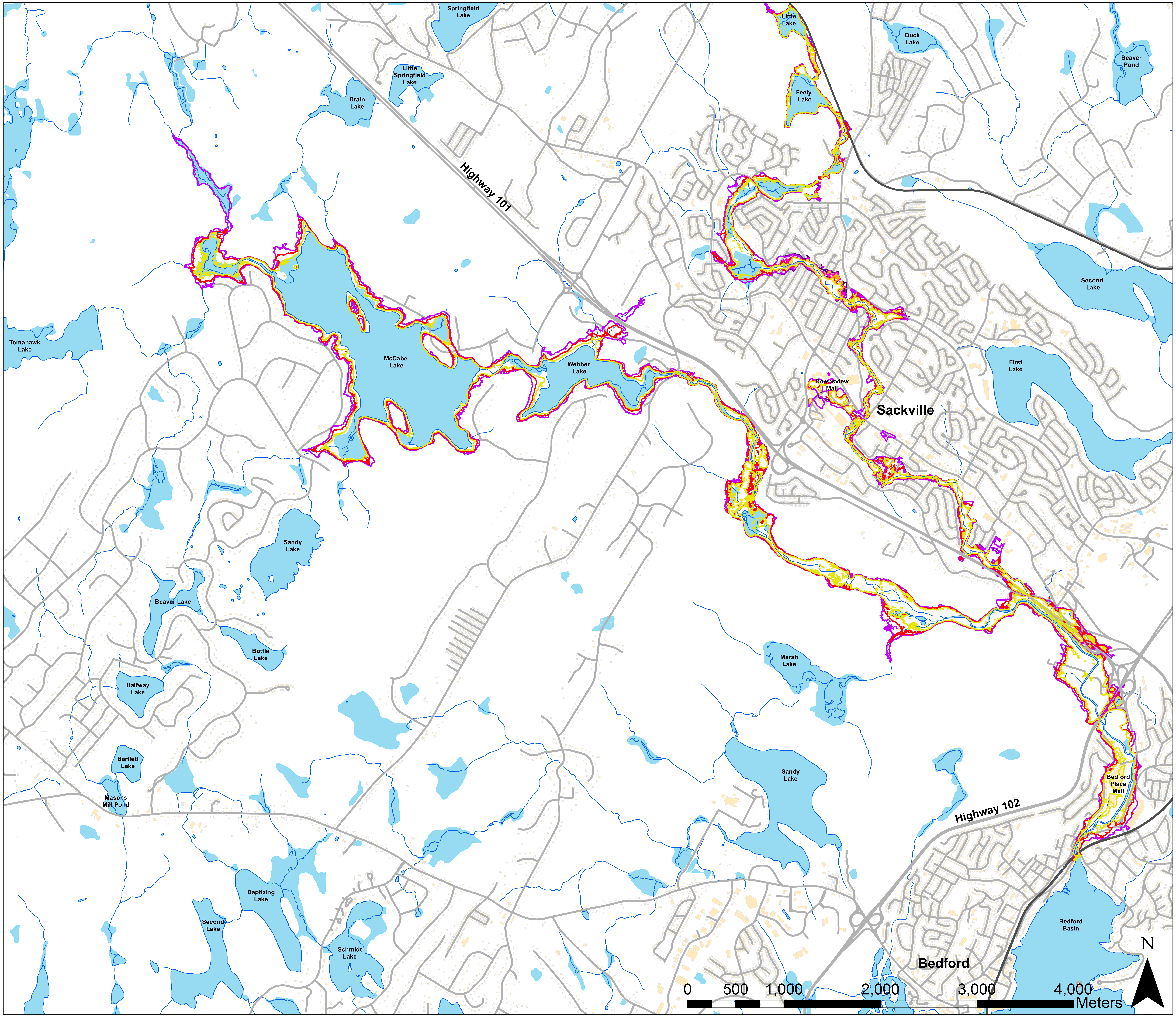

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Sackville Rivers Mitigation Planning Study

Flood Line Delineation

Map 10:

Beaver Bank Road Bridge Upsizing:

Legend

- Historical Maximum Flow Flood Line with Beaver Bank Road Bridge Upsizing
- Historical Maximum Flow Flood Line
- 1 in 5-Year Flood Line with Beaver Bank Road Bridge Upsizing
- Base 1 in 5-Year Flood Line
- 1 in 100-Year Flood with Beaver Bank Road Bridge Upsizing
- Base 1 in 100-Year Flood Line
- Buildings
- Railways
- Roads
- Watercourses
- Waterbodies

SCALE: 1:18,000

Date: March 4, 2020
Project #: 19-174

DESIGN POINT
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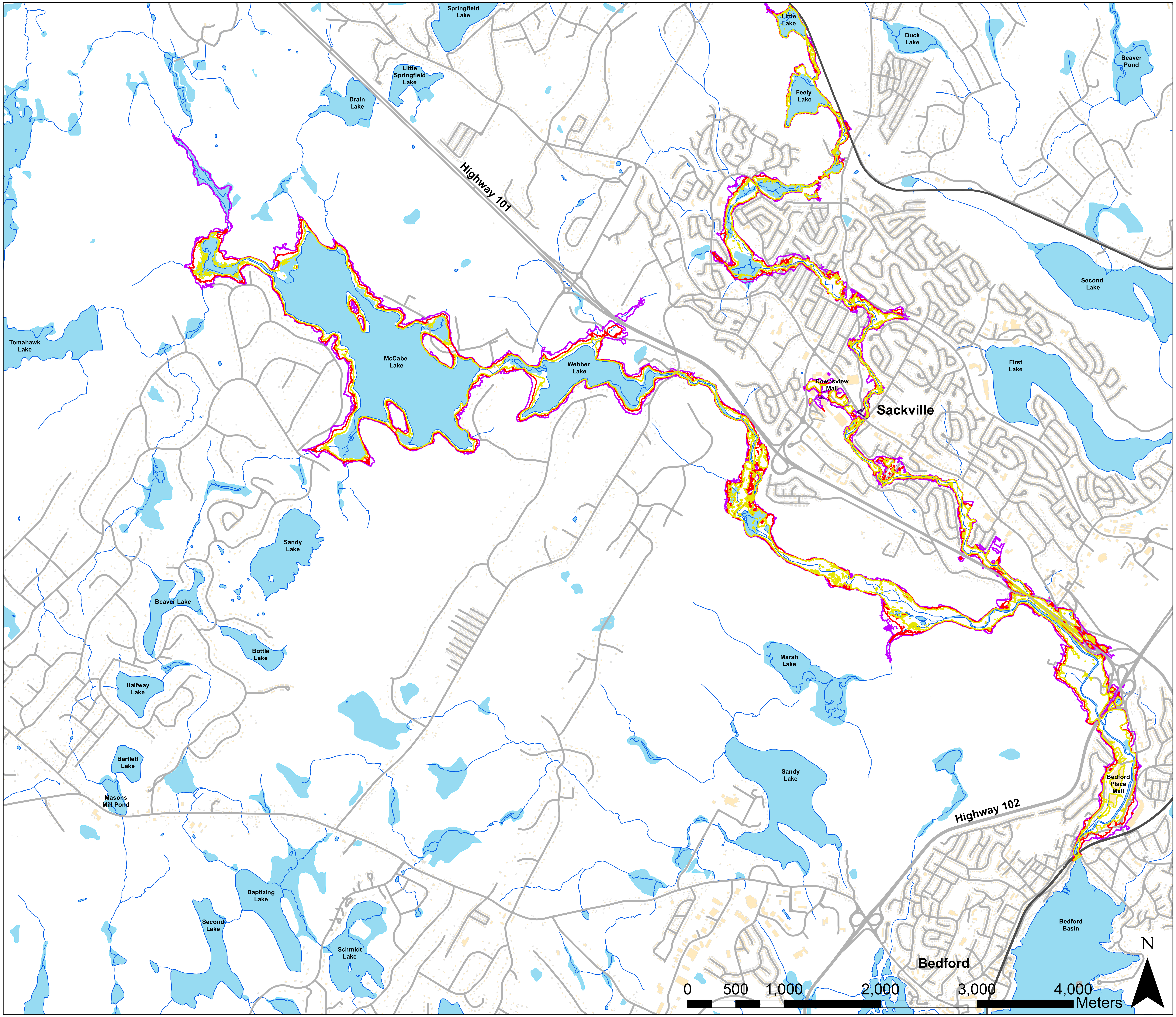

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Sackville Rivers Mitigation Planning Study

Flood Line Delineation

Map 11:

Sackville Drive Bridge Upsizing:

Legend

- Historical Maximum Flow Flood Line with Sackville Drive Bridge Upsizing
- Historical Maximum Flow Flood Line
- 1 in 5 Year-Flood Line with Sackville Drive Bridge Upsizing
- Base 1 in 5-Year Flood Line
- 1 in 100-Year Flood Line with Sackville Drive Bridge Upsizing
- Base 1 in 100-Year Flood Line
- Buildings
- Railways
- Roads
- Watercourses
- Waterbodies

SCALE: 1:18,000

Date: March 4, 2020
Project #: 19-174

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